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Estimated Bycatch of Loggerhead Sea Turtles (*Caretta caretta*) in U.S. Mid-Atlantic Scallop Trawl Gear, 2004-2005, and in Scallop Dredge Gear, 2005

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Abstract

In the Mid-Atlantic region of the United States, fisheries observers have documented the incidental capture of loggerhead turtles (*Caretta caretta*) in both dredge and trawl gear harvesting Atlantic sea scallops (*Placopecten magellanicus*). While the annual bycatch of turtles has been estimated in the Mid-Atlantic since 2001, bycatch of turtles has not yet been estimated in the Mid-Atlantic sea scallop trawl fishery. This report provides an average annual bycatch estimate of loggerhead turtles in the Mid-Atlantic sea scallop trawl fishery during 2004 and 2005, as well as an estimate of turtle bycatch in the Mid-Atlantic scallop dredge fishery in 2005. Due to the scarcity of observed turtle bycatch in the scallop trawl and dredge fisheries during 2004 and 2005, six different estimates were derived using three different methods. These methods include ratio estimation, the application of a previously developed Generalized Additive Model (GAM) describing turtle bycatch rates in Mid-Atlantic otter trawl gear, and development of a new GAM model describing turtle bycatch rates in scallop trawl gear. The six average annual estimates of loggerhead sea turtles in Mid-Atlantic scallop trawl gear ranged from 81 to 191 turtles (CVs ranged from 0.32 to 0.50). A GAM model was used to examine bycatch rates of turtles in dredge gear in 2005. The total estimated bycatch of loggerhead turtles in dredge gear in 2005 was 0 (CV=0.19).

Introduction

In the Mid-Atlantic region of the United States, commercial fishing vessels harvesting sea scallops (*Placopecten magellanicus*) using either scallop dredges or scallop trawls occasionally capture loggerhead sea turtles (*Caretta caretta*) as incidental bycatch. From 2001-2004, an estimated several hundred loggerheads were captured between June and November in scallop dredge gear in the Mid-Atlantic region (Murray 2004, 2004a, 2005). During 1996-2004, an estimated 616 loggerheads were captured annually in otter trawl gear in the Mid-Atlantic region (Murray 2006). The latter estimate, however, was for trawl gear designed primarily to harvest fish, and did not include trawls designed to harvest scallops.

A scallop trawl is a type of otter trawl modified to catch scallops. It is basically a modified flatfish net having 5½" mesh, with additional chafing gear on the bottom of the net (NEFMC 2003). Tickler chains are sometimes used ahead of the trawl to help move scallops off the seabed (NEFMC 2003). Compared to otter trawls, scallop trawls generally have no overhang in the net, and the doors are closer to the wings of the trawl (H. Milliken, pers. comm.)[1]. No Turtle Excluder Devices (TEDs) are currently used in scallop trawl gear.

A dedicated fisheries sampling program of the scallop trawl fishery began in 2004 due to increased concerns of turtle bycatch in this fishery. While estimates of turtle bycatch in the Mid-Atlantic sea scallop dredge fishery are available from 2001 onward (Murray 2004, 2004a, 2005), no estimates have yet been available for the scallop trawl fishery. This report provides an average annual estimate of loggerhead turtle interactions in the Mid-Atlantic scallop trawl fishery during 2004 and 2005.

This report also provides an estimate of loggerhead turtle bycatch in the Mid-Atlantic sea scallop dredge fishery in 2005. The total estimated number of loggerhead bycatch in the sea scallop dredge fishery in 2004 was reported in Murray (2005). The Mid-Atlantic scallop dredge and scallop trawl fishery are defined as occurring in the region south of 42°N to 35°15'N and west of 71°W. This boundary is based mainly on the distribution of the Mid-Atlantic sea scallop stock (Hart and Chute 2004). The spatial boundaries of the Mid-Atlantic for estimating bycatch in the scallop dredge fishery in 2005 differ slightly than those used to estimate bycatch in 2003 and 2004 (see Murray 2004, 2005), which were defined in relation to the annual distribution of commercial fishing effort.

Methods

In previous analyses of turtle bycatch in scallop dredge gear during 2003 and 2004 (Murray 2004, 2005) and otter trawl gear (Murray 2006), a model describing the relationship between bycatch rates and covariates was used to estimate total bycatch in the fishery. Compared to the data used in these analyses, the number of observed bycatches in scallop dredge gear in 2005, and in scallop trawl gear in 2004 and 2005, was relatively small (see below). Describing the relationship between turtle bycatch and covariates is a challenge because many assumptions invoked as part of this modeling may

[1] Henry Milliken, 13 April 2006. Northeast Fisheries Science Center, Woods Hole, MA.

be violated by the rarity of turtle bycatch (Barry and Welsh 2002). Therefore, several methods were employed to ensure that total bycatch estimated from these few observations was robust.

Scallop Trawl

For the Mid-Atlantic scallop trawl fishery, three different methods were used to estimate the average annual bycatch of loggerhead turtles. These included: (1) use of ratio estimators, (2) use of previously published model-based bycatch rates in otter trawl gear (Murray 2006) applied to scallop trawl effort[2], and (3) use of a simple Generalized Additive Model (GAM) specific to scallop trawl bycatch.

Using data collected by observers in the Mid-Atlantic between January 2004 and December 2005, the general approach was to first calculate the bycatch rate of loggerhead turtles (defined as the number of observed turtles caught per day fished, where day fished is calculated for each haul as the tow duration in days * number of trawls). Bycatch rates were applied to commercial fishing effort (where effort is expressed as days fished, calculated as the tow duration in days * number of trawls * number of hauls) to estimate annual loggerhead bycatch. The average annual bycatch is the total bycatch estimate over the two years split between 2004 and 2005.

Scallop Dredge

Only one approach (a simple GAM) was used to estimate the bycatch in 2005 of turtles in the Mid-Atlantic scallop dredge fishery. This year was unusual in that there was no "on-watch" turtle bycatch observed in the scallop dredge fishery. On any given scallop trip, observers are on- and off-watch on an irregular schedule throughout a 24-hour period. When an observer is on-watch, he or she is collecting information on the haul location, time, environmental conditions, the catch, and details of any protected species bycatch. When an observer is off-watch, a limited amount of information is recorded for the haul by the Captain, and the observer may be notified if a turtle is captured. Only bycatch from on-watch hauls are used to calculate bycatch rates; sampling rates of off-watch events are unknown because some off-watch events may not be reported. Normally, off-watch bycatch are assumed to occur at the same rate as that derived for on-watch hauls. During 2005, no on-watch takes were observed, but 3 off-watch takes were known to occur in the scallop dredge fishery. Therefore, based on traditional protocols, no turtle bycatch occurred in scallop dredge gear during 2005 so the observed bycatch rate was zero. Furthermore, bycatch rates were not applied from previously published studies because rates in the scallop dredge fishery vary from year to year due to changes in the spatial and temporal distribution of both the fishery and the turtles themselves (Murray 2005).

Data collected by observers in the Mid-Atlantic during June-November 2003-2005 were pooled to estimate bycatch in the 2005 dredge fishery. A GAM describing the probability of a turtle bycatch per unit dredge hour fished was developed from the observer data and applied to VTR dredge trips in the Mid-Atlantic during June-November

[2] Bycatch rates in otter trawl gear may be an appropriate proxy rate to apply to scallop trawl data because estimated bycatch rates in otter trawl gear are not affected by the target species (Murray 2006). Furthermore, the model developed to predict rates in otter trawl gear included data from trawls configured like scallop trawl gear (i.e., gear designed to target flatfish), and from otter trawls that landed scallops.

2005. Turtle bycatch in the sea scallop dredge fishery is unlikely to occur outside of this time frame, based on seasonal patterns in turtle distribution in the Mid-Atlantic (Morreale 1999, Shoop and Kenney 1992). Inter-annual differences in bycatch were accounted for by including year in the model.

Data Sources

Commercial VTR Data

All federally permitted vessels operating under the Atlantic Sea Scallop Fishery Management Plan must complete a Vessel Trip Report (VTR) providing information on fishing effort and landings for each fishing trip completed. This analysis uses VTR data from vessels who reported using scallop trawl or dredge gear, and does not include VTR data from vessels who reported use of otter trawls which targeted fish but may have landed scallops. Estimates of loggerhead turtle bycatch in otter trawl gear landing scallops was subsumed in previously reported bycatch estimates of loggerheads in Mid-Atlantic otter trawl gear (see Murray 2006).

Vessels in the scallop fleet may operate under either a limited access or general category permit. There are eight different types of scallop limited access permits, corresponding to the type of gear (dredge or trawl), the size of the dredge, and whether activity is full-time, part-time, or occasional. Full-time limited access vessels can land up to 18,000 lbs of scallop meats in the managed access areas (Amendment 10 to the Atlantic Sea Scallop FMP). General category vessels, and limited access vessels that have declared out of the days-at-sea (DAS) program or that have used up their DAS allocations, can land up to 400 lbs of scallop meat per trip (Amendment 10 to the Atlantic Sea Scallop FMP).

