Size distribution and trends in relative abundance of scalloped hammerheads (*Sphyrna lewini*) in the northern Gulf of Mexico, 2006-2021

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Size distribution and trends in relative abundance of scalloped hammerheads (*Sphyrna lewini*) in the northern Gulf of Mexico, 2006-2019

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Abstract

Scalloped hammerheads (*Sphyrna lewini*) are a common shelf-associated shark off the coast of Alabama. From May 2006 to October 2019, 230 scalloped hammerheads were captured during 1311 fisheries independent bottom longline sets. Trends in catch by sex were examined and catch data were standardized using a negative binomial generalized linear model to create a standardized index of relative abundance. Males were significantly larger and more abundant than females and few females larger than 175 cm stretch total length were caught. The standardized index of relative abundance indicated that the relative abundance of scalloped hammerheads in the sampling region has remained relatively stable over the past 14 years.

Introduction

Since 2006, fisheries independent bottom longline surveys have been conducted out of the Dauphin Island Sea Lab by the University of South Alabama. In recent years, Mississippi State University has collaborated on this effort. The majority of this survey work has taken place in the coastal and offshore waters of Alabama, though some work has been done in Louisiana, Mississippi, and Florida waters. The initial survey was designed as a complement to the annual National Marine Fisheries Service bottom longline survey; however, several survey design changes have taken place since then and ancillary surveys have been added. While little to no offshore sampling was done from 2006 to 2008, offshore sampling started in 2009 and has gradually increased in percentage of effort since then (Table 1; Appendix Figures 1-14). In total, 1454 sets have been completed to date. From these sets, scalloped hammerheads (*Sphyrna lewini*) were one of the most common shelf-associated sharks (n = 230). Length frequency distributions by sex and nominal and standardized catch per unit effort (CPUE, expressed as individuals 100 hooks^{-1} hour^{-1}) are presented below.

Methods

Field Sampling

Fisheries independent catch data were collected from 2006 to 2019 as part of inshore (Drymon et al., 2010) and offshore (Powers et al., 2018) bottom longline surveys conducted off the coasts of Louisiana, Mississippi, Alabama, and Florida (Figure 1). All bottom longline sampling followed standardized methods described in Drymon et al. (2020). Specifically, 100 gangions were clipped to a 1 nautical mile long 4mm monofilament mainline (454 kg test) and soaked for 1 hour. Each gangion was 3.66 m long, made up of 3mm monofilament (320 kg test), and terminated with a 15/0 circle hook baited with Atlantic mackerel (*Scomber scombrus*). All fishes that could be safely and easily handled were boated, measured to the nearest cm (standard, fork, and stretch total lengths), examined for sex and maturity, and weighed to the nearest 0.1 kg. Larger fishes were generally left in the water; for these individuals, maturity was not determined and stretch total length was estimated.

Length Frequency Analysis

A length frequency distribution for scalloped hammerheads was created. To examine for differences in catch based on sex, a binomial test was used to see if the male to female ratio differed significantly from a 1:1 ratio (α = 0.05). Additionally, a two-sample Kolmogorov-Smirnov test was used to examine differences in length between sexes (α = 0.05).

CPUE Analysis

Catch data were converted to nominal catch per unit effort (CPUE), expressed as individuals 100 hooks^{-1} hour^{-1}. Next, to standardized CPUE, a negative binomial generalized linear model (nbGLM; Hardin and Hilbe 2007) was fit to the data using the *glmmTMB* package (Brooks et al. 2017) in R (R Core Team 2021). Abiotic variables thought to influence CPUE were added to the model using forward step-wise model selection. The abiotic variables used in model selection were Year, Depth, Surface Temperature, Bottom Temperature, Surface Salinity, Bottom Salinity, Bottom Dissolved Oxygen, and Day Length (Table 2). All variables other than year were treated as continuous. The variable Year was included in all model runs. Soak Time was also included as an offset to account for variability in soak time. For model selection, Akaike's Information Criterion (AIC) was used to identify the best-fitting model. Model fit was examined using the *DHARMa* package (Hartig 2019) in R to examine residuals and check for uniformity, outliers, dispersion, and zero-inflation. To check for multicollinearity, the *performance* package (Lüdecke et al. 2021) in R was used to examine variance inflation factors (VIFs), with VIFs less than 10 signifying low correlation (Dormann et al. 2013). To check for evidence of temporal and spatial autocorrelation, the r packages *gstat* (Gräler) and *ncf* (Bjornstad 2020) were used. Lastly, the R package *emmeans* (Lenth 2021) was used to calculate the standardized CPUE.

Results

From 2006 to 2019, 230 scalloped hammerheads were captured during fisheries independent bottom longline surveys (n = 1311 sets; 10.9% with positive catch). Males (n = 152) were encountered more frequently than females (n = 57; $P = 0.001$; Figure 2). Males (193.9 cm mean STL) were also significantly larger than females (151.9 cm mean STL; $P = 0.001$). The final version of the nbGLM included the variables Year, Depth, Day Length, Bottom Temperature, and Bottom Salinity, as well as Soak Time as an offset (Table 3). The year 2009 was excluded from the nbGLM due to a lack of abiotic sampling from that year, which prevented model convergence. In addition, sets completed at depths greater than 150 m (n = 9) were excluded from analyses. The VIFs for all variables in the final model were less than three, indicating low correlation, and model fit was deemed appropriate based on residuals, uniformity, outliers, dispersion, or zero-inflation (Figure 3). There was some evidence of unaccounted for spatial autocorrelation in the data (Appendix Figure 15). Overall, there were no noticeable trends within the standardized index of relative abundance from 2006 to 2019 (Table 4; Figure 4). While nominal CPUE was noticeably lower from 2006 to 2010, this was due to changes in offshore sampling effort, rather than true changes in relative abundance (Figure 4).

Discussion

Our long-term fisheries independent bottom longline surveys did not show any significant changes or trends in scalloped hammerhead CPUE over time. However, our ability to assess changes in scalloped hammerhead relative abundance is limited given the distribution of our sampling effort. While scalloped hammerheads in our sampling region were caught more frequently at deeper depths, only 8.5% of our sampling occurred at depths greater than 50 meters. Additionally, there was a noticeable lack of females greater than 175 cm STL in our catch data (Figure 2), indicating that our bottom longline surveys are only sampling a subset of the scalloped hammerhead population. Sexual segregation has been previously documented for scalloped hammerheads in the Gulf of Mexico (Branstetter 1987; Drymon et al. 2020) and represents a potential barrier for modeling a fully representative index of scalloped hammerhead relative abundance. Larger females may be outside of our sampling region or more pelagic than males (Klimley 1987); however, we were not able to investigate this given the scope of our survey. Nevertheless, the standardized index created here suggests that the relative abundance of scalloped hammerheads in our sampling region has remained relatively stable over the past 14 years.

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Table 1: The number of fisheries independent bottom longline sets completed per year, as well as the percentage of sets that occurred at depths greater than 30 meters.

Year	N	% >30 m
2006	92	0.0%
2007	143	2.1%
2008	140	2.9%
2009	96	28.1%
2010	80	28.8%
2011	98	39.8%
2012	82	47.6%
2013	64	48.4%
2014	95	56.8%
2015	94	47.9%
2016	103	42.7%
2017	89	49.4%
2018	73	65.8%
2019	62	71.0%

N, number of sets; % >30 m, percentage of sets performed at depths greater than 30 meters.

Table 2: Summary of environmental data recorded from all bottom longline sets, as well as sets where scalloped hammerheads were caught.

	All Sets			Positive Catch Only		
	Min	Max	Mean	Min	Max	Mean
Depth (m)	1.500	111.000	22.422	2.700	104.000	45.267
Bottom Temperature (°C)	12.670	31.970	23.870	17.220	30.060	21.471
Bottom Salinity (psu)	0.031	37.970	32.548	23.868	37.640	35.557
Bottom Dissolved Oxygen (mg/L)	0.224	10.610	5.655	1.218	7.442	5.397

Table 3: Summary for the best fitting negative binomial generalized linear model.

Variable	Estimate	SE	Z	P
(Intercept)	-6.724	2.274	-2.957	**0.003**
2007	-0.620	0.733	-0.845	0.398
2008	-0.212	0.658	-0.322	0.748
2010	-0.986	1.174	-0.840	0.401
2011	-0.557	0.729	-0.764	0.445
2012	0.323	0.726	0.445	0.656
2013	1.331	0.748	1.779	0.075
2014	-0.272	0.640	-0.425	0.671
2015	-0.344	0.629	-0.547	0.584
2016	-0.070	0.616	-0.114	0.910
2017	-0.203	0.629	-0.322	0.747
2018	0.475	0.611	0.778	0.436
2019	-1.162	0.704	-1.650	0.099
Depth	0.041	0.005	7.744	**0.001**
Day Length	0.482	0.127	3.795	**0.001**
Bottom Temperature	-0.112	0.039	-2.856	**0.004**
Bottom Salinity	0.004	0.035	0.116	0.907

SE, standard error; Z, z value; *P*, p-value. Bold values indicate statistical significance ($P < 0.05$).

Table 4: Summary of the nominal and standardized CPUE estimates.

Year	Nominal	StdErr	N	% Positive	Standardized index	LCL	UCL	CV
2006	0.043	0.026	92	3.3%	0.127	0.045	0.360	0.531
2007	0.028	0.014	143	2.8%	0.068	0.025	0.187	0.515
2008	0.057	0.024	140	4.3%	0.103	0.048	0.219	0.387
2009	0.094	0.047	96	5.2%	NA	NA	NA	NA
2010	0.038	0.021	80	3.8%	0.047	0.006	0.363	1.038
2011	0.153	0.044	98	12.2%	0.073	0.029	0.184	0.474
2012	0.220	0.076	82	14.6%	0.175	0.071	0.430	0.458
2013	0.328	0.141	64	15.6%	0.480	0.182	1.267	0.495
2014	0.263	0.056	95	22.1%	0.097	0.051	0.182	0.322
2015	0.202	0.070	94	11.7%	0.090	0.049	0.165	0.310
2016	0.311	0.098	103	15.5%	0.118	0.068	0.206	0.284
2017	0.258	0.076	89	16.9%	0.104	0.057	0.189	0.308
2018	0.548	0.154	73	24.7%	0.204	0.120	0.348	0.271
2019	0.145	0.056	62	11.3%	0.040	0.017	0.092	0.430

Nominal, nominal catch per unit effort; StdErr, standard error; N, number of sets; % Positive, percentage of sets with positive catch; LCL, lower 95% confidence limit; UCL, upper 95% confidence limit; CV, coefficients of variation.

