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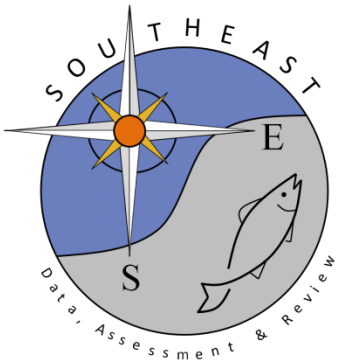
SEDAR52-WP-16

21 November 2017



Please cite this document as:

Pollack, Adam G. David S. Hanisko and G. Walter Ingram, Jr.. 2017. Red Snapper Abundance Indices from Bottom Longline Surveys in the Northern Gulf of Mexico. SEDAR52-WP-16. SEDAR, North Charleston, SC. 38 pp.

Red Snapper Abundance Indices from Bottom Longline Surveys in the Northern Gulf of Mexico

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Abstract: *Bottom longline data from three sampling programs were analyzed to calculate relative abundance indices for Red Snapper (Lutjanus campechanus) in the western and eastern Gulf of Mexico (GOM). The data sources included a long term (21 year) time series from the Southeast Fisheries Science Center Mississippi Laboratories (MSLABS), a single year of sampling from the Congressional Supplemental Sampling Program (CSSP) and a seven year time series from the Dauphin Island Sea Lab (DISL). While the survey gear was similar between the sampling programs the survey design and spatial coverage was slightly different (allocation of stations) between the MSLABS survey and CSSP survey, while vastly different spatially when compared to the DISL survey. Relative abundance indices are presented for the western GOM from the MSLABS and CSSP data, while three indices are presented for the eastern GOM: MSLABS and CSSP data, MSLABS, CSSP and DISL data and DISL data.*

Introduction

The Southeast Fisheries Science Center (SEFSC) Mississippi Laboratories (MSLABS) has conducted standardized bottom longline (NMFS 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 was not 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.

In addition to the NMFS BLL and CSSP surveys, the Dauphin Island Sea Lab (DISL) has conducted fishery-independent shark bottom longline surveys in the north-central GOM off Alabama. The gear used during the survey is similar to that used by the NMFS BLL and CSSP surveys, but utilizes a different sampling design. Details concerning the DISL surveys can be obtained from Dr. Sean Powers[1], DISL.

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Red Snapper (*Lutjanus campechanus*) captured during fishery-independent bottom longline surveys were first used the reflect relative trends in stock size for the western and eastern GOM during the Southeast Data Assessment and Review (SEDAR7) Update Assessment process in 2009 (SEDAR Red Snapper Update, 2009), and have since been incorporated into the SEDAR31 (2013) and SEDAR31 Update (2014) assessments. The formulation of the western (WGOM) and eastern (EGOM) indices has evolved over time. The SEDAR7 (2004) and SEDAR7 Update indices (2009) incorporated data only from the NMFS BLL survey. Initial WGOM and EGOM indices submitted for the SEDAR31 Data Workshop incorporate data from the NMFS BLL and CSSP surveys, but the EGOM index was updated to include DISL survey data for the Assessment Workshop. Detailed information concerning iterations of the indices is documented in Henwood *et al*. (2005), Ingram and Pollack (2012) and Ingram (2013).

Currently, the time series of data from the NMFS BLL survey available for analysis extends from 19995 to 2016, and the DISL survey from 2010 to 2016. This document outlines the development of Red Snapper indices for the western and eastern GOM continental shelf based on the same methodology used for the SEDAR31 Update assessment, the development of alternate indices to address inconsistent spatial coverage during the NMFS BLL surveys from 1995 to 2000 and alternate indices to address the overweighting of sampling effort in the eastern GOM introduced by the inclusion of the DISL survey.

Methodology

Survey Design

Details concerning methodologies and evolution of the NMFS BLL have been covered in previous documents (most recently LCS05/06-DW-27) and will not be repeated in this document. For reviews of the CSSP survey design see Campbell *et al*. 2012 and for the DISL survey contact Dr. Sean Powers. When the survey began in 1995, J-hooks were the standard gear. Over time a change was made to 15/0 circle hooks. Henwood *et al*. (2005) examined the difference in catch rates between the two hooks types and found significant difference in catch rates for Red Snapper.

Data

Data for the annual NMFS BLL survey was obtained from the SEFSC MSLABS Shark Unit and the CSSP data was obtained from an ORACLE database maintained at SEFSC MSLABS. Data from the CSSP was used to fill in gaps in the annual NMFS BLL survey due to vessel breakdowns and weather delays in 2011. The combined data from the NMFS BLL and CSSP surveys will be referred to as NMFS BLL from this point forward. Data for the DISL survey was obtained from Dr. Sean Powers and Dr. Marcus Drymon.

Data Exclusions

We examined the time series of data between 1995 and 2016 to develop Red Snapper abundance indices (Table 1). Because of the spatial distribution of sampling (mostly less than 55m) and the

use of J hooks instead of circle hooks, the years 1995 – 2000 were excluded from the analysis, mirroring the recommendations of Henwood *et al*. (2005). Additionally, for the western GOM index, the years 2005 and 2008 were excluded because of extremely low and spatially limited sampling (see Appendix Figure 1). For the eastern GOM, the year 2002 was excluded for reasons similar to those listed above for the western GOM and 2008 was excluded from the model because of the lack of positive captures. The standard NMFS BLL survey is typically conducted in July, August and September, with very few stations completed sporadically outside this time frame; therefore only stations conducted in July, August and September were included in the analysis.

