Appendix II:

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Interactions between sea turtles and dredge gear in the U.S. sea scallop (*Placopecten magellanicus*) fishery, 2001–2008

Kimberly T. Murray*

NOAA Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543, USA

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ABSTRACT

Since 2006, the National Marine Fisheries Service (NMFS) has mandated gear modifications ("chain mats") and fishing effort reductions in the U.S. Mid-Atlantic sea scallop dredge fishery to alleviate or minimize interactions with sea turtles. Turtle interactions with gear can be defined as those that are "observable" based on standard fishery observer protocols, plus unobserved interactions, which include both quantifiable and unquantifiable interactions. Once a gear modification is in place, a turtle interaction that was once observable may become unobservable, because the gear modification successfully prevented the turtle from being captured. This paper describes turtle interactions in scallop dredge gear from 2001 to 2008, identifies gear and environmental correlates with observable interaction rates, and reports the average annual number of interactions and adult-equivalent interactions before and after chain mats were mandated in the fishery. Fisheries observer data were used to develop a Generalized Additive Model (GAM) to estimate rates of observable interactions of hard-shelled turtles. These rates were applied to commercial dredge fishing effort to estimate the total number of observable interactions, and to infer the number of unobservable, yet quantifiable interactions after chain mats were implemented. Interaction rates of hard-shelled turtles were correlated with sea surface temperature, depth, and use of a chain mat. The average number of annual observable interactions of hard-shelled turtles in the Mid-Atlantic scallop dredge fishery prior to the implementation of chain mats (1 January 2001 through 25 September 2006) was estimated to be 288 turtles (CV = 0.14, 95% CI: 209–363), which is equivalent to 49 adults. After implementation of chain mats, the average annual number of observable interactions was estimated to be 20 turtles (CV = 0.48, 95% CI: 3–42), equivalent to 4 adults. If the rate of observable interactions from dredges without chain mats had been applied to trips with chain mats, the estimated number of observable and inferred interactions of hard-shelled species after chain mats were implemented would have been 125 turtles per year (CV = 0.15, 95% CI: 88–163). Results from this analysis suggest that chain mats and fishing effort reductions contributed to the decline in estimated turtle interactions after 2006.

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1. Introduction

Over the past decade, scientists, the fishing industry, environmental groups and protected species managers have aimed to reduce or alleviate interactions between sea turtles and dredge gear harvesting sea scallops (*Placopecten magellanicus*) in the U.S. scallop fishery. Studies estimated several hundred loggerhead turtle (*Caretta caretta*) interactions with dredge gear during 2001–2005 in the Mid-Atlantic (Murray, 2004a,b, 2005, 2007), and fisheries observers have documented additional turtle interactions in dredge gear in recent years. Since 2001, observers have mainly reported loggerhead interactions with dredge gear, though they reported 2 Kemp's ridleys (*Lepidochelys kempii*) in dredge gear outside the Mid-Atlantic region (this study). Loggerheads and Kemp's ridley are protected under the U.S. Endangered Species Act (ESA). Interactions between listed species and fishing gear are considered "takes" under the ESA and are prohibited, unless a special exemption has been granted under Section 7 or Section 10 of the ESA.

Protected species managers and the industry have modified scallop dredge gear to reduce the gear's impact on turtles. Turtle "chain mats" have been required in the dredge fishery since 25 September 2006 (Fig. 1), in waters south of 41°9.0′N during May 1–Nov 30 each year (U.S. Department of Commerce, 2009). Chain mats consist of vertical and horizontal chains hung between the sweep and cutting bar and are intended to reduce the severity of some turtle interactions by preventing turtles from entering the dredge bag. Interaction rates between turtles and dredges with and without chain mats are not expected to differ (NMFS, 2008). Monitoring the effectiveness of chain mats is difficult because interactions could still be occurring, but the chain mat prevents the turtle from being captured and observed. Quantifying the maximum potential number of turtle captures prevented by chain mats

* Tel.: +1 508 495 2197; fax: +1 508 495 2066.
E-mail address: Kimberly.Murray@noaa.gov

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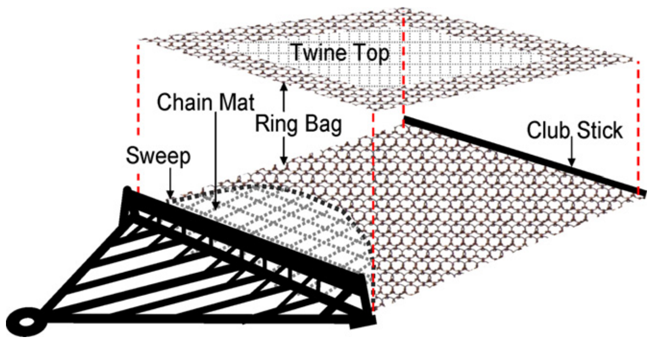

Fig. 1. Sea scallop dredge with turtle chain mat, strung between the sweep and cutting bar on the underside of the dredge bag.

would allow managers and the industry to better evaluate the gear modification.

The distribution of scallop fishing effort in the Mid-Atlantic responds to rotational area management, in which areas are closed to fishing periodically to protect juvenile scallops and then reopened for harvest once scallops reach a certain biomass. The goal of this system is to direct fishing effort to areas of high scallop biomass, thereby increasing scallop catch-per-unit-effort, while protecting juvenile scallops. Fishing activity inside the management areas is controlled via trip and possession limits, and outside of the management areas via days at sea limitations. The distribution and intensity of scallop fishing is very dynamic from year to year, as fishers respond to effort controls and the market.

While the Mid-Atlantic sea scallop fishery operates year-round, loggerhead turtles are typically present on the fishing grounds from late spring/early summer to the fall (Shoop and Kenney, 1992; Morreale and Standora, 2005; Hawkes et al., 2007; Mansfield et al., 2009). Fishery managers have implemented time/area closures or effort reductions in the Mid-Atlantic to minimize the industry's interactions with loggerheads. In order to balance turtle protection with the goals of rotational area management, fishing effort for the year remains allocated based on the scallop resource but limited in times and areas when turtles are present in the Mid-Atlantic (Fig. 2). For example, beginning in 2006 the National Marine Fisheries Service (NMFS) closed the "Elephant Trunk" sea scallop access area in the Mid-Atlantic from September 1 to October 31 to reduce sea turtle interactions, based on historic patterns of observed interactions in that area (U.S. Department of Commerce, 2006). Fishers can still take their allocated number of trips in this area, with the exception of September and October. In managing the fishery, NMFS must consider other times and areas for effort reductions each year to reduce impacts on sea turtles (NMFS, 2008).

