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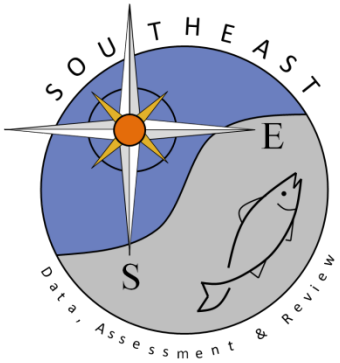

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Abstract: *The Southeast Fisheries Science Center Mississippi Laboratories (MSLABS) has conducted standardized bottom longline surveys in the Gulf of Mexico, Caribbean, and U.S. South Atlantic Ocean since 1995. In addition to the annual survey, in 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 has been used during previous assessments of red grouper (Epinephelus morio). This paper provides a new abundance index through 2017 for red grouper for the upcoming assessment.*

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 U.S South Atlantic Ocean (South Atlantic) since 1995. The objective of these surveys is to provide fisheries independent data for stock assessment purposes for as many species as possible. The surveys are conducted annually in U.S. waters of the GOM and/or the South Atlantic, and are 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 is not reviewed in this document.

In 2011, the Congressional Supplemental Sampling Program (CSSP) conducted monthly surveys from April through October in the GOM. See Campbell et al. 2012 for a full review of the program. Sampling under the CSSP 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 red grouper (*Epinephelus morio*) using the combined survey data.

Methodology

Survey Design

Details concerning the methodologies and evolution of the National Marine Fisheries Service (NMFS) BLL have been covered in previous documents (Ingram *et al*. 2005). Basic sample design utilizes a proportional allocation of stations based on the surface area of the continental

shelf width within NMFS statistical zones and depth zones (50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m). NMFS bottom longlines have maintained a standard configuration over the time series with the exception of hook type. Bottom longlines initially fished J-hooks when the survey began in 1995; a mixture of J-hooks and 15/0 circle hooks were utilized between 1999 and 2000; and 15/0 circle hooks were utilized exclusively after 2001.

Data

Data for the annual BLL survey was obtained from the SEFSC MSLABS Shark Unit and the CSSP data was obtained from 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. Age data was obtained from the SEFSC Panama City Laboratory. Details concerning the aging methodologies of red grouper can be found in Lombardi-Carlson (2014).

Data Exclusions

We used the time series of data between 2001 and 2017 to develop red grouper abundance indices (Table 1). Data from 1995 – 2000 was not used due to the use of J-type hooks, attributing to very few red grouper (53) being captured. When the hook type was changed to circle-hooks, red grouper catch increased by an order of magnitude (Ingram *et al*. 2005). Survey year 2002 was dropped from the analysis because of the limited spatial coverage in the eastern GOM (Appendix Figure 1).

Data was limited spatially to an area east of 87°W, since few red grouper (4) had been captured past this point. Depth was also used to limit the data, with no stations deeper than 118 m being used, since there were no records of red grouper being captured any deeper. In 2005, additional sampling was done in 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 conducted outside of August and September were removed. After limiting the data, 1,025 stations were used in the analysis.

Index Construction

Delta-lognormal modeling methods were used to estimate relative abundance indices for red grouper (Pennington 1983; Bradu and 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) $$p = \frac{e^{\mathbf{X\beta+\varepsilon}}}{1 + e^{\mathbf{X\beta+\varepsilon}}},$$

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 considered for inclusion in the submodels were:

Submodel Variables (GOM)

Year: 2001, 2003 – 2017
Depth: 9 – 118 m (continuous)
Area: Northern (north of 29°N), Central (between 27°N - 29°N), Southern (south of 27°N)
Time of Day: Day, Night

Results and Discussion

Distribution, Size and Age

The distribution of red grouper from NMFS BLL sets is presented in Figure 1, with annual abundance and distribution presented in Appendix Figure 1. There were 23 to 327 red grouper captured per year (Table 2), with a total of 1,355 red grouper captured between 2001 and 2017. Of the 1,355 red grouper captured, a total of 1,285 were measured from 2001 – 2017 with an average fork length of 503 mm (± 109 mm standard deviation). Figure 2 shows the length frequency distribution of red grouper captured in the GOM. The average age of red grouper collected on bottom longlines was 6.39 years old (Figure 3).

Abundance Index

The final delta-lognormal NMFS BLL index of red grouper abundance retained year, area, time of day and depth in the binomial submodel, and year and area in the lognormal submodel. A summary of the factors used in the model is presented in Appendix Table 1. Table 3 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 4,741.4 and 815.9, respectively. The diagnostic plots for the binomial and lognormal submodels are shown in Figure 4, and indicate the distribution of the residuals is approximately normal. Annual abundance indices are presented in Table 4 and Figure 5.

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Table 1. Summary of the total number of stations available for analysis (left) and the total number of stations used in the analysis (right).

	Gulf of Mexico			
Year	East	Central	West	Total
1995	34	27	13	74
1996	38	25	17	80
1997	61	32	71	164
1998				
1999	57	104		161
2000	63	51	23	137
2001	130	64	83	277
2002	43	71	98	212
2003	163	54	63	280
2004	136	60	53	249
2005	80	15		95
2006	62	37	50	149
2007	70	38	47	155
2008	75	7	26	108
2009	91	42	51	184
2010	86	31	31	148
2011	177	54	65	296
2012	74	35	33	142
2013	75	47	45	167
2014	62	29	26	117
2015	85	35	41	161
2016	83	31	38	152
2017	64	34	51	149
Total	*1809*	*923*	*925*	*3657*

	Eastern Gulf of Mexico			
Year	Northern	Central	Southern	Total
2001	28	41	24	93
2002				
2003	28	41	48	117
2004	24	33	41	98
2005	3	12	25	40
2006	4	13	22	39
2007	13	9	20	42
2008	18	18	24	60
2009	14	19	30	63
2010	20	17	30	67
2011	32	48	42	122
2012	10	21	18	49
2013	16	15	16	47
2014	11	12	19	42
2015	18	17	18	53
2016	17	16	16	49
2017	12	14	18	44
Total	*268*	*346*	*411*	*1025*

Table 2. Summary of the red grouper length data collected from the NMFS Bottom Longline Survey conducted between 2001 and 2017.

