NOAA Technical Memorandum NMFS-NE-299

Loggerhead Turtle Interactions in Mid-Atlantic Bottom Trawl Gear, 2001-2019

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts
March 2023

NOAA Technical Memorandum NMFS-NE-299

This series represents a secondary level of scientific publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Loggerhead Turtle Interactions in Mid-Atlantic Bottom Trawl Gear, 2001-2019

Kristin Precoda[1], Kimberly Murray[2], Sean Hayes[2]

[1] Integrated Statistics, 16 Sumner Street, Woods Hole, MA 02543
[2] NOAA Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts
March 2023

Editorial Notes

Information Quality Act Compliance: In accordance with section 515 of Public Law 106-554, the Northeast Fisheries Science Center (NEFSC) completed both technical and policy reviews for this report. These pre-dissemination reviews are on file at the NEFSC Editorial Office.

Species Names: The NEFSC Editorial Office's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes, mollusks, and decapod crustaceans and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals. Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

Statistical Terms: The NEFSC Editorial Office's policy on the use of statistical terms in all technical communications is generally to follow the International Standards Organization's handbook of statistical methods.

TABLE OF CONTENTS

1. ABSTRACT

This document describes analyses performed to examine whether the rate of interactions between loggerhead sea turtles (*Caretta caretta*) and bottom trawl fishing gear has changed over the period of 2001-2019 in order to test some of the assumptions of the approach currently used to estimate fisheries interactions in the Mid-Atlantic scallop dredge fishery. Most vessels dredging for Atlantic sea scallops (*Placopecten magellanicus*) are required to use chain mats and turtle deflector dredges, and turtles may interact with such modified gear without being captured. Consequently, fewer interactions between turtles and dredge gear may be observed than actually occur. However, we expect interactions with bottom trawl gear to be proportional to interactions with dredge gear. Therefore, we examine interaction rates over time based on observations on vessels using bottom trawl gear in the area between 37° N and 42° N latitude and west of 71° W longitude, where the majority of the Atlantic sea scallop dredge fishing effort occurs. To begin, we compare the 2 fisheries in terms of their spatial and temporal footprints and observed takes, and calculate the correlation of the observed interaction rates in the 2 fisheries prior to the introduction of modified gear. Then we measure whether interaction rates in the trawl fishery have changed significantly over time, using 2 approaches. Results of the first approach suggest that in 2010, 2016, and 2017, the interaction rate was significantly lower than the rate calculated for 2001-2006; no year had an interaction rate significantly higher than in that period. Results of the second approach suggest that if latitude, sea surface temperature (SST), and depth are accounted for in estimating the bycatch rate, year does not contribute significantly to explaining variations in the rate. We conclude that using historic interaction rates—prior to the introduction of modified gear—to estimate turtle interactions in the dredge fishery in more recent years may overestimate interactions in some individual years, but there is no evidence to suggest underestimation. Environmental and fishing conditions may help explain variations each year.

2. INTRODUCTION

Loggerhead sea turtles (*Caretta caretta*) forage in the U.S. Mid-Atlantic region in the warmer months (Griffin et al. 2013; Patel et al. 2016; Winton et al. 2018) and are captured incidentally in commercial fisheries (Murray 2011, 2015a; Warden 2011). Sea turtles in U.S. waters are protected under the Endangered Species Act, and the definition of a “take” under the Act includes interactions between sea turtles and commercial fishing gear (Endangered Species Act). Over the past several decades, the Northeast Fisheries Observer Program (NEFOP) has deployed observers on commercial fishing vessels to collect data on protected species bycatch which are then used to estimate the total number of interactions each year in bottom trawl, scallop dredge, and gillnet fisheries (Murray 2009, 2011, 2015a). While changes to gear and fishing practices can often be taken into consideration when estimating interaction rates, some modifications, such as those designed to prevent animals from being captured in gear, mean that interactions can occur which are not and cannot be reflected in the observer data that is used to estimate total interactions. For instance, most vessels dredging for Atlantic sea scallops (*Placopecten magellanicus*) in the Mid-Atlantic have been required to use chain mats since 2006 (Endangered and Threatened Wildlife…) and turtle deflector dredges (TDDs) since 2013 (Fisheries of the Northeastern United States…). Chain mats prevent turtles from entering the dredge bag, while TDDs allow turtles to go up and over the dredge frame rather than be caught underneath it. Since the implementation of chain mats and TDDs in the scallop dredge fishery, observers have recorded very few turtle interactions (Murray 2015b, 2021). Because turtles may interact with such modified gear without being captured and brought on board, there may be more interactions between turtles and dredge gear than are observed. An approach has been developed to estimate both observable and unobservable interactions in the dredge fishery (Warden and Murray 2011); however, the approach relies on historic interaction rates in the dredge fishery (prior to 2006) that are assumed to not vary over time (Murray 2021). By contrast, most of the bottom trawl fishery in the Greater Atlantic Region does not employ devices to reduce turtle mortality (Murray 2020).

Here, we assess whether the rate of interactions between turtles and bottom trawl fishing gear has changed over the period of 2001-2019 to examine the assumption that historic interaction rates in the dredge fishery have not varied over time. First, we compare the 2 fisheries in terms of their spatial and temporal footprints and observed takes, and measure whether interaction rates in the 2 fisheries were correlated prior to the introduction of chain mats and TDDs. Second, we measure whether interaction rates in the trawl fishery have changed significantly over time, and finally, we discuss the results of these findings in the context of estimating interactions in the current scallop dredge fishery.