This analysis estimates turtle "interactions" rather than "bycatch". Bycatch typically refers to discarded plus retained incidental catch (Alverson et al., 1994), and may also include unobserved mortality (NMFS, 1998). In the case of ESA protected species, bycatch estimates typically include animals captured in the bag or observed interacting with the gear (Murray, 2004a,b, 2005, 2007, 2009), both of which are considered "takes" under the ESA. Once a gear modification is in place, interactions may still occur but will not be observed if the modification successfully prevents capture of the animal. Therefore, traditional methods to estimate bycatch will under-represent the level of takes in the fishery.

The total number of interactions can be defined as those that are "observable" based on standard fishery observer protocols, plus unobserved interactions, which include both quantifiable and unquantifiable interactions. Unobserved, quantifiable interactions can be estimated after a gear modification is in place, based on what is known about gear and environmental factors affecting observable interaction rates. Unobserved, unquantified interactions will

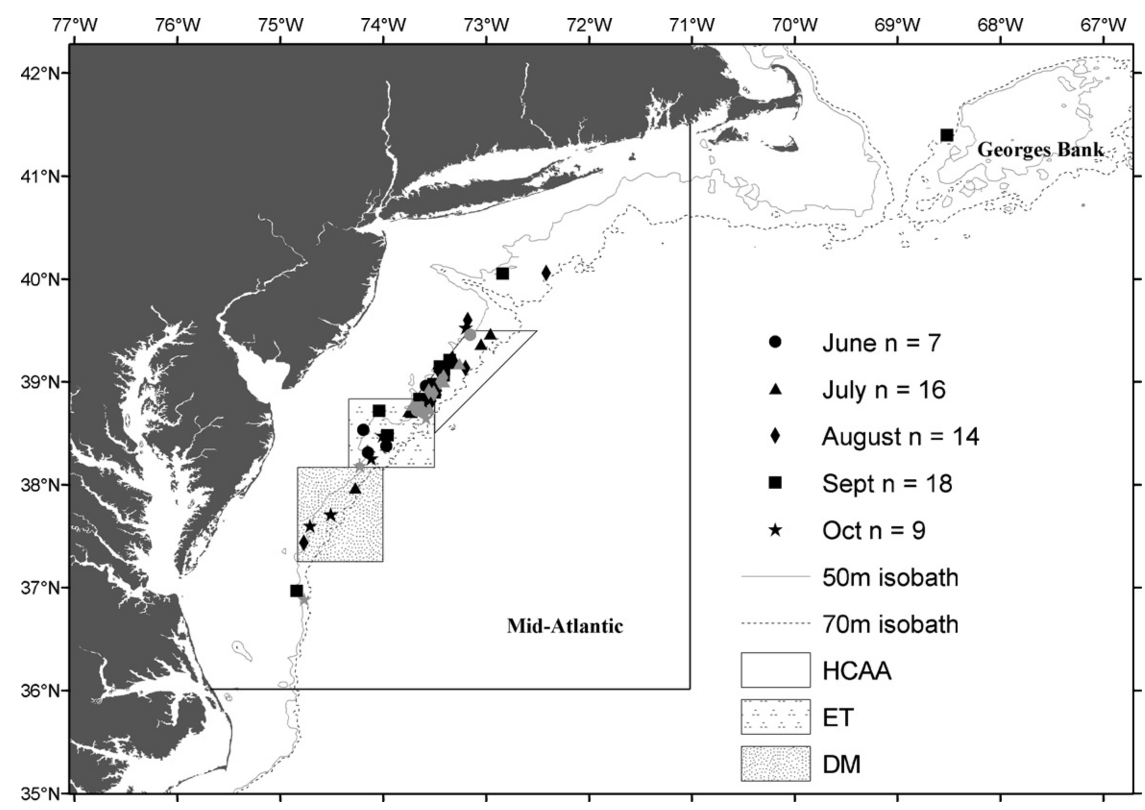

Fig. 2. Distribution of observed sea turtles in scallop dredge gear during on-watch hauls 2001–2008, showing boundaries of Mid-Atlantic study area and Mid-Atlantic scallop fishery management areas. Unidentified turtle species are in gray, and the turtle outside of the study area is a Kemp's ridley. HCAA = Hudson Canyon Access Area, ET = Elephant Trunk, DM = Delmarva.

occur whether there is a gear modification or not, but cannot be estimated due to a lack of evidence.

The purposes of this paper are to: (a) characterize turtle interactions in scallop dredge gear during 2001–2008; (b) identify factors correlated with estimated rates of observable interactions of hard-shelled turtle species over this time period in the Mid-Atlantic; (c) estimate the average annual number of observable interactions prior to the implementation of chain mats; and (d) estimate the average annual number of observable interactions plus unobserved, quantifiable loggerhead interactions after implementation of chain mats. This analysis also reports adult equivalent interactions, an important metric for understanding population level impacts of fisheries interactions (Haas, 2010). Results from this analysis will increase information available to fisheries managers, industry, and researchers aiming to understand and reduce the impacts of scallop dredge gear on turtles in the western North Atlantic.

2. Methods

2.1. Study region

The U.S. commercial scallop dredge fishery occurs mainly in the Mid-Atlantic and on Georges Bank. From 2001 to 2008, 25% of commercial scallop dredge effort (i.e. fishing hours) was outside of the Mid-Atlantic, where 2 Kemp's ridley turtle were observed. To date, observed turtle catches on Georges Bank are too rare to produce scientifically-defensible estimates of sea turtle interactions with scallop dredge gear. Therefore, an estimate for hard-shelled turtle species was calculated only for the Mid-Atlantic, defined in this study as west of 71°W and south of 42°N, to the southern limit of the distribution of the sea scallop dredge fishery (~36°N), extending westward to the coastline.

2.2. Data sources

2.2.1. Observer data

Data collected by NMFS Northeast Fisheries Science Center observers aboard commercial scallop dredges during 2001–2008 were analyzed to derive sea turtle interaction rates, expressed as the number of observed turtles per fishing hour. Observable interaction rates were estimated based on turtles reported via standard Northeast Fisheries Observer Program (NEFOP) sampling protocols when an observer was "on-watch", i.e. systematically collecting data on the haul characteristics, the catch, and details of any protected species interaction. Observable interaction rates were based on turtles either captured in or on the dredge gear, or observed interacting with the gear. Observers may collect data opportunistically when they are "off-watch", but these data are not used in the calculation of interaction rates because it is not known what fraction of off-watch interactions are reported. The quality of information collected by observers on turtles caught during on and off-watch hauls does not differ, so off-watch observations of turtles are included only in the description of fisheries interactions. Observers sampled roughly 3% of commercial fishing effort in the Mid-Atlantic during 2001–2008 (Table 1), proportional in space and time to commercial effort throughout the year.

2.2.2. Commercial data

Mandatory Vessel Trip Reports (VTRs) completed by commercial scallop fishermen during 2001–2008 provided a measure of total fishing effort. "Fishing hour" was the total amount of hours spent fishing per dredge. Trips used either 1 dredge (55%) or 2 dredges (45%). Dredge trips were coded as using a chain mat if they fished south of 41°9.0′N during 1 May to 30 November after September 25, 2006 (34% of all trips), when chain mats became mandatory in the fishery.

