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Estimated Average Annual Bycatch of Loggerhead Sea Turtles (*Caretta caretta*) in U.S. Mid-Atlantic Bottom Otter Trawl Gear, 1996-2004

by Kimberly T. Murray

September 2006

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Abstract

During 1994-2004, fisheries observers documented interactions between bottom otter trawl gear and loggerhead (*Caretta caretta*), Kemp's ridley (*Lepidochelys kempi*) and leatherback (*Dermochelys coriacea*) turtles in the U.S. Mid-Atlantic region (i.e., south of 41°30'N/66°W to approximately 35º00'N/75°30'W). Most of these interactions were with loggerhead turtles, although Kemp's ridley and leatherback turtles were also observed in small numbers. Due to the low number of Kemp's ridley and leatherback interactions, bycatch rates and total mortality were only estimated for loggerhead turtles. Vessel Trip Reports from fishermen operating bottom otter trawl gear in the Mid-Atlantic were used to expand predicted bycatch rates to total estimated bycatch. Due to reduced quality of VTR data in 1994 and 1995, bycatch is reported from 1996-2004 only. Significant factors affecting sea turtle bycatch were latitude zone, depth, sea surface temperature, and the use of a working Turtle Excluder Device (TED). A working TED is defined as one which is not clogged (e.g., with fish or debris). Predicted bycatch rates were stratified by the combination of significant variables. Estimated average annual bycatch of loggerhead turtles in Mid-Atlantic bottom otter trawl gear during 1996-2004 was 616 animals (C.V.=0.23, 95% C.I. over the 9 year period: 367-890).

INTRODUCTION

Four species of sea turtles inhabit U.S. Mid-Atlantic waters seasonally, emigrating north from southern latitudes in spring and returning south in the fall (Shoop and Kenney 1992; Musick and Limpus 1997). All of these species (loggerhead [*Caretta caretta*], Kemp's ridley [*Lepidochelys kempi*], leatherback [*Dermochelys coriacea*], green [*Chelonia mydas*]) are listed as either endangered or threatened under the U.S. Endangered Species Act of 1973. The spatial distribution of turtles in the Mid-Atlantic is coincident with a number of fisheries operating in both inshore and offshore waters during this period.

From 1994-2004, observers aboard commercial fishing vessels documented interactions between turtles and bottom otter trawl gear in the region from Cape Hatteras, NC to Long Island, NY. Most of these interactions included loggerhead turtles, although small numbers of interactions with Kemp's ridley and leatherback turtles were also observed.

In this report bycatch rates of loggerhead turtles (defined as the number of turtles caught per day fished, where day fished is equal to hours fished/24) are derived from data collected by observers in the Mid-Atlantic between January 1994 and December 2004, and applied to commercial fishing activity (where effort is expressed as days fished) to estimate annual loggerhead bycatch. Bycatch was estimated only for loggerheads as there were too few documented interactions of other turtle species to derive reliable bycatch estimates for these species. Fishing effort data in 1994 and 1995 were excluded from the bycatch rate expansion due to the lower quality of the commercial data in these years. Thus, this report provides an estimate of the average annual bycatch of loggerhead sea turtles in bottom otter trawl gear operating in the Mid-Atlantic during 1996 through 2004.

METHODS

DATA SOURCES

Observer Data

Information collected by observers aboard vessels using bottom otter trawl gear in the Mid-Atlantic was used to model the expected number of turtles caught per day fished. This analysis uses data collected from 18,665 hauls over 1,937 trips. For each haul, observers recorded information such as location, average depth, tow duration, tow speed, whether a Turtle Excluder Device (TED) was used in the trawl net, whether obstructions blocked the TED opening, fish species targeted on the haul, and whether a turtle interaction occurred. In this analysis, the geographic location of a turtle interaction corresponds to the location recorded for the beginning of the haul because observers do not know when during the haul an interaction takes place[1]. Other sources of data were used when information collected by observers was incomplete, or to refine the information recorded. For instance, bathymetry data was acquired from a secondary

[1] Mean haul duration was 2.6 hours, ranging from 0.1 to 7.0 hours.

source in order to get a measurement of depth at the beginning of each fishing haul, rather than the average depth over the length of the haul. This was done so that depth information matched the location that was assigned to each turtle interaction.

The model developed from observer data was used to predict loggerhead bycatch rates in several strata. In this analysis, rates are stratified in two latitude zones, with a combination of gear, sea surface temperature, and depth categories (see Turtle Bycatch Model below). Predicted bycatch rates are expanded using commercial fishing effort to estimate total annual bycatch of loggerheads in Mid-Atlantic bottom otter trawl fisheries.

Observer coverage of Mid-Atlantic bottom otter trawl gear during 1996-2004 was designed primarily to monitor fish discards and marine mammal interactions. During the fall of 1998 and early 1999 there was some sampling dedicated to observing turtle interactions in the southern Mid-Atlantic. Coverage (% observed days fished/Vessel Trip Report [VTR] days fished) during 1996-2004 averaged 0.8% (Table 1a). Coverage per year ranged from 0.2% to 4.8% between 1996 and 2004, with the most coverage occurring in 2003 and 2004. Coverage in the two Mid-Atlantic latitude zones in which bycatch rates were stratified was 0.7 and 1.1% (Table 1b).

Spatial Extent of Bycatch Estimates

In this analysis, the Mid-Atlantic was defined as the region from the shoreline below 41°30'N/66°W to the southern extent of the Northeast Fisheries Science Center observer data collection, around 35°00'N/75°30'W.

Types of Trawl Nets

Bottom otter trawl nets used in the Mid-Atlantic include a variety of net types. One type is a flynet, a high profile trawl used for fish that school higher in the water column than typical groundfish, and commonly used in depths less than 36 m (NCDMF, 2004). During 1994-1998, observers documented turtle interactions in flynets (see Results below). Since 2000, however, observers no longer recorded the type of trawl net used during a haul, so there was incomplete information to assess differences in bycatch rates due to net type[2]. Instead, other factors such as depth, head rope length, and target species were examined to serve as a proxy for different net configurations.

The trawl nets analyzed here are designed primarily to target fish. Nets designed to catch scallops are not included in the analysis because a dedicated sampling program for scallop trawl gear did not begin until mid-2004. Thus, any turtle bycatch which may have occurred during 1994-2004 in scallop trawl gear was largely unknown. Moreover, there were no observer data to compare similarities in fishing practices between nets designed to catch fish versus those designed to catch scallops.

[2] Net type information on 88% of observed hauls was unknown or missing.

Source of SST and Depth Data for Observer Data

Observers did not record sea surface temperature (SST) information on sixty-three percent of observed hauls. As a result, SST data for each haul were obtained from 5-day SST composites derived from a variety of satellite imagery sources, or 5-day climatology images downloaded from NASA's Jet Propulsion Laboratory[3]. The climatology images are SST values averaged over 1985-1999 on a 9 km grid. Satellite imagery sources included AVHRR Pathfinder Version 5, Modis Aqua, Modis Terra, and GOES satellites[4]. Available data from these sources were combined to create a 5-day median composite image for each calendar day. A Visual Basic for Applications routine in ArcGIS 9.1 extracted SST values at point locations (or used a median value from a 3x3 cell window) for both the 5-day median composites and the climatology. When choosing which SST data to use in the analysis, the 5-day medians were preferred over the climatology, and point locations were preferred over the 3x3 cell medians. To screen for anomalous temperature values derived from daily images, a field was created by taking the difference between the best daily 5-day SSTs and the best climatology available. If the difference was greater than +/-2.5°C (7% of data) then the best climatology data was used instead of the daily images as the final SST.

