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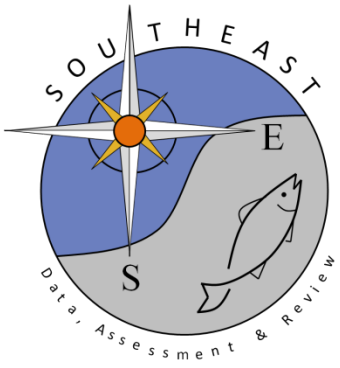

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Scalloped and Great Hammerheads Abundance Indices from NMFS Bottom Longline Surveys in the Northern Gulf of Mexico and Western North Atlantic

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Abstract: *The Southeast Fisheries Science Center Mississippi Laboratories (MSLABS) has conducted standardized bottom longline surveys in the Gulf of Mexico (GOM), Caribbean, and Western North Atlantic Ocean (Atlantic) since 1995. Additionally in 2011, the Congressional Supplemental Sampling Program (CSSP) was conducted, where high levels of standardized bottom longline survey effort were maintained from April through October. Data from the MSLABS Bottom Longline Survey and the CSSP Survey were used to produce a relative abundance index for scalloped hammerhead (Sphyrna lewini) and great hammerhead (Sphyrna mokarran). One abundance index was calculated for great hammerhead that included data from both the GOM and Atlantic. Three abundance indices were calculated for scalloped hammerhead, with one covering both the GOM and Atlantic, and with the other two covering the GOM and Atlantic separately.*

Introduction

The Southeast Fisheries Science Center (SEFSC) Mississippi Laboratories (MSLABS) has conducted standardized bottom longline (BLL) surveys in the Gulf of Mexico (GOM), Caribbean, and Western North Atlantic Ocean (Atlantic) since 1995. The objective of these surveys is to provide fisheries independent data for stock assessment purposes for as many species as possible. These surveys are conducted annually in U.S. waters of the GOM and/or the Atlantic, and provide an important source of fisheries independent information on sharks, snappers and groupers. The evolution of these surveys has been the subject of many documents [e.g., Ingram *et al*. 2005 (LCS05/06-DW-27)] and will not be described again in this document.

In 2011, the Congressional Supplemental Sampling Program (CSSP) was conducted, where high levels of survey effort were maintained from April through October (for a full review of the CSSP see Campbell *et al.* 2012). This program was conducted using the same gear as the annual bottom longline survey and a similar survey design. The only difference was the CSSP sampled out to 400 m, whereas, the annual survey samples to a depth of 366 m. The purpose of this document is to provide an abundance index for scalloped hammerhead (*Sphyrna lewini*) and great hammerhead (*Sphyrna mokarran*).

Methodology

Survey Design

Details concerning methodologies and evolution of the NMFS BLL have been covered in previous documents (most recently LCS05/06-DW-27). Basic sample design was a proportional allocation of stations based on continental shelf width within statistical zones and stratified by depth (50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m).

When the survey began in 1995, J-hooks were the standard gear. Over time a change was made to 15/0 circle hooks. However, Henwood *et al.* (2005) examined the difference in catch rates between the two hooks types and found no significant difference in catch rates for either scalloped or great hammerhead.

Data

Data for the annual BLL survey and the CSSP survey was queried from the SEFSC MSLABS ORACLE database. Data from the CSSP was used to fill in gaps in the annual BLL survey due to vessel breakdowns and weather delays in 2011. Only data from the August survey was used for the Eastern GOM and only data from the September survey was used for the Western and Central GOM in order to not over represent any one area of the GOM. These time frames historically match up with when the annual BLL survey sampled those areas. For this document, the combined dataset will be hereafter referred to as NMFS BLL.

Data Exclusions

We used the time series of data between 1995 and 2019 to develop great and scalloped hammerheads abundance indices (Table 1). In 2005, additional sampling was done in late October and November (43 stations) since most of the survey was canceled due to Hurricane Katrina. However, there was little temporal overlap in other years (17 stations in 2004), so all stations done outside of June, July, August and September were removed. After limiting the data, 4,956 stations were used in the analysis. Finally, for the purpose of this analysis, all age 0 scalloped hammerhead (FL < 61 cm) were removed when building the dataset for the abundance indices.

Index Construction

Delta-lognormal modeling methods were used to estimate relative abundance indices for great and scalloped hammerheads (Pennington, 1983; Bradu & Mundlak, 1970). 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 (*cf.* Lo *et al*. 1992).

The delta-lognormal index of relative abundance (I_y) 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) $p = \frac{e^{X\beta+\varepsilon}}{1+e^{X\beta+\varepsilon}}$,

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 using the delta method approximation

(4) $V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y)$.

A covariance term is not included in the variance estimator since there is no correlation between the estimator of the proportion positive and the mean CPUE given presence. The two estimators are derived independently and have been shown to not covary for a given year (Christman, unpublished).

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 $\alpha = 0.05$. 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. Variables that could be included in the submodels were:

Submodel Variables (Great Hammerhead)

Year: 1995 – 1997, 1999 – 2019
Depth: 9 – 387 m (continuous)
Area: North Atlantic (north of 32°N), South Atlantic (south of 32°N), Eastern GOM (east of 88°W), Central GOM (88°W – 93°W), Western GOM (west of 93°W)
Hook Type: Circle hook, J-hook

Submodel Variables (Scalloped Hammerhead – GOM and Atlantic)

Year: 1995 – 1997, 1999 – 2019
Depth: 9 – 387 m (continuous)
Area: North Atlantic (north of 32°N), South Atlantic (south of 32°N), Eastern GOM (east of 88°W), Central GOM (88°W – 93°W), Western GOM (west of 93°W)
Hook Type: Circle hook, J-hook

Submodel Variables (Scalloped Hammerhead – Atlantic)

Year: 1995 – 1996, 2000, 2002, 2005 – 2006, 2008 – 2019
Depth: 9 – 183 m (continuous)
Latitude: 26.8 – 36.5°N (continuous)
Hook Type: Circle hook, J-hook

Submodel Variables (Scalloped Hammerhead – GOM)

Year: 1995 – 1997, 1999 – 2015
Depth: 9 – 183 m (continuous)
Area: Eastern GOM (east of 88°W), Central GOM (88°W – 93°W), Western GOM (west of 93°W)
Hook Type: Circle hook, J-hook

Results and Discussion

Size and Distribution – Great Hammerhead

The distribution of great hammerhead is presented in Figure 1, with annual abundance and distribution presented in Appendix Figure 1. There were 1 to 16 great hammerheads captured per year (Table 2). Of the 132 great hammerhead captured, 82 were measured from 1995 – 2019 with an average fork length of 1688 mm. In addition, 47 individuals only had an estimated length taken, which were generally larger animals (Figure 3) with an average length of 1942 mm. With the addition of the estimated lengths, the average fork length increases to 1780 mm.

Size and Distribution – Scalloped Hammerhead

The distribution of scalloped hammerhead is presented in Figure 2, with annual abundance and distribution presented in Appendix Figure 2. There were 6 to 48 scalloped hammerheads captured per year (Table 3). Of the 493 scalloped hammerhead captured, 360 were measured from 1995 – 2019 with an average fork length of 1233 mm. In addition, 109 individuals only had an estimated length taken (Figure 4), with an average length of 1573 mm. Even with the addition of the estimated lengths, the average fork length only increases to 1312 mm.

Abundance Index – Great Hammerhead

For the NMFS BLL abundance index of great hammerhead, year and depth were retained in the binomial submodel, while only year was retained in the lognormal submodel. A summary of the factors used in the analysis is presented in Appendix Table 1. Table 4 summarizes 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 38,624.9 and 19.5, respectively. The diagnostic plots for the binomial and lognormal submodels are shown in Figures 5. Annual abundance indices are presented in Table 5 and Figure 6.

Abundance Index – Scalloped Hammerhead – GOM and Atlantic

For the NMFS BLL abundance index of scalloped hammerhead (GOM and Atlantic), year and area were retained in both the binomial and lognormal submodels. A summary of the factors used in the analysis is presented in Appendix Table 2. Table 6 summarizes 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 28,897.6 and 412.9, respectively. The diagnostic plots for the binomial and lognormal submodels are shown in Figures 7. Annual abundance indices are presented in Table 7 and Figure 8.

Abundance Index – Scalloped Hammerhead –Atlantic

For the NMFS BLL abundance index of scalloped hammerhead (Atlantic), year, depth, and latitude were retained in the binomial submodel, while only year and latitude were retained in the lognormal submodel. A summary of the factors used in the analysis is presented in Appendix Table 3. Table 8 summarizes 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 5430.8 and 100.8, respectively. The diagnostic plots for the binomial and lognormal submodels are shown in Figures 9. Annual abundance indices are presented in Table 9 and Figure 10.

Abundance Index – Scalloped Hammerhead – GOM

For the NMFS BLL abundance index of scalloped hammerhead (GOM), year and area were retained in both the binomial and lognormal submodels. A summary of the factors used in the analysis is presented in Appendix Table 4. Table 10 summarizes 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 23,053.2 and 300.2, respectively. The diagnostic plots for the binomial and lognormal submodels are shown in Figures 11. Annual abundance indices are presented in Table 11 and Figure 12.

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Table 1. Summary of the total number of stations sampled per year used in the analysis.

		Gulf of Mexico			
Year	Atlantic	East	Central	West	Total
1995	43	34	27	13	117
1996	30	37	25	17	109
1997	64	61	32	71	228
1998					
1999		57	104		161
2000	105	63	51	23	242
2001		130	64	83	277
2002	176	43	71	98	388
2003		163	54	63	280
2004	40	136	60	53	289
2005	27	79	14		120
2006	57	62	37	50	206
2007		69	38	47	154
2008	37	75	7	26	145
2009	32	91	42	51	216
2010	26	86	31	31	174
2011	49	177	54	65	345
2012	41	74	35	33	183
2013	36	75	47	45	203
2014	46	62	29	27	164
2015	43	84	35	41	203
2016	48	84	31	38	201
2017	41	64	34	51	190
2018	43	74	36	39	192
2019	51	58	24	36	169
Total	*1035*	*1938*	*982*	*1001*	*4956*

Table 2. Summary of the great hammerhead length data (measured not estimated) collected from NMFS Bottom Longline surveys conducted between 1995 and 2019.

Survey Year	Number of Stations	Number Collected	Number Measured	Minimum Fork Length (mm)	Maximum Fork Length (mm)	Mean Fork Length (mm)	Standard Deviation
1995	117	7	5	1540	2235	2027	281
1996	109	5					
1997	228	6	2	960	964	962	3
1998							
1999	161	1	1	1561	1561	1561	
2000	242	2	2	2342	2342	2342	0
2001	277	6	1	1010	1010	1010	
2002	388	3	1	1330	1330	1330	
2003	280	8	2	1350	1434	1392	59
2004	289	6	1	940	940	940	
2005	120	1	1	1820	1820	1820	
2006	206	3	3	1233	1570	1422	172
2007	154	2	2	1245	1410	1328	117
2008	145	3	3	910	1850	1503	516
2009	216	5	5	1110	2000	1540	400
2010	174	8	5	1400	1830	1602	201
2011	345	3	1	1370	1370	1370	
2012	183	7	6	1550	2186	1846	273
2013	203	3	2	1344	2015	1680	474
2014	164	5	5	855	2250	1641	673
2015	203	6	3	1514	1908	1717	197
2016	201	7	6	1074	2340	1908	464
2017	190	10	8	934	2170	1611	475
2018	192	9	7	1189	2820	1964	571
2019	169	16	10	917	2400	1784	537

Total Number of Years	Total Number of Stations	Total Number Collected	Total Number Measured	Overall Mean Fork Length (mm)
24	4956	132	82	1688

Table 3. Summary of the scalloped hammerhead length data (measured not estimated) collected from NMFS Bottom Longline surveys conducted between 1995 and 2019.

Survey Year	Number of Stations	Number Collected	Number Measured	Minimum Fork Length (mm)	Maximum Fork Length (mm)	Mean Fork Length (mm)	Standard Deviation
1995	117	11	10	770	2427	1414	519
1996	109	6	3	980	1768	1444	412
1997	228	15	4	815	2000	1144	572
1998							
1999	161	15	12	482	2147	1366	477
2000	242	22	7	712	1232	954	178
2001	277	34	13	685	1100	857	129
2002	388	48	38	548	2108	1181	430
2003	280	36	16	867	2165	1103	329
2004	289	17	3	1048	1800	1313	423
2005	120	10	9	935	1560	1153	190
2006	206	20	18	543	1915	1175	387
2007	154	15	13	587	1945	1239	415
2008	145	10	8	660	2190	1182	520
2009	216	32	30	545	2090	1235	439
2010	174	25	18	740	2020	1202	436
2011	345	22	19	537	2180	1233	445
2012	183	11	10	845	1700	1282	239
2013	203	13	8	888	1830	1257	289
2014	164	13	12	815	1920	1302	389
2015	203	30	27	686	1830	1261	376
2016	201	19	18	845	1830	1234	280
2017	190	27	25	732	2110	1215	358
2018	192	21	20	548	1970	1342	444
2019	169	21	19	520	2122	1528	410

Total Number of Years	Total Number of Stations	Total Number Collected	Total Number Measured	Overall Mean Fork Length (mm)
24	4956	493	360	1233

Table 4. Summary of backward selection procedure for building delta-lognormal submodels for great hammerhead index of relative abundance from 1995 to 2015.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 38584.9)*						*Lognormal Submodel Type 3 Tests (AIC 40.1)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	4919	40.40	1.76	0.0139	0.0141	23	88	1.30	0.1891
Depth	1	4919	35.57	35.57	<.0001	<.0001	1	88	0.90	0.3443
Area	4	4919	1.27	0.32	0.8660	0.8660	4	88	0.84	0.5012
Hook Type	1	4919	0.22	0.22	0.6353	0.6353	1	88	2.71	0.1032
Model Run #2	*Binomial Submodel Type 3 Tests (AIC 38618.1)*						*Lognormal Submodel Type 3 Tests (AIC 29.5)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	4923	40.11	1.74	0.0150	0.0153	23	92	1.19	0.2774
Depth	1	4923	35.86	35.86	<.0001	<.0001	1	92	1.47	0.2287
Area				Dropped				Dropped		
Hook Type	1	4923	0.23	0.23	0.6301	0.6301	1	92	1.55	0.2164
Model Run #3	*Binomial Submodel Type 3 Tests (AIC 38624.9)*						*Lognormal Submodel Type 3 Tests (AIC 19.4)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	4924	42.55	1.85	0.0078	0.0080	23	93	1.12	0.3355
Depth	1	4924	35.82	35.82	<.0001	<.0001		Dropped		
Area				Dropped				Dropped		
Hook Type				Dropped			1	93	1.47	0.2283
Model Run #4	*Binomial Submodel Type 3 Tests (AIC 38624.9)*						*Lognormal Submodel Type 3 Tests (AIC 19.5)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	4924	42.55	1.85	0.0078	0.0080	23	94	1.09	0.3693
Depth	1	4924	35.82	35.82	<.0001	<.0001		Dropped		
Area				Dropped				Dropped		
Hook Type				Dropped				Dropped		

Table 5. Indices of great hammerhead abundance developed using the delta-lognormal model for 1995-2015. The nominal frequency of occurrence, the number of samples (*N*), the DL Index (number per trawl-hour), the DL 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.

Survey Year	Frequency	*N*	DL Index	Scaled Index	CV	LCL	UCL
1995	0.042735	117	0.015811	1.38192	0.51771	0.52146	3.66223
1996	0.036697	109	0.018194	1.59013	0.55640	0.56279	4.49285
1997	0.026316	228	0.006648	0.58105	0.49677	0.22714	1.48642
1998							
1999	0.006211	161	0.001557	0.13610	1.08122	0.02342	0.79099
2000	0.008264	242	0.001915	0.16741	0.78445	0.04191	0.66879
2001	0.021661	277	0.009457	0.82650	0.48222	0.33119	2.06256
2002	0.007732	388	0.003037	0.26544	0.64773	0.08125	0.86711
2003	0.025000	280	0.012158	1.06264	0.45386	0.44717	2.52521
2004	0.020761	289	0.008608	0.75236	0.48606	0.29951	1.88987
2005	0.008333	120	0.003732	0.32618	1.07378	0.05660	1.87973
2006	0.014563	205	0.005828	0.50937	0.65042	0.15528	1.67088
2007	0.012987	154	0.005616	0.49085	0.78241	0.12322	1.95528
2008	0.020690	145	0.007639	0.66763	0.65477	0.20217	2.20473
2009	0.023148	216	0.010640	0.92997	0.51935	0.34996	2.47127
2010	0.034483	174	0.021191	1.85208	0.47672	0.74919	4.57855
2011	0.008696	345	0.003835	0.33517	0.64763	0.10262	1.09475
2012	0.032787	183	0.017350	1.51637	0.47874	0.61127	3.76163
2013	0.014778	203	0.005815	0.50827	0.65101	0.15481	1.66881
2014	0.018293	164	0.012126	1.05982	0.64991	0.32334	3.47380
2015	0.029557	202	0.011203	0.97918	0.48921	0.38772	2.47291
2016	0.029851	201	0.013631	1.19131	0.48500	0.47512	2.98710
2017	0.047368	190	0.022568	1.97242	0.41430	0.88981	4.37223
2018	0.046875	192	0.020246	1.76955	0.41649	0.79519	3.93781
2019	0.076923	169	0.035792	3.12826	0.37150	1.52402	6.42117

Table 6. Summary of backward selection procedure for building delta-lognormal submodels for scalloped hammerhead index of relative abundance (GOM and Atlantic) from 1995 to 2019.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 28784.1)*						*Lognormal Submodel Type 3 Tests (AIC 429.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	4919	30.12	1.31	0.1459	0.1467	23	335	1.30	0.1659
Depth	1	4919	0.06	0.06	0.8026	0.8026	1	335	1.06	0.3049
Area	4	4919	137.89	34.47	<.0001	<.0001	4	335	3.14	0.0147
Hook Type	1	4919	0.04	0.04	0.8482	0.8482	1	335	2.77	0.0971
Model Run #2	*Binomial Submodel Type 3 Tests (AIC 28872.8)*						*Lognormal Submodel Type 3 Tests (AIC 411.9)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	4920	35.40	1.54	0.0474	0.0480	23	328	1.37	0.1230
Depth	1	4920	0.00	0.00	0.9861	0.9861		Dropped		
Area	4	4920	135.47	33.87	<.0001	<.0001	4	328	2.91	0.0218
Hook Type				Dropped			1	328	2.53	0.1128
Model Run #3	*Binomial Submodel Type 3 Tests (AIC 28897.6)*						*Lognormal Submodel Type 3 Tests (AIC 412.9)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	4928	36.00	1.57	0.0412	0.0417	23	329	1.44	0.0874
Depth				Dropped				Dropped		
Area	4	4928	134.94	33.73	<.0001	<.0001	4	329	2.87	0.0233
Hook Type				Dropped				Dropped		

Table 7. Indices of scalloped hammerhead abundance (GOM and Atlantic) developed using the delta-lognormal model for 1995-2019. The nominal frequency of occurrence, the number of samples (*N*), the DL Index (number per trawl-hour), the DL 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.