Depth was used to limit the data, with no stations deeper than 183 m being included, since there were no records of Red Snapper being caught any deeper. Since there was poor survey coverage from the standard NMFS BLL survey in 2011, data from the CSSP survey was used. This survey consisted of monthly sampling that covered the entire GOM. As to not over represent any one area of the GOM, only data from August CSSP survey was used for the Eastern GOM, while data from September CSSP survey was used for the Western and Central GOM. These time frames historically match up with when the annual NMFS BLL survey sampled those areas.

When the DISL data was combined with the NMFS BLL data, all stations done outside of July, August and September were removed in order to maintain the same time frame of sampling. For the DISL index, all stations sampled outside of March, April, May, June, August and September were excluded from analysis (note that no stations were sampled in July) because of lack of consistency through the years (only done early on in survey).

Index Construction

Delta-lognormal modeling methods were used to estimate relative abundance indices for Red Snapper (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) $$p = \frac{e^{\mathbf{X\beta+\varepsilon}}}{1+e^{\mathbf{X\beta+\varepsilon}}},$$

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 that could be included in the submodels were:

Submodel Variables (Western Gulf of Mexico – NMFS BLL)

Year: 2001 – 2004, 2006 – 2007, 2009 – 2016
Area: Texas (west of 94°W), Louisiana (89.15° W to 94°W)
Depth Zone: Shallow (9 – 55m), Mid (55 – 183 m)

Submodel Variables (Eastern Gulf of Mexico – NMFS BLL)

Year: 2001, 2003 – 2007, 2009 – 2016
Area: Mississippi/Alabama (87°W to 89.15°W), North Florida (north of 28°N and west of 87°W), South Florida (south of 28°N)
Depth Zone: Shallow (9 – 55m), Mid (55 – 183 m)

Submodel Variables (Eastern Gulf of Mexico – NMFS BLL/DISL)

Year: 2001, 2003 – 2007, 2009 – 2016
Area: Mississippi/Alabama (87°W to 89.15°W), North Florida (north of 28°N and west of 87°W), South Florida (south of 28°N)
Depth Zone: Shallow (9 – 55m), Mid (55 – 183 m)
Source: NMFS, DISL

Submodel Variables (Eastern Gulf of Mexico - DISL)

Year: 2010 – 2016
Depth Zone: Shallow (< 36.6 m), Mid (36.6 – 54.9 m) , Deep (> 54.9 m)
Season: Spring (March, April, May, June), Summer (August, September)

Results and Discussion

Size, Age and Distribution

The distribution of Red Snapper is presented in Figure 1, with annual abundance and distribution presented in Appendix Figures 1 and 2. Annual catch and length summaries for the eastern GOM, western GOM and DISL data are presented in Tables 2a, 2b and 3, respectively. Length and age distribution for all the iterations of the data are presented in Figures 2 and 3.

Continuity Runs

As part of the SEDAR process, we were asked to provide updated indices with the new terminal year to be used in sensitivity runs of the assessment model. The continuity runs that follow the methods outlined in Ingram and Pollack (2012) are presented in Tables 4 and 5 and in Figure 4.

Abundance Index – Western Gulf of Mexico – NMFS BLL

For the NMFS BLL abundance index of Red Snapper, year and depth were retained in both the binomial and lognormal submodels. A summary of the factors used in the analysis is presented in Appendix Table 1. 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 5,084.8 and 712.0, respectively. The diagnostic plots for the binomial and lognormal submodels are shown in Figure 5, and indicated the distribution of the residuals was approximately normal. Annual abundance indices are presented in Table 7 and Figure 6.

Abundance Index – Eastern Gulf of Mexico – NMFS BLL

For the NMFS BLL abundance index of Red Snapper, year, area 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 2. 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 7,706.6 and 206.5, respectively. There was an increase in the AIC when area was removed from the lognormal submodel (205.0 to 206.5), however since area was not significant the final model run was deemed acceptable. The diagnostic plots for the binomial and lognormal submodels are shown in Figure 7, and indicated the distribution of the residuals was approximately normal. Annual abundance indices are presented in Table 9 and Figure 8.

Abundance Index – Eastern Gulf of Mexico – NMFS BLL/DISL

For the NMFS/DISL BLL abundance index of Red Snapper, year, area and source were retained in the binomial submodel, while only year and source were retained in the lognormal submodel. A summary of the factors used in the analysis is presented in Appendix Table 3. 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 8,198.8 and 447.0, respectively. There was an increase in the AIC when area was removed from the lognormal submodel (445.5 to 447.0), however since area was not significant the final model run was deemed acceptable. The diagnostic plots for the binomial and lognormal submodels are shown in Figure 9, and indicated the distribution of the residuals was approximately normal. Annual abundance indices are presented in Table 11 and Figure 10.

Abundance Index – Eastern Gulf of Mexico - DISL

For the DISL BLL abundance index of Red Snapper, year was retained in the binomial submodel, while year and depth zone were retained in the lognormal submodel. A summary of the factors used in the analysis is presented in Appendix Table 4. Table 12 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 1,155.0 and 440.7, respectively. There was an increase in the AIC when area was removed from the lognormal submodel (439.6 to 440.7), however since season was not significant the final model run was deemed acceptable. The diagnostic plots for the binomial and lognormal submodels are shown in Figure 11, and indicated the distribution of the residuals was approximately normal. Annual abundance indices are presented in Table 13 and Figure 12.