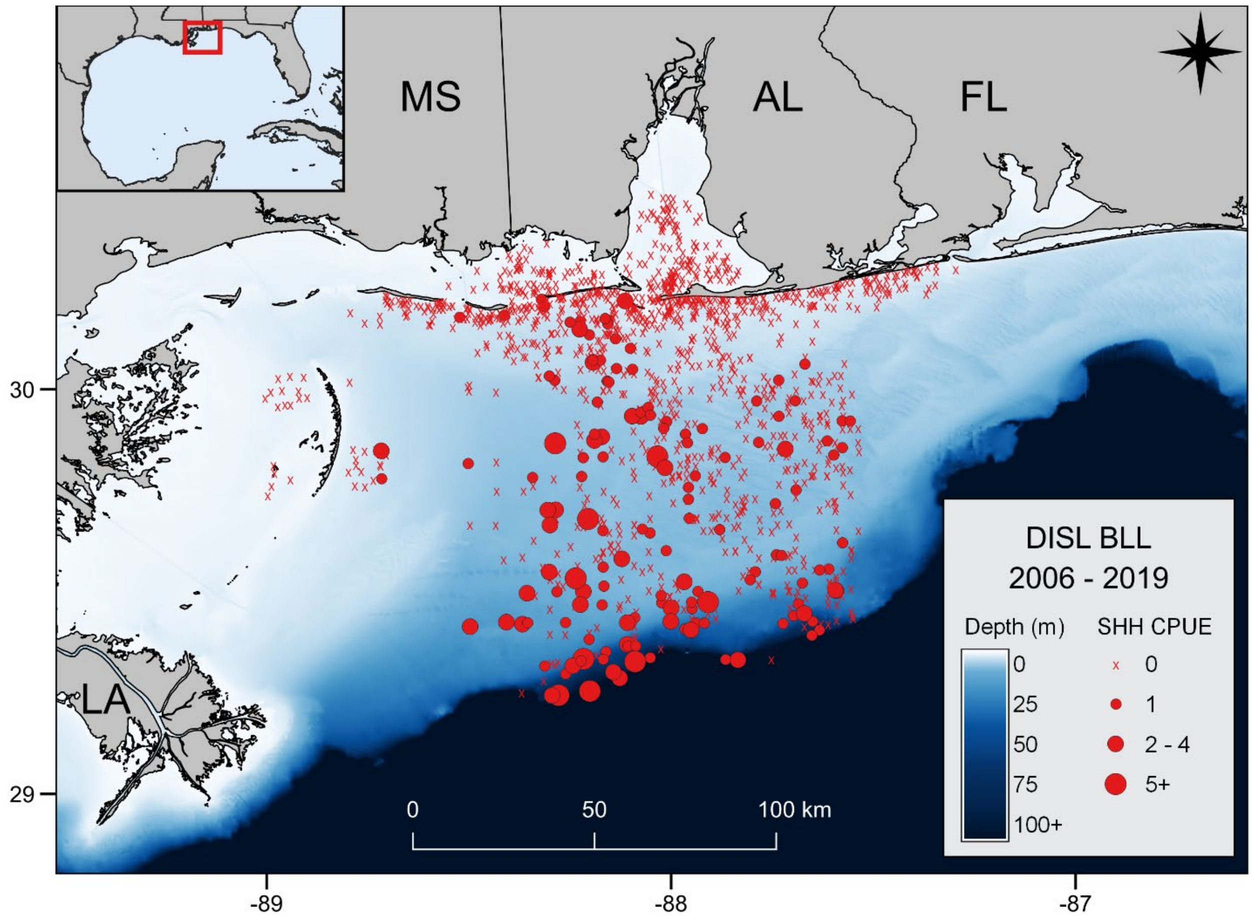


Figure 1: Catch per unit effort (CPUE, individuals 100 hooks^{-1} hour^{-1}) for scalloped hammerheads caught during fisheries independent bottom longline surveys from 2006 to 2019.

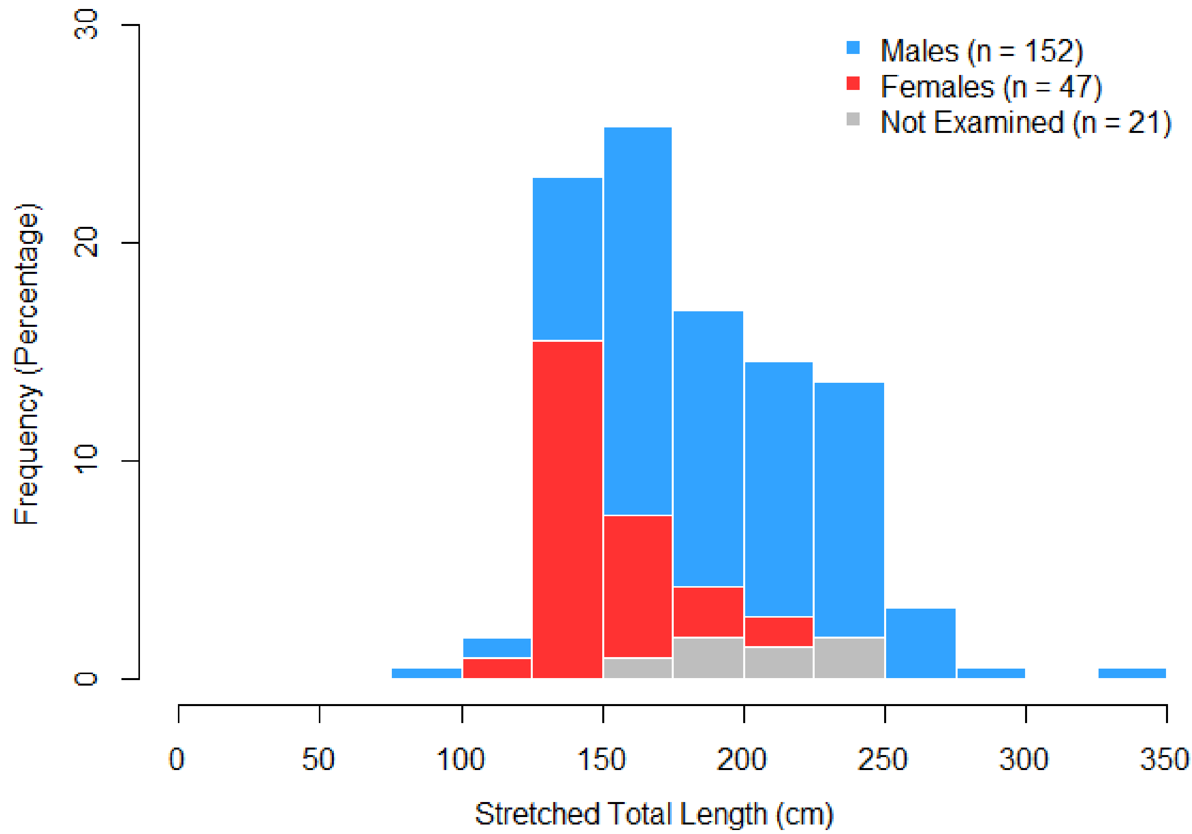


Figure 2: Length frequency distribution of scalloped hammerheads caught during fisheries independent bottom longline surveys broken down by sex.

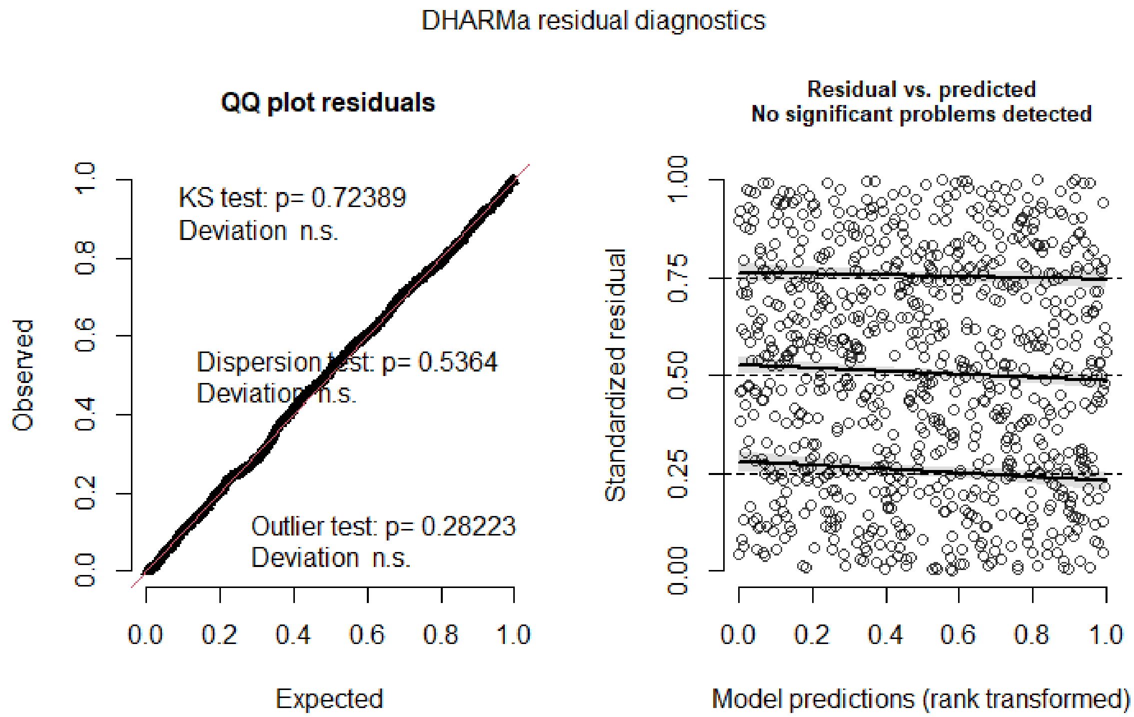


Figure 3: Residual diagnostic plots created using the DHARMa package to examine model fit.