2.2.3. Sea surface temperature (SST) and chlorophyll (CHL) data

Sea surface temperature (SST) data were obtained for all VTR scallop dredge trips from 5-day SST composites derived from AVHRR Pathfinder Version 5, Modis Aqua, Modis Terra, and GOES satellites, or 5-day climatology images downloaded from NASA's Jet Propulsion Laboratory (Warden and Orphanides, 2008). Similar data were obtained for observed hauls for which SST data were missing (35%, because observers did not collect SST prior to 2004). Satellite-derived SST differed from observer recorded data on average by 0.2 °C (R^2 = 0.90). Surface chlorophyll *a* concentrations were obtained for all VTR and observed trips from five day composites of SeaWiFS high resolution satellite images from 2001 to 2008 (Warden and Orphanides, 2008).

2.3. Analytic approach

2.3.1. Estimation of observable interaction rates

2.3.1.1. Interaction rate model. Unidentified hard-shelled species were pooled with loggerhead turtles to estimate rates of observable interactions. It is likely that all or most of the unidentified turtles are loggerheads because all positively-identified observed turtles in the Mid-Atlantic were loggerheads and observer comments regarding unidentified turtles were consistent with loggerhead characteristics. Interaction rates were expressed as:

$$R = \frac{\text{number of observed turtles}}{\text{observed fishing hour}} \quad (1)$$

A Generalized Additive Model (GAM) with a Poisson distribution (GAM function, SPLUS 7.0) was used to model the expected turtle interaction rate. The form of the Generalized Additive Model (GAM) can be written as:

$$\text{Log}(E[y_j]) = \log(\text{fishing hours}_j) + \alpha + \sum_{i=1}^{n} f_i(x_{ij}) + \xi \quad (2)$$

where y_j is the number of hard-shelled turtles observed on the jth haul, α is a constant intercept term, f_j are a series of smooth-

Table 1
Observer and commercial fishing effort, coverage levels, and observed on-watch turtles by year in Mid-Atlantic dredge gear. VTR = Vessel Trip Report commercial data; OC = Percent observer coverage, expressed as: (observed fishing hours/VTR fishing hours × 100). Cc = *Caretta caretta*, Lk = *Lepidochelys kempii*, Ui = Unidentified.

Year	Observed dredge hours	VTR dredge hours	OC	Cc	Lk	Ui
2001	9440	512,980	2%	2	0	9
2002	13,651	614,502	2%	15	0	2
2003	16,632	651,436	3%	17	0	5
2004	26,884	656,958	4%	8	0	0
2005	16,886	567,034	3%	0	0	0
2006	5175	324,973	2%	1	0	0
2007	12,711	386,143	3%	2	1	0
2008	24,280	430,438	6%	2	0	0
Total	125,658	4,144,464	3%	47	1	16

ing functions for each predictor variable, x_i describe environmental or fishing characteristics at each haul, and ξ is unexplained error (Hastie and Tibshirani, 1990).

2.3.1.2. Model selection process. Nine variables were tested in the model selection process. These variables were chosen based on *a priori* knowledge of factors affecting estimated interaction rates in scallop fisheries (Murray, 2004a,b, 2005, 2007) or anecdotal information. These included: sea surface temperature, depth, latitude, chlorophyll, use of a chain mat, time of day when the turtle was captured (binned into six 4 h periods), number of hauls made on a trip, the amount of scallop tons landed, and frame width of a dredge. After the preferred model was selected, year, spatial area, and month were tested to see if they explained significantly more variation in interaction rates than what was already explained by the preferred model. Spatial area referred to three scallop management areas and the open area outside the management areas. The model selection process was repeated separately with only loggerheads as the response to evaluate whether factors affecting estimated interaction rates changed.

The nine primary variables were tested in a forward stepwise model selection process (step.gam function, SPLUS 7.0). The null model consisting of the overall mean was the initial model in the stepwise procedure. At each step, the forward stepwise algorithm selected that variable which generated the greatest change in the Akaike Information Criterion (AIC) relative to all other model variables. Continuous variables were considered as smooth terms in the model using the default degrees of freedom in the fitting procedure. To ensure the step.gam procedure did not over fit, variables were also manually added to the null model, in the order in which the automated procedure selected the variables, and then evaluated with respect to the amount of deviance reduced. Variables that had a small change in AIC (i.e. <7), or that reduced the deviance by <2%, were not included in the model (Burnham and Anderson, 2002).

The final model was examined for overdispersion, measured by calculating the dispersion parameter (ϕ), defined as:

$$\phi = \frac{\Sigma(y_i - \hat{\mu}_i)^2/\hat{\mu}_i}{\text{residual df}} \quad (3)$$

2.3.2. Estimated turtle interactions

The final model was applied to VTR trips to derive an estimated hard-shelled turtle interaction rate for each VTR trip, and to estimate the number of observable interactions on each VTR trip. Total estimated observable interactions were the sum of the predicted number of turtle interactions over all trips in a year. Estimated loggerhead interactions were also derived by re-parameterizing the final model with loggerheads as the response and then applying the model in the same manner to VTR trips.

Unobserved, quantifiable interactions were estimated by applying the observed interaction rate of dredges with no chain mats to dredges with chain mats. To do this, both the hard-shelled turtle and loggerhead model were applied to VTR trips coded for having no chain mat. These additional unobserved interactions were estimated to have occurred, but were not observable because the chain mat prevented turtles from entering the dredge bag. The difference between the observable estimates and the unobserved but quantifiable estimates represents the number of turtle captures avoided due to the chain mat.

Bootstrap resampling was used to derive CVs around the average annual interaction estimates. Bootstrap replicates were generated by sampling hauls with replacement 1000 times from the original observer dataset, and then the preferred model parameterized with each replicate. Estimated interactions in each year were calculated by applying each replicate dataset to VTR dredge effort; 2006 was split into two periods, before and after chain mats. For each replicate, estimates of annual interactions were averaged in each time period (i.e. pre and post chain mat). CVs and 95% CIs around the average annual estimates were computed from the bootstrap replicates.

2.3.3. Estimated adult equivalent interactions

Observed sea turtles were grouped into size classes based on the six loggerhead life stages (TEWG 2009): Stage I (≤16.2 cm CCL), Stage II juvenile (>16.21–60.45 cm CCL), Stage III juvenile (>60.45 cm–75.72 cm CCL), Stage IVa juvenile (>75.72–88.61 cm CCL), Stage IVb juvenile (>88.61–101.5 cm CCL), and Stage V adult (>101.5 cm CCL). Because the life stages overlap (TEWG, 2009), size classes were truncated at the intersection of each life stage to create discrete size classes (Fig. 3a). Reproductive values (RV), defined as the contribution that the individual makes to current and future reproduction (Fisher, 1930), were assigned to the mid-point of each size class based on Wallace et al. (2008). Stage IV turtles were subdivided because RVs vary widely in this life stage. RVs assigned to each respective stage class were: 0.002, 0.008, 0.040, 0.124, 0.547, and 1.0. Similar RVs have been used for loggerheads (Bolten et al., 2010). RVs reported in Bolten et al. (2010) were not used because the RVs were based on ages rather than size, and included information on breeding/non-breeding adult stages which fisheries observers do not collect.