Survey Year	Number of Stations	Number Collected	Number Measured	Minimum Fork Length (mm)	Maximum Fork Length (mm)	Mean Fork Length (mm)	Standard Deviation
2001	93	83	79	290	837	502	112
2002							
2003	117	166	162	295	845	510	121
2004	98	176	169	305	786	500	104
2005	40	29	28	303	700	480	121
2006	39	34	32	370	669	520	87
2007	42	51	51	350	694	477	80
2008	60	33	31	275	800	548	132
2009	63	65	64	315	910	506	132
2010	67	85	81	320	810	506	113
2011	122	327	308	300	757	487	94
2012	49	121	111	320	749	507	90
2013	47	51	43	363	780	519	101
2014	42	23	22	376	779	528	119
2015	53	47	43	298	725	518	107
2016	49	27	26	257	789	534	146
2017	44	37	35	299	795	539	142
Total Number of Years	Total Number of Stations	Total Number Collected	Total Number Measured			Mean Fork Length (mm)	Mean Standard Deviation (mm)
16	1025	1355	1285			503	109

Table 3. Summary of backward selection procedure for building delta-lognormal submodels for red grouper index of relative abundance from 2001 to 2017.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 4741.4)*						*Lognormal Submodel Type 3 Tests (AIC 826.8)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	15	1003	28.73	1.92	0.0174	0.0186	15	305	3.20	<.0001
Depth	1	1003	56.74	56.74	<.0001	<.0001	1	305	0.65	0.4211
Area	2	1003	51.72	25.86	<.0001	<.0001	2	305	7.07	0.0010
Time of Day	1	1003	5.67	5.67	0.0173	0.0175	1	305	1.41	0.2353
Model Run #2	*Binomial Submodel Type 3 Tests (AIC 4741.4)*						*Lognormal Submodel Type 3 Tests (AIC 817.3)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	15	1003	28.73	1.92	0.0174	0.0186	15	306	3.21	<.0001
Depth	1	1003	56.74	56.74	<.0001	<.0001		Dropped		
Area	2	1003	51.72	25.86	<.0001	<.0001	2	306	6.84	0.0012
Time of Day	1	1003	5.67	5.67	0.0173	0.0175	1	306	1.47	0.2259
Model Run #3	*Binomial Submodel Type 3 Tests (AIC 4741.4)*						*Lognormal Submodel Type 3 Tests (AIC 815.9)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	15	1003	28.73	1.92	0.0174	0.0186	15	307	3.17	<.0001
Depth	1	1003	56.74	56.74	<.0001	<.0001		Dropped		
Area	2	1003	51.72	25.86	<.0001	<.0001	2	307	7.34	0.0008
Time of Day	1	1003	5.67	5.67	0.0173	0.0175		Dropped		

Table 4. Indices of red grouper abundance developed using the delta-lognormal (DL) model for 2001-2017. The nominal frequency of occurrence, the number of samples (*N*), the DL Index (number per 100 hook 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
2001	0.21505	93	0.76287	0.77227	0.28996	0.43750	1.36320
2002							
2003	0.34188	117	1.00941	1.02186	0.20188	0.68516	1.52402
2004	0.41837	98	1.63574	1.65591	0.19206	1.13168	2.42297
2005	0.25000	40	0.57707	0.58419	0.40656	0.26720	1.27723
2006	0.28205	39	0.53843	0.54507	0.39153	0.25611	1.16006
2007	0.19048	42	0.85285	0.86336	0.46480	0.35649	2.09094
2008	0.26667	60	0.58374	0.59094	0.32220	0.31518	1.10794
2009	0.34921	63	0.90425	0.91540	0.26371	0.54500	1.53752
2010	0.32836	67	1.23178	1.24697	0.26509	0.74046	2.09997
2011	0.40164	122	2.29871	2.32705	0.18112	1.62462	3.33317
2012	0.46939	49	2.10472	2.13067	0.25395	1.29234	3.51282
2013	0.34043	47	0.97325	0.98525	0.30522	0.54240	1.78967
2014	0.26190	42	0.57752	0.58464	0.38264	0.27914	1.22450
2015	0.24528	53	0.70813	0.71686	0.36116	0.35588	1.44400
2016	0.18367	49	0.33860	0.34277	0.43649	0.14869	0.79020
2017	0.31818	44	0.70807	0.71680	0.34154	0.36888	1.39288

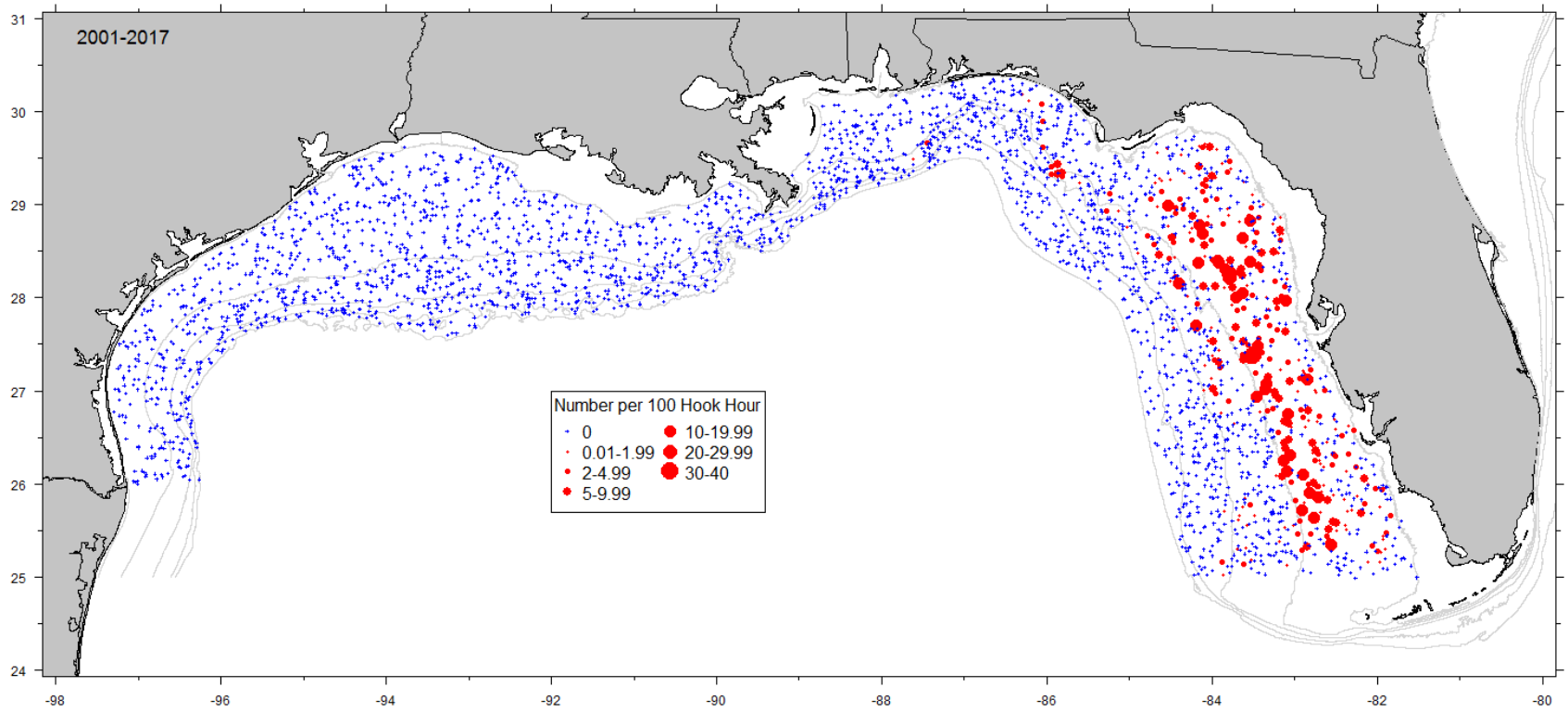


Figure 1. Stations sampled from 2001 to 2017 during the NMFS Bottom Longline Survey with the CPUE for red grouper.