Depth data for each observed haul were obtained using bathymetry information acquired from the National Geophysical Data Center[5]. Like SST, bottom depth was obtained via ArcGIS with the data representing the depth at the beginning of each fishing tow recorded by the observer. The NGDC data were used instead of the depth information recorded by the observer, which for many locations represented the average depth over the length of the tow[6].

Use of a Turtle Excluder Device

Under Amendment 2 to the Summer Flounder Fishery Management Plan (implemented in 1992), all vessels using bottom trawls to fish for summer flounder in specific times and areas off Virginia and North Carolina are required to use NMFS-approved Turtle Excluder Devices (TEDs) in their nets (Final Rule, FR 57:57358, 4 December 1992). The trawl fishery for summer flounder is one of two fisheries operating in the Mid-Atlantic which requires the use of TEDs[7].

Out of the 18,665 observed hauls used in this analysis, 224 hauls (1.2%) did not record information about the use of a Turtle Excluder Device (TED). For all hauls not targeting summer flounder, for which it was unknown whether the trawl was equipped with a TED, it was assumed the trawl was not equipped with a TED. Otherwise, use of a

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[3] Additional information on the climatology data source can be found at: http://podaac.jpl.nasa.gov/products/product111.html

[4] Additional information on the satellite data sources can be found at the following links:
AVHRR: http://podaac.jpl.nasa.gov/products/product216.html,
MODIS Terra and Aqua, see products 162 and 184: http://podaac.jpl.nasa.gov/products/product184.html,
GOES, see product 190: http://podaac.jpl.nasa.gov/products/product190.html

[5] Bathymetry data was acquired from ETOPO Global 2' Elevations CD, available from the National Geophysical Data Center (NGDC).

[6] Median depth difference between the beginning of the fishing haul and the average depth over the length of the haul was 7 m.

[7] TEDs are required in the shrimp fishery south of 36°33'008"N latitude though very little commercial effort (~.02%) is present in the area encompassed in this analysis.

TED was assumed based on requirements for TED use in the summer flounder fishery (Interim Final Rule, FR 58:48797, 20 September 1993). That is, an unknown haul was assumed to have an excluder if it operated south of 37°05'N (Cape Charles, VA) to 33°35'N (North Carolina-South Carolina border). After January 1996, for the period Jan 15-Mar 15, the northern TED boundary moved south to 35°46.1'N (Oregon Inlet) (Final Rule, FR 61:1846, 24 January 1996)[8]. Hence, it was assumed that any unknown hauls targeting summer flounder north of Oregon Inlet during these 3 months did not have an excluder, and any unknown hauls during the remainder of the year did. If an unknown haul operated south of Oregon Inlet, then the haul was assumed to have an excluder.

After correcting for unknown values, 348 (1.9%) observed hauls (2.0% days fished) used trawls equipped with TEDs. Almost all observed hauls (99.5%) using TEDs were targeting summer flounder. Of these 348 hauls, 18 (5.2%) were clogged with debris. In this analysis, a TED clogged with debris was assumed to be not working. To analyze whether bycatch rates differed depending on a working or non-working TED, hauls with non-working TEDs were grouped with hauls which did not have TEDs.

Commercial Data

All federally permitted vessels operating under Fishery Management Plans implemented by the NMFS Northeast Region are required to complete VTRs providing information on area fished and fishing effort for each fishing trip completed (Rago et al. 2005). Mandatory reporting in some fisheries began in April 1994, and by 1998 most fisheries had a mandatory VTR requirement[9]. Effort data in VTRs from fishermen operating bottom otter trawl gear in the Mid-Atlantic (i.e., south of 41°30'N) were used in conjunction with predicted bycatch rates to estimate total annual bycatch of loggerheads in the Mid-Atlantic bottom otter trawl fisheries. Several adjustments were made to the VTR data. First, missing data necessary for stratifying bycatch estimates were prorated or predicted based on information from other trips. Second, VTR effort was adjusted to account for effort which was not reflected in the database (for instance, if fishermen did not file a logbook record). Lastly, some assumptions were made about the proportion of trips using TEDs in trawl nets as well as the proportion of trips using working TEDs, because no information existed in VTR logbooks to indicate the use or condition of these devices.

All dealers who buy and sell fish regulated by federal FMPs are required to report 100% of their transactions (Rago et al. 2005). Thus, landings data from the dealer database are considered to be a near census of fishery harvests; however, the dealer reports do not contain any information on the fishing effort associated with the landings that they purchased or sold. A preliminary assessment of VTR data during 1994-2004

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[8] Thirty (0.1%) observed hauls targeting summer flounder took place between Cape Charles, VA and Oregon Inlet, NC during Jan 15-Mar 15, 1994 and 1995. During this time and area, TEDs were required; however, TEDs would not have been required here under the 1996 regulation which shifted the TED boundary south. Thus, using 1994/1995 data could cause the total bycatch estimates to be biased low in comparison to years with revised TED requirements. The small percentage of data (0.1%) involved, however, would make this bias negligible. Furthermore, the risk of interaction north of Oregon Inlet between Jan 15-Mar 15 is minimal due to cool water temperatures (FR 59:10584 March 7 1994).

[9] John Witzig, pers. comm. NOAA Fisheries, Northeast Regional Office, 30 January 2006.

revealed that data in 1994 and 1995 were of lower quality compared to data from years 1996-2004 based on comparisons with dealer data and observer sampling logs[10]. In general, there were relatively large discrepancies in the number of trips between dealer and VTR data in 1994 (this is understandable because reporting did not become effective until mid-1994 for many FMPs). Furthermore, discrepancies were apparent between the values recorded in some fields in the VTR and observer sampling logs in 1994-1995 for the same trips. Additionally, in the early years after trip reporting became mandatory, a large number of discrepancies were evident between the information content of the submitted logbooks and the representation of these data in the VTR database (NEFSC 1996, Wigley et al. 1998). As a result of these issues, bycatch estimates are provided only for 1996-2004.

Prorating VTR Effort

In this analysis, bycatch rates are stratified over two latitude zones. Twelve percent of VTR trips were missing latitude zone information. For these trips, the missing latitude zone was filled in from the statistical area recorded on the VTR log. For trips missing statistical area or where the statistical area bisected two latitude zones (1.6%), the number of days fished were prorated across bycatch strata based on the percentage of days fished in these strata from trips with known coordinates[11].

Source of SST and Depth data for VTR

Sea surface temperature data at each fishing position recorded in VTR logbooks were obtained from the same satellite or climatology data sources used to obtain observer data. SST values could not be obtained for 14.5% of VTR trips due to missing coordinate positions. For these events, SST was predicted by using a linear regression based on year, month, and statistical area (r^2=0.93).

For each fishing position recorded in VTR logbooks, depth data were obtained from the bathymetry data from the National Geophysical Data Center. Thus, the source for depth data was consistent across both the observer and commercial datasets.

Effort Adjustments

To assess shortcomings in the number of VTR trips reported during 1996-2004, the number of VTR trips (summed by year and state in which catch was landed) was compared to the number of trips in the dealer data (also summed by year and state). Comparisons between the number of reported trips in the VTR and dealer databases revealed that some states were underrepresented in the VTR database from 1996-2004. To account for "missing" effort in the VTR database, total days fished in the VTR data

[10] Orphanides, C. In prep. Assessment of Northwest Atlantic Vessel Trip Report trawl data relative to dealer and observer records. Northeast Fisheries Science Center, Woods Hole, MA.

