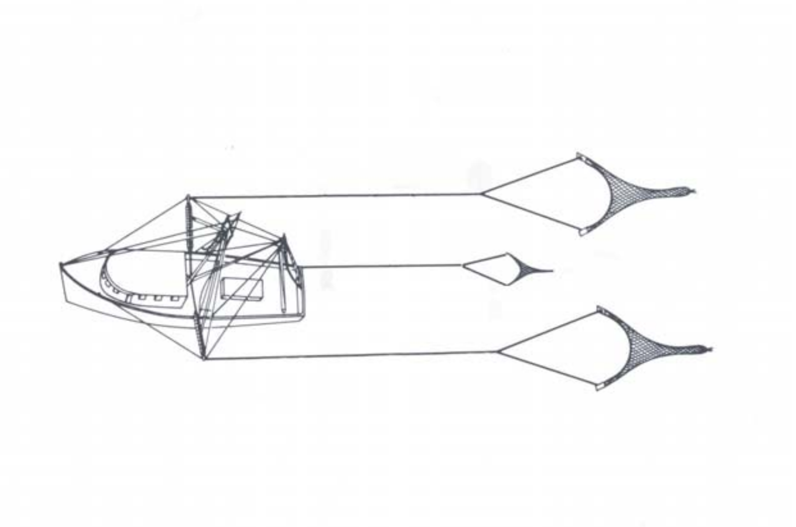
NOAA Technical Memorandum NMFS-SEFSC-490

ANALYSIS OF SEA TURTLE BYCATCH IN THE COMMERCIAL SHRIMP FISHERIES OF SOUTHEAST U.S. WATERS AND THE GULF OF MEXICO



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U. S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
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NOTICE

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ANALYSIS OF SEA TURTLE BYCATCH IN THE COMMERCIAL SHRIMP FISHERIES OF SOUTHEAST U.S. WATERS AND THE GULF OF MEXICO

The coastal shrimp trawl fisheries have long been the focus of conservation actions to reduce turtle bycatch and mortality in the Gulf of Mexico and the U.S. Atlantic (NRC, 1990). Calculation of catch rates of sea turtles in shrimp trawls is necessary to evaluate the impact on sea turtle populations. In this paper we analyze sea turtle bycatch to provide an estimate of the current number of interactions with otter trawl gear as well as an estimate of the number of fatal interactions in Southeast U.S. waters and the Gulf of Mexico. We also provide an estimate of the number of individuals likely to die in the future with the new regulations that will require an increase in the size of the escape openings in turtle excluder devices (TEDs). The new regulations will allow many more turtles to escape. Other gears also are discussed.

Our approach was to estimate the catch rates of sea turtles, by species, by geographic subregion, by depth stratum, and season, and to apply these catch rates to the reported effort of the commercial fleet during 2001 to estimate the total number of interactions. It must be noted that catch rate data exist only for otter trawls. Also, we estimate the number of interactions, not individual animals, as it is likely that animals interact with the fishery more than one time. The number of fatal interactions is a function of the effectiveness of TEDs on various sizes of turtles (larger turtles are less likely to escape through the openings) and the duration of tow times; this is a measure of number of turtles since an individual can only die once.

Finally, we note that there are numerous sources of variability and bias in this analysis. Where possible we attempt to quantify the magnitude and direction of these. Confidence intervals about the estimates are given where error can be quantified, but given the multitude of assumptions and sources of variability that are unquantified, they may give a false impression of our confidence in the estimates. They imply bounds, when really those bounds are unknown.

This report is organized by sections. We first provide estimates of fishing effort by shrimp trawls. Next we provide estimates of sea turtle CPUE in shrimp trawls and adjust those estimates with aerial survey data. Following those sections, we provide the results: estimates of the number of interactions, the number of interactions resulting in mortalities under current regulations, and the number of interactions which we expect will result in interactions once new TED regulations are enacted. We then discuss the potential for interactions in other gears and in the bait shrimp fisheries. Lastly, we provide the reader a summary discussion and make research recommendations.

Shrimp Fishery Effort

A variety of gears are used to catch shrimp commercially in the Gulf of Mexico and the Atlantic (**Table 1, Table 3**). Recreational effort and catch estimates do not exist. Commercial catch generally is reported by fishing zones, which can be summarized into 35 statistical zones (**Figure 1**, **Figure 2**). In the Gulf of Mexico these zones are divided into 5 fm intervals and all data collected are reported in these zone/depth locations for a total of 11 possible location cells (1 inshore and 10 offshore) within a given zone; all fishery data collected in depths greater than 45 fm are included in the > 45 fm location cell for the zone (Poffenberger, 1991). Fathoms are the units of depth used for the analyses herein since the Gulf data are reported already based on these units.

We divided the shelf into an inshore depth stratum (inside COLREG lines: bays and sounds), a nearshore depth stratum (10 fm) and an offshore depth stratum > 10 fm (**Figure 1**). In the Atlantic virtually all the shrimping effort occurs within 10 fm and thus there is no offshore stratum. Furthermore we divided the data temporally, into the "warm" or summer season when the shrimp fishery is most active (March-November) and the "cold" or winter season when the shrimp fishery is minimally active, mostly in offshore waters (see Figure 6-2, p. 88 in NRC, 1990). Statistical zones were combined to form two geographic subregions in the Gulf: eastern Gulf of Mexico (zones 1-12) and western Gulf of Mexico (zones 13-21) (**Figure 1**, **Figure 2**) and three subregions in the Atlantic: South (zones 24-30), Central (zones 31-33) and North (North Carolina).

Gulf Effort – Hours Fished

In the Gulf of Mexico shrimp fishery statistics database, gear is divided into two categories: shrimp trawls and other shrimp trawls, including otter and mongoose trawls. In the latter category are butterfly nets and skimmer trawls, gears used exclusively in inshore waters. Bait shrimp catch and effort is not reported, but other gears, such as wing nets and cast nets may be used to catch shrimp for bait. The estimation of shrimp fishery effort in the Gulf is dependent upon data summarized by location cells (Nance 1992). Estimates of monthly shrimp trawl fishing effort for each location cell requires two elements: (1) total pounds of shrimp caught by gear, and (2) average catch per unit of effort (CPUE; pounds per hour fished) for that gear. Total pounds caught is acquired from commercial seafood dealers located along the Gulf coast; CPUE is obtained from interviews with captains from shrimp vessels at the termination of their trip. Monthly effort (hours fished) for a location cell is estimated by dividing the monthly shrimp landings from a type of gear used in a location cell by the average CPUE for that gear during the same time and location cell combination. Otter trawl fishing effort (hours fished) in the Gulf of Mexico in 2001 is given in **Table 2**. This represents effort primarily for brown shrimp (*Farfantepenaeus aztecus*), pink shrimp (*F. duorarum*), and white shrimp (*Litopenaeus setiferus*), and to a lesser extent for rock shrimp (*Sicyonia* spp.), Trachypenaeus shrimp (*Trachypenaeus* spp.), seabobs (*Xiphopenaeus kroyeri)*, and royal red shrimp (*Pleoticus robustus)*.

Atlantic Effort – Trips Offloaded

For fishing that occurred in the southeast U.S. Atlantic (i.e., off the coast from North Carolina south through the middle Florida Keys), fishery statistics are collected by the fishery agency in each of the respective states and provided to the NMFS. The states of North Carolina[1], Georgia[2], and Florida[3] have a trip ticket program that was operational during 2001. For these programs, dealers are required, by state law, to report all purchases of fish and shellfish landed (off-loaded) at ports in the respective state. In addition to information on the species purchased, dealers are required to provide information on the type of fishing gear and the location of the fishing trips. The duration of a fishing trip can be determined by the start date and unloading (landing) date from the state's trip ticket data. For South Carolina, which did not have a comprehensive trip ticket program active during 2001, data for individual trips were provided by the majority of the dealers voluntarily and submitted to the state[4]. Information on the type of shrimp that were caught, the type of gear used for the trip, and the location of the fishing trip was provided. For South Carolina, however, duration of the fishing trip is not reported.

Based on locations fished, we assigned the reported fishing effort to statistical zones and depth strata (inshore vs ocean in the Atlantic), and based on date, assigned it to a season, summer or winter (**Table 4**). Although location fished is reported in North Carolina, some codes are very broad: ocean catches are reported as north or south of Cape Hatteras, within or outside state territorial waters. Inshore water body codes are more specific, but still some, such as the Intracoastal Waterway are problematic. For most water body codes we could assign the data to a particular statistical zone. For those waters that bridged zones, we attributed the effort to the zone associated with the city/county of landing. This was especially problematic for the ocean catches since ocean fishermen may be quite mobile, even fishing in waters off other states. Infrequently the place of landing was missing and then we attributed effort associated with that trip to zone 34. Bait shrimp statistics are reported separately in Florida and Georgia and are addressed later.

Sources of Error

NMFS and state port agents in the Gulf of Mexico collect shrimp statistics from two sources, seafood dealers and fisherman. Data on the amount and value of the shrimp from individual trips that are unloaded or landed at the dealers are collected from dealer records. Data that includes information on fishing effort and location for an individual trip is collected by interviewing the captain. Because the fishing trip is the basic sampling unit, the fundamental principle of the data collection procedures is to collect both the landing and interview data on a trip-by-trip basis. However, because the reported number of fishing trips that occur in the Gulf shrimp fishery are in the several hundred thousand range, not every trip has information on

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[1] North Carolina Division of Marine Fisheries. Unpublished Data. Lees Sabo, NCDMF, Morehead City, NN. Personal Communication (E-mail) October 31, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

[2] Georgia Department of Natural Resources. Unpublished Data. Julie Califf, GADNR, Brunswick, GA. Personal Communication (E-mail) October 17, 2002 to John Poffenberger, National Marine Fisheries Service, Miami, FL.

[3] Florida Fish and Wildlife Conservation Commission. Unpublished Data. Guy Davenport, National Marine Fisheries Service, Miami, FL. Personal Communication (E-mail) November 4, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

[4] South Carolina Department of Natural Resources. Unpublished Data. Linda Hardy Bernstein, National Marine Fisheries Service, Beaufort, NC. Personal Communication (E-mail) October 18, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

fishing effort and location from an interview. The port agent must assign a catch location for the landings for each trip, and uses information obtained from the dealer, other interviews, or historical knowledge of the fleet's activity to perform this assignment activity. Thus, some error in assignment of locations of the catch can occur from the judgment of the port agents, or even during the interview process after a 60-day trip. However, these potential errors were considered random in nature and the directional bias was considered negligible.

The Gulf and South Atlantic Fisheries Foundation, Inc. received funding to address the question of possible location error and directional bias in the shrimp effort data. A proposal to tackle this research question was successful submitted by LGL. The first year of the effort involved development of a simple, reliable, and low-cost GPS unit (Electronic Logbook, ELB) that could accurately measure the magnitude and spatial patterns of fishing effort with a trip. This unit was successfully developed and has been shown to provide a very good measure of effort, with minimal inconvenience and cost (Gallaway, et. al., in press).

This ELB unit has been successfully used in subsequent years in a small pilot study program to provided comparisons of actual areas fished, pounds landed from these areas, and catch rates in these areas as measured using ELBs to the corresponding estimates made by port agents (135 trips of evaluation). The results from the pilot study program show that some directional bias does occur, and that CPUE is often underestimated (Gallaway, et. al., in review). If the results from this study are representative of the fleet as a whole, the shrimp effort in the mid-shelf area could be overestimated, whereas the nearshore and deepwater effort could be underestimated. The results from the study suggest that a cooperative program involving both the NMFS and industry should be implemented using ELB technology and the port agent network to obtain more precise and accurate estimates of shrimp trawling effort with minimal impact on the fishers.

Effort presented thus far is without consideration of fishing power relative to the vulnerability of sea turtles to capture. The catch of sea turtles may be influenced by the number, size, and characteristics of nets being fished as well as the speed of the vessel. Because data are not available to characterize the fleet, or to evaluate these factors on the catchability of sea turtles we must assume that each vessel can be characterized by the averages and assume that one unit of effort has the same fishing power throughout the fishery in the Gulf or in the Atlantic, inshore and in the ocean. In general, vessels working inshore waters are small compared to those in the ocean (an exception is the large vessels working inshore sounds of N.C.). Smaller vessels working inshore likely have less fishing power – they generally do not pull as many nets and often the nets are smaller. Equating their fishing power with that of the offshore fleets will result in an overestimation of turtle catch for the inshore vessels.

The NMFS data collection program for shrimp statistics includes only the commercial sector landing table shrimp (shrimp for human consumption); live bait shrimp statistics are available only for Florida's east coast and Georgia. The statistics do not include shrimp harvested by recreational fishermen, nor does it include catches by small, part-time commercial fishermen that sell their catches along the roadsides (Poffenberger, 1991). The "recreational" effort may be substantial, but because they generally are restricted to using a small amount of gear in inshore waters, turtle mortality likely is not high. Failure to include this sector's effort will result in an underestimation of the number of interactions with sea turtles.

The calculation of effort data in the Gulf is dependent on the assumption that the interviews accurately portray the catch and effort of the entire fleet for a particular location cell. During peak shrimp production about 70-80% of the landings have an average CPUE associated with them. Infrequently location cells have landings reported but no interviews; usually the CPUE is estimated from a month-specific statistical model based on the independent variables of year and geographic location. This model was developed based on historical data and r^2=0.50 for most monthly models. (Nance, 1992).

Table 1. Estimated effort in 2001 (hours fished), reported by gear type, for the Gulf of Mexico. Bait shrimp trips are not included.

	Gear		
Zone	**Shrimp Trawl**	**Other**	**Description of Other**
1	36787	0	
2	252021	0	
3	44014	0	
4	30537	0	
2	24320	0	
6	55090	0	
7	79948	76	skimmer trawls
8	59995	0	
9	7616	0	
10	135119	2964	skimmer trawls
11	458494	3772	skimmer trawls
12	225661	90119	skimmer trawls and butterfly nets
13	851217	132194	skimmer trawls and butterfly nets
14	645386	467629	skimmer trawls and butterfly nets
15	468928	7746	skimmer trawls and butterfly nets
16	475874	15745	skimmer trawls and butterfly nets
17	704769	2171	skimmer trawls and butterfly nets
18	482935	0	
19	1175512	0	
20	242435	0	
21	190378	0	

Table 2. Shrimp trawl fishing effort (hours fished) estimated in the Gulf of Mexico in 2001 by subregion and season. Bait shrimp trips are not included.

Season / Depth stratum	Subregion	
	Western Gulf (zones 13-21)	Eastern Gulf (zones 1-12)
Summer (Mar-Nov)		
Inshore	734951	429285
Nearshore (0-10 fm)	1933570	261442
Offshore (> 10 fm)	1762230	462184
Winter (Dec-Feb)		
Inshore	17851	18668
Nearshore (0-10 fm)	342913	39870
Offshore (> 10 fm)	445917	198151

Table 3. Fishing effort in 2001 (trips), reported by gear type, in Southeast U.S. waters. Bait shrimp trips are not included, except in the Carolinas where they cannot be distinguished from trips made for table shrimp.

Zone	Gears								
	Shrimp Trawl	Skimmer Trawl	Butterfly Net	Beam/ Roller Trawl	Channel Net	Pot / Trap	Seine	Hand Gears[5]	Other
25	0	0	540	281	0	0	0	0	0
26	33	0	0	0	0	0	0	0	0
27	38	0	0	0	0	0	0	0	0
28	496	0	0	0	0	0	0	3	0
29	223	0	0	0	0	0	0	22	0
30	2302	0	0	0	0	0	0	19	0
31	2969	0	0	0	0	0	0	123	10
32	5950	0	0	0	0	0	0	1	0
33	2067	0	0	0	157	6	0	119	0
34	6122	1760	0	0	1610	14	0	31	0
35	3167	11	6	0	0	4	7	1	0

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[5] Hand gears include dip nets and cast nets.

Table 4. Shrimp trawl fishing effort (trips) in the Atlantic in 2001 by subregion and season. Bait shrimp trips are not included, except for in the Carolinas where they cannot be distinguished from trips made for table shrimp.

Season / Depth stratum	**Subregion**		
	South (zones 24-30)	**Central (zones 31-33)**	**North (zones ≥34)**
Summer (Mar-Nov)			
Inshore	454	411	7312
Ocean	1906	9038	1902
Winter (Dec-Feb)			
Inshore	101	36	39
Ocean	631	1401	36

Figure 1. Statistical reporting zones and depth strata in the Gulf of Mexico. The nearshore stratum is 0-10 fm and the offshore stratum is > 10 fm. The inshore stratum, shown in white, is inside the COLREG lines.

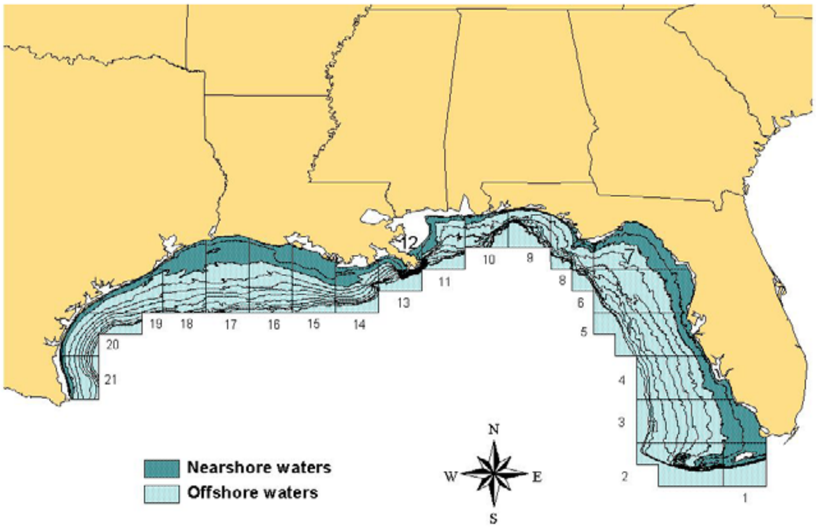
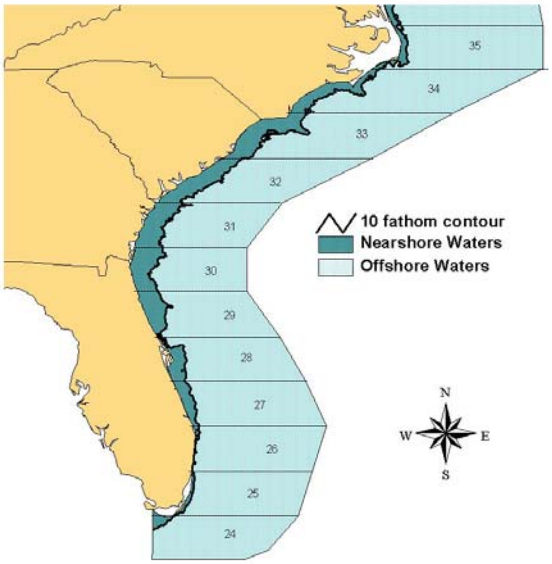


Figure 2. Statistical reporting zones for the Southeast U.S.



Evaluation of Trip as the Appropriate Unit of Effort in the Atlantic

As the duration of a trip increases, it is expected that the probability of a turtle capture during that trip also increases. Fishing trips are of variable durations and this factor is not accounted for in the effort data reported above for the Atlantic. Catch rates of turtles can be expressed as catch per unit effort, where that effort can be trip, day, hour, or other standard units (see section Catch Rates in Shrimp Trawls, below). The most comprehensive recent study of sea turtle interaction rates was conducted by the Gulf and South Atlantic Fisheries Foundation. If sampling by the Foundation to obtain the catch rates accurately mirrors the fleet in trip duration then there is no reason to convert reported trips to any other unit. If the duration of the sampled trips varies significantly from that of the fleet, it may then be necessary to use days or even to convert to hours fished. Doing so, though, introduces additional error.

The Florida Trip Ticket system includes a field to record time (duration) of a trip, either in hours or days. About half of the trips reported duration in days (calendar days) while the remainder reported in hours. No effort was reported for 8 (0.25%) trips. Hours reported ranged from 1 to 48 per trip. A frequency distribution indicated a strong peak at 6-9 hours and most were less than 12 hours. We assumed that all trips reporting less than 12 hours fished were 1 day and that trips reporting > 12 hours were multiple days and estimated the duration by assuming that 12 hours represented a day. We assigned those trips reporting no effort the mean number of days fished by other vessels landing in Florida and fishing in the same season x subregion x depth stratum. Trips landing in Florida during the summer averaged 3.7 d (n=2482, SE=0.10, mode=1, range=1-65) and those landing during the winter averaged 3.6 d (n=745, SE=0.16, mode=1, range=1-30). Trips longer than a few days in duration likely are by vessels capable of individually and quickly freezing the shrimp; some have resupply vessels which allow them to stay at sea for extended periods of time and to hold shrimp until they are more marketable and prices increase.

Days fished usually are recorded in the Georgia trip ticket data; however, 549 (17.7%) reported no effort. We assigned those trips reporting no effort the mean number of days fished by other vessels landing in Georgia and fishing in the same season x subregion x depth stratum. Trips landing in Georgia during the summer averaged 4.3 d (n=2122, SE=0.06, mode=3, range=1-36) and those landing during the winter averaged 4.1 d (n=435, SE=0.13, mode=3, range=1-30).

The duration of trips offloading in South Carolina has not been recorded in recent years, but historically such data has been collected[6], most recently for 1989-1990 from the South Atlantic Detailed Shrimp Program (Anon., 2002). Many dealers reported weekly the number of trips offloaded (since this was not mandatory, some dealers reported only monthly and port agents had to impute the weekly data). Trips landing in South Carolina during the summer averaged 2.5 d (n=17847, SE=0.02, mode=1, range=1-78) and those landing during the winter averaged 2.3 d (n=1978, SE=0.03, mode=1, range=1-15).

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[6] South Carolina Department of Natural Resources. Unpublished data. Linda Hardy Bernstein, National Marine Fisheries Service, Beaufort, NC. Personal communication (E-mail) October 18, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

North Carolina trip tickets do not record the duration of a trip, but that information can be inferred by comparing the trip start date and the date of offloading, reported for all but 26 trips (0.25%). Trips starting and landing on the same date were assigned a trip duration of 1 d. Those trips reporting no effort were assigned the mean number of days fished by other vessels landing in North Carolina and fishing in the same season x subregion x depth stratum. Trips landing in North Carolina during the summer averaged 1.6 d (n=10352, SE=0.01, mode=1, range=1-18) and those landing during the winter averaged 1.7 d (n=128, SE=0.14, mode=1, range=1-11).

The average duration of Atlantic trips in our sampling data for sea turtle CPUE (see section on Catch Rates in Shrimp Trawls, below) is significantly greater than the duration of trips by the fleet, as shown above. Thus days fished (not number of trips) were determined to be the most appropriate measure of effort in the Atlantic (**Table 5**).

Sources of Error

The sources of error are many. Most important is the accuracy of the trip ticket data. We are making assumptions concerning the duration of trips when data are missing or when the computed duration was 0 d, and about hourly data reported in Florida. We cannot evaluate the accuracy of these assumptions. Secondly, we assume that the proportion of time fishing is the same for all trips; some vessels may have more transit time, especially the freezer boats which are capable of ranging widely. Thus, we may be overestimating actual effort. For South Carolina we assume that data collected for 1989-1990 are representative of fishing today; there is no evidence to indicate that the fleet is fishing any differently then now.[7] Not all S.C. dealers reported on trip tickets in 1989-1990. The program was voluntary (only monthly summaries were mandatory). Thus trip duration (calendar days) was imputed using reported catch divided by average catch/day from the trip tickets that month. Also, if the dealer did not fill out "calendar days fished' on the ticket, that field was assigned by the port agent by comparing that ticket with the last date of unloading along with the amount of the catch and the agent's fishery knowledge. This would be a maximum estimate of the calendar days fished for the trip.[8]

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[7] Nan Jenkins, South Carolina Department of Natural Resources, Charleston, SC. Personal communication (E-mail) October 23, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

[8] Nan Jenkins, S.C. Department of Natural Resources, Charleston, SC. Personal communication (E-mail) October 16, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

Table 5. Shrimp trawl effort (days fished) estimated in the Atlantic in 2001, by subregion and season. Bait shrimp trips are not included, except for in the Carolinas where they cannot be distinguished from trips for table shrimp.

Season / Depth stratum	**Subregion**		
	South (zones 24-30)	**Central (zones 31-33)**	**North (zones ≥34)**
Summer (Mar-Nov)			
Inshore	626	430	12352
Ocean	8331	26947	2418
Winter (Dec-Feb)			
Inshore	116	36	44
Ocean	2578	4164	84

Catch Rates Of Sea Turtles In Shrimp Trawls

Observer data sets that quantify sea turtle catch per unit effort (CPUE) have very limited spatial and temporal coverage. The most comprehensive recent study on the interaction rates of sea turtles and shrimp trawls was conducted in 1997-1998 by the Gulf and South Atlantic Fisheries Foundation (1998; Jamir, 1999). All other recent studies available either were much smaller in geographic and temporal scope or used a net other than a shrimp trawl. The Foundation study was limited to the western Gulf of Mexico and the coastal Atlantic between northern Florida and South Carolina (see Foundation Data below). One option is to apply these rates to the entire Gulf of Mexico or Atlantic, respectively, for all times of the year. However, both the overall density and species composition of sea turtles are known to vary significantly across longitudinal and latitudinal scales. For example, sea turtle density is significantly higher in the eastern Gulf of Mexico and along the Florida coast in comparison to the western Gulf of Mexico along Louisiana and Texas (McDaniel *et al*. 2000). Strandings, too, differ in number and species composition between the eastern and western Gulf of Mexico (**Table 6**). Catch rates for a region with relatively low turtle abundance (e.g., Western Gulf of Mexico) would be expected to be less than those in an area with significantly higher turtle abundance (e.g., Eastern Gulf of Mexico). The preferred option is to account for the relative density of turtles across geographic areas and adjust catch rates accordingly. Extrapolating CPUE information from localized observations requires information on the relative density of turtles across geographic regions. For this, we used aerial survey data collected in the Gulf of Mexico and U.S. Atlantic.

Foundation Data

While aboard actively fishing commercial shrimp trawlers, the Foundation monitored the catch of sea turtles in nets not equipped with TEDs. From May 1997-May 1998 641 tows were observed in southeastern U.S. waters and 1,133 tows were observed in the waters of the Gulf of Mexico. In the Atlantic 274 turtles were captured and 26[9] were captured in the Gulf. Tows in shallow waters (<15 fm) were restricted to 55 minutes during April through October and to 75 minutes from November through March to minimize the mortality of sea turtles. Tow times in waters deeper than 15 fm were not restricted. Details on the study can be found in Gulf and South Atlantic Fisheries Foundation (1998) and Jamir (1999).

