POPULATION DYNAMICS AND MOVEMENTS OF THE KEMP'S RIDLEY SEA TURTLE, *LEPIDOCHELYS KEMPII*, IN THE NORTHWESTERN GULF OF MEXICO

A Dissertation

by

ERIN ELIZABETH SENEY

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

DOCTOR OF PHILOSOPHY

December 2008

Major Subject: Wildlife and Fisheries Sciences

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ABSTRACT

Population Dynamics and Movements of the Kemp's Ridley Sea Turtle, *Lepidochelys kempii*, in the Northwestern Gulf of Mexico. (December 2008)

Erin Elizabeth Seney, B.A., University of Virginia;
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The Kemp's ridley sea turtle, *Lepidochelys kempii*, is recovering from devastating declines that reduced nesting activity from a single-day estimate of 10,000-40,000 females in 1947 to fewer than 300 during all of 1985. Nesting beach monitoring is crucial to estimating population size and reproductive activity, but in-water data are essential for understanding population dynamics and evaluating management strategies.

Hook-and-line, stranding, and nesting records, satellite telemetry, and diet analyses were used to characterize ridley population dynamics and movements in the northwestern Gulf of Mexico during 2003-2007. Recreational hook-and-line captures comprised approximately one third of non-nesting encounters along Galveston and Jefferson Counties, Texas. The hook-and-line dataset displayed similar geographical and monthly trends to that of strandings, but was devoid of pelagic-stage, subadult, and adult ridleys.

Coastal and bay waters along the upper Texas and western Louisiana coasts were utilized by immature ridleys during warmer months. Nesting occurred along Galveston Island on both armored and unarmored beaches. Inter-nesting females exhibited fidelity to Galveston during nesting season and subsequently migrated to federal waters offshore Louisiana. Crabs were important components of benthic-stage (>25 cm SCL) ridley diet, while worm tubes were targeted by some individuals.

Short satellite track durations for immature ridleys precipitated examinations of biofouling, attachment protocols, and turtle excluder device (TED) interactions. Antifouling paints drastically reduced fouling of transmitters. A less-rigid neoprene attachment method was developed to increase transmitter retention on fast-growing juveniles, but further trials are necessary. Transmitters were not damaged or lost during TED trials, but turtle escape times increased when transmitters wedged between TED bars.

Projected population growth will increase numbers of Kemp’s ridleys utilizing the Gulf of Mexico and interacting with human activities. Future research should examine year-round distribution and abundance of all life history stages and further characterize recreational hook-and-line capture, nesting activity, movements, and diet. Education efforts targeting the beach-going public, beach residents and workers, and the recreational fishing sector should be employed to promote sea turtle reporting and minimize negative interactions. State and federal managers should examine anthropogenic impacts within the region and determine the need for mitigation and/or regulations to promote continued species recovery.

DEDICATION

For my husband Bryan,
impromptu photographer, expert proofreader, and chef du jour.

ACKNOWLEDGEMENTS

First and foremost I would like to thank my committee chair, Dr. André Landry, for his support throughout my tenure at Texas A&M. His dedication to Texas' marine resources is exceptional, and his drive for improvement has been a constant motivator. Likewise, I would like to thank my committee members, Drs. Lee Fitzgerald, Kirk Winemiller, and Wyndylyn von Zharen, for their support in my research and enhancing my understanding of herpetology, population dynamics, and management.

Much of my research was made possible by support from the NOAA Sea Turtle Facility (NOAA STF) in Galveston. Ben Higgins facilitated my access to hook-and-line-caught, nesting, and stranded ridleys, and he played an integral role in trials conducted with the facility's captive-reared loggerheads. Shanna Kethan taught me the in's and out's of NOAA STF protocols, as well as how to make a 'bad turtle day' more bearable. NOAA's 'volunteer' veterinarian, Dr. Joe Flanagan of the Houston Zoo, examined hook-and-line caught turtles, removed hooks, and drove to Galveston to ultrasound nesters at the drop of a hat and shared his passion for turtles along the way. NOAA volunteer Rob Morehead provided engineering expertise and hands-on assistance in development of a new attachment technique, and countless other NOAA STF staff and volunteers participated in turtle response, data and sample collection, husbandry, rehabilitation, and release.

Numerous pier operators and members of the public are acknowledged for their crucial role in reporting hook-and-line-caught, nesting, and stranded turtles. Thanks are also due to the *R/V Caretta*'s (NOAA Fisheries Pascagoula) divers, crew, and support staff who not only tolerated the bigger, angrier loggerheads used in transmitter-TED interaction trials, but also shared their expertise and video footage. Tracking of two relocation trawl-caught ridleys was facilitated by the New Orleans and Galveston Districts of the USACE and Coastwise Consulting, Inc.

My research, data analyses, and document preparation have been greatly enhanced by assistance from numerous individuals. Dr. Kate Mansfield of the University of Miami gave me guidance throughout my indoctrination to satellite tracking and related analysis. Michael Coyne of SEATURTLE.ORG provided an invaluable service in his creation and maintenance of the Satellite Tracking and Analysis Tool. Dr. Donna Shaver and Cynthia Rubio of Padre Island National Seashore answered countless questions and supplied several hard-to-find reports. My understanding of Texas sea turtle policies was enhanced through e-mail and telephone discussions with Rob Hauch (USACE), Mike Ray (TPWD), Ben Rhame (TGLO), and Catherine Yeargan (USFWS).

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To those mentioned above and those I inadvertently missed: thank you!

NOMENCLATURE

ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
AVHRR	Advanced Very High Resolution Radiometer
CCL	Curved carapace length
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CFR	Code of Federal Regulations
CMTTP	Cooperative Marine Turtle Tagging Program
ERC	Epibiont Research Cooperative
ESA	Endangered Species Act
FAC	Florida Administrative Code
FWC	Florida Fish and Wildlife Conservation Commission
GOES	Geostationary Operational Environmental Satellites
HEART	Help Endangered Animals-Ridley Turtles
IAC	Inter-American Convention for the Protection and Conservation of Sea Turtles
ICC	International Chamber of Commerce
IUCN	World Conservation Union (International Union for the Conservation of Nature)
MANOVA	Multivariate analysis of variance
MNWR	McFaddin National Wildlife Refuge
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act

NGO	Non-governmental organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAA STF	NOAA Fisheries Sea Turtle Facility
NPS	National Park Service
PF	PowerFast
PINS	Padre Island National Seashore
PTT	Platform terminal transmitter
SCL	Straight carapace length
SRSP	Sea Rim State Park
SST	Sea surface temperature
STFERL	Sea Turtle and Fisheries Ecology Research Laboratory
STRP	Sea Turtle Restoration Project
STSSN	Sea Turtle Stranding and Salvage Network
SW	Sonic-Weld
TAC	Texas Administrative Code
TAMUG	Texas A&M University at Galveston
TED	Turtle excluder device
TEWG	Turtle Expert Working Group
TGLO	Texas General Land Office
TOBA	Texas Open Beach Advocates
TPNWR	Texas Point National Wildlife Refuge

TPWC	Texas Parks and Wildlife Code
TPWD	Texas Parks and Wildlife Department
USACE	United States Army Corps of Engineers
USC	United States Code
USFWS	United States Fish and Wildlife Service

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CHAPTER I

INTRODUCTION: THE KEMP'S RIDLEY SEA TURTLE

Five species of sea turtles are found in the Gulf of Mexico and northwestern Atlantic Ocean. These are the loggerhead, *Caretta caretta*; green, *Chelonia mydas*; hawksbill, *Eretmochelys imbricata*; leatherback, *Dermochelys coriacea*; and Kemp's ridley, *Lepidochelys kempii* (Hildebrand 1982, Pritchard 1997). The latter is classified as 'Endangered' under the U.S. Endangered Species Act (50 US Code of Federal Regulations 17.11) and 'Critically Endangered' by the World Conservation Union (IUCN 2006), whereas it is protected from trade under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2007). The Kemp's ridley is considered the rarest sea turtle species in the world, and its limited geographic distribution may make it conservation dependent indefinitely (Pritchard 1997).

SPECIES DESCRIPTION

The Kemp's ridley is one of six extant species in the family Cheloniidae and one of two in the genus *Lepidochelys* (Pritchard 1997). The Kemp's ridley and olive ridley, *L. olivacea*, are genetically distinct sister species, likely isolated from each other after formation of the Isthmus of Panama. This theory of isolation is supported by mitochondrial DNA analyses indicating the two species diverged 3 to 6 million years ago (Bowen et al. 1991).

The Kemp's ridley is the smallest sea turtle species, with adults weighing 22-54 kg and measuring 52-78 cm in straight carapace length (SCL, Márquez-M 1994, Musick 2002). Hatchlings are dark gray or black in color, with slightly imbricated scutes, and

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This dissertation follows the style of Endangered Species Research.

possess three dorsal longitudinal ridges and four ventral longitudinal ridges (Márquez-M 1994). With age, the carapace changes from dark gray to olive gray, the plastron becomes yellow to white in color, scutes are no longer imbricated, and longitudinal ridges disappear (Márquez-M 1994, Musick 2002). Most individuals have five pair of costal scutes, five vertebral scutes, a nuchal scute touching the first pair of costals, and four pairs of pored inframarginal scutes (Márquez-M 1994, Musick 2002). The head is broad and pointed, with two pair of prefrontal scales, and there are two claws on each flipper, although the secondary claws may be lost from the front limbs in adults (Márquez-M 1994, Pritchard & Mortimer 1999, Musick 2002).

The Turtle Expert Working Group (TEWG 2000) considers Kemp's ridleys up to 20 cm SCL post-hatchlings, those 20-60 cm SCL benthic immatures, and those above 60 cm SCL adults. Based on the estimates of Snover et al. (2007), the post-hatchling stage extends from hatching to approximately age 2, and the benthic immature stage lasts an average of 10 years. Age at maturity for the Kemp's ridley is estimated at 10-17 years, with a mean of 12 years (Snover et al. 2007). Mature males have longer tails than do females, as well as curved front claws and dekeratinized plastrons (Owens 1997). Although there appears to be some regional variation, most recent studies predicted female-biased sex ratios for various segments of the Kemp's ridley population (reviewed by Wibbels 2007).

LIFE HISTORY

Distribution. Adult and immature Kemp's ridleys occur year-round in the Gulf of Mexico, and juvenile conspecifics are also found in the northwestern Atlantic Ocean as far north as Nova Scotia, Canada, in warmer months (Musick & Limpus 1997, Pritchard 2007). Small juveniles are also known to drift into European waters during winter months (Márquez-M 1994). Important seasonal foraging grounds have been documented in coastal areas of the northern Gulf of Mexico, as well as Long Island Sound, Chesapeake Bay, and the North Carolina sounds (reviewed by Ogren 1989, Musick & Limpus 1997, Pritchard 2007). Beaches at and around Rancho Nuevo in

Tamaulipas, Mexico, serve as nesting grounds for almost the entire population (Pritchard 2007), but nesting also occurs along the Mexican Gulf coast (Texas border to Yucatan Peninsula) and in Texas, USA, (Márquez-M 1994, Shaver 2005a, Pritchard 2007). Limited nesting has also been confirmed in North Carolina, South Carolina, Georgia, Florida, and Alabama, USA and Magdalena, Columbia (Márquez-M 1994, Shaver 2005a, Williams et al. 2006).

Kemp's ridley hatchlings are assumed to be entrained by the Mexican Current and then swept into the northern Gulf of Mexico (Collard & Ogren 1990, Musick & Limpus 1997). Most juveniles are retained in the Gulf during the approximately 2-year pelagic stage, but up to 25% may be entrained in the Florida Current and transported up the Atlantic coast by the Gulf Stream (Musick & Limpus 1997, Musick 2002). Post-hatchlings have been reported in floating mats of vegetation (*Sargassum* spp.), and they are assumed to spend much of their time associated with these mats (Bjorndal 1997, Musick & Limpus 1997). Benthic-stage immature ridleys occur in shallow nearshore habitats in the northwestern Atlantic and the Gulf of Mexico, whereas adults are restricted primarily to nearshore habitats in the Gulf of Mexico (reviewed by Ogren 1989, Márquez-M 1994, Musick & Limpus 1997, Musick 2002). Both immature and mature individuals undertake seasonal foraging migrations, and adults also make migrations to mate and nest (Miller 1997, Musick & Limpus 1997). Immature ridleys that forage in New England, New York, and the Chesapeake Bay, USA have been documented migrating south in the fall and winter (reviewed by Musick & Limpus 1997), and those in the Gulf of Mexico migrate south or offshore during colder months (Renaud & Williams 2005, Schmid & Witzell 2006).

Reproduction. Little is known about pre-mating migrations and mating behavior except for that in Tamaulipas, Mexico. Reproductive females begin to arrive offshore of Rancho Nuevo in March-April, but most arrive during May-June. Males are usually not observed, but they have been taken in trawlers off Rancho Nuevo during April and November (Márquez-M 1994). Mating occurs offshore of the nesting beach, and females come ashore during daylight to nest (Márquez-M 1994, Miller 1997). An estimated 20%

of Rancho Nuevo females nest annually, 60% biannually, 15% every 3 years, and 5% every 4 years, and males may breed annually (TEWG 2000). Nesting peaks during April-June and continues through August (Márquez-M 1994). Females typically lay 2-3 clutches in a season, each comprised of approximately 100 eggs (TEWG 2000, Rostal 2005). Sexual differentiation is determined by temperature during the middle third of incubation, with males forming at cooler temperatures (Wibbels 2007). A pivotal temperature of 30.2 C was estimated by Shaver and colleagues (1988), with temperatures of approximately 31.0 C or greater producing all females and 28.0 C or less producing all males.

Diet. Pelagic stage Kemp's ridleys are believed to feed on crustaceans and molluscs that associate with *Sargassum* mats, and post-pelagic juveniles, subadults, and adults are benthic carnivores, feeding primarily on crabs (Bjorndal 1997). Small juveniles from New York appear to concentrate foraging efforts on walking crabs, particularly the nine-spined spider crab (*Libinia emarginata*), and Atlantic rock crab (*Cancer irroratus*) (Burke et al. 1993, Burke et al. 1994). Larger conspecifics sampled in Virginia (Seney & Musick 2005), Georgia (Frick & Mason 1998), and Texas (Shaver 1991, Werner 1994) consumed a large amount of blue crabs (*Callinectes sapidus*) and other portunids, in addition to walking crabs such as spider crabs (*Libinia* spp.), purse crabs (*Persephona mediteranea*), and stone crabs (*Menippe* spp.). In contrast, Witzell and Schmid (2005) reported that immature ridleys captured in southwest Florida rarely consumed portunid crabs and instead fed primarily on tunicates (*Molgula occidentalis*) and walking crabs. Various molluscs, finfish, shrimp, jellyfish, Atlantic horseshoe crab (*Limulus polyphemus*), cownose ray (*Rhinoptera bonasus*), diamondback terrapin (*Malaclemys terrapin*), and vegetation have also been reported in Kemp's ridley diet (Shaver 1991, Werner 1994, Frick & Mason 1998, Frick et al. 1999, Seney & Musick 2005, Witzell & Schmid 2005).

POPULATION TRENDS

The Kemp’s ridley is currently exhibiting a recovery from devastating declines that reduced its Rancho Nuevo nesting population from a single-day estimate of 10,000-40,000 females in 1947 to fewer than 300 during all of 1985 (Carr 1963, Hildebrand 1963, US Fish & Wildlife Service [USFWS] & National Marine Fisheries Service [NMFS] 1992, Márquez et al. 2005). Since then, exponential nesting increases of 12 to 19% per year have been observed (Fig. 1.1), likely due to egg and nester protection and integration of turtle excluder devices (TEDs) into the US and Mexican shrimp fisheries (Lewison et al. 2003, Heppell et al. 2007). The trend at Rancho Nuevo has been complemented by commencement and growth of Kemp’s ridley nesting on the Texas coast. This activity has grown from 1-2 nests annually prior to 1995 to a record of 128 documented in 2007 (Shaver & Caillouet 1998, D. Shaver pers. comm.). Although most ridley nesting in Texas occurs at Padre Island National Seashore (PINS) and southward (Shaver et al. 2005a, Shaver & Wibbels 2007), nesting along the upper Texas coast since 2002 may suggest a northern expansion or reestablishment of this species’ nesting range in the western Gulf (Fig. 1.2).

RECOVERY PLAN NEEDS

In-water information. Although beach monitoring is crucial to estimating size of the nesting population and its reproductive activity, at-sea life history information is essential for evaluating management strategies and understanding population dynamics of all life history stages. The Kemp’s Ridley Recovery Plan (USFWS & NMFS 1992) lists determining the ‘seasonal use of nearshore habitat by juveniles/subadults’ and determining ‘migratory paths and foraging areas’ of the Kemp’s ridley as necessary components of a strategy to achieve this species’ recovery, but such data are currently sparse. An ongoing revision of the recovery plan and recent 5-year review of the species’ status have highlighted these informational gaps (NMFS & USFWS 2007).

In-water distribution and abundance data for Kemp’s ridleys in the western Gulf of Mexico are largely the result of entanglement net surveys conducted by the Sea Turtle

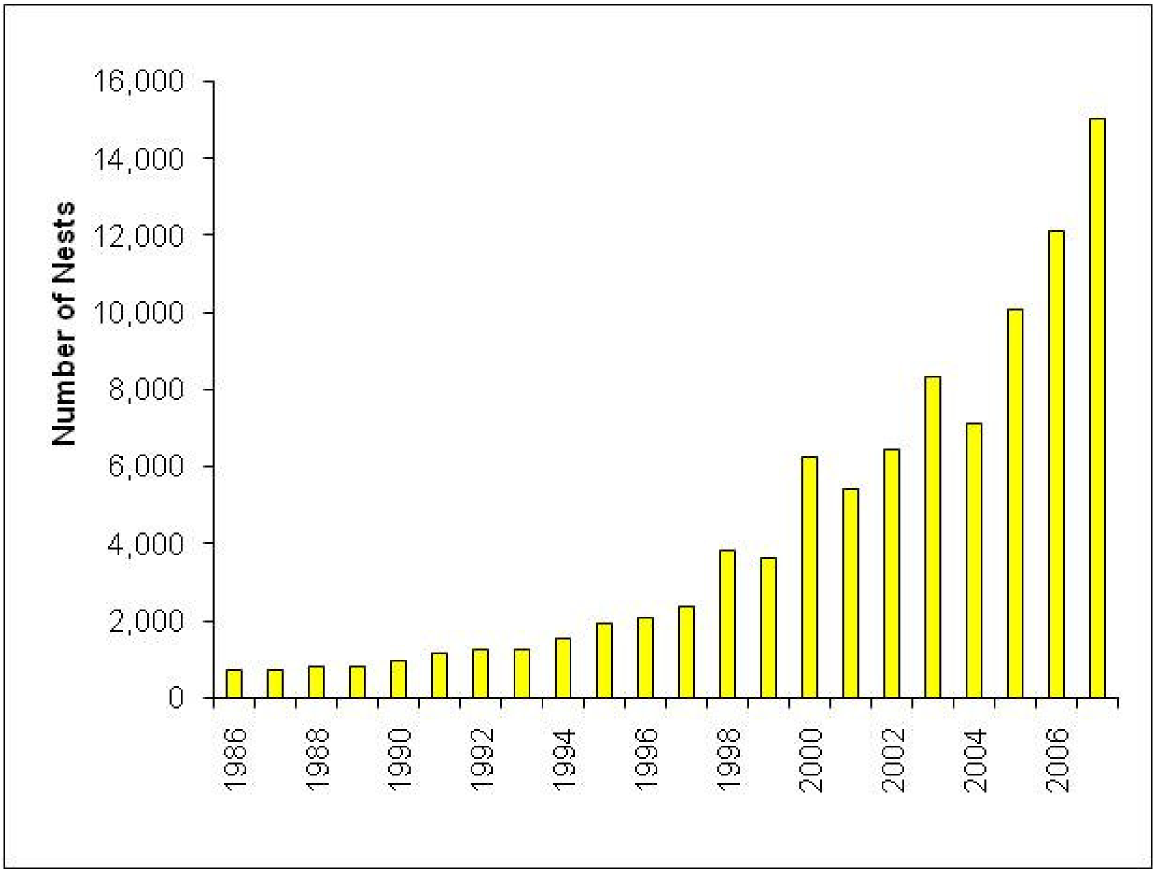


Fig. 1.1. *Lepidochelys kempii.* Nests recorded by the Mexico/USA bi-national project in Tamaulipas and Veracruz, Mexico during 1985-2007 (compiled from USFWS et al. 2006, 2007 bi-national meeting pers. comm.). Note: total for 2007 does not include Veracruz.

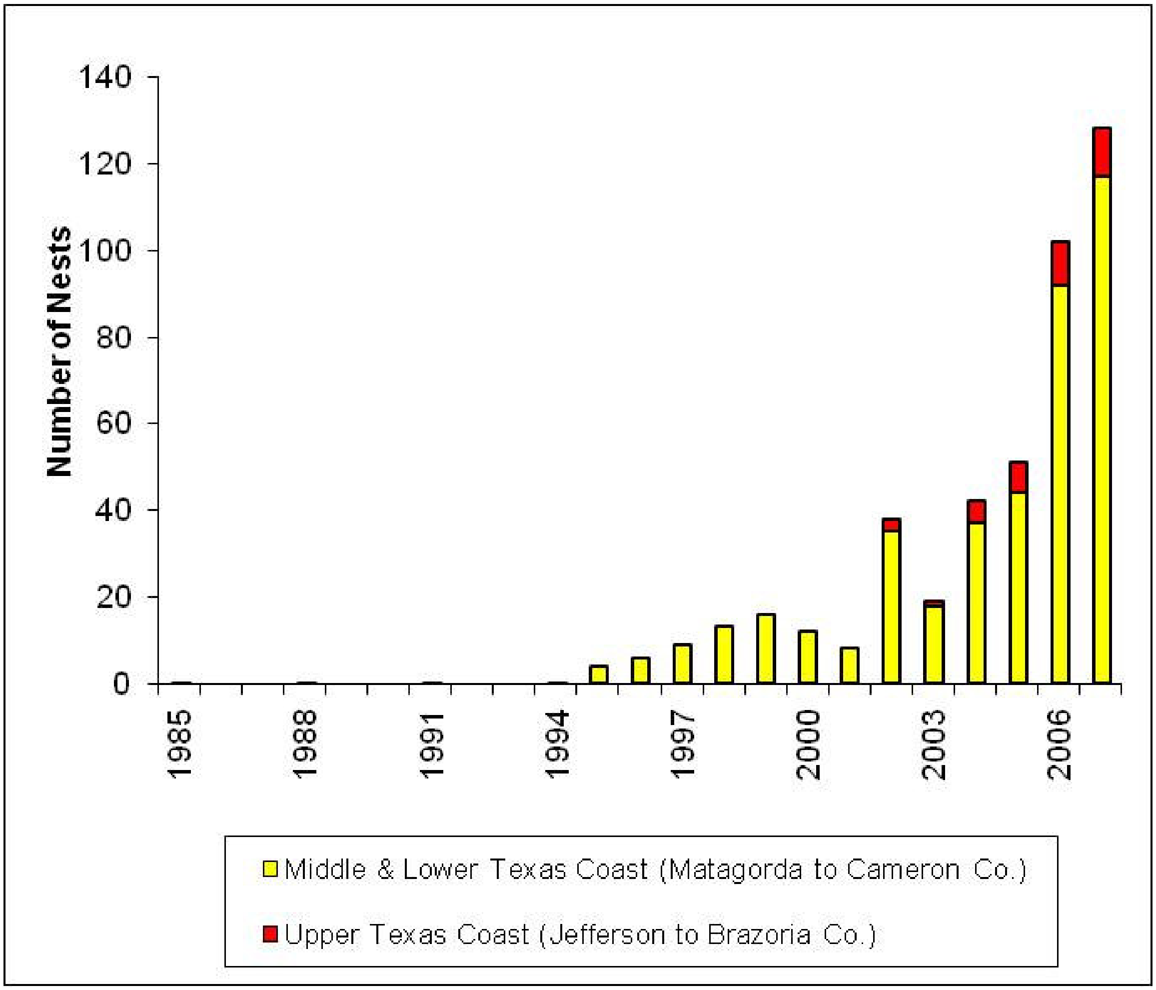


Fig. 1.2. *Lepidochelys kempii.* Nesting trends in Texas, USA (compiled from: Shaver 1994, 1996-2002, 2004, 2005b, 2006a-b, 2007, 2008, Shaver & Caillouet 1998).

and Fisheries Ecology Research Laboratory (STFERL) at Texas A&M University at Galveston (TAMUG) across 10 nearshore study areas between Grand Isle, Louisiana, and South Padre Island, Texas, during 1992-2002 (Landry & Costa 1999, Metz 2004, Landry et al. 2005). These surveys indicated that juvenile and subadult ridleys (20-55 cm SCL) occupied nearshore waters of the northwestern Gulf during March through October, displaying strong fidelity to tidal passes and adjacent beachfront waters (Landry & Costa 1999). Specifically, Sabine Pass, Texas, and Calcasieu Pass, Louisiana, were identified as index habitats where all post-pelagic life history stages could be found seasonally. These locales provide foraging opportunities for ridleys in the form of blue crabs and other crustaceans, as well as bycatch discarded by the shrimp fleet (Ogren 1989, Landry & Costa 1999, Landry et al. 2005).

Ridley abundance at the Sabine Pass and Calcasieu Pass index habitats peaked during 1993-1997 but experienced declines through 2002, despite increased nesting at Rancho Nuevo. Metz (2004) found no correlation between ridley abundance at these index habitats and hatchling abundance at Rancho Nuevo, and this conclusion begs several questions, all of which require answers to better understand the dynamics of a species theoretically experiencing exponential population increases. These questions include:

(1) Do juvenile and subadult ridleys no longer recruit to index habitats along the upper Texas and Louisiana coasts, as the STFERL data suggest?
(2) If not, why has this recruitment pattern changed?
(3) Are these post-pelagic stages recruiting to index habitats and/or foraging grounds further east?

Answers to questions such as these are critical, given predictive models suggesting that lowering mortality of juveniles and subadults is essential to the continued recovery of the Kemp's ridley (TEWG 2000, Heppell et al. 2007). Accurate characterizations of ridley distribution and habitat use, as well as the roles environmental conditions, natural prey, and anthropogenic food sources play in influencing ridley movements will fill informational gaps for the northwestern Gulf of Mexico, as well as provide necessary data for the revision of the Kemp's Ridley Recovery Plan.

Captures in the recreational hook-and-line fishery. In 2001, the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service compiled a list of the primary threats to the recovery of sea turtles, not the least of which was interaction with a variety of fisheries. The 'fisheries or fishing gear of concern' were: trawls, longlines, gillnets, trap and pot fisheries, poundnets, dredge fisheries, and recreational gear, including hook-and-line (NMFS 2001). Although the NOAA Fisheries Sea Turtle Facility in Galveston responds to calls regarding turtles caught on recreational hook-and-line at upper Texas coast piers and beaches (Cannon et al. 1994, C. Fontaine and B. Higgins pers. comm.), it is likely that only a fraction of these incidental captures is reported annually. A total of 112 ridleys was reported at piers along the entire Texas coast during 1980-1992, and 39 of these were documented in 1992 alone (Cannon et al. 1994). The modal size of these ridleys (30.1-40.0 cm curved carapace length [CCL], Cannon et al. 1994) mirrors the dominant size range reported by STFERL netting surveys (Landry & Costa 1999, Metz 2004, Landry et al. 2005). As such, these ridleys constitute a cost-effective, qualitative means (compared to netting operations) of updating information on abundance, population structure, distribution, and movements, while providing an opportunity for hooked individuals to be radiographed, assessed for fishing-related trauma, rehabilitated (if necessary), and characterized as to their diet and post-release behavior.

Upper Texas coast nesting activity. Recent increases in Kemp's ridley nesting along the upper Texas coast (Shaver et al. 2005a, Shaver & Wibbels 2007) warrant examination of this apparent nesting range expansion or reestablishment. Systematic nesting surveys have been ongoing at PINS since 1986, and the resulting data and associated satellite telemetry have been used by managers to evaluate and modify state policy. Inter- and post-nesting movements documented during 1997-2000 were utilized by the Texas Parks and Wildlife Department in conjunction with stranding data to develop an extended shrimp closure off the lower Texas coast (Shaver & Rubio 2008).

Characterizing nesting activity and use of Texas coastal waters by female ridleys is essential to determining the region's importance as nesting, inter-nesting, and migratory habitat, as well as identifying conflicts with human activities.

Diet. Gut content analysis can provide insight to the role of an organism in its environment, and some studies have used diet to examine competition and habitat segregation between and within sea turtle species (Keinath et al. 1987, Shaver 1991, Burke et al. 1993, Seney & Musick 2005). Diet can also be used to determine life history stages of sea turtles, based on the presence of predominantly pelagic or benthic prey items (van Nierop & den Hartog 1984, Plotkin 1996). Likewise, prey composition may indicate interactions with fisheries. Sea turtles are not considered to be fast or agile enough to catch large amounts of fish, and, therefore, any ingested fish are assumed to be acquired either as discarded fishery bycatch or in nets (Shoop & Ruckdeschel 1982, Lutcavage & Musick 1985, Seney & Musick 2007). In the northwestern Gulf of Mexico, consumption of common bait or bycatch species may indicate interactions with recreational hook-and-line and commercial shrimp fisheries, respectively, whereas presence of *Sargassum* spp. and associated invertebrates suggests that an individual has recently moved from the pelagic to the neritic zone.

RESEARCH OBJECTIVES

Continued recovery of the Kemp's ridley and revision of the outdated Kemp's Ridley Recovery Plan require filling in-water information voids, including those related to distribution, habitat use, and fishery interactions of all life history stages. In light of these data needs and sampling opportunities along the upper Texas coast, the following research objectives were identified:

(1) To document hook-and-line capture of Kemp's ridleys along the upper Texas coast and assess associated trauma, rehabilitation success, and post-release behavior.

(2) To determine Kemp's ridley nesting dynamics on the upper Texas coast, inter-nesting movements, and nesting site fidelity.

(3) To characterize movements, migrations, habitat preferences, and diet of benthic-stage Kemp's ridleys in the northwestern Gulf of Mexico.

CHAPTER II

RECREATIONAL HOOK-AND-LINE CAPTURE OF KEMP'S RIDLEYS ON THE UPPER TEXAS COAST

INTRODUCTION

Interaction with a variety of fisheries is among the primary threats to recovery of sea turtles as listed by NOAA Fisheries Service (NMFS 2001). The 'fisheries or fishing gear of concern' were: trawls, longlines, gillnets, trap and pot fisheries, poundnets, dredge fisheries, and recreational gear including hook-and-line. Research and regulations have largely addressed commercial trawling (Magnuson et al. 1990, Epperly 2003) and longlining (Witzell 1984, 1999, Watson & Kerstetter 2006), with other commercial fisheries receiving more attention within the last decade (TEWG 2000, NMFS & USFWS 2007). Interactions between sea turtles and recreational fishing, including ingestion of baited hooks, foul-hooking (flipper, neck, etc.), and entanglement, and their impacts on sea turtle behavior and survival remain largely unquantified. State stranding networks, however, do periodically respond to incidentally captured and dead stranded turtles bearing hooks (Cannon et al. 1994, Witzell & Teas 1994).

The NOAA Fisheries Sea Turtle Facility (NOAA STF) in Galveston, Texas, responds to reports of sea turtles caught on recreational hook-and-line along the upper Texas coast (UTC, Fig. 2.1). These turtles are comprised primarily of immature (25-45 cm SCL) Kemp's ridleys (Cannon et al. 1994), and it is likely that only a small fraction of incidental hook-and-line captures is reported annually (Cannon 1995, B. Higgins pers. comm.). Cannon et al.'s (1994) review of 1980-1992 hook-and-line and stranding data indicated that 112 Kemp's ridleys were reported as live hook-and-line captures along the entire Texas coast. Hooks were found during necropsies of six dead stranded conspecifics during this period, but the authors did not specify the ultimate cause(s) of death. Thirty-nine of these interactions (33%) occurred during 1992, and 62 (53%) were between the Bolivar Peninsula (Galveston County) and the Texas-Louisiana border. A total of 170 Kemp's ridley hook-and-line encounters, comprised of 55 live captures

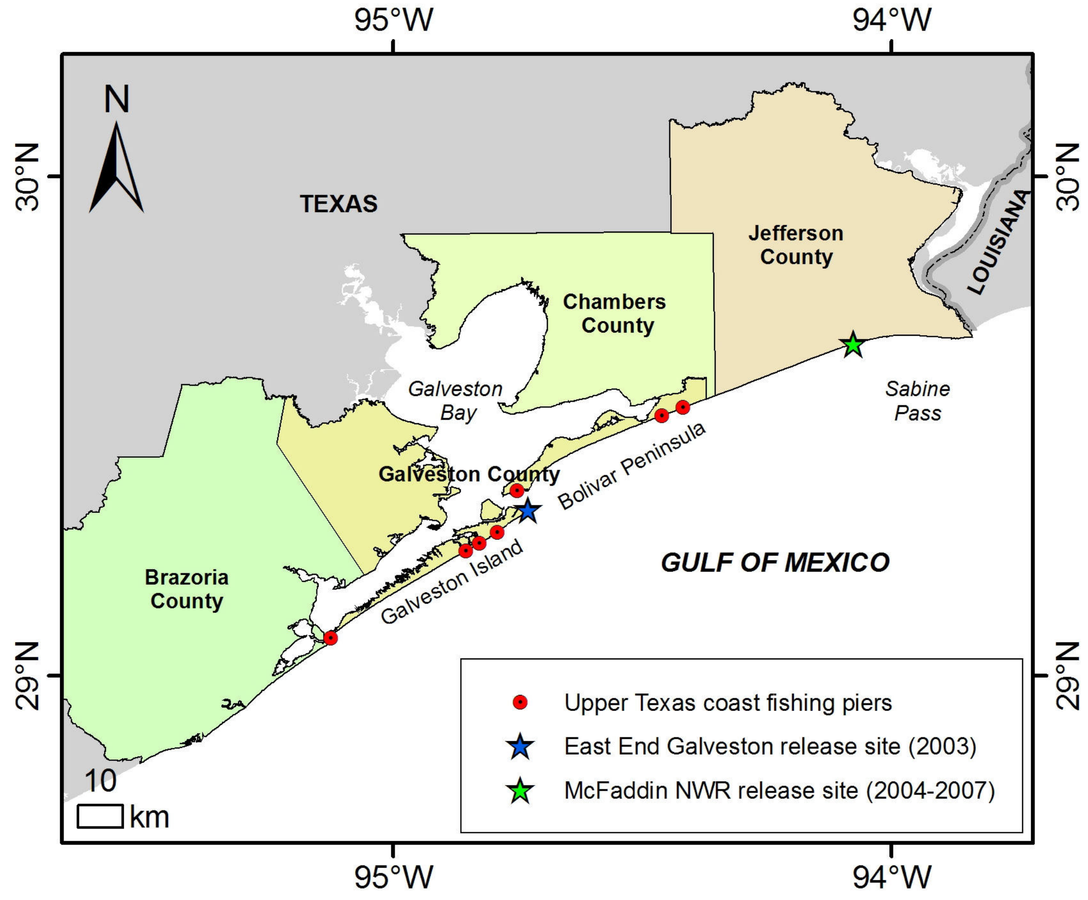


Fig. 2.1. Upper Texas coast (UTC). Location of counties, fishing piers, and primary release sites of hook-and-line-caught sea turtles. Note: groin locations are not depicted.

examined by biologists, 99 live captures released immediately by anglers, and an additional 16 dead strandings (hooks found during necropsy), was recorded along the UTC during 1980-1995, with 135 (79%) occurring during 1992-1995 (Caillouet unpubl. memo, 1996). Increased reports of hook-and-line captures during the mid-1990s may have been due to public education efforts targeting anglers, better survival of immature ridleys due to shrimping regulations, and/or the initial stages of recovery exhibited by the overall population (Cannon et al. 1994, Cannon 1995, Lewison et al. 2003). Additionally, 63% of Kemp’s ridleys reported after hook-and-line capture in 1980-1992 were tagged individuals from NOAA’s headstart project, suggesting that either headstarted individuals outnumbered ‘wild’ conspecifics, or that anglers accustomed to reporting fish bearing tags were more likely to report a tagged turtle versus an untagged one (Cannon et al. 1994).

The 30.1-40.0 cm SCL modal size class of ridleys examined by the NOAA STF during 1980-1995 (Cannon et al. 1994, Cannon 1995) mirrors the dominant size range reported by TAMUG netting surveys conducted during 1992-2002 (Landry & Costa 1999, Metz 2004). The majority of ridley captures in the TAMUG surveys occurred in the northwestern Gulf of Mexico during April through August, but netting efforts were concentrated at Sabine and Calcasieu Passes (Landry & Costa 1999, Metz 2004). A review of Kemp’s ridley encounters in Texas during 1940-1990 indicated that most were found primarily along the upper Texas coast and in spring and summer (Manzella & Williams 1992). Historical hook-and-line data (1980-1992) indicated ridleys were rarely reported along the uppermost portion of the Texas coast (McFaddin National Wildlife Refuge, Sea Rim State Park) prior to 1 July, whereas few were reported on Galveston Island after 1 May (Cannon 1995).

Retrieval of ridleys taken in the nearshore recreational fishery along the UTC represents an opportunity for captures to be documented, assessed for fishing-related trauma, radiographed for internal hooks, rehabilitated (if necessary), and characterized as to their post-release movements and fidelity to piers. Incidental hook-and-line captures may also constitute a cost-effective, albeit qualitative, means of updating information on ridley abundance, population structure, and distribution, as compared to netting operations. A similar opportunistic, qualitative approach was taken by Manzella and Williams (1992) who used historical stranding, nesting, and incidental capture records to examine spatial and temporal distribution of ridleys. Likewise, Witzell (1999) analyzed longline logbook records to characterize loggerhead and leatherback distributions. The 1991-1992 Marine Recreational Fishery Statistics Survey was utilized to examine seasonal distribution patterns of sea turtles along the U.S. Atlantic and Gulf coasts, but reliance on survey and interview data prohibited identification of species-specific trends (Braun-McNeill & Epperly 2002).

OBJECTIVES

Although the Kemp's ridley appears to be undergoing exponential growth at its primary nesting beaches in Mexico (Heppell et al. 2007), data on the species' in-water distribution and abundance are relatively sparse (NMFS & USFWS 2007). Shrimping has arguably been the largest in-water anthropogenic threat to Kemp's ridleys (Magnuson et al. 1990, Frazier et al. 2007), but required use of TEDs in U.S. and Mexican shrimp fisheries appears to have dramatically decreased this threat (Lewison et al. 2003, Heppell et al. 2007). Kemp's ridleys rarely interact with longline fisheries (NMFS & USFWS 2007), whereas encounters with many other fisheries, especially recreational ones, remain largely unexamined. In light of these informational gaps and the reliance of Kemp's ridleys on the northwestern Gulf of Mexico as developmental habitat, the following objectives were identified:

(1) To document hook-and-line capture of sea turtles along the upper Texas coast.
(2) To examine the utility of incidental hook-and-line captures for characterizing seasonal and spatial distribution of Kemp's ridleys.
(3) To examine fidelity of Kemp's ridleys to recreational fishing areas along the upper Texas coast.

MATERIALS AND METHODS

Hook-and-line captures. Posters listing appropriate contact information for the Texas Sea Turtle Stranding and Salvage Network (STSSN) were placed at fishing piers, bait shops, parks, refuges, and other appropriate venues along the UTC (Brazoria, Galveston, Chambers, and Jefferson Counties, Fig. 2.1) during 2004-2007. TAMUG STFERL and/or NOAA STF personnel also instructed employees at upper Texas coast piers (Fig. 2.1) regarding retrieval of all sea turtles captured on hook-and-line gear during 2003- 2007. Although Kemp's ridleys were the focus of this study, other species were recovered for hook removal, measurement, and tagging. Hooked turtles were retrieved as quickly as possible and transported to the NOAA STF for holding, removal of hooks from the mouth, measurements, and photographs. Capture data and measurements were recorded on a standard national STSSN form, with hooking information documented in the comments section. Digital photographs were taken of all turtles, and tagging and release data were provided to the Cooperative Marine Turtle Tagging Program (CMTTP) at the Archie Carr Center for Sea Turtle Research (Gainesville, Florida).

Each hook-and-line capture was subsequently transported to the Houston Zoo for radiographs to detect and evaluate the need to remove ingested hooks and to conduct other necessary medical procedures. Hooks visible from the oral cavity where removed non-surgically through the mouth, whereas those in the esophagus were removed either orally or surgically by a veterinarian (J.P. Flanagan, DVM). Hooks in the stomach or intestinal tract were allowed to pass naturally. After examination and necessary procedures, each turtle was returned to the NOAA STF and held for further treatment as prescribed. Turtles were equipped with two metal flipper tags and a passive integrated transponder (PIT) tag prior to release. Twelve ridleys were also outfitted with satellite transmitters as part of the ongoing STFERL research program (see Chapter V). Hook-and-line-caught turtles were released primarily from the east end of Galveston Island in 2003 and from the east end of McFaddin National Wildlife Refuge (MNWR) near Sabine Pass during 2004-2007 (Fig. 2.1). MNWR was selected as the release site in the latter years to minimize recaptures, and thereby risk of potentially fatal interactions, at Galveston County fishing piers. Two larger loggerheads (>70 cm SCL) were released 32 km (20 mi) offshore.

Data analyses. Location and morphometric data from hook-and-line-caught ridleys were compared to those for stranded conspecifics documented by the NOAA STF along the upper Texas coast during 2003-2007. Anecdotal reports of hook-and-line captures and strandings were not included in any analyses. A multivariate analysis of variance (MANOVA) was conducted in SPSS 11.5 to compare ridley size (SCL) and location along the Texas coast (degrees north latitude) in relation to year (2003-2007), month (January-December), and event type (hook-and-line or stranding). Strandings for which SCL was not measured and those that occurred within Galveston Bay (i.e., inshore) were excluded from this analysis. A significance level of $\alpha < 0.05$ was utilized for the MANOVA and associated analyses of variance (ANOVA).

RESULTS

Forty-seven hook-and-line-caught sea turtles, comprised of 42 Kemp's ridleys, 4 loggerheads, and 1 green turtle, were retrieved along the upper Texas coast during 2003-2007 (Fig. 2.2). These were from Galveston (n = 45) and Jefferson Counties (n = 2), with no hook-and-line captures reported from Brazoria or Chambers County or from inshore waters. Thirty-four of these captures (31 ridleys, 2 loggerheads, and 1 green) originated from the same pier on Galveston Island, and other captures were reported from two piers on the Bolivar Peninsula (5 ridleys, 2 loggerheads) and from surf fisherman along the UTC (6 ridleys). During the same time period, 87 stranded ridleys were documented in Galveston and Jefferson Counties, and none were recorded in Chambers County (Fig. 2.3). Eleven of these strandings occurred on Galveston Bay (inshore) and were excluded from statistical analyses.

Kemp's ridleys. Hook location was known for 34 of the 42 hook-and-line-caught ridleys. Of these, over half were hooked in the mouth or jaw (n = 19) and over a third (n = 13) were throat-hooked or had swallowed the hook (Fig. 2.4-2.5). The

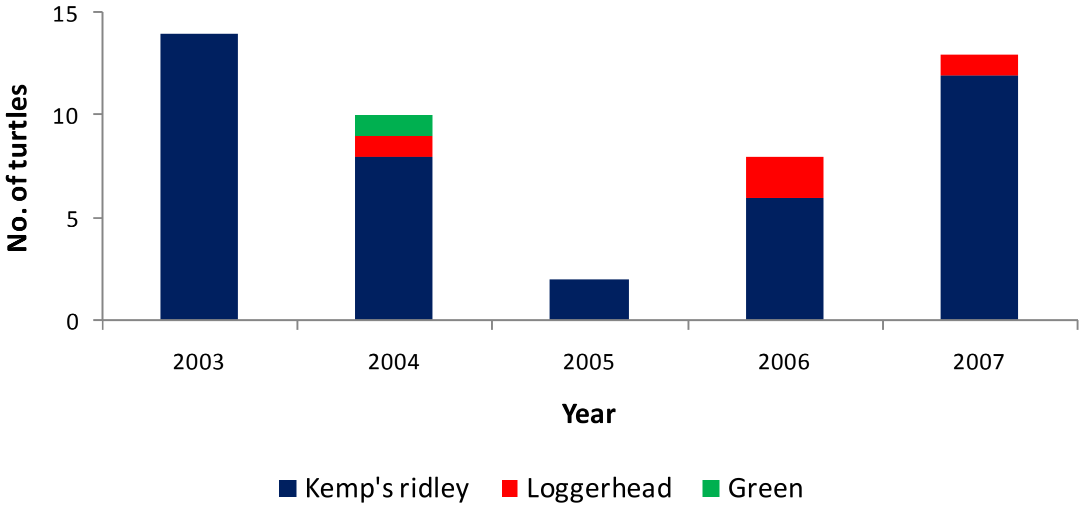


Fig. 2.2. Hook-and-line captures. Annual species composition of all hook-and-line-caught sea turtles examined during 2003-2007.