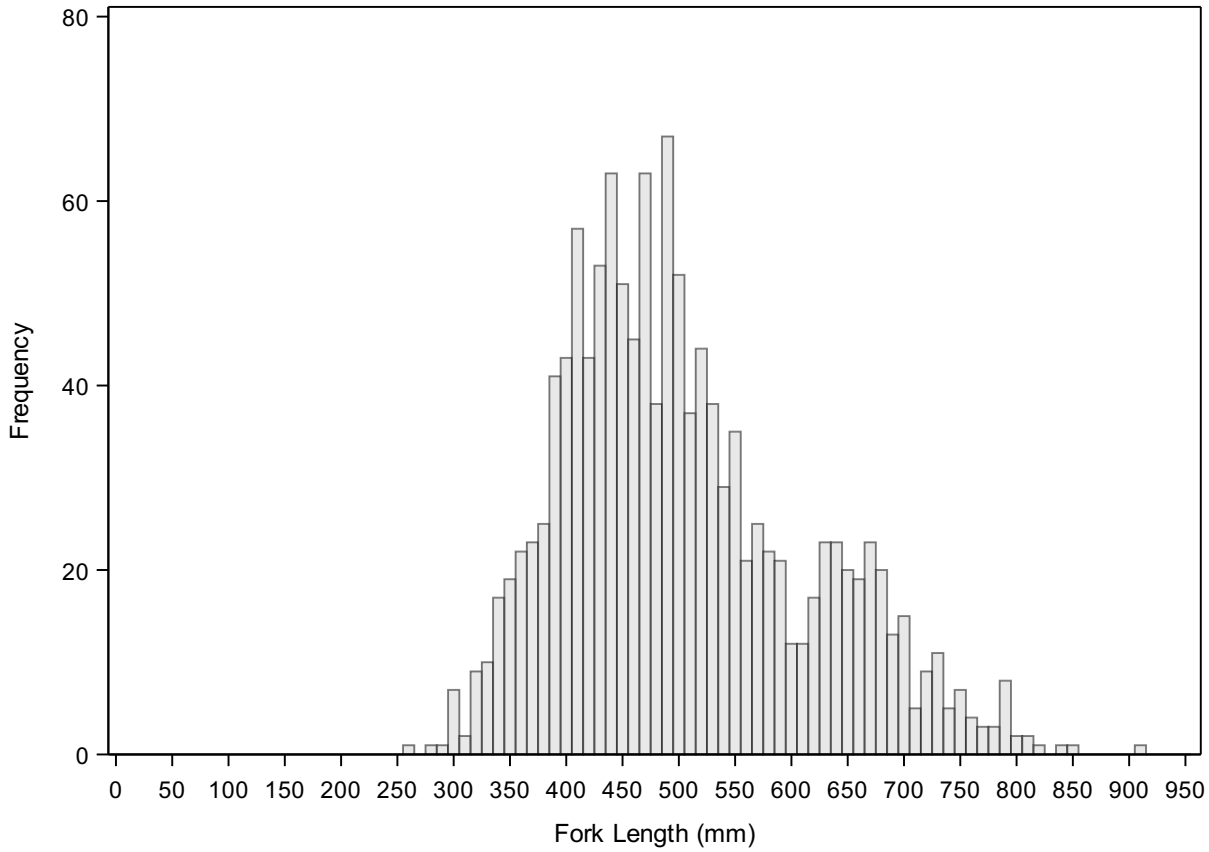


Figure 2. Length frequency histogram for red groupers captured in the Gulf of Mexico during the NMFS Bottom Longline Survey from 2001 - 2017.