Concerns over the Incorporation of the DISL Data

During the SEDAR31 Data Workshop, it was recommended that the DISL survey data be incorporated into the NMFS BLL time series. While this did not seem to be problematic at the time, the inclusion of the DISL data appears to be driving the overall index in the later years and may not be fully representative of the dynamics of the Red Snapper population across the entire eastern GOM. Of particular concern are the seemingly diverging trends in the individual indices which are showing a marked increase in the NMFS BLL index, particularly over the last few years and a slight decreasing trend in the DISL index. In addition, the frequency of occurrence between the surveys differs significantly (12% compared to 59% between 2010 and 2016 for the NMFS BLL and DISL, respectively). Finally, the length composition (Figure 2) of the two surveys also appears to differ (mean total length 696 mm compared to 757 mm, NMFS BLL and DISL, respectively), which may be due to the areas sampled by each survey (eastern GOM vs. area off AL and MS).

Based on these concerns, it is our recommendation that the NMFS BLL index (without the DISL data) be used in this assessment. This is not to say that the DISL BLL index should be not be considered for use in the assessment, but should be looked at independently from the NMFS BLL index.

Further research on combining the time series from NMFS and DISL is needed. A research recommendation would be to examine a method to weight the respective indices before combining them in order to account for the differences in spatial coverage of the surveys. This was attempted for this working paper; however we were unable to get the models to converge.

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

	Eastern Gulf of Mexico				Western Gulf of Mexico		
Year	NMFS	CSSP	DISL	Total	NMFS	CSSP	Total
1995	49			49	25		25
1996	47			47	32		32
1997	67			67	97		97
1999	81			81	80		80
2000	87			87	50		50
2001	124			124	125		125
2002	49			49	150		150
2003	155			155	100		100
2004	133			133	78		78
2005	47			47			
2006	57			57	71		71
2007	63			63	70		70
2008	67			67	21		21
2009	88			88	77		77
2010	83		13	96	48		48
2011	82	80	9	171	28	53	81
2012	68		12	80	53		53
2013	80		10	90	65		65
2014	56		31	87	46		46
2015	81		27	108	58		58
2016	58		27	85	50		50
Total	*1622*	*80*	*129*	*1831*	*1324*	*53*	*1377*

Table 2a. Summary of the Red Snapper length data collected from NMFS Bottom Longline surveys conducted between 1995 and 2016 in the eastern Gulf of Mexico.

Survey Year	Number of Stations	Number Collected	Number Measured	Minimum Total Length (mm)	Maximum Total Length (mm)	Mean Total Length (mm)	Standard Deviation
1995	49	0					
1996	47	1	1	712	712	712	.
1997	67	1	1	880	880	880	.
1998							
1999	81	3	3	785	990	885	103
2000	87	1	1	640	640	640	.
2001	124	4	3	625	950	747	177
2002							
2003	155	9	9	511	826	612	106
2004	133	7	7	534	739	601	69
2005	47	2	2	680	692	686	8
2006	57	2	2	795	862	829	47
2007	63	7	6	575	713	669	54
2008	67	0					
2009	88	10	8	516	720	641	78
2010	83	19	19	495	872	648	109
2011	162	56	54	442	941	612	107
2012	68	18	15	525	905	753	111
2013	80	22	20	535	861	710	83
2014	56	14	12	579	906	788	82
2015	81	28	24	606	949	771	89
2016	58	54	53	449	900	739	87

Total Number of Years	Total Number of Stations	Total Number Collected	Total Number Measured			Overall Mean Total Length (mm)	
20	1653	258	240			696	

Table 2b. Summary of the Red Snapper length data collected from NMFS Bottom Longline surveys conducted between 1995 and 2016 in the western Gulf of Mexico.

Survey Year	Number of Stations	Number Collected	Number Measured	Minimum Total Length (mm)	Maximum Total Length (mm)	Mean Total Length (mm)	Standard Deviation
1995	25	6	6	700	917	854	80
1996	32	1	1	860	860	860	.
1997	97	11	11	730	950	851	65
1998							
1999	80	2	2	865	865	865	0
2000	50	12	12	770	921	833	49
2001	125	87	84	427	927	767	91
2002	150	76	74	409	950	799	101
2003	100	62	60	385	940	739	123
2004	78	50	50	480	940	710	122
2005							
2006	71	35	32	534	909	800	86
2007	70	41	40	380	970	759	106
2008							
2009	77	75	70	445	940	725	118
2010	48	36	35	520	880	701	92
2011	81	131	127	400	910	686	117
2012	53	136	126	524	904	751	73
2013	65	147	140	587	920	750	64
2014	46	61	58	565	882	754	66
2015	58	243	229	464	935	746	82
2016	50	152	140	331	882	738	67

Total Number of Years	Total Number of Stations	Total Number Collected	Total Number Measured			Overall Mean Total Length (mm)	
19	1356	1364	1297			745	

Table 3. Summary of the Red Snapper length data collected from DISL Bottom Longline surveys conducted between 2010 and 2016.