[11] The frequency of trips missing latitude information averaged around 18% between 1996-2000, and decreased to around 4% between 2001-2004.

were adjusted upward to allow for proper expansion of the observed bycatch rates. States with more dealer reported trips than VTR trips had the VTR days fished increased based on the percent difference between the two databases.

In this analysis, turtle bycatch rates are stratified by two latitude zones. The percentage of effort represented by state in each latitude stratum, combined with information obtained from comparisons with dealer data, was used to adjust effort within each latitude zone. Thus the total VTR effort within a stratum was adjusted as:

$$[\Sigma(\text{Total Days Fished})_{ij} * (\%\ \text{State Representation})_{ijk} * (\text{State Adjustment factor})_{ijk}] + (\text{Total Days Fished})_{ij}$$

where i = latitude stratum, j = year, k = state and

The state adjustment factor = 1 + x,

where x represents the percentage increase needed for a particular state based on comparisons with dealer data. VTR trips over all states were adjusted upwards an average of 11%.

Use of a Turtle Excluder Device

In this analysis, turtle bycatch rates were stratified based on whether a working TED was present; however, there is no information in VTR logbooks to indicate use or condition of this device. For this analysis, it was assumed that the amount of VTR effort with or without a TED was the same as the percentage of observed effort with or without a TED[12]. In addition, it was assumed that the amount of VTR effort with a working TED was the same as the percentage of observed effort with a working TED.

To derive the amount of VTR effort that used a TED, the total adjusted effort in each stratum was multiplied by the proportion of observed hauls with a TED in the same stratum. The amount of effort using a TED was then multiplied by the proportion of observed hauls with a working TED in the same stratum. Approximately 2.0% of VTR effort in the Mid-Atlantic used working TEDs (Table 2).

[12] To check whether this assumption was valid, a second method for estimating the amount of VTR effort using TEDs was calculated. In the second method, VTR vessels were assumed to use TEDs based on regulations for requiring excluders in the trawl fishery for summer flounder (see “The Use of a Turtle Excluder Device” under “Observer Data”). Under this method, approximately 2.7% of VTR effort would use TEDs if there was 100% compliance with the rule. Examination of the observer data revealed that there was not 100% compliance (compliance with the rule was roughly 73%). Therefore, the assumption that 1.9% of VTR effort used TEDs was considered reasonable.

TURTLE BYCATCH MODEL

The bycatch rate of turtles was calculated as:

$$\frac{\text{Number of Observed Turtles}}{\text{Days Fished}}$$

where

$$\text{Days Fished} = \frac{\text{Hours Fished}}{24}$$

and hours fished equals the amount of time the net is towed through the water.

A Poisson regression (GAM function, SPLUS 7.0) was used to model the expected turtle bycatch per day fished, because the number of turtles caught on a haul ranged from 0 to 5. The model can be written as:

$$\log(turtlebyc \,/\, dysfished) = f_0 + f_1 x_1 + f_2 x_2 + \ldots f_i x_i$$

where f_i are smoothing functions, and x_i are predictor variables describing environmental, gear, or fishing characteristics.

Model Development

Identifying characteristics associated with bycatch rates can be used to stratify observations, thus increasing the precision of estimated rates by removing variability between strata (Dixon et al. 2005). In a preliminary analysis, a full Generalized Additive Model (GAM) was fit to the data in order to identify covariates associated with turtle bycatch rates (Table 2). Depth and SST were entered into the model as continuous variables. Due to low observer coverage, all years were pooled in fitting the bycatch model. In the GAM, parameters of the continuous prediction variables were estimated by a smoothing spline. GAM smoothers summarize the trend of a response measurement as a function of one or more predictor measurements (Hastie and Tibshirani 1990), and can be used to guide the dichotomization of continuous variables (Hin et al. 1999) or to consolidate categorical variables into larger groupings. A forward stepwise selection method selected variables that resulted in the greatest change in the Akaike Information Criterion (AIC) value relative to all other variables in the scope of the model (StepAIC function, SPLUS 7.0). The AIC is defined as:

$$AIC = -2\log(L(\theta \mid y)) + 2K$$

where $\log(L(\theta \mid y))$ is the numerical value of the log-likelihood at its maximum point and K is the number of estimable parameters (Burnham and Anderson, 2002). The AIC is a measure of the goodness of fit that includes the level of parsimony, defined as a model that fits the data well and includes as few parameters as necessary (Burnham and Anderson, 2002). This process suggested that latitude, depth, SST, and TED group resulted in the greatest change in AIC.

Next, GAM smoothers were used to categorize latitude, depth, and SST variables according to their effect on the bycatch rates (Figure 1). For continuous variables (depth and SST), the effect of the variable on the bycatch rate is higher at values where the curve is above zero. Sea surface temperature was binned into two categories: high (>18°C) and low (≤18°C). Depth was binned into two categories: shallow (<50m) and deep waters (≥50m). For categorical variables (latitude), values above zero were grouped together, and values below zero were grouped together. Latitude was grouped into two broader "latitude zone" categories: latzone3438 (34°N -38°59'N) and latzone3941 (39°N -41°30'N). Grouping variables was done to prorate portions of commercial fishing effort into appropriate bycatch strata, and to expand bycatch rates to a total estimate.

Model Selection

To select the best-fitting model, variables were tested individually in a forward stepwise selection. Depth and SST were entered as categorical variables defined from the GAM smoothers, and latitude zone was substituted for latitude. The order in which variables entered the model corresponded to the order in which variables reduced the AIC from most to least. The best-fitting model was determined by evaluating the AIC in combination with p-values from a chi-squared test (ANOVA function) to evaluate model improvement at each step. A variable was retained if the p-value between two models was less than or equal to 0.05 and the AIC value declined.

Possible overdispersion in the data was evaluated by examining the ratio of the residual deviance to the residual degrees of freedom in the final model (Hardin and Hilbe 2001).

Model Validation

The observed number of turtle interactions was compared to the expected number of interactions from the model within each bycatch stratum. Goodness-of-fit of the model was then evaluated using a Pearson chi-square statistic (McCullagh and Nelder 1983).

Estimated Average Annual Bycatch

Bycatch rates were stratified based on significant factors found to affect turtle bycatch in the Mid-Atlantic. The coefficient of variation (CV) and 95% confidence interval (CI) for each stratum-specific bycatch rate were estimated by bootstrap resampling (Efron and Tibshirani, 1993). The resampling unit was a single trip with its associated hauls. Replicate bycatch rates were generated by sampling with replacement 1000 times from the original data set. In each stratum, the CV was defined as the standard deviation of the bootstrap replicate bycatch rate divided by the mean bycatch rate from the original dataset.

Within each stratum, the estimated average annual turtle bycatch was calculated as the product of the predicted bycatch rate for that stratum and the average annual number of days fished by the trawl fishery in that stratum from 1996-2004:

$$\frac{\sum \text{Predicted Bycatch}_i}{\sum \text{Days Fished}_i} \times (\text{Average Days Fished per Year})_i$$

where i = stratum. Average annual bycatch was the sum of the stratified bycatch estimates.

A CV and 95% confidence interval for the average annual bycatch aggregated over all strata in each latitude zone were also calculated from the bootstrap replicates. Average annual bycatch was first calculated by stratum in each latitude zone:

$$B_{s\,i}^{U} = R_s^{U} E_{s\,i}$$

where

$B_{s\,i}^{U}$ is the expected average annual bycatch in stratum *s* in bootstrap replicate U in latitude zone *i*,

R_s^{U} is the predicted bycatch rate for stratum s in bootstrap replicate U, and

$E_{s\,i}$ is the average annual VTR effort in stratum *s* in latitude zone *i*.