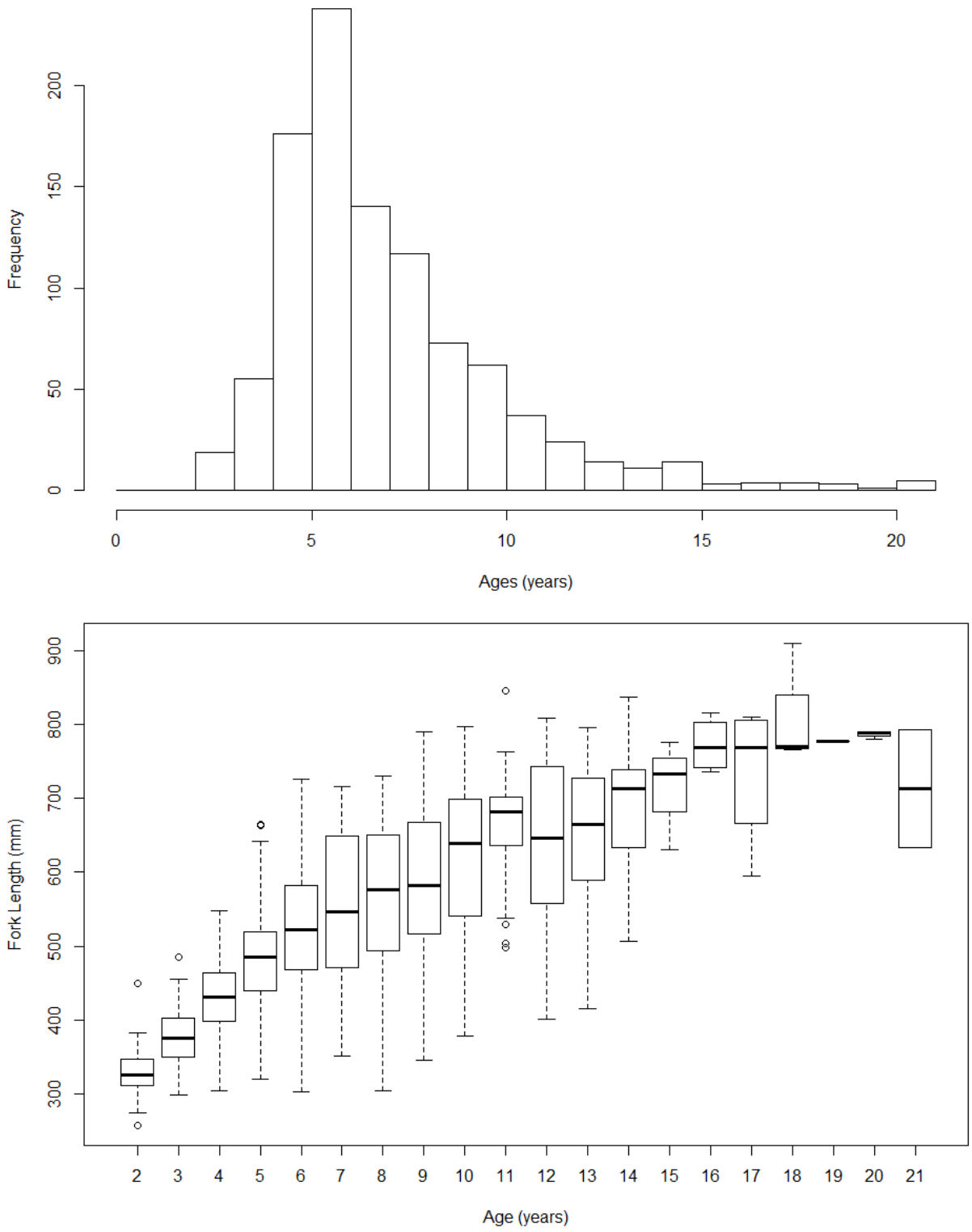


Figure 3. Age distribution of red grouper (n = 1,000) captured during the NMFS Bottom Longline Survey (top) and length at age information (bottom).

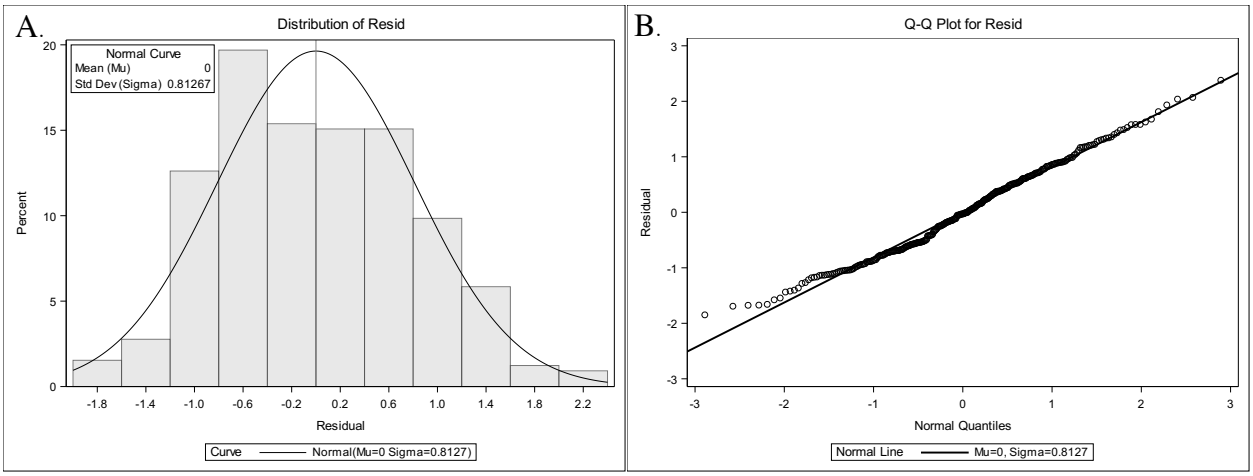


Figure 4. Diagnostic plots for lognormal component of the red grouper NMFS Bottom Longline Survey model: **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