Survey Year	Number of Stations	Number Collected	Number Measured	Minimum Total Length (mm)	Maximum Total Length (mm)	Mean Total Length (mm)	Standard Deviation
2010	15	13	13	437	932	739	121
2011	25	59	57	382	970	691	112
2012	30	179	169	376	928	725	115
2013	27	70	62	455	956	751	104
2014	59	309	284	415	977	765	80
2015	54	156	144	395	933	781	75
2016	54	209	195	416	956	778	85

Total Number of Years	Total Number of Stations	Total Number Collected	Total Number Measured	Overall Mean Total Length (mm)
7	264	995	924	757

Table 4. Continuity index of Red Snapper abundance developed using the delta-lognormal model for 1996-2016 for the western Gulf of Mexico. 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
1996	0.03125	32	0.02846	0.02457	1.21296	0.00367	0.16464
1997	0.08247	97	0.36638	0.31627	0.42222	0.14069	0.71098
1998		0					
1999	0.02500	80	0.08767	0.07568	0.86065	0.01707	0.33548
2000	0.26168	107	0.66821	0.57682	0.24199	0.35795	0.92950
2001	0.20000	125	0.55180	0.47633	0.25698	0.28725	0.78987
2002	0.23333	150	0.50258	0.43384	0.21531	0.28342	0.66410
2003	0.20000	100	0.55993	0.48335	0.28274	0.27757	0.84166
2004	0.21053	95	0.64257	0.55469	0.28126	0.31943	0.96319
2005		0					
2006	0.18310	71	0.52198	0.45059	0.34989	0.22835	0.88912
2007	0.18571	70	0.52118	0.44989	0.34982	0.22802	0.88764
2008	0.28571	21	0.52550	0.45362	0.49831	0.17686	1.16348
2009	0.29870	77	1.03285	0.89158	0.25600	0.53866	1.47570
2010	0.16667	48	0.40387	0.34863	0.45438	0.14658	0.82921
2011	0.31250	208	1.50025	1.29505	0.15028	0.96046	1.74620
2012	0.35849	53	2.64373	2.28213	0.26752	1.34889	3.86105
2013	0.35385	65	2.36069	2.03780	0.24010	1.26919	3.27187
2014	0.32609	46	1.58315	1.36661	0.31033	0.74519	2.50623
2015	0.46552	58	4.22627	3.64821	0.20834	2.41564	5.50968
2016	0.48000	50	3.28346	2.83436	0.22293	1.82457	4.40302

Table 5. Continuity index of Red Snapper abundance developed using the delta-lognormal model for 1996-2016 for the eastern Gulf of Mexico. 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
1996	0.02128	47	0.02201	0.05899	1.22143	0.00873	0.39879
1997	0.01493	67	0.01378	0.03692	1.22405	0.00545	0.25030
1998		0					
1999	0.03546	141	0.08628	0.23125	0.57021	0.08002	0.66824
2000	0.00885	113	0.00843	0.02259	1.22656	0.00332	0.15351
2001	0.02419	124	0.03762	0.10082	0.73195	0.02720	0.37366
2002	0.04082	49	0.04592	0.12308	0.88237	0.02698	0.56142
2003	0.03226	155	0.06347	0.17012	0.57077	0.05882	0.49205
2004	0.03008	133	0.06570	0.17609	0.63629	0.05487	0.56515
2005	0.02128	47	0.04327	0.11598	1.22143	0.01716	0.78407
2006	0.03509	57	0.04207	0.11276	0.88401	0.02467	0.51544
2007	0.03175	63	0.08793	0.23565	0.88496	0.05149	1.07858
2008	0	67					
2009	0.07955	88	0.13664	0.36622	0.47748	0.14795	0.90650
2010	0.16667	96	0.36840	0.98737	0.30993	0.53879	1.80941
2011	0.12952	332	0.34749	0.93132	0.19395	0.63414	1.36776
2012	0.20000	80	0.96800	2.59436	0.30652	1.42476	4.72409
2013	0.14444	90	0.67772	1.81637	0.34556	0.92785	3.55576
2014	0.32184	87	1.50916	4.04474	0.22373	2.59976	6.29287
2015	0.25926	108	0.87685	2.35008	0.22871	1.49606	3.69160
2016	0.32941	85	1.68846	4.52529	0.22312	2.91206	7.03223

Table 6. Summary of backward selection procedure for building delta-lognormal submodels for Red Snapper index of relative abundance for the western Gulf of Mexico from 2001 to 2016.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 5100.3)*						*Lognormal Submodel Type 3 Tests (AIC 712.7)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	13	1056	56.84	4.37	<.0001	<.0001	13	269	4.70	<.0001
Area	1	1056	1.90	1.90	0.1676	0.1679	1	269	2.08	0.1503
Depth Zone	1	1056	117.04	117.04	<.0001	<.0001	1	269	9.13	0.0028
Model Run #2	*Binomial Submodel Type 3 Tests (AIC 5084.8)*						*Lognormal Submodel Type 3 Tests (AIC 712.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	13	1057	57.16	4.40	<.0001	<.0001	13	270	4.65	<.0001
Area				Dropped				Dropped		
Depth Zone	1	1057	117.04	117.04	<.0001	<.0001	1	270	9.20	0.0027

