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STANDARDIZED CATCH RATES OF ATLANTIC SHARPNOSE (*RHIZOPRIONODON TERRAENOVAE*) AND BONNETHEAD (*SPHYRNA TIBURO*) SHARKS COLLECTED DURING A GILLNET SURVEY IN MISSISSIPPI COASTAL WATERS, 1998-2011.

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Beginning in 1998, an ongoing monthly standardized gillnet survey has been conducted in Mississippi coastal waters from March to October each year. This fisheries independent dataset was developed to monitor the abundance and distribution of various elasmobranch and teleost species within Mississippi's coastal waters. As a result of 270 net sets and 882 hours of effort, 2,557 Atlantic sharpnose and 217 bonnethead sharks were collected. Standardized catch rates were estimated using a Generalized Linear Mixed modeling approach assuming a delta-lognormal error distribution. Other than slight peaks observed in 2000 and 2007, standardized catch rates remained stable across the time series for Atlantic sharpnose and bonnethead sharks, respectively.

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INTRODUCTION

Through the combined effort of the University of Mississippi and the University of Southern Mississippi's Gulf Coast Research Laboratory (GCRL) a standardized gillnet survey within the waters of the Mississippi Sound has been conducted monthly from March to October, since 1998. The dataset began in 1998 in the north central GOM, with a three year study funded by NOAA's Marine Fisheries Initiative (MARFIN). The study focused on identifying and characterizing shark nursery grounds in Mississippi and Alabama waters and established a baseline for shark abundance in these areas (Parsons and Hoffmayer, 2005; Parsons and Hoffmayer, 2007). In 2001, the survey was partially continued (unfunded) in an effort to preserve some of the long-term monitoring of shark numbers. The following year (2002) no effort was put towards continuing the survey. Beginning in 2003, the gillnet survey was funded through combined efforts of the Gulfspan Program (NOAA) and the Mississippi Department of Marine Resources through the U.S. Fish and Wildlife Service (Sports Fish Restoration Act). The primary objective of this survey was to collect data on the seasonal abundance and distribution of local shark species in Mississippi waters.

METHODOLOGY

Sampling Locations

From 1998 to 2011 sharks were collected at various sites along the Mississippi coast extending east to west from Petit Bois Island to St. Louis Bay. In general, collections were made from March to October with two to three locations sampled each month. Sampling was confined to the waters of the Mississippi Sound. Initially, sampling locations were selected such that a large geographical area and a range of environmental conditions could be covered. However, unless sampling was limited by conditions such as weather, sea state, and shrimp boat activity, locations were typically selected in close proximity to the barrier islands.

From 1998 to 2000 two locations were sampled each month, with one location (Horn Island) established as a long-term sampling location. During 2001, because no funding was available, the long-term Horn Island location was sampled monthly, along with a few other locations when available. With limited funding in 2003, only a few locations were sampled, primarily locations where previous sampling was conducted. From 2004 to 2009, two to three regions were sampled monthly, with waters around west Horn, west Cat, and southwest Round Islands as the three primary sampling regions. Each region was defined by a 3.8 x 2.8 km sampling area where monthly locations were randomly selected (Figure 1). In addition to the three primary sampling regions, sampling occurred in other areas, opportunistically. In 2010, the sampling protocol was modified to increase the number of monthly locations (7-8 per month), and new sampling regions were added to the Mississippi Sound sampling universe, including east Cat, east Ship, west Ship, Deer, east Horn, Sand, and Petit Bois Islands (Figure 1). To increase the number of sampling locations, the soak times were reduced from five to two hours.

Sampling Protocol

Sampling was conducted with a 152.4 x 3 m gillnet consisting of five 30.5 meter panels of 4.5, 5.1, 5.7, 6.4, and 7.0 cm square mesh. The net was typically fished between the hours of 0800 and 2000. Depending upon the rate of capture and the environmental conditions prevalent, the net was checked every 0.5 to 1.0 hour. Each time the net was checked, the time of day over which those sharks were captured was recorded. As expeditiously as possible, each shark captured was identified and measured (fork length, FL) and its sex and, when possible, maturity state recorded. Water temperature (°C), salinity (psu), and dissolved oxygen (mg/l) were measured at the water's surface and near the bottom at each sampling location. We also recorded depth (m), turbidity (cm), sea state (m) and used a GPS to record latitude and longitude.

Analysis

For the purpose of analysis, age-0 or young-of-the-year (YOY) sharks were excluded from the abundance indices for both Atlantic sharpnose and bonnethead sharks resulting in age-1+ indices. Catch rates were standardized as catch per unit effort (CPUE) in sharks 100 m net $^{-1}$ hour $^{-1}$. Length frequency distributions were constructed for Altantic sharpnose and bonnethead sharks ranging from 350 to 900+ mm FL using 50 mm increments.

Index Construction

Delta-lognormal modeling methods were used to estimate relative abundance indices for Atlantic sharpnose sharks (Lo *et al*. 1992). The main advantage of using this method is allowance for the probability of zero catch (Ortiz *et al.* 2000). The index computed by this method is a mathematical combination of yearly abundance estimates from two distinct generalized linear models: a binomial (logistic) model which describes proportion of positive abundance values (i.e. presence/absence) and a lognormal model which describes variability in only the nonzero abundance data (Lo *et al*. 1992).

The delta-lognormal index of relative abundance (I_y) as described by Lo *et al*. (1992) was estimated as:

(1) $$I_y = c_y p_y,$$

where c_y is the estimate of mean CPUE for positive catches only for year *y*, and p_y is the estimate of mean probability of occurrence during year *y*. Both c_y and p_y were estimated using generalized linear models. Data used to estimate abundance for positive catches (*c*) and probability of occurrence (*p*) were assumed to have a lognormal distribution and a binomial distribution, respectively, and modeled using the following equations:

(2) $$\ln(c) = X\beta + \varepsilon$$

and

(3) $$p = \frac{e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}}{1+e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}},$$

respectively, where *c* is a vector of the positive catch data, *p* is a vector of the presence/absence data, *X* is the design matrix for main effects, β is the parameter vector for main effects, and ε is a vector of independent normally distributed errors with expectation zero and variance σ^2. Therefore, c_y and p_y were estimated as least-squares means for each year along with their corresponding standard errors, SE (c_y) and SE(p_y), respectively. From these estimates, I_y was calculated, as in equation (1), and its variance calculated as:

(4) $$V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y) + 2c_y p_y \mathrm{Cov}(c, p),$$

where:

(5) $$\mathrm{Cov}(c, p) \approx \rho_{\mathrm{c,p}}\left[\mathrm{SE}(c_y)\mathrm{SE}(p_y)\right],$$

and $\rho_{c,p}$ denotes correlation of *c* and *p* among years.

The submodels of the delta-lognormal model were built using a backward selection procedure based on type 3 analyses with an inclusion level of significance of $\alpha = 0.10$. Binomial submodel performance was evaluated using AIC, while the performance of the lognormal submodel was evaluated based on analyses of residual scatter and QQ plots in addition to AIC.

For all indices developed, the factors YEAR, MONTH, AREA, DEPTH, SET TIME, EFFORT, and BOTTOM (BOT) TEMPERATURE (TEMP), SALINITY (SAL), and DISSOLVED OXYGEN (DO) were examined for inclusion in the catch rate models. The factor MONTH includes the months that sampling was conducted from March to October. The Mississippi Sound was divided into two zones: east to west (1 and 2) which is represented by factor AREA. The factor SET TIME refers to the time of day the gillnet was first deployed at the sampling location. Since soak time changed throughout the duration of the survey, the hours the net soaked is represented by the factor EFFORT. The factors DEPTH, TEMP, SAL, and DO included values present in the data set. The factor YEAR included each year in the time series from 1998 to 2011, and was included in the model whether it explained the data or not, so that an annual catch rate series was produced.

Data Filtering

The initial model run for bonnetheads with all the data included would not converge. After examining all the different factors in the model, it was evident that the two years with zero catch of bonnethead sharks (2003-2004) was responsible. Since there was only limited sampling effort (n = 18) during 2003-04, we decided to remove this data from the model. Once these data were removed, the model was able to converge.

RESULTS

From 1998 to 2011, 270 locations in Mississippi were sampled resulting in 882 hours of effort. During this time 2,557 Atlantic sharpnose (Figure 2) and 217 bonnethead sharks (Figure 3) were collected. The total number of Atlantic sharpnose and bonnethead sharks captured ranged from 5 to 431 (Table 1) and 0 to 56 (Table 2), respectively. Approximately 61% of the stations contained positive catches of Atlantic sharpnose sharks, whereas 25% of the stations contained positive catches of bonnethead sharks. In the Mississippi gillnet survey, Atlantic sharpnose sharks ranged in size from 405 to 884 mm FL (mean: 653 ± 2.3 mm FL), whereas bonnethead sharks ranged in size from 359 to 868 mm FL (mean: 656 ± 7.6 mm FL). The length frequency histograms indicated that 98.4% of the Atlantic sharpnose sharks were between 450 and 850 mm FL (Figure 4), and 66.4% of the bonnethead sharks were between 600 and 800 mm FL (Figure 5). The nominal CPUE and number of stations with a positive catch for Atlantic sharpnose and bonnethead sharks are presented in Figure 6 and 11, respectively, which indicated annual variation in nominal CPUE, with varying proportion of positive catches over the years.

Atlantic sharpnose shark Catch

For the Atlantic sharpnose shark model, YEAR, AREA, TEMPBOT, DEPTH, and SOAK were retained in the binomial submodel. The variables retained in the lognormal submodel were YEAR, MONTH, AREA, SALBOT, and TEMPBOT. Table 2 summarizes the backward selection procedure used to select the final set of variables used in the submodels and their significance. The AIC for the binomial and lognormal submodels were 1306.6 and 478.3, respectively. The diagnostic plots for the binomial and lognormal submodels are shown in Figures 7-9, and indicated the distribution of the residuals is approximately normal. Annual abundance indices are presented in Figure 10 and Table 4. Nominal and standardized Atlantic sharpnose shark catch rates remained relatively stable throughout the survey with a slight peak in abundance occurring in 2000 (Figure 10).

Bonnethead shark Catch

For the bonnethead shark model, YEAR, AREA, and MONTH were retained in the binomial submodel through the backward selection procedure based on type 3 analysis. Likewise, the variables retained in the lognormal submodel were YEAR, MONTH, TEMPBOT, and SOAK. The AIC for the binomial submodel increased from model run #6 to #7 when non-significant variables were removed. The AIC for the lognormal submodel also increased from model run #5 to #6 when non-significant variables were removed, however, it declined in subsequent runs. Due to the increases of AIC values of each of the submodels, it was decided for the final model (run #9) would be developed from run #6 binomial results and run #5 lognormal results. Table 5 summarizes the backward selection procedure used to select the final set of variables used in the submodels and their significance. The AIC for the binomial and lognormal submodels of the final run (#9) were 1072.2 and 153.4, respectively.

The diagnostic plots for the binomial and lognormal submodels are shown in Figures 12-14, and indicated the distribution of the residuals is approximately normal. Annual abundance indices are presented in Figure 15 and Table 6. Nominal and standardized bonnethead shark catch rates remained relatively stable throughout the survey with a slight peak in abundance occurring in 2007 (Figure 15).

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Table 1. Summary of the Atlantic Sharpnose shark data used in these analyses collected during the Mississippi bottom longline survey conducted between 2004 and 2011.