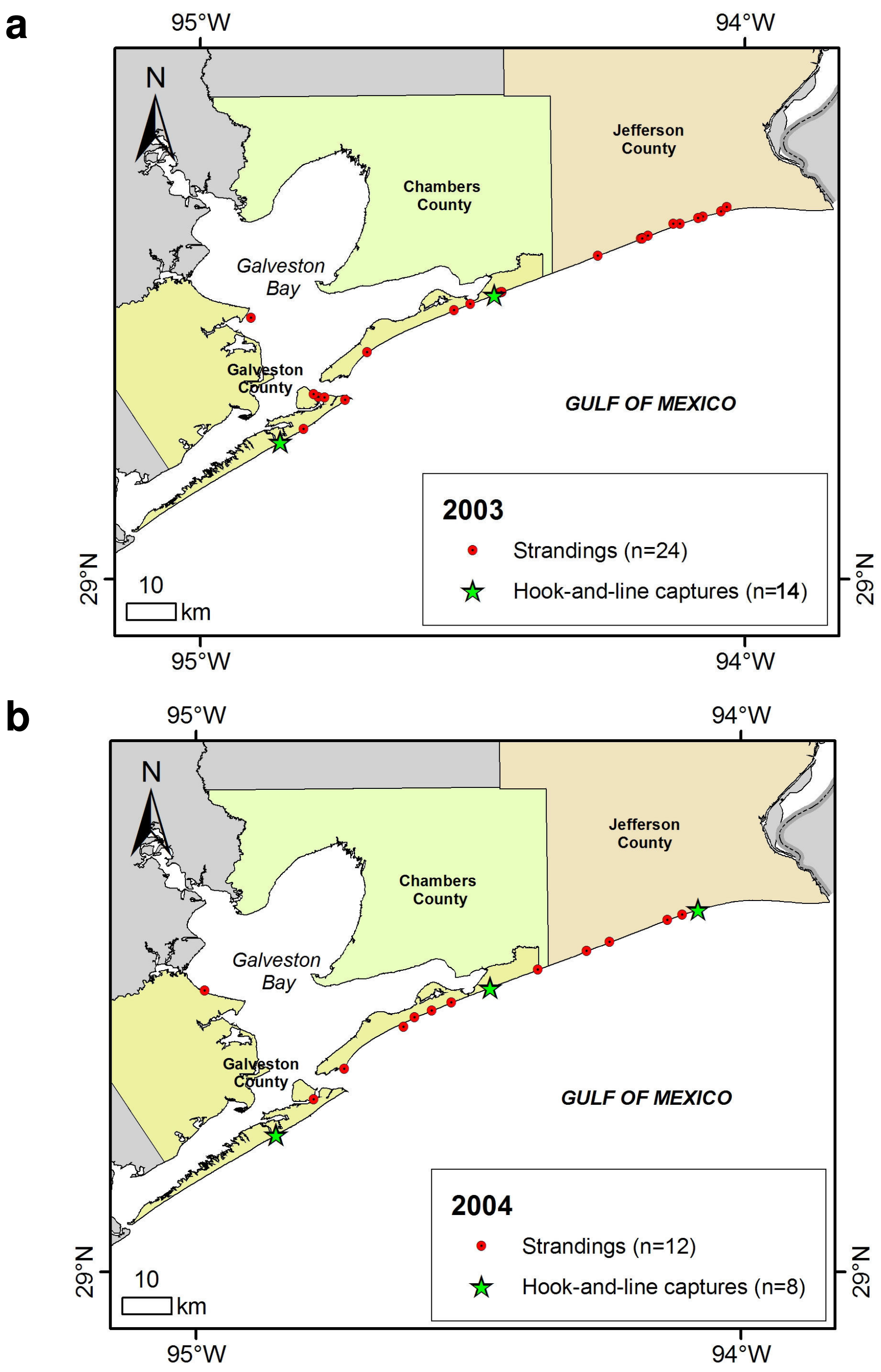


Fig. 2.3. *Lepidochelys kempii.* Locations of hook-and-line-caught and stranded Kemp's ridleys documented along the UTC during (a) 2003, (b) 2004, (c) 2005, (d) 2006, and (e) 2007. Note: Most hook-and-line captures originated from three Galveston County fishing piers, and as such, individual turtles are not distinguishable in most years.

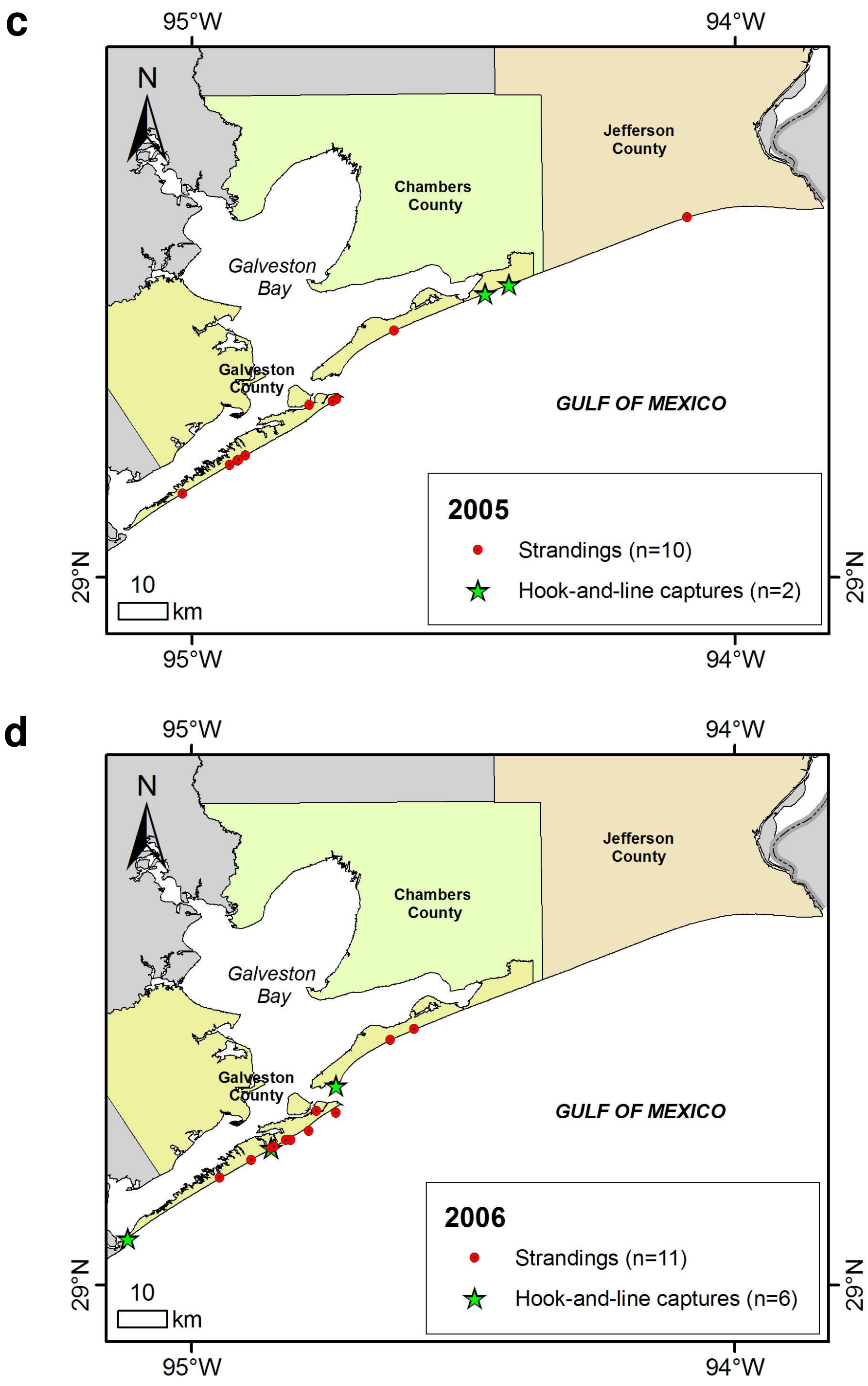
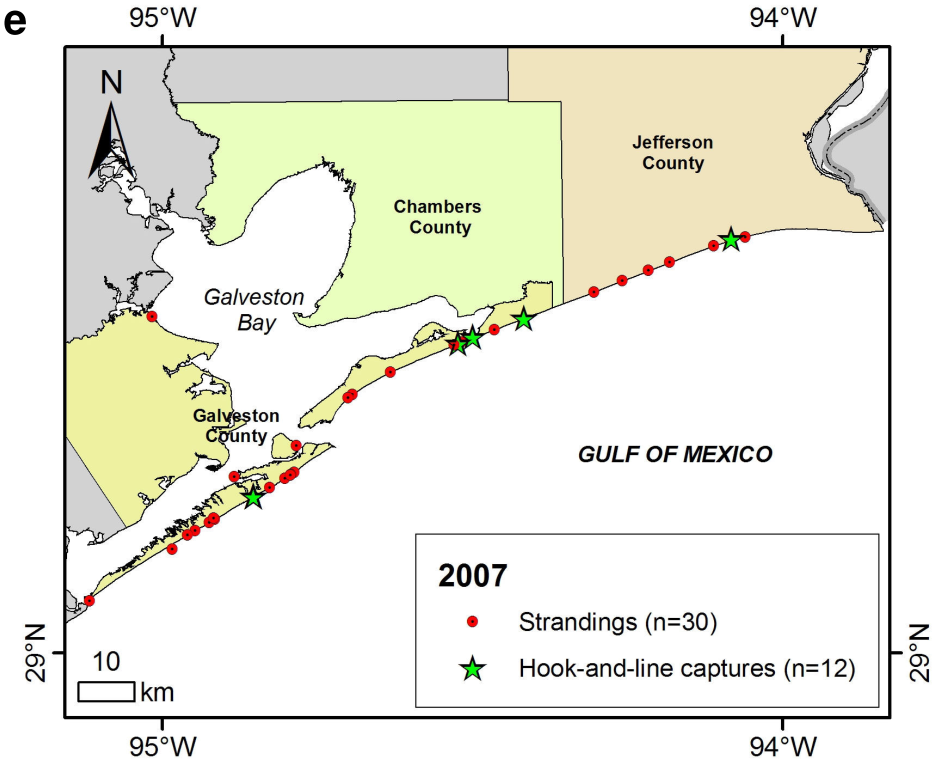


Fig. 2.3. Continued.



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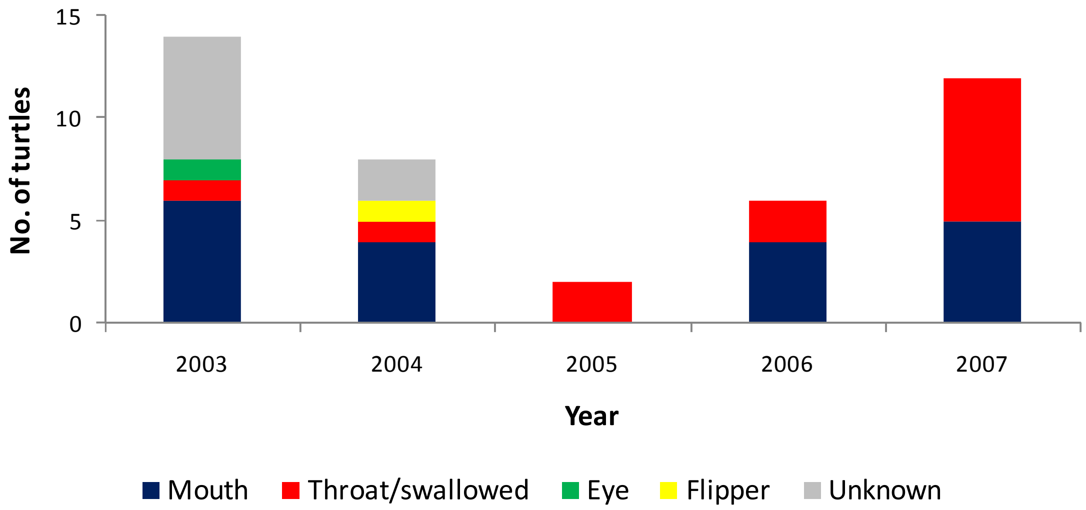


Fig. 2.4. *Lepidochelys kempii.* Location of fishing hook in Kemp's ridleys caught on recreational hook-and-line along the UTC and subsequently examined in 2003-2007.

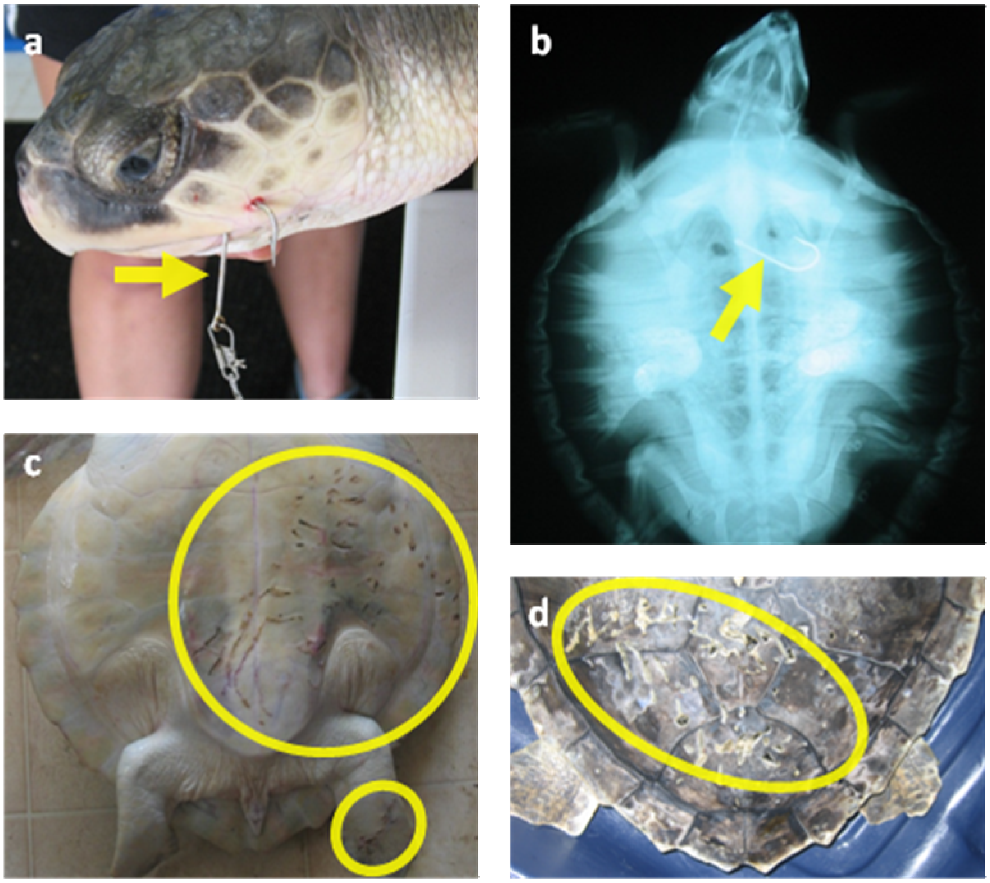


Fig. 2.5. *Lepidochelys kempii.* (a) Hook through jaw, (b) radiograph of swallowed hook, and shark bites on (c) plastron and rear flipper and (d) carapace. Photos by E. Seney.

remaining turtles were foul-hooked: one in an eye and another in a front flipper. Radiographs revealed a second hook, presumably from a prior hook-and-line encounter, in the GI tract of two ridleys. Fishing gear was removed from 17 ridleys by anglers prior to response, but data were not available on hook type. Hooks removed from turtles during rehabilitation were comprised primarily of 'J' hooks on single rigs. Three circle hooks and one treble hook were also observed in 2007. Baits included shrimp, squid, mullet (*Mugil* spp.), and other bony fish, and no ridleys were caught on artificial lures or crab.

Apart from capture-related injuries, the only fresh wounds documented on hooked ridleys were shark bites on two individuals (confirmed by P. Motta pers. comm., Fig. 2.5). Among 87 stranded conspecifics, four exhibited clear interactions with hook-and-line gear. One live ridley (34.0 cm SCL) was recovered at a pier entangled in monofilament and fishing weights (no hooks), whereas three stranded dead with gear attached (one flipper-hooked, one mouth-hooked, and one entangled in monofilament: $\bar{x} \pm 1$ SD = 44.4 ± 11.3 cm SCL). No internal hooks were identified in stranded ridleys, but decomposition state prevented necropsy of all individuals. Forty hook-and-line-caught ridleys and the entangled stranding were successfully rehabilitated and released within 1-53 d of capture. Two other hook-and-line captures died in captivity: one of aspiration pneumonia in 2003 and another due to a hook piercing its esophagus in 2007.

Ridleys caught on recreational hook-and-line during 2003-2007 averaged 34.6 cm SCL (SD = 5.0 cm, n = 42), and their size distribution fell within a larger range displayed by strandings from Galveston and Jefferson Counties ($\bar{x} \pm 1$ SD = 40.4 ± 15.0 cm SCL, n = 81, Fig. 2.6). Hook-and-line captures were retrieved between March and October, with 81% during April-June, while strandings were documented in March-December and peaked in the spring (55% in April-May, Fig. 2.7). MANOVA indicated that source (hook-and-line vs. stranding, $p = 0.042$) and the interaction between source and year ($p = 0.006$) had a significant effect on ridley SCL and location along the UTC (degrees north latitude), whereas year, month, and the other interaction terms did not (Table 2.1). Examination of the associated ANOVAs (Table 2.2) revealed that SCL was

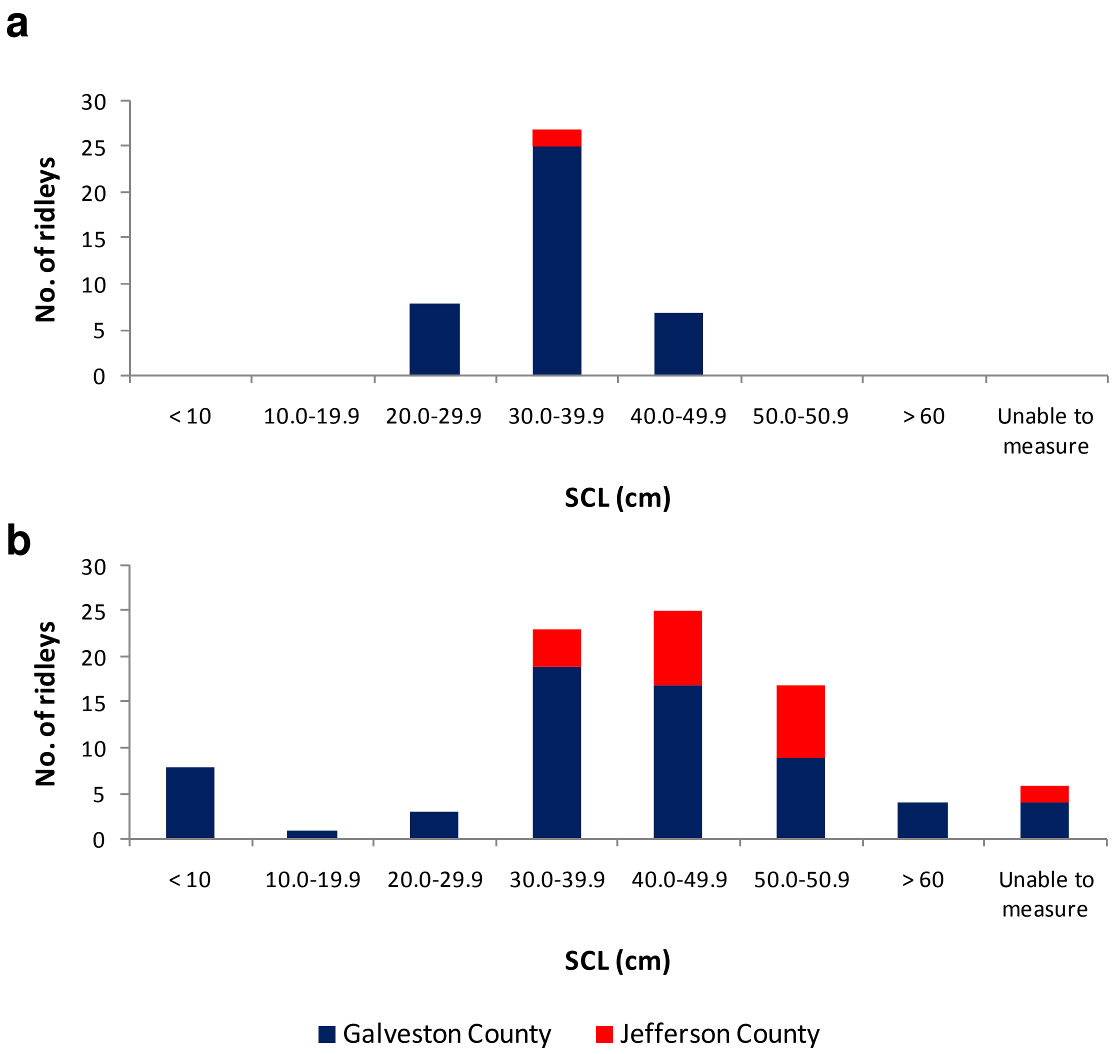


Fig. 2.6. *Lepidochelys kempii.* Size distributions of (a) hook-and-line-caught and (b) stranded Kemp's ridleys encountered in Galveston and Jefferson Counties during 2003-2007.

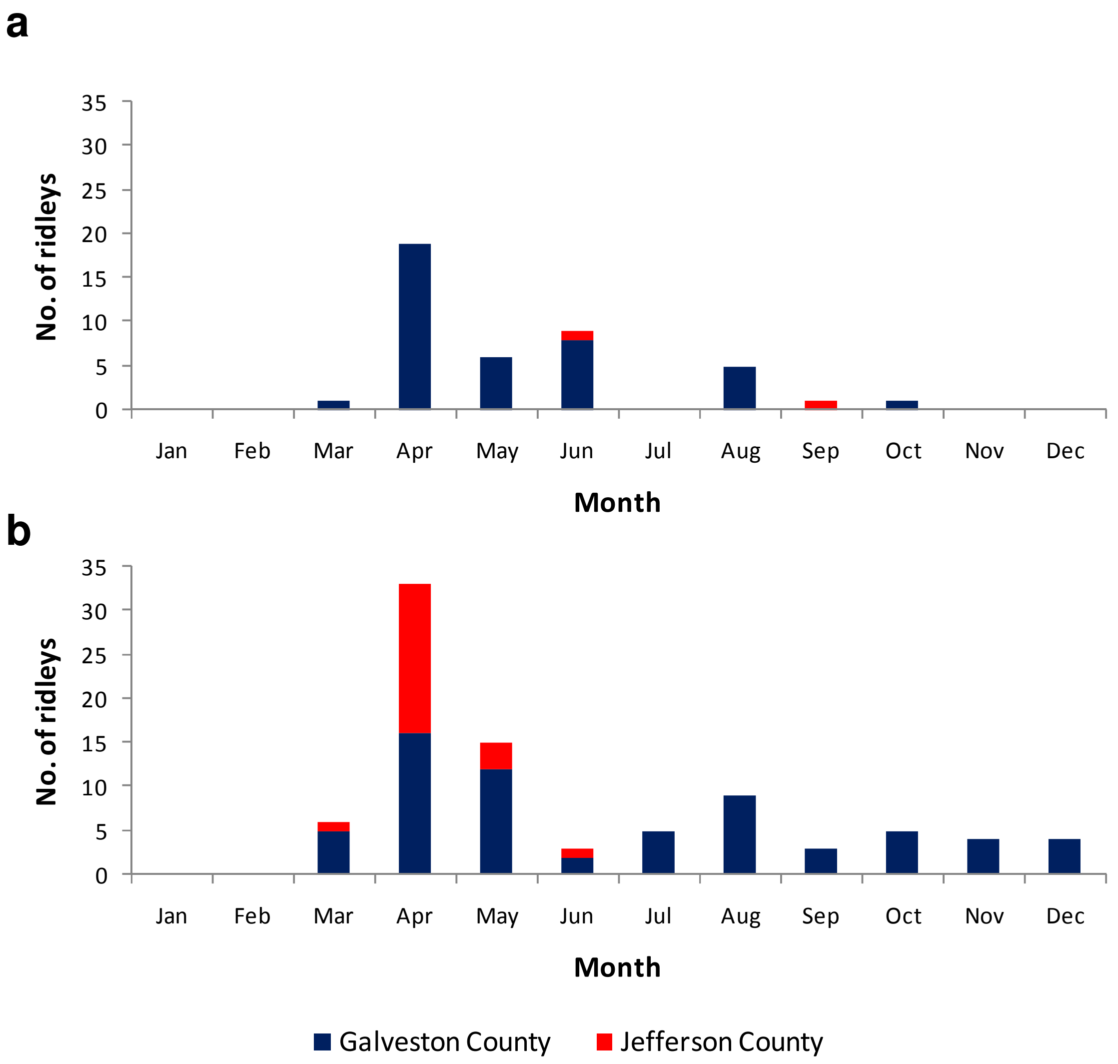


Fig. 2.7. *Lepidochelys kempii.* Monthly distribution of (a) hook-and-line-caught and (b) stranded Kemp's ridleys encountered in Galveston and Jefferson Counties during 2003-2007.

Table 2.1. Results of multivariate analysis of variance (MANOVA) for dependent variables, straight carapace length (SCL) and degrees latitude.

Effect	**Hotelling's Trace**	**F**	**Hypothesis df**	**Error df**	***p***	**η_p^2**
Year	0.162	1.394	8	138	0.204	0.075
Month	0.242	0.927	18	138	0.548	0.108
Source	0.094	3.305b	2	70	0.042	0.086
Year x Month	0.412	1.016	28	138	0.453	0.171
Year x Source	0.331	2.855	8	138	0.006	0.142
Month x Source	0.150	1.034	10	138	0.418	0.070
Year x Month x Source	0.003	0.114	2	70	0.892	0.003

Table 2.2. Results of analysis of variance (ANOVA) for dependent variables, (a) straight carapace length (SCL) and (b) degrees latitude, associated with MANOVA (Table 2.1).

Dependent variable	**Source**	**df**	**F**	***p***	**η_p^2**
A. SCL	Model	41	49.541	< 0.001	0.966
	Year	4	1.788	0.141	0.092
	Month	9	1.087	0.383	0.121
	Source	1	6.215	0.015	0.080
	Year x Month	14	0.820	0.645	0.139
	Year x Source	4	2.499	0.050	0.123
	Month x Source	5	0.680	0.640	0.046
	Year x Month x Source	1	0.001	0.975	< 0.001
	Error	71			
	Total	112			
B. Latitude	Model	41	137,540.400	< 0.001	1.000
	Year	4	1.144	0.343	0.061
	Month	9	0.804	0.614	0.093
	Source	1	0.842	0.362	0.012
	Year x Month	14	1.223	0.278	0.194
	Year x Source	4	3.146	0.019	0.151
	Month x Source	5	1.329	0.262	0.086
	Year x Month x Source	1	0.226	0.636	0.003
	Error	71			
	Total	112			

significantly affected by turtle source (*p* = 0.015), whereas the interaction between year and turtle source significantly affected location (*p* = 0.019).

Only one hook-and-line-caught ridley retrieved during the study had preexisting tags. This was a juvenile caught at a Galveston pier in May 2003, released on the east end of Galveston, and recaptured at a Gilchrist (Bolivar Peninsula) pier in July 2003 (53 d at large). Two other tag returns, one live hook-and-line capture and one dead stranding, have been recorded among 2003-2007 UTC hook-and-captures, but neither was examined by biologists. A juvenile ridley caught and released in August 2004 was reported to the CMTTP in May 2005 as a dead stranding along Galveston Bay in Chambers County. Another juvenile caught and released in September 2004 was recaptured on hook-and-line near its initial capture location at MNWR in May 2005, but this event was not reported until several days later. The low level of site fidelity indicated by tag returns was reinforced by satellite tracking of 12 immature ridleys ($\bar{x} \pm 1$ SD = 35.5 ± 3.3 cm SCL) caught on hook-and-line, rehabilitated, and subsequently released at MNWR in 2004-2007 (see Chapter V). Only one individual, a juvenile tracked in 2004, returned to its capture location (Gilchrist) while tracked (n = 12, $\bar{x} \pm 1$ SD = 47 ± 27 d).

Other sea turtle species. Four immature loggerheads averaging 68.6 cm SCL (SD = 7.9 cm) and one immature green turtle (33.1 cm SCL) were retrieved from Galveston County piers during 2003-2007 (Fig. 2.2). Loggerheads were caught in April, August, and September, and the green was caught in May. Three loggerheads swallowed hooks, whereas the fourth was hooked in the shoulder, and the green was hooked in the neck. One loggerhead was caught at least three times in one day before retrieval, and two others bore gear from previous interactions with hook-and-line; a radiograph revealed a second hook in the intestinal tract of one individual, while a second was entangled in monofilament, hooks, and weights at the time of capture. All four loggerheads and the green turtle were successfully rehabilitated and released, and none had been recorded as recaptures or strandings as of July 2008.

Two stranded loggerheads also exhibited definite signs of interactions with hooks during 2003-2007. A live stranded individual (69.5 cm SCL) that subsequently died from shark wounds had part of a 'large,' rusted fish hook walled off in its esophagus, minimal fat reserves, and no food in its digestive tract. A dead stranded loggerhead (56.5 cm SCL) had a large circle hook with over 1 m of monofilament attached embedded in its flipper. This hook was probably used by a commercial vessel targeting reef fish (C. Bergmann pers. comm.). No stranded green turtles or any hawksbills or leatherbacks were recorded to have interacted with recreational hook-and-line gear along the UTC during 2003-2007.

DISCUSSION AND CONCLUSIONS

Kemp's ridleys. Recreational hook-and-line captures comprised 33% of documented non-nesting Kemp's ridley encounters along Galveston and Jefferson Counties during 2003-2007 (n = 129). Distribution of captures along the UTC was skewed toward fishing piers and varied by year but was not significantly different from that of strandings (Fig. 2.3, Table 2.2). Monthly distributions of 2003-2007 UTC hook-and-line captures were similar to each other, as well as to those previously recorded for hook-and-line-caught ridleys along the UTC (Cannon et al. 1992, Cannon 1995) and the Florida panhandle (Rudloe & Rudloe 2005).

Geographical and temporal distributions of hook-and-line-caught and stranded ridleys were likely more similar than the aforementioned data indicated, given that only three of seven UTC piers reported any captures, few turtles were retrieved from surf fishermen, and none were retrieved from the numerous groins along Galveston Island. The distribution among piers was likely affected by closures at the Gilchrist and High Island piers during 2003-2005 due to changes in ownership and tropical weather systems. Additionally, the Gilchrist pier did not reopen after Hurricane Rita hit the UTC in September 2005. Still, a seemingly disproportionate proportion of ridleys documented on hook-and-line (74%) were reported from a single pier at 89th Street on Galveston Island. Despite their close proximity, no documented hook-and-line captures were recorded from piers located at 25th and 61st Street. The latter two piers do not extend as far into the Gulf as the 89th Street Pier, but some captures were reported from them in years past (NOAA STF unpubl. data) and one anecdotal report was received from the 61st Street pier in 2005. TAMUG and NOAA STF personnel received 1-7 anecdotal reports annually regarding captures at Galveston Island piers and Galveston and Jefferson County beaches. The most noteworthy report occurred on a weekend in August 2004, when an angler claimed to have observed 'more than ten' ridleys caught at MNWR, although it is likely that one or more turtles were captured multiple times.

Perceived discrepancies between documented (i.e., examined) and actual numbers of captures during both this study and that in the 1990s (Cannon 1995) highlight the need for annual education of anglers and pier operators regarding reporting of hooked sea turtles. Such efforts are especially important in light of the fact that a third of documented hook-and-line-caught ridleys swallowed the hook during 2003-2007 (Fig. 2.4), and two additional ridleys had other hooks in their gut at the time of capture. Although some hooks may pass naturally without complications, those that become embedded in the oral cavity or digestive tract could lead to death due to decreased feeding ability, intestinal blockage, internal bleeding, and/or infection (Rudloe & Rudloe 2005, J. Flanagan pers. comm.). Reporting and subsequent retrieval of all hooked turtles allows for each to be radiographed, hooks removed as appropriate, and the animal to be tagged before relocation and release. Tagging not only allows for examination of fidelity to fishing areas (Rudloe & Rudloe 2005), but may increase the likelihood that a turtle will be reported if caught again (Cannon 1995).

Although hook-and-line-caught and stranded ridleys displayed similar geographical (Fig. 2.3) and monthly trends (Fig. 2.7), SCL distributions (Fig. 2.6) were significantly different between the two groups (Table 2.2). The hook-and-line dataset was devoid of hatchling and pelagic stage juveniles (<25 cm SCL), as well as subadults and adults (>45 cm SCL). A similar size discrepancy was noted for ridleys caught on hook-and-line on the Florida panhandle during 1991-2003 (Rudloe & Rudloe 2005). Hatchlings and pelagic stage individuals normally occur offshore and feed at the surface

(Ogren 1989, Collard & Ogren 1990, Shaver 1991), and therefore would not be expected to interact with coastal hook-and-line gear. In contrast, subadults and adults seasonally inhabit nearshore waters of the UTC (Landry & Costa 1999, Shaver & Rubio 2008, Chapter IV) and display similar feeding preferences to those of juveniles (Shaver 1991, Chapter VII). The 30-40 cm SCL size class was most commonly recorded in both the present study and earlier examinations of hook-and-line capture on the UTC (Cannon et al. 1994, Cannon 1995); however, some individuals 'over 50 cm SCL' were documented in 1980-1992 (Cannon et al. 1992) and one 50.3 cm SCL ridley was recorded in 1994 (Cannon 1995). Most adult females (>60 cm SCL) do not remain in nearshore Texas waters after the April-July nesting season (Shaver & Rubio 2008, Chapter IV), which may decrease interactions with nearshore hook-and-line gear, but it is unknown why the subadult size class (45-60 cm SCL) is poorly represented among UTC hook-and-line captures. Possible explanations include utilization of different foraging areas than those of juveniles, smaller numbers of subadults in the population versus numbers of juveniles, and/or decreased ability or desire of anglers to land larger individuals. Likewise, larger turtles may be more susceptible to breaking anglers' lines, thus decreasing catch rate.

Low site fidelity exhibited by UTC hook-and-line captures contrasted that of ridleys caught at piers in the Florida panhandle during 1991-2003 (Rudloe & Rudloe 2005). Of 62 individuals caught on hook-and-line, tagged, and released, 9 ridleys (15%) were recaptured a total of 12 times. These were comprised of nine instances of individuals caught, released, and recaptured at the same pier (averaging 4.2 mo at large) and three involving relocated turtles that returned to their pier of capture (4.7 mo average). Two of these ridleys were visually confirmed in the vicinity of a pier for 4 and 10 mos, respectively. Such fidelity to a pier puts turtles at risk of multiple hook ingestions, fouling-hooking, and entanglement (Rudloe & Rudloe 2005, present study), as well as ingestion of anthropogenic debris (Chapter VII) and interactions with large sharks (Fig. 2.5). Low tag recovery rates and minimal return of tracked UTC ridleys to initial capture locales suggest that relocation of hooked turtles to MNWR is an effective means of reducing future interactions in the study area, although it is recognized that some recaptures may not have been reported.

Other sea turtle species. Although loggerheads were recorded much less frequently as hook-and-line captures than were ridleys, several individuals exhibited short-term fidelity to fishing piers and repeated interactions with hook-and-line gear. Loggerheads typically occur further offshore the UTC than do ridleys (Landry & Costa 1999), which may explain their reduced interaction with onshore fishing activities. The species is known, however, to ingest baited longline hooks offshore (Witzell 1999), so it is not surprising that those foraging nearshore exhibit the potential to interact with recreational gear. Loggerheads are also likely to interact with offshore recreational fishing, but the extent of such interactions is largely unquantified in the western Gulf of Mexico.

Concluding remarks. Documentation of hook-and-line-caught sea turtles constituted a relatively high proportion (33%) of non-nesting Kemp's ridley encounters along the UTC. Ridley captures occurred within the same geographical regions as strandings, but most were reported from fishing piers, which received posters and annual instruction from TAMUG and NOAA personnel. Hook-and-line captures undoubtedly occur along the UTC more frequently than reported, dictating a need for increased angler and pier operator education to better quantify the interaction and ensure all hooks are safely removed and rehabilitation provided, when necessary. Integration of questions about sea turtle captures into existing recreational surveys (Braun-McNeill & Epperly 2002) would help determine the extent of sea turtle interactions with both land-based and offshore recreational fishing, as well as temporal and spatial distributions of sea turtles along the Texas coast. Likewise, establishment of a hook-and-line capture reporting system, similar to that employed in North Carolina (Braun-McNeill pers. comm.) would facilitate further assessment of sea turtle distribution and recreational fishing interactions while promoting public education.

Although hook-and-line-caught and stranded ridleys exhibited similar distribution trends, examination of incidental capture data does not constitute a surrogate for in-water surveys, as evidenced by the lack of subadult and adult individuals from the hook-and-line dataset. Likewise, disparities between number of reports and actual number of captured turtles and an inability to accurately measure fishing effort indicate that hook-and-line data should only be used in a qualitative fashion. Techniques such as entanglement netting and trawling should be utilized in conjunction with stranding and nesting surveys to better understand the seasonal and geographic distribution of all life history stages. As the Kemp’s ridley population continues to increase (Heppell et al. 2007), interactions with recreational fishing gear and other human activities are also likely to rise. Understanding these interactions, as well as the dynamics of all life history stages, should facilitate effective management and public education practices regarding ridleys and other sea turtle species.

CHAPTER III

KEMP'S RIDLEY NESTING DYNAMICS ON THE UPPER TEXAS COAST

INTRODUCTION

Nesting by the critically-endangered Kemp's ridley sea turtle, *Lepidochelys kempii*, has been increasing exponentially at primary nesting grounds in Mexico since 1985 (Márquez et al. 2005, Heppell et al. 2007). This activity has been centered at Rancho Nuevo and surrounding beaches along the Mexican state of Tamaulipas but also occurs in the states of Veracruz and Campeche (Márquez et al. 2005). Kemp's ridley nesting has also been documented in the southeastern United States. During 1985-2006, 332 nests were documented in Texas, whereas 29 more were found elsewhere in the southeast U.S. (Shaver 2005a, 2006b, 2007). Nests outside of Texas were comprised of 2 in North Carolina; 1 in South Carolina; 1 in Georgia; 22 in Florida; and 3 in Alabama (Shaver 2005a, 2006b, 2007, Williams et al. 2006). During 1985-2006, 214 (64.5%) of Texas' documented ridley nests occurred along North Padre Island, with the majority of these found within Padre Island National Seashore (PINS; Shaver 2005a, 2006b, 2007). Nesting was first documented in Galveston, Brazoria, and Matagorda Counties during 2002 (Shaver 2005a, Fig. 3.1), and efforts to detect nests and characterize nesting activity along the upper Texas coast (UTC) have since increased (Shaver 2008).

OBJECTIVES

Increased Kemp's ridley nesting along the UTC warrants a characterization of this activity in order to provide researchers and regulatory agencies sufficient information for managing an endangered species utilizing Texas beaches and adjacent waters. In light of these data needs and sampling opportunities presented by nesting along the UTC, the following research objectives were identified:

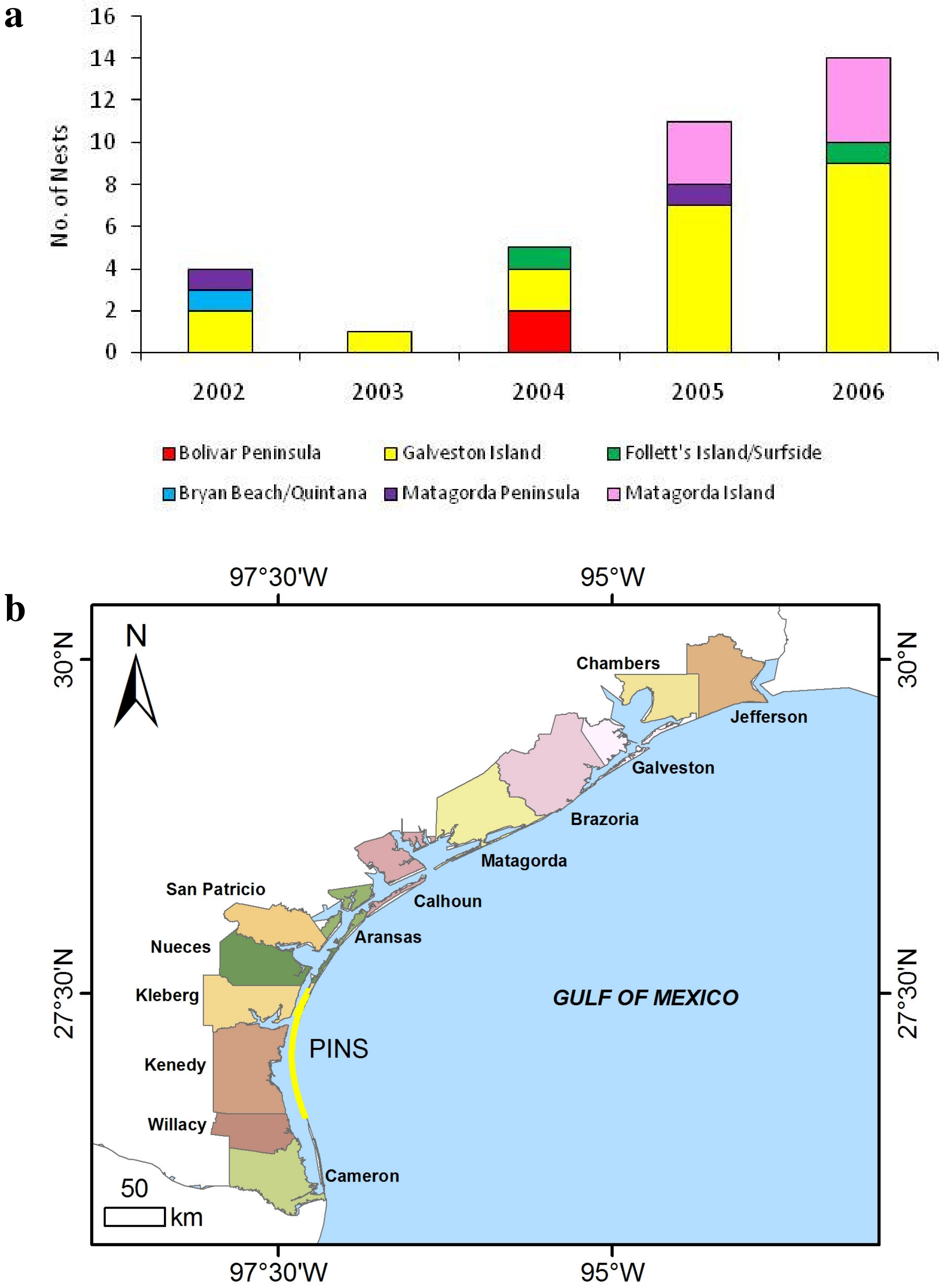


Fig. 3.1. *Lepidochelys kempii.* (a) Nests documented in Galveston, Brazoria, and Matagorda Counties, Texas, USA, during 2002-2006 (compiled from: Shaver 2005b, 2006a, 2006b, 2007). (b) Counties along Texas coast and location of Padre Island National Seashore (PINS, highlighted in yellow).

(1) To characterize female Kemp's ridleys nesting on the UTC in terms of origin (wild stock or headstart), morphometrics, and where possible, age and within-season reproductive potential.

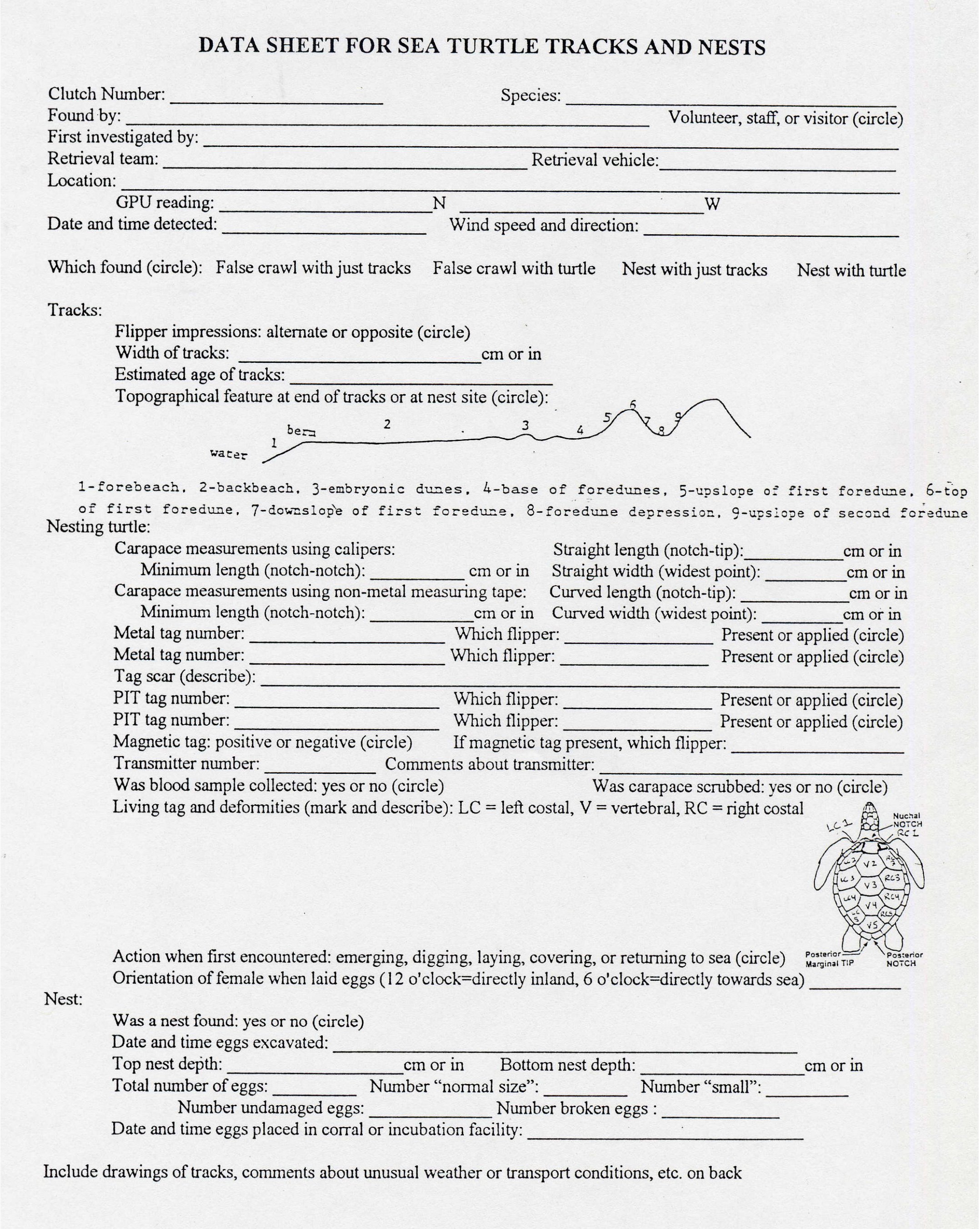
(2) To characterize Kemp's ridley nesting dynamics and nest site location on the UTC.

(3) To characterize Kemp's ridley clutches deposited on the UTC.

MATERIALS AND METHODS

The TAMUG STFERL coordinated with and assisted the NOAA STF in the latter's response to UTC (Jefferson, Chambers, Galveston, and Brazoria Counties, Fig. 3.1) nesting during 2005 and 2006. Systematic nesting patrols were not conducted, and the STEFERL and NOAA STF relied on the public and city and county beach staff to report nesting turtles and tracks. A toll-free hotline maintained by the Sea Turtle Restoration Project and Help Endangered Animals-Ridley Turtles (HEART) facilitated reporting nesting activity to a 24-hour on-call cell phone monitored by NOAA STF staff. Upon receipt of any nesting report, the NOAA STF contacted STFERL personnel, and arrangements were made to respond as quickly as possible.