Survey Year	Frequency	*N*	DL Index	Scaled Index	CV	LCL	UCL
1995	0.08547	117	0.08117	0.87972	0.33720	0.45636	1.69583
1996	0.05505	109	0.05249	0.56890	0.43796	0.24614	1.31487
1997	0.05263	228	0.06317	0.68463	0.30999	0.37356	1.25475
1998							
1999	0.06832	161	0.05031	0.54526	0.33867	0.28209	1.05396
2000	0.07851	242	0.07129	0.77264	0.24692	0.47498	1.25685
2001	0.09025	277	0.11451	1.24105	0.21911	0.80481	1.91373
2002	0.09536	388	0.09302	1.00813	0.17662	0.71004	1.43137
2003	0.09643	280	0.15389	1.66786	0.20886	1.10325	2.52141
2004	0.04152	289	0.05606	0.60756	0.31223	0.33012	1.11816
2005	0.04167	120	0.11150	1.20851	0.47520	0.49014	2.97978
2006	0.04369	205	0.05975	0.64759	0.35789	0.32341	1.29671
2007	0.07143	154	0.08758	0.94927	0.32704	0.50178	1.79582
2008	0.05517	145	0.09524	1.03223	0.37209	0.50235	2.12103
2009	0.07407	216	0.12856	1.39338	0.26775	0.82322	2.35843
2010	0.10920	174	0.14234	1.54277	0.24158	0.95814	2.48410
2011	0.04638	345	0.06595	0.71479	0.26866	0.42157	1.21194
2012	0.04918	183	0.06034	0.65399	0.35794	0.32658	1.30964
2013	0.05911	203	0.06066	0.65750	0.31154	0.35771	1.20852
2014	0.06098	164	0.07852	0.85100	0.33731	0.44137	1.64079
2015	0.11330	202	0.15691	1.70067	0.21935	1.10236	2.62371
2016	0.06468	201	0.09387	1.01737	0.29498	0.57093	1.81290
2017	0.10000	190	0.12593	1.36486	0.24334	0.84480	2.20506
2018	0.07813	192	0.09359	1.01436	0.27518	0.59091	1.74127
2019	0.07692	169	0.11773	1.27599	0.29370	0.71779	2.26827

Table 8. Summary of backward selection procedure for building delta-lognormal submodels for scalloped hammerhead index of relative abundance (Atlantic) from 1995 to 2019.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 5430.8)*						*Lognormal Submodel Type 3 Tests (AIC 111.1)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	17	910	24.69	1.45	0.1018	0.1050	17	56	1.60	0.0961
Depth	1	910	32.58	32.58	<.0001	<.0001	1	56	0.45	0.5069
Latitude	1	910	11.23	11.23	0.0008	0.0008	1	56	3.67	0.0606
Model Run #2	*Binomial Submodel Type 3 Tests (AIC 5430.8)*						*Lognormal Submodel Type 3 Tests (AIC 100.8)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	17	910	24.69	1.45	0.1018	0.1050	17	58	1.62	0.0875
Depth	1	910	32.58	32.58	<.0001	<.0001		Dropped		
Latitude	1	910	11.23	11.23	0.0008	0.0008	1	58	4.61	0.0360

Table 9. Indices of scalloped hammerhead abundance (Atlantic) developed using the delta-lognormal model for 1995-2019. The nominal frequency of occurrence, the number of samples (*N*), the DL Index (number per trawl-hour), the DL 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. Atlantic

Survey Year	Frequency	*N*	DL Index	Scaled Index	CV	LCL	UCL
1995	0.06977	43	0.06811	0.68246	0.62364	0.21688	2.14748
1996	0.03333	30	0.03383	0.33895	1.10772	0.05661	2.02931
1997							
1998							
1999							
2000	0.01905	105	0.01621	0.16243	0.78127	0.04084	0.64599
2001							
2002	0.09659	176	0.07358	0.73724	0.31031	0.40202	1.35196
2003							
2004							
2005	0.03704	27	0.03068	0.30743	1.10356	0.05159	1.83209
2006	0.05263	56	0.10527	1.05483	0.64591	0.32381	3.43618
2007							
2008	0.10811	37	0.14933	1.49635	0.52678	0.55615	4.02600
2009	0.12500	32	0.19432	1.94709	0.62303	0.61936	6.12108
2010	0.26923	26	0.22902	2.29483	0.40762	1.04764	5.02679
2011	0.10204	49	0.13532	1.35595	0.49248	0.53392	3.44357
2012	0.04878	41	0.06362	0.63748	0.78291	0.15992	2.54114
2013	0.08333	36	0.09971	0.99913	0.63569	0.31160	3.20363
2014	0.06522	46	0.05991	0.60032	0.66504	0.17896	2.01385
2015	0.18605	43	0.23564	2.36111	0.36978	1.15389	4.83134
2016	0.04167	48	0.03647	0.36544	0.77696	0.09245	1.44457
2017	0.12195	41	0.09053	0.90716	0.54889	0.32505	2.53175
2018	0.06977	43	0.05517	0.55286	0.64155	0.17086	1.78888
2019	0.07843	51	0.11965	1.19896	0.55180	0.42756	3.36213

Table 10. Summary of backward selection procedure for building delta-lognormal submodels for scalloped hammerhead index of relative abundance (GOM) from 1995 to 2019.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 23042.4)*						*Lognormal Submodel Type 3 Tests (AIC 311.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	3887	27.37	1.19	0.2407	0.2416	23	252	1.09	0.3594
Depth	1	3887	1.52	1.52	0.2171	0.2172	1	252	1.44	0.2309
Area	2	3887	129.77	64.89	<.0001	<.0001	2	252	4.38	0.0135
Hook Type	1	3887	0.79	0.79	0.3735	0.3736	1	252	1.69	0.1943
Model Run #2	*Binomial Submodel Type 3 Tests (AIC 23038.4)*						*Lognormal Submodel Type 3 Tests (AIC 299.4)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	3888	26.99	1.17	0.2562	0.2571	23	253	1.10	0.3475
Depth	1	3888	1.52	1.52	0.2171	0.2172		Dropped		
Area	2	3888	129.80	64.90	<.0001	<.0001	2	253	4.62	0.0107
Hook Type				Dropped			1	253	1.72	0.1910
Model Run #3	*Binomial Submodel Type 3 Tests (AIC 23053.2)*						*Lognormal Submodel Type 3 Tests (AIC 300.2)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	23	3895	27.11	1.18	0.2515	0.2524	23	254	1.18	0.2601
Depth				Dropped				Dropped		
Area	2	3895	129.97	64.98	<.0001	<.0001	2	254	4.61	0.0108
Hook Type				Dropped				Dropped		

Table 11. Indices of scalloped hammerhead abundance (GOM) developed using the delta-lognormal model for 1995-2019. The nominal frequency of occurrence, the number of samples (*N*), the DL Index (number per trawl-hour), the DL 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. GOM

Survey Year	Frequency	*N*	DL Index	Scaled Index	CV	LCL	UCL
1995	0.09459	74	0.09020	1.01245	0.40225	0.46666	2.19658
1996	0.06329	79	0.05650	0.63417	0.47567	0.25700	1.56491
1997	0.07317	164	0.08565	0.96137	0.30574	0.52873	1.74802
1998							
1999	0.06832	161	0.04816	0.54059	0.33178	0.28326	1.03170
2000	0.12409	137	0.11108	1.24671	0.25883	0.74917	2.07467
2001	0.09025	277	0.10893	1.22258	0.21094	0.80547	1.85569
2002	0.09434	212	0.07983	0.89602	0.24068	0.55744	1.44023
2003	0.09643	280	0.14654	1.64473	0.20033	1.10611	2.44561
2004	0.04819	249	0.06195	0.69534	0.30683	0.38165	1.26688
2005	0.04301	93	0.14537	1.63167	0.52478	0.60846	4.37554
2006	0.04027	149	0.04208	0.47225	0.43454	0.20556	1.08495
2007	0.07143	154	0.08360	0.93827	0.31945	0.50300	1.75020
2008	0.03704	108	0.08214	0.92189	0.52247	0.34511	2.46263
2009	0.06522	184	0.09536	1.07031	0.30532	0.58911	1.94456
2010	0.08108	148	0.10973	1.23159	0.30244	0.68155	2.22555
2011	0.03716	296	0.04729	0.53081	0.31959	0.28449	0.99039
2012	0.04930	142	0.05450	0.61176	0.40185	0.28217	1.32630
2013	0.05389	167	0.05014	0.56278	0.35589	0.28209	1.12276
2014	0.05932	118	0.07022	0.78820	0.40022	0.36462	1.70384
2015	0.09375	159	0.13053	1.46508	0.27052	0.86104	2.49286
2016	0.07190	153	0.11092	1.24495	0.31679	0.67072	2.31081
2017	0.09396	149	0.11953	1.34159	0.28125	0.77261	2.32957
2018	0.08054	149	0.09885	1.10950	0.30463	0.61147	2.01316
2019	0.07627	118	0.10918	1.22541	0.35035	0.62049	2.42004

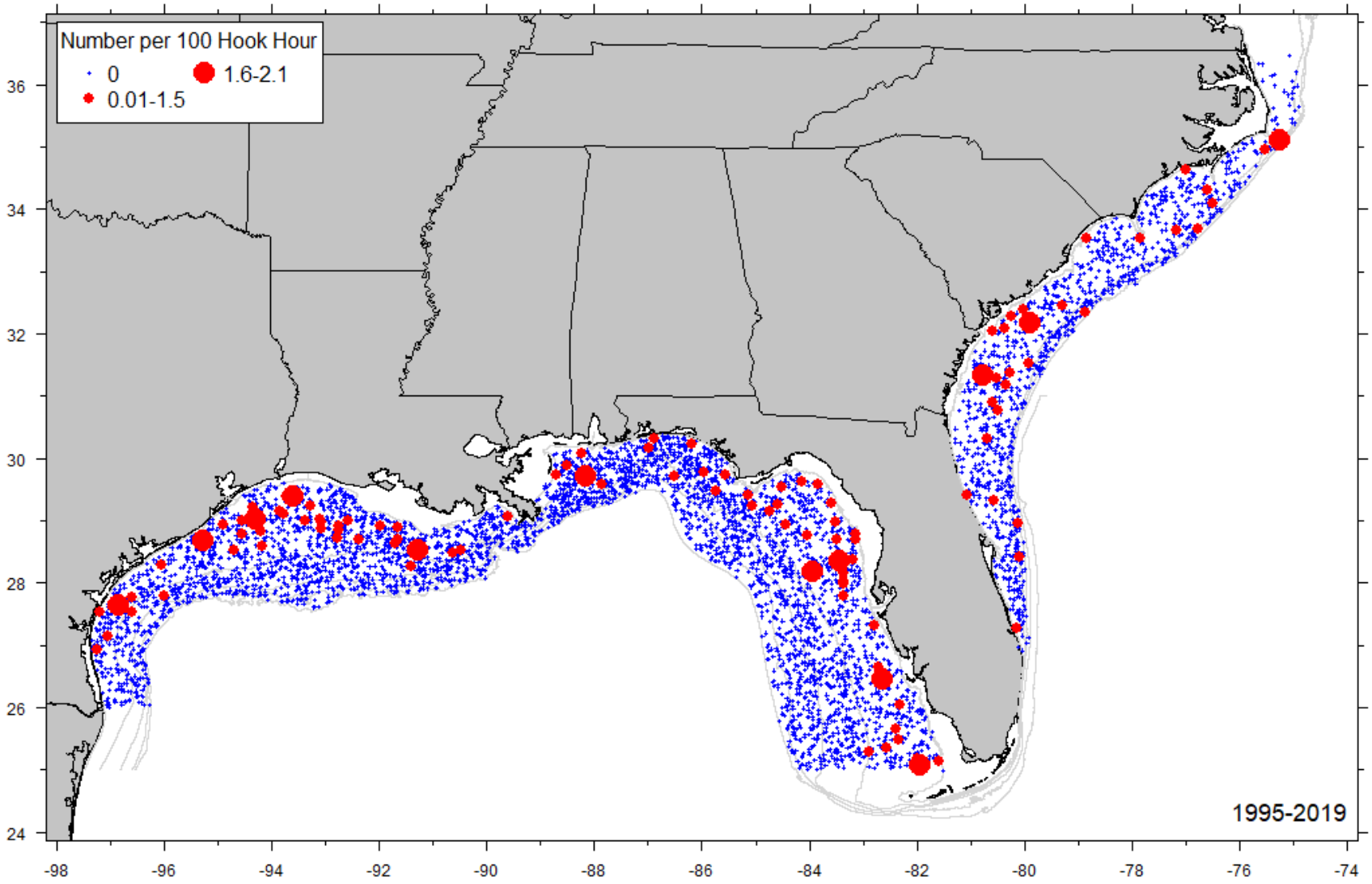


Figure 1. Stations sampled from 1995 to 2015 during the NMFS Bottom Longline Survey with the CPUE for great hammerhead.

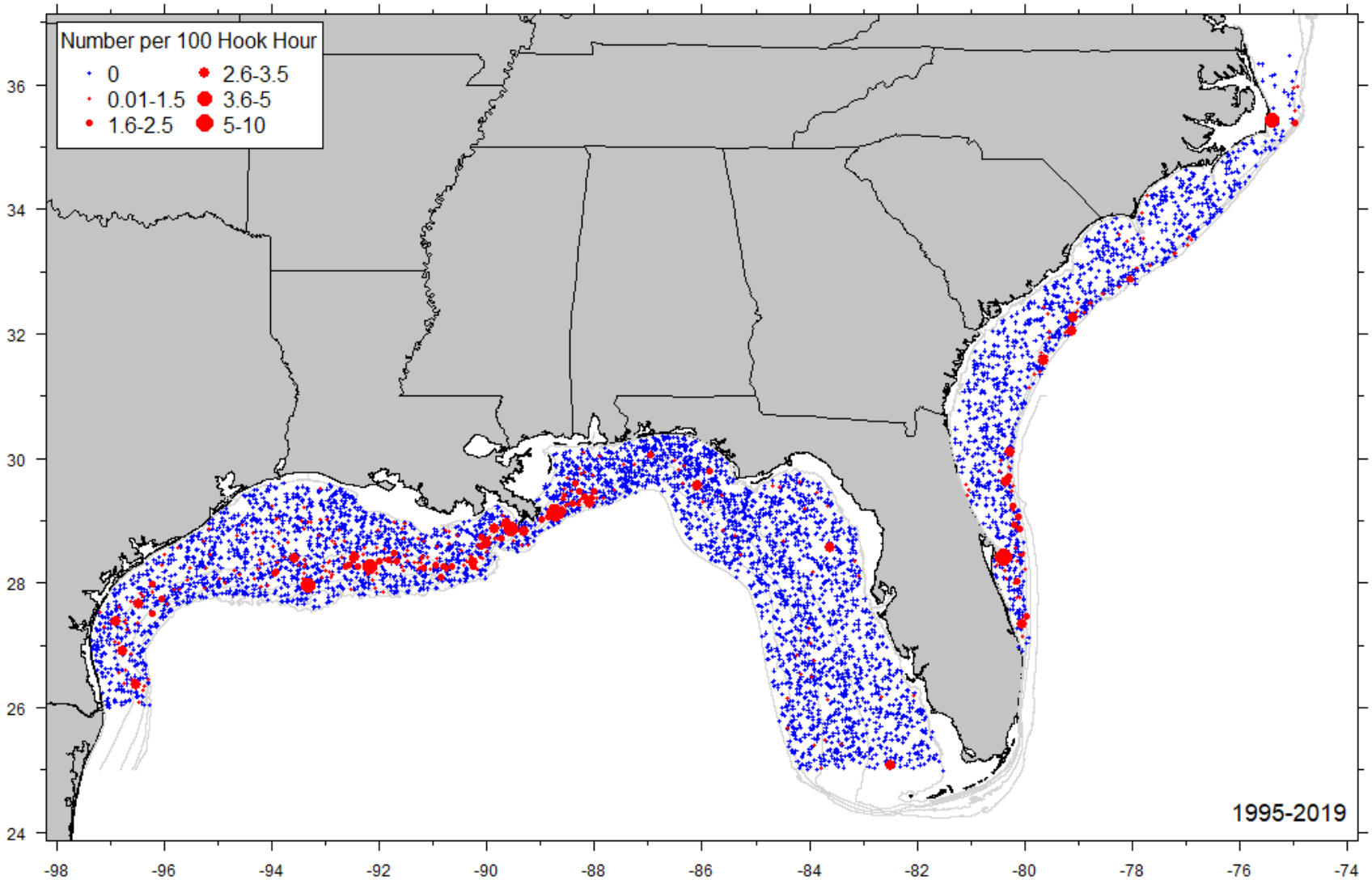


Figure 2. Stations sampled from 1995 to 2015 during the NMFS Bottom Longline Survey with the CPUE for scalloped hammerhead.

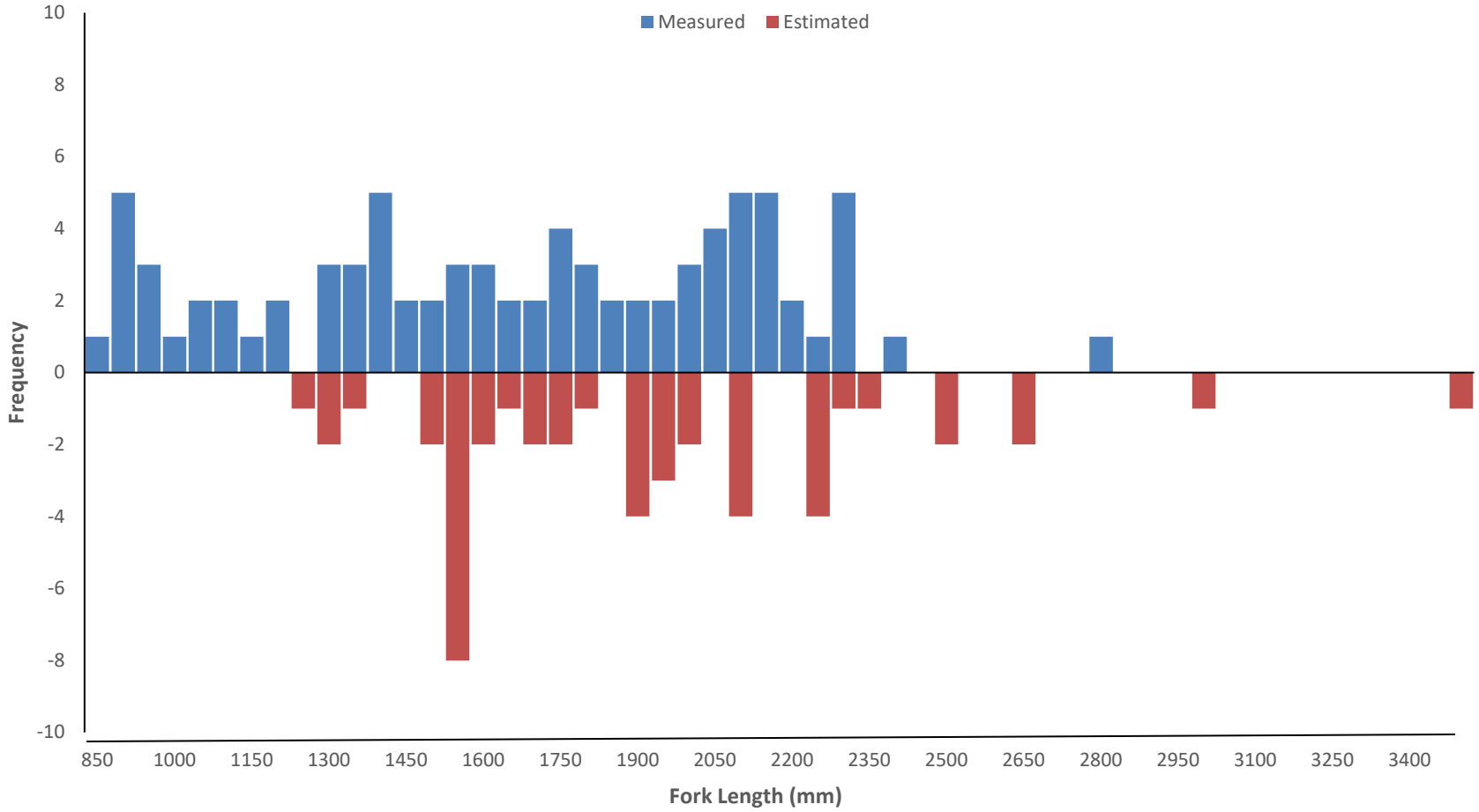


Figure 3. Length frequency histogram for measured and length estimated Hammerhead s captured in the Atlantic and Gulf of Mexico during the NMFS Bottom Longline Survey from 1995-2015.