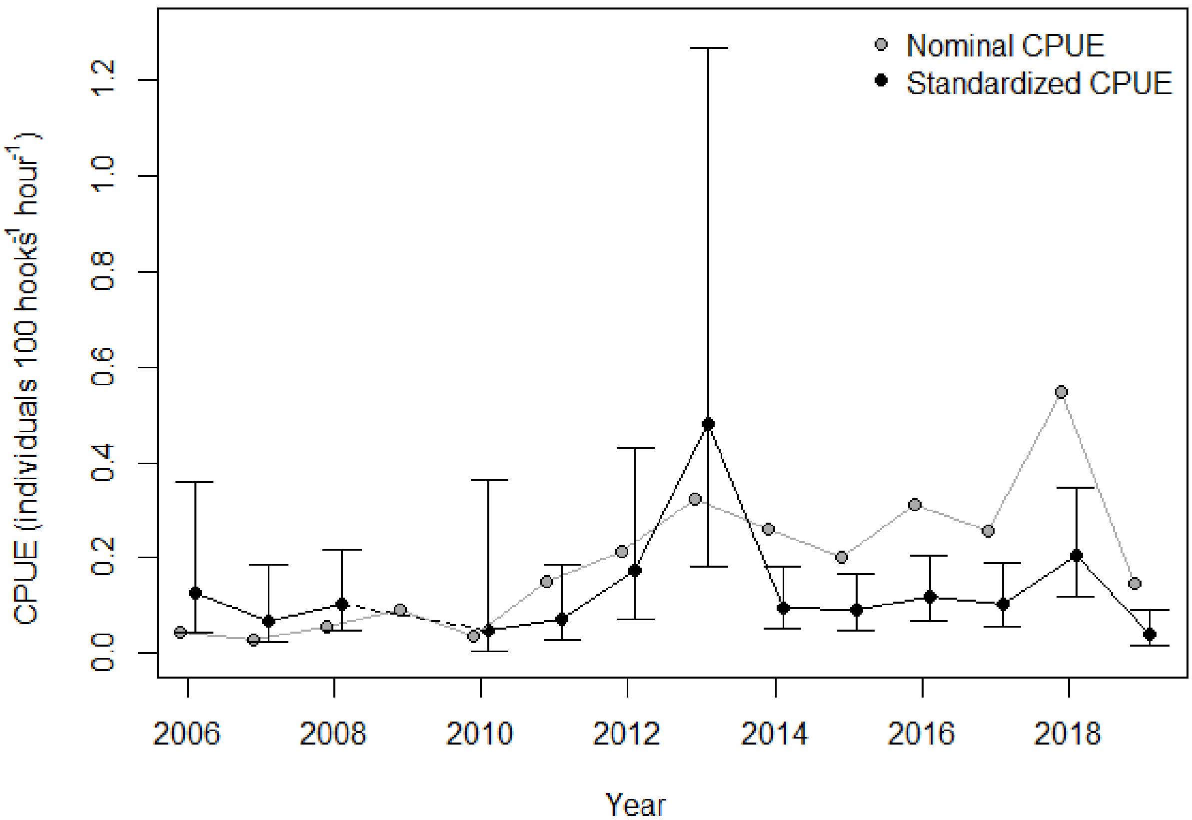
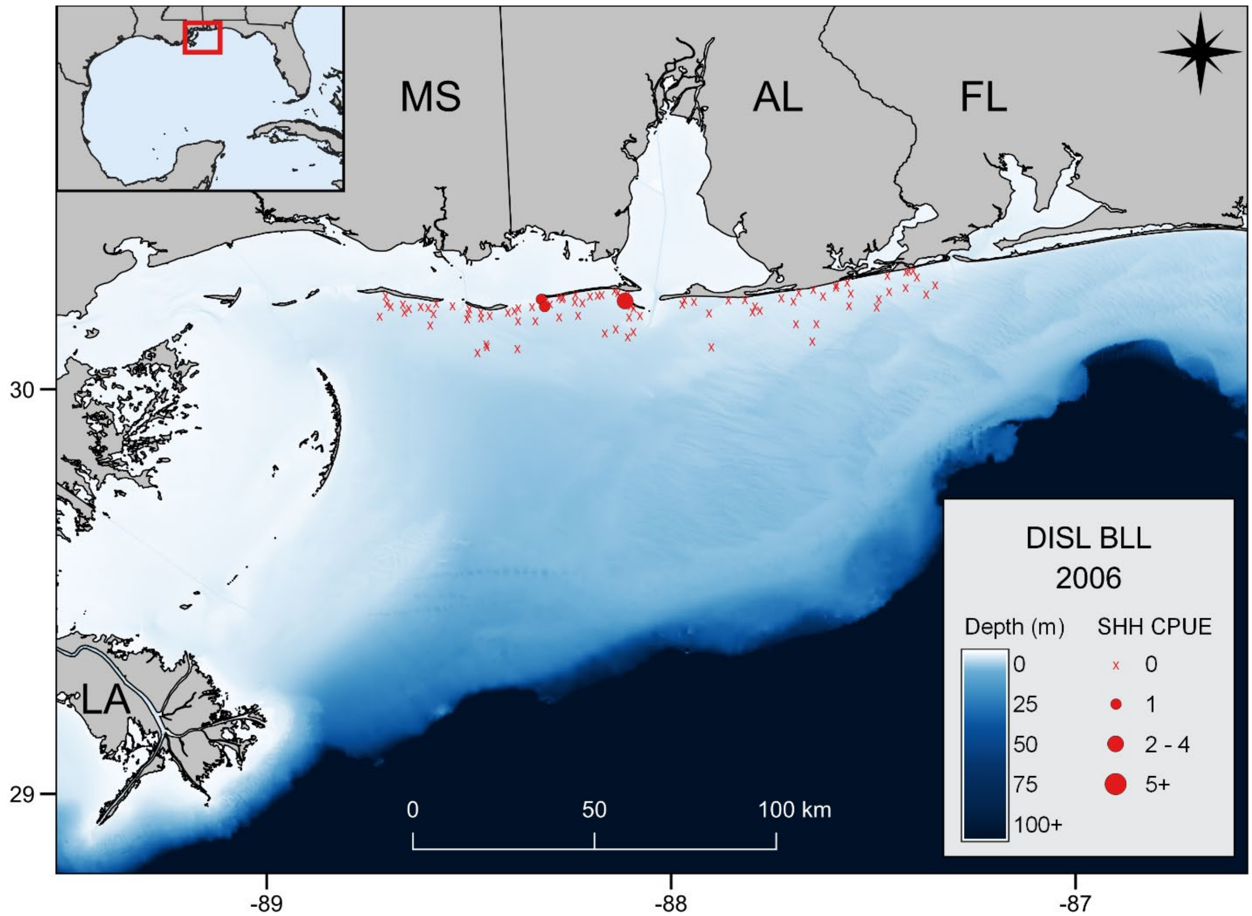
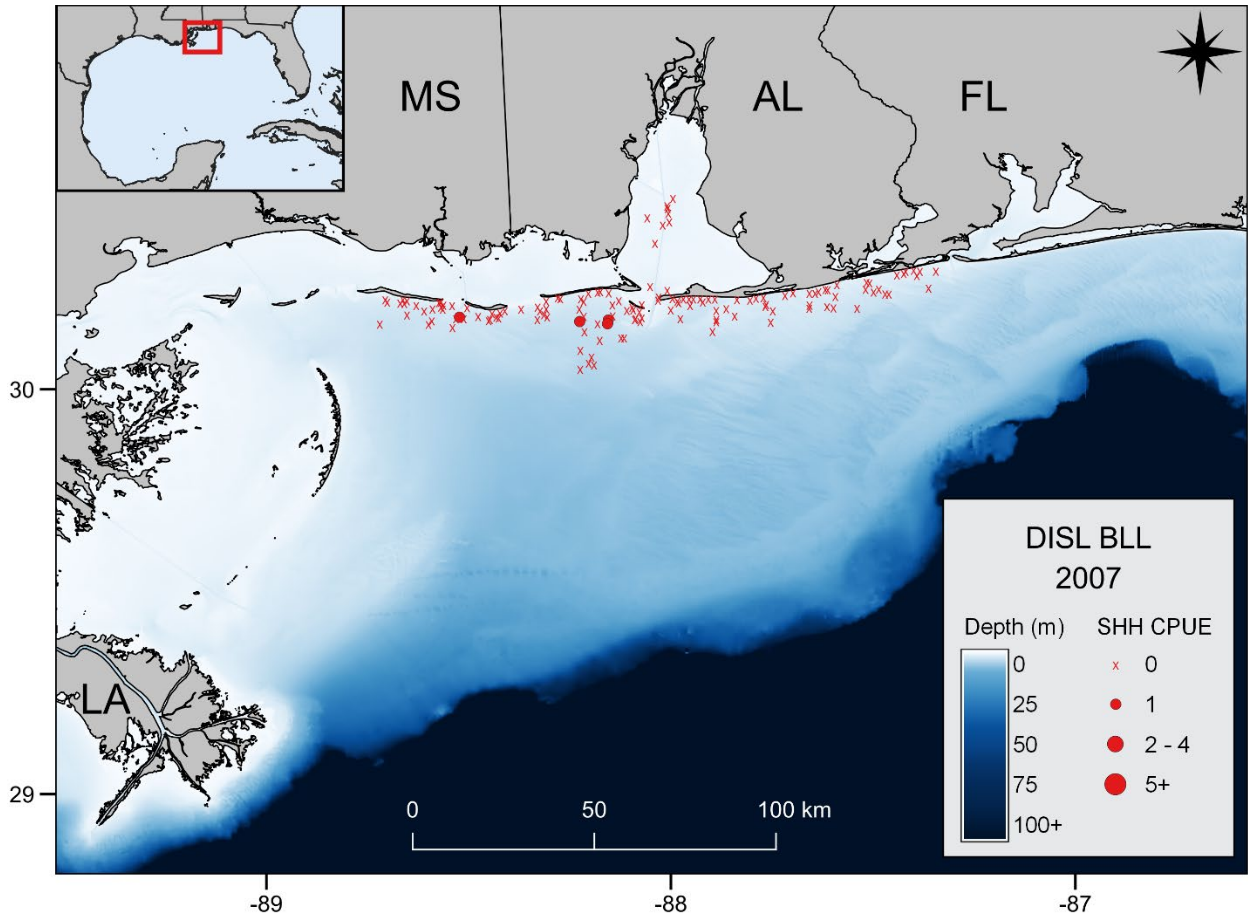


