A SPATIAL ANALYSIS OF SEA TURTLE ABUNDANCE AND SHRIMPING INTENSITY IN THE GULF OF MEXICO: RECOMMENDATIONS FOR CONSERVATION AND MANAGEMENT

by

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ABSTRACT

All species of sea turtles in United States waters are listed on the Endangered Species Act as endangered or threatened. Bycatch in shrimp trawl fisheries has been determined to be a major source of mortality for large juvenile and adult turtles. Turtle Excluder Devices (TEDs) are now required in all US shrimp trawls, but stranding mortality remains high. Identifying the areas of high sea turtle density and shrimping intensity is critical before recommending other management alternatives. In this project, sea turtle spatial dynamics for the United States Gulf of Mexico were determined by analyzing NMFS aerial survey sea turtle sightings in September, October, and November 1992, 1993, and 1994. Using strip transect methodology, the abundance of turtles in each subzone was estimated based on the aerial survey turtle sightings. Shrimping intensity was determined for each subzone in 2 analyses: all months in 1992, 1993, and 1994; and only the months of the aerial survey – September, October, and November 1992, 1993, and 1994. A GIS was then applied to obtain a spatial overlap of sea turtle density and shrimping intensity interactions in the Gulf. Hypotheses for the reasoning behind the distribution of turtles in the Gulf include a better turtle habitat in the Eastern Gulf; the reduction of turtles by the intense shrimp fishery; low oxygen levels off the Louisiana coast; turtles feeding on shrimp vessel bycatch and so inhabiting the same area as shrimpers; and turtles inhabiting nearshore areas. The results showed that sea turtles were observed at much higher rates along the coast of Florida as compared to the Western Gulf, and the highest density of observed turtles occurred in the Florida Keys region (0.525 turtles/km^2). All-year shrimping intensity was highest in the Western Gulf along the coast of Texas and Louisiana, but shrimping intensity for the fall months was dissipated and noticeably reduced. Among alternative management scenarios, area closures would best prevent turtles from future extinction, but management strategies ultimately depend on the goals of NMFS. For instance, deciding which areas to close would vary if NMFS objectives were to protect turtles in areas of high abundance, in areas of high species diversity, or in high shrimping intensity areas. Closing areas with low shrimping intensity and high turtle abundance would maintain the shrimping industry while protecting a large number of turtles. Alternative management strategies are also discussed to help protect these endangered and threatened species. Future turtle conservation measures should incorporate spatial closures, increased TED enforcement, better communication among Gulf stakeholders, and additional in-water studies of species abundance.

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1.0 PURPOSE OF THIS PROJECT

All species of sea turtles in United States waters are listed on the Endangered Species Act (ESA) as endangered or threatened. Bycatch in shrimp trawl fisheries has been determined to be a major source of mortality for large juvenile to adult sea turtles. In response to the high turtle bycatch in shrimp trawls, Turtle Excluder Devices (TEDs) have been required in shrimp trawls since 1990. Most shrimpers are properly installing and using TEDs, but turtle strandings remain high.

In this study we analyzed the spatial overlap of sea turtle densities and shrimping intensity in the United States Gulf of Mexico. The ultimate purpose of this study is to evaluate the potential utility of closed areas or seasons to protect sea turtles. It is important to determine where the turtles are located, as well as areas of high shrimping intensity, in order to provide endangered sea turtles with the most efficient protection.

In the following report, the biology of sea turtles will first be addressed, followed by a detailed look into the Gulf shrimp fishery. The history of sea turtle regulations affecting shrimp fishers will then be outlined, followed by the research methodology, results of this project, hypotheses and discussion of results, and area closure management strategies for sea turtles and shrimp fishers in the Gulf. Several other management options will be also addressed, but the best method to implement is dependent on the particular goals and objectives of the National Marine Fisheries Service (NMFS).

2.0 GULF OF MEXICO

2.1 ENVIRONMENTAL CHARACTERISTICS

The Gulf of Mexico (hearby referred to as the "Gulf") incorporates United States as well as Mexican waters. The United States Gulf is located at approximately 81° to 97° longitude and 24° to 31° latitude. The Gulf is structured like the Mediterranean Sea, consisting of a marginal ocean basin lying in between two continents (Gross, 1993). The Gulf lies in between North and South America and has a surface area of approximately 564,200 square kilometers and a maximum depth of about 3,850 meters (Minerals Management Service web page, 1997). The dominating current in the Gulf is the Loop Current, which circles eastward and southward (Figure 1). The Loop Current enters the Gulf through the Yucatan Straits and moves northward as far as the 100-meter isobath. Off of the Mississippi Delta tip, the Loop Current turns clockwise to the south and parallels the southwestern continental shelf (National Oceanic and Atmospheric Administration, 1996). Large eddies, rotating clockwise, break off and spin toward the Texas coast, bringing large amounts of water and marine life into the western Gulf waters. The continental shelf and slope ecosystems are rich with nutrients, with approximately 3 billion tons of organic carbon fueling the productive ecosystems in the Gulf. Furthermore, a large amount of freshwater enters the Gulf, with the Mississippi River alone carrying 64% of the 1.06 trillion cubic meters of water reaching the Gulf (Minerals Management Service web page, 1997).

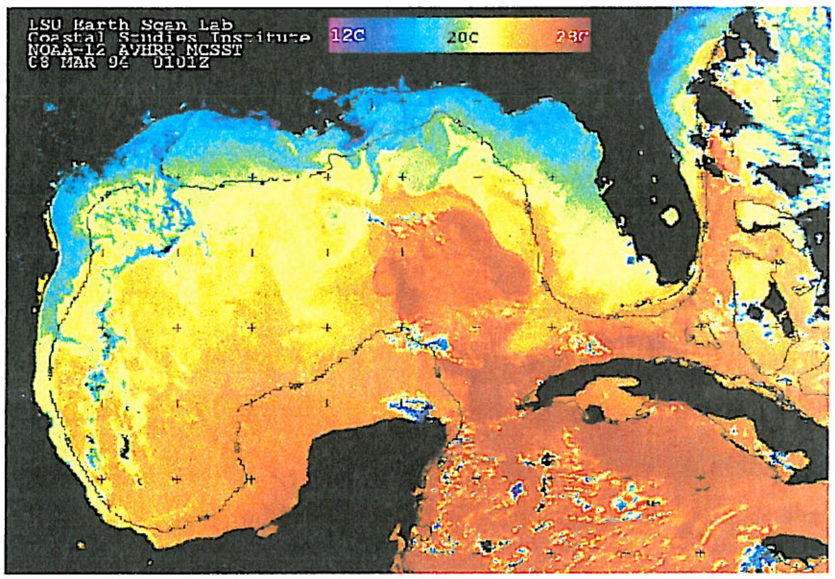

Figure 1. The Gulf of Mexico and Loop Current, as depicted from NOAA polar orbiting satellite imagery (Louisiana State University Earth Scan Laboratory, 1994).

The large amount of runoff (containing nitrogen and other pollutants) from the Mississippi River has contributed to the hypoxic bottom water in offshore Louisiana. The hypoxic bottom water area has expanded since the mid-1980s, resulting in the annual loss of over 18,000 km^2 of the prime shrimp habitat. This hypoxic region affects 34% of the total bottom area off the Louisiana and Texas coasts out to 64 meters depth (LGL Ecological Research Associates, 1997). Therefore, fishing in the hypoxic region is reduced, and many shrimpers are moving to other areas (Turner, 1995).

The United States Gulf waters are divided into 21 statistical zones, as determined by NMFS. The statistical zones extend from the Florida Keys (Zone 1) to the southern tip of Texas (Zone 21) and in this study, the depth contours were in 18.3 meter (10 fathom) intervals (Appendix 1). Each statistical zone has an area code index, determined by the prominent city, bay, or federal game reserve associated with the area (Table 1).

Gulf of Mexico Statistical Zone	**Area Code**
1	Key West
2	Dry Tortugas
3	Everglades
4	Naples
5	Tampa
6	Tarpon Springs
7	Apalachee
8	Panama City
9	Fort Walton
10	Mobile
11	Biloxi
12	Chandeleur
13	Barataria
14	Terrebonne
15	Atchafalaya
16	Rockerfeller
17	Calcasieu
18	Galveston
19	Freeport
20	Corpus Christi
21	Brownsville

Table 1. The area code index for each statistical zone in the US Gulf of Mexico. (Gulf of Mexico Fishery Management Council, 1981)

2.2 MANAGEMENT PROBLEMS

Since the Gulf encompasses an extremely large area, management, research, and enforcement issues are problematic. The regulatory stakeholders involved in this issue are also extensive. In the United States, five states border the Gulf: Florida, Alabama, Mississippi, Louisiana, and Texas. State waters extend out to 3 miles, except on the west coast of Florida and Texas where state jurisdiction claims waters out to 9 miles. The various states have different fishing regulations, including different gear requirements, fishing seasons, and licensing procedures. Beyond the state jurisdictions (the majority of the Gulf waters), the federal government is responsible for management and regulatory authority out to the Exclusive Economic Zone (200 miles).

Furthermore, the responsibility for sea turtles is split between two federal agencies. The US Fish and Wildlife Service (FWS) has responsibility for sea turtles on land (i.e. when they are nesting) and the National Marine Fisheries Service (NMFS) has responsibility when the turtles are in the water. In addition to providing protection for sea turtles, NMFS also manages and regulates the shrimping industry.

Given this divided regulatory authority, management policies constructed for the Gulf should be organized, thorough, and flexible. The Gulf of Mexico is a prime target for an adaptive management approach, in which various techniques are tried as experiments (Lee, 1993). Failed and successful procedures provide a basis for learning, and lay the groundwork for future regulations. Managers must learn from their mistakes in order to successfully manage the vast, complicated Gulf waters.

3.0 SEA TURTLE LIFE HISTORIES

3.1 SEA TURTLE BIOLOGY

There are eight species of sea turtles, grouped into two families. Seven species belong to the family Cheloniidae, known as the hard-shelled turtles, and one species (the leatherback) belongs to the family Dermochelyidae. The five species of sea turtles that reside in coastal United States waters are the loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), Kemp's ridley (*Lepidochelys kempi*) and leatherback (*Dermochelys coriacea*) sea turtle. Regardless of the different body attributes, the five species have several similar characteristics, including relatively nonretractile extremities, extensively roofed skulls, and limbs converted to flippers with one or two claws and little independent movement of the digits (Magnuson et al., 1990). Even though all five species have been found in the Gulf of Mexico, the species that are most common are the loggerhead, Kemp's ridley, and green sea turtles.

The loggerhead is listed as threatened throughout its range, but according to the NFMS and FWS in 1995, nesting information shows that the loggerhead's status has probably worsened in recent years. However, the Turtle Expert Working Group found that subpopulations of loggerhead turtles in the southern Florida region are stable and may be increasing (Turtle Expert Working Group, 1998). In addition, more boaters and fishers are reporting a higher frequency of turtles today than several years ago, although this information has not been extensively analyzed. The loggerhead populations are most likely increasing, but it seems to be too early to determine the exact status of the loggerhead and potential rate of increase. Therefore, protection must continue.

The loggerhead has a reddish-brown carapace and a light brown or yellowish plastron. Nesting adult loggerheads in the southeastern United States average about 92 cm in straight carapace length (SCL) and mean mass of 115 kg (Magnuson et al., 1990; NMFS and FWS, 1995). They tend to be larger than ridleys and hawksbills but smaller than greens and leatherbacks. Age at maturity is estimated to be between 10-30 years, with a maximum lifespan of about 62 years. In United States territory, loggerheads occur in the Atlantic, Gulf of Mexico, and Caribbean waters, with 90% of the US nesting activity occurring on eastern Florida beaches. The largest nesting areas in the Gulf are on various beaches along the Florida coast and on the Chandeleur and Breton Islands in Louisiana (Carr et al., 1982). The diet of the loggerhead depends on the life stage, but subadult and adult turtles feed primarily on crabs, sea pens, and benthic mollusks (Magnuson et al., 1990).

The Kemp's ridley is the most endangered of all sea turtles, found primarily in the Gulf of Mexico waters. The Kemp's ridley is one of the smallest sea turtles, with adults measuring around 65 cm SCL and weighing generally less than 45 kg (Magnuson et al., 1990; USF&WS and NMFS, 1992). The carapace appears light olive to light gray, the plastron white or cream colored, and in adults, the shell is nearly as wide as it is long. Juvenile, subadult, and adult turtles are shallow water, benthic feeders preferring various species of crab, shrimp, and other invertebrates (Magnuson et al., 1990; FWS and NMFS, 1992, NMFS and FWS, 1995). The shallow Gulf waters along the Louisiana coast are thought to be major foraging areas for adult Kemp's ridleys (Carr et al., 1982). Protection is extremely important for this species because Kemp's ridleys only nest on one beach in Tamaulipas, Mexico: Rancho Nuevo at 23 N latitude. Kemp's exhibit a mass nesting effort, known as an "arribada", in which the nesting females emerge synchronously during the day to nest in aggregations.

However, over the last three years several nests have been found on South Padre Island, Texas, possibly resulting from previous headstarting efforts. Headstarting was an experimental program, initiated in 1977, in which hatchlings were reared in captivity for several months to reduce early hatchling mortality. After the eggs were laid, they were moved to Padre Island and allowed to imprint on the local sand. The hatchlings were then reared in captivity at the NMFS Laboratory in Galveston, Texas until they were large enough (~1 year) to have a better chance of survival in the wild (Magnuson et al., 1990; Heppell and Crowder, 1998). Currently the headstarting program is no longer underway, due to various doubts about its success (Woody, 1990; Frazer, 1992). Monitoring the success of headstarted turtles continues none the less.

Less than 50 years ago, Kemp's ridley was an abundant sea turtle in the Gulf of Mexico, with an estimated 40,000 females nesting one day in 1947. Unfortunately this number declined drastically to around 300 nesting females in 1987, as a result of human interactions such as the bycatch of adult turtles in trawl fisheries and the harvest of eggs on beaches (Heppell and Crowder, 1998). Furthermore, we have a substantial lack of knowledge about Kemp's ridley life cycles. The time it takes for Kemp's ridleys to reach sexual maturity, how long they live, and the specific mating areas are not known with certainty.

The green turtle is a circumglobal species, listed as endangered in Florida and Pacific Mexico, and threatened throughout the rest of it's range (Pritchard, 1997). This species is the largest hard-shelled sea turtle, with the adult southeastern populations averaging 101 cm SCL and 136 kg body weight (Magnuson et al., 1990). Adult carapaces vary from black to gray to greenish to brown, with a yellowish white plastron. The green turtle has a smaller head in proportion to its body, a distinguishing characteristic when identifying this species. United States populations of green turtles are found along coastal Texas and Florida grass beds, with the most nesting females occurring on Florida's east coast. Adult green sea turtles are herbivorous, feeding on seagrasses and macroalgae.

Two other species of endangered sea turtles found sporadically in Gulf of Mexico waters are the leatherback and hawksbill sea turtles. The leatherback is the largest of all living sea turtles, with an adult length of 150-170 cm SCL and weight reaching 500 kg (Magnuson et al., 1990; NMFS and FWS, 1995). The slightly flexible carapace is covered with tough, oil-saturated black connective tissue raised in seven longitudinal ridges. Leatherbacks have been sighted in deep waters (>100 m) having a large pelagic distribution, and occasionally, low-density nesting occurs in Florida (~20-30 turtles/year). This species eats primarily jellyfish and other coelenterates.

Hawksbills are relatively small sea turtles with an adult SCL of 66 to 86 cm and a mean mass of 80 kg (NMFS and FWS, 1995). This species is easily recognized by it's colorful carapace, radiating in a "sunburst" pattern of brown and black on an amber background, a narrow head, and tapering "beak." Hawksbills are sedentary tropical and subtropical species, foraging near rock or reef habitats on sponges and other encrusting organisms.

3.2 SEA TURTLE BEHAVIOR

Sea turtles have several at-sea characteristics that make them very difficult to study, as well as to successfully protect. They spend only about 4-41% of their time at the surface (varies with species), so they are in direct human contact only when they nest, entangle in fishing gear, surface, or strand on beaches (Epperly et al., 1995b; Lutcavage and Lutz, 1997). Their life cycles do not promote necessary research, because they spend many years drifting in the current as young juveniles or engaging in extensive migratory patterns (e.g. the leatherback). Other species, like the loggerhead, may hibernate in muddy areas during the cooler months and are not easily located (Shoop and Kenney, 1992).

Turtles are poikilotherms, so their range is not randomly distributed but instead generally associated with water temperature. Most sea turtles are tropical species, but habitat ranges and migratory patterns vary with each species. For example, an experiment by Shoop and Kenney (1992) frequently found loggerheads in waters ranging from 21-24 °C, and leatherbacks in slightly cooler waters of 18-23 °C. Leatherbacks can withstand colder temperatures because their physiology differs from other turtles. Leatherbacks have an endothermic capacity, which allows them to thermoregulate in cold water. They are able to thermoregulate as a result of their large body size, thick insulation, elevated metabolism, and altered blood flow (Spotila et al., 1997). Epperly et al. (1995b) sighted and captured the majority of their turtles (varying species) in waters above 11 °C, and Coles et al. (1994) found that loggerheads and Kemp's ridleys utilized a narrow temperature range of 14 to 28 °C. Overall, temperature, the availability of food, and suitable nesting beaches probably are the most important factors determining sea turtle distribution and abundance.

The specific reproductive behavior characteristics of sea turtles vary among species, but generally the reproduction methods are similar. Nesting females are iteroparous and show philopatry between nesting seasons and site fixity between successive nests in the same season (Turtle Expert Working Group, 1998). Sea turtles lay their eggs at the same nesting beach year after year, but most adult females do not nest each year. For example, on average female loggerheads nest every 2.5 years (Turtle Expert Working Group, 1998). Many females will lay two or more clutches of eggs a year in separate sand-covered cavities, with approximately 100 eggs per nest. These nests are laid above the beach high tide line, but often must be moved because of human interference or beach degradation. The eggs incubate for approximately 2 months, and then the hatchlings emerge from the cavity nest and head to the ocean. The turtles that reach the ocean travel with the current, and begin what Carr (1986) called the "lost years." Eventually, juveniles and adults find their way to specified feeding grounds or mating areas, after which the females travel to the nesting beaches to lay another clutch of eggs (Miller, 1997). These separate life stages and habitats may occur in remote locations, often very far apart from one another.

3.3 SEA TURTLE MORTALITY

Sea turtles range throughout the world, but all species that live in United States territory are listed on the Endangered Species Act (ESA) of 1973 as endangered or threatened. The ESA makes it illegal to "harass, harm, pursue, hunt, shoot, wound, kill, capture or collect endangered species" (16 U.S.C. §1538). The Act also provides for acquisition and protection of turtle nesting habitats and for establishing marine sanctuaries for turtles (Florida Department of Natural Resources, 1997).

Unfortunately the population levels of several species of sea turtles (e.g. Kemp's ridleys) are extremely low. A variety of threats have contributed to this decline, and recent management techniques are trying to address these factors. In the past, sea turtle meat and eggs were frequently eaten and carapaces used for jewelry, but now sea turtles are protected by the ESA and the Convention on International Trade in Endangered Species of Wild Fauna and

Flora (CITES). CITES is an international treaty developed in 1973 that regulates trade in certain wildlife species. All species of sea turtles are on Appendix I, meaning that any type of trade involving these species is prohibited.

However, sea turtles still have several threats to their survival, including direct human contact, natural predation, dredging and drilling of sea floors, pollution, boat collisions, oil rig removal, and fishing activities (Magnuson et al., 1990).

During the early stages of life, sea turtles are most vulnerable to predation and human development. On the nesting beaches, sea walls and beach armoring techniques can obstruct adult females from laying their eggs, and artificial lighting oftentimes disorients the hatchlings so they cannot find the ocean. The mere presence of humans, by way of beach vehicles, beach cleaning, and beach renourishment, can deter adult females from nesting or the eggs from developing properly. Eggs and hatchlings are also susceptible to a variety of predatory influences, like birds, ghost crabs, and human poaching. In many tropical countries, sea turtle eggs are considered to be a delicacy and poachers are offered a high price for the endangered eggs. The small percentage of hatchlings that survive on land are also vulnerable to predation in the marine environment (e.g. fish and crabs). Fortunately, nesting beach protection (e.g. cages), nest relocation, monitoring, egg hatcheries, and increased human educational activities (e.g. regulating beach lighting) have alleviated some of the mortality in the egg and hatchling stages.

Population growth rates of loggerheads and Kemp's ridleys are strongly influenced by changes in survival of large juveniles (Crowder et al., 1994; Turtle Expert Working Group, 1998). The threats to juvenile turtles are similar to those for adults, but unfortunately these mortalities are mostly human induced (Table 2). Collision with boats can stun or easily kill sea turtles, and many stranded turtles have obvious propeller or collision marks (R. Boettcher, STSSN, personal communication). Sea turtles congregate around oil platforms for largely unknown reasons, but it is thought that the platforms provide resting places or feeding grounds for the turtles. Regardless of the exact association, the sea turtles are killed upon oilrig removal. Currently, the Minerals Management Service requires specific procedures to ensure that sea turtles are not affected by the explosions (Turtle Expert Working Group, 1998). In addition, dredging activity can kill sea turtles by entrainment in the hopper dredges. Pollution either entangles sea turtles in the water or suffocates the turtle. Discarded fishing line or gill nets are not easily visible in the water, so sea turtles are often entangled in these lines and later drown. Turtles commonly ingest plastic or mistake debris for food, as seen with the leatherback sea turtle. The leatherback's normal diet consists of jellyfish, but similar-looking plastic bags are often found in the turtle's stomach contents (Magnuson et al., 1990).

Human-induced mortality source	**Estimated mortality* (number/year)**
Shrimp trawling	5,500 – 55,000
Other fisheries	550 – 5,500
Dredging	55 – 550
Boat collisions	55 – 550
Petroleum platform removal	15 – 150

Table 2. Order-of-magnitude estimates for human induced mortality for two species of sea turtles. (Magnuson et al., 1990)
*Note: These numbers are order-of-magnitude mortality estimates for both juvenile and adult loggerheads and Kemp's ridleys.

Several fishery practices can cause sea turtle mortality. Pelagic longline fisheries (Williams et al., 1996), finfish trawls, seines, gill nets, traps, and lost fishing gear cause a small amount of sea turtle mortality. However, the largest source of sea turtle mortality has occurred from shrimp trawling. A 1990 National Research Council report estimated that 5,000 to 55,000 sea turtles die each year in shrimping activities, more than any other human caused mortality (Table 2). Turtles are caught in the trawl net as the fishing gear travels along the bottom of the ocean, and then the turtles are unable to reach the surface for air.

Sea turtle mortality may be related to strandings data. The term strandings refers to the number of dead sea turtle carcasses that wash up on the beach. Oftentimes, it is difficult to determine the cause of death of a stranded turtle, because many turtles are severely decomposed or have been subject to other influences (i.e. predation or boat collisions after they are already dead). Some turtles might not even wash up on the beach at all and others are never found on inaccessible beaches or marshland (e.g. Louisiana coast).

Seasonality affects turtle mortality, with more turtles stranding in warmer months as a result of increased fishing pressure and decreased water oxygen levels. A turtle captured in a shrimp trawl could be released comatose but alive, and the stress, lack of oxygen, and lactic acid buildup could quickly lead to death. For example, after capture it takes as long as 24 hours for the lactic acid to return to normal values (Magnuson et al., 1990). A comatose turtle looks deceased, with suppressed reflexes and no sign of breathing for up to an hour. The heart rate of such a turtle might be as low as one beat per 3 minutes. Shrimp fishers that release comatose turtles cannot predict their fate, but comatose turtles most likely die once back in the water (Magnuson et al., 1990). Furthermore, turtles caught in more than one trawl over a short period of time (i.e. in high shrimping areas) will not be able to cope with the increased stress and lactic acid buildup.

The number of sea turtles dying in trawls depends on the length of the tow time, area fished, and time of year. On board observers and detailed research studies have found that with a tow time of 60 minutes or less there is nearly zero mortality. However, the rate rises rapidly with increasing tow times to about 50% with tow times in excess of 200 minutes (Magnuson et al., 1990; Henwood and Stuntz, 1987). More turtles are also captured in areas of historically high sea turtle abundance. For example, if more turtles were found in nearshore waters of 0-18.3 meters (0-10 fathoms), shrimpers fishing in this area would most likely capture a greater amount of turtles.

Stranding network volunteers have documented drastic increases in sea turtle strandings with the opening of waters to shrimping. With an increase in shrimping effort, the number of turtles stranded dramatically increases, in the Atlantic waters as well as the Gulf. For example, no dead turtles washed ashore more than two days before or five days after the opening and closing dates of the South Carolina shrimp fishery (Murphy and Hopkins-Murphy, 1989). With the start of shrimp seasons, there has been a higher level of sea turtle strandings regardless of TED use. Caillouet et al. (1996) found a relation between sea turtle stranding rates (mortality) and shrimp fishing intensities, but this association did not verify that shrimping caused the strandings. The findings were, however, consistent with earlier studies in that sea turtles are caught and killed incidentally in shrimping and that some turtles caught in the trawls do strand. It is very important to note that the direct linkage between shrimp trawls and stranded turtles has not been verified; many captured sea turtles do not wash up on the beach and for the ones that do strand, the different causes of death offshore are very difficult to determine.

4.0 GULF OF MEXICO SHRIMP FISHERY

In order to accurately assess shrimp fishing and sea turtle interactions, it is necessary to first explore the shrimping industry. Previous shrimping statistics provide valuable information on the seasonal and geographic distribution of the shrimp fleet. The location and magnitude of shrimping effort is an intricate part of management and policy decisions regarding sea turtles and other marine life.

The Gulf shrimp fishery is managed by NFMS and the corresponding state department on a day to day basis. However, the Gulf of Mexico Fishery Management Council was responsible for constructing the Fishery Management Plan for the Shrimp Fishery of the Gulf of Mexico, (United States waters) in 1981. The Magnuson Act of 1976 formulated 8 Regional Fishery Management Councils in order to write all of the fishery management plans. The Gulf Fishery Management Council, located in Tampa, Florida, is responsible for offering continual advice and updated information on the Shrimp Fishery Management Plan (Gulf of Mexico Fishery Management Council, 1981).

Shrimping has the highest product value of any fishery in the United States, and the Gulf fishery is the largest shrimp fishery in the United States (Magnuson et al., 1990). The Gulf brings in eight times the amount of the shrimp landed in the South Atlantic shrimp fishery, while the entire southeastern (both the Gulf and Atlantic) shrimp fishery represented 80% of the 293 million pounds of shrimp caught in 1993 (Weber et al., 1995). In the Gulf, the majority of the shrimp caught are in Texas and Louisiana waters. During the prime shrimping season from May to August, 35% of the shrimp caught in the Gulf of Mexico is landed in Texas ports, while 46% is landed in Louisiana ports. This distribution has remained relatively constant for the last 15 years (Nance, 1996).

Shrimping is most intense in these areas during the spring and summer when the surface waters are warm. Therefore, these fishing seasons are in direct conflict with turtle protection because sea turtles are most abundant in the northwestern Gulf during the spring and early summer (Caillouet et al., 1991).

4.1 SHRIMP NATURAL HISTORY

There are three species of shrimp that compose the majority of the shrimp caught in the Gulf. Brown shrimp (*Penaeus aztecus*) and white shrimp (*Penaeus setiferus*) are the most common along the northern and western coasts, while pink shrimp (*Penaeus duorarum*) concentrate in the south and east (Kutkuhn, 1962; Weber et al., 1995). During the spawning season, sexually mature or "roe" females release their eggs offshore and the hatchlings subsequently develop through several larval stages. Eventually the young shrimp move into estuarine salt marsh creeks along the coast where they reach a juvenile and sub-adult stage. As growth continues, the shrimp slowly migrate seaward (Murphy and Hopkins-Murphy, 1989). Brown shrimp are found in waters less than 55 meters deep beginning in mid-May, with peak seasons in June and July. White shrimp are usually caught in waters less than 30 meters deep and have peak catches in May, late summer, and early fall. Pink shrimp are found in waters less than 46 meters deep and have seasonal peaks between May and October (Weber et al., 1995). As the weather cools, larger adult white shrimp move offshore and southward along the coast, and brown and pink shrimp often burrow in the ocean floor during the cooler months (Murphy and Hopkins-Murphy, 1989).

4.2 SHRIMPING LOGISTICS

Shrimp have been harvested since 1816, but commercial catch statistics were not recorded until 1880. In 1917, otter trawls became the preferred gear used by shrimp fishers, accounting for 90% of the catch. At this time, shrimp catches rose dramatically, as well as the amount of bycatch produced per trawl (Murphy and Hopkins-Murphy, 1989).

The current method of catching shrimp can vary with the fisher and area, but specific regulations guide the construction and use of the trawls, butterfly nets, and skimmer nets used in the shrimp fishery. The most common method is still the otter trawl, which can be fifteen feet high and more than 40 feet across (Henwood et al., 1992; Louisiana Department of Natural Resources, 1997). The shrimp fishers pull two to four trawls along the ocean bottom, and the disturbed shrimp are channeled into the trawl nets as the vessel passes through the water. The trapped species are forced to the back of the trawl and into the bag, or cod-end. After the tow is finished, the trawl is brought on board and the shrimp are separated from the other species. Most of the additional bycatch is thrown overboard, dead.

Bycatch is defined as catches or mortalities due to interaction with fishing gear. More specifically, bycatch includes nontarget species retained by the fishery, animals discarded after capture, and mortalities of animals that encounter the gear but are not retained by it (Crowder and Murawski, in press).

There has been much debate over the amount of bycatch caught with each pound of shrimp, with numbers varying with the shrimper, environmentalist, or agency's viewpoint. However, the estimates range from 4 to 9 pounds of bycatch to every pound of shrimp landed (Weber et al., 1995), with bycatch composing at least 80% of the total catch weight in bay shrimp trawls (Texas State web page, 1997).

The area of highest fishing intensity depends on state regulations (e.g. closures) and the time of year. Most of the US southeast shrimping effort occurs in the central and western Gulf of Mexico, Louisiana and Texas Zones 13-21 (Henwood et al., 1992; B. Gallaway, LGL, personal communication). The Western Gulf shrimp fishery, in Louisiana and Texas, is composed of a bay (inshore) fishery and an offshore fishery. Offshore is defined as "those waters seaward of the 72 COLREGS demarcation line, as depicted or noted on nautical charts published by the National Oceanic and Atmospheric Administration" (Henwood et al., 1992).

Inshore fishers, defined as shrimpers in the inshore bays and estuary waters, mostly consist of bait shrimpers. These fishers do not drag their trawls as long as commercial offshore shrimpers, and because few turtles are historically found in inshore areas (Reeves and Leatherwood, 1983), these inshore fishers are not considered to be a large threat to sea turtles. It is important to realize, however, that as sea turtle populations increase (as they are speculated to do in the near future) turtles could begin to spend more time in inshore areas. Therefore, future management regulations must take inshore fisheries into consideration as well as offshore shrimpers. Fortunately, most shrimp fishers, inshore and offshore, have to engage in sea turtle protection technologies called Turtle Excluder Devices (TEDs). All shrimpers must pull a TED if they have a mechanical device on board for pulling up their nets. The exception is for licensed bait shrimpers who have hand-pulled nets and have less than 30 minute tow times. TED regulations will be discussed in detail in the next section.

There are differences in the Eastern and Western Gulf fisheries, as well as the Louisiana and Texas shrimping industries. Overall, the Louisiana shrimp fishery is larger and more ethnically homogeneous compared to the Texas fishery (Nance et al., 1991). There are seasonal differences as well, exemplified by Louisiana and Texas waters having different shrimp seasons.

4.2.1 Louisiana Shrimp Fishery Seasons

In Louisiana, the waters are divided into inshore waters (bays and sounds), offshore territorial seas, and the federal Exclusive Economic Zone (EEZ). The shrimping line that separates the inshore waters from offshore waters generally follows the coastline, and the state territorial waters and the EEZ are separated by a line running three miles from the Louisiana shore (Louisiana Department of Natural Resources, 1997). Louisiana requires a commercial fisher license, a vessel license, and a gear license (e.g. shrimp trawl or butterfly net license). These licenses are much more expensive as a non-resident than a Louisiana resident – a commercial fisherman's license costs $55 for a resident and $460 for a non-resident (Louisiana Department of Natural Resources, 1997).

The federal waters off Louisiana are open all year round, except for a closed season that may be initiated during the winter months, usually beginning in January and extending into April or May (Louisiana Department of Natural Resources, 1997; M. Johnson, USCG, personal communication). There are 2 seasons (spring and fall) in the inshore waters, with the heaviest fishing pressure occurring from 15 May to 15 July, and 15 August to 15 November (Gallaway et al., 1995). The brown shrimp season opens in late May, usually around Memorial Day. The opening date depends on the outcome of the State Wildlife Commission's review; they study samples of shrimp taken in late April or early May to determine when to open the season. The decision is based on whether 50% of the shrimp caught will meet or exceed the minimum landing size of 100 count or larger. The count is the number of shrimp heads in a specified catch size (usually a pound). For example, with a 100-count catch there would be many small shrimp (heads) in the catch, while in a 20-count catch the shrimp would be substantially larger (20 shrimp heads in a pound).

After the brown shrimp season opens, it lasts until July or until the white shrimp first appear. When the white shrimp appear, the shrimping waters close for 2-3 weeks although managers may keep some inland areas open. The white shrimp season runs from approximately the first weekend in August to December 31.

Fishers track and fish the juvenile and subadult brown and white shrimp as they move from the nearshore Gulf (0-9.1 meters) to the deeper Gulf waters. The main target of the Gulf fishery, brown shrimp, eventually migrate offshore towards Mexico, but white shrimp stay close to the Gulf shore. The white shrimp fishing effort has been thought to cause the highest degree of turtle mortality, because most of this effort is concentrated close to shore where most of the turtles occur (Gallaway et al., 1995).

4.2.2 TEXAS SHRIMP FISHERY SEASONS

In Texas, the state jurisdiction extends 9 miles offshore and both vessels and operators are licensed (M. Hightower, NMFS, personal communication). In mid-May (approximately May 15), all state waters from the beach outward to 9 nautical miles are closed, termed the "Texas Closure." The main purpose of the Texas Closure is to allow brown shrimp to reach a larger, more valuable size prior to harvest (NMFS, 1995a). The Texas Parks and Wildlife Department determines the closure dates through the monitoring of ecological conditions and the size of shrimp distributed from the bays. The size restriction helps to eliminate discarding undersized shrimp during the period of rapid growth, so the fishers obtain a higher market value for the larger shrimp (Nance, 1996).

Since 1960, the closure dates have been modified 14 times, but the duration of the closure remains between 45 and 60 days (Texas State web page, 1997). The Gulf Fishery Management Council has complied with the Texas State Closure, by simultaneously closing the federal waters since 1981. From 1989 to the present, all waters up to 200 miles off the Texas coastline are closed to shrimp fishing during the Closure (Gallaway et al., 1995; Texas State web page, 1997; Gulf Fishery Management Council, 1981).

When shrimp fishing is closed in Texas and Louisiana state waters are open, most commercial shrimping (except bait shrimping) occurs Louisiana waters. Finally, in early July, or when the shrimp are at their optimal size, the Texas waters open and most of the shrimping activity in the Gulf is concentrated in this area. An adverse effect of the Texas Closure is that with the opening of the Texas waters, most of the shrimping intensity occurs within this area. For example in 1987 and 1988, Texas vessels fished off Louisiana during the closure period but quickly migrated back to Texas after the closure. Many other vessels moved into these waters as well, with 11% of the Texas landings coming from out of state shrimp boats (Nance et al., 1990). More effort is concentrated in Texas waters, so more pulse fishing and therefore more sea turtle captures could potentially occur. In fact, sea turtle strandings are much higher before and after the Texas Closure and drop considerably during the shrimp fishing closure (Weber et al., 1995).

4.2.3 EASTERN GULF SHRIMP FISHERY SEASONS

In Mississippi, Alabama, and Florida, there is a smaller amount of shrimping activity in comparison to the areas west of the Mississippi River. From the Alabama border to St. Marks (the Apalachee Bay), Florida, the fishery consists of brown and white shrimp. West of the Apalachee Bay, pink shrimp are the primary species, and major pink shrimp fisheries are located in the Tortugas, Sanibel, and Tampa Bay, Florida.

The pink shrimp fishery in the southwestern Florida area is now protected by the Dry Tortugas Shrimp Sanctuary. Located in NMFS Statistical Zones 1, 2 and 3, the Sanctuary incorporates the majority of Florida Bay (Appendix 2). Federal and state waters (out to 9 miles) are both included in the sanctuary. The sanctuary is permanently closed to commercial fishing in Florida waters, and the only legal fishery is a small live bait fishery with a roller frame trawl. Short seasonal openings are allowed in specific federal water areas, but these areas are negligible in comparison to the size of the entire sanctuary. Furthermore, the area around the Dry Tortugas Shrimp Sanctuary is subject to a variable closure by the Director of the Southeast Regional NMFS office (W. Teehan, FMFC, personal communication). The purpose of this sanctuary is to protect small pink shrimp until they have generally reached a size of 69-count or larger (Gulf of Mexico Fishery Management Council, 1981).

There are several regulations specific to the state of Florida. According to Section 16 Article X in the Constitution of the State of Florida (commonly referred to as the Florida net ban), as of January 1, 1995, trawls must have a surface area of less than 500 ft^2 per net within 3 nautical miles of the Florida coast (Marston and Nelson, 1994). Greater than 3 miles from the shoreline, the net ban did not change shrimp trawling regulations. Furthermore, from Tampa to south of Tallahassee, the only shrimping gear allowed is the roller frame trawl. Roller frame trawls have a roller on the bottom with an attached net, held open by a rectangular structure (usually around 16 feet wide by 3 feet high). Compared to the otter trawl, the roller frame is thought to be less damaging to the extensive seagrass habitat in this area (W. Teehan, FMFC, personal communication).

4.3 DECLINE OF THE GULF SHRIMP FISHERY

There is some animosity between offshore and inshore shrimpers in the Gulf. The offshore shrimpers feel that the inshore shrimp fishers are harming the young shrimp by not allowing the shrimp to grow to the commercially viable optimal size. By exploiting these young shrimp, the future catch of large offshore shrimp will be reduced. Growth overfishing has been documented in the Texas shrimp fishery and most likely occurs in Louisiana waters as well. Growth overfishing occurs when fishers catch shrimp before they are at the most economically efficient market size, and therefore average size landed is reduced. In addition, recruitment overfishing could potentially occur, in which shrimp are caught before they spawn and subsequently the few adults cannot maintain recruitment. If this trend continues, the populations of adults would decline, spawning success would decrease, and the fishery would ultimately collapse (Texas State web page, 1997).

Shrimp are common property resources, and competition has led to the overcapitalization of the fishing fleet. Currently, fishers have few regulatory limitations on the catch of Gulf shrimp. Any increase in fishing effort could also result in more turtle bycatch (Ward et al., 1996).

The fishing industry, environmental community, and governmental agencies all desire a sustainable Gulf ecosystem, with productive resources. The majority of the stakeholders in the shrimp fishery want to keep the industry viable in order to ensure good catch rates, maintain key species, protect ecosystem function, and prolong future economic gains. Therefore, most constituents are concerned with growth overfishing and any economic decline of the Gulf shrimp fishery.