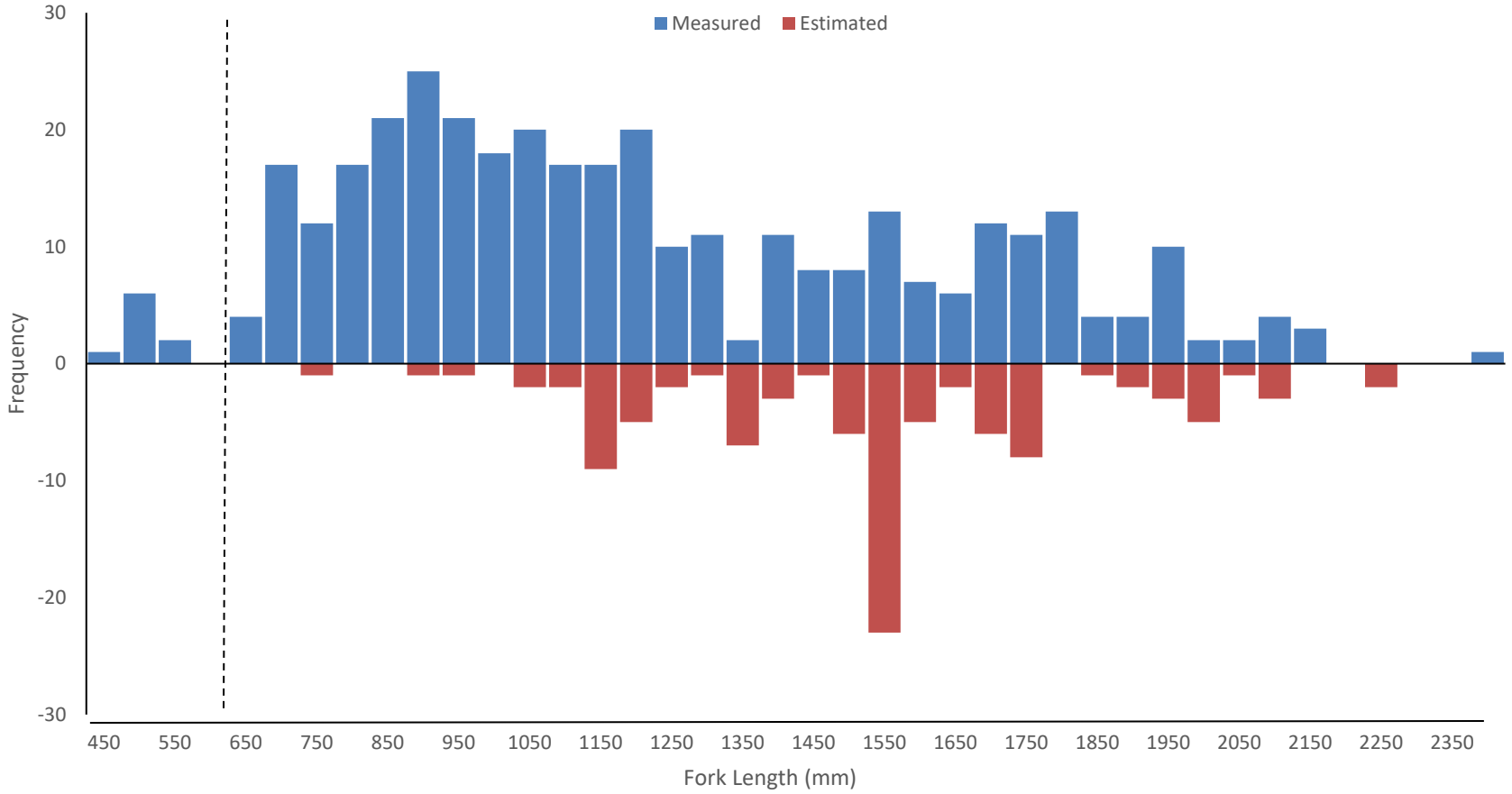


Figure 4. Length frequency histogram for measured and length estimated scalloped hammerhead s captured in the Atlantic and Gulf of Mexico during the NMFS Bottom Longline Survey from 1995-2019. Note that all scalloped hammerhead less than 610 mm FL (dotted line) were removed prior to analysis.

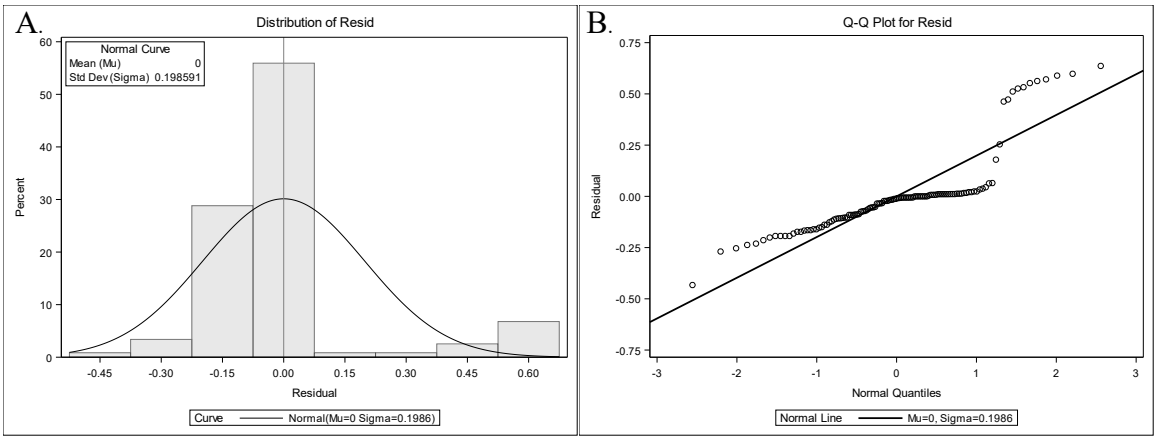


Figure 5. Diagnostic plots for lognormal component of the great hammerhead NMFS Bottom Longline Surveys model: **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

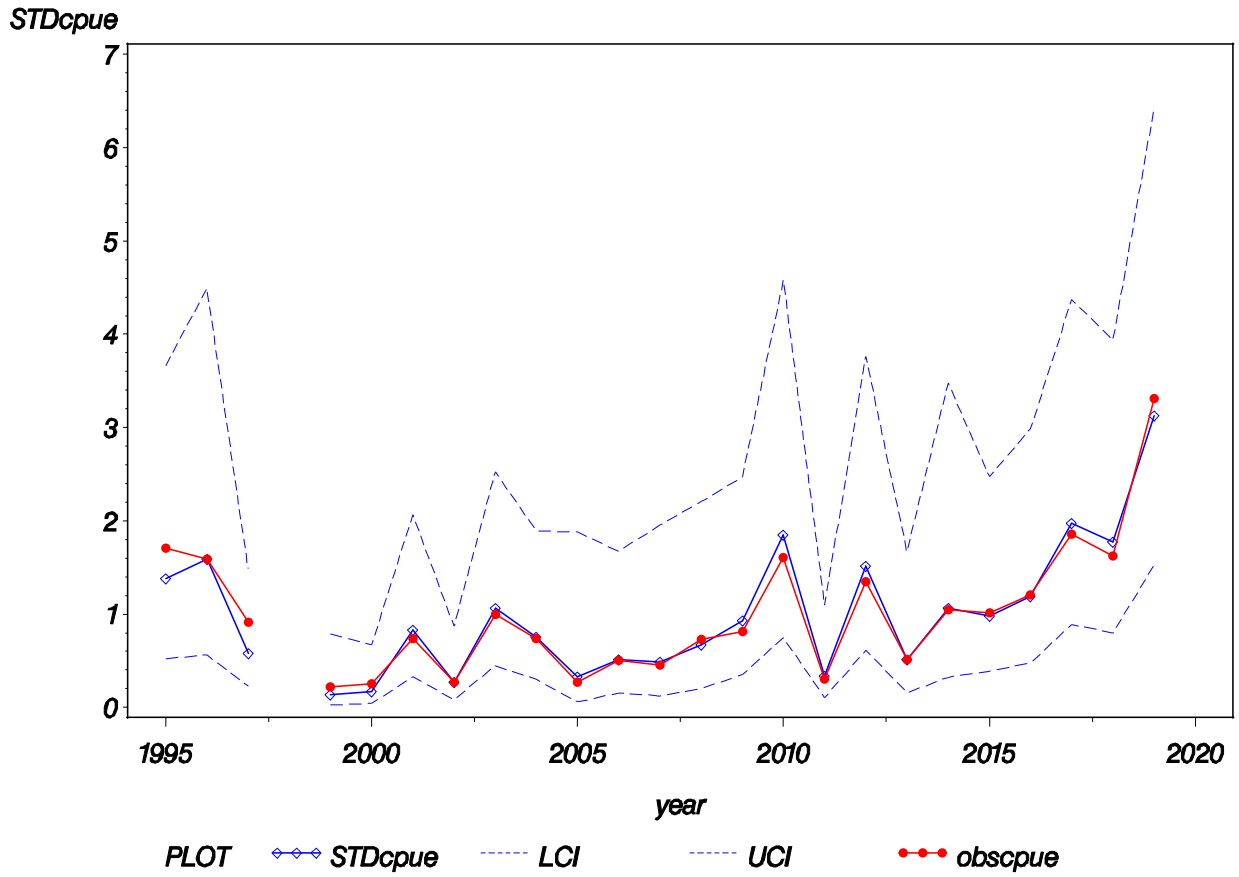


Figure 6. Annual index of abundance for great hammerhead from the NMFS Bottom Longline Surveys from 1995 – 2019.

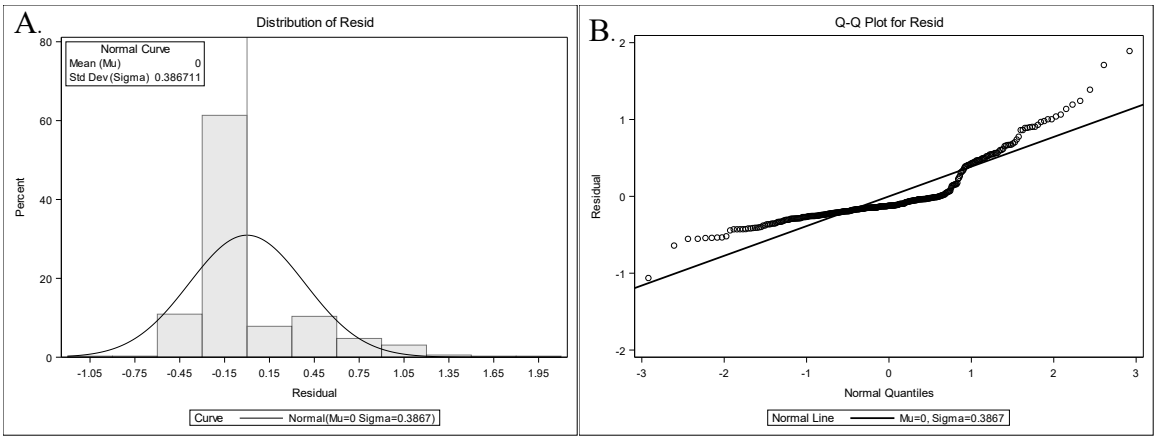


Figure 7. Diagnostic plots for lognormal component of the scalloped hammerhead NMFS Bottom Longline Surveys mode (GOM and Atlantic)l: **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

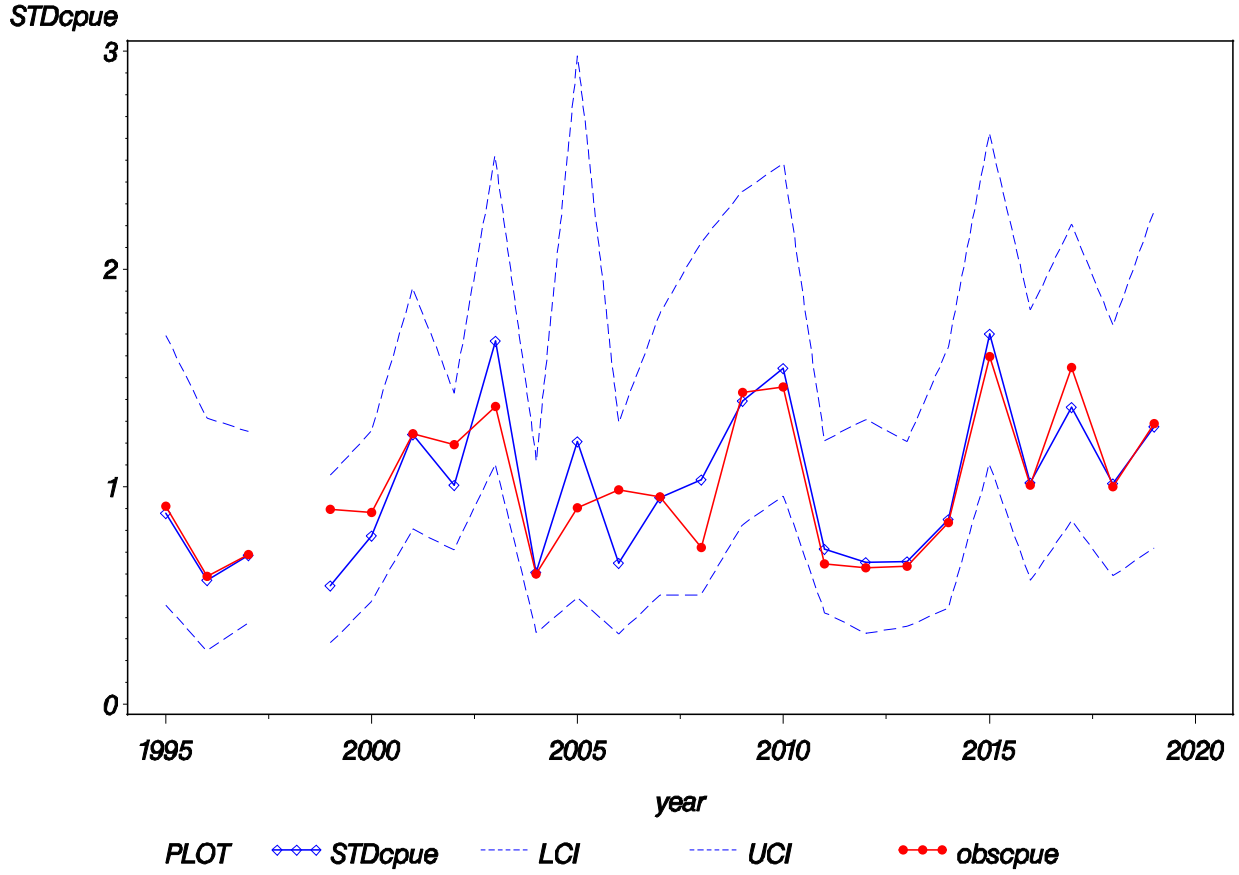


Figure 8. Annual index of abundance for scalloped hammerhead from the NMFS Bottom Longline Surveys from 1995 – 2019.

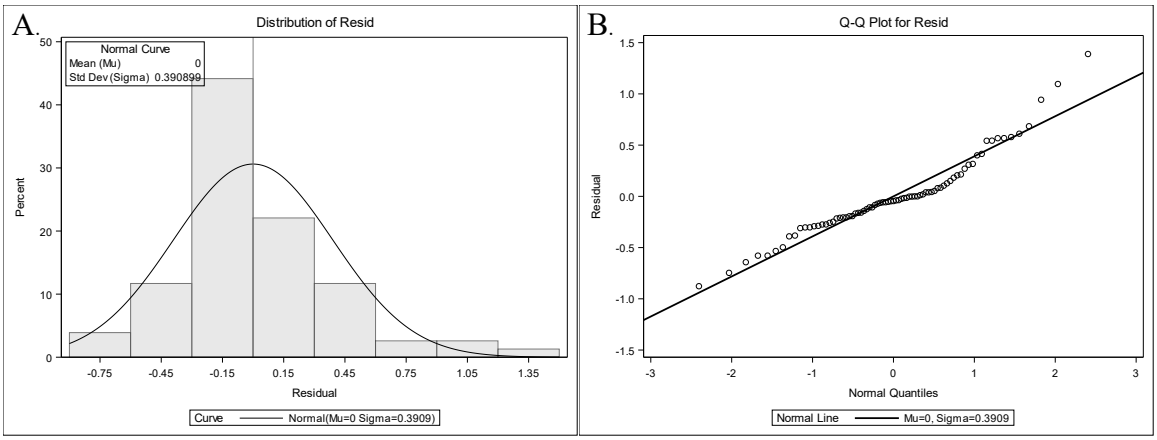


Figure 9. Diagnostic plots for lognormal component of the scalloped hammerhead NMFS Bottom Longline Surveys model (Atlantic): **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