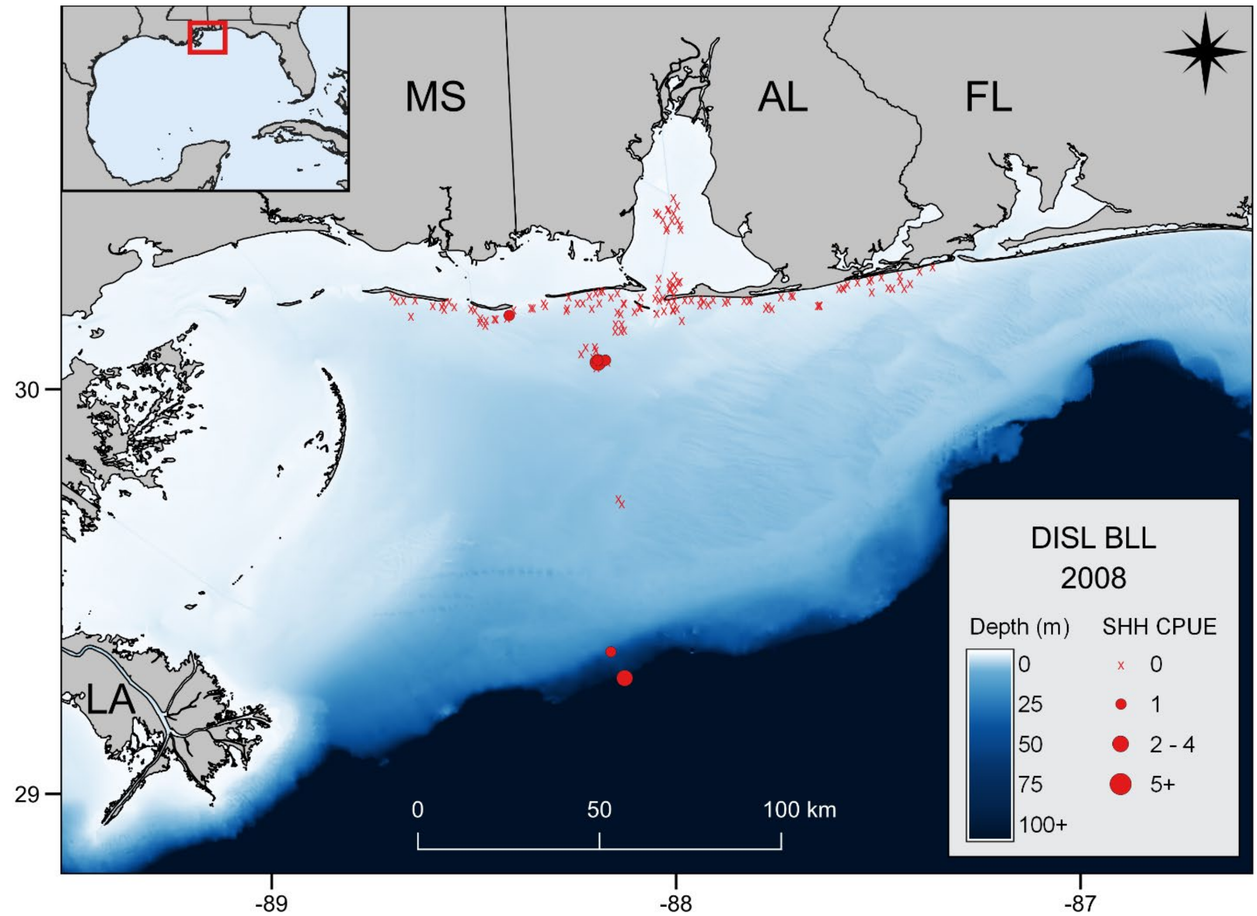
Figure 4: Nominal (grey circles) and standardized (black circles) CPUE of scalloped hammerheads from the bottom longline survey, 2006 – 2019. Error bars represent 95% confidence intervals. For 2009, there is no standardized CPUE estimate due to a lack of positive catch data with corresponding abiotic measurements from that year.



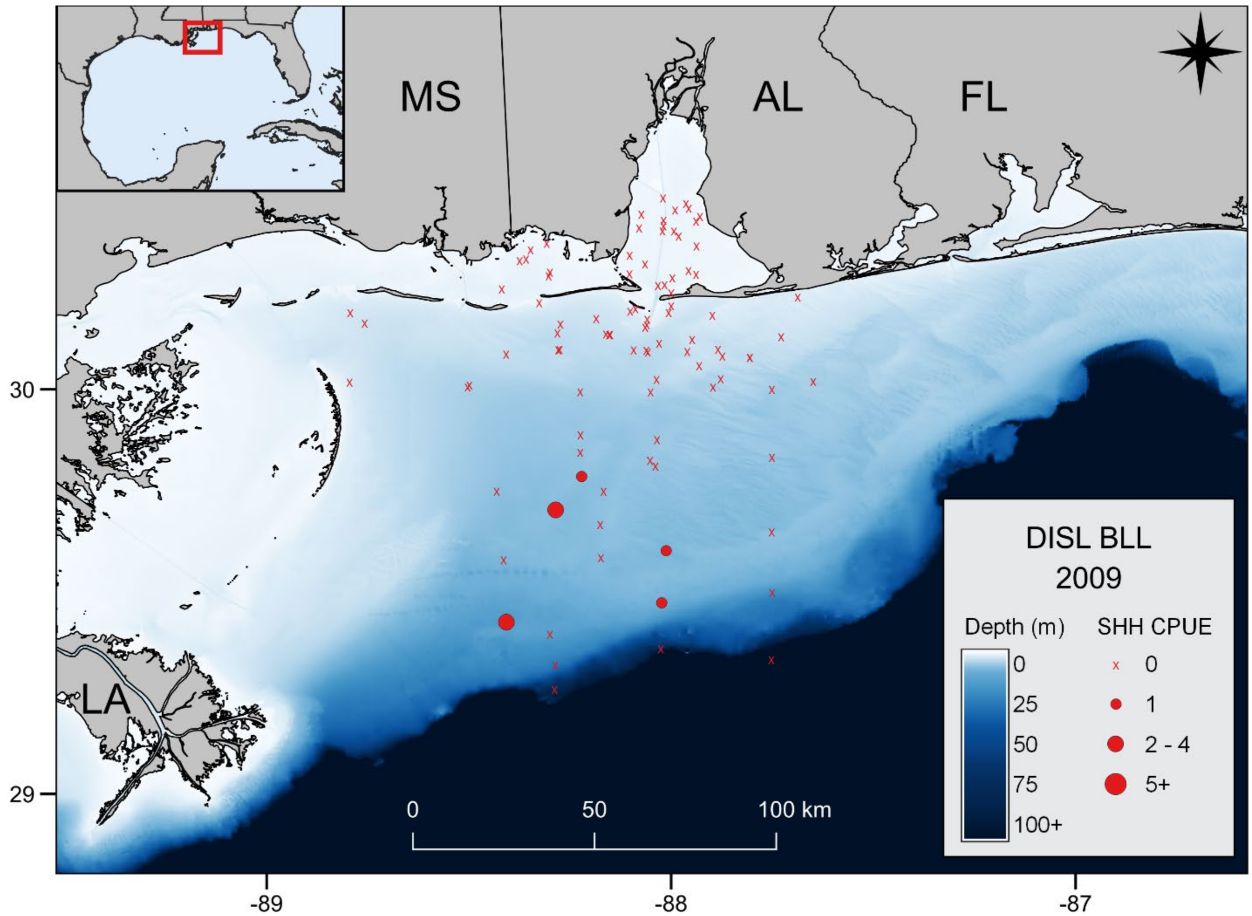
Appendix Figure 1. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2006.