The number of estimated adult equivalent (AE) interactions over all six life stages and all eight years was calculated as:

$$\text{AE} = \sum_{j=1}^{8}\sum_{i=1}^{6} B_j * P_i * \text{RV}_i \quad (4)$$

where B = total estimated turtle interactions in dredge gear in year j, P = the proportion of loggerheads observed in life stage i, and RV_i = the reproductive value for life stage i. Loggerhead RVs and size classes were applied to the estimated hard-shelled interactions and the loggerhead interactions because unidentified turtles were not measured and many were likely loggerheads. It is assumed the unidentified turtles followed the same size distribution as the observed loggerheads. If the unidentified turtles were disproportionately smaller, the estimated adult equivalent interactions would be biased high, or if some were Kemp's ridleys the estimate would be biased low.

3. Results

During 2001–2008, observers reported 47 loggerheads, 1 Kemp's ridley, and 16 unidentified turtle interactions in scallop dredge gear (Table 1, Fig. 2). In addition, 15 turtle interactions (9 loggerheads, 1 Kemp's ridley, 5 unidentified) occurred on hauls when an observer was "off-watch" and were excluded from the rate analysis. Lastly, 8 severely decomposed turtles were caught in scallop dredge gear from 2001 to 2008, though these turtle were also excluded from the analysis because the state of decomposition suggested they died prior to interacting with the gear.

3.1. Characteristics of observed interactions

3.1.1. Temporal and spatial distribution

During 2001–2008, observers recorded loggerhead interactions between June 17 and Oct 14, from 36°53′N to 40°3′N. Loggerhead interactions occurred in waters 36–68 m deep, and in surface water temperatures ranging from 18 °C to 25 °C. The unidentified species of turtles were observed within the same time and area as loggerheads. The 2 Kemp's ridley turtles were observed north of 40°55′N and east of 70°W. One Kemp's ridley was observed in September in waters 77 m and 16 °C; the other occurred in August but the

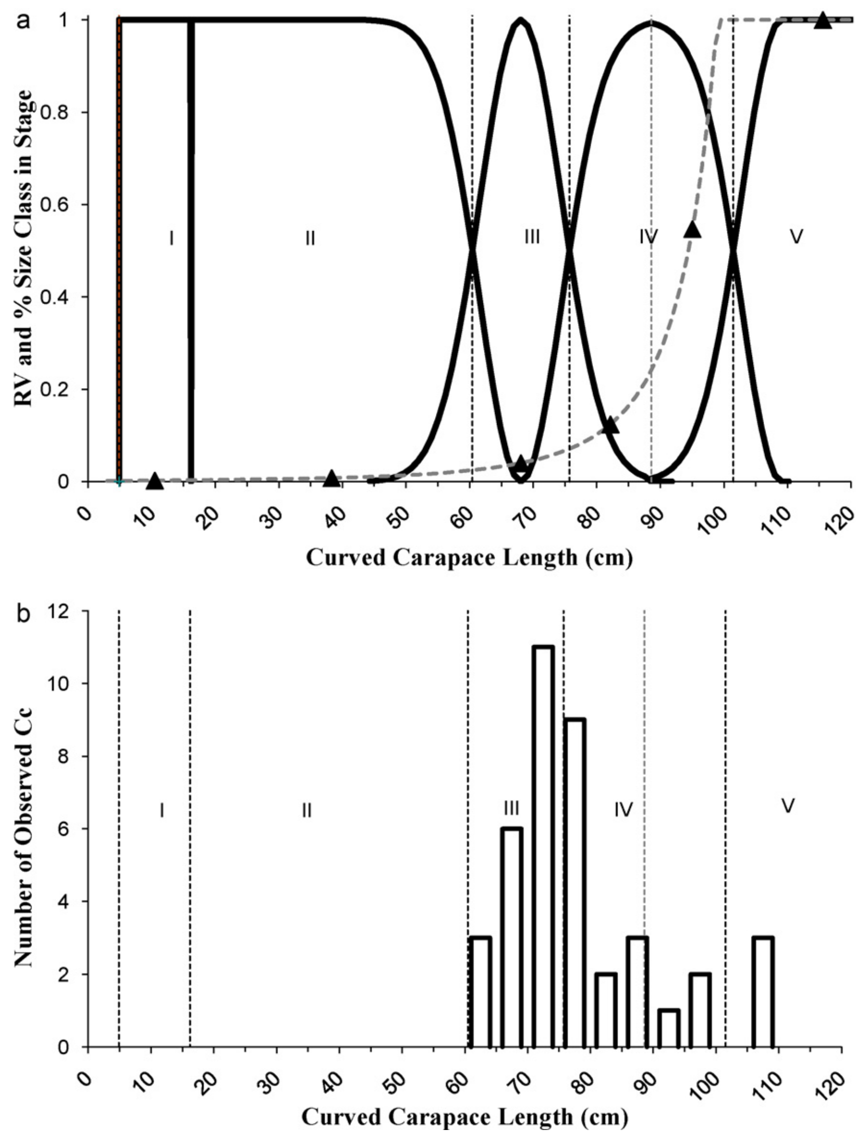

Fig. 3. (a) Loggerhead life stage (TEWG, 2009) and Reproductive Values (Wallace et al., 2008) (gray dashed line). Size class breaks are represented by dashed lines, and RVs at the mid-point of each size class represented by black triangles; (b) Distribution of observed loggerhead turtle sizes overlaid on life stage classes (dashed lines).

observer was "off-watch" and did not record depth or temperature information on the haul.

3.1.2. Turtle sizes and life stage

Curved carapace length (CCL, curvilinear length of the carapace from the nuchal notch to the posterior marginal tip measured to the nearest 0.10 cm) and curved carapace width (CCW, curvilinear width of the carapace across the widest part of the shell) of the observed loggerheads ranged between 62 and 107 cm CCL and 45 and 99 cm CCW ($n = 40$ turtles) (Fig. 3b). Sizes of observed loggerheads corresponded to Stage III (53%), Stage IV (40%), and Stage V (7%) life stage classes. One Kemp's ridley was 24.3 cm CCL and 26 cm CCW; the other Kemp's ridley and unidentified turtles were not measured.

3.1.3. Animal condition

During 2001–2008, 88% ($n = 49$) of observed loggerheads interacting with dredge gear during on and off-watch hauls were alive (with or without injuries), and 12% ($n = 7$) were dead. One Kemp's ridley was alive and the other was dead. All of the unidentified species were alive. Seventy-eight percent ($n = 18$) of the Stage III loggerheads were alive, and 100% were alive in Stage classes IV and V.