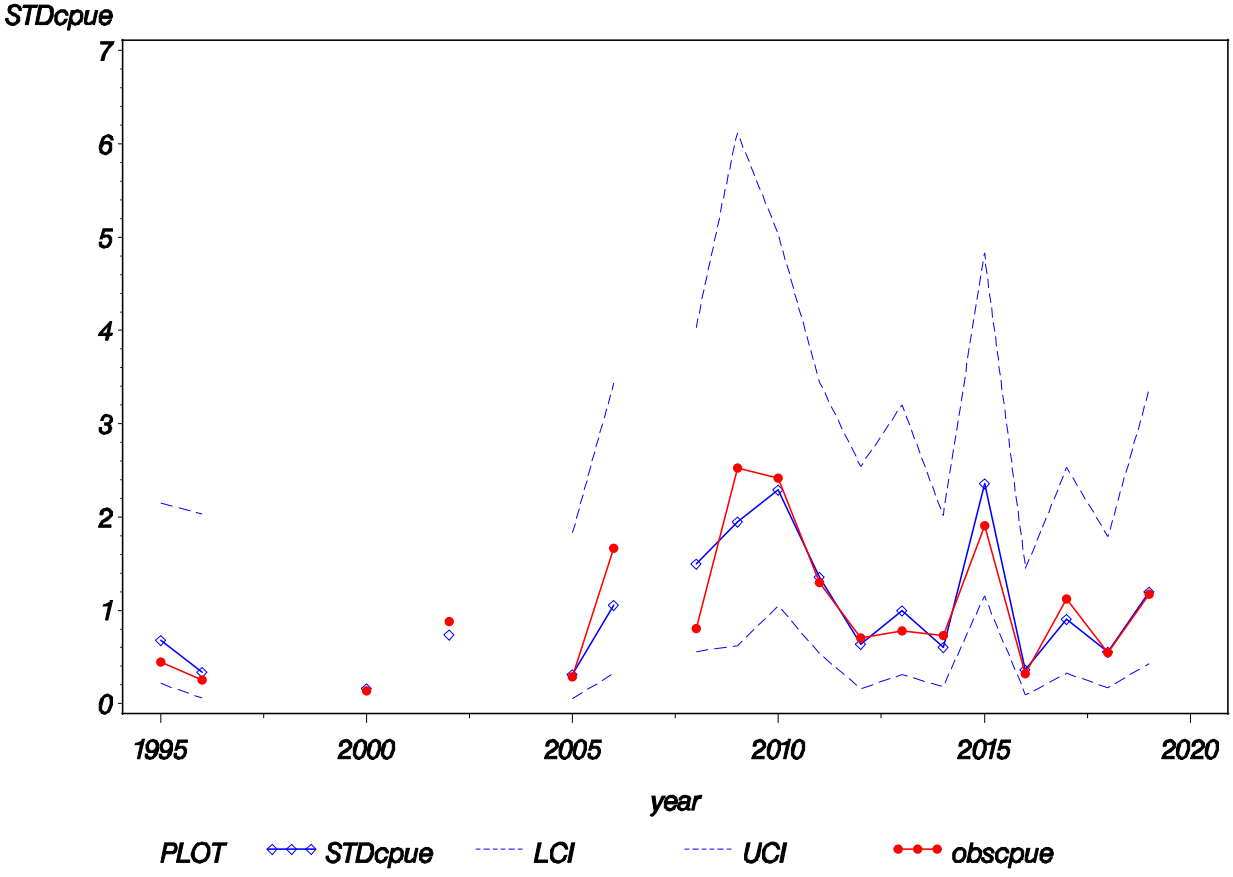


Figure 10. Annual index of abundance for scalloped hammerhead from the NMFS Bottom Longline Surveys from 1995 – 2015. Atlantic

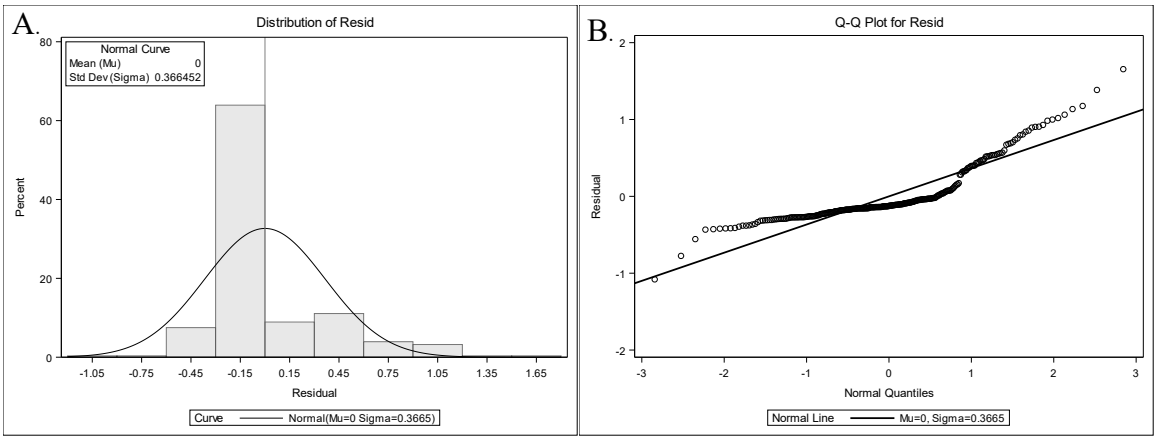


Figure 11. Diagnostic plots for lognormal component of the scalloped hammerhead NMFS Bottom Longline Surveys model (GOM): **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

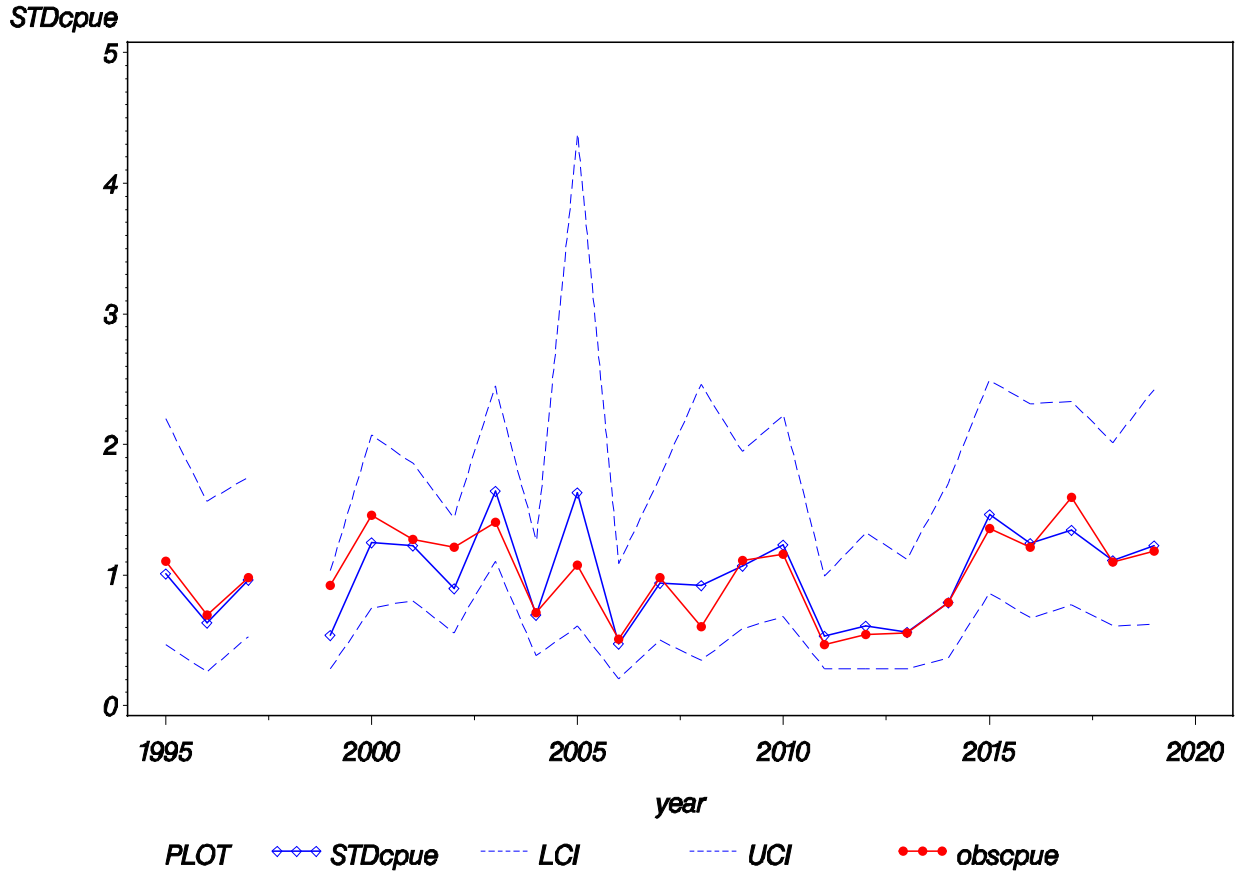


Figure 12. Annual index of abundance for scalloped hammerhead (GOM) from the NMFS Bottom Longline Surveys from 1995 – 2015.

Appendix

Appendix Table 1. Summary of the factors used in constructing the great hammerhead abundance index from the NMFS Bottom Longline Survey data.

Factor	Level	Number of Observations	Number of Positive Observations	Proportion Positive	Mean CPUE
Year	1995	117	5	0.042735	0.048850
Year	1996	109	4	0.036697	0.045420
Year	1997	228	6	0.026316	0.026049
Year	1999	161	1	0.006211	0.006211
Year	2000	242	2	0.008264	0.007135
Year	2001	277	6	0.021661	0.021044
Year	2002	388	3	0.007732	0.007647
Year	2003	280	7	0.025000	0.028509
Year	2004	289	6	0.020761	0.021115
Year	2005	120	1	0.008333	0.007692
Year	2006	206	3	0.014563	0.014397
Year	2007	154	2	0.012987	0.012881
Year	2008	145	3	0.020690	0.020810
Year	2009	216	5	0.023148	0.023294
Year	2010	174	6	0.034483	0.046024
Year	2011	345	3	0.008696	0.008702
Year	2012	183	6	0.032787	0.038680
Year	2013	203	3	0.014778	0.014592
Year	2014	164	3	0.018293	0.029952
Year	2015	203	6	0.029557	0.029010
Year	2016	201	6	0.029851	0.034467
Year	2017	190	9	0.047368	0.053234
Year	2018	192	9	0.046875	0.046386
Year	2019	169	13	0.076923	0.094840
Area	North Atlantic	519	17	0.032755	0.036130
Area	South Atlantic	516	13	0.025194	0.026410
Area	Eastern Gulf	1938	40	0.020640	0.022603
Area	Central Gulf	982	18	0.018330	0.020322
Area	Western Gulf	1001	30	0.029970	0.033806
Hook Type	Circle	4210	103	0.024466	0.027171
Hook Type	J Hook	746	15	0.020107	0.020890

Appendix Table 2. Summary of the factors used in constructing the scalloped hammerhead abundance index (GOM and Atlantic) from the NMFS Bottom Longline Survey data.

Factor	Level	Number of Observations	Number of Positive Observations	Proportion Positive	Mean CPUE
Year	1995	117	10	0.08547	0.08507
Year	1996	109	6	0.05505	0.05491
Year	1997	228	12	0.05263	0.06432
Year	1998				
Year	1999	161	11	0.06832	0.08403
Year	2000	242	19	0.07851	0.08267
Year	2001	277	25	0.09025	0.11627
Year	2002	388	37	0.09536	0.11176
Year	2003	280	27	0.09643	0.12813
Year	2004	289	12	0.04152	0.05601
Year	2005	120	5	0.04167	0.08456
Year	2006	206	9	0.04369	0.09213
Year	2007	154	11	0.07143	0.08931
Year	2008	145	8	0.05517	0.06743
Year	2009	216	16	0.07407	0.13432
Year	2010	174	19	0.10920	0.13661
Year	2011	345	16	0.04638	0.06027
Year	2012	183	9	0.04918	0.05872
Year	2013	203	12	0.05911	0.05941
Year	2014	164	10	0.06098	0.07818
Year	2015	203	23	0.11330	0.14964
Year	2016	201	13	0.06468	0.09420
Year	2017	190	19	0.10000	0.14495
Year	2018	192	15	0.07813	0.09346
Year	2019	169	13	0.07692	0.12068
Area	North Atlantic	519	33	0.06358	0.07851
Area	South Atlantic	516	44	0.08527	0.13278
Area	Eastern Gulf	1938	49	0.02528	0.02850
Area	Central Gulf	982	148	0.15071	0.20751
Area	Western Gulf	1001	83	0.08292	0.10031
Hook Type	Circle	4210	306	0.07268	0.09759
Hook Type	J Hook	746	51	0.06836	0.07767

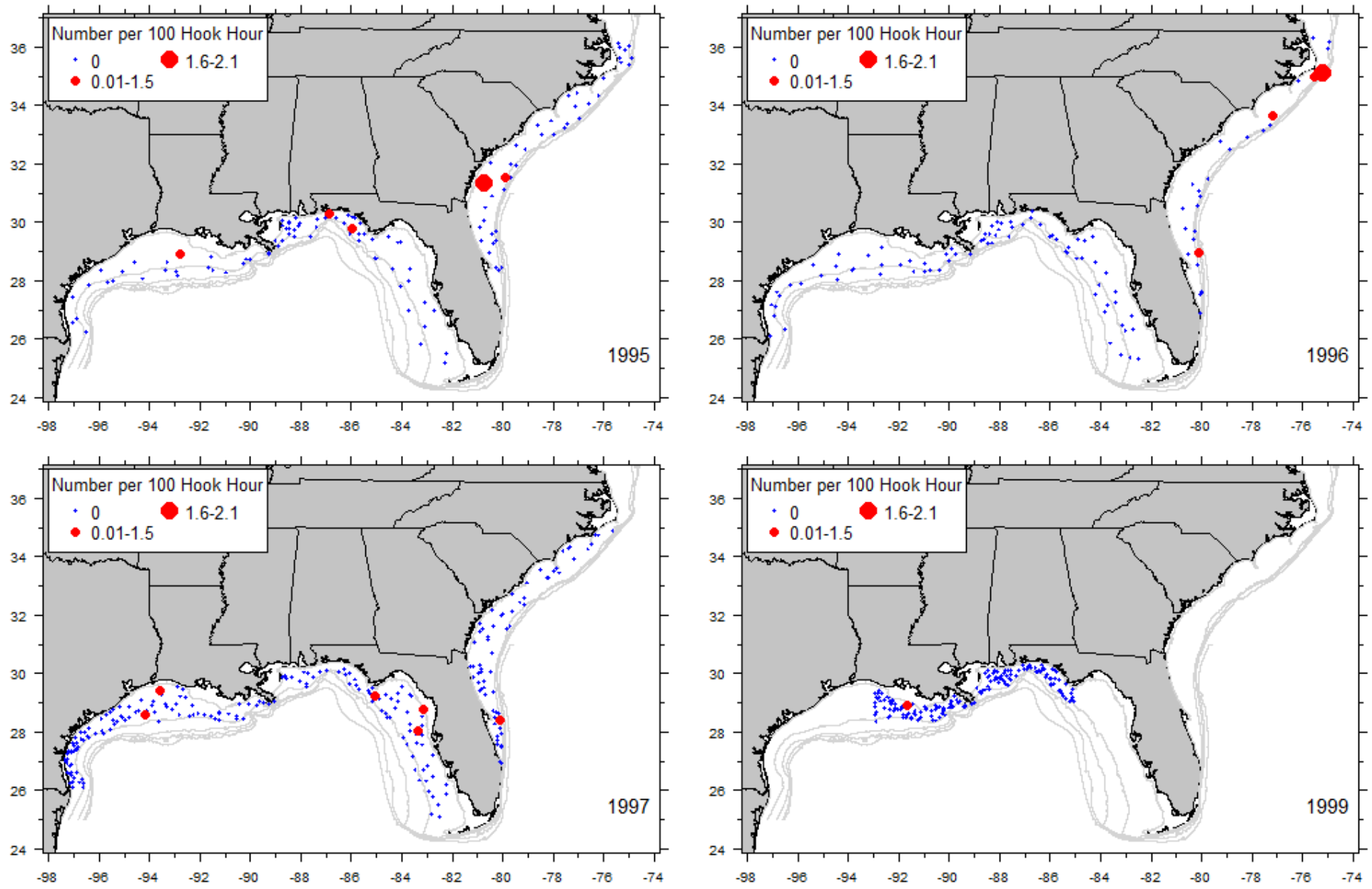
Appendix Table 3. Summary of the factors used in constructing the scalloped hammerhead abundance index (Atlantic) from the NMFS Bottom Longline Survey data.

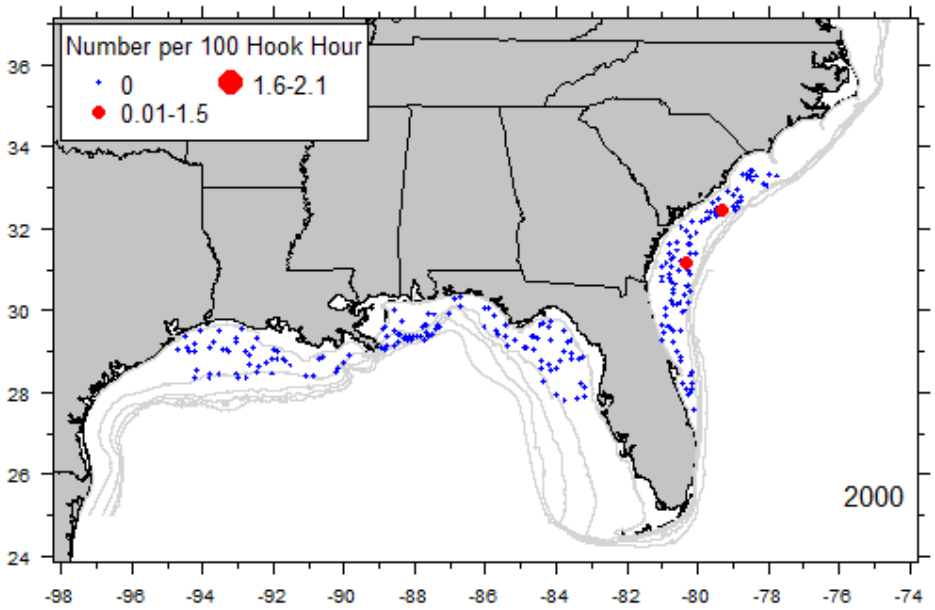
Factor	Level	Number of Observations	Number of Positive Observations	Proportion Positive	Mean CPUE
Year	1995	43	3	0.06977	0.05733
Year	1996	30	1	0.03333	0.03279
Year	1997				
Year	1998				
Year	1999				
Year	2000	105	2	0.01905	0.01721
Year	2001				
Year	2002	176	17	0.09659	0.11316
Year	2003				
Year	2004				
Year	2005	27	1	0.03704	0.03704
Year	2006	57	3	0.05263	0.21370
Year	2007				
Year	2008	37	4	0.10811	0.10282
Year	2009	32	4	0.12500	0.32382
Year	2010	26	7	0.26923	0.31034
Year	2011	49	5	0.10204	0.16632
Year	2012	41	2	0.04878	0.09077
Year	2013	36	3	0.08333	0.10018
Year	2014	46	3	0.06522	0.09321
Year	2015	43	8	0.18605	0.24487
Year	2016	48	2	0.04167	0.04135
Year	2017	41	5	0.12195	0.14332
Year	2018	43	3	0.06977	0.06978
Year	2019	51	4	0.07843	0.14999
Hook Type	Circle	824	74	0.08981	0.12927
Hook Type	J Hook	107	3	0.02804	0.02608

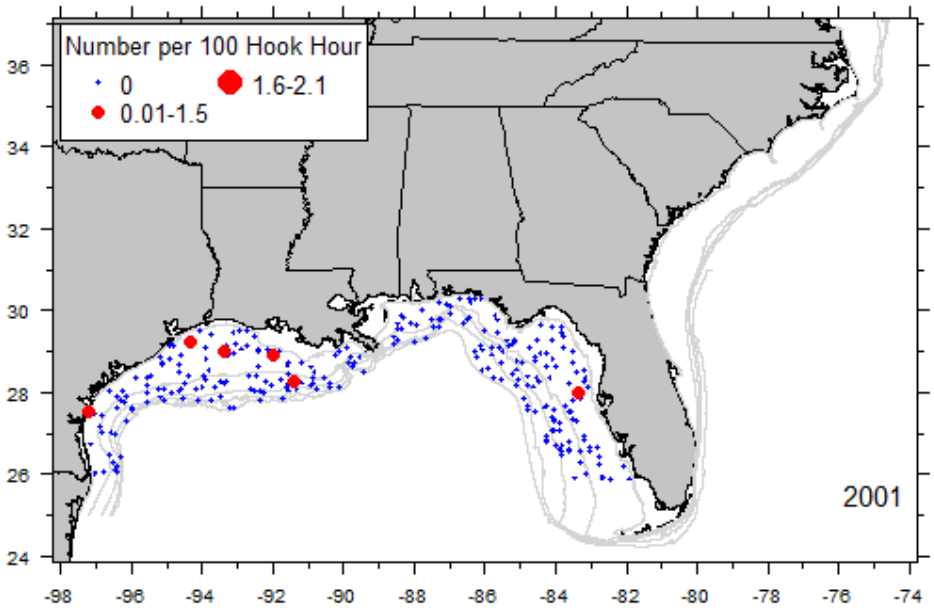
Appendix Table 4. Summary of the factors used in constructing the scalloped hammerhead abundance index (GOM) from the NMFS Bottom Longline Survey data.