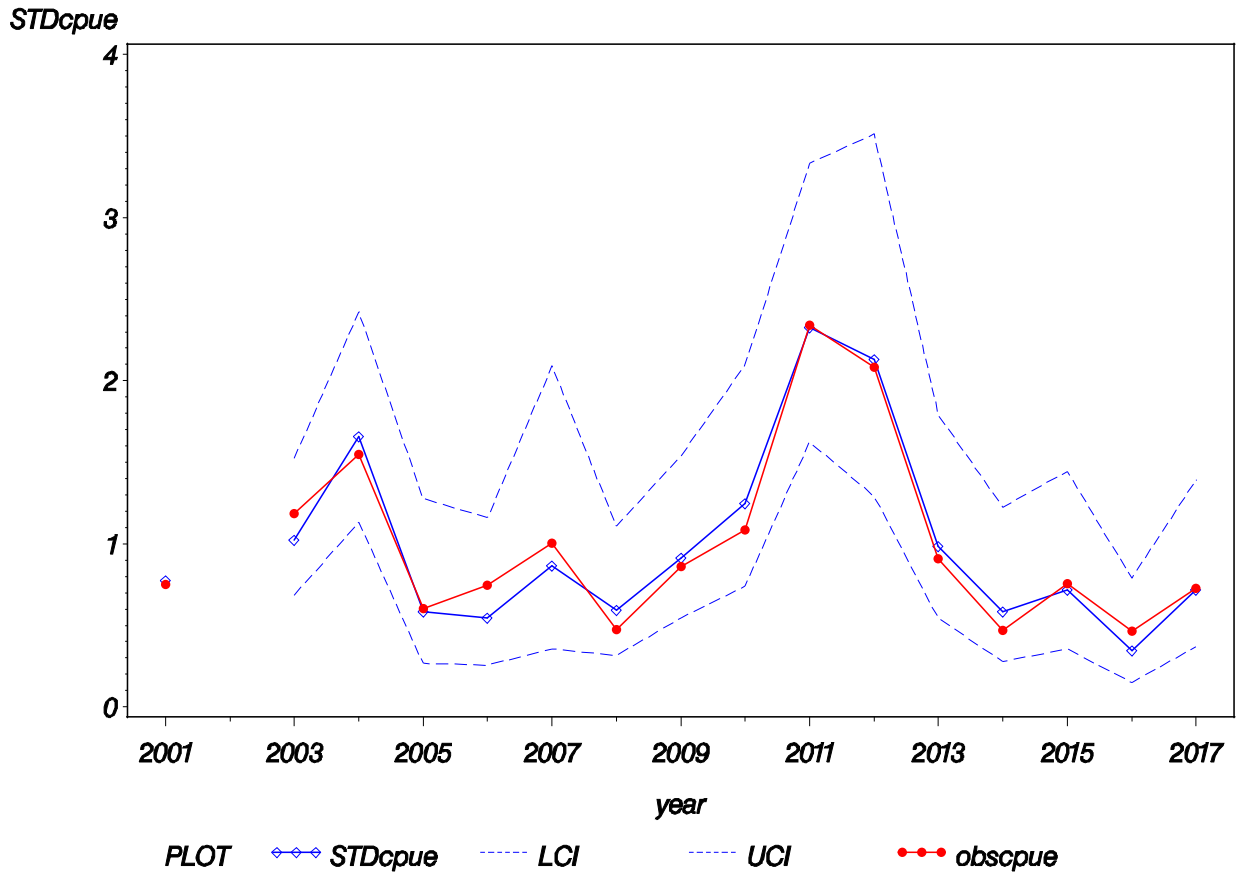


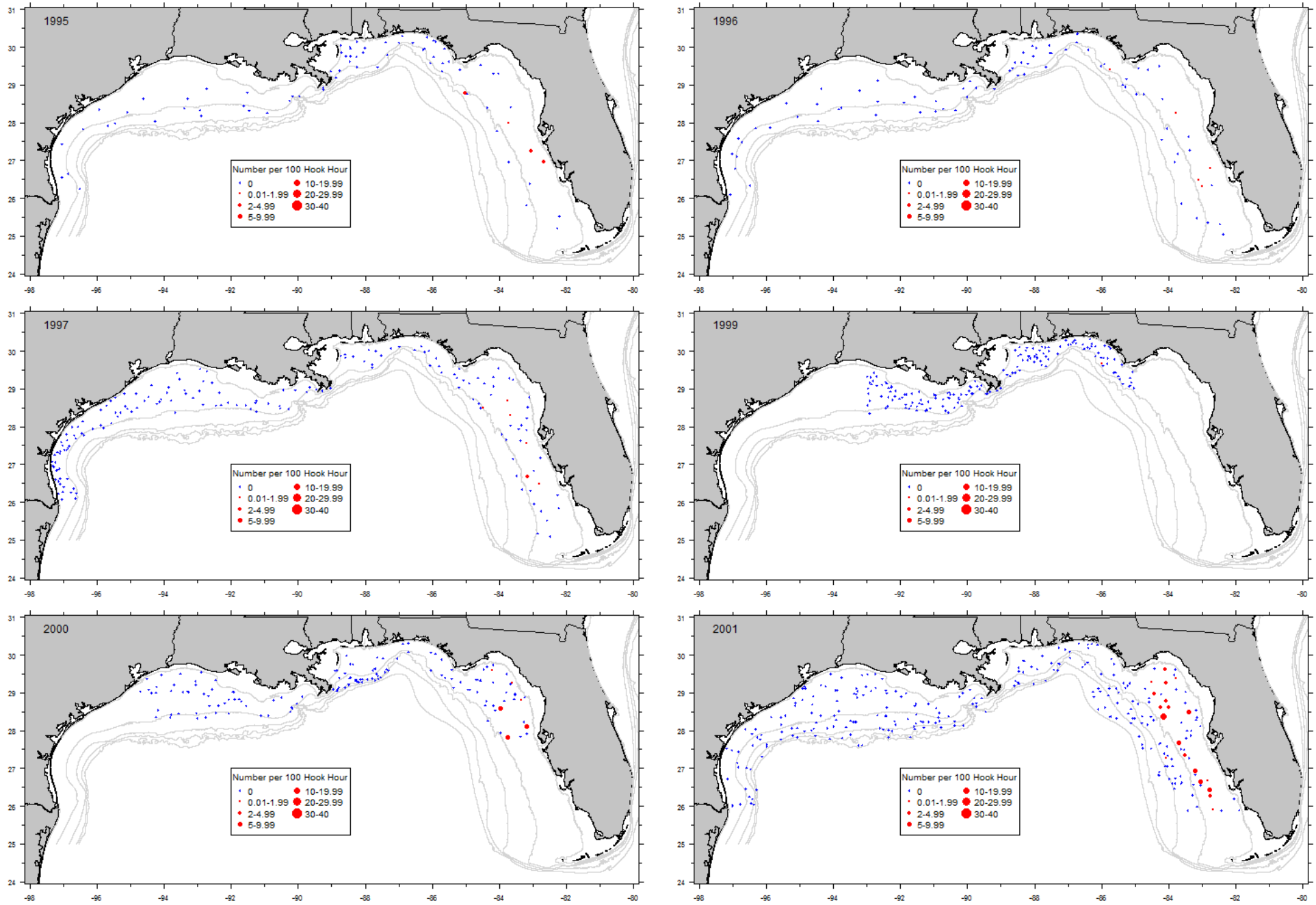
Figure 5. Annual index of abundance for red grouper from the NMFS Bottom Longline Survey from 2001 – 2017.

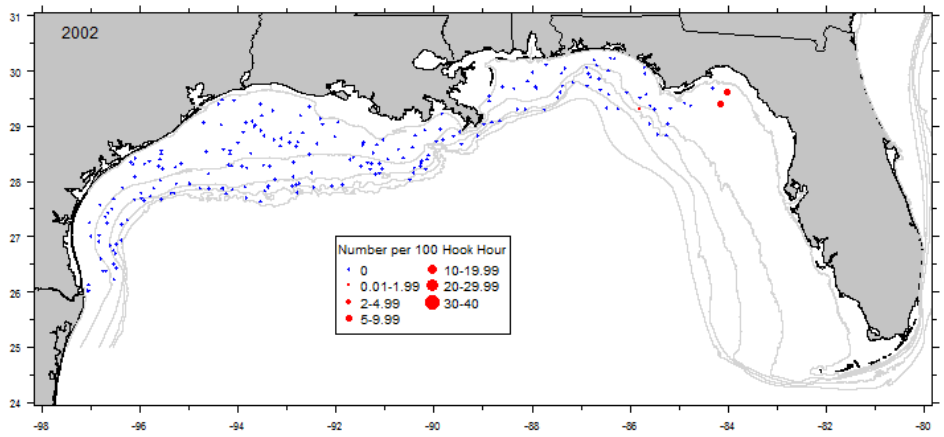
Appendix

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

Factor	Level	Number of Observations	Number of Positive Observations	Proportion Positive	Mean CPUE
Year	2001	93	20	0.21505	0.87628
Year	2003	117	40	0.34188	1.38033
Year	2004	98	41	0.41837	1.80487
Year	2005	40	10	0.25000	0.70350
Year	2006	39	11	0.28205	0.87280
Year	2007	42	8	0.19048	1.16871
Year	2008	60	16	0.26667	0.55240
Year	2009	63	22	0.34921	1.00165
Year	2010	67	22	0.32836	1.26605
Year	2011	122	49	0.40164	2.73074
Year	2012	49	23	0.46939	2.42892
Year	2013	47	16	0.34043	1.05748
Year	2014	42	11	0.26190	0.54866
Year	2015	53	13	0.24528	0.88301
Year	2016	49	9	0.18367	0.54368
Year	2017	44	14	0.31818	0.84554
Area	Northern	268	46	0.17164	0.41627
Area	Central	346	146	0.42197	2.14292
Area	Southern	411	133	0.32360	1.20377
Time of Day	Day	502	181	0.36056	1.66553
Time of Day	Night	523	144	0.27533	0.97833

Appendix Figure 1. Annual survey effort and catch of red grouper from the NMFS Bottom Longline Survey (1995-2017).