Survey Year	Number of Stations	Number Collected	Number Measured	Minimum Fork Length (mm)	Maximum Fork Length (mm)	Mean Fork Length (mm)	Standard Deviation
1998	15	207	207	415	847	662	110
1999	17	225	224	421	884	701	101
2000	14	431	431	454	859	711	99
2001	7	213	208	431	883	677	117
2003	6	5	5	691	785	748	36
2004	12	34	33	572	874	739	56
2005	13	112	109	460	856	720	86
2006	22	221	214	414	864	643	122
2007	17	197	193	438	840	627	101
2008	20	212	204	440	820	641	100
2009	18	137	134	440	776	610	91
2010	55	273	268	407	865	621	108
2011	54	290	280	405	798	475	92
Total Number of Years	Total Number of Stations	Total Number Collected	Total Number Measured			Overall Mean Fork Length (mm)	
13	270	2557	2510			653	

Table 2. Summary of the bonnethead shark data used in these analyses collected during the Mississippi bottom longline survey conducted between 2004 and 2011.

Survey Year	Number of Stations	Number Collected	Number Measured	Minimum Fork Length (mm)	Maximum Fork Length (mm)	Mean Fork Length (mm)	Standard Deviation
1998	15	17	15	523	853	716	107
1999	17	7	7	586	819	724	83
2000	14	5	5	507	577	536	33
2001	7	2	2	640	794	717	109
2003	6	0	-	-	-	-	-
2004	12	0	-	-	-	-	-
2005	13	12	11	587	811	715	76
2006	22	16	16	432	810	660	104
2007	17	56	54	425	868	676	99
2008	20	14	14	460	820	579	111
2009	18	37	37	435	785	690	66
2010	55	27	27	425	768	605	115
2011	54	24	23	359	829	589	143
Total Number of Years	Total Number of Stations	Total Number Collected	Total Number Measured			Overall Mean Fork Length (mm)	
13	270	217	211			656	

Table 3. Summary of the backward selection procedure for building delta-lognormal submodels for the Atlantic sharpnose shark full index of relative abundance from 1998 to 2011.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 1384.3)*						*Lognormal Submodel Type 3 Tests (AIC 485.5)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	12	244	19.31	1.61	0.0813	0.0895	12	139	3.44	0.0002
Month	7	244	9.73	1.39	0.2041	0.2097	7	139	6.08	<.0001
Area	1	244	13.67	13.67	0.0002	0.0003	1	139	4.66	0.0326
Salbot	1	244	4.67	4.67	0.0307	0.0317	1	139	19.24	<.0001
Tempbot	1	244	5.34	5.34	0.0209	0.0217	1	139	8.54	0.0041
DObot	1	244	0.07	0.07	0.7963	0.7965	1	139	0.99	0.3218
Depth	1	244	4.13	4.13	0.0420	0.0431	1	139	0.68	0.4115
Soak	1	244	7.33	7.33	0.0068	0.0073	1	139	0.09	0.7656

Model Run #2	*Binomial Submodel Type 3 Tests (AIC 1379.6)*						*Lognormal Submodel Type 3 Tests (AIC 483.3)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	12	245	19.52	1.63	0.0766	0.0846	12	140	3.47	0.0002
Month	7	245	9.78	1.40	0.2012	0.2068	7	140	6.13	<.0001
Area	1	245	13.88	13.88	0.0002	0.0002	1	140	4.68	0.0323
Salbot	1	245	4.71	4.71	0.0299	0.0309	1	140	19.28	<.0001
Tempbot	1	245	5.31	5.31	0.0212	0.0220	1	140	9.06	0.0031
DObot					Dropped		1	140	1.01	0.3172
Depth	1	245	4.14	4.14	0.0420	0.0430	1	140	0.63	0.4301
Soak	1	245	7.79	7.79	0.0052	0.0057			Dropped	

Model Run #3	*Binomial Submodel Type 3 Tests (AIC 1317.1)*						*Lognormal Submodel Type 3 Tests (AIC 480.6)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	12	252	23.31	1.94	0.0252	0.0301	12	141	3.42	0.0002
Month					Dropped		7	141	6.11	<.0001
Area	1	252	19.98	19.98	<.0001	<.0001	1	141	5.51	0.0203
Salbot	1	252	1.92	1.92	0.1661	0.1674	1	141	18.82	<.0001
Tempbot	1	252	11.14	11.14	0.0008	0.0010	1	141	9.52	0.0024
DObot					Dropped		1	141	1.44	0.2322
Depth	1	252	6.61	6.61	0.0101	0.0107			Dropped	
Soak	1	252	12.20	12.20	0.0005	0.0006			Dropped	

Model Run #4	*Binomial Submodel Type 3 Tests (AIC 1306.6)*						*Lognormal Submodel Type 3 Tests (AIC 478.3)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	12	253	23.72	1.98	0.0222	0.0268	12	142	3.44	0.0002
Month					Dropped		7	142	5.95	<.0001
Area	1	253	25.21	25.21	<.0001	<.0001	1	142	5.95	0.0160
Salbot					Dropped		1	142	17.38	<.0001
Tempbot	1	253	10.56	10.56	0.0012	0.0013	1	142	9.18	0.0029
DObot					Dropped				Dropped	
Depth	1	253	10.33	10.33	0.0013	0.0015			Dropped	
Soak	1	253	12.33	12.33	0.0004	0.0005			Dropped	

Table 4. Indices for Atlantic sharpnose shark catch rates from 1998 to 2011 developed using the delta-lognormal model. The nominal frequency of occurrence, the number of samples (n), the Lo Index (numbers per 100 GN per hour), the Lo indices scaled to a mean of one for the time series, the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	Frequency	n	Lo Index	Scaled Index	CV	LCL	UCL
1998	0.60000	15	2.5456	1.22203	0.60983	0.39689	3.7627
1999	0.70588	17	4.4705	2.14611	0.50550	0.82663	5.5718
2000	0.92857	14	11.5587	5.54886	0.43175	2.42714	12.6856
2001	0.71429	7	1.0017	0.48089	0.95250	0.09641	2.3988
2003	0.33333	6	0.0780	0.03743	1.36361	0.00482	0.2908
2004	0.41667	12	0.3642	0.17486	0.83418	0.04087	0.7481
2005	0.61538	13	0.4697	0.22548	0.70731	0.06308	0.8060
2006	0.77273	22	0.7905	0.37948	0.41737	0.17026	0.8458
2007	0.88235	17	0.7373	0.35396	0.43244	0.15464	0.8102
2008	0.60000	20	1.1427	0.54856	0.54338	0.19835	1.5171
2009	0.55556	18	0.5527	0.26534	0.65893	0.07984	0.8818
2010	0.65455	55	1.8016	0.86486	0.22784	0.55150	1.3563
2011	0.38889	54	1.5667	0.75213	0.34318	0.38590	1.4659

Table 5. Summary of the backward selection procedure for building delta-lognormal submodels for the bonnethead shark full index of relative abundance from 1998 to 2011.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 1085.9)*						*Lognormal Submodel Type 3 Tests (AIC 160.8)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	10	206	7.76	0.78	0.6523	0.6519	10	43	0.48	0.8945
Area	1	206	2.63	2.63	0.1047	0.1062	1	43	0.68	0.4135
Month	6	206	12.83	2.14	0.0458	0.0505	6	43	1.36	0.2538
Tempbot	1	206	3.57	3.57	0.0590	0.0604	1	43	1.95	0.1697
Depth	1	206	0.06	0.06	0.8054	0.8056	1	43	0.94	0.3379
Soak	1	206	0.01	0.01	0.9143	0.9144	1	43	4.05	0.0505
DObot	1	206	0.11	0.11	0.7447	0.7450	1	43	0.49	0.4892
Salbot	1	206	1.27	1.27	0.2606	0.2619	1	43	0.17	0.6832

Model Run #2	*Binomial Submodel Type 3 Tests (AIC 1085.5)*						*Lognormal Submodel Type 3 Tests (AIC 156.6)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	10	207	9.24	0.92	0.5097	0.5123	10	44	0.47	0.8981
Area	1	207	2.63	2.63	0.1046	0.1061	1	44	1.10	0.3005
Month	6	207	13.13	2.19	0.0411	0.0455	6	44	1.44	0.2207
Tempbot	1	207	3.62	3.62	0.0571	0.0585	1	44	1.84	0.1823
Depth	1	207	0.06	0.06	0.8061	0.8064	1	44	0.79	0.3791
Soak					Dropped		1	44	3.96	0.0530
DObot	1	207	0.10	0.10	0.7539	0.7542	1	44	0.49	0.4891
Salbot	1	207	1.29	1.29	0.2566	0.2579			Dropped	

Model Run #3	*Binomial Submodel Type 3 Tests (AIC 1082.7)*						*Lognormal Submodel Type 3 Tests (AIC 154.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	10	208	9.28	0.93	0.5062	0.5088	10	45	0.44	0.9184
Area	1	208	2.60	2.60	0.1070	0.1085	1	45	1.43	0.2383
Month	6	208	13.66	2.28	0.0337	0.0377	6	45	1.57	0.1781
Tempbot	1	208	3.62	3.62	0.0572	0.0586	1	45	1.72	0.1967
Depth					Dropped		1	45	1.61	0.2117
Soak					Dropped		1	45	3.69	0.0612
DObot	1	208	0.13	0.13	0.7144	0.7148			Dropped	
Salbot	1	208	1.59	1.59	0.2067	0.2081			Dropped	

Model Run #4	*Binomial Submodel Type 3 Tests (AIC 1079.6)*						*Lognormal Submodel Type 3 Tests (AIC 154.6)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	10	209	9.20	0.92	0.5130	0.5155	10	46	0.49	0.8894
Area	1	209	2.51	2.51	0.1132	0.1148			Dropped	
Month	6	209	14.26	2.38	0.0268	0.0305	6	46	1.49	0.2025
Tempbot	1	209	3.84	3.84	0.0501	0.0514	1	46	2.55	0.1168
Depth					Dropped		1	46	1.63	0.2086
Soak					Dropped		1	46	3.96	0.0525
DObot					Dropped				Dropped	
Salbot	1	209	2.17	2.17	0.1411	0.1426			Dropped	

Model Run #5	*Binomial Submodel Type 3 Tests (AIC 1074.6)*						*Lognormal Submodel Type 3 Tests (AIC 153.4)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	10	210	12.50	1.25	0.2527	0.2607	10	47	0.49	0.8859
Area	1	210	4.59	4.59	0.0321	0.0333			Dropped	
Month	6	210	12.96	2.16	0.0437	0.0482	6	47	1.43	0.2233
Tempbot	1	210	2.13	2.13	0.1446	0.1461	1	47	3.32	0.0748
Depth					Dropped				Dropped	
Soak					Dropped		1	47	3.32	0.0746
DObot					Dropped				Dropped	
Salbot					Dropped				Dropped	

Model Run #6	*Binomial Submodel Type 3 Tests (AIC 1072.2)*						*Lognormal Submodel Type 3 Tests (AIC 162.6)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	10	211	13.05	1.30	0.2211	0.2295	10	53	0.33	0.9691
Area	1	211	5.52	5.52	0.0188	0.0198			Dropped	
Month	6	211	11.41	1.90	0.0766	0.0820			Dropped	
Tempbot					Dropped		1	53	1.11	0.2973
Depth					Dropped				Dropped	
Soak					Dropped		1	53	1.99	0.1644
DObot					Dropped				Dropped	
Salbot					Dropped				Dropped	