Because completion of vessel trip reports is mandatory and trips in the sea scallop fishery are closely monitored (i.e., vessel monitoring systems are mandatory for general category and limited access scallop trawl and dredge vessels), the analysis assumes that the VTR data represent 100% of scallop trawl and dredge activity. The number of vessel trips using scallop trawls in the VTR database was compared to that in the dealer database to assess whether there may be shortcomings in the number of VTR trips (as was done for otter trawl gear in Murray 2006). Landings data from the dealer database are typically considered to be a near census of fishery harvests; however, the dealer reports do not contain any information on the fishing effort (i.e., days fished) associated with the landings purchased or sold. A preliminary examination revealed that the dealer database included only about 1/3 the number of scallop trawl trips as in the VTR database[3]. Therefore, VTR scallop trawl trips were not evaluated or adjusted with respect to scallop trawl trips in the dealer data.

[3] This may be because some VTR trips with scallop trawl gear are not reflected in the dealer database when pulling the data by gear code, because collection of gear code information was not required when an electronic data collection system began in May 2004. In addition, because otter trawl gear configured to catch fish can also catch scallops, there may be discrepancies between the VTR and dealer databases in the type of trawl reported (otter trawl versus scallop trawl) for the same trip.

VTR Scallop Trawl Data

During 2004-2005, a total of 4,433 vessel trips reported use of scallop trawl gear in the Northeast and Mid-Atlantic regions, of which 4,356 (98%) were in the Mid-Atlantic (Table 1a). Most of the Mid-Atlantic fishing trips (93%) were concentrated between latitudes 37 and 39°N (Figure 1), and roughly 90% of all scallop trawl trips fished waters 30-60m deep. While the Mid-Atlantic scallop trawl fishery occurs year-round, most of the trips (91%) during 2004-2005 occurred from May to October. Scallop trawl effort in 2004 was not considerably different than effort in 2005 (1406.31 days fished in 2004, versus 1553.53 days fished in 2005). Effective 23 July 2004 under Amendment 10 to the Atlantic Sea Scallop Fishery Management Plan (FMP), vessels were prohibited from fishing in the Elephant Trunk Closed Area (Figure 1) until 2007.

Roughly 47% of scallop trawl effort (in terms of days fished) in the Mid-Atlantic was by limited access vessels and 53% by general category vessels. Scallop trawl vessels fishing under limited access permits are generally larger than scallop trawl vessels fishing under general category permits and take longer trips. The mean gross tonnage of limited access trawl vessels in 2004-05 was 127 tons (versus 94 tons for general category vessels), and the average length of a trip was 7.5 days (versus 2 days for general category vessels). Average fishing effort per trip (i.e., the amount of time the net was in the water, expressed as days fished) was higher for limited access vessels (5 days fished versus 0.4 days fished for general category vessels). Limited access vessels operate farther offshore than general category vessels (46% of all trips by limited access vessels were in waters between 60-80m, versus 4% in this same depth zone for general category vessels).

The size and quantity of the gear are similar between the two permit groups. The mean foot rope length of trawl nets used by both groups is 54 feet. The majority of the scallop trawl fleet (73% and 75% for limited access and general category vessels, respectively) operates with two trawl nets deployed port and starboard of the vessel.

VTR Scallop Dredge Data

During 2005, a total of 18,724 vessel trips reported use of scallop dredge gear in the Northeast and Mid-Atlantic regions, of which 13,524 (72%) were in the Mid-Atlantic region (Table 1b). Roughly 85% of scallop dredge effort (in terms of dredge hours) in the Mid-Atlantic was by limited access vessels and 15% by general category vessels.

Eight trips (0.07% of Mid-Atlantic dredge hours) reported using a turtle chain mat, a grid-like configuration of chains designed to exclude turtles from entering the dredge bag[4]. Trips with chain mats were likely under-reported, because 9 dredge trips were observed in 2005 using chain mats (see Observer Coverage below). Use of turtle chain mats was voluntary in 2005. In the Mid-Atlantic region during 2005, vessels using dredges were not permitted to fish in the Elephant Trunk Closed Area (Amendment 10 to the Atlantic Sea Scallop Fishery Management Plan), and only a limited number of trips were authorized in the Hudson Canyon Access Area (Framework 16/39 to the Atlantic Sea Scallop Fishery Management Plan).

[4] On 15 August 2005, the Northeast Regional Office, Vessel Trip Reporting Office, sent a letter to Limited Access permit holders indicating a new gear code was available on VTR logs indicating use of a chain mat. See http://www.nero.noaa.gov/nero/nr/nrdoc/nrphlo5/05ScallopGearCodePHL.pdf

Observer Data

Observer Coverage

During 2004-2005, a total of 181 trips were observed in the Mid-Atlantic scallop trawl fishery, or 2.7% of total scallop trawl fishing effort in terms of days fished (Table 1a, Figure 1). Coverage was relatively higher during March and July-October compared to other months. Across both years, observers sampled 1.7% of limited access scallop trawl effort and 3.6% of general category scallop trawl effort.

In 2005, a total of 227 trips were observed in the Mid-Atlantic scallop dredge fishery, or 3.0% of total scallop dredge effort in terms of dredge hours (Table 1b, Figure 2). A total of 8044.9 dredge hours (3.0% of total effort) were observed between June and November. On 9 observed trips (412 dredge hauls or 2.4% of observed dredge hours in the Mid-Atlantic) vessels used turtle chain mats. Observers sampled 3.3% of limited access scallop dredge effort and 1.4% of general category scallop dredge effort.

Observed Turtle Bycatch in Scallop Trawl Gear

Eight loggerhead sea turtle bycatch were observed on vessels using scallop trawl gear during 2004 and 2005 (Table 2, Figure 3). Three turtles were caught on a single trip in 2004, and two turtles were caught on the same haul in 2005. Turtle bycatch occurred in June (2 turtles), July (3 turtles), and October (3 turtles). All turtles were released alive, 1 of which required resuscitation. The turtles were caught in depths between 38 and 53m, four of which were between 51 and 53m. Turtles were caught in waters between 20.8 and 25.8°C. Hauls capturing turtles were towing between 2.8 and 4.0 knots, with trawl foot rope lengths ranging from 40-76ft.

Turtle Bycatch in Scallop Dredge Gear

Two loggerhead and 1 Kemp's ridley sea turtle bycatch occurred in 2005 during off-watch hauls. The Kemp's ridley was captured near Georges Bank in August, while the 2 loggerhead turtles were caught on the same trip in the Mid-Atlantic during October. All three turtles were released alive. This was the first positively identified Kemp's ridley turtle taken in the sea scallop fishery, and the first in the Georges Bank region. In this report, an estimate is provided for loggerhead turtles in the Mid-Atlantic only, because the capture of a single Kemp's ridley turtle on Georges Bank is insufficient to develop a robust bycatch estimate for the Georges Bank region.

Sea Surface Temperature Data

Sea surface temperature (SST) data were obtained for all VTR scallop trawl and dredge trips 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[5]. Similar data were obtained for observed hauls for which SST data were missing (6% of scallop trawl hauls[6]). The climatology images are SST values averaged

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

[6] Sea surface temperature was also obtained from satellite sources on observed hauls in otter trawl gear (Murray 2006). For these data, satellite-derived SST differed from observer recorded data on average by 2.5°C (R^2=0.86).

over 1985-1999 on a 9km grid . Satellite imagery sources included AVHRR Pathfinder Version 5, Modis Aqua, Modis Terra, and GOES satellites[7]. 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.

Missing Data

Missing VTR data necessary for calculating bycatch estimates were either filled in or predicted using information from other trips. SST data could not be acquired for VTR logs missing latitude and/or longitude information (8% of scallop trawl trips, 6% of scallop dredge trips). For most of these missing values, SST was predicted using a linear regression based on statistical area fished, month, and year (R^2=0.91). Otherwise SST was filled in using the mean SST from trips with known SST in the same state, month, and year.

Missing depth data on VTR logs (5% of scallop trawl trips, 6% of scallop dredge trips[8]) were obtained using bathymetry information acquired from the National Geophysical Data Center[9]. Bottom depth was obtained using a Visual Basic for Applications routine in ArcGIS 9.1 which extracted depth values at latitude and longitude locations reported on the VTR log.

Finally, missing latitude zone information (8% of scallop trawl trips[10]) was filled in based on the statistical area in which the vessel fished.