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Number per 100 Hook Hour
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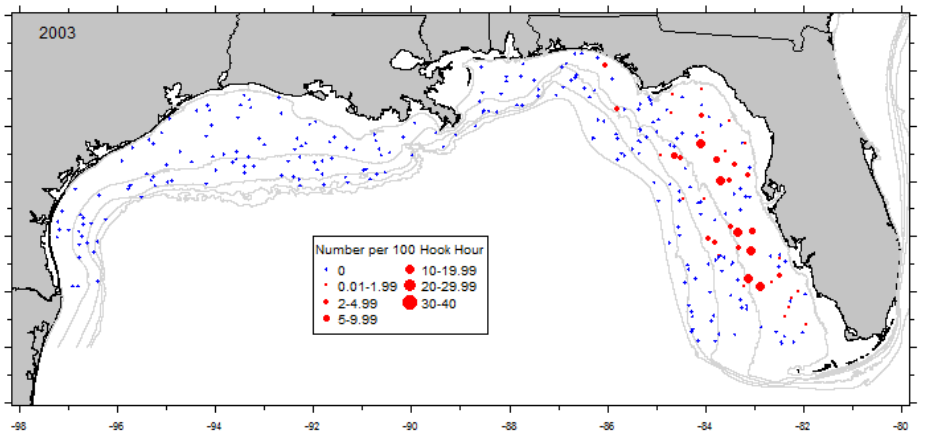
2-4.99
5-9.99
10-19.99
20-29.99
30-40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Number per 100 Hook Hour
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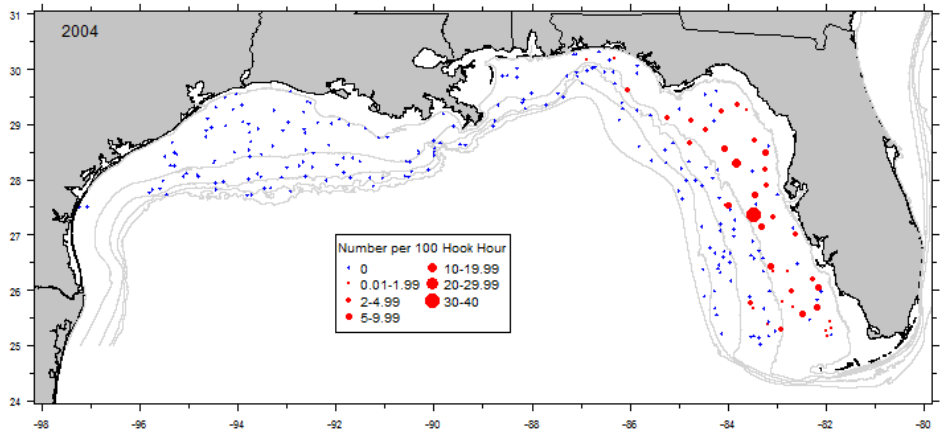
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40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Number per 100 Hook Hour
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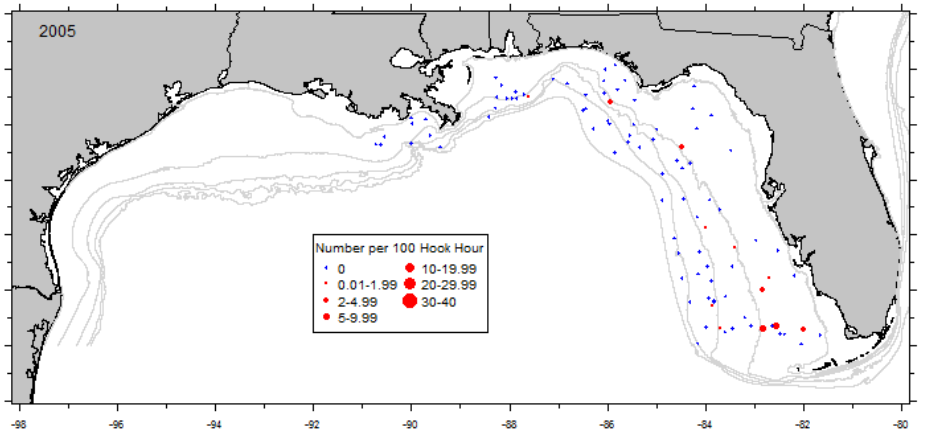
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40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Number per 100 Hook Hour
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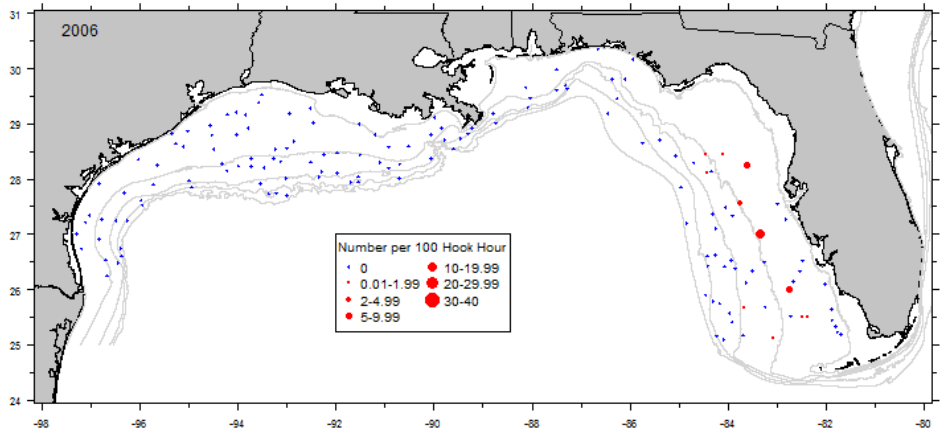
2-4.99
5-9.99
10-19.99
20-29.99
30-40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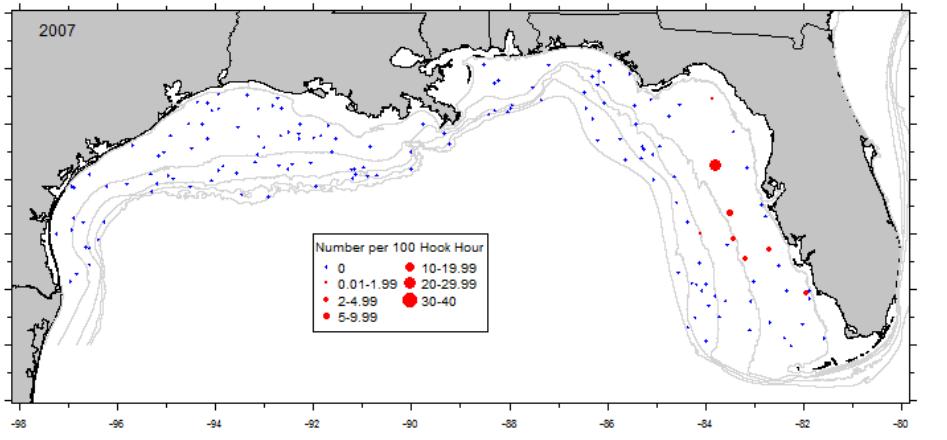
10-19.99
20-29.99
30-40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Number per 100 Hook Hour
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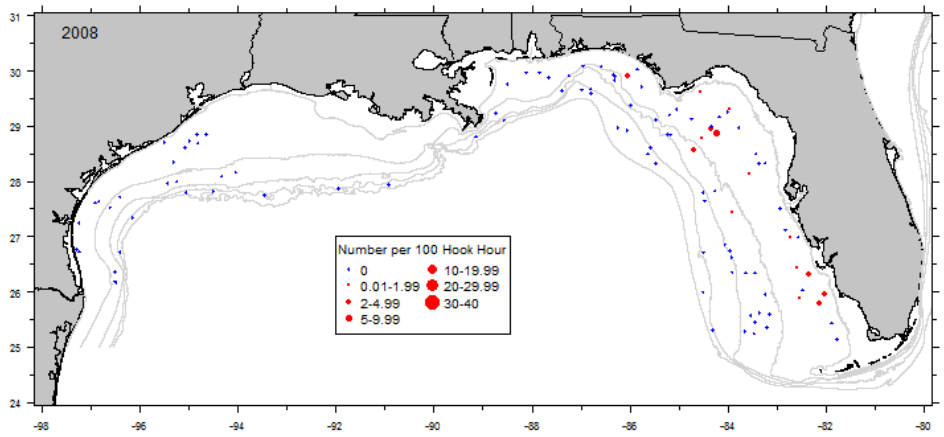
10-19.99
20-29.99
30-40