The distribution of the Foundation's sampling effort was not proportional to the fleet's effort in a given stratum (**Figure 3, Figure 4**) and therefore the samples cannot be considered to be random samples. Thus, samples were stratified so that catch rates for each stratum could be calculated. The stratification used is the same that was used to stratify effort data and is described above.

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[9] One tow in the Gulf of Mexico resulted in the capture of a Kemp's ridley, but there was no effort (tow duration) recorded for that tow. Thus, our analysis is based on the capture of 25, not 26 turtles, in the Gulf.

Table 6. Strandings of sea turtles in the Gulf of Mexico, May 1997-May 1998, the period of time that the Foundation study was conducted. Note the difference in species composition between the Eastern Gulf and Western Gulf during each time period. Species codes are Cc=loggerhead, Cm=green, Dc=leatherback, Ei=hawksbill, Lk=Kemp's ridley, and Un=unidentified.

May 1997-May 1998 Species Proportions By Season - W. Gulf (zones 13-21) vs. E. Gulf (zones 1-12, 24, 25)					
true strandings only - no H, no T, no PH, no IC					
Winter (Dec - Feb)					
Western Gulf			Eastern Gulf		
Species	Number	Percent	Species	Number	Percent
Cc	16	41	Cc	12	20
Cm	5	13	Cm	35	59
Dc	0	0	Dc	3	5
Ei	3	8	Ei	2	3
Lk	14	36	Lk	5	9
Un	1	3	Un	2	3
Total	39		Total	59	
Spring (Mar - May)					
Western Gulf			Eastern Gulf		
Species	Number	Percent	Species	Number	Percent
Cc	105	32	Cc	125	55
Cm	22	7	Cm	26	12
Dc	12	4	Dc	2	1
Ei	7	2	Ei	4	2
Lk	169	52	Lk	60	26
Un	11	3	Un	10	4
Total	326		Total	227	
Summer (Jun - Aug)					
Western Gulf			Eastern Gulf		
Species	Number	Percent	Species	Number	Percent
Cc	61	44	Cc	74	67
Cm	9	7	Cm	5	4
Dc	0	0	Dc	2	2
Ei	3	2	Ei	2	2
Lk	59	43	Lk	15	13
Un	6	4	Un	13	12
Total	138		Total	111	
Fall (Sep - Nov)					
Western Gulf			Eastern Gulf		
Species	Number	Percent	Species	Number	Percent
Cc	46	37	Cc	38	53
Cm	9	7	Cm	14	19
Dc	0	0	Dc	0	0
Ei	4	3	Ei	2	3
Lk	62	50	Lk	14	19
Un	4	3	Un	4	6
Total	125		Total	72	
All Seasons Combined					
Western Gulf			Eastern Gulf		
Species	Number	Percent	Species	Number	Percent
Cc	228	36	Cc	249	53
Cm	45	7	Cm	80	17
Dc	12	2	Dc	7	2
Ei	17	3	Ei	10	2
Lk	304	48	Lk	94	20
Un	22	4	Un	29	6
Total	628		Total	469	

The original catch and effort data collected in the Foundation study were re-analyzed here. Catch and effort data were stratified by (1) OCEAN AREA - (i) western Gulf of Mexico (west of the 89°W), (ii) the Atlantic, (2) SPECIES, (3) SEASON - (i) summer = March-November, (ii) winter = December-February. The data were further stratified in the western Gulf by (4) DEPTH STRATA - (i) Nearshore: 0-10 fm, (ii) Offshore > 10 fm (there was no sampling effort in inshore waters), and in the Atlantic by (5) SUBREGION- (i) South: < 31°N (statistical zones 29-30), (ii) Central: ≥ 31°N (zones 31-33) (Atlantic zones are the integer value of latitude in decimal degrees). We attempted to align units of sampling effort with the units of total fishery effort collected by NMFS programs in the respective areas. A sampling unit in the western Gulf is a unique tow, and effort is measured in hours, the same units as reported for the fishery. Trips are the units used to report Atlantic fishing effort, but the trips that the Foundation sampled in the Atlantic generally were longer duration (mean=10.4 d, SE=1.83, mode=5 d, n=12 trips[10]) than reported for the fishery (see Evaluation of Trip as the Appropriate Unit of Effort in the Atlantic, above). Thus, trip is not a measure that is comparable in effort in the fishery and the Foundation study. Therefore, for this analysis a sampling unit in the Atlantic is a fishing day, which usually consists of more than one tow (**Table 7**). Catch and effort in the Atlantic are standardized by tows as in the Gulf data (**Table 7C**) to facilitate comparison between the two regions. **Table 7** gives a summary of sampling effort.

Sampling effort in the Western Gulf totaled 5018.2 hours and in the Atlantic totaled 596.5 hours in 128 days of fishing **(Table 7).** No sampling occurred in the eastern Gulf or in the North subregion of the Atlantic. There was no sampling in winter in the Atlantic, and the only winter effort in the western Gulf occurred in the offshore stratum in 1997. The depth distribution of Foundation effort is shown in **Figure 5**. In the Atlantic, the effort was restricted to 0-10 fm. - less than 0.2% of the effort (1/641 tows) was in depths > 10 fm. Less than 0.5% of the effort (5/1133 tows) in the western Gulf was in depths greater than 40 fm.

Stratified catch and CPUE statistics are tabulated in **Table 8**. Loggerheads (*Caretta caretta*) (western Gulf - 8, Atlantic - 201) and Kemp's ridleys (*Lepidochelys kempii*)(western Gulf - 15, Atlantic - 67) were the most common species in the catch. Greens (*Chelonia mydas*) were rarely caught (western Gulf - 2, Atlantic - 5), and only one leatherback (*Dermochelys coriacea*) was caught in total (western Gulf). Atlantic catches were much higher than western Gulf catches, although Atlantic effort in hours was an order of magnitude lower than effort in the western Gulf. Observed mean CPUE = total catch/total effort (see effort in **Table 7**) in each stratum. CPUE was much lower in winter than summer.

Table 9 shows the point and precision estimates of the CPUE by species and stratum. The number of observations or the sample size (n) is in tows in the western Gulf (**A**) and in days (**B**) or tows (**C**) in the Atlantic. The observed mean CPUE and standard deviation (std) are given for each stratum that had effort. Strata with no effort have no estimates. The 95% confidence limits (ucl = upper, lcl = lower) are computed by the non-parametric bootstrap percentile (PCTL) method. Bootstrap normal and parametric normal confidence limits also are computed for comparison (SAS Institute, 2000; Lunneborg, 2000). Bootstrapping was based on 1000

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[10] 5 of the 12 trips had effort in more than one subregion. Thus, it is not possible to report trip statistics by subregion.

replicates of n observations within a stratum. The three methods gave very similar confidence intervals, indicating that the bootstrapped distribution is roughly normal. The major advantages of the bootstrap PCTL over the other two methods are that the limits do not extend into the negative range, and that no assumptions are made concerning sampling distribution, except that sampling is random and representative. The coefficient of variation (cv) and variance (var) of the original observed dataset (sample size = n) are calculated for each stratum.

Sources of Error

Bycatch surveys typically contain a large proportion of zero observations, resulting in highly skewed sample distributions. The ordinary sample mean CPUE statistic may underestimate the true population mean, and to a greater extent, the ordinary sample variance may underestimate the true variability of the mean statistic. A widely practiced method is to separate zero and non-zero values (delta method) and fit a distribution model (often lognormal) solely to the non-zero values (Pennington, 1983). This method assumes a lognormal sample distribution for non-zero values, and is not robust to small departures from model assumptions (Myers and Pepin, 1990). With small sample sizes, such departures often cannot be detected, therefore obscuring the magnitude and direction of bias. As there are no extremely large observations in the bycatch data, the ordinary estimator of mean CPUE should be relatively unbiased, and any gain with the delta-distribution method is expected to be minor, and in that latter case if and only if the lognormal distribution is a good fit to non-zero catch rates.

The confidence interval of the estimator of the mean is generated by the bootstrap percentile method, which does not rely on any assumptions regarding the underlying sample distribution. Its main virtue in this case is that the interval cannot extend beyond the possible range of values of the statistic. Simple random sampling and finite variance is assumed, but it is no remedy for inadequate sample size. For this analysis, the population from which samples are drawn must be strictly defined and inferences applied on that particular population. Asymptotic in simple random samples, the bootstrap percentile method should have the same accuracy as the traditional normal approximation. Bias would be amplified in the same direction as the statistic for which the interval was generated (i.e. negative in this case). The bootstrap percentile and the bootstrap normal and parametric normal estimates of the confidence interval compare reasonably well. The upper limit of the bootstrap percentile interval is slightly higher than the normal intervals, and that may compensate somewhat for the possible underestimation of the population mean by the ordinary sample mean.

It is a fundamental assumption of this analysis that the observed CPUE is representative of normal fishery behavior and sampling locations. If the observed component of the fleet is not representative then the analysis is biased. We are concerned about this assumption, especially as applied to the Atlantic where virtually all tows by the Foundation were limited to minimize turtle mortality. Time fishing (sum of all tows) averaged 4.8 hr/day (SE=0.25, n=71) in the Central subregion and 4.4 hr/day (SE=0.17, n=57) in the South subregion. It appears that the fleet may fish more hours during a day than sampled by the Foundation. Thus, we are underestimating catch per day. Boats landing in Georgia during summer 2001 reported average fishing time of 8.0 hr/day (SE=0.38, n=1442). Sampling by observers of NMFS and the Foundation, 1997-2002 (see Tow Times, below) yielded fishing time during the summer that averaged 6.5 hr/day

(SE=0.31, n=142) in the Central subregion and 6.6 hr/day (SE=0.60, n=6) in the South subregion.

Table 7. Effort in Foundation data (1997-1998) by YEAR, SEASON - (i) summer = March-November, (ii) winter = December-February, in A) the western Gulf of Mexico (west of 89^{o}W), where a unique tow as a sampling unit and effort is measured in hours, B) the Atlantic, with a fishing day as a sampling unit, and C) in the Atlantic, with a tow as the sampling unit, for comparison with Gulf effort. Effort is further stratified by DEPTH STRATA in the western Gulf (zones 15-21) - (i) Nearshore: 0-10 fm, (ii) Offshore: >10 fm, and by SUBREGION in the Atlantic - (i) South: zones 29-30, (ii) Central: zones 31-32. There was no effort northward of zone 32, and no effort in winter. The total number of samples (n), the mean, standard deviation (std), and the minimum (min) and maximum (max) effort per sample are tabulated.

A. WESTERN GULF

YEAR	SEASON	DEPTH STRATA	total tows n	total hrs	hrs/tow			
					mean	std	min	max
1997	summer	Nearshore	321	291.7	0.91	0.3	0.2	5.6
1997	summer	Offshore	542	3089.3	5.7	3.7	0.2	14.5
1997	winter	Offshore	93	822.4	8.84	3.56	1.3	15.3
1998	summer	Nearshore	106	101.4	0.96	0.15	0.2	1.2
1998	summer	Offshore	71	713.4	10.05	3.46	1.9	14.7
ALL			1133	5018.2	4.4291	4.1648	15.3	0.2

B. ATLANTIC

YEAR	SEASON	SUBREGION	total days n	total hrs	hrs/day			
					mean	std	min	max
1997	summer	Central	66	330.1	5	2.11	0.9	10.8
1997	summer	South	30	148.6	4.95	1.45	0.8	7.2
1998	summer	Central	5	13	2.6	0.67	1.8	3.6
1998	summer	South	27	104.8	3.88	0.83	0.9	4.8
ALL			128	596.5	4.6602	1.817	10.8	0.8

C. ATLANTIC

YEAR	SEASON	SUBREGION	total tows n	total hrs	hrs/tow			
					mean	std	min	max
1997	summer	Central	374	330.1	0.88	0.16	0.2	1.2
1997	summer	South	153	148.6	0.97	0.13	0.8	1.2
1998	summer	Central	15	13	0.87	0.13	0.4	0.9
1998	summer	South	99	104.8	1.06	0.16	0.6	1.2
ALL			641	596.5	4.6602	1.817	10.8	0.8

Table 8. Catch statistics from the Foundation data in A) the western Gulf of Mexico, where a sampling unit is a tow, B) the Atlantic, with a fishing day as a sampling unit, and C) the Atlantic, with a tow as a sampling unit for comparison with the Gulf data. Catch and effort data are stratified by SPECIES, YEAR, SEASON, DEPTH STRATA (Gulf)/SUBREGION (Atlantic). There was no winter effort in the Atlantic, where almost all effort was in <=10 fm (see **Figure 5**).

A. WESTERN GULF

			CPUE (catch/hr)				CATCH (catch/tow)				
YEAR	SEASON	DEPTH STRATA	mean	std	min	max	total	mean	std	min	max
GREEN											
1997	summer	Nearshore	0.0035	0.062	0	1.1111	1	0.0031	0.0558	0	1
1997	summer	Offshore	0	0	0	0	0	0	0	0	0
1997	winter	Offshore	0.0008	0.0077	0	0.0741	1	0.0108	0.1037	0	1
1998	summer	Nearshore	0	0	0	0	0	0	0	0	0
1998	summer	Offshore	0	0	0	0	0	0	0	0	0
LEATHERBACK											
1997	summer	Nearshore	0	0	0	0	0	0	0	0	0
1997	summer	Offshore	0	0	0	0	0	0	0	0	0
1997	winter	Offshore	0	0	0	0	0	0	0	0	0
1998	summer	Nearshore	0	0	0	0	0	0	0	0	0
1998	summer	Offshore	0	0	0	0	0	0	0	0	0
LOGGERHE											
1997	summer	Nearshore	0.0138	0.1234	0	1.1111	4	0.0125	0.1111	0	1
1997	summer	Offshore	0.0007	0.0113	0	0.2083	2	0.0037	0.0607	0	1
1997	winter	Offshore	0.0014	0.0131	0	0.1266	1	0.0108	0.1037	0	1
1998	summer	Nearshore	0.0079	0.0809	0	0.8333	1	0.0094	0.0971	0	1
1998	summer	Offshore	0	0	0	0	0	0	0	0	0
RIDLEY											
1997	summer	Nearshore	0.0329	0.218	0	2.5	9	0.028	0.1833	0	2
1997	summer	Offshore	0.0003	0.008	0	0.1852	1	0.0018	0.043	0	1
1997	winter	Offshore	0	0	0	0	0	0	0	0	0
1998	summer	Nearshore	0.0498	0.2261	0	1.1111	5	0.0472	0.213	0	1
1998	summer	Offshore	0	0	0	0	0	0	0	0	0

B. ATLANTIC

			CPUE (catch/day)				CATCH
YEAR	SEASON	SUBREGION	mean	std	min	max	total
GREEN							
1997	summer	Central	0	0	0	0	0
1997	summer	South	0.0333	0.1826	0	1	1
1998	summer	Central	0.2	0.4472	0	1	1
1998	summer	South	0.1111	0.3203	0	1	3
LEATHERBACK							
1997	summer	Central	0.0152	0.1231	0	1	1
1997	summer	South	0	0	0	0	0
1998	summer	Central	0	0	0	0	0
1998	summer	South	0	0	0	0	0
LOGGERHEAD							
1997	summer	Central	1.4848	1.8418	0	7	98
1997	summer	South	1.8	2.929	0	14	54
1998	summer	Central	0.2	0.4472	0	1	1
1998	summer	South	1.7778	2.6938	0	11	48
RIDLEY							
1997	summer	Central	0.1364	0.3877	0	2	9
1997	summer	South	0.5333	0.9732	0	4	16
1998	summer	Central	0	0	0	0	0
1998	summer	South	1.5556	3.4567	0	15	42

C. ATLANTIC

			CPUE (catch/hr)						CATCH	(catch/tow)	
YEAR	SEASON	SUBREGION	mean	std	min	max	total	mean	std	min	Max
GREEN											
1997	summer	Central	0	0	0	0	0	0	0	0	0
1997	summer	South	0.0073	0.0898	0	1.1111	1	0.0065	0.0808	0	1
1998	summer	Central	0.0741	0.2869	0	1.1111	1	0.0667	0.2582	0	1
1998	summer	South	0.0253	0.1436	0	0.8333	3	0.0303	0.1723	0	1
LEATHERBACK											
1997	summer	Central	0.003	0.0575	0	1.1111	1	0.0027	0.0517	0	1
1997	summer	South	0	0	0	0	0	0	0	0	0
1998	summer	Central	0	0	0	0	0	0	0	0	0
1998	summer	South	0	0	0	0	0	0	0	0	0
LOGGERHEAD											
1997	summer	Central	0.3109	0.7133	0	5.5556	98	0.262	0.6001	0	5
1997	summer	South	0.3758	0.9138	0	5.5556	54	0.3529	0.8388	0	5
1998	summer	Central	0.0741	0.2869	0	1.1111	1	0.0667	0.2582	0	1
1998	summer	South	0.4338	0.8705	0	5.8333	48	0.4848	1.0138	0	7
RIDLEY											
1997	summer	Central	0.0241	0.1559	0	1.25	9	0.0241	0.1535	0	1
1997	summer	South	0.1144	0.3817	0	2.2222	16	0.1046	0.3472	0	2
1998	summer	Central	0	0	0	0	0	0	0	0	0
1998	summer	South	0.3732	0.8595	0	4.1667	42	0.4242	1.0111	0	5

Table 9. Catch per unit effort (CPUE) statistics from the Foundation data in A) the western Gulf of Mexico, where a sampling unit is a tow, B) the Atlantic, with a fishing day as a sampling unit, and C) the Atlantic, with a tow as a sampling unit for comparison with the Gulf data. The statistics are further stratified by SPECIES, SEASON, DEPTH STRATA (Gulf)/SUBREGION (Atlantic). The observed mean CPUE, standard deviation (std), and coefficient of variation (cv) of the mean are given for each stratum that had effort. Strata with no effort are not listed. The 95% confidence limits (ucl = upper, lcl = lower) are computed by the non-parametric bootstrap percentile (PCTL) method. Bootstrap normal and parametric normal confidence limits are also computed for comparison. Bootstrapping was based on 1000 replicates of n observations within a stratum.

A. WESTERN GULF

CPUE (catch/hr)

SEASON	DEPTH STRATA	n	mean	std	cv	ucl	lcl	cl method
GREEN								
summer	Nearshore	427	0.0026	0.0538	1.0014	0.0077	-0.0025	Normal
						0.0078	-0.0026	Bootstrap Normal
						0.0078	0	Bootstrap PCTL
summer	Ofshore	613	0	-	-	-	-	-
winter	Offshore	93	0.0008	0.0077	0.9981	0.0024	-0.0008	Normal
						0.0023	-0.0007	Bootstrap Normal
						0.0024	0	Bootstrap PCTL
LEATHERBACK								
summer	Nearshore	427	0	-	-	-	-	-
summer	Offshore	613	0	-	-	-	-	-
winter	Offshore	93	0	-	-	-	-	-
LOGGERHEAD								
summer	Nearshore	427	0.0124	0.1143	0.4461	0.0232	0.0015	Normal
						0.0231	0.0017	Bootstrap Normal
						0.0247	0.0026	Bootstrap PCTL
summer	Offshore	613	0.0006	0.0106	0.7135	0.0014	-0.0002	Normal
						0.0014	-0.0002	Bootstrap Normal
						0.0015	0	Bootstrap PCTL
winter	Offshore	93	0.0014	0.0131	0.9703	0.0041	-0.0013	Normal
						0.004	-0.0013	Bootstrap Normal
						0.0041	0	Bootstrap PCTL
RIDLEY								
summer	Nearshore	427	0.0371	0.2199	0.2868	0.058	0.0162	Normal
						0.0582	0.016	Bootstrap Normal
						0.0598	0.0181	Bootstrap PCTL
summer	Offshore	613	0.0003	0.0075	1.0097	0.0009	-0.0003	Normal
						0.0009	-0.0003	Bootstrap Normal
						0.0009	0	Bootstrap PCTL
winter	Offshore	93	0	-	-	-	-	-

B. ATLANTIC

CPUE (catch/day)

SEASON	SUBREGION	n	mean	std	cv	ucl	lcl	cl method
GREEN								
summer	South	57	0.0702	0.2577	0.4862	0.1386	0.0018	Normal
						0.1364	0.004	Bootstrap Normal
						0.1404	0.0175	Bootstrap PCTL
summer	Central	71	0.0141	0.1187	0.9991	0.0422	-0.014	Normal
						0.0407	-0.0126	Bootstrap Normal
						0.0423	0	Bootstrap PCTL
LEATHERBACK								
summer	Central	71	0.0141	0.1187	0.9991	0.0422	-0.014	Normal
						0.0421	-0.0139	Bootstrap Normal
						0.0423	0	Bootstrap PCTL
summer	South	57	1.7895	2.795	0.2069	2.5311	1.0479	Normal
						2.4985	1.0804	Bootstrap Normal
						2.5263	1.0965	Bootstrap PCTL
summer	Central	71	1.3944	1.8085	0.1539	1.8224	0.9663	Normal
						1.7996	0.9892	Bootstrap Normal
						1.7887	1	Bootstrap PCTL
RIDLEY								
summer	South	57	1.0175	2.5106	0.3268	1.6837	0.3514	Normal
						1.6814	0.3537	Bootstrap Normal
						1.7719	0.4561	Bootstrap PCTL
summer	Central	71	0.1268	0.3753	0.3513	0.2156	0.0379	Normal
						0.2128	0.0407	Bootstrap Normal
						0.2254	0.0563	Bootstrap PCTL

C. ATLANTIC

CPUE (catch/hr)

SEASON	ZONE (°N)	n	mean	std	cv	ucl	lcl	cl method
GREEN								
summer	South	252	0.0143	0.1141	0.5026	0.0285	0.0002	Normal
						0.0282	0.0004	Bootstrap Normal
						0.0292	0.0033	Bootstrap PCTL
summer	Central	389	0.0029	0.0563	0.9843	0.0085	-0.0028	Normal
						0.0084	-0.0027	Bootstrap Normal
						0.0086	0	Bootstrap PCTL
LEATHERBACK								
summer	Central	389	0.0029	0.0563	0.9843	0.0085	-0.0028	Normal
						0.0085	-0.0028	Bootstrap Normal
						0.01	0	Bootstrap PCTL
LOGGERHEAD								
summer	South	252	0.3986	0.8958	0.1416	0.5097	0.2875	Normal
						0.5099	0.2873	Bootstrap Normal
						0.5105	0.2902	Bootstrap PCTL
summer	Central	389	0.3018	0.703	0.1181	0.3718	0.2317	Normal
						0.3699	0.2337	Bootstrap Normal
						0.3703	0.2378	Bootstrap PCTL
RIDLEY								
summer	South	252	0.216	0.6267	0.1828	0.2938	0.1383	Normal
						0.2939	0.1382	Bootstrap Normal
						0.3015	0.1438	Bootstrap PCTL
summer	Central	389	0.0232	0.1529	0.3342	0.0384	0.008	Normal
						0.038	0.0084	Bootstrap Normal
						0.0393	0.01	Bootstrap PCTL

Figure 3. Fleet Effort (24 hr. days fished), 1997-1998 and Foundation Sampling Effort (hours fished) in the Gulf of Mexico.

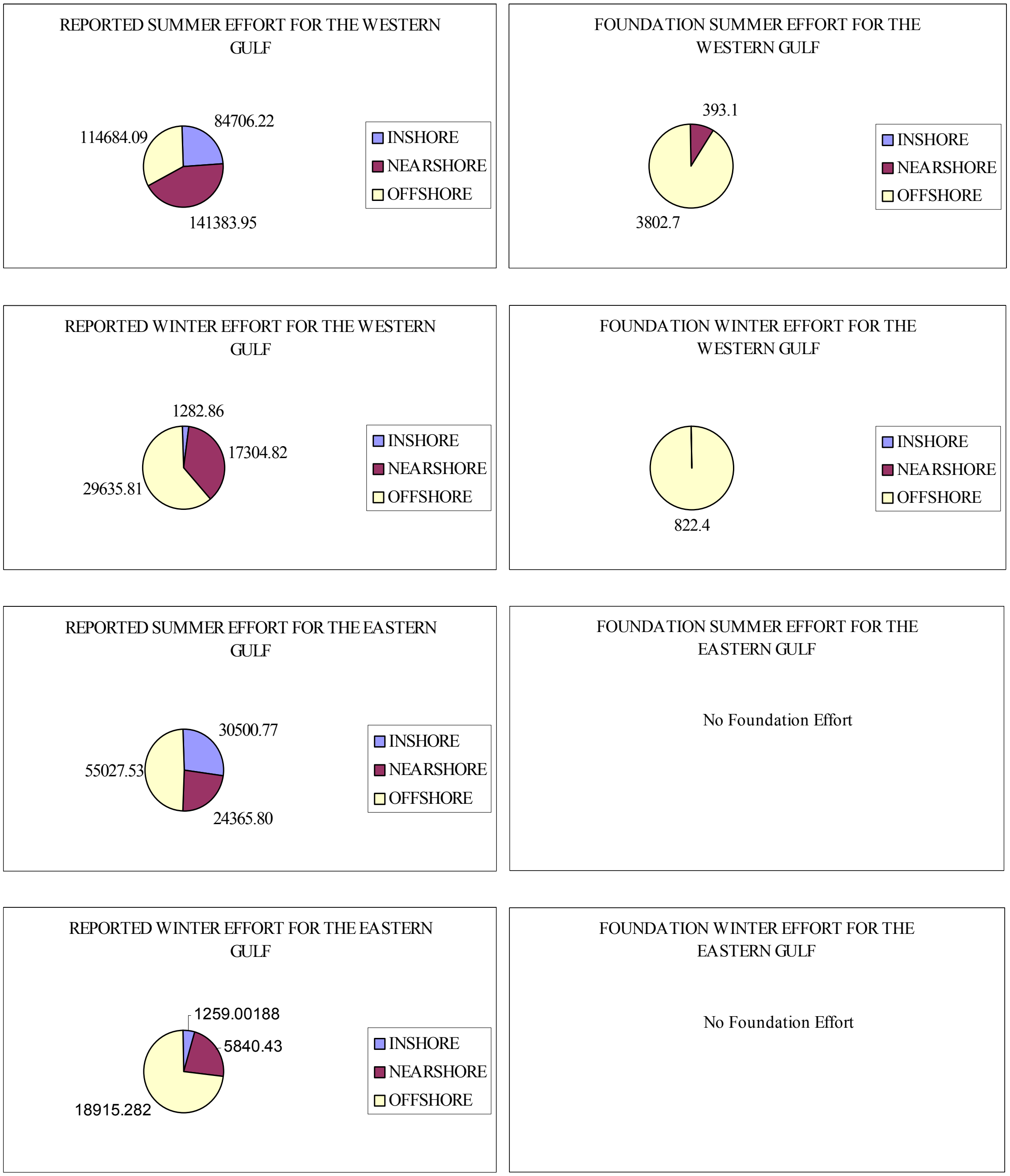


Figure 4. Fleet effort (trips) in 1997-1998 and Foundation sampling effort (days) in the Atlantic. Zones 1-3 correspond to South, Central, and North subregions, respectively.