Morphological measurements, existing tags, nesting date and location, clutch size, and other pertinent data were recorded for any intercepted females and all nest sites on a standard Texas nesting datasheet (Fig. 3.2). Females were thoroughly examined for metal flipper tags, passive integrated transponder (PIT) tags, living tissue tags, and coded wire tags to determine whether they had been part of the experimental headstart program housed at the NOAA STF during 1978-2000 (Klima & McVey 1982, Fontaine & Shaver 2005). Metal flipper tags and PIT tags were applied to females that were not already tagged. Six females, three from each year, were transported back to the NOAA STF for attachment of satellite transmitters and subsequent tracking (see Chapter IV), whereas other intercepted females were released immediately following examination and tagging. All six tracked females, as well as one additional female in 2006, were examined via ultrasound to determine whether developing egg follicles were present and



DATA SHEET FOR SEA TURTLE TRACKS AND NESTS

Clutch Number: ______________________ Species: __________________________________

Found by: ____ Volunteer, staff, or visitor (circle)

First investigated by: ____

Retrieval team: _____________________________________ Retrieval vehicle: ______________________

Location: ____

GPU reading: ______________________N _________________________W

Date and time detected: _____________________ Wind speed and direction: __________________________

Which found (circle): False crawl with just tracks False crawl with turtle Nest with just tracks Nest with turtle

Tracks:

Flipper impressions: alternate or opposite (circle)

Width of tracks: ________________________cm or in

Estimated age of tracks: ____________________________

Topographical feature at end of tracks or at nest site (circle):

1-forebeach, 2-backbeach, 3-embryonic dunes, 4-base of foredunes, 5-upslope of first foredune, 6-top of first foredune, 7-downslope of first foredune, 8-foredune depression, 9-upslope of second foredune

Nesting turtle:

Carapace measurements using calipers: Straight length (notch-tip):__________cm or in

Minimum length (notch-notch): __________ cm or in Straight width (widest point): _________cm or in

Carapace measurements using non-metal measuring tape: Curved length (notch-tip): ___________cm or in

Minimum length (notch-notch): ___________cm or in Curved width (widest point): _________cm or in

Metal tag number: ____________________ Which flipper: _______________ Present or applied (circle)

Metal tag number: ____________________ Which flipper: _______________ Present or applied (circle)

Tag scar (describe): ____

PIT tag number: _____________________ Which flipper: _______________ Present or applied (circle)

PIT tag number: _____________________ Which flipper: _______________ Present or applied (circle)

Magnetic tag: positive or negative (circle) If magnetic tag present, which flipper: ________________

Transmitter number: ___________ Comments about transmitter: _______________________________

Was blood sample collected: yes or no (circle) Was carapace scrubbed: yes or no (circle)

Living tag and deformities (mark and describe): LC = left costal, V = vertebral, RC = right costal

Action when first encountered: emerging, digging, laying, covering, or returning to sea (circle)

Orientation of female when laid eggs (12 o'clock=directly inland, 6 o'clock=directly towards sea) __________

Nest:

Was a nest found: yes or no (circle)

Date and time eggs excavated: ____

Top nest depth: __________________cm or in Bottom nest depth: ________________cm or in

Total number of eggs: _________ Number "normal size": _________ Number "small": _________

Number undamaged eggs: _____________ Number broken eggs : _____________

Date and time eggs placed in corral or incubation facility: _____________________________

Include drawings of tracks, comments about unusual weather or transport conditions, etc. on back

Fig. 3.2. Texas sea turtle nesting form used to record data during 2005 and 2006 (courtesy of PINS Division of Sea Turtle Science and Recovery).

thus indicate the likelihood of subsequent nesting within a season.

Eggs at each nest site were excavated, packed in Styrofoam coolers with sand from the nest cavity, and transported to an incubation facility at PINS (Shaver 2005a). The NOAA STF and STFERL reported all nesting data to the Texas sea turtle nesting coordinator located at PINS, who later confirmed the species of nesters that were not encountered and provided hatch success percentage for each nest. Potential relationships between nester size and clutch characteristics were examined with linear regression using SPSS 11.5.

RESULTS

Seventeen Kemp's ridley nests were documented along the UTC during 16 May-20 June 2005 (n = 7) and 28 April-14 June 2006 (n = 10). Sixteen of these nests occurred in Galveston County along Galveston Island, whereas one was recorded in Brazoria County near Surfside (Table 3.1, Fig. 3.3).

Turtle characteristics. Eight individual females averaging 63.2 cm straight carapace length (SCL, SD = 2.3 cm) were examined at nine different UTC nest sites during 2005-2006 (Table 3.1). These included five headstarted individuals from the 1989 (n = 1), 1991 (n = 1), and 1992 (n = 3) year classes, as well as three wild (non-headstarted) conspecifics. At nesting, the headstarted ridleys were 13 (n = 3), 15 (n = 1), and 17 (n = 1) years of age, and none had been recorded nesting, on the UTC or otherwise, in previous years.

Seven females examined via ultrasound after nesting (Table 3.1), and each possessed developing egg follicles. The first six females possessed relatively dense developing egg follicles, whereas the female that nested in Brazoria County in late May 2006 (RRV233) exhibited much less dense follicles (J. Flanagan unpubl. data). Two individuals were confirmed nesting twice within the same season. SSD127 was examined by biologists after nesting 16 May and 20 June 2005 (35 d between documented nests), whereas RRV315 nested 6 May 2006 and was indentified from video footage provided by beachgoers at a 26 May 2006 nest site (20 d between documented

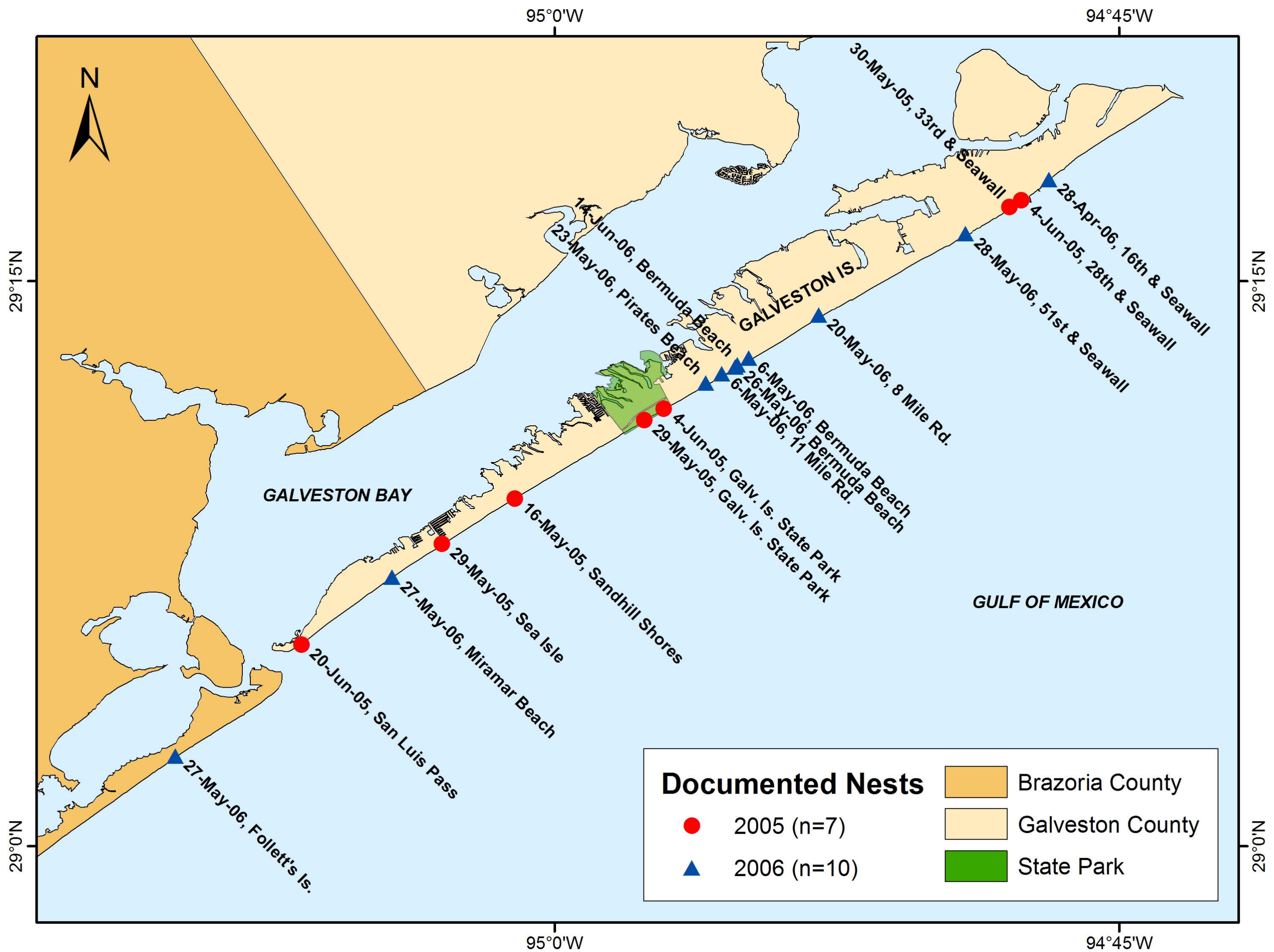
Table 3.1. *Lepidochelys kempii* . Data collected from nests and females along the upper Texas coast, 2005–2006. Turtle type details in parentheses: HS, headstart (including year); W, wild; SCL, straight carapace length (from notch to tip).

Clutch Details							Turtle Details				
UTC Clutch No.	Date and Time Detected	Location	Nest Site	No. Eggs in Clutch	No. Eggs Incubated	Hatch Success (%)	Examined by Biologists?	Primary Tag (type)	SCL (cm)	Ultrasound?	Tracked?
2005-1	16 May 2005 1000	Sandhill Shores, Galveston Is.	In dune	101	101	66.3	Yes	SSD127 (1992 HS)	65.8	Yes	Yes
2005-2	29 May 2005 0800	Galveston Island State Park	Foot of dune	103	103	98.1	Yes	RRV251 (W)	62.5	Yes	Yes
2005-3	29 May 2005 1000	Sea Isle, Galveston Is.	Foot of dune	87	87	94.3	No	Unknown	N/A	N/A	N/A
2005-4	30 May 2005 0800	33rd St. and Seawall Blvd., Galveston Is.	In dune	108	108	95.3	Yes	RRV253 (1992 HS)	63.0	Yes	Yes
2005-5	4 June 2005 0630	Galveston Island State Park	Foot of dune	108	108	97.2	No	Unknown	N/A	N/A	N/A
2005-6	4 June 2005 1000	28th St. and Seawall Blvd., Galveston Is.	Between high tide line and dune	78	78	28.2	Yes	RRV371 (1992 HS)	60.0	No	No
2005-7	20 June 2005 0830	San Luis Pass, Galveston Is.	Between high tide line and dune	104	104	98.1	Yes	SSD127 (1992 HS)	65.5	No	Yes
2006-1	28 April 2006 1330	16th St. and Seawall Blvd., Galveston Is.	Near seawall (no true dune)	118	116	76.7	Yes	RRV231 (W)	67.2	Yes	Yes
2006-2	6 May 2006 1500	11 Mile Rd., Galveston Is.	Foot of dune	87	87	5.7	Yes	RRV315 (1989 HS)	61.5	Yes	Yes
2006-3	6 May 2006 1530	Bermuda Beach, Galveston Is.	Near road (no true dune)	119	119	27.7	Yes	RRV255 (1991 HS)	62.1	Yes	No
2006-4	20 May 2006 0800	8 Mile Rd., Galveston Is.	Foot of dune	71	71	0.0	No	Unknown	N/A	N/A	N/A
2006-5	23 May 2006 0700	Pirates Beach, Galveston Is.	Near base of geotextile tube (no true dune)	118	118	84.7	No	Unknown	N/A	N/A	N/A
2006-6	26 May 2006 1200	Bermuda Beach, Galveston Is.	Foot of dune	94	93	23.7	No	RRV315 (1989 HS)[a]	N/A	No	Yes[a]
2006-7	27 May 2006 0900	Miramar Beach, Galveston Is.	Between high tide line and dune	81	81	86.4	No	Unknown	N/A	N/A	N/A
2006-8	27 May 2006 1030	Follett's Is./Surfside, Brazoria County	Between high tide line and dune	99	99	92.9	Yes	RRV233 (W)	63.8	Yes	Yes
2006-9	28 May 2006 0600	51st St. and Seawall Blvd., Galveston Is.	Just above high tide line	97	97	93.8	No	Unknown	N/A	N/A	N/A
2006-10	14 June 2006 0500	Bermuda Beach, Galveston Is.	Foot of dune	116	116	97.4	No	Unknown (probably RRV231)[b]	N/A	N/A	Yes[b]

[a] Turtle identified from videotape provided by beach visitor.

[b] Beach visitor saw turtle with transmitter returning to water at nest site.

Fig. 3.3 *Lepidochelys kempii*. Locations of nests documented in Galveston and Brazoria Counties, Texas, during 2005-2006 (coordinates courtesy of S. Kethan, NOAA STF). Figure located on next page.


95°0'W
94°45'W
29°15'N
29°0'N
N
30-May-05, 33rd & Seawall
28-Apr-06, 16th & Seawall
4-Jun-05, 28th & Seawall
28-May-06, 51st & Seawall
GALVESTON IS.
20-May-06, 8 Mile Rd.
14-Jun-06, Bermuda Beach
23-May-06, Pirates Beach
6-May-06, Bermuda Beach
26-May-06, Bermuda Beach
6-May-06, 11 Mile Rd.
4-Jun-05, Galv. Is. State Park
29-May-05, Galv. Is. State Park
GALVESTON BAY
16-May-05, Sandhill Shores
29-May-05, Sea Isle
27-May-06, Miramar Beach
20-Jun-05, San Luis Pass
27-May-06, Follett's Is.
GULF OF MEXICO
Documented Nests
● 2005 (n=7)
▲ 2006 (n=10)
Brazoria County
Galveston County
State Park

nests). Additionally, a beachgoer's observation that a post-nesting female entering the water bore a satellite transmitter, when combined with tracking data (Chapter IV), suggested that RRV231 laid the 14 June 2006 clutch (47 d between documented nests).

RRV315's 20 d interval is similar to inter-nesting intervals recorded at Rancho Nuevo (e.g. 1990: $\bar{x} \pm 1$ SD = 25 ± 4 d, reported in Rostal 2005), whereas the 35 and 47 d intervals were unusually long for the species. These extended durations suggest an undocumented nesting event occurred between both SSD127 and RRV231's documented nests. Likewise, individuals appeared to nest 1-2 times within a season on the UTC based on visual confirmation of nests and ultrasounds of nesters, whereas satellite telemetry (Chapter IV) indicated four females each nested three times per season, at 2-3 week intervals.

Nest site characteristics. The UTC nest sites selected by female Kemp's ridleys during 2005-2006 (Table 3.1) varied in location along the beach profile, degree of coastal armoring, and level of human activity. The first five nests of the 2005 season were laid either in dunes or at the foot of dunes, whereas the latter two were between the high tide line and dune line. In 2006, nests 1-6 and 10 were either at the foot of a dune or near the foot of a man-made structure, whereas nests 2006-7 and 2006-8 were between the high tide line and dune, and 2006-9 was just above the high tide line. Estimated wind speeds at nest sites ranged from 5 to 20 knots and were of southeasterly and southwesterly directions.

Four nests, two in each year, were deposited along the armored Galveston Seawall (Fig. 3.3). Two (2005-4, 2006-9) occurred early in the morning (0600-0800) when there was little beach activity, and a third (2006-1) was deposited in a relatively deserted area on an overcast, windy afternoon (1330), whereas the other female (2005-6) emerged from the water mid-morning (1000) among beachgoers, blankets, and umbrellas. The other five 2005 nests were laid (or tracks discovered) at times and in areas with little beach traffic: two within Galveston Island State Park, two adjacent to West End housing developments, and one in an undeveloped area bordering San Luis Pass. Excepting the one in Brazoria County, nests documented during 2006 occurred primarily in developed areas, including the Seawall (n = 2), at the base of a geotextile tube in Pirates Beach (n = 1), and near houses and roads in Bermuda Beach (n = 3). Direct human interaction occurred once in Bermuda Beach, where a female nested on the beach-side of a road after beachgoers moved her off the road. In general, nests occurring later in the day (1000 or later) were concurrent with higher levels of human activity on the beach, but reliance on the public to report nesting events may have impacted this result. Early morning nests (0500-1000) were typically reported by beach workers or individuals on a morning walk, whereas those later in the day were more often reported by stationary groups of people at the beach.

Clutch characteristics. The 17 nests deposited on the UTC during 2005-2006 contained 71-119 eggs ($\bar{x} \pm 1$ SD = 99 ± 15), and their hatch success ranged from 0 to 98% ($\bar{x} \pm 1$ SD = 69 ± 36%). Of the clutches belonging to a ‘known’ female, those from headstarted ridleys (n = 7) were slightly smaller ($\bar{x} \pm 1$ SD = 99 ± 14) and had lower hatch success ($\bar{x} \pm 1$ SD = 49% ± 37%) than those deposited by wild conspecifics (n = 3, clutch size: $\bar{x} \pm 1$ SD = 107 ± 10, hatch success: $\bar{x} \pm 1$ SD = 89% ± 11%), but sample sizes were too small to warrant statistical comparison. Although not statistically significant, positive correlations were apparent (Fig. 3.4) between female SCL (n = 10) and both clutch size ($p = 0.056$) and hatch success ($p = 0.064$). Wild females were, on average, slightly larger than headstarted individuals. Additionally, smaller, headstarted females yielded all of the hatch success values below 50% for clutches of known origin (Fig. 3.4).

DISCUSSION AND CONCLUSIONS

There is growing evidence that the critically-endangered Kemp’s ridley is in the midst of population recovery. Increases in annual number of nesting females documented at this species’ primary nesting beach, Rancho Nuevo, as well as associated increases in nests laid, eggs produced, and hatchlings released (USFWS et al. 2006) are significant signs of enhanced survival and increased reproductive potential within the population. The species is also exhibiting another trend associated with population

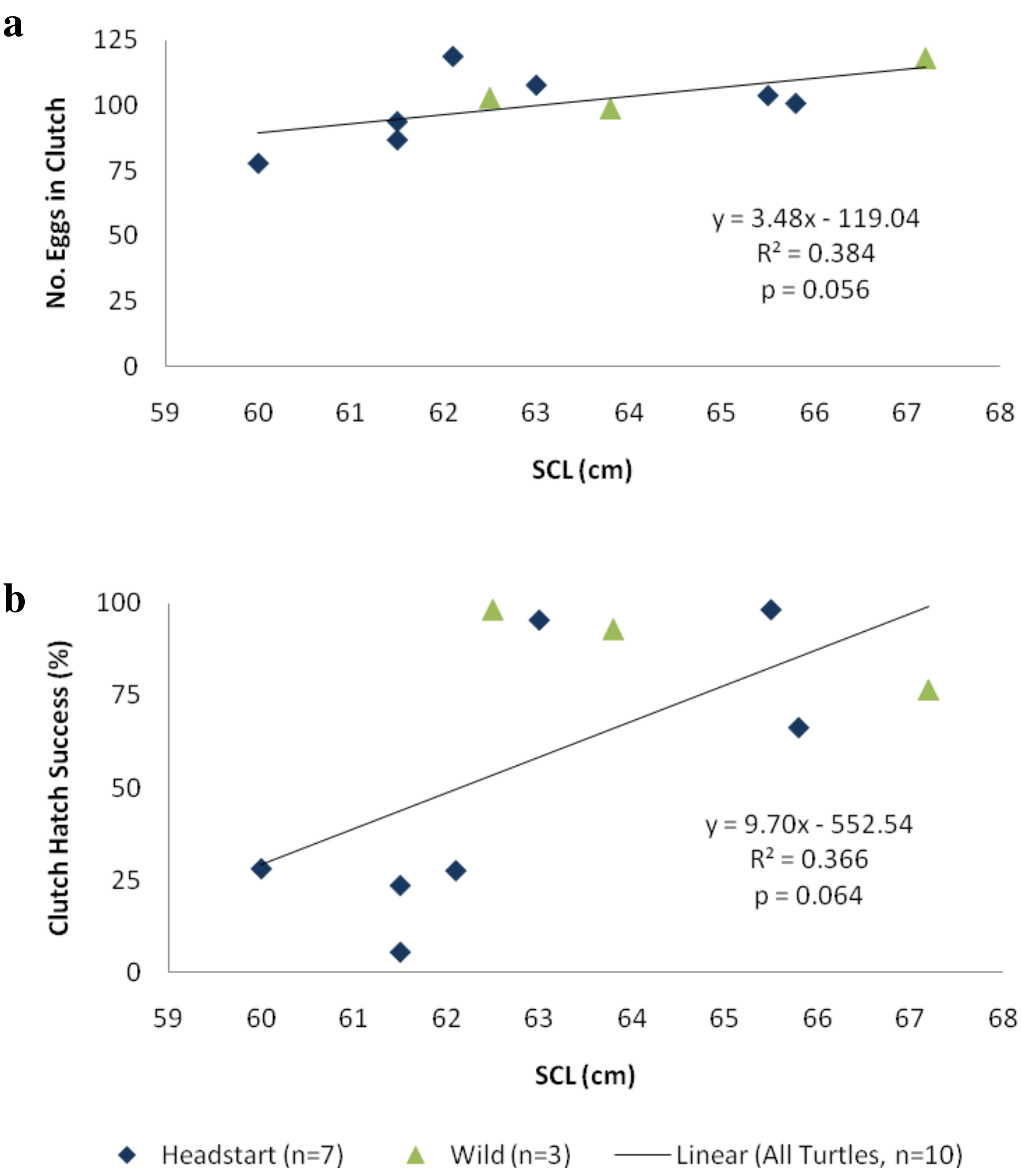


Figure 3.4. *Lepidochelys kempii.* Plots and associated linear regressions of (a) clutch size and (b) hatch success versus nester straight carapace length (SCL) for nests detected in Galveston and Brazoria Counties, Texas, USA (data courtesy of S. Kethan, NOAA STF and D. Shaver, PINS Division of Sea Turtle Science and Recovery).

increase: extension or perhaps reestablishment of its nesting range. The 25 nests documented along the UTC (Galveston and Brazoria Counties) during 2002-2006 comprised over 10% of nests reported statewide during this period and nearly 8% of the 1985-2006 state total (Shaver 2005a, 2005b, 2006a, 2006b, 2007). These trends indicate that a northern expansion or reestablishment of this species' nesting range is occurring along the UTC and that these nesters warrant consideration within management schemes.

Three of the four nesters encountered on Galveston Island beaches in 2005 were individuals from the 1992 headstart year class, while two headstarted counterparts (1989 and 1991) nested on the island in 2006. Additionally, three wild (non-headstarted) turtles were documented nesting on the UTC during 2005-2006. The degree to which the headstarting process has influenced propensity to nest on the UTC and fidelity to the area during the nesting season is unknown. Gauging its impact will take years of directed nest patrols to complete. Documentation of three wild ridleys nesting on the UTC, however, serves to diminish potential concern that the perceived northward expansion of nesting by this species is an aberration due, in part, to possible imprinting of headstarted cohorts to the Galveston area.

Behavior of both wild and headstarted ridleys nesting along the UTC in 2005-2006 was similar to that of conspecifics at Rancho Nuevo and on the lower Texas coast (Shaver et al. 2005, USFWS et al. 2006). All UTC nests occurred within what is considered the ridley nesting season of April through July. The mean SCL of 63.2 cm ($n = 8$) is well within the range of that for mature nesters (Márquez-M 1994, Musick 2002), while their average clutch size of 99 ($n = 17$) was also typical of this species' egg production (TEWG 2000, Rostal 2005). UTC nesting activity, like that recorded elsewhere for the species, occurred during daylight hours and most frequently under relatively high wind conditions. Average hatch success of UTC ridley nests incubated at PINS during 2005-2006 (69%) was similar to statewide values during those years (72% and 77%, Shaver 2007) and to those recorded historically in Mexico (1978-2005: $\bar{x} \pm 1$ SD = 66 ± 7%, USFWS et al. 2006). Five nests, including four from three different headstarted females and one of unknown origin, had hatch success values less than 30%, which could have been due to a variety of factors, including size and age of the nesters, as well as handling, packing, and transport techniques. The lowest value (0%) was recorded for a nest discovered at 0800, whose eggs may have been deposited the day before and therefore more susceptible to damage from handling and transport. Annual egg-packing trainings are now conducted by the NOAA STF for UTC personnel permitted to excavate nests. These trainings, along with increased public education and patrolling efforts aimed at finding nests close to the time of oviposition, should minimize the negative effects of egg handling by researchers.

Preferred UTC ridley nesting habitat was in or near dunes in armored and unarmored regions, and some individuals nested at the base of human structures in areas with little to no dune. Nesting near such structures and in areas of high human activity deviates from nesting behavior along the protected beaches of PINS and remote shores of Rancho Nuevo, and exposes both nesting females and their clutches to a variety of anthropogenic risks. As noted previously, beachgoers moved one nester off a Bermuda Beach road in 2006, and two 2005 nest sites along the Galveston Seawall were located in areas where *Sargassum* and sand were dumped by Galveston Parks Board personnel during beach raking activities in June 2005 (pers. obs.). Other potential risks to nesters, nests, and hatchlings along the UTC include, but are not limited to, beach driving, erosion and associated high tides, coastal development, dune fencing, beach renourishment, and fire ants. Efforts should be made to better understand such risks and minimize negative effects of ongoing activities, including new development and coastal armoring along Galveston Island and the Bolivar Peninsula, on nests and nesting turtles. Education of local government officials, coastal residents, and visitors should aid in these undertakings.

The UTC holds unknown potential as ridley nesting habitat. The number of nests documented in the region is likely a conservative number, given a lack of standardized nesting patrols and outreach required to educate the public to report nesting activity. These inadequacies are supported by abnormally long inter-nesting intervals observed for SSD127 and RRV231, as well as research suggesting most Kemp's ridleys nest three times per season (Rostal 2005). As such, the 8 individual females examined on the UTC during 2005-2006 may have laid as many as 24 nests, whereas only 17 were located. Statewide, females are intercepted at less than half of documented nest sites (Shaver 2005), so additional individuals and their respective nests may have been missed entirely. Anecdotal reports of previously undocumented UTC nests made to the author and NOAA STF personnel during 2005-2006, as well as *in situ* incubation of a nest discovered hatching along the Galveston Seawall in 2007 (Shaver 2008), also suggest that some nests go undetected on the UTC. In 2007, the TAMUG STFERL and local non-governmental organization HEART undertook efforts to establish systematic patrols on Galveston Island (Landry & Hughes 2008) and to increase public education efforts on the UTC, respectively. These efforts will be expanded to other regions (A. Landry pers. comm.), allowing researchers to more accurately quantify UTC nesting activity and managers to better assess current sea turtle nesting management practices in the region. Efforts to fully understand the role of the UTC in Kemp's ridley ecology and recovery should continue, and education of the beach-going public will be pivotal in terms of reporting nesting and minimizing negative anthropogenic interactions. Potential management implications of UTC nesting activity and associated tracking will be discussed further in Chapter IV.

CHAPTER IV

MOVEMENTS OF KEMP'S RIDLEY SEA TURTLES NESTING ON THE UPPER TEXAS COAST: IMPLICATIONS FOR MANAGEMENT*

INTRODUCTION

The Kemp's ridley sea turtle *Lepidochelys kempii* is listed as critically endangered by the World Conservation Union and as endangered under the US Endangered Species Act (IUCN 2006, 50 US Code of Federal Regulations [CFR] 17.11). No nesting sites were known for the species until 1961, when Henry Hildebrand discovered a 1947 film depicting a daytime nesting aggregation (*arribada*) of an estimated 10 000 to 40 000 females at Rancho Nuevo, Tamaulipas, Mexico (Carr 1963, Hildebrand 1963). By 1965, the largest *arribada*s at Rancho Nuevo numbered less than 5000 ridleys (Pritchard 1997), and conservation efforts were initiated by the Mexican National Fisheries Institute (INP) in 1966 (Márquez et al. 2005). The US Fish and Wildlife Service (USFWS) and the Mexican INP began a bi-national research and protection program for Kemp's ridleys at Rancho Nuevo in 1978 (Márquez et al. 2005, Heppell et al. 2007). Exponential nesting increases of 12 to 19% yr–1 have been observed at Rancho Nuevo since 1985, likely due to egg protection and integration of turtle excluder devices (TEDs) into the US and Mexican shrimp fisheries (Lewison et al. 2003, Heppell et al. 2007).

Bi-national conservation initiatives at Rancho Nuevo were supplemented by efforts to establish a Kemp's ridley nesting colony at Padre Island National Seashore (PINS) in Texas, USA (Fig. 4.1) and development of an experimental headstart program at the US National Marine Fisheries Service (NMFS, now the National Oceanic and Atmospheric Administration [NOAA] Fisheries Service) Galveston Laboratory (Klima

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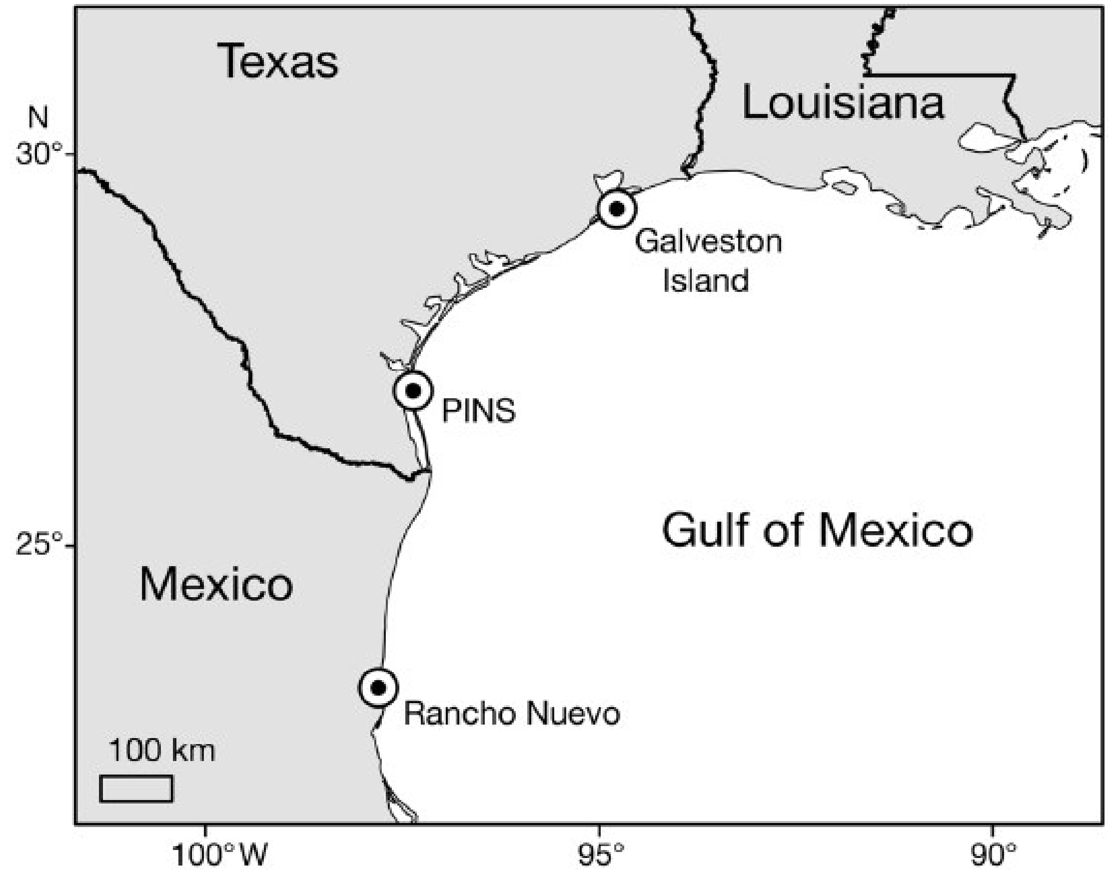

Fig. 4.1. Western Gulf of Mexico showing the locations of Rancho Nuevo, Tampaulipas, Mexico, Padre Island National Seashore (PINS), and Galveston Island, Texas, USA.

& McVey 1982, Fontaine & Shaver 2005). From 1978 to 2000, 27 137 Kemp's ridley hatchlings were transferred to the NMFS Galveston Laboratory from PINS (PINS-imprinted) or directly from Rancho Nuevo (Mexico-imprinted) for captive-rearing (Fontaine & Shaver 2005, Shaver 2005). The majority of these hatchlings were raised in captivity (i.e. 'headstarted') for 9 to 10 mo, with 23 987 conspecifics subsequently tagged and released into the Gulf of Mexico primarily off PINS and Galveston from 1979 to 2003 (Shaver 2005, Shaver & Wibbels 2007, B. Higgins pers. comm.).

Historical accounts compiled by Hildebrand (1963), Shaver & Caillouet (1998), and Burchfield (2005) indicate that limited Kemp's ridley nesting was documented along North Padre Island, Texas as early as 1948. This activity grew from 1 to 2 nests annually prior to 1995 (Shaver & Caillouet 1998) to a record of 102 documented along the Texas coast in 2006 (D. Shaver pers. comm.). Although most ridley nesting in Texas occurs at PINS, 26 nests documented along the upper Texas coast in Brazoria and Galveston Counties from 2002 to 2006 (Shaver et al. 2005a, Shaver & Wibbels 2007, NOAA Fisheries Sea Turtle Facility [NOAA STF] unpubl. data courtesy of S. Kethan) suggest a reestablishment or northern expansion of the species' nesting range. Nine females that nested on the upper Texas coast from 2002 to 2006 were Mexico-imprinted headstarts from the 1989, 1991, and 1992 year-classes, whereas 3 others were wild (non-headstart) females that lacked both tags and tag scars (Shaver et al. 2005a, Shaver & Wibbels 2007, NOAA STF unpubl. data courtesy of S. Kethan). These data suggest 'natural' Kemp's ridley nesting on the upper Texas coast, in addition to that by Mexico-imprinted headstarts.

The written history of Galveston Island is largely devoid of specific references to sea turtles on land (cf. sea turtles *landed*, but not necessarily *caught* in the area); however, there are 2 specific accounts that, when combined with current knowledge of Kemp's ridley nesting behavior, suggest that recent nesting on the upper Texas coast represents a reestablishment of the species' historical nesting range. Evidence that the upper Texas coast was a historical nesting site is inherent in Burchfield's (2005) suggestion that an account describing 'clusters of mammoth turtles' on a Galveston

Island beach during April or May 1851 (Vielé 1858) refers to nesting Kemp's ridleys. Likewise, *The Galveston News* reported that approximately a dozen sea turtles were encountered on the beach at 41st Street on Galveston Island on 14 May 1880. Although the newspaper mentions that 'those [sea turtles] usually found in the bay are called loggerheads' (Anonymous 1880), it should be noted that the Kemp's ridley was not formally described as a species until 1880, and as late as the 1970s, ridleys were often sold and reported as loggerhead *Caretta caretta* meat (Rebel 1974). Even today, the 2 species are often confused by the public, and Kemp's ridleys are also occasionally misidentified as green turtles *Chelonia mydas* due to their 'greenish' coloration (E. E. Seney pers. obs.). The timing of the 1851 and 1880 accounts suggests Kemp's ridley nesting activity, given that the species often nests during daylight hours, and in April and May, whereas both loggerhead and green turtles typically nest in Texas later in the year and at night (Burchfield 2005, D. Shaver pers. comm.).

The current criteria for downlisting the Kemp's ridley from 'endangered' to 'threatened' under the US Endangered Species Act include attaining 'a population of at least 10 000 females nesting in a season' (USFWS & NMFS 1992). The aforementioned nesting trends, in conjunction with recent reductions in shrimping effort in the Gulf of Mexico (LGL Ecological Research Associates 2007) and declines in Texas ridley strandings (Lewison et al. 2003), are indications that this species' recovery is underway. Reaching the goal of 10 000 females (USFWS & NMFS 1992) will require continued management and enforcement efforts, assessing and reducing fishery impacts, evaluation of nearshore time/area fishery closures, and increased efforts to understand the species' ecology and survival (Lewison et al. 2003, Heppell et al. 2007). Additionally, Caillouet (2005, 2006) recommends that ongoing revisions to the Kemp's Ridley Recovery Plan (USFWS & NMFS 1992) reevaluate the 10 000-nest benchmark, designate 'Texas beaches as known nesting habitats,' and provide increased protection for all ridley life stages on Texas beaches and in state waters.

Extensive urbanization, development, and tourism along the upper Texas coast, particularly in Galveston County, present additional obstacles that nesting ridleys do not typically encounter at PINS and other protected beaches. Upper Texas coast nesting has occurred near densely populated areas and on beaches subject to vehicular traffic, raking, coastal armoring, and artificial nourishment. Anticipated growth in ridley nesting activity and concurrent use of beaches by humans will likely translate into ecotourism opportunities (Campbell 2003), as well as a vast array of resource management concerns. Characterizing nesting activity and use of Texas coastal waters by ridleys during the nesting season is essential to identifying and resolving conflicts between these activities and those of the beach-going public, in addition to exploring new ecotourism opportunities.

MATERIALS AND METHODS

Satellite telemetry. Six Kemp's ridleys were selected for tracking after nesting on the upper Texas coast (Galveston and Brazoria Counties) during May 2005 and from April to May 2006. Individuals tracked during 2005 were fitted with Telonics ST-10 (n = 2) or ST-20 (n = 1) platform terminal transmitters (PTTs), and those tracked during 2006 were fitted with Sirtrack KiwiSat 101 (n = 2) or KiwiSat 202 (n = 1) PTTs. Prior to transmitter application, each turtle's anterior carapace scutes were sanded and cleaned with acetone. The 2005 PTTs were attached to the carapace with PowerFast two-part marine epoxy. A layer of PowerFast covered by SonicWeld steel-reinforced epoxy putty (Mansfield & Musick 2004) was used to attach the 2006 units, which were sprayed with a clear antifouling paint (Tempo Marine) prior to attachment. Additionally, two coats of a brush-on antifouling paint (Interlux Micron Extra with 'Biolux') were applied to the non-metal surfaces of the transmitters and cured adhesives in 2006. Each tracked ridley was ultrasounded by J. Flanagan, Doctor of Veterinary Medicine at the Houston Zoo, and released within 24 h of egg deposition near her initial nesting site.

The Telonics ST-10 and ST-20 and Sirtrack KiwiSat 101 PTTs were set to a duty cycle of 6 h on:6 h off, whereas the KiwiSat 202 unit had a duty cycle of 6 h on:18 h off. Messages received from satellites were processed by CLS America (formerly Service Argos) to give Doppler-derived locations and classified based on the number of

messages used in processing. Location classes (LC) 3, 2, 1, and 0 were derived from at least 4 messages and had estimated accuracies of <150 m, <350 m, <1000 m, and >1000 m, respectively. The other classes (A, B, Z) did not yield estimates of accuracy.
LC A and LC B were calculated from 3 and 2 messages, respectively, whereas LC Z 'indicate[d] that the location process failed' (CLS America 2007, www.clsamerica.com/ argos-system/faq.html). Studies using fixed transmitters (Hays et al. 2001) and units attached to captive gray seals *Halichoerus grypus* (Vincent et al. 2002) have indicated that LC A locations are of similar accuracy to LC 1 and that both LC A and LC B can provide useful information after appropriate filtering.

Data filtering and analysis. Location data were filtered using criteria similar to those utilized in prior studies on adult female olive ridleys *Lepidochelys olivacea* (Plotkin 1998) and adult male Kemp's ridleys (Shaver et al. 2005b). The SEATURTLE.ORG Satellite Tracking and Analysis Tool (STAT, Coyne & Godley 2005) was used to exclude locations that fell into any of the following categories: (1) LC Z, (2) locations that required straight-line swimming speeds over 6 km h–1, and (3) locations that occurred at elevations over 0.5 m. Obviously erroneous points (e.g. those that 'crisscrossed' land or large areas of water) that remained after the STAT filtering process were removed manually in ArcMap 9.1. Water depth and sea surface temperature at the accepted locations were determined by STAT (Coyne & Godley 2005) using data produced by NOAA's National Geophysical Data Center and NOAA's Geostationary Operational Environmental Satellites (GOES) sea surface temperature (SST), respectively.

Mean daily locations were generated from the accepted locations for each turtle in order to minimize autocorrelation in spatial analyses (James et al. 2005). The resulting coordinates were included in kernel density estimation (KDE) analyses across all individuals within respective nesting seasons and the 2 nesting seasons combined. Each nesting season was defined by the dates during which nesting was documented on the upper Texas coast. The Home Range Tools for ArcGIS extension (Rodgers et al. 2005) and fixed least squares cross-validation smoothing factor (*h*cv) were used for each KDE

(Worton 1995, Seaman & Powell 1996), whereas the 50% probability contour was designated as 'the core area of activity' (Hooge et al. 1999). Each KDE output was clipped in ArcMap 9.1 to exclude land, followed by calculation of the in-water area (km2) within each 50% contour. The use of duty cycles necessitated examination of tracklines, rather than raw Argos data, to infer nesting events. Each filtered track was visually examined for movement patterns similar to those documented during 2 confirmed nesting events by tracked ridleys. Unconfirmed, but probable, nesting events were inferred at the end of short periods (2 to 3 d) during which the turtle moved and remained close to shore on the Gulf side of Galveston Island and after which the turtle clearly left the area. In the future, this process could be improved by deploying PTTs without a duty cycle in order to pinpoint nesting events during prolonged haulout times.

Examination of existing management scheme. In addition to examining Kemp's ridley nesting dynamics and post-nesting movements, we sought to apply these results to management of sea turtle nesting along the upper Texas coast. Applicable sea turtle and protected species legislation was identified using resources such as LexisNexis (www.lexisnexis.com), the US Government Printing Office Access website (www.gpoaccess.gov), and the Texas Administrative Code (TAC, www.sos.state.tx.us/ tac). Local sea turtle policy, protocols, and practices were compiled from personal knowledge and personal communications with pertinent officials from federal and state agencies.

RESULTS

The 6 ridleys (Table 4.1) intercepted while nesting on the upper Texas coast and subsequently tracked averaged 64.0 cm straight carapace length (SCL, SD = 2.1, n = 6). All possessed egg follicles prior to transmitter deployment (J. Flanagan unpubl. data), implying that they were likely to nest again during their respective nesting seasons; however, the last turtle tracked in 2006 (RRV233) exhibited much less dense follicles

Table 4.1 *Lepidochelys kempii.* Nesting and tracking details for 6 Kemp's ridley sea turtles from the upper Texas coast, 2005–2006. Turtle type details in parentheses: HS, headstart (including year); W, wild; SCL, straight carapace length (from notch to tip); PTT, platform terminal transmitter manufacturer and type; No. accepted locations, locations remaining after filtering raw Argos data.

Turtle ID (type)	SCL (cm)	Initial nesting location	PTT	Date of deployment	No. of days tracked	No. accepted locations	Confirmed nesting date(s)	Inferred nesting date(s)
SSD127 (1992 HS)	65.8	Galveston Is.	Telonics ST-10	17 May 2005	44	27	16 May 2005 20 June 2005	4 June 2005
RRV251 (W)	62.5	Galveston Is.	Telonics ST-10	29 May 2005	20[a]	8	29 May 2005	None
RRV253 (1992 HS)	63.0	Galveston Is.	Telonics ST-20	31 May 2005	50	93	30 May 2005	13 June 2005 26 June 2005
RRV231 (W)	67.2	Galveston Is.	Sirtrack KS101	28 Apr 2006	146	170	28 April 2006	19 May 2006 14 June 2006[b]
RRV315 (1989 HS)	61.5	Galveston Is.	Sirtrack KS101	7 May 2006	87	197	6 May 2006 26 May 2006	10 June 2006
RRV233 (W)	63.8	Surfside	Sirtrack KS202	27 May 2006	132	190	27 May 2006	None

[a] Turtle stranded dead on Galveston Island

[b] Beach visitor saw turtle with transmitter returning to water at nest site

than did the other five nesters (J. Flanagan unpubl. data), suggesting she might not nest again.

The average track duration (Table 4.1) of 80 d (SD = 51, n = 6) included that from a 2005 nester (RRV251) that stranded dead; excluding this track increased average track duration to 92 d (SD = 47, n = 5). The stranded turtle, which was reported and examined within a few hours of death, exhibited no external abnormalities other than 4 areas of exposed bone on the plastron and moderate barnacle coverage on the PTT. A necropsy of RRV251 revealed signs of both trauma and drowning, including hemorrhaging in both pectoral muscles and fluid and clotted blood in the lungs (J. Flanagan & E. Seney unpubl. data), whereas a histological examination by the Texas Veterinary Medical Diagnostic Laboratory identified parasitic ova in some tissues (P. Varner unpubl. data). There were no indications that the PTT had any impact on this turtle's health, and none of the Argos data or tracks suggested that any of the other females were dead or debilitated at the time transmissions ceased. Barnacle growth seen on the stranded ridley's PTT and on that of SSD127 at her second documented nesting event suggested that fouling of the saltwater switches may have been a cause of transmission loss in 2005. Antifouling paints were incorporated into the attachment protocol in 2006, likely contributing to the increase in average track duration (mean, *x*– ± 1 SD = 122 ± 32 d, n = 3). Additionally, the antenna on SSD127's PTT was bent nearly parallel to the turtle's carapace when she renested, suggesting antenna loss as another possible cause of transmission loss for both years.

Inter-nesting habitat. SSD127 and RRV315 were confirmed renesting via visual observations 35 and 20 d, respectively, after initial nesting encounters, whereas satellite tracks of these females and 2 other individuals (RRV253, RRV231) indicated they nested again in the Galveston area (Fig. 4.2, Table 4.1). Based on documented nesting events and satellite tracks, it was estimated that each of these 4 ridleys nested on the upper Texas coast a total of 3 times, at 2 to 3 wk intervals (Table 4.1). RRV251 stranded dead 20 d after her first nesting encounter, and no shelled eggs were found

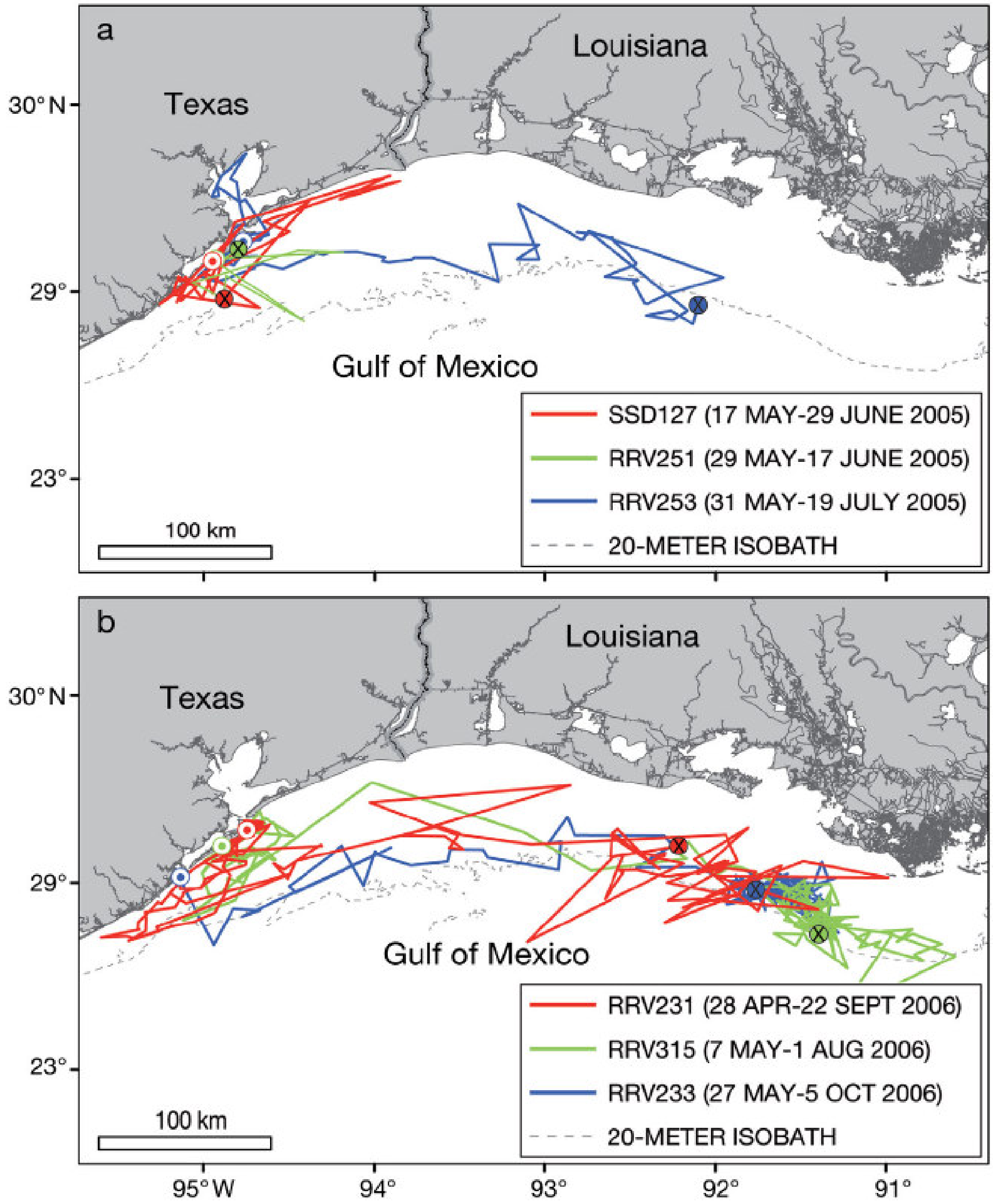

Fig. 4.2. *Lepidochelys kempii.* Filtered tracks for 6 Kemp's ridley sea turtles encountered nesting on the upper Texas coast during (a) 2005 and (b) 2006. ⊙ : start; ⊗ : end point of each track.