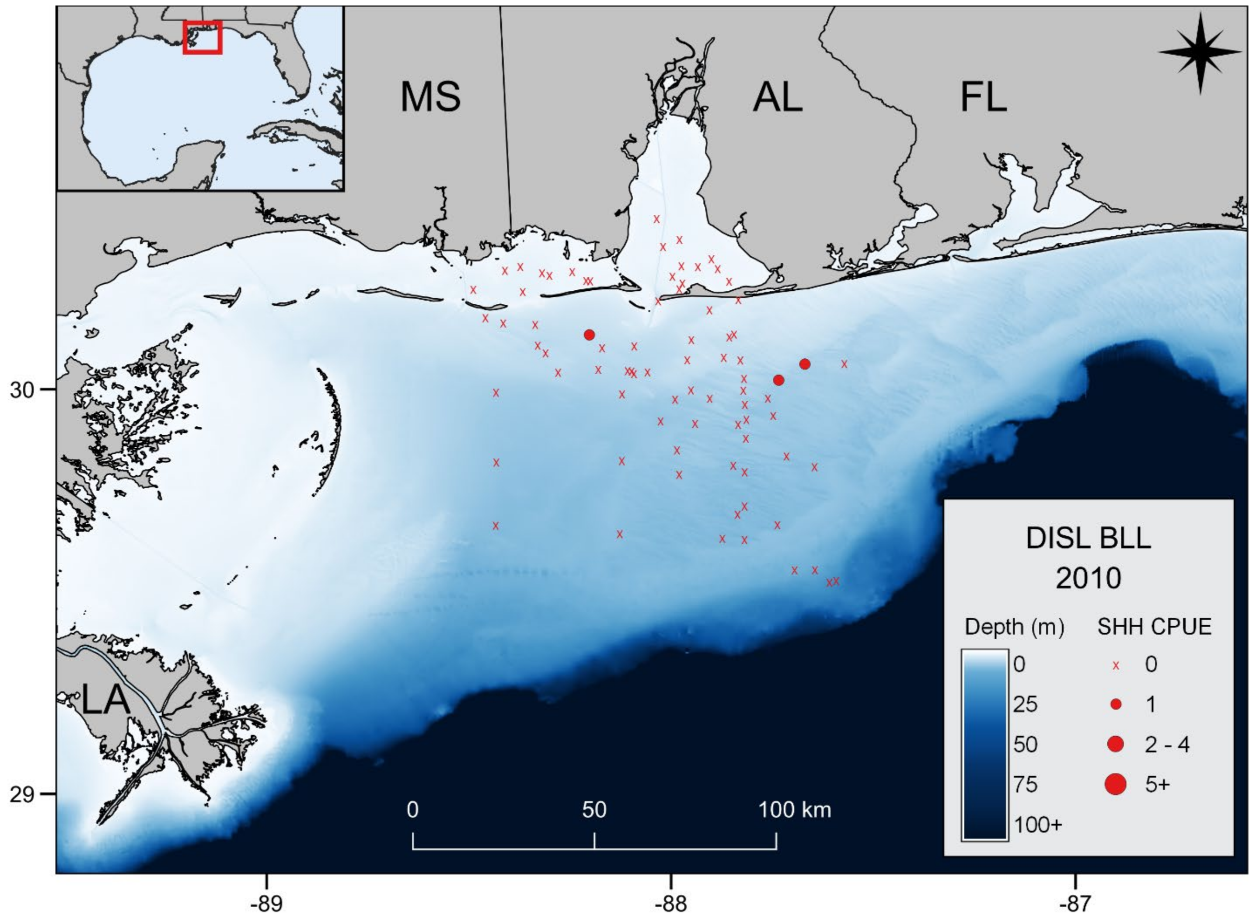
Appendix Figure 2. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2007.



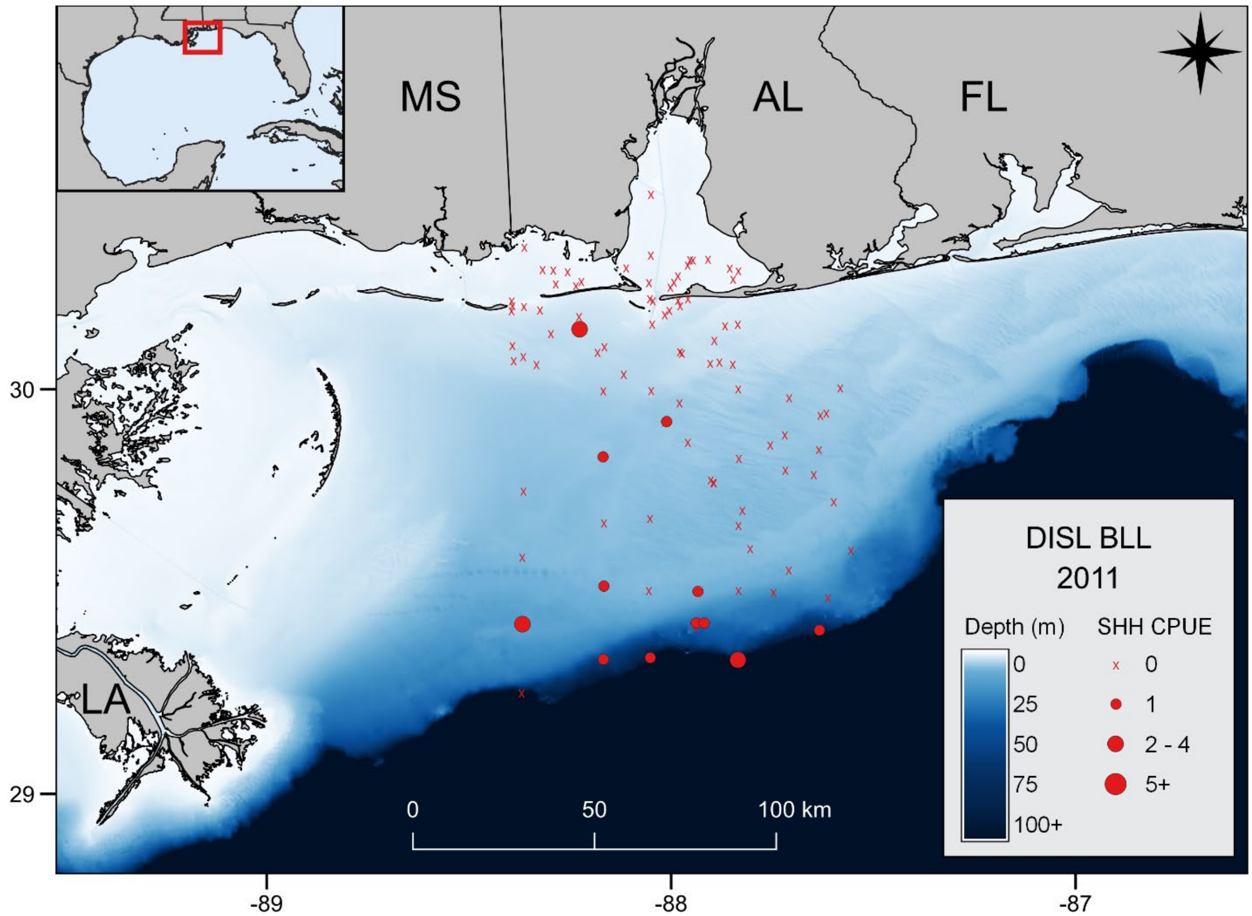
Appendix Figure 3. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2008.



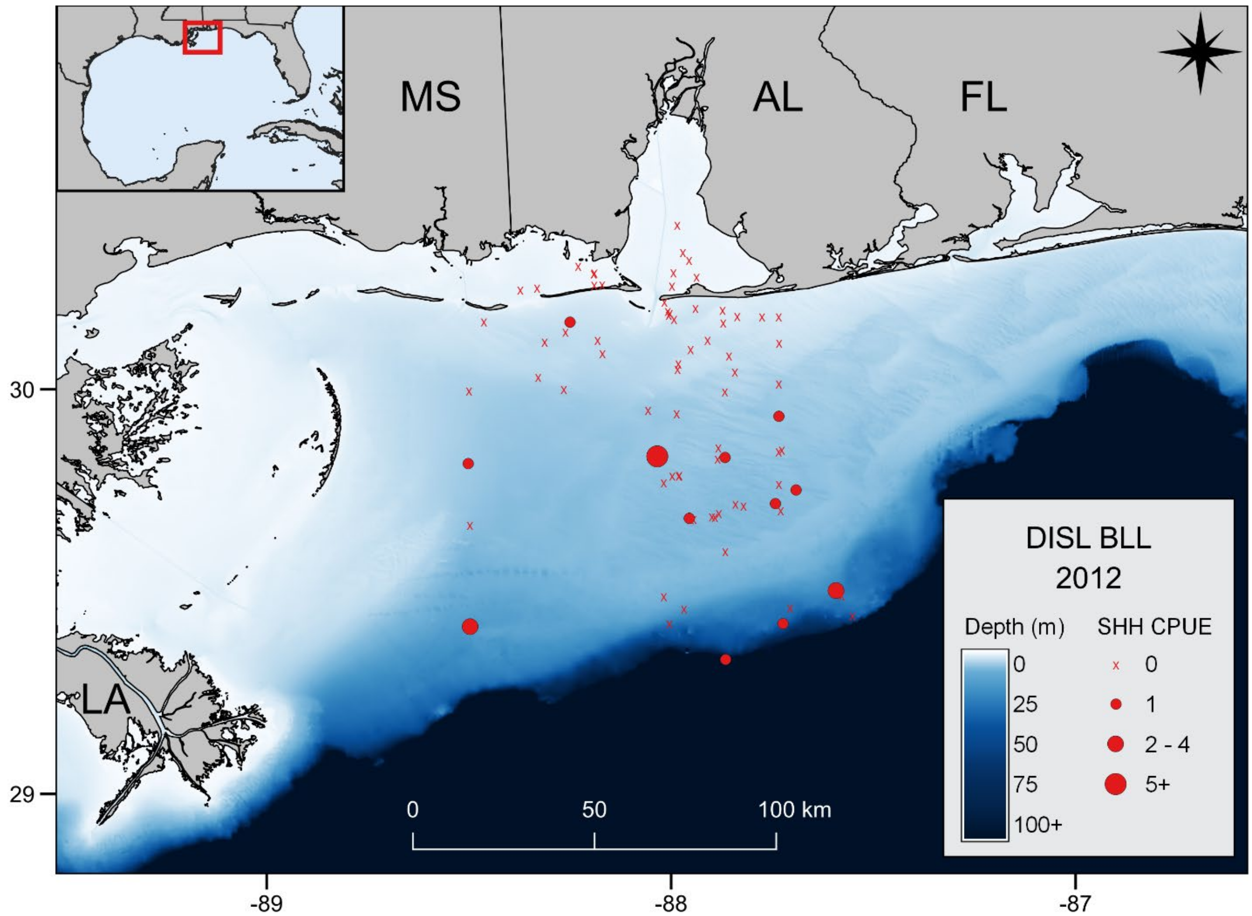
Appendix Figure 4. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2009.