Model Run #7	*Binomial Submodel Type 3 Tests (AIC 1154.7)*						*Lognormal Submodel Type 3 Tests (AIC 159.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	10	240	12.01	1.20	0.2844	0.2910	10	54	0.28	0.9839
Area	1	240	4.43	4.43	0.0353	0.0363			Dropped	
Month					Dropped				Dropped	
Tempbot					Dropped				Dropped	
Depth					Dropped				Dropped	
Soak					Dropped		1	54	2.17	0.1465
DObot					Dropped				Dropped	
Salbot					Dropped				Dropped	

Model Run #8	*Binomial Submodel Type 3 Tests (AIC 1154.7)*						*Lognormal Submodel Type 3 Tests (AIC 159.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	10	240	12.01	1.20	0.2844	0.2910	10	55	0.48	0.8947
Area	1	240	4.43	4.43	0.0353	0.0363			Dropped	
Month					Dropped				Dropped	
Tempbot					Dropped				Dropped	
Depth					Dropped				Dropped	
Soak					Dropped				Dropped	
DObot					Dropped				Dropped	
Salbot					Dropped				Dropped	

Model Run #9	*Binomial Submodel Type 3 Tests (AIC 1072.2)*						*Lognormal Submodel Type 3 Tests (AIC 153.4)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	10	211	13.05	1.30	0.2211	0.2295	10	47	0.49	0.8859
Area	1	211	5.52	5.52	0.0188	0.0198			Dropped	
Month	6	211	11.41	1.90	0.0766	0.0820	6	47	1.43	0.2233
Tempbot					Dropped		1	47	3.32	0.0748
Depth					Dropped				Dropped	
Soak					Dropped		1	47	3.32	0.0746
DObot					Dropped				Dropped	
Salbot					Dropped				Dropped	

Table 6. Indices for bonnethead shark catch rates from 1998 to 2011 developed using the delta-lognormal model. The nominal frequency of occurrence, the number of samples (n), the Lo Index (numbers per 100 GN per hour), the Lo indices scaled to a mean of one for the time series, the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

SurveyYear	Frequency	n	Lo Index	Scaled Index	CV	LCL	UCL
1998	0.33333	15	0.23654	1.52819	0.60720	0.49839	4.68584
1999	0.17647	17	0.10240	0.66156	0.80557	0.16081	2.72167
2000	0.14286	14	0.05361	0.34638	1.03020	0.06322	1.89794
2001	0.14286	7	0.02330	0.15053	1.39328	0.01886	1.20174
2005	0.38462	13	0.14792	0.95567	0.60551	0.31251	2.92250
2006	0.31818	22	0.11949	0.77199	0.53018	0.28531	2.08888
2007	0.58824	17	0.53503	3.45668	0.40365	1.58926	7.51837
2008	0.25000	20	0.14619	0.94448	0.68433	0.27344	3.26223
2009	0.27778	18	0.15388	0.99415	0.66089	0.29824	3.31391
2010	0.23636	55	0.10245	0.66189	0.44422	0.28325	1.54664
2011	0.18519	54	0.08180	0.52849	0.49538	0.20708	1.34878

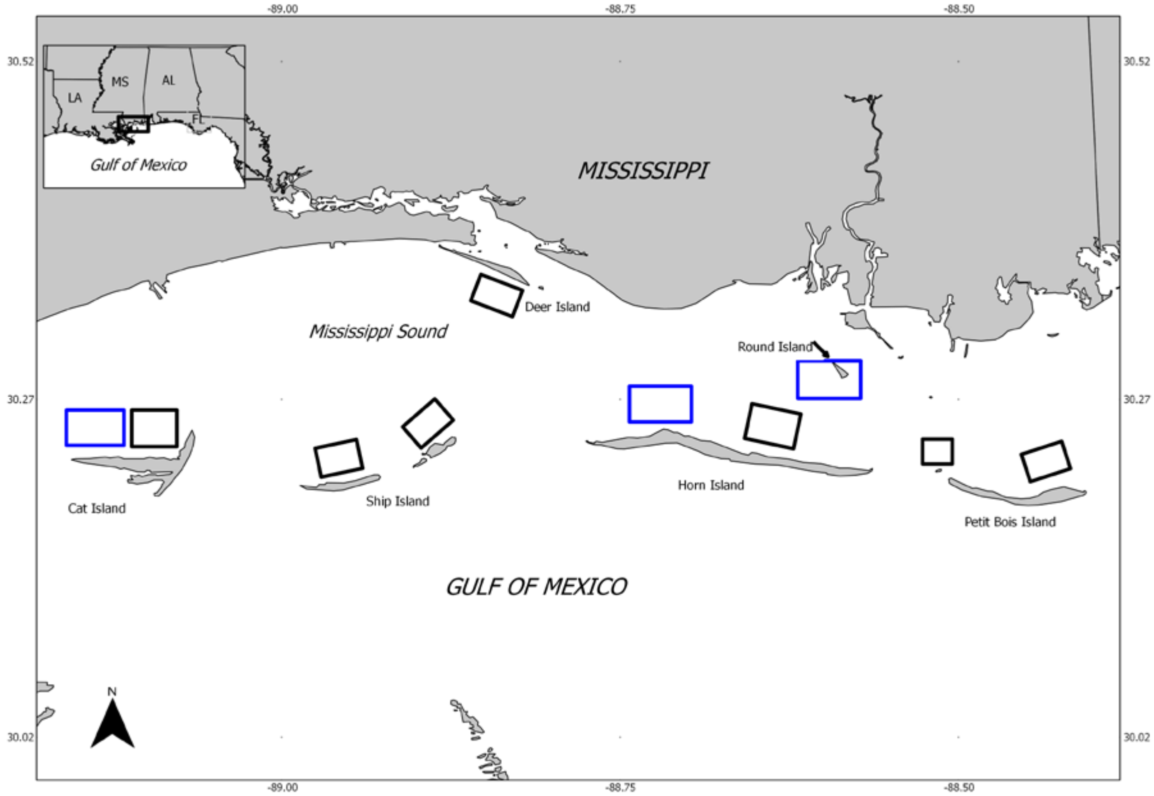


Figure 1. Sampling universe for the Mississippi gillnet survey from 1998-2011. Each rectangle represents a sampling region, from which randomly selected sampling locations were chosen. The blue rectangles represent the primary sampling regions that were sampled from 1998-2009, and the black rectangles represent the expanded sampling regions which were incorporated in 2010.

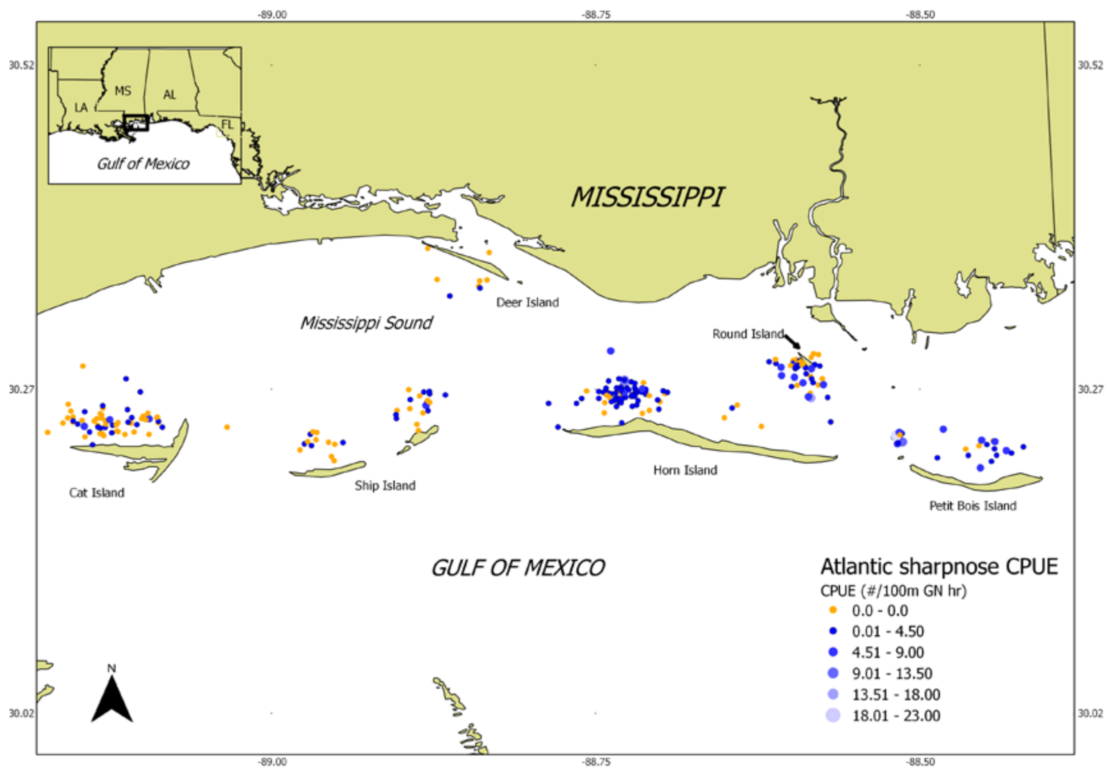


Figure 2. Stations sampled from 1998 to 2011 during the Mississippi gillnet survey with total Atlantic sharpnose shark CPUE presented.

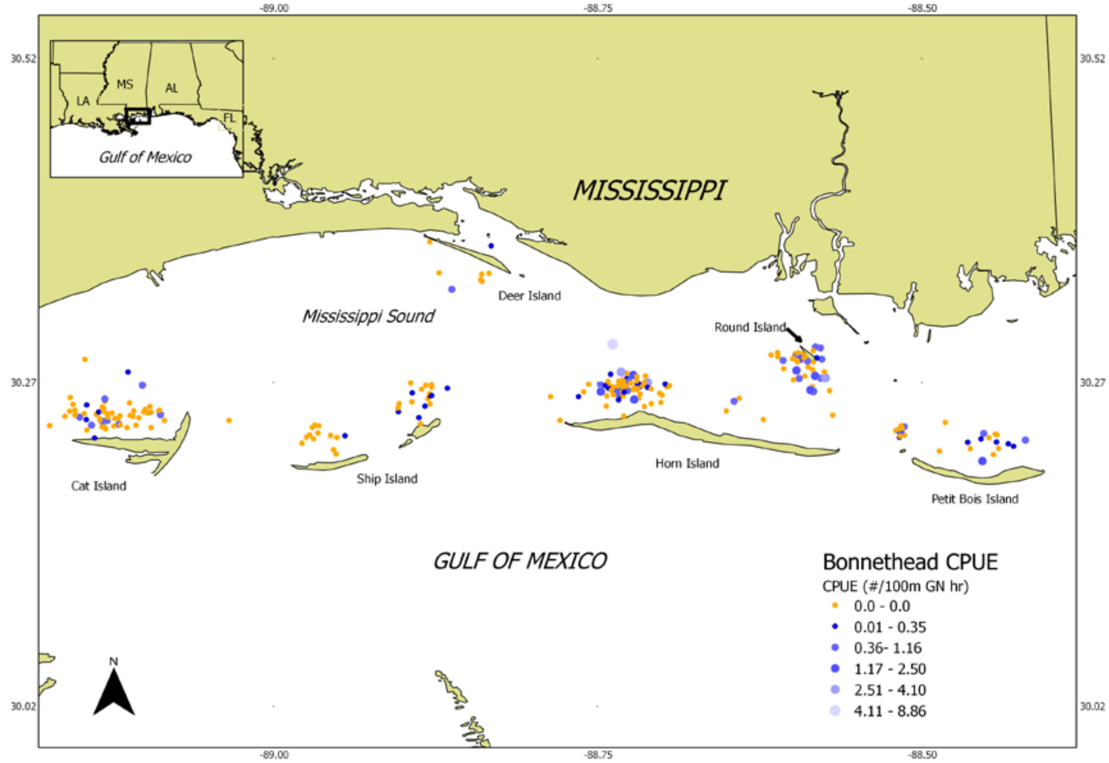


Figure 3. Stations sampled from 1998 to 2011 during the Mississippi gillnet survey with total bonnethead shark CPUE presented.