3.1.4. Entanglement situations

Entanglement situations are reported here for turtles observed in dredge gear from 2006 to 2008 only, because detailed descriptions of interactions between observed turtles and scallop dredge gear prior to this time have been described in Haas et al. (2008). Five loggerheads were caught in dredge gear equipped with chain mats, including two which occurred on off-watch hauls (Table 2). With the exception of one chain mat, all of the chain mats were properly configured. On properly configured chain mats the horizontal chains must intersect the vertical chains such that the length of each side of the openings formed by the intersecting chains is less than or equal to 14″ (35.5 cm), with the exception of the side of any individual opening created by the sweep (50 CFR 223.206(d)(11)). Two loggerheads and a Kemp's ridley were captured in hauls without chain mats (two were before or outside of the regulatory period/area, and the other had improper connections in the chains so was considered to have no chain mat).

Table 2
Entanglement situations of sea turtles observed in scallop dredge gear, 2006–2008. Cc = *Caretta caretta*, Lk = *Lepidochelys kempii*.

	Chain mat properly configured	Species	Animal condition	Position of entanglement, per observer/captain comments
Dredge with chain mat	Y	Cc	Alive, injured	Turtle stuck on the outside of the turtle chain mat
	Y	Cc	Alive, injured	Turtle on top of dredge frame
	N	Cc	Alive, injured	Chains measured 16“at top and 20” at bottom. Loggerhead caught inside the dredge bag.
	Y	Cc	Dead	Turtle wedged between bale bars
	Y	Cc	Dead	Turtle wedged between bale bars
Dredge without chain mat	N/A	Cc	Alive, injured	Turtle caught inside dredge bag
	N/A	Lk	Dead	Turtle caught inside dredge bag
	N/A	Cc	Alive, injured	Turtle hanging on outside of dredge bag by its flipper

3.2. Commercial effort characteristics

Commercial fishing effort in the Mid-Atlantic declined in scope and magnitude after the implementation of chain mats (Figs. 4 and 5). Fishing effort in the Mid-Atlantic is influenced by scallop rotational management that results in higher scallop catches per unit effort, days at sea allocations in the fishery, and management actions to shift effort from areas and times of potential turtle interactions. From 2001 to September 2006 (prior to chain mats), the average dredge hours fished per year from November to May was ~260,000 h, and from June to October was ~248,000 h. From September 2006 to 2008, the average dredge hours fished per year from November to May was ~148,000 h, and from June to October was ~119,000 h. During the months sea turtles are generally present in the Mid-Atlantic (June–October), effort declined by roughly 52%.

3.3. Estimation of observable interaction rates

3.3.1. Interaction rate model

Factors correlated with observable interaction rates of hard-shelled turtles in the Mid-Atlantic sea scallop dredge fishery included: SST (smoothed), depth (smoothed), and use of a chain mat (Table 3 and Fig. 6). Cumulatively these variables explained 21% of the variation in observable interaction rates. Year, spatial area, and month explained <1% additional variance over these variables so were not included in the final model. Factors correlated with observable rates of pooled species (unidentified and

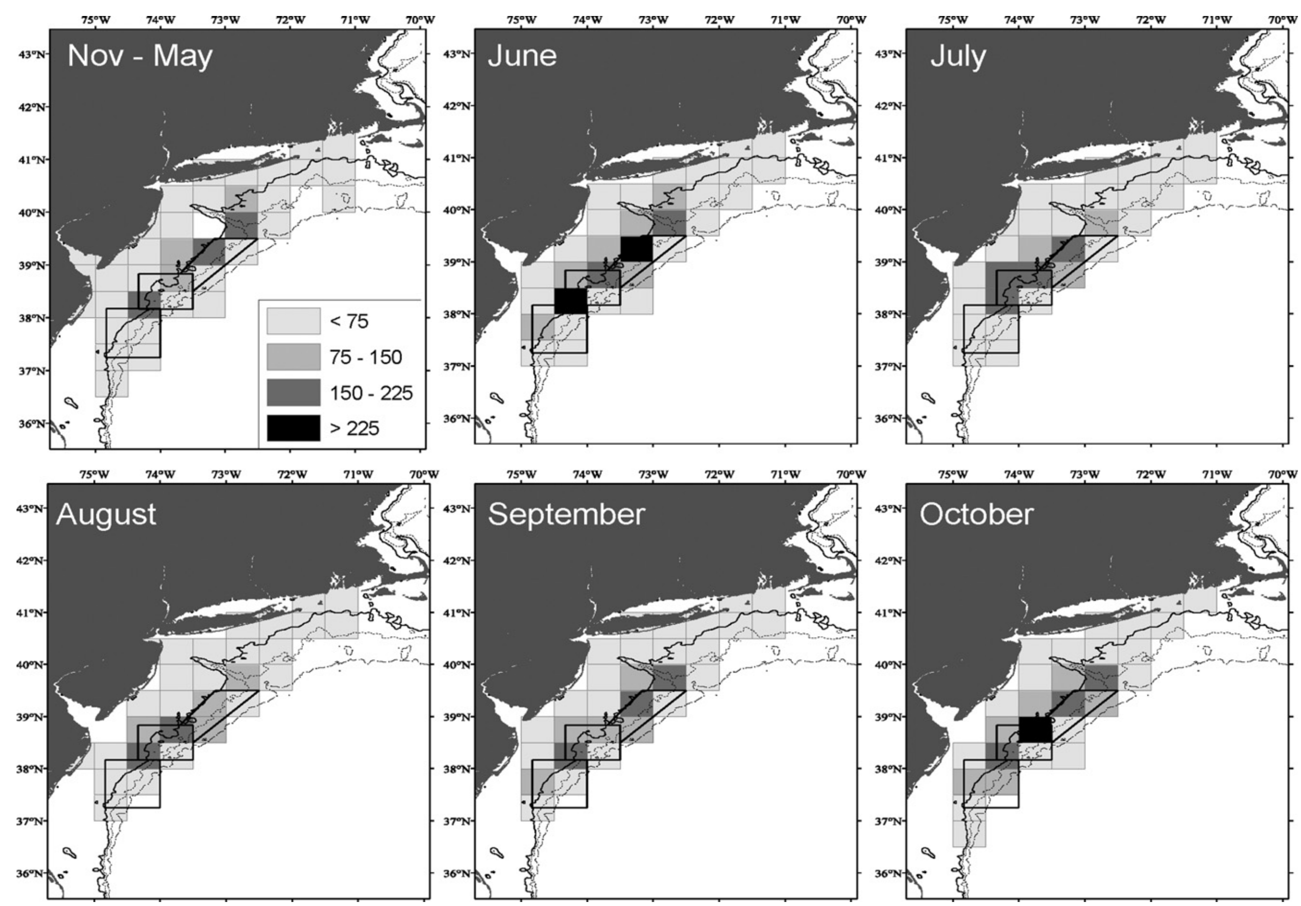

Fig. 4. Distribution over 30' squares of commercial fishing effort on VTR dredge trips, 2001–September 25 2006 (pre chain mats). Each square represents the total amount of dredge hours fished per day in each stratum (where stratum is month block within 2001–September 25 2006). Squares with fewer than 10 VTR trips have been excluded. The 50 m, 70 m, and 200 m bathymetry lines are shown. From north to south, the Hudson Canyon Access Area, Elephant Trunk, and Delmarva scallop management areas are represented by the black rectangles.