There has been some speculation in recent years that the Gulf of Mexico shrimp industry is declining. The unit of measurement must be considered however, since the number of shrimping licenses does not reflect the number of actual fishers and vessels (Murphy and Hopkins-Murphy, 1989). Many captains have more than one license for different states and the shrimp fleets are very mobile. The licensing system varies with the state in question, because states either license vessels, individuals, gear, or all of the above. In order to accurately assess the number of fishers in a given area at a given time, the number of shrimping boats must be determined.

Figure 2 shows the number of Coast Guard documented vessels that unloaded Gulf shrimp at a US port at least once in a given year. The vessels are categorized as shrimp boats less than 15.3 meters (generally low fishing efficiency) and vessels greater than 15.3 meters (high efficiency). This data was obtained from the NMFS laboratory in Galveston. There are generally more vessels greater than 15.3 meters than smaller vessels (less than 15.3 meters). If size is truly indicative of efficiency, this would indicate that Gulf shrimp fishery vessels before 1992 were generally large and relatively efficient. After 1991, the efficiency (i.e. size) drastically declines, but there is still a greater proportion of vessels greater than 15.3 meters.

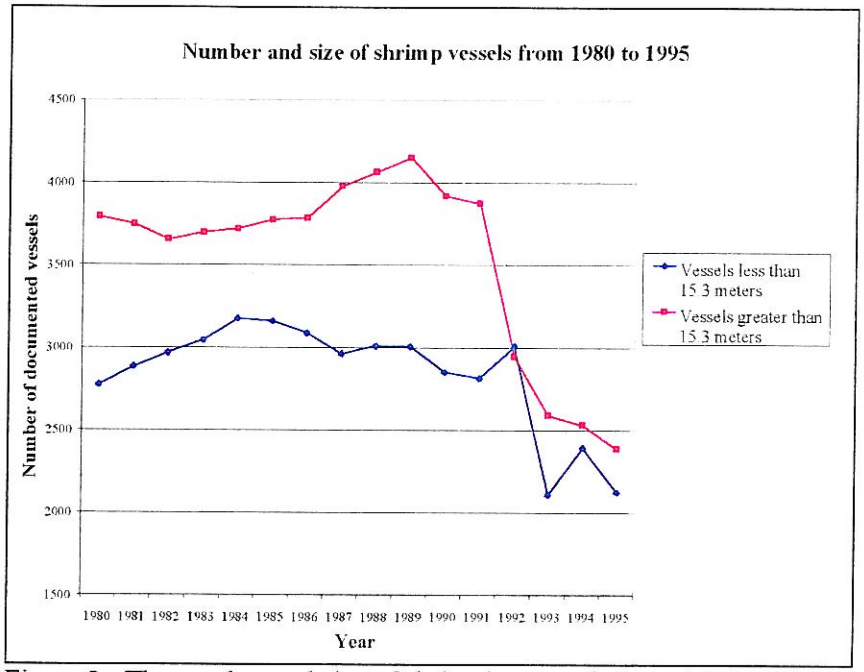

Figure 2. The number and size of shrimping vessels from 1980 to 1995 based on Coast Guard reports.

However, Margo Hightower (the NMFS Fishery Reporting Specialist in Galveston, Texas) feels that the number of shrimp boats has declined steadily since the late 1980s. This may have been due to increased operation and fuel costs as well as the initiation of new technology, such as Turtle Excluder Devices (Texas State web page, 1997). Most of the fishers who dropped out of the shrimping industry either entered another fishing industry (e.g. tuna), moved to another location (e.g. Mexico), or sold their boat.

Nance (1993) stated that offshore vessel trips have been generally stable over time, and only the Eastern Gulf trips have declined. The catch per unit effort (CPUE) has declined slightly since the early 1980s, so with each fishing trip the shrimp fishers are catching a smaller amount of shrimp. A small Louisiana shrimp fisherman, for example, cannot fish to the same magnitude or compete in the market system with some of the large commercial boats, so the individual is eventually forced out of business.

The decline in the Gulf shrimp fishery could be attributable to the hypoxic zone off the coast of Louisiana (Zones 13-17). In 1996, approximately 18,000 km^2 of bottom water was affected, stretching southeast of New Orleans to the mouth of the Sabine River on the Texas border (Turner, 1995). This hypoxic zone has little productive value in terms of shrimp fishing, because shrimp and shrimp prey are dying or migrating as a result of the anaerobic conditions. Another problem with hypoxic areas is that the remaining productive areas surrounding the zone usually become quickly overfished (Turner, 1995). The hypoxic zone is speculated to have drastic effects on the Western Gulf fishery.

The number of shrimp fishers is actually not the best indicator of the biological shrimp population. Overfishing is a common practice in US waters, and there could possibly be too many boats for the number of shrimp available. It is extremely important to also research the longevity and current population status of the Gulf shrimp population. Annual shrimp crops depend on environmental changes, such as salinity, water temperature, rainfall, sediment and nutrient loading, and ocean currents (Murphy and Hopkins-Murphy, 1989). All of these conditions affect spawning periods, growth rates, and migration.

Although shrimp are influenced by changes in the environment, the Gulf of Mexico total catch seems to slightly rise and fall on an 8-10 year cycle (M. Hightower, NMFS, personal communication). This trend is exemplified in Figure 3. The yearly catch does fluctuate, but based on this data, the total poundage could be slightly decreasing. These Gulf catch statistics are in total amount of heads-off shrimp (lbs.) caught for each year. When comparing this trend to the number of shrimper vessel trips, the number of trips also fluctuate and the trip numbers seem to follow behind the catch statistics (Figure 4). High catches lead to a greater number of vessel trips (e.g. 1986), while a decrease in the number of vessel trips follows low total shrimp catches (e.g. 1988). Overall, the total number of trips has declined considerably from the 1980s.

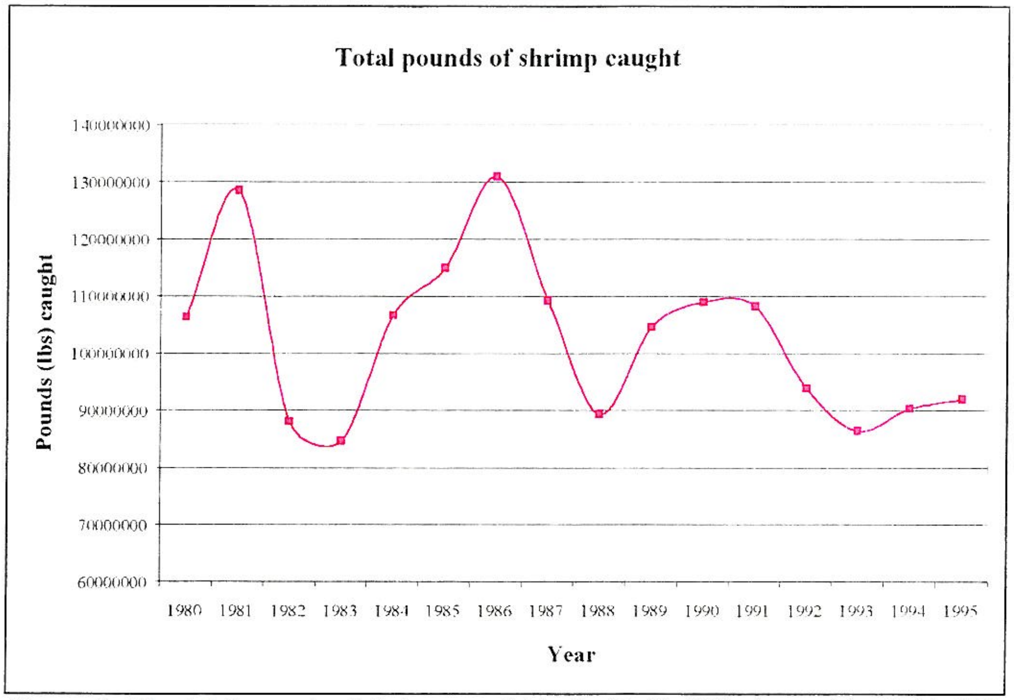

Figure 3. The total pounds of shrimp caught in the Gulf of Mexico and landed in US ports. The poundage is in total heads-off shrimp for each year (1980-1995).

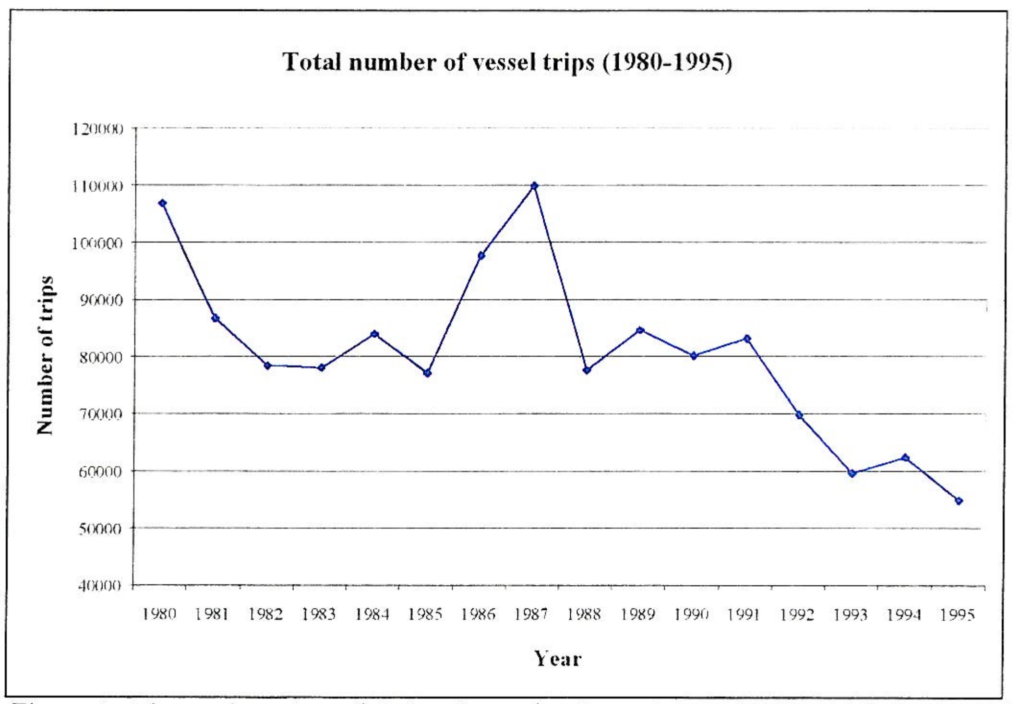

Figure 4. The total number of shrimp boat trips for each year (1980-1995) for the United States Gulf of Mexico.

Regardless of the small amount of cyclic activity in Gulf landings, on a larger scale the amount of shrimp catch remains fairly constant year after year. Landings have fluctuated considerably, but other studies have indicated that there hasn't been a dramatic increase or decrease in shrimp catch since the late 1950s (Murphy and Hopkins-Murphy, 1989). Shrimp have a high growth rate, high fecundity, and high death rate; therefore they basically restore their population every year (B. Gallaway, LGL, personal communication).

5.0 INTERACTION OF SEA TURTLES AND SHRIMP FISHERS

Environmentalists have been concerned with the demise of the sea turtle since the ESA listing. The interactions between sea turtles and shrimp fishers have been historically wrought with complications and bitterness. Sea turtles are caught in shrimp trawls as shrimp fishers drag the huge nets through the water, and the turtles eventually die from asphyxiation or stress. Seventy to eighty percent of dead turtle strandings have been associated with the shrimp trawl fishery (Magnuson et al., 1990), but it has not been proven that increased strandings are caused by shrimp fishing (Crowder et al., 1995). There are strong correlations between shrimp fishing and sea turtle mortality, but one cannot statistically infer causation from correlation.

The reason sea turtles are caught in shrimp trawls is relatively unclear: are the shrimpers fishing in areas with high turtle populations or do the sea turtles follow the shrimping trawls to feed on bycatch? Sea turtles and shrimp fishing are often located in the same areas. As mentioned earlier, the majority of shrimp trawling and sea turtle sightings occur in the spring and summer, when the surface water is warm. Most shrimp fishing occurs close to shore and turtles are also found generally in the nearshore environment. In addition, Kemp's ridleys and loggerheads eat shrimp, so it is possible that the turtles are looking for food in the same habitat where shrimpers trawl. Shrimp trawls also provide large amounts of discarded bycatch, potentially serving as turtle food. This association would result in more turtles congregating in habitats around the shrimp boats, subject to capture in the trawls. Furthermore, the continuous availability of food might alter turtle distribution, keeping them in the area where bycatch is available (Shoop and Kenney, 1992). It would be difficult to determine which came first: the turtles or the shrimp fishers.

Regardless of the specific reasoning, extreme measures must be taken to ensure turtle recovery. In order to reduce the amount of sea turtles caught in trawl nets, various management devices, such as Turtle Excluder Devices (TEDs), area closures, and gear restrictions have been implemented. Most of the research and management techniques to date have concentrated on TEDs. TEDs include cage-like structures that fit in the body of a trawl net, in front of the tail bag, to prevent turtles and large fish from being caught. The turtle cannot pass through the bars of the TED, and is forced out of the net through an escape hatch. TEDs have been determined to successfully decrease sea turtle mortality, as shown by reducing South Carolina sea turtle strandings by approximately 44% compared to trawls without TEDs (Crowder et al., 1995).

An outline of sea turtle regulation history is presented here so future legislative options might build on and amplify the existing regulations.

5.1 HISTORY OF TED REGULATIONS

5.1.1 ORIGINAL RESISTANCE

The history of TEDs is extremely complicated and full of regulatory, managerial, and technological problems. From the onset, shrimp fishers were not receptive to the idea of a TED. On the other hand, sea turtle conservationists have strongly fought for universal TED implementation and strong regulations to ensure correct use.

The first regulation regarding sea turtles occurred in 1981 and involved resuscitation (Coyne, 1997). This final rule required sea turtles to be resuscitated before returning to the water. Unfortunately, this rule had little effect since the fear of being caught with an endangered turtle far outweighed the motivation to resuscitate and transport an animal.

NMFS developed the first TED in 1981 as a response to the large numbers of sea turtles washing along the southeastern shore of the United States. The first TED reduced sea turtle captures by 97% and adequately maintained shrimp catch, but it was relatively cumbersome in shrimpers' nets (Weber et al., 1995). Instead of enforcing TEDs via regulations, NMFS relied on voluntary TED use by the shrimpers. The outcome was undesirable, with very poor compliance of less than 5% (Risenhoover, 1990).

In 1982, the Center for Environmental Education (now the Center for Marine Conservation) formulated a group of environmental and industry representatives, called the TED Voluntary Use Committee, in order to coordinate turtle and shrimping activities. In 1983, the TED Voluntary Use Committee decided that within the next three years the majority of southeastern shrimpers should be using a TED. However, the next four years was characterized by heated TED debates, noncompliance by most of the shrimp fishers, and intense research by NMFS to improve TEDs' structure. With shrimper input, NMFS finally developed a lightweight collapsible TED that eliminated most sea turtles, maintained shrimp catch, and reduced finfish bycatch by 50-70% (Weber et al., 1995).

With much resistance from the House of Representatives, the Concerned Shrimpers of Louisiana, and the State of Louisiana, NMFS finally published regulations requiring TED use on June 29, 1987. These regulations required TEDs in most trawls in most areas at most times from North Carolina to Texas, and approximately 7,000 out of 20,000 shrimp boats were required to use TEDs (50 CFR 217, 222, and 227, June 29, 1987; Weber et al., 1995). Obviously these rulings were met with much resistance from fishers, and even though the courts upheld TED regulations, in April 1988 NMFS suspended TED regulations everywhere.

In another blow to TED implementation, President Reagan signed a reauthorization of the Endangered Species Act in October 1988 that further suspended universal TED regulations. This bill delayed the implementation of TEDs until May 1, 1989 in offshore waters and required a study by a National Research Council (Magnuson et al., 1990) to review sea turtle conservation. This report was the most thorough and influential sea turtle study at this time. The NRC panel also found that shrimp trawling was the greatest cause of sea turtle mortality, with approximately 5,500-55,000 loggerheads and Kemp's ridleys killed each year by shrimping efforts. Other observations and analyses found that the total shrimp catch was slightly higher with TEDs, and the amount of shrimp escaping through the TED was less than one percent. Furthermore, sea turtle strandings were dramatically lower with TED use. As a result of this information, the committee developed several conservation recommendations to protect sea turtles, including requiring TEDs in all areas at all times, tow time limits, and limited time or area closures for high turtle concentration areas ("hot spots"). Unfortunately, most of these recommendations were initially overlooked.

Several states did take their own initiative and implemented TEDs in state waters. The on-again, off-again TED enforcement stimulated South Carolina to adopt their own TED regulations in 1988, requiring TEDs in all fishing waters (Weber et al., 1995). In January of

1989, Florida required TEDs in waters where massive Kemp's ridley strandings occurred, and Georgia implemented statewide TED requirements in October of 1990. These states are covered by both federal and state regulations, but because the State of Louisiana lost a lawsuit to the federal government regarding TEDs in 1988, federal regulations take precedent over state laws (D. Crouse, CMC, personal communication). Although some states were realizing the effectiveness of TEDs and enforcing regulations in the late 1980s, many Gulf of Mexico states (e.g. Louisiana and Texas) were still strongly resisting TED use.

Due to political pressure from Congressman Wilbert "Billy" Tauzin of Louisiana, Secretary of Commerce Robert Mosbacher again suspended TED rules in July 1989 in order to investigate claims of TED clogging by sargassum. NMFS found that very few TEDs were clogged by sargassum, so Mosbacher reinstated the regulations, leading to shrimp fishers blockading several Texas shipping channels to protest TED enforcement. Several heated and violent fights between Coast Guard officers and shrimp fishers led to the immediate suspension of TED rules.

Enforcement efforts by the Coast Guard found noncompliance with TED regulations among most Gulf fishers. This apparent disregard for sea turtle conservation led to a federal court ruling that stated the suspension of TED regulations was unlawful. The court also ordered NMFS to reinstate the TED regulations or to develop alternate measures to protect sea turtles (Weber et al., 1995). During the summer of 1989, NMFS required shortened tow times in place of TEDs, but TED regulations were eventually reinstated because shortened tow times were easily violated and difficult to enforce. Therefore, in 1990, TEDs were in place throughout the Gulf.

To complement these sea turtle protection measures, Congress passed Public Law 101-162 on November 21, 1989. As stated in this law, Section 609 required a shrimp ban from countries not participating in sea turtle protection measures. On May 1, 1991, it became illegal to import shrimp from countries that did not meet conservation requirements. Unfortunately, in April 1998, the World Trade Organization (WTO) upheld the free trade agreement and ruled against the US law blocking shrimp imports from countries not using TEDs.

On August 1, 1991, after much pressure from conservation groups and the NRC study, NMFS published a proposed rule to extend TED requirements to the fall season in the Atlantic, but resisted extending TED requirements to other areas. After additional TED suspensions relating to Hurricane Andrew and large amounts of debris clogging TEDs in the fall of 1992, NMFS finally required all shrimp trawlers in offshore areas and larger inshore trawlers to use TEDs all year, beginning January 1, 1993. The requirements for smaller trawls to use TEDs in bays and sounds were delayed until December 1, 1994 (Weber et al., 1995). TED acceptance was further strengthened by Mexico legislation requiring all Gulf shrimp trawlers to use TEDs beginning in April 1993.

During 1992 to 1994, TED compliance rates were relatively constant at 92%, but even with TED regulations in place and high compliance in the majority of the Gulf, three times the average number of historical strandings occurred along the Texas, Louisiana, Georgia, and northeast Florida coast after the start of the 1994 shrimping season (M. Johnson, USCG, personal communication). The major cause of these strandings was determined to be improper use of TEDs by Gulf shrimpers, ineffective TEDs, and intensive fishing in areas of high sea turtle abundance during the spring and summer of 1994 (50 CFR Parts 217 and 227, December 19, 1996).

5.1.2 The 1994 Biological Opinion

The large increase in 1994 strandings forced NMFS to re-evaluate their regulations and conduct further research into the existing technology, pursuant to Section 7 of the ESA. Subsequently, NMFS issued a biological opinion on November 14, 1994 concluding that the "continued long-term operation of the shrimp fishery in the southeastern United States under the current management regime was likely to jeopardize the Kemp's ridley population, and impede the recovery of the threatened loggerhead population" (NMFS, 1995b).

This biological opinion also established several measures to protect sea turtles, including an incidental take statement and the formation of an Emergency Response Plan (ERP) in Special Management Areas. The ERP was designed to respond to future stranding events and ensure compliance with sea turtle conservation measures. Published on March 14, 1995, the ERP established two elevated enforcement areas, the Atlantic Interim Special Management Area and the Northern Gulf Interim Special Management Area. The Northern Gulf Interim Special Management Area included waters off Louisiana and Texas from the COLREGS line out to ten nautical miles (Statistical Zones 13 through 20), while the Atlantic

Interim Special Management Area included Statistical Zones 30 and 31 from the COLREGS line out to ten nautical miles (NMFS, 1995b).

The incidental take statement identified an indicated take level (ITL) from the average number of weekly strandings in each NMFS statistical zone for the last three years. The ITL was set at two times the weekly three year stranding average for each zone (50 CFR Parts 217 and 227, December 19, 1996). As the regulations stand, each Sea Turtle Stranding and Salvage Network (STSSN) State Coordinator is required to document the strandings for each week in both the Special Management Areas and other zones (R. Boettcher, STSSN, personal communication). The STSSN State Coordinator will notify the STSSN National Coordinator if strandings are reaching an elevated level.

Restrictions in the Interim Special Management Areas would be implemented when up to 75% of the ITL is reached for 2 consecutive weeks, or when the Assistant Administrator for Fisheries, in consultation with the Regional Director, the Southeast Enforcement Division Special Agent in Charge, the Southeast General Council Senior Enforcement Attorney and the Protected Resources Office Director, determines that other factors including noncompliance or high nearshore shrimping effort require additional management measures (NMFS, 1995b). If elevated strandings (greater than 75% of the ITL) occur in 2 consecutive weeks, the zone would be closed out to 10 nautical miles for 30 days.

The original ERP restrictions included the prohibition of soft TEDs; prohibition of bottom opening TEDs; prohibition of try nets unless they are equipped with legal TEDs (try nets are small nets used to determine whether shrimp are present); and the prohibition of webbing flaps that cover the TED escape opening. These restrictions would remain in effect for 30 days after the implementation of the ERP.

Furthermore, beginning in 1995, from April 1 through November 30, there would be elevated enforcement by a trained NMFS TED law enforcement team (the TEDLET) and Coast Guard officers within these Interim Special Management Areas. For areas outside of the Interim Special Management Areas (Zones 1-11, and 21), the STSSN National and State Coordinators would be responsible for evaluating the local mortality and conditions.

On May 18, 1995, NMFS modified the original ERP, based on numerous comments from the shrimping industry, in hopes of relieving the burdensome requirement on shrimp trawlers while still providing protection for sea turtles. The new proposed rule required try nets to be equipped with NMFS-approved TEDs, unless the try nets have a headrope length of 12 feet (3.6 m) or less and a footrope length of 15 feet (4.5 m) or less (50 CFR Parts 217 and 227, May 18, 1995). All other gear restrictions and regulations remained the same.

Under the guidance of the ERP, NMFS implemented 30-day additional gear restrictions four times in 1995, twice in the Gulf and twice in the Atlantic. However, NMFS did not follow through with implementation during a June 16, 1995 proposed rule in Texas. Elevated strandings required gear restrictions in Texas waters out to 10 nautical miles for a 30-day period, but after many public hearings NMFS decided not to implement a final rule (50 CFR Part 227, August 18, 1995). The reasons behind this decision were the apparent willingness of industry to voluntarily adopt gear restrictions, the deployment of the TEDLET and trained Coast Guard groups, and the late opening of Texas waters to shrimping. In 1996, temporary gear restrictions were implemented only one time in Georgia waters. These sea turtle protection measures must be consistently implemented in order to be effective.

A report by LGL Ecological Research Associates, Inc. for the Texas Shrimpers Association (TSA) analyzed sea turtle and shrimp fishery interactions in April 1995, and on September 13, 1995, an advance notice of proposed rulemaking (ANPR) requested comments on this report. This ANPR also announced that NMFS was considering additional regulations to conserve sea turtles. After many comments from industry, governmental, and environmental representatives, NMFS issued a proposed rule on April 24, 1996 that strengthened the regulations protecting sea turtles. This rule was necessary to enhance the effectiveness of regulations protecting sea turtles in shrimp trawls in the southeastern United States Atlantic and Gulf waters.

The proposed amendments were: removal of all soft TEDs effective December 31, 1996; requirement of NMFS hard TEDs in try nets with a headrope length greater than 12 ft and a footrope length greater than 15 ft by December 31, 1996; establishment of Shrimp Fishery Sea Turtle Conservation Areas (SFSTCAs) in the northwestern Gulf of Mexico, consisting of the offshore waters out to 10 nautical miles along the coasts of Louisiana and Texas (from the Mississippi River South Pass to the US-Mexican border), and in the Atlantic consisting of the inshore and offshore waters out to 10 nautical miles along the coasts of

Georgia and South Carolina (from the Georgia-Florida border to the North Carolina-South Carolina border); and, within these SFSTCAs, requirement of the new try net regulations, prohibition of soft TEDs, and prohibition of bottom opening hard TEDs effective 30 days after publication of the final rule (50 CFR Parts 217 and 227, December 19, 1996).

After comments on the proposed rule, analyses by the Turtle Expert Working Group, and additional tests on trawl gear performance and sea turtle interactions, NMFS came to a conclusion on June 11, 1996. NMFS stated that "continued, long-term operation of the shrimp fishery in the southeastern United States under the proposed sea turtle conservation regulations, establishment of a vessel registration system, maintenance of the TED enforcement team and the TED technology transfer program is not likely to jeopardize the continued existence of Kemp's ridley and loggerhead sea turtles" (50 CFR Parts 217 and 227, December 19, 1996).

Late in 1996, President Clinton signed H.R. 3610, "The Omnibus Consolidated Appropriations Act, 1997." This report directed NMFS not to decertify any TEDs until every effort has been made to improve existing devices to increase turtle escapement (50 CFR Parts 217 and 227, December 19, 1996). Therefore, the final rule issued on December 19, 1996 did not remove the approval of existing soft TEDs until 1 year after the date of publication. The one-year lag time provided the opportunity for testing and improving existing or new soft TEDs in cooperation with the shrimping industry.

As of December 19, 1996, the final rule included the following regulations: removal of the Morrison, Parrish, Andrews, and Taylor soft TEDs effective December 19, 1997; requirement of NMFS hard TEDs in try nets with a headrope length greater than 12 ft and a footrope length greater than 15 ft by December 19, 1997; establishment of Shrimp Fishery Sea Turtle Conservation Areas (SFSTCAs); and within these SFSTCAs, require the new try net regulations, prohibit soft TEDs, and prohibit bottom opening hard TEDs effective March 1, 1997 (50 CFR Parts 217 and 227, December 19, 1996).

NMFS is currently working with the industry in hopes of coming to a cooperative agreement on gear restrictions and sea turtle exclusion rates. If additional soft TEDs are developed that successfully exclude sea turtles, these TEDs will be approved for use without delay. As of April 9, 1998, one soft TED (the Parker TED) had been approved for an 18-month trial period by the NMFS (National Oceanographic and Atmospheric Administration

Constituent Affairs, 1998). To ensure that the Parker soft TED will be effective under commercial fishing conditions, NMFS developed an enforcement operations plan, an observer program, and a soft TED manufacturer's training program. Additionally, NMFS is currently working on a rule package to authorize a modified Morrison soft TED (C. Coogan, NMFS, personal communication).

The current regulations authorize several hard TEDs with different shapes and sizes, but all approved TEDs follow several specific minimum requirements (50 CFR 227.72(e), December 31, 1995). Some of the most common TEDs are the Matagorda, Cameron, Georgia jumper, and NMFS hard TEDs.

5.2 TED COMPLIANCE

One major problem with TEDs and sea turtle conservation is the enforcement of the existing regulations. Sea turtles cannot recover if current conservation techniques are not implemented. Successful monitoring of coastal areas and public and industry educational programs are essential for sea turtle conservation. The US Coast Guard and NMFS monitor TED use, but the number of enforcement officers is far from adequate. The Gulf of Mexico is divided into 2 Coast Guard territories, but most of the valuable shrimping area and the majority of the Gulf falls into District 8. The 8th District out of New Orleans incorporates NMFS Statistical Zones 7 to 21, and District 7 out of Miami monitors Zones 1 through 6. Both Coast Guard offices monitor many other oceanic issues as well, so a limited amount of time is devoted strictly to TED enforcement. Since the Coast Guard is busy handling other national oceanic problems, NMFS must initiate most of the enforcement. However, there are only 23 NMFS officers to monitor compliance in the entire southeastern United States, and these officers have many responsibilities and other fisheries to monitor (D. Crouse, CMC, personal communication).

The compliance rates are calculated by dividing the number of violations by the number of boats boarded. When TEDs were first initiated around 1989, there were very poor compliance rates for the Gulf. However, in 1993 most shrimpers were accepting and continuously using TEDs, but there were, and still are, large pockets of resistance (e.g. Western Louisiana). From 1992 to 1994 the compliance rates held steady at 92%, a satisfactory rate of compliance, but many shrimpers were found to have improperly installed their TEDs (M.

Johnson, USCG, personal communication). With the new 1994 NMFS regulations developed to better protect sea turtles, TED enforcement increased. This escalated enforcement by the Coast Guard resulted in a decline in compliance rates as a result of the new regulations.

In order to increase TED compliance in 1994 and 1995, the Coast Guard and NMFS initiated conservation measures including TED workshops for shrimp fishers to teach correct implementation, a Gulf Regional Fisheries Training Center to teach boarding efficiency and TED observing to Coast Guard officers, and detailed information exchange between the Coast Guard, NMFS, and other environmental organizations (M. Johnson, USCG, personal communication). During these workshops, NMFS stressed that a net loss of shrimp was not necessarily the result of TED use, since most shrimp trawls with TEDs actually increase shrimp catch by eliminating heavy bycatch and increasing tow times. As a result of these innovative educational efforts, the industry adhered to the new regulations and rates shot up to 97.6%. There has definitely been an improvement in Coast Guard and industry relationships, as a result of these cooperative and communicative measures.

Prior to 1994, the Coast Guard did not track TED use as thoroughly, but up through 1992 the 8th District averaged 1000 boardings per year. These boardings incorporate all fish and mammal species monitoring, but most of the boardings involve TED enforcement. Overall, there are many more TED boardings than finfish boardings, but that is in direct proportion to the amount of fishers in the Gulf of Mexico. There is an overwhelming ratio of 3 shrimp fishers to 1 hook and line fisherman in the Gulf (M. Johnson, USCG, personal communication). In 1993 the number of boardings doubled to 2000, and as a result of the emphasis on TED regulations in 1994, total boardings increased to 4000 per year. This number stayed at 4000 in 1995, which divided into 3000 TED boardings and 1000 finfish boardings. In 1996, total boardings were around 3500, with 2724 TED boardings. As of June 11, 1997, the Coast Guard had conducted 1111 TED boardings out of approximately 3000 total boardings, and the compliance rate in the Gulf was 97.6%. Even though the peak shrimping period had not started yet, LCDR Mark Johnson, the fisheries expert in Coast Guard District 8, was very optimistic about compliance rates holding steady.

When the Coast Guard enforcement agency moves into an area, the compliance rates generally decline. After the agency is in the area for approximately 2-3 weeks, the compliance rates increase. As with any enforcement effort, more violators are detected every time a new area is entered. The Coast Guard usually stays in an area for a 2-week period on average, but officers must continue monitoring until the desired compliance is up to the master plan percentage (predetermined by Coast Guard officials). The total number of TED boardings are dropping because compliance rates are increasing, fishers are accepting TED regulations, and, according to the Coast Guard, increased monitoring would not produce different compliance results. The Coast Guard does not have the manpower to continue strict monitoring efforts if the compliance rates continue to remain high (M. Johnson, USCG, personal communication).

In contrast to the high levels of compliance found by the Coast Guard and NMFS, Earth Island Institute and the US Humane Society conducted an undercover investigation in April 1997 that found the contrary. This report found that 13 out of 41 shrimp trawlers defeated the TED regulations (with 41% noncompliance). The researchers, focusing on Texas ports, directly observed incorrectly implemented TEDs and spoke to several fishers that did not use TEDs. This study is very controversial and questionable given the methods used to detect noncompliance and the scientific basis behind the study. However scientifically controversial, the reported facts remain the same: the undercover investigators found evidence of noncompliance in Texas ports. This specific study interviewed fishers who sewed their TEDs shut, openly killed or injured sea turtles, and felt strong opposition to TED use and enforcement. Furthermore, The Humane Society of the United States report found that shrimp fishers monitor various radios to detect enforcement agency locations. The fishers know when patrols are in the area and "can untie their TEDs in a matter of minutes" (The Humane Society of the United States, 1997). Because many scientists and managers are skeptical of this study's merit, it is doubtful that many new regulations will be based on these results.

Regardless of the high compliance percentages, some fishers will always try to bend the rules. There are two common methods for sewing TEDs shut, according to Coast Guard reports. The fisherman can use a thick nylon monofilament line to hold the TED flap to the net, and string the line up to the deck. The TED is rigged so that during a haulback, the deck hand can pull the line and all of the contents in the net dump out into the water. Another method entails a solid object, like a chopstick, inserted into the TED to hold it shut. When the enforcement agency boards the boat, the deckhand can shield the TED with his/her body and pull the solid object out, showing a clean TED (M. Johnson, USCG, personal communication). On some boats, there is not an opening in the net at all. An extra piece of material, or a "fake flap", is attached to the net to give the appearance of the TED being open (The Humane Society of the United States, 1997).

The shrimp fishers in the Gulf still harbor resentment of the federal government because of TED legislation, but they are using the devices nonetheless (McQuaid, 1996). The main reason that shrimp fishers are still hesitant about effectively using TEDs is that they fear a substantial shrimp loss. However, shrimp loss was only found to be 0.7% in a study using Georgia and Super Shooter TED-equipped nets (Renaud et al., 1991). Furthermore, the Georgia and Super Shooter TEDs showed no significant difference in shrimp catch per unit effort (CPUE) between standard and TED-equipped nets. When TEDs are properly installed and used, shrimp loss is minimal and the CPUE does not differ from a standard net. In another study by Renaud et al. (1993), reductions in shrimp harvest were found to range between 3.6-13.6%, depending on the type of TED. Regardless, the reduced shrimp catch with a TED-equipped trawl does not create additional shrimp mortality and these shrimp are then subject to recapture (Ward et al., 1996). Shrimp lost from the first trawl could then be caught by the same shrimper in a second trawl. Obviously, additional research, money, and effort need to focus on new technology for reducing sea turtle captures and maintaining a viable shrimping industry.

6.0 A SEA TURTLE SPATIAL ANALYSIS IN THE GULF

Given the complex sea turtle and shrimper associations, future studies must concentrate on the location of the sea turtles and the circumstances of the biological interactions. Managers, scientists, and policy makers need to know where the sea turtles are located if conservation methods are to be initiated.

Sea turtle population estimates and mortality have long been concepts of skepticism and debate. Nesting turtle populations have been historically used as a basis for measuring offshore turtle populations. Yearly trends in number of sea turtle nests remain the most widely available and accepted indicator of turtle populations (Turtle Expert Working Group, 1998). However, these numbers are definitely skewed since they only account for the number of reproductively active females in the population, and not the males or juvenile sea turtles. For example, in some species like *Caretta caretta*, sexual maturity is delayed so nesting trends are extremely impractical for loggerhead population estimates. Beach strandings have also been used to determine offshore mortality and the number of turtles in the water. But a larger amount of stranded turtles does not necessarily imply that there are more turtles offshore. At-sea mortality could be the result of several environmental and human initiated factors, and the source of mortality could affect the entire offshore population. Therefore, an in-water survey is the best available method to determine actual sea turtle populations. One possibility is a fishery independent survey using trawls with no TEDs and short tow times. This method would capture turtles so they could be counted, but the short tow times (less than 60 minutes) would not increase mortality (Henwood and Stuntz, 1987). There are many finfish trawlers that could be trained to record the number of turtles caught or detected in the water.

Another method to measure the number of offshore sea turtles is through an aerial survey flight. Aerial surveys are considered to be the only practicable means of determining the relative distribution and abundance of animals over extensive areas (Bayliss, 1986). In this study, aerial survey data were used to assess the spatial dynamics of sea turtles in the Gulf. However, at-sea aerial observations should not be considered synonymous with the total population of marine turtles. Aerial surveys only account for the percentage of turtles near the surface, and these turtles are generally only a small proportion of the total population. Regardless of the number of turtles observed, aerial surveys are useful for mapping the relative abundance of sea turtles and high intensity locations. In a given area, the number of turtles on the surface should be similar in proportion to the number of turtles submerged throughout the entire Gulf. This study maps the abundance of sea turtles in the Gulf, as well as the areas of high shrimping intensity, to exemplify the Gulf sea turtle and shrimping dynamics.

7.0 AERIAL SURVEY METHODOLOGY

7.1 AERIAL SURVEY LOGISTICS

Sea turtle observations were obtained via several aerial surveys conducted by NMFS in the Gulf of Mexico. The data set used in this analysis was compiled and received from NMFS Pascagoula. The aerial survey sea turtle sightings were collected from 1992 to 1994 in three separate surveys. During these surveys, sea turtle sightings were recorded and an adequate sea turtle database was compiled. The attributes of the aerial survey are shown in Appendix 3.

7.1.1 THE 1992-1994 GOMEX SURVEYS

The purpose of this survey was to estimate cetacean abundance and distribution in the Gulf of Mexico coastal and continental shelf waters. The survey was designed to replicate the 1983-85 Regional GOMEX surveys, using the same depth-stratified block design as practiced in Thompson et al. (1991). The GOMEX surveys, taken from the Gulf of Mexico, were conducted during 1992, 1993, and 1994 time periods. GOMEX92 was conducted from September 13 to October 24, 1992 from Brownsville, TX to Lafayette, LA (Anon., 1992). GOMEX93 was conducted from September 17 to October 19, 1993 from Lafayette, LA to Cedar Key, FL and GOMEX94 was performed from September 28 to November 9, 1994 from Cedar Key, FL to Key West, FL. The transects extended from the shoreline to approximately 9.3 km past the 193 m (100 fathom) isobath. A more detailed description of the methods and procedures can be found in Blaylock (1993) and Blaylock and Hoggard (1994).

The survey platform was a NOAA owned DeHavilland DH-6 Twin Otter aircraft with a plastic bubble window on each side of the plane. Thus, observers on both sides had forward, lateral, rear, and downward visibility. The location data and sightings were collected into a portable computer interfaced with a global positioning system (GPS). A Loran-C navigation receiver backed up the GPS system. All GOMEX surveys were conducted at an altitude of 229 m and an approximate speed of 220 km/hr.