The average annual bycatch for bootstrap replicate U in latitude zone *i*, B^{U}_{i}, is then given by:

$$B^{U}_{i} = \sum_{s} B_{s\,i}^{U}$$

The CV and 95 % CI of the average annual bycatch estimate was computed for B^{U}_{i}.

RESULTS

OBSERVED CATCHES

Observers documented 66 loggerhead turtle interactions with bottom otter trawl gear from 1994-2004 (Table 3, Figure 2). In addition, observers documented interactions with 2 Kemp's ridley, 1 leatherback, and 3 unknown turtle species. These latter interactions were excluded from the bycatch analysis due to the low number of observed interactions. Of the 66 documented loggerhead interactions, 38 (57%) were alive and uninjured, and 28 (43%) were dead, injured, resuscitated, or of unknown condition.

Observed loggerhead interactions occurred throughout most of the year, with most in waters off the coast of North Carolina. Fifty-eight interactions (88%) occurred in latitude zone 3438, and 8 (12%) in latitude zone 3941. Twenty-one (32%) of the interactions occurred in waters ≤18°C. Only two (3%) of the interactions occurred in waters deeper than 31 m. No interactions occurred in March, April, or May. The size of the cod end mesh in nets which took turtles ranged from 1.7" to 6.6". Duration of tows with bycatch ranged from a half hour to over 5 hours. Eight interactions (12%) occurred on 4 vessels equipped with TEDs. Seven of the eight interactions occurred when the TED was clogged with debris. No interactions in TEDs (both working and non-working) occurred after 1999. At least twenty-three interactions (35%) occurred in flynets targeting either croaker or weakfish. Loggerhead turtles were captured on vessels targeting summer flounder (50%), croaker (27%), weakfish (11%), long-finned squid (8%), groundfish (3%) and short-finned squid (1%).

Loggerhead turtle interactions occurred on 27 trips, with 1 trip catching 12 turtles, and another trip catching 8 turtles. On these two trips interactions occurred in flynets. Twenty-one (32%) of the interactions occurred in 1994, and 15 (23%) occurred in 1999.

In addition to the 66 interactions, ten severely decomposed turtles and 1 moderately decomposed turtle were caught incidentally in trawl gear during 1994-2004. Three of the 11 interactions were with loggerhead turtles and the other 8 were with unknown species. These 11 animals were not included in the bycatch analysis because it was assumed that these mortalities did not occur in the trawl gear. Four of the ten severely decomposed turtles occurred on 1 trip in 2002 and were wrapped in gillnet gear.

TURTLE BYCATCH MODEL

Factors Affecting Bycatch Rates

Significant factors affecting sea turtle bycatch were latitude zone, depth, SST, and the use of a working TED (Table 4). Predicted bycatch rates were stratified by the combination of these factors (Table 5). Because TEDs were not used in latitudes north of 38°N, predicted bycatch rates for hauls with a TED are only reported for latitude zone 3438. The predicted number of catches was similar to the observed number of catches in each stratum (Table 6), indicating the model fit the data reasonably well ($\chi^2_5 = 9.04$, p = 0.11). Data also did not appear overdispersed (residual deviance/residual df for selected model = 0.03).

The highest bycatch rate occurred between 34°N and 39°N in waters shallower than 50 m and warmer than 18°C, and involved vessels using either no TED or a non-working TED (Table 5). Bycatch rates were much lower on hauls equipped with working TEDs. On average, the model predicted that in any given latitude zone, depth, and SST stratum, bycatch rates with a working TED were 11% of the bycatch rate without a working TED.

Mesh size of the cod end, towspeed, and head rope length of the trawl net did not significantly affect bycatch rates. Species targeted on a haul also did not have a significant effect on turtle bycatch rates.

ESTIMATED AVERAGE ANNUAL BYCATCH

Estimated average annual bycatch of turtles per year in Mid-Atlantic bottom otter trawl fisheries, averaged over 1996-2004, is as follows:

Latitude Zone	Average Turtle Bycatch/Year 1996-2004	CV	95% CI*
Lat3941	147	0.42	36-271
Lat3438	469	0.28	240-736
Total Mid-Atlantic	616	0.23	367-890

*Confidence intervals represent an average over nine years of data rather than a single year.

In the southern Mid-Atlantic (between 34°N and 38°59'N), most of the estimated bycatch (443 of 469 estimated takes: 94%) took place in waters shallower than 50 m in gear without working TEDs (Table 7).

DISCUSSION

FACTORS AFFECTING BYCATCH RATES

The incidental capture of turtles in bottom otter trawl gear occurs throughout most of the year in the Mid-Atlantic. Based on factors examined in this analysis, the probability of interacting with a turtle is driven by the overlap between fishing activity and turtles in various thermal and bathymetric regimes. Highest bycatch rates in bottom otter trawl gear during 1994-2004 occurred in shallow waters (<50 m) of the southern Mid-Atlantic (between 34°N and 38°59'N). Many turtle interactions have been documented off the Outer Banks of North Carolina in winter, when turtles are associated with warm Gulf Stream waters occurring over shallow areas (<70 m) of the continental shelf (Epperly et al. 1995). These favorable temperature and depth regimes put the concentrated population at risk for interaction with fishing gear (Epperly et al. 1995).

In this analysis, trawl nets equipped with properly functioning TEDs had a lower bycatch rate than nets without TEDs. The Flounder TED is a special hard TED designed for use in the summer flounder fishery (regulations for the technical specification are at 50 CFR 223.207). The Flounder TED must be installed into a cylindrical piece of webbing called a TED extension, constructed of webbing no larger than 3.5" stretched mesh (Interim Final Rule, FR 64:55860, effective 15 November 1999). Prior to this requirement, the minimum mesh size for extensions in trawl nets fishing for summer flounder was 5.5" (Amendment 10 to the Summer Flounder, Scup, and Black Sea Bass Fishery Management Plan).

Observed loggerhead turtle interactions in nets equipped with TEDs occurred prior to the changes in mesh size regulations in November 1999. On some hauls, observers commented that turtles' flippers became entangled in the 5.5" mesh, preventing their escape through the TED opening. Skates and large fish also blocked the TED opening, trapping turtles. In addition, observers noted (from captains) that turtles had difficulty exiting the TED because the larger mesh webbing had difficulty maintaining the correct shape.

Based on observer data in this analysis, 5.2% of TEDs (18 of 348 hauls) were not working (i.e., clogged with debris). The number of hauls with non-working TEDs was too small over the 9-year time series to examine whether the bycatch rate of non-working TEDs differed before and after the mesh changes in 1999.

In the southern latitude zone (between 34°N and 38°59'N), 12 interactions occurred on a single trip, and 8 interactions occurred on another. All of these 20 interactions interactions occurred in flynets targeting either weakfish or croaker. Surrogates were used to analyze the effect of different net types on bycatch rates because information on net type was lacking for most of these data. Still, there may be other factors not examined here that could influence the probability of catching a turtle, such as the wing mesh of the net or where the net fishes in the water column.

Trawl gear in the Mid-Atlantic targets a multitude of fish species, yet turtle interactions occurred on hauls targeting only six species groups (Table 3). The lack of observed turtle interactions on hauls targeting fish species other than these may be due to lower observer coverage levels for that particular sector of the trawl fishery. For instance, all documented takes in 1999 occurred on hauls targeting summer flounder in latitude zone 3438. During 1999, there was observer coverage dedicated specifically to monitoring turtle interactions with vessels targeting summer flounder[13], despite there being commercial fishing activity for other species in this area. Based on this analysis, the likelihood of interacting with a turtle depends on the time and area in which fishing takes place rather than the fish species being targeted. Increased observer coverage allocated over temporal and spatial strata may provide more information about the likelihood of turtle bycatch in trawls targeting other fish species.