Analytic Approach

Bycatch Rates and Total Estimated Bycatch in Scallop Trawl Gear

In this analysis, bycatch rates of turtles in scallop trawl gear were calculated using three different methods (Table 3). The first method used ratio estimation (Levy and Lemeshow 1999) to estimate, from observed turtle bycatch rates, total bycatch in the scallop trawl fishery. Estimates derived from ratio estimators were stratified four different ways, resulting in four different total bycatch estimates. The stratification

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[7] 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

[8] Bottom depth was obtained from the same bathymetry sources for VTR trips using otter trawl gear (Murray 2006). For these data, secondary depth data differed from VTR recorded depth data on average by 18m (R^2=0.68). Secondary depth data are obtained at the point location reported on the VTR log, while VTR recorded depth represents the average depth fished over the length of the trip.

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

[10] Normally, latitude zone information comes from the latitude reported on the VTR log. For trips without missing latitude (92%), latitude zone was filled in from statistical area fished to assess how well statistical area could be used to approximate latitude zone; statistical area indicated the same latitude zone as latitude fished.

schemes are based on factors previously found to be significant in affecting bycatch rates in the scallop dredge fishery in 2003 and 2004 (Murray 2004, 2005), and in Mid-Atlantic otter trawl fisheries during 1996-2004 (Murray 2006). The second approach used a model developed for predicting bycatch rates in Mid-Atlantic otter trawl gear (Murray 2006). In the third approach, a new model was developed using the observed scallop trawl data. Four covariates hypothesized to influence turtle bycatch rates from *a priori* knowledge (Murray 2006, 2005, 2004, 2004a), were explored in developing a simple model.

The 3 methods above generated a total of six different total bycatch estimates. The calculation of bycatch rates and total estimated bycatch in each of these methods is detailed below:

Ratio Estimate Method

Total bycatch estimates were obtained using ratio estimators derived using four different covariate stratification schemes (Murray 2004, 2005, 2006). The four schemes were as follows:

1) Sea surface temperature, grouped into high temperature (>=22°C) or low temperature (<22°C) categories between the months June to November [n=2 strata] (Murray 2004).
2) Depth, grouped into deep (>=70m), mid (>=54m and <70m), and shallow (<54m) categories between the months June to November [n=3 strata] (Murray 2005).
3) Latitude zone (39-41°30'N, or 34-38°59'N), depth (deep: >=50m, shallow: <50m), and sea surface temperature (hi: >18°C, low: <=18°C) from January to December [n=8 strata] (Murray 2006).
4) Depth (deep: >=50m, shallow: <50m) and sea surface temperature (hi: >18°C, low: <=18°C) from January to December [n=4 strata].

Stratification schemes 1 and 2 were based on factors previously found to be significant in affecting estimated bycatch rates in the sea scallop dredge fishery. The time period was limited to June to November when turtles and the scallop dredge fishery generally co-occur both temporally and spatially. No turtle bycatch has been observed between December and May in the sea scallop dredge fishery so for these 2 schemes the estimated bycatch during these six months was set to zero. Stratification schemes 3 and 4 were based on factors previously found to be significant in affecting turtle bycatch rates in otter trawl gear. These schemes include all months because turtle bycatch has been observed in otter trawl gear during winter months, in areas where scallop trawl activity occurs.

Total estimated turtle bycatch during 2004-2005 was calculated as the product of the observed bycatch rate in each stratum and the total number of days fished by vessels using scallop trawl gear in that stratum during 2004-2005. For each stratum, h, the bycatch rate, r, is calculated as:

$$r = \frac{\sum_{i=1}^{n_h} turtles}{\sum_{i=1}^{n_h} observed\ days\ fished} \quad (1)$$

where

n = the number of hauls in each stratum and,
days fished = tow duration (hrs)/24 * number of trawls.

In each stratum, total estimated bycatch, *b*, is then:

$$b_h = r_h (E_h) \quad (2)$$

where E_h= Total VTR days fished, calculated as:

days fished = tow duration (hrs)/24 * number of trawls * number of hauls,

with scallop trawls in stratum *h.*

Total estimated bycatch, *B*, over all strata is the sum of the stratified estimates:

$$B = \sum_{i=1}^{N} b_h \quad (3)$$

where *N* = total number of strata.

Finally, the estimated average annual bycatch, *AB*, is simply:

$$AB = B/2 \quad (4)$$

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 haul. 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.

A CV and 95% CI for the average annual bycatch aggregated over all strata was also calculated from the bootstrap replicates. Average annual bycatch was first calculated by stratum:

$$B_s^U = R_s^U E_s \quad (5)$$

where

B_s^U is the expected average annual bycatch in stratum *s* in bootstrap replicate U,

R_s^U is the bycatch rate for stratum *s* in bootstrap replicate U, and

E_s is the average annual VTR effort in stratum *s*.

The average annual bycatch for bootstrap replicate U, B^U , is then given by:

$$B^U = \sum_s B_s^U \qquad (6)$$

The CV and 95 % C.I. of the average annual bycatch estimate was computed for B^U .

Application of Rates from Otter Trawl Model

In a previous analysis of turtle bycatch rates in Mid-Atlantic otter trawl gear during 1996-2004 (Murray 2006), a Generalized Additive Model (GAM) was used to derive bycatch rates as a function of latitude zone, sea surface temperature, depth, and use of a working Turtle Excluder Device (TED). The general form of a Generalized Additive Model (GAM) can be written as:

$$Y = \alpha + \sum_{j=1}^{n} f_j(X_j) + \xi \qquad (7)$$

where Y is the dependent variable (log transformed turtle bycatch per day fished), f_j are a series of smoothing functions, and X_j are predictor variables describing environmental or fishing characteristics (Hastie and Tibshirani 1990).

Predicted bycatch rates in the otter trawl model were stratified by the combination of latitude zone, sea surface temperature, depth, and use of a working TED. For estimating bycatch in scallop trawl gear, the predicted otter trawl bycatch rates were applied to sea scallop trawl effort stratified in the identical latitude, depth and SST combinations. Bycatch rates of otter trawls using working TEDs were not applied to the scallop trawl effort data because scallop trawl vessels are not required to use TEDs.

The total estimated turtle bycatch during 2004-2005 was then calculated by multiplying the model-predicted bycatch rate in each stratum by the total amount of scallop trawl effort (in days fished) in that stratum during 2004-2005:

$$b_h = mr_h(E_h) \qquad (8)$$

where mr_h= model predicted bycatch rate of turtles in otter trawl gear in stratum *h*, and
E_h = Total days fished by scallop trawl gear in stratum *h* (derived from VTR data).

Total estimated bycatch was the sum of the stratified bycatch estimates, and the estimated average annual bycatch was the total divided by 2 (equations 3, 4).

A CV and 95% CI for the average annual bycatch aggregated over all strata was calculated from stratum-specific bootstrap replicates calculated from the original otter trawl model, applied to average annual VTR scallop trawl effort (equations 5,6).

Scallop Trawl Model

A Poisson regression (GAM function, SPLUS 7.0) was used to model the expected turtle bycatch per day fished as a function of environmental and fishing variables. These variables were: sea surface temperature, depth, latitude, permit plan (general category or limited access), and an interaction between latitude and sea surface temperature (Table 4). A forward stepwise selection algorithm (STEP.GAM function, SPLUS 7.0) selected those variables that generated the greatest change in the Akaike Information Criterion (AIC) value relative to all the other variables in the model. From a series of candidate models, the model with the lowest AIC is considered to be the best fit (Burnham and Anderson, 2002). Continuous variables (depth, water temperature, and latitude) were considered as smooth terms in the model using the default degrees of freedom in the fitting procedure. After examining smooth curves for each covariate, SST appeared to have a more linear relationship with bycatch rates compared to the other covariates, so SST was also considered as a linear term.

The final model using the observer data was fit to the VTR data to derive an estimated number of turtle takes per VTR trip. Total estimated bycatch was then the sum of estimated takes over all VTR trips, and the average annual bycatch was the total divided by 2.

A CV and 95% CI for the average annual bycatch was estimated by bootstrap resampling. The resampling unit was a haul. Bootstrap replicates were generated by sampling with replacement 1000 times from the original dataset, and then the selected model was fit to each replicate. Total estimated bycatch was then predicted by applying each replicate dataset to VTR data. A CV and 95% CI were calculated from the replicate bycatch estimates.

Bycatch Rates and Total Estimated Bycatch in Scallop Dredge Gear

A GAM model assuming a Poisson distribution was used to examine the relationship between bycatch rates of turtles in scallop dredge gear (defined as turtle bycatch per dredge hour) and environmental and gear factors. Because the observed number of turtles for 2005 was 0 (counting only on-watch takes), years 2003-2005 were pooled to estimate bycatch in 2005. Year was retained in the model to explain a year effect. Although the number of bycatch events over all years in dredge gear ranged from 0 to 1, a Poisson distribution was used because the probability of more than 1 turtle being captured at once in dredge gear is possible[11].