7.2 AERIAL SURVEY ENVIRONMENTAL CHARACTERISTICS

The data used in this analysis were obtained from 3 separate aerial surveys ranging from 1992 to 1994, and as stated, the specific individual conditions vary slightly. However, the overall caveats and survey problems are consistent for each survey flight. Weather, time of day, observer variations, habitat, behavior of the animal, and the size of the organism influence the probability of detection (Buckland et al., 1993). Survey characteristics should be considered when performing a survey, but Mullin et al. (1991) found that windy weather is most often the greatest hindrance in completing a survey.

7.2.1 WATER CLARITY

In any aerial survey, conditions vary from day to day and some organisms may be missed due to minor weather variations. Water clarity directly affects the ability to view animals in the water, and obviously in clearer water more turtles are observed. In the Gulf, water clarity varies with area. The coast of Florida has better water clarity compared to murky Louisiana waters. However, in some areas of Florida (e.g. near the Ten Thousand Islands south of Cape Ramono) the waters can become very turbulent and approach the same water clarity as Louisiana waters. This is probably largely due to increased runoff and nutrient loading around the Everglades area (W. Teehan, FMFC, personal communication). Some waters in Texas (especially in Zones 20 and 21) are also very clear, oftentimes similar to Florida clarity (M. Renaud, NMFS, personal communication). Therefore it is difficult to extrapolate an overall clarity for each Gulf of Mexico region. In each aerial survey however, surveys were not conducted if the water was not reasonably clear and the sea state was above a Beaufort scale of 3.

A Beaufort scale of 1 and 2 is characterized as a smooth water surface without breaking waves, and a scale of 3 consists of a sea state with scattered white caps (Fritts and Reynolds, 1981). Any unsatisfactory weather conditions would affect the recording of sea turtles since turtles are rarely seen at a distance (Fritts and Reynolds, 1981). For example, Bayliss (1986) found that overcast weather depressed turtle counts. In each survey there were several days when the survey was conducted at less than optimal weather conditions. Since there should be a random arrangement of Beaufort 1, 2, and 3 type days in each survey, one survey year would not be less reliable than another would. For example, the probability of a cloudy, choppy day was the same for the 1992 GOMEX study as it was for the 1994 GOMEX survey. Therefore, the number of inadequate days should be relatively constant over all surveying years and the overall turtle distribution estimates would not be altered.

7.2.2 SUN STATE

Sun state obviously affects the ability to observe organisms in the water, but again, the surveys were not conducted if visibility was not adequate. Solar glare was a large hindrance in sighting species, as the amount of reflected sunlight from the ocean surface affected the observer's ability to detect organisms. Since the location of the aircraft, position of the sun, and intensity of the sunlight are dynamic factors, a portion of the glare could not be avoided (Fritts and Reynolds, 1981).

Sea turtle surfacing times are greatly influenced by the time of day, with one study finding the 0700 hour to have the longest turtle surfacing times (Murphy and Hopkins-Murphy, 1989). With a longer surfacing time, more animals would be able to be observed. Since each study was conducted in mid-day hours, the number of animals observed was probably relatively high for each survey (compared to dusk hours). Even though the time of day influences turtle sightings, Bayliss (1986) found that turtle observations increased at high tide. This study did not distinguish species based on tide levels.

7.2.3 Observer Characteristics

For each survey, the observers were trained on aerial survey specifics and species identification, or the observers were already experts in aerial surveying. Even so, there is some degree of error with each observer. Visual scan patterns, observer confidence, and individual reaction times are important factors, but these variations can be minimized by extensive training (Fritts and Reynolds, 1981). The observer's interest in the survey, training, and experience are additional reasons why individuals vary widely in their ability to detect objects (Buckland et al., 1993). Observer fatigue is a large problem in aerial surveys, so to alleviate fatigue and possible missed sightings in these surveys, each observer was rotated approximately every 30 minutes.

7.2.4 Sea Turtle Species Characteristics

Turtles were usually seen floating at the surface or swimming immediately below the surface, and the behavior of the sea turtle greatly affects the outcome of the sighting (W. Hoggard, NMFS, personal communication). Turtles were most often viewed directly from above and rarely seen from a distance. Head width, carapace length, body proportions, and color are useful criteria when identifying turtles, but these characteristics depended upon adequate light, sufficient observation time, and proper sighting angle (Fritts and Reynolds, 1981).

Loggerhead sea turtles are easy to identify from aerial survey flights. They are relatively large bodied with massive heads, and are reddish-brown in color. Usually, only larger sea turtles are identified from aerial surveys, so smaller Kemp's ridleys and juveniles could have been difficult to observe at high altitudes. When a small sea turtle was seen with a roundish, gray-colored carapace, this turtle was determined to be a Kemp's ridley. Leatherback turtles are easily separated from other turtle species in aerial flights, as a result of their unique body characteristics. Species identification is possible at high altitudes with leatherbacks or loggerheads, but it becomes risky with Kemp's ridleys or juvenile turtles. Therefore, combining all species in the data set alleviated any identification problems.

There is the potential to miss a portion of the turtles in an aerial survey. A previous study by Mullin et al. (1991) concluded the underestimation of sea turtle density by an unknown degree. They found that they missed sighting some of the larger marine mammal herds, later identified through an aerial survey videotape. In this study, a missed turtle in one area was probably missed in another area (given the similar weather and surveying conditions for each year). This study only deals with a spatial estimate, and not the total population of turtles, a missed turtle in each zone would not greatly affect the spatial dynamics. Therefore, the proportion of turtles sighted would be representative of the overall Gulf population. In addition, juvenile sea turtles were most likely undetected in aerial surveys as a result of their small size. A future in-water turtle survey should be conducted in order to adequately assess the number of juvenile sea turtles.

7.2.5 Water Depth

There could be a difference between shallow water and deep water aerial survey sightings. Waters of moderate to shallow depth usually support a higher degree of species diversity and abundance than waters offshore (Norse, 1993; Fritts and Reynolds, 1981). Deeper waters allow the turtles to spend more time under the water and they could easily be missed in a survey. In shallow water, the turtles have a narrower depth range in which to dive and could spend more time at the surface, making it easier to see a turtle in an aerial survey. On the other hand, turtles could spend the same amount of time on the surface in deep and shallow waters, and the difference would lie with deep water turtles spending more time swimming in the water column than on the bottom. The sighting ability would probably be the same in shallow and deep waters. Either way, water depth has the potential to affect aerial survey sightings.

In addition, nearshore waters in the Gulf of Mexico are generally more turbid than offshore waters as a result of increased sediment load and coastal development (S. Epperly, NMFS, personal communication). The Gulf water clarity would allow an aerial observer to see deeper into the water column in the offshore waters. With an increased visibility in the deep water column, more turtles could be seen under the water. Water depth could influence the results of a Gulf aerial survey by increasing the number of turtles sighted offshore, even though more species have historically been found to reside in shallower coastal waters.

7.2.6 ALTITUDE

Fritts and Reynolds (1981) defined a high altitude flight to be one of approximately 228 meters. They found that at higher elevations a broader field of vision is obtained and a longer amount of time is available to correctly identify an organism. At a higher elevation, the observer has a large picture of the entire surveying area and can observe a wide range of water. At lower altitudes more animals can be seen and recorded, but the fast flying time relative to the ocean surface could result in missed species. Furthermore, at lower altitudes many species hear the noisy aircraft and subsequently dive. As the aircraft passes the animal, the organism is underwater and not available for recording. A 1988 oil platform survey, conducted at a low altitude (229 meters) and a slow survey speed (167 km/hr), actually saw sea turtles diving in response to the plane (Lohoefener et al., 1990).

Sea turtle aerial surveys are conducted much differently than marine mammal or fishery surveys. If the aerial survey was conducted specifically for sea turtles, the optimal altitude would probably be lower (167 m) compared to the optimal altitude for marine mammals at 250 m (W. Hoggard, NMFS, personal communication). A lower altitude would affect the ability to view small sea turtles, different species, and perhaps change the estimated density numbers. Regardless of a high or low surveying altitude, if the altitude remained the same over the entire Gulf, the proportion of turtles would be constant if the surveying conditions were similar (comparable Gulf turtle densities).

Given the obvious surveying hindrances, there is still a substantial amount of validity in an aerial survey. Epperly et al. (1995a) found that an average of 97.2% plywood "turtle" models were seen from an aerial survey pass at 152 m. Realizing the logical options, aerial surveys seem to be the best available and practical indicators of in-water sea turtle abundance.

8.0 CALCULATING SEA TURTLE DENSITIES

8.1 BACKGROUND

Before conducting any analyses, all of the sighted sea turtle species were pooled together (including both hardshells and leatherbacks). As mentioned previously, pooling all species not only alleviated the problem of species identification, but also created an extensive sea turtle data base with a larger sample size. All sea turtle species found in the Gulf are listed as threatened or endangered under the ESA, so each species in question deserves increased protection and innovative management techniques.

Only relative sea turtle densities were calculated in this analysis; we did not try to estimate the actual sea turtle population. There are several problems in calculating the entire sea turtle population for the Gulf of Mexico. First of all, in an aerial survey the observer cannot view every organism, since most turtles spend a significant portion of their lives under water. Sightings only account for a small proportion of the turtles in the Gulf, and time spent at or near the surface varies with each sea turtle species. Usually turtles at the surface are engaging in basking, feeding, orientation, and mating, and are subsequently easy to detect. But sea turtles spend only about 4-41% of the time at the surface (Epperly et al., 1995b; Musick et al., 1994; Lutcavage and Lutz, 1997), so it is difficult to determine the overall population size for each species.

In order to estimate total population size, submersion adjustment factors have been used in previous studies to correct for the submerged turtles (Musick et al., 1994). Because this study was only concerned with the relative abundance and proportion of turtles in the Gulf, not the total population size, the submergence correction factor was not implemented. The submersion adjustment factor only represents a scaling factor for the total population size, and is not needed for an assessment of the relative abundance of turtles in the Gulf. The percentage of surface time varies with each species, but because all of the species sighted were pooled together, the submergence times should be constant over the entire Gulf. For example, the amount of time a sea turtle spends under water should not drastically affect the proportion of sea turtle sightings from Zone 3 to Zone 17, because the submergence times for all turtles in each zone would be generally equal. Alternatively, if submergence times vary with species and different species vary in distribution over the Gulf, the frequency of turtle sightings could be different in each location. Therefore the relative abundances could vary. These factors should be considered when interpreting the results.

Plotting the exact locations of sea turtle sightings from the aerial survey data would give a rough estimate of sea turtle spatial dynamics. However, these plots do not correct for different transect lengths or the amount of area surveyed. For instance, an initial observation shows that there are many more sea turtles in the Florida Keys region (Zones 1 and 2). This assumption could be true, but there are also more transects flown in this area when compared to Zones 8 and 9. If more effort is spent in one zone, more species would be sighted creating an inaccurate abundance estimate. So the question remains, is there a high abundance of turtles in a particular area, or is there just a greater amount of surveying effort?

In order to address this question, sea turtle densities were calculated to find the actual number of sighted turtles in a given area. Density estimates correct for the surveying effort and give a more reliable indicator of sea turtle spatial dynamics by incorporating the transect lengths and area sampled. Even though the 1992, 1993, and 1994 GOMEX surveys were conducted in line transect format, strip transect methodology was used to calculate densities. All of the information needed for strip transect methods can be obtained from line transect surveys.

8.2 ESTIMATES OF DENSITY

8.2.1 STRIP TRANSECT METHODOLOGY

The basic premise behind strip transect methodology is that a strip of a specific width is defined in the aerial survey and only the animals within this strip are counted. Densities and variances of the density estimates can then be calculated once a strip width and area are determined.

One problem with strip transect methods is that if a strip is too narrow (which therefore assures that all the surfaced animals are seen) the confidence intervals on the total estimate would be unsatisfactorily wide (Eberhardt et al., 1979). Furthermore, it is difficult to accurately determine where the visibility drops off. The width of the strip is determined by the researcher, and this can introduce a degree of error.

Strip transect methods are effective in estimating relative species abundance, but if we were interested in calculating the population size of the Gulf of Mexico sea turtles, line transect methods would be more applicable.

8.2.2 Line Transect Methodology

Line transect methods are based on the theory that as an observer searches farther from the flight line, more animals will be missed because detection probability decreases with distance (Jefferson, 1996). There is a greater likelihood to observe an animal closer to the flight line of the survey platform, as opposed to one at a distance. The value of g(0) refers to the probability of detecting an object, given a specified distance from the line. At a distance of 0, g(0) would equal 1.

Line transect methods implies several assumptions outlined in Burnham et al. (1980): the animals directly on the line will never be missed (seen with probability 1); animals are viewed at fixed initial sighting positions; no animal is counted twice; sightings are independent events; and the transect is randomly located in the survey area. These assumptions ensure the accuracy of line transect methods for estimating densities, but any of these assumptions can be violated in aerial survey sampling.

As stated in Burnham et al. (1980), the problem in line transect analysis is to construct a probability density function (pdf) based on perpendicular sighting distances to estimate f(0). The perpendicular sighting distance is the distance from the flight line to the sighted organism. The value of f(0) is defined as the inverse of one-half the effective strip width (width from the plane to the determined strip distance), which is found to be the pdf value exactly on the flight line at a perpendicular distance equal to 0 (Epperly et al., 1995a). The value of f(0) is influenced by the ability to view animals from an aerial survey altitude. The ability to see animals in cloudy and clear water would differ and therefore the f(0) values would vary.

8.3 DATA ANALYSIS

8.3.1 Data Manipulation

Each aerial survey conducted in 1992, 1993, and 1994 used the same surveying technique: the same altitude, the same aircraft, and the same speed. The area surveyed was the only parameter that varied from year to year. As outlined previously, the ability to view species is largely dependent on the altitude, weather, and surveying technique. If the surveying methods are the same, the ability to sight turtles would be similar for all years surveyed, given minor weather fluctuations. Given this rationale, surveys conducted in 1992, 1993 and 1994 were combined to find the sea turtle densities throughout the Gulf. Combining surveys also provided a comprehensive view of the entire Gulf (Zones 1-21) instead of just the Western, Central or Eastern regions. The goal of this study was to delineate a spatial trend over the entire Gulf, so combining the years would provide a more encompassing view of the complete area.

Before determining sea turtle densities, the data were converted into a useable format. The data set contained values for the sighting angles and altitude of the aircraft, so perpendicular sighting distances were calculated using basic geometric equations (Appendix 4). The sighting angle is the angle between the line of travel and the line of sight to the object at the moment of detection (Burnham et al., 1980). The sighting angle is usually recorded in the aerial survey data set. If the values were given in sighting increments (e.g. 1-8), the sighting angle was determined to be the midpoint of the sighting increment range. For example, if the sighting increment value was 3 (range of 21-30°), the sighting angle was determined to be 25.5°. This method has been used in previous aerial survey density estimates and it is the best way to effectively estimate the sighting angle based on the available data (K. Mullin, NMFS, personal communication).

Each specific transect length was also calculated. The aerial survey flew at different latitudes and longitudes, and the length of a minute longitude varies with latitude. Therefore, a cosine conversion was implemented into the geometric equation to find the length of each transect.

The transects were then divided into depth bins, in order to create individual transects for each depth zone. For instance, a transect that was flown from 0 to 73.2 meters (0 to 40 fathoms) was divided into 4 subtransects (e.g. 1 transect for 0-18.3 m; 1 transect for 18.3-36.6 m; and so on). All surveying effort beyond 73.2 meters (40 fathoms) was combined. The process of dividing the transects incorporated the starting, continual spacing, and ending cards as defined in the aerial survey, and determining when these cards crossed the depth field in the data set. Sea turtles are commonly found in shallower waters, so the main purpose of dividing the transects into depth bins was to determine if the densities of turtles in the nearshore subzones were higher than those more offshore (e.g. 54.9-73.2 meters). The areas intersected by the fishing statistical district and depth zone will be referred to as a "subzone" (Appendix 1).

A histogram was constructed of all the perpendicular sighting distances grouped into 1992, 1993, and 1994 years in 50-meter intervals (Figure 5). From this histogram, a strip width of 50-250 meters was established. The frequencies of turtles within each perpendicular sighting distance range are represented in percentages of the total number of turtles sighted in each year. The heavy black vertical lines represent the range of the strip width, and the majority of values within this strip are higher than the perpendicular sighting distance values outside the strip. By choosing a starting strip distance of 50 meters from the survey platform, we reduced the probability that a turtle was missed due to nearness to the plane. Nearness to the plane could result in turtles diving to avoid the noisy aircraft or acute observer viewing angle (Epperly et al., 1995a). The ending distance of 250 meters was determined by the decline in perpendicular sighting distance values. This strip width would reduce the probability of missing a turtle due to the distance from the plane (reduced detection). The strip of 50 to 250 meters was measured on both sides of the plane for a total strip width of 400 meters.

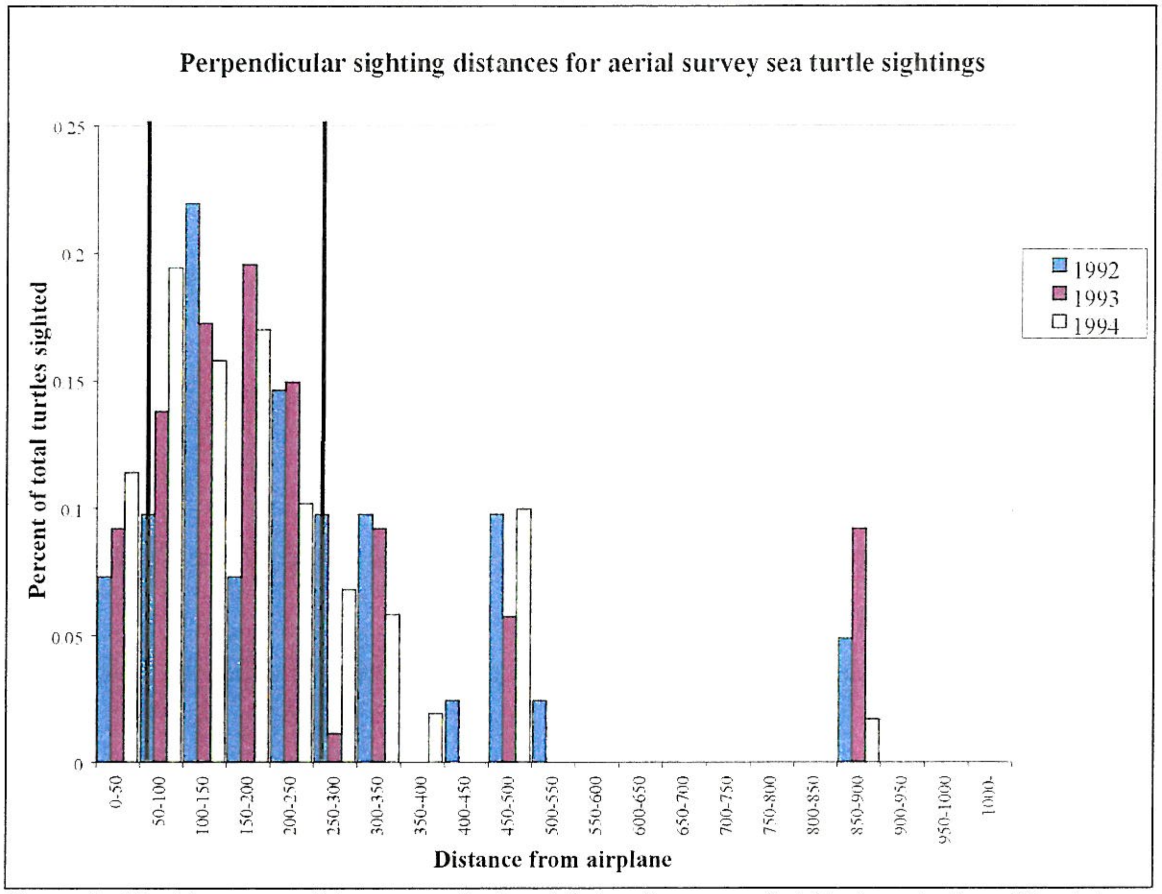

Figure 5. The histogram of the perpendicular sighting distances of sighted sea turtles. The data are divided into surveying years, and within the heavy black lines represent the selected strip width (50-250 meters).

8.3.2 STRIP TRANSECT CALCULATIONS

Turtle observations sighted within the strip width of 400 meters were used to calculate ratio-to-size estimates of density. Another estimate of density, the proportional-to-size estimate, could have been used, but when the sampling area is small there is unlikely to be any detectable difference between the two methods (Cochran, 1977; Jolly and Watson, 1979). The ratio-to-size estimate is usually used when the probabilities of species detection are equal, but again, there would be little difference between the two methods in this study.

After the transects were divided into subzones, turtle densities were then found for each subzone (5 depth bins x 20 statistical zones = 100 total subzones). Strip transect methods estimate turtle densities by considering the number of turtles sighted as well as the length and area of the transect (survey effort). The density of turtles on the surface of the subzone (D_R) is found by dividing the number of turtles sighted in the subzone (Y_R) by the total area surveyed in the subzone (M_R):

$$\hat{D}_R = \frac{Y_R}{M_R},$$

Y_R is the sum of the number of turtles in each transect i and M_R is the sum of the area surveyed in each transect i (km^2):

$$Y_R = \sum_{i=1}^{n} y_i \qquad\qquad M_R = \sum_{i-1}^{n} m_i$$

where y_i = the number of turtles in the i^{th} transect; m_i= the area surveyed in the i^{th} transect (km^2), and n = the number of strip transects sampled.

For each subzone density estimate, the variance was calculated using the following equation:

$$V(\hat{D}_R) = \frac{1 - \frac{n}{N}}{n\overline{M}^2} \times \frac{\sum_{i=1}^{n} m_i^2 (D_i - \hat{D}_R)^2}{n-1}$$

where N = the number of strip transects possible in the subzone, given the individual strip area and the total area of the subzone; and

$$D_i = \frac{y_i}{m_i} \qquad\qquad \overline{M} = \frac{M_R}{n}$$

where D_i is the density of turtles in the i^{th} transect; and M is the average area of a single transect (km^2).

When using the ratio-to-size estimate, a bias correction factor must be used in order to determine what proportion of the area was sampled (Cochran, 1977). This correction factor (1-n/N) is calculated by finding how many strips (given the determined strip width) can be laid side by side in the total area of subzone (the distance from one side to the other). In our study, the subzones were not uniform so the distance from one side to the other side of the zone was extremely difficult to determine. Furthermore, within the subzones, some of the transects were not parallel to each other. When determining the distance from one side of the zone to the other, the starting and ending point varied depending on the orientation of the transect. The correction factor is a ratio of the number of possible transects to the total subzone, so the units in question should not alter the variance estimate. Using the distance of the individual strip and the distance from one side of the subzone to the other would be comparable to determining the area of the individual strip and the area of the total subzone. Therefore, to alleviate the problem of the variable subzone lengths and transect locations, we used an area ratio as the bias correction factor instead of a distance ratio. The bias correction factor is thus (1 – the area sampled in the subzone / the total area in the subzone).

8.4 THE DIFFERENCE BETWEEN STRIP AND LINE TRANSECT METHODS

As mentioned previously, there are several differences in strip and line transect sampling. In this study we chose to employ strip transect methods in order to avoid the extensive line transect assumptions. However, several problems must be acknowledged with strip transect methods. One assumption of strip transect methods is that ALL animals are detected within the strip width. This is extremely hard to verify with sea turtle aerial survey data, and this assumption could have been violated. Additionally, in order to avoid missing surfaced animals, the strip must be quite narrow. If the strip is too narrow, the numbers recorded may be so small as to result in unsatisfactory estimates with wide confidence limits. If the strip is too wide, serious underestimation will result (Eberhardt et al., 1979). Obviously, strip transect methods have some caveats that should be avoided with future research. In this study however, strip transect methodology had several advantages over line transect methods.

First, turtles are rarely seen from a distance in an aerial survey (Fritts and Reynolds, 1981). Line transect methodology requires sighting species at varying distances in order to conduct a reliable pdf. It is difficult to determine if all turtles are seen on the transect line at great distances. Furthermore, a definite mathematical relationship between visibility and distance from the observer has not been established (Eberhardt et al., 1979). Turtles viewed from the air are usually dark in color, but they are difficult to see at an angle (Fritts and Reynolds, 1981). With strip transect methods, the chosen strip was 200 meters on each side of the plane and this was determined to be a sufficient distance to view the majority of the animals

(Figure 5). Line transect methods would be inefficient if density estimates are based largely on the ability to view turtles at great distances.

Second, strip transect methods have been shown to underestimate turtle densities, while line transect methods can underestimate or overestimate densities depending on the universality of the pdf. For example, a study by Epperly et al. (1995a) determined that strip transect density estimates were lower than line transect densities in 75% of the samples. In this Epperly et al. study, line transect densities were probably overestimated, while strip transect densities were underestimated. With line transect studies, the researcher cannot to determine which way the bias is going (over- or underestimation), therefore these results should not dictate a policy decision. Sea turtles are endangered species and the populations remain small, so underestimating the number of turtles in the water would not be detrimental. On the other hand, line transect methods could either under- or overestimate the number of turtles in the water and subsequent management decisions would therefore be based on these uncertain approximations. If the bias is consistent, a reliable relative abundance can be obtained; the problem lies when the direction of the bias is uncertain (as with line transect methods).

Third, strip transect methods are more reliable for this study's purpose. One criticism of strip transect methods is that observations outside the strip width are not included in the density estimates. In-water turtle data are difficult to obtain and accurate data sets are scarce. Furthermore, every sighted turtle is important because sea turtles are rare species and minimal in-water research has been conducted on these animals (Eberhardt et al., 1979). This study eliminated 37.2% of the sighted turtles by excluding the animals within the 0-50 meter and greater than 250 meter zones. Excluding a large percentage of turtles could impact density estimates, but without additional research, it would be difficult to estimate this influence. Regardless, the sightings within the specified strip width should provide a reliable estimate of relative turtle abundance.

The choice of strip or line transect methods also depends on the study goals. Excluding data points would be extremely detrimental if the goal was to estimate the total population. Line transect methods would be better for population density objectives, because all sightings are used in the calculations. In this study, the goal was not to establish population densities, but instead to determine relative abundance estimates for turtles throughout the Gulf of Mexico.

Therefore, if strip transect methods were used throughout the Gulf, the relative abundances would be comparable. While excluding data might be risky when calculating densities of endangered species, this study chose a careful, relatively narrow strip width to get a reliable estimate of the relative density in the subzones.

Finally, strip transect methods do not need to determine a f(0), but one of the major facets of line transect methods is the calculation of f(0). As mentioned previously, f(0) is dependent on the ability to view organisms from an aerial survey. The ability to view a turtle in clear water would be different than the ability to see an animal in cloudy water, so the f(0) could differ in each of these two locations. If the sighting conditions are similar, one f(0) can be calculated. The problem with the Gulf of Mexico is that the water clarity differs drastically from location to location. For example, the Gulf coast of Florida generally has clear water, but with the increased sediment load and coastal development, several areas can become extremely turbid. It is difficult to generalize the overall water clarity in the Gulf, because it changes so radically in short distances. A f(0) could have been calculated with each small change in water clarity, but that was not realistic for this study. Strip transect methods do not require the calculation of f(0), so the potential for error with varying water clarity would be eliminated.

9.0 ADDITIONAL MATERIALS USED IN ANALYSIS

9.1 SHRIMPING EFFORT DATA COLLECTION

Gulf of Mexico shrimping effort is collected through a port agent program, currently run by the NMFS Fishery Reporting Specialist, Margo Hightower, in Louisiana and Texas. Two types of data are used to estimate shrimping effort: dealer data (landings through a recognized dealer) and interview data (actual interviews with captains following a fishing trip) (Nance, 1993). There are 13 NMFS port agents who monitor the shrimp landings and interview the boat captains. The data administrators are extremely adamant about data quality, editing, and maintenance, so this Gulf of Mexico shrimping effort data is considered very reliable (M. Hightower, NMFS, personal communication).

The port agent asks the captain a series of detailed questions about where they fished, (including fishing depth and location), duration, type of gear used, and time of day. The current port agents have been with the agency for many years, and the fishers know these agents and regard them as trustworthy. The port agent system is based upon trust, strengthened by the fact that the agents do not report any violations. The port agents are only interested in where the shrimp are caught, so the fishers now realize that they are not penalized for telling the truth, even if they are breaking the respective fishing laws.

Alternatively, Florida fishing effort is determined by a trip ticket system, and then compiled in the NMFS Galveston lab. The trip ticket system requires the fishers to fill out a form with several questions, including where they fished, what type of gear they used, and what size shrimp they caught.

One problem with the port agent process is that it is not randomized. The captains must be willing and present at the port in order to be interviewed. Several years ago, the State of Texas tried to randomize the interviewing process via a computer-generated list, but this process was unsuccessful. Most shrimp boats do not have a specified landing port or arrival time, so the interviewers did not know when or where the boats would be, and many times the shrimping boats were too busy or unavailable for an interview. Therefore, the port agents must talk to the local shrimp houses, get an estimate of shrimp boat arrival times, and interview to the available captains.

The port agent program has been in effect for many years, but prior to May 1984 the interviewing process was voluntary. In May of 1984, it became mandatory to give shrimp fishing information to NMFS port agents. However, when TEDs were first implemented in 1987 and 1988, the interviewing rates started to drop off. Many fishers refused to give interviews during this time, because they viewed NMFS as the opposition agency. When TEDs were made mandatory in May 1989, the port agent process became dangerous. The shrimp fishers were extremely irate about TEDs and retaliated by blocking shipping ports and other violent techniques. As a cautionary measure to protect the safety of the port agents, 60% of the captain interviewing was curtailed for several months during 1989 in Texas and for several years in Louisiana (M. Hightower, NMFS, personal communication). During the years of limited data, the majority of shrimping effort was determined by modeling techniques in order to estimate effort for the entire Gulf.

Because the interviewing process is not randomized and the interviewers have to collect data where available, there are many areas in the Gulf that do not have any actual shrimping effort data estimates. In order to assign shrimping effort to these areas, a statistical model was constructed to assign effort to the fishing zones and depths. Ms. Hightower feels that this process is the best way to estimate shrimping effort throughout the Gulf, and to date this technique has been the most successful.

9.2 SHRIMPING INTENSITY

The shrimping effort data received by NMFS Galveston was measured in days fished (24 hours of actual fishing). Each subzone does not have the same area throughout the Gulf of Mexico. Therefore, in order to standardize the effort and correct for the different areas, the data was converted to standardized shrimping intensity. Shrimping intensity was found for each subzone by dividing the shrimping effort (in days fished) by the actual area of the geographical unit. The areas of the subzones were determined previously by Patella (1975). Standardized fishing intensity was measured in days fished per km^2.

In this analysis, only the offshore waters were studied. Data limitations restricted the reporting of inshore water areas, therefore shrimping intensity could not be determined for inshore bays and sounds. Although a substantial amount of shrimping effort is conducted in inshore waters, few turtles are sighted in these areas. In an aerial survey of South Texas waters, only one sea turtle was observed in waters inshore (Reeves and Leatherwood, 1983). Increased shrimping intensity in the inshore waters should not have a large effect on sea turtle populations if there are not many sea turtles in this area. However, this study was conducted in the early 1980s (before TEDs) when turtle populations were extremely low. The general consensus is that there are more turtles in the waters today, so we must realize that these Western Gulf inshore numbers could be much larger. In North Carolina inshore waters, a study by Epperly et al. (1995a) documented a substantial number of turtles. Future studies should be conducted to adequately monitor the density of sea turtles in Gulf of Mexico inshore waters.

These analyses were performed with two separate shrimping intensities. The aerial surveys were conducted from September to October in 1992 and 1993, and from September to November in 1994. One analysis only averaged the shrimping intensity for those particular months to provide for a consistent comparison with the aerial survey sea turtle sightings. In addition, a second analysis used all the shrimping months (January through December) to determine the average shrimping intensity for the entire year. It is possible that turtle sightings are affected by shrimping effort in the preceding months (e.g. May and June), and not only in the current month. The analysis with all-year shrimping takes into consideration previous shrimping activity, which is important because the majority of the shrimping effort occurs in the summer months.

Before mapping the shrimping intensity to determine the Gulf spatial characteristics, the shrimping intensities were converted into the same spatial format as the sea turtle densities. For the reasons explained previously, turtle densities were grouped over the years 1992-1994 to provide a more reliable estimate of overall turtle spatial dynamics. Therefore, shrimping effort was congregated the same way for a more effective spatial comparison with turtle densities.

Also, to compare shrimping intensity with sea turtle densities, the depth bins and areas in question must be the same. The shrimping intensity was originally calculated in 9.1 meter (5 fathom) intervals, but the turtle sightings were combined into 18.3 meter (10 fathom) groupings. Thus, the Gulf of Mexico waters were divided into 18.3 meter (10 fathom) intervals, with all shrimping intensity combined beyond 73.2 meters (40 fathoms). The shrimping effort in waters deeper than 73.2 meters was joined because the percentage of shrimping in deep ocean waters is negligible compared to coastline waters. For example, in the all-year analysis, only 1.5% of the total shrimping effort was found beyond 73.2 meters, whereas 45.8% was fished in 0-18.3 meters (Figure 6). During the fall months, 0.4% of the shrimping effort was found beyond 73.2 meters, and 55.2% occurred in 0-10 fathom waters. In addition, sea turtles in the Gulf of Mexico are generally seen in waters less than 54.9 meters (Murphy and Hopkins-Murphy, 1989; Shoop and Kenney, 1992).

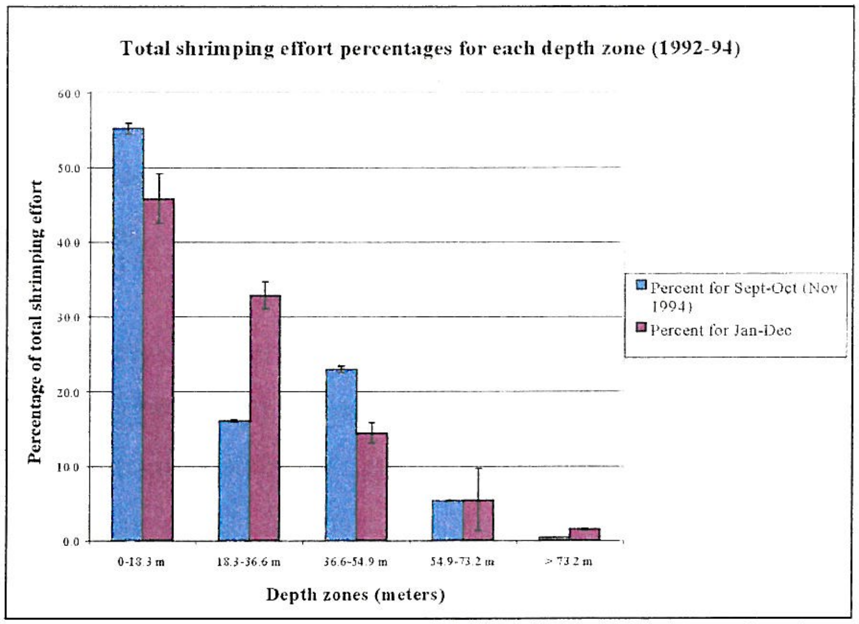

Figure 6. Shrimping intensity (averaged for all year and September through November only) with standard deviations shown.

9.3 ADDITIONAL GIS CONTOURS

Depth contours, statistical zones, and Gulf of Mexico detailed coastline files were obtained from the NMFS lab in Galveston, Texas. The Geological Information System (GIS) packages used were UNIX based ArcInfo and ArcView. ArcInfo was utilized to build map coverages and to edit files, while ArcView was used for overlaying maps and creating a final map product. The GIS allowed for easy file conversion and many file manipulations to obtain a satisfactory map for management use. The map scale depicting the entire Gulf was a 1:15,055,847 ratio in a geographic projection. The maps detailing the Florida Keys region were in a 1:1,234,362 scale, and the dissolved oxygen layouts were in a 1:6,880,442 scale. The map units were in decimal degrees.

9.3.1 COASTLINE CONTOURS

East, west, and north coastline boundaries of the Gulf of Mexico were combined to create a map of the entire United States Gulf coastline. Detailed maps of the Gulf states (Texas, Louisiana, Mississippi, Alabama, and Florida) were overlaid onto the coastline map. This delineated the specific state boundaries as well as distinguishing state features. The state profiles came from the U.S. Geological Survey (USGS) home page in a 1:2,000,000-Scale Digital Line Graph (DLG) file.

9.3.2 Depth Contours

The depth contours received from NMFS were delineated into 9.1 meter (5 fathom) intervals, digitized from NOAA navigational maps. These files have been used in previous abundance estimates and spatial analyses of shrimping effort and sea turtles in the Gulf (Gallaway et al., 1995; Caillouet et al., 1996). The depth contours were combined and the intervals used in this analysis were in 18.3 meter (10 fathom) increments.

After combining all of the depth contours in the GIS, there were some places where the digitizing was choppy and extremely uneven. For example, the 18.3 meter (10 fathom) line went over the 64 meter (35 fathom) line in various places. These depth intervals are obviously not the actual coverages, so the digitizing was probably incorrect. However, these depth contours are taken directly from a NOAA map, so most places were not edited unless obvious mistakes occurred. The depth file was manually edited by deleting the overlapping arc and then connecting it to the corresponding depth line. This process probably resulted in the biggest source of error over the entire map building process. However, the original coverages were most likely not correct because several depths intersected one another in sporadic locations. Connecting the new line to the next arc was the most rational option, providing the most likely contour.

In the Florida Keys area (Zone 1), there were not any depth coverages for 36.6, 54.9, or 73.2 meters (20, 30, or 40 fathoms). The original digitized contours of 36.6, 54.9, and 73.2 meters terminated midway through Zone 1. In this case, the area in question was so small that the existing depth lines were extended to follow the other contours. For example, the 54.9 meter depth line would most likely be in between the 45.7 and 64 meter lines and because this area is extremely small, the 54.9 meter line was manually drawn in between the 45.7 and 64 meter lines. While this might have resulted in a small degree of error, the technique used was the most logical and correct method available.

In order to form a polygon bin for the 0-18.3 meter depth interval, the 0 meter line had to be determined. Offshore areas are defined as seaward of the COLREGs demarcation line, and inshore areas consist of bays and sounds along the Gulf coast (Nance, 1992; Caillouet et al., 1996). A map of the specific COLREGs line was not available, but inshore areas on this map were delineated as all bays, sounds, and waters inshore of barrier islands. Therefore, barrier islands were connected to give a 0 meter marker (all waters behind the islands are inshore waters) because the actual coastline would not be accurate for the 0-18.3 meter depth bin. A line was also digitized to partition the bays and sounds from the coastline, again to form a 0-18.3 depth bin excluding all inshore waters.

9.3.3 STATISTICAL ZONE CONTOURS

The statistical zone coverage from NMFS did not include Statistical Zone 12. However, these boundaries are easy to define from previous literature, other maps, and latitude and longitude points, so the boundary of Zone 12 was digitized into the coverage. Guided by latitude, longitude, and the Chandeleur Islands at the edge of Zone 12, the zone structure and attachment to the Louisiana State tip was drawn. The eastern boundary of statistical Zone 12 is delineated by a set of barrier islands (Chandeleur Islands), with all waters inside the barrier islands considered to be inshore waters. Therefore, all waters in Zone 12 are inshore (50 CFR Parts 217, 222 and 227, June 29, 1987) and because this study only focused on shrimping effort and turtles in offshore waters, Zone 12 was not considered in the analysis.