The model developed in this analysis is an explanatory model that estimates total bycatch of loggerhead turtles in Mid-Atlantic bottom otter trawl gear during 1996-2004. Before this model can be used as a predictive model to estimate the annual bycatch of turtles beyond 2004, several factors should be considered, such as annual trends in fishing effort, possible changes in turtle abundance and distribution, and SST patterns. Predicted bycatch rates were derived from all observed hauls in the Mid-Atlantic pooled over 9 years. This analysis assumes that bycatch rates follow a constant trend across the 9-year period. If annual trends in turtle bycatch rates are not constant, then applying long-term average bycatch rates to estimate total bycatch in future years could be biased depending on changes in fishing effort, turtle abundance and distribution, or environmental anomalies.

The model used to predict bycatch rates in the trawl fishery grouped the continuous variables (depth and SST) into discrete categories. This was done to prorate commercial fishing effort that was missing latitude information into appropriate bycatch strata, and to expand bycatch rates to a total estimate. Because of grouping, bycatch rates in the model are assigned a constant rate between 0-18°C, and are assigned another rate value for temperatures greater than 18°C. While these groupings may be appropriate for stratifying rates to estimate total bycatch, a different approach should be explored for models intended to inform mitigation strategies (such as time/area closures).

Future work should investigate other statistical models to evaluate bycatch. This analysis assumed observed hauls were independent. However, information collected on hauls within trips is hierarchical; with this structure, one might expect bycatches within a

[13] Mike Tork, pers. comm. NOAA Fisheries, Northeast Fisheries Science Center, 17 May 2006.

trip to be more closely related than bycatches across trips (McCracken 2004). An alternative model suitable to this type of structure is the Generalized Linear Mixed Model (GLMM) (McCracken 2004; Venables and Dichmont 2004). GLMMs, however, require more information to support the complex algorithms necessary to fit the model (McCracken 2004). Therefore, the use of GLMMs for rare events such as turtle bycatch may be limited. Alternatively, other sampling units could be used to expand the bycatch rates (Borges et al. 2005). For example, modeling bycatch per trip may avoid any dependence on hauls within trips, though some information concerning the predictor variables may be lost at this level (McCracken 2004).

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Table 1a. Observer coverage (% observed days fished/VTR days fished) in Mid-Atlantic Bottom Otter Trawl Gear, 1996-2004

Year	Total Observed Days Fished	Total VTR Days Fished*	% Observer Coverage
1996	126.13	23860.32	0.5
1997	137.93	34295.63	0.4
1998	70.88	37328.72	0.2
1999	110.36	33540.51	0.3
2000	146.06	27380.27	0.5
2001	85.57	26146.49	0.3
2002	215.57	23399.60	0.9
2003	318.90	19246.24	1.7
2004	572.26	11962.10	4.8
Total	1783.66	237159.89	0.8

*VTR Days Fished have been adjusted upwards – see Commercial Data, Effort Adjustments

Table 1b. Observer coverage (% observed days fished/VTR days fished) in Mid-Atlantic Bottom Otter Trawl Gear, 1996-2004, by Latitude Zone

Latitude Zone	Total Observed Days Fished	Total VTR Days Fished	% Observer Coverage
Lat3941: 39-41°30’N	1352.74	197892.85	0.7
Lat3438: 34-38°59’N	430.92	39267.04	1.1
Total	1783.66	237159.89	0.8

Table 2. Variables examined in an analysis of factors affecting loggerhead sea turtle bycatch in Mid-Atlantic otter trawl gear. Percentage of observed days fished and VTR days fished are shown for categorical variables, as is the range of values for continuous variables.

Variable	**Definition**	**% Observed Days Fished**	**% VTR Days Fished**
Latitude+	Latitude 34-34°59'N Latitude 35-35°59'N Latitude 36-36°59'N Latitude 37-37°59'N Latitude 38-38°59'N Latitude 39-39°59'N Latitude 40-40°59'N Latitude 41-41°30'N	0.1% 1.7% 4.1% 6.3% 12.5% 13.7% 23.9% 37.7%	0.6% 2.2% 2.8% 4.6% 7.0% 13.9% 39.5% 29.4%
Latitude Zone	Lat3438: 34-38°59'N Lat3941: 39-41°30'N	24.7% 75.3%	17.7% 82.3%
Excluder Use	Not present or clogged: 0 Present and not clogged: 1	98.0% 2.0%	98.0% 2.0%
Depth	Bottom depth (m)	2-383m	2-822m
SST	Sea surface temperature (C)	3.7-25.4°C	2.2-27.6°C
Depth Categorical+	Deep: ≤50m Shallow: <50m	59.9% 40.1%	56.3% 43.7%
SST Categorical+	Hi: >18°C Low:≤18°C	19.7% 80.3%	24.6% 75.4%
Towspeed	Towing speed of vessel (kt)	1.5-4.9kn	Not available
Head Rope Length	Length of the trawl net head rope (m)	11.5-88m	Not available
Gross Tonnage	Tonnage of vessel	5-372 tons	2-372 tons
Mesh Size	Mesh size of the codend (inches)	1 – 6.7 inches	1-8.0 inches
Species	Fish species targeted on trip*	Cod (6.8%) Haddock (7.1%) Long-fin squid (18.2%) Mixed ground (9.7%) Short-fin squid (5.9%) Summer flounder (18.8%) Winter flounder (7.1%) YT flounder (10.8%) Croaker (0.6%) Weakfish (0.5%) Other species (14.5%)	3.0% 2.6% 19.9% 2.2% 1.8% 16.4% 9.5% 8.5% 0.6% 0.5% 35.0%

+ Latitude was not tested together with latitude zone. Depth and SST categorical variables were not tested together with Depth and SST continuous variables.
*For VTR trips, "target" species defined as the most amount of species caught on a trip. For observer trips, target species defined as the species sought after on a trip.

Table 3. Loggerhead sea turtle bycatch in Mid-Atlantic bottom trawl gear 1994-2004. Species targeted are: sufl = summer flounder; croa = croaker; weak = weakfish; lfsq = long-finned squid; sfsq = short-finned squid; mxgr = mixed groundfish. An "Unk" flynet code means it was unknown whether a flynet was used.