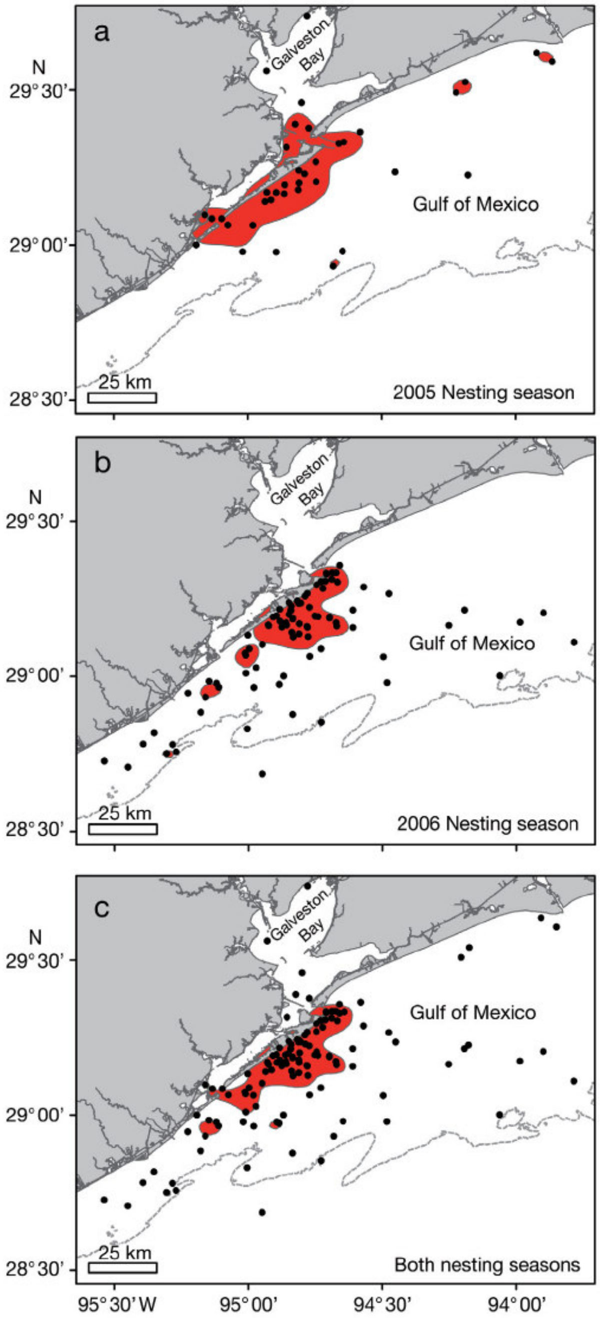

Fig. 4.3. Fig. 3. *Lepidochelys kempii.* Mean daily locations (●) for each turtle and core areas of activity (50% kernel contours, red shaded areas) during the (a) 2005 (n = 37, $h_{cv} = 0.193$), (b) 2006 (n = 87, $h_{cv} = 0.148$), and (c) combined 2005-2006 (n = 124, $h_{cv} = 0.133$) upper Texas coast Kemp's ridley nesting seasons, where (h_{cv}) is the fixed least squares cross-validation smoothing factor. The 50% kernel contours encompass 1017 km^2, 622 km^2, and 716 km^2 of in-water area in (a), (b) and (c), respectively. Dashed lines: 20 m isobath.

during the necropsy, suggesting she may have nested again prior to stranding. The last female tracked (RRV233) exhibited fewer follicles at the time of ultrasound and immediately left the upper Texas coast after PTT deployment, indicating she had completed her nesting cycle. Given that Kemp's ridleys typically lay 2 to 3 nests per year (TEWG 2000, Rostal 2005), it is likely that RRV233 nested undetected earlier in the 2006 season. Core areas of activity (50% kernel contours) for the 2005 nesting season (16 May to 20 June), 2006 nesting season (28 April to 14 June), and both nesting seasons combined centered on Galveston Island (Fig. 4.3). Approximately 80% of the accepted locations during the 2 nesting seasons occurred in waters less than 10 m deep. During these time periods, GOES SST data were available for 221 of the filtered locations, and the 6 ridleys occupied waters at 24.5 to 30.7° C SST ($\bar{x} \pm 1$ SD = 27.0 ± 1.7°C) during their respective nesting seasons.

Migration and foraging habitat. Of the post-nesting ridleys, 4 were tracked beyond the May to June 2005 (RRV253) and April to June 2006 (RRV231, RRV315, RRV233) nesting seasons (Fig. 4.2). These turtles migrated along the Texas and Louisiana continental shelf, predominantly in waters less than 20 m deep. All four established foraging sites offshore of the central Louisiana coast (Vermilion, Iberia, St. Mary, and Terrebonne Parishes), and remained in waters 10 to 30 m deep throughout the duration of their tracks. SST values recorded after the nesting season were 27.7 to 31.6°C ($\bar{x} \pm 1$ SD = 29.8 ± 0.8°C, n = 394); however, departure of these females from the Galveston area did not correlate with any temperature changes.

Nesting management on the upper Texas coast. Examination of ridley nesting management on the upper Texas coast required consideration of stakeholders ranging from international to federal, state, and local entities to non-governmental organizations (NGOs), members of the public, and the turtles themselves. The primary stakeholders identified for upper Texas coast ridley nesting are listed in Table 4.2 and further described in the following.

Table 4.2. Primary stakeholders for Kemp's ridley nesting on the upper Texas coast.

Stakeholder	Role/interest
International	
Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC)	Ratified by 12 nations (in force May 2001)[a]
Mexico	Primary nesting ground located in Tamaulipas.[b] IAC party[a]
United States	Secondary nesting grounds along Texas coast.[c] IAC party[a]
Federal	
National Park Service	Oversees National Seashore system.[d] (Includes Padre Island National Seashore's nesting response and monitoring, research, and management of Texas nesting data per agreement with USFWS)
NOAA Fisheries Service	Jurisdiction over sea turtles in the water.[e] (Includes upper Texas coast nesting response by NOAA Fisheries Galveston per agreement with USFWS)
US Army Corps of Engineers	Beach renourishment and channel dredging[f]
US Fish & Wildlife Service	Jurisdiction over sea turtles on land.[g] Oversees National Wildlife Refuge system[h] (Texas Point, McFaddin, San Bernard, Aransas, and Laguna Atascosa National Wildlife Refuges are located on the Texas gulf coast). Local USFWS offices defer to PINS for state nesting program managment and to NOAA Fisheries Galveston for upper Texas coast nesting response[i]
State of Texas	
Texas General Land Office	Jurisdiction over beach projects and dune related activities in Texas[j]
Texas Parks and Wildlife Department	Jurisdiction over protected species and fisheries in Texas. Oversees Texas state park system (Sea Rim, Galveston Island, and Mustang Island State Parks are located on the Texas gulf coast)[k]
Texas A&M University System	Sea turtle research and upper Texas coast nesting response
University of Texas System	Sea turtle research and middle Texas coast nesting response
County and local	
Brazoria County	Local government and law enforcement
Chambers County	Local government and law enforcement
Galveston County	Local government and law enforcement
Jefferson County	Local government and law enforcement
City of Galveston (Galveston County)	Local government and law enforcement
City of Jamaica Beach (Galveston County)	Local government and law enforcement
Village of Surfside (Brazoria County)	Local government and law enforcement
Texas-based non-governmental organizations	
Coastal Conservation Association (CCA) - Texas	Promotes conservation of marine species, particularly recreational gamefish (www.ccatexas.org)
Help Endangered Animals-Ridley Turtles (HEART)	Public education and fundraising (www.ridleyturtles.org)
Recreational Fishing Alliance - Texas State Chapter	Promotes conservation of marine species, particularly recreational gamefish (www.rfatexas.org)
Texas Open Beach Advocates (TOBA)	Promotes each access rights, public education and stewardship (www.texasopenbeaches.org)
Texas Shrimp Association	Represents interests of Texas shrimpers
General public	
Global community	Intrinsic and existence value of species.[l] Educational values[m]
Texas coast residents	Intrinsic and existence value of species.[l] Educational values.[m] Possible interactions with nesting turtles/nests/hatchlings[n]
Texas coast businesses	Possible interactions with nesting turtles/nests/hatchlings.[n] Possibility for ecotourism[m]
Texas coast visitors	Possible interactions with nesting turtles/nests/hatchlings.[n] Educational values[m]

[a] IAC Secretariat (2004)

[b] Márquez et al. (2005)

[c] Shaver (2005)

[d] 36 CFR 1.2

[e] 50 CFR 222.23, 50 CFR 227.4

[f] 33 CFR 320.1

[g] 50 CFR 17.11

[h] 50 CFR 25.11

[i] Per memorandum of understanding

[j] 31 TAC 15, 16, 25

[k] 31 TAC 55, 57, 58, 59, 65

[l] Witherington & Frazer (2003)

[m] Campbell (2003)

[n] USFWS & NMFS (1992)

The USA and Mexico are parties to the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC Secretariat 2004), which requires they undertake appropriate measures to protect and conserve sea turtle species and their habitats. The Kemp's ridley was originally listed in the USA as an endangered species in 1970 (50 CFR 17.11, as amended 2 December 1970) and is currently protected under the US Endangered Species Act of 1973 (ESA, 7 United States Code [USC] 136, 16 USC 460 et seq.). Sea turtles fall under the jurisdictions of the USFWS (50 CFR 17.11) and NOAA Fisheries Service (50 CFR 222.23, 50 CFR 227.4), whereas Section 7 of the ESA requires other federal agencies to consult with USFWS and NOAA regarding any activities that may impact sea turtles. Measures must be taken to reduce bycatch, including sea turtles, in US fisheries under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), as overseen by the NOAA Fisheries Service (16 USC 1801 et seq.), and this requirement is also inherent in the IAC. The NOAA Fisheries Service (50 CFR 222.23, 50 CFR 227.4), USFWS (50 CFR 17.11), and US Coast Guard (50 CFR 622.41) provide federal enforcement of sea turtle regulations, and the USFWS oversees the National Wildlife Refuge System (50 CFR 25.11), which includes 5 refuges along the Texas Gulf coast.

Within Texas, USFWS currently defers to the National Park Service (NPS), specifically PINS (36 CFR 7.75), regarding protocols for collection of sea turtle nesting data, nest relocation, and incubation of eggs (D. Shaver pers. comm.). The length of the Texas coast necessitates dividing sea turtle nesting patrols, nesting response, and stranding response among multiple agencies, including NPS and various national wildlife refuges, state universities, and non-profit organizations. The NOAA STF currently conducts nesting and stranding response, data collection, and nest excavations on the upper Texas coast, per a memorandum of understanding with USFWS (C. Yeargan pers. comm.). Additionally, Texas A&M University at Galveston (TAMUG) has assisted the NOAA STF with nesting response since 2005 and will take on a larger role in 2008.

The Texas Parks and Wildlife Department (TPWD) has jurisdiction over protected species in Texas, including all federally protected species and others threatened with extinction within the state (31 TAC 65, 5 Texas Parks and Wildlife Code [TPWC] 68). TPWD also maintains the state park system and constituent beaches (31 TAC 59) and oversees commercial and recreational fishing activities in state waters, which extend 9 nautical miles offshore of the Texas coast (31 TAC 57-58, 5 TPWC 46-47, 66). In addition to permitting research and recovery activities in Texas, TPWD's primary role with regard to sea turtles is that of in-water enforcement (M. Ray pers. comm.). All shrimpers must comply with state and federal TED regulations and with shrimp fishery closures, which occur annually along the upper Texas coast from 15 May to 15 July and along the lower and middle Texas coast from 1 December to 15 July (TPWD 2006).

The Texas General Land Office (TGLO) is tasked with management of human impacts on the state's beach/dune system, including the conservation of 'flora and fauna and their habitat' and acting in accordance with federal and TPWD protected species regulations (31 TAC 15). State and federally-funded beach and dune projects that impact sea turtles are required by TGLO to have appropriate USFWS consultation, mitigation, and/or monitoring, in addition to applicable US Army Corps of Engineers (USACE) and state permits (B. Rhame pers. comm.). Locally and privately-funded beach projects are also required to obtain appropriate permits, and TGLO recommends (but does not require) that those projects with potential sea turtle impacts contact USFWS for consultation (B. Rhame pers. comm.).

Local citizens, businesses, and visitors are also stakeholders for upper Texas coast nesting issues, and their voices are often heard through local and national NGOs, increasingly in the form of lawsuits. The 1989 decision of the US District Court for the District of Columbia in *National Wildlife Federation, et al. v. Robert A. Mosbacher, U.S. Secretary of Commerce* required NMFS to reinstate suspended TED regulations and enforcement (1989 US Dist Lexis 9748). Likewise in 1995, the US District Court for Orlando, Florida held that a 'species protected under [the] ESA has standing to sue on its own right to enforce provisions of [the] ESA' in its decision of *Loggerhead Turtle et al. v. the County Council of Volusia County, Florida* (896 Fed Suppl 1170, p. 1177). Although the vitality of endangered species' legal standing has been questioned, recent lawsuits have successfully forced state and local governments to enforce the ESA (Brader 2005).

Houston, Texas-based HEART (Help Endangered Animals-Ridley Turtles) is the Gulf of Mexico office for the California-based Sea Turtle Restoration Project (STRP), and is an NGO focused primarily on public awareness, including volunteer nesting patrols, fundraising, and activism (HEART, www.savetexasseaturtles.org/). HEART is particularly vocal with regard to issues pertaining to shrimping and Kemp's ridley nesting, and both HEART and STRP were plaintiffs in a 1994 civil suit brought against NMFS (C. Allen pers. comm.) that resulted in an Emergency Response Plan detailing federal policy to ensure compliance of sea turtle regulations (NOAA 1995).

Commercial marine fisheries are also represented by NGOs, including the Texas Shrimp Association, and such organizations have a vested interest in the impact of sea turtle regulations on their industries. Likewise, recreational anglers are represented by a variety of organizations (e.g. Coastal Conservation Association, Texas and the Recreational Fishing Alliance, Texas State Chapter), and a subset of this group may include anglers who, like many Texas beachgoers, currently drive legally on beaches where sea turtle nesting has been documented. Texas Open Beach Advocates (TOBA) is a Galveston Island-based group that promotes free public access to Texas beaches, including driving, under the Texas Open Beaches Act (61 Texas Natural Resources Code 011), as well as stewardship and preservation of beaches (TOBA, www.texasopenbeaches.org/open.htm).

DISCUSSION AND CONCLUSIONS

Marine turtle satellite telemetry has grown from the experimental tracking of adult female loggerhead sea turtles during 1979 and 1980 (Stoneburner 1982, Timko & Kolz 1982) to a standard method for examining movements of 6 of the world's 7 species

(Godley et al. 2008). Satellite tracking has been utilized to document extended post-nesting movements, such as those of leatherback turtles *Dermochelys coriacea* spanning the Atlantic (James et al. 2005) and Pacific Oceans (Benson et al. 2007), as well as more localized inter-nesting movements (e.g. olive ridleys: Plotkin 1998; loggerheads: Stoneburner 1982, Godley et al. 2003; green turtles: Hays et al. 1999, Troëng et al. 2005b; and hawksbill turtles *Eretmochelys imbricata*: Troëng et al. 2005a, Whiting et al. 2006).

Use of satellite telemetry on adult Kemp's ridleys was preceded by deployment of radio transmitters on 9 post-nesting individuals at Rancho Nuevo in 1980. These females exhibited random movement in the vicinity of the nesting beach for up to 2 d and subsequently displayed longshore movements of at least 10 km (Mendonça & Pritchard 1986). Fourteen postnesting females satellite tracked from Rancho Nuevo in 1987 and 1988 remained in coastal waters less than 50 m in depth (R. Byles unpubl. data). Individual adult females tracked by Renaud et al. (1996) and Gitschlag (1996) exhibited longshore migrations, with the individual observed by the former being tracked from foraging grounds in Louisiana to Rancho Nuevo, where she was documented nesting.

Implications of telemetry results. Satellite tracks for Kemp's ridleys nesting on the upper Texas coast in 2005 and 2006 provided evidence that this region holds unknown potential as nesting habitat. Although these data and tracks were based on a limited sample of ridleys from the Galveston area, the number of nesters on the upper Texas coast is annually increasing in a fashion similar to that at PINS (Shaver & Rubio 2008), where most of the state's nesting activity has occurred historically (Shaver & Caillouet 1998). Additionally, the number of nests documented on the upper Texas coast from 2002 to 2006 is likely a conservative number, given the lack of standardized nesting patrols and outreach required to educate the beach-going public to report nesting activity. These issues are currently being addressed by TAMUG and HEART, and standardized nesting patrols, volunteer patrols, and increased public outreach occurred during 2007.

Nesting activity and inter-nesting movements summarized above in ‘Results’ suggest that upper Texas coast beaches provide nesting habitat to both headstarted and ‘wild’ Kemp’s ridleys that spend their inter-nesting intervals in waters adjacent to these beaches from approximately April to June. Satellite telemetry data, along with ultrasound detection of developing follicles, also suggest each of these females nested more than once on upper Texas coast beaches. Although tracks were of limited duration, core activity areas generated from filtered data indicate relatively restricted, nearshore movement among nesters during the inter-nesting period. This restricted movement implies a strong fidelity to the upper Texas coast that is supported by the confirmed renestings by SSD127 and RRV315 on Galveston Island. Similar fidelity has been exhibited by other female ridleys along PINS during the nesting season (Shaver & Rubio 2008). The postreproductive migrations by 4 upper Texas coast nesters along the Texas and Louisiana continental shelf also mirrored movements of many females tracked from PINS (Shaver & Rubio 2008) and 4 tracked from Galveston in 2007 (A. Landry & C. Hughes unpubl. data). Likewise, immature ridleys tracked from seasonal foraging grounds along the northwestern Gulf of Mexico (Renaud & Williams 2005), the Florida Gulf coast (Schmid & Witzell 2006), and New York (Morreale & Standora 2005) utilized nearshore waters for both foraging and migration.

Documentation of nesting activity on the upper Texas coast also provided evidence that Kemp’s ridleys nest along the upper Texas coast and establish fidelity to constituent habitats during some or all phases of the nesting season. This nesting activity, like that seen in preliminary trends in south Texas (Shaver & Caillouet 1998), is likely to increase with this species’ ongoing recovery. This increase will result in more mature females utilizing upper Texas coast waters and beaches where they lack the levels of protection currently afforded them along the middle and lower coast, including the extended nearshore shrimp closure and protected beaches along PINS. The need for mitigation measures, such as regulations affording increased protection to sea turtles along upper Texas beaches and coastal waters, should be examined and considered by state and federal managers in order to reduce threats to the increasing number of nesting Kemp’s ridleys in the region and their progeny. Such measures will help to (1) ensure the realization of any latent nesting potential along the upper Texas coast, (2) increase researchers’ and regulatory personnel’s ability to assess this nesting activity and the importance of constituent beaches to ridley recovery, (3) develop management strategies that incorporate upper Texas coast beaches and adjacent waters, (4) maintain and enhance the integrity of nesting habitat and adjacent waters, and (5) increase the potential for educational outreach and responsible ecotourism on upper Texas coast beaches.

Nesting management on the upper Texas coast. The likelihood of increased Kemp’s ridley nesting and associated human interactions on the upper Texas coast warrants a proactive and coordinated management approach in order to comply with the ESA and Kemp’s Ridley Recovery Plan, avoid civil lawsuits, and enhance opportunities for nature-based educational outreach and tourism. Nesting response and documentation on the upper Texas coast should continue within the framework of the statewide program overseen by PINS; however, a highly developed coastal zone and involvement of multiple agencies and municipalities necessitate a more complex management approach than that taken along the protected beaches of south Texas. The USFWS has primary jurisdiction over sea turtle nesting, and as such, the agency has a responsibility to spearhead integrated ridley nesting management efforts on the upper Texas coast or to designate a surrogate agency to do so. The PINS program, along with requirements set forth by the ESA, Kemp’s Ridley Recovery Plan, and various federal and state regulations, provide substantial framework for nesting management on the upper Texas coast. Guidance applicable to urban areas may be gleaned from international documents such as the Rio Declaration on the Environment and Development (United Nations 1992) and the International Chamber of Commerce (ICC) Business Charter for Sustainable Development (ICC 1991), including use of a precautionary, rather than reactionary, approach.

An examination of sea turtle policies and practices within the state of Florida may provide a further framework for TPWD and TGLO to minimize sea turtle–human interactions on Texas nesting beaches, particularly in urban areas along the upper Texas coast. Florida's Marine Turtle Protection Act (Florida Statute 370.12) outlines general guidelines for the state, and specific issues are further outlined in the Florida Administrative Code (FAC). The state has developed a model lighting ordinance for marine turtle protection to guide local governments in creating their own ordinances (62B FAC 55). Additionally, the Florida Fish and Wildlife Conservation Commission (FWC) provides guidelines for minimizing effects of lighting, beach furniture, mechanical beach cleaning, and coastal armoring on sea turtles (FWC 2002). Florida's Bureau of Beaches and Coastal Systems must ensure that beach construction activities 'will not cause a significant adverse impact to marine turtles,' and that measures are taken to protect turtles and their habitat, which may include limitations on the nature and timing of permitted activities (62B FAC 33).

Effective management of sea turtle nesting and human interactions along developed beaches of the upper Texas coast requires cooperation by local governments with state and federal agencies involved in sea turtle nesting response and management. South Padre Island, Texas, which is comprised primarily of developed beaches, may present an appropriate sea turtle nesting 'model' for developed areas of the upper Texas coast in Galveston and Brazoria Counties. In contrast, the majority of beaches along Chambers and Jefferson Counties are contained within the McFaddin National Wildlife Refuge (MNWR), Sea Rim State Park (SRSP), and Texas Point National Wildlife Refuge (TPNWR), warranting a management scheme similar to that at PINS and other protected beaches. Nesting has not been documented in the 2 uppermost Texas counties, but these beaches are not currently patrolled for sea turtles aside from a weekly stranding survey conducted by the NOAA STF. Wide beaches appropriate for ridley nesting exist along the eastern portion of MNWR and within SRSP and TPNWR (E. E. Seney pers. obs.), and structured patrols by USFWS and TPWD are necessary to determine whether nesting occurs and to dictate the need for management schemes and increased public education in these areas. Alternatively, funds to monitor potential, as well as known, nesting beaches may be available through competitive conservation grants under Section 6 of the ESA, as administered by TWPD and USFWS.

Concluding remarks. Use of satellite telemetry has confirmed that beaches and nearshore waters of the upper Texas coast are nesting and inter-nesting habitats for the Kemp's ridley sea turtle. Current management schemes, however, limit researchers' abilities to fully assess sea turtle nesting in the region, and limited protection measures are in force to control and minimize interactions between nesting ridleys and human development, beach use, and in-water activities. Effective protection and management of nesting ridleys requires stakeholder involvement and ultimately coordinated efforts by federal, state, and local agencies. Such a scheme will not only facilitate the recovery of an endangered species, but should minimize liability of involved parties and may facilitate ecotourism.

CHAPTER V

MOVEMENTS OF KEMP'S RIDLEY SEA TURTLES IN THE NORTHWESTERN GULF OF MEXICO

INTRODUCTION

Although monitoring of sea turtle nesting beaches is crucial to estimation of population size and reproductive activity, at-sea life history data are essential for understanding population dynamics of all life stages, as well as implementing and evaluating management strategies. The Kemp's Ridley Recovery Plan (USFWS & NMFS 1992) identifies the 'seasonal use of nearshore habitat by juveniles/subadults' and determining 'migratory paths and foraging areas' of the Kemp's ridley as necessary components of a strategy to achieve this species' recovery, but such data are currently sparse. Scientists, resource managers, and environmentalists attending 2004 and 2006 stakeholders meetings to outline possible recovery plan revisions listed collection of in-water data as a priority (E. Possardt unpubl. reports), and a recent five-year review of the species' status also highlighted these informational gaps (NMFS & USFWS 2007).

Entanglement net surveys conducted during 1992-2002 along the Texas and Louisiana coasts indicated that immature Kemp's ridleys (20-55 cm SCL) occupied nearshore waters of the northwestern Gulf during March-October, displaying site fidelity to tidal passes and adjacent beachfront waters (Landry & Costa 1999, Metz 2004, Landry et al. 2005). Sabine Pass, Texas, and Calcasieu Pass, Louisiana, were identified as Kemp's ridley index habitats where all post-pelagic life stages occurred seasonally (Landry & Costa 1999). Movements of ridleys captured at Bolivar Roads (Texas), Sabine, and Calcasieu Passes and subsequently satellite, sonic, and/or radio-tracked (Renuad & Williams 2005) reinforced fidelity trends observed in the netting surveys. Sixty of 78 tracked juveniles (<50 cm SCL) remained within 15 km of their release site during May-September, whereas the other 18 moved 20-80 km, with migration occurring between Sabine and Calcasieu Passes and between Calcasieu and Mermentau (Louisiana) Passes. Larger conspecifics (>50 cm SCL, n = 10) never remained within 5 km of their release sites for more than 5 d, and their movements spanned coastal waters from Tamaulipas, Mexico, to Florida (Renaud & Williams 2005). Ridleys tracked in the northern Gulf of Mexico during fall and winter months moved offshore and/or south in response to seasonal decreases in water temperature (Renaud & Williams 2005, Schmid & Witzell 2006).

Movements of female ridleys intercepted nesting at Rancho Nuevo, Tamaulipas, Mexico (Mendonça & Pritchard 1986, Byles 1988) and in south Texas (Shaver & Rubio 2008) have also been examined via telemetry. Nine post-nesting females radio-tracked from Rancho Nuevo during 1980 exhibited random movement near the nesting beach for up to 2 d and subsequently displayed longshore movements of at least 10 km (Mendonça & Pritchard 1986). Five of these individuals returned to waters off Rancho Nuevo after absences of 13−15 d, and at least two of these nested more than once. Satellite transmitters were deployed on 18 post-nesting females at Rancho Nuevo during 1987 and 1988, and 14 transmitted data (Byles 1988). Four females traveled north, seven went south and southwest, and the three tracks with the shortest duration ended in the vicinity of Rancho Nuevo. Data received from these early satellite transmitter designs characterized general movements, but did not allow for identification of individual nesting events. More recent research has utilized satellite tracks to estimate approximate date and location of subsequent nesting events (Shaver & Rubio 2008, also see Chapter IV). During 1997-2006, 36 satellite transmitters were deployed on 17 wild and 11 headstarted females intercepted nesting at PINS or on Mustang Island, Texas (Shaver & Rubio 2008). Most of these females migrated along the Texas coast into Louisiana waters after the nesting season, with some traveling as far as the Florida Keys. Two headstarted females, however, remained offshore of PINS, and five wild ridleys briefly entered Mexican waters prior to moving northward along the Texas coast.

OBJECTIVES

Characterization of the Kemp's ridley's use of the northwestern Gulf of Mexico is crucial to the species' management, given that the region provides developmental foraging grounds (Landry & Costa 1999, Landry et al. 2005) and predictive models suggest lowering mortality of immature individuals is essential to continued recovery (TEWG 2000, Heppell et al. 2007). Likewise, increased use of the upper Texas coast as nesting habitat warrants examination of the movements of adult females. As such, the following research objectives were identified:

(1) Characterize movements of benthic-stage Kemp's ridleys in the northwestern Gulf of Mexico.
(2) Identify Kemp's ridley foraging grounds in the northwestern Gulf of Mexico.

MATERIALS AND METHODS

Twenty-two benthic-stage Kemp's ridleys, including recreational hook-and-line captures, post-nesting females, dredge relocation trawl captures, and rehabilitated strandings, were satellite-tracked in the northwestern Gulf of Mexico during 2004-2007. Hooked and stranded individuals received appropriate treatment at the Houston Zoo and NOAA STF, and each was cleared by Houston Zoo veterinary staff prior to transmitter application.

All ridleys were outfitted with back-pack style PTTs, including 1 Wildlife Computers SPOT4, 2 Telonics ST-10s, 2 Telonics ST-20s, 15 Sirtrack KiwiSat 202s, and 2 Sirtrack KiwiSat 101s. In all cases, the transmitter weighed less than 3% of the turtle's weight in air and was attached along the turtle's first and second vertebral scutes. PTTs were attached to juveniles (n = 4), subadults (n = 1), and adult females (n = 3) during 2004-2005 using (Mansfield & Musick 2004), with a spray-on antifouling paint (Tempo Marine) applied to non-metal surfaces of the last three deployed in 2005. This method was modified in 2006 (n = 3 juveniles, 4 adult females) to include a layer of Sonic-Weld epoxy putty over the PowerFast epoxy (Mansfield & Musick 2004). All 2006 units were sprayed with antifouling paint prior to attachment, and two coats of brush-on antifouling paint (Interlux Micron Extra) were applied the epoxy, putty, and non-metal surfaces of the PTTs after attachment. In 2007, an experimental method incorporating 3.0 mm neoprene to accommodate growth of smaller turtles (described in

Chapter VI) was utilized for all attachments (n = 7 juveniles). PowerFast was used to adhere a neoprene mount to each turtle's carapace and the PTT to the neoprene, while antifouling protocols matched those utilized in 2006.

All juvenile ridleys (n = 14) were released from the east end of McFaddin National Wildlife Refuge near Sabine Pass, Texas, whereas nesting females (n = 6) were released in close proximity to their nest site. A trawl-caught adult female was released at Crystal Beach, Texas, and a stranded subadult was released from Jamaica Beach on Galveston Island. Daily maps of each track were available to the public online at www.seaturtle.org/tracking.

PTTs were programmed with a duty cycle of 6 hours on:18 hours off (n = 17) or 6 hours on:6 hours off (n = 5) to conserve battery life. Location messages received from satellites were processed by CLS America (see Chapter IV) and subsequently archived and filtered. SEATURTLE.ORG's STAT (Coyne & Godley 2005) was used to exclude locations that fell into any of the following categories: (1) LC Z, (2) those requiring straight-line swimming speeds over 6 km per hour, and (3) those at elevations over 0.5 m. The initial filter was modified to exclude points at elevations over 1.0 m for two tracks that entered coastal lakes (Sabine Lake and Lake Calcasieu), but the rest of the filtering protocol remained the same. Obviously erroneous points that remained after filtering were removed manually, and the remaining (accepted) locations were used to depict tracklines in ArcMap 9.1.

Mean daily locations for each turtle were generated from accepted locations in ArcMap 9.1 to minimize autocorrelation in spatial analyses (James et al. 2005). The resulting coordinates were examined for directional movement by calculating Rayleigh's Z for each turtle (Mansfield 2006) using the Animal Movements Extension for ArcView 3.2 (Hooge & Eichenlaub 2000). Home range analysis was not conducted on tracks that were directional in nature (i.e., value of Z was significant, $\alpha < 0.05$), whereas daily mean locations for each non-directional track were included in individual kernel density estimation (KDE) analyses. The Home Range Tools for ArcGIS extension (Rodgers et al. 2005) and fixed least squares cross-validation smoothing factor (h_{cv}) were used for each KDE (Worton 1995, Seaman & Powell 1996), whereas the 50% probability contour was designated as 'the core area of activity' (Hooge et al. 1999) for each turtle. The KDE outputs were clipped in ArcMap 9.1 to exclude land, followed by calculation of the in-water area (km^2) within each contour. Relationships among in-water core areas, track duration, and life history stage were examined in SPSS 11.5 using analysis of covariance (ANCOVA). Partial eta-squared (η_p^2), an estimate of effect size that incorporates statistical error (Cohen 1973), was used to determine the relative effects of ANCOVA components. Additional KDE analyses were conducted on all mean daily locations from adult females (n = 7), immature ridleys (n = 15), and all ridleys (n = 22) to generate density contours at 10%-intervals.

Water depth and sea surface temperature at all accepted locations were determined by STAT (Coyne & Godley 2005) using data produced by NOAA's National Geophysical Data Center and NOAA's Advanced Very High Resolution Radiometer (AVHRR) daily SST, respectively. The AVHRR SST was chosen in lieu of NOAA's GOES system to allow for the best SST coverage among all tracked ridleys. Depth and SST were compared between life history stages and among months and years using analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) in SPSS 11.5. Partial eta-squared (η_p^2) was used to determine the relative effects of factors and their interactions in ANOVA and MANOVA.

RESULTS

Fifteen immature ridleys averaging 36.3 cm SCL (SD = 4.7 cm) and seven adult females averaging 63.8 cm SCL (SD = 2.0 cm) were outfitted with platform terminal transmitters and released off the upper Texas coast during 2004-2007. These were comprised of: 12 recreational hook-and-line captures, 2 dredge relocation trawl captures, 2 rehabilitated strandings, and 6 nesters. Immature ridleys were tracked 11-106 d ($\bar{x} \pm 1$ SD = 46 ± 24 d) as compared to 20-277 d ($\bar{x} \pm 1$ SD = 108 ± 88 d) for adult conspecifics (Table 5.1). A substantial increase in number of high quality LC's and in message

Table 5.1. *Lepidochelys kempii*. Tracking details for 22 Kemp's ridley sea turtles from the northwestern Gulf of Mexico, 2004–2007. SCL, straight carapace length (from notch to tip); Source: HL, hook-and-line; N, nester; RT, relocation trawl; S, stranding; PTT, platform terminal transmitter manufacturer and type; No. accepted locations, locations remaining after filtering raw Argos data. 'In-water area' values exclude portions of 50% KDE contours that fell on land.

Turtle ID	SCL (cm)	Initial encounter location	Source	PTT	Date of deployment	Release location	No. of days tracked	No. of accepted locations	50% KDE in-water area (km^2)
RRV216	34.9	Bolivar Peninsula	HL	Wildlife Computers SPOT4	21-Sep-2004	McFaddin NWR	58	16	713
SSD127	65.8	Galveston Island	N	Telonics ST-10	17-May-2005	Galveston Island	44	27	1,340
RRV223	49.6	Galveston Island	S	Telonics ST-20	25-May-2005	Galveston Island	44	37	n/a (migration)
RRV251	62.5	Galveston Island	N	Telonics ST-10	29-May-2005	Galveston Island	20	8	1,929
RRV253	63.0	Galveston Island	N	Telonics ST-20	31-May-2005	Galveston Island	50	93	n/a (migration)
RRV270	30.2	Bolivar Peninsula	HL	Sirtrack KS202	25-Jul-2005	McFaddin NWR	12	24	n/a (too short)
RRV268	36.2	Bolivar Peninsula	HL	Sirtrack KS202	2-Aug-2005	McFaddin NWR	32	35	1,439
TTC857	34.4	Calcasieu Pass	RT	Sirtrack KS202	6-Sep-2005	McFaddin NWR	41	26	2,650
RRV283	33.9	Galveston Island	HL	Sirtrack KS202	17-Apr-2006	McFaddin NWR	20	34	1,151
RRV285	33.7	Galveston Island	HL	Sirtrack KS202	25-Apr-2006	McFaddin NWR	57	119	2,048
RRV231	67.2	Galveston Island	N	Sirtrack KS101	28-Apr-2006	Galveston Island	148	170	2,198
RRV315	61.5	Galveston Island	N	Sirtrack KS101	7-May-2006	Galveston Island	87	197	1,560
RRV233	63.8	Surfside	N	Sirtrack KS202	27-May-2006	Surfside	132	190	513
RRV297	34.0	Galveston Island	S	Sirtrack KS202	31-Jul-2006	McFaddin NWR	42	48	240
TTN799	62.8	Sabine Pass	RT	Sirtrack KS202	16-Aug-2006	McFaddin NWR	277	202	2,324
RRV309	34.2	Galveston Island	HL	Sirtrack KS202	23-Apr-2007	McFaddin NWR	51	46	243
RRV321	41.2	Galveston Island	HL	Sirtrack KS202	23-Apr-2007	McFaddin NWR	106	67	789
RRV327	37.9	Galveston Island	HL	Sirtrack KS202	1-May-2007	McFaddin NWR	72	48	351
RRV329	34.6	Galveston Island	HL	Sirtrack KS202	15-May-2007	McFaddin NWR	50	27	192
RRV333	31.4	Galveston Island	HL	Sirtrack KS202	12-Jul-2007	McFaddin NWR	56	35	n/a (migration)
RRV335	38.3	McFaddin NWR	HL	Sirtrack KS202	12-Jul-2007	McFaddin NWR	11	5	n/a (too short)
RRV337	39.8	Galveston Island	HL	Sirtrack KS202	14-Aug-2007	McFaddin NWR	35	24	294

duration indicated that immature ridley RRV270's PTT was at the water's surface, and mortality was the probable cause of transmission cessation (Hays et al. 2003). One post-nesting female stranded dead 20 days after release (RRV251, see Chapter IV), whereas the survival of 2006 nester RRV315 was confirmed when she nested again on Galveston Island in 2008 (NOAA STF unpubl.). LC and transmission data gave no indication that any of the other 19 ridleys were dead or debilitated at the time transmissions ceased, nor have any been documented as recaptures or strandings. Potential causes of premature transmission cessation relative to expected battery life are discussed in Chapter VI.

Movements of satellite-tracked ridleys (Fig. 5.1-5.3, Appendix A) were restricted to the continental shelf from Matagorda Bay, Texas (Calhoun and Matagorda Counties), east to waters offshore of Timbalier Bay, Louisiana (Terrebonne and Lafourche Parishes). Coastal waters of the northwestern Gulf were utilized by immature ridleys as foraging areas in all years, with movements concentrated near tidal passes and fishing piers in 2004-2006 (Fig. 5.1) and near tidal passes and within bay systems in 2007 (Fig. 5.2). Females tracked during their inter-nesting intervals exhibited fidelity to the Galveston area and, upon entering the post-nesting stage, moved eastward along the continental shelf to foraging areas offshore of central Louisiana (Fig. 5.3).

Two satellite tracks (RRV270 and RRV335) were too short in duration for KDE, whereas three ridleys (RRV223, RRV253, and RRV333) exhibited statistically significant directional movement. Fifty-percent KDE contours (core activity areas) were generated for each of the remaining 17 tracks (Fig. 5.1-5.3). The in-water areas within each contour ranged from 192 to 2,650 km^2 ($\bar{x}$ ± 1 SD = 919 ± 825 km^2, n = 11) for immature ridleys and 513 to 2,324 km^2 ($\bar{x}$ ± 1 SD = 1,644 km^2 ± 668 km^2, n = 6) for adult females (Table 5.1). ANCOVA (Table 5.2) indicated that life history stage (immature vs. adult) had a significant effect on the size of core activity areas ($p = 0.034$), whereas number of days tracked did not ($p = 0.276$).

Immature ridleys were recorded in waters as deep as 60.08 m, but the majority were in shallow waters (<10 m) or above sea level in coastal lakes or bays ($\bar{x}$ ± 1 SD = 9.02 ± 13.87 m, n = 591 locations, Table 5.3, Fig. 5.4a). Female ridleys occurred at an

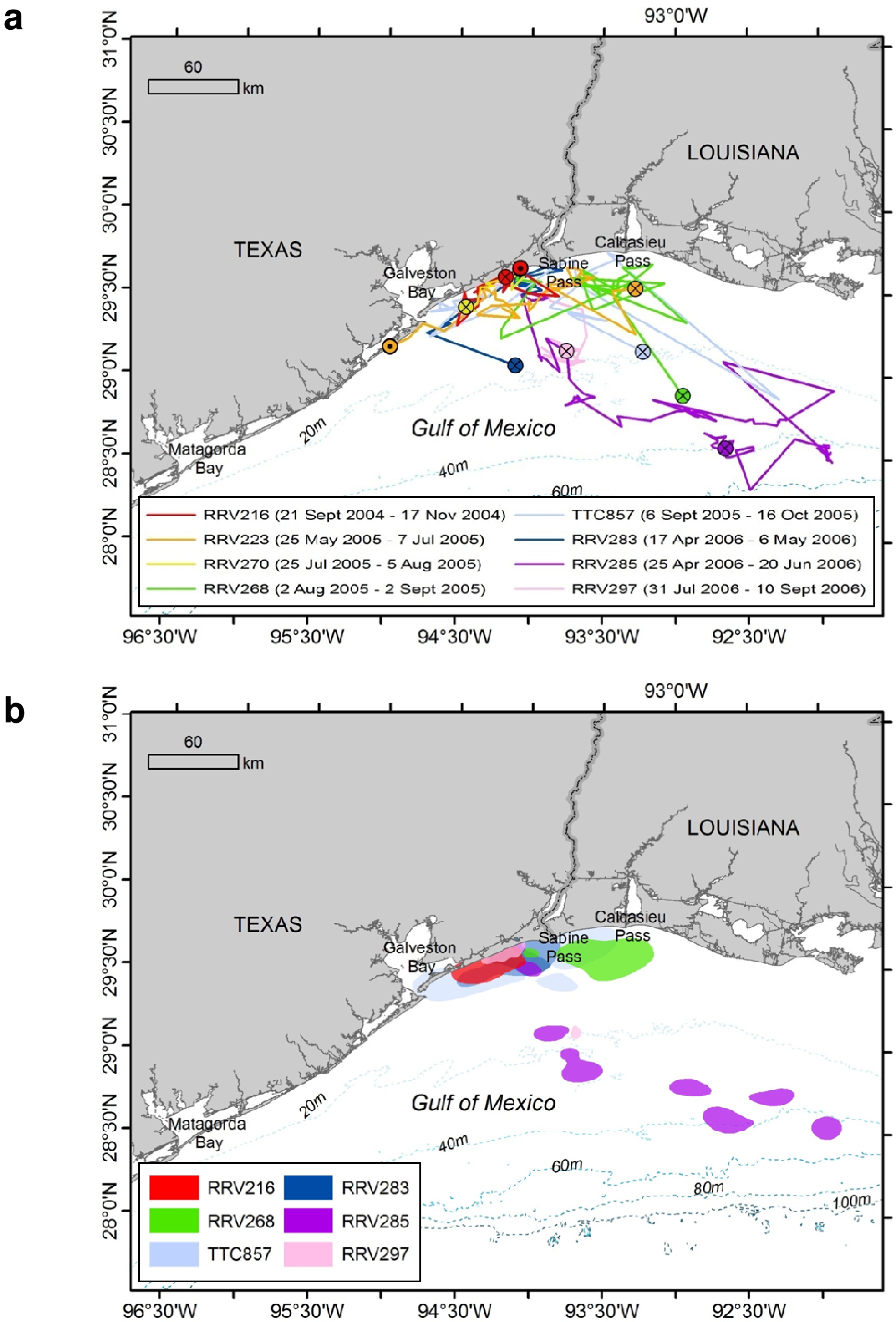

Fig. 5.1. *Lepidochelys kempii*. Immature individuals tracked during 2004-2006 (n = 8). (a) Filtered tracks. ⊙: Release and ⊗: end of track. All individuals except for RRV223 were released from McFaddin National Wildlife Refuge near Sabine Pass, Texas. (b) Core areas (50% KDE). KDE was not conducted for RRV223 (directional track) or RRV270 (track too short).

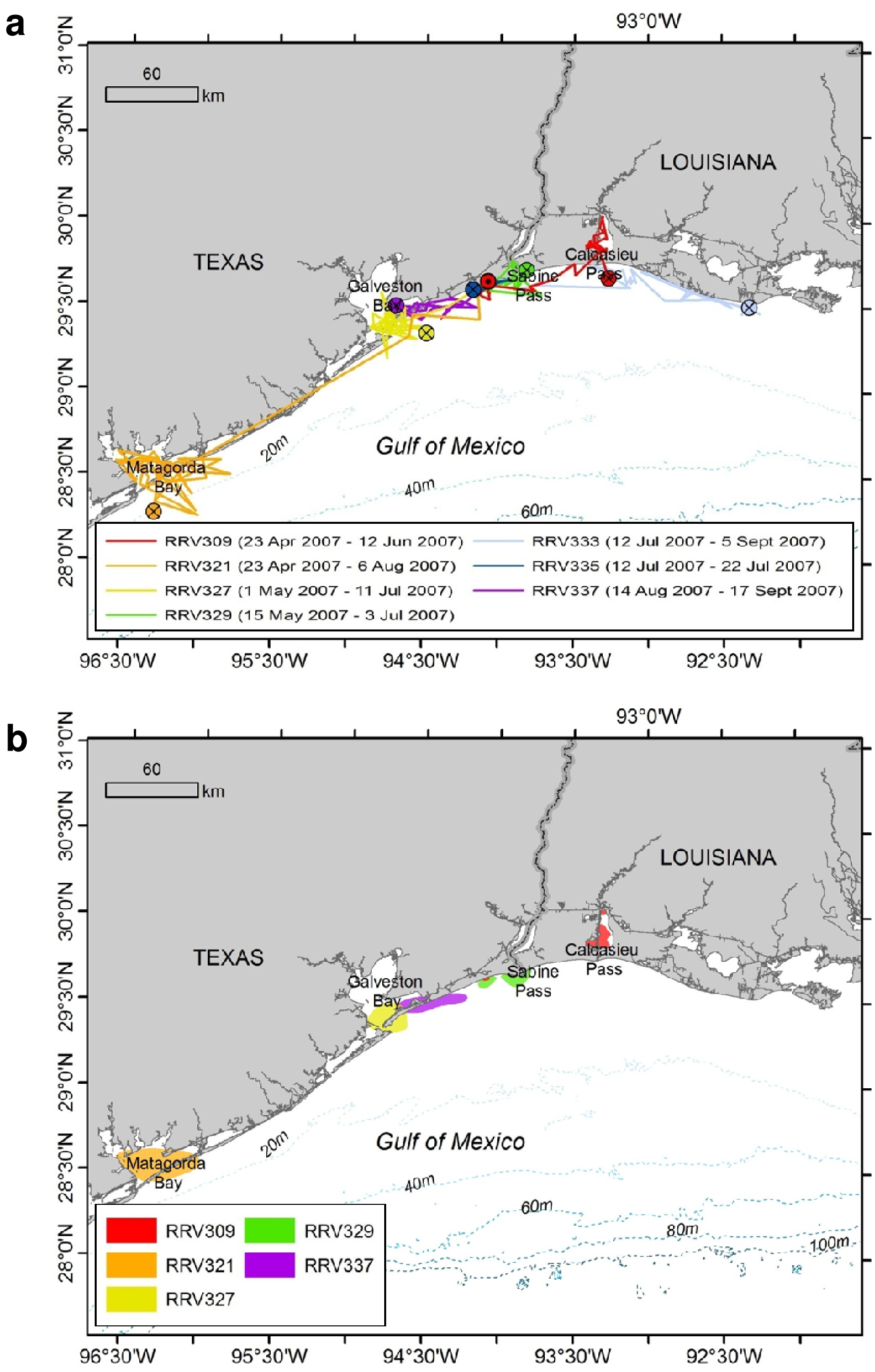

Fig. 5.2. *Lepidochelys kempii*. Immature individuals tracked during 2007 (n = 7). (a) Filtered tracks. ⊙: Release and ⊗: end of track. All individuals were released from McFaddin National Wildlife Refuge near Sabine Pass, Texas. (b) Core areas (50% KDE). KDE was not conducted for RRV333 (directional track) or RRV335 (track too short).