Table 7. Indices of Red Snapper abundance developed using the delta-lognormal model for 2001-2016 for the western Gulf of Mexico. 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
2001	0.20000	125	0.56417	0.38808	0.25809	0.23354	0.64490
2002	0.23333	150	0.51326	0.35306	0.21606	0.23031	0.54123
2003	0.20000	100	0.57119	0.39291	0.28347	0.22533	0.68513
2004	0.19231	78	0.62785	0.43189	0.32558	0.22891	0.81485
2005							
2006	0.18310	71	0.53212	0.36604	0.35068	0.18523	0.72332
2007	0.18571	70	0.52946	0.36421	0.35079	0.18427	0.71986
2008							
2009	0.29870	77	1.04702	0.72022	0.25650	0.43472	1.19323
2010	0.16667	48	0.41639	0.28643	0.45607	0.12007	0.68327
2011	0.30864	81	1.41447	0.97298	0.24193	0.60388	1.56770
2012	0.35849	53	2.65667	1.82747	0.26859	1.07797	3.09811
2013	0.35385	65	2.36465	1.62660	0.24149	1.01038	2.61862
2014	0.32609	46	1.59979	1.10046	0.31091	0.59941	2.02034
2015	0.46552	58	4.22464	2.90604	0.21035	1.91677	4.40588
2016	0.48000	50	3.29070	2.26360	0.22481	1.45189	3.52912

Table 8. Summary of backward selection procedure for building delta-lognormal submodels for Red Snapper index of relative abundance for the eastern Gulf of Mexico from 2001 to 2016.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 7706.6)*						*Lognormal Submodel Type 3 Tests (AIC 206.9)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	13	1236	36.32	2.79	0.0005	0.0006	13	80	1.53	0.1250
Area	2	1236	54.29	27.15	<.0001	<.0001	2	80	2.27	0.1097
Depth Zone	1	1236	5.69	5.69	0.0171	0.0172	1	80	0.08	0.7802
Model Run #2	*Binomial Submodel Type 3 Tests (AIC 7706.6)*						*Lognormal Submodel Type 3 Tests (AIC 205.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	13	1236	36.32	2.79	0.0005	0.0006	13	81	1.54	0.1207
Area	2	1236	54.29	27.15	<.0001	<.0001	2	81	2.30	0.1073
Depth Zone	1	1236	5.69	5.69	0.0171	0.0172		Dropped		
Model Run #3	*Binomial Submodel Type 3 Tests (AIC 7706.6)*						*Lognormal Submodel Type 3 Tests (AIC 206.5)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	13	1236	36.32	2.79	0.0005	0.0006	13	83	1.58	0.1079
Area	2	1236	54.29	27.15	<.0001	<.0001		Dropped		
Depth Zone	1	1236	5.69	5.69	0.0171	0.0172		Dropped		

Table 9. Indices of Red Snapper abundance developed using the delta-lognormal model for 2001-2016 for the eastern Gulf of Mexico. 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
2001	0.02419	124	0.03448	0.14969	0.73285	0.04034	0.55549
2002							
2003	0.03247	154	0.06913	0.30011	0.56854	0.10414	0.86490
2004	0.03008	133	0.06929	0.30080	0.63560	0.09382	0.96436
2005	0.02128	47	0.09350	0.40589	1.20998	0.06075	2.71178
2006	0.03509	57	0.04720	0.20491	0.89103	0.04442	0.94529
2007	0.03175	63	0.09540	0.41415	0.88781	0.09015	1.90259
2008	0	67					
2009	0.07955	88	0.14303	0.62091	0.47885	0.25025	1.54059
2010	0.14458	83	0.29727	1.29050	0.35639	0.64626	2.57696
2011	0.14907	161	0.43138	1.87268	0.25512	1.13332	3.09437
2012	0.08824	68	0.19289	0.83735	0.51079	0.31967	2.19341
2013	0.06250	80	0.16196	0.70311	0.57962	0.23964	2.06296
2014	0.14286	56	0.31918	1.38561	0.43961	0.59777	3.21178
2015	0.11111	81	0.34461	1.49600	0.42377	0.66366	3.37228
2016	0.15517	58	0.92562	4.01828	0.40640	1.83844	8.78278

Table 10. Summary of backward selection procedure for building delta-lognormal submodels for Red Snapper index of relative abundance for the eastern Gulf of Mexico (with DISL) from 2001 to 2016.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 8207.1)*						*Lognormal Submodel Type 3 Tests (AIC 446.6)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	13	1364	24.33	1.87	0.0283	0.0293	13	164	1.48	0.1306
Area	2	1364	41.02	20.51	<.0001	<.0001	2	164	2.19	0.1151
Depth Zone	1	1364	2.88	2.88	0.0897	0.0899	1	164	0.78	0.3776
Source	1	1364	17.27	17.27	<.0001	<.0001	1	164	1.88	0.1719
Model Run #2	*Binomial Submodel Type 3 Tests (AIC 8198.8)*						*Lognormal Submodel Type 3 Tests (AIC 445.5)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	13	1365	23.73	1.83	0.0337	0.0348	13	165	1.43	0.1510
Area	2	1365	38.63	19.31	<.0001	<.0001	2	165	2.36	0.0980
Depth Zone				Dropped				Dropped		
Source	1	1365	15.99	15.99	<.0001	<.0001	1	165	2.79	0.0966
Model Run #3	*Binomial Submodel Type 3 Tests (AIC 8198.8)*						*Lognormal Submodel Type 3 Tests (AIC 447.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	13	1365	23.73	1.83	0.0337	0.0348	13	167	1.43	0.1523
Area	2	1365	38.63	19.31	<.0001	<.0001		Dropped		
Depth Zone				Dropped				Dropped		
Source	1	1365	15.99	15.99	<.0001	<.0001	1	167	15.57	0.0001