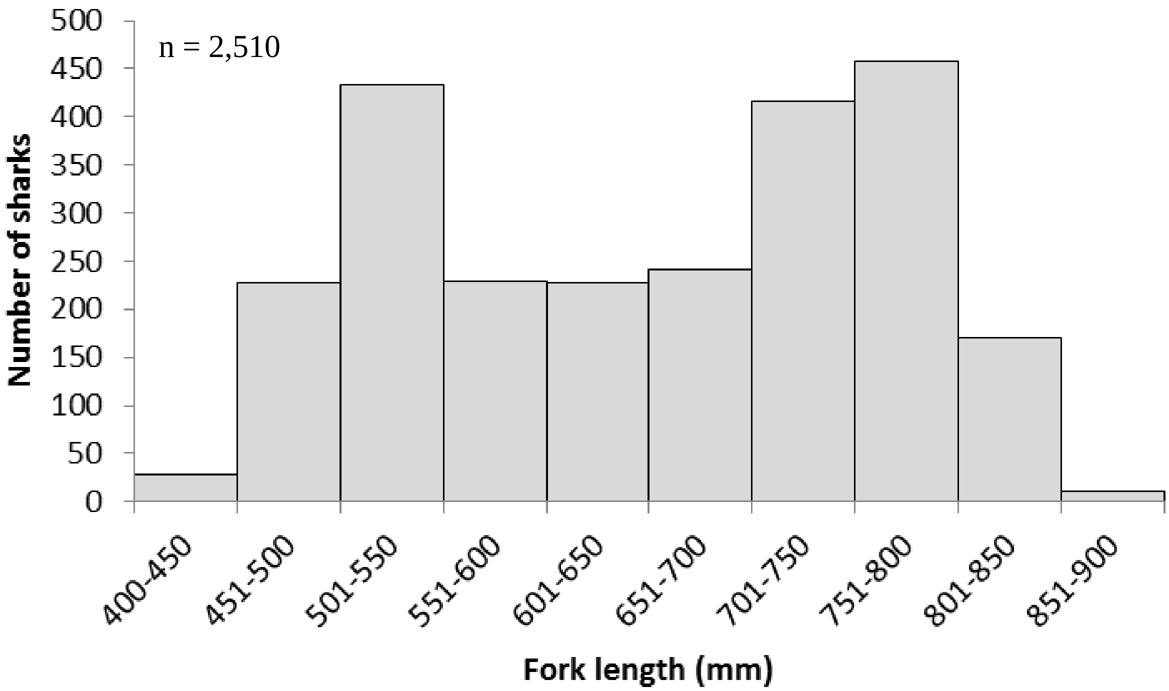


Figure 4. Length frequency distribution for Atlantic sharpnose sharks caught during the Mississippi gillnet survey from 1998-2011.

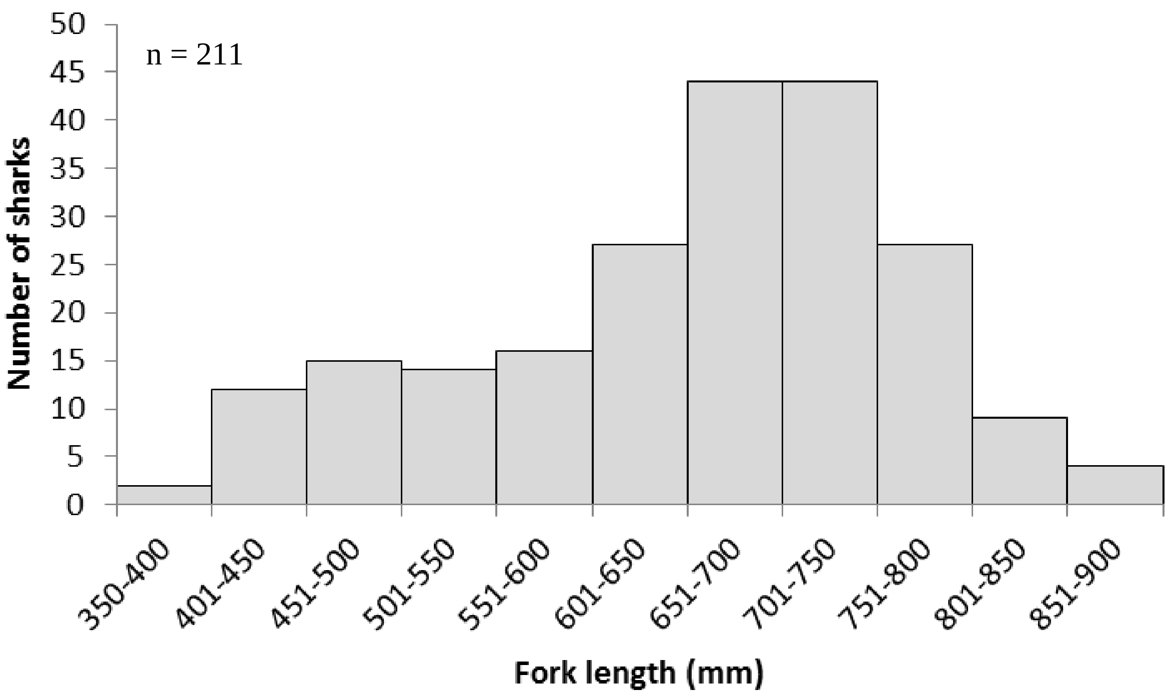


Figure 5. Length frequency distribution for bonnethead sharks caught during the Mississippi gillnet survey from 1998-2011.

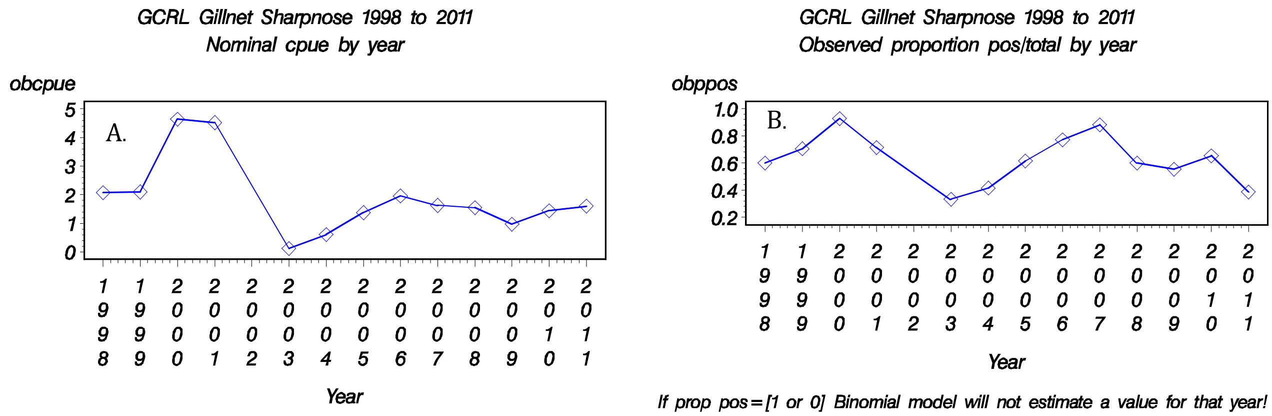


Figure 6. Annual trends for Atlantic sharpnose sharks captured during Mississippi gillnet surveys from 1998 to 2011 in **A.** nominal CPUE and **B.** proportion of positive stations.

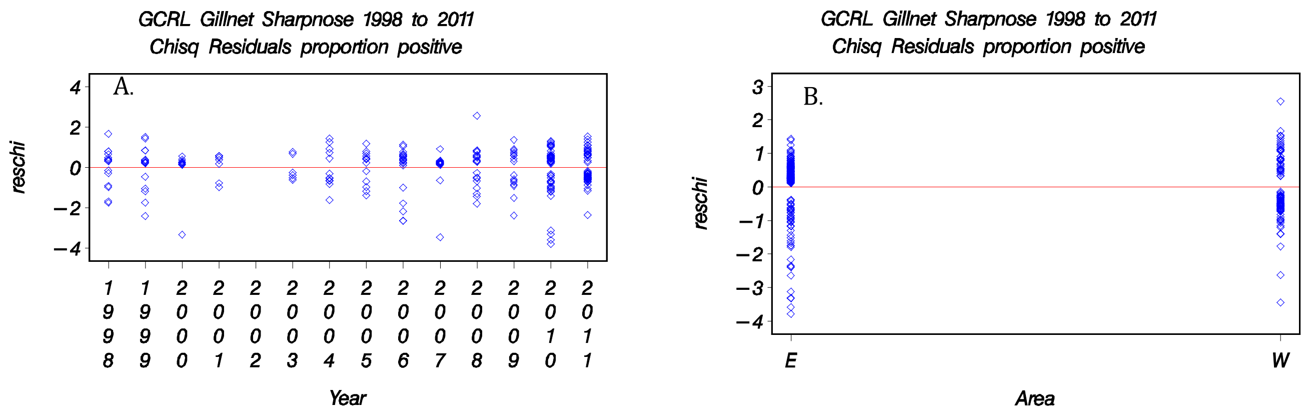


Figure 7. Diagnostic plots for the binomial component of the Atlantic sharpnose shark Mississippi gillnet survey model: **A.** the Chi-Square residuals by year, **B.** the Chi-Square residuals by area.