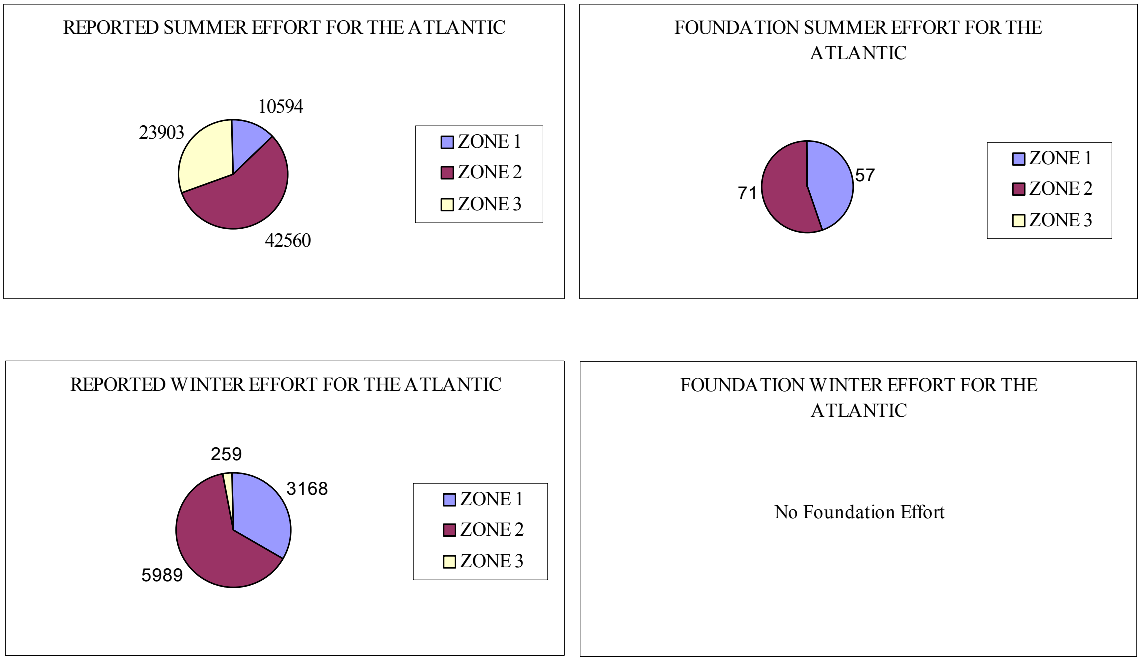
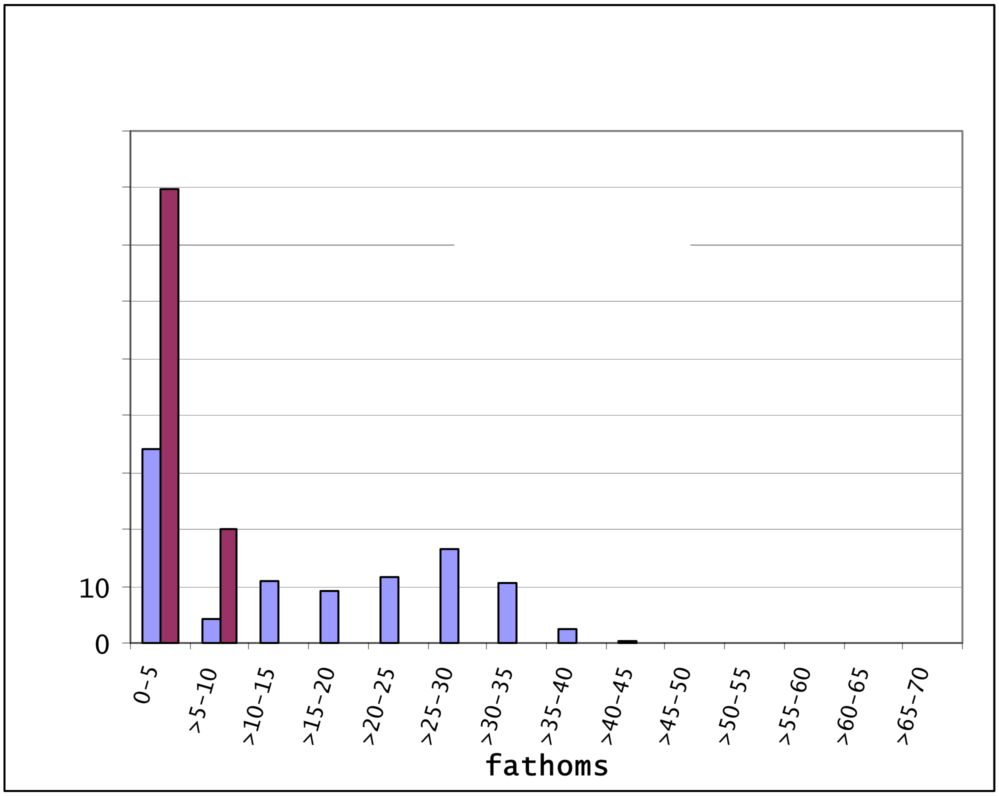


Figure 5. Depth distribution of Foundation effort. Less than 0.5% of the effort (5/1133 tows) in the western Gulf was in depths greater than 40 fm. Less than 0.2% of the effort (1/641 tows) in the Atlantic was in depths greater than 10 fm.



Aerial Survey Data

Results of aerial surveys conducted in the Gulf of Mexico and U.S. Atlantic were used to calculate relative abundance indices for sea turtles using line transect methodology. Derived relative abundance estimates will be used to extrapolate CPUE data from localized observer programs to other regions in the Gulf of Mexico and coastal Atlantic. The presented estimates do not represent absolute abundance but rather minimum population sizes. Sea turtles are easily missed during aerial surveys because they are relatively small, may have a similar coloration to the water in turbid areas, and spend a significant amount of time underwater.

Aerial survey spatial and temporal coverage

Extensive aerial surveys of the Gulf of Mexico were undertaken by the Southeast Fisheries Science Center (SEFSC) during fall (September – November) between 1992-1994 and 1996. The surveys were stratified into inshore (0-10 fathoms) and offshore (10 –100 fathoms) areas. The western Gulf of Mexico, including the coasts of Texas and Louisiana, were covered in 1992 and 1996, the central Gulf from eastern Louisiana to the Florida panhandle during 1993, and the Gulf coast of Florida to Key West during 1994 **(Figure 6**). These surveys included effort in bays and estuaries, but this effort was excluded from the current analysis.

An aerial survey of the coastal US Atlantic was undertaken from July-August 2002. The survey included the coastline from Sandy Hook, New Jersey (40.5 ºN latitude) to Ft. Pierce, FL (27.2 ºN). The survey effort was allocated into 0-20m (10.9 fathoms) and 0-40m (21.9 fathoms) depth strata **(Figure 7**).

Aerial survey methodology

Both Gulf of Mexico and Atlantic surveys employed a DeHavilland Twin Otter aircraft flying at a ground speed of 204 km/hr and an altitude of 229 m. Survey effort was generally restricted to periods of calm sea state (Beaufort Scale 0-3) and good visibility conditions. Two visual observers were stationed in large bubble windows in the forward portion of the aircraft and looked outward and down to spot both marine mammals and sea turtles. Because the plane is a high-wing aircraft equipped with bubble windows, it was possible for the observers to visualize the trackline directly beneath the airplane. A third person was stationed at a recorder position and recorded all turtle and marine mammal sightings on a lap top computer. The data entry program also recorded aircraft position at 30 second intervals, and changes in environmental conditions (e.g., glare, sea state, weather) during survey operations. The species and number of turtles (group size) for each sighting were recorded while the observers were "on effort".

An angle measurement, θ, to each sighting was taken either by using an inclinometer or designating the sighting into 10º angle "bins" based upon markings on the bubble windows. For sightings where only an interval measurement was available, angle measures were "smeared" by adding a random value between –5 and 5 to the mid-point of the angle increment (e.g., 15 º, Buckland *et al.*1993). The perpendicular distance to the sighting (PSD) in meters was calculated as PSD = tan(θ) * Altitude. During the analysis stage, sightings from the first two angle bins (0-10º and 10-20º) were combined because it is often difficult to tell which bin the sighting fell in due to the extremely oblique angle. The resulting distance intervals were 0-83 m, 83-132 m, 132-192 m, 192-272 m, 272 – 396 m, 396-629 m, and > 629 m.

Line transect analysis

The standard theory for line-transect sampling is well developed and has been routinely applied in a variety of wildlife population assessments in both terrestrial and marine habitats (Buckland *et al.* 1993). Given a random distribution of a particular survey line relative to the distribution of a population of interest, then the probability of observing an animal at any distance away from the transect line is equal. Assuming that all animals or groups of animals within a particular distance (W = strip width) on either side of the line are observed, then the density of animals in the area is:

$$(1) \qquad D = \frac{n}{2LW},$$

where *n* is the number of groups observed and *L* is the length of the transect line.

However, line transect theory as described in Buckland *et al.* (1993) recognizes that the probability of observing an animal or group generally declines with increasing distance away from the trackline. The distance sampling approach therefore examines the distribution of sighting frequency as a function of distance away from the trackline and corrects the density estimate for the sighting function, g(x). The sighting function can take any integrable form, however in practice it is generally constrained to be monotonically decreasing vs. the distance away from the trackline, x. The probability of sighting an animal within a strip is then the area under this function divided by the total strip width:

$$(2) \quad P_a = \frac{\int_0^w g(x)dx}{W} .$$

To calculate the probability of sighting an animal at any distance away from the trackline, the sighting function is rescaled to the probability distribution function (pdf), *f(x)* as:

$$(3) \qquad f(x) = \frac{g(x)}{\int_0^w g(x)dx} .$$

The assumption is made that the sighting probability on the trackline is unity (g(0) = 1) allowing one to solve for the pdf at x = 0 as:

$$(4) \qquad f(0) = \frac{1}{\int\limits_0^w g(x)dx} ,$$

and the quantity μ, or the effective strip width is:

$$(5) \qquad \mu = \int\limits_0^w g(x)dx ,$$

alternatively expressed as $\mu = P_a * w$. The density estimate given in eqn. 1 is therefore modified to:

$$(6)\qquad D = \frac{n}{2L\mu}\,.$$

If the objects being observed occur in clusters, or groups, then equation 6 reflects the density of these groups and is simply modified to:

$$(7)\qquad D = \frac{nE(s)}{2L\mu}\,,$$

where E(s) is the expected or average number of animals occurring in each group. The total abundance of animals in a given region of area *A* is then *N* = *D* * *A*.

Variance in the abundance estimate is calculated following the delta method outlined by Seber (1982) for combining uncorrelated variances. Thus, the variance in the density estimate is given as:

$$(8)\quad \mathrm{var}(D) = D^{-2}\cdot\left\{\frac{\mathrm{var}(n)}{n^2}+\frac{\mathrm{var}(f(0))}{f(0)^2}+\frac{\mathrm{var}(E(s))}{E(s)^2}\right\}$$

where var(x) indicates the variance of the respective quantities. The variance of mean group size [var(E(s))] is calculated using the standard expression for variance and the variance of the inverse sighting function [*f(0)*] is calculated based upon the maximum likelihood fitting procedure used to derive the sighting function. The quantity var(n) is the variance of the expected number of animals observed during the survey. The sampling unit for the current survey is considered a single transect line. For each of *k* defined effort units where l_i is the length of each unit and *L* is the sum of all transect lengths, var(n) is estimated as:

$$(9)\qquad \mathrm{var}(n) = L\sum_{i=1}^{k} l_i\left(\frac{n_i}{l_i}-\frac{n}{L}\right)^2 \Big/ (k-1)\,,$$

where n_i is the number of groups seen on transect *i* and *n* is the total number of groups observed during the survey. This variance estimator assumes both independence of encounter rates between transect lines and that the mean encounter rates (n/l) are normally distributed. Severe violations of these assumptions due to spatial contagion may result in inaccurate variance estimation. To account for these factors, variance may also be calculated through non-parametric bootstrap resampling of transects (Buckland *et al.* 1993).

A fundamental assumption in this approach is that the probability of sighting animals on the trackline, g(0), is 1. This is required to accomplish the formulation of eqn. 4 and the solution for the effective strip width. In practice, it is likely that some animals will be missed on the trackline, and therefore g(0) is < 1. The failure of this assumption introduces a direct, negative bias in the density estimate. This source of bias is termed “visibility bias”.

Visibility bias can be separated into two somewhat independent components, availability bias and perception bias (Marsh & Sinclair 1989). Availability bias occurs when the animals can not be observed within the searched area. For example, if bird nests are obscured by vegetation or marine mammals are underwater. This type of bias is often accounted for by separate models of animal availability to the observer. For example, detailed models of observer search behavior and animal dive-surface intervals for marine mammals (Barlow, 1999). Perception bias results from animals that were available to be seen, but were missed by the observers. Primary factors that influence perception bias include weather conditions, observer fatigue, and observer experience (Laake *et al.*, 1997). Perception bias can often be reduced with adequate training of observers, frequent rotation to avoid fatigue, and limiting survey effort to periods where viewing conditions are favorable.

Survey results – Gulf of Mexico

In the Gulf of Mexico, survey effort was post-stratified into four geographic and depth strata to reflect expected changes in turtle density and the distribution of shrimping effort. Effort was stratified geographically into two subregions: the eastern (≤ 89 ºE longitude) and western (> 89 ºE longitude) Gulf, and into two depth strata: inshore (0-10 fathoms) and offshore (10-40 fathoms, **Figure 8**) depth strata (**Table 10**).

A total of 637 sightings of sea turtles were made in the Gulf of Mexico in waters < 40 fathoms in depth, and as expected there were strong geographic differences in sighting rates and species composition. In general, sighting rates were much higher in the eastern Gulf and inshore strata than in the western Gulf. Loggerhead turtles were sighted throughout the Gulf, though had a very low occurrence in the offshore strata in the Western Gulf (**Figure 9A**). Kemp's ridley turtles were sited primarily in the inshore strata and most commonly occurred in the eastern Gulf (**Figure 9B**). Green turtles occurred further offshore and were primarily sighted in the southern portion of the Florida Gulf coast (**Figure 9C**). Hawksbill turtles (*Eretmochelys imbricata*) likewise occurred primarily in southwest Florida (**Figure 10A**). Leatherback turtles were more broadly distributed and were observed primarily in the offshore strata (**Figure 10B**). Finally, many sightings could not be accurately identified to species and were described as un-identified hardshells (**Figure 10C**). The majority of these sightings occurred in southern Florida where green, hawksbill, ridley, and loggerheads were common.

Minimum abundance of sea turtles in each stratum were calculated employing line transect distance methods described above. A common sighting function was derived across all species and strata to provide sufficient sample size for a robust estimate of the sighting function. The detection function was determined by evaluating the goodness-of-fit between several alternative models that satisfy the shape criterion for the relationship between distance from the trackline and sighting probability (Buckland *et al.* 1993). A primary characteristic of these models is that they assume a monotonic decline in sighting probability as the distance from the trackline increases. Sightings were grouped into the interval categories described above that are associated with the angle intervals used during the survey, and data were right-truncated at 629 m. The histogram of sighting frequencies with respect to distance from the trackline was examined to determine the sighting function that best fit the data. Both half-normal and hazard rate models with polynomial expansion terms were evaluated for goodness-of-fit. The "best" detection function was selected based on the minimum Akaike Information Criterion (AIC, Buckland *et al.* 1993).

The sighting frequency indicates a decline in sighting probability from the trackline out to approximately 150 m PSD (**Figure 11**). This is a relatively common problem encountered in aerial surveys for turtles and results in an unknown degree of bias in derived abundance estimates. The sighting function providing the best fit to these data was the half-normal curve with no adjustment terms (**Figure 11**); however, this function did not adequately fit the data as indicated by a significant goodness of fit chi-square ($\chi^2 = 11.46$, df = 3, $p < 0.01$). The fitted sighting function projects a uniform sighting probability equal to 1 back from 130 m to the trackline. Because the actual sighting probability declines over this interval, the resulting abundance estimate is negatively biased due to the poor fit of the sighting curve. The sighting function resulted in a calculated effective strip half-width (μ) of 324.9 m (CV = 4.3%).

Minimum density estimates for each species and unidentified hardshell turtles are presented in **Table 11**. Note that these are minimum density estimates and should only be interpreted as relative abundance indices between strata. For most species, minimum turtle density is approximately 10x higher in the eastern Gulf of Mexico in comparison to the Western Gulf (**Table 11**). The patterns in depth distribution were not as strong. Loggerheads had approximately equal densities between the inshore and offshore strata, though they were more abundant in shallower water in the Western Gulf. Kemp's ridley turtles had higher density in the inshore Eastern Gulf subregion, while green turtles were generally more abundant in the offshore stratum (**Table 11**). Hawksbill turtles were present only in the eastern Gulf and were approximately evenly distributed between the inshore and offshore strata (**Table 11**). Leatherbacks were broadly distributed at low abundance throughout the Gulf with no clear spatial pattern in density (**Table 11**).

Survey results – coastal Atlantic

Survey effort was stratified into three latitudinal strata again determined by the distribution of shrimping effort and available observer data. These included southern (28º - <31º N latitude), central (31º - <34º N latitude), and northern (34º - <36º N latitude) strata. All analyses were limited to the depth strata between 0-10 fathoms as very little Atlantic shrimping effort occurred outside this depth range (**Figure 12**, **Table 12**).

There were a total of 169 on effort sightings in depths <10 fathoms across the three latitudinal strata. Only loggerhead, leatherback, and un-identified hardshell turtles were observed during the survey. Loggerhead turtles were sighted consistently throughout the survey range in both deep and shallow water (**Figure 13A**). Leatherback turtles occurred only in the central stratum in water <10 fathoms, and were more common in deeper water (**Figure 13B**). There were 12 sightings that could not be identified to species, and these occurred most commonly in the central and southern strata (**Figure 13C).**

The sighting function for the Atlantic survey was developed in an equivalent manner to that of the Gulf of Mexico surveys. As in the Gulf surveys, the sighting function exhibited a significant drop-off near the trackline with peak sighting rates at approximately 150 m PSD

(**Figure 14**). The best fitting sighting function was a hazard rate function with no adjustment terms; however, the model did not adequately fit the data ($\chi^2 = 1834$, df = 3, $p < 0.001$). The fitted function results in an effective strip width (μ) of 340.0 m (CV = 4.92%).

Minimum density estimates for identified turtles and unidentified hardshells are presented in **Table 13**. As with the Gulf of Mexico surveys, these values should be considered indices of relative abundance as opposed to estimates of absolute numbers. The fact that no Kemp's ridley or green turtles were identified during the survey is problematic, as both species are known to occur along the Atlantic coast. It is highly likely that these relatively small, cryptically colored species were missed during the survey. Loggerhead turtles were broadly distributed and were abundant in all three strata. However, they were more abundant in the southern portion of the survey area in the Central and South subregions (**Table 13**). Leatherback turtles occurred in relatively low density and were most abundant in the Central subregion. Un-identified turtle densities showed a similar geographic pattern to that of loggerheads, with highest densities in the southern portion of the range (**Table 13**).

Apportioning unidentified turtles:

The species composition of turtles classified as unidentified hardshells should reflect the regional species composition. However, this may be biased against difficult to identify species. For example, identification of loggerheads is fairly clear, but it is more difficult to distinguish between Kemp's ridley and green turtles. Thus, un-identified turtles would include a higher relative proportion of the more difficult to identify species. Nonetheless, to accurately reflect regional relative abundance, it is necessary to apportion the hardshell turtles to species categories. A proportion of the hardshell density is allocated to each species, excluding leatherbacks, as their relative abundance within a stratum. Thus, for a given species, *i*,:

$$(10) \quad P_i = \frac{D_i}{\sum_{j=1}^{s} D_j},$$

where D_x is the density of a given species for all *s* hardshell species. For the Gulf of Mexico, the hardshell species include loggerhead, green, Kemp's ridley, and hawksbill turtles. The corrected density of species *i* including unidentified hardshells is then:

$$(11) \qquad correctedD_i = D_i + P_i D_{hardshell},$$

where $D_{hardshell}$ is the density of unidentified turtles in the stratum.

When apportioning unidentified turtles, it is also necessary to combine variances to arrive at an appropriate estimator of variance for the corrected densities. Assuming that all densities values are uncorrelated, then the combined CV for two or more estimates is equal to the square root of the sum of squared CVs for each estimate, equivalent to equation 8 above. However, it is necessary to calculate and combine variances at each step in the calculation including the CV of the denominator in equation 10, the CV of P_i, the CV of $P_iD_{hardshell}$, and the CV of $correctedD_i$ (equation 11). In estimating the CV for the total of all estimates (the denominator in equation 10), we accounted for the fact that each estimate shares a common value for $f(0)$ using appropriate equations given in Buckland *et al.* (1993, pg. 100-101). Since it is likely that there is positive correlation between each value, the variance estimates are positively biased for the corrected densities. Corrected density estimates for each species and strata are shown in **Table 14**.

Sources of Error

The density estimates presented here suffer from a number of potential biases. Most notably, the presented estimates are negatively biased by the assumption that all animals occurring on the trackline are seen by the observers. The level of visibility bias is likely to be severe for sea turtles because they are relatively small and easily missed by observers, and because they spend a considerable amount of time beneath the surface where they are not available to the survey. In addition, the decline in sighting rates near the trackline and poor fit of the sighting function introduces potential negative bias.

However, for the purposes of this analysis the negative biases in the absolute density estimates are less important. These analyses are being used to assess the relative distribution of sea turtles between regions, and we implicitly assume that the sighting probabilities, and associated biases, are equal across regions. This assumption may be violated due to potential variation in the sighting conditions within regions. In the Gulf of Mexico surveys, for example, the eastern and western strata were surveyed in different years. Differing water turbidity, for example, between years could potentially influence sighting probabilities and would confound the perceived differences in animal density across geographic regions. The degree of this type of bias is likely to be relatively minor as the same aircraft and personnel were used and surveys were only conducted in good weather conditions.

A potentially more serious source of relative bias in density estimates exists due to varying levels of sightability for the different species. It is notable in the Atlantic that no Kemp's ridley or green turtles were observed during the surveys; however, these species are known to occur in the central and southern strata and are frequently captured in shrimp trawls. The relatively small size of these turtles and similar coloration to the water may limit the ability of visual observers to both see and identify these species during surveys, but the use of trained observers may increase the sightings of these species. In contrast, loggerhead turtles are somewhat larger and their coloration causes them to stand out clearly against the greenish background of nearshore waters. The Gulf of Mexico surveys appear to have been more efficient at observing and identifying these species. It remains unclear as to whether this is due to differences in observer personnel or higher relative abundance of these species in the Gulf than the Atlantic.

The variance estimates for all density measures were relatively large, particularly after combining estimates with unidentified hardshells. The high degree of variation in this data results from the relatively low abundances of sea turtles and more likely the relatively low probability of actually seeing turtles. There are several assumptions made during the analysis that result in bias in the estimates of variance. First, during model fitting a relatively limited range of potential models was explored; forcing the choice of a monotonically declining function artificially reduces the degree of uncertainty in the estimate of effective strip width. Fitting a more complex model to these data would result in a higher level of uncertainty because of the increase in parameters with a relatively small number of model degrees of freedom. Second, in apportioning hardshell turtles across the other species groups in the Gulf, we explicitly assume there is no correlation between identified and unidentified turtle densities. If the terms are in fact correlated, this would result in a decrease in variance of their combined density estimate. Thus, the variances in the "corrected density" estimates (**Table 14**) are likely positively biased. Finally, variable sighting conditions due to environmental factors and weather conditions both during and between surveys will contribute additional unquantified variance to the resulting estimates.

The results of the Gulf of Mexico and Atlantic aerial surveys indicate differences in turtle density and species composition as a function of geographic region and water depth. These estimates suffer from several sources of negative bias and the resulting variances suffer from potential sources of both positive and negative bias. However, given the quantified differences in relative density, particularly in the Gulf of Mexico, these surveys provide useful information with which to infer relative catch rates in shrimp trawl fisheries across regions.

Table 10. Summary of survey effort by strata during Gulf of Mexico aerial surveys.

Stratum	Boundary	Stratum Area (km^2)	Total Effort (km)	Total On-Effort Turtle Sightings
		Western Gulf		
Inshore	0-10 fathoms	31,189	4,652	42
Offshore	10-40 fathoms	72,262	5,915	15
		Eastern Gulf		
Inshore	0-10 fathoms	46,907	5,976	392
Offshore	10-40 fathoms	105,158	3,693	188

Table 11. Minimum density estimates (N/sq km) for sea turtles by species in the Gulf of Mexico. Standard errors for each quantity are shown in parentheses. %CV=Percent coefficient of variation (100 * Standard Error / Estimate).

Subregion	Number of Groups	Group Density	Average Group Size	Turtle Density	Density %CV	95% Confidence Interval
Loggerhead						
W. Gulf 0-10 fm.	28	0.0093 (0.003)	0.991 (0.0245)	0.0092	33.92	0.0048 – 0.0176
W. Gulf 10-40 fm.	7	0.0019 (0.002)	1.143 (0.143)	0.0021	108.47	0.0004 – 0.0118
E. Gulf 0-10 fm.	144	0.0371 (0.004)	1.069 (0.002)	0.0397	11.84	0.0314 – 0.0500
E. Gulf 10-40 fm.	69	0.0288 (0.004)	1.145 (0.069)	0.0329	15.73	0.0242 – 0.0448
Kemp's ridley						
W. Gulf 0-10 fm.	1	0.0003 (0.0004)	1 (N/A)	0.0003	134.14	0.0001 – 0.0024
W. Gulf 10-40 fm.	0	0	0	0		
E. Gulf 0-10 fm.	20	0.0052 (0.002)	1.150 (0.109)	0.0059	32.94	0.0031 – 0.0111
E. Gulf 10-40 fm.	1	0.0004 (0.0002)	2 (N/A)	0.0008	40.89	0.0004 – 0.0018
Green						
W. Gulf 0-10 fm.	1	0.0003 (0.0004)	2 (N/A)	0.0006	197.28	0.0001 – 0.0079
W. Gulf 10-40 fm.	2	0.0005 (0.0002)	1 (0)	0.00052	45.18	0.0002 – 0.0012
E. Gulf 0-10 fm.	5	0.0013 (0.0006)	1.2 (0.200)	0.00154	50.33	0.0006 – 0.0039
E. Gulf 10-40 fm.	18	0.0075 (0.0016)	1.333 (0.1809)	0.0100	25.69	0.0061 – 0.0165

Table 11 (continued). Minimum density estimates (N km^{-2}) for sea turtles by species in the Gulf of Mexico. Standard errors for each quantity are shown in parenthesis. %CV = Percent coefficient of variation (100 * Standard Error / Estimate).