3. METHODS

3.1 Data

We chose 2001 as the starting point of the time period to be studied, as that is when observers were first placed on sea scallop dredge vessels and began observing turtle interactions in the scallop fishery. Two data sources that cover the time period of 2001-2019 were considered. The first is fishery-dependent data from the NEFOP and At-Sea Monitoring (ASM) programs, under which observers are placed on randomly selected commercial fishing vessels. Interaction rates are normally calculated from such fishery-dependent data. The second data set, which we investigated as a potential additional source of information, is fishery-independent data from research cruises conducted by the Northeast Fisheries Science Center. The cruises have surveyed approximately the same locations for several decades and are conducted in the spring and fall of each year. Because a change in survey practices between 2008 and 2009 could not easily be disentangled from changes in turtle interaction rates over time, and because there was so much less survey data than observer data that pooling the 2 types of data would likely not bring much benefit, we decided to use only the fishery-dependent observer data and not analyze the fishery-independent survey data.

3.1.1 Observer Data: Bottom Trawl

Loggerhead interactions most commonly occur between May and November; however, because climate change might lead to turtles entering the area of the Mid-Atlantic scallop fishery (between approximately 37° N and 42° N latitude and west of 71° W longitude) outside these months, all observed tows from any time of year were included. Tows in the observer data that used excluder or separator[1] devices were omitted so as to remove uncertainty about whether these

[1] See Northeast Fisheries Observer Program manual for definitions, available at: https://aquadocs.org/handle/1834/30751

devices might have rendered some interactions unobservable. Within the area between 37° N and 42° N latitude and west of 71° W longitude, the 2001-2019 observer data contained 12,044 trips comprising 65,447 tows, 7,207.49 days of fishing effort, and a total of 113 loggerhead interactions (Figure 1a). One turtle that had been identified only as “unknown species of hardshell turtle” was labeled as a loggerhead based on comments written by the observer (Murray 2015). Of the 113 interactions, 71 occurred on trips that had only a single loggerhead interaction. The total observed days of bottom trawl fishing from 2001-2019 are shown in Figure 1b.

Tows from the same fishing trip are likely to have some similarities. To avoid data dependency, as well as to reduce the interaction rate variance caused by having a very small integer number of interactions (typically 0 or 1) per tow, tows on the same fishing trip were merged into a single trip-level record. Sea surface temperature (SST), depth, latitude, and longitude for each individual tow were weighted by the fraction of that tow’s fishing time out of the trip’s total fishing time, then summed. For example, if a trip had only 2 tows, one lasting 2 hours with an SST of 11°C and the other lasting 1 hour with an SST of 10°C, the trip’s combined SST would be 2/3 * 11 + 1/3 * 10 = 10.67°C. The fishing time for individual tows and the number of loggerhead interactions on individual tows were summed to obtain the trip’s total fishing time and total number of loggerhead interactions. The day of the year for the trip was the median of the days of the year over tows on that trip. A presence/absence variable for each trip was created which indicated whether there was a loggerhead interaction on that trip.

3.1.2 Observer Data: Dredge

All observed interactions of loggerheads with scallop dredge gear occurred west of 72.4° W longitude and south of 40.1° N latitude; within the area west of 71° W longitude and between 37° N and 42° N latitude, there were 188,742 dredge tows from 2001-2019. Tows from all months were included. The 188,742 tows included a total of 54 loggerhead interactions (Figure 2a) and came from 4683 trips with 14,587.92 days of observed fishing effort (Figure 2b). Three trips had 3 interactions each, 6 trips had 2 interactions, and the 33 remaining interactions occurred on trips with only 1 interaction each.

3.2 Comparison of Trawl and Dredge Fisheries

The bottom trawl and scallop dredge fisheries are both benthic fisheries, operating in approximately the same region in the Mid-Atlantic. We assume that turtles’ use of the water column is the same when either gear is being fished and that turtles behave similarly around the 2 gear types. We also assume that because observer effort is allocated randomly and in proportion to commercial effort, the realized distribution of observer effort in both the bottom trawl and scallop dredge fisheries is representative of the corresponding commercial effort.

To compare the spatial footprints of the trawl and dredge fisheries in the Mid-Atlantic between 37° N and 42° N latitude and west of 71° W longitude, we summed the observed number of hours fished within each 10-minute latitude/longitude square in that region over the period of 2001-2019 and calculated the percent of the total observed fishing effort in the region that fell within each 10-minute square. We created maps showing these data and the locations of observed interactions with loggerhead turtles. We also compared the depths of observed tows in each fishery.

We charted the number of observed fishing hours per month and number of observed loggerhead interactions within the region per month over 2001-2019 to compare the seasonality of turtle interactions with the 2 fisheries.

Finally, we plotted and calculated the correlation of the interaction rates in the region in the 2 fisheries for 2001-2006, before the implementation of regulations requiring chain mats and turtle deflector dredges.

3.3 Interaction Rates in Trawl Gear

We took 2 approaches to examining the interaction rate over time in the bottom trawl fishery. The first approach considers the rate without taking into account any changes that may have occurred over time in the fishery, for example in the location, depth, or SST where the fishery operates. This approach may be of most interest if the goal is simply to understand whether the overall number of turtle interactions per unit of fishing effort is changing over time. The second approach models the rate conditioned on variables that may affect the interaction rate: that is, if those variables are held constant, is there a change that is unaccounted for and that may be attributed to time? This second approach is relevant to the question of whether the number of turtle interactions under a particular set of conditions is changing; the overall number of interactions may increase or decrease if the conditions change, and what is important to this question is to distinguish between a change in number of interactions that is due to changing conditions and a change that is not due to those conditions.