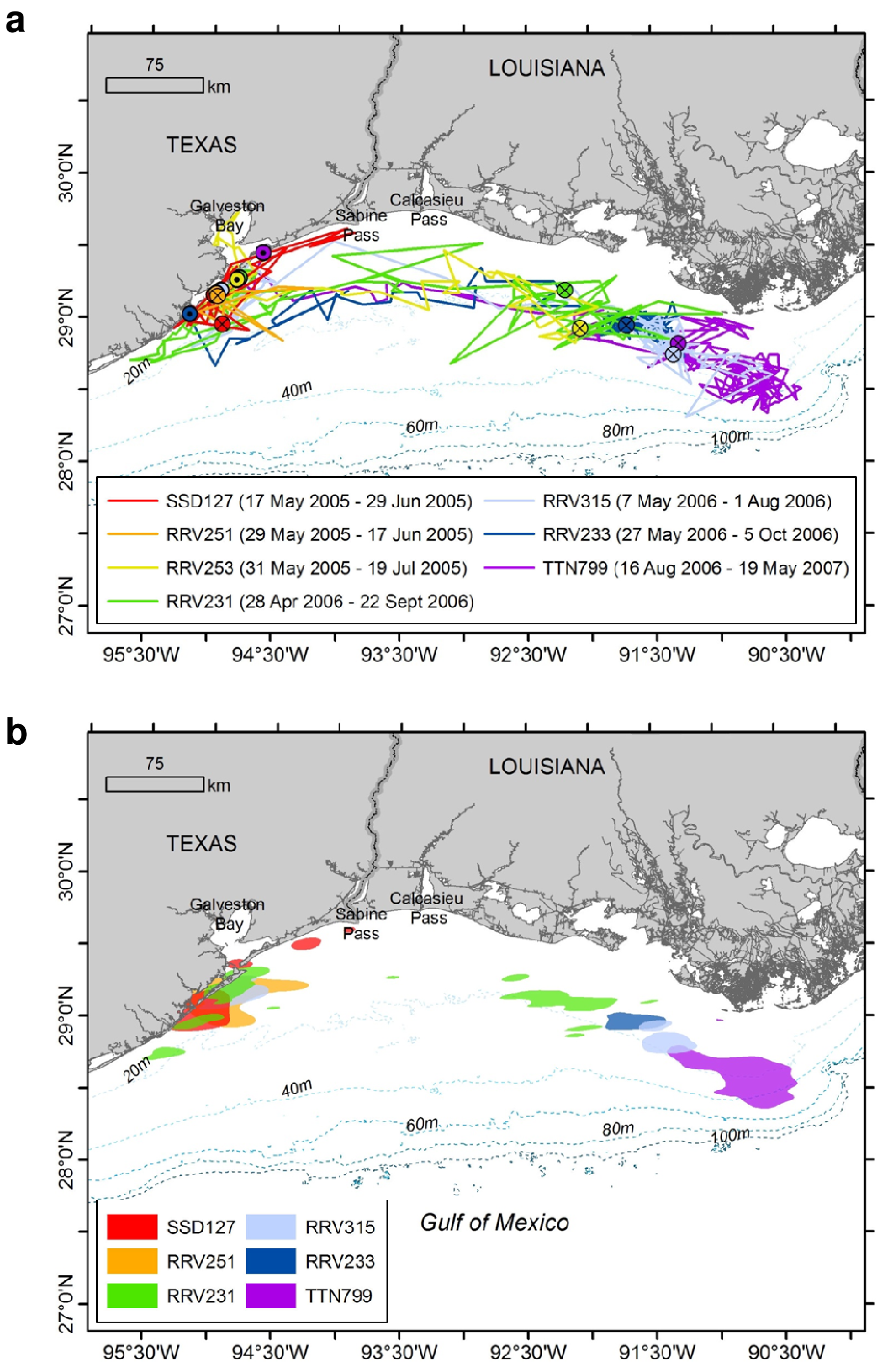

Fig. 5.3. *Lepidochelys kempii*. Adult females tracked during 2005-2007 (n = 7). (a) Filtered tracks. ⊙: Release and ⊗: end of track. (b) Core areas (50% KDE). KDE was not conducted for RRV253 (directional track).

Table 5.2. Results of analysis of covariance (ANCOVA) for dependent variable, in-water area of 50% KDE.

Source	**df**	**F**	***p***	η_p^2
Model	3	12.431	< 0.001	0.727
Life history stage (factor)	2	4.340	0.034	0.383
No. of days tracked (covariate)	1	1.287	0.276	0.084
Error	14			
Total	17			

Table 5.3. *Lepidochelys kempii* . Depth and AVHRR SST values for 22 tracked Kemp's ridleys. Depth: positive values are above sea level (primarily in bays), negative values are below sea level. AVHRR data were not available for all locations.

		Depth (m)					AVHRR SST (C)				
Turtle ID	Life history stage	Mean	SD	Minimum	Maximum	No. Locations	Mean	SD	Minimum	Maximum	No. Locations
RRV216	Immature	-1.99	1.80	0.37	-5.94	27	27.08	1.21	25.00	29.00	14
SSD127	Adult	-3.87	4.89	0.37	-19.02	8	28.16	1.59	26.10	30.20	24
RRV223	Immature	-3.96	3.02	0.40	-16.00	93	29.05	1.72	25.70	31.47	37
RRV251	Adult	-8.19	7.28	-0.99	-21.06	170	29.09	1.22	27.50	30.40	8
RRV253	Adult	-9.78	8.65	0.29	-28.88	197	29.92	1.08	26.60	31.74	84
RRV270	Immature	-1.85	1.04	0.08	-4.00	190	30.96	0.30	30.60	31.30	24
RRV268	Immature	-5.69	4.79	-1.24	-27.77	16	31.43	0.45	30.39	32.10	33
TTC857	Immature	-4.65	6.57	0.44	-28.56	37	29.28	1.07	26.84	30.64	25
RRV283	Immature	-2.83	2.90	0.14	-17.85	24	24.39	0.96	22.90	25.80	29
RRV285	Immature	-32.98	11.78	-1.00	-60.08	35	26.86	1.51	24.40	29.50	110
RRV231	Adult	-9.23	7.90	0.46	-33.84	26	27.39	2.25	24.50	32.40	143
RRV315	Adult	-12.67	7.36	0.35	-63.79	34	28.88	2.39	24.70	32.36	169
RRV233	Adult	-15.44	2.73	-5.00	-25.02	119	30.09	1.09	26.50	32.61	162
RRV297	Immature	-8.05	8.87	0.48	-20.00	48	30.28	0.41	29.60	31.00	37
TTN799	Adult	-22.17	11.87	0.24	-52.12	202	23.01	4.02	17.37	31.35	179
RRV309	Immature	0.22	1.25	1.00	-3.00	46	21.87	1.16	21.00	24.10	14
RRV321	Immature	-3.70	6.10	0.43	-28.64	67	26.31	3.54	21.00	30.06	25
RRV327	Immature	-1.20	0.94	0.49	-4.46	48	27.17	2.36	23.20	29.35	14
RRV329	Immature	-0.31	1.12	1.00	-3.90	27	27.33	1.75	25.20	29.70	12
RRV333	Immature	-1.39	1.27	0.50	-4.70	35	30.56	0.93	29.38	32.60	17
RRV335	Immature	-0.64	0.51	0.04	-1.00	5	29.13	0.23	29.00	29.40	3
RRV337	Immature	-1.01	0.85	0.27	-3.40	24	30.55	0.83	29.13	31.80	10
All	n=22	-12.10	11.77	1.00	-63.79	1,478	27.74	3.42	17.10	32.61	1,173
Immatures	n=15	-9.02	13.87	1.00	-60.08	591	28.05	2.77	21.00	32.60	404
Adults	n=7	-14.16	9.59	0.46	-63.79	887	27.58	3.70	17.10	32.61	769

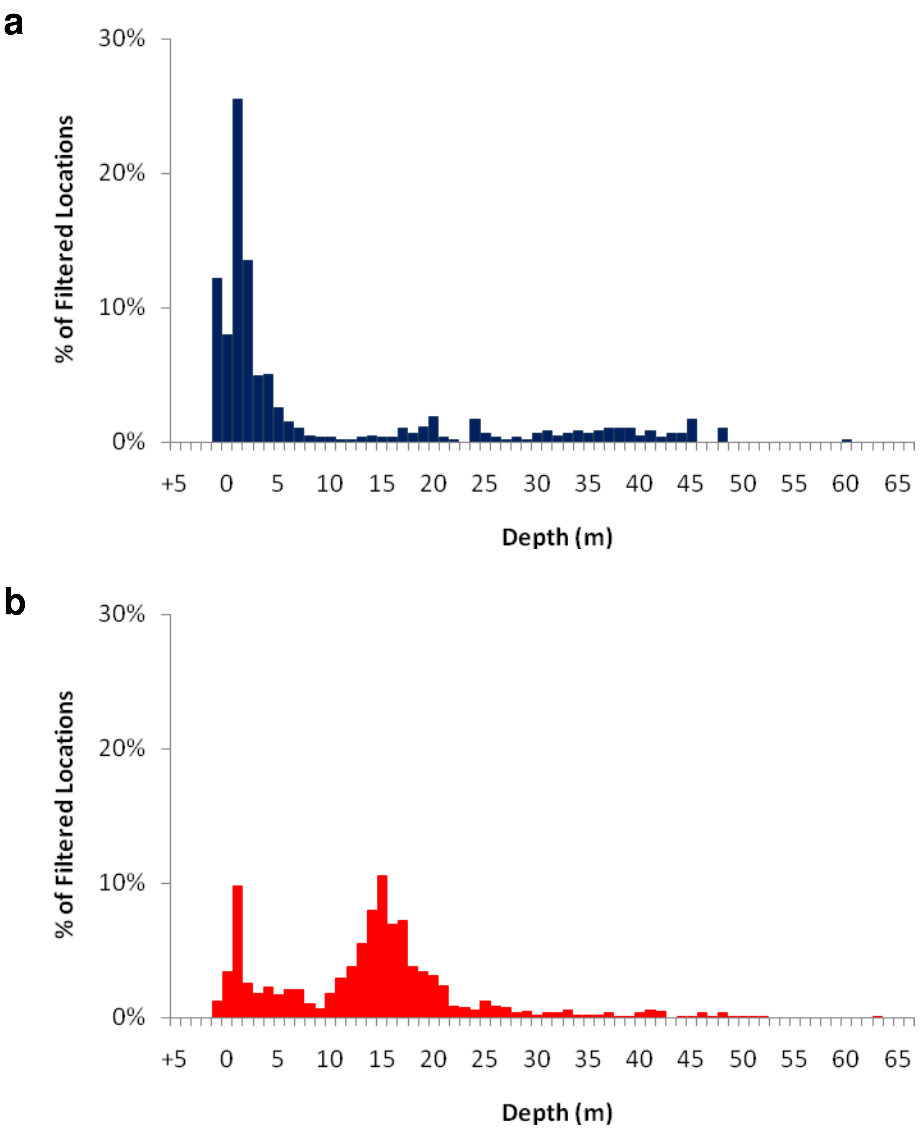

Figure 5.4. Water depth distributions. (a) 15 immature ridleys, 591 locations. (b) 7 adult female ridleys, 887 locations.

average depth of 14.16 m (SD = 9.59 m, n = 887 locations, Table 5.3) and displayed peaks in occurrence nearshore at 0-3 m and offshore at 10-20 m (Fig. 5.4b). AVHRR SST values (Table 5.3, Fig. 5.5) for immature ridleys ranged from 21.0 to 32.60 C and averaged 28.05 C (SD = 2.77 C, n = 404 locations), and similar values were recorded for adult females (17.1-32.61 C, $\bar{x}$ ± 1 SD = 27.58 ± 3.70 C, n = 769 locations). Ninety-one percent of immature and 82% of adult female SST values were between 24 and 32 C.

MANOVA examining the effects of month (January-December), year (2004-2007), and life history stage (immature or adult) on depth and SST values (Table 5.4) indicated all three factors and associated interactions significantly affected the multivariate model. Month had a disproportionately high η_p^2 value (0.821), followed distantly by two interaction terms containing month (month x life history stage, η_p^2 = 0.277; month x year, η_p^2 = 0.231) and year (η_p^2= 0.111). Examination of the associated ANOVAs (Table 5.5) indicated that depth was significantly affected by all three factors and all interactions terms, whereas SST was not significantly affected by life history stage (p = 0.079) or two interaction terms (year x life history stage, p = 0.560; month x year x life history stage, p = 0.472). Depth values were affected most by month (η_p^2 = 0.361), month x year (η_p^2 = 0.328), and month x life history stage (η_p^2 = 0.410), whereas month had a disproportionately large effect on SST (η_p^2 = 0.896).

Kernel analyses combining all daily average locations for immature ridleys (Fig. 5.6a) and adult females (Fig. 5.6b) reinforced the aforementioned trend in water depth between life history stages. Most ‘high use’ areas for tracked immature ridleys occurred within shallow Texas state waters (up to 9 nm [~16.7 km] from shore) between Galveston Island and Sabine Pass. Tracked females exhibited two high use areas: (1) Texas state waters along Galveston Island during the nesting season and (2) deeper federal waters offshore of central and eastern Louisiana (more than 3 nm [~5.6 km] from shore) after a post-nesting migration.

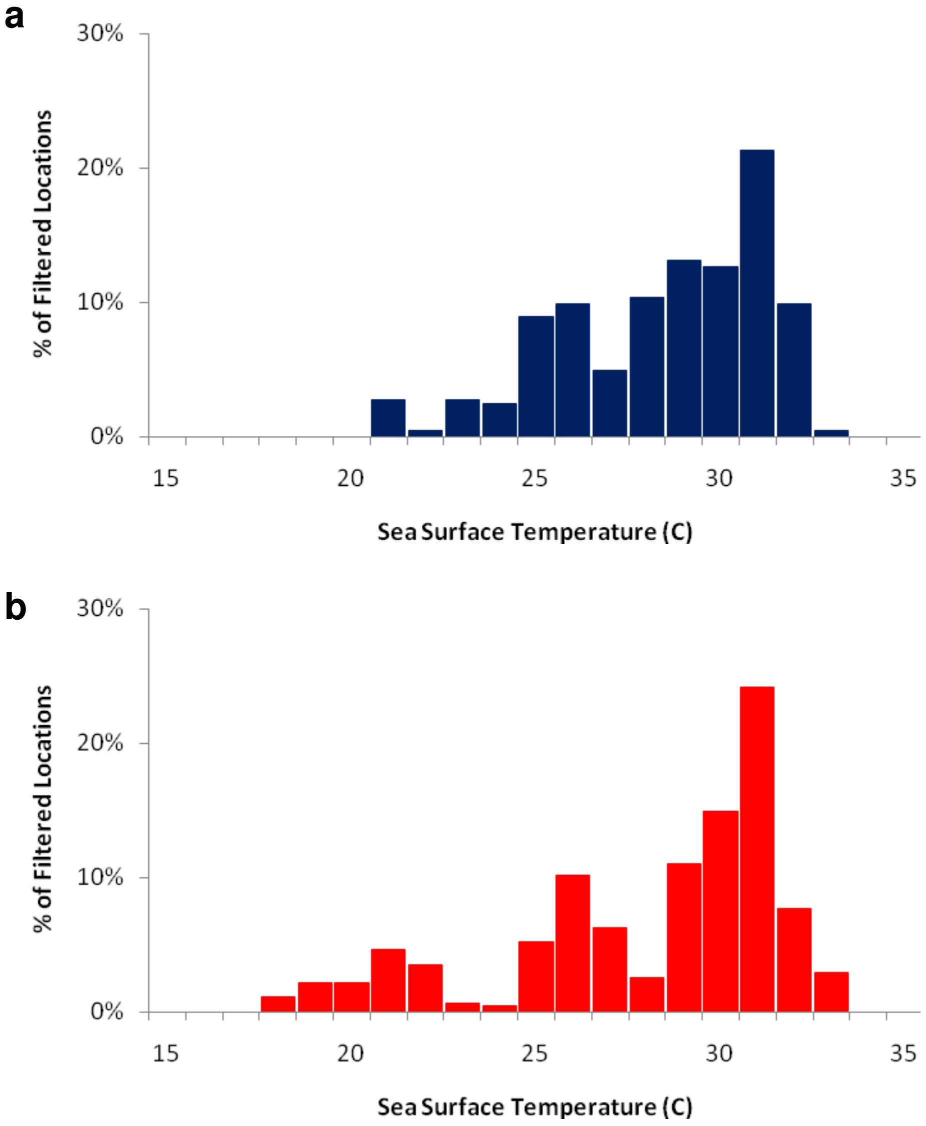

Figure 5.5. AVHRR SST distributions. (a) 15 immature ridleys, 404 locations. (b) 7 adult female ridleys, 769 locations.

Table 5.4. Results of multivariate analysis of variance (MANOVA) for dependent variables, depth and AVHRR SST.

Effect	**Hotelling's Trace**	**F**	**Hypothesis df**	**Error df**	***p***	**η_p^2**
Month	9.172	474.010	22	2,274	< 0.001	0.821
Year	0.250	47.367	6	2,274	< 0.001	0.111
Life history stage	0.013	7.465	2	1,138	0.001	0.013
Month x Year	0.602	34.235	20	2,274	< 0.001	0.231
Month x Life history stage	0.767	87.242	10	2,274	< 0.001	0.277
Year x Life history stage	0.094	53.336	2	1,138	< 0.001	0.086
Month x Year x Life history stage	0.008	4.723	2	1,138	0.009	0.008

Table 5.5. Results of analysis of variance (ANOVA) for dependent variables, (a) depth and (b) AVHRR SST associated with MANOVA (Table 5.4).

Dependent variable	**Source**	**df**	**F**	***p***	**η_p^2**
A. Depth	Model	34	276.804	< 0.001	0.892
	Month	11	58.506	< 0.001	0.361
	Year	3	84.901	< 0.001	0.183
	Life history stage	1	11.776	0.001	0.010
	Month x Year	10	55.595	< 0.001	0.328
	Month x Life history stage	5	158.512	< 0.001	0.410
	Year x Life history stage	1	106.354	< 0.001	0.085
	Month x Year x Life history stage	1	8.912	0.003	0.008
	Error	1,139			
	Total	1,173			
B. AVHRR SST	Model	34	30,924.943	< 0.001	0.999
	Month	11	889.824	< 0.001	0.896
	Year	3	10.170	< 0.001	0.026
	Life history stage	1	3.098	0.079	0.003
	Month x Year	10	12.846	< 0.001	0.101
	Month x Life history stage	5	15.801	< 0.001	0.065
	Year x Life history stage	1	0.340	0.560	< 0.001
	Month x Year x Life history stage	1	0.518	0.472	< 0.001
	Error	1,139			
	Total	1,173			

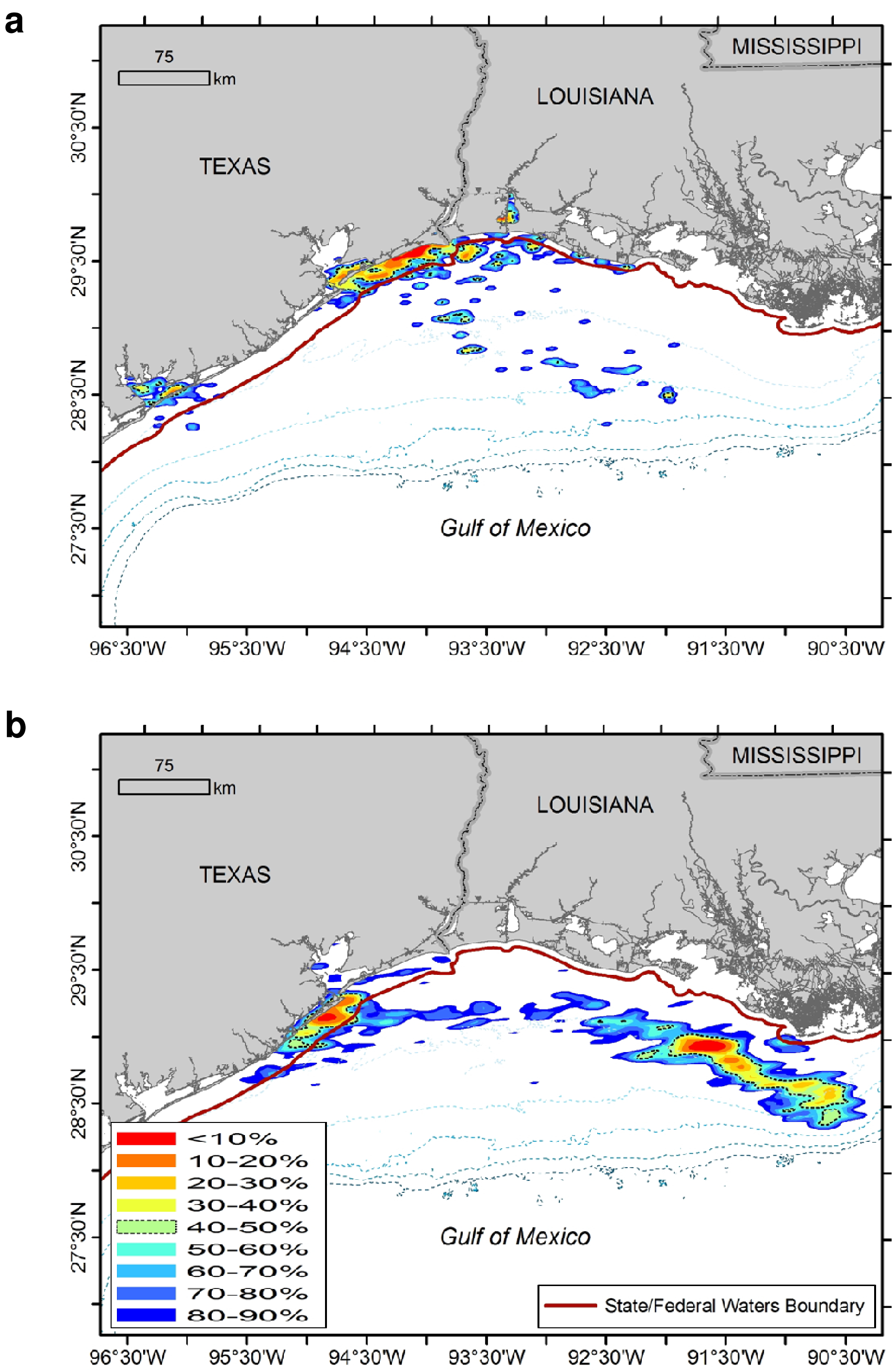

Figure 5.6. *Lepidochelys kempii*. Use of the northwestern Gulf of Mexico, as estimated with KDE. (A) 15 immature ridleys (n = 358 average daily locations). (B) 7 adult female ridleys (n = 508 average daily locations).

DISCUSSION

Tidal passes, bays, and coastal lakes within Texas and Louisiana state waters served as foraging areas for immature Kemp's ridleys in the northwestern Gulf of Mexico during 2004-2007 (Fig. 5.1-5.2, 5.6). Movements of immature individuals varied in direction and destination, but all traversed shallow nearshore areas, remaining primarily in waters less than 10 m deep. This behavior is similar to that reported by Renaud and Williams (2005), who found that 57 of 78 juveniles satellite and/or radio tracked during 1988-1996 remained in shallow northwestern Gulf waters during June through September. Daily locations of 60 'habitat faithful' juvenile ridleys (Renaud & Williams 2005) were often concentrated outside of Sabine and Calcasieu Passes on the lee side of jetties, but these turtles were both captured and released in these areas. The remaining 18 juveniles tracked by Renaud and Williams (2005) left their release sites, but typically moved between Sabine and Calcasieu Passes or between Calcasieu Pass and Mermentau Pass, Louisiana.

Although immature ridleys tracked in prior studies and in 2004-2006 during the present study favored tidal passes of the northwestern Gulf (Renaud & Williams 2005), four individuals in tracked in 2007 entered four different bay systems, and a fifth exhibited directional movement along the Louisiana coastline. Only one of the fifteen tracked immature ridleys, a 2004 hook-and-line capture (RRV216), showed fidelity to its capture location (Gilchrist), whereas the 2005 relocation trawl capture (TTC857) reached its capture location (Calcasieu Pass) near the end of its 41-day track (Fig. 5.1). Nine juvenile ridleys, one stranding (entanglement), two hook-and-line captures in 2006, and six hook-and-line captures from 2007, originated from the same fishing pier in Galveston, and yet none returned to the pier; rather they moved alongshore and later offshore or into bay systems (Fig. 5.1-5.2). These results contrasted with not only site fidelity previously observed in the northwestern Gulf (Renaud & Williams 2005), but also with seasonal and inter-seasonal fidelity exhibited along the Florida Gulf coast. Six immature ridleys tracked by Schmid and Witzell (2006) remained in the Cedar Keys, Florida, after transmitter deployment in October 2000, began migrating south through offshore waters in December, moved northward in February 2001, and eventually returned to the Cedar Keys.

Despite some differences between the movement patterns of immature ridleys tracked in the current study and those tracked previously in the northwestern Gulf (Renaud & Williams 2005) and Florida (Schmid & Witzell 2006), the characteristics among some seasonal foraging sites are similar. For example, Texas and Louisiana bays may offer the same foraging advantages as the lee side of tidal passes, such as providing immature ridleys protection from adverse sea conditions, better visibility for foraging, and access to abundant populations of blue crabs (More 1969, Britton & Morton 1989, Metz 2004, Minello et al. 2008) and other benthic prey. Nearshore Gulf waters through which all immature ridleys tracked in 2004-2007 moved and some established short-term residency also provide foraging opportunities. Such areas are often characterized by abundant blue crab assemblages (Metz 2004) as well as shrimping and associated discard of bycatch (Caillouet et al. 1996). Moreover, state-mandated removal of abandoned crab traps (78 Texas Parks and Wildlife Code 115) and recent reductions in Texas shrimping effort (LGL Ecological Research Associates 2007) have likely reduced mortality of blue crabs and other benthic organisms, and in turn made Texas coastal waters and bays more attractive to foraging ridleys.

In contrast to the immature ridleys, adult females inhabited nearshore waters along Galveston Island during nesting season (April-June/July) and then utilized the 20-m isobath as a migratory path to foraging grounds in Louisiana (Fig. 5.6). This pattern is similar to that of many post-nesting ridleys tracked during 1997-2006 along the continental shelf from PINS in south Texas to foraging areas between Sabine Pass and the Florida Keys (Shaver & Rubio 2008). In both 2005 and 2006, post-nesting females from the upper Texas coast eventually established relatively large home ranges in federal waters offshore Louisiana at depths of 20-50 m (Fig. 5.3, 5.6). These large core areas of activity, as compared to immature individuals tracked during 2004-2007, were not a function of the adults’ longer track durations. This suggests that females may need to move more frequently to find sufficient prey and/or appropriate environmental conditions offshore, but longer track durations are required for immature individuals to better compare movement patterns across seasons. Differences in depths utilized by tracked ridleys were a primarily a function of month and its interaction with both year and life history stage. Likewise, differences in SST were dictated primarily by time of year (i.e., month), and life history stage had no significant effect on SST.

CONCLUSIONS AND RECOMMENDATIONS

Juvenile and subadult Kemp's ridleys recruit to coastal waters of the northwestern Gulf of Mexico during early spring where they remain through summer and fall, whereas adult females utilize these waters for nesting, foraging, and migrating during spring and summer. Favorable water temperatures and abundant food, presumably in the form of blue crabs, other invertebrates, and bycatch discarded by the shrimping industry, render shallow nearshore waters ideal habitats for foraging ridleys. During 2004-2007, ridley movements were documented primarily along the upper Texas-southwestern Louisiana coast, with individual 'core' activity scattered among nearshore Gulf waters, tidal passes, bays, and coastal lakes. Migratory behavior of immature and inter-nesting individuals was largely confined to nearshore regions of Texas and western Louisiana, whereas post-nesting females migrated across deeper, federal waters on the Texas-Louisiana continental shelf.

Tracking results reported herein identified a variety of northwestern Gulf locations as ridley foraging sites, but the overall trends mirrored previous tracking and monitoring conducted in the region. Specifically, immature Kemp's ridleys exhibit a strong dependency on shallow Gulf waters as developmental habitat, whereas nesting females utilize the same areas as reproductive, foraging, and migratory habitat, and post-nesting females move further offshore. This dependence on the northwestern Gulf of Mexico for seasonal foraging grounds and migratory corridors should be incorporated into revision of the Kemp's Ridley Recovery Plan, whereas research efforts should continue in the region to better determine seasonal distributions, abundances, population dynamics, and mortality risks.

CHAPTER VI

FACTORS AFFECTING SEA TURTLE SATELLITE TRACK DURATION

INTRODUCTION

Advances in the global satellite network, satellite transmitter miniaturization, and new deployment techniques have allowed for increased use of satellite telemetry as a tool for examining long-term movements of sea turtles and other vertebrate species (Coyne and Godley 2005). Personnel at the TAMUG STFERL attached PTTs to eight Kemp's ridley sea turtles using PowerFast two-part marine epoxy during 2004-2005 (see Chapters IV and V). All transmitted for considerably shorter periods than expected, with five immature individuals tracked for 12-57 d ($\bar{x} \pm 1$ SD = 37 ± 17 d) and three adult females for 20-50 d ($\bar{x} \pm 1$ SD = 38 ± 16 d). Several different transmitter models were utilized, but battery lives of 180-365 d or more were expected from all units. This discrepancy prompted concerns regarding causes for premature transmission loss including turtle mortality, antenna damage, biofouling, and attachment failure.

Turtle mortality. Sea turtles face a large number of threats, both on land and in the sea (Lutcavage et al. 1997), and all species are protected at national and/or international levels (IUCN 2006, CITES 2007, 50 US Code of Federal Regulations 17.11). In recent years, satellite telemetry has been utilized to infer mortality, and in some instances, poaching and stranding events have later been confirmed by researchers. In comparison to a PTT-outfitted turtle that is healthy and behaving normally, one that is dead, debilitated, or on the deck of a boat will generate satellite data that show a sudden increase in the quality of Argos location classes, repeated high-quality locations from the same area, and increased message durations and surface times (Hays et al. 2003). Satellite data from PTTs have been used to infer death of loggerhead (*Caretta caretta*, Hays et al. 2003, Hays et al. 2004), leatherback (*Dermochelys coriacea*, Hays et al. 2003), and Kemp's ridley sea turtles (Chapter V). Direct observations of mortality events have been supplemented by satellite data for Kemp's ridley (Chapter IV), leatherback (Hays et al. 2003), eastern Pacific green (*Chelonia mydas agassizii*, Hays et al. 2003), and Atlantic green sea turtles (*Chelonia mydas mydas*, T. Metz pers. comm.). Poaching events have also been confirmed for tracked green turtles (G. Gearheart pers. comm., W.J. Nichols pers. comm.). Other potential causes of mortality include, but are not limited to, incidental interactions with fishing gear, boat strikes, and debris ingestion, as well as natural mortality due to shark predation, disease, and parasites (George 1997, Lutcavage et al. 1997, Schwartz 2000, Heithaus et al. 2008).

Damage to PTT antenna. Cessation of satellite transmissions due to antenna damage or loss is often inferred, given the inclination of sea turtles, particularly loggerheads and ridleys, to ‘wedge’ and/or ‘groom’ themselves under rocks, reefs, and other overhanging structures both in the wild and in captivity (Caine 1986, Schofield et al. 2006, Frick & McFall 2007, B. Higgins pers. comm., E. Seney pers. obs.). Documented examples of such damage are rare, but loss of transmissions from an adult female Kemp’s ridley occurred 9 d after the turtle was photographed nesting with a severely bent antenna (Fig. 6.1, Chapter IV). This mode of transmission loss is further supported by an adult female loggerhead tracked in Chesapeake Bay that was recaptured twice with a PTT still attached, but with damage to the antenna that rendered it unable to transmit data to satellites (Fig. 6.1, Mansfield 2006).

Biofouling of PTT. A large variety of barnacles and other invertebrates is known to colonize the shells and skin of sea turtles, and these assemblages vary geographically and with turtle species (Caine 1986, reviewed by Epibiont Research Cooperative [ERC] 2007). Epiobont communities are typically more diverse and dense on loggerheads (*Caretta caretta*) than those on other sea turtles species (Caine 1986, Frick et al. 2004, ERC 2007). Relatively few epibiont species have been documented on Kemp’s ridleys (ERC 2007), and barnacle densities are usually very low on healthy benthic stage immature and adult individuals in the western Gulf of Mexico (E. Seney pers. obs.). In contrast, two adult female Kemp’s ridleys tracked by the STFERL in 2005 (Chapters IV and V) had moderate barnacle and algae coverage on their transmitters and the surrounding PowerFast epoxy 20 and 35 d after release (Fig. 6.2). This unexpected result

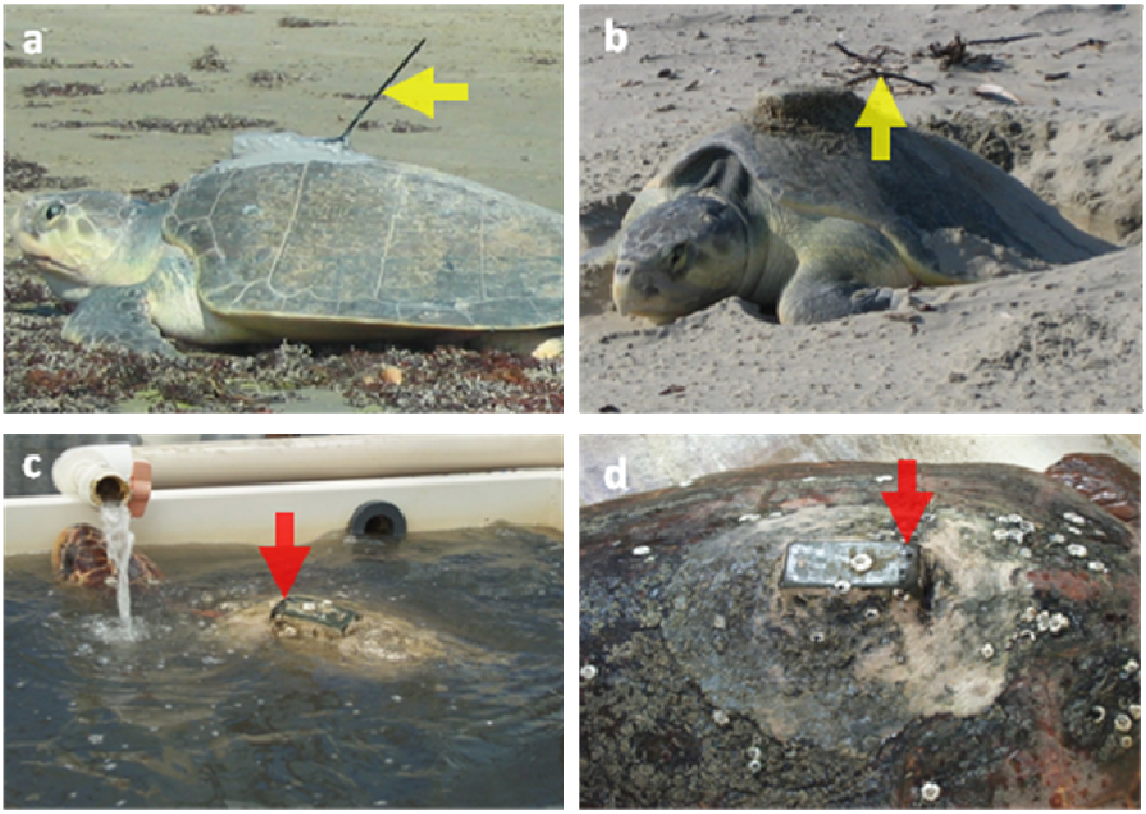

Fig. 6.1. Antenna damage. Condition of PTT antenna (black, indicated by yellow arrows) on adult female Kemp's ridley, SSD127, (a) at release and (b) nesting 35 d later (tracked by TAMUG, see Chapter IV). (c)-(d) Adult female loggerhead, SSB919, recaptured with PTT lacking antenna (indicated by red arrows, tracked by Virginia Institute of Marine Science, see Mansfield 2006). Photos by E. Seney (a, c, d) and R. Walker (b).

dictated a need to modify PTT deployment methods, as growth of epibiota over a unit's saltwater switches can cause transmissions to cease (K. Lay pers. comm.). Application of marine anti-fouling paints has been used successfully in tracking other sea turtle species (Eckert et al. 2006, Troëng et al. 2006, M. Dodd pers. comm., A. Tucker pers. comm.), and should be effective for tracking Kemp's ridleys in the Gulf of Mexico.

PTT attachment failure. Loss of the entire attachment and associated PTT could be due to multiple factors including insufficient attachment method, high turtle growth rate, or an unnatural 'impact' event such as a boat strike or movement through a turtle excluder device (TED). In addition to the STFERL's 2004-2005 tracks, premature transmission loss was also observed for Kemp's ridleys satellite tracked in Pamlico Sound, North Carolina, by Read et al. (2004). During 2002-2003, seven immature ridleys were tracked for 0-129 d ($\bar{x}$ ± 1 SD = 33 ± 44 d) using two transmitter sizes and attachment methods. Five were outfitted with smaller satellite transmitters using only PowerFast epoxy, whereas the largest two ridleys received transmitters attached with PowerFast epoxy covered by two layers of fiberglass cloth. Individuals bearing smaller transmitters were tracked for 0-31 d ($\bar{x}$ ± 1 SD = 18.0 ± 13.2 d, n = 5), and the larger ridleys (> 50 cm SCL) were tracked for 15 and 129 d ($\bar{x}$ ± 1 SD = 72.0 ± 80.6, n = 2; Read et al. 2004). Although the sample size was small, the North Carolina data provide evidence in addition to that of the STFERL that turtle size and/or attachment method may impact satellite track duration.

A potential cause for track duration differences among different-sized turtles is the decreased growth rate observed in larger subadults and adults. Sea turtle growth has been fit to several parametric age-based models, including the von Bertalanffy, Logistic, and Gompertz growth functions (Chaloupka & Musick 1997). All of these functions depict asymptotic growth, with rapid growth rates at younger ages/sizes followed by decreasing growth rates as the curve approaches an asymptote. Both Kemp's ridleys and loggerheads have exhibited rapid growth rates in captivity during the first two years of life at the NSTF (Higgins 2003), and asymptotic growth has been observed for recaptured captive-reared (Caillouet et al. 1995) and wild Kemp's ridleys (Zug et al.

Fig. 6.2. Biofouling. (a)-(b) Stranded Kemp's ridley, RRV251, 20 d after PTT delpoyment and (c)-(d) Kemp's ridley, SSD127, nesting 35 d after PTT deployment (Chapter IV). Locations of saltwater switches are indicated by red circles in (b) and (d). Photos by E. Seney (a-b), R. Walker (c), and H. Walker (d).

1997, Snover et al. 2007). Long-term mark-recapture studies in Florida have yielded SCL growth rates of 5.9-8.8 cm/y offshore Cape Canaveral, 3.6-5.4 cm/y in the Cedar Keys, and 1.8-12.2 cm/y ($\bar{x} \pm 1$ SD = 6.5 ± 3 cm) in Gullivan Bay (Schmid & Witzell 1997, Wiztell & Schmid 2004). In the latter study, ridleys in the 20.0-39.9 cm SCL size class grew significantly faster than those 40.0-59.9 cm SCL (Witzell & Schmid 2004).

Rapid growth rates of immature turtles may substantially increase the surface area of carapace underneath a satellite transmitter attachment within a relatively short time. The resulting increased stress on this attachment may cause the transmitter to become unattached in a shorter time period than would a similarly attached transmitter on a mature, and thus slower-growing, individual of the same species. As such, less-rigid methods may prove effective for maintaining PTT-attachment integrity and, in so doing, increasing transmission periods from immature turtles. Likewise, attachment site preparation may be more important for these smaller, faster-growing individuals than that for larger conspecifics.

OBJECTIVES

To further investigate potential causes of satellite transmission loss and to improve track durations, trials were conducted to achieve the following objectives:

(1) To examine PTT biofouling rates and effectiveness of antifouling paints.
(2) To compare existing and experimental PTT attachment techniques.
(3) To examine interactions between PTT-outfitted sea turtles and TED-equipped shrimp trawls.

MATERIALS AND METHODS

Biofouling trial. Transmitter deployment was simulated at the TAMUG Boat Basin on Pelican Island, Galveston Bay, Texas to qualitatively evaluate biofouling. This was a small-scale pilot study conducted in parallel with one at Mote Marine Laboratory in Sarasota, Florida, wherein both trials utilized the same protocols (Tucker et al. 2007). The evaluation concept used a two-factor analysis of variance (ANOVA) design with interaction, but the study had inadequate replicates for statistical analysis. At each site, four replica ('dummy') Sirtrack KiwiSat 202 PTTs (approximately 8×4×2 cm), each with a different treatment, were bolted to the exterior of a weighted 5-gal (18.9-l) bucket and covered with PowerFast two-part marine epoxy to mimic attachment to a sea turtle carapace. The treatments were comprised of: (A) control with a bare PTT and bare epoxy attachment area, (B) Tempo Marine clear spray-on antifouling paint on the PTT, excepting the saltwater switches and antenna, and no treatment to the epoxy, (C) Interlux brush-on antifouling paint to the epoxy but no PTT treatment, and (D) a combination of spray-on treatment to the PTT and brush-on paint to the epoxy (Fig. 6.3). The TAMUG bucket was submerged off a dock 9 August to 9 November 2006 (93 d) and retrieved weekly for examination and photographs.

Attachment trials. Three attachment trials were conducted with captive-reared juvenile loggerhead sea turtles at the NOAA Sea Turtle Facility (NOAA STF) in Galveston, Texas. In the first, four 29-month old loggerheads averaging 40.1 cm SCL (SD = 1.3 cm) were outfitted with dummy PTTs on 10 January 2006 to compare two attachment methods (Fig. 6.4). Dummy Sirtrack KiwiSat 202 PTTs (approximately 8×4×2 cm) were attached along the first two vertebral scutes with PowerFast two-part marine epoxy (PF-only, n = 2) or PowerFast covered with Sonic-Weld steel-reinforced epoxy (PF/SW, n = 2, Mansfield & Musick 2004). These loggerheads were held at the NOAA STF in a divided raceway from 10 January-23 May 2006 and maintained according to NOAA STF husbandry standards (Higgins 2003). Transmitter attachments were examined for integrity and photographed weekly, and turtles were measured monthly.

The second attachment trial examined the PF-only and PF/SW methods (Fig. 6.4) as well as experimental techniques incorporating neoprene (Fig. 6.5). Twenty 30-month old captive-reared loggerheads, averaging 43.6 cm SCL (SD = 1.0 cm), were randomly assigned to a control group (no PTT) or one of four attachment types: PF-only, PF/SW, and two experimental methods integrating 1.5 mm neoprene and 3.0 mm neoprene. Four

Fig. 6.3. Biofouling trial. Treatments on bucket: (a) control, (b) spray-on anti-fouling paint, (c) brush-on antifouling paint, and (d) both antifouling paints. Photos by E. Seney.

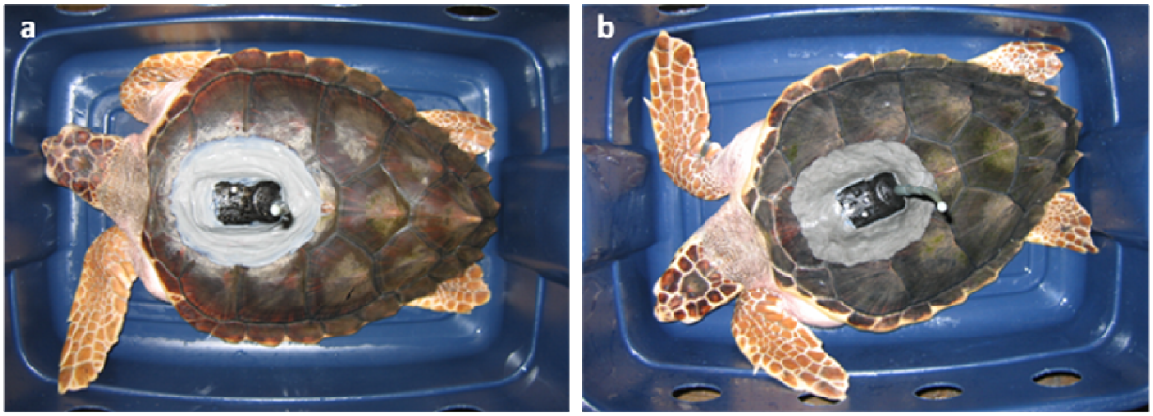

Fig. 6.4. Attachment trials. Captive-reared juvenile loggerhead sea turtles outfitted with dummy PTTs attached using the (a) PowerFast-only and (b) PowerFast/Sonic-Weld attachment methods. Photos by E. Seney.

loggerheads comprised the control group, and the other sixteen were subsequently outfitted with dummy KiwiSat 202 PTTs using the four attachment methods on 2-3 February 2007. Protocols used to attached the four PF-only and four PF/SW units matched those used in 2006 with two exceptions: (1) 60-grit sandpaper was utilized instead of 100-grit to sand the attachment site and sides and underside of the transmitter and (2) the first 10-15 cm of PowerFast epoxy discharged from the applicator nozzle was discarded because it may not cure properly (R. Morehead unpubl.). The remaining eight turtles were split evenly between the neoprene treatments. Pieces of 1.5 mm (1.5 mm group) and 3.0 mm (3.0 mm group) neoprene were cut 3-4 cm larger than the base of each dummy PTT, resulting in pieces approximately 14×10 cm with rounded edges. An outline of the neoprene was traced onto each turtle's carapace at the attachment site, overlapping the first and second vertebral scutes. 'Mega blue' room-temperature vulcanizing (RTV) silicone was then used to outline the scutes at the attachment site, acting as a barrier to epoxy along these areas of shell growth (Fig. 6.5a). Once the silicone set, PowerFast was applied at the attachment site, avoiding the silicone and thereby allowing for less-encumbered growth along the scutes' suture lines (Fig. 6.5b). The neoprene was then carefully placed on top of the epoxy (Fig. 6.5c), and once this attachment was secure, the transmitter was attached to the neoprene with PowerFast (Fig. 6.5d). The 20 loggerheads were evenly distributed among four raceways (1 of each attachment and 1 control per raceway) and maintained under NOAA STF husbandry protocols (Higgins 2003) through 17 May 2007. PTTs were manually checked and photographed weekly, whereas turtles were measured monthly.