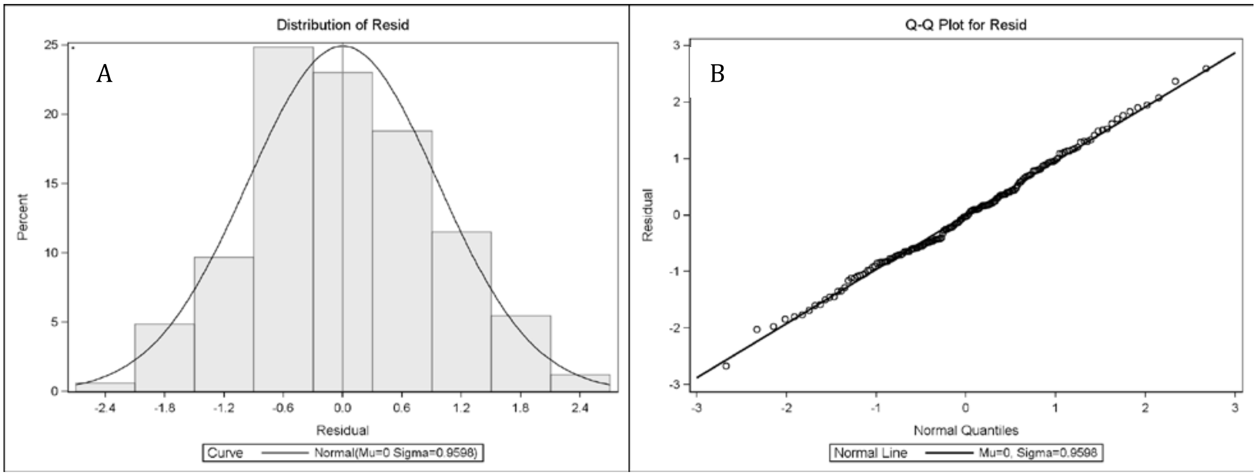


Figure 8. Diagnostic plots for the lognormal component of the Atlantic sharpnose shark Mississippi gillnet survey model: **A.** the frequency distribution of log(CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

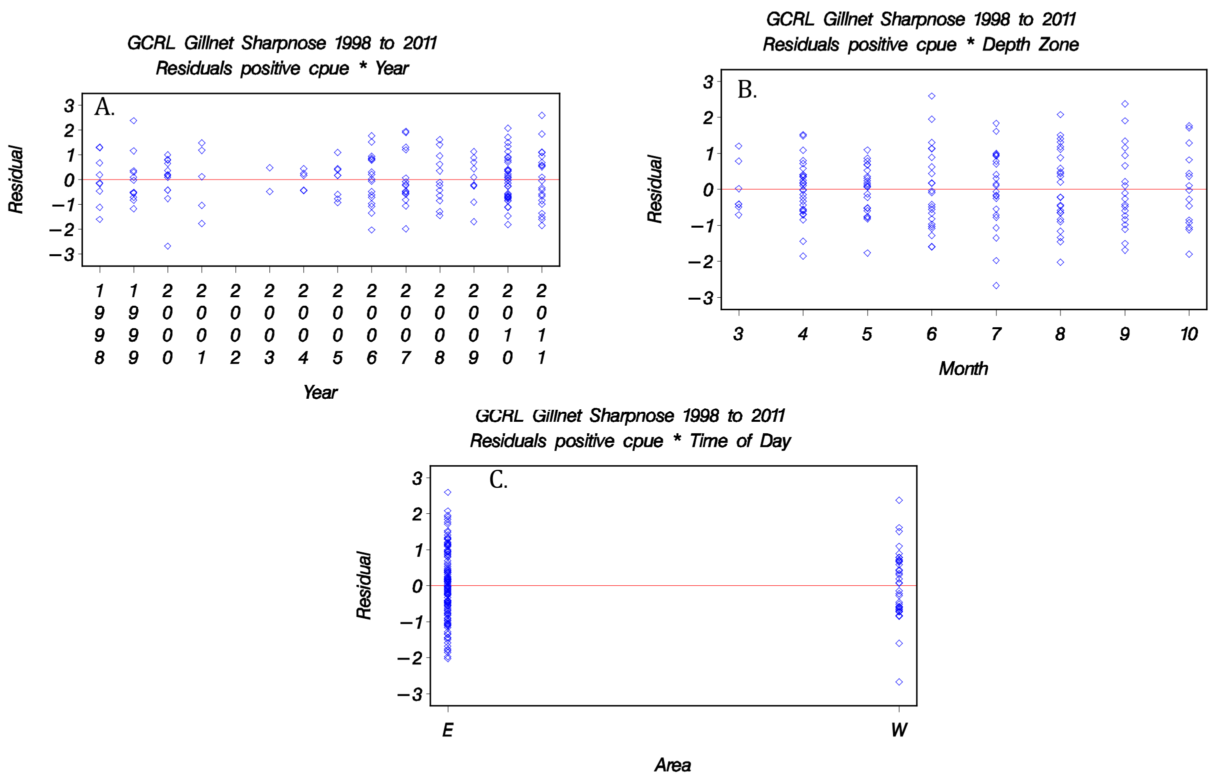


Figure 9. Diagnostic plots for the lognormal component of the Atlantic sharpnose shark Mississippi gillnet survey model: **A.** the Chi-Square residuals by year, **B.** the Chi-Square residuals by month, and **C**. Chi-Square residuals by area.

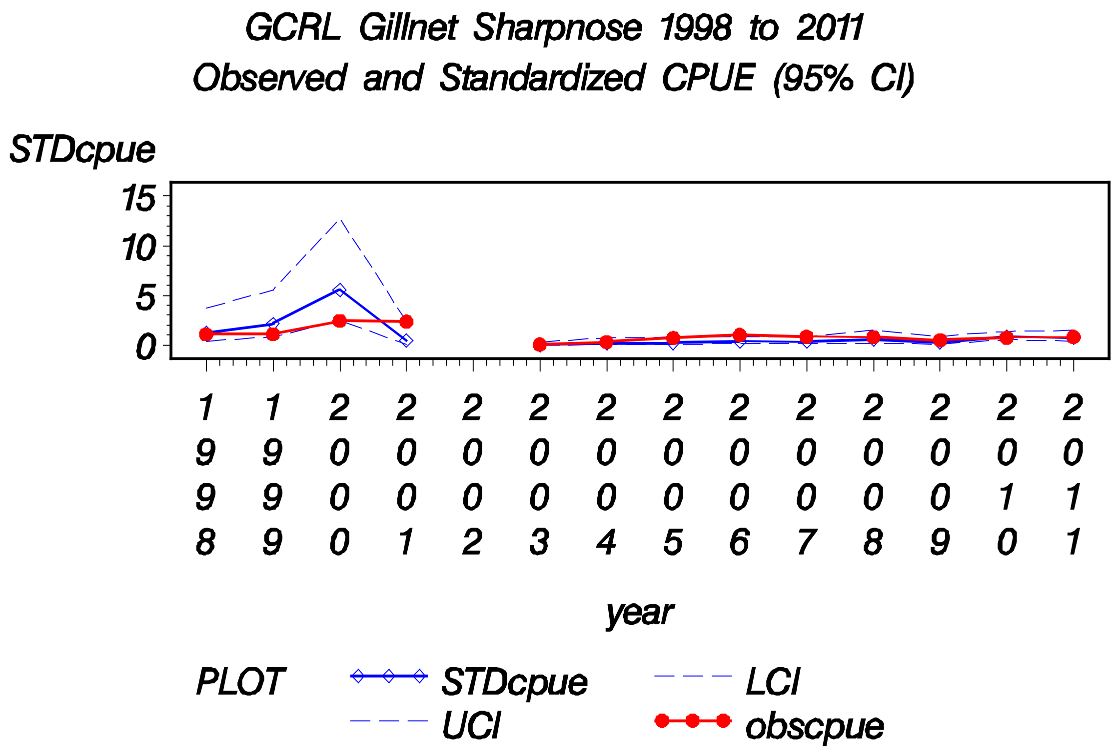


Figure 10. Observed and standardized CPUE for Atlantic sharpnose shark catch in the Mississippi gillnet survey from 1998-2011.

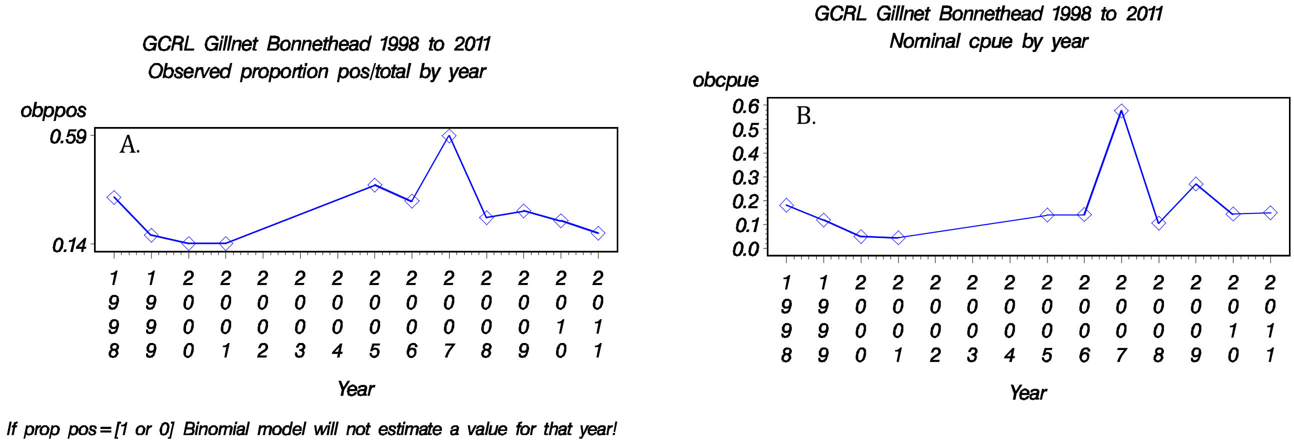


Figure 11. Annual trends for bonnethead sharks captured during Mississippi gillnet surveys from 1998 to 2011 in **A.** nominal CPUE and **B.** proportion of positive stations.

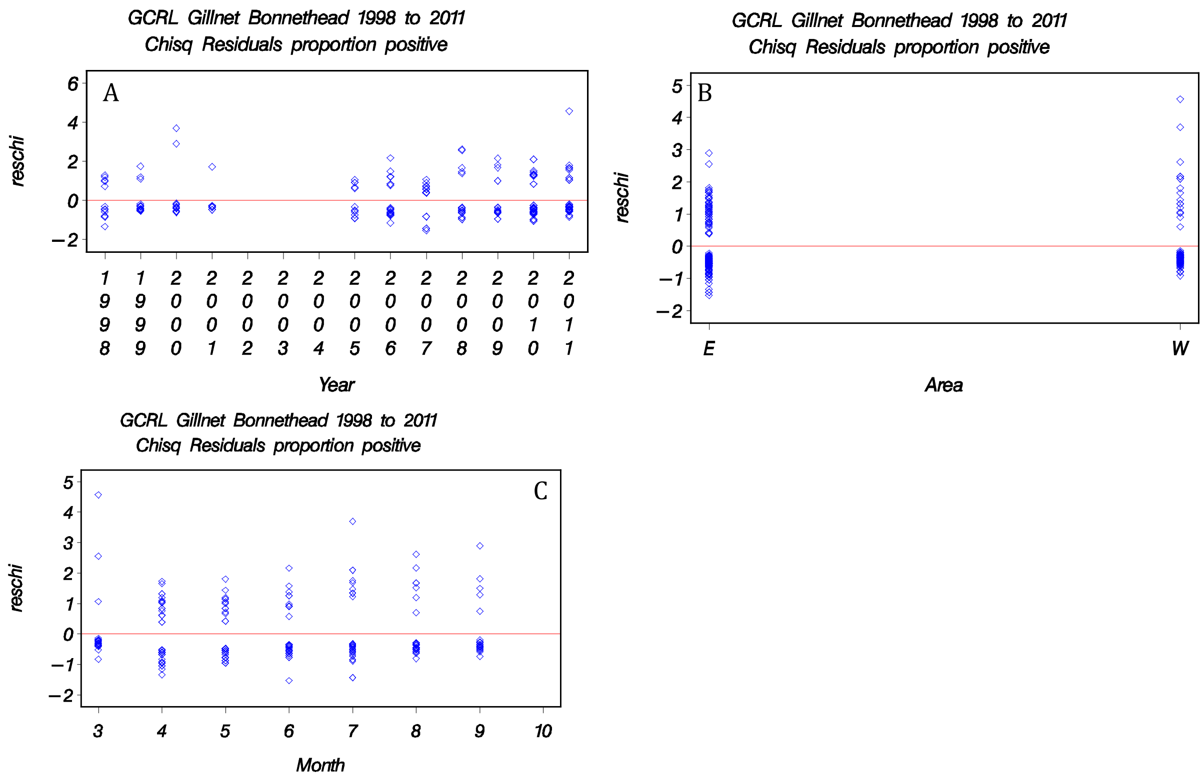


Figure 12. Diagnostic plots for the binomial component of the bonnethead shark Mississippi gillnet survey model: **A.** the Chi-Square residuals by year, **B.** the Chi-Square residuals by area, **C.** the Chi-Square residuals by month.