Subregion	Number of Groups	Group Density	Average Group Size	Turtle Density	Density %CV	95% Confidence Interval
Hawksbill						
W. Gulf 0-10 fm.	0	0	0	0		
W. Gulf 10-40 fm.	0	0	0	0		
E. Gulf 0-10 fm.	101	0.0260 (0.004)	1.634 (0.144)	0.0425	18.41	0.0297 – 0.0608
E. Gulf 10-40 fm.	38	0.0158 (0.0046)	1.447 (0.0043)	0.0229	31.89	0.0124 – 0.0423
Leatherback						
W. Gulf 0-10 fm.	1	0.0003 (0.0004)	1 (N/A)	0.0003	139.66	0.00004 – 0.0026
W. Gulf 10-40 fm.	2	0.0005 (0.0003)	1 (0)	0.0005	49.63	0.0002 – 0.0013
E. Gulf 0-10 fm.	1	0.0026 (0.0027)	1 (N/A)	0.0026	104.56	0.0004 – 0.0140
E. Gulf 10-40 fm.	7	0.0029 (0.0010)	1 (0)	0.0029	34.82	0.0015 – 0.0057
Unidentified Hardshell						
W. Gulf 0-10 fm.	7	0.0023 (0.0012)	1.143 (0.1429)	0.0026	54.73	0.0009 – 0.0073
W. Gulf 10-40 fm.	3	0.0008 (0.0006)	1 (0)	0.0008	81.50	0.0002 – 0.0032
E. Gulf 0-10 fm.	89	0.0229 (0.0028)	1.337 (0.2827)	0.0306	24.59	0.0190 – 0.0495
E. Gulf 10-40 fm.	41	0.0171 (0.00370)	1.463 (0.1642)	0.0250	24.39	0.0156 – 0.0402

Table 12. Summary of survey effort by strata during Atlantic aerial survey.

Subregion	Boundary	Stratum Area (km^2)	Total Effort (km)	Total On-Effort Turtle Sightings
North	34- <36º N	3,986	560	22
Central	31- <34º N	15,577	1378	109
South	28- <31º N	4,651	304	37

Table 13. Miminum density estimates (N / sq. km) for sea turtles by species in the Atlantic. Standard errors for each quantity are shown in parentheses. %CV = Percent coefficient of variation (100 * Standard Error / Estimate).

Stratum	Number of Groups	Group Density	Average Group Size	Turtle Density	Density %CV	95% Confidence Interval
Loggerhead						
North	21	0.0551 (0.01675)	1.1429 (0.07825)	0.0629	31.15	0.03425 – 0.1159
Central	91	0.0971 (0.0143)	1.3626 (0.0849)	0.1323	16.03	0.0963 – 0.1817
South	39	0.1885 (0.0404)	1.2821 (0.08172)	0.2417	22.35	0.1538 - 0.3796
Leatherback						
North	0	0	0	0		
Central	5	0.0053 (0.00371)	1.4 (0.2449)	0.0075	70.94	0.00207 – 0.0270
South	0	0	0	0		
Unidentified Hardshell						
North	1	0.0026 (0.0039)	1 (N/A)	0.0026	148.75	0.00029 – 0.0230
Central	6	0.0064 (0.0032)	1.036 (0.1170)	0.0066	51.37	0.0025 – 0.0176
South	5	0.0242 (0.0088)	1.2 (0.2000)	0.0289	45.95	0.0118 – 0.0712

Table 14. Corrected density estimates for each turtle species including a proportion of the unidentified turtle density in the Gulf of Mexico and Atlantic surveys. The estimate for loggerhead in the North Atlantic subregion does not include hardshell density. Variance estimates reflect the combined uncertainty in these parameters assuming uncorrelated values. %CV = Percent coefficient of variation (100 * Standard Error / Estimate).

Subregion	Proportion of Total	Corrected Density (N km^2)	%CV Corrected Density	95% CI Corrected Density
Loggerhead – Gulf of Mexico				
West, 0-10 fm	0.902	0.0115	80.1	0.0030 – 0.0443
West, 10-40 fm	0.800	0.0027	185.7	0.0003 – 0.0278
East, 0-10 fm	0.443	0.0532	31.7	0.0295 – 0.0961
East, 10-40 fm	0.493	0.0452	36.0	0.0233 – 0.0880
Kemp's ridley – Gulf of Mexico				
West, 0-10 fm	0.032	0.0004	200.2	0.0000 – 0.0047
West, 10-40 fm	0	0	0	
East, 0-10 fm	0.065	0.0079	53.8	0.0030 – 0.0207
East, 10-40 fm	0.013	0.0011	64.4	0.0004 – 0.0035
Green – Gulf of Mexico				
West, 0-10 fm	0.064	0.0008	286.2	0.0000 – 0.0142
West, 10-40 fm	0.200	0.0007	122.6	0.0001 – 0.0042
East, 0-10 fm	0.017	0.0021	76.1	0.0006 – 0.0075
East, 10-40 fm	0.150	0.0137	46.1	0.0060 – 0.0317
Hawksbill – Gulf of Mexico				
West, 0-10 fm	0	0	0	
West, 10-40 fm	0	0	0	
East, 0-10 fm	0.473	0.0569	37.4	0.0285 – 0.1135
East, 10-40 fm	0.344	0.0315	53.3	0.0122 – 0.0816
Leatherback – Gulf of Mexico				
West, 0-10 fm		0.0003	139.66	0.00004 – 0.0026
West, 10-40 fm		0.0005	49.63	0.0002 – 0.0013
East, 0-10 fm		0.0026	104.56	0.0004 – 0.0140
East, 10-40 fm		0.0029	34.82	0.0015 – 0.0057
Loggerhead - Atlantic				
North		0.0630	30.3	0.0373 – 0.1137
Central		0.1389	15.5	0.1035– 0.1864
South		0.2707	20.7	0.1833 – 0.3997
Leatherback – Atlantic				
North		0		
Central		0.0075	70.94	0.00207 – 0.0270
South		0		

Figure 6. Survey area and tracklines during the NMFS 1992-1994 and 1996 Gulf of Mexico aerial surveys for sea turtle abundance.

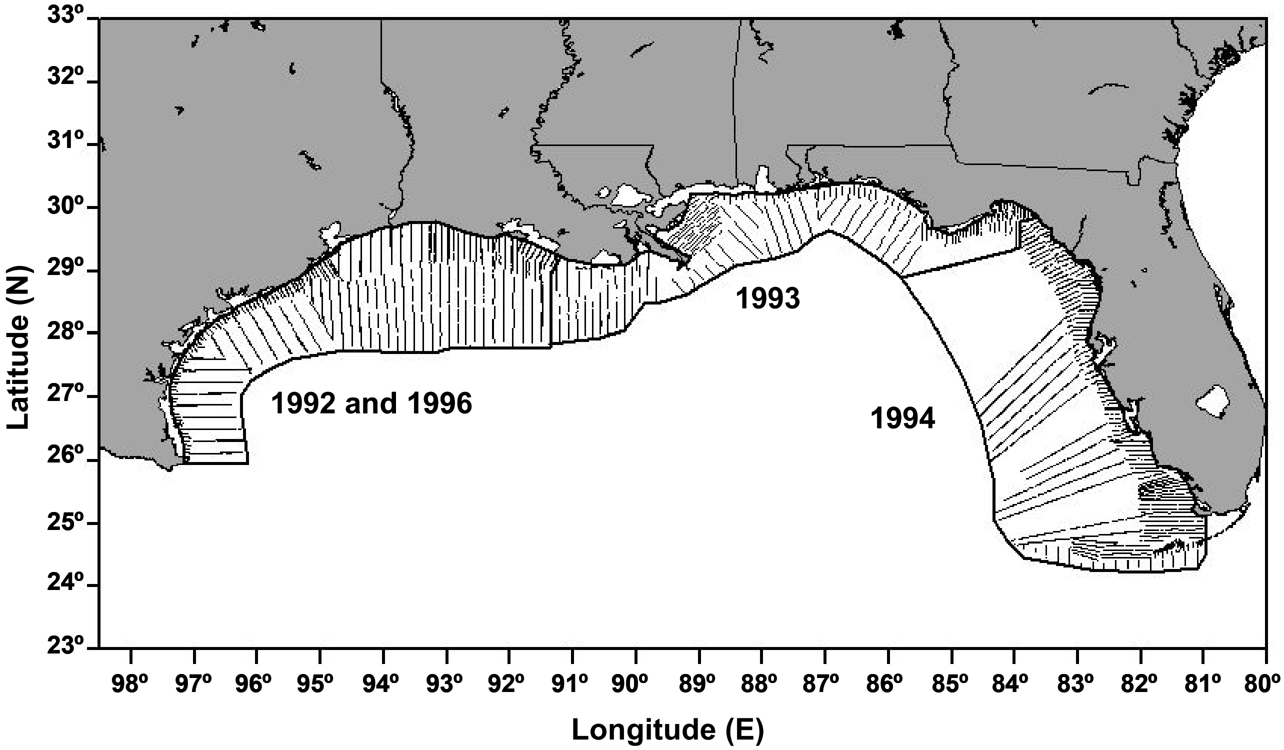


Figure 7. Survey area and tracklines during the summer 2002 Atlantic aerial surveys.

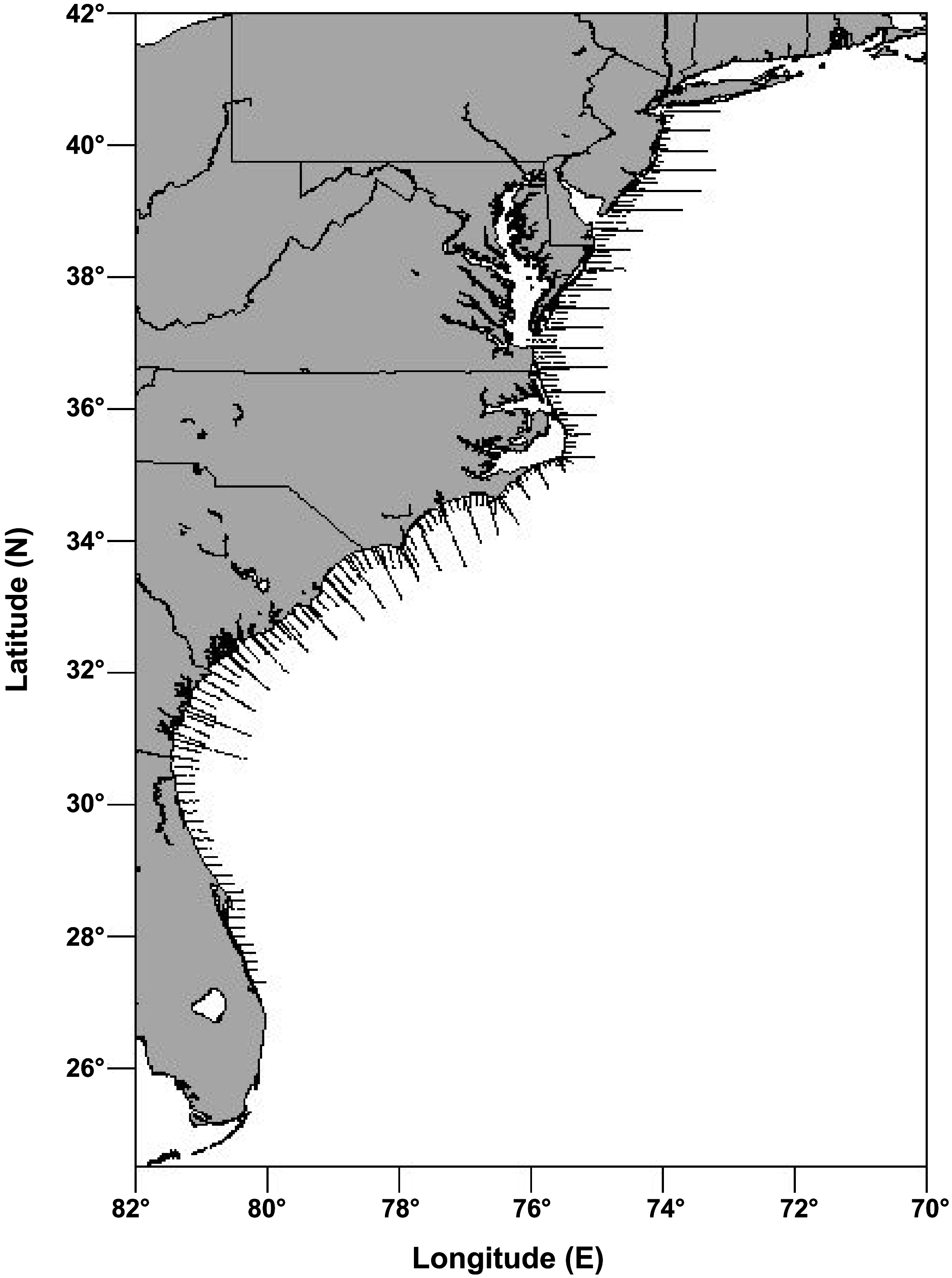


Figure 8. Geographic and depth strata used for density estimates in the Gulf of Mexico.

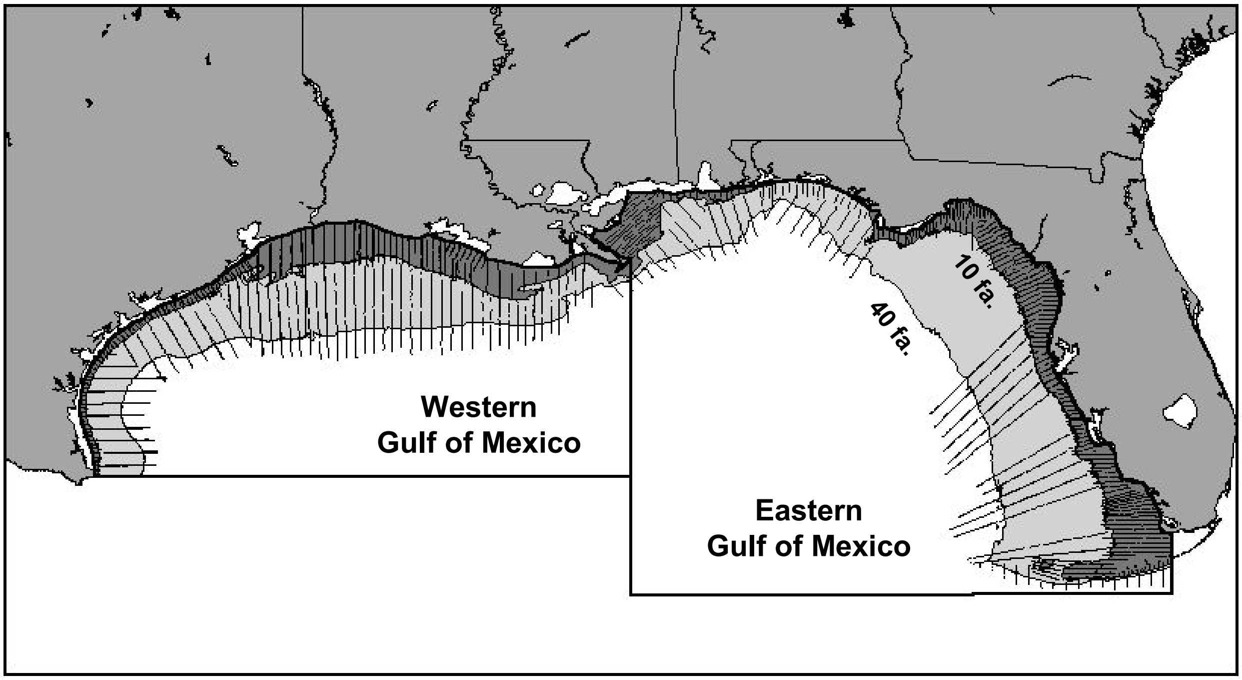


Figure 9. Distribution of sightings for (A) Loggerhead, (B) Kemp's ridley, and (C) Green turtles in the Gulf of Mexico.

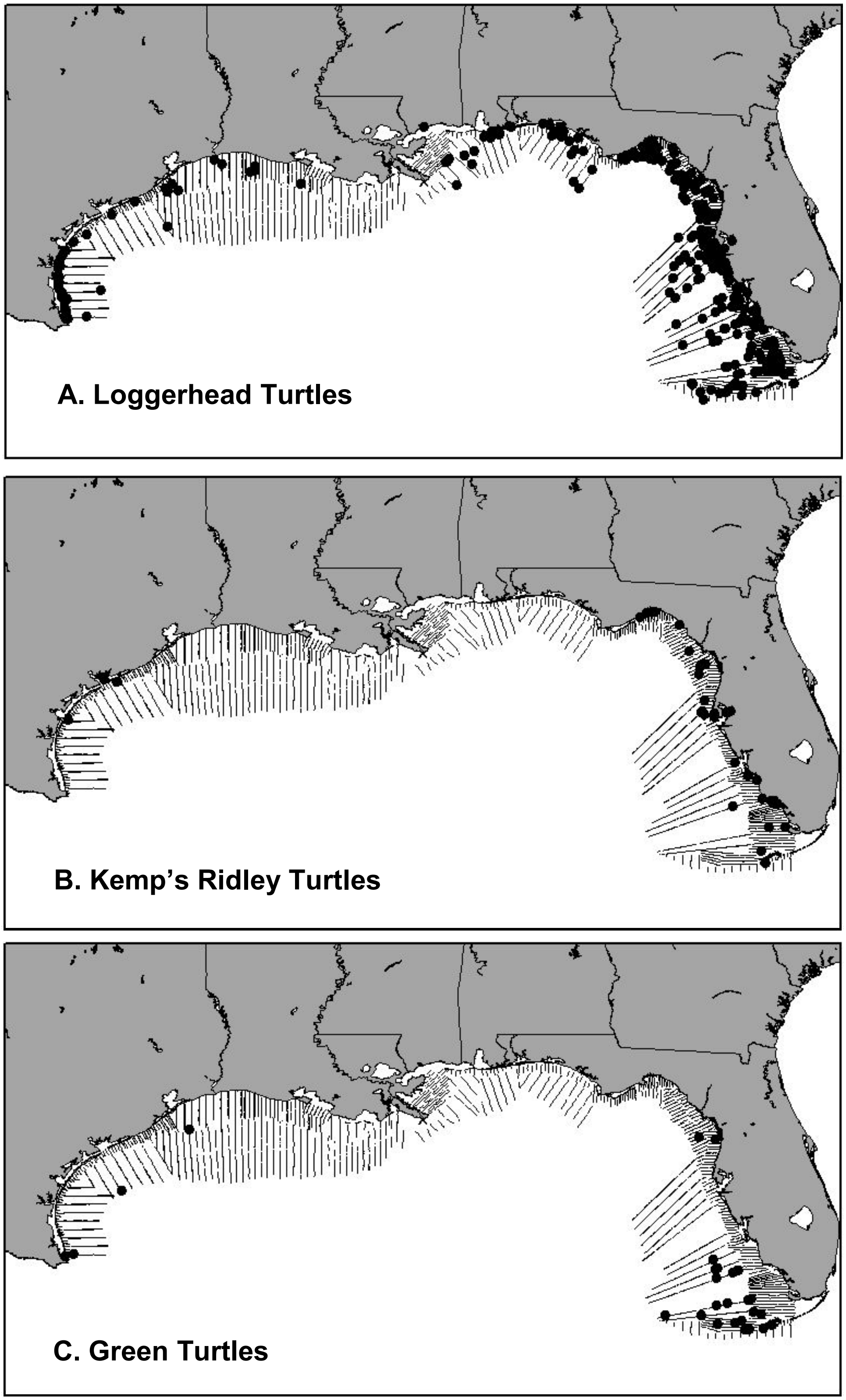
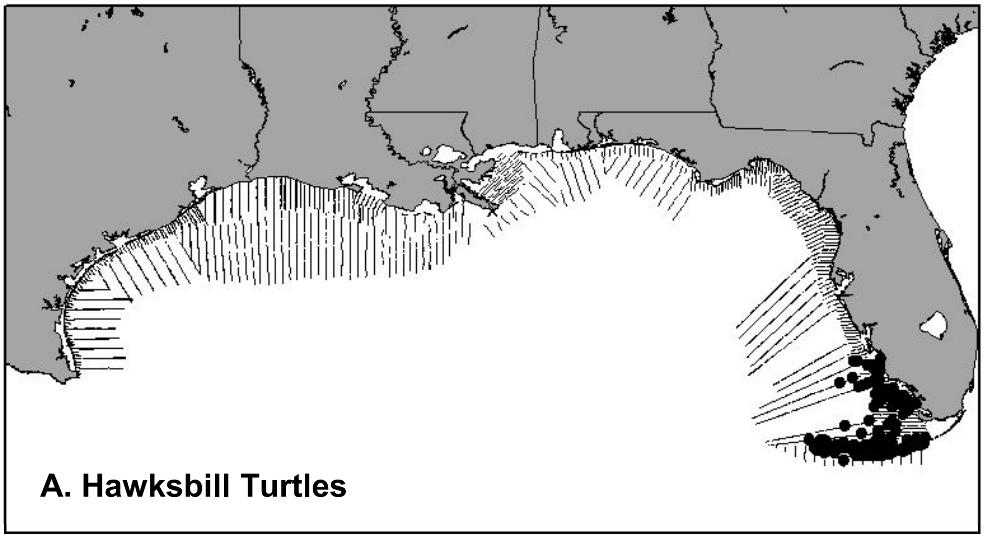
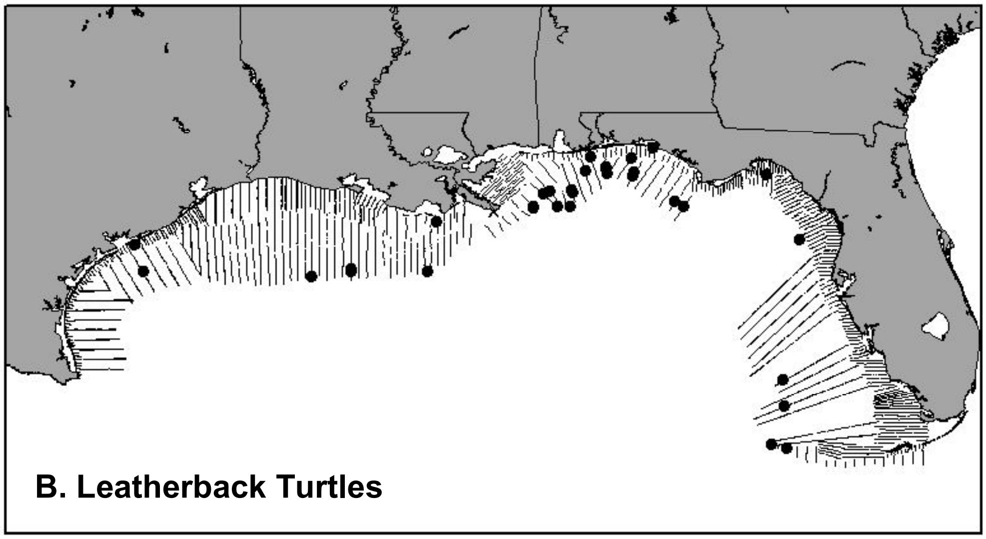


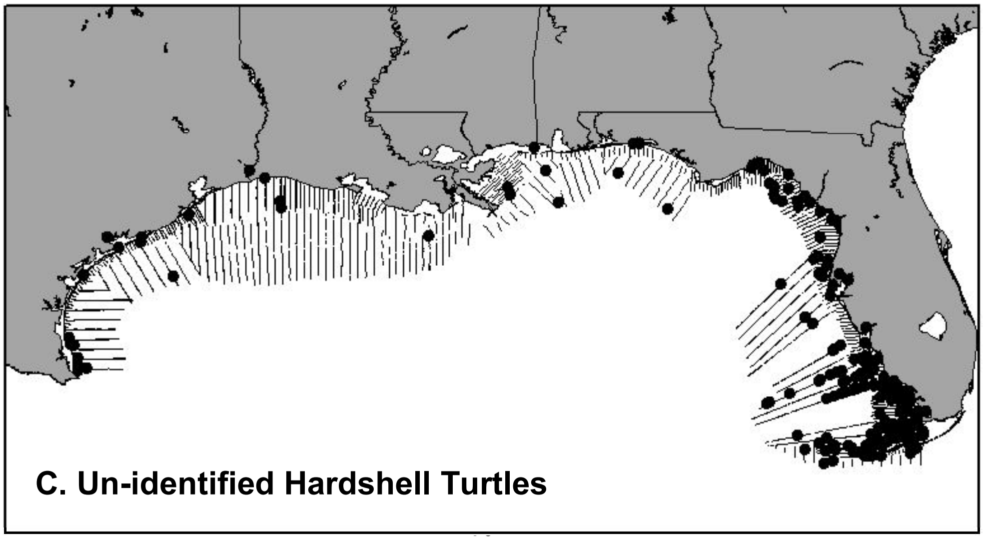
Figure 10. Distribution of sightings for (A) Hawksbill, (B) Leatherback, and (C) unidentified hardshell turtles in the Gulf of Mexico.



A. Hawksbill Turtles



B. Leatherback Turtles



C. Un-identified Hardshell Turtles

Figure 11. Sighting probability as a function of distance from the trackline for Gulf of Mexico turtles. The bars indicate scaled sighting frequencies within distance intervals and the line indicates the fitted half-normal curve.