3.3.1 Unconditional Interaction Rate

The unconditional interaction rate was defined as the number of observed loggerhead interactions per hour of observed bottom trawl tows. To examine whether the unconditional interaction rate from 2007-2019 was different from the rate from 2001-2006, we used a nonparametric approach so that no particular type of change (e.g., linear, exponential, or even monotonic) is assumed. To estimate the variability in the interaction rate from 2001-2006, we used bootstrapping (R boot package; Canty and Ripley 2021; Davison and Hinkley 1997) and randomly sampled 10,000 sets of 500 trips over that time period and calculated the interaction rate for each of the 10,000 sets. Then we calculated 2-sided p-values for how likely each subsequent year's interaction rate was to have been drawn from the distribution of 2001-2006 interaction rates. p-values were computed by inverting adjusted bootstrap percentile confidence intervals (Hall 1992; Thulin 2021a, 2021b).

3.3.2 Conditional Interaction Rate

Several generalized additive models (GAMs) were explored, modeling either the number of loggerhead interactions per day of fishing effort (i.e., per day of tow time) or the probability of a loggerhead interaction per day of fishing effort. Predictor variables were SST (°C), depth (meters), latitude, days fished, and year. SST, depth, and latitude have previously been shown to be correlated with loggerhead interaction rates with trawl gear (e.g., Warden 2011; Murray 2011; Murray and Orphanides 2013).

One model used a binomial distribution and logit link function to fit a model to the presence or absence of loggerhead bycatch on a trip. The log of days fished was specified to be an offset (i.e., its coefficient was forced to be 1). Model checking revealed that latitude was best modeled as linearly related to the response variable, and no smooth was applied to latitude.

The counts of total loggerhead interactions per trip have a larger variance than the mean. Thus, a second approach used a negative binomial and log link function to model the count of loggerhead interactions. No smooth was used for the log of days fished, as it was expected to be linearly related to the log of the number of loggerhead interactions. In one version of this model, the log of days fished was specified to be an offset; in another, the model was allowed to estimate a coefficient for the log of days fished. Again, latitude was best handled with a linear relationship rather than with a smooth.

Finally, we fit a model of the counts of total loggerhead interactions using a Tweedie distribution and estimating the Tweedie power parameter; the advantage of a Tweedie distribution is that it allows a range of mean-variance relationships. The log of days fished was treated as an offset, and no smooth was applied to latitude.

Model diagnostics and checking included plotting residuals, examining concurvity between terms, and looking at basis dimension adequacy. Metrics used for model quality were the mean absolute percentage error (MAPE), mean absolute error (MAE), Spearman's ρ between fitted and observed values, average squared prediction error (ASPE), and deviance explained. MAPE, MAE, Spearman's ρ, and ASPE were computed using 200-fold cross-validation.

The package mgcv (Wood 2011, 2017) in R (R Core Team 2020) was used to fit models and perform diagnostics. Smoothing parameters were estimated via restricted maximum likelihood (REML).

4. RESULTS

4.1 Comparison of Trawl and Dredge Fisheries

Figure 3 maps observed tows and intensity of effort in the area between 37° N and 42° N latitude and west of 71° W longitude, from 2001-2019, together with the locations of observed loggerhead interactions. The spatial footprints of the 2 fisheries are similar at a broad scale. In the dredge fishery, loggerhead interactions occurred in areas with greater fishing effort; in the bottom trawl fishery, which had fewer total observed hours of fishing effort, loggerhead interactions were more widely distributed. The median depth of bottom trawls within this spatial area was 64 m, compared with a median depth of 53 m for dredge tows within the same area. The depths of the dredge tows represented a subset of the depths of the bottom trawls.

Figure 4a shows that the number of observed hours fished slowly declined over the second half of the year in the dredge fishery, when all observed turtle interactions occurred; the highest rates of observed interactions occurred from July-September. In the bottom trawl fishery (Figure 4b), the number of observed hours fished generally increased over the second half of the year, when nearly all loggerhead interactions were observed, and the highest rates of observed interactions occurred from September-October.

The observed interaction rates for 2001-2006 are plotted in Figure 5. The annual number of observed interactions per bottom trawl hour fished was well correlated with the number per dredge hour fished (r=0.92, p=0.009).

4.2 Interaction Rates with Trawl Gear

4.2.1 Unconditional Interaction Rate

The resampled estimates of 2001-2006 interaction rate per hour of observed bottom trawl tows and the annual interaction rates from 2007-2019 are shown in Figure 6. The 2-sided p-values for how likely each annual rate was to be drawn from the same distribution as the 2001-2006 rate are given in Table 1. Three of the 13 annual rates, shown as orange dots in Figure 6, were below a

Bonferroni-corrected significance threshold, indicating significantly lower interaction rates in those years compared to the rate in 2001-2006.

4.2.2 Conditional Interaction Rate

The binomial, negative binomial, and Tweedie GAMs produced similar results, had fairly similar values for quality metrics, led to similar conclusions, and could not be clearly distinguished. The negative binomial model has the advantage over the binomial model of fitting counts rather than presence or absence of loggerhead interactions, and the advantage over the Tweedie model of easier interpretation and fewer estimated parameters. The residuals of the negative binomial model were also generally smaller than the Tweedie residuals. For those reasons, the negative binomial model was preferred. The selected model is given in Equation 1.

Equation 1.

$$\begin{aligned} log\ (count\ of\ loggerheads) \\ &= s(SST) + s(depth) + s(year) - \ 0.9720\ \times latitude \\ &+ offset(log\ (days\ fished)\ ) \end{aligned}$$

The model in Equation 1 can be interpreted as saying that the log of the rate of loggerhead interactions per day of tow time is modeled with a combination of SST, depth, year, and latitude. The effect of latitude is linear: for every additional degree of latitude, all else being equal, the log of the rate of interactions on average decreases by a fixed amount (-0.9720), or equivalently, the expected rate of interactions is multiplied by 0.378 (=exp(-0.9720)). That is, if 2 fishing trips are identical in all respects but separated by 1 degree of latitude, the more northerly trip would be expected to have only 37.8% as many interactions as the more southerly one would have. The relationships between the rate of loggerhead interactions and SST and depth are more complicated to interpret. Given the data, the model derived smooth, curved functions relating SST and depth to the log of the rate of loggerhead interactions. The smoothed functions of SST and depth both made statistically significant contributions to the model. The best relationship the model found between year and the log of the rate of loggerhead interactions is also a smooth function, but this function was not a significant contributor and could be removed if our goal were to develop the best model of the rate of interactions.