Table 11. Indices of Red Snapper abundance developed using the delta-lognormal model for 2001-2016 for the eastern Gulf of Mexico (with DISL). 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
2001	0.02419	124	0.10699	0.27844	0.68272	0.08081	0.95940
2002							
2003	0.03247	154	0.09299	0.24199	0.67082	0.07151	0.81895
2004	0.03008	133	0.17418	0.45330	0.59315	0.15118	1.35922
2005	0.02128	47	0.06366	0.16568	1.58299	0.01764	1.55637
2006	0.03509	57	0.13458	0.35024	0.78372	0.08776	1.39773
2007	0.03175	63	0.47627	1.23947	0.66895	0.36729	4.18272
2008	0	67					
2009	0.07955	88	0.36536	0.95083	0.41846	0.42579	2.12329
2010	0.16667	96	0.42640	1.10969	0.32585	0.58787	2.09469
2011	0.17059	170	0.55295	1.43901	0.25892	0.86459	2.39508
2012	0.20000	80	0.62212	1.61904	0.35010	0.82018	3.19598
2013	0.14444	90	0.42729	1.11200	0.49822	0.43362	2.85164
2014	0.32184	87	0.65258	1.69829	0.32474	0.90153	3.19921
2015	0.25926	108	0.40078	1.04300	0.32827	0.55007	1.97764
2016	0.32941	85	0.88341	2.29903	0.29777	1.28344	4.11826

Table 12. Summary of backward selection procedure for building delta-lognormal submodels for Red Snapper index of relative abundance for the eastern Gulf of Mexico (DISL only) from 2001 to 2016.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC 1166.8)*						*Lognormal Submodel Type 3 Tests (AIC 439.6)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	6	254	10.88	1.81	0.0922	0.0969	6	159	2.26	0.0402
Depth Zone	2	254	5.65	2.82	0.0594	0.0613	2	159	6.17	0.0026
Season	1	254	1.45	1.45	0.2279	0.2290	1	159	3.26	0.0729
Model Run #2	*Binomial Submodel Type 3 Tests (AIC 1164.4)*						*Lognormal Submodel Type 3 Tests (AIC 440.7)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	6	255	10.24	1.71	0.1151	0.1200	6	160	2.29	0.0377
Depth Zone	2	255	5.42	2.71	0.0664	0.0683	2	160	6.31	0.0023
Season				Dropped				Dropped		
Model Run #3	*Binomial Submodel Type 3 Tests (AIC 1155.0)*						*Lognormal Submodel Type 3 Tests (AIC 440.7)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	6	257	11.82	1.97	0.0661	0.0704	6	160	2.29	0.0377
Depth Zone				Dropped			2	160	6.31	0.0023
Season				Dropped				Dropped		

Table 13. Indices of Red Snapper abundance developed using the delta-lognormal model for 2010-2016 for the eastern Gulf of Mexico (DISL only). 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
2010	0.26667	15	1.02782	0.29404	0.60321	0.09650	0.89591
2011	0.52000	25	2.08615	0.59680	0.31000	0.32563	1.09382
2012	0.73333	30	6.51904	1.86497	0.21899	1.20971	2.87514
2013	0.59259	27	3.23441	0.92530	0.27209	0.54219	1.57910
2014	0.66102	59	4.69362	1.34275	0.17280	0.95281	1.89227
2015	0.66667	54	2.94917	0.84370	0.17899	0.59148	1.20347
2016	0.72222	54	3.95850	1.13245	0.16885	0.80981	1.58363