9.4 STRANDINGS DATA

This study did not extensively analyze sea turtle strandings because we were not explicitly concerned with the reason for the strandings. We were, however, interested in the spatial pattern of strandings, and the distribution of different species throughout the Gulf. Strandings data were obtained from the Sea Turtle Stranding and Salvage Network (STSSN) National Coordinator. Only the fall months of September, October, and November 1992, 1993, and 1994 were considered in order to maintain consistency with the aerial survey and shrimping data. The strandings were then divided into the 20 NMFS Statistical Zones used in this study. The number of turtles stranded in each zone, as well as the different species in each zone was established.

This information provided a basic estimation of what species were located in what areas, to assume general species diversity. For instance, if many different kinds of species were found in a particular zone, policymakers might want to manage this area to increase multiple species protection. If a large number of Kemp's ridleys strand in a particular zone, this could indicate that more Kemp's ridleys inhabit this area and thus, shrimp fishing should be carefully monitored to ensure minimal Kemp's ridley mortality.

10.0 HYPOTHESES

Air and water temperature are likely to influence turtle movement, but other options could also determine Gulf spatial patterns. Before any analyses were conducted, several hypotheses were developed in relation to the location of sea turtles and shrimp fishing in the Gulf:

H_{o1} = A higher abundance of turtles will be located in the Eastern Gulf because habitat in the Eastern Gulf is more suitable for turtles than in the Western Gulf.

H_{o2} = A higher abundance of turtles will be located in the Eastern Gulf because intense shrimp fishing in the Western Gulf has reduced turtles in this location.

H_{o3} = Turtles will not be located off of the Louisiana coast as a result of the hypoxic bottom water conditions.

H_{o4} = Turtles are attracted to shrimp vessel bycatch so turtles and high shrimping intensity will be located in the same areas.

H_{o5} = A higher abundance of turtles will be found in nearshore waters compared to offshore depth zones.

10.1 HYPOTHESIS 1 – SUITABLE TURTLE HABITAT

Depending on the species of turtle and the life stage, the habitat requirements for turtles vary. Hatchlings live in different areas than juveniles, who usually live in different areas than adults. Turtles inhabit different nursery, feeding, and mating grounds throughout their life cycles. Different species in the Gulf have varying distributions, as green turtles inhabit shallow, nearshore, and reef areas with abundant seagrass and algae; loggerheads are found on sandy reefs and in shallow bays with abundant crabs and mollusks; and Kemp's ridleys occur in shallow waters with sandy and/or muddy bottoms with abundant crabs, shrimp and mollusks (Miller, 1997).

Sea turtle foraging occurs over a wide range, but the primary foraging areas for marine turtles are located in average sea surface temperatures and on the relatively shallow continental shelf areas. The majority of the Gulf of Mexico has broad continental shelves and slopes with gradual hills (Kennett, 1982). However, Florida waters are thought to have better habitat availability for turtles than the Texas and Louisiana coasts. The coast of Florida has a wider continental shelf than the Texas coast, with Florida waters generally being shallower.

Seagrass communities are among the most productive, species rich coastal ecosystems and Florida has one of the world's largest seagrass communities (National Oceanic and Atmospheric Administration, 1996). Seagrasses are prevalent off the Florida coast because shallow water allows more sunlight to reach the bottom and stimulate plant growth. Some species of sea turtles (e.g. greens) feed on seagrasses, but seagrasses also provide habitat for other species such as stone crabs, lobsters, shrimp, and mollusks (Valiela, 1995). These crustaceans are primary food sources for loggerhead and Kemp's ridley sea turtles. The southern edge of the Florida Keys also has an extensive reef tract, suitable for turtle habitat. Therefore, one may expect to find more turtles off the Florida coast because of the shallow continental shelf, reef structures, and abundant seagrasses. In addition, high shrimping also occurs around extensive Florida seagrass beds because pink shrimp commonly reside in seagrasses, especially around the Dry Tortugas (National Oceanic and Atmospheric Administration, 1996).

The Western Gulf habitat is composed of some seagrasses, but these areas are generally more dispersed than the Florida west coast and the beds are commonly located in inshore waters. One reason seagrasses are not found as often in the Western Gulf is that the water clarity is poor and not conducive to seagrass survival.

Sediment type could also explain the distribution of sea turtles in the Gulf (Lohoefener et al., 1990). Generally, more turtles seem to inhabit sandy bottom substrate rather than muddy bottom waters. Foraging for prey would be easier in a sandy habitat, because water clarity remains high for these highly visual predators. Muddy sediments contribute to turbid and murky water that may reduce search efficiency. In a study by Lohoefener et al. (1990), significantly more turtles than expected were observed over the sandy sediments east of the Mississippi River. The Gulf coast of Florida is made up of sandy, coarse carbonate substrate, which is suitable habitat for many sea turtle species (Darnell and Kleypas, 1987).

The Western Gulf usually has a muddier bottom, as a result of the large sediment load from the Mississippi River. Contributing to the high level of sediment deposition in this region, the Western Gulf margin has an unique series of gentle folds parallel to the coastline. These folds act as sediment dams to terrigeneous sediment (Kennett, 1982). West of the Mississippi River is made up of fine grain sediment, but from the middle of the Louisiana coast to approximately Zone 18, the sediment is coarse quartz (Darnell et al., 1983). However, a substantial number of Kemp's ridleys could be found in the Western Gulf region because Kemp's ridleys have been shown to inhabit muddy bottoms (Miller, 1997).

10.2 HYPOTHESIS 2 – TURTLE REDUCTION WITH INTENSE SHRIMPING EFFORT

Shrimp fishing is a significant source of sea turtle mortality (Magnuson et al., 1990). Before TEDs were developed, many turtles died in shrimp trawls; 70-80% of strandings are trawling related, but current sea turtle mortality has been successfully reduced through the use of TEDs (Crowder et al., 1995). TEDs were not universally implemented in offshore Gulf waters until 1990, and even then, shrimpers did not generally accept and correctly use this technology. As a result, in the study years 1992, 1993, and 1994, many turtles were probably still being killed in shrimp trawls.

If turtles were once abundant throughout the Gulf, intensive shrimp trawling in areas off of Louisiana and Texas could have drastically reduced these populations. With a high level of shrimp trawling over many decades, more turtles would be caught in the trawls, leading to a decrease in turtle abundance in these areas. Turtle spatial dynamics in the Gulf could be a result of shrimpers reducing the abundance of turtles in high shrimping intensity areas. This would lead to shrimping displacing the turtles in the Western Gulf areas.

10.3 HYPOTHESIS 3 – HYPOXIC BOTTOM WATER CONDITIONS

The large hypoxic zone off the Louisiana coast is caused primarily by the Mississippi River outflow. Runoff from the Mississippi River containing pollutants and nitrogen has significantly contributed to the large oxygen-depleted hypoxic zone in the bottom waters of Zones 13-17. The hypoxic zone generally occurs from late spring to early fall, and breaks up around September and October.

Oxygen deficient conditions do not directly threaten air-breathing sea turtles, but they do affect the distribution of benthic shrimp and other crustaceans that are primary prey for Kemp's ridleys and loggerheads (Gallaway et al., 1995). A hypoxic area would contain a limited biological community and reduced prey. Without an adequate supply of food, turtles would not likely inhabit these locations. This study was conducted in the fall months when the hypoxic zone was dispersing, but the hypoxic zone could still affect the bottom substrate and organisms. Biota affected by the hypoxic conditions would die or move elsewhere during the summer. It has been speculated that several months are required before bottom dwelling organisms move back into the newly oxygenated waters (K. Craig, DUML, personal communication).

If the hypoxic zone influences turtle prey and distribution, turtles would not be present in the hypoxic areas in the Western Gulf. Shrimping is limited in this hypoxic zone as well, because the worms that live on the bottom are staples for shrimp and these worms are dying from lack of oxygen (Turner, 1995). However, there could be shrimping effort associated with this area because of the modeling techniques used for effort interpolation.

10.4 HYPOTHESIS 4 – TURTLES AND SHRIMPING IN THE SAME AREA

Another possibility dictating spatial dynamics in the Gulf is that turtles and shrimp fishers are located in the same area. Turtles are thought to feed on bycatch from shrimp boats, which includes small shrimp, fish, crabs, and mollusks. Species feeding on crabs and bottom-dwelling invertebrates (e.g. Kemp's ridleys and loggerheads) could associate themselves with the shrimp vessels in order to consume the bycatch. Adult Kemp's ridleys primarily feed on crabs and often have fish in their guts that they could not normally catch (Manzella et al., 1988). Because Kemp's are generally too slow to capture these species themselves, these turtles are probably learning to feed on discarded trawl bycatch (Magnuson et al., 1990). In one analysis, the gut contents of 101 stranded Kemp's ridleys contained numerous shrimp, so it appears that Kemp's ridleys are consuming items discarded from shrimp trawls (Shaver, 1991). Furthermore, many Kemp's ridleys have crabs and fish with the small gastropod scavenger *Nassarius* in their guts. This is a strong indication that the food was already dead when it was consumed by the turtle (Manzella et al., 1988).

Unfortunately, turtles occupying active shrimping grounds would then have a greater likelihood of becoming entangled in the shrimp trawl. Juvenile Kemp's ridleys inhabit many of the same areas where shrimp and crabs occur, so it is not unusual that a large number of these turtles are caught in shrimp trawls (Manzella et al., 1988).

If turtles are feeding on shrimp bycatch, the spatial analysis would depict turtles and shrimp intensity in the same locations. More shrimping occurs in the Western Gulf, so under this rationale, a greater abundance of turtles would be noted in the Western Gulf as well.

10.5 HYPOTHESIS 5 – TURTLES LOCATED IN NEARSHORE AREAS

A study by Gallaway et al. (1995) stated that more turtles (Kemp's ridleys in particular) live in nearshore waters. Gallaway et al. (1995) based this suggestion on the location of trawl captured turtles and satellite tracking data. Kemp's ridley turtles are generally found close to shore (0-9.1 m depth), while loggerheads are found further offshore than ridleys. The majority of loggerheads have been observed in waters less than 20 meters deep (Hildebrand, 1983; Lohoefener et al., 1990). For reasons outlined previously, this study did not distinguish among different turtle species, but most turtles (with an exception for leatherbacks) are thought to inhabit shallow water along the coasts.

Turtles would inhabit shallow waters for several reasons. First of all, in shallow water the turtle would expend less energy swimming to the surface to breathe. A deep water species must swim a greater distance to the surface and therefore spend less time feeding at the bottom. In order to conserve energy and increase feeding time, a turtle might inhabit nearshore waters if prey distributions do not change substantially with depth.

Second, species diversity is generally higher in shallower waters (Norse, 1993). Prey would generally be more copious in nearshore waters and turtles would have a greater selection and abundance of food. More prey would indicate a larger number of turtles. In addition, green turtles feed on seagrasses which are only found in shallow waters with plentiful sunlight.

As a result of the above reasoning, a greater abundance of turtles is expected to be close to shore throughout the Gulf. The spatial distribution of turtles might vary from the Eastern to Western Gulf, but in general we expect to find more turtles in waters less than 18.3 meters.

11.0 SPATIAL ANALYSIS RESULTS

The results of this project included several maps of shrimping effort and sea turtle strandings in the Gulf. The goal was to determine potential turtle "hot spots" and areas of high shrimping intensity. A hot spot would be a subzone or area with high turtle densities, indicating a potential area closure site. For each of the 100 subzones, sea turtle abundance was calculated, as well as all-year shrimping intensity and shrimping intensity for September, October, and, in 1994, November. Strandings data were then tabulated for each statistical zone to estimate the differences in species diversity within the zones. For the purpose of these analyses, the Western Gulf is considered to be the area west of the Mississippi River (Zones 13-21), while the Eastern Gulf includes all waters east of the Mississippi River (Zones 1-11). Zone 12 was not included in this analysis.

11.1 SEA TURTLE DENSITIES

As shown in Appendix 5, sea turtle abundance varies throughout the Gulf. Turtle abundance is shown in quantile divisions, with an equal number of values in each class. For example, there are a large amount of subzones with zero turtle abundance, so the zero value is shown as a separate category.

Turtle densities and variances for each subzone are shown in Appendix 6. Also presented in this table are the number of transects flown in the subzone, the average area of the transects in the subzone (given the 400 meter strip width and each specific transect length), and the number of turtles sighted within each subzone.

The abundance values vary with each region, with numbers in the Eastern Gulf being generally higher than values in the Western Gulf. The southern Florida zones (Zones 1-3) generally have a higher turtle abundance than any other region (Appendix 5 and 7). Throughout the Gulf, turtle abundance extends into the deeper waters as well, and, as depicted from the map in Appendix 5, high turtle densities are not always found in all nearshore waters. The west coast of Florida produces turtle density values that are on average 60 times higher than the Western Gulf, but 3 times lower than the southern Florida areas. The overall values remain high (greater than 0.047 turtles/km^2) through the Big Bend region of Zone 7, but numbers drop off and are lower from Zones 8 to Zone 11. West of the Mississippi River, turtle abundance is extremely low, with most of the subzones lacking turtles altogether. Those subzones that do have some level of turtle abundance only have 1 or 2 turtles in the area (Appendix 6). However, the southern Texas turtle abundance is 20 times higher than the other Western Gulf zones. Turtle sightings in Zones 20 and 21 extend beyond the nearshore environment, with several turtles found in waters out to 73.2 meters.

Five general areas of turtle abundance can be determined: southern Florida with high turtle density in Zones 1-3; the Florida west coast (Zones 4-7) also with a high level of turtle abundance but slightly lower than the Florida Keys region; the Florida panhandle, Alabama, and Mississippi areas (Zones 8-11) with a medium degree of turtles; the Western Gulf Zones

13-19 with a very low abundance of turtles; and the southern Texas region (Zones 20 and 21) with a higher density of turtles than other Western Gulf regions, but not as high as the Florida abundance. The Florida panhandle region is comparable to the southern Texas sea turtle abundance estimates.

When comparing the Eastern and Western Gulf, the Eastern Gulf has a substantially larger turtle abundance than the Western Gulf (Figure 7). Only 6% of the total turtle abundance is found in the Western Gulf zones, and most of this 6% is found in Zones 20 and 21.

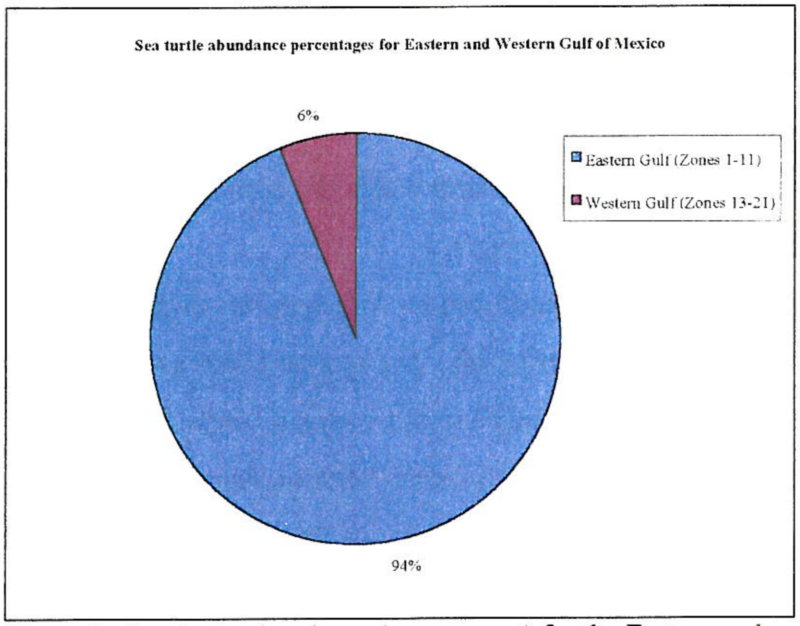

Figure 7. Sea turtle abundance (as a percent) for the Eastern and Western Gulf of Mexico, September to November 1992-1994.

11.2 SHRIMPING INTENSITY

11.2.1 SHRIMPING INTENSITY – ALL YEAR

As shown in Appendix 8, all-year shrimping intensity varies throughout the Gulf. Similar to the turtle abundances, shrimping intensity is shown in quantile divisions, where there are an equal number of values in each class. Each range has the same number of values in it, so one can determine which shrimping intensity values are high in relation to all others.

Shrimping intensity averaged over all months in 1992-1994 shows a very distinct trend. The Western Gulf has an extremely high level of shrimping, as does Zone 11 on the eastern side of the Mississippi River. In almost all of the western subzones, shrimping does not fall below 0.439 days fished/km^2. To the east of Zone 11, shrimping intensity decreases and the Florida intensity is negligible in comparison to the Western Gulf. One area of high shrimping intensity does occur outside the Dry Tortugas Shrimp Sanctuary in 18.3 to 36.6 meters in Zone 2. Shrimpers concentrate around the sanctuary in order to catch the shrimp soon after the large shrimp leave the protected nursery habitat. Furthermore, there are a substantial amount of mangroves and seagrasses located in these southern Florida subzones which provide excellent shrimp nursery habitat. A detailed view of the shrimping intensity occurring in the Florida Keys region is found in Appendix 9. Throughout the Gulf, shrimp fishing is generally found close to shore, in waters less than 54.9 meters. Little fishing occurs outside 73.2 meters, as depicted by the blue colors in Appendix 8.

The trend of high shrimping in Western Gulf waters and lower shrimping intensity in the Eastern Gulf is as expected; previous literature has shown that the majority of shrimp fishing occurs in the Western Gulf from Zones 13-21 (Henwood et al., 1992; Nance, 1996). For example, this study only found 16% of the shrimping occurring in the Eastern Gulf (Figure 8).

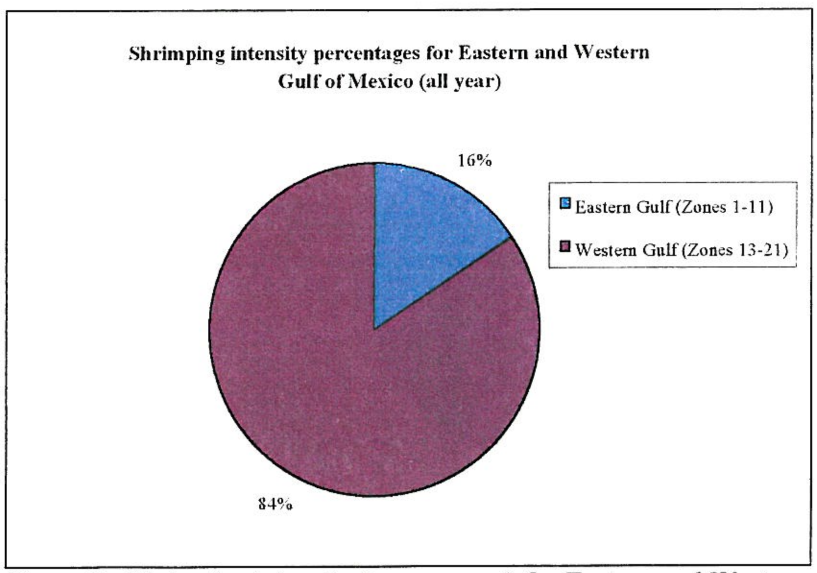

Figure 8. Shrimping intensity (as a percent) for Eastern and Western Gulf of Mexico, averaged over all months in 1992-1994.

11.2.2 SHRIMPING INTENSITY – SEPTEMBER THROUGH NOVEMBER

For easy comparison, the scale used for all-year shrimping effort was also used for the September through November analysis. Therefore, the number of values in each range are not equal (i.e. the quantile division was not used). The map in Appendix 10 shows that shrimping intensity during the fall months is very different than in the previous all-year estimate. A close-up view of the Florida Keys region is found in Appendix 11. Shrimping intensity is low and scattered throughout the Gulf, with noticeably absent high shrimping intensity in the Western Gulf region. These fall intensities are low because shrimping does not occur to a large extent during the months of September, October, and November. Most of the effort concentrated in the summer months of June, July, and August.

As a result, these spatial dynamics are much different than previous estimates of shrimping intensity. The Western Gulf does not contain the overwhelming majority of the intensity and shrimping is much patchier than in the all-year analysis. Only 47% of the shrimping intensity occurs in Western Gulf waters from September to November (Figure 9). The Louisiana and Texas intensity has dissipated, but a high level of shrimping intensity remains in one small subzone in Zone 13. A greater amount of intensity is still located generally close to shore, with limited effort beyond 73.2 meters.

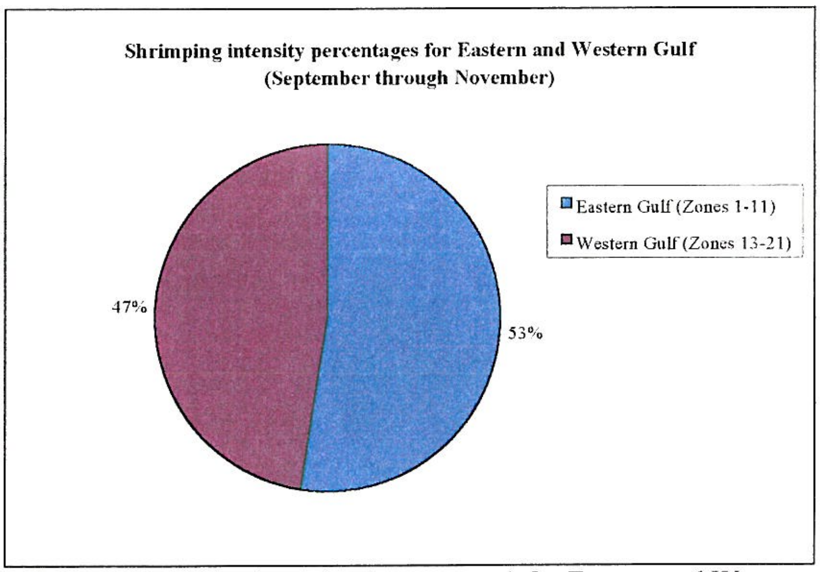

Figure 9. Shrimping intensity (as a percent) for Eastern and Western Gulf of Mexico, averaged from September to November, 1992-1994.

11.3 SEA TURTLE DENSITIES AND SHRIMPING EFFORT

In order to compare shrimping intensity and sea turtle abundance, it was first necessary to rank the values. All values for turtle abundance, shrimping all-year, and shrimping for September through November were split into thirds to give a low, medium, and high category (Table 3). When ranking the values, the September through November shrimping intensity values were not on the same scale as the all-year shrimping effort. The fall month intensities represent high, medium, and low shrimping relative to other values during these months, not compared to the all-year intensities. Each value was considered in the ranking (e.g. all "0" values) and the result was 9 different combinations of shrimping intensity and sea turtle abundance. These values were then used to formulate maps of high, medium, and low shrimping intensity coupled with high, medium, and low turtle abundance. This ranking system would allow for comparison between high and low areas of shrimping and turtle abundance to determine the feasibility of area closures.

	High values	**Medium values**	**Low values**
Turtle abundance	≥ 0.032	< 0.032 and $\neq 0$	$= 0$
Shrimping (all months)	≥ 0.513	$0.037 \leq x < 0.513$	< 0.037
Shrimping (Sept-Nov)	≥ 0.115	$0.014 \leq x < 0.115$	< 0.014

Table 3. Ranking of turtle abundance and shrimping intensity (all-year and September through November) values for 1992-1994.

11.3.1 Ranking of Intensities - All Year Shrimping

The rankings of sea turtle abundance and all-year shrimping intensity are shown on the map in Appendix 12. As expected, the southern Florida region mostly has high turtle abundances and low shrimping intensity. One exception is the area around the Dry Tortugas Shrimp Sanctuary: Zone 1 and 2 from 18.3 to 36.6 meters (Appendix 13). These subzones have high shrimping and high turtles, which could pose a serious threat to turtle survival. From Zone 13 to Zone 19, shrimping intensity is high and turtle abundance is low (with a few patches of medium abundance). The low turtles and high shrimping trend will be interesting to note for future management decisions. In the southern Texas region (Zones 20 and 21), 4 out of the 10 subzones have high shrimping and medium turtle abundance. Two other zones in this region have high shrimping intensity and high turtle abundance, another important aspect to note for management recommendations. Other important subzones to consider are those with 1) low shrimping intensity and high turtles and 2) high shrimping intensity and medium turtle abundance.

By plotting sea turtle densities and all-year shrimping intensity for each statistical zone (in percent total abundance and intensity), a negative correlation can be depicted (Figure 10). Shrimping intensity is low in the Eastern Gulf and then rapidly increases after Zone 11.

Intensities in the other Western Gulf zones are not as high as in Zone 13, but they are much higher than in the Eastern Gulf. In comparison, turtle abundance increases as shrimping effort decreases. Turtle abundance is high in Zone 1 and 2, and then drops steadily down to Zone 8. After the slight jump in abundance in Zone 11, turtle densities are reduced in the remainder of the Western Gulf. This negatively correlated trend will be given consideration in later sections of this paper.

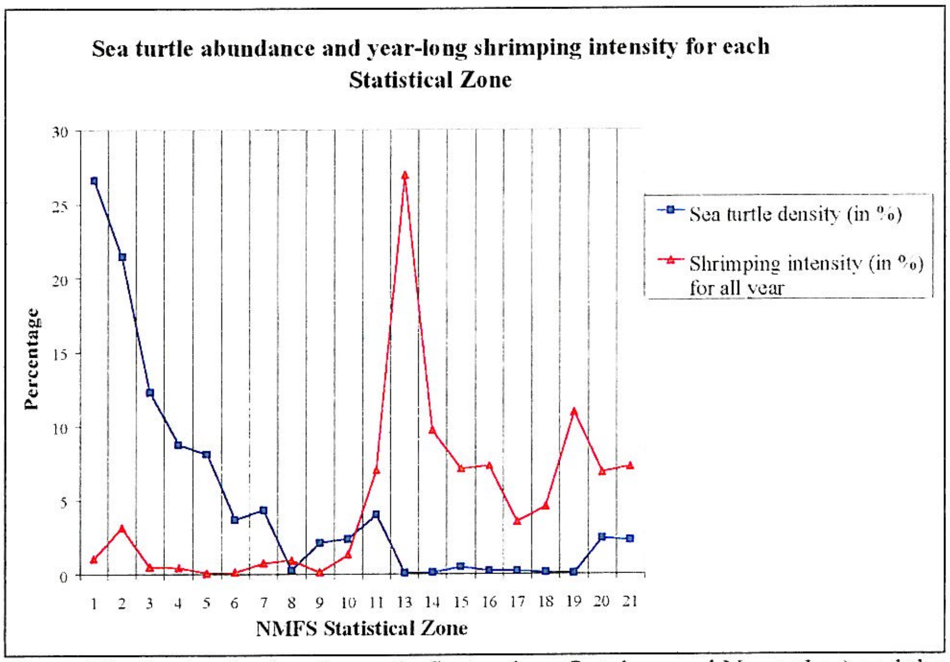

Figure 10. Sea turtle abundance (in September, October, and November) and the average year-long shrimping intensity (in percentages) for each NMFS statistical zone. The study years were from 1992-1994.

11.3.2 Ranking of Intensities - Shrimping from September to November

The fall shrimping and sea turtle abundance ranking is more variable than in the preceding analysis, because shrimping intensity is more scattered in the fall months. However, several trends can be established from the map in Appendix 14. Florida waters have many subzones with high shrimping intensity and high sea turtle abundance, as do several subzones off the Mississippi, Alabama, and Texas coasts (Appendix 14 and 15). In comparison to the all-year analysis, these fall months show a greater amount of high and medium shrimping activity in Florida waters, which can be problematic with the high abundance of turtles found here. The Mississippi and Alabama coasts have a medium abundance of turtles with high shrimping intensity, therefore these locations should not be disregarded as possible areas of concern. Other trends to note are that subzones off the Louisiana and northern Texas coasts have medium to low shrimping intensity with low turtles, while in southern Texas shrimping remains high with a medium abundance of turtles.

Turtle abundance and shrimping intensity by statistical zone (in percentage of total abundance and intensity) is shown in Figure 11. The shrimping intensity varies significantly with the zone in question, with drastic increases and decreases of intensity from Zone 7 to Zone 14. Turtle abundance does not follow this sporadic trend, with turtle values generally decreasing after Zone 5. The trend of high shrimping intensity and low turtle abundance does not hold true for several zones in this analysis – both turtle density and shrimping intensity have similarly low values in Zones 8 and 15. Interestingly, when shrimping drastically declines in Zone 11, turtle density increases. However, this association could be from a variety of other influences (e.g. habitat, external environmental conditions).

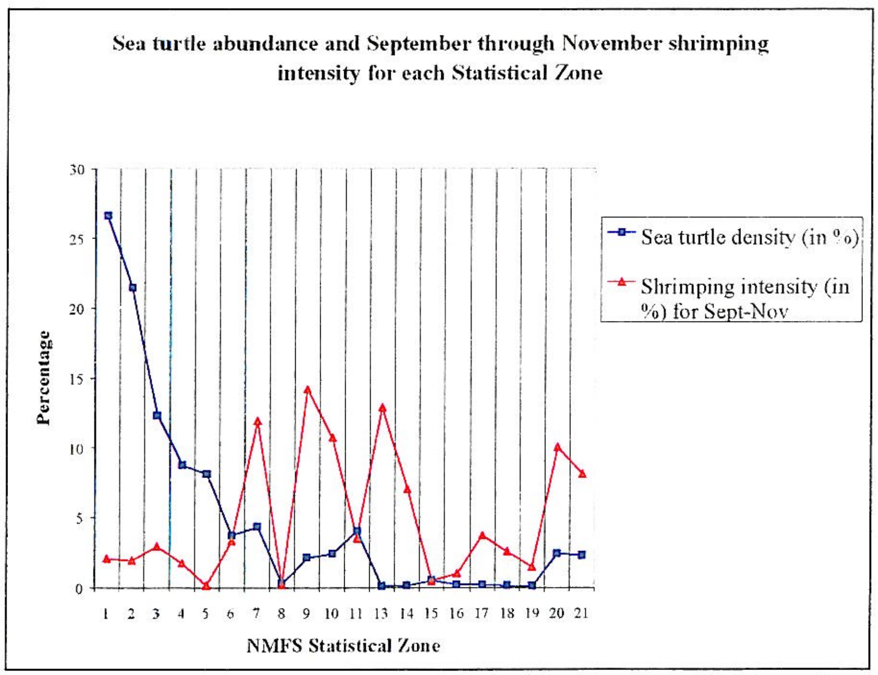

Figure 11. Sea turtle abundance and shrimping effort averaged from September to November 1992-1994 (in percentages) for each NMFS statistical zone.

11.3.3 SHRIMPING INTENSITY AND SEA TURTLES BY DEPTH ZONE

One goal of this study was to examine the abundance of turtles and shrimping intensity by depth contours. As shown in Figure 12, the level of all-year shrimping intensity steadily decreases (almost linearly) when moving offshore. September through November shrimping intensity generally decreases offshore, but the level is greater in the 36.6-54.9 meter subzone than in the 18.3-36.6 meter subzone. Furthermore, nearshore shrimping (0-18.3 meters) is greater in September to November than it is over the all-year estimate. As depicted in this graph, a greater proportion of shrimping occurs in nearshore waters.

The turtle abundance estimates are somewhat surprising. The nearshore values are much lower than expected, with only 11.8% of the total abundance of turtles found in the 0 to 18.3 meter depth zone. The values for 18.3 to 73.2 meters are relatively constant, with a large decrease in abundance after 73.2 meters. From these study results, it is evident that turtle abundance drops off after a certain depth (~73.2 meters).

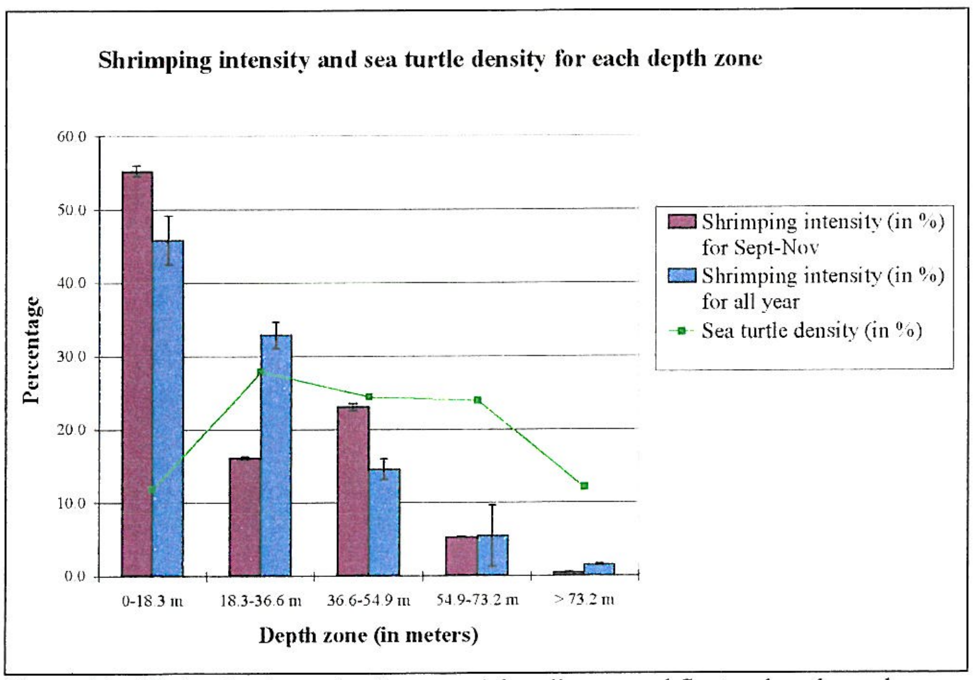

Figure 12. Shrimping intensity (averaged for all year and September through November only) and sea turtle abundance for each depth zone. The depth zones are in meters, and the survey years range from 1992-1994. Standard deviations are shown for shrimping intensity.

This unusual depth trend could be a result of the differences in turtle species in the Eastern and Western Gulf waters. The Western Gulf, with a higher proportion of Kemp's ridleys, might have a higher nearshore abundance because more Kemp's ridleys are found close to shore. Kemp's ridleys are also rare and thus would not be as prevalent in the data. The large number of turtles depicted in the Eastern Gulf could overshadow Western Gulf turtle depth preferences and alter the depth pattern throughout the entire Gulf. The reason the Eastern and Western Gulf zones were separated is that aggregate pattern in the previous graph might be dominated by the Eastern Gulf data.

Dividing the data into Eastern and Western Gulf zones depicts a slightly different distribution. All-year shrimping intensity in the Eastern Gulf is much higher in the 18.3 to 36.6 meter category than any other depth zones, while shrimping intensity for September through November is highest in the nearshore zones of 0-18.3 meters and generally declines with depth (Figure 13). Nearshore (0-18.3 meters) turtle abundance in the Eastern Gulf is slightly lower than in the midwater zones, but after 54.9 meters, the turtle densities decline.

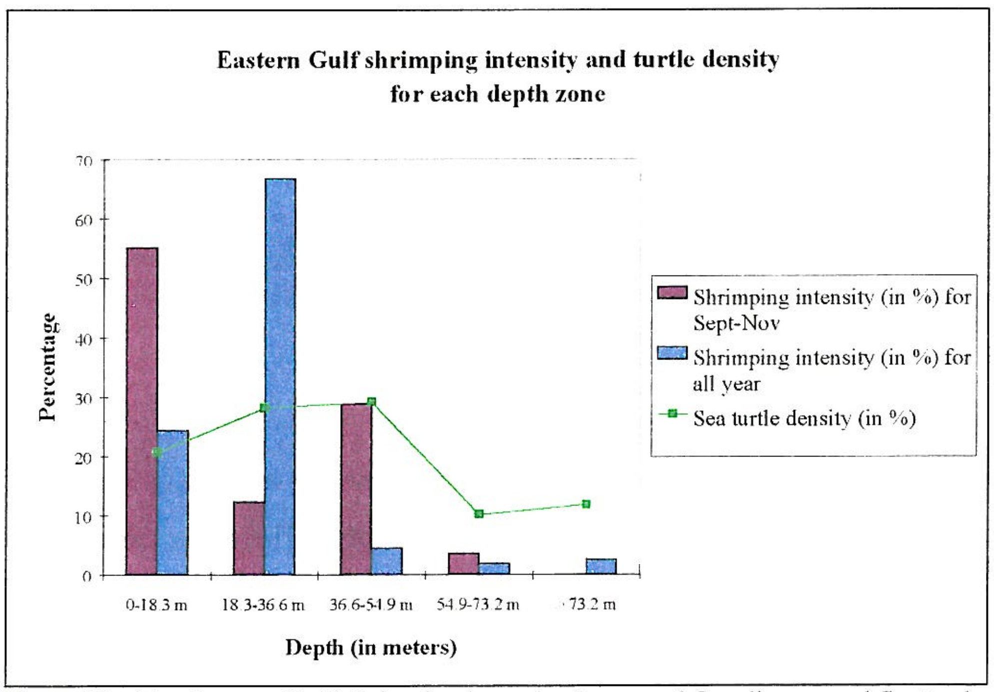

Figure 13. The Eastern Gulf shrimping intensity (averaged for all year and September through November only) and sea turtle abundance for each depth zone. The Eastern Gulf consists of Zones 1-11.

The Western Gulf shrimping intensities for the all-year and fall estimates are highest nearshore and gradually taper off with depth. The nearshore turtle abundances are much higher than the combined Gulf values, with the largest density of turtles found in the 0 to 18.3 meter depth zone (Figure 14). There is another high peak of turtle abundance around 36.6 to 54.9 meters, and the density increases again beyond 73.2 meters.

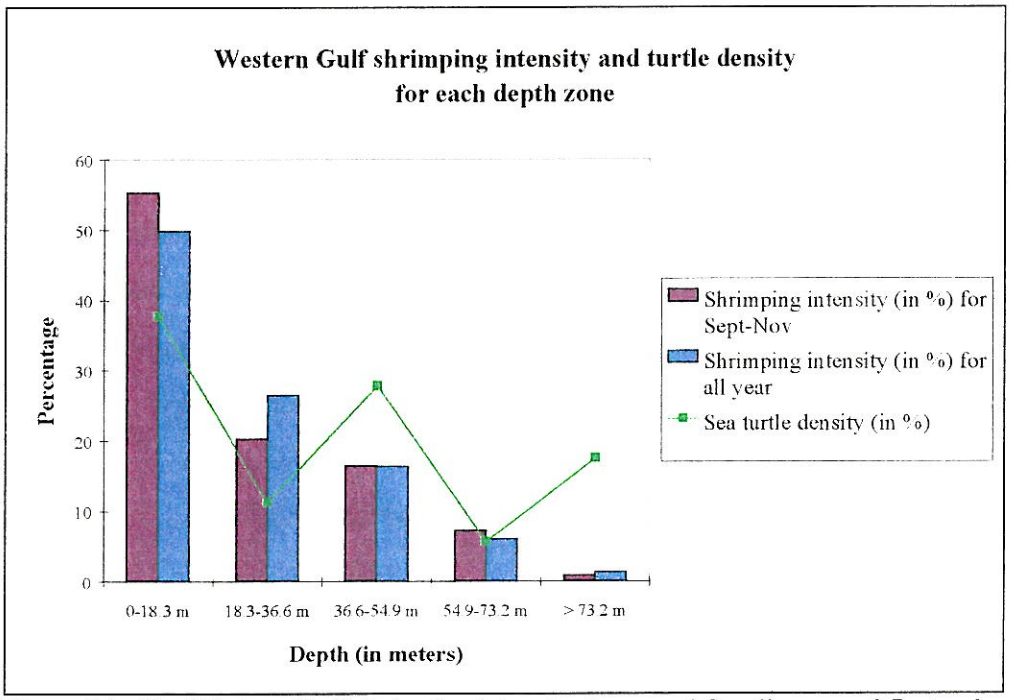

Figure 14. The Western Gulf shrimping intensity (averaged for all year and September through November only) and sea turtle abundance for each depth zone. The Western Gulf consists of Zones 13-21.