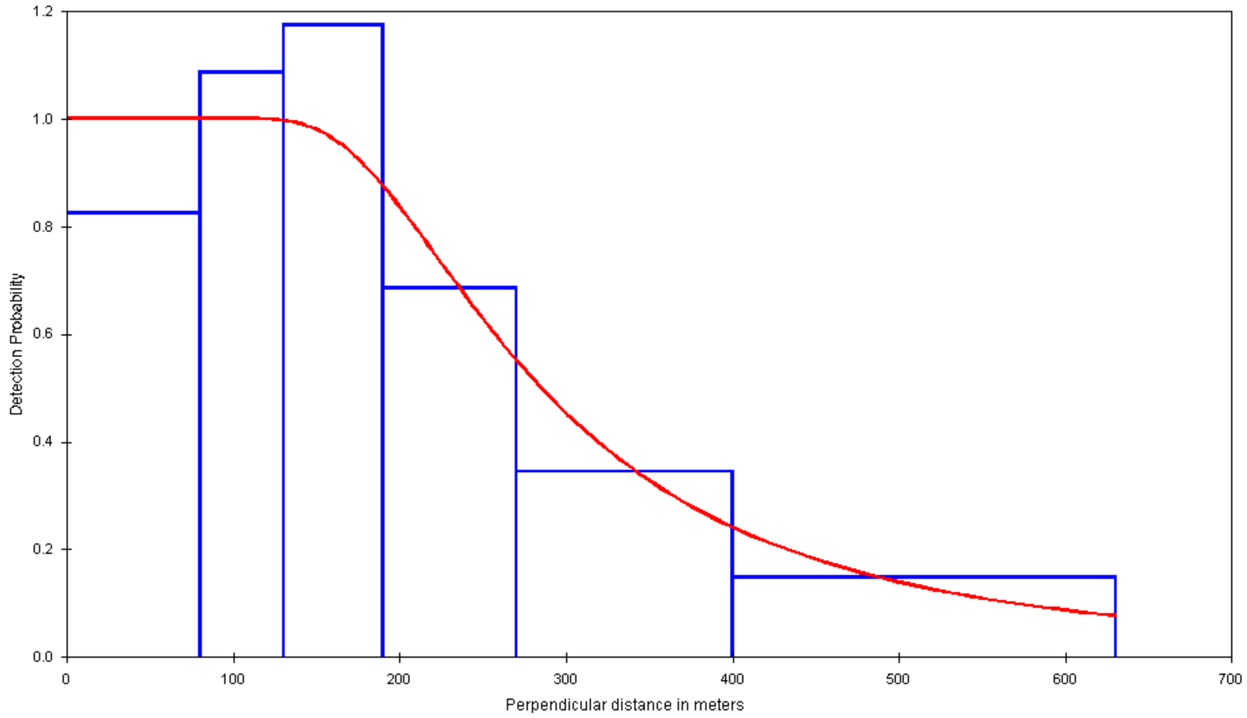


Figure 12. Latitudinal strata used for density estimates in the Atlantic. The 10 fathom isobath is shown.

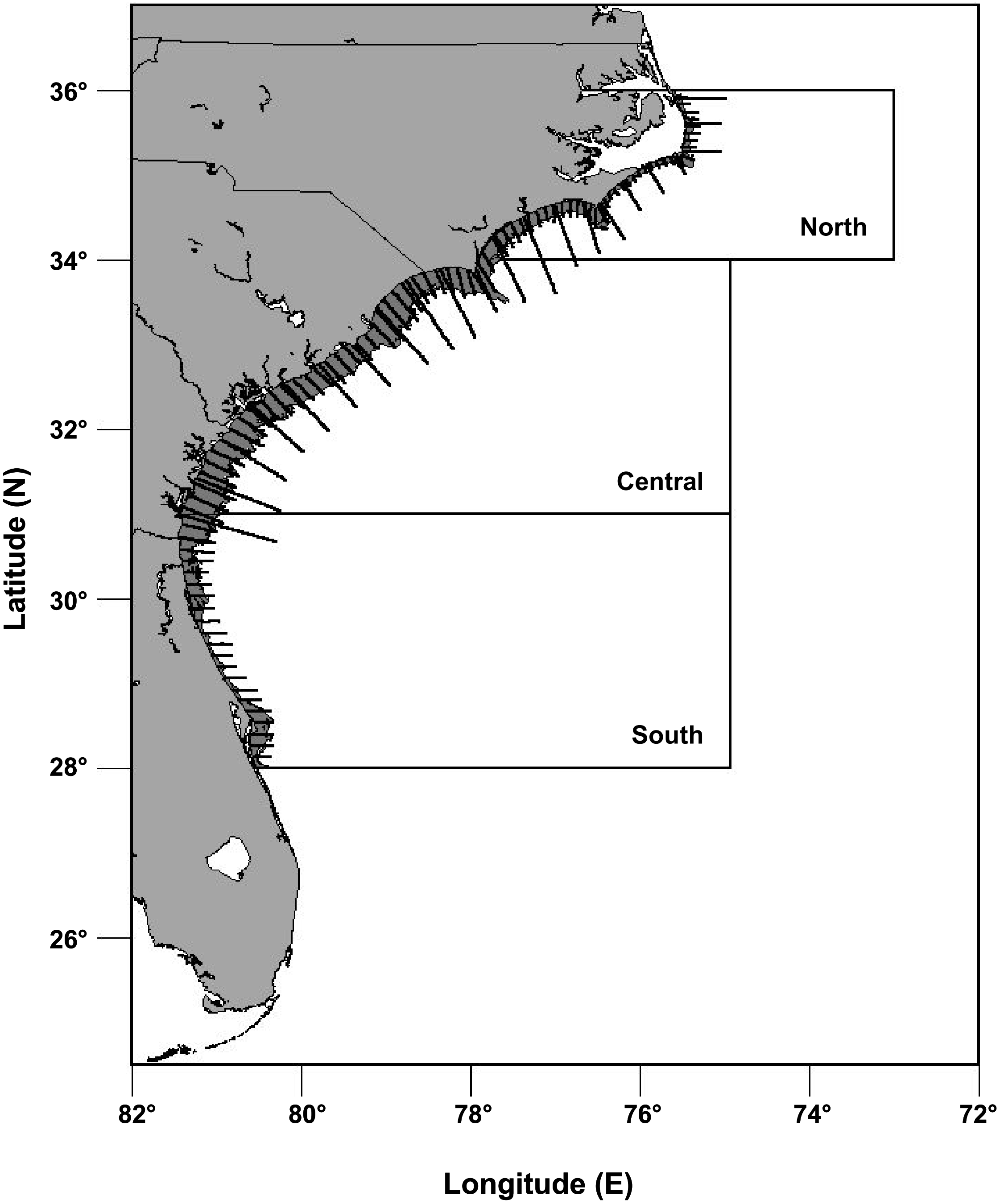


Figure 13. Distribution of sightings for (A) loggerhead, (B) leatherback, and (C) unidentified hardshell turtles in the Atlantic.

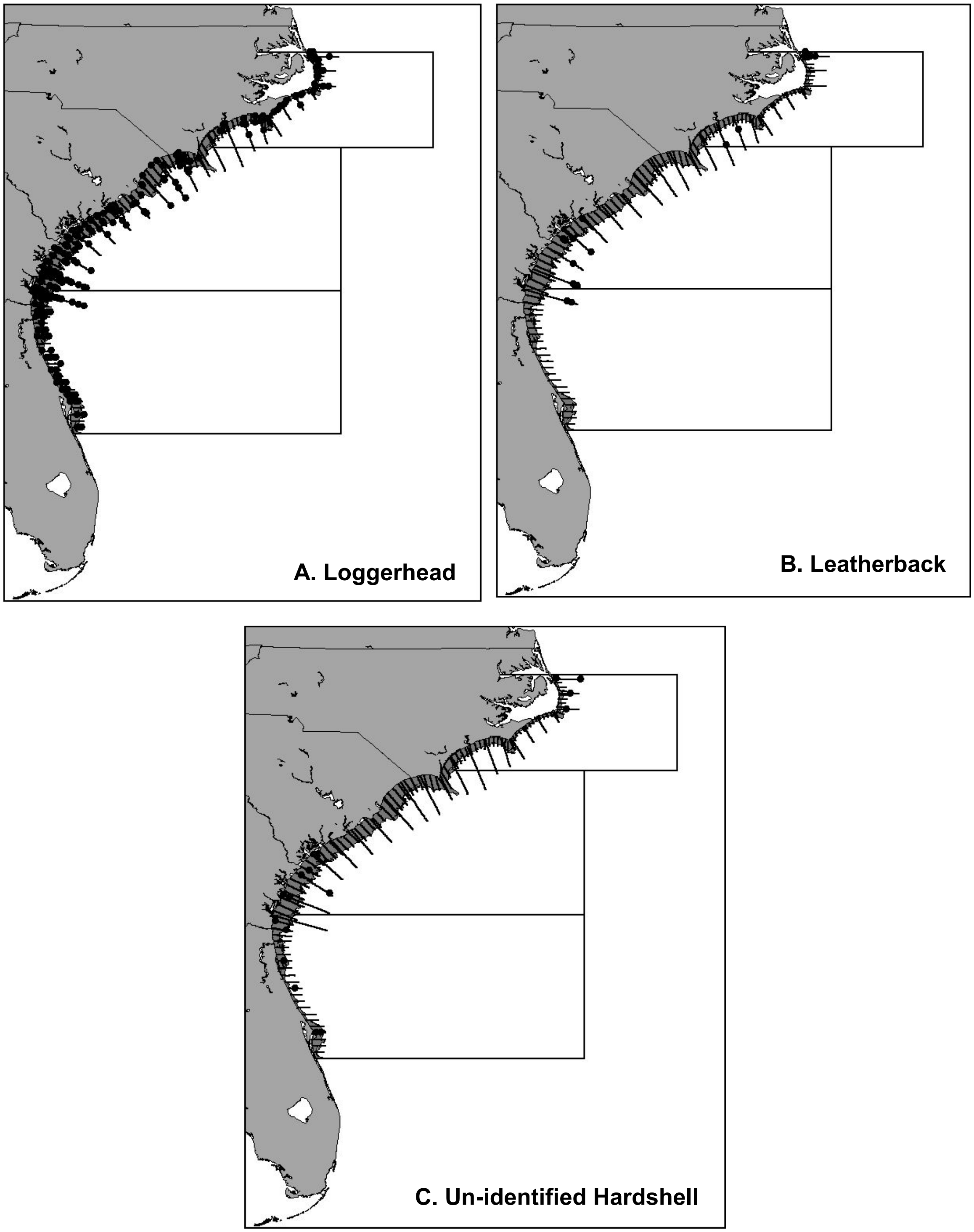
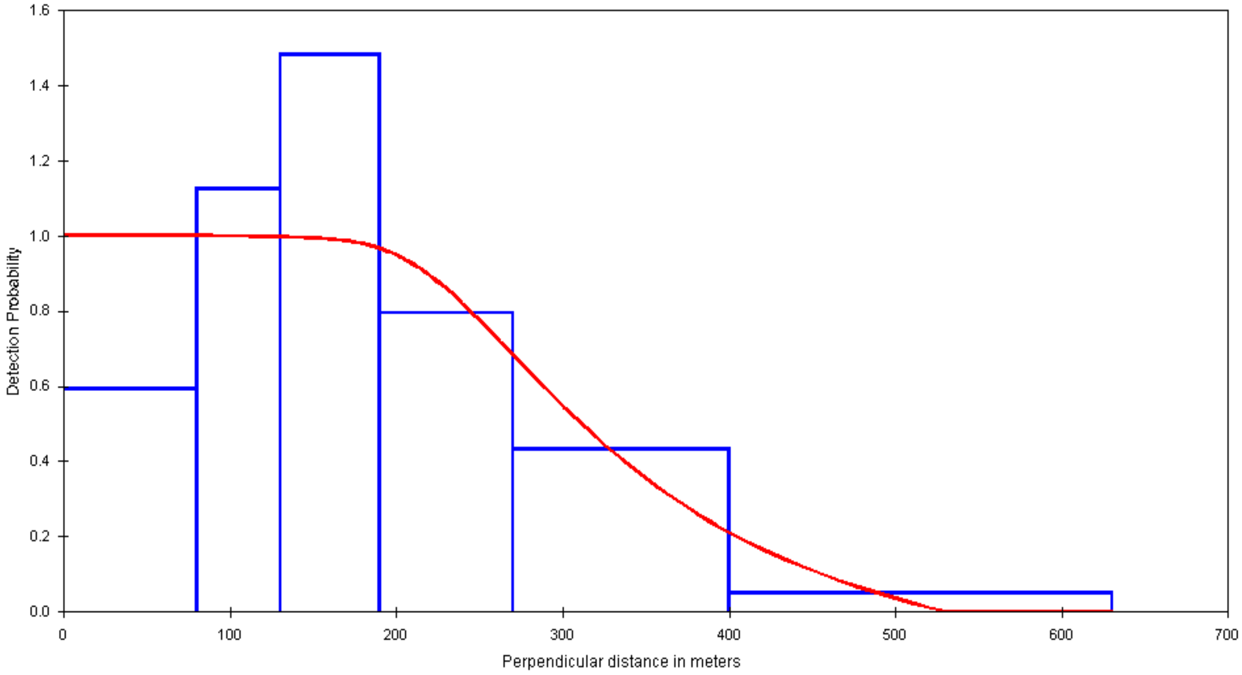


Figure 14. Sighting probability as a function of distance from the trackline for Atlantic turtles. The bars indicate scaled sighting frequencies within distance intervals and the line indicates the fitted hazard rate curve.



Adjusted Catch Rates

CPUE for those species and strata where data were available are presented for summer and winter in

Table 15 and **Table 16**. When available, CPUE estimates from the Foundation study were used. Foundation data were available in the western Gulf of Mexico for loggerheads (summer Nearshore and Offshore, winter Offshore), Kemp's ridley (summer Nearshore and Offshore), and green (summer Nearshore, winter Offshore). In the Atlantic, the Foundation study provided estimates of CPUE for loggerhead (summer Central and South), Kemp's ridley (summer Central and South), green (summer Central and South), and leatherback (summer Central)

If there were no Foundation CPUE data for a species in a given strata, estimates were obtained with one of two methods. The primary method used a "catchability" estimate for a species in a given strata, and we extrapolated to other nearby strata using the catchability estimate and relative abundance from the aerial surveys. In the absence of such information, our alternative method to estimate CPUE was to use the CPUE of that species from the most similar strata where we did have an estimate.

"Catchability" (Q_i) was estimated as follows:

$$Q_i = C_{ij} / A_{ij}$$

Where A_{ij} is aerial survey abundance index for species i in stratum j and C_{ij} is CPUE in trawls for species i in stratum j. If there were no CPUE estimates for a particular stratum, we made the assumption that Q_i is the same as the nearest stratum with data, within a region (Gulf or Atlantic). We estimated C_{ik} for a different stratum k, when no CPUE data were available, using the aerial survey abundance for that strata and the catchability from a nearby strata as:

$$C_{ik} = Q_i * A_{ik}$$

We estimated the CV for Qi using the following equations (Seber, 1982):

$$CV\ (Q_i) = \text{sqrt}\ (CV(A_{ij})^2 + CV(C_{ij})^2)$$

$$CV\ (C_{ik}) = \text{sqrt}\ (CV(Q_i)^2 + CV(A_{ik})^2)$$

For any species where we do have both a C_{ij} and an A_{ij}, we can estimate Q_i and extrapolate to other strata. Q_i could not be estimated for a species where A_{ij} is unknown. In these cases, we assigned a nearby CPUE to the strata.

In the Gulf of Mexico we have summer abundance (A_{ij}) and CPUE estimates (Q_i) in the western Gulf of Mexico for loggerhead (Nearshore and Offshore), Kemp's ridley (Nearshore), and green (Nearshore). For the Atlantic, we only have abundance and CPUE estimates in the Central and South subregions for loggerheads.

CPUE was estimated using the catchability method in the Gulf of Mexico during the summer for loggerhead (eastern Nearshore and Offshore), Kemp's ridley (eastern Nearshore and Offshore), and green (western Offshore, eastern Nearshore and Offshore). For leatherback in the Gulf of Mexico, we applied the catchability estimate from the Atlantic to the abundance estimates of the Gulf of Mexico for all strata to estimate CPUE. The application of Q_i between regions was necessary because we had no data on CPUE for leatherbacks in the Gulf of Mexico. In the Atlantic, the catchability method only was used for loggerhead during the summer in the North subregion.

Due to a lack of data we were not able to estimate any CPUE for hawksbill turtles. There were no CPUE estimates in the Foundation data, and we had only density estimates from the eastern Gulf of Mexico. The absence of any data on the CPUE of hawksbill may be attributed to the fact that they associate with coral reefs or live bottom (NMFS and USFWS 1993). This association reflects their diet of sponges, which require hard-bottom substrate for attachment. Otter trawls do not operate in the vicinity of coral reefs. When not on reefs, hawksbills are likely to engage in directed movements between reefs. These directed movements would minimize their time over open bottom where trawls are likely to be operating. Additionally, aerial survey sightings of hawksbills are concentrated in southwest Florida (**Figure 10**). Large portions of this area are closed to fishing (Everglades National Park), which would minimize any interaction with trawls.

Sources of Error

Foremost among the sources of error are the problems encountered with the sightability of Kemp's ridley and green turtles during aerial surveys. This is especially an issue in areas such as the northern Gulf of Mexico or the Atlantic where none or few were sighted, but other sources of information indicate their presence. There may be several sources of bias using aerial survey data for these two species that are smaller and have less contrast than the loggerhead or leatherback turtles. Water clarity differs within and among subregions; it is less likely that these two species can be detected in turbid waters (e.g., northern Gulf of Mexico). Also, there may be size differences between subregions; larger turtles are more readily sighted. For example, green turtles stranding in the eastern Gulf of Mexico 1999-2001 are larger (mean SCL=46.6 cm, SE=0.11, n=160) than greens stranding in the western Gulf of Mexico (mean SCL=30.2 cm, SE=0.08, n=113).[11] These problems render any estimates of adjusted catch rates and therefore estimates of interactions and mortalities for these two species especially inaccurate. We believe that for the eastern Gulf of Mexico, the direction of the bias is to overestimate the CPUE for these two species when adjusting the empirical CPUE data from the western Gulf of Mexico with the aerial survey data. Thus, our adjusted CPUE estimates for green and Kemp's ridley turtles likely are high. In the absence of other information indicating a difference in density among the subregions for these two species, it may be best to apply the unadjusted CPUEs from a nearby strata to strata with no empirical CPUE estimates. These estimates also may be biased, but the direction is unknown.

Another source of error is the subregion divisions chosen. The divisions should be based on the known distribution patterns for each species, ideally stratifying to minimize the variance within each subregion. We chose to minimize the number of subregions and use one overall stratification scheme because of the dearth of data. Modifications of the boundaries between subregions may yield different results. This may be especially true for the Gulf of Mexico that might have best been divided into three, not two subregions: western, northern, and eastern.

Although we have utilized the best available data, there are still potential sources of error in strata where we had neither CPUE from the Foundation nor the data to estimate a CPUE using our catchability method. In these cases we had to assume the CPUE for that particular strata was equivalent to the CPUE from an adjacent strata (Inshore estimates were assumed to be the same as Nearshore) or season (almost all winter CPUE were assumed to be the same as the summer CPUE).

Applying the same CPUE to a given inshore strata based on the CPUE from nearshore strata, often extrapolated itself, assumes that turtle density is similar in inshore and nearshore waters. For some species, such as green turtles we know that this generally is not true, except during their migrations, since this species is related with seagrass habitats in inshore waters, or when very small, with nearshore worm reefs (Hirth, 1997). Conversely, it is unlikely that a

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[11] Wendy Teas, National Marine Fisheries Service, Miami, FL. Personal communication (E-mail) November 25, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

pelagic species such as the leatherback is as abundant in inshore waters as it is in nearshore or offshore waters.

Applying the same CPUE to a given strata in both the summer and winter implies that turtles are similarly distributed between seasons. Differences in distribution, and therefore CPUE, are likely to exist between seasons and strata, but no data exist to estimate a CPUE in some strata.

Additionally, our estimates of variance for the catchability method (expressed here as 95% confidence intervals) are likely to be underestimated. This approximation assumes the two variables are uncorrelated and the CV of the denominator is low for ratios (Q_i). These assumptions are violated here. Ignoring the covariance between the two results in an overestimate of the CV, and a large denominator produces an underestimate of the variance. With our data, we are likely to be underestimating the variance of our estimate.

Table 15. Estimated catch rates of sea turtles captured in shrimp trawls in the Gulf of Mexico, March-November, by subregion and depth stratum. Cells with bold type represent CPUE measured by the Foundation, shaded cells were estimated using the catchability method, and cells in normal type with no shading are estimates applied from similar strata. Numbers in parentheses are the 95% confidence intervals.

Area /Subregion	**Depth Stratum**	**Species**			
		Leatherback	**Loggerhead**	**Kemp's ridley**	**Green**
Gulf of Mexico (catch/hr)					
Eastern	Inshore	0.00101 (0 to 0.00416)	0.0574 (0 to 0.1664)	0.7327 (0 to 3.7383)	0.0068 (0 to 0.0486)
	Nearshore	0.00101 (0 to 0.00416)	0.0574 (0 to 0.1664)	0.7327 (0 to 3.7383)	0.0068 (0 to 0.0486)
	Offshore	0.00112 (0 to 0.00.390)	0.0100 (0 to 0.0498)	0.1021 (0 to 0.5265)	0.0445 (0 to 0.3122)
Western	Inshore	0.00012 (0 to 0.00053)	0.0124 (0.0026 to 0.0247)	0.0371 (0.0181to 0.0598)	0.0026 (0 to 0.0077)
	Nearshore	0.00012 (0 to 0.00053)	**0.0124** **(0.0026 to 0.0247)**	**0.0371** **(0.0181to 0.0598)**	**0.0026** **(0 to 0.0077)**
	Offshore	0.00019 (0 to 0.00069)	**0.0006** **(0 to 0.0014)**	**0.0003** **(0 to 0.0009)**	0.0023 (0 to 0.0169)
Atlantic (catch/day)					
North	Inshore	0.0141 (0 to 0.0422)	0.6325 (0.3004 to 0.9645)	0.1268 (0.0563 to 0.2254)	0.0141 (0 to 0.0422)
	Ocean	0.0141 (0 to 0.0422)	0.6325 (0.3004 to 0.9645)	0.1268 (0.0563 to 0.2254)	0.0141 (0 to 0.0422)
Central	Inshore	0.0141 (0 to 0.0422)	1.3944 (1 to 1.7887)	0.1268 (0.0563 to 0.2254)	0.0141 (0 to 0.0422)
	Ocean	**0.0141** **(0 to 0.0422)**	**1.3944** **(1 to 1.7887)**	**0.1268** **(0.0563 to 0.2254)**	**0.0141** **(0 to 0.0422)**
South	Inshore	0.0141 (0 to 0.0422)	1.7895 (1.0479 to 2.5311)	1.0175 (0.4561 to 1.7719)	0.0702 (0.0175 to 0.1404)
	Ocean	0.0141 (0 to 0.0422)	**1.7895** **(1.0479 to 2.5311)**	**1.0175** **(0.0563 to 0.2254)**	**0.0702** **(0.0175 to 0.1404)**

Table 16. Estimated catch rate of sea turtles captured in shrimp trawls in the Gulf of Mexico, December-February, by subregion and depth stratum. Cells with bold type represent CPUE measured by the Foundation and cells in normal type are estimates applied from similar strata. Numbers in parentheses are the 95% confidence interval.

Area /Subregion	**Depth Stratum**	**Species**			
		Leatherback	**Loggerhead**	**Kemp's ridley**	**Green**
Gulf of Mexico (catch/hr)					
Eastern	Inshore	0.00101 (0 to 0.00416)	0.0574 (0 to 0.1664)	0.7327 (0 to 3.7383)	0.0068 (0 to 0.0486)
	Nearshore	0.00101 (0 to 0.00416)	0.0574 (0 to 0.1664)	0.7327 (0 to 3.7383)	0.0068 (0 to 0.0486)
	Offshore	0.00112 (0 to 0.00.390)	0.0100 (0 to 0.0498)	0.1021 (0 to 0.5265)	0.0445 (0 to 0.3122)
Western	Inshore	0.00012 (0 to 0.00053)	0.0124 (0.0026 to 0.0247)	0.0371 (0.0181to 0.0598)	0.0026 (0 to 0.0077)
	Nearshore	0.00012 (0 to 0.00053)	0.0124 (0.0026 to 0.0247)	0.0371 (0.0181to 0.0598)	0.0026 (0 to 0.0077)
	Offshore	0.00019 (0 to 0.00069)	**0.0014** **(0 to 0.0041)**	0.0003 (0 to 0.0009)	**0.0008** **(0 to 0.0024)**
Atlantic (catch/day)					
North	Inshore	0.0141 (0 to 0.0422)	0.6325 (0.3004 to 0.9645)	0.1268 (0.0563 to 0.2254)	0.0141 (0 to 0.0422)
	Ocean	0.0141 (0 to 0.0422)	0.6325 (0.3004 to 0.9645)	0.1268 (0.0563 to 0.2254)	0.0141 (0 to 0.0422)
Central	Inshore	0.0141 (0 to 0.0422)	1.3944 (1 to 1.7887)	0.1268 (0.0563 to 0.2254)	0.0141 (0 to 0.0422)
	Ocean	0.0141 (0 to 0.0422)	1.3944 (1 to 1.7887)	0.1268 (0.0563 to 0.2254)	0.0141 (0 to 0.0422)
South	Inshore	0.0141 (0 to 0.0422)	1.7895 (1.0479 to 2.5311)	1.0175 (0.4561 to 1.7719)	0.0702 (0.0175 to 0.1404)
	Ocean	0.0141 (0 to 0.0422)	1.7895 (1.0479 to 2.5311)	1.0175 (0.0563 to 0.2254)	0.0702 (0.0175 to 0.1404)

Estimated Number Of Interactions With Shrimp Trawls

We used effort data from 2001 and the CPUE data from the Adjusted Catch Rate section to determine the number of interactions of turtles with shrimp trawls. Data on effort was collected by State and NMFS port agents. The number of interactions with shrimp trawls was calculated for each species and strata using the equation:

$$\text{Interactions} = \text{CPUE}_{\text{species, strata, time}}, \times \text{effort}_{\text{strata, time}}$$

Results on the number of interactions are presented in **Table 17** and **Table 18**. In the Gulf of Mexico, Kemp's ridley had the most interactions followed by loggerhead, green, and leatherback. Interactions in the Atlantic were highest for loggerheads, followed by Kemp's ridley, leatherbacks, and green. The number of interactions for hawksbills could not be determined anywhere because no data were available for CPUE.