A third trial was conducted to further examine effects of carapace turtle growth on the four attachments types. Eight 23-month old captive-reared loggerheads, averaging 36.8 cm SCL (SD = 0.9 cm), were outfitted with dummy KiwiSat202s (two per attachment, randomly assigned) on 20 July 2007. The turtles were housed in two raceways, maintained under NSTF husbandry protocols (Higgins 2003), and fed to achieve high growth rates. Attachments were checked manually each week and photographed every 1-2 weeks. All turtles were measured monthly and when their PTTs

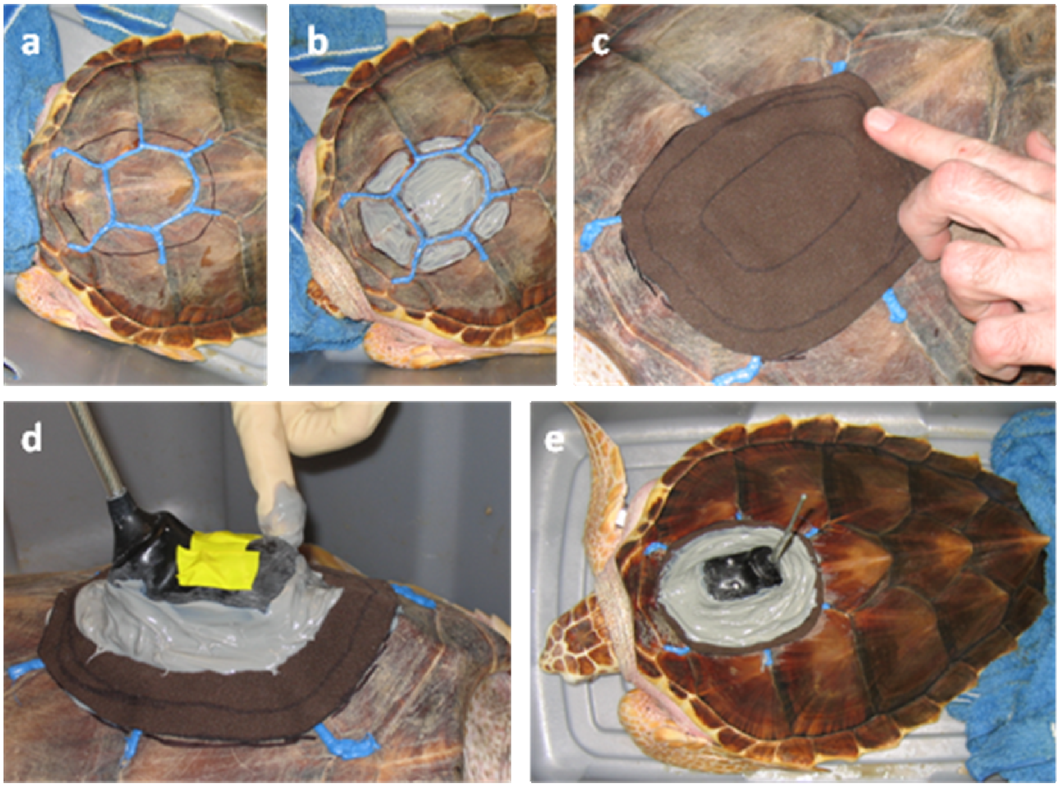

Fig. 6.5. Neoprene attachment technique. (a) RTV silicone (blue) and outline of neoprene attachment site, (b) PowerFast epoxy on attachment site, (c) attachment of neoprene to carapace, (d) attachment of PTT to neoprene, and (e) completed attachment on captive-reared loggerhead sea turtle. Photos by E. Seney.

were shed. Once an individual lost its PTT, food rations were reduced to that of the general population, and the turtle was no longer included in growth measurements.

Loggerheads in the first two trials were transported overnight 23-24 May 2006, and 17-18 May 2007, respectively, from Galveston, Texas, to Panama City, Florida, for use in NOAA's annual TED testing. Upon arrival, they were placed in outdoor pens for semi-wild conditioning (Higgins 2003) and monitored for transmitter loss. PTTs that remained attached were removed prior to July 2006 and July 2007 releases in Sebastian Inlet, Florida. In the third trial, PTTs that remained attached on 17 February 2008, were removed so that the turtles could be utilized in another research project. Individual growth was plotted for each trial, and average daily growth was estimated using linear regression.

TED trials. A pilot study to examine potential interactions between satellite transmitters and TEDs was conducted with eight 34-month-old captive-reared loggerheads in June 2006, and a follow-up trial was conducted with twenty 34-month-old captive-reared individuals in June 2007. In both years, the same procedures were utilized. Loggerheads were transported from the NOAA STF in Galveston, Texas, to Panama City, Florida, in mid-May and then conditioned in outdoor pens for 4-5 weeks. Trials were conducted from the NOAA Fisheries shrimp trawler *R/V Caretta* near Panama City, and adhered to the NOAA standard small turtle TED test protocol (NMFS 1990). The turtles were evenly split between experimental (outfitted with dummy Sirtrack KiwiSat 202 PTTs) and control (no PTTs) groups, with experimental turtles bearing PF-only (n = 2) and PF/SW (n = 2) attachments in 2006, and PF/SW (n = 4) and neoprene (n = 6) attachments in 2007. Each loggerhead was sent through 15.2-m (50-ft) 'Western jib' trawl equipped with a bottom-opening Super-Shooter (BOSS) TED at a 50-degree angle (Fig. 6.6). All turtles were video-recorded, and each was given up to 5 min to escape through the TED prior to being classified as a 'capture' and freed by divers. Turtles were recovered and returned to the surface using floats. The pilot study occurred on 22 June 2006, whereas the second trial was conducted during 22 and 24

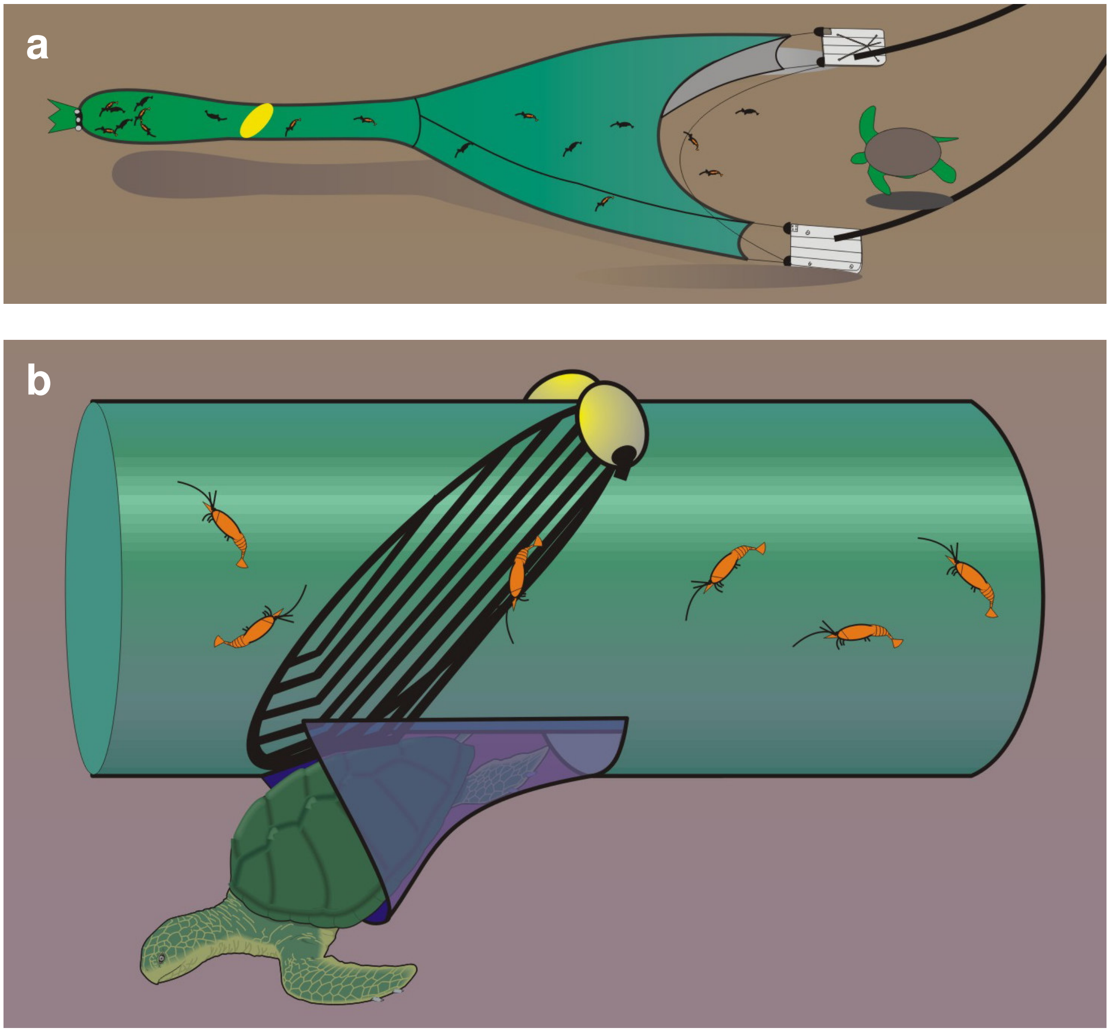

Fig. 6.6. Turtle excluder device. (a) Shrimp trawl equipped with a bottom-opening Super-Shooter turtle excluder device (TED, highlighted in yellow) and (b) sea turtle exiting TED. Diagrams courtesy of the Harvesting Systems Branch, NOAA Fisheries Pascagoula Laboratory.

June 2007. Dummy transmitters were removed after each trial, and the loggerheads were released at Sebastian Inlet, Florida, in July 2006 and July 2007, respectively.

Video footage was examined to accurately time each turtle's passage through the trawl and to record outcome (capture or escape) and orientation of the turtle to the TED (carapace-, plastron-, or head-first). Statistics were not conducted on the smaller 2006 data set, whereas the 2007 data were examined statistically using Levene's F test and a two-tailed t-test. Potential differences in environmental conditions between years and the two year classes of turtles prevented merging the two data sets for statistical analysis.

RESULTS

Biofouling trial. Fouling organisms, including barnacles, tube worms, algae, and oysters, colonized all non-painted areas of the dummy PTTs and surrounding epoxy (Fig. 6.7). Epifaunal growth was most rapid on the control (treatment A) with barnacles completely covering the saltwater switches in less than 4 weeks. Within this same time period, substantial algal growth covered the other non-painted PTT (C), while both painted PTTs were essentially free of fouling (treatments B and D). At the culmination of the trial (Day 93), acorn barnacles and/or oysters covered non-painted surfaces of all treatments, whereas little to no epibiota colonized painted areas of the PTTs (B and D). Throughout the trial, the only fouling on painted epoxy (C and D) was thin layers of algae and/or silt. Additionally, both PTTs without the brush-on paint (A and B) had barnacle-covered antennae by the end of the trial, whereas PTTs with painted epoxy (C and D) only had minimal algal growth on their antennae. Fouling similar to that seen on saltwater switches of the non-treated PTT (A) would probably have rendered a real unit non-functional within 4 weeks, whereas growth between the switches of PTT C (brush-on paint only) would likely have caused loss of transmissions within 8-12 weeks (K. Lay pers. comm.).

Attachment trials. Loggerheads in the initial attachment trial grew an average of 1.3 cm SCL (SD = 0.5 cm, n = 4) during 10 January–11 May 2006, and all transmitters were still attached on 23 May 2006 (Day 135). After the turtles were placed in outdoor

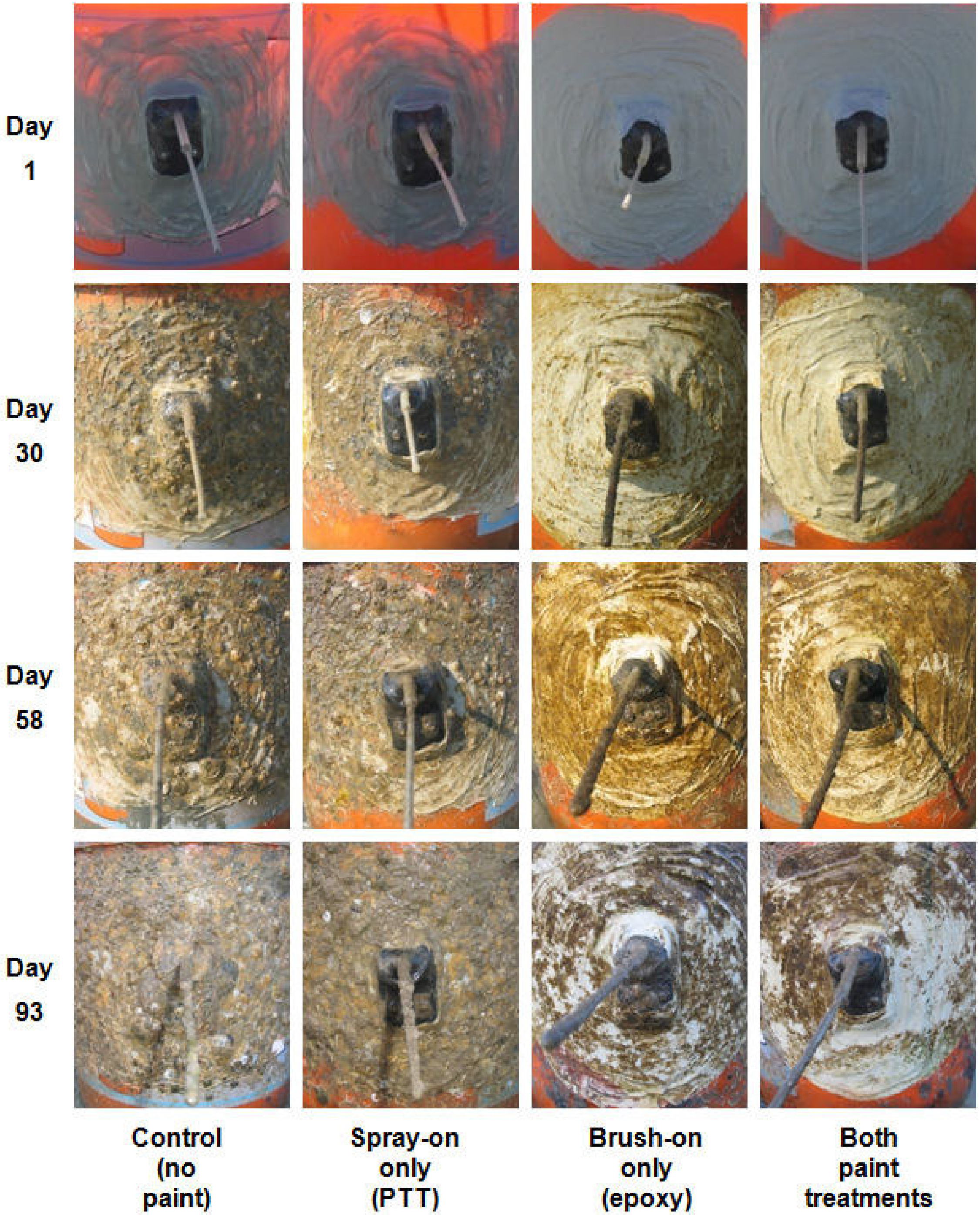

Fig. 6.7. Biofouling trial. Progression of fouling on PTTs at four week intervals. Photos by E. Seney.

pens in Panama City on 24 May, one of the experimental loggerheads was observed rubbing against a piling (B. Higgins pers. comm.). Both PF-only attachments were shed from the turtles within 4 hours (Day 136), and one transmitter was found at the piling's base. These loggerheads had grown 1.3 and 2.2 cm SCL during 10 January-11 May (Fig. 6.8). One PF/SW attachment held until 4 June (Day 146), while the other remained secure until its removal on 22 June (Day 164). The PF/SW loggerheads grew 2.5 and 1.5 cm SCL, respectively, during 10 January-13 June 2006, and linear regression estimated average growth of all four loggerheads as 0.012 cm/d during this time period (Fig. 6.8).

PTT-outfitted loggerheads in the second attachment trial grew an average of 2.3 cm SCL (SD = 0.5 cm, n = 16, average rate = 0.022 cm/d) prior to their departure for Panama City on 17 May 2007 (Day 103), and all PTTs were attached when the turtles were placed in pens the following day. The trial was terminated on 15 June 2007 (Day 132), and all sixteen PTTs remained attached, despite increased growth rates (0.038 cm/d) in Panama City due, in part, to higher feeding rates. Overall, the PTT-outfitted individuals grew an average of 3.4 cm SCL (SD = 0.4 cm, n = 16), which was comparable to the controls ($\bar{x}$ ± 1 SD = 3.4 ± 0.8 cm, n = 4, Fig. 6.8). Linear regression estimated average growth rate of all loggerheads (n = 20) and that of all PTT-outfitted individuals (n = 16) as 0.024 cm/d during the course of the trial.

Higher loggerhead growth rates (0.045 cm/d) were recorded in the third trial (Fig. 6.8), during which two PTTs were shed (Table 6.1). Sections of PowerFast on the perimeter of one 3.0 mm neoprene attachment were unattached on 8 October (Day 81), and the PTT fell off on 11 October 2007 (Day 84, 3.7 cm SCL growth). Likewise, gaps were noticed along the perimeter of one PF-only attachment on 11 November (Day 105), and this unit came off on 23 November 2007 (Day 127, 5.4 cm SCL growth). Although no other PTTs fell off during the 213-day trial, gaps occurred along the perimeter of remaining non-neoprene attachments (beginning on Days 74, 85, and 105; Fig. 6.9), and two of the three remaining neoprene attachments became loose or unattached on the edges (beginning on Days 140 and 211), but remained secure in the center (Table 6.1). The six loggerheads with PTTs still attached on 17 February 2008 (Day 213) grew an

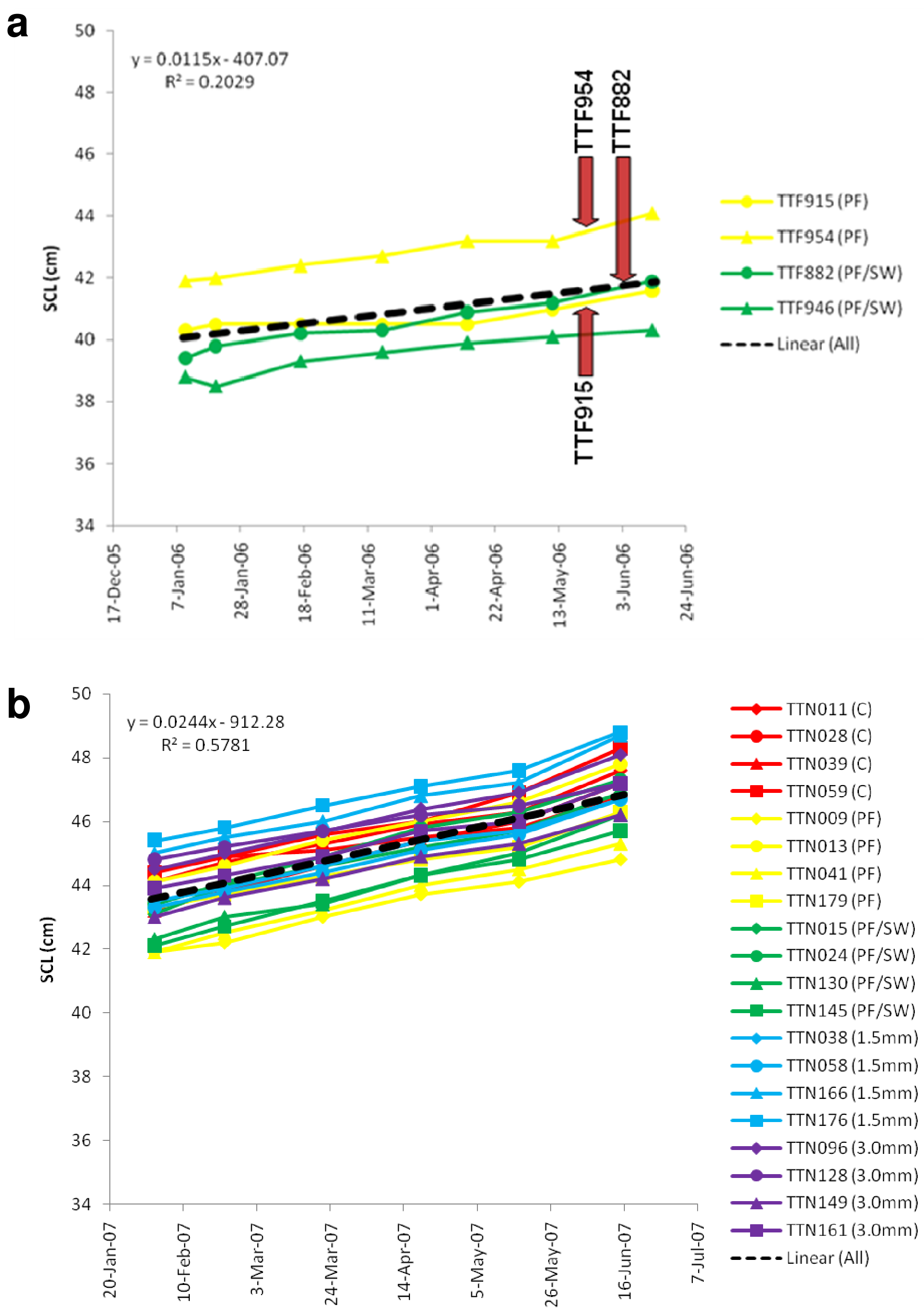

Fig. 6.8. Attachment trials. Growth of captive-reared loggerhead sea turtles in the (a) January-June 2006, (b) February-June 2007, and (c) July 2007-February 2008 attachment trials. Equations represent the best-fit linear growth function for each trial. Arrows indicate dates of PTT losses.

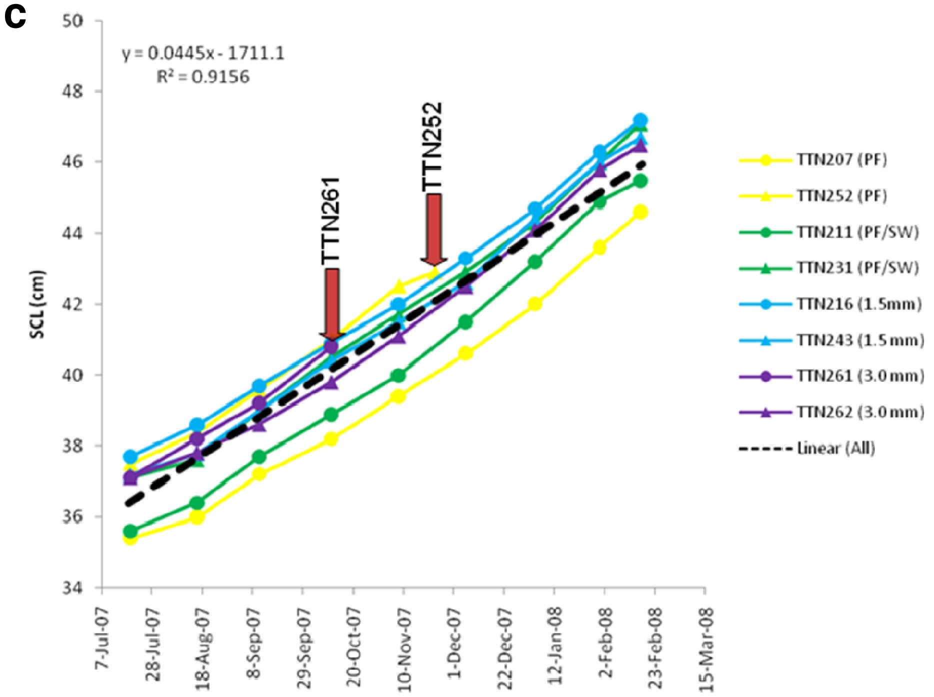

Fig. 6.8. Continued.

Table 6.1. Summary of 20 July 2007-17 February 2008 PTT attachment trial utilizing captive-reared loggerheads. Transmitter attachment: PowerFast epoxy (PF-only), PowerFast epoxy and Sonic-Weld epoxy putty (PF/SW), 1.5 mm neoprene and PowerFast (1.5 mm), and 3.0 mm neoprene and PowerFast (3.0 mm).

		PTT attachment integrity and loss				Manual PTT removal		
Flipper Tag	**Transmitter attachment**	**Date (day) gaps[1] started**	**Date (day) became loose**	**Date (day) PTT lost**	**SCL (cm) growth at PTT loss**	**Date (day) PTT removed**	**SCL (cm) growth at PTT removal**	**Removal time (sec)**
TTN207	PF	11-Oct-2007 (Day 84)	31-Jan-2008 (Day 196)	--	--	17-Feb-2008 (Day 213)	9.2	<5
TTN252	PF	1-Nov-2007 (Day 105)	--	23-Nov-2007 (Day 127)	5.4	--	--	--
TTN211	PF/SW	1-Oct-2007 (Day 74)	7-Feb-2008 (Day 203)	--	--	17-Feb-2008 (Day 213)	9.9	<5
TTN231	PF/SW	1-Nov-2007 (Day 105)	17-Feb-2008 (Day 213)	--	--	17-Feb-2008 (Day 213)	10.0	<5
TTN216	1.5 mm	--	--	--	--	17-Feb-2008 (Day 213)	9.5	~120
TTN243	1.5 mm	--	6-Dec-2007 (Day 140)[2]	--	--	17-Feb-2008 (Day 213)	9.5	<5
TTN261	3.0 mm	--	8-Oct-2007 (Day 81)	11-Oct-2007 (Day 84)	3.7	--	--	--
TTN262	3.0 mm	--	15-Feb-2008 (Day 211)[3]	--	--	17-Feb-2008 (Day 213)	9.4	~30

[1] See Fig. 6.9.

[2] All perimeter sections became loose, but center was still secure 17-Feb-2008.

[3] Left and right anterior perimeter sections became loose, but rest of perimeter and center was still secure 17-Feb-2008.

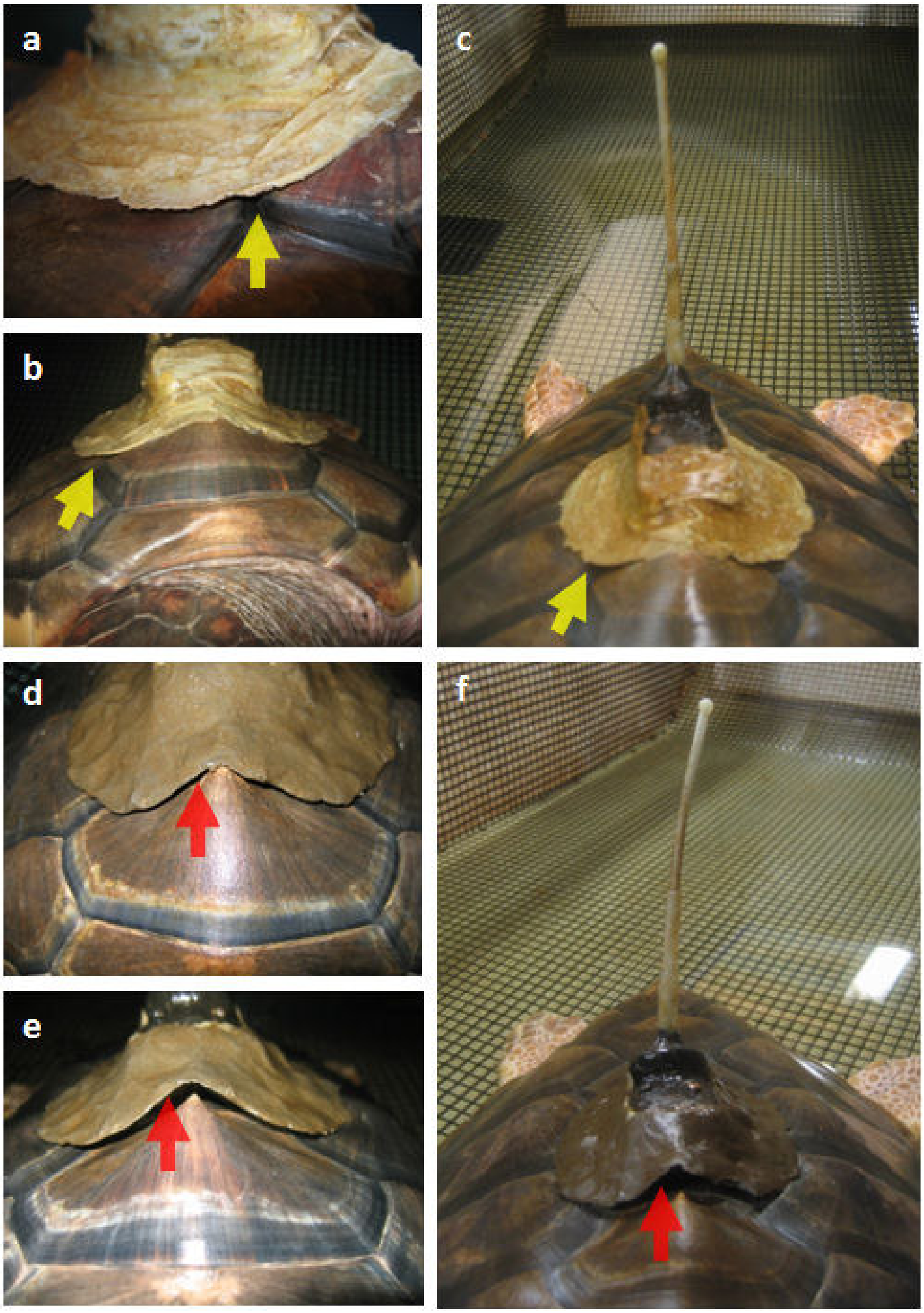

Fig. 6.9. Attachment 'gaps.' PowerFast-only attachment on TTN207 (a) 11 October 2007, (b) 1 November 2007, and (c) 15 February 2008 (9.2 cm SCL growth). PowerFast/Sonic-Weld attachment on TTN211 (d) 4 October 2007, (e) 23 November 2007, and (f) 15 February 2008 (9.9 cm SCL growth). In both series, the arrow points to the same location in each of the three images. Photos by E. Seney.

average of 9.6 cm (SD = 0.3) during the trial. Four attachments were removed manually with a plastic pry bar within 5 sec (PF-only, both PF/SW, 1.5 mm). Removal of the remaining 1.5 mm and 3.0 mm neoprene attachments took approximately 120 sec and 30 sec, respectively (Table 6.1).

TED trials. Results of the PTT-TED interaction trials are summarized in Tables 6.2-6.3. In the initial pilot study, two of eight loggerheads, one experimental and one control, failed to escape within 5 min, and were recorded as ‘captures’ (Table 6.2); however, the transmitter did not impede the experimental turtle’s passage through the trawl. The other turtles successfully escaped via the TED, but two experimental loggerheads were slowed after they encountered the TED carapace-first and their transmitters temporarily wedged between its bars. In total, five individuals encountered the TED carapace-first, whereas two hit plastron-first, and one control did not reach the TED within 5 min (Table 6.2, Fig. 6.10). The three controls that exited the TED did so in an average of 52 sec (SD = 32 sec), whereas the PTT-outfitted loggerheads did so in 127 sec (SD = 59, n = 3). The dummy transmitters, their antennae, and attachments sustained no obvious damage.

A second, larger trial was conducted to further explore potentially harmful interactions between PTT-outfitted juvenile sea turtles and TEDs. One control turtle was recorded as a ‘capture,’ whereas nine remaining controls and all PTT-outfitted turtles were excluded from the trawl. Experimental loggerheads encountered the TED in varied orientations, whereas most controls did so plastron-first (Table 6.3, Fig. 6.10). Although they eventually escaped via the TED, two individuals bearing PTTs were slowed when their transmitters wedged between the TED’s bars (Fig. 6.11). Excluding the ‘captured’ turtle, controls exited the TED in an average of 63 sec (SD = 31 sec, n = 9), as compared to 107 sec (SD = 101 sec, n = 10) for experimental counterparts. This difference was not statistically significant (t = -1.318, $p = 0.215$), but there was a significant difference between the two groups’ variances (Levene’s F = 7.551, $p = 0.014$). As in 2006, none of the dummy transmitters, their antennae, or attachments sustained obvious damage.

Table 6.2. Summay of 2006 PTT-TED interaction trial (pilot study) results.

Turtle	Transmitter attachment	Time in net (min:sec)	Turtle orientation to TED	Result
1	None (Control)	01:06	Plastron-first	Escape
2	**PowerFast only**	**01:05**	**Carapace-first**	**Escape**
3	None (Control)	01:14	Carapace-first	Escape
4	**PowerFast/Sonic-Weld**	**05:00**	**Plastron-first**	**Capture**
5	None (Control)	05:00	N/A - did not reach TED	Capture
6	**PowerFast/Sonic-Weld**	**03:03**	**Carapace-first**	**Escape**
7	None (Control)	00:16	Carapace-first	Escape
8	**PowerFast only**	**02:13**	**Carapace-first**	**Escape**

Table 6.3. Summay of 2007 PTT-TED interaction trial results.

Turtle	Transmitter attachment	Time in net	Turtle orientation to TED	Result
1	None (Control)	01:00	Carapace-first	Escape
2	**PowerFast/Neoprene**	**00:38**	**Plastron-first**	**Escape**
3	None (Control)	05:00	Carapace-first	Capture
4	**PowerFast/Sonic-Weld**	**04:54**	**Plastron-first**	**Escape**
5	None (Control)	00:44	Plastron-first	Escape
6	**PowerFast/Neoprene**	**00:14**	**Head-first**	**Escape**
7	None (Control)	01:12	Carapace-first	Escape
8	**PowerFast/Sonic-Weld**	**02:05**	**Carapace-first**	**Escape**
9	None (Control)	00:40	Carapace-first	Escape
10	**PowerFast/Neoprene**	**02:13**	**Plastron-first**	**Escape**
11	None (Control)	01:38	Carapace-first	Escape
12	**PowerFast/Sonic-Weld**	**04:20**	**Plastron-first**	**Escape**
13	None (Control)	00:46	Plastron-first	Escape
14	**PowerFast/Neoprene**	**01:55**	**Carapace-first**	**Escape**
15	None (Control)	02:04	Carapace-first	Escape
16	**PowerFast/Sonic-Weld**	**00:14**	**Head-first**	**Escape**
17	None (Control)	00:28	Carapace-first	Escape
18	**PowerFast/Neoprene**	**00:51**	**Plastron-first**	**Escape**
19	None (Control)	00:52	Carapace-first	Escape
20	**PowerFast/Neoprene**	**00:24**	**Plastron-first**	**Escape**

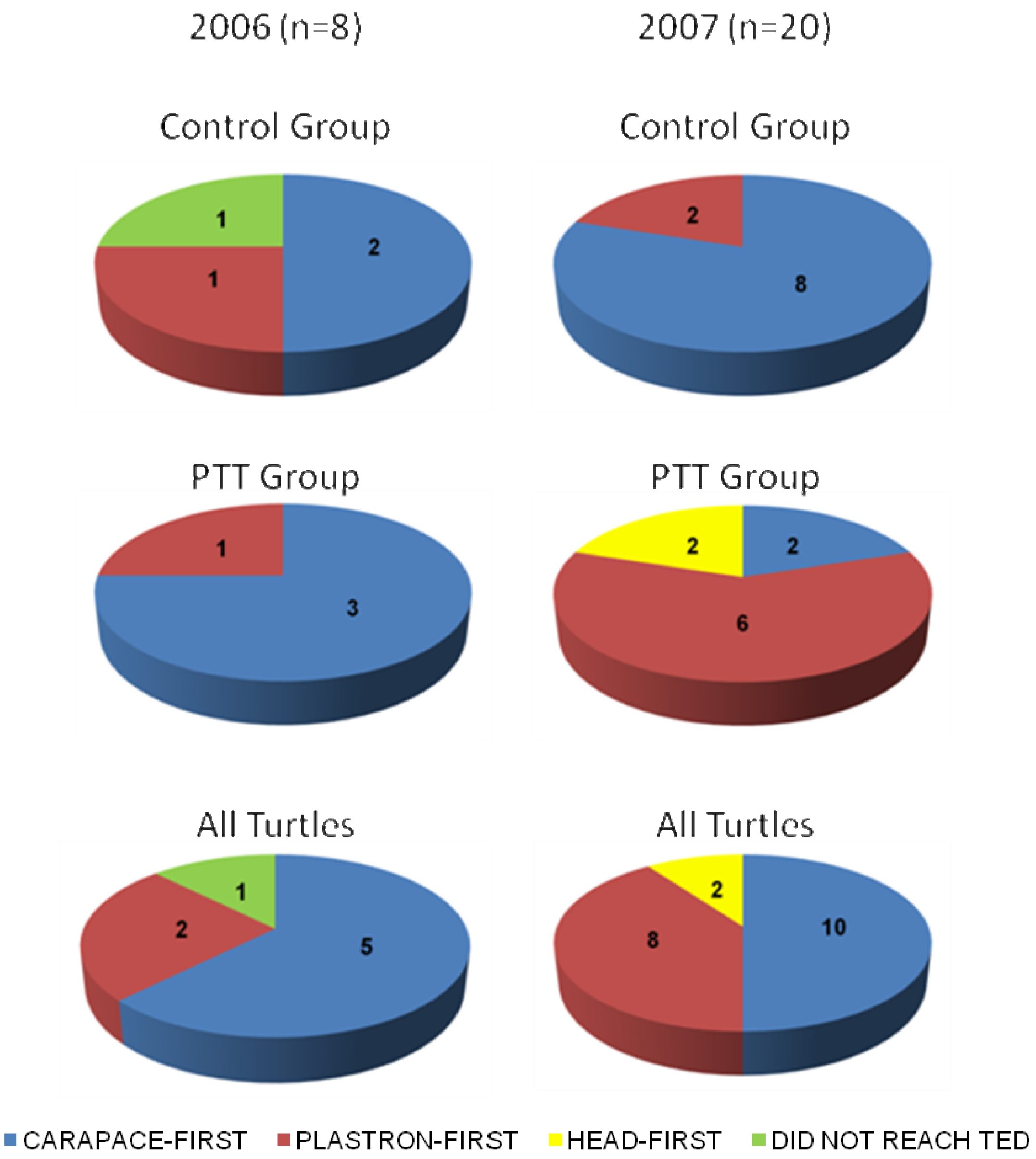

Fig. 6.10. PTT-TED interaction trials. Orientation of control and PTT-outfitted loggerheads to the TED in 2006 (left) and 2007 (right) trials.

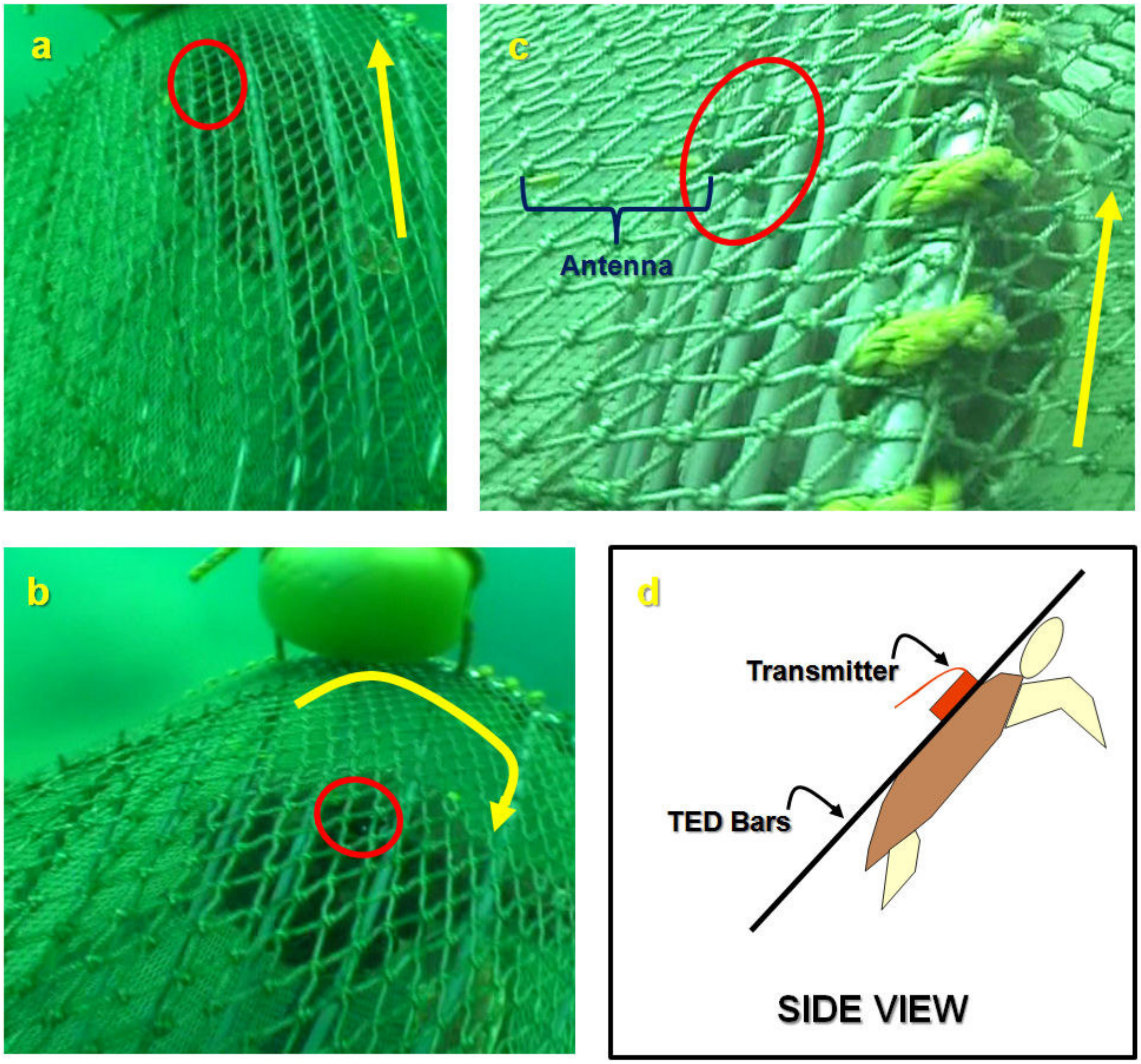

Fig. 6.11. PTT-TED interactions. Video frames of 2007 loggerhead #8 (a) with transmitter wedged between TED bars and (b) freeing itself. (c) Close-up of PTT on loggerhead #14 between TED bars. Transmitter circled in red; yellow arrow indicates direction of turtle's movement. (d) Diagram of interaction (courtesy of B. Higgins, NOAA Sea Turtle Facility).

DISCUSSION AND CONCLUSIONS

Biofouling. Qualitative examination of antifouling paints showed that a combination of spray and brush-on paints reduced the rate of biofouling more than did either treatment alone. Results of the concurrent trial conducted in Sarasota, Florida, mirrored those observed at Pelican Island, Texas, although the biofouling organisms were primarily worm tubes in Florida versus algae, acorn barnacles, and oysters at the Texas site (Tucker et al. 2007). The trial also indicated that effective inhibition of biofouling requires treatment across the entire transmitter and epoxied surfaces, as the combined treatment of PTT and epoxy was more effective than either treatment alone.

Follow-up studies are warranted, but these short, small-scale trials indicated that biofouling can present a significant concern for estuarine and marine tracking studies, particularly in waters with high turbidity. In addition to prolonging track length, prevention of epifaunal colonization will also minimize drag caused by the PTT, and thereby reduce impacts on the turtle’s swimming efficiency. Future studies should include any other common antifouling treatments appropriate for sea turtle PTTs, be conducted in additional geographical regions, and perhaps utilize functional PTTs as a final step (Tucker et al. 2007). Toxicity concerns prompted the STFERL to utilize a different, U.S. Environmental Protection Agency-approved, spray-on product (Aquaguard Alumi-Koat) in concert with the same brush-on paint (Interlux) in 2007. Although other factors may have contributed, 2007 track lengths were similar or better than those recorded with the Tempo Marine paint during 2006 (Chapter V, Hughes & Landry unpubl., Metz & Landry unpubl.), suggesting the two spray-on products are comparable in reducing at-sea biofouling.

Attachment. Dummy transmitters in the first attachment trial remained attached to juvenile loggerheads held in a captive environment for over 4 months, but questions remained as to impact of turtle growth and mechanical damage on attachment integrity in the wild. Based on this trial and the aforementioned biofouling trial, the STFERL modified its attachment techniques during the 2006 field season (Chapter V) to include Sonic-Weld and two antifouling paints. These modifications appeared to improve transmitter life on adult Kemp's ridleys tracked in the northwestern Gulf of Mexico (2006: 87-277 d, $\bar{x}$ ± 1 SD = 161 ± 82 d, n = 4; ANOVA vs. 2005: $p = 0.05$), but not on juveniles (2006: 20-57 d, $\bar{x}$ ± 1 SD = 40 ± 19 d, n = 3; ANOVA vs. 2004-2005: $p = 0.87$). Shorter than anticipated track durations have also been observed for juvenile Kemp's ridleys and green turtles along the middle and lower Texas coast (Metz & Landry unpubl.) and juvenile green turtles in Florida (A. Stamper pers. comm.).

Concerns regarding fast growth rates of juvenile sea turtles prompted efforts to improve adhesion of the epoxy and development of attachment methods incorporating neoprene in 2007. Although loggerheads in the second trial exhibited an average growth rate double that of the first, no PTTs were shed during a 4.5 month period that included a month in outdoor pens. This result suggested that better attachment site preparation and/or discarding potentially unmixed epoxy from the PowerFast mixing nozzle improved the PF-only and PF/SW methods used in the initial trial and during 2004-2006 STFERL tracking. Additionally, the experimental neoprene methods showed promise and merited further examination, given that neoprene attachments performed as well as non-neoprene methods and appeared to have stretched with the turtles' carapaces (pers. obs.).