11.4 SEA TURTLE STRANDINGS

The strandings for each subzone were used to calculate the stranded species distribution in September, October, and November of 1992, 1993, and 1994. The species depicted in this study are not the necessarily the species found directly offshore, but only the different species that have stranded. A larger number of Kemp's ridley strandings does not necessarily mean that there are more Kemp's ridleys in the water, because this species is more likely to strand. Kemp's ridleys cannot survive underwater as long as other sea turtle species, so when they are submerged in trawl nets, they drown easier (Magnuson et al., 1990).

To assist in developing potential management alternatives, the number of turtles for each NMFS statistical zone was established, as well as the species found in each zone. From this information, more turtles were found to strand in Zones 17-20 in the Western Gulf (Figure 15). In addition, a high number of strandings occurred in Zone 1 (in the Florida Keys) and Zone 5 (near Tampa, Florida) relative to all other zones.

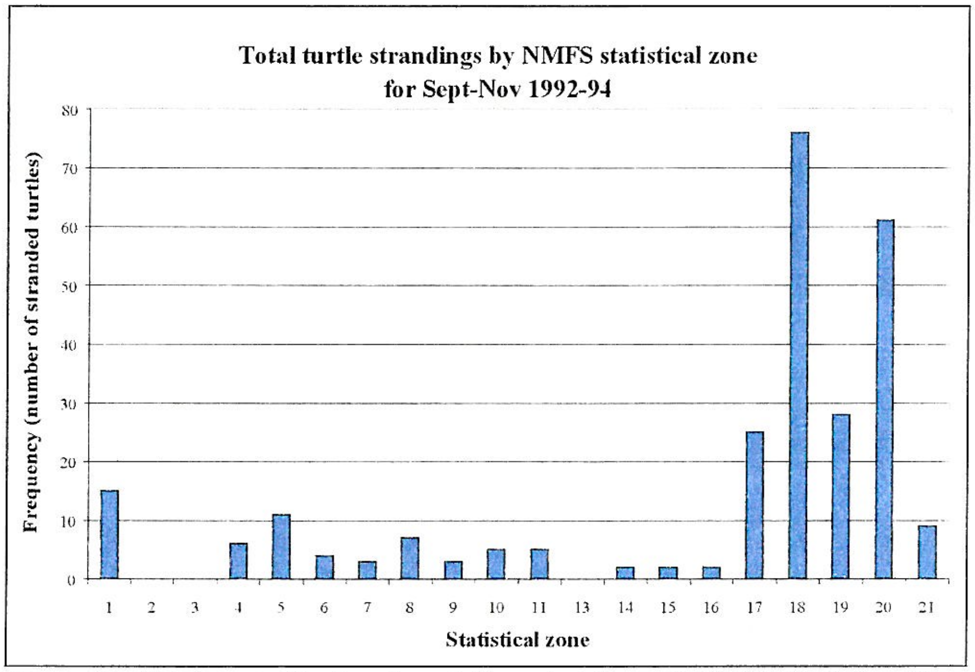

Figure 15. Total sea turtle strandings (all species) for each NMFS Statistical Zone, in September, October and November 1992, 1993, and 1994.

Because the highest strandings were found in Zones 1, 5, 17, 18, 19, 20 and 21, we chose to closely examine these zones for differences in stranded species (Figure 16). Zones 20 and 21 were found to have more different species than any other zone, which could be translated into a higher level of species diversity in these zones. These southern Texas zones included stranded green, hawksbill, loggerhead and Kemp's ridley turtles. Zone 1 has more green turtles stranded than any other area, while Zone 17 consists mostly of Kemp's ridleys. Twenty-four Kemp's ridleys out of 25 total turtles stranded in Zone 17, which could suggest a potential Kemp's ridley hot spot. Zone 18 had the largest number of turtle strandings, and out of the total 76 turtles in this zone, 53 of these turtles were the highly endangered Kemp's ridley. The absence of hawksbills in Zones 5, 17, and 18 could indicate that the habitat in these areas is not suitable for these species or the water temperatures are too cold.

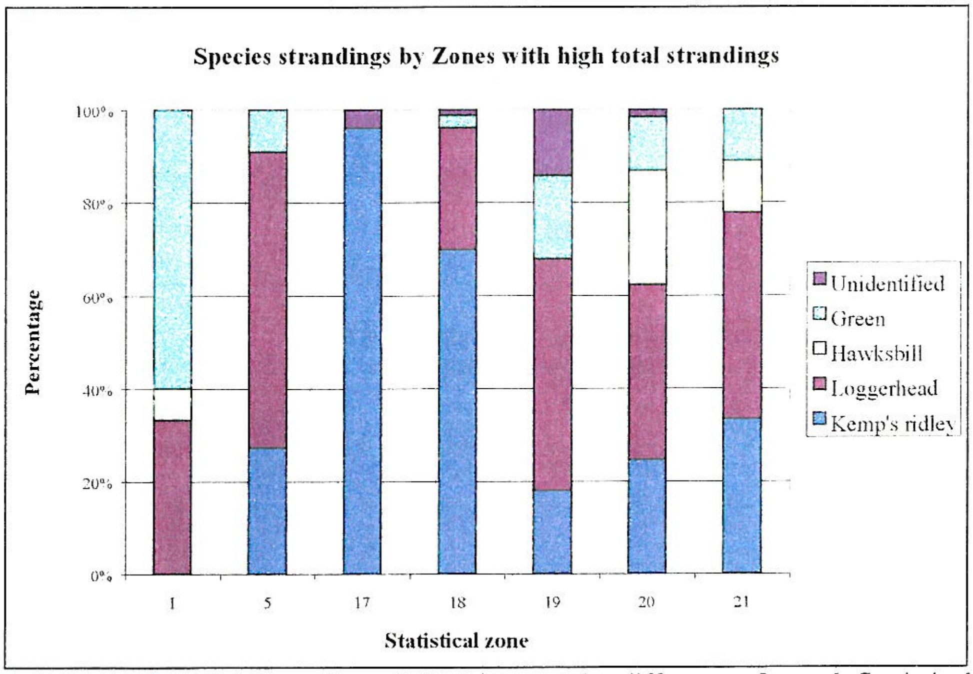

Figure 16. Sea turtle strandings divided into species differences for each Statistical Zone with high total turtle strandings, for September through November 1992-1994.

Kemp's ridley turtles were the most common species to strand, followed by loggerheads. Kemp's ridleys comprised 43.9% of the total strandings, and 34.5% of the strandings were loggerheads (out of a total 264 stranded turtles during this time period). These species might be more abundant in the Gulf than hawksbills or leatherbacks, but Kemp's ridleys are the most endangered sea turtle so these high strandings may well be detrimental. The high strandings in 1994 were a basis for subsequent changes in management policies, so the stranding levels should have decreased after the new regulations took effect. This study was only concerned with the years of the aerial survey (1992-1994), so strandings data beyond 1994 were not analyzed.

12.0 DISCUSSION OF RESULTS

The results of this study outline the distribution of sea turtles and shrimping intensity throughout the entire Gulf. Turtles are more abundant along the coast of Florida, and generally rare from the mouth of the Mississippi River to the middle of the Texas coast. The GIS maps show that shrimping is higher in the Western Gulf throughout the entire year, but the fall months have a scattered shrimping intensity distribution. Comparing shrimping intensity to turtle distribution gives a more comprehensive view of the actual dynamics in the Gulf. However, why turtles and shrimp fishing intensity are distributed in this pattern is not known with certainty.

It could be more logical to heavily weigh the analysis of September through November shrimping intensity over the all-year shrimping effort analysis because the aerial survey was conducted in the fall months. But the association between all-year shrimping effort and turtle abundance is more pronounced. It could be that sea turtle abundance is heavily influenced by shrimping pressure over the entire year. Shrimping is highest in the late spring and summer months, and turtles in September and October could still be responding to the intense shrimping effort during the summer months. A variety of factors could be involved here, but summer shrimping effort could be dictating where the turtles are located in the fall. Therefore, the distribution of turtles in the fall might not be greatly affected by the fall shrimping intensity. This possibility is exemplified by the lack of a clear pattern between fall shrimping intensity and turtle distribution. Regardless, both analyses were considered because determining which months most heavily impact turtle abundance is not predicable.

In this section, the original hypotheses will be addressed to determine their role in influencing turtle abundance. Several assumptions can be made about the Gulf spatial dynamics and what factors influence the distribution of turtles, but the location of turtles is most likely a result of the accumulation of several factors. Although one hypothesis might seem more reasonable than another, a variety of additive conditions might dictate whether turtles are found in a particular area.

12.1 HYPOTHESIS 1 – SUITABLE TURTLE HABITAT

This hypothesis stated that turtles would be more likely to inhabit Eastern Gulf waters because the habitat is more suitable. Florida waters encompass the majority of the Eastern Gulf, with only a small portion of the Eastern Gulf found in Mississippi and Alabama jurisdictions. Florida waters are warm, with a shallow, wide continental shelf and extensive sea grass beds. These waters also have sandy bottoms ideal for turtle habitat.

Based on this analysis, turtles do appear to congregate in Florida waters. The majority of the turtles were found in southern Florida (Zones 1-3), but the entire Florida west coast has high turtle abundance up to the Big Bend region in Zone 7. Once the shelf starts to narrow and waters become deeper (Zone 8-11), the abundance of turtles declines. Turtles are still present in these areas but their density is obviously reduced.

Seagrasses are common along the east coast of Florida, especially in waters around the Ten Thousand Islands (Zone 3, 0-18.3 meters). A relatively high abundance of turtles is located in this zone. In addition, Zone 1 was determined to have the highest number of stranded green turtles. Greens eat seagrass and are more likely to be found in shallow, warm Florida waters than in any other Gulf zone. The large proportion of green turtles in southern Florida waters (and not in any other zones) could easily contribute to the high turtle density found in Zone 1. Overall, turtle abundance seems to correspond to the prevalence of seagrass and wide continental shelf margins.

The bathymetry slope in Zone 1 and 2 contradicts this hypothesis to an extent. In the southern Florida region, the depth drops off quickly after the shallow shelf around the Keys. These zones have high turtle abundances in all depth bins (except for 0-18.3 meters, which was not sampled), and these deep waters on the south side of the Keys do not have any seagrass beds. One possible reason there is a high abundance of turtles in deep water southern Florida regions is that these subzones are the furthest south and the Gulf Stream brings warm water into this area (Figure 1). The Gulf Stream transports between 75 and 115 x 10^6 m^3/sec of seawater northward (Kennett, 1982). This current passes through the Caribbean Sea, southeastern Gulf of Mexico, and the Florida Straits. Young juvenile turtles floating with the Gulf Stream could end up in southern Florida and use these areas as feeding grounds. The Gulf Loop Current does bring warm water and marine life into the Western Gulf, but the southern Florida areas are in constant contact with the large warm water flow. The depth bins in Zone 1 and 2 are also extremely narrow, so turtles would not have as great an opportunity to differentiate between depths in a reduced zone area.

The Florida Keys also have the only coral reef in the continental United States, and turtles (e.g. hawksbills and greens) are commonly associated with reef structures. The depth zones to the southern side of the Florida Keys contain reef structures, but to the northern side the waters consist mainly of seagrass beds (National Oceanic and Atmospheric Administration, 1996). A large abundance of turtles were found on the southern side of the Keys, but to the north of the Keys the waters were not sampled.

The waters around the Mississippi River and in southern Texas have steeper continental shelves, and compared to the Eastern Gulf, lower turtle densities are found in these regions. However, several zones in the Western Gulf have wide continental margins comparable to those along the Florida coast. For example, Zone 16 depth contours are similar to Zone 4 in Florida, but there are many more turtles in Zone 4. This could indicate that turtles are choosing areas independent of continental margin width.

The Western Gulf waters generally have muddier bottoms as a result of the high sediment load in the Mississippi River (Darnell et al., 1983). Sediment pours out of the Mississippi and is carried with the currents to Louisiana and Texas waters. Kemp's ridley sea turtles often inhabit muddy substrate, and are frequently found in Louisiana and Texas waters (Miller, 1997; Gallaway et al., 1995). Therefore, the habitat in the Western Gulf could be more suitable for Kemp's ridley populations, but it is important to recognize that Kemp's could be inhabiting these waters for other reasons. The southern Texas zones have coarser sediments than the other Western Gulf zones, and greater abundances of turtles are found in these zones in comparison to the zones with muddy substrate. Florida waters also have coarse sediment. This suggests that the majority of the turtles sighted in this survey more commonly inhabit areas with coarse, sandy sediment.

The aerial survey sea turtle abundances do coincide with this particular hypothesis in that Florida subzones with a wide continental shelf, sandy bottom, and more seagrasses have high turtle abundances. Turtle density is lower in colder zones with steep continental shelves.

12.2 HYPOTHESIS 2 – TURTLE REDUCTION WITH INTENSE SHRIMPING EFFORT

With high shrimping intensity, more turtles would be subject to capture even with TED use. Before TEDs were required in the Gulf in 1990, shrimp trawls captured and drowned large numbers of turtles annually. These years of major turtle mortality in high shrimping areas could have had a drastic effect on turtle species, by wiping out most of the existing populations that may have once occupied these zones. This section is not intended to criticize the shrimping industry, but instead to offer possible suggestions on the distribution of turtles in the Gulf.

Based on the results of this study, turtle depletion by shrimp trawling is possible. In the analysis with all-year shrimping intensity, there is a detectable negative correlation between shrimping intensity and turtle abundance. Turtles are noticeably absent from Western Gulf Zones 13-19, and these zones have the highest shrimping intensity throughout the Gulf. In areas where there is limited shrimping (Florida offshore waters), turtle abundance is higher. A large proportion of Western Gulf zones have the high shrimping/low turtles ranking, while a significant number of zones off the Florida coast have low shrimping/high turtle abundance (Appendix 12). The majority of the map is comprised of those two categories, leading to the speculation that shrimping influences turtle existence substantially.

The trend is not as clear with September through November shrimping intensity. Shrimping is patchy throughout the Gulf, and the categories of high shrimping/high turtles and medium shrimping/high turtles make up the majority of the subzones. Shrimping has generally dissipated in the fall, so the limited effort in these months probably does not affect turtle distribution as much as the summer months do.

Furthermore, a high number of strandings in 1992, 1993, and 1994 occur in the Western Gulf zones. Zones 17-21 have a substantial amount of the total turtle strandings and shrimping intensity is also very high in these zones. A higher level of shrimping intensity seems to lead to a higher level of sea turtle strandings. Shrimping could also influence turtle abundance by reducing the amount of turtles in the water.

Based on the results of this study and the negative correlation (Figure 10), the shrimping industry and high shrimping effort are possible contributors to the Gulf sea turtle distribution. Turtles are not found where most of the shrimping intensity is located, from either historical reduction, habitat modification, reduced feeding opportunities or for reasons not mentioned. If shrimpers were not using TEDs correctly in 1992-1994 (or in previous years), a high level of turtle capture and mortality of the small number of resident turtles would ensue, leading to the rarity of species in these areas.

12.3 HYPOTHESIS 3 – HYPOXIC BOTTOM WATER CONDITIONS

Low oxygen levels in the bottom water of certain Louisiana zones have the potential to influence turtle distribution. The lack of adequate oxygen would affect turtle distribution by reducing the amount of prey in the areas in question. The low levels of turtle abundance off the coast of Louisiana (Zones 13-16, approximately 9.1 to 36.6 meters) could be a result of low bottom water oxygen levels in the same area. In this study, the effect of hypoxia on turtles is difficult to establish with confidence, because the hypoxic zone only directly influenced two survey years (1992 and 1993) and at the time of the survey the hypoxic zone was breaking apart. Regardless, hypoxia is a significant problem in the Gulf that should be considered when studying turtles, shrimp, or any biological community.

Maps of the hypoxic waters during the summer of 1992, 1993, and 1994 were obtained from SEAMAP trawling survey data (K. Craig, DUML, personal communication). The 0-2 mg/l values represent hypoxia conditions, which leads to direct mortality, reduced food resources, and altered migration patterns. The 2-5 mg/l bottom dissolved oxygen is slightly hypoxic, but the effect of this low oxygen varies with species. Some species are more susceptible to low oxygen levels and will die or change behavior patterns, while other species will not be affected or perhaps swim slower. Dissolved oxygen above 5 mg/l is considered to be normal oxygen levels capable of sustaining adequate populations. Data was unavailable for the gap in values off the Louisiana coast.

In 1992, the aerial survey spanned from the Texas-Mexican border to Lafayette in the middle of the Louisiana coast (approximately Zones 16-21). Prior to 1993, the average aerial extent of bottom water hypoxia in mid-summer was relatively small: approximately 8,000 to 9,000 km^2 (Rabalais et al., 1995). During this year, the areas of hypoxia were not extremely large, and low oxygen levels only affected several patches of the surveying area (Appendix 16). As shown in the map, the actual hypoxic areas of 0-2 mg/l are patchy and relatively small, but the 2-5 mg/l conditions extend to Zone 18. This low oxygen area (not characterized as complete hypoxia) could influence turtles and turtle prey species abundance, but that effect is not known with certainty. However, blue crabs, a significant turtle prey species, are absent in waters with less than 5 mg/l dissolved oxygen (L. Eby, DUML, personal communication). Thus, in 1992, the hypoxic conditions could have influenced turtle distribution in Zones 16, 17 and 18 off Louisiana, but low oxygen levels should not have greatly affected turtle distribution west of Zone 18.

The abundance of turtles in Zones 13-15 could have been greatly affected by low oxygen conditions. The disastrous Mississippi flood in the summer of 1993 produced a large hypoxic zone off the Louisiana coast. The Loop Current spread hypoxic waters to the west of the Mississippi, so 1993 bottom waters in selected Western Gulf zones had a reduced oxygen level (Appendix 17). The area of 0-2 mg/l dissolved oxygen is slightly larger than 1992, but the area with 2-5 mg/l bottom water conditions is much larger than previous estimates. These "medium" oxygen level areas could influence turtle distribution over the entire Western Gulf.

The 1993 aerial survey, ranging from Lafayette, LA (on the border of Zone 15 and 16) to Cedar Key, FL, was partly conducted in the region of hypoxia. Oxygen levels in 1993 could have influenced turtle abundance in these Western Gulf zones, reducing turtle numbers from the limited prey available. An important caveat is that the hypoxic zone breaks apart in the fall (September or October), which was the time of the GOMEX survey. Therefore, the air-breathing turtles in this study were not directly affected by the hypoxic conditions, but hypoxia would still reduce the bottom dwelling organisms turtles prey on.

The survey in 1994 was conducted along the coast of Florida, not in the zones of hypoxia. However, Louisiana turtles in 1994 could still have been affected by the hypoxic zone and probably are influenced by low oxygen levels to this day. The hypoxic zone has remained relatively large since 1993 and continues to affect biological communities in these specific locations. As shown in Appendix 18, the waters in 1994 have several areas of 0-2 mg/l dissolved oxygen, and a large portion of the Western Gulf has dissolved oxygen levels of 2-5 mg/l. Although this survey only showed the influence of two years of hypoxia on turtle distribution, the problem is still likely occurring (K. Craig, DUML, personal communication).

Hypoxia does have the potential to concentrate fishing intensity. Fishers are moving out of the hypoxic zone to nearby fringe locations in order to increase their fish catch. Turtles might also move out of the hypoxic area, in response to the low oxygen levels, reduced food supply, and availability of bycatch (food) from shrimp trawls in the fringe locations. The end result is fishers, shrimp, and turtles in the same nearshore locations, intensifying the bycatch problem. As is evident, many factors must be considered when addressing shrimping, turtles and hypoxia in the Gulf.

12.4 HYPOTHESIS 4 – TURTLES AND SHRIMPING IN THE SAME AREA

The hypothesis that turtles and shrimpers are located in the same waters because turtles feed on shrimp bycatch cannot be upheld based on the results of this research. Especially evident in the analysis of all-year shrimping effort, high abundances of turtles are found in areas without high shrimping intensity. High areas of shrimping intensity do not usually have high turtle abundances, contrary to the original bycatch/feeding hypothesis. Turtles might eat shrimp trawl bycatch when they happen to be in the same area, but turtles do not seem to distribute themselves around shrimp trawls. A turtle could perhaps follow a shrimp boat once the boat is in the zone of turtle inhabitance, but it is illogical that the turtle travels to other areas of the Gulf in order to feed on shrimp boat bycatch.

In the September-November all-year analysis, high levels of shrimping intensity and high turtle abundance are more common. This trend could be a result of the reduced intensity in the fall. The shrimping is not as concentrated or dynamic, so turtles and shrimp trawlers could co-inhabit (with turtles feeding on bycatch) without any threat to sea turtle survival. Regardless, the assumption that turtles are found in the same area as shrimp trawls cannot be totally validated by this study.

However, if turtles frequently fed on shrimp boat bycatch in the past, the turtles surrounding the trawl would have had a greater likelihood of becoming entangled in the shrimp trawl. The lack of turtle abundance in areas of high shrimping intensity could be a result of turtles following the shrimp trawls for food and then drowning once entangled in the net. The populations of turtles that engaged in these feedings would therefore be dead, with lower turtle densities in these areas. This reasoning, however speculative, would result in fewer turtles in the areas of high shrimping intensity.

12.5 HYPOTHESIS 5 – TURTLES LOCATED IN NEARSHORE AREAS

Turtles were hypothesized to inhabit nearshore waters due to an increase in prey availability and conservation of energy. Based on the maps outlining sea turtle abundance, turtles do not seem to inhabit nearshore waters more frequently than offshore areas (considering all Gulf waters). The lack of nearshore turtles is contradictory to data proposed by Gallaway et al. (1995) in a previous study. The Gallaway et al. report suggested that more Kemp's ridleys are found close to shore (within 10 km of shoreline) and these species concentrate in Zones 17 and 18. We did not analyze Kemp's ridleys or any other species separately; this study cannot generalize the different species spatial dynamics but only the general trends of all species in the Gulf.

However, when considering the Eastern and Western Gulf waters separately, the trends are slightly different. The Eastern Gulf still does not have a higher abundance of turtles nearshore but the Western Gulf does have a noticeably larger proportion of turtles in the 0-18.3 meter range. The high nearshore abundance in the Western Gulf is logical given that more Kemp's ridleys inhabit Western Gulf waters close to shore. In addition, loggerheads are found farther offshore than Kemp's ridleys, and loggerheads are the most common species found throughout the Gulf. More turtles were found on the western coast of Florida, so many of these species were probably loggerheads. Given this rationale, it is not surprising that more turtles are found in waters greater than 18.3 meters. Differentiating between Eastern and Western waters greatly alters the turtle depth distributions so managers must take these differences into consideration when determining the effectiveness of management alternatives.

The Western Gulf does have a high proportion of turtles close to shore, but the nearshore abundances are still lower than expected, based on estimates in previous literature (Magnuson et al., 1990; Gallaway et al., 1995; Renaud, 1995). There could be a lack of turtles in nearshore areas as a result of intensive shrimp fishing close to shore. Most of the shrimping intensity in the Gulf occurs within 0-9.1 meters (0-5 fathoms), and several species of turtles are found to live in shallow water areas. For example, Kemp's ridley turtles equipped with satellite transmitters were found in shallow waters along the western Louisiana and upper Texas coast during the summer (Gallaway et al., 1995). A satellite telemetry study by Renaud (1995) found the majority of Kemp's ridleys in waters within 15 km of the shore and in water depths of less than 18 meters. With intensive fishing effort in these same areas, a localized depletion of turtles could result.

However, the GOMEX aerial surveys were conducted in the proposed areas of Kemp's ridley abundance (Texas and Louisiana waters) and few turtles were seen close to shore. Based on the results of this study, closing down the nearshore waters to fishing (10 km from the shoreline) might not protect a large amount of turtles if few turtles are located in these areas.

Given the turtle spatial dynamics, the hypothesis that more turtles are found close to shore cannot be accepted when considering the entire Gulf. However, Western Gulf waters do have a larger abundance of turtles nearshore in comparison to the other depth zones. Nearshore Eastern Gulf waters have a slightly lower level of turtle densities than the 18.3 to 54.9 meter zones. Overall, the abundance of turtles in the 0-18.3 meter zone is slightly lower than expected (based on previous literature), but the caveats associated with detecting species close to shore must be considered.

13.0 STUDY CAVEATS

As with many other scientific studies, there are several potential problems associated with using the best available data. This project used the best data available from NMFS on in-water sea turtle estimates in the Gulf. The problems with the data probably did not influence the overall outcome of this study to a large extent, and we feel that our results are reliable and should be considered in future management decisions. This study represents a new method of addressing sea turtle conservation in that in-water surveys should play an increasing role in turtle research and in order to strengthen turtle protection, area closures should supplement current TED technologies. Regardless, it is necessary to address the potential problems of this study for managers to take into consideration.

13.1 LOGISTICAL PROBLEMS

The first problem is that the survey was not conducted in the same months as high shrimping intensity. The survey was conducted in September, October, and, in 1994, November, while the months of highest shrimping activity occur in the summer months of June, July and August. The variation between the aerial survey sea turtle sightings and shrimping intensity could result in the abundances of turtles in high shrimping effort months being different than the abundances described in this study. Shrimping in the fall months is sporadic and doesn't follow a general trend throughout the Gulf, unlike the all-year shrimping effort. The high levels of shrimping in the summer months could influence the distribution of turtles in a manner different from the fall months. Shrimping effort for the entire year is very high in the locations of low turtle abundance calculated in this study. Whether or not the turtle distribution in the summer months is the same as the fall remains unclear.

Furthermore, it is difficult to determine exactly how turtle distribution is affected by shrimping effort. Turtles would obviously be influenced by shrimping effort in the same month, but shrimping in the summer could also affect turtle distribution. For example, high shrimping intensity in July could reduce turtle abundance, destroy habitat, or decrease the available food supply found in September and October. The two different analyses of shrimping intensity (all-year and selected survey months) were conducted as a result of this discrepancy.

Another problem mentioned previously is that the aerial surveys were conducted specifically for cetaceans in coastal waters and on the continental shelf. Therefore, the survey platform could have been slightly biased in detecting large pods of cetaceans instead of small individual sea turtles. The observers are experienced in detecting all varieties of animals, but some turtles could have been missed. A sea turtle aerial survey should ideally be conducted at an altitude around 152 to 167 meters, but the GOMEX surveys were flown at 229 meters (Blaylock, 1993; Epperly et al., 1995a; W. Hoggard, NMFS, personal communication). In a sea turtle aerial survey by Epperly et al. (1995a), the surveying speed was slower than in the GOMEX surveys: 128 km/hr in the Epperly et al. study and 220 km/hr in the GOMEX surveys. These differences could have resulted in missed turtles, but if the surveying conditions were the same over the entire Gulf (which they were), the spatial dynamics of sea turtle abundance should not be affected. Therefore, this survey could have underestimated the abundance of turtles to an unknown degree, but as described previously, it is better to underestimate the abundance of an endangered species than overestimate. The important aspect of this study is not the actual number of turtles, but instead, the spatial dynamics of turtles throughout the Gulf for area closure options.

A third problem involves the lack of data in several areas along the Florida coast. Subzones 1 and 2 in 0-18.3 meters were not sampled, as well as waters beyond 54.9 meters in Zone 6. Turtle densities were not calculated for the areas with missing data, and therefore the abundance estimates could be exceptionally high or very low. Zones 1 and 2 (0-18.3 meters) likely have high turtle abundance because the surrounding waters have extremely high turtle densities. Although this speculation cannot be validated, the nearshore waters could have a greater abundance of turtles if Zone 1 and 2 turtles were included. Eastern Gulf turtle abundance in the 0-18.3 depth zone would therefore increase (Figure 13). The lack of data in the Florida Keys region is not critical to turtle protection because most of the area is included in the Florida Keys National Marine Sanctuary (National Oceanic and Atmospheric Administration, 1996).

As a result of the surveying technique, nearshore turtles could have been missed. One reason for the low proportion of nearshore sightings is that nearshore waters are often murky and brown due to the large sediment load. Increased nutrients (fertilizer) and coastal development in Florida, as well as the Mississippi River outflow, may create a unsatisfactory medium for turtle aerial surveys. Turtles in the murky nearshore zones could have been missed, but the waters are so shallow in the nearshore areas that observers usually can see straight to the bottom. The inability to view turtles in slightly turbid waters could offset the ability to see farther into the water column in shallow waters.

Another possible reason for the low numbers of nearshore turtles is that young juvenile turtles are commonly found close to the shoreline and the small size of these species would be difficult to detect in an aerial survey. Most of the adult and larger juvenile turtles are seen from the air, but observers realize that not all small turtles (especially Kemp's ridleys) can be distinguished from a high altitude. If the missed species were Kemp's ridleys and Kemp's are the species found closest to shore, this could result in a low abundance of turtles in the 0-18.3 meter zone.

Although the Eastern Gulf has a higher proportion of turtles most likely due to better habitat availability, low fishing pressure and high oxygen levels, the densities in the Western Gulf could be drastically underestimated. The waters of the Western Gulf are generally more turbid than the Eastern Gulf, and the Eastern Gulf waters are so clear that submerged turtles are often detected. Murky waters would reduce the ability to count submerged turtles in the Western Gulf, so the low abundances in the Western zones could be a result of poor water clarity and not from the intense fishing pressure or low oxygen levels as originally hypothesized.

If Kemp's ridleys are found mostly in the Western Gulf and Kemp's ridleys are extremely rare, these factors would contribute to the low turtle abundance in the Western Gulf. Kemp's ridleys would be present in these areas but they are too few in number to frequently detect in an aerial survey. In addition, the low abundance in the Western Gulf could be a result of the difficulty in detecting juvenile Kemp's ridleys (with small carapaces) in an aerial survey flight. Furthermore, if Kemp's ridleys commonly occur in the Western Gulf, with turbid and murky waters, these species could remain undetected. If Kemp's ridley turtles were missed in the survey, the Western Gulf would have an artificially low turtle abundance.

Alternatively, Kemp's ridleys have different physiology from other sea turtles, which does not enable them to survive as long underwater (Magnuson et al., 1990). Therefore, Kemp's ridleys would be found on the surface more often and be more likely to be spotted in an aerial survey. As a result, the number of Kemp's ridleys could be higher than other species on the surface and the abundance estimates would be comparable throughout the Gulf.

The final problem with this study involves shrimping effort data collection from the port agent program. The port agent program has been widely used in previous research, but there are several concerns about this data set. Even though cooperation is mandatory, the number of interviews may not represent the true proportion of landings and effort because the interviews are not randomized. In addition, NMFS has to use modeling techniques in order to estimate the catch per unit effort (CPUE) in areas with inadequate interviews. This leads to shrimping effort being assigned to areas where none occurs. For example, the large hypoxic zone found in offshore Louisiana severely decreases the amount of shrimp available for harvest. Therefore, little shrimping probably occurs in this hypoxic zone, contrary to the shrimping effort model estimate. Additional research should concentrate on shrimping and the hypoxic zone to verify this assumption.

Another problem with the shrimping effort data set is that several characteristics of fishing power (e.g. vessel size, number of vessels) have varied during the period represented by the historical data set (Griffin et al., 1997). Griffin, Shah, and Nance (1997) have addressed these concerns by developing a statistically valid effort estimation method, but this data set was not available at the time of this study. This project used the best available data to perform these analyses.

13.2 FUTURE RESEARCH

Regardless of the potential problems in this study, this research provides fuel for thinking about possible management techniques necessary for turtle conservation. TEDs have been estimated to reduce turtle mortality by approximately 44% in the southwest Atlantic (Crowder et al., 1995); but if strandings continue and TED compliance remains high, other management options should be considered. Turtle protection may not be sufficient under the

ESA if juvenile and adult turtles are still dying in large numbers. If nothing else, this study should stimulate future research by NMFS and other academics.

Another aerial survey should be conducted in months of high shrimping activity in order to determine if turtles change distribution based on the intensity of shrimping or season. To provide an estimate of how turtles respond to intense fishing pressure, the survey could be conducted in three different time periods in the same location. For example, a survey in Zone 19 could be conducted before the Texas Closure (late April/early May), during the Texas Closure (June), and after the Texas Closure (late July/early August). The survey should be flown in long straight transects from the shore to approximately 91.5 meters (50 fathoms) offshore, and be performed especially for turtles with trained observers, an ideal flight altitude and an ideal surveying speed. With this specific survey platform, observers would be able to identify more individual species and detect a greater number of juveniles and small Kemp's ridleys. This theoretical survey would provide a better estimate of how turtles react to high shrimping intensity.

An in-water survey for turtles is the best estimate of species abundance, as opposed to estimating turtle densities from nesting females or strandings. An aerial survey is one method to determine the abundance of species in the water, but a trawl survey is another technique. There are many finfish trawlers that capture sea turtles without harming the turtle. Finfish trawls are conducted over short durations, unlike shrimp trawlers who leave their gear down for several hours. Henwood and Stuntz (1987) found that a trawl dropped for less than 60 minutes results in near zero turtle mortality. Therefore, these short finfish trawls could provide a reliable source for in-water turtle abundance without killing the turtle. Both aerial surveys and trawl surveys should be conducted more frequently to accurately estimate the number of sea turtles in the water.

It is important to establish an effective cooperative relationship with the trawl fishers and managers, so the fishers would record all turtles captured. Techniques of maintaining accuracy and fisher cooperation include on-board researchers or fisher incentives (money; publicity; personal sense of goodwill and species conservation). If researchers and fishers are capturing a greater number of turtles in their nets, this might indicate that there are more turtles in the water. Actually, the general perception is that fishers are seeing more turtles in the water today than in previous years, but data were not available for this study.

Another area of research that should be addressed is the impact of the Louisiana hypoxic zone on turtles and shrimp. In the recent past, there have been several conferences addressing the role of hypoxia in the northern Gulf ecosystem (e.g. the December 1995 Hypoxia Management Conference). Future studies should measure the affects of low oxygen on shrimp and shrimp prey, and whether these impacts change the distribution and socio-economic status of the Louisiana shrimp fleet. Turtles eat benthic organisms (crabs and mollusks), so evaluating the location of turtle prey in response to the low oxygen zone is essential for future turtle protection.

The final recommendation for future research entails analyzing different years to determine long term trends in turtle abundance. This study only considered 3 years (1992, 1993, and 1994) after TED implementation in the Gulf. Granted, some shrimpers were not receptive to TED technology at this time, but overall compliance in the Gulf was 92% from 1992-1994. In the early 1980's, compliance was low (around 5%), but since 1995, compliance has been calculated at 97.6% (M. Johnson, USCG, personal communication). A study in pre-TED years (1987) and post-TED years (1995) would allow for some generalization about the affect of TEDs on sea turtle abundance. This research should use the same density estimations (strip or line transect methods) and, in order to accurately compare the two years, the survey platforms should be comparable.

14.0 AREA CLOSURE MANAGEMENT STRATEGIES

Sea turtle conservation efforts require continuous scientific research and additional education efforts. Simultaneously, policy makers must realize that we need to progress with innovative management plans. TEDs have been effective in reducing sea turtle mortality (Turtle Expert Working Group, 1998), but they are not necessarily the ultimate management technique. If high sea turtle strandings continue in the future, we must develop other management options that are realistic for all stakeholders.

The purpose of this section is to address potential areas for seasonal or regional closures based on the distribution of sea turtle abundance and shrimping intensity. Granted, area closure management options might not be the most practical solution for every situation, so TED requirements should continue. If NMFS decides that area closures are the best way to prevent future turtle extinction, these closures should complement the existing protection strategies. TEDs have reduced a substantial amount of turtle mortality, but strandings cannot be totally prevented without restricting fishing activity. Regardless of the policy option, managers must be completely dedicated to sea turtle protection efforts and continued enforcement.

Several area closure management techniques have recently been considered in certain Gulf locations. For example, in Texas a small scale area closure has been contemplated in areas with high shrimping intensity and high turtle abundance. Closing certain channels and a one-mile circumference around the channels would protect turtles in these areas (C. Coogan, NMFS, personal communication). However, strandings data must support closing these inlets by validating the presence of turtles. This technique is additionally a good shrimp fishery measure because small shrimp will be protected in these channels and growth overfishing will be prevented. These shrimp will then be able to move offshore without the threat of overfishing and grow to a more marketable size.

Spatial closures have already been implemented in other Gulf shrimp fisheries. In Florida, managers have developed a policy in which spatial closures are established in exchange for the removal of the shrimp size requirement (W. Teehan, FMFC, personal communication). Permanent nursery areas are set up in order to protect the juvenile shrimp and to increase the future yield of adult shrimp. Fishers are very receptive to this program, because they catch larger, more economically valuable shrimp and the nurseries are protected to ensure the long-term survival of the fishery. Recently, the Florida Marine Fisheries Commission has set up a nursery in the Big Bend area (from Tampa to St. Marks) in which they closed a half million acres in waters 1.8 meters or less. There are five shrimping regions in Florida where this program is applicable.

Incentives should be offered to fishers before closing any shrimping area. Possible incentives include monetary rewards for leaving the fishery and job placement. In order to compensate for the loss of freedom associated with fishing, the fishers could uptake a small scale business dealing with the marine environment. For example, operating a commercial fishing charter boat, operating a dive boat, or entering the ecotourism industry are possible marine based employment positions. Fishers could also seek employment as a NMFS port agent representative or an assistant for developing new TED technology. However, fishers need to be receptive to the idea of area closures for the system to work.

The specific type of area closure management strategy implemented ultimately depends on the goals of NMFS. Specific ESA recovery goals, staff areas of interest, and political or constituent pressure can easily dictate policymaking. For example, if NMFS wanted to conserve turtles in areas of high abundance, area closures in high turtle abundance subzones would be most effective. One conservation strategy would be to close waters with high turtle abundance and low shrimping intensity. Restricting fishing in these areas would maintain the social and economic structure of the shrimping industry. For example, a realistic area closure could occur in subzones greater than 36.6 meters in Zone 3 (as shown by the coral shades in Appendix 12). Closing these waters would not displace many fishers (given the low shrimping intensity) and protect turtles in areas of highest abundance. Furthermore, closing an area with little shrimping activity and high turtle abundance would be easier to implement and be more readily accepted by shrimpers.

Another conservation technique is to close waters with high turtle density and high shrimping intensity. Areas of high shrimping are the biggest threat to sea turtle populations, because turtles can be captured and stressed even with TED use. The reason high turtle abundance occurs in areas with high shrimping intensity is not necessarily that turtles are unaffected by shrimp trawls. The turtle abundance in these locations is high **relative** to all other subzones. High turtle abundance in a certain area does not mean that the density of turtles is exceptionally large; it also does not mean that we should forget about protecting species in these areas because population numbers are high. All sea turtles are either threatened or endangered and the populations are fragile, so great care should be taken to alleviate any potential mortality source.