2008
Number per 100 Hook Hour
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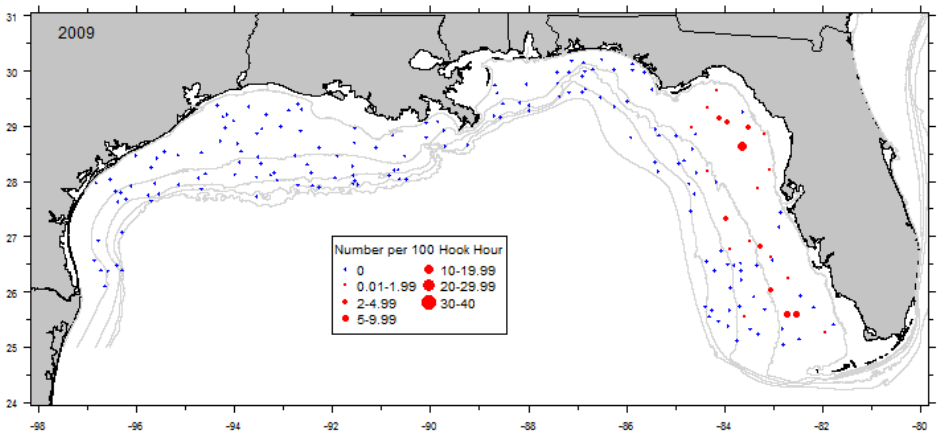
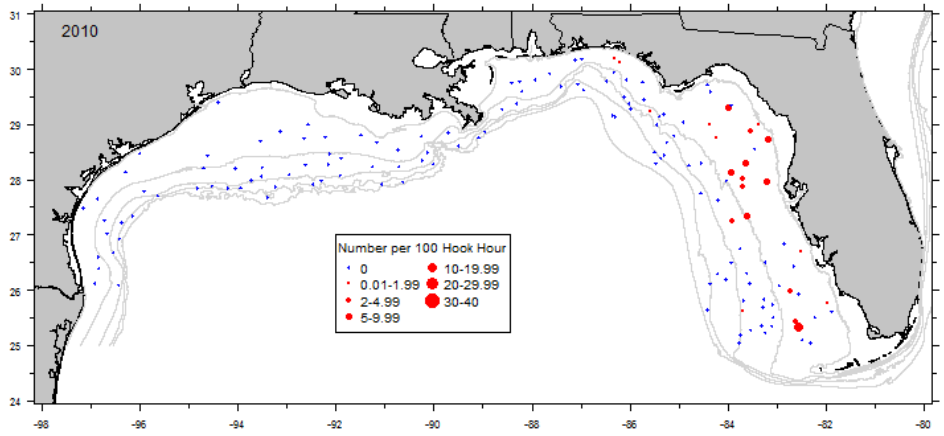
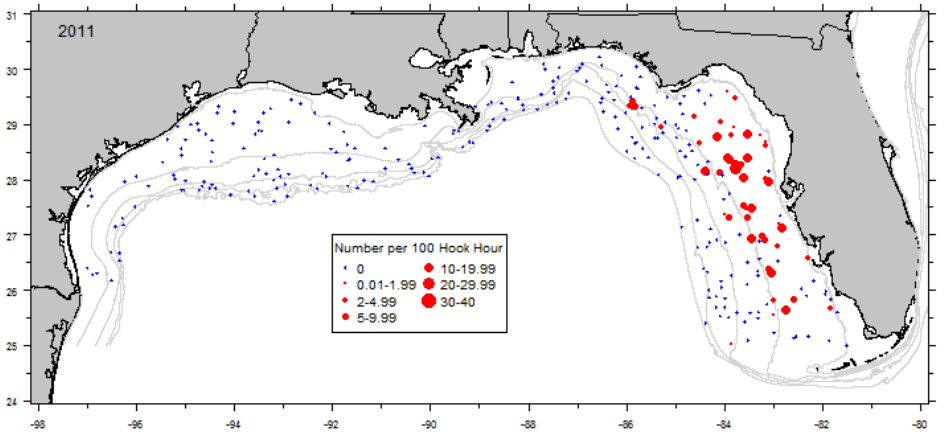
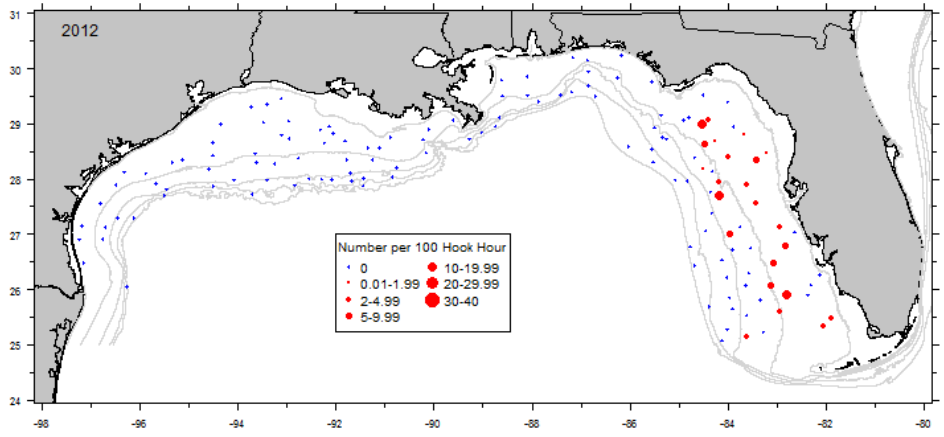
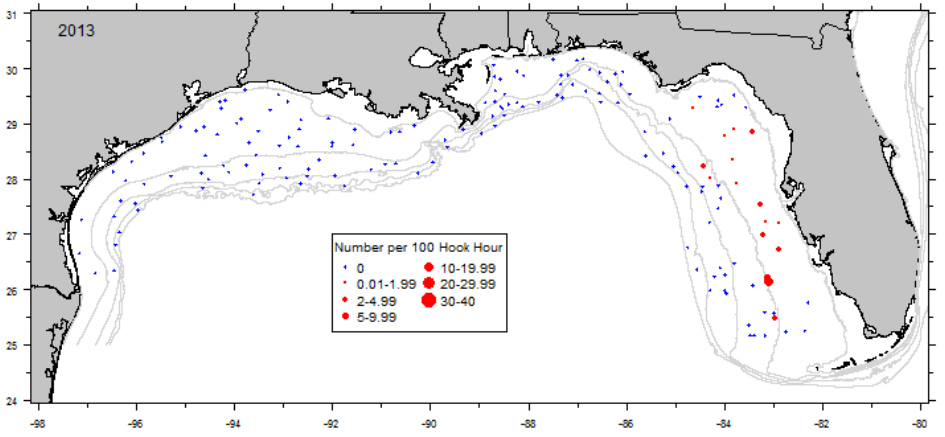
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40