Trip	No. Turtles	Animal Condition	Year	Month	Depth (m)	SST (° C)	Tow speed	Head rope length (m)	TED Used	Working TED Used	Gross Tonnage	Mesh Size (in)	Haul Duration (hours)	Target spp.	Flynet	Latzone
A	1	Alive, not injured	1994	10	28	17.3	3.5	15.2	0	No	116	5.5	4.0	sufl	Unk	lat3438
B	5	3 Alive, cond unk; 2 Alive, not injured	1994	12	24	19.8	3.0	32.6	0	No	159	3.1	2.5	croa	Yes	lat3438
B	1	Alive, injured	1994	12	26	21.2	3.0	32.6	0	No	159	3.1	1.3	croa	Yes	lat3438
B	3	3 Alive, not injured	1994	12	23	21.2	3.0	32.6	0	No	159	3.1	1.3	croa	Yes	lat3438
B	1	Dead	1994	12	24	21.2	3.0	32.6	0	No	159	3.1	2.2	croa	Yes	lat3438
B	2	2 Alive, not injured	1994	12	15	21.5	3.0	32.6	0	No	159	3.1	2.2	croa	Yes	lat3438
C	1	Alive, cond.unk.	1994	12	24	19.2	3.0	12.8	1	Yes	159	5.2	3.4	sufl	Unk	lat3438
C	1	Alive, not injured	1994	12	21	21.0	3.0	32.6	0	No	159	3.1	0.9	weak	Yes	lat3438
C	1	Alive, not injured	1994	12	12	20.9	3.0	32.6	0	No	159	3.1	1.7	weak	Yes	lat3438
C	1	Alive, not injured	1994	12	23	20.9	3.0	32.6	0	No	159	3.1	1.7	weak	Yes	lat3438
C	1	Alive, not injured	1994	12	21	21.0	3.0	32.6	0	No	159	3.1	1.6	weak	Yes	lat3438
C	1	Alive, not injured	1994	12	23	20.9	3.0	32.6	0	No	159	3.1	1.9	weak	Yes	lat3438
C	1	Alive, not injured	1994	12	14	20.9	3.0	32.6	0	No	159	3.1	2.3	weak	Yes	lat3438
C	1	Alive, not injured	1994	12	20	19.1	3.0	32.6	0	No	159	3.1	2.0	weak	Yes	lat3438
D	1	Alive, cond.unk.	1995	6	20	18.3	3.0	20.7	0	No	42	2.0	1.1	lfsq	Unk	lat3438
E	1	Alive, not injured	1995	9	174	22.0	3.0	46.9	0	No	246	2.4	1.9	sfsq	Unk	lat3941
F	1	Alive, not injured	1995	10	19	20.0	3.1	22.9	0	No	129	5.9	4.2	sufl	Unk	lat3438
G	1	Alive, not injured	1995	11	26	19.7	3.0	19.8	0	No	129	5.5	4.0	sufl	No	lat3438

Trip	No. Turtles	Animal Condition	Year	Month	Depth (m)	SST (° C)	Tow speed	Head rope length (m)	TED Used	Working TED Used	Gross Tonnage	Mesh Size (in)	Haul Duration (hours)	Target spp.	Flynet	Latzone
G	2	2 Alive, not injured	1995	11	28	20.0	3.0	19.8	0	No	129	5.5	4.0	sufl	No	lat3438
H	2	1 Alive, injured; 1 Alive, not injured	1996	8	7	22.0	2.0	18.9	0	No	38	2.0	2.6	mxgr	Unk	lat3941
I	1	Alive, not injured	1996	8	29	22.4	3.0	30.5	0	No	86	1.9	3.3	lfsq	Unk	lat3941
J	1	Dead	1996	9	20	23.2	3.5	54.9	0	No	170	3.3	1.5	croa	Yes	lat3438
K	1	Alive, not injured	1996	10	24	17.7	2.9	18.3	0	No	128	6.6	4.3	sufl	Unk	lat3438
K	1	Alive, injured	1996	10	30	17.6	3.7	18.3	0	No	128	6.6	4.2	sufl	Unk	lat3438
K	1	Dead	1996	10	30	17.6	3.2	18.3	0	No	128	6.6	4.5	sufl	Unk	lat3438
L	1	Alive, not injured	1997	7	19	23.9	2.8	33.5	0	No	137	1.9	3.6	lfsq	Unk	lat3941
M	1	Dead	1998	12	15	18.5	3.0	25.9	0	No	115	1.9	1.6	croa	Yes	lat3438
M	1	Alive, not injured	1998	12	23	19.9	2.9	25.9	0	No	115	1.9	0.9	croa	Yes	lat3438
N	1	Alive, injured	1998	12	9	17.0	3.1	25.9	0	No	95	1.9	1.4	croa	Yes	lat3438
O	1	Alive, not injured	1999	1	27	17.3	3.1	15.8	1	No	114	5.6	3.4	sufl	No	lat3438
O	1	Alive, not injured	1999	1	20	16.8	3.1	15.8	1	No	114	5.6	4.7	sufl	No	lat3438
O	2	2 Dead	1999	1	25	17.0	3.1	15.8	1	No	114	5.6	4.4	sufl	No	lat3438
P	1	Alive, not injured	1999	1	25	17.3	3.1	21.3	1	No	196	5.5	4.2	sufl	Unk	lat3438
P	2	1 Alive,not injured; 1 Dead	1999	1	23	17.1	3.1	21.3	0	No	196	5.5	2.5	sufl	Unk	lat3438
P	1	Alive, injured	1999	1	31	16.2	3.1	21.3	0	No	196	5.5	3.1	sufl	Unk	lat3438
P	1	Alive, cond.unk.	1999	1	23	14.9	3.0	21.3	1	No	196	5.5	3.2	sufl	Unk	lat3438
Q	1	Dead	1999	1	27	17.3	2.8	21.3	1	No	179	5.5	5.1	sufl	Unk	lat3438
Q	2	1 Alive, cond.unk.; 1 Alive, injured	1999	1	30	15.8	2.8	21.3	0	No	179	5.5	5.5	sufl	Unk	lat3438

Trip	No. Turtles	Animal Condition	Year	Month	Depth (m)	SST (° C)	Tow speed	Head rope length (m)	TED Used	Working TED Used	Gross Tonnage	Mesh Size (in)	Haul Duration (hours)	Target spp.	Flynet	Latzone
R	3	2 Alive, cond.unk.; 1 Alive, not injured	1999	2	26	18.2	3.5	15.8	0	No	134	5.1	3.4	sufl	Unk	lat3438
S	1	Alive, not injured	2002	1	34	13.1	3.0	19.5	0	No	196	5.0	3.8	sufl	Unk	lat3438
T	1	Alive, not injured	2002	9	21	21.4	3.0	21.3	0	No	137	5.1	2.4	sufl	Unk	lat3941
U	2	1 Alive, not injured; 1 Resuscitated	2002	9	20	23.0	3.0	21.3	0	No	140	5.1	2.3	sufl	Unk	lat3438
V	1	Dead	2002	10	76	20.0	2.8	26.5	0	No	99	2.0	2.4	lfsq	Unk	lat3941
W	1	Alive, cond.unk.	2003	6	19	20.4	2.9	18.3	0	No	32	5.0	1.9	sufl	Unk	lat3438
X	1	Dead	2003	11	30	14.8	3.1	23.2	0	No	108	5.5	2.1	sufl	Unk	lat3438
X	1	Alive, not injured	2003	11	31	15.1	2.9	23.2	0	No	108	5.5	2.9	sufl	Unk	lat3438
X	1	Alive, not injured	2003	11	30	15.0	2.9	23.2	0	No	108	5.5	3.2	sufl	Unk	lat3438
Y	1	Resuscitated	2004	7	30	19.6	3.5	21.3	0	No	71	1.7	1.8	lfsq	Unk	lat3941
Z	1	Alive, not injured	2004	10	22	18.7	2.7	18.3	0	No	26	5.3	1.3	sufl	Unk	lat3438
AA	1	Alive, not injured	2004	10	17	19.2	3.0	24.4	0	No	146	4.6	0.5	croa	Unk	lat3438
AA	1	Alive, not injured	2004	10	16	19.6	2.9	24.4	0	No	146	4.6	1.1	croa	Unk	lat3438

Table 4. Significant variables in the model to predict loggerhead turtle bycatch rates in Mid-Atlantic bottom otter trawl gear.