However, closing areas with high shrimping and high turtle abundance is not as socially acceptable as closing low shrimping areas, so this option could be difficult to implement. A substantial amount of shrimpers would be forced out of their traditional fishing areas and need to move to another region. The political and economic ramifications could be exceptionally large, so careful consideration should be taken before policy is enacted.

With this type of area closure technique, the area that might be the most logical to close is the region around the Dry Tortugas Shrimp Sanctuary (Appendix 2). This sanctuary is currently closed to shrimp fishing during most of the year, but a large amount of effort is concentrated on the fringes of the sanctuary. A portion of the water in Zones 1, 2 and 3 is already closed, so expanding this sanctuary would not require a large amount of additional planning. Enlarging the Zone 2 area to include waters out to 36.6 meters would protect turtles and the wide variety of marine life found around the diverse Florida Keys (Appendix 14).

Another area closure management strategy could test the likelihood that high shrimping intensity has reduced local turtle populations or altered nursery habitats. If NMFS is concerned about the shrimping industry depleting a large number of turtles, they could test adaptive management techniques off the coast of Louisiana. Closing a zone with high shrimping intensity and low turtle abundance (e.g. Zone 17) would give turtles the opportunity to reoccupy these waters. If historical levels of high shrimping intensity have contributed to the low sea turtle abundance in Western Louisiana, closing the high shrimping waters would result in a turtle density increase. By removing the shrimping pressure, the populations could rebound. A substantial amount of time should be given to test this adaptive management strategy because turtles are long lived, slowly maturing animals. If after a 10-year closure turtle abundance has increased, this could indicate that shrimping has negatively impacted turtle density in this area. Unfortunately, this technique is relatively impractical because the shrimp fishery in Louisiana dominates the local culture and economic system so it would be difficult to enact this type of closure. However, if NMFS wanted to test the depletion hypothesis, this is an option they could consider.

If NMFS wanted to protect species diversity, an area closure could be implemented in areas with high numbers of different turtle species. This study did not distinguish between different species of turtles, but strandings data can be used to estimate the areas with high proportions of different types of stranded species. Zones 20 and 21 in southern Texas have a high number of different types of stranded species, including loggerheads, Kemp's ridleys, green, and hawksbill turtles (Figure 16). In order to conserve the greatest number of species, southern Texas waters could be seasonally closed to shrimping.

When analyzing the strandings data, the size of the turtle and species type should be considered. A substantial number of hawksbills are found in southern Texas waters, but these turtles are mostly post-hatchlings (<10 cm in length). Even though these turtles are probably floating with the currents and not using any habitat in this area (W. Teas, NMFS, personal communication), the turtles are still subject to mortality by southern Texas fisheries. Closing this area to shrimp fishing could protect a large number of post-hatchlings, even though these smaller turtles are not generally as valuable to the total population status (Crowder et al., 1994).

The species of turtle also affects the effectiveness of an area closure. Green turtles in southern Texas are probably using the bay seagrass beds, so offshore closures would not affect the inshore green turtle populations to a large extent.

On the other hand, the majority of large juvenile and adult Kemp's ridley strandings occur in southern Texas. In 1997, an alarming number of Kemp's ridleys washed up on Texas beaches, the most since 1994. A total of 523 sea turtles washed up on Texas beaches, and 21 out of 180 Kemp's ridleys were adults (Tinsley, 1998). Large juvenile and adult turtles contribute greatly to future population levels because most of these turtles are capable of reproduction. Therefore, if a large number of rare Kemp's ridley adults are dying, this would be detrimental to the future population. The large number of strandings occurring with high TED compliance (97%) indicates that additional protection measures should be initiated. Area closures around southern Texas (off South Padre Island) are necessary for the survival of juvenile and adult Kemp's ridleys.

An area closure in these Texas waters would also protect Kemp's ridleys nesting on South Padre Island, Texas. Headstarting was conducted to imprint Kemp's ridleys on the Texas beach, and in 1997, nine Kemp's ridley nests were found along the Texas coast. These turtles were not necessarily headstarted turtles, but regardless, this beach could become a second nesting population for these endangered species. If a highly endangered sea turtle is nesting in this area, the beach and surrounding waters could be protected to allow for future nesting possibilities. Closing this area could alleviate the possibility of shrimping mortality on the females while they travel to the nesting sites. A shrimp vessel offshore could easily entangle a nesting turtle in the trawl, and the additional stress of the capture could affect the reproduction process or prevent the female from nesting altogether.

An additional protection measure for Kemp's ridleys would involve closing portions of Zones 17 and 18 to shrimp fishing. Strandings data from September, October, and November in 1992, 1993, and 1994 depicted a large number of Kemp's ridleys stranding in these zones (Figure 16). If the Kemp's ridley recovery goal is to protect species disregarding any other factor (i.e. the socio-economic aspect of the shrimp fishery), Zones 17 and 18 nearshore waters should be considered for closure.

Another strategy for deciding which areas to close for turtle protection is the ratio of shrimp catch to sea turtle bycatch (SC/STBC). Areas with low numbers would be potential closure sites, because this would suggest a limited shrimp catch and high sea turtle mortality. This would initially require some observer coverage onboard the shrimp boats to monitor bycatch levels, but 100% observer coverage is relatively impractical with such a large fishery. The ratio of shrimp catch per effort to sea turtle catch per effort could also be used as a closure index (SC per Effort/STBC per Effort).

Given the above rationale, spatial or seasonal closures should be considered for the Gulf shrimp fishery. Permanent spatial closures are often effective, but seasonal closures are not always the best regulations for promoting sea turtle conservation. Closed areas are useful strategies for meeting conservationist objectives, but these closures can often encourage overcapacity (McGoodwin, 1990). For example, in the open season, the fishers seek more effective ways to maximize their catch rates (more effective fishing vessels and technology) and fish more intensively (Waters, 1991). Seasonal closures would result in pulse fishing during the fringe period of the closure and more turtles would be captured in trawls during this time, most likely multiple times. Is a shorter shrimping season worth additional sea turtle captures and subsequent mortality immediately after the season opens?

Furthermore, unless NMFS finds that unauthorized levels of take are occurring and reaching levels that will jeopardize recovery, NMFS will probably have trouble justifying new regulations on the Gulf shrimping industry (C. Coogan, NMFS, personal communication). When contemplating area closures, one must realize that there is the possibility that shrimping effort will move as a result of the closure and high strandings will follow the effort, and not decrease as expected. Regardless, the options presented above should be taken into consideration if, in the future, sea turtle mortality increases. The recent increase in 1997 strandings could be an instigator for additional management regulations.

15.0 ADDITIONAL MANAGEMENT STRATEGIES

Scientists are studying sea turtle biology, genetics, distribution, and migratory patterns, but without solid management strategies the species may well go extinct. These organisms require ongoing scientific research since we know very little about their unique lifestyles, but at the same time, policy makers need to move forward with innovative conservation plans. NMFS has formulated several regulations that have helped conserve sea turtles, namely TEDs technology, SFSTCAs, and specific gear requirements. But the job is not finished. If the sea turtle populations continue to decline in the future, humans must look to other management options to protect sea turtles, from unwanted bycatch and other natural predators and disasters.

Understandably, conservation is a difficult task. We must realize that conservation is a reflection of an affluent society. Underdeveloped countries have a harder time conserving an available resource, even though the resource is endangered. Grassroot development is essential for turtle protection, especially in developing countries. Many sea turtle conservation opportunities exist in developing countries, and the developed countries should support these activities. Controlling poaching by increased enforcement and limiting development on nesting beaches are two options being developed by local people. Other sea turtle protection measures include establishing turtle camps with extensive protection, educating the local people (especially children) about turtles and conservation practices, developing alternate, readily available food sources, and promoting low-impact tourist activities (El Custodio de las Tortugas web page, 1997). All of these solutions involve integrating the agencies, citizens, and fishers in the area.

There need to be additional measures for protecting sea turtles in United States waters, even with the effective regulations in place. For example, even if a turtle is released unharmed from a shrimp trawl, some degree of stress is placed on the species. After multiple captures in the same area (as a result of pulse fishing), these turtles will eventually die from asphyxiation and stress (Magnuson et al., 1990). Mortalities that occur after escape or release have been attributed to capture associated stress. Long term studies measuring individual and cumulative effects of stress on sea turtles could be conducted, but unfortunately the plight of the sea turtle needs to be improved immediately. Since all sea turtle species are either endangered or threatened, managers cannot wait for future research to implement protective policies. Therefore, current regulations and policy decisions must consider the best available information.

If the current trend of sea turtle mortality and capture remains the same and we allow this trend to continue, the species will probably perish. Even though the current mortality trends are not as grim as they once were, strengthening protection is necessary to increase species numbers. The following management techniques were obtained from an extensive literature review on practical alternatives for the Gulf shrimp fishery. These ideas should only serve as possible options for turtle conservation, and not necessarily as explicit guidelines for managers to follow.

15.1 INCREASED COMMUNICATION AMONG STAKEHOLDERS

One of the most serious challenges in addressing Gulf shrimp fishery bycatch is the lack of effective communication among scientists, fishery managers and agencies, fishery user groups, the environmental community, and other stakeholders. This miscommunication can lead to the deliberate or inadvertent release of misleading information. Oftentimes, barriers to successful conflict resolution include mutual mistrust, the amount of money and time needed to implement effective programs, the lack of a coherent management authority, and scientific uncertainties (Policansky, 1996).

Additional scientific information is obviously needed in the sea turtle community, because little is actually known about these endangered species. A good scientific understanding reduces mistrust, saves time and money, and encourages coherent management authority. The Turtle Expert Working Group (1998) recommended future studies including long term, in-water indices of sea turtle abundance. These studies would provide valuable information about underwater sea turtle life, especially for small pelagic juvenile sea turtles' "lost years."

Fishers tend to perceive the continued introduction of new, more restrictive, costly, and complex regulations as a source of instability in the fishery. This leads to the fishers viewing the management agency as part of or the source of the problem (Weber, 1991). The result is a complicated, oppositional relationship between fishers and the fishery managers. Obviously, this is not the most effective way to promote innovative conservation strategies.

One of the priorities for efficient communication is to understand the objectives and goals of each party involved. If these goals are not compatible, initial efforts should prioritize finding solutions everyone is comfortable with. If some parties are not ready to collaborate, they could be left out of the initial stages and included when they see a successful cooperative developing (M. Hall, IATTC, personal communication).

Establishing "key informants" is essential for effective communication. These informants would be from the fishery, and they would be familiar with the problems and the fishery. Furthermore, these individuals should be open-minded, trusted, and respected by their colleagues. They would represent the other fishers in stakeholder meetings with environmentalists, managers, scientists, and governmental officials. Managers and scientists can more effectively address issues and develop regulations with a small group of fishers, and then these informants can go back to their fishery and rehash the proceedings. Fishers might be more disposed to accept regulations if educational efforts can be backed by sound data (outlining the turtle/shrimp fishery decline problem) and explanations of fishery principles understood by fishers (McGoodwin, 1990).

With the new initiative in technology and communication around the world, the communication problem could be easily solved. Electronic systems would increase communication and offer information and data sharing among those affected by sea turtle conservation and the shrimping industry. While the majority of the focus is on species research and gear development, much remains to be done regarding information and technology transfer to fishers and other stakeholders, such as environmental groups. Everyone must work together to protect the environment and marine species for future generations.

15.2 PROMOTE CO-MANAGEMENT

Fishery co-management is defined as an arrangement where responsibility for resource management is shared between the government and user groups (Sen and Nielsen, 1996). A co-management structure incorporates the government and user groups as equal partners for all management tasks and at all stages of the management process. The development of such a user group in the Gulf shrimp fishery would be an effective way to communicate with NMFS.

A Gulf state shrimping organization could work with NMFS in a cooperative agreement for the benefit of the shrimp fishery and sea turtle protection.

A Gulf state shrimping organization would bring in individuals from different areas that are working for the same outcome: a successful shrimp catch. By including open water as well as inshore shrimpers, and Florida as well as Texas shrimp fishers, this Gulf state organization could work together for the best possible outcome for all.

However, historically nearshore and offshore shrimp fishers have not had compatible goals and fishing methods. Oftentimes they do not agree on fishing practices and catch sizes. As stated previously, sea turtles are usually found closer to shore (0-36.6 meters), so the nearshore shrimpers could have a greater impact on sea turtle mortality. Perhaps the best way to conserve sea turtles is through a shrimping organization of only nearshore shrimpers, with similar problems, fishing techniques, goals, and culture. These fishers would more likely agree on a conservation strategy effective for their particular fishery, rather than both offshore and nearshore shrimp fishers with different goals. In other fisheries, small scale fishers have shown the will to join forces in defense of their fisheries and future sustainability (McGoodwin, 1990).

The Gulf state shrimping organization would have many potential benefits, for the industry as well as other people involved in sea turtle conservation. This conglomerate would represent a central body for working relationships with other countries, environmental groups, or governmental agencies. With a unified shrimping organization, it would be easier to address future problems, new technology, and new conservation schemes. Pooling shrimp fishery resources would also benefit the industry by promoting gear or other research, assist in the training and education of the fishers, and maintaining a healthy and successful Gulf shrimp fishery.

This group must be kept to a reasonable size, preferably 20 or smaller. With a smaller group, there is a better chance to find a successful solution, and conflict is kept to a minimum (M. Orbach, DUML, personal communication). Someone who has a knowledgeable background in the shrimping industry, but is able to cross many boundaries within the industry, could lead the organization. The chair should have a positive attitude, extraordinary communication skills, a creative approach to potential solutions, and effective leadership capabilities (M. Hall, IATTC, personal communication).

15.3 ADDITIONAL FUNDS FOR TURTLE PROTECTION

The US government could allot more money for sea turtle protection and conservation. The monies could assist in the development of new technology for the shrimp fishers and stimulate research. With increased technological fixes and more effective TEDs and bycatch reduction devices (BRDs), the shrimp fishers could protect sea turtles and efficiently catch more shrimp simultaneously.

Many studies have addressed the success of TEDs in protecting turtles, but TEDs also reduce the catch of finfish. Implementing and perfecting the use of these devices could benefit the entire ecosystem in the long run. Managers are now studying BRDs to reduce finfish bycatch in the Gulf fishery. Hendrickson and Griffin (1993) used a bioeconomic fisheries simulation model to test the effectiveness of BRDs and area closures for finfish bycatch reduction. BRDs were more effective and generated fewer discards than closures at a lower cost. However, this study only evaluated finfish bycatch, so the same results cannot necessarily be applied to turtle protection with TEDs and area closures. BRDs seem adequate for reducing finfish bycatch, but TEDs would still be needed to successfully protect the turtles.

If industry takes a large part in the development of future conservation plans, the historical adversarial relationship between fishers and agencies will be hopefully be eliminated. The shrimp fishers could assist with practical alternatives for sea turtle protection, as well as advise on technological designs. Additional funds could be distributed to the shrimpers in order to develop new technological solutions.

15.4 NEARSHORE SHRIMP CLOSURES

One proposed management option is to close all nearshore waters to shrimping to protect Kemp's ridley sea turtles. They are the most endangered sea turtle and their physiology is different than other sea turtles, making them extremely vulnerable to fishing pressure. Kemp's ridleys cannot survive underwater as long as other sea turtle species, so when they are submerged in trawl nets, they drown faster (Magnuson et al., 1990). Their susceptibility to this increased mortality promotes the necessity for immediate protection, whatever the cost. Fishing pressure in offshore waters (greater than 36.6 meters) should not influence Kemp's ridley survival to a large extent, because these turtles do not usually live in deep waters due to foraging and habitat constraints (FWS and NMFS, 1992).

Gallaway et al. (1995) stated that Kemp's ridleys inhabit nearshore waters. If TEDs do not seem to be increasing Kemp's ridley populations to the established recovery levels, managers could restrict shrimping in the most highly populated Kemp's ridley locations. If strandings continue, especially immediately after the end of the Texas Closure, additional measures should be taken to protect the turtles. Most of the shrimping effort is concentrated in the nearshore waters, but unfortunately this is where the most turtles are located.

Gallaway et al. (1995) proposed closing all shrimping within 10 km of the shoreline. This would protect Kemp's ridleys close to shore and only displace one nearshore (white) shrimp fishery. This management alternative might protect Kemp's from extinction, but the socio-economic implications of closing the entire nearshore fishery and depth zone are enormous. This type of closure would be relatively impractical in the Gulf shrimp fishery.

15.5 INCREASING VIOLATOR FINES

The government must enforce the rules so that shrimp fishers have a reasonable expectation of being caught if they attempt to disregard the turtle conservation regulations (i.e. disabling TEDs or fishing in closed waters). Waters (1991) has found that there must be a relatively severe penalty for cheating, such as temporary or permanent revocation of fishing privileges or loss of catch, in order to initiate 100% compliance. If fishers are caught cheating and banned from the fishery, other shrimpers would refrain from conducting similar illegal proceedings. The "shame theory" has been seen to work in other cases, such as in the Eastern Tropical Pacific dolphin-tuna problem (M. Hall, IATTC, personal communication). Fishers do not want to seem different (or worse in this case) than their peers. If there is a weekly report identifying the violators, fishers might be more inclined to try to keep their name off the public list.

Furthermore, according to The Humane Society of the United States (1997), a highly visible and well-funded reward system for information leading to the apprehension of TED violators would increase fisher cooperation. Financial rewards would be an interesting option for the Gulf shrimp fishery, because many fishers are concerned about losing money in the future fishery. The rewards to the cooperating shrimp fishers could be distributed from the money collected from the violators. However, great care should be taken to ensure that the shrimpers do not become suspicious of each other. The goal is to make shrimpers work together for the benefit of the environment, and unfortunately a reward system could result in spying, arguments, and mistrust.

Another option outlined by the Humane Society of the United States (1997) is to develop a protocol to ban convicted vessel Captains and vessel owners from the shrimp industry if they are twice convicted of dismantling their TEDs. This procedure could only work if each and every violator is treated in the same fashion. If one shrimper finds out that another Captain paid a large fine instead of leaving the industry, the entire program would be undermined.

These alternatives should be remembered if the state of turtle conservation becomes overwhelmingly bleak, but until then, these procedures might be interpreted as unnecessarily harsh for the Gulf shrimp fishery.

15.6 RESTRICTING TOW TIMES

Requiring shortened tow times in certain hot spot areas would reduce the submergence time of captured turtles. On-board observers and detailed research studies have found that with a tow time of 60 minutes there is near zero mortality. However, rates rise rapidly with increasing tow times to approximately 50% with tow times in excess of 200 minutes (Magnuson et al., 1990; Henwood and Stuntz, 1987). Unfortunately, many shrimp trawls are conducted for several hours at a time.

Shortened tow times could be enforced through a monitoring device attached to the trawl. NFMS agents could collect these devices at the ports, record the time submerged, and report any violations. Unfortunately, these apparatuses are very expensive and relatively impractical (C. Coogan, NFMS, personal communication). Enforcement of restricted tow times without monitoring devices is also difficult. In 1989, NMFS tried to restrict tow times in place of TED requirements, but agents were not able to adequately enforce the shortened times and TEDs were reinstated.

Given the previous difficulty with TED implementation, the likelihood a tow time monitor would be accepted in the Gulf shrimp fishery is extremely small.

15.7 SHRIMP FISHING EFFORT REDUCTION

15.7.1 Limited Entry

One of the major problems with the Gulf of Mexico shrimp fishery is open access. Allowing anyone and everyone to fish creates an overabundance of shrimp fishers that are fishing for a decreasing amount of shrimp. As Hardin (1968) wrote, "Freedom in a commons brings ruin to all." Unfortunately, the Gulf shrimp fishery is overcapitalized and generates excessive shrimp fishing effort levels (Ward et al., 1996). The number of vessels fishing for shrimp has increased, but the amount of shrimp available has remained relatively constant. Furthermore, the vessels and number of nets have gotten bigger, the cost of operating the vessels has increased, and US shrimp fishers have to compete with cheap, imported, farm-raised shrimp. The number of vessels must decline if shrimpers are going to be able to survive economically.

The entire economic performance of a fishery suffers when there are too many vessels catching a limited amount of shrimp, termed overcapitalization. A limited entry system could be constructed to restrict the amount of fishing pressure in the Gulf. The benefits of a limited entry program include increased shrimper profits, long-term resource conservation, and maximum benefits from a publicly owned renewable natural resource (Texas State web page, 1997). Several studies have outlined the benefits of a limited entry system to fishers and a sustainable fishery, but a limited entry system could additionally benefit turtles.

By limiting fishers and increasing the amount of shrimp available for harvest, the turtle mortality might decline as well. Limiting the number of boats would reduce multiple captures of turtles through the reduction of intense, pulse-type fishing effort in certain areas. Together with synchronized regional openings and closings, pulse fishing could be reduced and the fishing concentration could be shifted to other areas. Also, if there are more shrimp to catch with a limited number of boats, the shrimp fishers would catch more with each trawl. They would not have to trawl as long for an ideal amount of catch (which could be predetermined), and shorter trawl times have been shown to result in lower sea turtle mortality (Henwood and Stuntz, 1987). A limited entry program would decrease the number of shrimp fishers, and a smaller number of people could be easier to educate and monitor. Eventually a type of shrimper natural selection could occur in order to remove the environmentally destructive fishers and to keep the most turtle friendly shrimpers in the industry. Subsequently everyone wins: the shrimp fishers, by catching more shrimp with less effort, and the turtles, with lower mortality from shortened trawling times.

A limited entry system could create additional benefits to shrimp fishers (McGoodwin, 1990; Waters, 1991). In addition, turtle mortality could decrease from the reduction in effort. If the fishery continues to be overcapitalized, turtle strandings continue and NMFS does nothing to limit entry, the turtles, shrimp fishers and ecosystem will all be the losers.

15.7.2 Individual Transferable Quotas

An individual transferable quota (ITQ) program is an upcoming management technique that has been implemented in several fishery areas. An ITQ assigns each certified fisher a share of the year's preset total catch, and the fisherman then can fish anytime he/she wanted to fill that quota or sell the share to someone else. This gives the fishers a reason to conserve the resource: to protect the species in order to ensure future fish populations and economic gain.

An ITQ system would decrease the shrimping effort in the Gulf and with a decrease in effort, fewer turtles will be caught in shrimper nets. Ideally, turtle populations would subsequently increase.

This technique has been studied by NMFS for implementation in the Gulf shrimp fishery. Some fishers feel that shrimping will unfortunately be the next fishery to test with an ITQ system, regardless of the feasibility (McQuaid, 1996). The ITQ program looks good on paper and it works successfully in other fisheries, but this particular management technique will be difficult to execute in the Gulf shrimp fishery.

One reason ITQs would be problematic in the Gulf shrimp fishery is that the assessment of a species such as shrimp is difficult. This species basically restores its' population every year due to a high growth rate, high fecundity and high death rate (B. Gallaway, LGL, personal communication). Therefore, setting the total allowable catch of shrimp would be difficult from the onset because it fluctuates greatly.

Several other reasons why ITQS would be difficult to implement in the Gulf are that there are limited resources (money and personnel) available to enforce the program and the area in question is too large. The Gulf shrimp fishery spans over several states, and there are many vessels involved. For example, at the opening of the Texas season, fishers from various states come into the Texas waters, some as far away as North Carolina. The problems lies with how to manage the numerous people and large amount of boats entering and leaving the area on a short time frame. Unless the fishery implements massive automation via scanners and increased technology, the ITQ program looks impossible. Unfortunately, the increased equipment and technology would raise the fishing budget to a level that the local areas and fishing management personnel cannot afford. Furthermore, the lack of personal contact that comes with automation and new equipment would eliminate the sense of trust NMFS has worked hard to develop with the local fishers (M. Hightower, NMFS, personal communication).

16.0 CONCLUSION

Turtles need additional protection from both natural and human induced mortality sources. Over the past several years, sea turtle strandings have remained at a less than optimal level, and the great increase in 1997 sea turtles deaths is second only to the high levels of 1994 strandings (with 527 recorded turtle deaths). A total of 523 sea turtles washed up on Texas beaches in 1997, and 180 were the highly endangered Kemp's ridley turtle. This high level of mortality is continuing regardless of enforcement efforts that verify TEDs are being properly installed and used in the Gulf. Therefore, NMFS must look to other alternatives (in addition to TEDs) in order to prevent future turtle extinction.

One option that would likely reduce sea turtle mortality is area closure implementation in specific Gulf waters. This analysis shows that several areas have the potential to become effective spatial closures for sea turtle protection. Depending upon the specific goals behind turtle conservation and the accepted reasoning for the Gulf turtle distribution, several possible spatial closures could be enacted. The most logical solution is to close zones with high turtle abundance and low shrimping activity. This option would be more practical and more likely to be accepted by shrimpers and environmentalists. While any area closure forcing a fisher out of the industry will be severely criticized, this option will maintain the overall social and economic structure of the Gulf shrimp fishery.

Another area to consider for closure is the southern Texas region around South Padre Island. Kemp ridleys and other turtles commonly inhabit these waters, as exemplified by the recent increase in strandings and nesting females, as well as the noticeable abundance of offshore turtles found in this spatial analysis. The government has spent millions of dollars implementing the headstarting program, and we now see several nesting females on this Texas beach. Regardless of whether these are headstarted turtles or not, we should try to protect these turtles in the most effective manner.

This type of closure could also be acceptable to the environmental community because turtles would be protected in areas with high densities. We can only speculate the reasoning behind the low turtle abundance, so instead of closing zones with "potential" high turtle densities, we could protect species in areas where turtles are noticeably abundant. This is not to say that areas with low turtle abundance could not be considered for area closures; but if only one strategy is developed, it should protect turtles in high density areas.

If conducted properly, I feel that aerial survey methods are an effective means of analyzing the number of turtles in the water. NMFS could allot more money for turtle-specific aerial surveys in hopes of establishing turtle spatial patterns, possible feeding grounds, and the turtle spatial dynamics in times of intense shrimping. In addition to aerial surveys, other in-water studies could be organized as well, like finfish trawling surveys. Great care should be taken to ensure that these methods are not invasive or directly damaging to the turtle populations.

Obviously, future studies could be initiated in order to learn more about these unique and endangered species. This project should serve as a catalyst for future thinking and research on the spatial dynamics of sea turtles and shrimping intensity in the Gulf of Mexico and other areas.

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REFERENCES

Anonomous. 1992. GOMEX92, Gulf of Mexico regional aerial survey design, September-October 1992. NMFS-SEFSC Contribution MIA-91/92-72, September 1992, 26 pp.

Bayliss, P. 1986. Factors affecting aerial surveys of marine fauna, and their relationship to a census of dugongs in the coastal waters of the Northern Territory. Australian Wildlife Resources 13: 27-37.

Blaylock, R.A. 1993. GOMEX92: Survey data documentation report, Gulf of Mexico regional aerial survey, September-October, 1992. SEFSC Contribution MIA-92/93-24, January 1993, 45 pp.

Blaylock, R.A. and W. Hoggard. 1994. Preliminary estimates of bottlenose dolphin abundance in southern U.S. Atlantic and Gulf of Mexico continental shelf waters. NOAA Technical Memorandum NMFS-SEFSC-356, 10 pp.

Buckland, S.T., D.R. Anderson, K.P. Burnham, and J.L. Laake. 1993. Distance Sampling: Estimating abundance of biological populations. Chapman & Hall, London.

Burnham, K.P., D.R. Anderson, and J.L. Laake. 1980. Estimation of density from line transect sampling of biological populations. Wildlife Monographs 72:1-202.

Caillouet, C.W., Jr., M.J. Duronslet, A.M. Landry, Jr., D.B. Revera, D.J. Shaver, K.M. Stanley, R.W. Heinly, and E.K. Stabenau. 1991. Sea turtle strandings and shrimp fishing effort in the Northwestern Gulf of Mexico, 1986-1989. Fish. Bull. 89(4):712-718.

Caillouet, C.W., Jr., D.J. Shaver, W.G. Teas, J.M. Nance, D.B. Revera, and A.C. Cannon. 1996. Relationship between sea turtle stranding rates and shrimp fishing intensities in the northwestern Gulf of Mexico: 1986-1989 versus 1990-1993. Fish. Bull. 94:237-249.

Carr, A. 1986. New perspectives on the pelagic stage of sea turtle development. U.S. Dept. Commerce. NOAA Tech. Memo. NMFS-SEFC-190.

Carr, A., A. Meylan, J. Mortimer, K. Bjorndal, T. Carr. 1982. Surveys of sea turtle populations and habitats in the Western Atlantic. NOAA Tech. Memo. NMFS-SEFC-91.

Cochran, W.G. 1977. Sampling Techniques. John Wiley & Sons, Inc. New York, NY.

Coles, W.C., J.A. Keinath, D.E. Barnard, J.A. Musick. 1994. Sea surface temperatures and sea turtle position correlations. In: Proceedings of the Fourteenth Annual Symposium on sea turtle biology and conservation, p. 211-212. K.A. Bjorndal, A.B. Bolten, D.A. Johnson, P.J. Eliazar (compilers). NOAA Tech. Memo. NMFS-SEFSC-351.

Coyne, M. 1997. Kemp's Ridley Conservation. <http:\\www.phoenix.net/~coynem/conserv/conserv/html>

Crowder, L.B., D.T. Crouse, S.S. Heppell, and T.H. Martin. 1994. Predicting the impact of turtle excluder devices on loggerhead sea turtle populations. Ecological Applications 4:437-445.

Crowder, L.B., S.R. Hopkins-Murphy, and J. A. Royle. 1995. Effects of Turtle Excluder Devices (TEDs) on Loggerhead sea turtle strandings with implications for conservation. Copeia. 1995:773-779.

Crowder, L.B. and S.A. Murawski. (due out June 1998). Fisheries bycatch: Implications for management. Fisheries (in press).

Darnell, R.M., R.E. Defenbaugh, and D. Moore. 1983. Northwestern Gulf Shelf Bio-Atlas: A study of the distribution of demersal fishers and penaeid shrimp of soft bottoms of the continental shelf from the Rio Grande to the Mississippi River Delta. Dept. of Interior, Minerals Management Service, Gulf of Mexico Outer Continental Shelf Regional Office. Open File Report 82-04.

Darnell, R.M., and J.A. Kleypas. 1987. Eastern Gulf Shelf Bio-Atlas: A study of the distribution of demersal fishers and penaeid shrimp of soft bottoms of the continental shelf from the Mississippi River Delta to the Florida Keys. Dept. of Interior, Minerals Management Service, Gulf of Mexico Outer Continental Shelf Regional Office. MMS 86-0041.

Eberhardt, L.L., D.G. Chapman, and J.R. Gilbert. 1979. A Review of Marine Mammal Census Methods. Wildlife Monographs 63:1-46.

El Custodio de las Tortugas web page. 29 September 1997. Sea Turtle Protection. <http://balsam.methow.com/~custodio/pages/turtle.html>

Epperly, S.P., J. Braun, and A.J. Chester. 1995a. Aerial surveys for sea turtles in North Carolina inshore waters. Fishery Bulletin 93:254-261.

Epperly, S.P., J. Braun, A.J. Chester, F.A. Cross, J.V. Merriner, and P.A. Tester. 1995b. Winter Distribution of Sea Turtles in the Vicinity of Cape Hatteras and their Interactions with the Summer Flounder Trawl Fishery. Bulletin of Marine Science 56(2): 547-568.

Federal Register. June 29, 1987. 50 CFR Parts 217, 222 and 227, Volume 52, Number 124.

Federal Register. May 18, 1995. 50 CFR Parts 217 and 227, Volume 60, Number 96.

Federal Register. August 18, 1995. 50 CFR Part 227, Volume 60, Number 160.

Federal Register. December 19, 1996. 50 CFR Parts 217 and 227, Volume 61, Number 245.

Florida Department of Natural Resources Marine Research Institute – Gulf Information Network. Economic Importance/Historical Highlights. <http://www.epa.gov/gumpo/ wais_docs/ seast12.html>

Frazer, N.B. 1992. Sea turtle conservation and halfway technology. Conservation Biology 6: 179-184.

Fritts, T.H. and R.P. Reynolds. 1981. Pilot Study of the Marine Mammals, Birds, and Turtles in OCS Areas of the Gulf of Mexico. U.S. Fish and Wildlife Service, Division of Biological Services, Washington, D.C. FWS/OBS-81/36.

Gallaway, B.J., J.D. Bryan, L.R. Martin, and J.G. Cole. 1995. Sea Turtle and Shrimp Fishery Interactions - Is a New Management Strategy needed? LGL Ecological Research Associates, Inc. prepared for the Texas Shrimp Association.

Griffin, W.L., A.K. Shah, and J.M. Nance. 1997. Estimation of standardized effort in the heterogeneous Gulf of Mexico shrimp fleet. Marine Fisheries Review 59(3):23-33.

Gross, M.G. 1993 (6th edition). Oceanography, a view of earth. Prentice Hall, Englewood Cliffs, NJ.

Gulf of Mexico Fishery Management Council. 1981. Fishery Management Plan for the Shrimp Fishery of the Gulf of Mexico, United States Waters. Tampa, FL

Hardin, G. 1968. The Tragedy of the Commons. Science 162:1243-1248.

Hendrickson, H.M. and W.L. Griffin. 1993. An analysis of management policies for reducing shrimp bycatch in the Gulf of Mexico. North American Journal of Fisheries Management 13:686-697.

Henwood, T.A. and W.E. Stuntz. 1987. Analysis of sea turtle captures and mortalities during commercial shrimp trawling. Fish. Bull. 85:813-817.

Henwood, T., W. Stuntz, and N. Thompson. 1992. Evaluation of U.S. turtle protective measures under existing TED regulations, including estimates of shrimp trawler related mortality in the Wider Caribbean. NOAA Tech. Memo. NFMS-SEFSC-303, 15p.

Heppell, S.S. and L.B. Crowder. (due out 1998). Prognostic evaluation of enhancement programs using population models and life history analysis. Bulletin of Marine Science (in press).

Hildebrand, H.H. 1983. Random notes on sea turtles in the western Gulf of Mexico. Pp. 34-40 *in* D.W. Owens, D. Crowell, G. Dienderg, M. Grassman, S. McCain, Y. Morris, N. Schwantes, and T. Wibbels (eds.). Western Gulf of Mexico sea turtle workshop proceedings. Off. Sea Grant, Texas A&M Univ. Publ. TAMU-Sg-84-105.

The Humane Society of the United States in cooperation with Sea Turtle Restoration Project of Earth Island Institute. 1997. Report of Investigation into Violations of Turtle Excluder Device Regulations by Texas Shrimp Fishermen. Washington, D.C.

Jefferson, T.A. 1996. Estimates of abundance of cetaceans in offshore waters of the Northwestern Gulf of Mexico, 1992-1993. The Southwestern Naturalist 41(3):279-287.

Jolly, G.M., and R.M. Watson. 1979. Aerial sample survey methods in the quantitative assessment of ecological resources. *In* R.M. Cormack, G.P. Patil, and D.S. Robson (eds.), Sampling biological populations, p. 203-216. Int. Co-operative Publishing House, Farland, MD.

Kennett, J.P. 1982. Marine Geology. Prentice Hall, Englewood Cliffs, NJ.

Kutkuhn, J.H. 1962. Gulf of Mexico commercial shrimp populations - trends and characteristics, 1956-59. Fisheries Bulletin 62:343-402.

Lee, K.N. 1993. Compass and Gyroscope: integrating science and politics for the environment. Island Press, Washington, D.C.

LGL Ecological Research Associates, Inc. 1997. A summary of recent applications of the TSA database to bycatch issues in the Gulf of Mexico. (unpublished document)

Lohoefener, R., W. Hoggard, K. Mullin, C. Roden, and C. Rogers. 1990. Association of sea turtles with petroleum platforms in the north-central Gulf of Mexico. OCS Study/MMS 90-0025. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA. 90 pp.

Louisiana Department of Natural Resources. 1997. Department of Wildlife and Fisheries: The 1998 Louisiana Commercial Fishing Regulations. <http://www.dnr.state.la.us/>

Louisiana State University Earth Scan Laboratory, Coastal Studies Institute. 08 March 1994. NOAA Polar Orbiting Satellites, NOAA-12 AVHRR MCSST. <http://www.esl.lsu.edu/htmls/ocean_apps.html>

Lutcavage, M.E. and P.L. Lutz. 1997. Diving Physiology. Pages 277-296 *in* P.L. Lutz and J.A. Musick, eds. The Biology of Sea Turtles. CRC Press, Boca Raton, Florida.

Magnuson, J.J., J.A. Bjorndal, W.D. DuPaul, G.L. Graham, D.W. Owens, C.H. Peterson, P.C.H. Pritchard, J.I. Richardson, G.E. Saul, and C.W. West. 1990. Decline of Sea Turtles:

Causes and Prevention. Committee on Sea Turtle Conservation, Board of Environmental Studies and Toxicology, Board on Biology, Commission on Life Sciences, National Research Council, National Academy Press, Washington, D.C. 259 p.

Manzella, S.A., C.W. Caillouet, and C.T. Fontaine. 1988. Kemp's ridley, *Lepidochelys kempi*, sea turtle head start tag recoveries: distribution, habitat, and method of recovery. Marine Fisheries Review 50(3): 24-32.

Marston, R.Q. and R.S. Nelson. 1994. New directions in the management of Florida's marine fisheries: A report to the Florida Marine Fisheries Commission following passage of Article X, Section 16 of the Constitution of the state of Florida.

McGoodwin, J.R. 1990. Crisis in the World's Fisheries: People, Problems, and Policies. Stanford University Press, Stanford, CA.

McQuaid, J. 1996. Gulf shrimpers take a pounding. "Oceans of Trouble" The Times-Picaynne. <http://spj.org/sdxawards/08pubservice/tp5d01.htm>

Miller, J.D. 1997. Reproduction in Sea Turtles. Pages 51-82 *in* P.L. Lutz and J.A. Musick, eds. The Biology of Sea Turtles. CRC Press, Boca Raton, Florida.

Minerals Management Service. 1997. Gulf of Mexico Environmental Information. <http://www.mms.gov/omm/gomr/homepg/regulate/environ/env_pge2.html>

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

Murphy, T.M. and S.R. Hopkins-Murphy. 1989. Sea turtle and shrimp fishing interactions: a summary and critique of relevant information. CMC publication, Washington, D.C. 52p.

Musick, J.A., D.E. Barnard, J.A. Keinath. 1994. Aerial estimates of seasonal distribution and abundance of sea turtles near the Cape Hatteras faunal barrier. In: Proceedings of the Thirteenth Annual Symposium on Sea Turtle Biology and Conservation. B.A. Schroeder and B.E. Witherington (compilers). NOAA Tech. Memo. NMFS-SEFSC-341.

Nance, J.M. 1992. Estimation of Effort for the Gulf of Mexico Shrimp Fishery. NOAA Technical Memorandum, NMFS-SEFSC-300, 12 pp.

_______. 1993. Effort trends for the Gulf of Mexico shrimp fishery. NOAA Technical Memorandum, NMFS-SEFSC-337.

_______. 1996. Biological Review of the 1995 Texas Closure. NOAA Technical Memorandum, NMFS-SEFSC-379, 27 pp.

Nance, J.M., E.F. Klima, E.S. Denton, K.N. Baxter and F.J. Patella. 1990. Biological Review of the 1989 Texas Closure for the Brown Shrimp Fishery off Texas and Louisiana. NOAA Technical Memorandum, NMFS-SEFC-248.