Explanatory variables in the model included sea surface temperature, depth, latitude, year, use of a chain mat, and an interaction between water temperature and latitude (Table 5). A forward stepwise selection algorithm (STEP.GAM function, SPLUS 7.0) selected those variables that generated the greatest change in the Akaike Information Criterion (AIC) value relative to all variables in the model. Continuous variables (depth, sea surface temperature, and latitude) were considered as smooth terms

[11] A model assuming a binomial distribution was also investigated and the parameter coefficients of the Poisson model and binomial model differed very little.

in the model using the default degrees of freedom in the fitting procedure. SST was also considered as a linear term.

The final model from the observer data was fit to VTR scallop dredge data in 2005 to estimate the expected number of turtles per VTR trip in 2005. Total estimated bycatch was then the sum of estimated takes over all VTR trips.

A CV and 95% CI for the bycatch estimate in 2005 were estimated by bootstrap resampling. The resampling unit was a haul. Bootstrap replicates were generated by sampling with replacement 1000 times from the original dataset, and then the selected model was fit to each replicate. Total estimated bycatch was then predicted by applying each replicate dataset to 2005 VTR data. A CV and 95% CI were calculated from the replicate bycatch estimates.

Results

Total Estimated Bycatch in Scallop Trawl Gear

The six average annual estimates of loggerhead sea turtle bycatch in the Mid-Atlantic sea scallop trawl fishery during 2004-2005 range between 81 and 191 turtles (Table 6). Applying model-derived bycatch rates in otter trawl gear to scallop trawl gear resulted in the largest estimate, while a ratio estimate stratified by depth resulted in the smallest estimate. Results from each of the methods are described below:

Ratio Estimates

Average annual estimates of loggerhead sea turtle bycatch derived using ratio estimators range from 81 (CV=0.39, 95% CI: 20-149) to 141 animals (CV=0.46, 95% CI: 34-292) (Tables 7a-d). All four point estimates are within the 95% confidence interval of the ratio estimate with the smallest CV (Table 6).

Application of the Otter Trawl Model

The average annual estimate of loggerhead sea turtle bycatch calculated by applying turtle bycatch rates in otter trawl gear is 191 turtles (CV=0.32, 95% CI: 90-320) (Table 8). Previously estimated otter trawl rates were highest in the southern Mid-Atlantic (34-38°59'N), in depths less than 50m, in warm (>18ºC) water. This stratum accounts for 86% of the total estimated turtle bycatch in scallop trawl gear.

Scallop Trawl Model

Sea surface temperature (fit with a smoothing spline) had the largest effect on estimated loggerhead bycatch rates in the scallop trawl fishery (Table 9). Sea surface temperature was the only variable that had a lower AIC than the null model, and reduced the total deviance by 19% (Pseudo R^2=1-57.67/71.38=0.192). The effect of SST on the bycatch rate was less pronounced at temperatures below roughly 20°C, though there was also a high degree of uncertainty in the data at lower temperatures (Figure 4).

Fitting this model to VTR effort over 2004 and 2005 resulted in an average annual bycatch estimate in Mid-Atlantic scallop trawl gear of 134 turtles (CV=0.45, 95% CI: 37-257) (Table 6).

Total Estimated Bycatch in Scallop Dredge Gear

Sea surface temperature (fit as a smoothing spline), depth, and year had the largest effect on estimated loggerhead bycatch rates in the scallop dredge fishery during 2003-2005 (Table 10), and reduced the total deviance by 20% (Pseudo R^2=1-301.24/378.71=0.18). Turtle bycatch rates in the dredge fishery during 2003-2005 were lower at temperatures below roughly 20°C, and at depths shallower than 45m and deeper than 60m (Figure 5). Fitting this model to VTR dredge effort in the Mid-Atlantic from June to November 2005 resulted in a total bycatch estimate of 0.00014 turtles (CV=0.19).

Discussion

Total Estimated Bycatch in Scallop Trawl Gear

Estimating total bycatch employing a variety of methods and stratification schemes demonstrates that point estimates will differ depending on the analytical approach. With so few observed turtle bycatches in the scallop trawl fishery during 2004-2005, it is difficult to conduct a rigorous statistical evaluation of each approach to select a preferred model. The range of estimates presented here, from 81 to 191 turtles, is within the confidence intervals for almost all of the estimates. Without strong evidence to select or eliminate a particular model, all 6 estimates are equally valid. The midpoint of the range of all six estimates is 136 turtles, which is a reasonable point estimate of the average annual bycatch of loggerhead sea turtles in the Mid-Atlantic scallop trawl fishery during 2004-2005.

The methods used here to estimate total bycatch in the scallop trawl fishery do not address the clustered nature of the observed bycatch. In this analysis 3 turtle bycatches occurred on 1 trip and 2 occurred on a single haul. Hauls within a trip may be more closely related to each other than to hauls in other trips because they are typically close together in time and space. Moreover, some trips may have more probability relative to others of interacting with a turtle for reasons not examined here. Failure to account for the possible lack of independence among observations may place undue emphasis on the effect of a variable on the response (Keitt et al. 2002). The methods used here also do not address the large number of zeros in the data being modeled. “Zero-inflated” data typically require specialized methods for statistical analysis (Cunningham and Lindenmayer 2005). If more data are available in the future other techniques to model an extremely rare event within hierarchical data should be considered (McCracken 2004).

With rare events like turtle bycatch, however, data are almost always scarce. This analysis demonstrates that with limited data total bycatch estimates calculated from ratio estimators are not orders of magnitude different than those calculated from simple GAM models, and vice versa. Thus, there may be flexibility in choosing a particular method for future bycatch analyses, though reasons for turtle bycatch occurring on a particular haul or trip need to be closely examined.

The challenge in using ratio estimators for future bycatch analyses is choosing how to stratify the data. Bycatch rates in a fishery are influenced by a myriad of dynamic conditions in any given year, including the abundance and distribution of turtles, environmental conditions, and the distribution of fishing effort. Groupings created for

explanatory variables such as SST and depth are not likely to be consistent across years or fisheries. For example, in 2001-2002 a higher probability of turtle bycatch in scallop dredge gear occurred in 2 areas of the Mid-Atlantic after waters warmed to 19°C, and in 2003, higher probabilities occurred over the whole Mid-Atlantic after waters warmed to 22°C.

Categories created to characterize bycatch rates in scallop dredge and otter trawl fisheries in previous years may not necessarily be the best for the scallop trawl fishery during 2004-2005. For instance, bycatch rates in otter trawl gear differed significantly between depths shallower and deeper than 50m (Murray 2006). All of the bycatch in the scallop trawl fishery occurred between 38 and 53m, half of which were between 51 and 53m. Dividing depth at 50m leads to separate bycatch rates at 51m and at 49m for estimating bycatch in the scallop trawl fishery. The choice of where to cut an explanatory variable will affect the bycatch rate and total estimated bycatch.

Fitting a GAM with continuous (versus categorical) covariates avoids the need to stratify bycatch rates into discrete categories which may fluctuate interannually. If data are too limited to fit complex models to the data, different stratification schemes should be carefully considered if a ratio estimator approach is used. As was done in this analysis, *a priori* knowledge of factors influencing the bycatch rates of turtles can be used to guide the choice of stratification schemes.

In this analysis CVs are calculated with a bootstrap procedure in which the resampling unit is the haul. Thus, the same sampling unit used for calculating bycatch rates is also used to bootstrap the rates. In other analyses of bycatch (Bravington and Bisack, 1996) the bootstrap resampling unit was the trip to ensure any within trip dependence in the original data was carried over into the bootstrap estimates. To compare approaches, CVs were calculated two different ways for one of the ratio estimates. Aggregate CVs when resampling by haul or by trip did not differ appreciably (CV=0.44 when resampling by haul versus CV = 0.47 when resampling by trip).

Total Estimated Bycatch in Scallop Dredge Gear

The small effect of SST and depth, coupled with the lack of observed bycatch events in 2005 over a large number of hauls, caused the expected number of turtles per VTR trip in 2005 to be very low. Although 3 off-watch takes occurred in the dredge fishery in 2005, there are insufficient data and surety associated with off-watch events (i.e., associated effort characteristics are lacking, and sampling rates are unknown) to allow these events to be used in the estimation of total turtle bycatch in the fishery. Therefore, based on traditional sampling protocols that only on-watch takes be used in a bycatch analysis, the total estimate of bycatch in 2005 is zero.

It is possible that more turtle interactions in dredge gear may have occurred in 2005 but were not observed. The distribution of commercial scallop dredge effort and observer coverage in 2005 does not explain the lack of observed turtle bycatch. Compared to 2003 and 2004, the distribution of commercial scallop dredge effort in 2005 was not concentrated in colder temperatures or deeper waters, times and areas where estimated turtle bycatch rates have historically been lower (Murray 2004a, 2005) (see text table below).