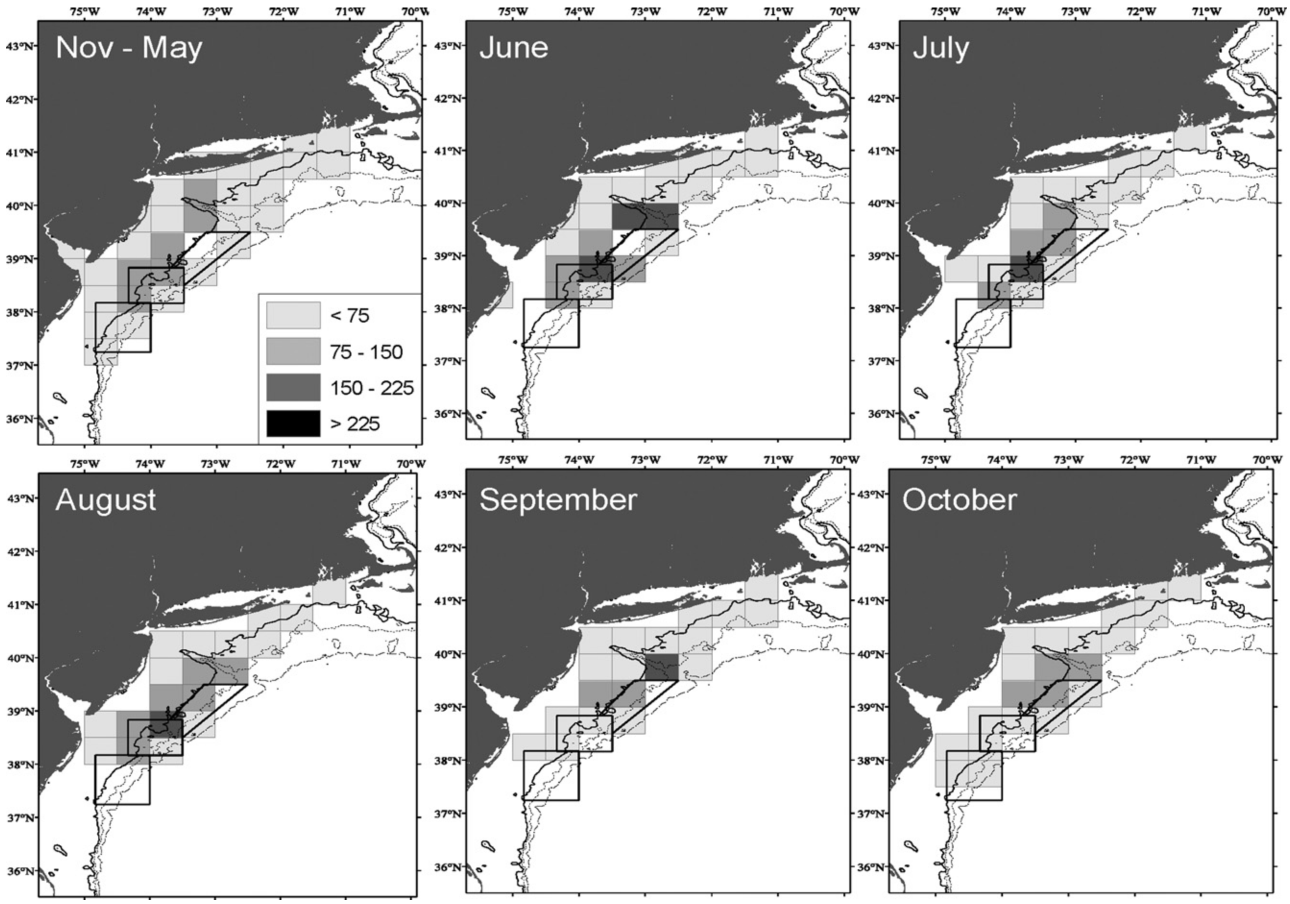

Fig. 5. Distribution over 30′ squares of commercial fishing effort on VTR dredge trips, September 26 2006–2008 (post chain mats). Each square represents the total amount of dredge hours fished per day in each stratum (where stratum is month block within September 26 2006–2008). Squares with fewer than 10 VTR trips have been excluded. The 50 m, 70 m, and 200 m bathymetry lines are shown. From north to south, the Hudson Canyon Access Area, Elephant Trunk, and Delmarva scallop management areas are represented by the black rectangles.

loggerheads) were the same as those when modeling only loggerheads as the response. The estimated dispersion parameter of the selected model was 0.90, indicating no overdispersion (Burnham and Anderson, 2002).

The model suggests that the observable interaction rate of a chain mat equipped dredge is ~1/7 the rate of a dredge without a chain mat, when holding all other variables constant in the model. When the interaction rate of dredges without chain mats was applied to VTR trips in the Mid-Atlantic, the average estimated rates were highest from July to October (Fig. 7). The higher rates in October were primarily south of 39°N.

3.4. Estimated interactions

The average annual amount of observable turtle interactions in the Mid-Atlantic scallop dredge fishery from 2001 to 25 September 2006 (prior to the implementation of chain mats) was 288 estimated hard-shelled species per year (CV = 0.14, 95% CI: 209–363),

Table 3
Variables examined in an analysis of factors correlated with rates of observable interactions of loggerhead turtles in dredge gear. "Secondary" variables were tested separately, after the best-fitting candidate model was selected. The selected model is highlighted in gray.