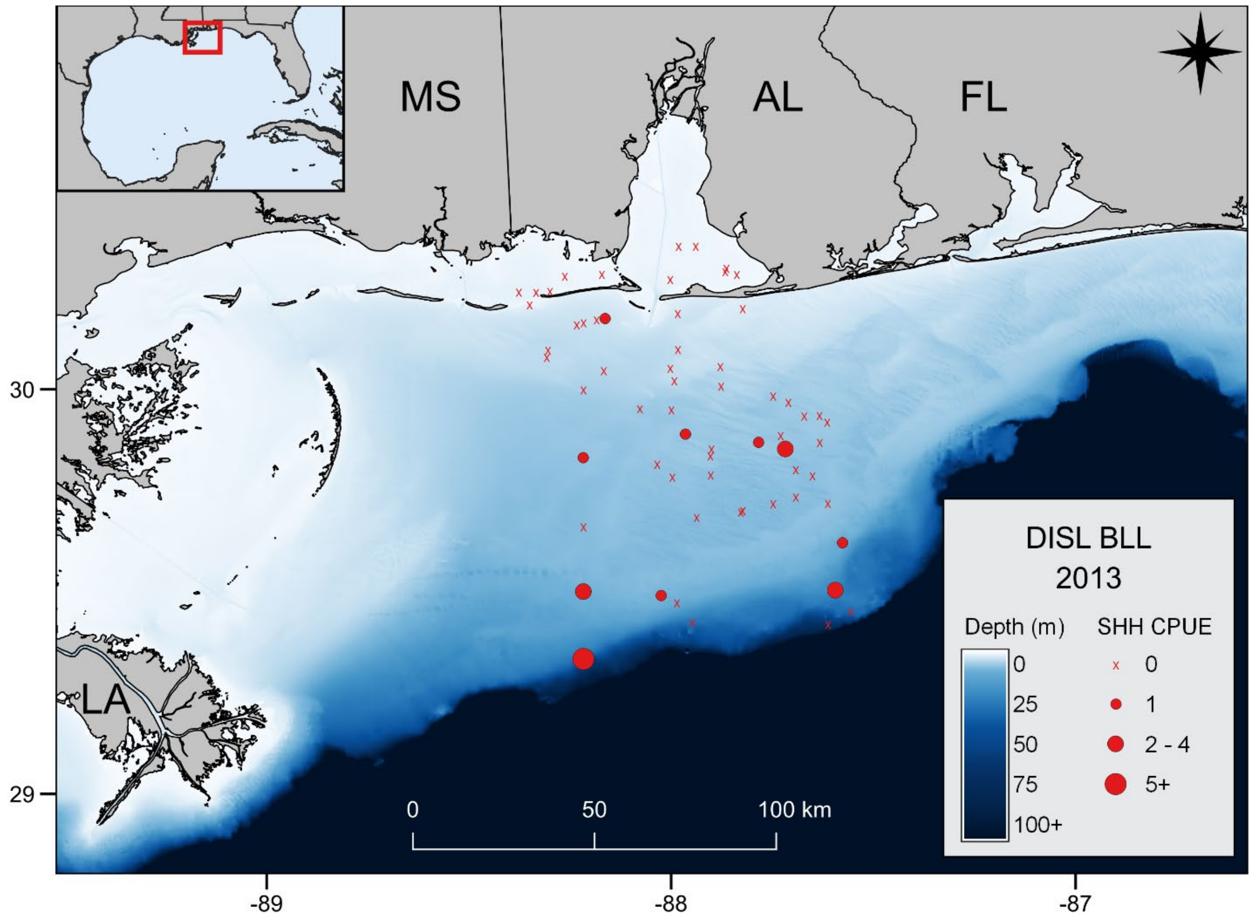
Appendix Figure 5. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2010.



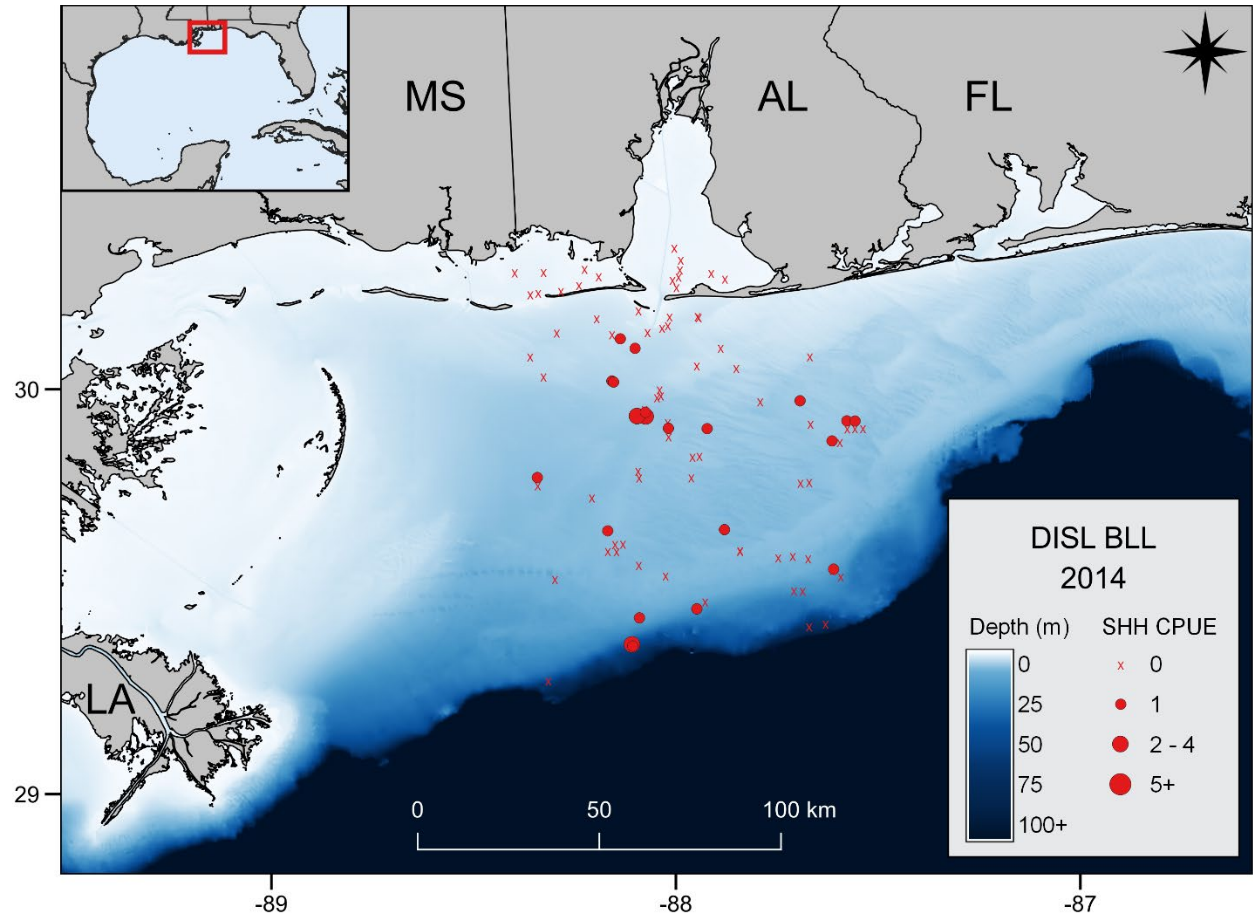
Appendix Figure 6. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2011.



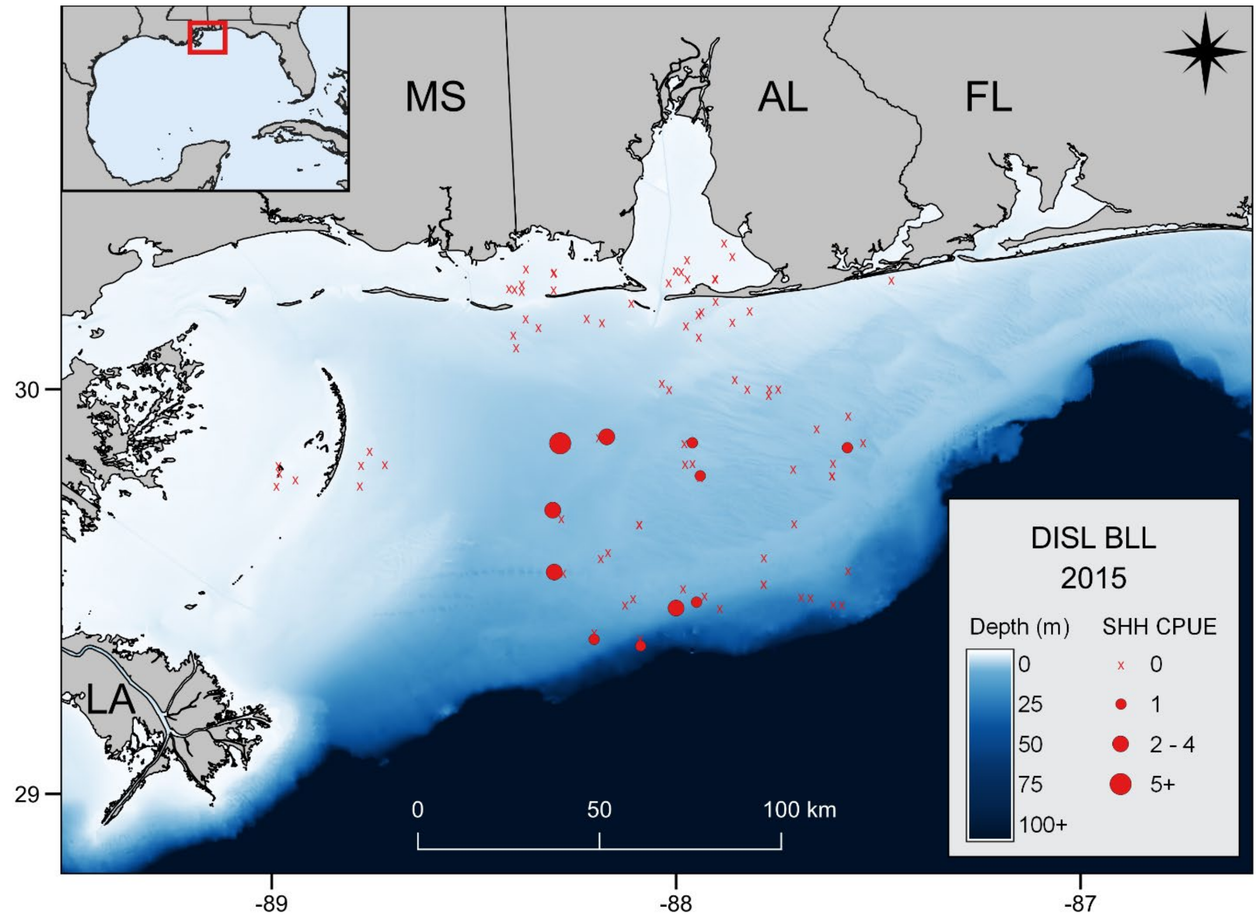
Appendix Figure 7. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2012.