Figure 7 shows a plot of the smooth of year on a scale of loggerhead counts per hour fished, using prediction from the fitted negative binomial model with latitude, SST, and depth set to their medians. Some caution is warranted in interpreting the model results as there is a significant though weak correlation ($r^2 = 0.03$) between latitude and year.

It may be noted that there is uncertainty in the estimated count of turtle bycatch per hour of fishing each year as well as overall uncertainty (e.g., the deviance explained by the model is 36.6%). The main challenge appears to be the large standard errors around the estimated count per day of fishing in a given year, rather than the length of the time series, despite the number of observed trips per year more than doubling in 2016 and later compared to 2008 and earlier.

5. DISCUSSION

The correlation between the observed interaction rates in the 2 fisheries from 2001-2006 is consistent with the interpretation that the 2 fisheries are “sampling” the turtle population proportionally to each other. At a fine scale, some areas and some months show differences in effort and interactions due to different management regimes and styles of fishing in the 2 fisheries.

The analysis of unconditional bottom trawl interaction rates suggests that in 2010, 2016, and 2017, the interaction rate was significantly lower than in the period of 2001-2006; no year had an interaction rate significantly higher than in that period (Table 1). Two points should be highlighted about these results. First, the results imply that a process for estimating bycatch which assumes the interaction rate remains unchanged from what it was from 2001-2006 would overestimate the bycatch in 2010, 2016, and 2017 but would not lead to underestimates of the bycatch from 2007-2019. Second, the analysis of conditional interaction rates over time (Table 2, Figure 7) did not provide sufficient evidence to conclude that there is an effect of year on the rate of loggerhead interactions with bottom trawl gear, while there are significant effects of latitude, SST, and depth on the interaction rate. Together, the unconditional and conditional rate analyses can be interpreted as saying that in 3 years over the period of 2007-2019, changes in aspects of the fishery (e.g., latitude, SST, depth) may have led to lower rates of interactions with loggerheads. As some species distributions shift poleward under a changing climate, there is concern that shifting turtle distributions could lead to greater overlap between loggerheads and the scallop dredge and bottom trawl fisheries, resulting in increased interactions. Modeling interaction rates as a function of environmental variables could capture climate-induced variation in interaction rate.

The results reported here are important because the current method of estimating takes in the dredge fishery relies on rates observed primarily from 2001-2006 because of the very limited number of observed takes after gear modifications were implemented. Our results, based on an independent set of data, show interaction rates in the trawl fishery in 3 years after 2006 are different from the 2001-2006 period; however, there is no evidence for an increasing interaction rate between turtles and bottom trawl gear in the region where the scallop dredge fishery operates, even when controlling for latitude and other variables. It appears reasonable to assume that there would be a similar lack of evidence for an increasing interaction rate between turtles and scallop dredge gear.

6. CONCLUSIONS

The findings above suggest that in a few years after 2006, there were significantly lower loggerhead interaction rates in trawl gear in the Mid-Atlantic scallop dredge fishing region than from 2001-2006. Relying on historic interaction rates in dredge gear to estimate interactions in more recent time periods may have overestimated “unobservable” interactions (Murray 2021) in some years, but could be viewed as a cautious approach when assessing the impact of these interactions on the overall population. Due to the infrequency of observing turtle interactions in modified dredge gear that is designed to exclude them, we suggest that observations from the bottom trawl fishery can be used to monitor the loggerhead interaction rate with gear that has no turtle excluder or separator devices, as we have done here. Finally, if a significant increase in the interaction rate in the trawl fishery is found in the future, or if there is some other signal that indicates conditions have changed in a biologically relevant way, the assumptions used in the bycatch estimation process in the dredge fishery may then need to be reevaluated.

7. FIGURES AND TABLES

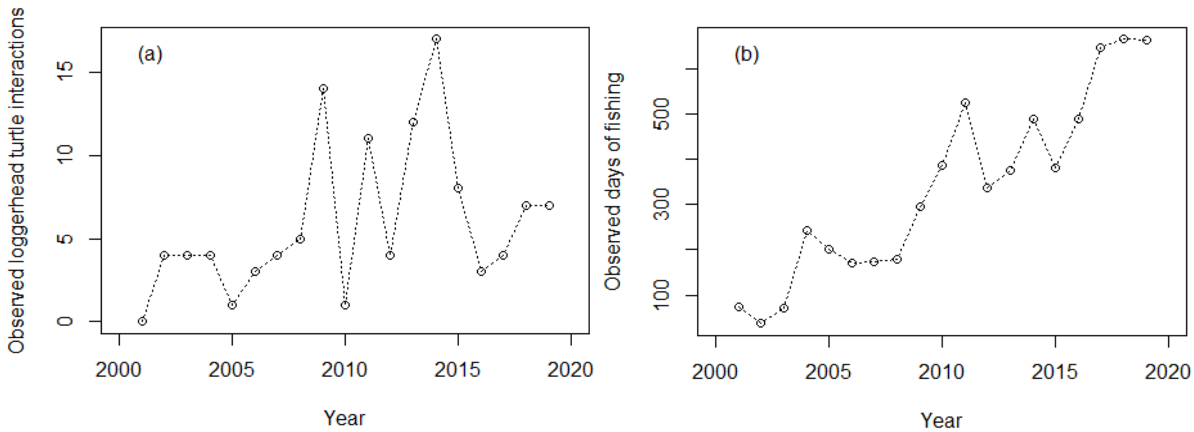

Figure 1. (a) Number of observed loggerhead turtles (*Caretta caretta*) in bottom trawl gear, 2001-2019, between 37° N and 42° N latitude and west of 71° W longitude. (b) Total observed days of bottom trawl fishing in the same region and time period.