Sources of Error

All the sources of error in aspects of the analysis thus far culminate herein, resulting in very large confidence intervals. Many of the assumptions have no error measurement associated with them and therefore are not incorporated. Thus, the error reported is an underestimate.

The estimates of the number of interactions are subject to the same biases discussed in the Adjusted Catch Rates section as they were determined by multiplying CPUE and effort. If we did not have a Foundation CPUE or were unable to calculate a CPUE, we had to apply the CPUE from similar strata and assume that was representative for the unknown strata. On one hand, the take of all species in inshore waters likely is overestimated since the fishing power of inshore vessels for a unit of effort (hours or days) likely is less than that of the ocean vessels. Conversely, the density of all species except leatherbacks may be different (higher) than the density in ocean waters.

Almost all the winter CPUE data was assumed to be the same as the summer CPUE due to the lack of Foundation and aerial survey effort in that season. Applying the same CPUE to a given strata in both the summer and winter implies that turtles are similarly distributed between seasons. Differences in distribution, and therefore CPUE, are likely to exist between seasons and strata, but no data exist to estimate a CPUE in some strata. Our estimates of the number of interactions were computed using the CPUE from similar strata when no other data were available.

Table 17. Estimated number of sea turtle interactions in shrimp trawls in the Gulf of Mexico and Southeast U.S. Atlantic, March-November, 2001, by subregion and depth stratum. Confidence intervals (95%) are given in parentheses.

Area /Subregion	**Depth Stratum**	**Species**			
		Leatherback	**Loggerhead**	**Kemp's ridley**	**Green**
Gulf of Mexico					
Eastern	Inshore	434 (0 to 1786)	24641 (0 to 71433)	314537 (0 to 1604798)	2919 (0 to 20863)
	Nearshore	264 (0 to 1088)	15007 (0 to 43504)	191559 (0 to 977349)	1778 (0 to 12706)
	Offshore	517 (0 to 1803)	4622 (0 to 23017)	47189 ((0 to 243340)	20567 (0 to 144294)
Western	Inshore	88 (0 to 390)	9113 (1911 to 18153)	27267 (13303 to 43950)	1911 (0 to 5659)
	Nearshore	224 (0 to 1025)	23976 (5027 to 47759)	71735 (34998 to 115628)	5027 (0 to 14888)
	Offshore	335 (0 to 1216)	1057 (0 to 2467)	529 (0 to 1586)	4053 (0 to 29782)
Atlantic					
North	Inshore	174 (0 to 521)	7812 (3711 to 11913)	1566 (695 to 2784)	174 (0 to 521)
	Ocean	34 (0 to 102)	1529 (726 to 2332)	307 (136 to 545)	34 (0 to 102)
Central	Inshore	6 (0 to 18)	599 (430 to 769)	55 (24 to 97)	6 (0 to 18)
	Ocean	380 (0 to 1137)	37575 (26947 to 48201)	3417 (1517 to 6074)	380 (0 to 1137)
South	Inshore	9 (0 to 26)	1120 (656 to 1584)	637 (286 to 1109)	44 (11 to 88)
	Ocean	117 (0 to 352)	14909 (8730 to 21088)	8477 (3800 to 14762)	585 (146 to 1170)

Table 18. Estimated number of sea turtle interactions in shrimp trawls in the Gulf of Mexico and Southeast U.S. Atlantic, December-February, 2001, by subregion and depth stratum. Confidence intervals (95%) are given parentheses.

Area /Subregion	**Depth Stratum**	**Species**			
		Leatherback	**Loggerhead**	**Kemp's ridley**	**Green**
Gulf of Mexico					
Eastern	Inshore	19 (0 to 78)	1072 (0 to 3106)	13678 (0 to 69788)	127 (0 to 907)
	Nearshore	40 (0 to 167)	2289 (0 to 6634)	29213 (0 to 149047)	271 (0 to 1938)
	Offshore	222 (0 to 773)	1982 (0 to 9868)	20231 (0 to 104327)	8818 (0 to 61863)
Western	Inshore	2 (0 to 9)	221 (46 to 441)	662 (289 to 1068)	46 (0 to 137)
	Nearshore	40 (0 to 182)	4252 (892 to 8470)	12722 (5555 to 20506)	892 (0 to 2640)
	Offshore	85 (0 to 308)	624 (0 to 1828)	134 (0 to 401)	357 (0 to 1070)
Atlantic					
North	Inshore	1 (0 to 2)	27 (13 to 42)	6 (2 to 9)	1 (0 to 2)
	Ocean	1 (0 to 4)	53 (25 to 81)	11 (3 to 19)	1 (0 to 4)
Central	Inshore	1 (0 to 2)	50 (36 to 64)	5 (1 to 8)	1 (0 to 2)
	Ocean	59 (0 to 176)	5807 (4164 to 7449)	528 (158 to 898)	59 (0 to 176)
South	Inshore	2 (0 to 5)	208 (122 to 294)	118 (53 to 206)	8 (2 to 16)
	Ocean	36 (0 to 109)	4613 (2701 to 6525)	2623 (1176 to 4568)	181 (45 to 362)

Estimated Lethal Interactions In Shrimp Trawls

Not all turtles will escape the shrimp trawls even though virtually all have turtle excluder devices (TEDs), but not all turtles retained will drown. TEDs are not 100% effective regardless of the size of the turtle. Some vessels are using TEDs with openings large enough to potentially exclude turtles of all species and sizes. Turtles caught on these vessels are expected to escape. A proportion of those not caught on vessels using the largest opening TEDs will be retained in the trawls because they are too large and, at a minimum, their survival will be a function of the duration of forced submergence and water temperature. Below we estimate the number of turtles escaping the nets through TEDs, based on regulations in place currently, then estimate the mortality of those retained in the nets.

TED Effectiveness

Effectiveness of control TEDs

Some turtles do not escape through TEDs even though they are small enough to fit through the openings. Some may be exhausted to the point that they do not explore the TED area or struggle, and fail to escape. To be certified by NMFS, a TED design must be 97% effective in excluding sea turtles (Federal Register, 1987, 1992). During 1995-2002 TED certification trials, 250 captive-reared turtles were tested in nets with a control TED (Top Opening Super Shooter) and all but 11 escaped within 5 minutes of being introduced into the trawl.[12] In 2000 and 2002 tests of the double cover flap and of the 71" opening, in both top opening and bottom opening configurations, all 70 turtles tested escaped.[12] In a 2002 study aboard the Georgia Bulldog, all 29 wild turtles encountered when using TEDs with large openings escaped (**Table 19**).[13] These combined data indicate a TED effectiveness of 96.3%, which probably is conservative because the test of a given animal was terminated if a captive-reared turtle did not escaped within 5 minutes. Of those trials using large openings, 100% (n=99) of the turtles escaped. Thus, we are assuming that properly installed TEDs are at least 97% effective in excluding wild sea turtles, assuming the turtles are small enough to fit through the openings. Thus, 3% of the interactions will result in turtles being retained in the trawl, regardless of the size of the turtles.

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[12] National Marine Fisheries Service, Pascagoula, MS. Unpublished Data. John Mitchell, National Marine Fisheries Service, Pascagoula, MS. Personal Communication (E-mail) November 12, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

[13] National Marine Fisheries Service, Pascagoula, MS Unpublished Reports. An evaluations of modified TED Flap Designs on the exclusion of wild sea turtles off the Southeast Atlantic Coast May 13-17, 2002, 5p; Trip report for testing modified flaps for sea turtle exclusion off the Atlantic coast of Georgia & Florida, August1-5, 2002, 5 p. A remote video camera attached to a shrimp trawl near the TED was used to obtain the observations.

Leatherback modification of TED opening

TED openings can be modified to accommodate the escape of large leatherback turtles (Federal Register 1993, 1994, 1995). These modifications have been required during times when the density of leatherbacks exceeded a defined threshold off Georgia or the Carolinas or when strandings exceeded background levels, such as off Florida or Texas. Some fishermen subjected to these periodic regulations now choose to use these TEDs year round. These large-opening TEDs should allow for the escape of all turtles, including mature leatherbacks.[14] Current use of these leatherback modifications is shown in **Table 20**. Based on the size of the offshore fleet, we estimate that 7% of the fleet operating in the offshore waters of the western Gulf of Mexico is using the leatherback modification and 11% of the fleet operating in the offshore waters of the eastern Gulf is using it.[15] Usage is much higher in the Atlantic, and they are used some in the inshore waters of North Carolina.

Conventional TEDs

TED opening dimensions differ between the Gulf and the Atlantic (Federal Register, 1992). Height is measured simultaneously with width and is measured at the midpoint of the straight-line distance of width (i.e., the width and height of a taut triangle is measured). Along the Atlantic Coast these requirements are width ≥35 in and height ≥12 in. In the Gulf of Mexico these measurements are width ≥32 in and height ≥10 in.

Not all turtles will escape the trawls even though virtually all have turtle excluder devices (TEDs). Epperly and Teas (2002) identified the small size of TED escape openings as the cause of significant mortality on loggerheads turtles before they were reaching the average size of maturation. Green turtles also were being retained, but at a lower rate than loggerheads. Virtually all Kemp's ridleys, a smaller species, could escape through the existing openings. It is assumed that all leatherbacks would be retained in the trawls. Strandings data were too sparse to evaluate hawksbills relative to the size of TED openings.

Foundation data collected in the western Gulf of Mexico 1997-1998 demonstrate the problem. Seventy-five percent of the loggerheads captured but none of the greens and Kemp's ridleys captured were too large to fit through existing TED openings in the Gulf. These data indicate a TED effectiveness for loggerheads in the Gulf of Mexico of 25%. During the months of the study and in the same zones, 32.8% of the turtles that stranded and were measured were small enough (≤65.3 cm SCL_{std}) to fit through the 10 inch height opening of the Gulf TEDs.[16] Since 1998, 68-79% of the loggerheads stranding annually in the western Gulf (zones 13-21)

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[14] Sheryan Epperly, National Marine Fisheries Service, Miami, FL and Peter Dutton, National Marine Fisheries Service, La Jolla, CA. Unpublished data. During the 2000 nesting season measurements were obtained from leatherback turtles nesting in St. Croix, U.S. Virgin Islands (n=23) and Suriname, S.A. (n=30). An analysis (August 18, 2000) of width, body depth, and circumference indicated that all measured turtles could fit through the existing opening of TEDs equipped with the leatherback modification.

[15] John Mitchell, National Marine Fisheries Service, Pascagoula, MS. Personal communiation (E-mail) October 30, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

[16] Wendy Teas, National Marine Fisheries Service, Miami, FL Personal communication (E-mail) October 17, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

have been deeper bodied than the 10 inch height opening of the Gulf TEDs.[17] The loggerhead strandings closely reflect the in-water population, based on size. It appears that in the Gulf, because of the relatively small TED opening size, few loggerhead turtles would fit through existing TED openings. Thus, the entire benthic population is being "sampled" and some drowned without size bias.

Similarly, Foundation data collected in the Atlantic shows that 2.5% (5 of 201) of the loggerheads captured but none of the greens or Kemp's ridleys captured were too large to fit through existing TED openings in the Atlantic. South Carolina Marine Resource Division fishery-dependent data collected aboard commercial trawlers working without TEDs during late May/early June through late July/early August, 2000-2001, off South Carolina and Georgia (n=277 tows) indicate that 1.7% of the turtles they captured (1 of 58) would be too large.[18] The combined datasets yield a TED effectiveness percentage of 97.7% for loggerheads in the Atlantic. During the same months and in the same area where the Foundation study was conducted in the Atlantic, 85.8% of the loggerheads stranding were small enough (≤79.8 cm SCL_{std}) to have fit through the minimum opening size of TEDs in the Atlantic.[16] In the Atlantic, TED openings are larger and most turtles do fit through the TEDs. Thus, although all size turtles are being sampled, not all are being retained and drowned - only the largest ones are. Thus, since strandings reflect only the mortalities, we would expect to see a size bias - a larger proportion of large turtles stranding than those turtles represent in the in-water population.

Turtles that are retained in the trawl may slide out of the mouth of the trawl or through the TED opening during haulback and it is never recognized that a turtle has been caught. In May and August of 2002, NMFS conducted a study in offshore waters of Georgia to observe the behavior of wild turtles encountering various sized TED openings[13]. A remote video camera attached to a shrimp trawl near the TED was used to obtain the observations. All wild turtles encountering TEDs with large openings escaped. Twenty-one wild turtles were observed encountering an opening which was 1 inch larger in height than the Gulf of Mexico minimum TED opening size; 5 did not escape after 10 minutes of their first encounter with the device. Upon haulback, 3 washed out of the TED at the surface and 2 were removed through the mouth of the trawl.

Effective May 20, 2002 all vessels fishing in South Carolina waters are required to use a TED with an opening of 35" wide x 20" high.[19] Based on measurements provided by the South Carolina Department of Natural Resources for loggerheads nesting on Cape Island, SC (n= 87), virtually all loggerheads should fit through this size opening.[20]

In summary, in South Carolina waters leatherbacks may be retained but all other turtles likely escape, based on the size of the TED opening. Elsewhere we assume that the fleet is using the minimum size openings required for the region. We therefore assume that, based on size,

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[17] Wendy Teas, National Marine Fisheries Service, Miami, FL. Personal communication (E-mail) August 15, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

[18] Phil Maier, South Carolina Department of Natural Resources, Charleston, SC. Personal communication (E-mail with data attached) October 9, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

[19] Code of Laws of South Carolina, Section 50-5-765.

[20] Sally Murphy, South Carolina Department of Natural Resources, Charleston, SC. Personal communication (e-mail with data attached) August 22, 2002 to John Mitchell, National Marine Fisheries Service, Pascagoula, MS.

green, hawksbills, and Kemp's ridley all can escape through existing openings, but that not all loggerheads can. In the Gulf of Mexico 25% of the loggerheads may escape and in the Atlantic 97.7% may escape. The consequence of being retained in the nets is that the turtle is forcefully submerged and possibly drowned. The likelihood of the interaction becoming lethal is a function of the duration of the tow and water temperature.

Sources of error

Noticably absent is good information on the sizes of TED openings in use in each of our strata. There is error in our estimates of the proportion of the fleet using leatherback TEDs. We assumed that the proportion of the fleet not using the leatherback modification of TEDs are pulling TEDs with the minimum sized opening. Many are pulling TEDs with larger openings, especially in the Atlantic. Conversely, in the Gulf a substantial number are pulling TEDs with openings smaller than the requirement, but within the tolerance allowed by enforcement personnel.[21]

Table 19. Escape of wild turtles through various TED openings during tests aboard the Georgia Bulldog, May and August, 2002.

TED Opening	Turtle Escapes	Turtle Captures
71-inch	9	0
Double Cover	7	0
35" x 20"	13	0

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[21] Jack Forrester, National Marine Fisheries Service, Pascagoula, MS. Personal communication October 30, 2002 to John Mitchell, National Marine Fisheries Service, Pascagoula, MS. Gear Specialists with NMFS Harvesting Systems Branch assisted State and Federal fisheries enforcement personnel in conducting TED compliance boardings during the 2002 Texas shrimp opening. All of the inspections were conducted in nearshore waters from Galveston to Port Aransas. Thirty percent of the TEDs which were inspected had escape openings smaller than the Gulf minimum size (32" x 10").

Table 20. Current ongoing use of TEDs with leatherback modifications.[22] It is assumed that no inshore boats are using the modification, except where noted, and that in the Gulf there is no usage in nearshore waters.

State/Area	Percent Using Modified TED
Texas, offshore	≤15%
Louisiana, offshore	≤5%
Mississippi, offshore	≤5%
Alabama, offshore	≤5%
Florida, west coast, offshore	15%
Florida, east coast, ocean	70%
Georgia, ocean	68%[23]
South Carolina, ocean	50%[24]
North Carolina, ocean	35%
North Carolina, inshore	≤10%

Mortality As A Function Of Tow Time And Water Temperature

Henwood and Stuntz (1987) found a statistically significant relationship between tow time and mortality of sea turtles ($r=0.98$, $p<0.001$) using data from 3 NMFS fishery observer programs 1973-1984. They regressed average mortality over minutes fished broken into intervals of 30 minutes. The National Research Council (1990) revisited the data and found substantial differences in mortality between seasons using time intervals of ten minutes. They pointed out that Henwood and Stuntz assumed all comatose turtles survived and were treated as alive. The NRC noted that all resuscitated individuals do not survive. Furthermore it is assumed that comatose turtles likely would be returned to the water if an observer was not aboard to resuscitate it, surely resulting in the death of the turtle. We reanalyzed the dataset to estimate the mortality resulting from interactions between sea turtles and otter trawls.

Following the recommendations of the NRC, we divided the data by season and combined dead and comatose turtles into one category to determine mortality. Per above discussions of effort and catch, seasons were defined as “summer” (March-November) and

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[22] John Mitchell, National Marine Fisheries Service, Pascagoula, MS. Personal communication (e-mail) October 29, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL. Estimates are based on information obtained from boardings with NMFS Law Enforcement and Coast Guard and from conversations with net shops, as well as estimates made by the staff of the Harvesting Systems Branch of the NOAA Fisheries Mississippi Laboratories.

[23] Mark Dodd, Georgia Department of Natural Resources, Brunswick GA. Personal Communication (e-mail) October 9, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL. Estimate is based on a sample of approximately 90 interviews at 13 different docks in the state during 2001.

[24] David Whitaker, South Carolina Department of Natural Resources, Charleston, SC. Personal communication (e-mail) October 9, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL. Estimate is based on reports from fishermen and SCDNR staff.

winter (December-February). **Figure 15** and **Figure 16** show mortality versus tow time in intervals of ten minutes. For ease of presentation, summer mortality was divided into three periods: 0 to 50 min, 51 to 200 min, and 201 to 610 min, which represent the 3 "stages" of the response curve. Winter mortality was divided into just two categories: 0 to 60 min and 61 to 420 min. These divisions are logical breaks based on the data with mortality low during short tows and high in long tows.

We used logistic regression to model tow time versus turtle mortality, and found the models fit the data well in both seasons (**Table 21**, **Table 22**, and **Figure 17**). The models accounted for 62% and 70% of the variation in summer and winter, respectively. The predictive ability of our models was very good based on the association of the predicted probabilities with the observed responses (Somers' D_{xy} in **Table 21**).

The findings here are consistent with and expand upon what has been reported by the NRC and Henwood and Stuntz. Specifically, tows of short duration have little effect on mortality, intermediate tow times result in a rapid escalation to mortality, and eventually reach a plateau of high mortality. Mortality will be high on long tows, but will not equal 100% as a turtle caught within the last hour of a long tow would likely survive.

The NRC also acknowledged that if tow times were restricted to less than 40 min in the summer and less than 60 min in the winter, few animals would drown, and current regulations incorporated those findings (Federal Register, 1992); previously, tow duration was allowed to be 90 min (Federal Register, 1987). Our analysis of the same dataset differs, and indicates that the stress of being captured in a trawl is greater in cold water than in warm water. For example, in the summer the mortality associated with a 40 min tow is predicted at 3% whereas the same tow duration in the winter would yield a mortality of 5%. To achieve a negligible mortality rate (defined by NRC as <1%) the tows in both seasons would need to be less than 10 min.

Sources of Error

The largest source of error is the small sample size for very short tow times and long tow times. Short tow times are unlikely to cause mortality in turtles, but long tow times have very high mortality. Only animals captured within the last 60 minutes of a long tow are likely to have high survivorship. Data with more replicates of short and long tow time might produce a model that explains more of the variation.

Additionally, we followed the recommendation of the NAS and included all comatose turtles in the mortality calculations by assuming they were not resuscitated. We wanted to be conservative with our estimates of mortality. If some comatose turtles were resuscitated and survived, mortality would be slightly lower then we found in this analysis.

Table 21. Logistic models of mortality.

Season	Logistic Model[1]	R-Square	Deviance	Somers' D_{xy}[2]
Summer	-4.6815 + 0.0314x	0.6161	Value=346.61, df= 151, p<0.0001	0.914
Winter	-4.7967 + 0.0469x	0.7007	Value=121.26, df= 59, p<0.0001	0.899

[1] where x is the tow duration

[2] Index of rank correlation between the predicted probabilities and the observed response

Table 22. Statistical evaluation of parameters in logistic regression models.

Season	Parameter	Estimate	Significance
Summer	Intercept	-4.6815	SE=0.1543, p<0.0001
	Coefficient (tow time)	0.0314	SE=0.0012, p<0.0001
Winter	Intercept	-4.7967	SE=0.2858, p<0.0001
	Coefficient (tow time)	0.0469	SE=0.00346, p<0.0001

Figure 15. Tow durations and mortality (dead and comatose) of sea turtles during the summer.

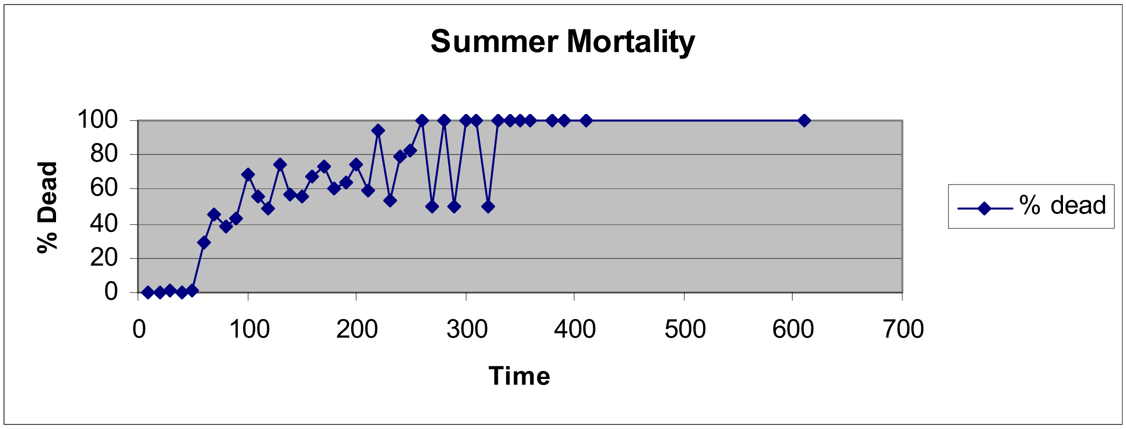


Figure 16. Tow durations and mortality (dead and comatose) of sea turtles during the winter.

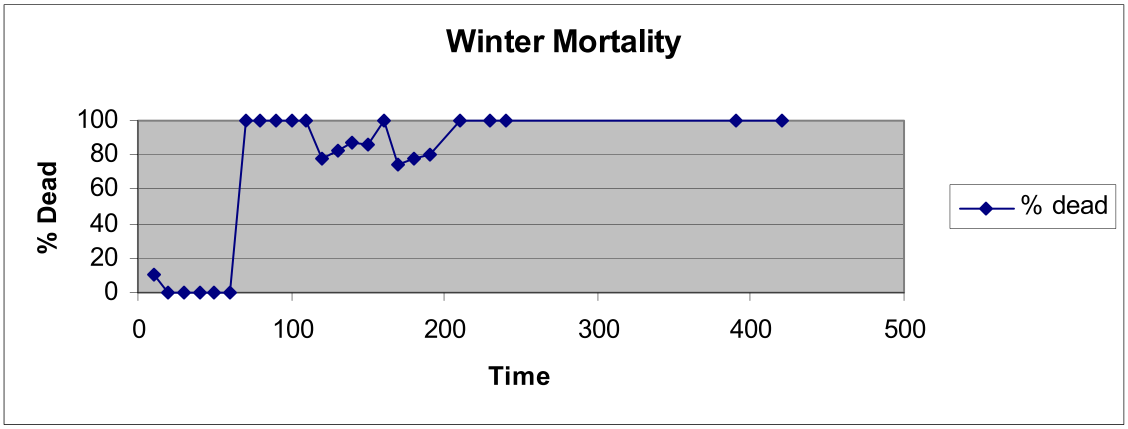
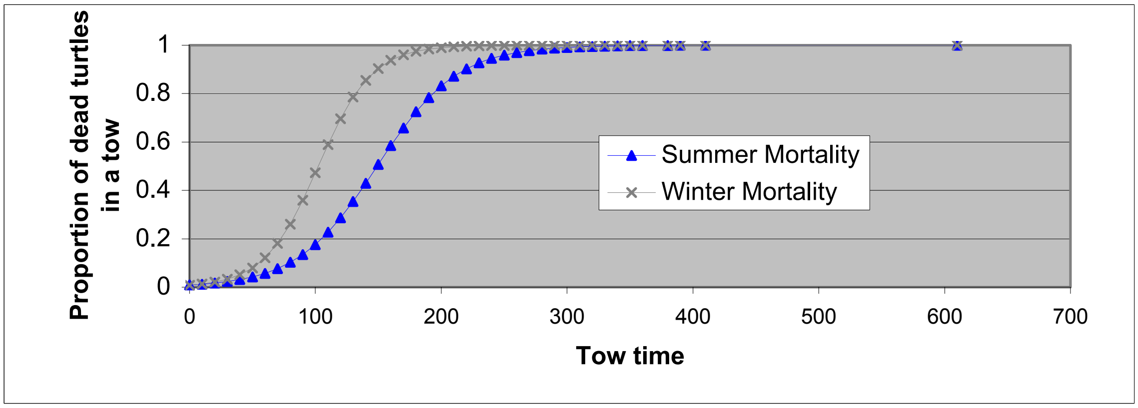


Figure 17. Logistic curves for sea turtle mortality.



Tow Times

In 1992, a joint government/commercial research program between NOAA Fisheries Galveston Laboratory and the Gulf and South Atlantic Fisheries Foundation, Inc. (Foundation) was implemented to collect species-specific data from the U.S. southeastern shrimp fishery. The primary objectives of this ongoing research effort are to provide and manage observer-collected data on shrimp trawl bycatch, and to evaluate the effectiveness of bycatch reduction devices (BRD) in finfish reduction and shrimp retention during commercial shrimping operations in the Gulf of Mexico and southeastern Atlantic. Observer data are used to refine catch rate estimates by area and season. These data also can be used to characterize the fishery: number of tows per day, tow durations, number of nets, etc. This is not the same study used to obtain sea turtle CPUE estimates above.

A comprehensive description of program guidelines for the Cooperative Shrimp Bycatch Characterization Study is presented in the research plan that was prepared by the Foundation under the direction of a Steering Committee composed of individuals representing industry, environmental, state, and Federal interests (Hoar et al., 1992). The intent of the sampling design is to evaluate BRD designs during commercial shrimp fishery operations. The sampling universe consists of all tows from all vessels shrimping in the south U.S. Atlantic and Gulf of Mexico. Parameters of interest are the differences between BRD and control nets as related to catch totals and size distributions of all species incidentally taken by the shrimp fleet.