Percent VTR Scallop Dredge Hours by Sea Surface Temperature and Depth Strata in 2003-2005 Mid-Atlantic Sea Scallop Dredge Fishery				
SST/Depth Strata	Definition	2003	2004	2005
Hi Temp/Deep Depth	>=22°C, >=70m	0.3%	4.5%	0.5%
Hi Temp/Medium Depth	>=22°C, >=54m and <70m	14.9%	17.2%	13.7%
Hi Temp/Shallow Depth	>=22°C, <54m	24.8%	14.7%	15.3%
Low Temp/Deep Depth	<22°C, >=70m	0.8%	4.6%	1.9%
Low Temp/Medium Depth	<22°C, >=54m and <70m	27.5%	32.7%	33.7%
Low Temp/Shallow Depth	<22°C, <54m	31.7%	26.4%	34.9%

Also, there were equivalent levels of coverage in most temperature and depth strata in 2005 compared to previous years (see text table below).

Percent Observer coverage (Observed Dredge Hours/VTR Dredge Hours *100) by Sea Surface Temperature and Depth Strata in 2003-2005 Mid-Atlantic Sea Scallop Dredge Fishery				
SST/Depth Strata	Definition	2003	2004	2005
Hi Temp/Deep Depth	>=22°C, >=70m	0.4%	7.7%	18.4%
Hi Temp/Medium Depth	>=22°C, >=54m and <70m	4.0%	6.9%	6.2%
Hi Temp/Shallow Depth	>=22°C, <54m	2.4%	4.9%	3.5%
Low Temp/Deep Depth	<22°C, >=70m	2.1%	5.9%	4.2%
Low Temp/Medium Depth	<22°C, >=54m and <70m	2.8%	3.9%	2.5%
Low Temp/Shallow Depth	<22°C, <54m	2.3%	3.6%	1.3%

Factors influencing estimated bycatch rates of turtles in scallop dredge gear in the Mid-Atlantic fluctuate from year to year (Murray 2004a, 2005), as does the total estimated bycatch. There is no evidence from this analysis to suggest that the estimate in 2005 is a good predictor of bycatch in subsequent years. A longer-term view of loggerhead bycatch, such as an average over multiple years, may be more appropriate when considering bycatch of turtles in the Mid-Atlantic scallop dredge fishery.

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Table 1a. Observed and commercial (VTR) effort in Mid-Atlantic scallop trawl gear 2004-2005. Days fished reflects the amount of time the gear is in the water.

Month	Observed Days Fished	Observed Trips	Observed Hauls	VTR Days Fished	VTR Trips	VTR Hauls	% Coverage (Observed days fished/ VTR days fished)*100
January	0.29	4	10	41.03	27	534	0.7%
February	0.25	2	7	27.41	25	296	0.9%
March	7.98	3	100	70.85	46	589	11.3%
April	0.09	1	3	143.41	86	1,347	0.1%
May	3.03	8	21	433.65	414	3,886	0.7%
June	3.83	13	36	418.58	700	4,661	0.9%
July	11.26	34	117	463.63	847	5,167	2.4%
August	18.46	53	192	483.76	955	4,807	3.8%
September	10.60	25	117	326.21	626	3,616	3.2%
October	15.87	26	152	286.93	402	2,681	5.5%
November	7.97	11	73	200.82	163	1,719	4.0%
December	0.34	1	2	63.56	65	592	0.5%
Total	**79.97**	**181**	**830**	**2,959.84**	**4,356**	**29,895**	**2.7%**

Table 1b. Observed and commercial (VTR) effort in Mid-Atlantic scallop dredge gear, 2005.

Month	Observed Dredge Hours	Observed Trips	Observed Hauls	VTR Dredge Hours	VTR Trips	VTR Hauls	% Coverage (Observed dredge hours/VTR dredge hours)*100
January	1,236.3	11	551	14,789.6	298	9,231	8.4%
February	1,459.3	18	682	32,414.9	490	18,942	4.5%
March	2,032.6	13	914	50,705.1	776	28,689	4.0%
April	1,546.4	11	706	71,483.6	916	42,262	2.2%
May	2,275.2	24	1083	93,806.3	1,423	55,287	2.4%
June	1,283.4	14	756	94,134.1	1,671	59,364	1.4%
July	1,625.8	32	865	56,002.4	1,468	38,526	2.9%
August	1,606.6	24	848	39,163.6	1,721	31,193	4.1%
September	1,529.7	27	851	35,675.9	1,569	27,599	4.3%
October	1,405.3	26	684	32,299.6	1,222	22,535	4.4%
November	594.1	16	258	25,497.3	1,142	16,993	2.3%
December	307.5	11	167	19,951.1	828	13,651	1.5%
Total	**16,902.2**	**227**	**8,365**	**565,923.6**	**13,524**	**364,272**	**3.0%**

Table 2. Loggerhead turtle bycatch in scallop trawl gear 2004-2005. For permit plan, "LA" stands for Limited Access, and "GC" stands for General Category.

Trip	Number of turtles	Year	Month	Statistical Area	SST (ºC)	Depth (m)	Towspeed (k)	Foot rope length (ft)	Permit Plan	Gross tonnage of vessel	Animal Condition
A	1	2004	Oct	621	22.2	38.4	4.0	65	LA	121	Alive
A	1	2004	Oct	621	23.7	38.4	4.0	65	LA	121	Alive
A	1	2004	Oct	621	22.0	43.9	4.0	65	LA	121	Alive
B	2	2005	Jun	626	20.8	51.2	2.8	76	GC	117	Alive
C	1	2005	Jul	626	22.5	51.2	3.0	55	GC	41	Alive
D	1	2005	Jul	626	22.2	53.0	3.3	40	GC	111	Alive
E	1	2005	Jul	621	25.8	45.7	3.4	42	GC	133	Resuscitated

Table 3. Overview of analytic approaches used to estimate sea turtle bycatch in the scallop trawl and dredge fisheries.

Analytic Approach	Scallop Trawl	Scallop Dredge
Ratio estimators with stratification based on previous analysis.	Model 1. Stratified from analysis of 2003 scallop dredge data SST (>=22ºC or <22ºC) from June through November [n=2 strata] (Murray 2004). Model 2. Stratified from analysis of 2004 scallop dredge data Depth (>=70m, >=54m and <70m, <54m) from June through November [n=3 strata] (Murray 2005). Model 3. Stratified from analysis of 1994-2004 trawl data Latitude zone (39-41°30'N, or 34-38°59'N), depth (>=50m, <50m), and SST (>18°C, <=18°C) from January through December [n=8 strata] (Murray 2006). Model 4. Same as Model 3 but no latitude Depth (>=50m, <50m) and SST (>18°C, <=18°C) from January through December [n=4 strata] (Murray 2006).	n/a
Apply proxy bycatch rates to scallop trawl commercial effort.	Model 5. Apply bycatch rates from 1994-2004 otter trawl data Rates stratified by latitude zone (39-41°30'N, or 34-38°59'N), depth (deep: >=50m, shallow: <50m), and SST (hi: >18°C, low: <=18°C) from January to December [n=8 strata] (Murray 2006).	n/a
Build simple GAM.	Model 6. Build and select GAM from a few covariates	Model 7. Build and select GAM from a few covariates.

Table 4. Variables examined in an analysis of factors affecting loggerhead sea turtle bycatch in Mid-Atlantic scallop trawl gear. The 99% range of observed days fished and VTR days fished are shown for continuous variables, and percentage of each for categorical variables.

Variable	Definition	Observed Days Fished	VTR Days Fished
Latitude	Latitude point (in decimal degrees)	37.35°N- 40.78°N	35.33°N-40.83°N
Depth	Bottom depth (m)	18-41m	4-71m
SST	Sea surface temperature (C)	2.8-28.1°C	2.9-32.4°C
Permit Plan	General Category or Limited Access	GC: 69.3% LA: 30.7%	GC: 52.4% LA: 47.6%
SST*Latitude			

Table 5. Variables examined in an analysis of factors affecting loggerhead sea turtle bycatch in Mid-Atlantic scallop dredge gear June to November 2003-2005. A model developed from observer data over years 2003-2005 is fit to VTR effort in 2005. The 99% range of observed days fished and VTR days fished are shown for continuous variables, and percentage of each for categorical variables.

Variable	Definition	Observed Dredge Hours 2003-2005	VTR Dredge Hours 2005
Latitude	Latitude point (in decimal degrees)	37.2°N-41.06°N	35.08°N-41.39°N
Depth	Bottom depth (m)	3.6-99m	3.6-150m
SST	Sea surface temperature (C)	8.1-27.2°C	9.5-28.5°C
Year	2003 2004 2005	2003: 29.5% 2004: 48.3% 2005: 22.2%	2003: NA 2004: NA 2005: 100.0%
Chain Mat[+]	Use of a Turtle Excluder Chain Mat	Yes: 2.5% No: 97.5%	Yes: 0.07% No: 99.93%
SST*Latitude			

[+]There were no observed dredge hours with chain mats in 2003.

Table 6. Summary of average annual estimates of loggerhead sea turtles in Mid-Atlantic scallop trawl gear over 2004-2005 using 3 different methods.