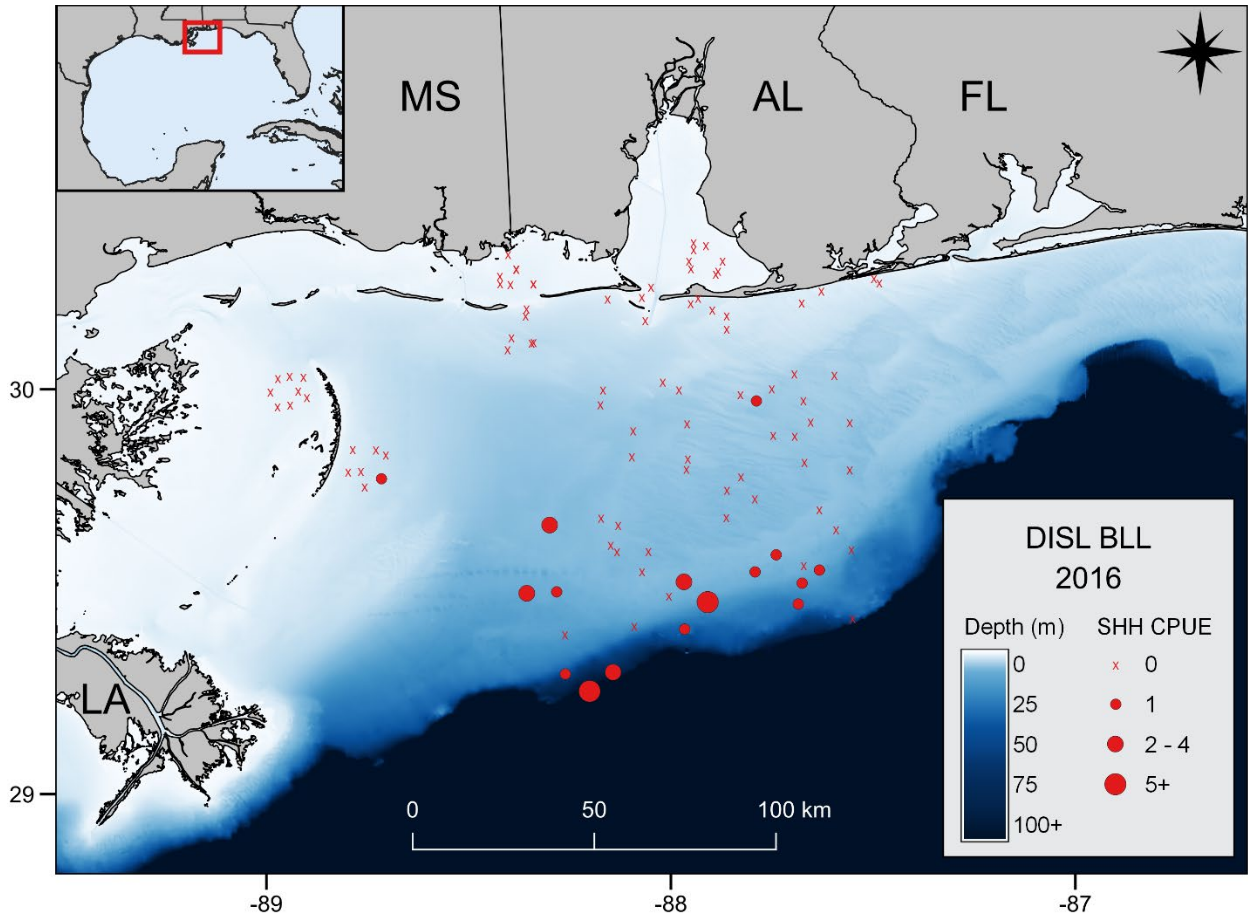
Appendix Figure 8. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2013.



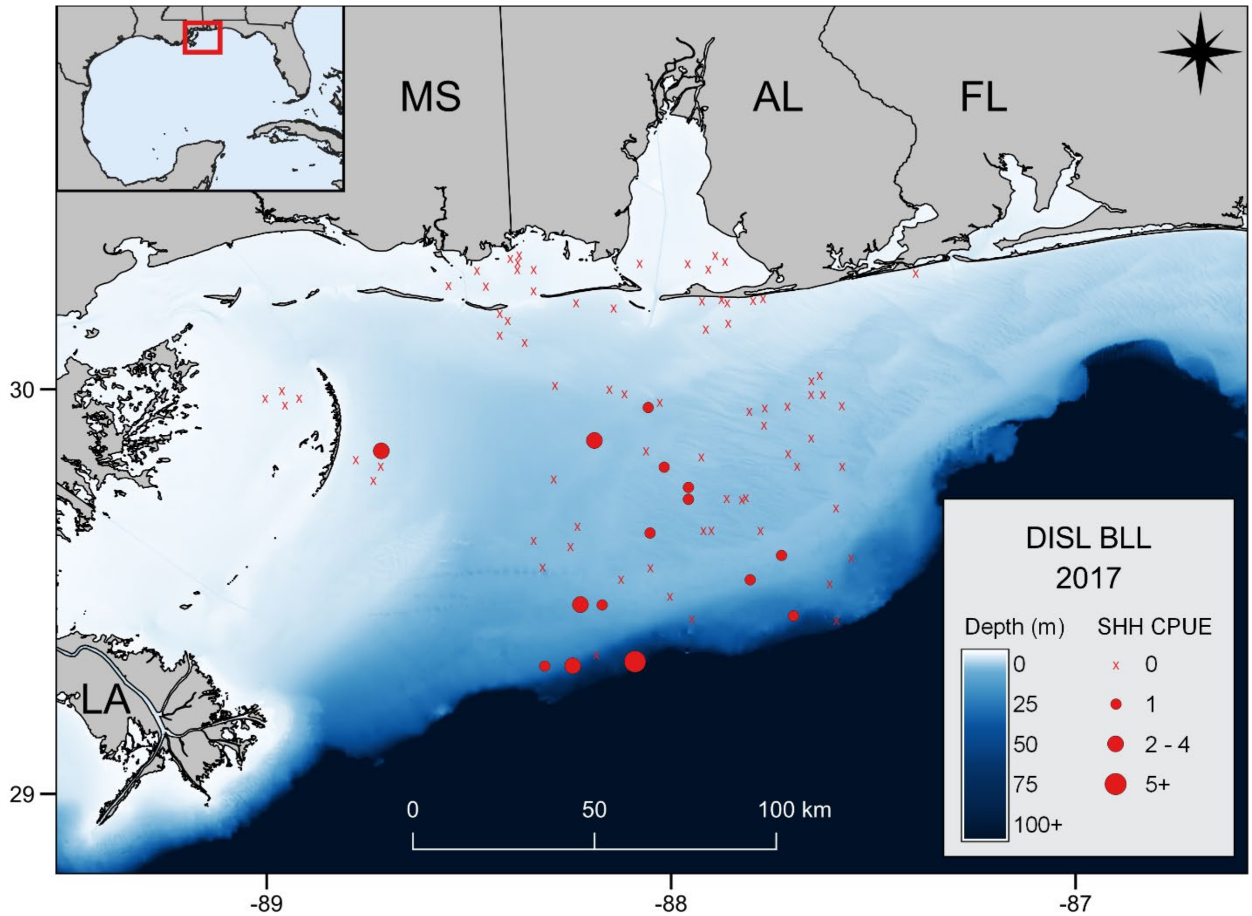
Appendix Figure 9. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2014.