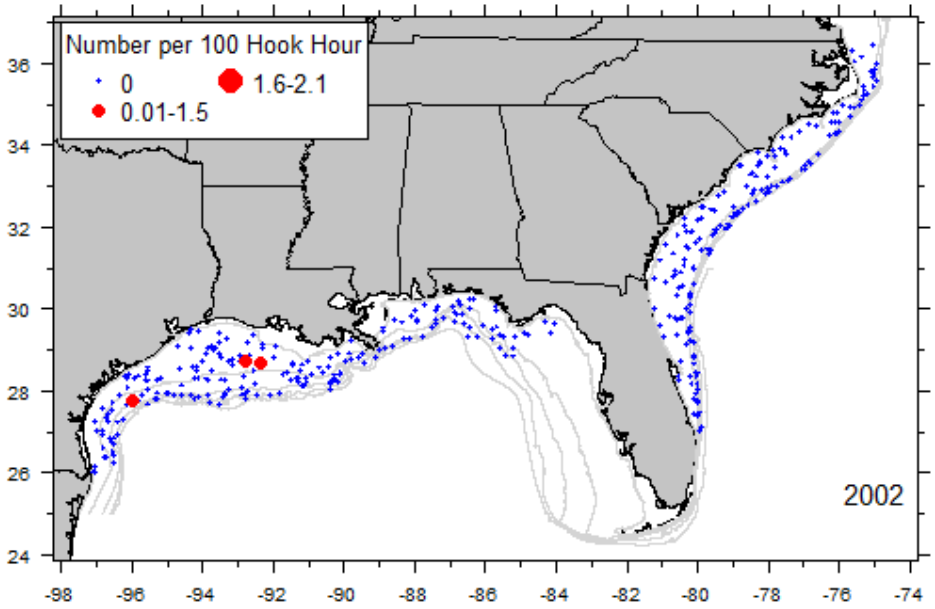
Factor	Level	Number of Observations	Number of Positive Observations	Proportion Positive	Mean CPUE
Year	1995	74	7	0.09459	0.10119
Year	1996	79	5	0.06329	0.06331
Year	1997	164	12	0.07317	0.08942
Year	1998				
Year	1999	161	11	0.06832	0.08403
Year	2000	137	17	0.12409	0.13283
Year	2001	277	25	0.09025	0.11627
Year	2002	212	20	0.09434	0.11059
Year	2003	280	27	0.09643	0.12813
Year	2004	249	12	0.04819	0.06501
Year	2005	93	4	0.04301	0.09836
Year	2006	149	6	0.04027	0.04644
Year	2007	154	11	0.07143	0.08931
Year	2008	108	4	0.03704	0.05531
Year	2009	184	12	0.06522	0.10137
Year	2010	148	12	0.08108	0.10609
Year	2011	296	11	0.03716	0.04271
Year	2012	142	7	0.04930	0.04947
Year	2013	167	9	0.05389	0.05062
Year	2014	118	7	0.05932	0.07232
Year	2015	160	15	0.09375	0.12388
Year	2016	153	11	0.07190	0.11078
Year	2017	149	14	0.09396	0.14539
Year	2018	149	12	0.08054	0.10029
Year	2019	118	9	0.07627	0.10802
Area	Eastern Gulf	1938	49	0.02528	0.02850
Area	Central Gulf	982	148	0.15071	0.20751
Area	Western Gulf	1001	83	0.08292	0.10031
Hook Type	Circle	3346	232	0.06934	0.09096
Hook Type	J Hook	575	48	0.08348	0.09591

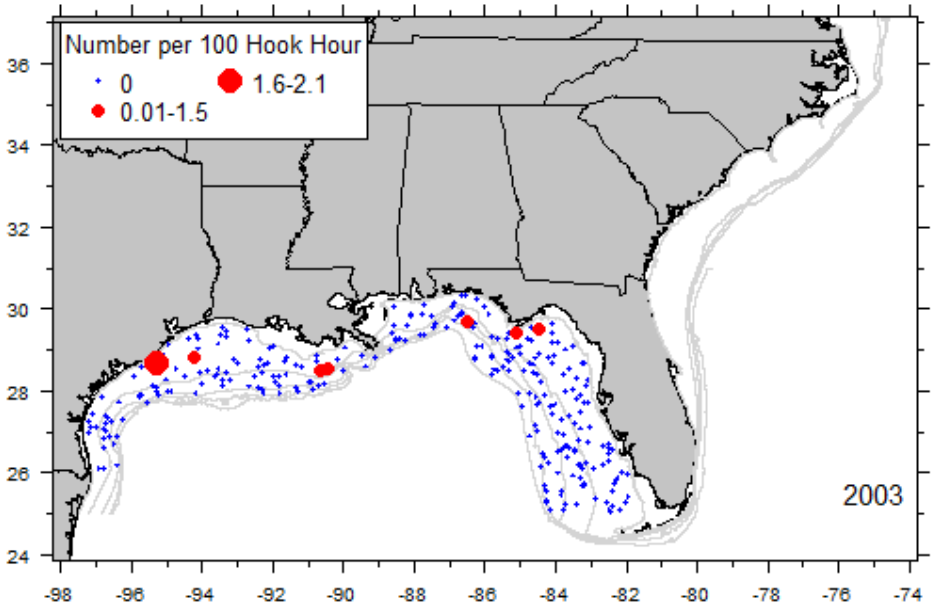
Appendix Figure 1. Annual survey effort and catch of great hammerhead from the NMFS bottom longline survey (1995-2019).