Nance, J.M., N. Garfield, and J.A. Paredes. 1991. A demographic profile of participants in two Gulf of Mexico inshore shrimp fisheries and their response to the Texas Closure. Marine Fisheries Review 53(1), p. 10-18.

National Marine Fisheries Service. 1995a. Texas Shrimp Closure for 1995 set at 200 nautical miles. News Bulletin NR95-04, January 30, 1995. National Marine Fisheries Service-Southeast Regional Office.

__________. 1995b. The Sea Turtle/Shrimp Fishery Emergency Response Plan. March 14, 1995. Memorandum for distribution, NOAA, NMFS, SERO, St. Petersburg, FL.

__________. 1996. Aerial survey data base description. NMFS-Southeast Fisheries Science Center.

National Marine Fisheries Service and U.S. Fish and Wildlife Service. 1995. Status Reviews for Sea Turtles Listed under the Endangered Species Act of 1973. National Marine Fisheries Service, Silver Spring, Maryland.

National Oceanic and Atmospheric Administration. 1996. Strategy for Stewardship: Florida Keys National Marine Sanctuary Final Management Plan and Environmental Impact Statement. Volume II of III, US Department of Commerce, NOAA, Silver Spring, MD.

National Oceanic and Atmospheric Administration Constituent Affairs email list. April 9, 1998. Shrimpers can use newly developed soft TEDs to protect sea turtles. NOAA-98 R120. email: <constaff@hulkhovis.rdc.noaa.gov>

Norse, E.A. (Ed). 1993. Global Marine Biological Diversity: a strategy for building conservation into decision making. Island Press, Washington, D.C.

Patella, F. 1975. Water Surface Area within Statistical subareas used in reporting gulf coast shrimp data. Mar. Fish. Rev. 37(12):22-24.

Policansky, D.D. 1996. Science, management and decision making. Bulletin of the Ecological Society of America, 77(2):356-365.

Pritchard, P.C.H. 1997. Evolution, Phylogeny, and Current Status. Pages 1-28 *in* P.L. Lutz and J.A. Musick, eds. The Biology of Sea Turtles. CRC Press, Boca Raton, Florida.

Rabalais, N.N., R.E. Turner, and W.J. Wiseman. 1995. Hypoxia in the Northern Gulf of Mexico: Past, Present and Future. Prepared for the Gulf of Mexico Program Hypoxia Management Conference, December 5-6, 1995.

Reeves, R.R. and S. Leatherwood. 1983. Autumn sightings of marine turtles (*Cheloniidae*) off south Texas. Southwestern Naturalist 28(3):281-288.

Renaud, M. 1995. Movements and submergence patterns of Kemp's ridley turtles (*Lepidochelys kempi*). Journal of Herpetology 29(3):370-374.

Renaud, M., G. Gitschlag, E. Klima, A. Shah, D. Koi, and J. Nance. 1991. Evaluation of the impacts of Turtle Excluder Devices (TEDs) on shrimp catch rates in coastal waters of the United States along the Gulf of Mexico and Atlantic, September 1989 through August 1990. NOAA Technical Memorandum, NMFS-SEFC-288.

Renaud, M., G. Gitschlag, E. Klima, A. Shah, D. Koi, and J. Nance. 1993. Loss of shrimp by Turtle Excluder Devices (TEDs) in coastal waters of the United States, North Carolina to Texas: March 1988 – August 1990. Fishery Bulletin 91, pp.129-137.

Risenhoover, A.D. 1990. Federal policy and the endangered species act : the politics, perceptions, and technologies of protecting sea turtles. Master's thesis from Texas A&M. Thesis R595.

Sen, S. and J.R. Nielsen. 1996. Fisheries co-management: a comparative analysis. Marine Policy: 20(5). pp. 405-481.

Shaver, D.J. 1991. Feeding ecology of wild and head-started Kemp's ridley sea turtles in south Texas (USA) waters. Journal of Herpetology 25(3):327-334.

Shoop, C.R. and R.D. Kenney. 1992. Seasonal Distributions and Abundances of Loggerhead and Leatherback Sea Turtles in Waters of the Northeastern United States. Herpetological Monographs 6:43-67.

Spotila, J.R., M.P. O'Connor, and F.V. Paladino. 1997. Thermal Biology. Pages 297-314 *in* P.L. Lutz and J.A. Musick, eds. The Biology of Sea Turtles. CRC Press, Boca Raton, Florida.

State of Texas. 1997. Texas Parks and Wildlife: Shrimp Fishery Management <http://www.tpwd.state.tx.us/fish/geninfo/>

Thompson, N.B., E.S. Denton, D.B. Koi, A. Martinez, K. Mullin. 1991. Turtles in the Gulf of Mexico: Pelagic Distributions and Commercial Shrimp Trawling. NOAA Technical Memorandum NMFS-SEFSC-286, 12 pp.

Tinsley, A. 1998. World's most endangered sea turtle in new danger. Scripps Howard Bureau, Austin, Texas.

Turner, A. 1995. River injects a dose of death into Gulf. Houston Chronicle, Houston, Texas.

Turtle Expert Working Group. 1998. An Assessment of the Kemp's ridley (*Lepidochelys kempi*) and Loggerhead (*Caretta caretta*) Sea Turtle Populations in the Western North Atlantic. NOAA Tech. Memo. NMFS-SEFSC-409. 96p.

U.S. Code. 1973. Title 16, Chapter 35, §1531 - §1544.

U.S. Fish and Wildlife Service and National Marine Fisheries Service. 1992. Recovery Plan for the Kemp's Ridley Sea Turtle (*Lepidochelys kempi*). National Marine Fisheries Service, St. Petersburg, Florida.

Valiela, I. 1995. Marine Ecological Processes. Springer-Verlag, New York, NY.

Ward, J., W. Griffin, and J. Nance. 1996. A bioeconomic analysis of existing and proposed fishery management alternatives to control sea turtle mortality in the Gulf of Mexico shrimp fishery. Final report prepared for Congress, Southeast Regional Office, National Marine Fisheries Service, St. Petersburg, FL, 44 pp.

Waters, J.R. 1991. Restricted access vs. open access methods of management: toward more effective regulation of fishing effort. Marine Fisheries Review 53(3), p. 1-10.

Weber, M., D. Crouse, R. Irvin, and S. Iudicello. 1995. Delay and Denial: A Political History of Sea Turtles and Shrimp Fishing. Center for Marine Conservation, Washington, D.C.

Williams, P., P.J. Anninos, P.T. Plotkin, and K.L. Salvini (compilers). 1996. Pelagic longline fishery-sea turtle interactions: Proceedings of an industry, academic and government experts, and stakeholders workshop held in Silver Spring, MD, 24-25 May 1994. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-OPR-7, 77 p.

Woody, J.B. 1990. Guest editorial: Is "headstarting" a reasonable conservation measure? "On the surface, yes: in reality, no.". Marine Turtle News. 50:8-11.

Personal communication

Boettcher, R. North Carolina Sea Turtle Project, Marshallberg, NC.
Coogan, C. NOAA/NMFS/SERO, St. Petersburg, FL
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Crouse, D. Center for Marine Conservation, Washington, D.C.
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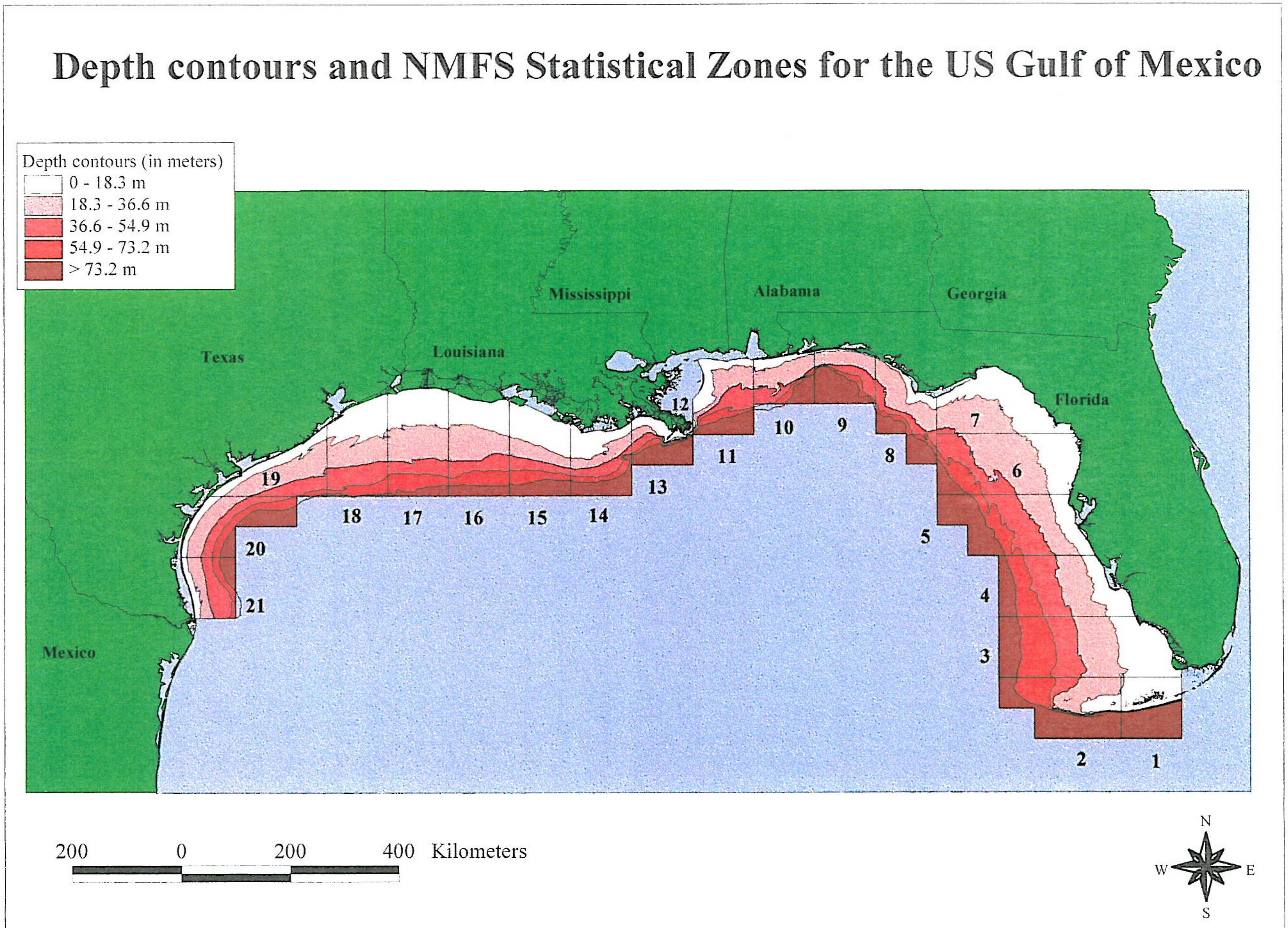
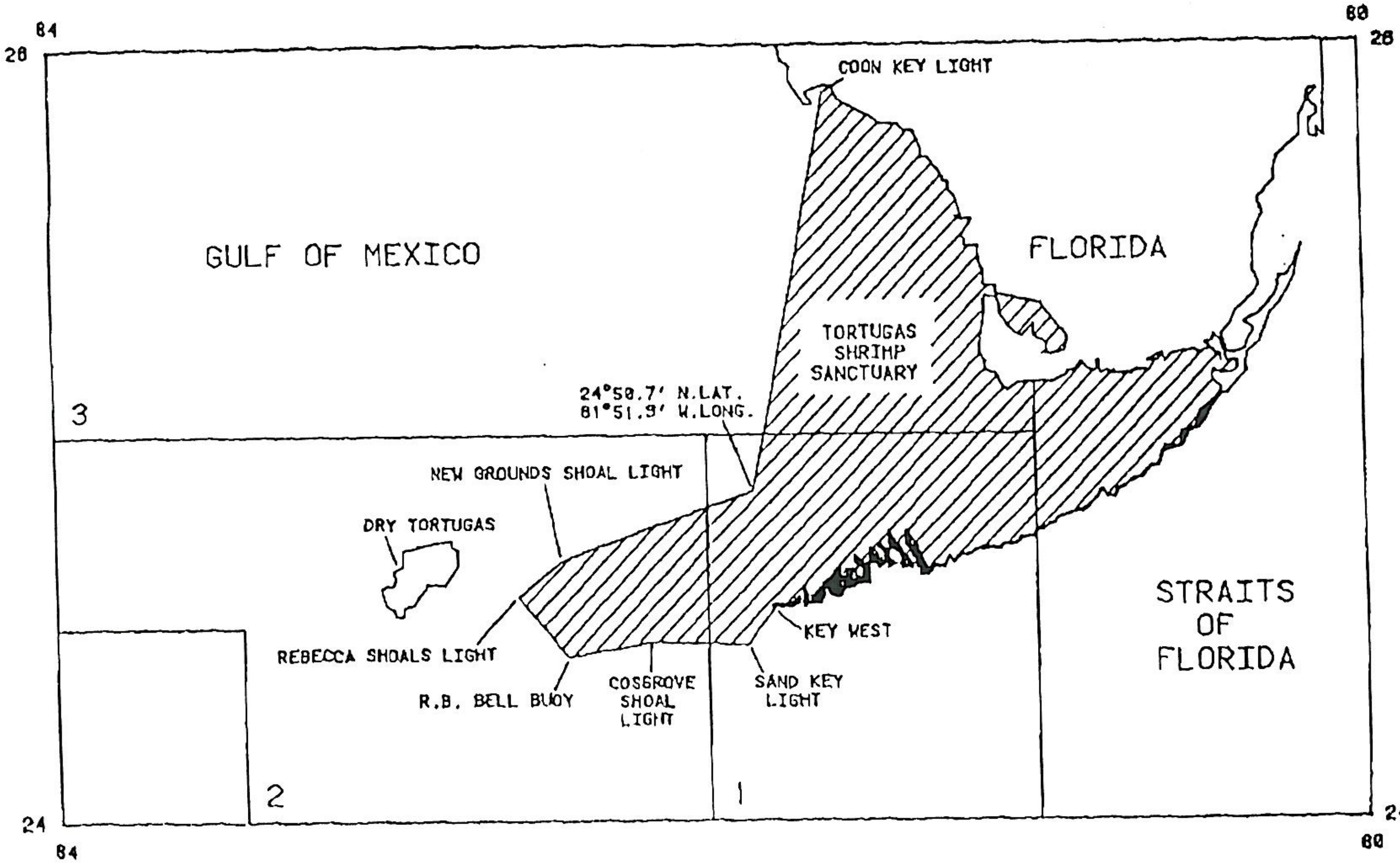
APPENDICES



Appendix 1. Depth contours (in 18.3 meter increments), NMFS statistical zones, and bordering states for the United States Gulf of Mexico.



Appendix 2. The location of the Dry Tortugas Shrimp Sanctuary fishing grounds and corresponding statistical zones.

Appendix 3. Description of the aerial survey data base obtained from the NMFS Southeast Fisheries Science Center (July 1996).

Variables and Variable Descriptions

1. Card
   A – begin a study area
   B – begin a transect
   C – environmental change (weather, sea state, etc.)
   D – sighting (marine mammal, sea turtle, bird, fish, pollution)
   E – going off effort (while "on" a transect)
   F – "off effort" sighting (sighting not to be included in the density estimate, e.g., sightings between transects, non-associated species sighted while investigating an "on-effort" sighting)
   G – back on effort
   H – end a transect
   I – end the study area
   J – end the data file

2. Study block (enter 00 while in transit to, from and between study areas)

3. Part (to avoid confusion if several data files are made during the same day)

4. Day

5. Month

6. Year

7. Hour

8. Minutes

9. Seconds

10. Latitude (to hundredths of a minute)

11. Longitude

12. Track (heading, 000-359°)

13. Ground speed (nautical miles per hour)

14. GPS status
    0 or A – good GPS signal
    1 or V – warning condition (position may not be accurate)

15. Left observer (each observer who participates in a SEFC marine mammal survey is assigned a unique number less than 99)

16. Right observer

17. Data recorder

18. Altitude (in feet)

19. Weather
    1 – clear (0-10% cloud cover)
    2 – partly cloudy (10-50%)
    3 – cloudy (50-100%)
    4 – light rain
    5 – clear with haze
    6 – partly cloudy with haze
    7 – cloudy with haze
    8 – fog or low clouds

20. Sea state (not the Beaufort scale)
    0 – slick calm, mirror like
    1 – small waves, few whitecaps
    2 – whitecaps 0-33%, waves 1-2 feet
    3 – whitecaps 33-50%, waves 2-3 feet
    4 – whitecaps 50-65%, waves 3-5 feet
    5 – whitecaps >65%, waves >5 feet (too rough to survey)

21. Water turbidity
    0 – good
    1 – fair
    2 – poor

22. Water color
    1 – brown
    2 – green
    3 – gray
    4 – blue
    5 – blue/green
    6 – brown/gray
    7 – green/gray
    8 – green/brown
    9 – dark green

23. Glare – at least 50% hindrance of normal viewing area
    0 – no hindrance to sighting
    1 – left side – hindrance
    2 – right side – hindrance
    3 – both sides – hindrance

24. Sunlight
    1 – none
    2 – fair
    3 – moderate
    4 – good
    5 – excellent

25. Water temperature (°C, decimal implied. e.g., 234 = 23.4)

26. Observer making a sighting
    1 – left
    2 – right
    3 – recorder
    4 – other

27. Sighting angle (from inclinometer)

28. Sighting interval (from marked intervals on bubble or calculated from sighting angle)
    0 – unknown interval
    1 – 0-10°
    2 – 11-20°
    3 – 21-30°
    4 – 31-40°
    5 – 41-50°
    6 – 51-60°
    7 – 61-70°
    8 – >70°

29. Species 1 (marine mammals, turtles, fishes, birds, pollution)

30. Herd size, school size, or pollution count 1 (herd sizes include adults and calves)

31. Number of calves 1 (number of animals less than one-half the length of the large animals in the herd)

32. Species 2

33. Herd or school size 2

34. Number of calves 2

35. Species 3

36. Herd or school size 3

37. Number of calves 3

38. Transect number (within a study area, including the "00" study area)

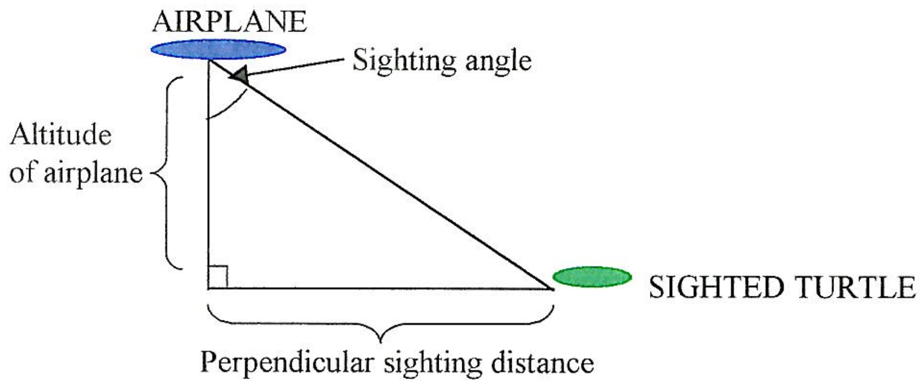
39. Effort status
    1 – on transect
    2 – before a study area, between transects in a study area or off-effort while on-transect

40. Habitat
    1 – bays, rivers, and sounds
    5 – nearshore and offshore waters

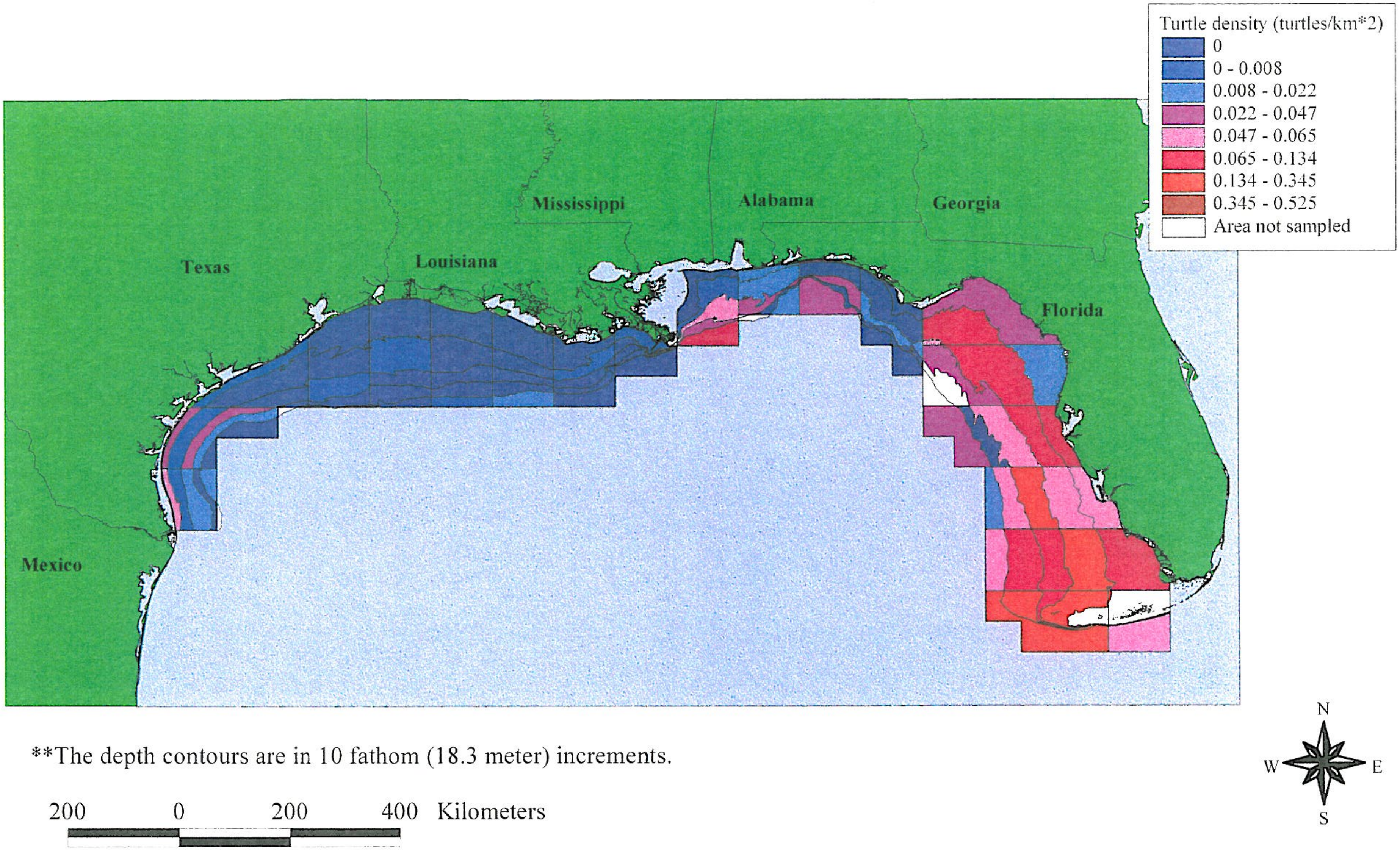
Appendix 4. The theory behind calculating perpendicular sighting distances from aerial survey data.

PERPENDICULAR SIGHTING DISTANCES

Tangent of sighting angle = perpendicular distance / altitude of plane



Gulf of Mexico Sea Turtle Abundance for survey years 1992-1994 (turtle/km*2)



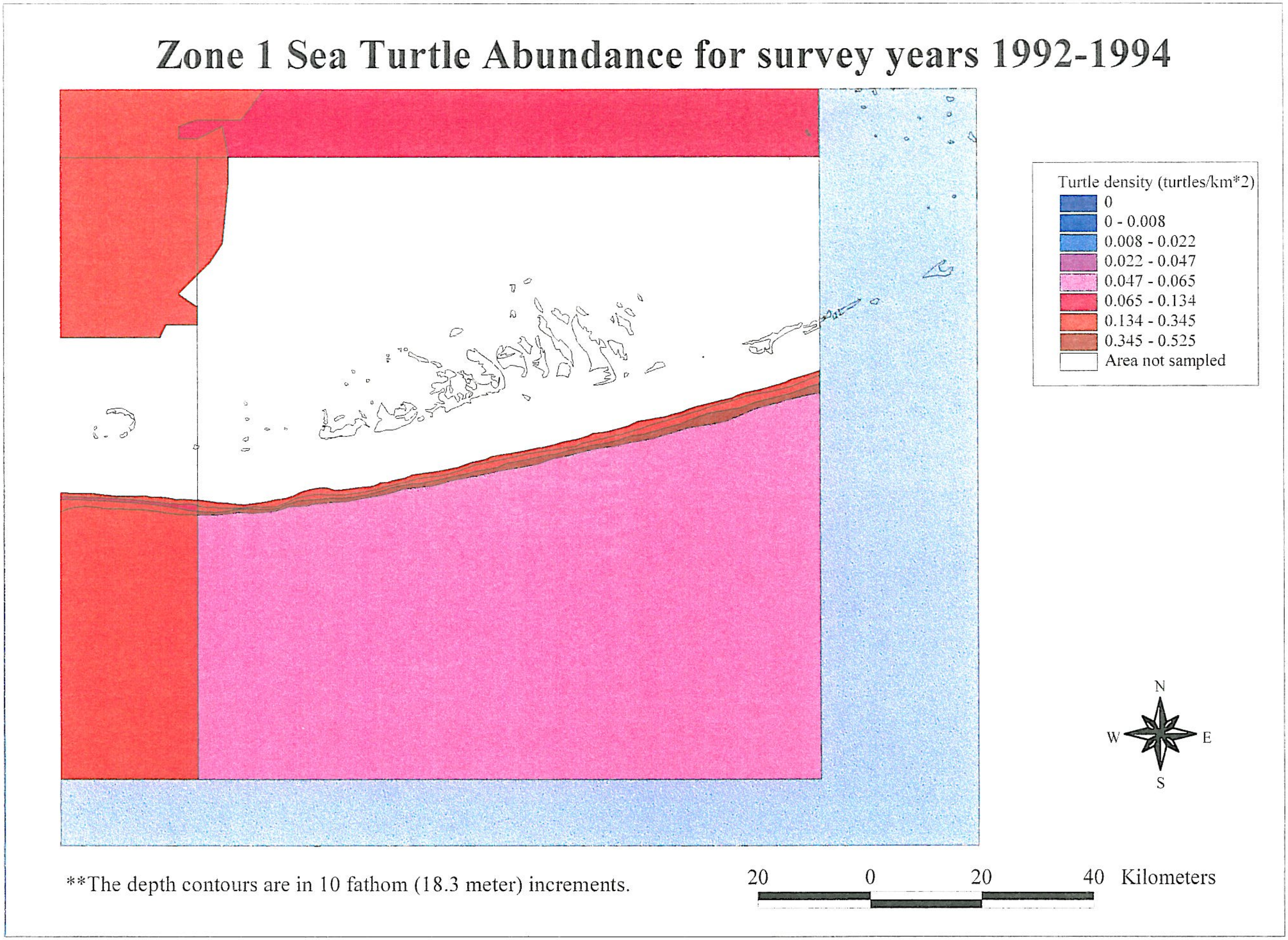
Appendix 5. Sea turtle abundance for September, October, and November 1992-1994 in the US Gulf of Mexico.

Appendix 6. The results of the strip transect method density estimates with corresponding variances, as found from the aerial survey data. The statistical zone, depth bin, number of transects flown in the subzone, the average area of the transects (given the 400 meter strip width and individual transect length), and the number of turtles sighted in each subzone are also presented. The cells without values were not sampled.

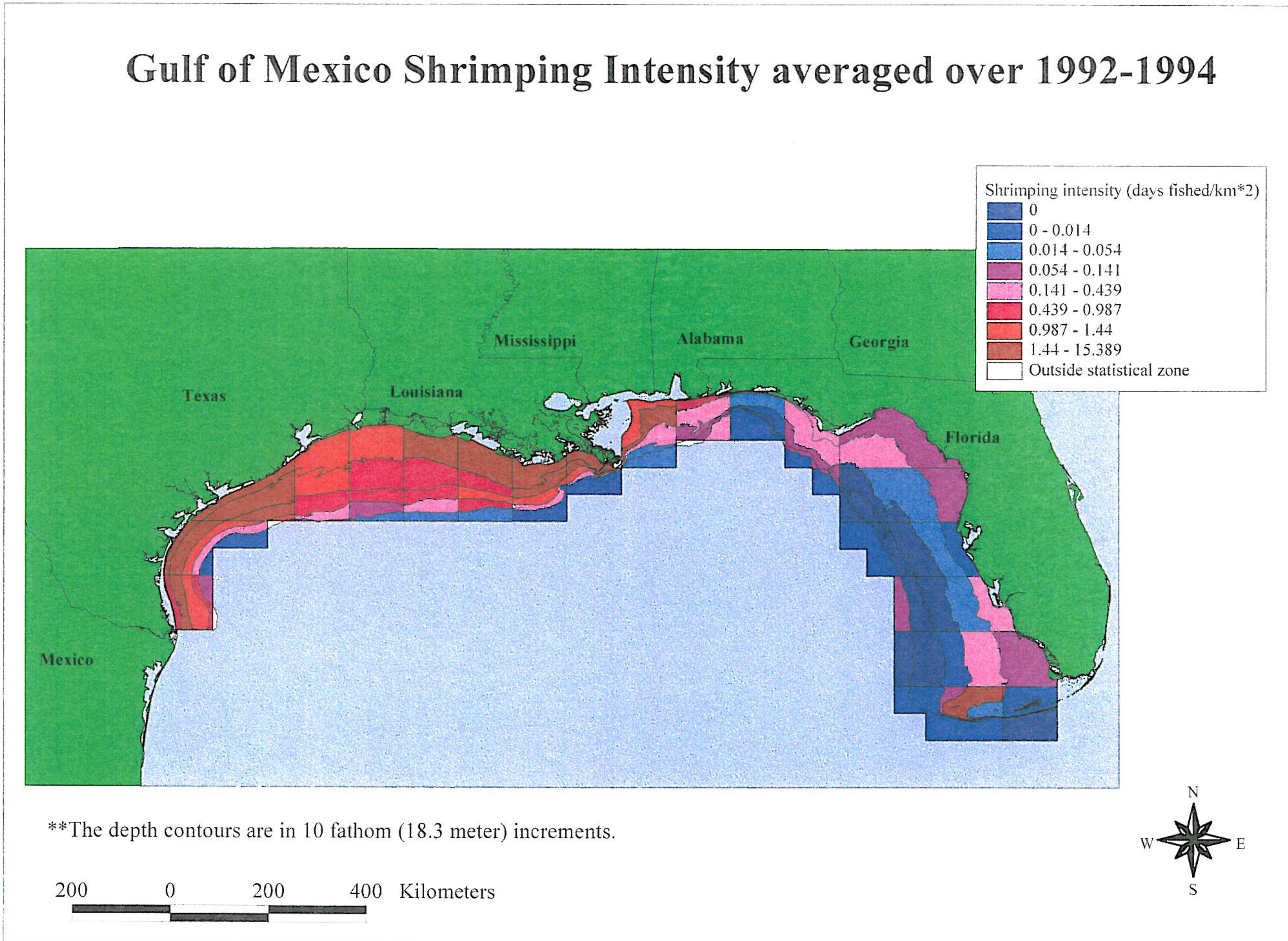
Statistical Zone	Depth Bin	Number of transects	Transect area	Number of turtles	Turtle density (per km^2)	Variance
1	0-18.3	0	0	0		
1	18.3-36.6	20	92.620	20	0.216	0.0016
1	36.6-54.9	5	12.091	3	0.248	0.0152
1	54.9-73.2	3	3.808	2	0.525	0.0336
1	> 73.2	8	34.664	2	0.058	0.0021
2	0-18.3	0	0.000	0		
2	18.3-36.6	3	23.157	8	0.345	0.0136
2	36.6-54.9	6	16.470	2	0.121	0.0022
2	54.9-73.2	12	55.416	12	0.217	0.0219
2	> 73.2	39	160.685	26	0.162	0.0043
3	0-18.3	9	79.690	9	0.113	0.0033
3	18.3-36.6	11	66.564	9	0.135	0.0011
3	36.6-54.9	11	149.944	13	0.087	0.0001
3	54.9-73.2	7	109.965	11	0.100	0.0001
3	> 73.2	11	181.913	9	0.049	0.0000
4	0-18.3	25	113.339	7	0.062	0.0002
4	18.3-36.6	46	184.822	12	0.065	0.0002
4	36.6-54.9	24	141.823	20	0.141	0.0005
4	54.9-73.2	6	67.307	4	0.059	0.0001
4	> 73.2	8	119.132	2	0.017	0.0002
5	0-18.3	36	113.565	10	0.088	0.0008
5	18.3-36.6	39	163.673	22	0.134	0.0007
5	36.6-54.9	20	112.141	6	0.054	0.0003
5	54.9-73.2	10	72.783	0	0.000	0.0000
5	> 73.2	6	92.462	4	0.043	0.0006
6	0-18.3	11	89.141	2	0.022	0.0002
6	18.3-36.6	27	195.544	16	0.082	0.0002
6	36.6-54.9	17	145.971	6	0.041	0.0000
6	54.9-73.2	0	0.000	0		
6	> 73.2	0	0.000	0		
7	0-18.3	23	150.036	7	0.047	0.0002
7	18.3-36.6	61	438.505	30	0.068	0.0002
7	36.6-54.9	16	108.907	6	0.055	0.0002
7	54.9-73.2	0	0.000	0		
7	> 73.2	0	0.000	0		

Statistical Zone	Depth Bin	Number of transects	Transect area	Number of turtles	Turtle density (per km²)	Variance
8	0-18.3	32	105.928	0	0.000	0.0000
8	18.3-36.6	17	109.072	0	0.000	0.0000
8	36.6-54.9	17	97.844	1	0.010	0.0001
8	54.9-73.2	3	12.008	0	0.000	0.0000
8	> 73.2	15	65.614	0	0.000	0.0000
9	0-18.3	15	37.341	1	0.027	0.0006
9	18.3-36.6	10	25.375	0	0.000	0.0000
9	36.6-54.9	17	93.043	3	0.032	0.0003
9	54.9-73.2	5	12.482	0	0.000	0.0000
9	> 73.2	12	82.746	2	0.024	0.0003
10	0-18.3	20	130.967	2	0.015	0.0001
10	18.3-36.6	11	45.426	1	0.022	0.0005
10	36.6-54.9	12	71.283	3	0.042	0.0004
10	54.9-73.2	7	36.174	0	0.000	0.0000
10	> 73.2	10	68.576	1	0.015	0.0002
11	0-18.3	22	158.026	0	0.000	0.0000
11	18.3-36.6	51	385.761	1	0.003	0.0000
11	36.6-54.9	12	92.025	6	0.065	0.0015
11	54.9-73.2	8	40.449	1	0.025	0.0003
11	> 73.2	11	45.578	3	0.066	0.0019
13	0-18.3	31	277.683	1	0.004	0.0000
13	18.3-36.6	42	391.655	0	0.000	0.0000
13	36.6-54.9	6	33.643	0	0.000	0.0000
13	54.9-73.2	6	18.310	0	0.000	0.0000
13	> 73.2	9	44.323	0	0.000	0.0000
14	0-18.3	6	44.116	0	0.000	0.0000
14	18.3-36.6	32	201.623	1	0.005	0.0000
14	36.6-54.9	15	76.880	0	0.000	0.0000
14	54.9-73.2	11	54.139	0	0.000	0.0000
14	> 73.2	23	129.793	0	0.000	0.0000
15	0-18.3	3	17.035	0	0.000	0.0000
15	18.3-36.6	18	160.426	0	0.000	0.0000
15	36.6-54.9	12	129.452	0	0.000	0.0000
15	54.9-73.2	7	62.471	0	0.000	0.0000
15	> 73.2	15	104.426	2	0.019	0.0003
16	0-18.3	4	42.605	0	0.000	0.0000
16	18.3-36.6	7	34.051	0	0.000	0.0000
16	36.6-54.9	16	171.755	0	0.000	0.0000
16	54.9-73.2	7	105.083	0	0.000	0.0000
16	> 73.2	14	122.793	1	0.008	0.0001

Statistical Zone	Depth Bin	Number of transects	Transect area	Number of turtles	Turtle density (per km²)	Variance
17	0-18.3	12	145.850	0	0.000	0.0000
17	18.3-36.6	12	120.473	1	0.008	0.0001
17	36.6-54.9	13	186.949	0	0.000	
17	54.9-73.2	8	149.115	0	0.000	0.0000
17	> 73.2	16	147.834	0	0.000	0.0000
18	0-18.3	11	92.903	0	0.000	0.0000
18	18.3-36.6	19	115.212	0	0.000	0.0000
18	36.6-54.9	20	201.814	1	0.005	0.0000
18	54.9-73.2	6	75.749	0	0.000	0.0000
18	> 73.2	13	108.827	0	0.000	0.0000
19	0-18.3	55	297.657	1	0.003	0.0000
19	18.3-36.6	47	343.473	0	0.000	0.0000
19	36.6-54.9	29	186.072	0	0.000	0.0000
19	54.9-73.2	5	55.340	0	0.000	0.0000
19	> 73.2	1	3.190	0	0.000	
20	0-18.3	31	161.739	4	0.025	0.0003
20	18.3-36.6	28	143.325	1	0.007	0.0000
20	36.6-54.9	17	63.236	3	0.047	0.0007
20	54.9-73.2	8	74.514	1	0.013	0.0002
20	> 73.2	23	149.601	0	0.000	0.0000
21	0-18.3	16	54.396	3	0.055	0.0008
21	18.3-36.6	33	153.424	1	0.007	0.0000
21	36.6-54.9	16	72.867	1	0.014	0.0002
21	54.9-73.2	5	33.338	0	0.000	0.0000
21	> 73.2	10	69.544	1	0.014	0.0002

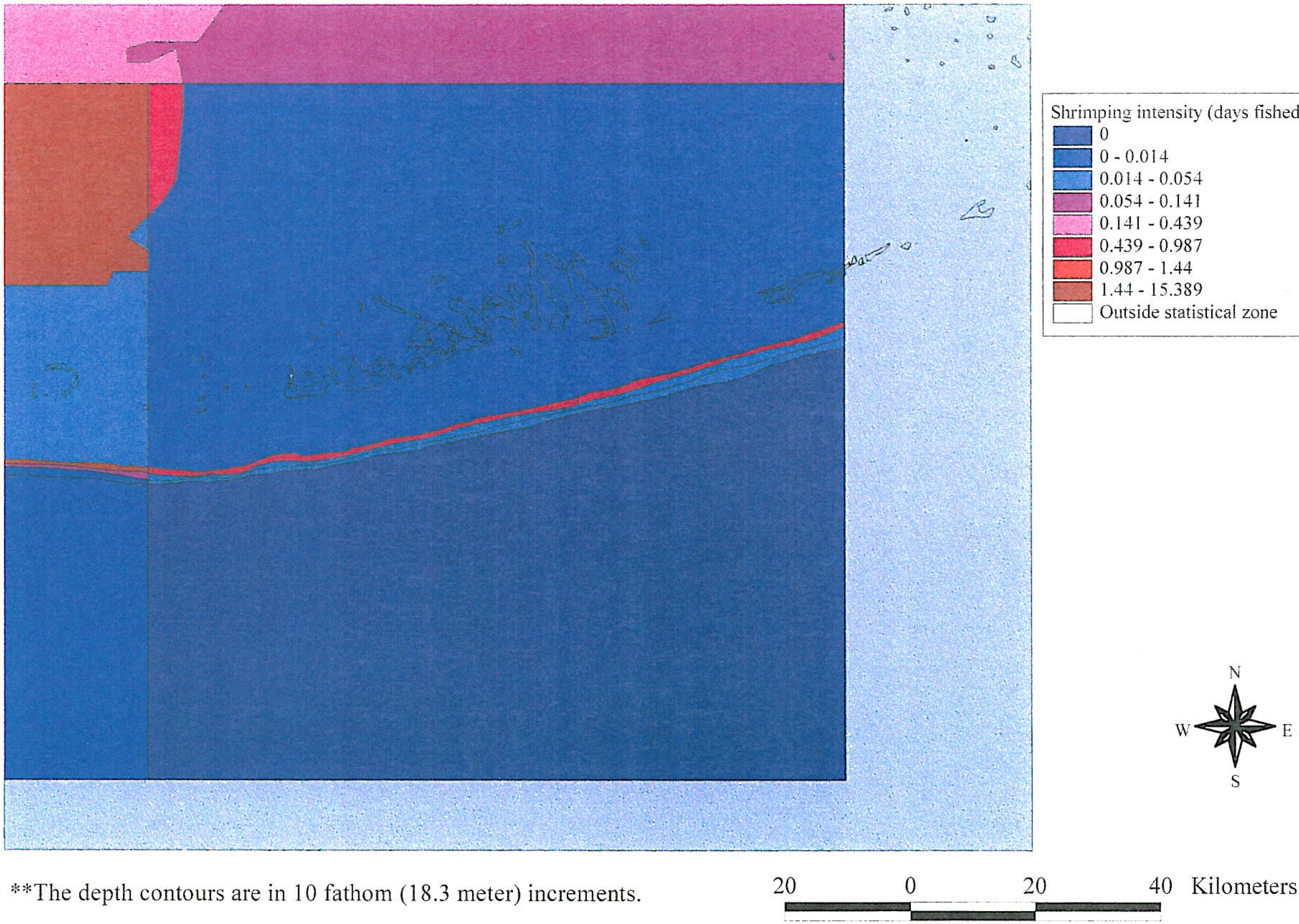


Appendix 7. Sea turtle abundance for September, October, and November 1992-1994 in the Florida Keys area (Zone 1).