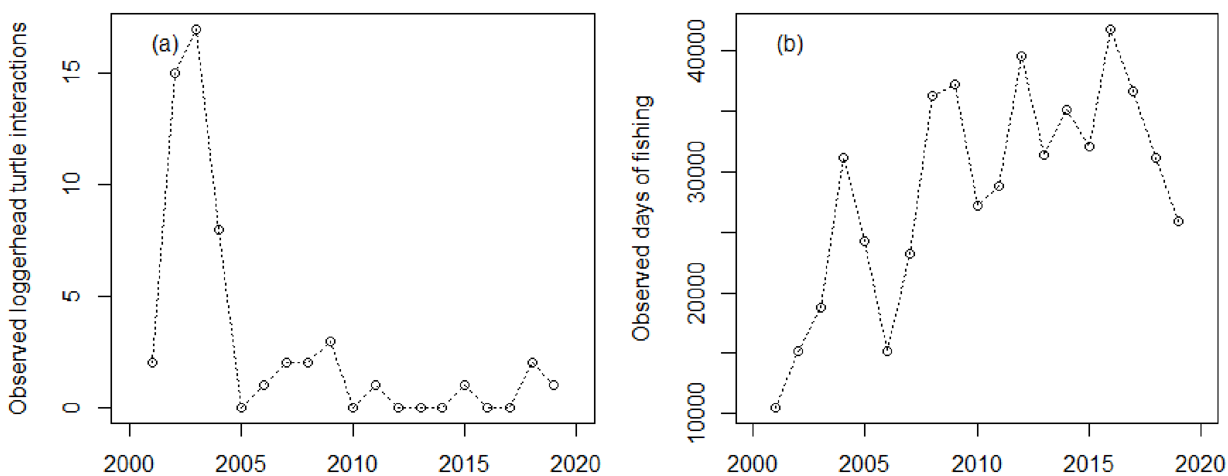

Figure 2. (a) Number of observed loggerhead turtles (*Caretta caretta*) in scallop dredge gear, 2001-2019, between 37° N and 42° N latitude and west of 71° W longitude. (b) Total observed days of scallop dredge fishing in the same region and time period.

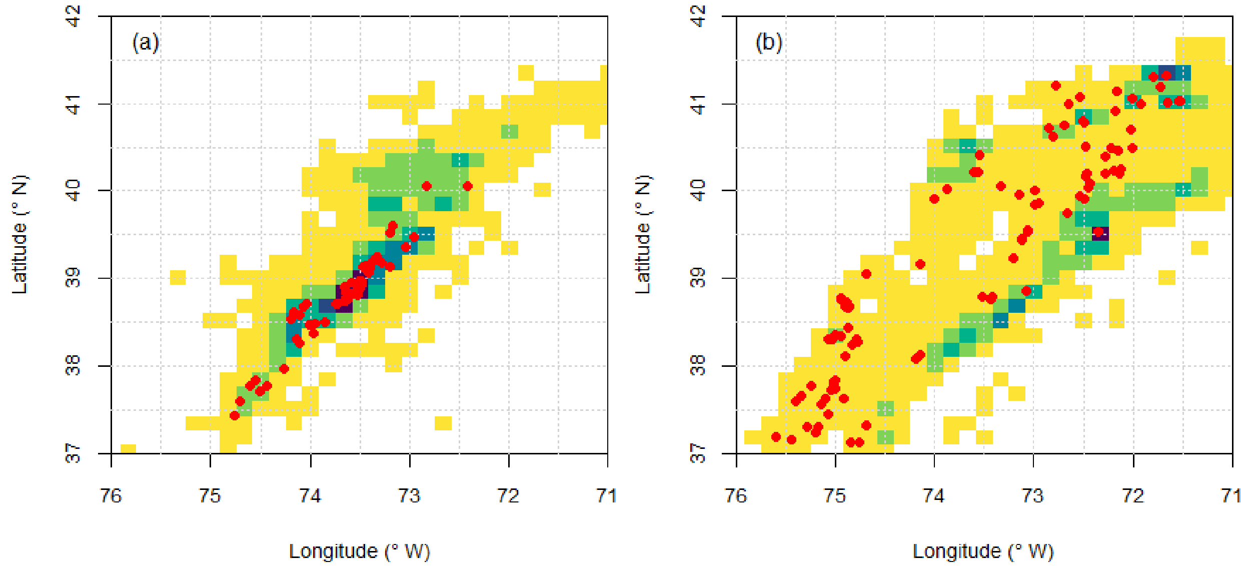

Figure 3. Locations of (a) observed dredge tows and (b) observed bottom trawl tows, 2001-2019, within 10-minute latitude/longitude squares, in the area between 37° N and 42° N latitude and west of 71° W latitude. The color of the 10-minute squares reflects the percentage of total observed fishing hours for the fishery that falls within that square; darker colors (blue) had more observed fishing hours. Red dots show locations of observed loggerhead turtle (*Caretta caretta*) interactions. Some interactions with bottom trawl tows occur in spatial areas where there is little or no dredge fishing effort.