NMFS-certified observers collect data aboard commercial shrimp vessels for the evaluation of specific BRD designs as related to bycatch reduction criteria established for Gulf of Mexico and southeastern Atlantic. Comparisons of catch data for nets equipped with TEDs versus nets with TED/BRD combinations are conducted. Experimental and control nets are alternated from starboard to port outboard nets to reduce net and side biases. Detailed measurement and written description of TED, BRD, net type, construction, installation, webbing, and other associated gear characteristics are recorded at the start and end of each trip, or when adjustments are made. For each tow, environmental parameters, bottom time (actual bottom time) and operational aspects relative to each net are documented. The total catch weight, and counts, weights and target species are obtained from the experimental and control nets. All sea turtles are identified to species, measured, tagged, photographed and released. A subsample of approximately 70 pounds (32 kg) from each net (experimental and control) are processed, time permitting, for bycatch characterization.

We examined data from 1997-2002. Observers monitored 88 trips ending in the Atlantic and 207 trips ending in the Gulf of Mexico. In the Atlantic, sampling effort included zones 27-32, but was concentrated in zones 31 and 32. There was no sampling effort in inshore waters of the Atlantic nor in the North subregion. In the Gulf, sampling was well distributed, occurring in the nearshore and offshore strata, in the eastern and western Gulf, summer and winter, but not in inshore waters. The location and season of a trip's assignment was based on the location and date of the last tow of the trip. Individual days/tows, however, were assigned to strata based on the day/tow-specific information. These data were used to determine tow durations in each season x subregion x depth stratum.

The distribution of tow times is given in **Table 23**. The proportion of animals dying in each strata was computed by determining the mortality associated with each tow, based on the tow's duration and season, and weighted by the proportion of time represented by that tow to the total amount of time towed in a particular stratum. Thus, these proportional mortality factors (**Table 24**) can be applied to the number of turtles being retained in the nets.

Sources of Error

This analysis assumes that the NMFS/Foundation dataset represents a random sample of the universe and is representative of the tow durations of the entire fleet. The extremely small number of vessels participating in the shrimp fishery observer program, in comparison to the number in the entire shrimp fleet, may yield biased results. It is assumed that the vessels participating are representative of fleet at large with respect to times and areas fished and fishing power. Sampling effort for BRD evaluation is conducted primarily in Federal waters in the Gulf of Mexico. It is not known whether the characteristics of the fleet fishing in offshore waters differ from those fishing in nearshore waters. Once selected, a vessel must meet specific housing and safety requirements before an observer can be placed on that vessel. Collectively, these factors may bias results in terms of extrapolation fleet wide.

Furthermore, the small sample sizes in some subregion x season x depth stratum also are a source of bias. Lastly, in the absence of data, we must assume that the tow times in inshore waters are the same as sampled in offshore waters. This likely is not true, except perhaps in the large inshore water bodies of North Carolina; we would expect tow times in inshore waters to be shorter than those of vessels operating in the ocean or Gulf. This will have the effect of overestimating the interactions and mortality in inshore waters.

Table 23. Distribution of tow time durations in summer (March-November) and winter (December-February). The proportion of tows made in each duration interval is given for each subregion x depth stratum x season, and the number of tows is given in parentheses. Nearshore is ≤10 fm and offshore is > 10 fm. Note that there was no effort in any inshore waters nor in the North subregion of the Atlantic.

Area /Subregion	Depth Stratum	Season				
		Summer			Winter	
		0-50 min	51-200 min	>200 min	0-60 min	>60 min
Gulf of Mexico						
Eastern	Nearshore	1.7 (6)	29.9 (106)	68.4 (242)	3.0 (1)	97.0 (32)
	Offshore	0.7 (5)	19.9 (150)	49.4 (597)	0.7 (1)	99.3 (133)
Western	Nearshore	1.1 (8)	27.8 (209)	71.1 (533)	0.0	100.0 (31)
	Offshore	0.6 (23)	15.4 (587)	84.0 (3196)	0.3 (1)	99.7 (375)
Atlantic						
Central	Ocean	4.1 (13)	65.9 (211)	30 (96)	16.7 (5)	83.3 (25)
South	Ocean	8.3 (1)	83.3 (10)	8.3 (1)	0.0	100.0 (52)

Table 24. The proportion of animals retained in trawls that likely drown, based on tow durations from NMFS/Foundation sampling data (bold type). In absence of data (normal type), it is assumed that the mortality rates in inshore waters are the same as in nearshore (Gulf) or ocean waters (Atlantic) and that the distribution of tow duration for the North subregion of the Atlantic, and therefore mortality rates, are the same as for the Central subregion of the Atlantic.

Area /Subregion	**Depth Stratum**	**Season**	
		Summer	**Winter**
Gulf of Mexico			
Eastern	Inshore	0.8899	0.9842
	Nearshore	**0.8899**	**0.9842**
	Offshore	**0.9351**	**0.9885**
Western	Inshore	0.9146	0.9826
	Nearshore	**0.9146**	**0.9826**
	Offshore	**0.9588**	**0.9978**
Atlantic			
North	Inshore	0.7303	0.8537
	Ocean	0.7303	0.8537
Central	Inshore	0.7303	0.8537
	Ocean	**0.7303**	**0.8537**
South	Inshore	0.4055	0.9930
	Ocean	**0.4055**	**0.9930**

Estimated Mortalities

To estimate the number of mortalities in shrimp trawls, we first assumed that 3% of all interactions would result in the animals being retained in the nets due to TED failure. Secondly, we used data on the usage of the leatherback TED modification and allowed that proportion of the remaining turtles to "escape". We then assumed that all turtles remaining, except leatherbacks and loggerheads, could escape through the openings existing in conventional TEDs. Next we allowed all turtles, except leatherbacks, to escape from TEDs in South Carolina waters (defined as all of zone 32 and 48% of zone 33[25]). We assumed that no leatherbacks could escape through conventional TED openings. Those loggerheads remaining were subjected to the size test – 75% of the loggerheads in the Gulf would be retained and 2.3% of the animals in the Atlantic would be retained. The number of lethal interactions was based on the number of animals of each species retained – the sum of those retained as a result of the 3% TED failure and those too big to fit through TEDs. The proportion of animals retained in trawls that likely died, based on tow durations from NMFS/Foundation sampling data is given in **Table 24** and the number of lethal interactions is given in **Table 25** and **Table 26**.

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[25] Trips made in zone 33 and landed in South Carolina represented 48.2% of all days reported fished in zone 33.

Sources of Error

All sources of error reported in this major section culminate herein. The estimates of error, and thus the confidence intervals are usually extremely large. Many sources are unaccounted for.

There is a bias that results in overestimates of moralities. At times when leatherback densities are high or strandings are elevated, the leatherback modification has been required. Except for the same TED failure rate, all other animals should escape. These estimates do not account for any possible requirement under emergency rules to use the leatherback TED modification.

Another factor that will result in an underestimate of mortalities are related to try nets. All try nets are not required to be equipped with TEDs. Turtles caught in these nets will be retained. If tow durations are brief, mortalities will be minimal. As tow durations increase the probability of deaths increase.

Table 25. Estimated number of interactions resulting in sea turtle mortalities, March-November, 2001. Confidence intervals (95%) are given in parentheses.

Area /Subregion	**Depth Stratum**	**Species**			
		Leatherback	**Loggerhead**	**Kemp's ridley**	**Green**
Gulf of Mexico					
Eastern	Inshore	381 (0-1572)	16426 (0-47617)	8304 (0-42367)	77 (0-551)
	Nearshore	232 (0-957)	10004 (0-29000)	5057 (0-25802)	47 (0-335)
	Offshore	430 (0-1497)	2912 (0-14502)	1317 (0-6789)	574 (0-4026)
Western	Inshore	80 (0-354)	6282 (1317-12514)	744 (363-1200)	52 (0-154)
	Nearshore	204 (0-933)	16527 (3465-32922)	1958 (955-3157)	137 (0-406)
	Offshore	296 (0-1077)	710 (0-1656)	15 (0-45)	116 (0-849)
Atlantic					
North	Inshore	115 (0-344)	285 (136-436)	34 (15-61)	4 (0-11)
	Ocean	16 (0-49)	50 (24-76)	7 (3-12)	1 (0-2)
Central	Inshore	4 (0-12)	18 (13-23)	1 (1-2)	<1 (0-<1)
	Ocean	125 (0-373)	917 (657-1176)	75 (33-133)	8 (0-25)
South	Inshore	4 (0-11)	24 (14-34)	8 (3-13)	1 (0-1)
	Ocean	15 (0-46)	222 (130-314)	103 (46-180)	7 (2-14)

Table 26. Estimated number of interactions resulting in mortalities of sea turtles, December-February, 2001. Confidence intervals (95%) are given in parentheses.

Area /Subregion	**Depth Stratum**	**Species**			
		Leatherback	**Loggerhead**	**Kemp's ridley**	**Green**
Gulf of Mexico					
Eastern	Inshore	18 (0-76)	795 (0-2306)	402 (0-2052)	4 (0-27)
	Nearshore	39 (0-163)	1699 (0-4925)	859 (0-4382)	8 (0-57)
	Offshore	194 (0-677)	1316 (0-6552)	595 (0-3067)	259 (0-1819)
Western	Inshore	2 (0-9)	164 (34 -327)	19 (9-31)	1 (0-4)
	Nearshore	39 (0-178)	3157 (662-6288)	374 (163-603)	26 (0-78)
	Offshore	78 (0-284)	437 (0-1279)	4 (0-12)	11 (0-32)
Atlantic					
North	Inshore	<1 (0-1)	1 (1-2)	<1 (0-<1)	<1 (0-<1)
	Ocean	1 (0-2)	2 (1-3)	<1 (0-<1)	<1 (0-<1)
Central	Inshore	<1 (0-1)	2 (1-2)	<1 (0-<1)	<1 (0-<1)
	Ocean	21 (0-64)	167 (120-214)	14 (4-23)	2 (0-5)
South	Inshore	2 (0-5)	11 (6-15)	4 (2-6)	<1 (0-<1)
	Ocean	12 (0-35)	168 (98-238)	78 (35-136)	5 (1-11)

Estimated Mortalities in Trawls Equipped with TEDs With Larger Escape Openings

An advance notice of a proposed rulemaking, to effect a change in TED requirements, was issued by NMFS (Federal Register, 2000). After consideration of public comments, NMFS advertised a proposed rule to change the TED requirements (Federal Register, 2001). In response to those comments NMFS is promulgating a final rule that will require TEDs used in trawls in the Atlantic ocean and in some Georgia and South Carolina embayments and TEDs used in the Gulf of Mexico to be equipped with a leatherback modification year round[26]. TEDs used in inshore waters of both regions will be required to have an opening that if measured simultaneously would be ≥35 inches in width and ≥ 20 inches in height. Thus, assuming that all TEDs will be installed properly, that compliance will be 100%, and that law enforcement will allow no tolerance of smaller openings, the expectation is that, based on the sizes of the TED openings, all turtles encountered in the ocean should be able to escape the trawl nets and that all but the infrequently encountered leatherback will be excluded from trawl nets used in inshore

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[26] Robert Hoffman, National Marine Fisheries Service, St. Petersburg, FL. Personal communication (E-mail) October 15, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

waters. There still will be TED failures (3%). Our estimates of mortality under the new rule are based solely on this 3% failure rate (**Table 27** and **Table 28**) of current interactions and the proportion of individuals that will die, based on tow times in each stratum.

Table 27. Estimated number of interactions resulting in sea turtle mortalities, March-November, 2001, under new regulations. Confidence intervals (95%) are given in parentheses.

Area /Subregion	**Depth Stratum**	**Species**			
		Leatherback	**Loggerhead**	**Kemp's ridley**	**Green**
Gulf of Mexico					
Eastern	Inshore	11 (0-47)	651 (0-1886)	8304 (0-42367)	77 (0-551)
	Nearshore	7 (0-29)	396 (0-1149)	5057 (0-25802)	47 (0-335)
	Offshore	14 (0-50)	129 (0-642)	1317 (0-6789)	574 (0-4026)
Western	Inshore	2 (0-11)	249 (52-496)	744 (363-1200)	52 (0-154)
	Nearshore	6 (0-28)	655 (137-1304)	1958 (955-3157)	137 (0-406)
	Offshore	10 (0-35)	30 (0-70)	15 (0-45)	116 (0-849)
Atlantic					
North	Inshore	4 (0-11)	171 (81-261)	34 (15-61)	4 (0-11)
	Ocean	1 (0-2)	33 (16-51)	7 (3-12)	1 (0-2)
Central	Inshore	<1 (0-<1)	13 (9-17)	1 (1-2)	<1 (0-<1)
	Ocean	8 (0-25)	823 (590-1056)	75 (33-133)	8 (0-25)
South	Inshore	<1 (0-<1)	14 (8-19)	8 (3-13)	1 (0-1)
	Ocean	1 (0-4)	181 (106-256)	103 (46-180)	7 (2-14)

Table 28. Estimated number of interactions resulting in mortalities of sea turtles, December-February, 2001 under new regulations. Confidence intervals (95%) are given in parentheses.

Area /Subregion	Depth Stratum	Species			
		Leatherback	**Loggerhead**	**Kemp's ridley**	**Green**
Gulf of Mexico					
Eastern	Inshore	1 (0-2)	32 (0-91)	402 (0-2052)	4 (0-27)
	Nearshore	1 (0-5)	67 (0-195)	859 (0-4382)	8 (0-57)
	Offshore	7 (0-23)	58 (0-290)	595 (0-3067)	259 (0-1819)
Western	Inshore	<1 (0-<1)	7 (1-13)	19 (9-31)	1 (0-4)
	Nearshore	1 (0-5)	125 (26-249)	374 (163-603)	26 (0-78)
	Offshore	3 (0-9)	19 (0-54)	4 (0-12)	11 (0-32)
Atlantic					
North	Inshore	<1 (0-<1)	4 (0-11)	<1 (0-<1)	<1 (0-<1)
	Ocean	<1 (0-<1)	1 (0-2)	<1 (0-<1)	<1 (0-<1)
Central	Inshore	<1 (0-<1)	1 (1-2)	<1 (0-<1)	<1 (0-<1)
	Ocean	2 (0-5)	149 (107-191)	14 (4-23)	2 (0-5)
South	Inshore	<1 (0-<1)	6 (4-9)	4 (2-6)	<1 (0-<1)
	Ocean	1 (0-3)	137 (80-194)	78 (35-136)	5 (1-11)

Estimated Number of Individuals Interacting with Shrimp Trawls

Turtles not drowned in trawls may be caught again, i.e., it is likely that an individual turtle may interact with shrimp trawls more than once. Shrimp trawling activity is aggregated and although use of neritic habitat by sea turtles is not well understood, individuals of various sea turtle species appear to exhibit site fidelity, restricting their activities to preferred foraging areas. Immature hawksbills foraging on reefs have been found to inhabit areas ranging from 0.01-0.21 km^2 over an 11-16 d period (van Dam and Diez, 1998). Similarly, juvenile green turtles monitored using sonic telemetry for several months in inshore waters occupied home ranges between 0.48-5.06 km^2 (Mendonca, 1983). Juvenile Kemp's ridley turtles followed using radio and sonic telemetry restricted their foraging activities to areas ranging from 5 to 30 km^2 (Schmid, 2000). The 10-80 km^2 foraging ranges estimated for juvenile loggerheads tracked using radio telemetry for 2-66 d (mean = 26.5 d) in a coastal bay are far larger than those found for other turtle species (Byles, 1988). However, mark-recapture data indicate that juvenile loggerheads in sub-tropical and temperate areas do exhibit site fidelity, as turtles often are recaptured at specific locations within a given year, as well as between years, after having undergone seasonal migrations (Avens et al., in review; Byles, 1988). During a mark-recapture study spanning four years, an average of 21% of juvenile loggerheads captured in Core Sound, North Carolina, and released near their capture locations were recaptured during the same year in which they were initially tagged and at the same general location in which they were originally caught (Avens et al., in review). Furthermore, between 4% and 21% of juvenile loggerheads tagged in North Carolina within a given year were recaptured in subsequent years, presumably after having migrated away from the capture area during winter months (Avens et al., in review).

Site fidelity, or a preference for a specific home range, can also be inferred by the tendency of animals to return to restricted areas after being displaced from those locations (Papi, 1992). Such homing behavior suggests a strong predilection for a given site especially if the resources at that site can be found elsewhere in the habitat, such as near the areas in which the animals were released. Green turtles displaced from their feeding sites in Bermuda and followed using sonic telemetry exhibited a strong tendency to return to preferred feeding areas (Ireland, 1980). Mark-recapture data show that juvenile loggerheads displaced from capture sites in sub-tropical and temperate areas will also return to their capture areas (Lutcavage and Musick, 1985; Byles, 1988). Over the course of a four-year study, 17% of juvenile loggerheads displaced 15-20 km from capture sites in the inshore waters of North Carolina were recaptured during the same year they were displaced in the same general area in which they were originally captured (Avens et al., in review).

Other tagging studies indicate recaptures in shrimp trawls are likely. Of 68 loggerhead turtles tagged by a single contracted trawler fishing off central and northeast Florida, 1986-1991, and recaptured, 69% were recaptured in shrimp trawls, most within a year of initial capture (Schmid, 1995); 89% of the recaptured Kemp's were caught in shrimp trawls. Henwood (1987) reported on the results of a relocation experiment which used a shrimp trawler in the vicinity of Cape Canaveral. Over a 132 day period in 1980, 1097 loggerhead turtles were tagged and relocated several kilometers away from the capture site. Subsequent to release, 183 individuals were recaptured: 146 were captured once, 22 were recaptured twice, 11 were recaptured 3 times, 3 were recaptured four times, and 1 was recaptured 5 times during the experiment. This yielded 240 recapture events (21.9%).[27]

In summary, it appears that at least 20% of the turtles involved in non-lethal interactions subsequently will be recaptured. The number of individuals represented by the interactions can be estimated as the sum of the number of lethal interactions and the number of individuals represented in the non-lethal interactions. The latter is estimated as the total non-lethal interactions reduced by the expected recapture rate (>20%).

Sources of Error

The estimate of 20% likely is biased quite low because the studies above generally worked with just a single fishing operation and did not receive recapture information from all the fishing operations in the vicinity. Such a low estimate of the recapture rate would have the effect of overestimating the number of individuals actually interacting with the gear.

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[27] National Marine Fisheries Service. Pascagoula Laboratory, Pascagoula, MS. Unpublished Data. Larisa Avens, National Marine Fisheries Service, Beaufort, NC. Personal Communication (E-mail) November 4, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

Interactions In Other Gears And The Bait Shrimp Fishery

Throughout the southeast region a variety of gear types other than otter trawls are used to commercially harvest table and bait shrimp. In this section we describe various gear types and level of use for which landing and effort data may not be recorded, or which may be combined with data for otter trawls. The gear described is used almost exclusively within inshore waters. Additionally, all of the gear types described are exempt from federal TED regulations, although there are some state TED requirements for specific gear. Skimmer trawls, butterfly nets, pusher head trawls (chopstick rigs), and licensed bait shrimpers must adhere to tow time restrictions. Tow time limits for TED exempt gear are, 55 minutes from April1 to October 31 and 75 minutes from November 1 to March 31.

Otter Trawls Used for Bait Shrimp

Otter trawls are the most common method of harvesting bait shrimp within the southeast U.S. coastal states. **Table 29** provides bait shrimping effort by gear type for Florida and Georgia during 2001. Trawl types used for bait shrimping may vary from flat nets to high opening mongoose trawls, depending on the season and targeted shrimp species. State regulations vary with regard to the size of gear and time of fishing. Commercial bait shrimpers using otter trawls are exempt from TED use under the assumption that they are towed for short durations of time to ensure that the shrimp can be harvested alive. Under federal law, a bait shrimp trawl is allowed a TED exemption if the vessel has a valid state bait shrimping license on board, has no more than 32 pounds of dead shrimp, and also has a container with circulating sea water system.

Sea turtles are susceptible to capture in bait shrimp trawls, but are assumed to have a high rate of survival because of short tow durations. When high opening trawls are used to harvest bait shrimp, the potential for turtle capture may be greater.

North Carolina

Otter trawls are not used for harvesting bait shrimp in North Carolina[28].

South Carolina

Otter trawls are not used to harvest bait shrimp in South Carolina waters[29].

Georgia

Otter trawl use for bait shrimp is relatively small in Georgia with approximately 40 boats participating in the fishery, but it is Georgia's third largest marine commercial fishery. The use of otter trawls in inshore waters for table shrimp is prohibited, but bait shrimping with the trawls is allowed. Participants must fish in defined zones in the upper reaches of the sounds and tidal

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[28] David Taylor. North Carolina Division of Marine Fisheries, Morehead City, NC. Personal communication November 14, 2002 to Dale Stevens, National Marine Fisheries Service, Pascagoula, MS.

[29] David Whittaker, South Carolina Department of Natural Resources, Charleston, SC. Personal communication (E-mail) October 18, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL.

creeks. This was enacted primarily to establish protected no trawl areas within penaeid shrimp nursery grounds, and to facilitate law enforcement of the fishery. All vessels except one are small hand retrieve operations. The largest net which may be used is a 20-ft headrope length. Tow times and fishing effort are relatively consistent throughout the year with a small peak in activity in May-June and August-October.[30] In a 1998 to 2001 study of the fishery, tow times ranged from 4 minutes to 52 minutes, with an average of 21 minutes (Gaddis et al., 2001).

Florida

Otter trawls are used to harvest bait shrimp in Florida state waters. Trawl size is limited to no more than 60 feet as measured around the perimeter, or leading edge of the trawl. Areas in which otter trawls are used for bait shrimp are not clearly defined, but it is presumed that they are common to the panhandle area and northeast Florida. In the year 2000, a total of 180 bait shrimp licenses were sold in the state, however a significant portion of these vessels may be using roller frame trawls.

Alabama

Bait shrimp are harvested throughout the inshore waters of Alabama exclusively with otter trawls. Bait shrimping is restricted to designated areas. A licensed bait shrimper may tow one trawl with a headrope length no greater than 16-ft. For the year 2000, a total of 44 resident bait shrimp licenses were issued for the state of Alabama (Bloom, 2001).

Mississippi

Bait shrimping in Mississippi is restricted by area and is conducted almost exclusively in river mouths and bays. A licensed bait shrimper may tow one trawl with a headrope length no greater than 16-ft. In the year 2000, a total of 46 bait shrimp (boat) licenses were issued.

Louisiana

Otter trawls used to harvest bait shrimp in Louisiana are limited in size to 25-ft. as measured along the headrope and 33-ft. as measured along the footrope. Bait shrimp may only be taken during daylight hours. No information regarding the number of licensed bait shrimpers in Louisiana were available.

Texas

Commercial bait shrimping in Texas is conducted almost exclusively with otter trawls and in all inshore waters. The season is open year round and restricted to daylight hours from August 15 through March 31. Trawl size is regulated with the majority of nets within a range of from the 25-ft to 40-ft. headrope length.[31] In the year 2000, a total of 1,363 bait shrimping licenses were issued in the state of Texas. Many fishermen who target table shrimp also hold a bait shrimping license.

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[30] Mark Dodd , Georgia Department of Natural Resources, Brunswick, GA. Personal communication (E-mail) October 23, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL

[31] Texas Administrative Code, RULE §58.164, Shrimping Inside Waters--Commercial Bait Shrimping

Table 29. Bait shrimp effort in 2001 (trips), reported by gear type, in Southeast U.S. waters. Data reported only for Florida and Georgia

Zone	Gears			
	Otter Trawl	Butterfly Net	Beam/ Roller Trawl	Hand Gears[32]
25	0	234	6105	0
26	0	0	0	0
27	0	0	0	7
28	7	79	0	3
29	0	54	0	33
30	658	0	0	4
31	2089	0	0	0
32	144	0	0	0

Roller Frame Trawls

Use of the roller frame trawl appears to be limited to Florida with no other southeast states reporting this gear type. The gear is used to harvest table and bait shrimp. Relatively unchanged since the 1960's, the roller frame trawl design consists of a net attached to a rectangular metal frame with a slotted roller along the entire lower portion of the frame (Ault et al., 1997). The gear is designed to reduce bottom damage by rolling over rather than dragging through the substrate. Most vessels pull two frames simultaneously and winches are used for gear retrieval. Frames sizes range between 10 and 16 ft. with reports of frames as large as 30 ft. in length from the St. Marks area[33]. Deflector bars are fixed across the mouth of the frame to help exclude non-target species, and also to prevent algae and debris from entering the net and crushing live catch. A 1989 Florida statute requires that these bars must be spaced, not more than 3-inches apart. In federal waters and in those states that do not regulate roller frames, federal regulations allow a 4-inch spacing between the bars. In a fishing configuration, the roller frame trawl has a vertical opening of approximately 2 to 2.5-ft[34]. It is unlikely that a sea turtle would become entrapped within a roller frame trawl due to the required deflector bars positioned across the trawl mouth. Slow moving turtles, caught in the path of the gear may become impinged against the frame for a short period and or be overrun by the gear.

In Florida, roller frames are allowed throughout the state but only are used in areas with seagrass and hard bottom. Roller frame gear may be found in the Big Bend area from St. Marks

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[32] Cast nets and dip nets.

[33] Lionel LaForce, National Marine Fisheries Service. Personal communication, November 7, 2002 to John Mitchell, National Marine Fisheries Service, Pascagoula, MS.

[34] John Mitchell, National Marine Fisheries Service, Pascagoula, MS, observation during gear evaluation dives, 1995.

to the Pasco/Pinellas county line for food and live bait; Pine Island and the southwest region for live bait; sparse use in the Florida Keys for live bait and Biscayne Bay for live bait. A 1997 study, which evaluated roller frame use for bait shrimp in Biscayne Bay, reported 25 vessels using this gear, with average trawling time of 25 minutes (Ault et al., 1997).