Method		Average Annual Estimate	C.V.	95% C.I.
Ratio Estimate	Stratification scheme 1: SST Strata	125	0.50	35-265
	Stratification scheme 2: Depth Strata	81	0.39	20-149
	Stratification scheme 3: Latitude, Depth, SST Strata	120	0.44	38-237
	Stratification scheme 4: Depth and SST Strata	141	0.46	34-292
Otter Trawl Model		191	0.32	90-320
Scallop Trawl Model		134	0.45	37-257

Table 7a. Ratio estimate of loggerhead turtle bycatch from June-November 2004-2005 in the Mid-Atlantic scallop trawl fishery. Bycatch rates are stratified by sea surface temperature.

SST Strata	Observed Days Fished	Observed Hauls	Observed Turtles	VTR Days Fished	VTR Hauls	% Coverage (obs days fished/ VTR days fished)	Observed Bycatch Rate	Total Estimated Bycatch 2004-2005	Average Estimate per Year (Total/2)	C.V. (C.I.)
>=22°C	49.2	499	6	1170.3	12,372	4.2%	0.1219	143		
<22°C	18.8	188	2	1009.6	10,279	1.9%	0.1064	107		
Total	**68.0**	**687**	**8**	**2179.9**	**22,651**	**3.1%**		**250**	**125**	**0.50 (35-265)**

Table 7b. Ratio estimate of loggerhead turtle bycatch from June-November 2004-2005 in the Mid-Atlantic scallop trawl fishery. Bycatch rates are stratified by depth.

Depth Strata	Observed Days Fished	Observed Hauls	Observed Turtles	VTR Days Fished	VTR Hauls	% Coverage (obs days fished/ VTR days fished)	Observed Bycatch Rate	Total Estimated Bycatch 2004-2005	Average Estimate per Year (Total/2)	C.V. (C.I.)
>=70m	0.8	9	0	152.1	1,172	0.5%	0	0		
>=54m and <70m	14.8	121	0	968.2	9,214	1.5%	0	0		
<54m	52.4	557	8	1059.6	12,265	5.0%	0.1527	162		
Total	**68.0**	**687**	**8**	**2179.9**	**22,651**	**3.1%**		**162**	**81**	**0.39 (20-149)**

Table 7c. Ratio estimate of loggerhead turtle bycatch from January-December 2004-2005 in the Mid-Atlantic scallop trawl fishery. Bycatch rates are stratified by latitude zone, sea surface temperature, and depth.

Latitude	Depth	SST	Observed Days Fished	Observed Hauls	Observed Turtles	VTR Days Fished	VTR Hauls	% Coverage (obs days fished/ VTR days fished)	Observed Bycatch Rate	Total Estimated Bycatch 2004-2005	Average Estimate per Year (Total/2)	C.V. (C.I.)
North	>=50m	>18°C	0	0	0	216.7	1,995	0%	0	0		
		<=18°C	4.67	45	0	142.9	1,526	3.3%	0	0		
	<50m	>18°C	0.65	3	0	26.4	488	2.5%	0	0		
		<=18°C	2.42	55	0	59.4	867	4.1%	0	0		
South	>=50m	>18°C	21.45	200	4	869.9	8,518	2.5%	0.1865	162		
		<=18°C	12.56	127	0	704.9	6,192	1.8%	0	0		
	<50m	>18°C	35.69	381	4	685.8	7,784	5.2%	0.1121	77		
		<=18°C	2.53	19	0	253.9	2,525	1.0%	0	0		
Total			**79.9**	**830**	**8**	**2959.9**	**29,895**	**2.7%**		**239**	**120**	**0.44 (38-237)**

Table 7d. Ratio estimate of loggerhead turtle bycatch from January-December 2004-2005 in the Mid-Atlantic scallop trawl fishery. Bycatch rates are stratified by sea surface temperature, and depth.

Depth	SST	Observed Days Fished	Observed Hauls	Observed Turtles	VTR Days Fished	VTR Hauls	% Coverage (obs days fished/ VTR days fished)	Observed Bycatch Rate	Total Estimated Bycatch 2004-2005	Average Estimate per Year (Total/2)	C.V. (C.I.)
>=50m	>18°C	21.5	200	4	1086.5	10,513	2.0%	0.1865	203		
	<=18°C	17.2	172	0	847.9	7,718	2.0%	0	0		
<50m	>18°C	36.3	384	4	712.2	8,272	5.1%	0.1101	78		
	<=18°C	4.9	74	0	313.3	3,392	1.6%	0	0		
Total		**79.9**	**830**	**8**	**2959.9**	**29,895**	**2.7%**		**281**	**141**	**0.46 (34-292)**

Table 8. Model-based estimate of loggerhead turtle bycatch from January-December 2004-2005 in the Mid-Atlantic scallop trawl fishery. Predicted bycatch rates are from observed hauls in the Mid-Atlantic using otter trawl gear without working TEDs (from Murray 2006).

Latitude	Depth	SST	Predicted turtles/days fished in otter trawl gear without working TEDs	VTR Scallop Trawl Days Fished	Total Estimated Bycatch Scallop Trawl Gear 2004-2005	Average Estimate per Year (Total/2)	C.V. (C.I.)
North	>=50m	>18°C	0.0007	216.7	0		
		<=18°C	0.0002	142.9	0		
	<50m	>18°C	0.0282	26.4	1		
		<=18°C	0.0086	59.4	1		
South	>=50m	>18°C	0.0119	869.9	10		
		<=18°C	0.0036	704.9	3		
	<50m	>18°C	0.4813	685.8	330		
		<=18°C	0.1474	253.9	37		
Total				**2959.9**	**382**	**191**	**0.32 (90-320)**

Table 9. AIC values from step-wise model selection to describe loggerhead turtle bycatch rates in Mid-Atlantic scallop trawl gear. SST and depth variables are fit non-parametrically with a smoothing spline (s), and SST was also fit as a linear term.

Model	**AIC**
Null model only	73.38
Null + s(SST)	67.41
Null + s(depth)	73.85
Null + s(latitude)	70.15
Null + permit plan	75.21
Null + SST*latitude	73.89
Null + SST	73.91
Null + s(SST) + s(depth)	71.37
Null + s(SST) + s(latitude)	71.28
Null + s(SST) + permit plan	68.97

Final model selected: loggerhead ~ s(SST) + offset(log(dysfish))

Null model deviance: 71.38
Residual deviance of final model: 57.67
Residual degrees of freedom of final model: 825.13

Table 10. AIC values from step-wise model selection to describe loggerhead turtle bycatch rates in Mid-Atlantic scallop dredge gear. SST and depth variables are fit non-parametrically with a smoothing spline(s).

Model	**AIC**
Null model only	380.71
Null model + Year	354.10
Null model + Year + SST	337.63
Null model + Year + SST + s(depth)	327.06
Null model + Year + s(SST) + s(depth)	322.78
Null model + Year + s(SST) + s(depth) + s(latitude)	450.53
Null model + Year + s(SST) + s(depth) + chain mat	324.33
Null model + Year + s(depth) + SST*latitude	449.75

Final model selected: loggerhead ~ Year + s(SST) + s(depth) + offset(log(dysfish))

Null model deviance: 378.71
Residual deviance of final model: 301.24
Residual degrees of freedom of final model: 17824.23

Figure 1. Observed and VTR trips using scallop trawl gear during 2004 and 2005.