Growth of the eight loggerheads in the third attachment trial was accelerated to an average rate nearly four times that of the first trial, and this growth appeared to cause attachment loosening and loss, as well as gaps between the adhesive(s) and carapace. The PF-only and PF/SW attachments sustained 5.4-10.0 cm growth, but gaps along the edges of these attachments initially became visible on Days 74-105. One PF-only attachment was lost 22 d after gaps appeared, whereas the other three non-neoprene attachments developed significant gaps (Fig. 6.9) along their entire perimeters and were removed with minimal effort upon termination of the third trial. In all likelihood, the three remaining non-neoprene attachments would have been shed much sooner in a natural environment, where turtles often rub on and/or sleep under hard substrates (Schofield et al. 2006, Frick & McFall 2007). This may have also been the case for the neoprene attachments, but the results suggest that carefully applied neoprene attachments have the potential to improve sea turtle track lengths. The neoprene methods successfully stretched and held during substantial carapace growth by three turtles ($\bar{x}$ = 9.5 cm SCL, SD = 0.1 cm). Although the six sections of PowerFast along the perimeters of two neoprene attachments (Fig. 6.5b) became loose, the center adhesive remained secure until the trial was terminated. Retention of three neoprene attachments suggests that loss of the fourth after only 3.7 cm growth may have occurred due to poor attachment (e.g., PowerFast cured along the scute suture line).

Seven Sirtrack KiwiSat 202s were deployed on immature Kemp's ridleys in the northwestern Gulf of Mexico in 2007 using the 3.0 mm neoprene/PowerFast attachment (Chapter V). These tracks were comparable, and in many instances better (11-106 d, $\bar{x} \pm 1$ SD = 54 ± 30 d, n = 7), than those recorded in 2004-2006 (12-57 d, $\bar{x} \pm 1$ SD = 37±17 d, n = 5), but differences were not statistically significant (ANOVA: 2004-2006 vs. 2007, $p = 0.205$). Despite this result, long-term trials on captive loggerheads indicated that further development of neoprene attachment methods may be beneficial for tracking smaller, faster-growing sea turtles. Future attachment trials should not only utilize turtles exhibiting high growth rates, but also provide natural and/or artificial substrates to determine effectiveness of neoprene and non-neoprene attachments subjected to more 'normal' turtle behavior.

TED interactions. TED trials did not result in any damage to the transmitters or attachments, but 4 out of 14 PTT-outfitted loggerheads (29%) were slowed when their PTT became wedged between TED bars. This result indicates that attachment of PTTs to smaller sea turtles can slow or, in worst cases, inhibit escape from TEDs, particularly bottom-opening configurations. Additionally, a loose or poorly secured transmitter could further impede a turtle's escape or become unattached if it got caught on or wedged between TED bars.

Orientation of PTT-outfitted turtles to the TED (Fig. 6.10) likely accounted for some of the difference in variance between the control and PTT-outfitted groups' exit times in the 2007 trial. This was exemplified by longer exit times for two experimental loggerheads encountering the TED carapace-first, as well as for two of three PTT-outfitted individuals impacting the TED in this fashion in 2006. Each of these four interactions resulted in the transmitter becoming wedged between the TED's bars, and only after periods of swimming upwards (away from the TED opening) was the turtle able to turn and free itself (Fig. 6.11). Overall, 15 of 28 loggerheads (54%) in the two trials impacted the TED carapace-first (Fig. 6.10), suggesting that conditions allowing or promoting carapace-first encounters are common. As such, researchers tracking small turtles in or near regions with shrimping activity should consider size and shape of the transmitter, the adhesives(s), and their combined footprint in order to minimize potentially detrimental interactions with TEDs.

RECOMMENDATIONS

Biofouling. Antifouling paints should be used to cover all non-metal surfaces of the PTT and surrounding adhesive to inhibit epifaunal growth that can cause loss of transmissions from tracked sea turtles. Here, a combination of spray- and brush-on antifouling paints was most effective at keeping the PTT and surrounding epoxy free of fouling, but covering all but the saltwater switches and antenna with brush-on paint may also provide similar benefits. Researchers who are unsure as to whether antifouling paints are necessary may wish to submerge dummy units to determine the region's potential for fouling during their tracking season(s).

Attachment. To increase bonding strength, the PTT attachment site and transmitter should be sanded with very coarse sandpaper (e.g., 60-grit) and properly cleaned prior to application of any adhesives. For attachments utilizing PowerFast epoxy, the initial 'squeezes' of epoxy from the mixing nozzle should be discarded to ensure proper curing. These steps should be employed for any size sea turtle, whereas a 'stretch-able' attachment may be useful in acquiring longer tracks from smaller, faster-growing individuals. The neoprene methods described above should be further investigated to determine their full utility, and improvements should be made as appropriate.

TED interactions. To minimize the potential for PTT-TED interactions that impact a satellite-tagged turtle's exclusion, adhesive should be applied around the transmitter to cover a larger surface area and decrease the slope between the PTT and carapace and/or a PTT design with a lower profile should be employed on smaller turtles.

CHAPTER VII

KEMP'S RIDLEY SEA TURTLE DIET ALONG THE UPPER TEXAS COAST

INTRODUCTION

Differences among life history stages, morphology, and prey availability often dictate sea turtle feeding strategies, as well as their geographical and temporal distributions. Kemp's ridley hatchlings from Tamaulipas, Mexico, nesting beaches are assumed to swim offshore during their 'frenzy' and become entrained in the anticyclonic Mexican Current, (Collard & Ogren 1990, Musick & Limpus 1997), while counterparts originating from the Texas coast likely encounter a cyclonic gyre north of the Mexican current (see Fig. 1 in Collard & Ogren 1990, Fig. 3 in Musick & Limpus 1997). All western Gulf hatchlings are probably transported in an easterly direction along the zone where the anticyclonic and cyclonic gyres meet, and some are swept into the northwestern Atlantic Ocean by the Florida Current (Collard & Ogren 1990). Once entrained by such currents, Kemp's ridley hatchlings probably become passive drifters within mats of *Sargassum* spp. (Collard & Ogren 1990), where they feed on pelagic molluscs and crabs, as well as *Sargassum* (Shaver 1991). An ontogenetic shift occurring at about 20-25 cm SCL, or about 2 years of age, induces small juveniles to leave pelagic *Sargassum* mats for coastal areas along the northern Gulf of Mexico and the northwestern Atlantic and forage on benthic invertebrates (Ogren 1989, Schmid & Witzell 1997, Landry & Costa 1999, Snover et al. 2007). Diet characterization, therefore, can be utilized to determine life history stage, in addition to important prey types for each stage.

Texas ridley diet. Shaver (1991) found crabs in 75% of dead stranded headstarted ridleys ($n = 51$, $\bar{x} \pm 1$ SD = 23.3 ± 0.8 cm curved carapace length, CCL) and 80% of wild conspecifics ($n = 50$, $\bar{x} \pm 1$ SD = 43.3 ± 2.2 cm CCL) in south Texas during 1983-1989. *Arenaeus cribrarius* (speckled swimming crab), *Callinectes sapidus* (common blue crab), *Persephona mediterranea* (mottled purse crab), and *Libinia* spp. (spider crab) were the crabs most frequently consumed by wild individuals 20-71 cm

CCL. Headstarted ridleys consumed greater amounts of molluscs, shrimp, and fish but fewer crab species than similar-sized wild individuals; however, overall diet suggested they were adapting to feeding in the wild (Shaver 1991).

Crabs, including *Callinectes* spp. and *Menippe* spp. (stone crab), were observed frequently and comprised the highest portion of total dry weight (62%) among 86 fecal samples from 71 wild (21.6-59.5 cm SCL) and 11 headstarted (26.0-35.9 cm SCL) ridleys captured at Sabine Pass, Texas, during April-November 1993 (Werner 1994). Frequency of occurrence of both crabs and molluscs increased with SCL, whereas occurrence of fish, vegetation, and debris was similar among size classes. No significant difference was detected in the diet of similar-sized (26.0-35.9 cm SCL) headstarted (n = 11) and wild cohorts (n = 27).

Gross diet examinations conducted on 176 stranded ridleys from the upper Texas and western Louisiana coasts in 1994 determined that 42% of gastrointestinal (GI) tracts contained fish, whereas crabs occurred in 40% (Cannon 1998). Additionally, anthropogenic items, including plastic and fishing hooks, were found in 9%. In contrast, the 1993 Sabine Pass study (Werner 1994) reported human debris in 45% of fecal samples (n = 86), while Shaver (1991) found anthropogenic items in the GI tracts of 23% of headstarted ridleys (n = 51) and 34% of wild conspecifics (n = 50) stranding in south Texas.

Florida Gulf coast diet. Fecal samples were utilized to examine the diets of Kemp's ridleys foraging within Florida's Cedar Keys (Schmid 1998) and Ten Thousand Islands (Witzell & Schmid 2005). Twelve samples collected in the Cedar Keys during 1986-1995 (SCL not reported) all contained crab, including blue and stone crab, whereas 64 immature ridleys ($\bar{x}$ ± 1 SD = 41.4 ± 5.8 cm SCL) encountered in the Ten Thousand Islands during 1999-2002 exhibited a preference for tunicates (*Molgula occidentalis*), as well as spider and purse crab.

U.S. Atlantic coast diet. Diet studies comprised of relatively large sample sizes have also been conducted on ridleys in New York, Virginia, and Georgia. The diets of small juveniles from Long Island, New York, were evaluated during 1985-1989 (Burke et al. 1993, Burke et al. 1994) using whole GI tracts from strandings (n = 18, $\bar{x}$ ± 1 SD = 30.5 ± 3.5 cm SCL) and fecal samples from ridleys caught incidentally in poundnets (n = 19, $\bar{x}$ ± 1 SD = 32.3 ± 4.9 cm SCL). Crustaceans accounted for the vast majority of prey items, with two walking crabs, the portly spider crab (*Libinia emarginata*) and Atlantic rock crab (*Cancer irroratus*), encountered most frequently.

Examination of gross necropsy reports, fecal samples, and whole GI tracts indicated immature Kemp's ridleys (n = 59; $\bar{x}$ ± 1 SD = 36.0 ± 8.6 cm SCL) encountered in Virginia during 1983-2002 preferred crabs, especially *Callinectes* spp. and *Libinia* spp. (Seney & Musick 2005). No inter-annual variation in diet was detected, but there were indications of seasonal variation, with ridley diet more diverse during May-July than August-October.

Stranded Kemp's ridleys ranging in size from small juveniles to adults primarily consumed 'shallow water inhabitants' along the northern Georgia coast during the mid-1990s (Creech & Allman 1997, Frick & Mason 1998). These prey included blue crabs, stone crabs, spider crabs, benthic finfish, and Carolina diamondback terrapin (*Malaclemys terrapin centrata*). Conspecifics stranding in southeastern Georgia ate a variety of gastropods and bivalves, as well as calico box crabs (*Hepatus ephiliticus*) and spider crabs (Creech & Allman 1997).

OBJECTIVES

Kemp's ridleys utilize the northwestern Gulf of Mexico seasonally as a developmental area and foraging ground (Landry & Costa 1999, Landry et al. 2005), with this distribution dictated in-part by food availability. As such, diet characterization can generate a better understanding of the species' ecology and thereby improve management schemes. A dietary analysis of Kemp's ridleys encountered along the upper Texas coast (UTC) was conducted:

(1) To characterize Kemp's ridley diet in the region.

(2) To examine feeding strategies (pelagic vs. benthic) among individuals.

MATERIALS AND METHODS

Fecal samples were opportunistically collected from wild Kemp's ridleys held in captivity at the NOAA Sea Turtle Facility in Galveston, Texas, during 2005-2007. These 19 ridleys included primarily incidental recreational hook-and-line captures, as well as live strandings and one dredge relocation trawl capture. Apart from hook or entanglement injuries, sampled individuals exhibited no signs of recent trauma, disease, or malnutrition. Each ridley was housed individually in an appropriately sized tank, which was checked for feces prior to daily cleaning. Fecal samples were collected within 72 hours of capture (Burke et al. 1994), and each was washed in a 0.5-mm (#35) brass sieve and preserved in 10% freshwater formalin for subsequent examination (Seney & Musick 2005).

Food items were identified to the lowest possible taxonomic level. Counts of individual prey items were estimated where appropriate, although it was recognized that a fecal sample does not constitute a standardized sample unit as compared to a whole GI tract (Burke et al. 1994, Seney & Musick 2005). Likewise, it should be noted that analysis of feces may result in some bias because undigested, excreted material is not likely to include gelatinous prey or other soft-bodied animals. Percent frequency of occurrence (%F) was calculated for each prey type, as well as for general prey groups: crustaceans, molluscs, echinoderms, annelids, fish, and plants.

Ridley SCLs were compared with one-way analysis of variance (ANOVA), whereas correspondence analysis (CA), a multivariate ordination technique, was utilized to identify any diet trends. The CAs incorporated prey count data for perceived target prey types: all crabs, Atlantic moon snails, worm tubes, and fish. Small molluscs (<1cm), sand dollar (*Echinarachnius parma*) fragments, and shell hash were assumed to be consumed incidentally from the benthos or as gut contents of other prey items (Plotkin et al. 1993, Seney & Musick 2007). Presence/absence of *Sargassum* in each sample was included to prevent exclusion of turtles for which this was the only food item; however, because presence/absence data are not typically used in CA (Greenacre 2007), the analyses were repeated without *Sargassum*. Trends identified by CA were further examined by performing two-way ANOVA on %F values for (1) general prey groups and (2) target prey. Both CA and ANOVA were conducted in Minitab 15, and values of %F were transformed according to Krebs (1989) prior to ANOVA:

$$\%F\text{-transformed} = \arcsin\sqrt{(\%F/100)}.$$

ANOVA was utilized in favor of multiple analysis of variance (MANOVA) because of small sample sizes (Seney & Musick 2005). A significance level of $p < 0.05$ was used in all tests.

RESULTS

Fecal samples were collected from 17 immature ridleys (18.6-41.2 cm SCL, $\bar{x} \pm 1$ SD = 32.3 ± 5.5 cm) encountered in Galveston County, Texas as recreational hook-and-line captures (n = 15) or strandings (n = 2) during 2005-2007 (Fig. 7.1). Samples were also collected from a subadult (58.2 cm SCL) that stranded in Matagorda County and an adult female (62.8 cm SCL) captured offshore Jefferson County. Overall, the sampled ridleys averaged 35.2 cm SCL (SD = 10.3).

At least 7 crab species, 12 mollusc species, tubes from 2 worm species, 1 echinoderm, and 1 bony fish were found in fecal samples (Table 7.1). Over half (53%) of the samples contained blue crab and/or *Callinectes* spp., while other common prey included calico box crab, hermit crabs (primarily *Pagurus* spp.), and polychaete worm tubes (Fig. 7.2). Moon snail shells were only found in samples containing hermit crabs, and in one instance, a crab was still in the shell. *Sargassum* occurred in 53% of samples, whereas 58% contained shell hash and/or rocks, and 21% contained terrestrial plants (Table 7.1). Samples from five ridleys ranging from 26.1-41.2 cm SCL contained both *Sargassum* and bottom material, suggesting surface and bottom feeding within relatively short periods of time. Anthropogenic debris was consumed by two ridleys, and mullet (*Mugil* sp.), a common bait, was consumed by another. Although not included in the fecal samples, seven hook-and-line caught turtles swallowed hooks, whereas the other

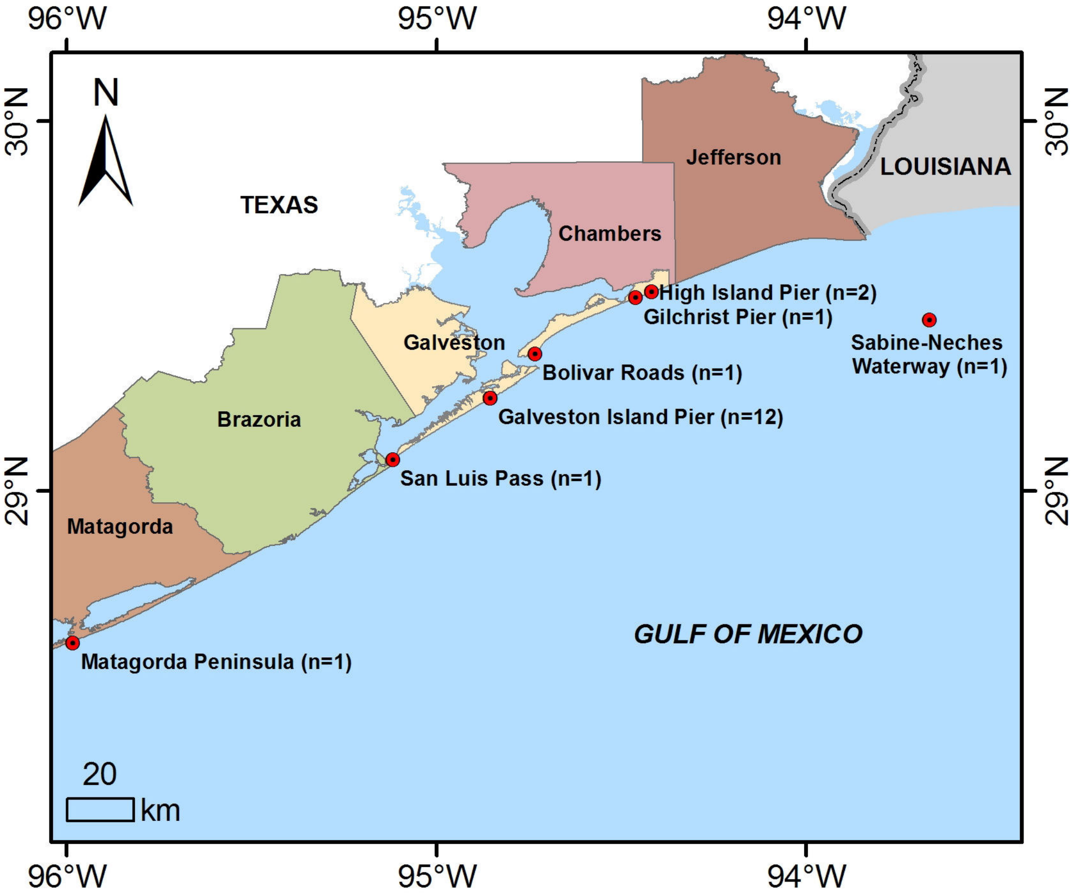

Figure 7.1. *Lepidochelys kempii.* Capture and stranding locations of Kemp's ridleys from which fecal samples were collected. Strandings originated from a Galveston Island pier (n = 2) and the Matagorda Peninsula (n = 1), whereas 1 ridley was captured by a dredge relocation trawl at the Sabine-Neches Waterway, and the 15 remaining individuals were hook-and-line captures.

Table 7.1. Frequency of occurrence (%F) of all prey items found in Kemp's ridley fecal samples collected along the upper Texas coast (n = 19, SCL: 35.2 ± 10.3 cm) during 2005-2007.

		%F
Crustaceans		**63.2**
Common blue crab	*Callinectes sapidus*	26.3
Unidentified portunid crab	*Callinectes* spp.	26.3
Calico box crab	*Hepatus ephiliticus*	21.1
Longnose spider crab	*Libinia dubia*	5.3
Lady crab sp.	*Ovalipes* sp.	5.3
Flatclaw hermit crab	*Pagurus pollicaris*	10.5
Unidentified hermit crab	--	10.5
Mottled purse crab	*Persephona mediterranea*	15.8
Molluscs		**47.4**
Blood ark	*Anadara ovalis*	5.3
Transverse ark	*Anadara transversa*	5.3
Ark sp.	*Anadara* sp.	10.5
Sawtooth penshell	*Atrina serrata*	5.3
Cerith sp.	*Bittium* sp.	26.3
Angelwing	*Cyrtopleura costata*	10.5
Wentletrap sp.	*Epitonium* sp.	5.3
Dwarf surfclam	*Mulinia lateralis*	5.3
Mottled dog whelk	*Nassarius vibex*	5.3
Atlantic moon snail	*Neverita duplicata*	10.5
Auger sp.	*Terebra* sp.	5.3
Unidentified bivalve	--	10.5
Unidentified gastropod	--	5.3
Unidentified mollusc (shell hash)	--	21.1
Annelids		**21.1**
Plumed worm (tube only)	*Diopatra cuprea*	21.1
Unidentified worm tube	--	5.3
Echinoderms		**10.5**
Sand dollar	*Echinarachnius parma*	10.5
Fish		**5.3**
Mullet sp.	*Mugil* sp.	5.3
Plants		**57.9**
Gulfweed spp.	*Sargassum* spp.	52.6
Unidentified marine plant	--	5.3
Terrestrial plant matter	--	21.1
Other		**21.1**
Aluminum	--	5.3
Candy wrapper	--	5.3
Feather	--	10.5
Rocks	--	10.5

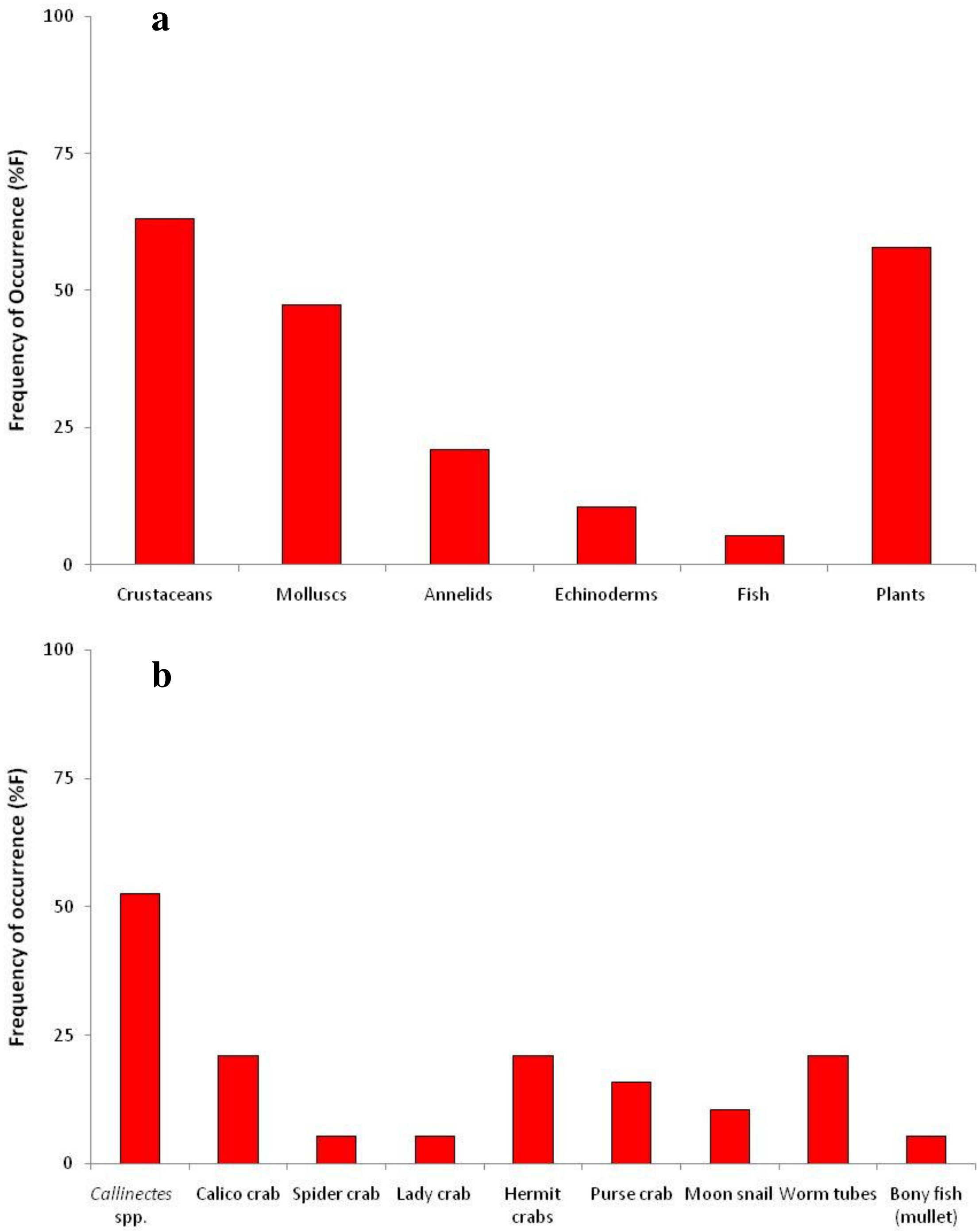

Figure 7.2. *Lepidochelys kempii.* Frequency of occurrence of (a) general prey groups and (b) target prey items in fecal samples collected along the upper Texas coast during 2005-2007 (n = 19).

eight were hooked in the mouth or jaw. Hooks were baited with shrimp, squid, mullet, and unidentified bony fish, and in no instance was crab documented as a bait.

All samples excepting one comprised of only mullet grouped together along Component 1 in a preliminary CA (Fig. 7.3a). Removal of this outlying sample separated the remaining prey types into three groups along Component 1: (1) *Sargassum* spp. and worm tubes, (2) *Callinectes* spp. and hermit crabs, and (3) moon snails and the remaining crab species (Fig. 7.3b). Repeating these two analyses with *Sargassum* spp. excluded from the CA did not significantly affect the results (Fig. 7.3c-d).

Three potential factors impacting diet differences, SCL, geographical region, and year, were examined using ANOVA. One-way ANOVAs comparing SCL indicated there were no significant size differences between (1) all 19 sampled ridleys and the 17 Galveston County turtles ($p = 0.299$) or (2) the 9 ridleys in 2006 and 8 in 2007 ($p = 0.880$). Likewise, two-way ANOVA indicated that there were no significant differences between general prey group or target prey %F for either pairing: (1) prey groups, $p = 0.398$ and target prey, $p = 0.058$ and (2) prey groups, $p = 0.295$ and target prey, $p = 0.051$. Lack of any significant difference among groups validated CA examination of the whole data set together, and no further CA was warranted.

DISCUSSION AND CONCLUSIONS

Although sample size was small, crabs were clearly important components of Kemp's ridley diet along the UTC. A portunid (i.e., swimming crab), the common blue crab, was the most common crab species, whereas hermit crabs, calico crabs, and purse crabs, all 'walking' crabs, were also observed relatively frequently. Molluscs did not appear to be target prey items, with only moon snail shells inhabited by hermit crabs and various shell fragments ingested during the course of benthic foraging. Crab-rich diets have also been reported for Kemp's ridleys in New York (Burke et al. 1993, Burke et al. 1994), Virginia (Seney & Musick 2005), Georgia (Creech & Allman 1997, Frick & Mason 1998), west-central Florida (Schmid 1998), the northwestern Gulf of Mexico (Werner 1994, Cannon 1998), and south Texas (Shaver 1991).

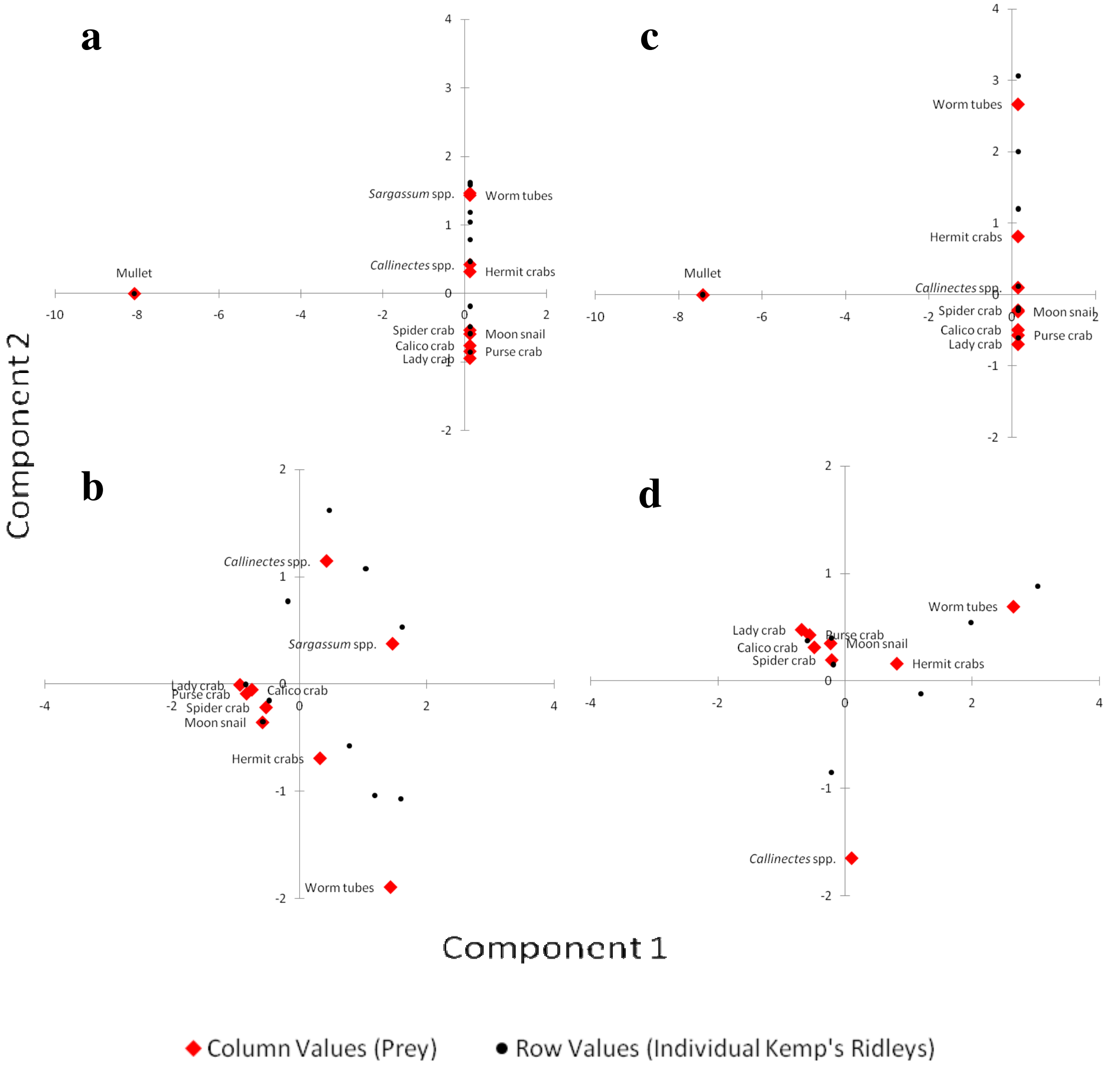

Figure 7.3. *Lepidochelys kempii.* Biplots of correspondence analyses (CA) conducted using prey counts for target prey items in fecal samples. (a) included all samples and all target prey types plus *Sargassum* spp., (b) excluded bony fish and one turtle that consumed only this prey type, (c) excluded *Sargassum* spp. and four samples that included only this prey type, (d) excluded both bony fish and *Sargassum* spp. and the five associated samples.

Worm tubes, and presumably the polychaetes that inhabited them, were also targeted by some ridleys, as has been observed elsewhere in the Gulf of Mexico. Large-scale studies in southwestern Florida (Witzell & Schmid 2005), Sabine Pass (Werner 1994), and south Texas (Shaver 1991) found unidentified worm tubes in 41, 21, and 4% of samples, respectively. The south Texas study (Shaver 1991) also observed a 6% frequency of occurrence for the plumed worm, *Diopatra cuprea*, which was found in 21% of samples in the current study.

Multivariate analyses, as well as presence of both *Sargassum* and bottom material in five samples, suggest that the UTC serves as habitat for new recruits transitioning from the pelagic stage to neritic, benthic feeding. Larger samples sizes are necessary to further elucidate dietary patterns, but trends observed in CA biplots suggest that Kemp's ridleys shifting from pelagic foraging may initially consume worm tubes prior to focusing on crabs (Fig. 7.3b, d). This strategy of foraging on sessile prey prior to motile prey is consistent with observations of small ridleys in New York feeding on slower, walking crabs (Burke et al. 1993, Burke et al. 1994), as compared to larger conspecifics found further south, which feed more often on faster, swimming crabs (Shaver 1991, Werner 1994, Seney & Musick 2005).

The transition from pelagic to benthic feeding may continue past the 20-25 cm SCL size range, as evidenced by ridleys 18.6-41.2 cm SCL consuming *Sargassum*, although it is possible that some plant matter was also consumed nearshore as benthic detritus. Over half of the ridleys (53%) sampled on the UTC during 2005-2007 had consumed *Sargassum*, falling between the results of the Sabine Pass study (70%F, Werner 1994) and the south Texas study (29%F, Shaver 1991). ANOVA indicated a nearly significant difference ($p = 0.051$) between UTC target prey species between 2006 and 2007, but larger samples sizes from more years are needed to further examine inter-annual trends, as well as the impact of SCL, if any, on diet composition.

Coastal waters along the UTC are nutrient-rich and thereby able to support relatively large populations of the benthic crustaceans consumed by Kemp's ridleys (Metz 2004). Abundant crab populations make the UTC an important developmental foraging ground for immature ridleys, which are capable of high growth rates and may reach maturity around age 10 (Snover et al. 2007). Human activities probably provide additional food sources beyond the UTC crab populations. Although, the samples presented above were biased towards ridleys captured on recreational hook-and-line gear, many of these turtles consumed crabs and tube worms, whereas only one sample contained fish. Undoubtedly, hook-and-line caught ridleys were attracted to hooks baited with fish, squid, and shrimp, but associations with fishing piers may have also been dictated by invertebrate communities living on or near the structural supports of the piers (Stewart 1983, Glasby & Connell 1999). Similar associations have been inferred for loggerhead sea turtles displaying fidelity to offshore oil platforms (Renaud & Carpenter 1994, Gitschlag et al. 1997), which support a host of invertebrates (Ellis et al. 1996). Additional anthropogenic food sources may occur in the form of unwanted bait and catch discarded by recreational anglers, as well as shrimping bycatch (Shaver 1991). Fecal samples examined here, however, showed little evidence of this type of feeding in that only one contained fish, and none contained squid or shrimp. Likewise, the only sample that included the snail *Nassarius vibex*, a common scavenger, contained other benthic prey (hermit crab, worm tubes), rather than potential fishery discards.

In addition to providing foraging opportunities, the UTC puts ridleys at risk for interactions with human activities, as evidenced by samples containing aluminum, a candy wrapper, and mullet, a common bait. Likewise, none of the 15 hook-and-line captured ridleys sampled on this study was caught on an artificial lure or was foul-hooked, suggesting that these individuals were targeting baited hooks as a foraging behavior. The impacts of anthropogenic factors, such as debris ingestion and interactions with recreational fishing, within the UTC developmental habitat should be reviewed by managers to ensure the species' recovery. This assessment is especially important given that the Kemp's ridley is theoretically experiencing exponential population growth (Heppell et al. 2007), which should increase the number of immature ridleys utilizing the UTC. Additionally, effects of fluctuations in the blue crab population and its commercial fishery on the growing ridley population should be assessed, as should the impacts of variable shrimping effort and associated bycatch discards. Further characterization of diet will allow for better understanding of the species' ecology and potentially lethal anthropogenic interactions, and ultimately aid in the management and recovery of the Kemp's ridley.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Habitat use. Examinations of hook-and-line capture, stranding, and nesting records, satellite telemetry, and diet analyses confirmed that the critically-endangered Kemp's ridley sea turtle utilizes the UTC and northwestern Gulf of Mexico throughout its life history. The region was used seasonally as developmental and nesting habitat, as well as a migration and foraging corridor, during 2004-2007. Small juveniles recruited to nearshore Texas waters, where they foraged on benthic food items. Immature ridleys (24-45 cm SCL) were found along the UTC primarily throughout warmer months (March-October), whereas UTC nesters occupied the region during nesting season (April-July). Immature ridleys and inter-nesting conspecifics occurred in relatively shallow, nearshore Texas state waters, and post-nesting females subsequently migrated through deeper, federal waters. Juveniles also entered inshore areas, such as bays and coastal lakes, along the Texas and Louisiana coasts. Immature and adult female ridleys primarily inhabited waters 24-32 C, and SST values varied by month, but not with life history stage.

UTC nesters exhibited fidelity to the Galveston area during the nesting season. Nesting occurred along much of Galveston Island, along most of the beach profile, and on both armored and unarmored beaches. Inter-nesting movements occurred primarily in nearshore waters (<10 m), and females departed the Galveston area after laying up to three clutches. Females then migrated along the 20-m isobath to federal waters offshore Louisiana, establishing home ranges at depths of 20-60 m. Tracked females established significantly larger core areas of activity ($\bar{x} \pm 1$ SD = 1,644 km^2 ± 668 km^2, n = 6) than did immature individuals ($\bar{x} \pm 1$ SD = 919 ± 825 km^2, n = 11), and this difference was not related to track duration. Maintenance of large core activity areas may have been a response to prey availability and/or water temperature.

Immature ridleys exhibited a preference for shallow (<10 m), nearshore areas along the UTC and western Louisiana coasts, but no distinct foraging 'hotspots' were pinpointed during 2004-2007 tracking. Few tracked individuals returned to their original capture location, and low numbers of within and between year tag returns were recorded. These data suggest that immature ridleys exhibit a preference for habitat type or prey concentrations, rather than specific locations, in the northwestern Gulf of Mexico. Track durations were not long enough to examine seasonal migration patterns of immature individuals.

Anthropogenic interactions. Use of the northwestern Gulf of Mexico as foraging and nesting habitat poses a number of anthropogenic threats to the Kemp's ridley. Approximately a third of non-nesting ridley records from the UTC involved hook-and-line capture, of which a third swallowed hooks. Foraging near recreational fishing areas not only exposes ridleys to potentially fatal hook interactions, but also puts them at risk for entanglement in or ingestion of fishing gear and other anthropogenic debris (Lutcavage et al. 1997, Frazier et al. 2007). Ridleys are also at risk for interactions with commercial fisheries, oil spills, and boat strikes in upper Texas and Louisiana coastal waters (Magnuson et al. 1990, Lutcavage et al. 1997, NMFS 2001, Frazier et al. 2007).

Diet of benthic stage ridleys may put the species at risk for indirect interactions with commercial fisheries. The ridley's preferred food item on the UTC, blue crab, is commercially exploited (More 1969, Hammerschmidt et al. 1998), and it may also be taken as bycatch in other fisheries (Harrington et al. 2005). Declines in blue crab populations and other natural prey items could precipitate diet shifts to anthropogenic food sources, such as baited hooks, discarded shrimp bycatch, and actively fishing nets and traps (Shaver 1991, Seney & Musick 2007). Such a shift would expose ridleys to direct interactions with fisheries, and thereby to hooking, entanglement, and drowning risks.

Nesting females and their clutches face additional anthropogenic threats on land including beach driving and habitat alteration from beach development, raking, armoring, and renourishment (Lutcavage et al. 1997). Sea-level rise may decrease available nesting habitat (Baker et al. 2006), and undetected nests left in situ may also be threatened by high tides and heightened erosion precipitated by beach development and armoring (Ravens & Sitanggang 2007). Predators introduced by or associated with humans, including fire ants, raccoons, and dogs, pose additional risks to both nests and hatchlings (Lutcavage et al. 1997).

Satellite tracking protocols. Relatively short track durations in 2004-2005 precipitated the need to examine potential impact of biofouling, attachment methods, and transmitter-TED interactions. Although Kemp's ridleys rarely host large amounts of epibiota, the warm, nutrient-rich waters of the UTC promoted growth on transmitters that could inhibit or cease transmissions. Integration of spray-on and brush-on antifouling paints into attachment protocols drastically reduced this growth.

Loss of transmitters applied with rigid adhesives was also identified as a potential factor causing shorter tracks from smaller, faster-growing ridleys. A less-rigid attachment technique incorporating neoprene was effective at withstanding high growth rates in captive-reared loggerheads, but no significant differences were recorded for track durations on wild ridleys.

Interactions between transmitter-outfitted sea turtles and TEDs were noted in trials conducted with captive-reared loggerheads. No transmitters were lost or damaged, but turtles encountering the TED carapace-first exhibited increased escape times when transmitters wedged between the TED's bars. In addition to posing a threat to the turtle, this interaction could also precipitate loss of a loose or poorly-adhered transmitter.

RECOMMENDATIONS

Research. Results discussed in preceding chapters identified general distribution and movement patterns for immature and adult female ridleys encountered along the upper Texas coast during March-October. Data and tracked animals were acquired primarily by opportunistic means, through public reporting of nesting, stranded, and hook-and-line caught individuals in the Galveston area. Future research should expand upon these methods and examine year-round distribution and abundance of all life history stages through both opportunistic reports and directed surveys. Specific areas which warrant attention along the UTC include:

- **Examination of recreational hook-and-line capture of sea turtles.** Protocols should be expanded to target not only pier-based fishing, but also surf, bay, and offshore anglers, to determine the extent of these interactions and gain insight to sea turtle distribution.
- **Identification of all sea turtle nesting habitat.** Cooperation and coordination among universities and state and federal agencies are necessary to determine the level of nesting activity and characterize habitat preferences in Brazoria, Galveston, Chambers, and Jefferson County through daily patrols during the nesting season. Heightened patrols will also allow for interception of nesting females across these counties, thereby permitting characterization of nesting female origin (i.e., wild or headstart) and tracking opportunities. Additionally, readily identifiable patrollers will enhance public education and awareness.
- **Examination of in-water distribution of benthic stage individuals.** Adult males and subadults are largely absent from UTC datasets, but in-water surveys are necessary to determine whether they utilize habitats frequented by juveniles and adult females. Entanglement netting and trawling should be used in conjunction with stranding, hook-and-line, and nesting data to examine seasonal distribution and abundance patterns among life stages.
- **Long-term movements of all benthic life stages.** Longer track durations are necessary to determine seasonal foraging and migration patterns. Attachment methods should be developed to facilitate longer tracks on juveniles, whereas less-studied segments of the population (subadults, adult males) should be targeted.
- **Diet monitoring.** Further characterization of diet will determine regional food preferences, as well as the extent to which different life stages forage on commercially-exploited species and anthropogenic food items (i.e., bycatch and

bait). Direct and indirect interactions with fisheries, extent of anthropogenic debris ingestion, and dietary shifts can be identified with large-scale collection of diet samples from live and dead individuals.

Public education. Development and tourism are widespread along the UTC, especially in Galveston County. As the ridley population increases, beachgoers, anglers, and boaters are more likely to encounter and possibly interact with turtles both on land and at sea. Widespread public education efforts are necessary to minimize negative anthropogenic interactions and to promote reporting of nesting, hook-and-line-caught, debilitated, and dead sea turtles. Sea turtles are widely recognized as 'charismatic megafauna,' so education efforts can also have a broader effect on marine and coastal ecosystems by encouraging residents and tourists to be more ecologically sensitive in their activities (Campbell 2003). Increased public awareness and preservation of sea turtles and their habitats can also facilitate responsible ecotourism ventures. Successful ecotourism, in turn, provides economic incentives to continue conservation, preservation, and education efforts by giving local businesses, governments, and residents a vested interest in sea turtle survival.

Public education efforts along the UTC should include:

- Wide-scale dissemination of information regarding sea turtle reporting, including media such as posters, signs, billboards, press releases, and public service announcements.
- Training of federal, state, and local government employees who are likely to encounter sea turtles during the course of their jobs, including law enforcement officers, park staff, lifeguards, and beach clean-up crews.
- Campaigns targeting the beach-going public and beachfront communities, hotels, and condos regarding sea turtle reporting, proper disposal and recycling of waste, and minimizing impacts of lighting, permanent structures, and beach furniture on nesters and emerging hatchlings.

- Campaigns targeting anglers, pier operators, and offshore fishing charters regarding recreational hook-and-line capture of sea turtles. Land-based anglers and piers should be instructed to safely land and report hooked turtles for retrieval, whereas those fishing offshore should be trained in handling, release, and reporting protocols. These efforts should also emphasize proper disposal or recycling of fishing gear.

Management. The northwestern Gulf of Mexico serves as an important developmental habitat and migratory corridor, as well as a minor nesting area, for the Kemp's ridley. Sufficient evidence exists (Magnuson et al. 1990, USFWS & NMFS 1992, Lutcavage et al. 1997, NMFS 2001) to suggest that use of shallow Gulf waters by ridleys exposes them to mortality risks that include, but are not limited to: (1) incidental capture in commercial and recreational gear, such as shrimp trawls and hook-and-line; (2) entanglement in and/or ingestion of discarded fishing line and other debris; (3) collision with boats and other water craft; (4) interaction with channel maintenance and other hopper dredging operations; and (5) contact with oil spills and toxic dinoflagellate blooms (i.e., 'red tide'). Projected population increases (Heppell et al. 2007) for the Kemp's ridley sea turtle will likely result in increased use of the northwestern Gulf by the species, and, in turn, more frequent encounters with human activities. The extent of these interactions and any need for mitigation measures or new regulations should be examined and considered by state and federal managers to facilitate the continued recovery of this and other sea turtle species in the Gulf of Mexico. Specific issues include, but are not limited to:

- **Interactions with commercial inshore fisheries.** Inshore waters of the UTC are foraging areas for both immature and adult female ridleys, as well as a migratory corridor for these life stages. State (TPWD) and federal managers (NOAA Fisheries Service) should examine shrimping regulations, which currently afford sea turtles less protection along the UTC than that along the middle and lower coast (TPWD 2006).

- **Interactions with recreational fisheries.** Kemp's ridleys clearly interact with recreational fisheries along the UTC, but the full extent of these interactions within the region and throughout the species range is largely unknown. Managers should consider public outreach to better quantify the extent of interaction and minimize negative effects on the population. The TPWD, USFWS, and NOAA Fisheries Service should coordinate on these efforts to establish unified protocols.
- **Interactions with beach activities.** Potential for interactions between nesting females and anthropogenic activities is relatively high along many UTC beaches. Specific risks should be indentified within the framework of nesting characterization and addressed in management schemes to minimize negative interactions. USFWS and TPWD should be actively involved in these nesting characterizations, particularly within federal and state parks, or identify and fund a surrogate to do so.
- **Interactions with offshore activities.** The impact of fisheries and other human activities on adult females foraging in federal waters offshore Louisiana, as well as other areas of the Gulf, is currently unknown and should be evaluated by the NOAA Fisheries Service to ensure survival of these reproductively valuable individuals.
- **Funding of monitoring and research programs.** State and federal agencies should ensure that adequate research funds are available for beach and in-water research to fully characterize sea turtles' dependence on the northwestern Gulf of Mexico. State, federal, and international legislation mandate collection of basic life history and distribution data to minimize negative anthropogenic effects on these species, and long-term programs are necessary to adequately evaluate population trends of these long-lived species.