Beam Trawls

The advent of the gasoline engine in the early 1900's led to the use of beam trawls in some areas of the southeast U.S. shrimp fishery, but have since been replaced with larger, conventional trawling gear (Hein and Meier, 1995). Beam trawls can be described as a shrimp trawl net, which is attached at the mouth to a rigid pole, beam or frame to maintain spread. No trawl boards or spreading devices are used. Use of a beam trawl in the Southeast U.S shrimp trawl fishery is reported only in Texas. Texas lists the beam trawl as an allowable gear type for commercial bait and table shrimp harvest in inshore waters only. The gear is restricted in size to no more than 25-ft in total width. A beam trawl may be used as a try net in Texas and is limited to 5-ft in total width.[35] Use of a beam-type trawl in Texas is minimal, and may be limited to approximately 15 vessels operating in the Corpus Christi area. Vessels were observed in this area towing a rectangular frame with an attached trawl. The frames had a vertical opening of from 6 to 8 feet and multiple, large poly-floats along the top. The vessels were observed towing the gear dead astern, in shallow water, so that the floats and the top of the frame were exposed at the surface. The trawls were not rigged with TEDs.[36] These trawls may be used on a very limited basis and for harvesting bait shrimp only.[37]

If used for harvesting table shrimp, beam trawls would have to be fitted with deflector bars, spaced no more than 4-inches apart, across the mouth of the trawl. If used for harvesting bait shrimp and thus TED exempt, the gear could potentially capture sea turtles. Assuming that the gear is hauled with the required tow time limits, which apply to bait shrimpers, turtle survival rates should be high.

Skimmer Trawls

Developed in coastal Louisiana in the early 1980's, the skimmer trawl has gained widespread popularity throughout the southeastern U.S. shrimp fishery. Skimmer trawls are pushed by the vessel rather than towed. The trawls are always fished in pairs, from the sides of the vessel. An advantage of the skimmer trawl over an otter trawl is that they are more maneuverable, especially in small bays and bayous and can fish more selectively, i.e. along channel edges. An additional advantage of the gear is that while retrieving the codend, the frame,

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[35] Texas Administrative Code, RULE §58.164, Shrimping Inside Waters--Commercial Bait Shrimping

[36] Lionel LaForce, National Marine Fisheries Service. Personal communication October 29, 2002 to John Mitchell, National Marine Fisheries Service, Pascagoula, MS.

[37] James Nance, National Marine Fisheries Service, Galveston, Texas. Personal communication (E-mail) November 5, 2002 to John Mitchell, National Marine Fisheries Service, Pascagoula, MS.

or mouth of the trawl, remains in a fishing configuration, thus little effort and time is required to dump the catch.

The trawl is held open by a metal framework and is fished on the bottom. A skimmer trawls consist of an “L” shaped frame constructed from metal pipe with a shoe or skid on the outboard leg. The outboard wing edge and headrope of the trawl is attached around the perimeter of the frame. The inboard wing edge of the trawl is sewn to a line suspended from the frame and terminates at a weight or bullet, which, when deployed, rides slightly off the bottom. A chained footrope and tickler chain are used. When fishing, the outboard shoe rides along the bottom, allowing the trawl to rise and fall with the bottom contour. The vertical height of the skimmer trawl varies depending on the target shrimp species, and may be as much as 12-ft in overall height.

Skimmer trawls are used exclusively in inshore waters in all states where the gear is allowed. Originally designed to catch white shrimp by fishing the entire water column, today skimmers may also be rigged with low opening nets and are used to target brown shrimp[38]. Within the last decade, an increasing number of inshore fishermen in North Carolina, Louisiana, Mississippi and Alabama have either fully converted their vessels from otter trawls to skimmer rigs, or switch out their gear on a seasonal basis. The TED exemption likely has caused many Louisiana fishermen to covert their gear to skimmer trawls (Horst and Holloway, 2002).

Skimmer trawls are exempt from TED regulations and must be fished in accordance with tow time restrictions. Skimmers were exempted from TEDs under the assumption that the trawl bags were typically retrieved at intervals that would not be fatal to sea turtles. The incidental capture of sea turtles in skimmer trawls has been documented in North Carolina (Coale et al., 1994; NMFS unpublished data[39]). Because skimmers are typically rigged to fish higher in the water column, the potential for turtle capture may be greater than a lower opening otter trawl.

North Carolina

The only southeast Atlantic state reporting skimmer trawl use is North Carolina. Introduced to North Carolina in the early 1990’s (Hines et al., 1993), the skimmer trawl has become the gear of choice for the commercial harvest of shrimp and recently has been tried for harvesting crab. Skimmers are used most often for white shrimp during mid-summer to fall in Pamlico and Core Sounds, south to New River inlet. It is reported that as many as 30 to 40% of vessels fishing in these waters are using skimmer trawls. Skimmer trawl use in Core Sound may be as high as 90%.[40]

Florida

Skimmer trawls are listed as an allowable gear type for shrimp harvest in Apalachicola Bay only. It has been reported that in the near future, the allowable use area will be enlarged to

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[38] Jack Forrester, National Marine Fisheries Service, Pascagoula, MS. Personal communication October 29, 2002 to John Mitchell, National Marine Fisheries Service, Pascagoula, MS.

[39] Joanne Braun-McNeill, National Marine Fisheries Service, Beaufort, NC. Personal communication (E-mail) October 24, 2002 to Sheryan Epperly National Marine Fisheries Service, Miami, FL.

[40] Parks Lewis, North Carolina Division of Marine Fisheries, Morehead City. Personal communication November 14, 2002 to Nick Hopkins, National Marine Fisheries Service, Pascagoula, MS.

include most of the northwest region of Florida.[41] Skimmer trawls are restricted to 500 square feet of mesh area with a maximum of two nets per vessel.

Alabama

An increasing number of skimmer trawls are being used in Alabama inshore waters. No delineation by gear type is made when licensing commercial shrimp vessels, however estimates range that between 40 to 60% of inshore vessels are using skimmer trawls on a regular or seasonal basis[42]. Skimmer trawls must adhere to otter trawl size restrictions, or no more than 50-ft. of overall trawl headrope length. This equates to two skimmer trawls with a frame size no larger than 25-ft.

Mississippi

Mississippi does not license commercial shrimp vessels by gear type. Estimates on skimmer trawl use range from 60 to 75% of the vessels operating in inshore waters.[43] In the year 2000, there were 577 commercial shrimp licenses issued for vessels 45-ft. in length or less. This figure may include some offshore vessels that would not use skimmer trawls. Skimmer trawls, like otter trawls must adhere are restricted in size to no more than 50-ft. of overall trawl headrope length. This equates to two skimmer trawls with a frame size no larger than 25-ft.

Louisiana

Skimmer trawls are used extensively throughout inshore Louisiana. Commercial license records indicate they are increasing in favor over otter trawl gear. In the year 1992, the number of individuals holding resident skimmer trawl licenses totaled 1,836. For the year 2000, this number was recorded as 3,655. Skimmers are restricted in size with a maximum allowable frame width of 16-ft. and a maximum frame height of 12-ft.

Texas

Skimmer trawls are not an allowable gear for harvesting shrimp in Texas state waters.

Butterfly Nets

Butterfly nets, sometimes called "wing nets" consist of a square metal frame that forms the mouth of the net. Webbing is attached to the frame and tapers back to a codend. The nets can be fished from a stationary platform or a pair of nets can be attached to either side of a vessel. The vessel is then anchored in a tidal current to capture emigrating shrimp, or the nets are pushed through the water by the vessel (Hein et al., 1995). In Louisiana, some shrimpers use them singly on a wharf or platform attached to the shore in man-made passes, bayous, or canals (Horst et al., 2002). The primary difference in fishing butterfly nets and skimmer trawls, is that the former is not fished on the bottom. Butterfly nets are typically set, or pushed so that the top of

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[41] Bill Teehan, Florida Fish and Wildlife Conservation Commission, Tallahassee, FL. Personal communication November 14, 2002 to Dale Stevens, National Marine Fisheries Service, Pascagoula, MS

[42] Drew Hopper, National Marine Fisheries Service, Pascagoula, MS. Personal communication November 12, 2002 to John Mitchell, National Marine Fisheries Service, Pascagoula, MS

[43] David Burrage, Mississippi State Coastal Research & Extension Center, Biloxi, MS Personal communication November 14, 2002 to John Mitchell National Marine Fisheries Service, Pascagoula, MS

the frame, and net are exposed above the surface of the water. As with skimmer trawls, the catch may be picked up and dumped without raising the entire net out of the water. Vessels fishing with butterfly nets typically operate in the deeper parts of rivers, channels and canals, avoiding gear contact with the sloping banks.

Butterfly nets are exempt from TED regulations and must be fished in accordance with regulated tow times. Like skimmer trawls, the gear is capable of incidental sea turtle capture. Because the gear is fished of the bottom, in deeper parts of channels, the chance of turtle interaction with this gear may be somewhat less than skimmer gear.

North Carolina

Butterfly net use is minimal in North Carolina. Approximately 2 or 3 individuals may be actively using this gear[44]

South Carolina

Butterfly nets are specifically outlawed in South Carolina.

Georgia

Butterfly nets are not used to harvest shrimp in Georgia.[45]

Florida

Florida lists “wing nets” as an allowable gear type. They are allowed for commercial food harvest in Biscayne Bay and live bait harvest in Volusia County (inshore waters). Butterfly nets, like skimmer and otter trawls, are restricted to 500 square feet of mesh area with a maximum of two nets per vessel.

Alabama & Mississippi

We found no reports of butterfly nets being used in Alabama or Mississippi.

Louisiana

While not as popular as they once were, butterfly nets are still in use in Louisiana. Many fishermen have converted their gear to the more versatile skimmer rigs. In the year 2000, the number of individuals holding resident butterfly net licenses totaled 1,337. Although not confirmed, butterfly nets are likely restricted in size similar to that of skimmer trawls with a maximum allowable frame width of 16-ft. and a maximum frame height of 12-ft.

Texas

Butterfly nets are not listed as allowable gear for harvesting shrimp in Texas.

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[44] Don Hesselman, North Carolina Division of Marine Fisheries, Morehead City, NC. Personal communication (E-mail) November 14, 2002) to John Mitchell, National Marine Fisheries Service, Pascagoula, MS.

[45] Mark Dodd , Georgia Department of Natural Resources, Brunswick, GA. Personal communication (E-mail) October 23, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL

Channel Nets

Channel nets may take different forms depending on the region or area fished. In general they are funnel-shaped, stationary nets that are set in high flow channels, canals and rivers to catch emigrating shrimp. The mouth of the net is spread by attaching it to poles, stakes, anchors or buoys. The net terminates in a codend, much like an otter trawl, and is emptied by lifting it into a boat or taking the bag to shore if possible. No reports on the dimensions of channel nets were obtained in the preparation of this report, however, South Carolina fishing regulations governing the use of this gear restrict the mouth of the net, as measured across the float line (headrope), to no more than 80-ft in total length.

Channel nets are not described under the federal TED requirement, presumably due to the minimal use of this gear in the southeast U.S. shrimp fishery. Channel nets have been documented to capture sea turtles[46]. South Carolina has enacted a TED requirement for channel nets (see description below). This rule is the only TED requirement for fixed shrimping gear among the southeast coastal states.

North Carolina

Approximately 15 to 20 individuals fishing channel nets are reported.[47] Landings data provided by the North Carolina Division of Marine Fisheries report a total of 185,567 pounds of shrimp landed by channel nets in the year 2001.

South Carolina

The state issues no more than a total of sixty licenses for the use of channel nets in any one year. Each net is restricted in size to no more than 80-ft. in total float line length. No channel net when set may be unattended for more than twenty-four hours. A hard or soft TED must be used in a channel net set within specified areas. TEDs are not required in channel nets that are set in North Santee Bay.

Georgia

No channel net fishing for shrimp is reported from Georgia[48]

Florida

Channel nets are not listed as allowable gear for harvesting shrimp in Florida.

Alabama and Mississippi

No channel net fishing for shrimp is reported for Alabama or Mississippi.

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[46] Joanne Braun-McNeill, National Marine Fisheries Service, Beaufort, NC. Personal communication (E-mail) October 24, 2002 to Sheryan Epperly National Marine Fisheries Service, Miami, FL

[47] Parks Lewis, North Carolina Division of Marine Fisheries, Morehead City. Personal communication November 14, 2002 to Nick Hopkins, National Marine Fisheries Service, Pascagoula, MS.

[48] Mark Dodd , Georgia Department of Natural Resources, Brunswick, GA. Personal communication (E-mail) October 23, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL

Louisiana

Although once used in Louisiana, channel nets are not an allowable gear for the harvest of shrimp.

Texas

Channel nets are not listed as an allowable gear for harvesting shrimp in Texas.

Cast Nets

Cast nets are conical shaped nets, which are thrown from the shore or a boat to cover a bottom area where shrimp may be located. When the net is deployed, it covers a circular area on the bottom, the size of which is determined by the circumference of the net. The perimeter of a cast net is weighted with multiple lead weights to maintain bottom contact. The net is cinched into a closed position through a series of lines attached radially along the net perimeter and running through the interior of the net and out of a thimble at the apex of the cone. From the cone, the lines are spliced to form a single line that is used for retrieval of the net. As the net is cinched together, shrimp are entangled within the folds of the net, and are shaken out at the surface. Cast nets used to commercially harvest food shrimp may be as large as 12 ft (commercial) in radius (Gaddis et al., 2002).

There have been no reported turtle interactions with cast nets from any states. While the possibility of turtle capture exists with this gear, because the gear is retrieved almost immediately after deployment it is unlikely that a turtle would be harmed by the gear if caught.

North Carolina

Cast net landings data for 2001 report a total of 289 pounds. This indicates minimal use of cast nets for food shrimp in North Carolina.

South Carolina

All cast netting in South Carolina is in estuarine areas. A large recreational cast net fishery called the "shrimp-baiting fishery" exists. One report estimates that approximately 14,000 bait shrimp licenses are issued annually. Cast netters place bait balls (fish meal and mud) on the bottom and then cast on the bait for shrimp[49]. Poles must mark bait deposits with a total of 10 poles per boat per day allowed. The season is restricted to a 60-day period between September 1 and November 15.

Georgia

Commercial and recreational cast netting for food shrimp is allowed. A limited access system was enacted in 1998, which allows a maximum of 200 commercial licenses and restricts net radii to 8 ft for recreational users and to 12 ft for commercial users. Commercial license holders may possess no more than 60 quarts of heads-on shrimp per individual boat/day. Restrictions on modifications to cast nets which improved their fishing efficiency may have reduced the number of participants in this fishery (Gaddis et al., 2002).

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[49] David Whittaker, South Carolina Department of Natural Resources, Charleston, SC. Personal communication (E-mail) October 23, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL

Florida, Alabama & Mississippi

Cast nets are not listed as allowable gear for the commercial harvest of shrimp in Florida, Alabama or Mississippi.

Louisiana

Cast nets are an allowable gear for the commercial harvest of shrimp. No information on size limits of the nets was found. In the year 2000, 580 resident dip net/cast net licenses were issued. Not all holders of this license were cast netters as dip nets are used in Louisiana for shad and herring.

Texas

Cast nets are not listed as allowable gear for the commercial harvest of shrimp in Texas.

Other Gear

Dip Nets

Dip nets can be described as a hand-held net consisting of a mesh bag suspended from a circular, oval, or rectangular rigid frame attached to a handle. The incidental capture of sea turtles would be rare if at all, and only with juvenile animals. Dip nets are not reported as gear used for harvesting shrimp in North Carolina, South Carolina, Georgia, Mississippi, Alabama, Louisiana or Texas. Florida lists dip nets as allowable gear for recreational shrimping, and restricts the size of the net to no larger than 96 inches around the perimeter.

Seines

Seines are single panels of mesh webbing, which are typically moved through the water by persons walking along a channel bank or shoreline, although boats may be used as well. Seines vary in overall length and depth usually covering the entire water column of the area being fished. The top line of the seine may be floated in order to keep the panel taught. This is especially important with large seines. Seines are primarily used for harvesting fish, although shrimp may be a bycatch of this gear. Mesh size will vary according to target species. If used for shrimp, the mesh size would likely be less than 2-inches in stretched length. Sea turtle captures are possible with seine gear, and depending on the length, depth and mesh size of the panel, a turtle could become entangled by creating a "pocket" or by folding the panel around itself. Sea turtle captures in seine gear have not been recorded.

Beach seines are listed as one of the gear types within shrimp landings database for North Carolina, however there were no recorded landings for 2001. In South Carolina, haul seines are legal for commercial fish harvesting with less than 24 individuals participating in the fishery.[50] They also can be used to harvest shrimp in Georgia. Florida lists a beach or haul seine as allowable recreational shrimping gear. Seines are not listed as allowable gear for the commercial harvest of shrimp in Alabama and Mississippi and Texas. Louisiana issued seine licenses until 1995 for the harvest of fish only.

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[50] David Whittaker, South Carolina Department of Natural Resources, Charleston, SC. Personal communication (E-mail) October 23, 2002 to Sheryan Epperly, National Marine Fisheries Service, Miami, FL

Pots and Traps

Traps or pots designed to capture shrimp are not commonly used. The traps are constructed of wire mesh similar to that used for crab pot construction. The most common design is similar to that of a blue crab trap with inverted cones used to entrap the shrimp. Traps may be staked or marked with a line attached to a float at the surface. Traps most likely are baited with fishmeal. Turtles may be attracted to the bait and investigate the pot. There have been observations of sea turtles damaging crab trap pots, presumably to get to the bait[51] Turtle entrapment in a pot or trap used to harvest shrimp is not likely, but entanglement in the buoy lines of crab, lobster, and fish pots has been documented.

Crab pots are listed as one of the gear types within shrimp landings database for North Carolina, with a total of 105 pounds landed for the year 2001. Trap and pot gear used for shrimp harvest is illegal in South Carolina. There are no reports of this gear being used in Georgia, Florida, Alabama, Mississippi, Louisiana and Texas.

Pusher head trawls (chopstick rigs)

Introduced in Louisiana the early 1980's by Vietnamese fishermen, the chopstick rig consists of a rigid or flexible frame and net that is attached to a pair of long poles mounted to the bow of a boat. At the bottom of each pole is a skid or shoe to allow the frame and net to follow the contour of the sea floor. The gear is pushed out in front of the vessel, allowing exceptional maneuverability. As with butterfly and skimmer nets, the trawl bag is retrieved and dumped without raising the entire net. This gear was designated illegal in Louisiana in 1984, but exists today among approximately 4 to 6 vessels in Mississippi.[52] Pusher head trawls are listed as TED exempt, but must be fished in accordance with tow time restrictions. Like skimmer and butterfly trawls, pusher head trawls are capable of incidentally capturing sea turtles, thus turtle survival is dependent on adherence to tow times.

Sources of Error

Skimmer trawl use in the inshore shrimp fishery of Louisiana, Mississippi, Alabama, Florida and North Carolina is clearly on the rise. Because this gear is TED exempt, and enforcement of tow time limitations difficult, an accurate estimate of effort for this gear becomes increasingly important. Although our estimates of skimmer trawl use were obtained through interviews with state fisheries managers, researchers and fishermen we feel they may be conservative. A more thorough appraisal of the extent to which skimmer trawls are being used in the southeast U.S. shrimp fishery is warranted.

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[51] Jeff Gearhart, North Carolina Division of Marine Fisheries, Morehead City NC. Personal communication February 1998 to John Mitchell National Marine Fisheries Service, Pascagoula, MS.

[52] David Burrage, Mississippi State Coastal Research & Extension Center, Biloxi, MS. Personal communication November 14, 2002. to John Mitchell National Marine Fisheries Service, Pascagoula, MS.

Discussion

Assuming a stable population, we do expect the new regulations to result in increased interactions, mostly because more turtles will escape and be available for subsequent recapture. As sea turtle populations begin to recover, the rates of interactions also will increase. It is extremely important to minimize the impact of those interactions to facilitate the growth of all turtle populations. The new TED regulation will reduce mortalities significantly – 71% over current levels of mortality (**Table 30**).

Loggerheads and leatherbacks will be the beneficiaries of the new regulation; their mortalities should be reduced 94% and 97%, respectively, over current levels of mortality. Under current regulations, only small juvenile loggerheads are able to escape through conventional TED openings and it is unlikely any leatherbacks escape. A recent stock assessment of the loggerhead populations of the Western North Atlantic used estimates of annual survival rates to evaluate the proposed regulation (NMFS SEFSC, 2001). Extending the TED benefit to the larger turtles while simultaneously decreasing mortality on pelagic oceanic loggerheads would result in a positive population growth rate for the beleaguered northern subpopulation. This bycatch analysis does not alter that conclusion.

There are but a few other means to reduce mortalities in shrimp trawls further. Catch cannot be controlled with current net designs and the current position of TEDs. The first attempt to reduce the bycatch of sea turtles in shrimp trawls was to install a panel of large mesh webbing over the mouth of the trawl. The panel allowed shrimp to pass and excluded most sea turtles. The panel was heavy, though, and caused the mouth of the trawl to be drawn inward, reducing trawl efficiency and shrimp catch. Also, turtles sometimes became entangled in the large meshes of the panel (Oravetz and Grant, 1986). The next approach was to allow everything to enter the trawl, but separate the target species from the bycatch near the codend. This is the philosophy of modern TEDs. This strategy works and it will be extremely difficult to achieve a higher TED effectiveness than the 97% currently realized. There is some indication, however, that the larger openings may improve upon the effectiveness. Turtle interactions and mortalities can be reduced further by decreasing effort and/or fishing power. Also, turtle mortalities in try nets, skimmer trawls, beam trawls, channel nets, butterfly nets, and otter trawls used for bait shrimp can be reduced with the installation of TEDs, and less so, by reducing the allowed tow times.

Table 30. Estimated annual number of interactions between sea turtles and shrimp trawls in the Gulf of Mexico and southeast U.S. Atlantic shrimp fishery for food shrimp, estimated mortalities with current regulations, and estimated mortalities with proposed regulation. Confidence intervals (95%) are given in parentheses. Note that these estimates are subject to many sources of error, many unquantified. Please refer to the individual sections on *Sources of Error* throughout the report.

Species	Estimated Interactions With Current Regulations	Estimated Mortalities With Current Regulations	Estimated Mortalities With Proposed Regulation
Leatherback	3090 (0-11274)	2311 (0-8719)	80 (0-296)
Loggerhead	163160 (56139-337023)	62294 (6680-162419)	3948 (1221-8498)
Kemp's ridley	747205 (61996-3362865)	19972 (1633-90074)	19972 (1633-90074)
Green	48239 (204-300346)	1440 (3-8408)	1440 (3-8408)

Research Recommendations

Evaluation of the impact of a proposed action on the protected species requires (1) current information on the status of populations and stocks, (2) accurate estimates of sea turtle take currently, and (3) estimates of the number to be taken under the proposed action. The new TED rule is the proposed action that prompted this bycatch analysis. To estimate takes, information on catch rates and on the effort of the fleet is required. With this information, it is possible to predict the <u>number</u> of turtles taken (mortality) by species and size of individuals under current and proposed TED regulations. Mortality <u>rates</u> are needed to determine the effect that the proposed regulations will have on the populations or stocks of listed species.

For sea turtles in the North Atlantic, the only current information on status of stocks is from nesting beaches where number of nests are counted annually. This index of sea turtles is acceptable for nesting females, but tells us nothing about the status of hatchlings, juveniles, subadults or adult males, and provides no information on distribution and abundance away from the nesting beaches. Also from a management point of view, any measurable reduction in nesting turtles would be an "after-the-fact" indicator of something that adversely affected earlier life stages 10-30 years before. Currently, population growth is measured only on nesting beaches and these measurements figure prominently in the estimation of mortality rates used in sea turtle stock assessments (TEWG, 1998, 2000; NMFS SEFSC, 2001). Measures from other, younger life stages, are desirable, which means we must assess the in-water populations, both for population trends and to obtain demographic information critical to the models.

The in-water surveys must be conducted long-term. Such surveys are costly and labor intensive, and could only be accomplished with an agency commitment to support them for the long term. NMFS currently funds a few area specific monitoring programs using gill nets, pound nets, and a trawler in a limited area; these studies are relatively inexpensive given the turtle encounter rates and are of value in monitoring trends in specific areas; however, it is the sum of trends from many such programs that will be required to assess the growth rates of the populations. To assess the status of a population or stock, the surveys should cover the entire range of distribution for that stock; this can be multiple surveys as mentioned above, or larger, comprehensive surveys.

There are few means to conduct a comprehensive monitoring effort of sea turtles in the water with a single method and over the large geographic range. Two may be feasible. The first is random sampling with a trawler over the range of all species of interest. This type of survey would be expensive and time consuming and would probably require several years to cover the area. The advantage of this type of survey is having each captured turtle on deck for accurate identification, measurement, genetics, etc. The major disadvantage is expected low catch rates over large areas of the Gulf of Mexico and the associated lack of precision of estimates. This is a common problem when dealing with rare, threatened, and endangered species.

The second possible approach is aerial surveys, but it cannot be used alone. Aerial surveys have proven effective in sighting some sea turtle species in the water, and such surveys can cover large areas in a relatively short time frame. These surveys can provide an index of abundance, at least for leatherbacks and loggerheads, and insights into distribution patterns over the population range. These surveys are less costly and labor intensive than trawl surveys. Results from aerial surveys are more accurate when performed by a well-trained and experienced team of observers. The major drawback of aerial surveys is that identifications cannot be verified, demographic information cannot be obtained, and there is a size bias in our ability to sight smaller turtles. This size bias leads to underestimation of smaller species such as Kemp's ridleys. This bias may be resolved by concurrent trawl surveys and aerial surveys in several areas, and the in-water surveys may also provide the needed demographic data.

Long term surveys would provide the baseline information needed to monitor future trends in sea turtle abundance. Long term monitoring programs are the cornerstone of fisheries management in the southeast, and without such programs NMFS would not be able to provide information required for effective management of many fish species. The need for monitoring fish stocks is a concept that must be applied to management of endangered and threatened species if the agency is to meet mandates of the Endangered Species Act. Failure to monitor stocks places NMFS in a position of conducting Sec. 7 Consultations with little or no data to support the biological opinions.

In addition to the need for long term monitoring, information on the rate of turtle encounters by the shrimp fleet also is needed. For shrimp trawls, this information is best obtained through a "naked net" study similar to what was done by the Foundation study, but it needs to have a more rigorous experimental design to adequately sample all areas. Future opinions on the shrimp trawl fishery will need such results. All gears used in the fishery need to be included in the study. The total effort of the fleet is needed, also, across all areas, gears and interests (commercial and recreational). If the naked net study is not completely random then information on the characteristics of fleet, as related to the rate of sea turtle capture, is needed for each strata.

As with the long term monitoring, these surveys would be costly and time consuming. Unfortunately without this information, any bycatch analyses are fated to obtain the same high errors and huge confidence intervals that we realized here. Also, before any future bycatch analyses are undertaken, it is essential that information be collected on compliance with TEDs regulations and the sizes of openings in TEDs being used, especially in inshore waters. TED testing of wild animals, as documented by underwater video, should continue to measure TED effectiveness.

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