Latitude strata - Lat3941: 39-41°30'N, Lat3438: 34-38°59'N
Depth strata - Deep: ≥50m, Shallow: <50m
SST strata - Hi SST: > 18°C, Low SST: ≤18°C

Model	**Residual Deviance**	**Deviance Reduction**	**Pr(Chi)**	**AIC**
Null model only	803.86			805.86
Null + latitude zone	686.34	-117.52	0.00	690.34
Null + latitude zone + depth categorical	598.21	-88.13	0.00	604.21
Null + latitude zone+ depth categorical + SST categorical	571.78	-26.43	0.00	579.78
Null + latitude zone + depth categorical + SST categorical + working TED	561.29	-10.49	0.00	571.29

Table 5. Predicted bycatch rates in Mid-Atlantic bottom trawl gear. No Turtle Excluder Devices were used in latitude zone 3941. An observed trip may occur in multiple strata. "NC" means no observer coverage in that stratum.

Latitude Zone	**Working Excluder Used**	**Depth Zone**	**SST Group**	**Predicted Turtles/Days Fished**	**Total No. Observed Hauls**	**Total No. Observed Trips**
Lat3941	No	≥50m	>18°C	0.0007	779	125
			≤18°C	0.0002	7188	687
		<50m	>18°C	0.0282	1391	386
			≤18°C	0.0086	4622	783
Lat3438	No*	≥50m	>18°C	0.0119	686	90
			≤18°C	0.0036	1572	203
		<50m	>18°C	0.4813	1023	222
			≤18°C	0.1474	1074	185
	Yes	≥50m	>18°C	0.0013	NC	NC
			≤18°C	0.0004	12	5
		<50m	>18°C	0.0529	74	11
			≤18°C	0.0162	244	24
Total					18665	2721+

*Includes 18 observed hauls with non-working TEDs

+While this analysis uses data collected from 1,937 unique trips, the total trips listed here account for those occurring in more than 1 stratum.

Table 6. Observed versus predicted turtle catches in the model to predict turtle bycatch in Mid-Atlantic bottom trawl gear. A Pearson chi-squared goodness-of-fit test tests the null hypothesis that there is no difference in observed and predicted turtle interactions. "NC" means no observer coverage in that stratum.

Latitude Zone	**Working Excluder Used**	**Depth Zone**	**SST Group**	**Observed Turtles**	**Predicted Turtles**	**Pearson chi-squared p-value**
Lat3941	No	≥50m	>18°C	2	0	P = 0.11
			≤18°C	0	0	
		<50m	>18°C	6	4	
			≤18°C	0	4	
Lat3438	No*	≥50m	>18°C	0	1	
			≤18°C	0	1	
		<50m	>18°C	36	40	
			≤18°C	21	16	
	Yes	≥50m	>18°C	NC	NC	
			≤18°C	0	0	
		<50m	>18°C	1	0	
			≤18°C	0	0	
Total				66	66	

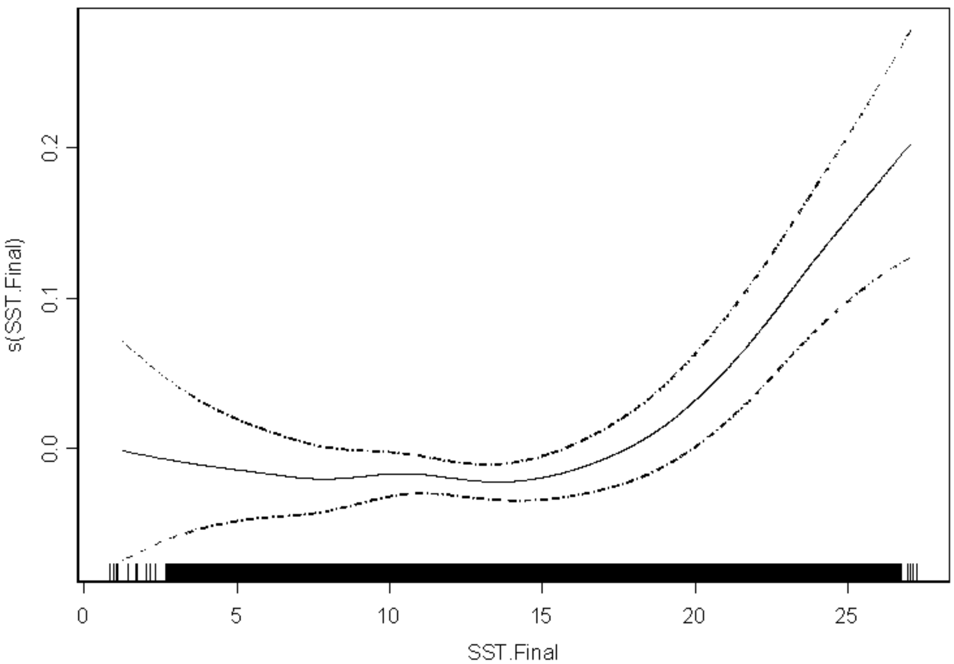
*Accounts for hauls with non-working TEDs

Table 7. Predicted bycatch rates of turtles and estimated average annual bycatch in Mid-Atlantic bottom trawl gear, 1996-2004.

Latitude Zone	**Working Excluder Used**	**Depth Zone**	**SST Group**	**Predicted Turtles/Days Fished**	**VTR Average Days Fished 1996-2004**	**Observed Average Days Fished 1996-2004**	**Estimated Bycatch per Year**	**Observer Coverage (% obs dys fished/VTR dys fished)**
Lat3941	No	≥50m	>18°C	0.0007	1977.18	9.55	1	0.5
			≤18°C	0.0002	10660.17	81.42	2	0.8
		<50m	>18°C	0.0282	3279.64	13.02	92	0.4
			≤18°C	0.0086	6071.10	46.32	52	0.8
Total					**21988.09**	**150.31**	**147**	**0.7**
Lat3438	No*	≥50m	>18°C	0.0119	578.58	9.98	7	1.7
			≤18°C	0.0036	1629.54	16.99	6	1.0
		<50m	>18°C	0.4813	588.64	7.63	283	1.3
			≤18°C	0.1474	1088.10	9.47	160	0.9
	Yes	≥50m	>18°C	0.0013	0	NC	0	0.0
			≤18°C	0.0004	1.64	0.03	0	1.8
		<50m	>18°C	0.0529	124.05	0.83	7	0.7
			≤18°C	0.0162	352.44	2.94	6	0.8
Total					**4362.99**	**47.87**	**469**	**1.1**
Grand Total					**26351.1**	**198.18**	**616**	**0.8**

*Accounts for hauls with non-working TEDs

Figure 1. Partial fit for the general additive model (GAM) of loggerhead sea turtle bycatch rates with sea surface temperature, depth, and latitude as covariates. Bycatch rates are higher at sea surface temperatures greater than 18°C, depths <50 m, and for hauls located in latitudes 34-38°N. 95% confidence bands are also shown.



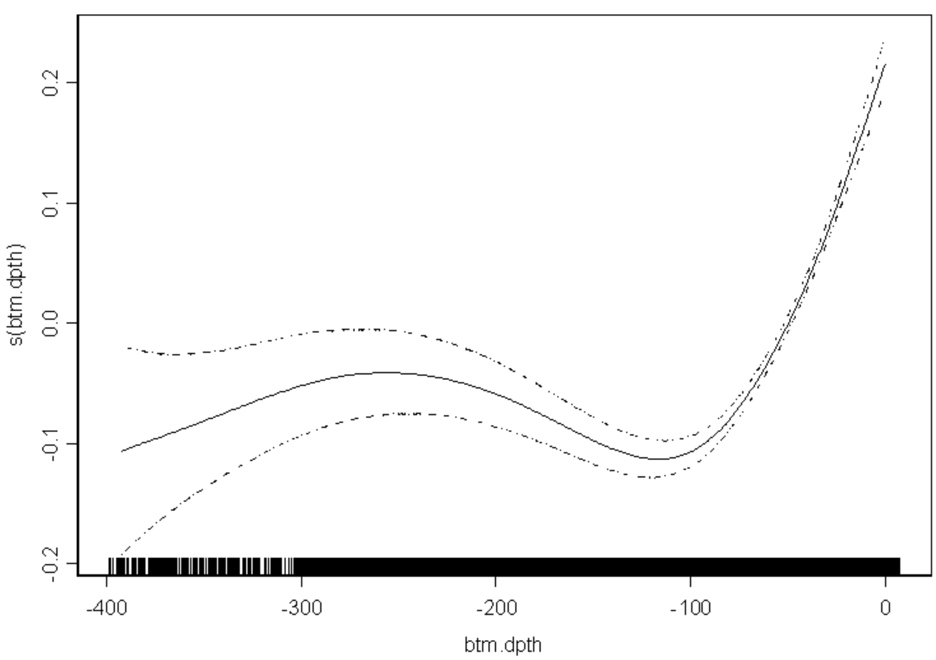


Figure 1 continued.