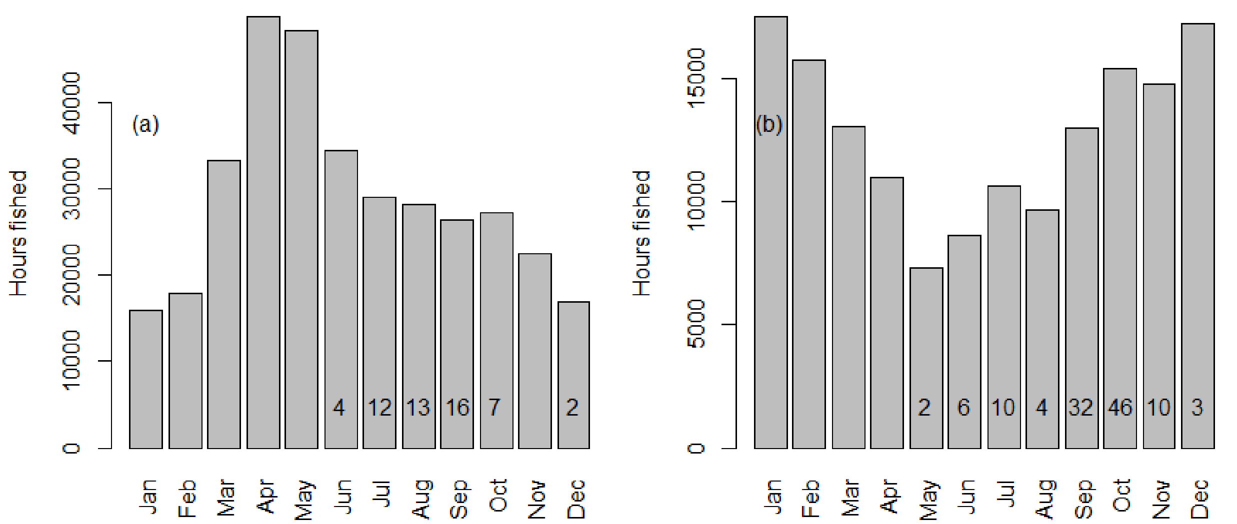

Figure 4. Hours of fishing effort by month, 2001-2019, between 37° N and 42° N latitude and west of 71° W longitude, for (a) observed dredge tows and (b) observed bottom trawl tows. The count of observed loggerhead turtle (*Caretta caretta*) interactions is shown at the base of each bar for each month that had observed interactions. Some months show differences in effort and interactions because of different management regimes in the 2 fisheries.

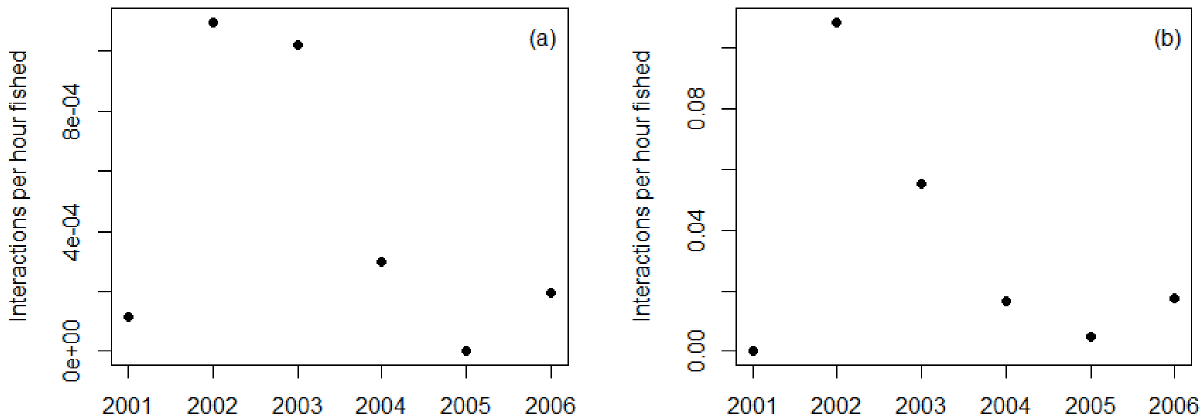

Figure 5. Interaction rates per hour fished in the region between 37° N and 42° N latitude and west of 71° W longitude for (a) observed dredge tows and (b) observed bottom trawl tows, 2001-2006.

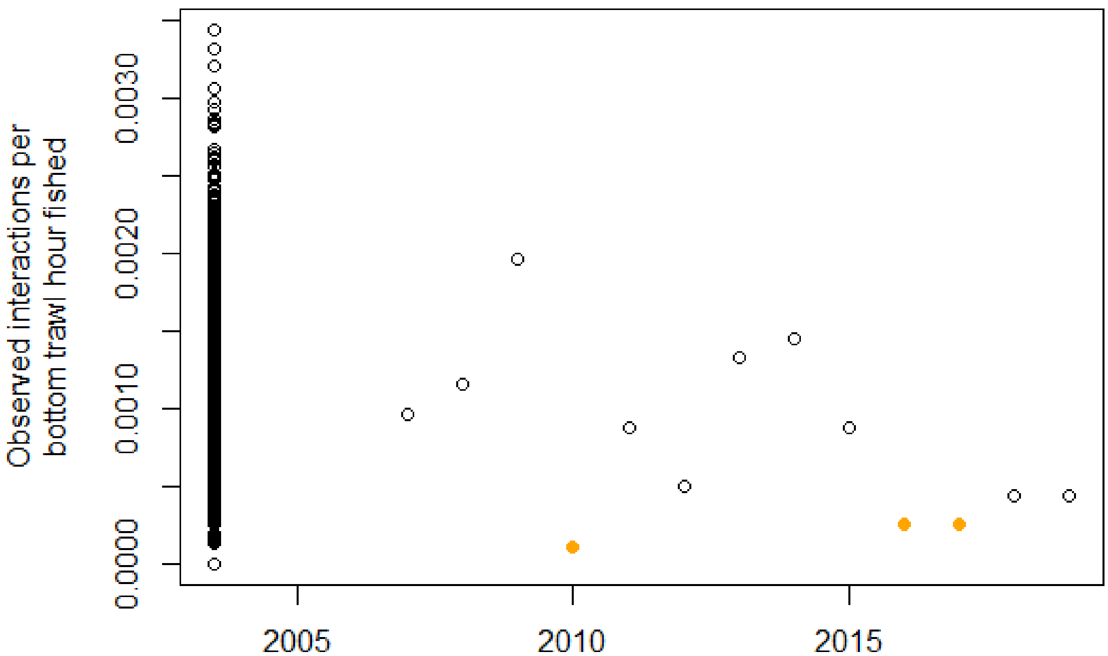

Figure 6. Rate of observed loggerhead turtle (*Caretta caretta*) interactions with bottom trawl gear per hour fished for 2001-2006 for 10,000 resampled sets of trips and annual rate for 2007-2019.