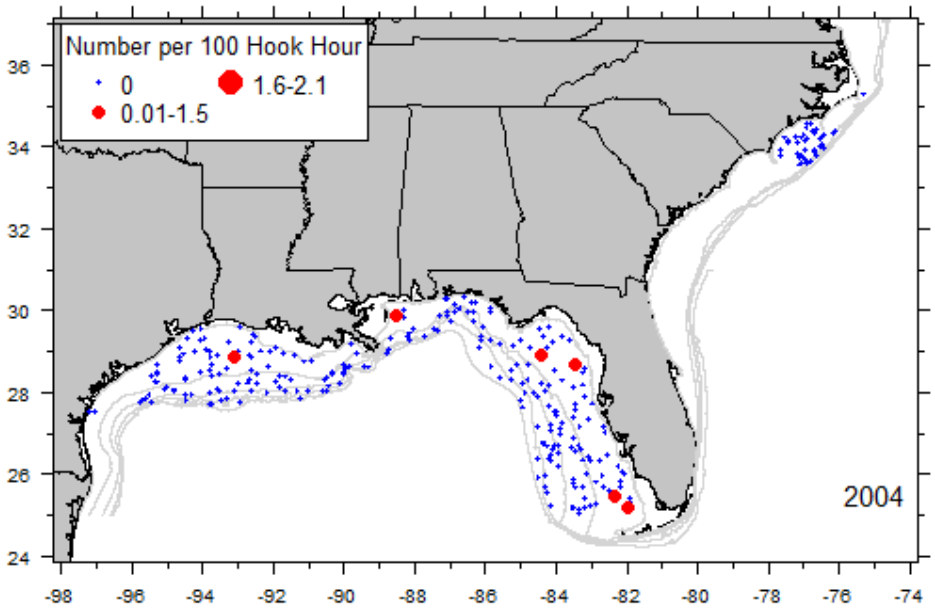


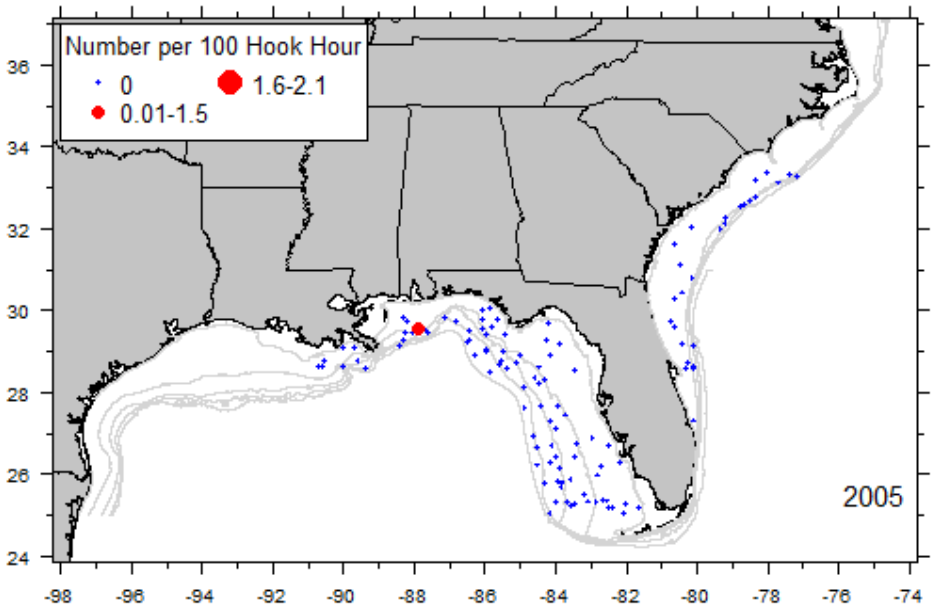

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2000

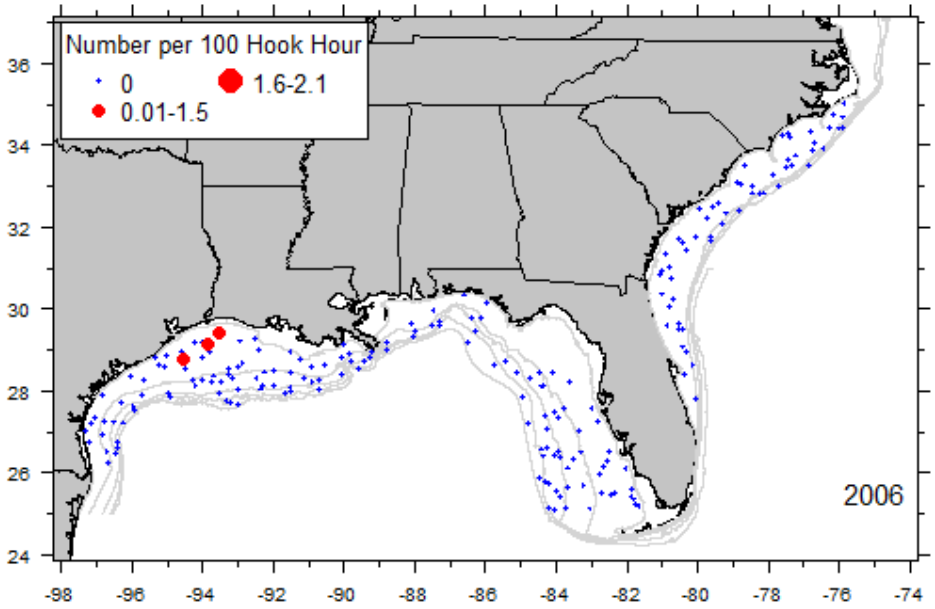

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2001

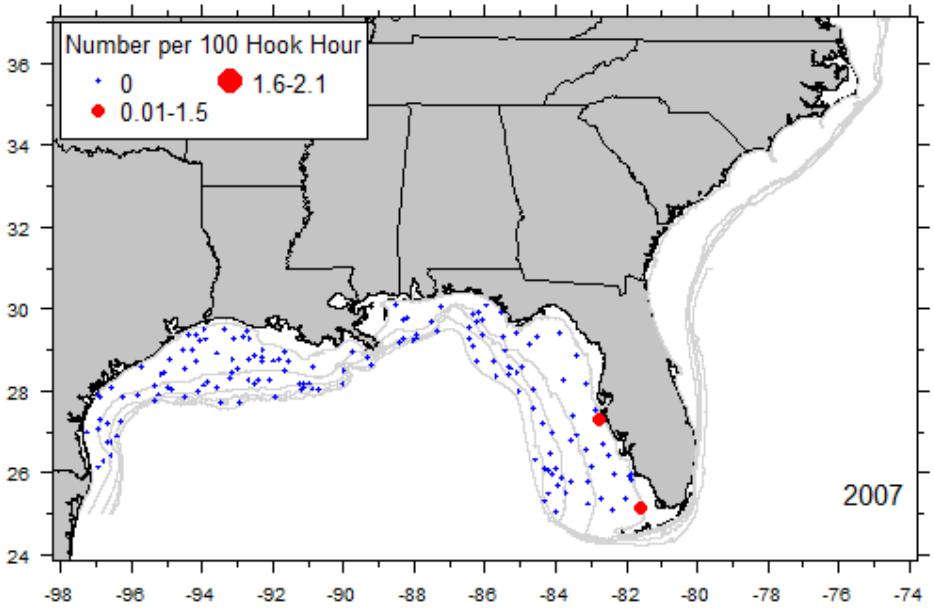

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2002

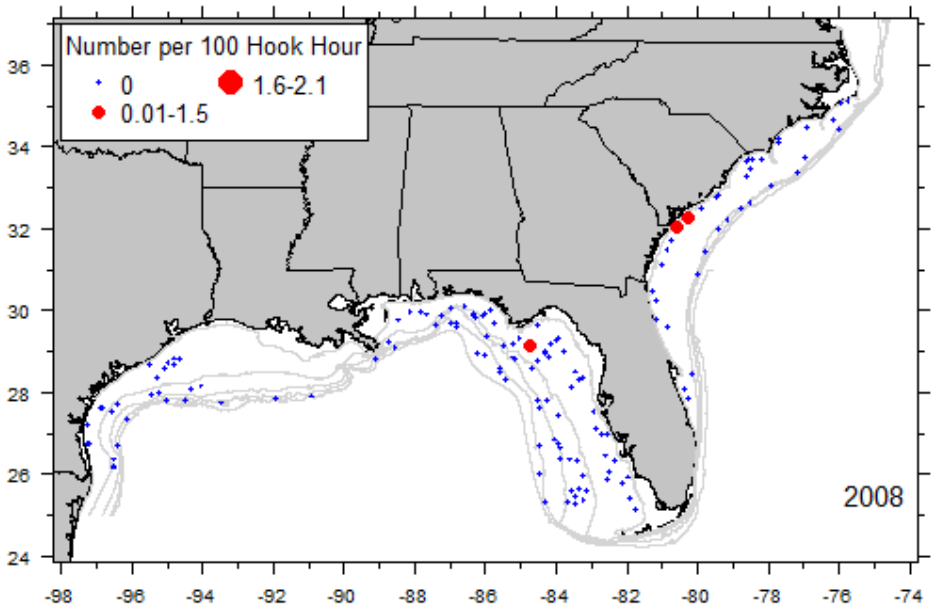

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2003

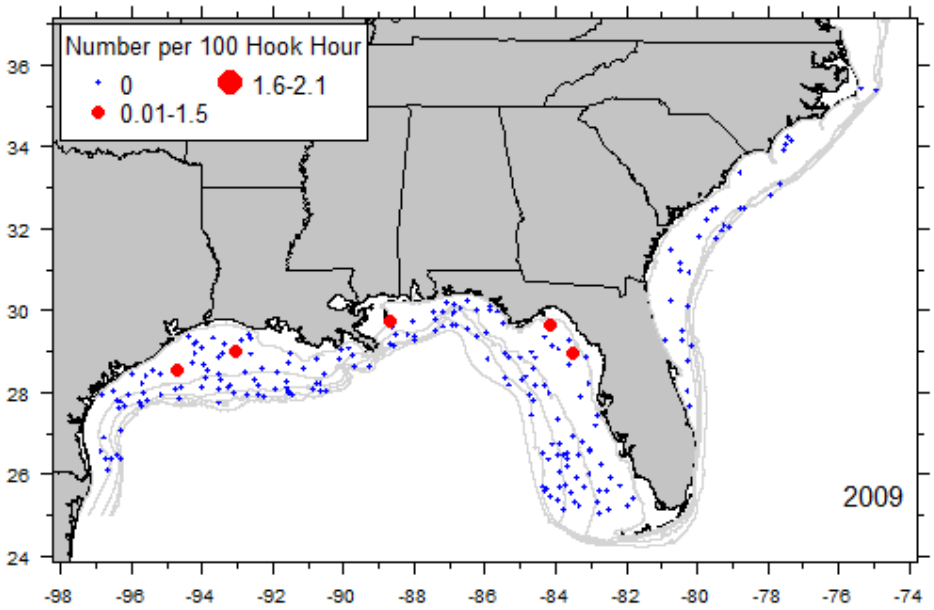

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2004

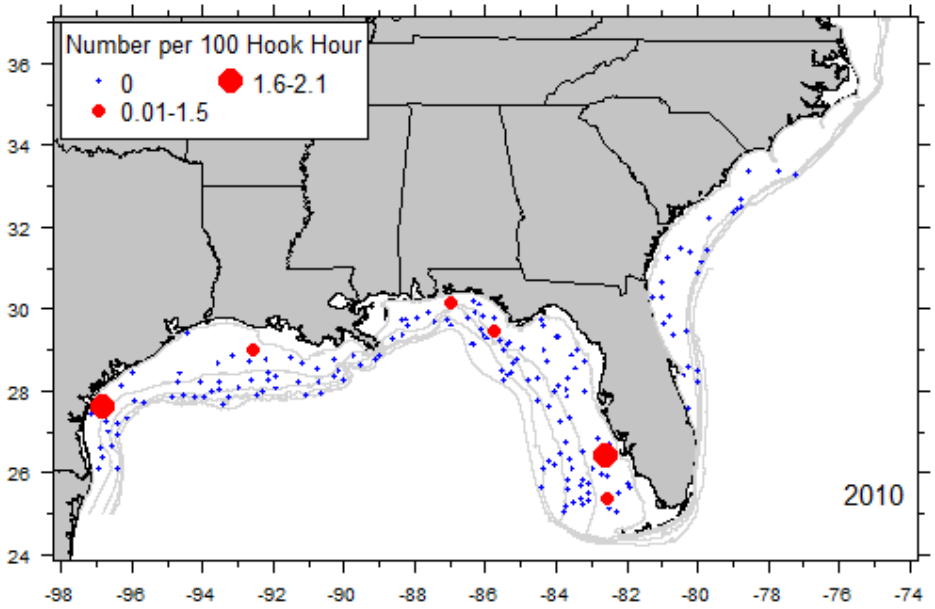

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2005

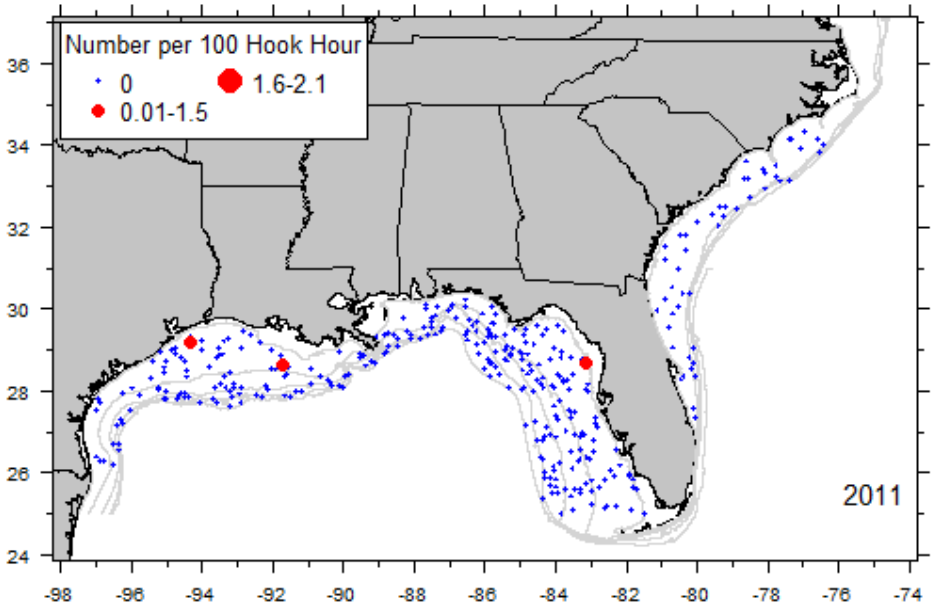

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2006

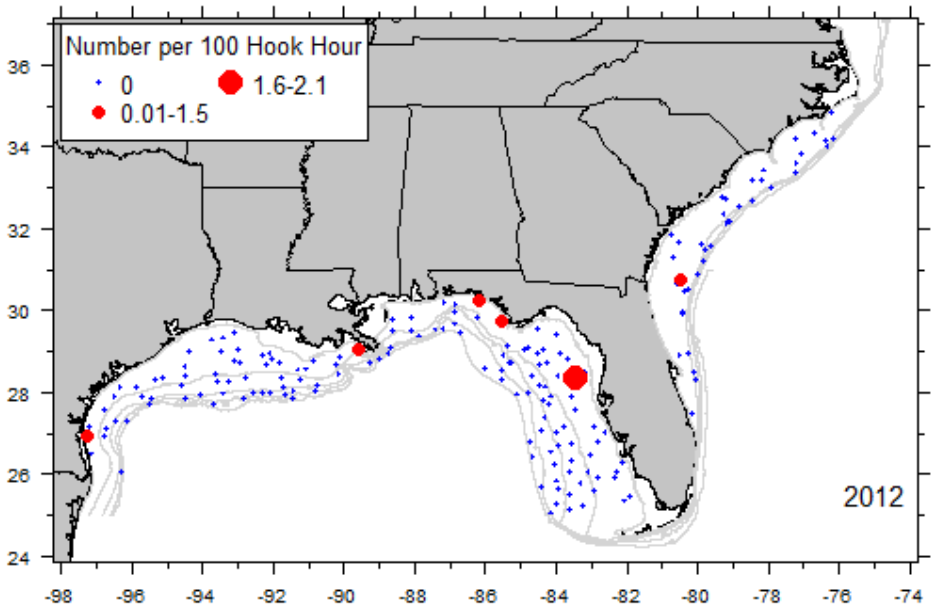

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2007

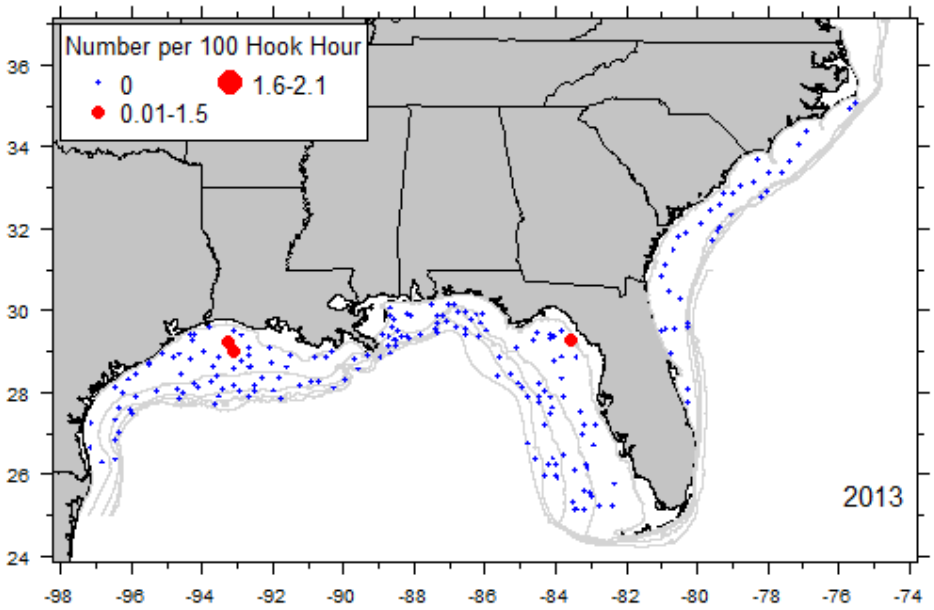

Number per 100 Hook Hour
0
1.6-2.1
0.01-1.5
2008

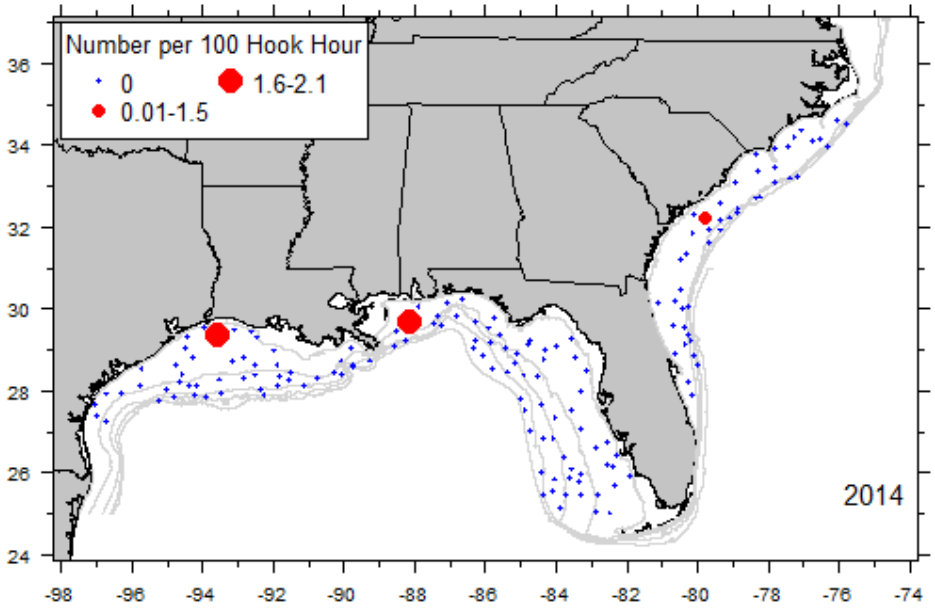

Number per 100 Hook Hour
0
1.6-2.1
0.01-1.5
2009

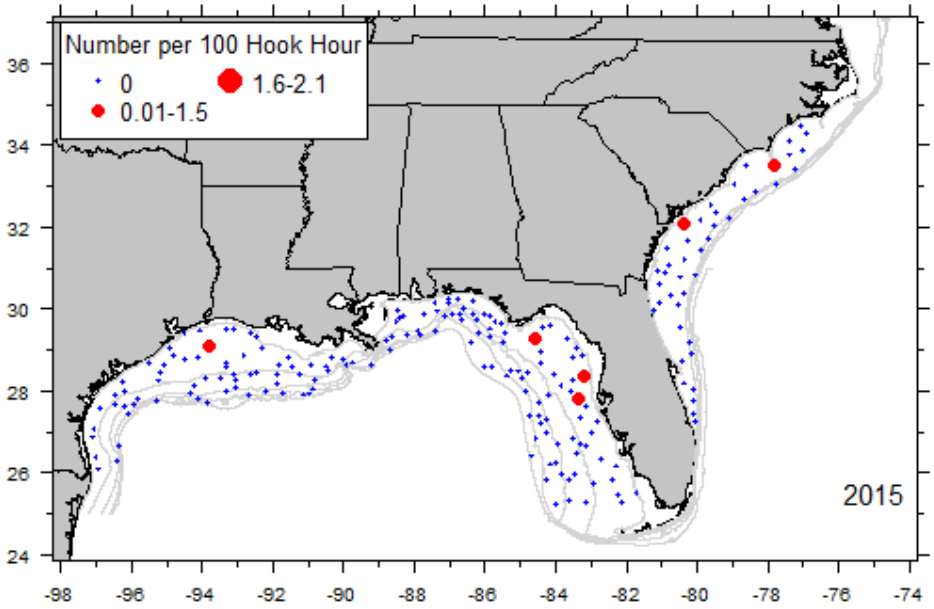