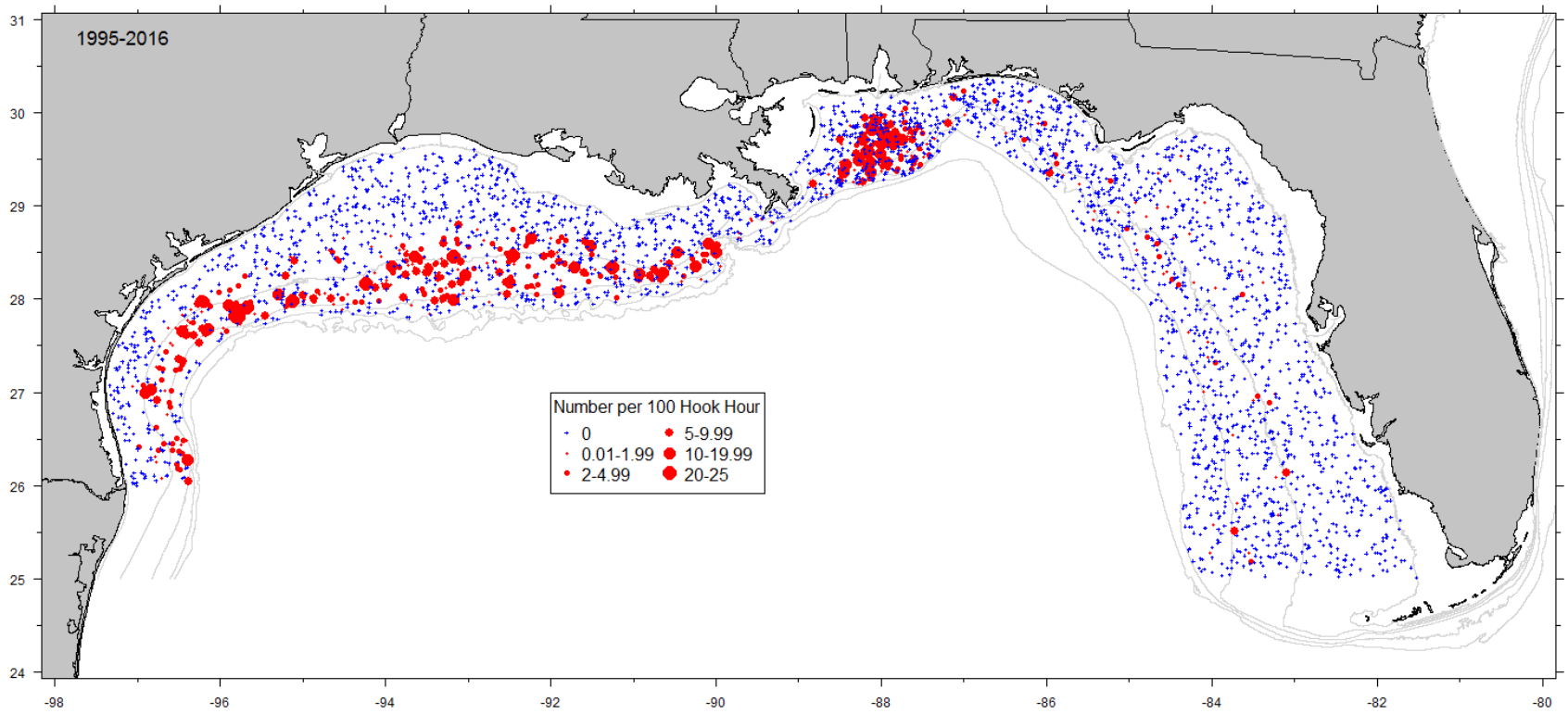


Figure 1. Stations sampled from 1995 to 2016 during the NMFS Bottom Longline Survey and DISL Bottom Longline Survey with the CPUE for Red Snapper.