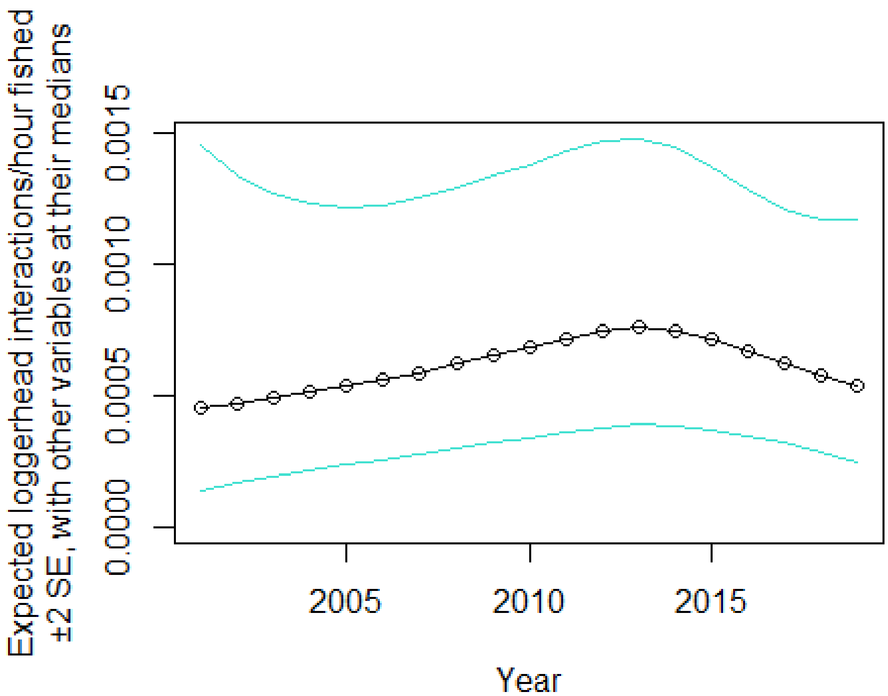

Figure 7. Expected count of loggerhead turtle (*Caretta caretta*) interactions per hour fished as year varies, predicted from the fitted negative binomial model with latitude, sea surface temperature (SST), and depth set to their medians.

Table 1. Two-sided p-values for annual interaction rates per bottom trawl hour fished, if they are drawn from the distribution of resampled 2001-2006 interaction rates. p-values which are below a Bonferroni-corrected threshold of α = 0.05/13 = 0.004 are marked with an asterisk.

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
p-value	0.72	0.34	0.01	1e-4*	0.95	0.13	0.16	0.09	0.96	2e-3*	2e-3*	0.07	0.07

Table 2. Estimated regression parameters and smooth degrees of freedom for the negative binomial generalized additive model (GAM) shown in Equation 1. The estimated value for the negative binomial parameter θ is 0.225. Adjusted R2 is 0.0921, and deviance explained is 36.6%. n=11,299.

Parametric coefficients	**Estimate**	**Standard error**	**Z value**	**p-value**
Intercept	33.9423	4.4065	7.703	< 0.0001
Latitude	-0.9720	0.1119	-8.689	< 0.0001
Smooth terms	**Effective degrees of freedom**	**Reference degrees of freedom**	**Chi-squared**	**p-value**
s(SST)	5.052	6.301	51.335	< 0.0001
s(depth)	3.547	4.234	37.822	< 0.0001
s(year)	2.115	2.646	2.657	0.515

8. REFERENCES CITED

Canty A and Ripley BD. 2021. boot: Bootstrap R (S-Plus) functions. R package version 1.3-28.

Ceriani SA and Meylan AB. 2017. Loggerhead Turtle – *Caretta caretta* (North West Atlantic subpopulation) (amended version of 2015 assessment). The International Union for Conservation of Nature (IUCN) Red List of Threatened Species 2017; [accessed 1 April 2022]. Accessible at: https://dx.doi.org/10.2305/IUCN.UK.2017-2.RLTS.T84131194A119339029.en

Davison AC and Hinkley DV. 1997. Bootstrap methods and their applications. Cambridge (UK): Cambridge University Press.

Fisheries of the Northeastern United States; Atlantic Sea Scallop Fishery; Framework Adjustment 23, 77 FR Sect. 20728 (2012).

Endangered and Threatened Wildlife; Sea Turtle Conservation, 71 FR Sect. 50361 (2006).

Endangered Species Act. U.S. Congress Code 16 Sect. 1534-1544. (1973).

Griffin DB, Murphy SR, Frick MG, Broderick AC, Coker JW, Coyne MS, Dodd M G, Godfrey MH, Godley BJ, Hawkes LA, et al. 2013. Foraging habitats and migration corridors utilized by a recovering subpopulation of adult female loggerhead sea turtles: implications for conservation. Mar Biol. 160(12):3071-3086.

Hall P. 1992. The bootstrap and Edgeworth expansion. New York City (NY): Springer Publishing. Springer Science+Business Media.