Model structure	Residual d.f.	Residual deviance	Cumulative % of deviance explained	AIC statistic	Pr (Chi)
Primary variables					
Null model	66,580.0	873.6		875.6	
Null + s(SST)	66,576.2	752.0	0.139	761.6	0.00
Null + s(SST) + s(depth)	66,572.2	708.5	0.189	726.2	0.00
Null + s(SST) + s(depth) + chain mat	66,571.2	688.4	0.212	708.0	0.00
Null + s(SST) + s(depth) + chain mat + s(scallop tons)	66,567.3	676.9	0.225	704.4	0.02
Null + s(SST) + s(depth) + chain mat + s(scallop tons) + s(latitude)	66,567.3	679.4	0.222	706.8	0.06
Null + s(SST) + s(depth) + chain mat + s(chlorophyll a)	66,567.3	685.4	0.215	712.8	0.54
Null + s(SST) + s(depth) + chain mat + time bin	66,570.2	687.0	0.214	708.6	0.24
Null + s(SST) + s(depth) + chain mat + number of hauls	66,570.2	688.2	0.212	709.9	0.72
Null + s(SST) + s(depth) + chain mat + dredge frame width	66,570.2	688.0	0.212	709.7	0.55
Secondary variables					
Null + s(SST) + s(depth) + chain mat + year	66,570.2	680.5	0.221	702.2	0.01
Null + s(SST) + s(depth) + chain mat + spatial area	66,566.2	677.5	0.224	707.2	0.05
Null + s(SST) + s(depth) + chain mat + month	66,560.3	687.0	0.214	728.4	0.10

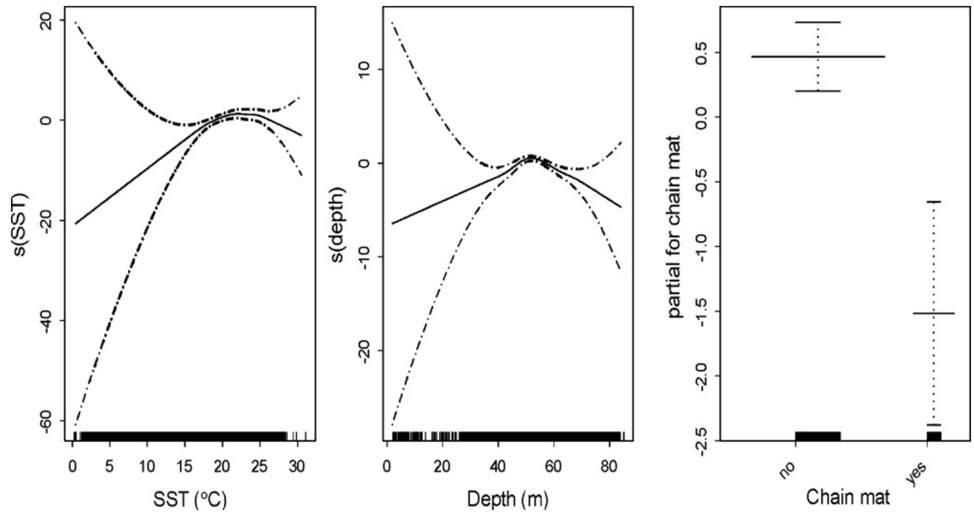

Fig. 6. Generalized additive model smoothers depicting effect of sea surface temperature, depth, and chain mats on hard-shelled turtle interaction rates. Rugplot on *x*-axis shows the number of observations; dashed lines are 95% confidence intervals.

which equates to 49 adult equivalents, and 218 loggerheads (CV = 0.16, 95% CI: 149–282), which equates to 37 adult equivalents (Table 4).

From 26 September 2006 to 2008 (after the implementation of chain mats) the average annual amount of observable interactions was 20 estimated hard-shelled turtles per year (CV = 0.48, 95% CI: 3–42), which equates to 4 adult equivalents, and 19 loggerheads (CV = 0.52, 95% CI: 2–41), which equates to 3 adult equivalents.

If the observable interaction rate from dredges without chain mats had been applied to trips that used chain mats from 26 September 2006 to 2008, the estimated number of observed inter-

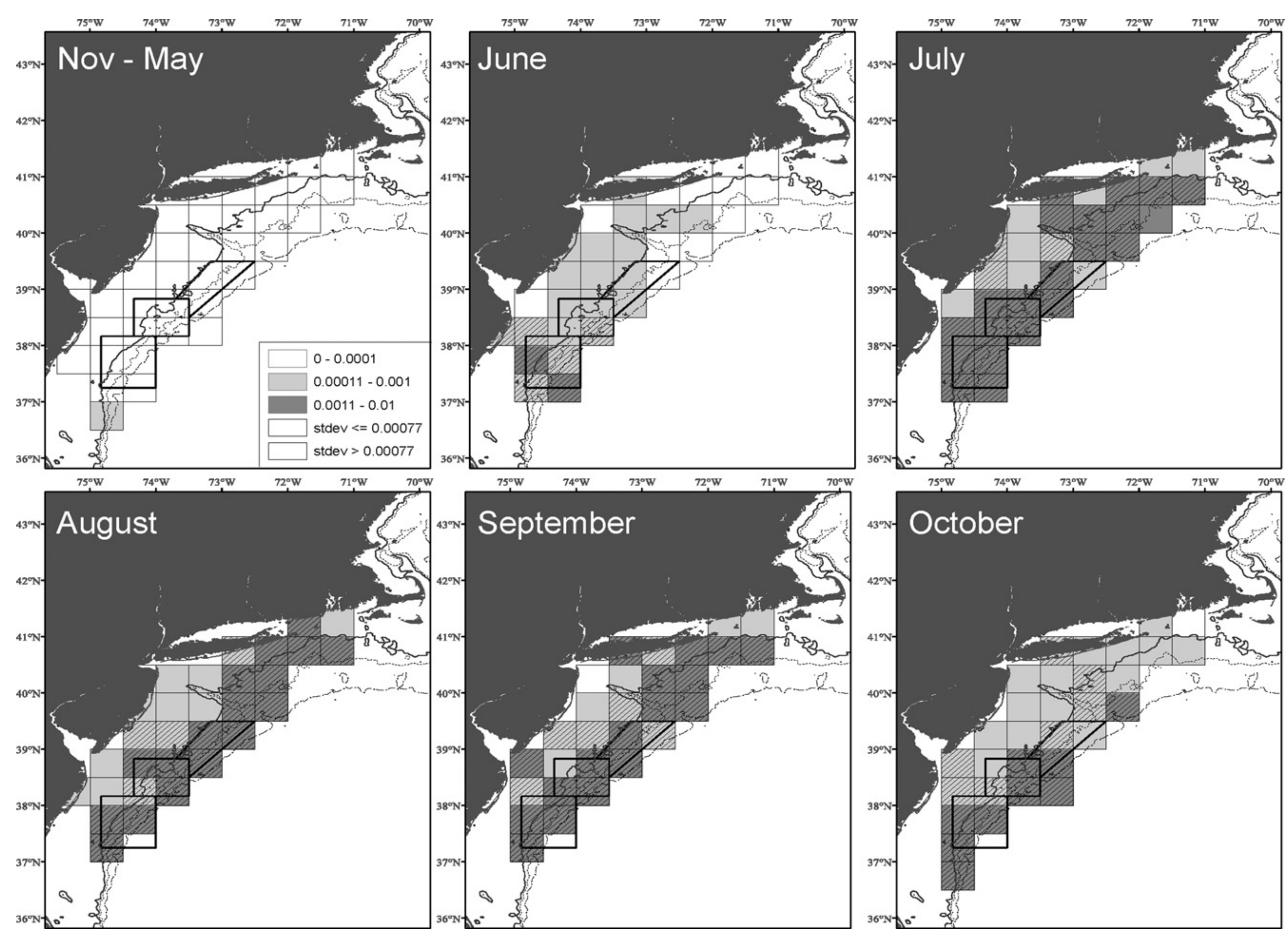

Fig. 7. Distribution over 30′ squares of average predicted interaction rates without chain mats on VTR dredge trips, 2001–2008. Squares with fewer than 10 VTR trips have been excluded. The 50 m, 70 m, and 200 m bathymetry lines are shown. From north to south, the Hudson Canyon Access Area, Elephant Trunk, and Delmarva scallop management areas are represented by the black rectangles. Median standard deviation around rates over all months = 0.00077.