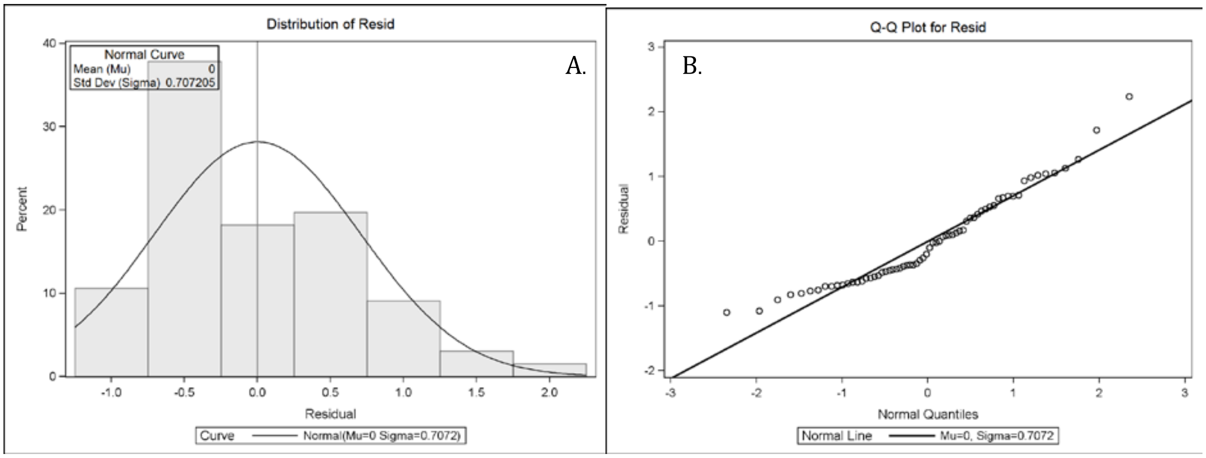


Figure 13. Diagnostic plots for the lognormal component of the bonnethead shark Mississippi gillnet survey model: **A.** the frequency distribution of log(CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

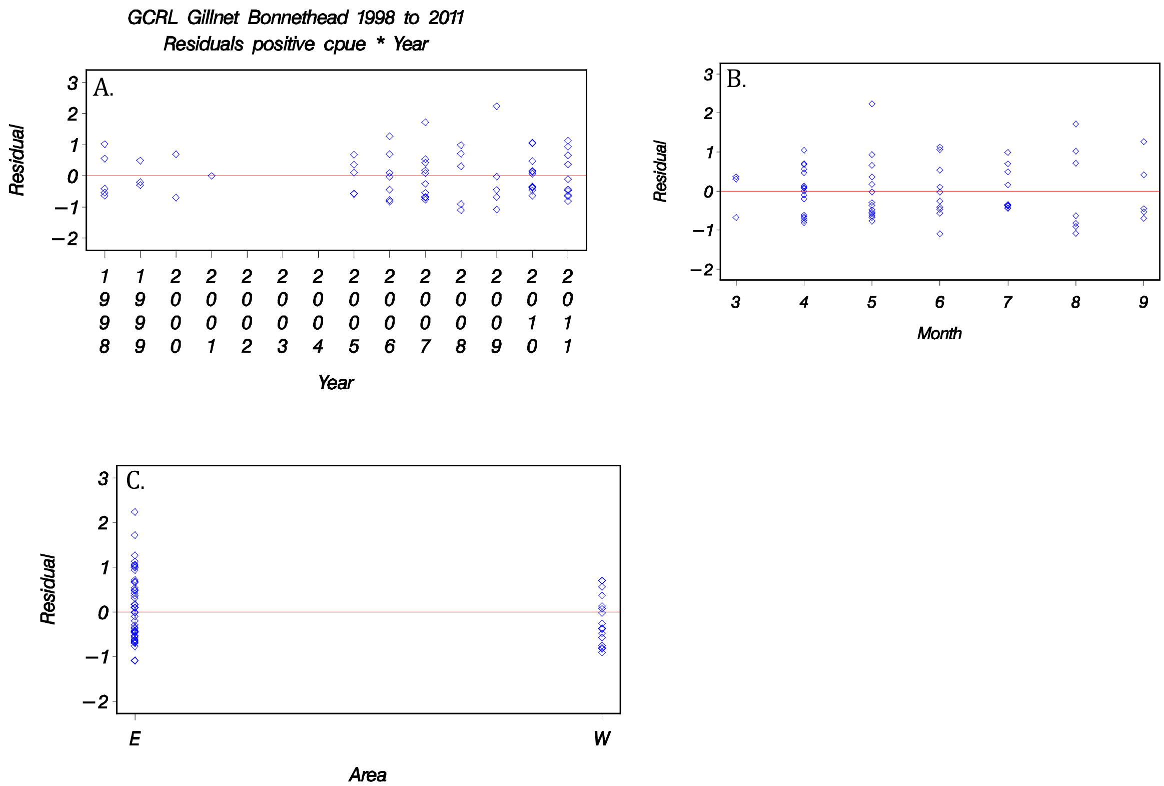


Figure 14. Diagnostic plots for the lognormal component of the bonnethead shark Mississippi gillnet survey model: **A.** the Chi-Square residuals by year, **B.** the Chi-Square residuals by month, and **C**. Chi-Square residuals by area.

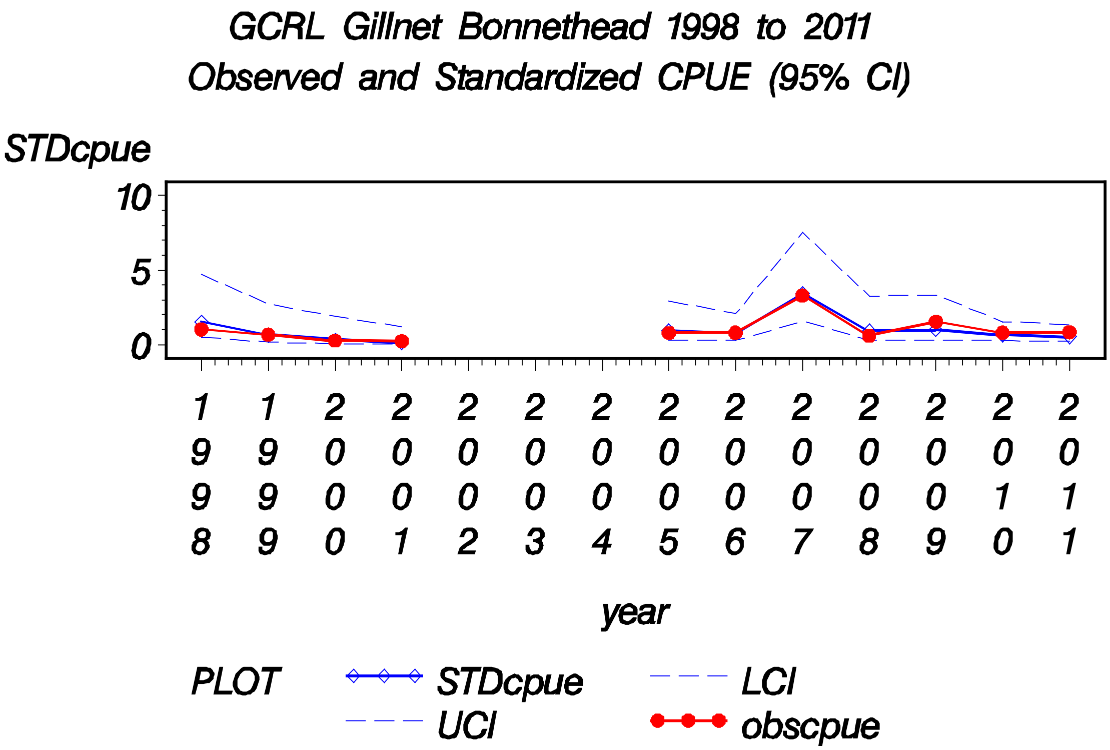
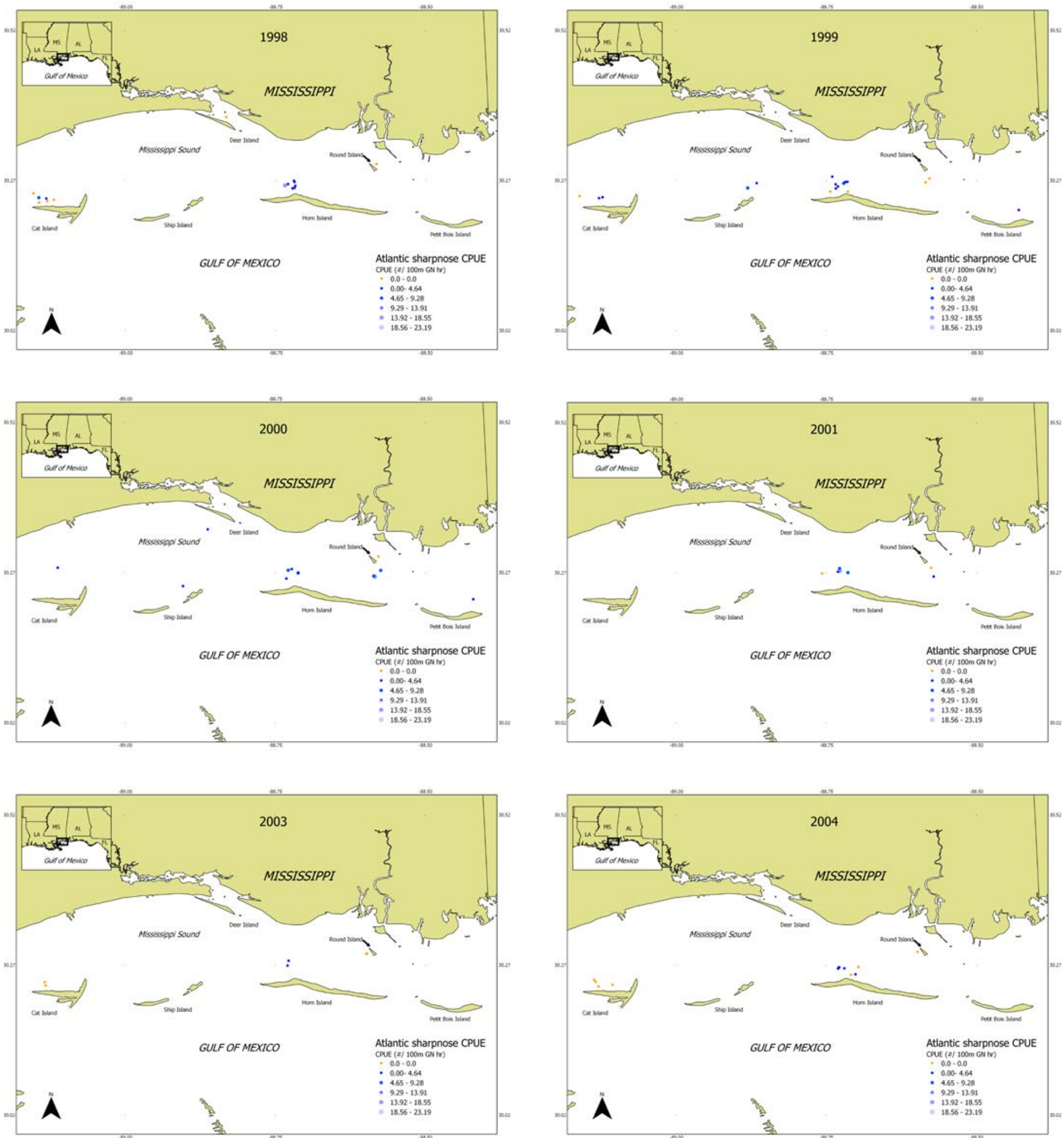


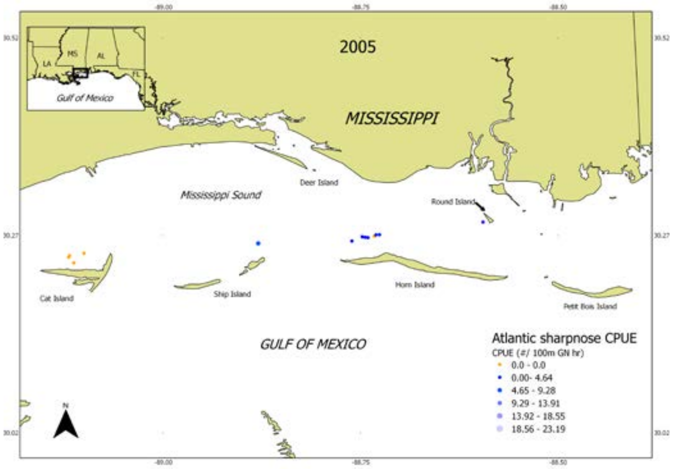
Figure 15. Observed and standardized CPUE for Atlantic sharpnose shark catch in the Mississippi gillnet survey from 1998-2011.