Hatch JM, Haas HL, Richards PM, Rose KA. 2019. Life-history constraints on maximum population growth for loggerhead turtles in the northwest Atlantic. Ecol Evol. 9(17):9442-9452.

Hatch JM, Haas HL, Sasso CR, Patel SH, Smolowitz RJ. 2022. Estimating the complex patterns of survey availability for loggerhead turtles. J Wildl Manage. e22208.

Murray KT. 2009. Characteristics and magnitude of sea turtle bycatch in U.S. Mid-Atlantic gillnet gear. Endang Species Res. 8:211-224.

Murray KT. 2011. Interactions between sea turtles and dredge gear in the US sea scallop (*Placopecten magellanicus*) fishery, 2001-2008. Fish Res. 107(1-3):137-146.

Murray KT. 2015a. The importance of location and operational fishing factors in estimating and reducing loggerhead turtle (*Caretta caretta*) interactions in US bottom trawl gear. Fish Res. 172:440-451.

Murray KT. 2015b. Estimated loggerhead (*Caretta caretta*) interactions in the Mid-Atlantic scallop dredge fishery, 2009-2014. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 15-20; 15 p. Accessible at: https://repository.library.noaa.gov/view/noaa/5046

Murray KT. 2020. Estimated magnitude of sea turtle interactions and mortality in US bottom trawl gear, 2014-2018. US Dept Commer, Northeast Fish Sci Cent Tech Memo 260; 19 p. Accessible at: https://repository.library.noaa.gov/view/noaa/23708

Murray KT. 2021. Estimated loggerhead (*Caretta caretta*) interactions in the Mid-Atlantic sea scallop dredge fishery, 2015-2019. US Dept Commer Northeast Fish Sci Cent Tech Memo 270; 13 p. Accessible at: https://repository.library.noaa.gov/view/noaa/31440

Murray KT and Orphanides CD. 2013. Estimating the risk of loggerhead turtle *Caretta caretta* bycatch in the US Mid-Atlantic using fishery-independent and-dependent data. Mar Ecol Prog Ser. 477:259-270.

Patel SH, Dodge KL, Haas HL, Smolowitz RJ. 2016. Videography reveals in-water behavior of loggerhead turtles (*Caretta caretta*) at a foraging ground. Front Mar Sci. 3:254.

R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/

Thulin M. 2021a. boot.pval: Bootstrap p-values. R package version 0.4, CRAN.R-project.org.

Thulin M. 2021b. Modern statistics with R. Eos Chasma Press.

Warden ML. 2011. Modeling loggerhead sea turtle (*Caretta caretta*) interactions with US Mid-Atlantic bottom trawl gear for fish and scallops, 2005-2008. Biol Conserv. 144(9):2202-2212.

Warden ML and Murray KT. 2011. Reframing protected species interactions with commercial fishing gear: Moving toward estimating the unobservable. Fish Res. 110(3):387-390.

Winton MV, Fay G, Haas HL, Arendt M, Barco S, James MC, Sasso C, Smolowitz R. 2018. Estimating the distribution and relative density of satellite-tagged loggerhead sea turtles using geostatistical mixed effects models. Mar Ecol Prog Ser. 586:217-232.

Wood SN. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. J R Stat Soc Series B Stat Methodol. 73(1):3-36.

Wood SN. 2017. Generalized additive models: an introduction with R. 2nd edition. UK: Chapman and Hall/CRC.

Procedures for Issuing Manuscripts
in the Northeast Fisheries Science Center Reference Document (CRD)
and the Technical Memorandum (TM) Series

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of the nation's ocean resources and their habitat." As the research arm of the NMFS's Greater Atlantic Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS's mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (e.g., anonymously peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own series.

NOAA Technical Memorandum NMFS-NE – This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review, and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document – This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review, and most issues receive copy editing.

CLEARANCE

All manuscripts submitted for issuance as CRDs must have cleared the NEFSC's manuscript/abstract/webpage review process. If your manuscript includes material from another work which has been copyrighted, you will need to work with the NEFSC's Editorial Office to arrange for permission to use that material by securing release signatures on the "NEFSC Use-of-Copyrighted-Work Permission Form."

For more information, NEFSC authors should see the NEFSC's online publication policy manual, "Manuscript/Abstract/Webpage Preparation, Review, & Dissemination: NEFSC Author's Guide to Policy, Process, and Procedure."

STYLE

The CRD series is obligated to conform with the style contained in the current edition of the United States Government Printing Office Style Manual; however, that style manual is silent on many aspects of scientific manuscripts. The CRD series relies more on the CSE Style Manual. Manuscripts should be prepared to conform with both of these style manuals.

The CRD series uses the Integrated Taxonomic Information System, the American Fisheries Society's guides, and the Society for Marine Mammalogy's guide for verifying scientific species names.

For in-text citations, use the name-date system. A special effort should be made to ensure all necessary bibliographic information is included in the list of references cited. Personal communications must include the date, full name, and full mailing address of the contact.

PREPARATION

Once your document has cleared the review process, the Editorial Office will contact you with publication needs—for example, revised text (if necessary) and separate digital figures and tables if they are embedded in the document. Materials may be submitted to the Editorial Office as email attachments or intranet downloads. Text files should be in Microsoft Word, tables may be in Word or Excel, and graphics files may be in a variety of formats (JPG, GIF, Excel, PowerPoint, etc.).

PRODUCTION AND DISTRIBUTION

The Editorial Office will perform a copy edit of the document and may request further revisions. The Editorial Office will develop the inside and outside front covers, the inside and outside back covers, and the title and bibliographic control pages of the document.

Once the CRD is ready, the Editorial Office will contact you to review it and submit corrections or changes before the document is posted online. A number of organizations and individuals in the Northeast Region will be notified by e-mail of the availability of the document online.