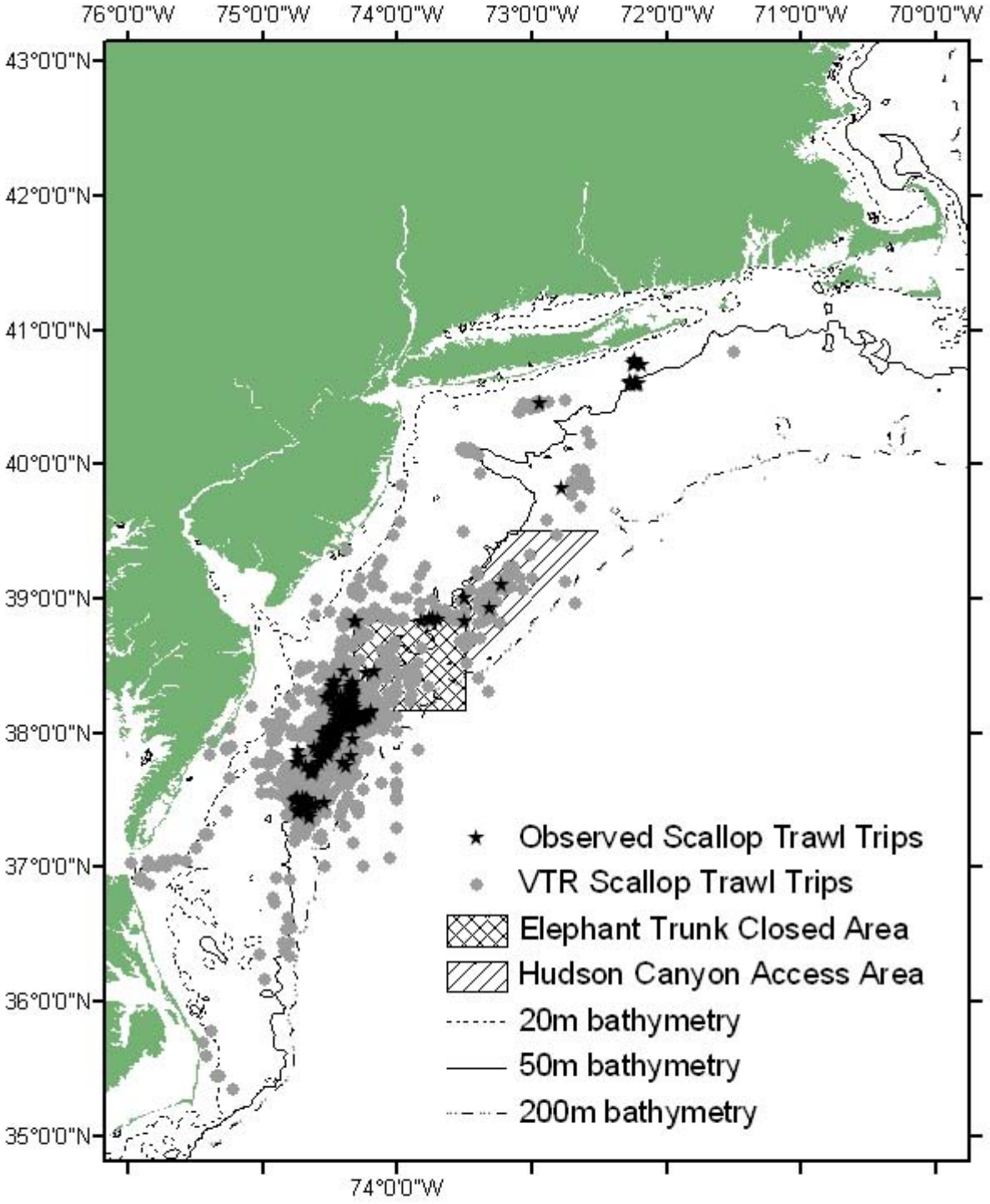


Figure 2. Observed and VTR trips using scallop dredge gear during June to November 2005.

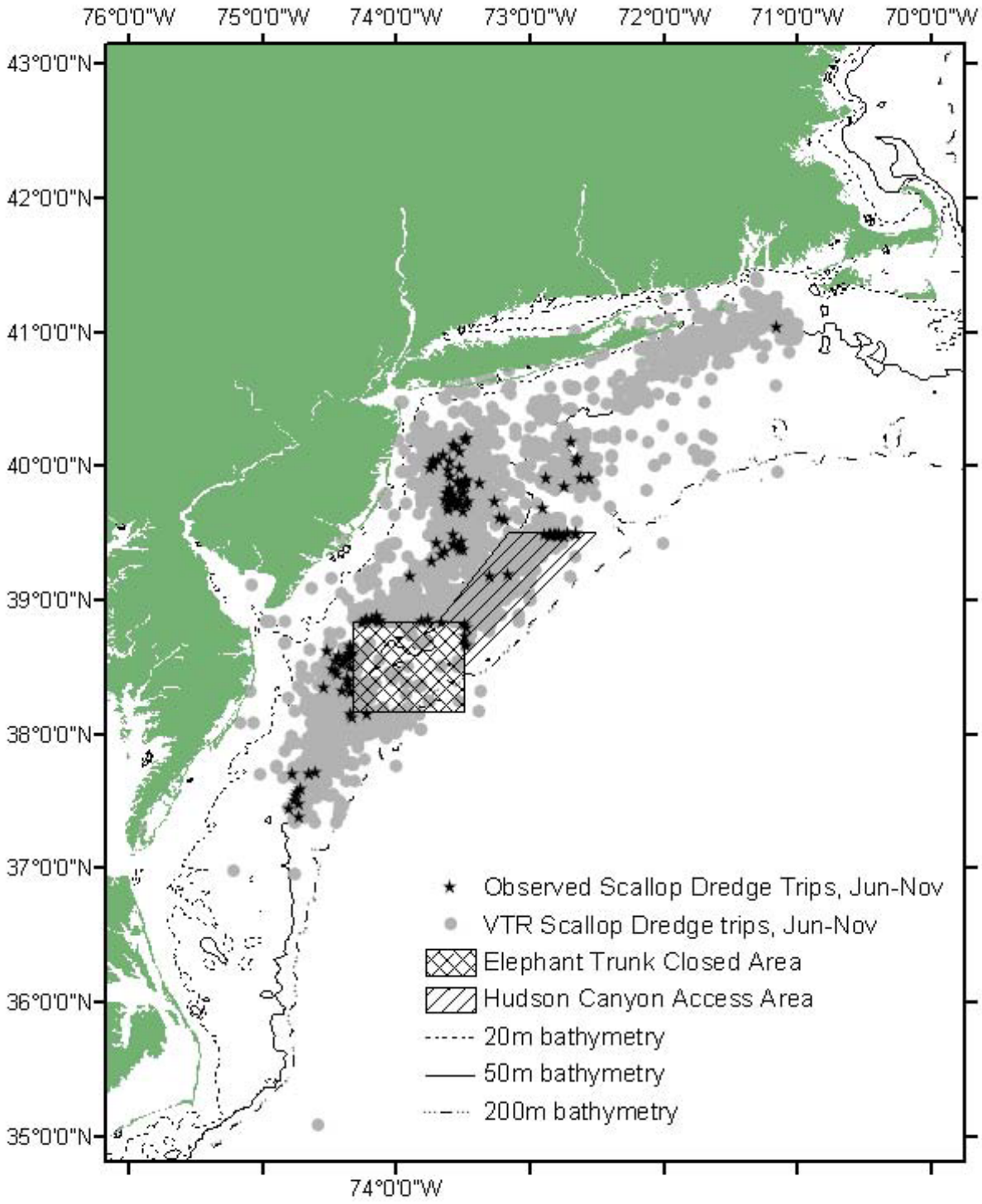


Figure 3. Loggerhead sea turtle bycatch in scallop trawl gear during 2004-2005.