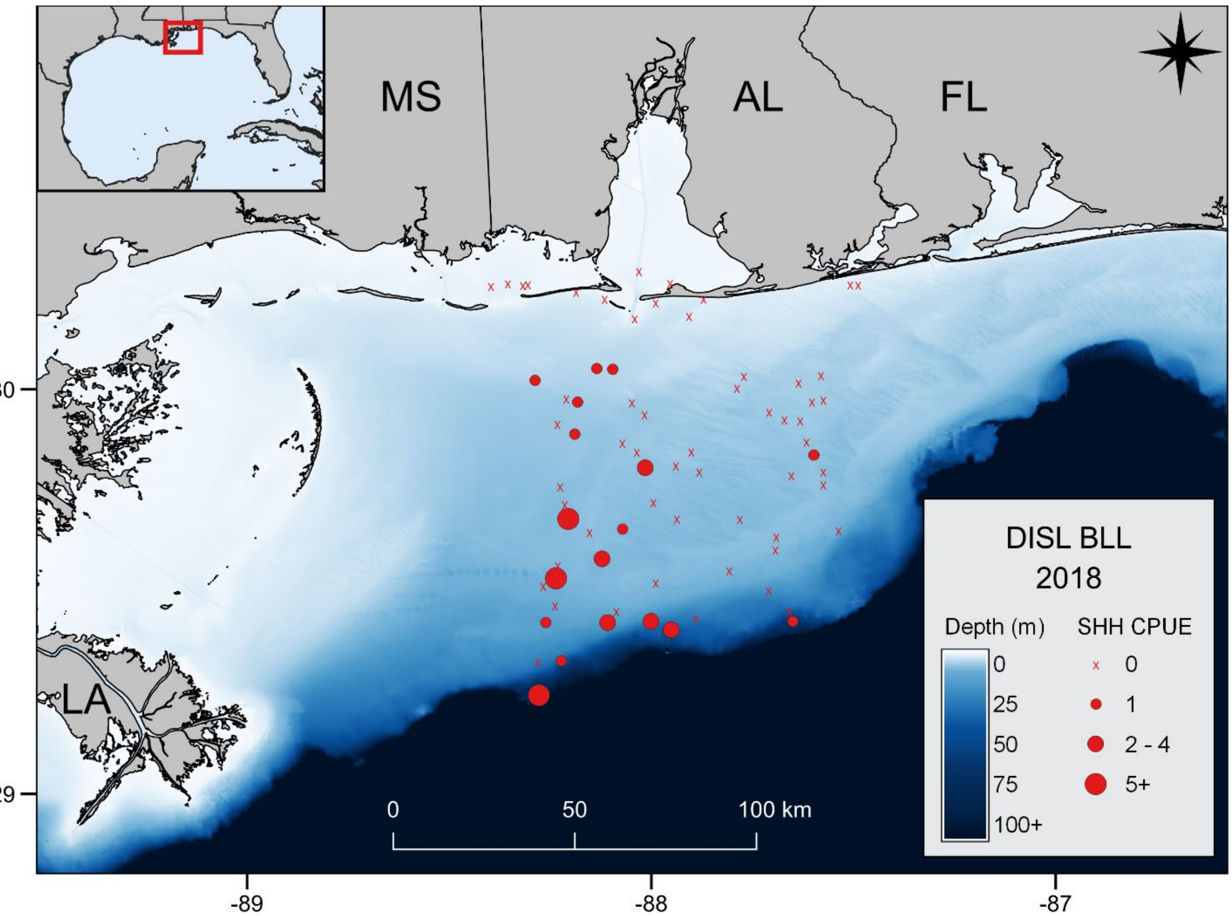
Appendix Figure 10. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2015.



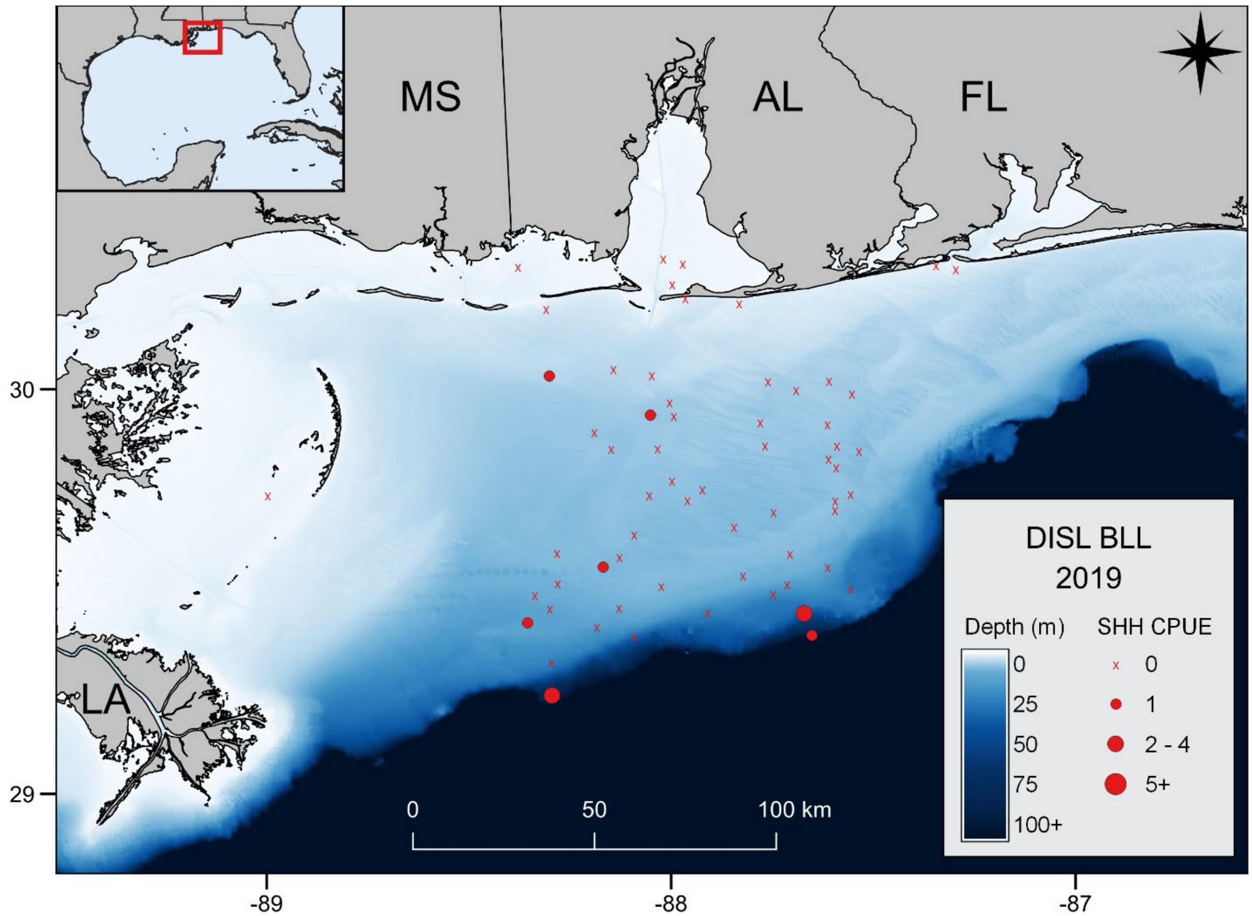
Appendix Figure 11. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2016.



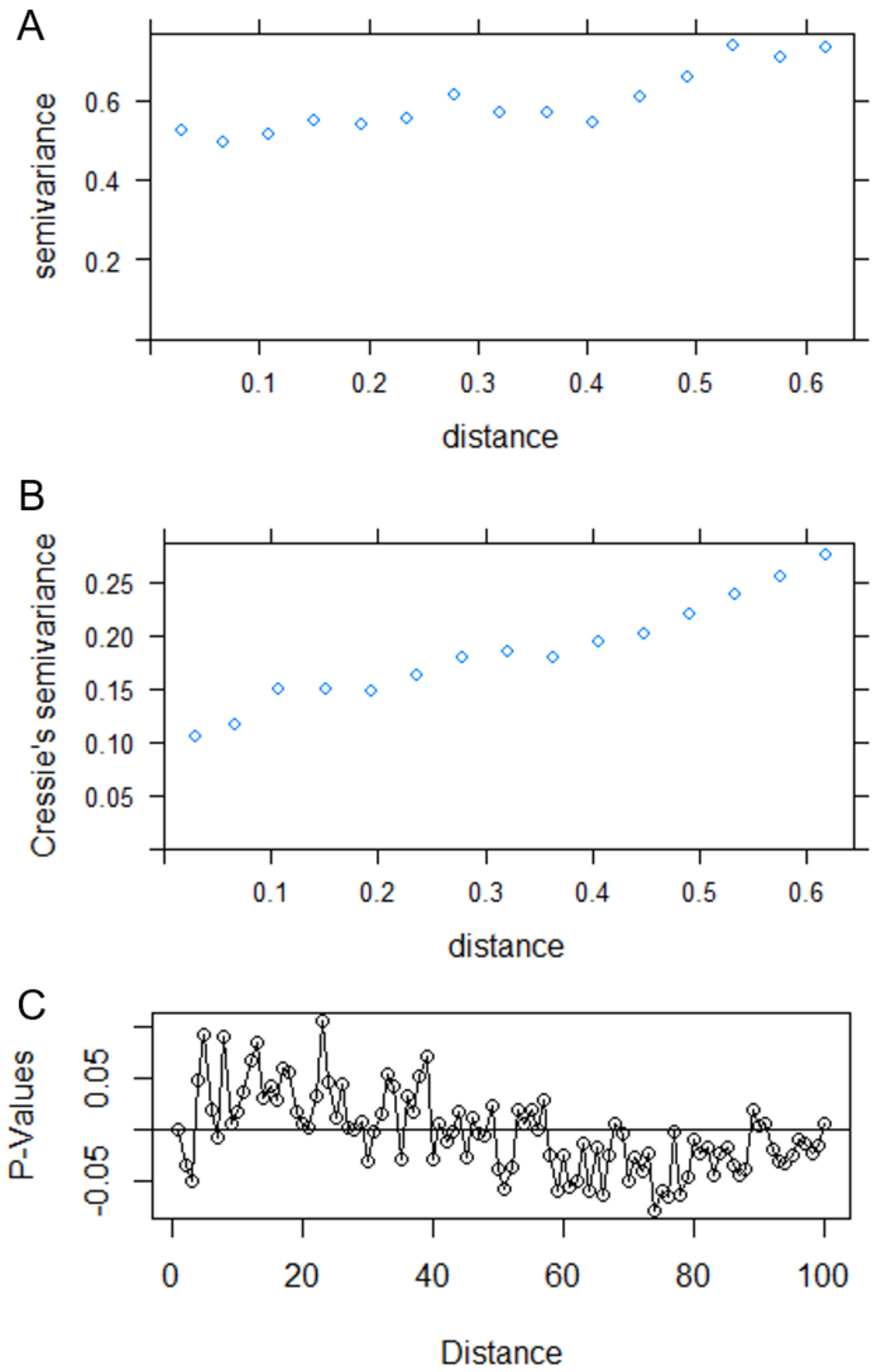
Appendix Figure 12. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2017.



Appendix Figure 13. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2018.



Appendix Figure 14. Catch per unit effort (CPUE, individuals 100 hooks-1 hour-1) for scalloped hammerheads caught during fisheries independent bottom longline surveys during 2019.



Appendix Figure 15: Associated variograms and correlogram from the best fitting negative binomial generalized linear model.