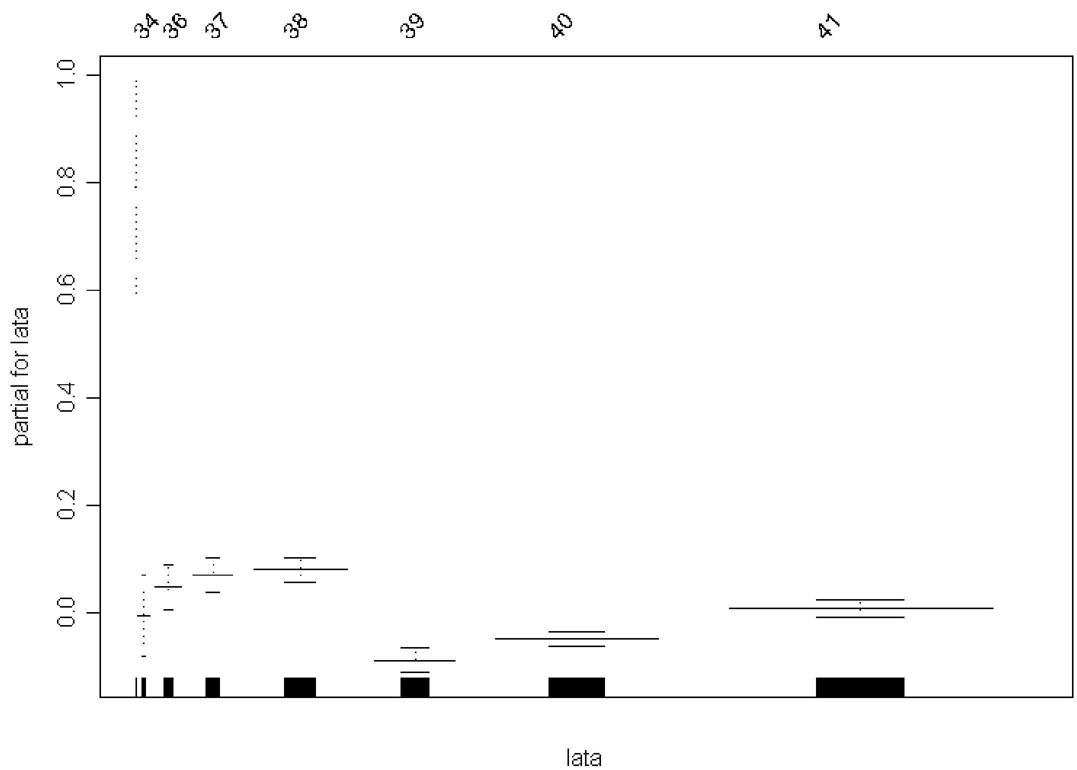
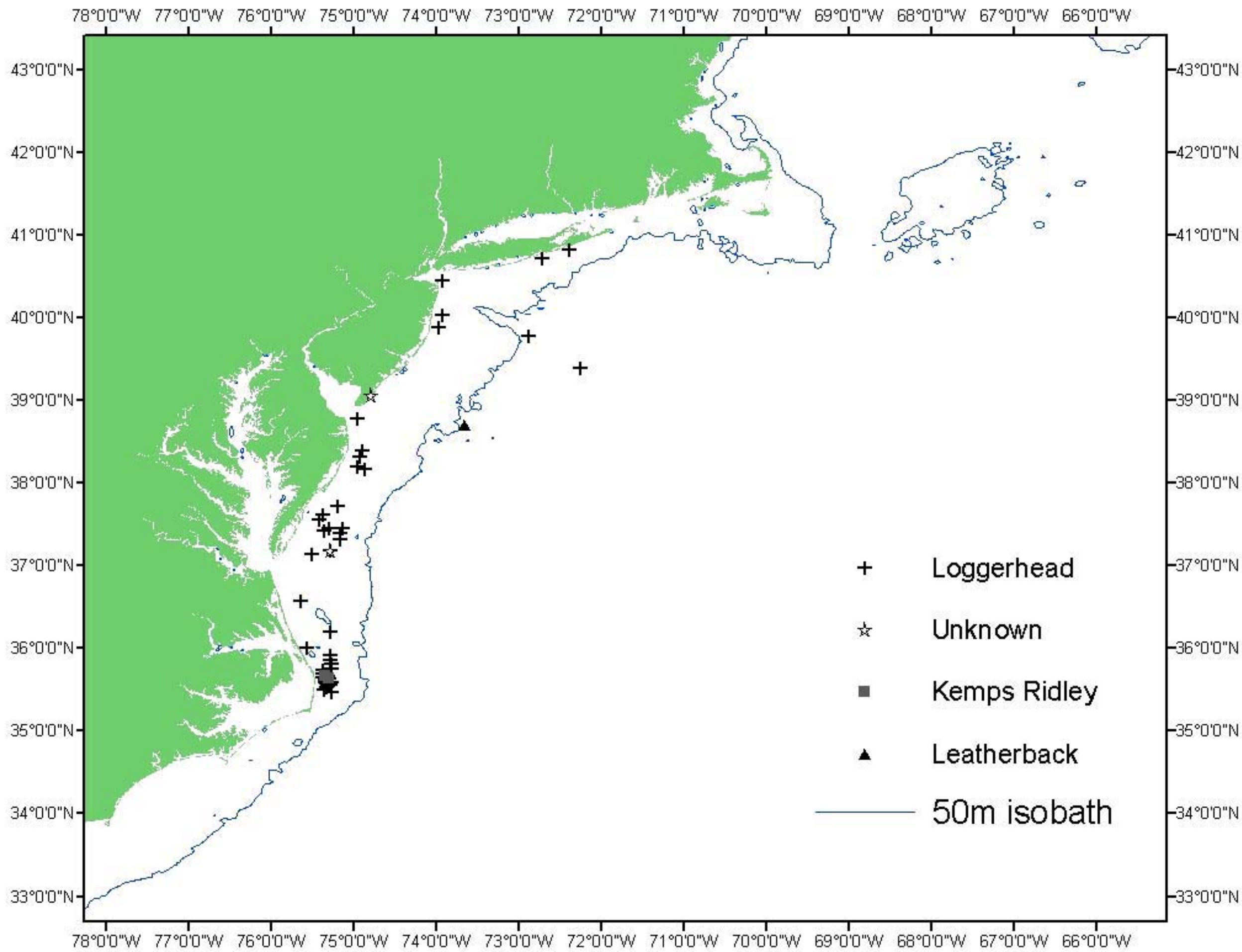


Figure 2. Distribution of observed turtle interactions by species in bottom otter trawl gear 1994-2004.



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