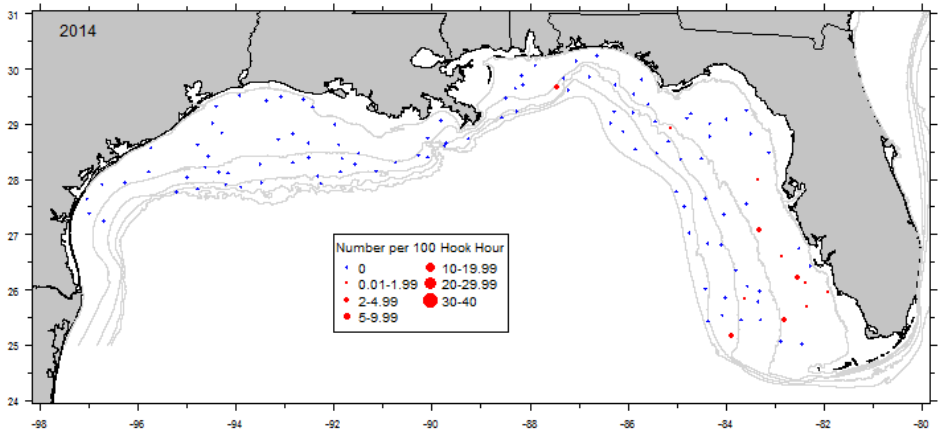

2009
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40

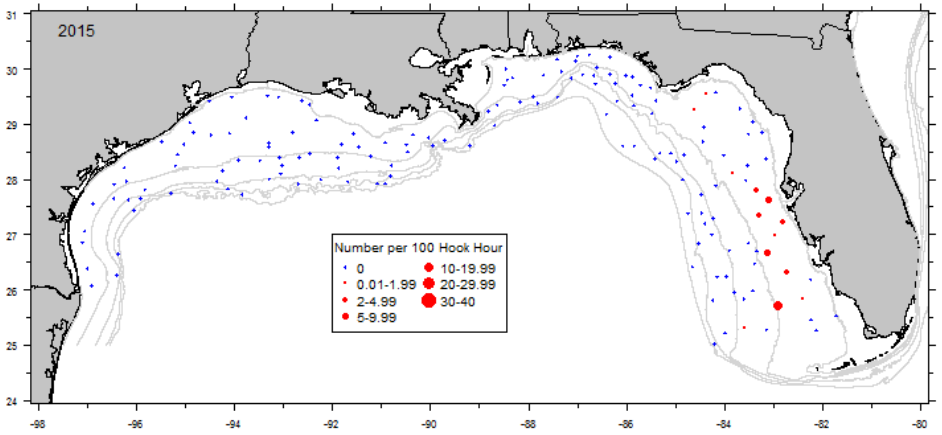

2010
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40

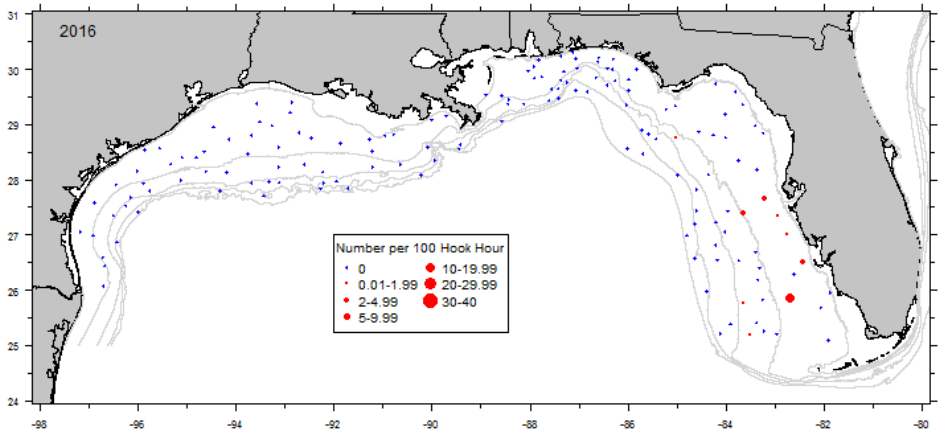

2011
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40

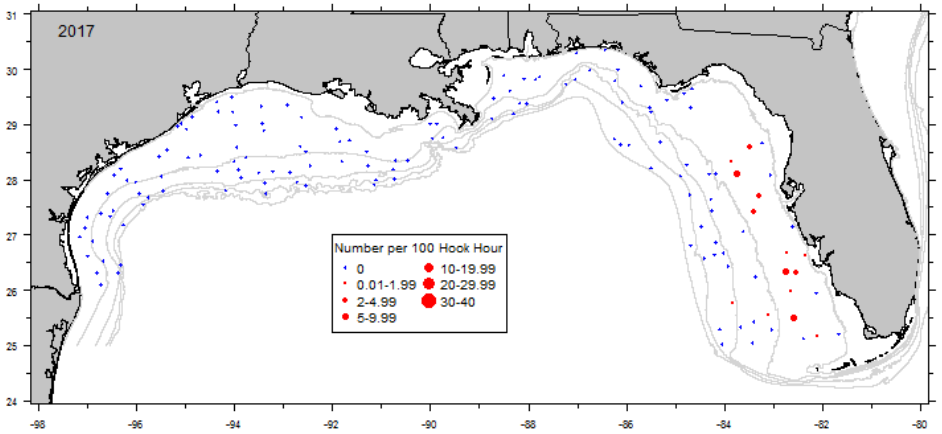

2012
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40


2013
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40


2014
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40


2015
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40


2016
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40


2017
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-29.99
30-40