Table 4
Average annual estimated interactions of hard-shelled (unidentified and loggerhead species pooled) and loggerhead turtles in the Mid-Atlantic scallop dredge fishery before and after chain mats were required on dredges (CV and 95% Confidence Interval). AE = adult equivalent estimated interactions. A = estimated interactions from dredges without chain mats; B = estimated observed interactions from dredges with or without chain mats; C = estimated observed and unobserved, quantifiable interactions from dredges without chain mats, to estimate the mat's maximum conservation value.

	Time period	Interactions		Interactions	
		Hard-shelled	AE	Loggerhead	AE
A	2001–25 Sept 2006	288 (0.14, 209–363)	49	218 (0.16, 149–282)	37
B	26 Sept 2006–2008	20 (0.48, 3–42)	3	19 (0.52, 2–41)	3
C	26 Sept 2006–2008	125 (0.15, 88–163)	22	95 (0.18, 63–130)	16

actions, plus unobserved, quantifiable interactions, would have been 125 hard-shelled species per year, and 95 loggerheads.

4. Discussion

These results suggest that the estimated rate of observable interactions increases as surface temperatures warm, and are higher around 40–60 m depth. These rates reflect the co-occurrence of sea turtles in the area (Braun-McNeill et al., 2008), the distribution of the scallop resource (Hart and Chute, 2004), and the behavior of turtles and scallop fishers. These broad times and areas suggest that high rates of observable interactions are not localized in space or time within a small area of the Mid-Atlantic. The risk of turtle interactions can be lowered if effort moves out of the Mid-Atlantic from July through October, versus shifting within the Mid-Atlantic during this time period. The Elephant Trunk closure during September and October is well placed as a conservation measure for turtles, so long as the effort does not increase in July or August in the Mid-Atlantic from effort redistributions.

The model unexpectedly predicted high interaction rates during July through September in the northeast region of the Mid-Atlantic, where no turtle interactions were observed. Few commercial dredge trips were observed (<1% observer coverage) in the Mid-Atlantic north of $\sim 40^\circ 30' N$ and west of $\sim 71^\circ W$, so the model may perform poorly in this region. If the model predicted zero turtle interactions for trips in this time and area the estimated interactions over all years would change by only ~1%, so the degree to which this affected the results was considered to be low. Turtle interactions could occur in this time and area, though more observer coverage is needed to determine whether rates are equivalent to rates farther south.

The percentage of dead turtles captured in dredge gear between 2001 and 2008 (12%) represents a minimum mortality estimate. Several turtles had injuries that may have led to mortalities, though guidelines to determine post-release lethal injuries are still being developed. The National Marine Fisheries Service has been consulting with experts to establish guidelines for assessing injuries to turtles captured in scallop dredge gear. Once these guidelines are established, turtle injuries from interactions with dredge gear can be reassessed to refine mortality rates in the fishery.

These results suggest that an estimated average of 105 turtles per year (125 turtles reduced to 20) were not captured because chain mats were implemented in 2006. Hence, the estimated maximum conservation benefit of the chain mats was 105 turtles per year. If all of these 105 turtles survived the interaction with the chain mat, and would not have survived had they been captured in the bag, then this 84% reduction would be viewed as the conservation benefit of chain mats. There is not enough information in this analysis to evaluate how the chain mat affected the injury and mortality rate of turtles in the gear, though by design the chain mat is intended to reduce injuries resulting from capture in the dredge bag. The realized conservation benefit could be better quantified if mortality and injury rates in traditional gear were refined, and mortality and injury rates in chain mat gear were known. There is no evidence to suggest that the injury rate of a chain mat equipped dredge is higher than that of a traditional dredge.

Reductions in fishing effort during months with high turtle interaction rates (July through October) contributed to the decline in estimated interactions after 2006. An estimated average of 163 turtle interactions per year (288 interactions reduced to 125, or a 57% reduction) were avoided from reductions in fishing effort from the pre-chain mat to post-chain mat period. Since 2006 the Elephant Trunk area was closed to fishing during September and October to protect sea turtles, the Delmarva area was closed to fishing year-round in 2007 and 2008 as part of rotational area management, and the Hudson Canyon Area was closed to fishing in 2008. These closures and other effort reductions tied to rotational area scallop management coincided with times and areas that historically had high turtle interaction rates.

The model developed in this analysis provides a tool to monitor turtle interactions with chain mats. NMFS is required to monitor levels of sea turtle interactions in the scallop fishery. With the use of chain mats preventing the observation of some turtle captures, and in turn preventing the ability to estimate the total number of interactions as had been done prior to chain mat use, the most recent ESA Biological Opinion on the fishery established a surrogate measure for monitoring the Incidental Take Statement (ITS) (NMFS, 2008). The ITS provides an exemption for the anticipated level of take by the fishery, while identifying measures necessary to minimize impacts from the exemption. The Opinion states that NMFS will use dredge hours as the surrogate measure of actual takes; if dredge hours do not exceed the benchmark level, it is presumed the ITS has not been exceeded. This study provides an alternate way to estimate loggerhead interactions in the fishery after 2005.

There are some statistical aspects of the model that should be considered prior to evaluating interactions in future years. First, the chain mat requirement is currently required every year from May to November. With each new year of data, hauls without chain mats will only be from the winter time, and therefore will not represent a random sample. Over the whole time series, hauls without chain mats will be clumped in the early years, and will also become disproportionately smaller in the dataset. In addition, observing and estimating interactions may become more complicated in the future if new modified dredges designed to direct turtles up and over the dredge are used in the fishery (Smolowitz et al., 2010).

In summary, this study offers new information to fisheries managers, the industry, and researchers aiming to reduce or alleviate turtle interactions in the Mid-Atlantic dredge fishery. The distribution of observable interaction rates in the fishery will help managers identify times and areas for further effort reductions if needed. Furthermore, reporting adult equivalent interactions may help managers prioritize conservation actions with limited resources (Wallace et al., 2008). The model developed here represents an alternative approach to monitoring turtle interactions with scallop dredge gear equipped with chain mats. Finally, this study suggests that chain mats and fishing effort reductions contributed to the decline in estimated turtle interactions after 2006.

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