Appendix 8. Shrimping intensity averaged for all months in 1992-1994 in the US Gulf of Mexico.

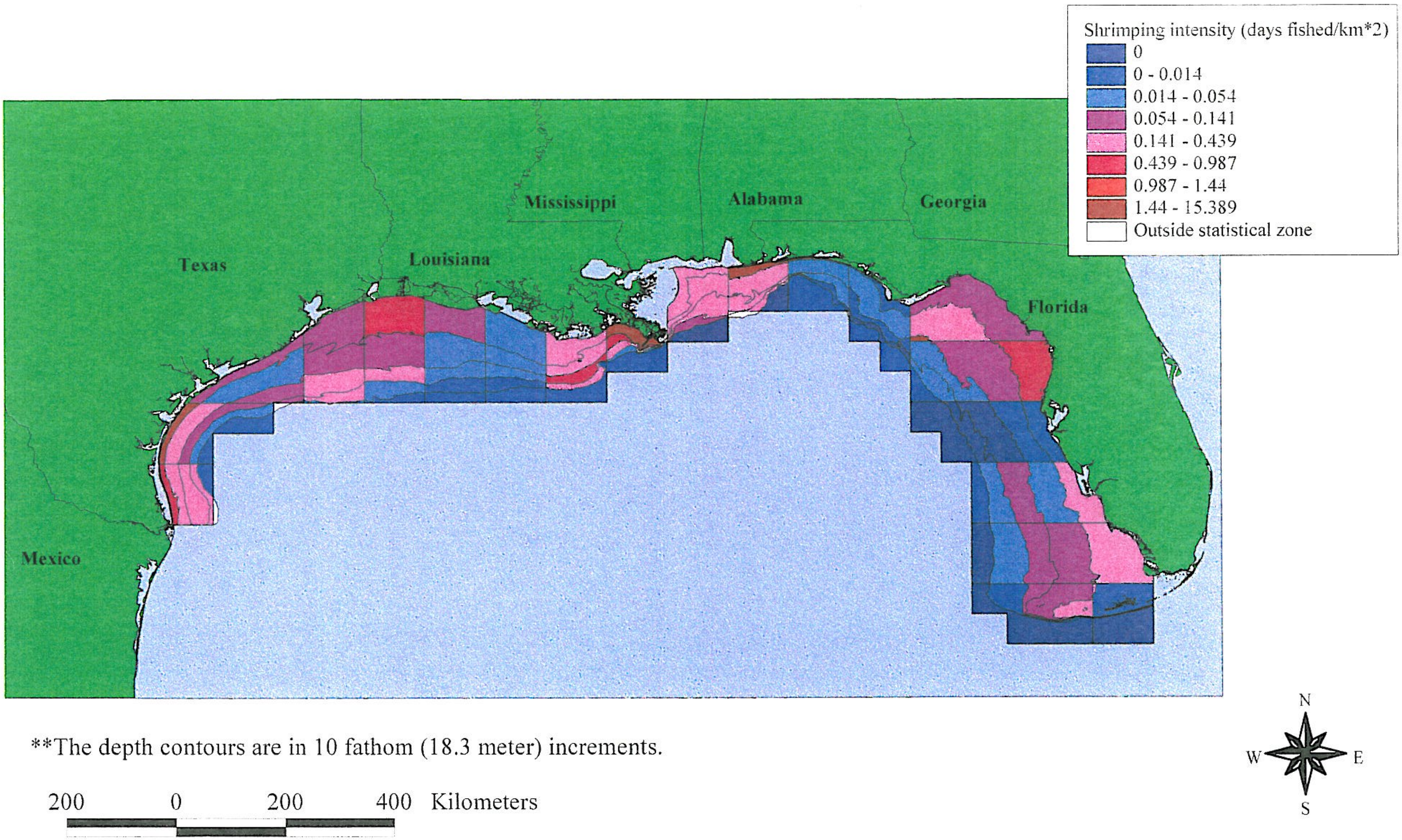
Zone 1 Shrimping Intensity for all months 1992-1994



**The depth contours are in 10 fathom (18.3 meter) increments.

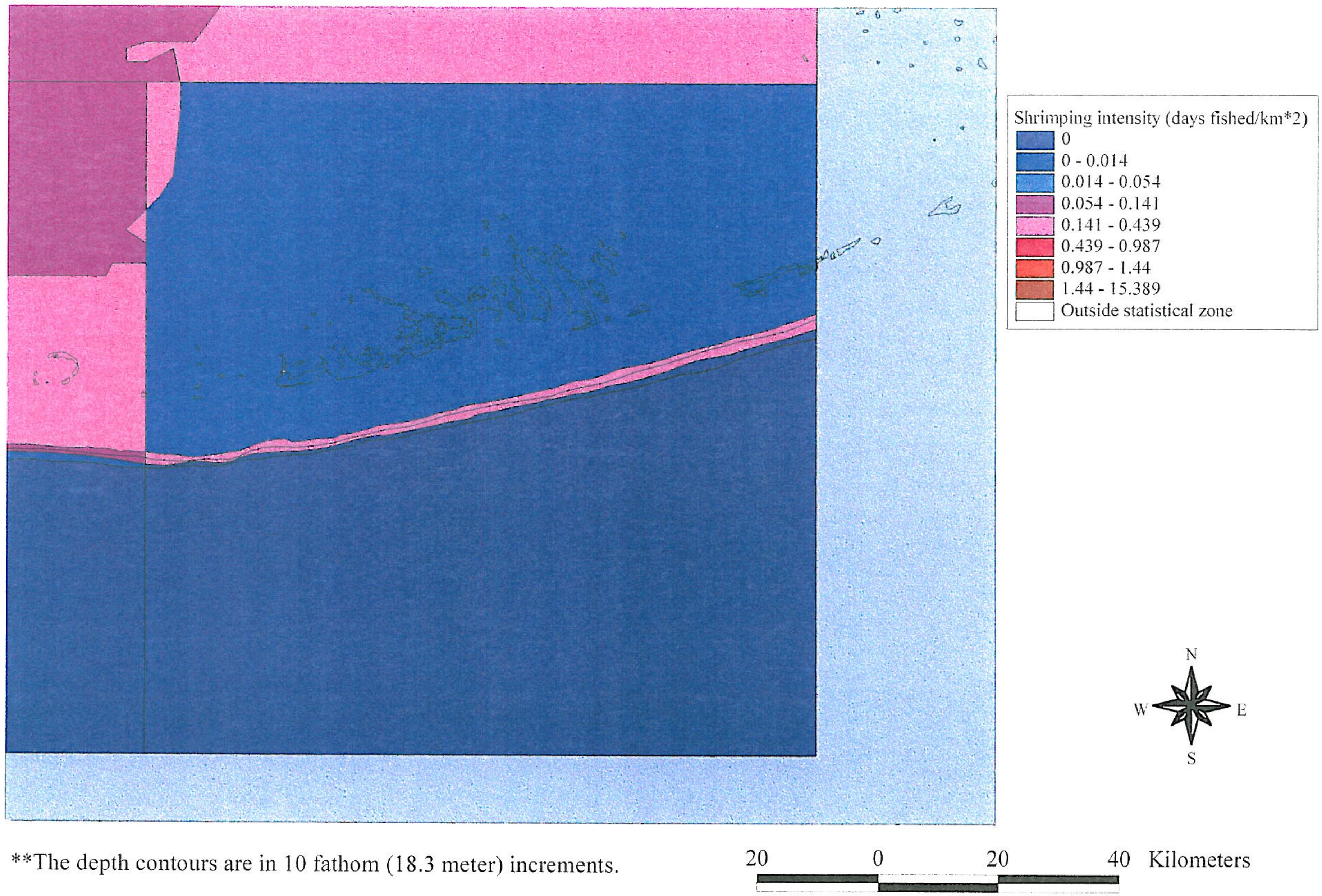
Appendix 9. Shrimping intensity averaged over all months in 1992, 1993, and 1994 for the Florida Keys area (Zone 1).

Gulf of Mexico Shrimping Intensity averaged over September-November 1992-1994



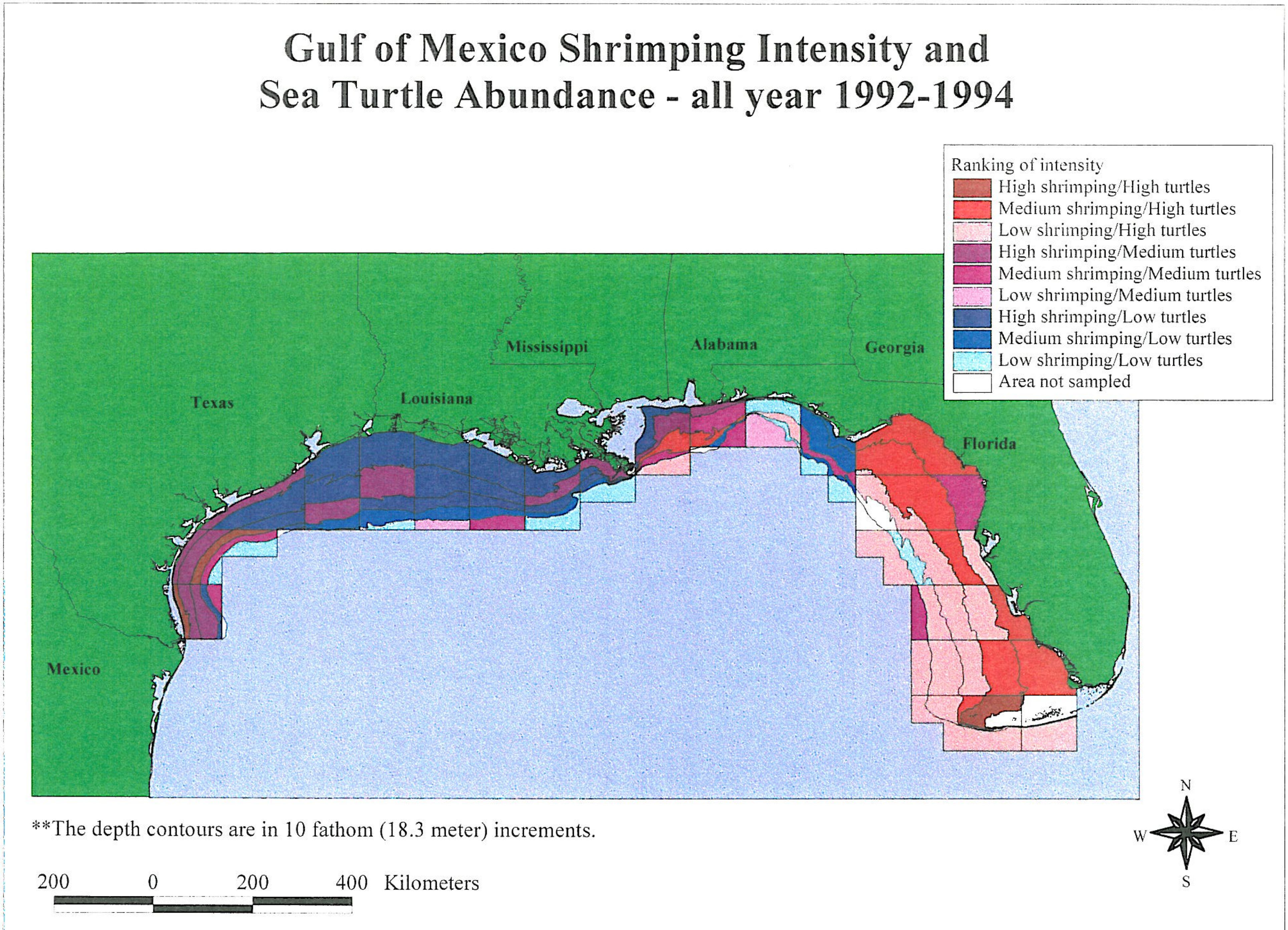
Appendix 10. Shrimping intensity averaged over September, October, and November 1992-1994 for the US Gulf of Mexico.

Zone 1 Shrimping Intensity for September-November 1992-1994

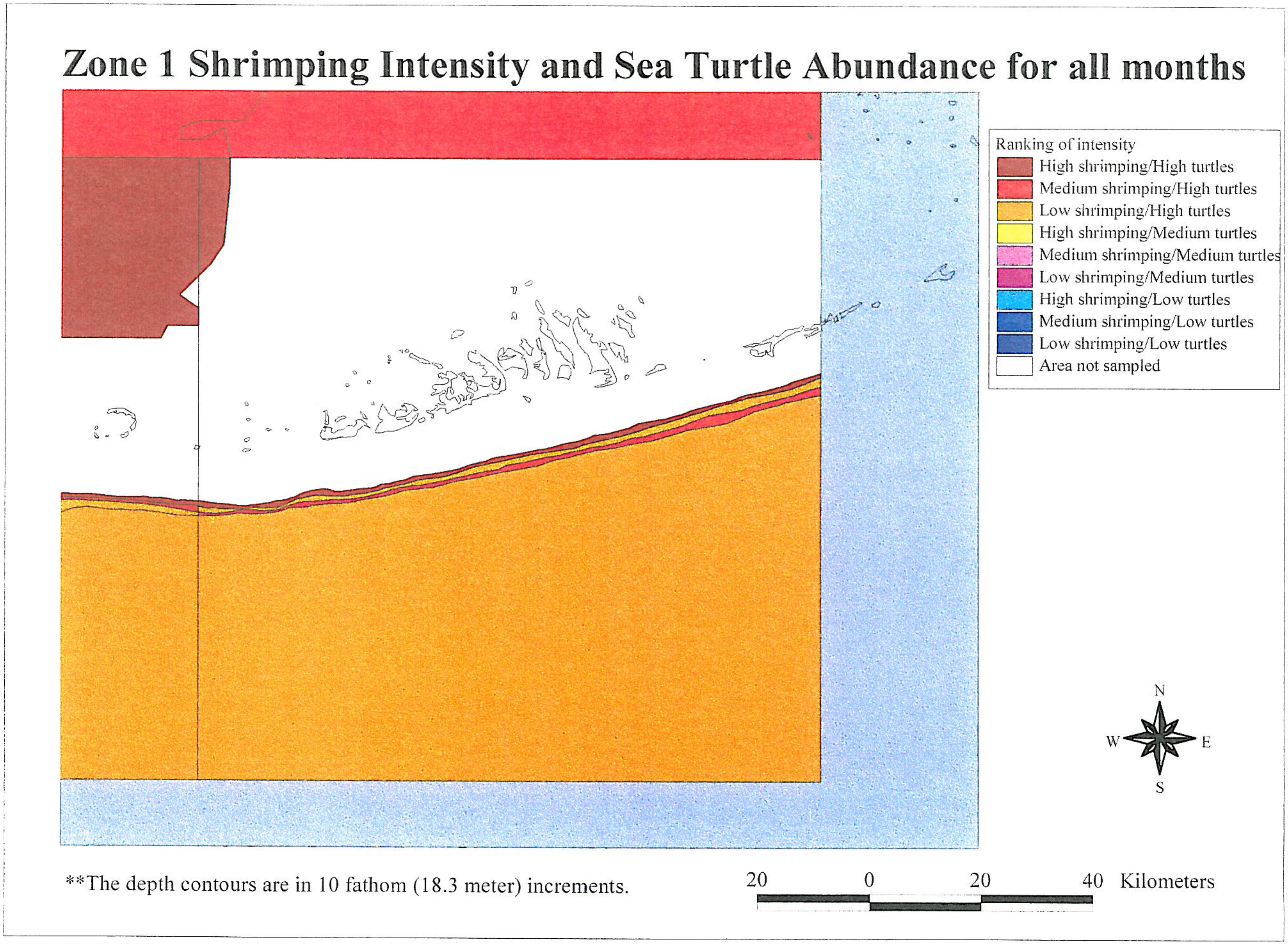


**The depth contours are in 10 fathom (18.3 meter) increments.

Appendix 11. Shrimping intensity averaged over September, October, and November 1992-1994 for the Florida Keys area (Zone 1).

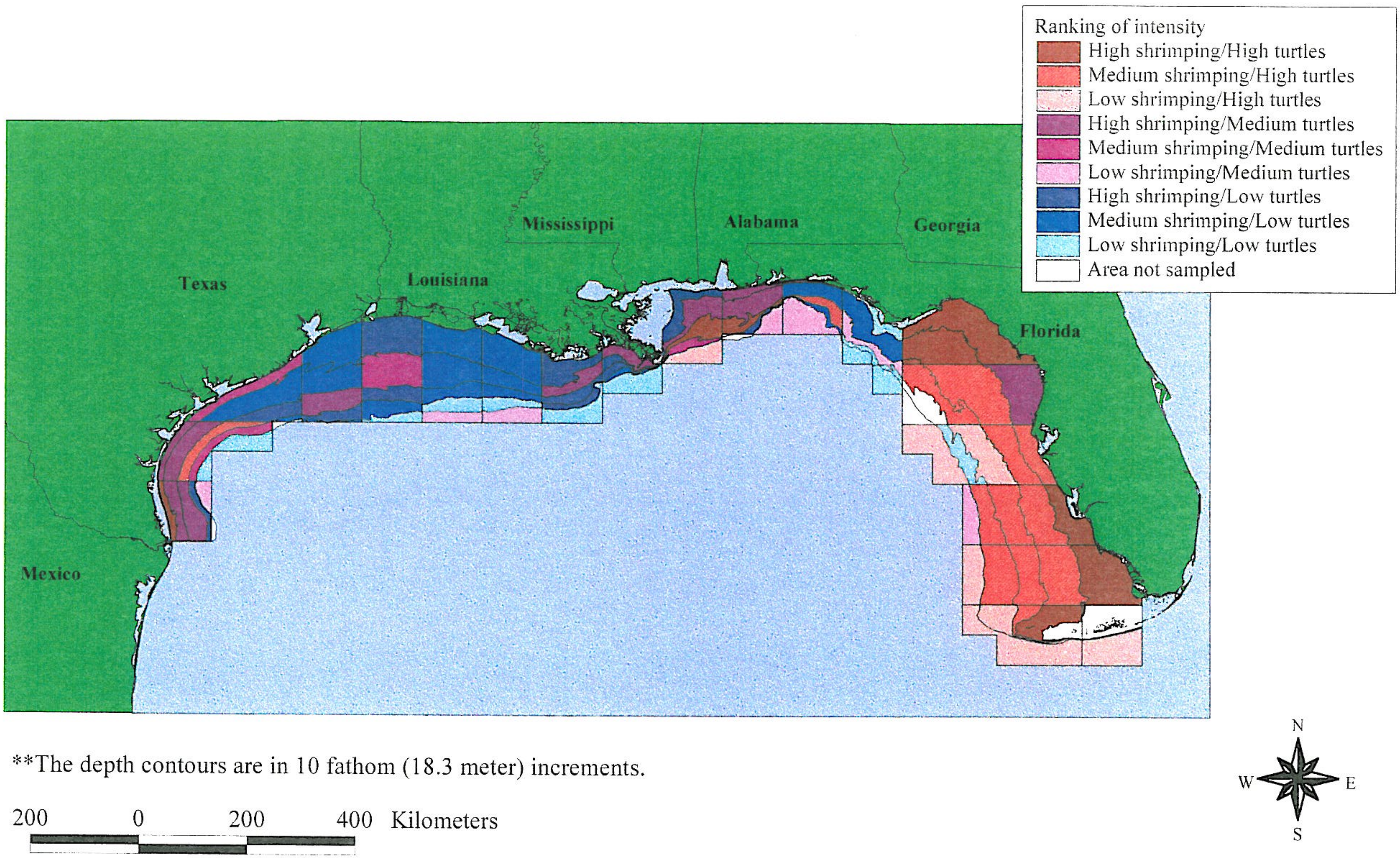


Appendix 12. Shrimping intensity and sea turtle abundance averaged for all months in 1992, 1993, and 1994 in the US Gulf of Mexico.



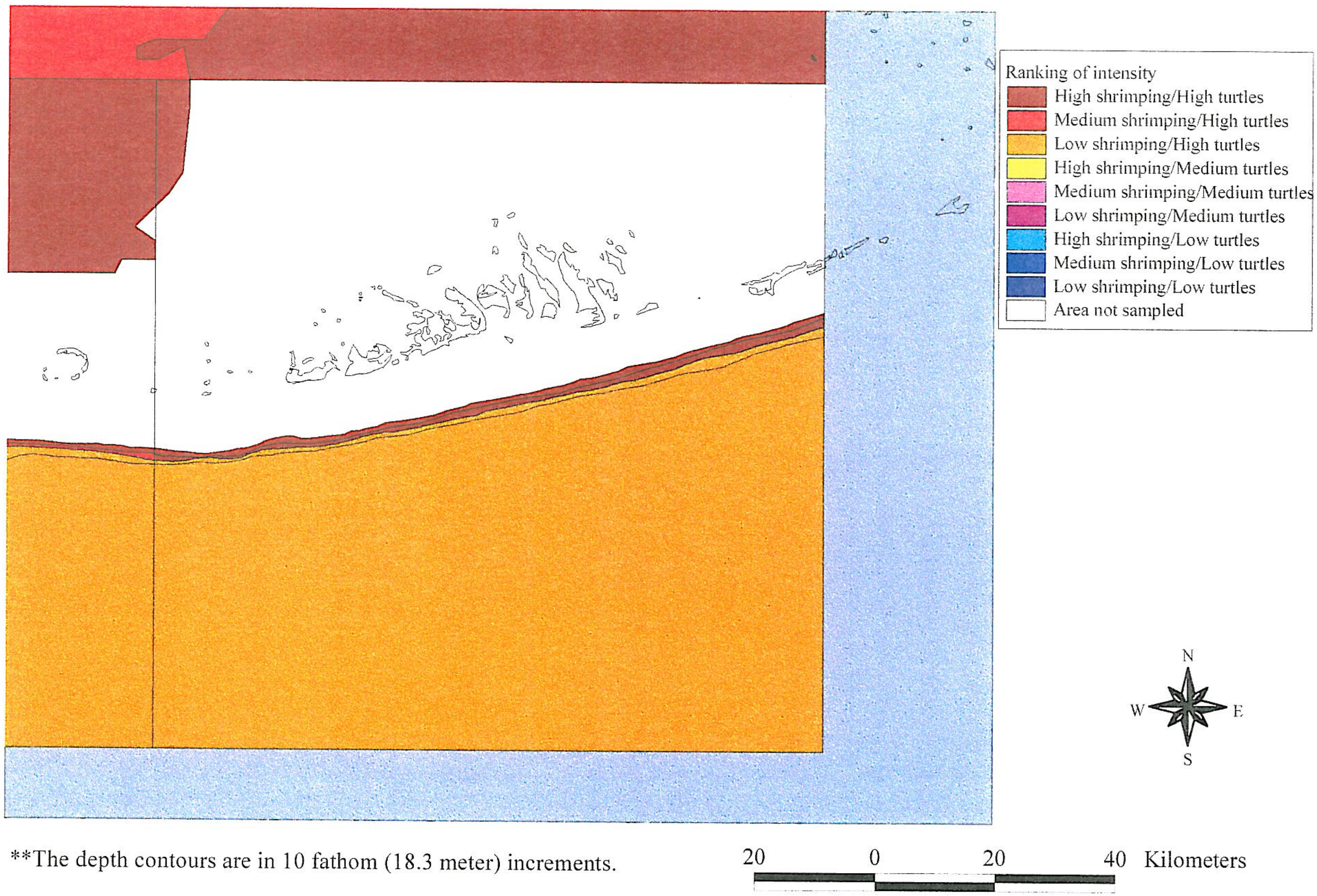
Appendix 13. Shrimping intensity and sea turtle abundance averaged over all months in 1992, 1993, and 1994 for the Florida Keys area (Zone 1).

Gulf of Mexico Shrimping Intensity and Sea Turtle Abundance - September through November 1992-1994



Appendix 14. Shrimping intensity and sea turtle abundance averaged over September, October, and November 1992-1994 for the US Gulf of Mexico.

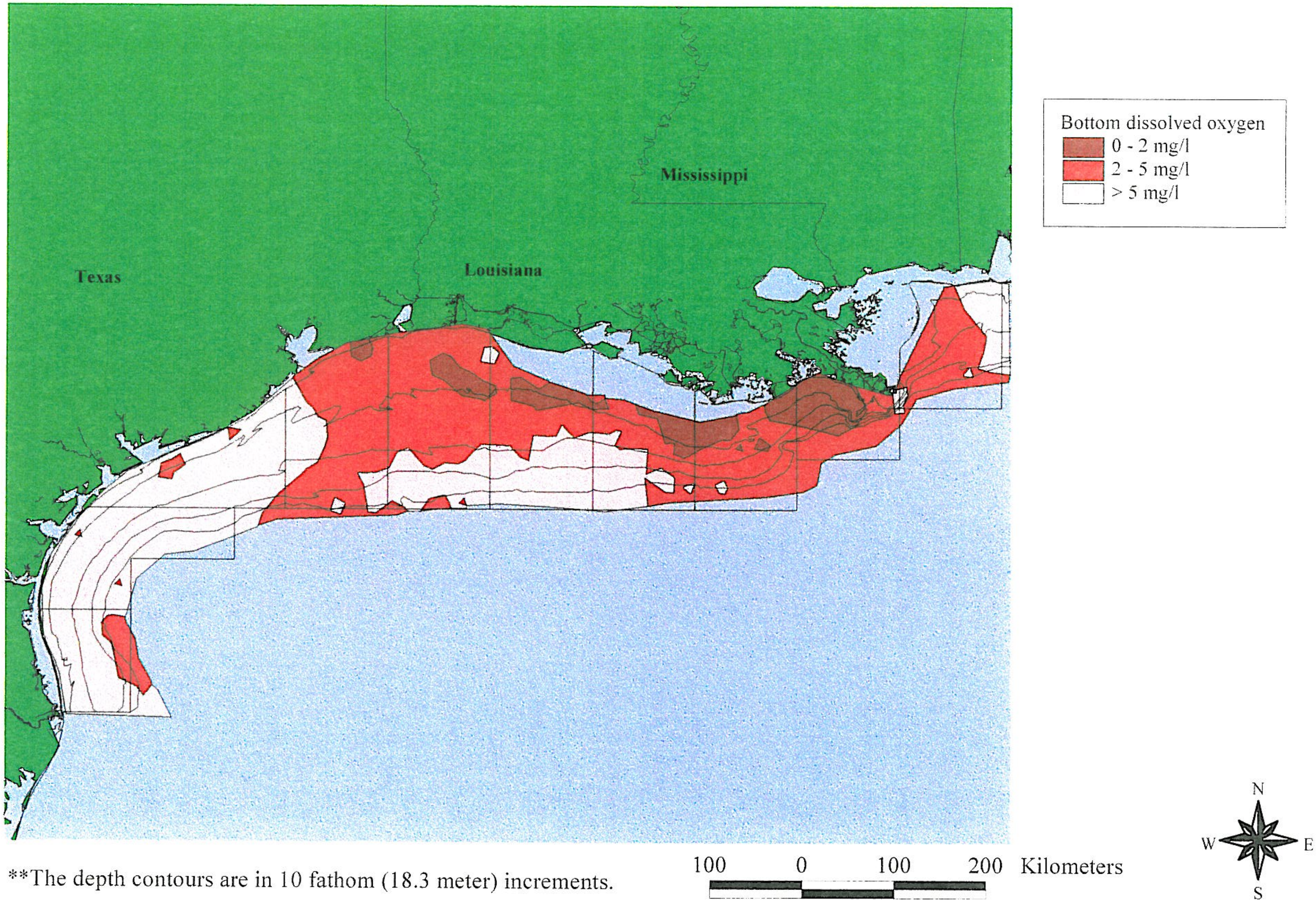
Zone 1 Shrimping Intensity and Sea Turtle Abundance for Sept.-Nov.



**The depth contours are in 10 fathom (18.3 meter) increments.

Appendix 15. Shrimping intensity and sea turtle abundance averaged over September, October, and November 1992-1994 for the Florida Keys area (Zone 1).

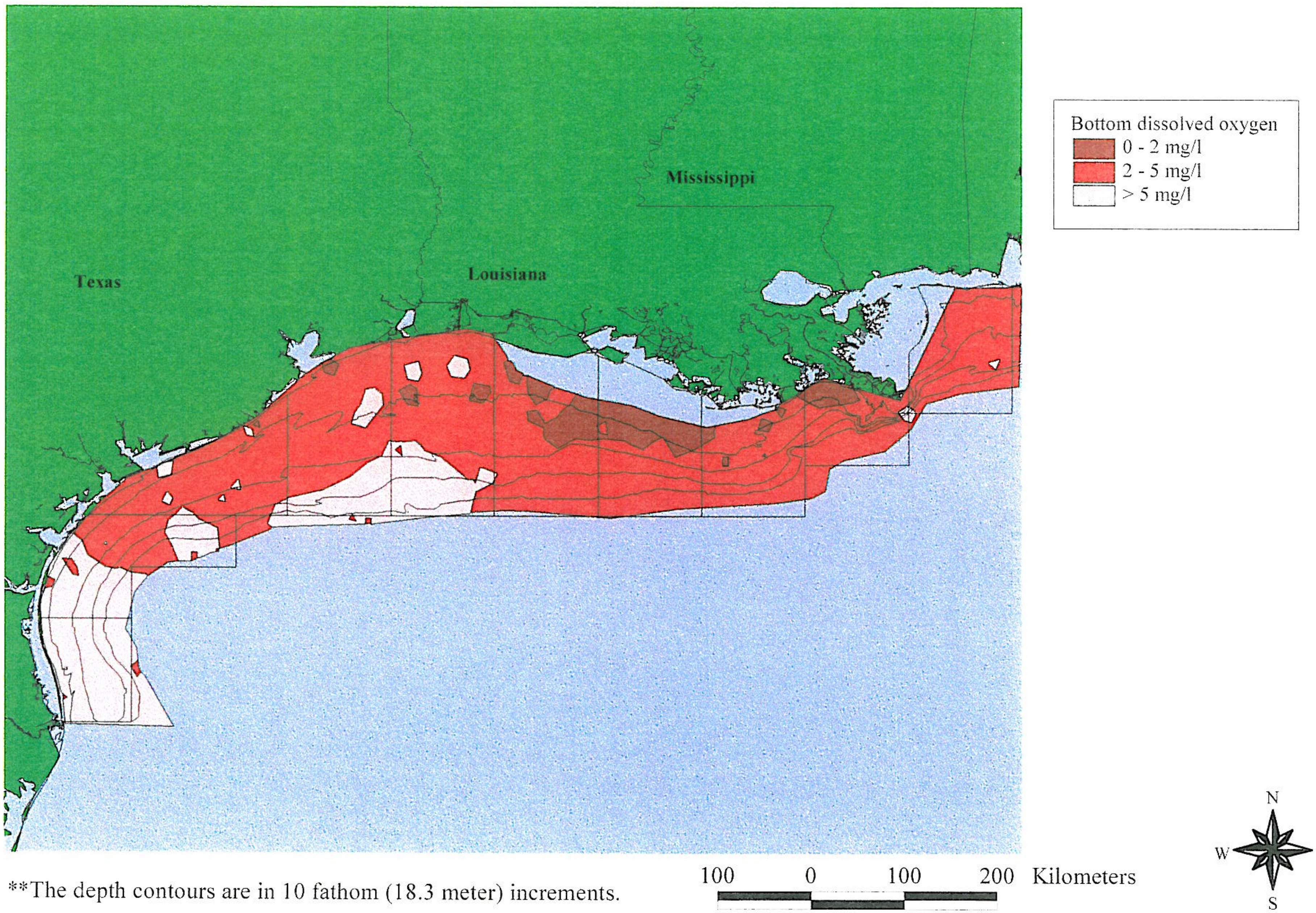
Areas of hypoxic bottom water during the summer of 1992



**The depth contours are in 10 fathom (18.3 meter) increments.

Appendix 16. The dissolved oxygen levels for selected US Gulf of Mexico zones during the summer of 1992.

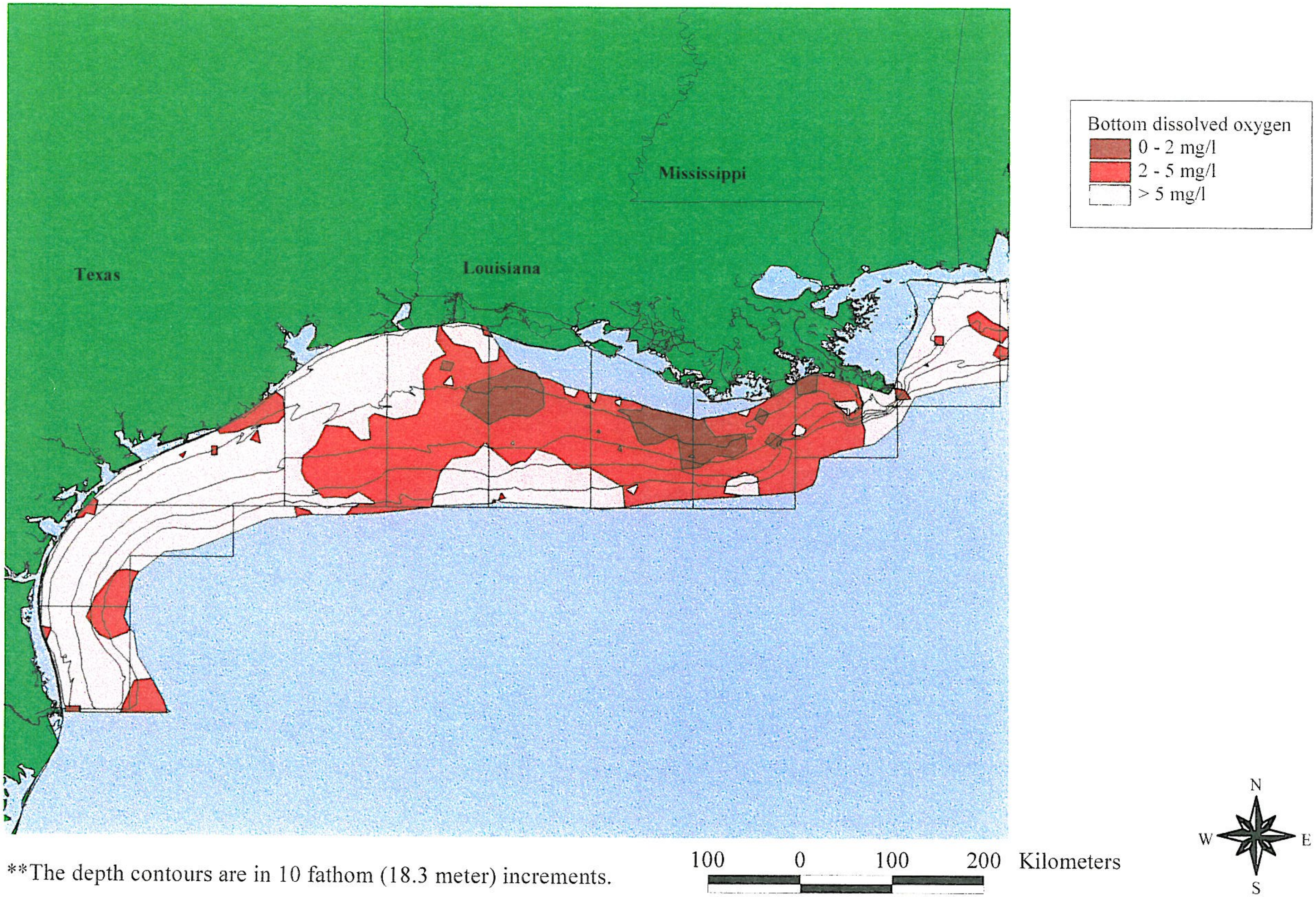
Areas of hypoxic bottom water during the summer of 1993



**The depth contours are in 10 fathom (18.3 meter) increments.

Appendix 17. The dissolved oxygen levels for selected US Gulf of Mexico zones during the summer of 1993.

Areas of hypoxic bottom water during the summer of 1994



**The depth contours are in 10 fathom (18.3 meter) increments.

Appendix 18. The dissolved oxygen levels for selected US Gulf of Mexico zones during the summer of 1994.

Appendix 19. The conversion table for depth zones in fathoms (received data unit), meters (as expressed in text), and miles.

Depth in fathoms	**Depth in meters**	**Depth in miles**
0-10	0-18.3	0-0.0113
10-20	18.3-36.6	0.0113-0.0227
20-30	36.6-54.9	0.0227-0.034
30-40	54.9-73.2	0.034-0.0454
> 40	> 73.2	> 0.0454