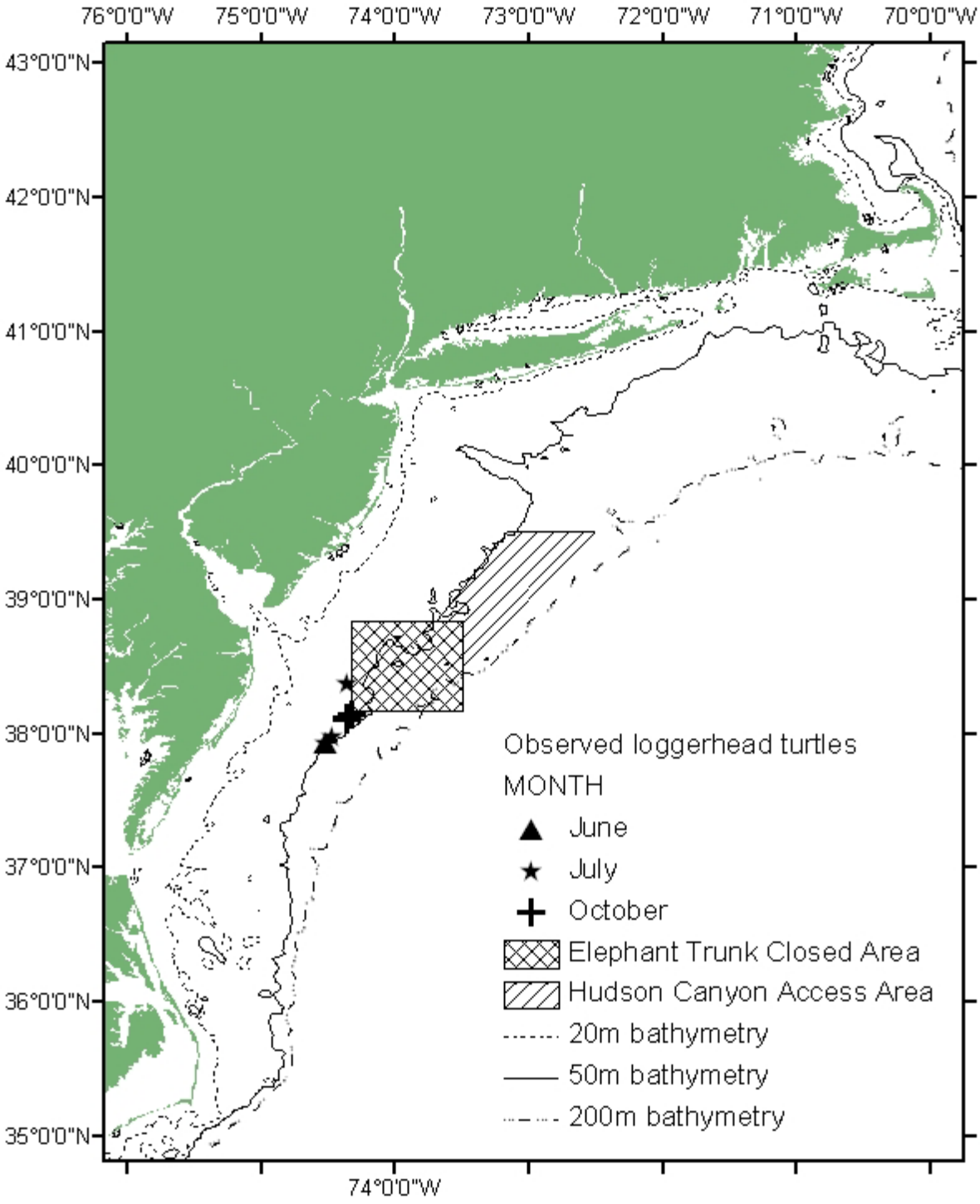


Figure 4. Partial fit for the general additive model (GAM) of loggerhead sea turtle bycatch rates in scallop trawl gear, with sea surface temperature as a covariate. The y-axis represents the effect of SST on the bycatch rate, with lower rates indicated where the curve is below zero. The rug-plot on the x-axis represents the number of observations, and dashed lines are the +/- 2 SE confidence bands.

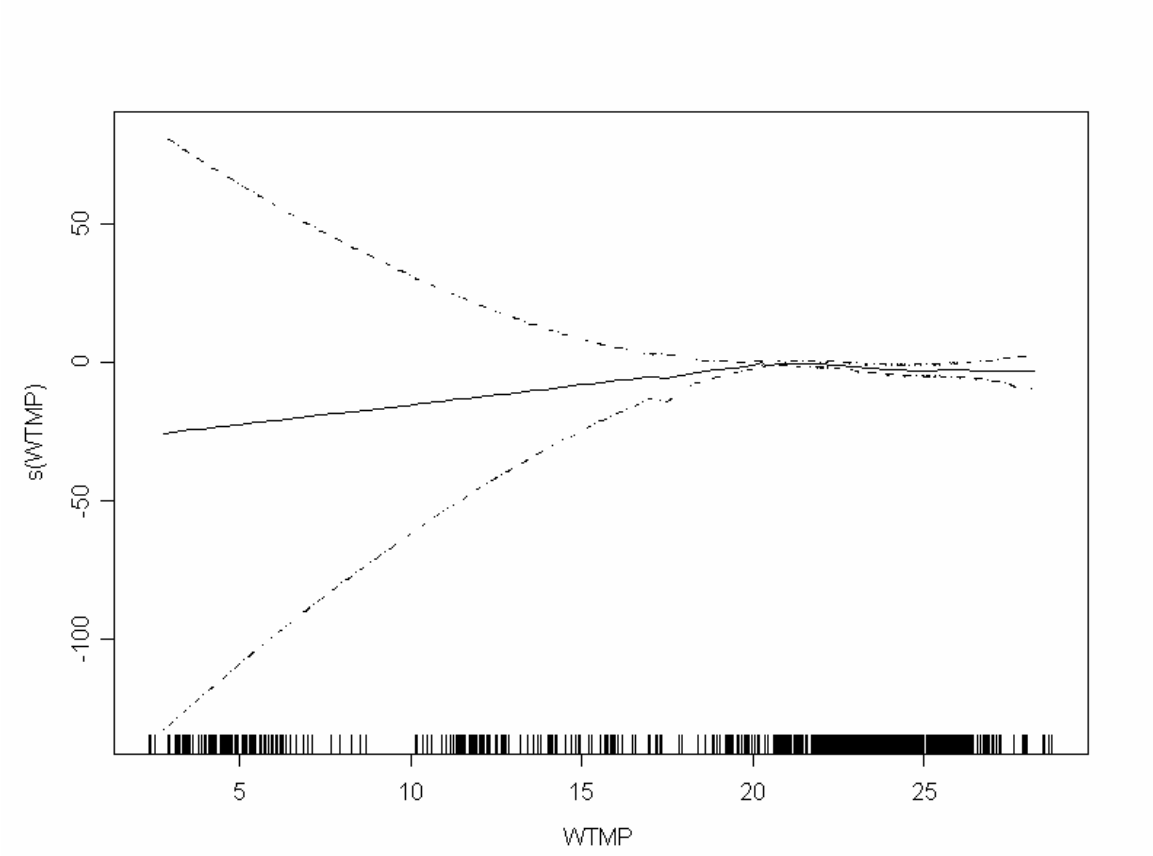
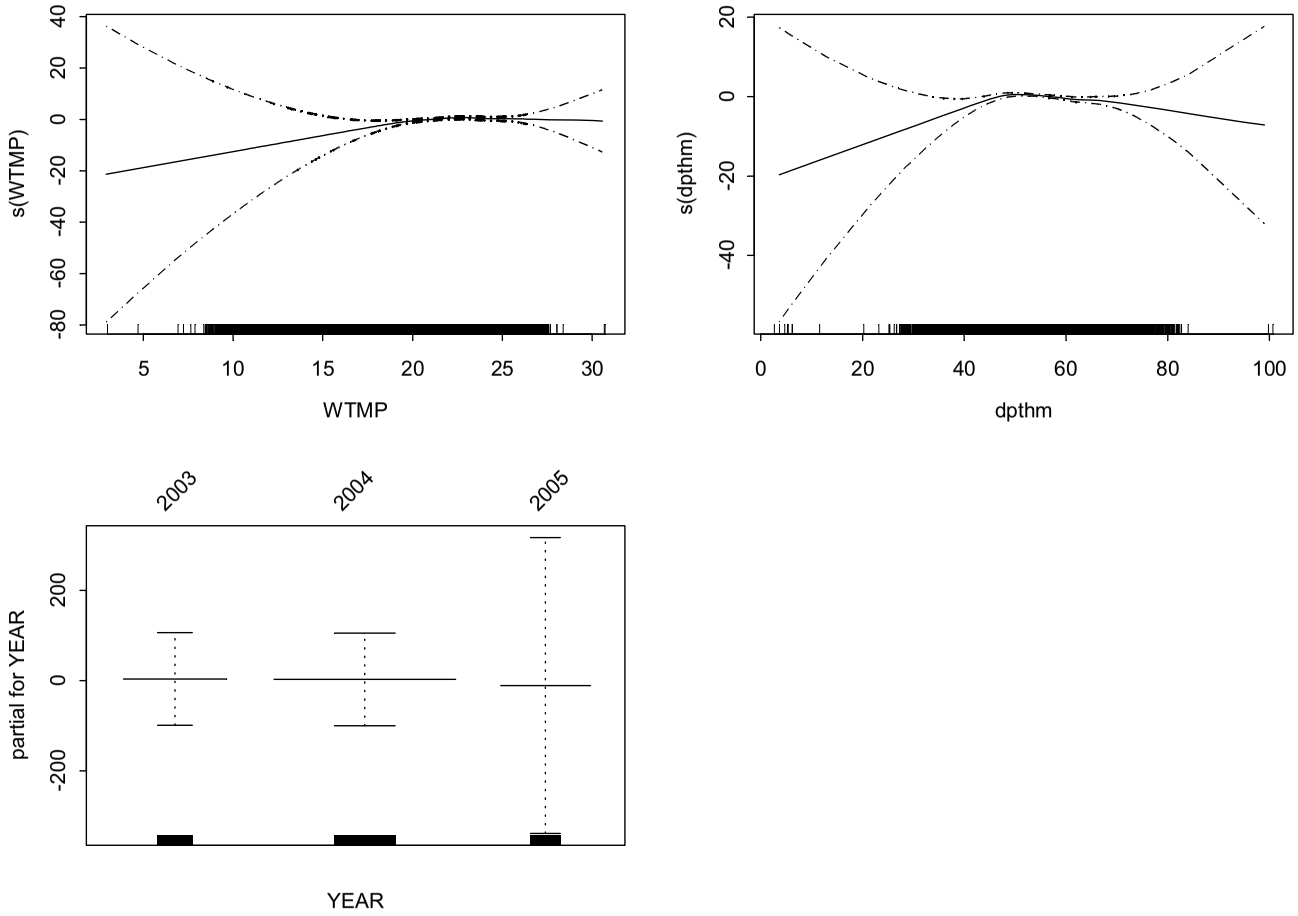


Figure 5. Partial fit for the general additive model (GAM) of loggerhead sea turtle bycatch rates in scallop dredge gear, with sea surface temperature, depth, and year as covariates. The y-axis represents the effect of the covariate on the bycatch rate, with lower rates indicated where the curve is below zero. The rug-plots on the x-axes represent the number of observations, and dashed lines are the +/- 2 SE confidence bands.



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