Number per 100 Hook Hour
0
1.6-2.1
0.01-1.5
2010

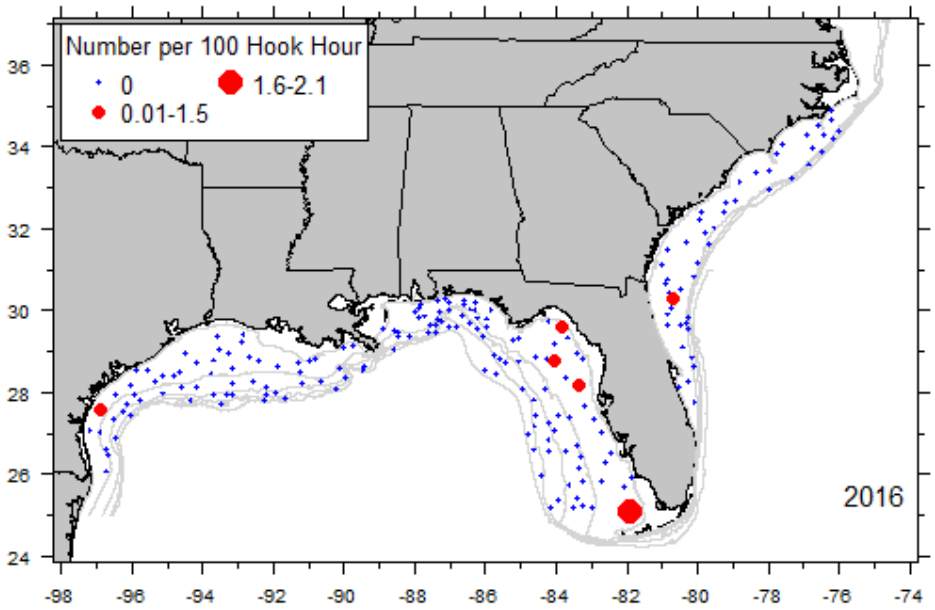

Number per 100 Hook Hour
0
1.6-2.1
0.01-1.5
2011

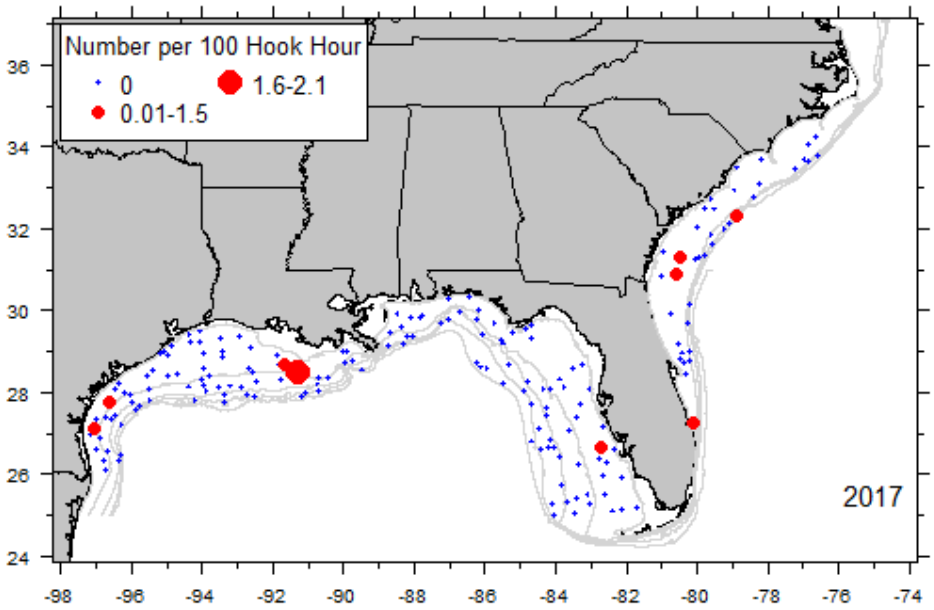

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2012

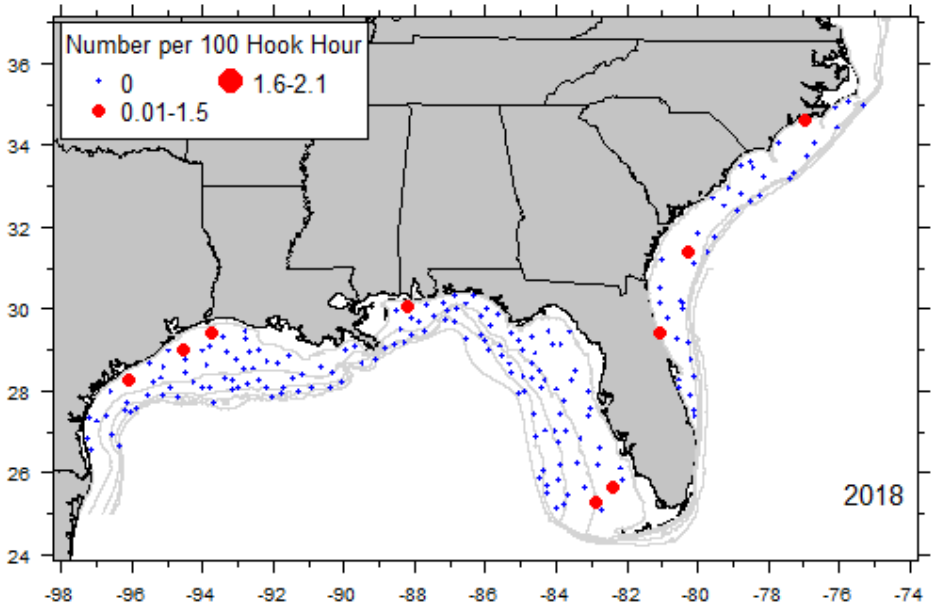

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2013

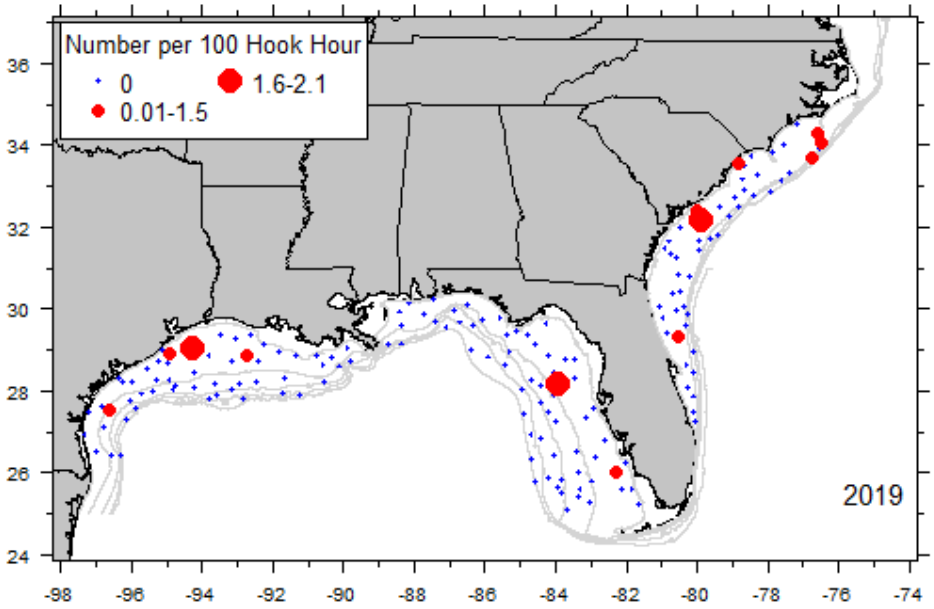

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2014


Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2015

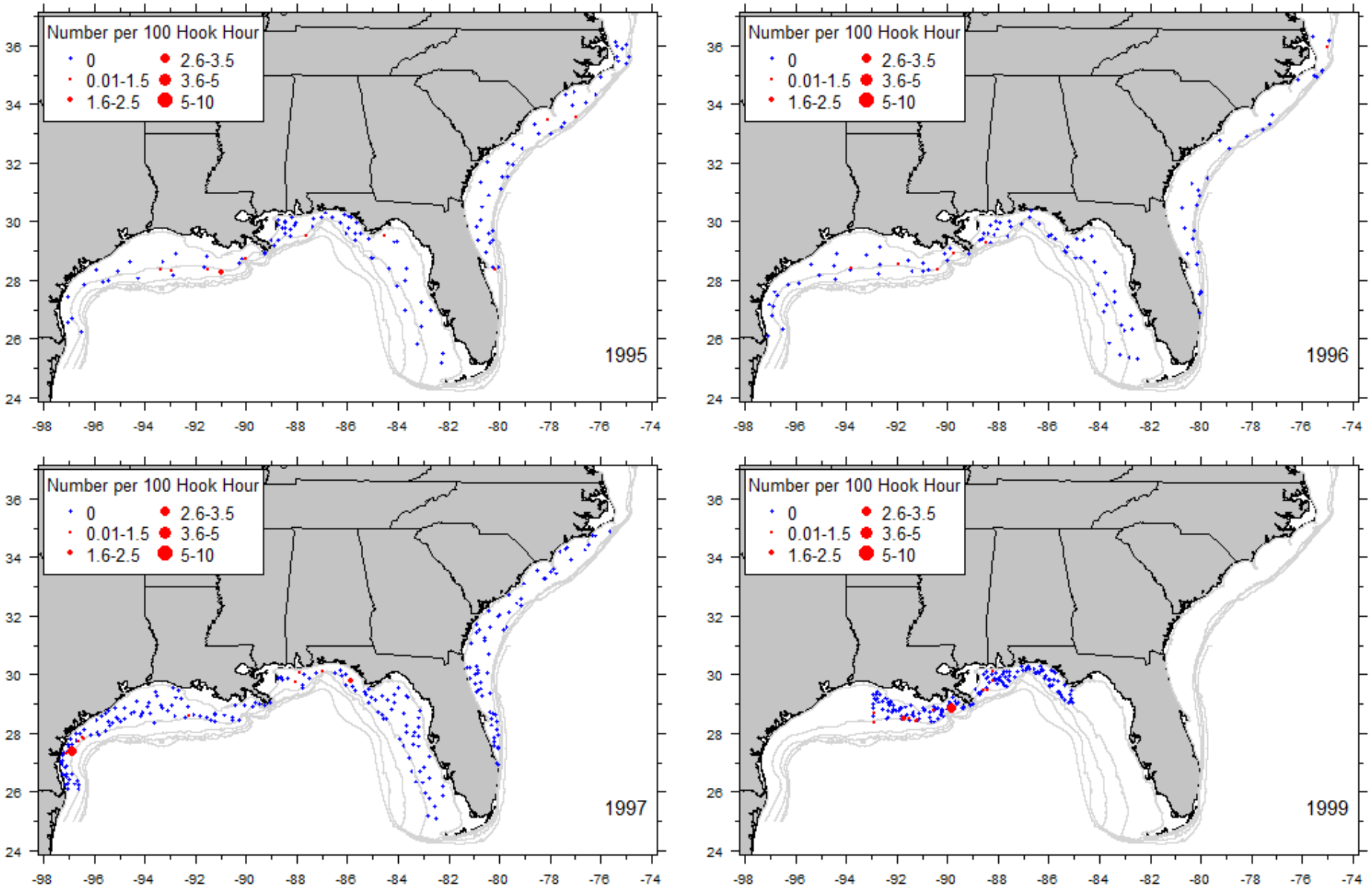

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2016

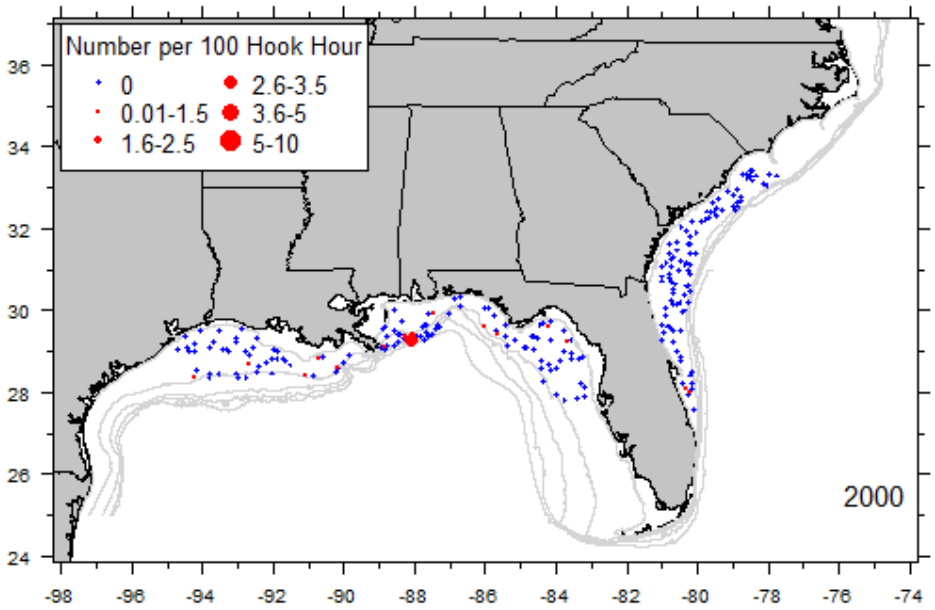

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2017

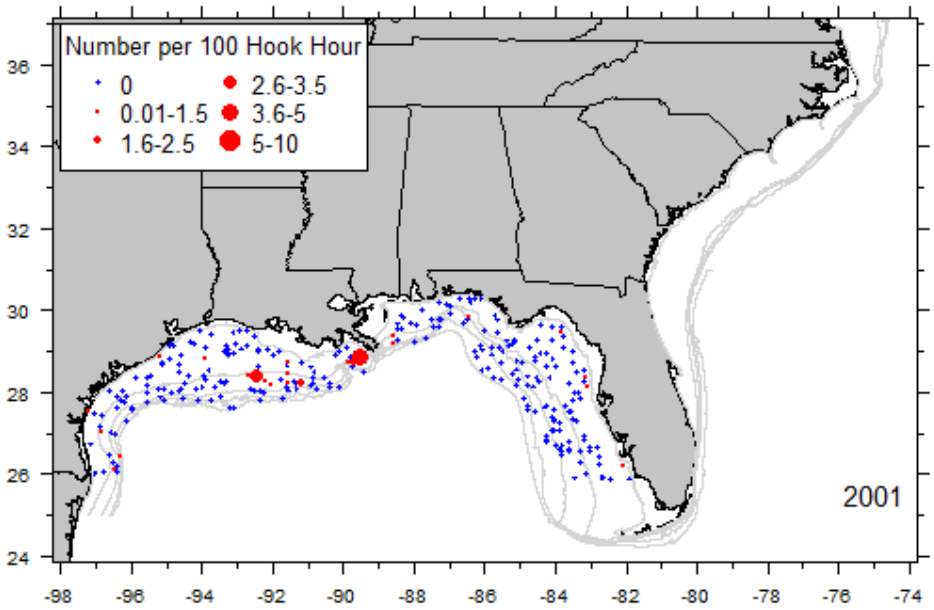

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2018

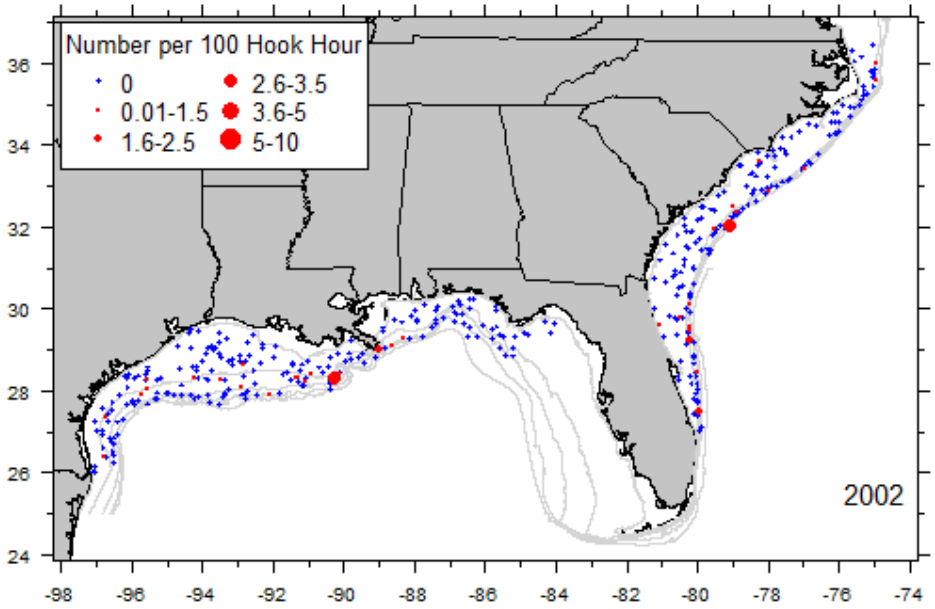

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.1
2019

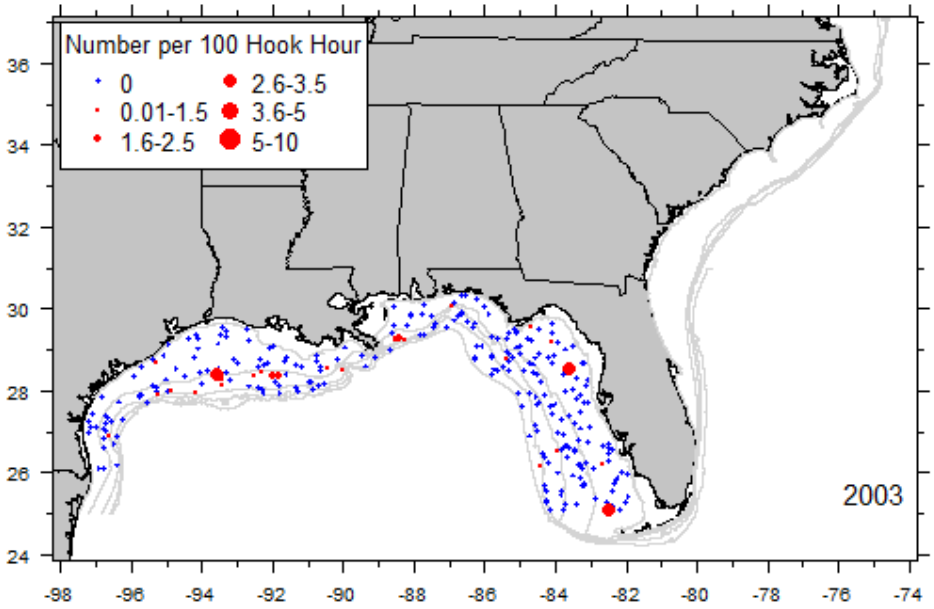
Appendix Figure 2. Annual survey effort and catch of scalloped hammerhead from the NMFS bottom longline survey (1995-2019).