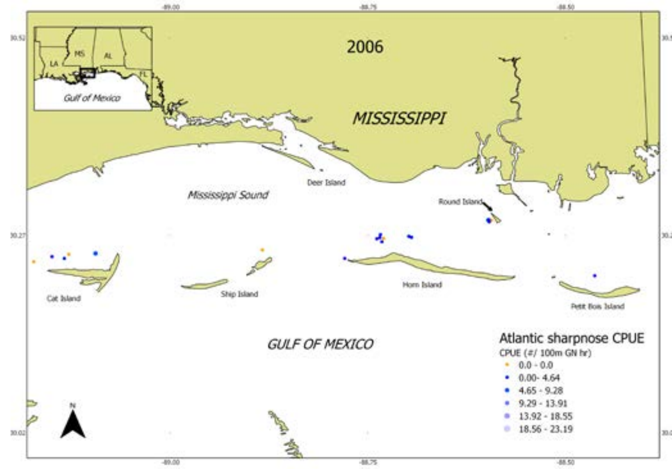
Appendix:

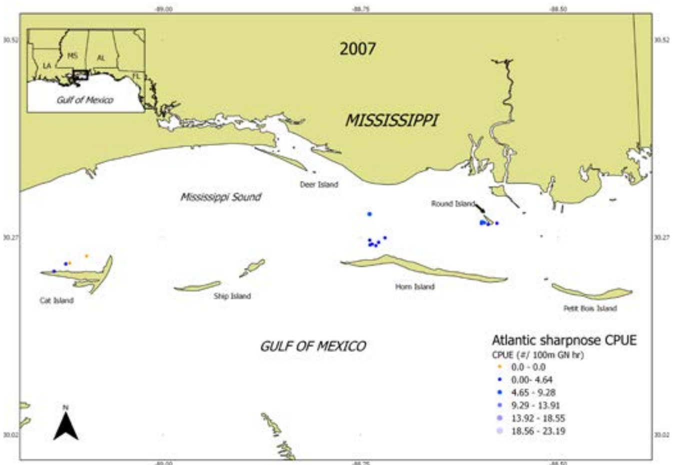
Annual Effort and Catch

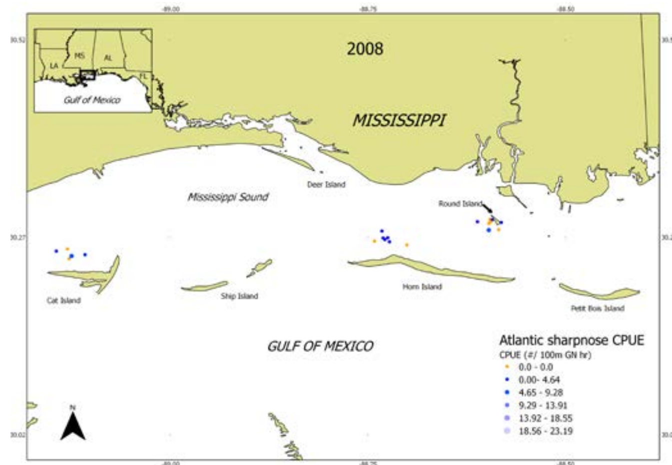
Appendix Figure 1. Annual survey effort and catch of Atlantic sharpnose sharks from the Mississippi gill net survey from 1998-2011.

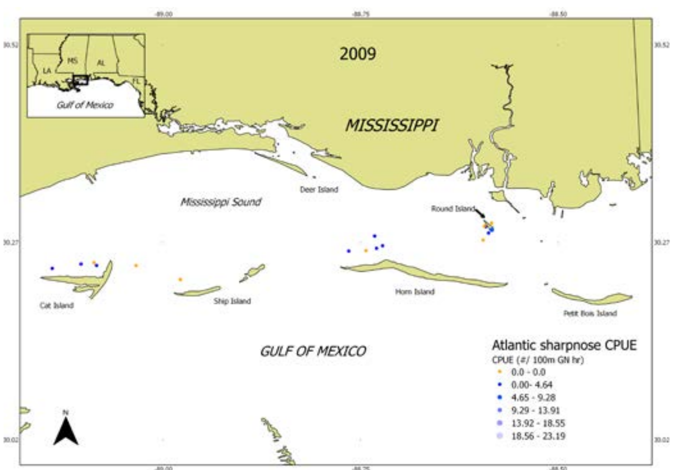


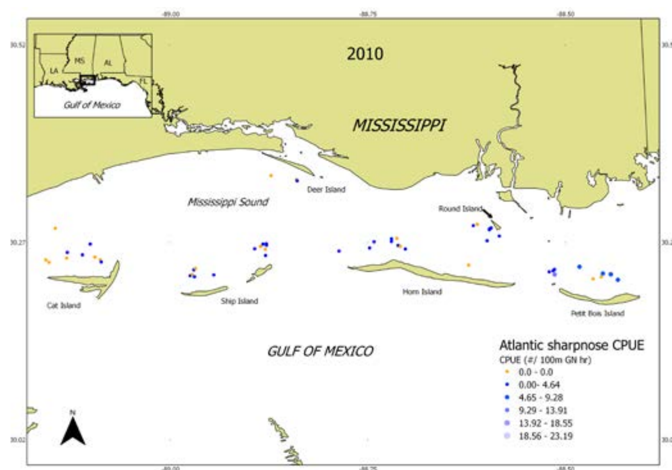

2005
MS
AL
LA
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Atlantic sharpnose CPUE
CPUE (#/ 100m GN hr)
0.0 - 0.0
0.00- 4.64
4.65 - 9.28
9.29 - 13.91
13.92 - 18.55
18.56 - 23.19
N

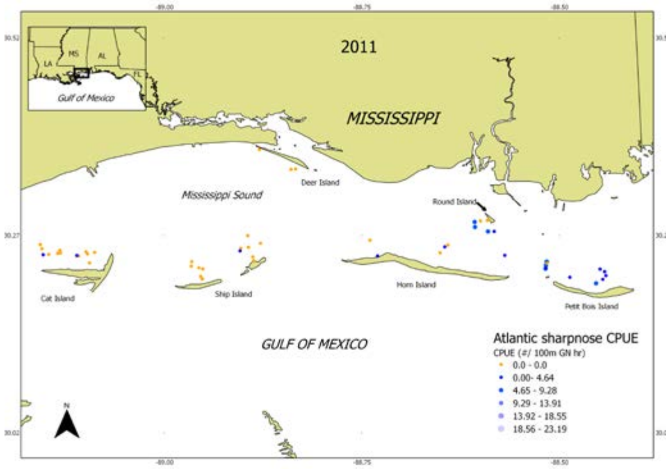

2006
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Atlantic sharpnose CPUE
CPUE (#/ 100m GN hr)
0.0 - 0.0
0.00- 4.64
4.65 - 9.28
9.29 - 13.91
13.92 - 18.55
18.56 - 23.19
N


2007
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Atlantic sharpnose CPUE
CPUE (#/ 100m GN hr)
0.0 - 0.0
0.00- 4.64
4.65 - 9.28
9.29 - 13.91
13.92 - 18.55
18.56 - 23.19
N

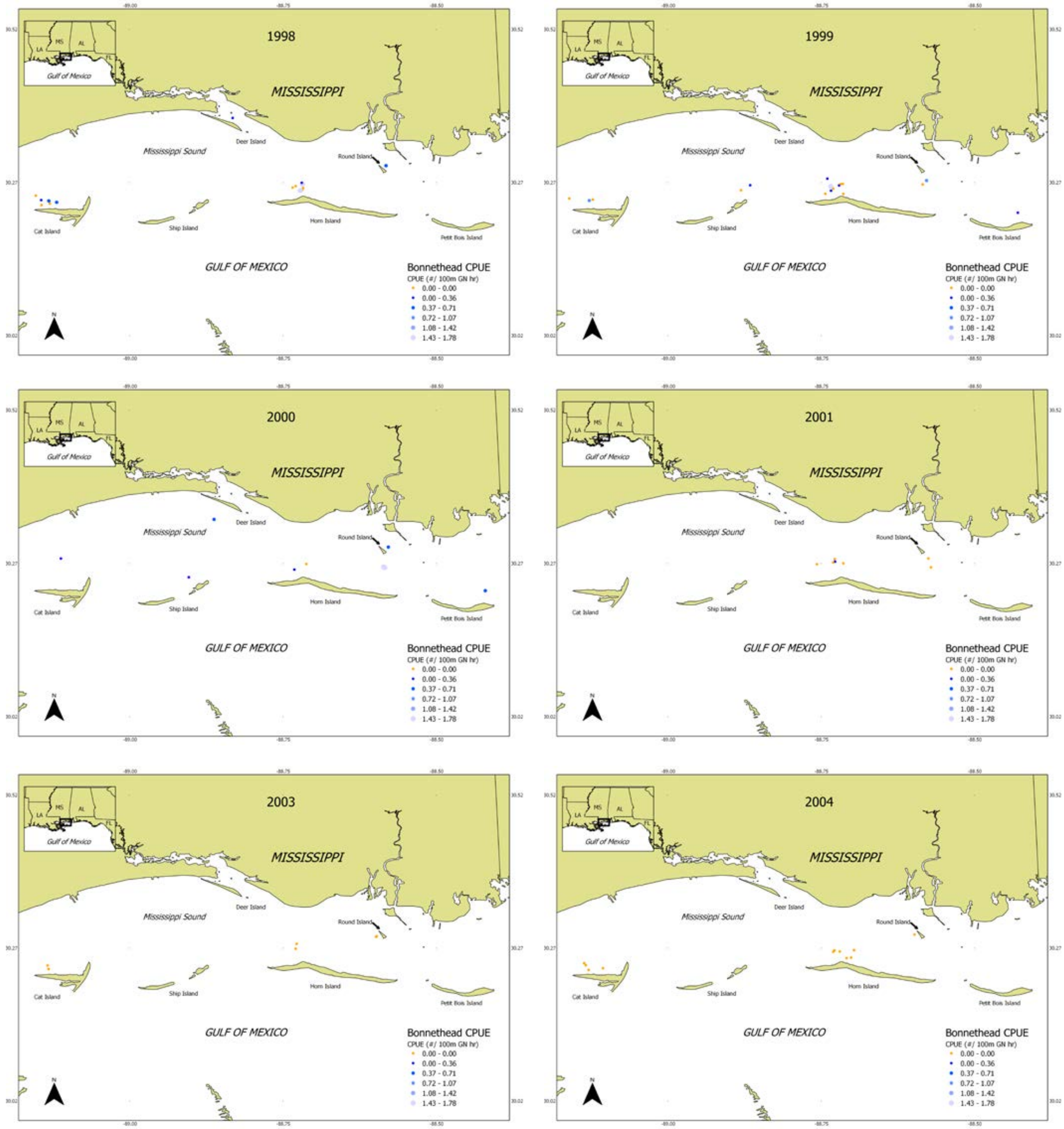

2008
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Atlantic sharpnose CPUE
CPUE (#/ 100m GN hr)
0.0 - 0.0
0.00- 4.64
4.65 - 9.28
9.29 - 13.91
13.92 - 18.55
18.56 - 23.19
N