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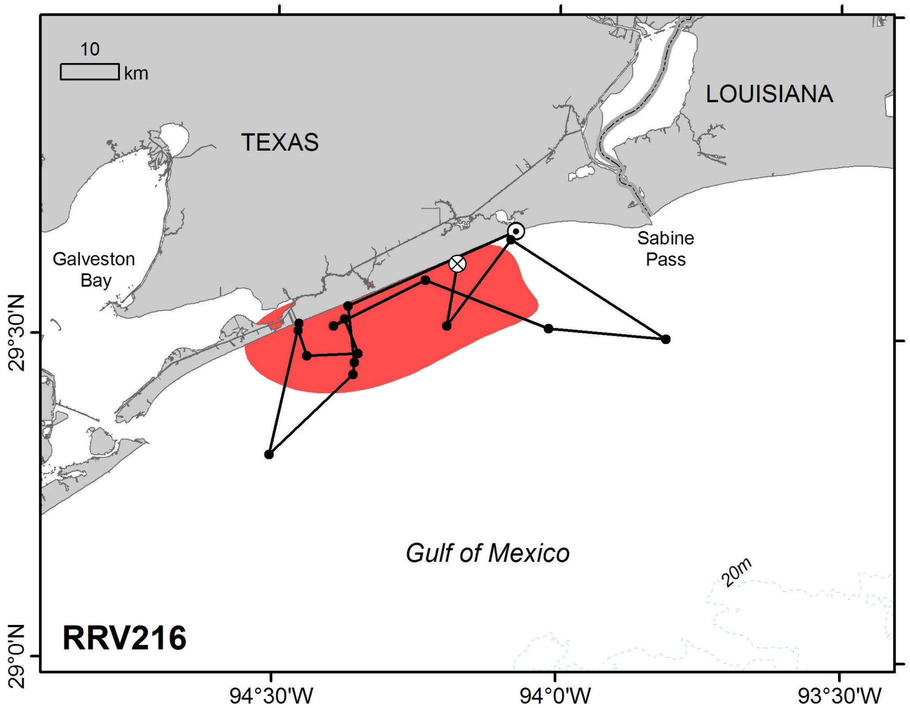
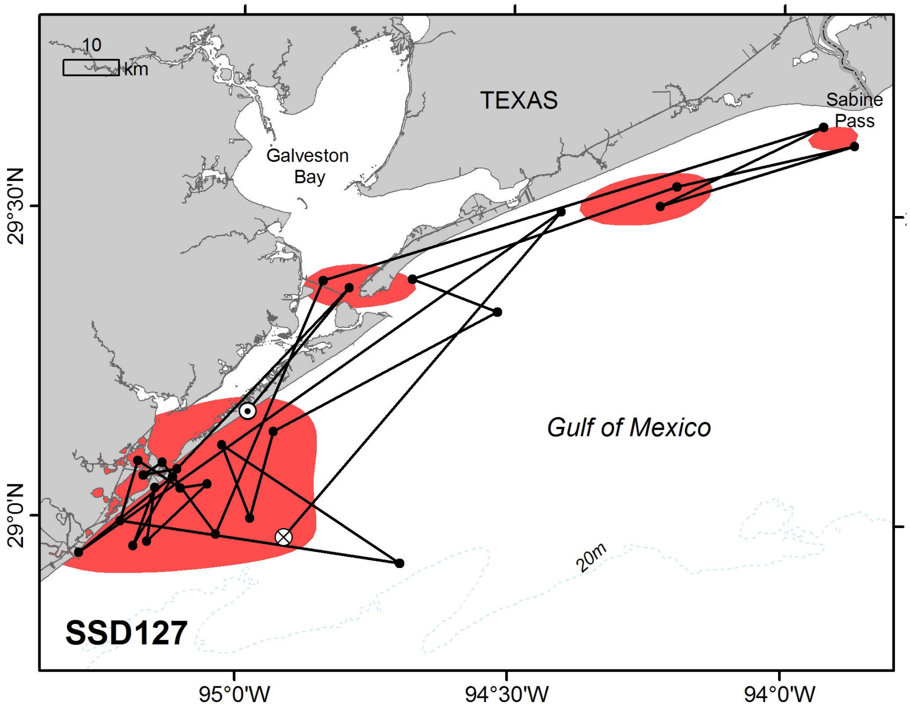
APPENDIX A

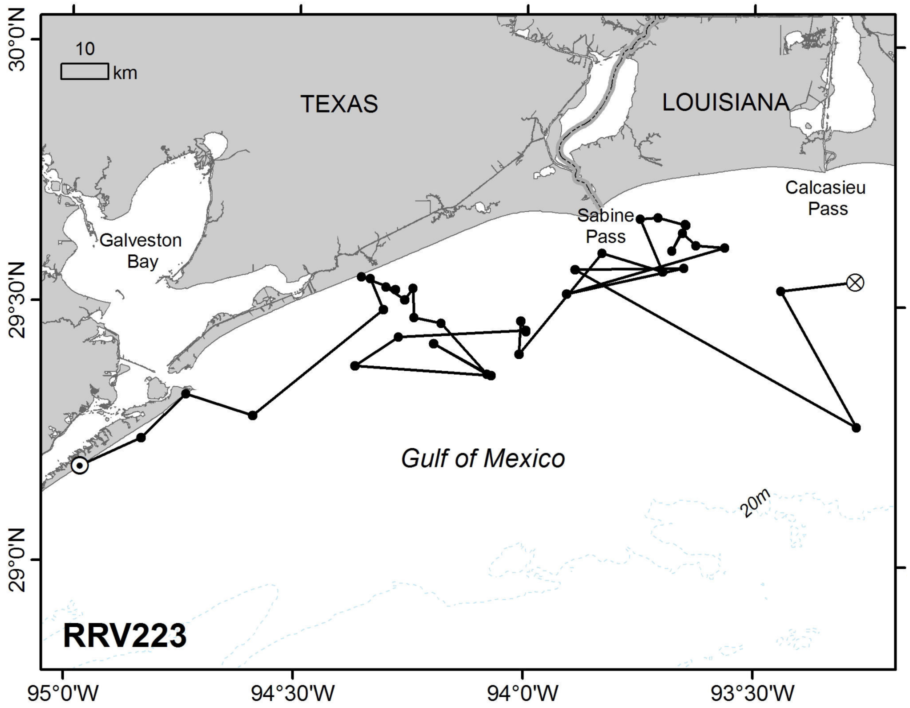
Tracklines and core activity areas for 22 Kemp's ridley sea turtles tracked in the northwestern Gulf of Mexico during 2004-2007. Locations connected by each black trackline include all filtered locations for that turtle, whereas the red area is the 50% kernel density estimation (KDE) contour, as calculated using a fixed least squares cross-validation smoothing factor (h_{cv}) and mean daily locations. KDE analysis was not conducted for individuals with tracks under 2 weeks in length or with significant directional movement (Rayleigh's Z). ⊙: Release and ⊗: end of track.



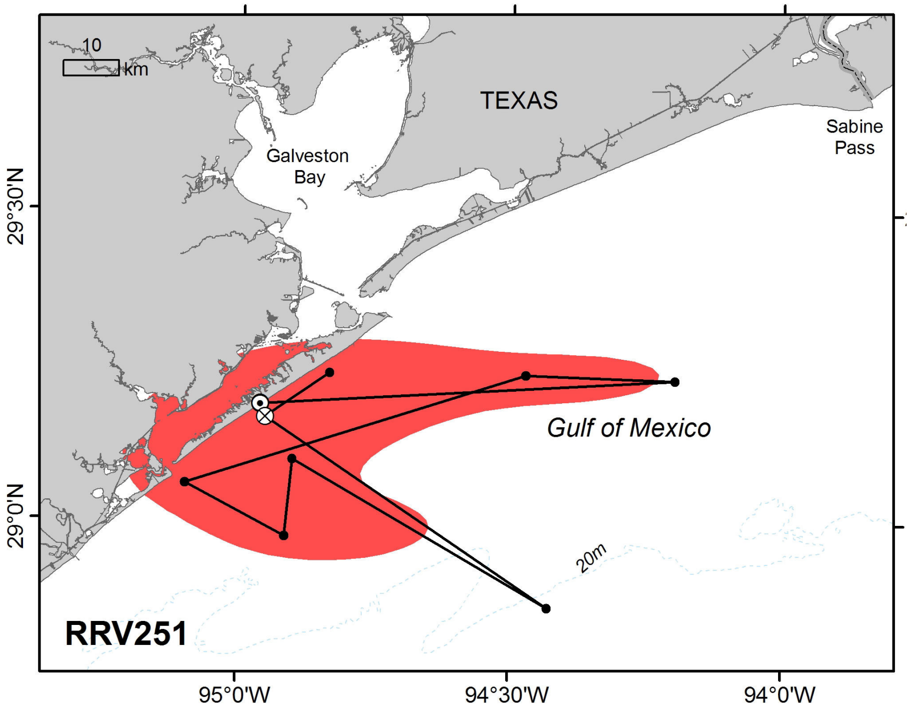
RRV216: 34.9 cm SCL hook-and-line capture, 21 September 2004-17 November 2004.



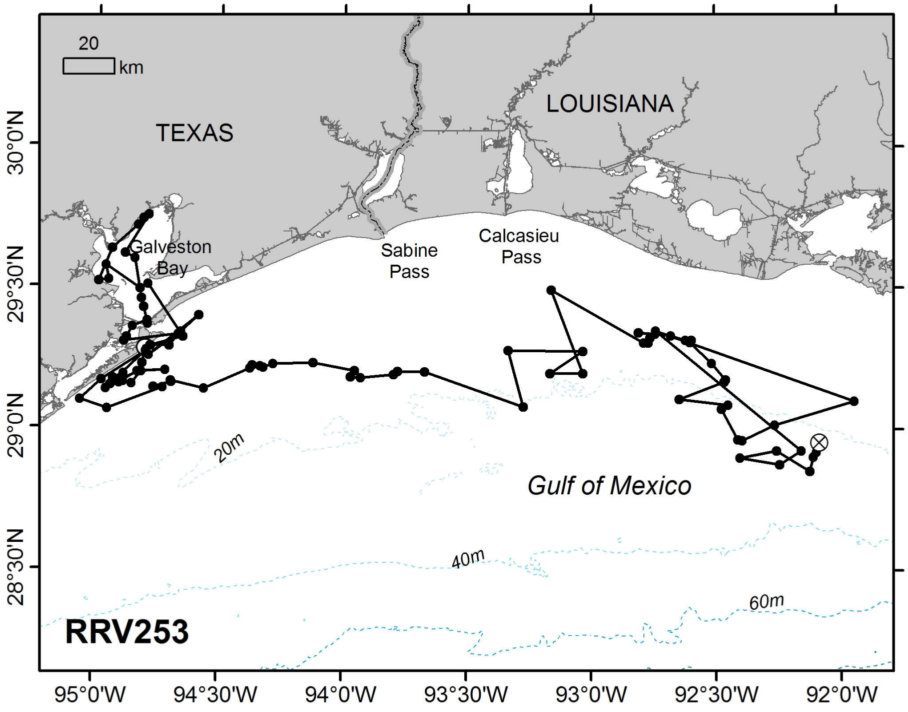
SSD127: 65.8 cm SCL nesting female, 17 May-29 June 2005.



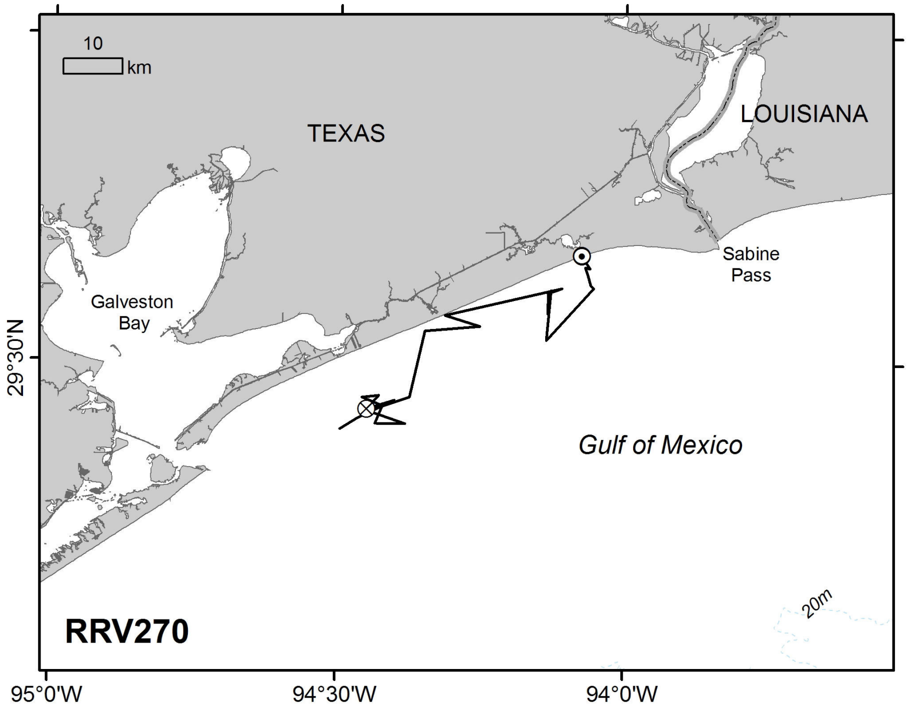
RRV223: 49.6 cm SCL stranding, 25 May-7 July 2005 (directional track, no KDE).



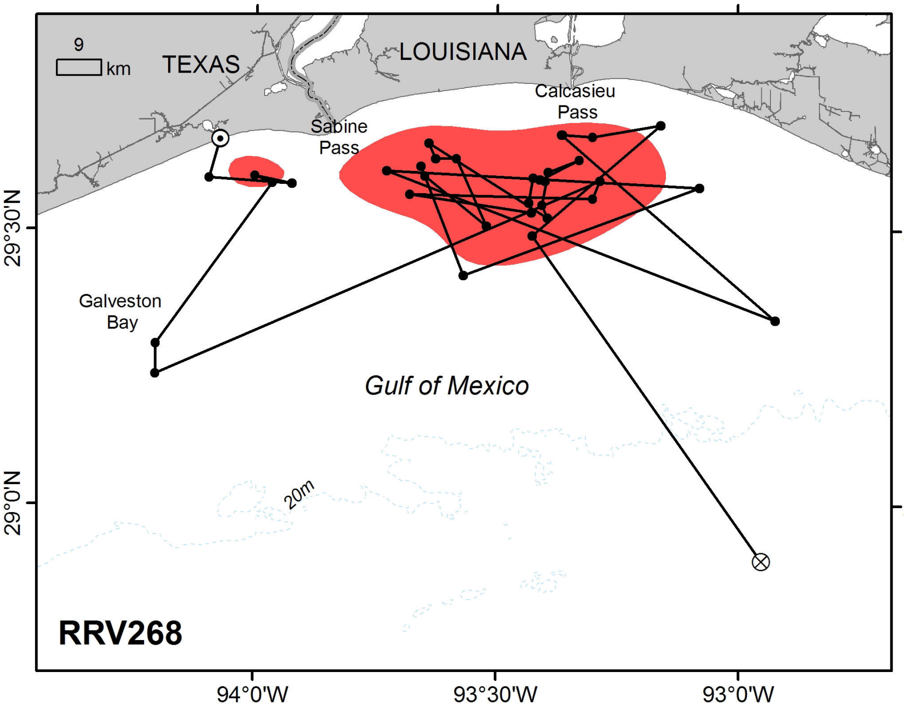
RRV251: 62.5 cm SCL nesting female, 29 May-17 June 2005.



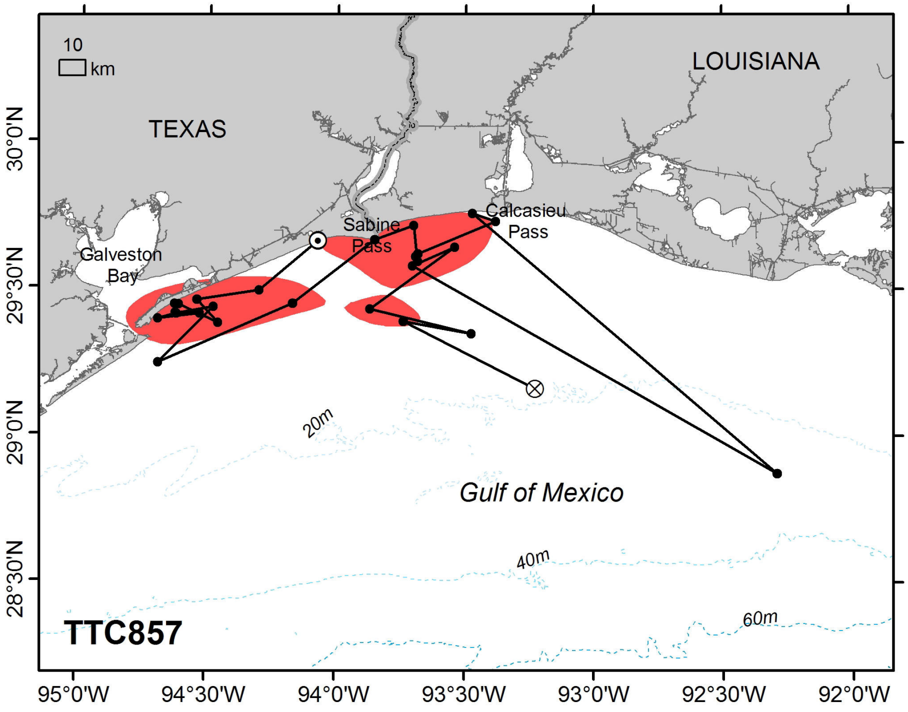
RRV253: 62.5 cm SCL nesting female, 31 May-19 July 2005 (directional track, no KDE).



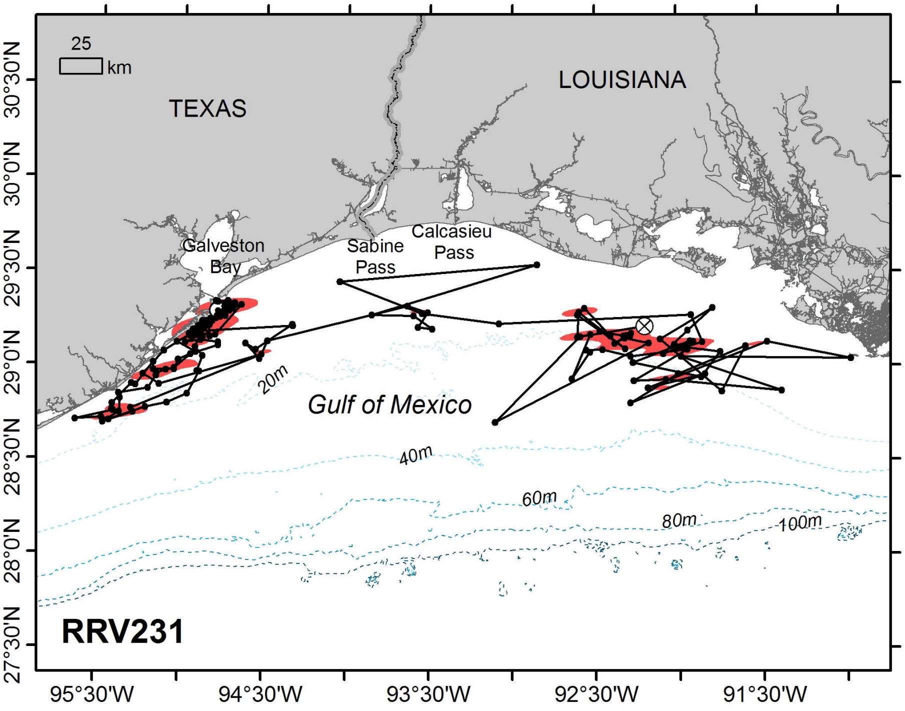
RRV270: 30.2 cm SCL hook-and-line capture, 25 July-5 August 2005 (too short for KDE).



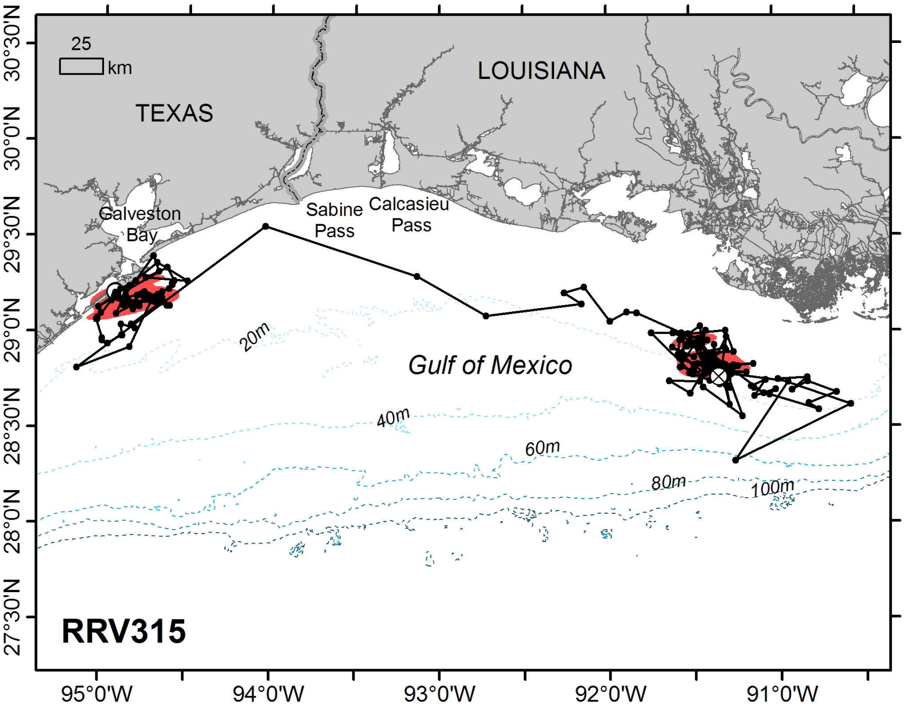
RRV268: 36.2 cm SCL hook-and-line capture, 2 August-2 September 2005.



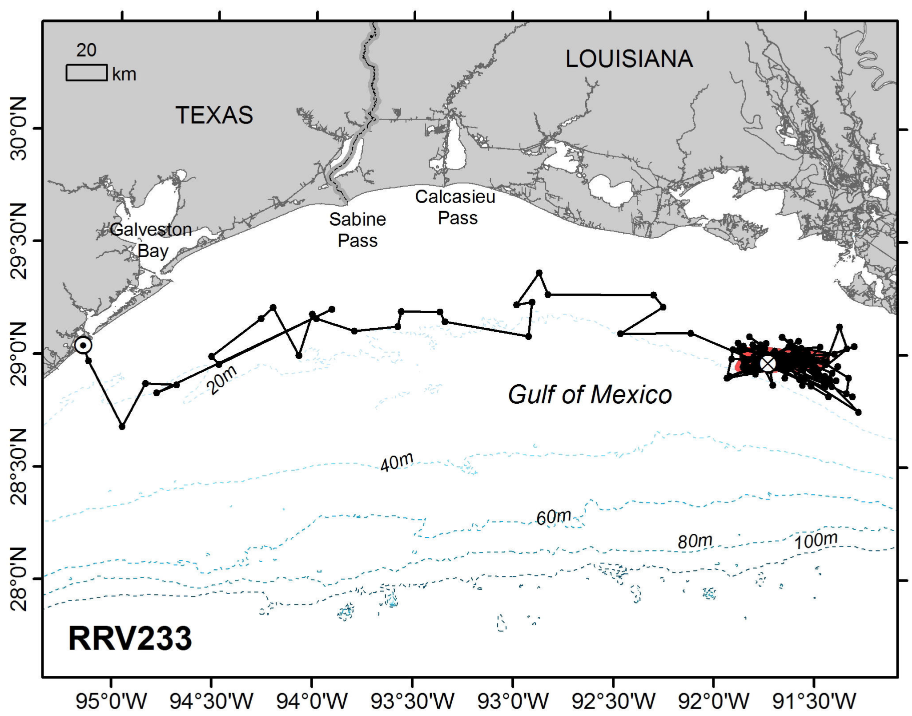
TTC857: 34.4 cm SCL relocation trawl capture, 6 September-16 October 2005.



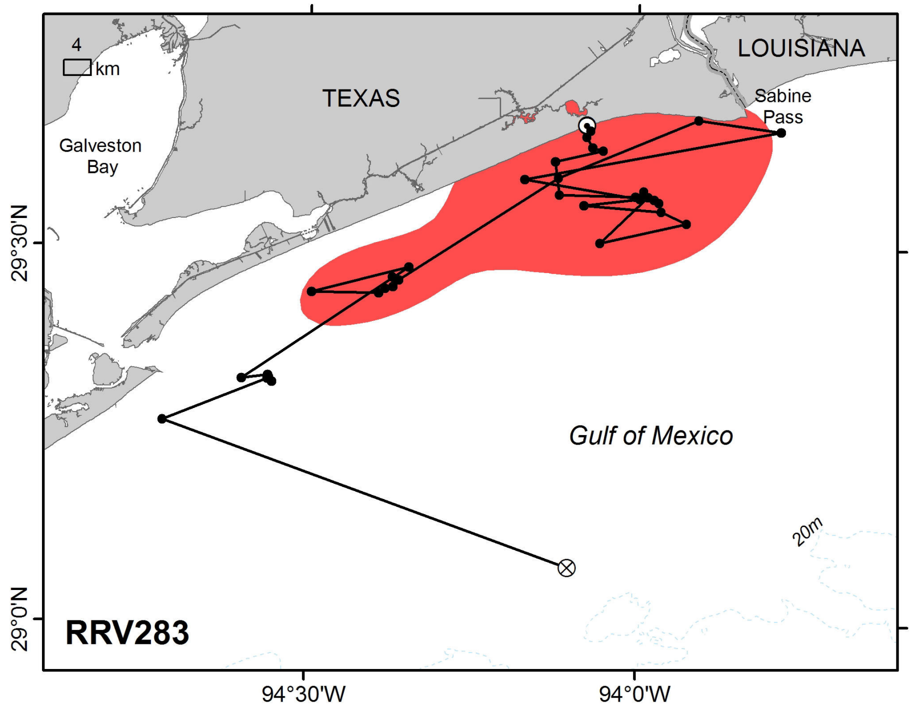
RRV231: 67.2 cm SCL nesting female, 28 April-22 September 2006.



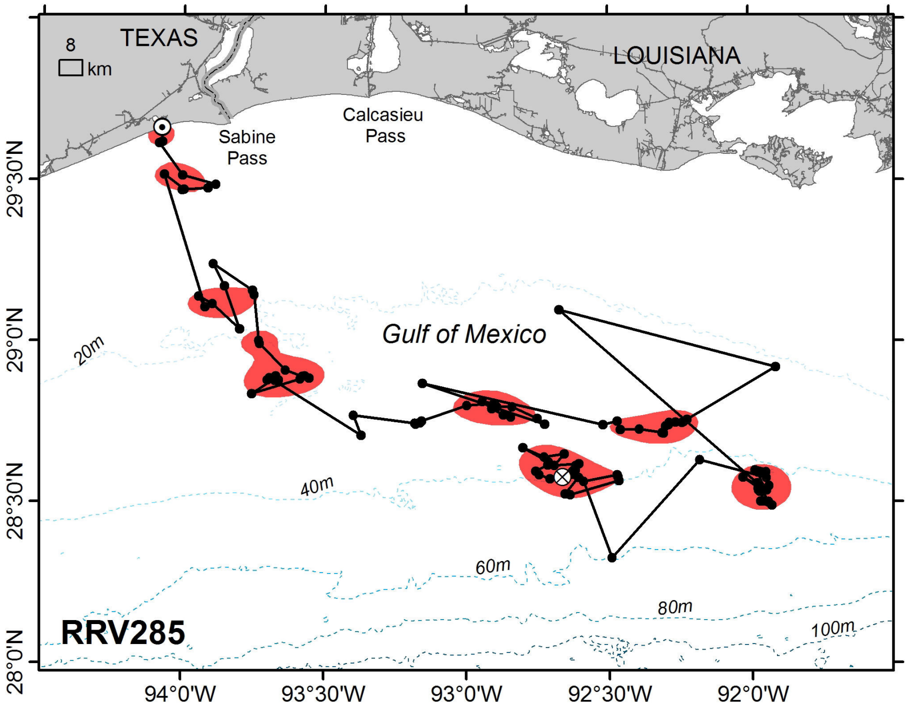
RRV315: 61.5 cm SCL nesting female, 7 May-1 August 2006.



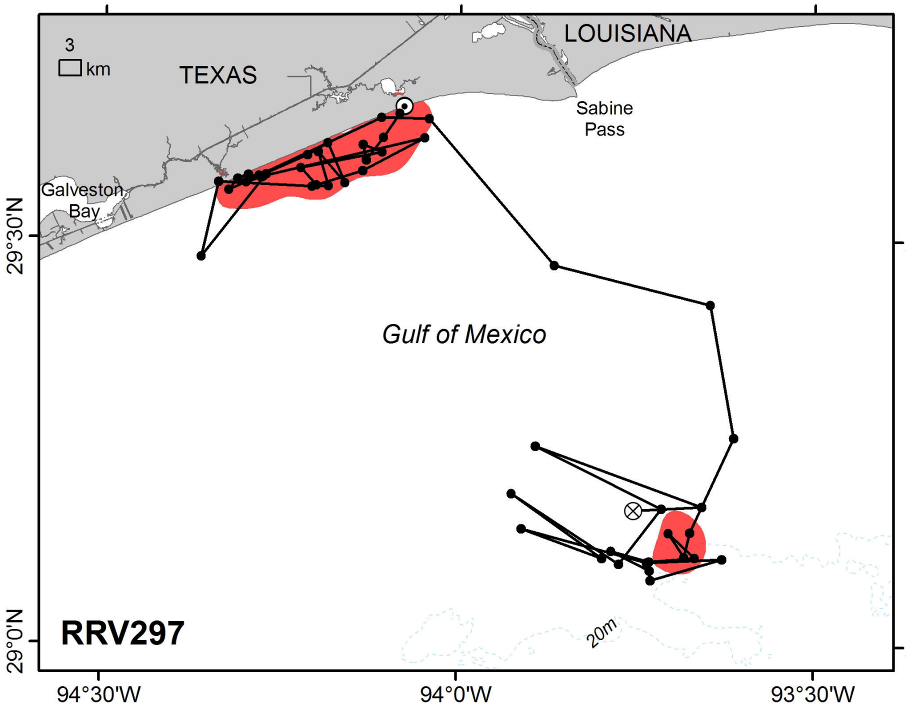
RRV233: 63.8 cm SCL nesting female, 27 May-5 October 2006.



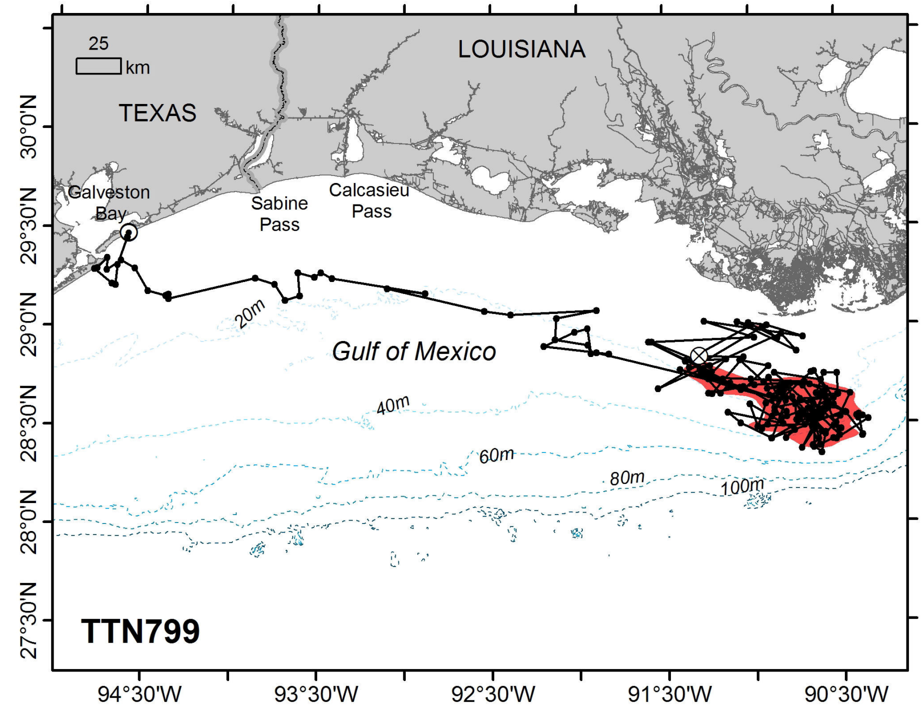
RRV283: 33.9 cm SCL hook-and-line capture, 17 April-6 May 2006.



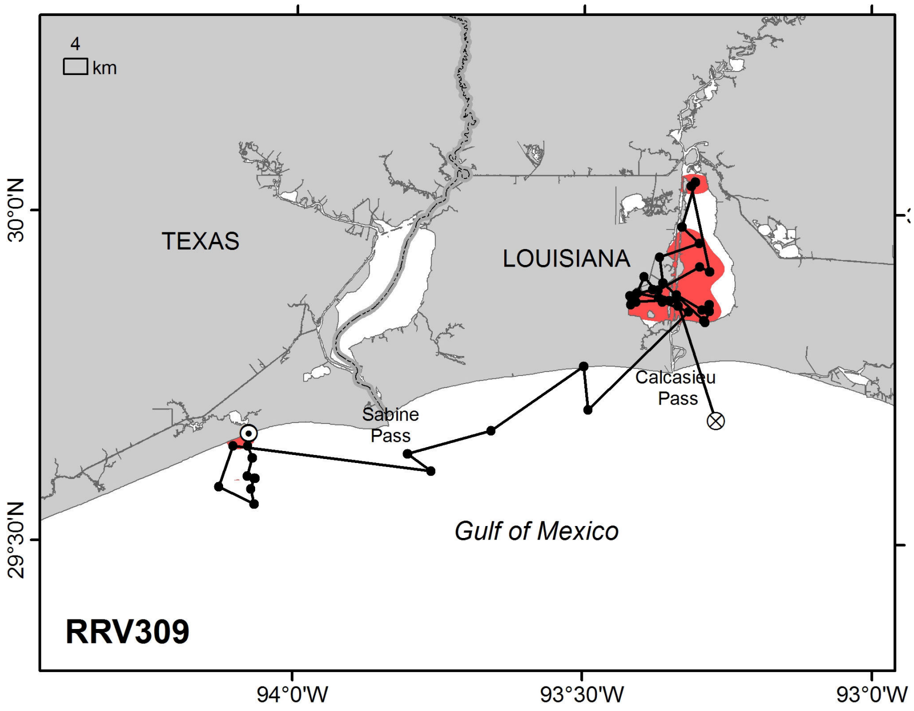
RRV285: 33.7 cm SCL hook-and-line capture, 25 April-20 June 2006.



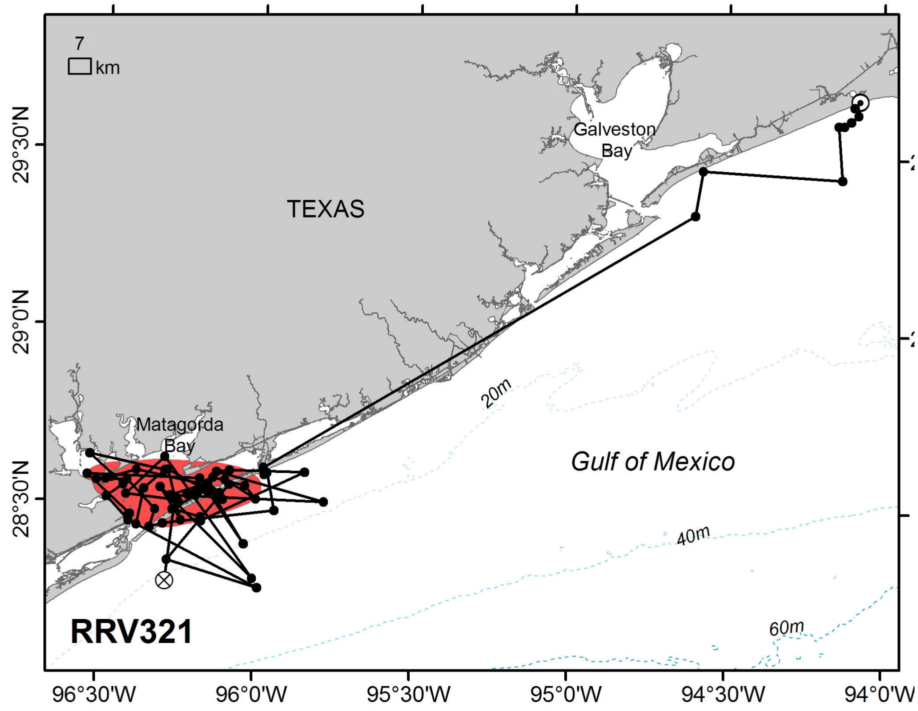
RRV297: 4.0 cm SCL stranding, 31 July-10 September 2006.



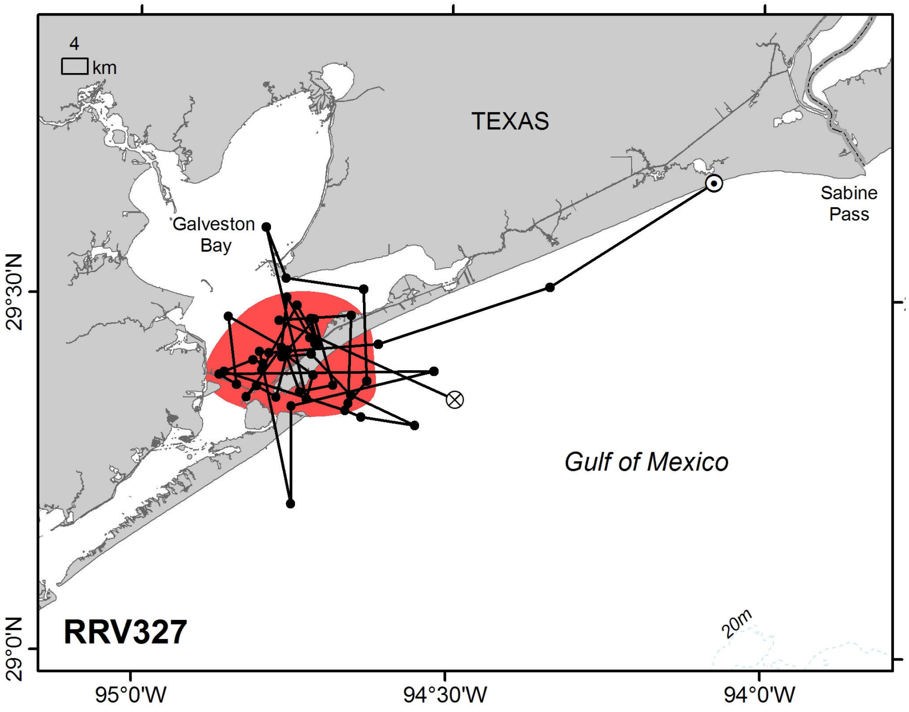
TTN799: 62.8 cm SCL relocation trawl capture, 16 August 2006-19 May 2007.



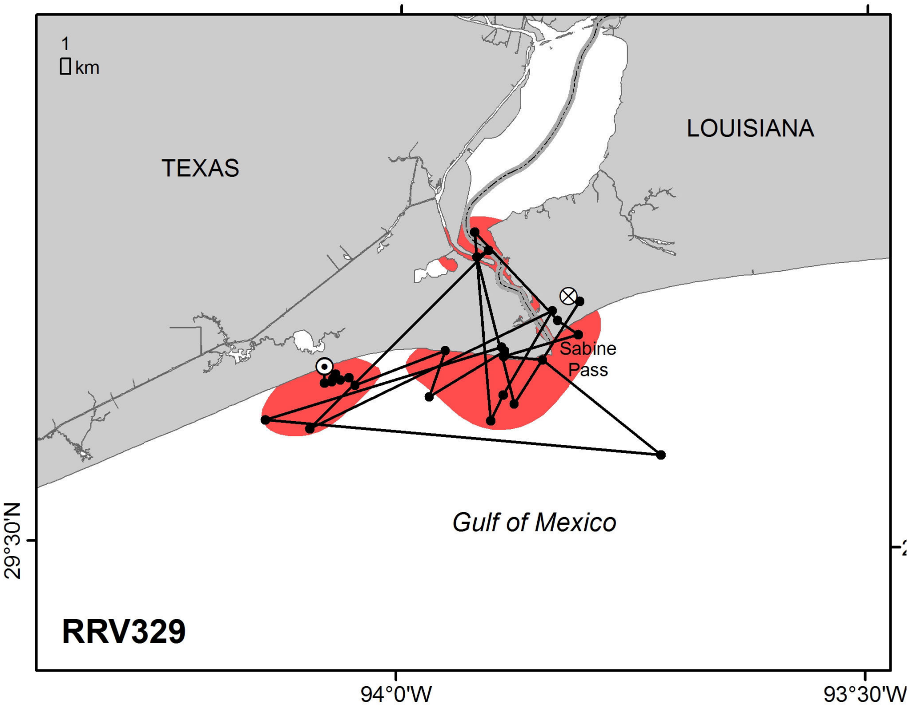
RRV309: 34.2 cm SCL hook-and-line capture, 23 April-12 June 2007.



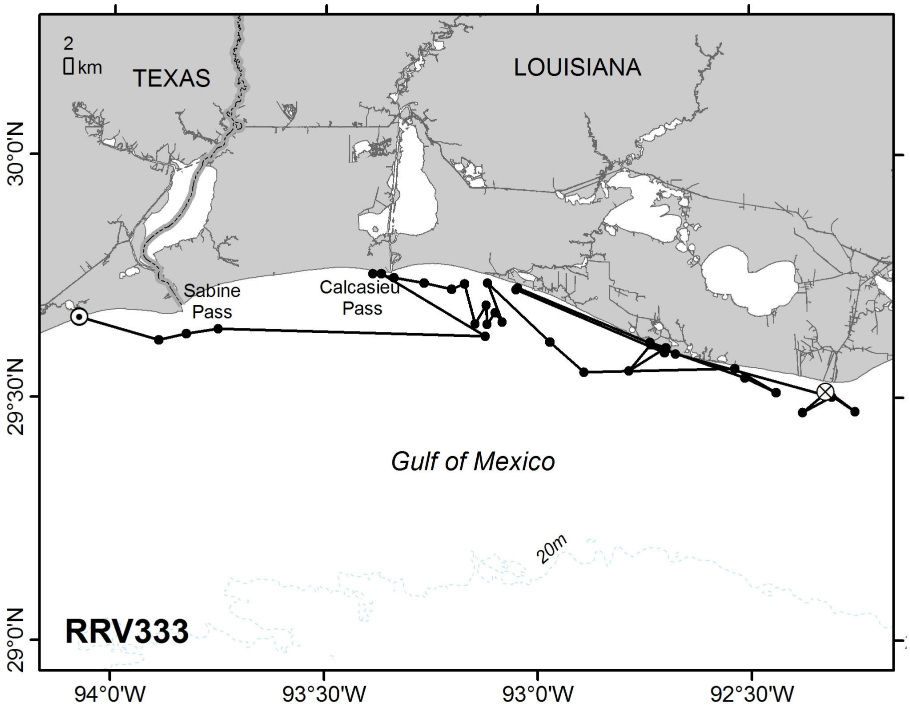
RRV321: 41.2 cm SCL hook-and-line capture, 23 April-6 Augst 2007.



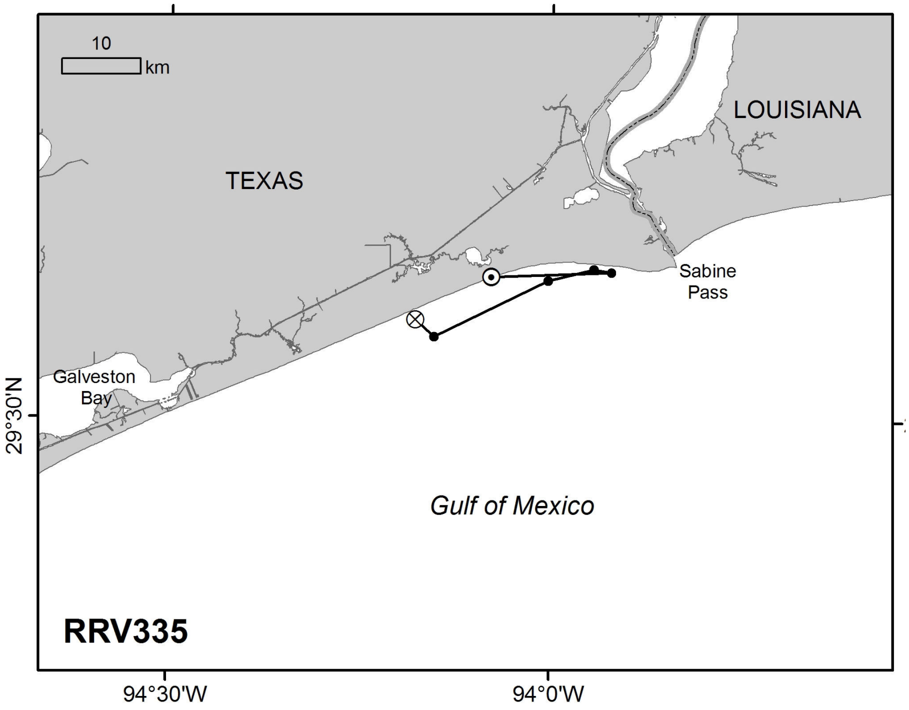
RRV327: 37.9 cm SCL hook-and-line capture, 1 May-11 July 2007.



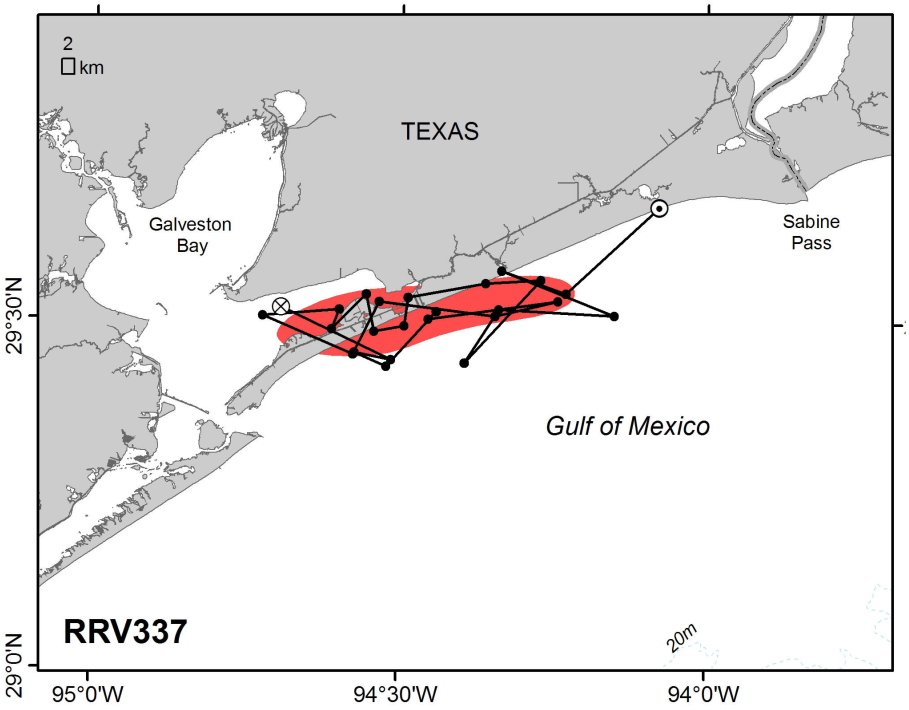
RRV329: 34.6 cm SCL hook-and-line capture, 15 May-3 July 2007.



RRV333: 31.4 cm SCL hook-and-line capture, 12 July-5 September 2007 (directional track, no KDE).



RRV335: 38.3 cm SCL hook-and-line capture, 12 July-22 July 2007 (too short for KDE).



RRV337: 39.8 cm SCL hook-and-line capture, 14 August-17 September 2007.

VITA

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