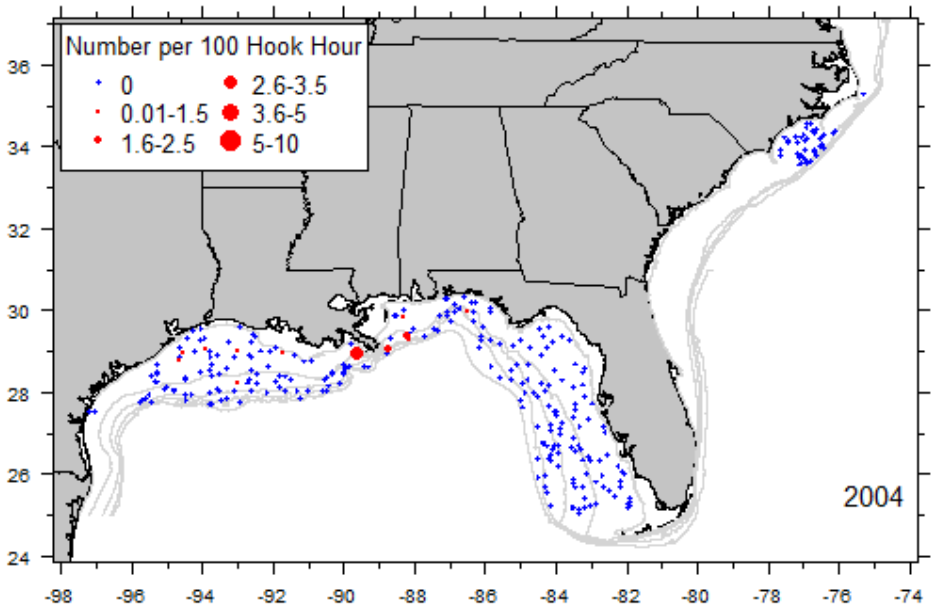


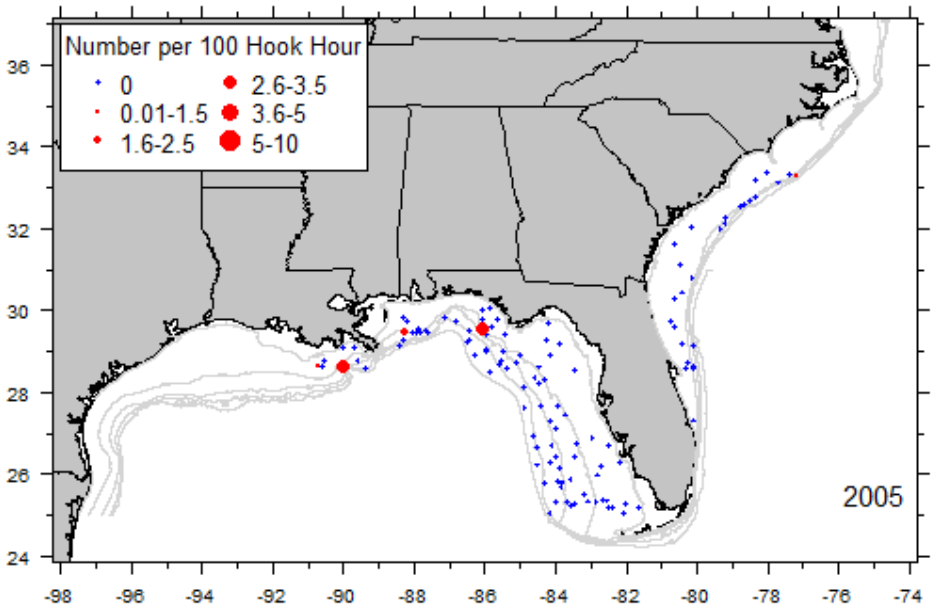

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2000

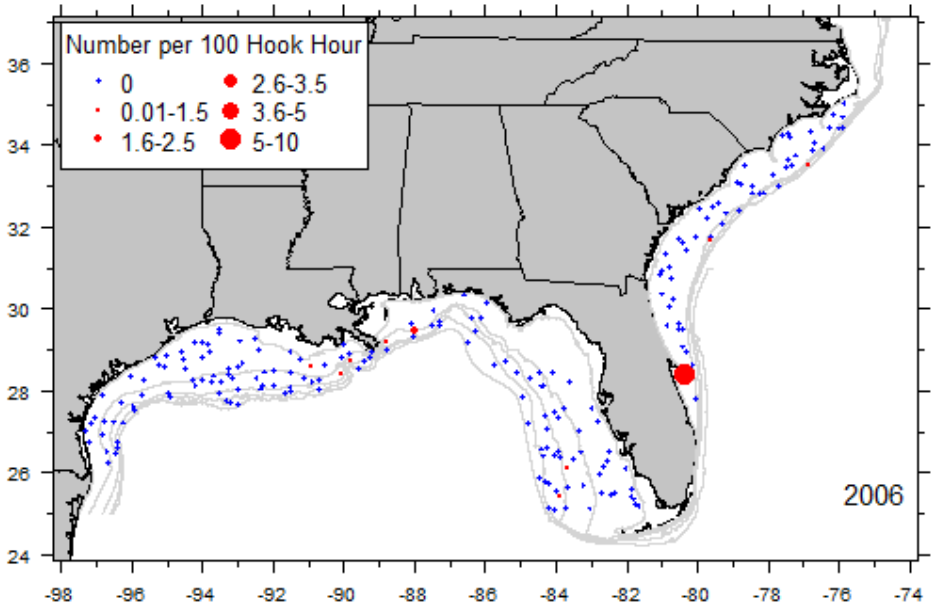

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2001

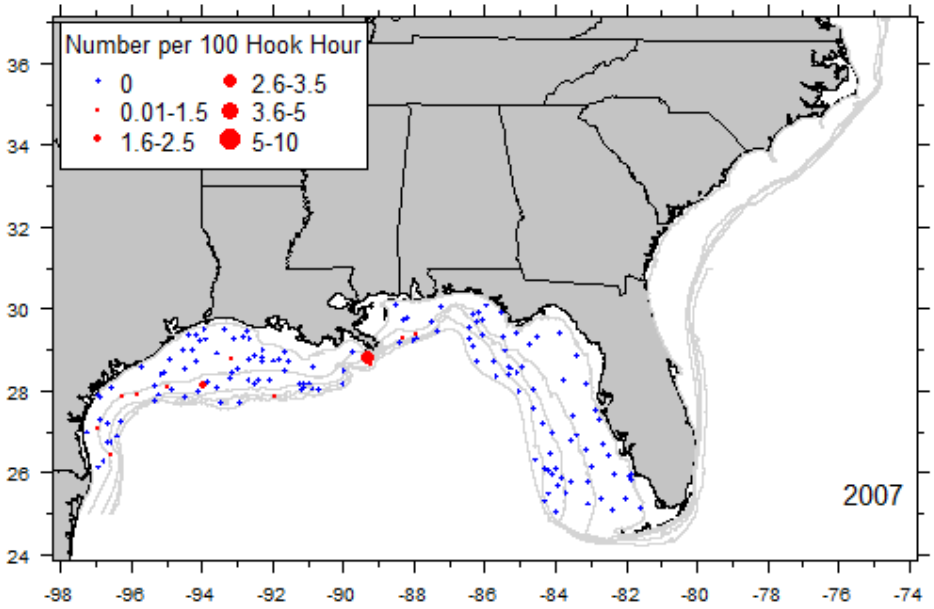

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2002

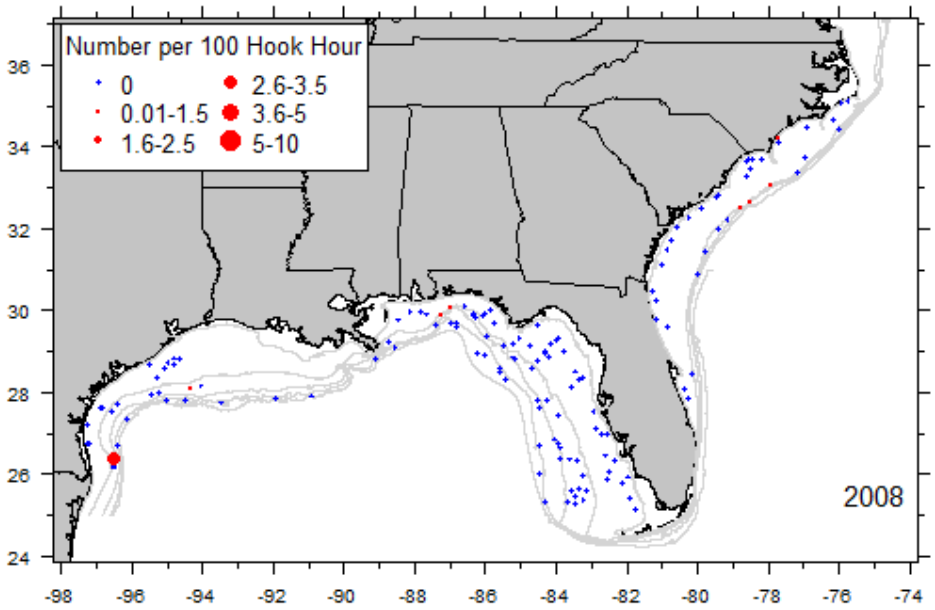

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2003

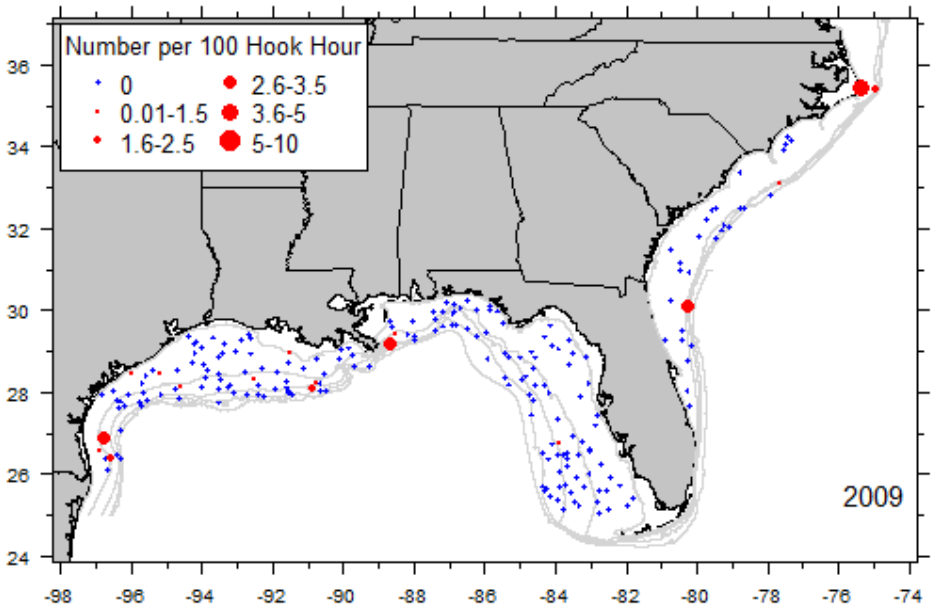

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2004

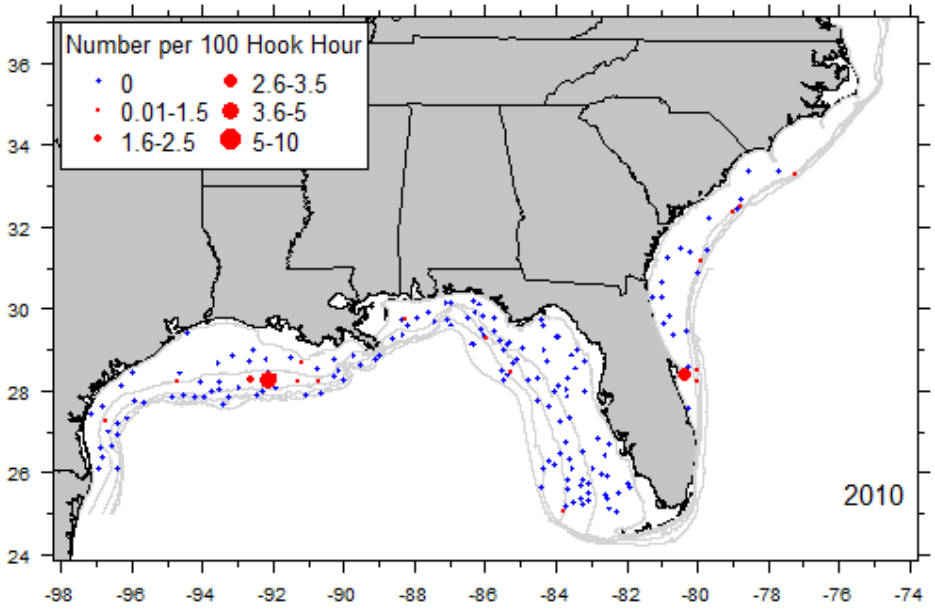

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2005

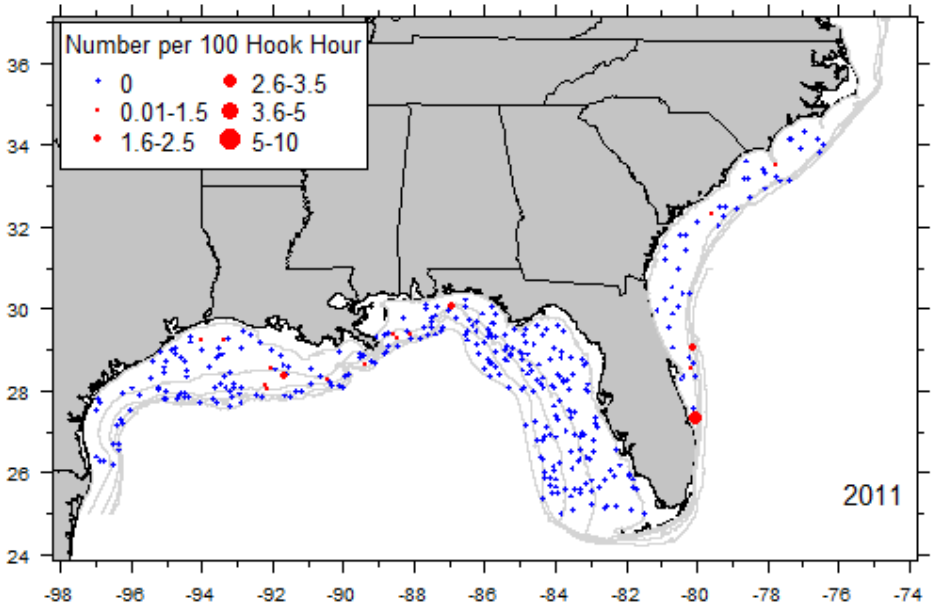

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2006

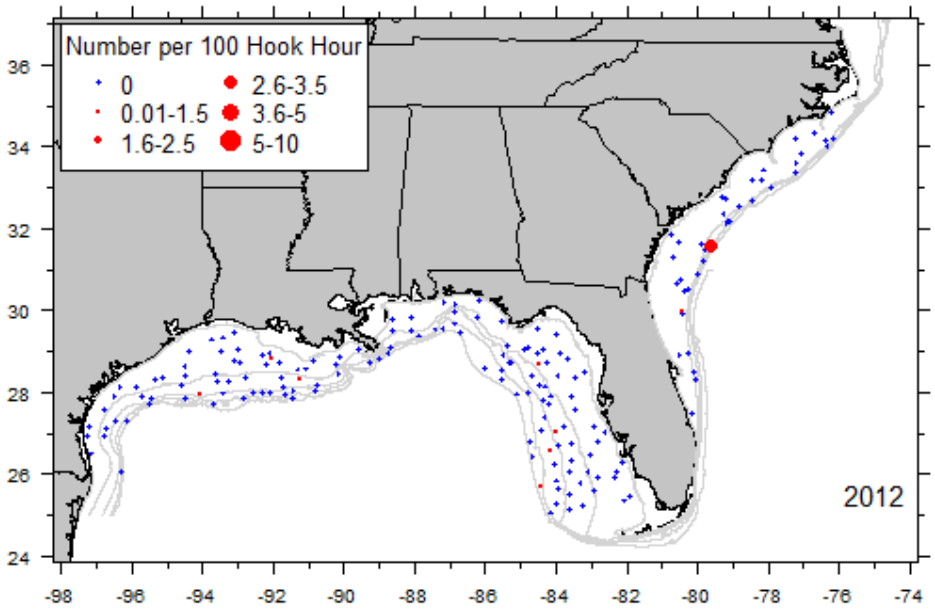

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2007

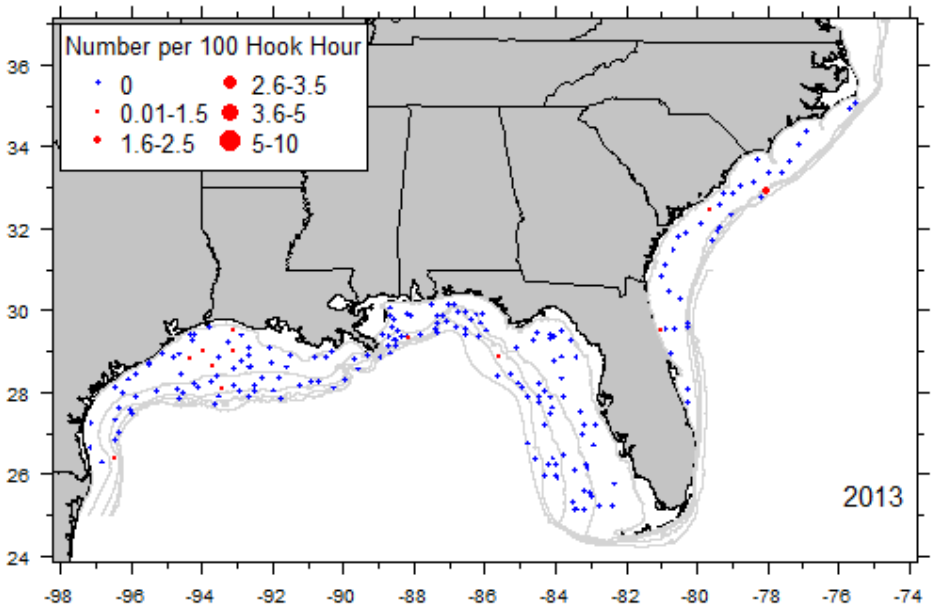

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2008

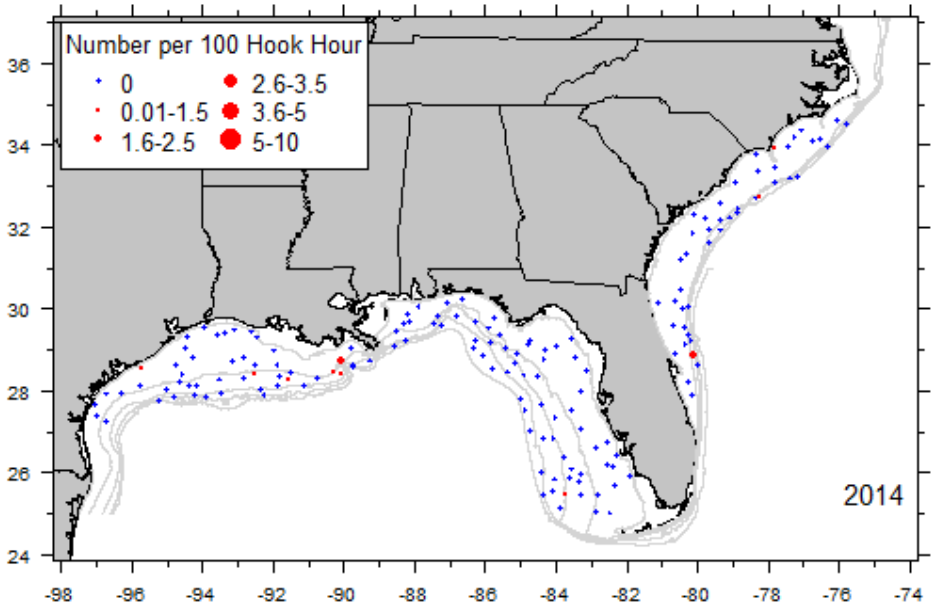

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2009

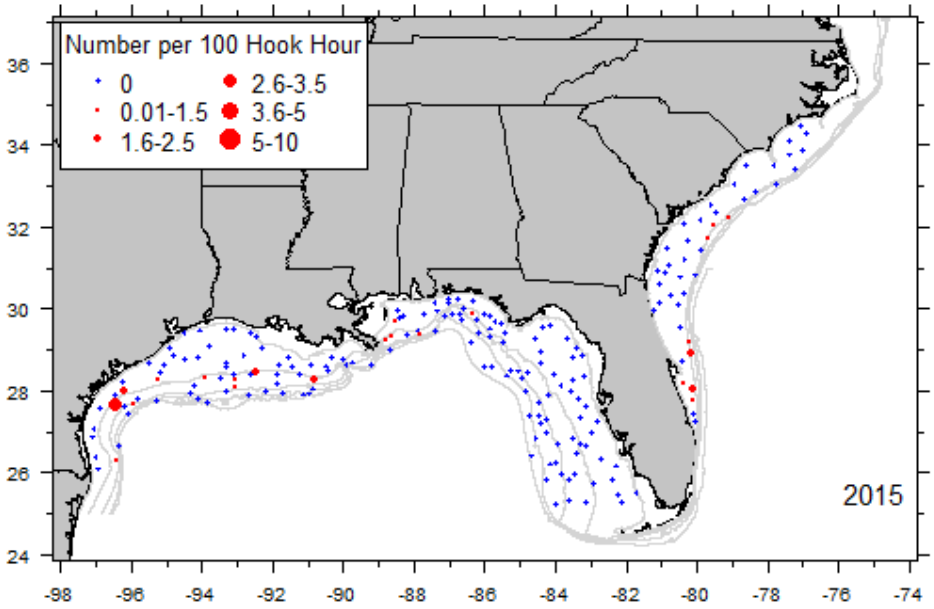

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2010

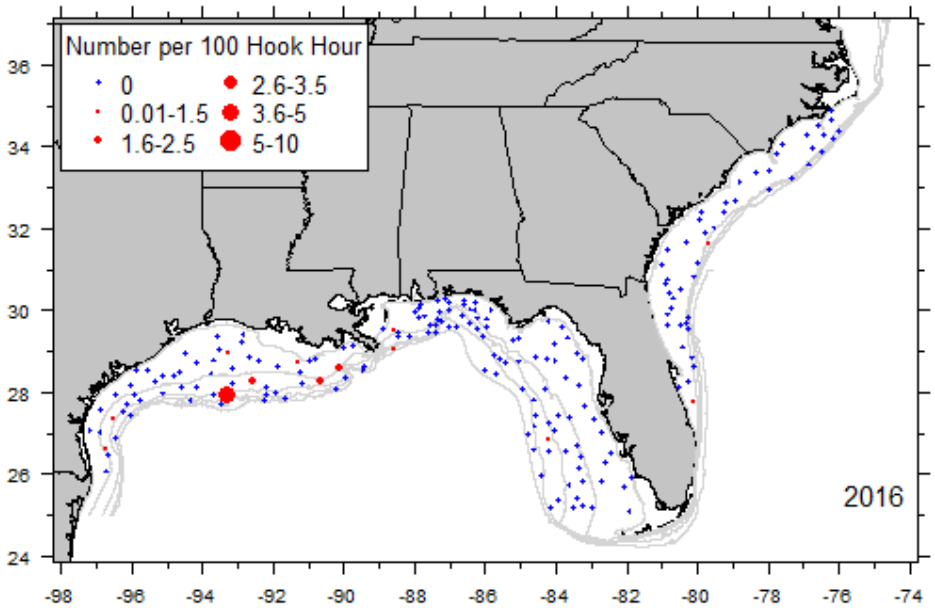

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2011

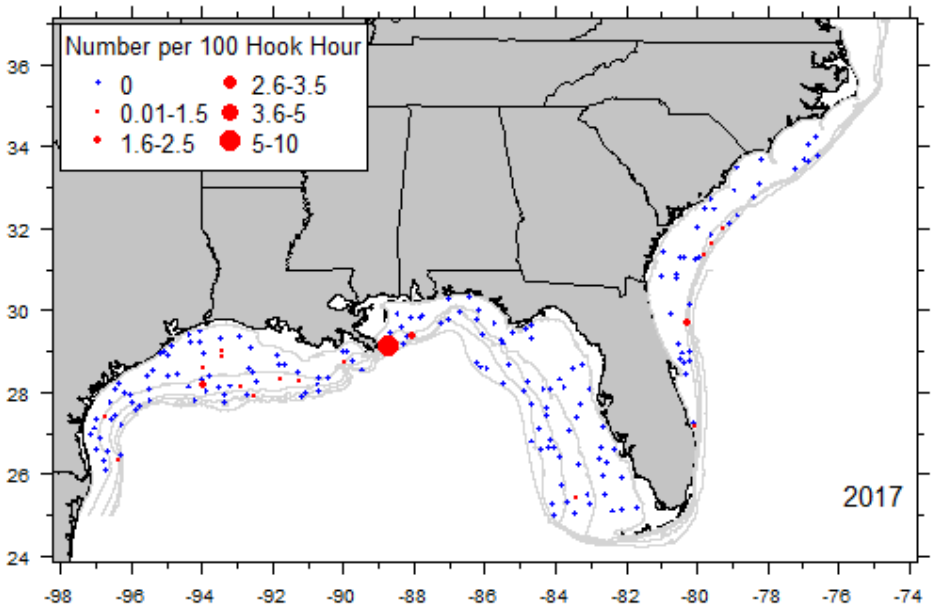

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2012

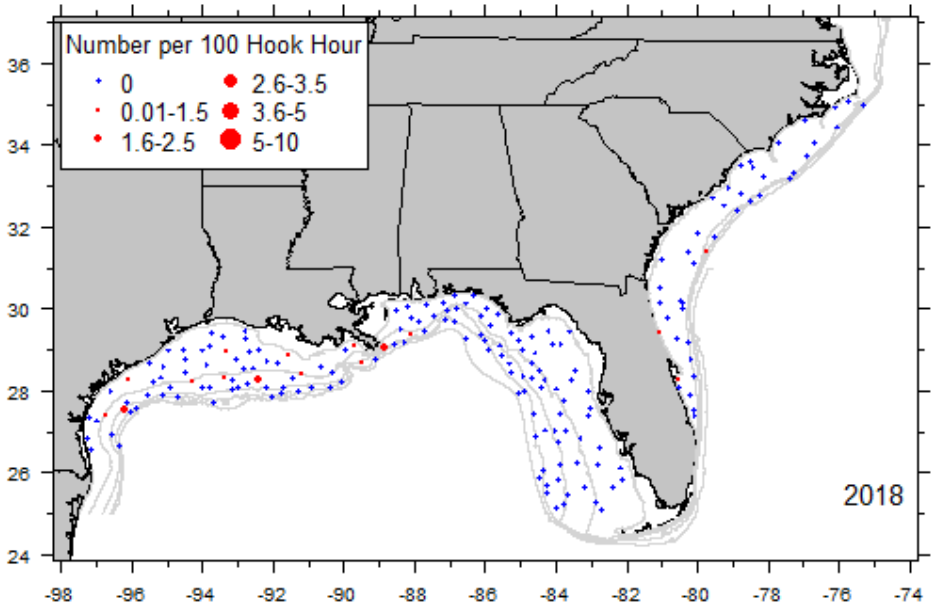

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2013

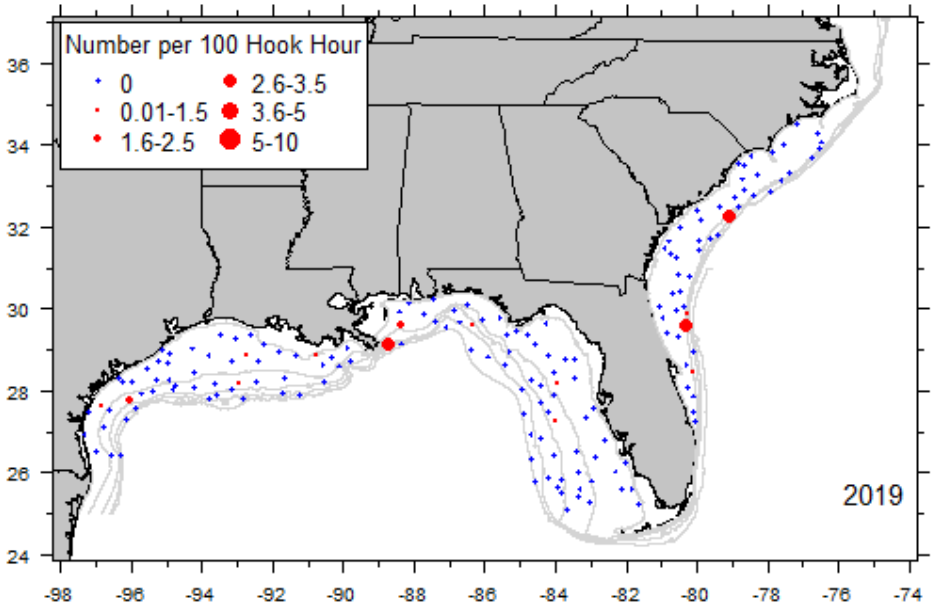

Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2014


Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2015


Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2016


Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2017


Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2018


Number per 100 Hook Hour
0
0.01-1.5
1.6-2.5
2.6-3.5
3.6-5
5-10
2019