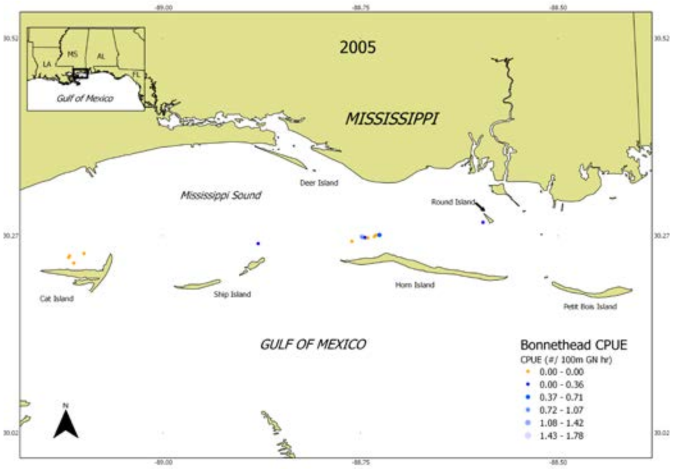

2009
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Atlantic sharpnose CPUE
CPUE (#/ 100m GN hr)
0.0 - 0.0
0.00- 4.64
4.65 - 9.28
9.29 - 13.91
13.92 - 18.55
18.56 - 23.19
N

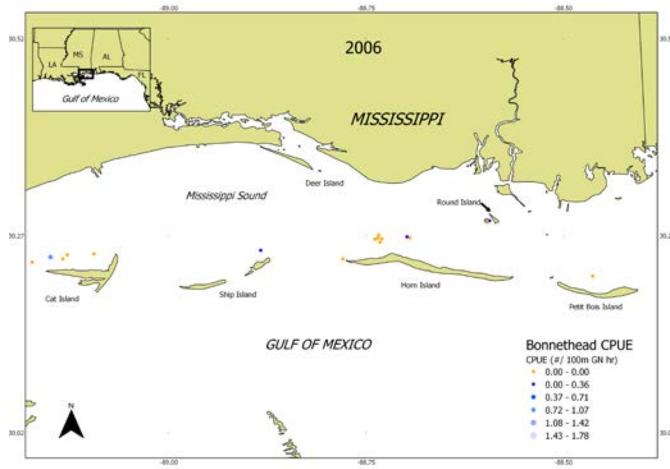

2010
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Atlantic sharpnose CPUE
CPUE (#/ 100m GN hr)
0.0 - 0.0
0.00- 4.64
4.65 - 9.28
9.29 - 13.91
13.92 - 18.55
18.56 - 23.19
N

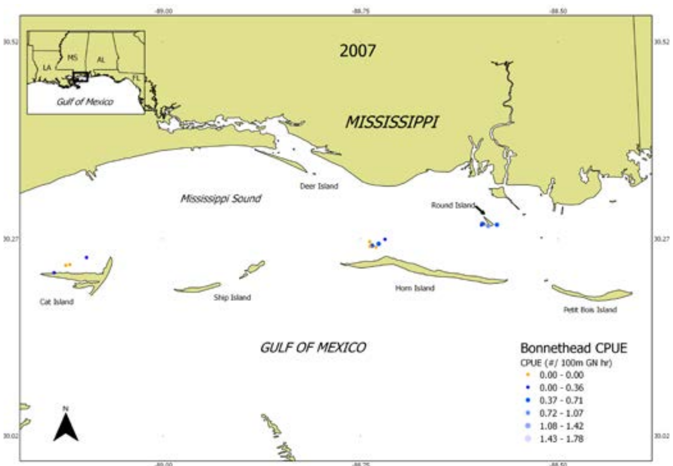

2011
MISSISSIPPI
LA
MS
AL
FL
Gulf of Mexico
Deer Island
Mississippi Sound
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Atlantic sharpnose CPUE
CPUE (#/ 100m GN hr)
0.0 - 0.0
0.00- 4.64
4.65 - 9.28
9.29 - 13.91
13.92 - 18.55
18.56 - 23.19
N

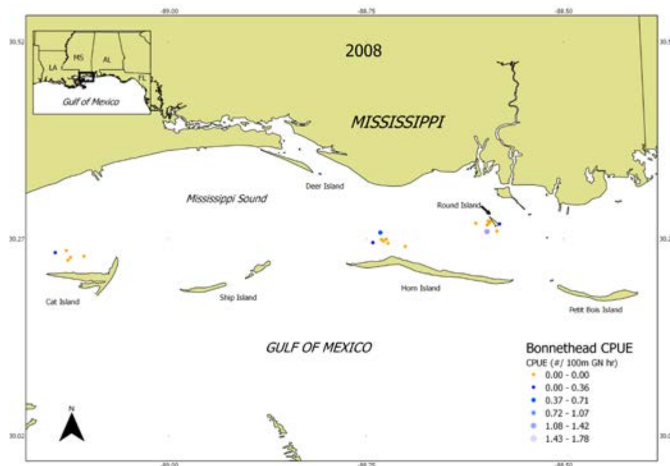
Appendix Figure 2. Annual survey effort and catch bonnethead sharks from the Mississippi gill net survey from 1998-2011.

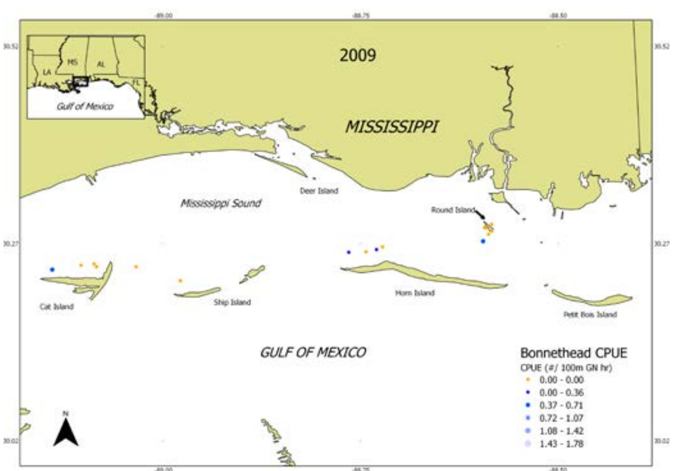


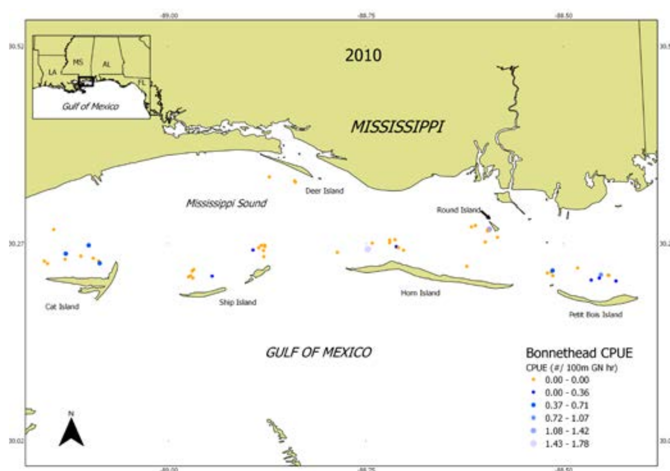

2005
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Bonnethead CPUE
CPUE (#/ 100m GN hr)
0.00 - 0.00
0.00 - 0.36
0.37 - 0.71
0.72 - 1.07
1.08 - 1.42
1.43 - 1.78
N

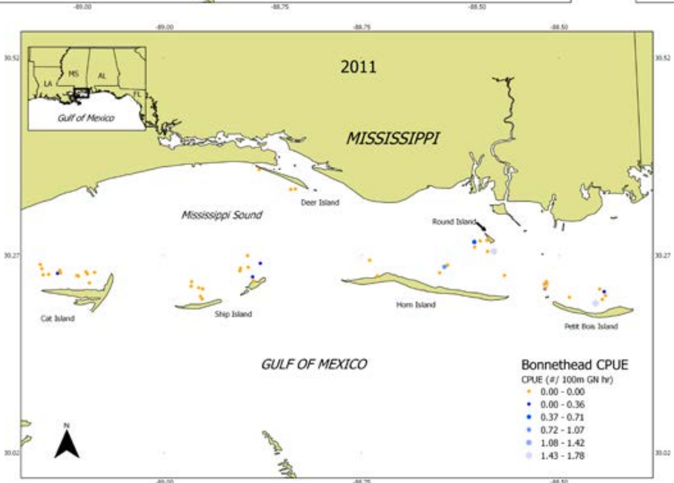

2006
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Bonnethead CPUE
CPUE (#/ 100m GN hr)
0.00 - 0.00
0.00 - 0.36
0.37 - 0.71
0.72 - 1.07
1.08 - 1.42
1.43 - 1.78
N


2007
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Bonnethead CPUE
CPUE (#/ 100m GN hr)
0.00 - 0.00
0.00 - 0.36
0.37 - 0.71
0.72 - 1.07
1.08 - 1.42
1.43 - 1.78
N


2008
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Bonnethead CPUE
CPUE (#/ 100m GN hr)
0.00 - 0.00
0.00 - 0.36
0.37 - 0.71
0.72 - 1.07
1.08 - 1.42
1.43 - 1.78
N


2009
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Bonnethead CPUE
CPUE (#/ 100m GN hr)
0.00 - 0.00
0.00 - 0.36
0.37 - 0.71
0.72 - 1.07
1.08 - 1.42
1.43 - 1.78
N


2010
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Bonnethead CPUE
CPUE (#/ 100m GN hr)
0.00 - 0.00
0.00 - 0.36
0.37 - 0.71
0.72 - 1.07
1.08 - 1.42
1.43 - 1.78
N


2011
MS
AL
LA
FL
Gulf of Mexico
MISSISSIPPI
Mississippi Sound
Deer Island
Round Island
Cat Island
Ship Island
Horn Island
Petit Bois Island
GULF OF MEXICO
Bonnethead CPUE
CPUE (#/ 100m GN hr)
0.00 - 0.00
0.00 - 0.36
0.37 - 0.71
0.72 - 1.07
1.08 - 1.42
1.43 - 1.78
N