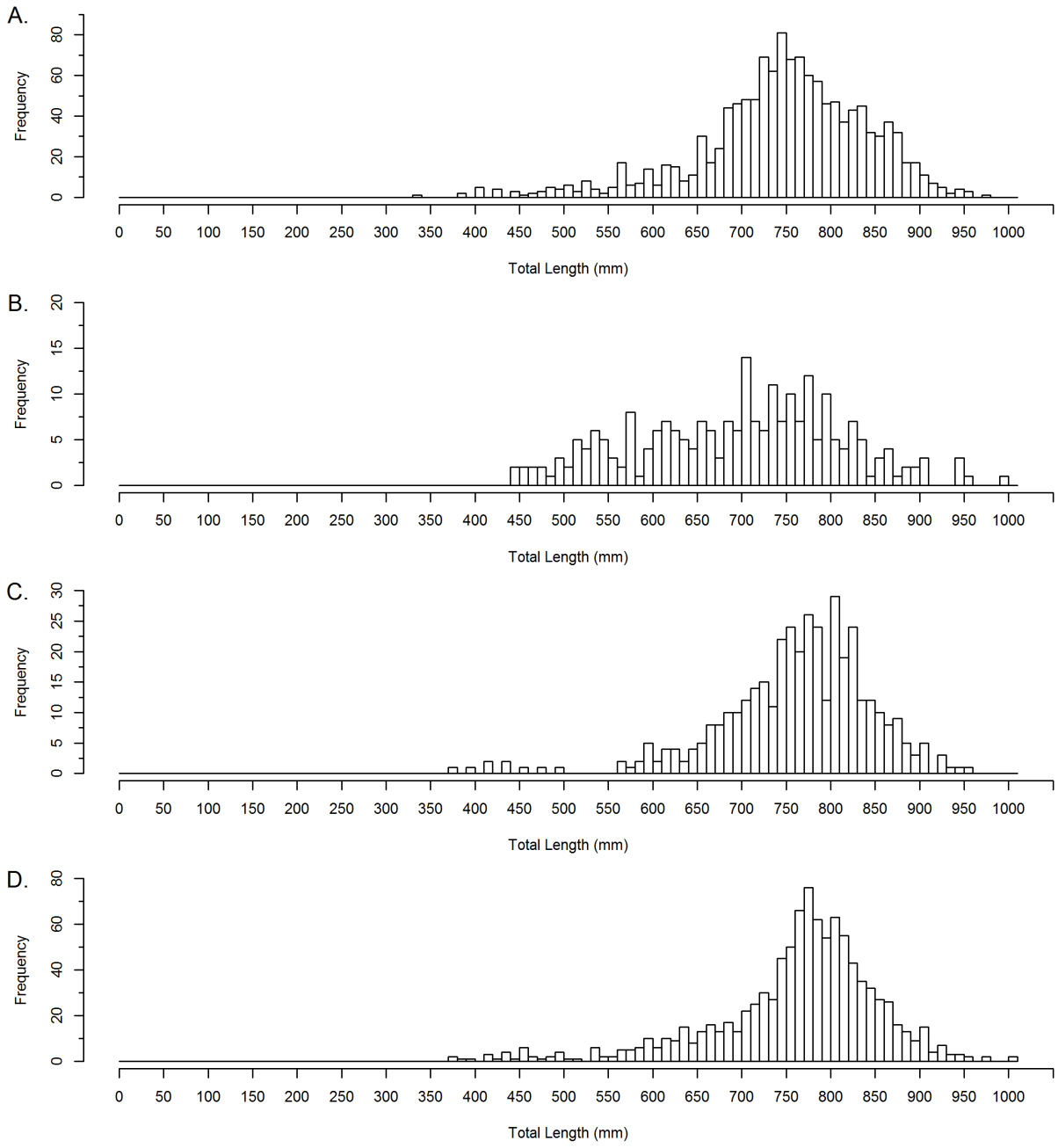


Figure 2. Length frequency histogram for Red Snapper captured in NMFS Bottom Longline / West Gulf (**A.**), NMFS Bottom Longline / East Gulf (**B.**), DISL Bottom Longline (limited) / East Gulf (**C.**) and DISL Bottom Longline (full) / East Gulf (**D.**).

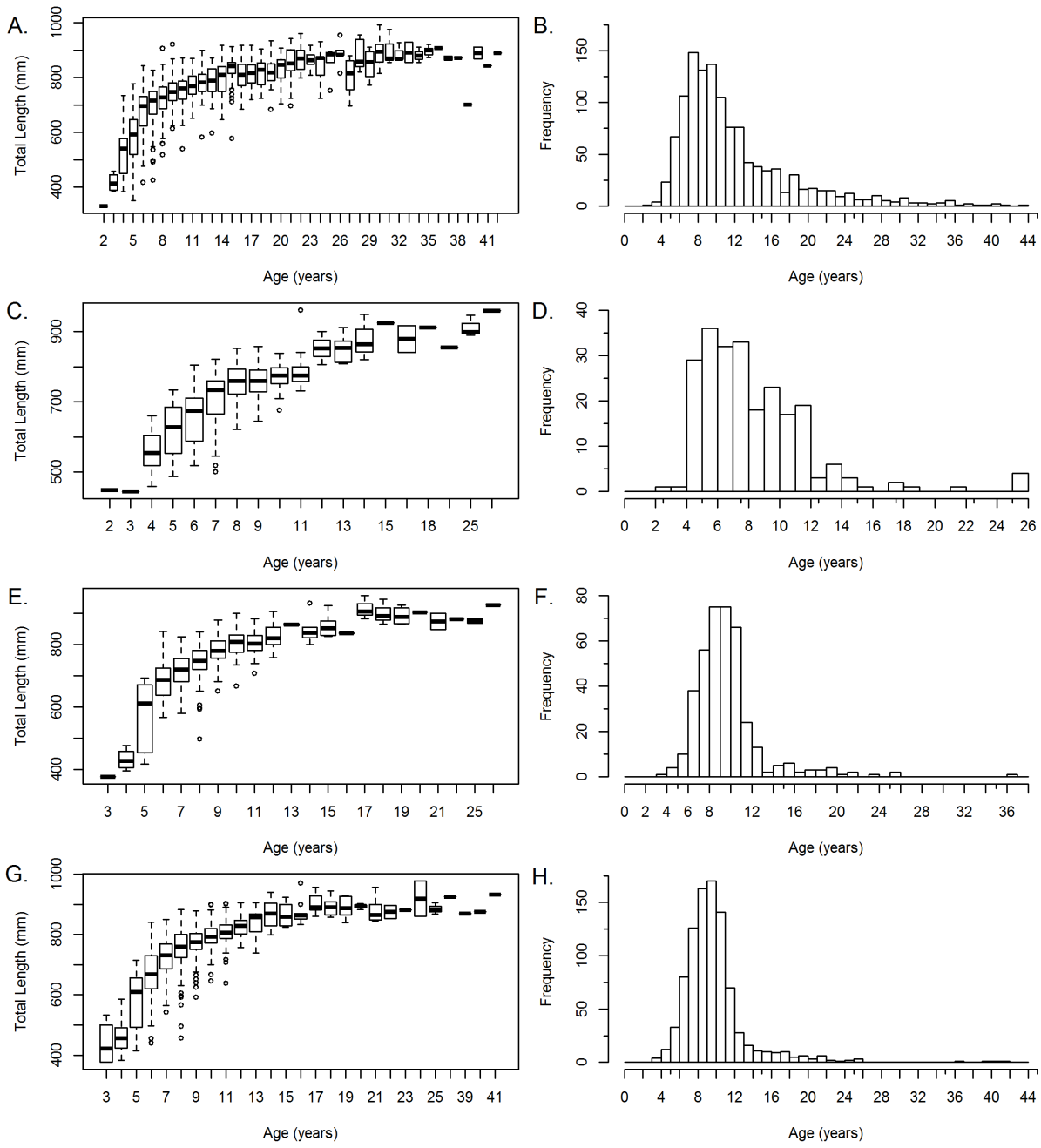


Figure 3. Breakdown of Red Snapper ages for fish caught in the: NMFS Bottom Longline / West Gulf (**A.** and **B.**), NMFS Bottom Longline / East Gulf (**C.** and **D.**), DISL Bottom Longline (limited) / East Gulf (**E.** and **F.**) and DISL Bottom Longline (full) / East Gulf (**G.** and **H.**).

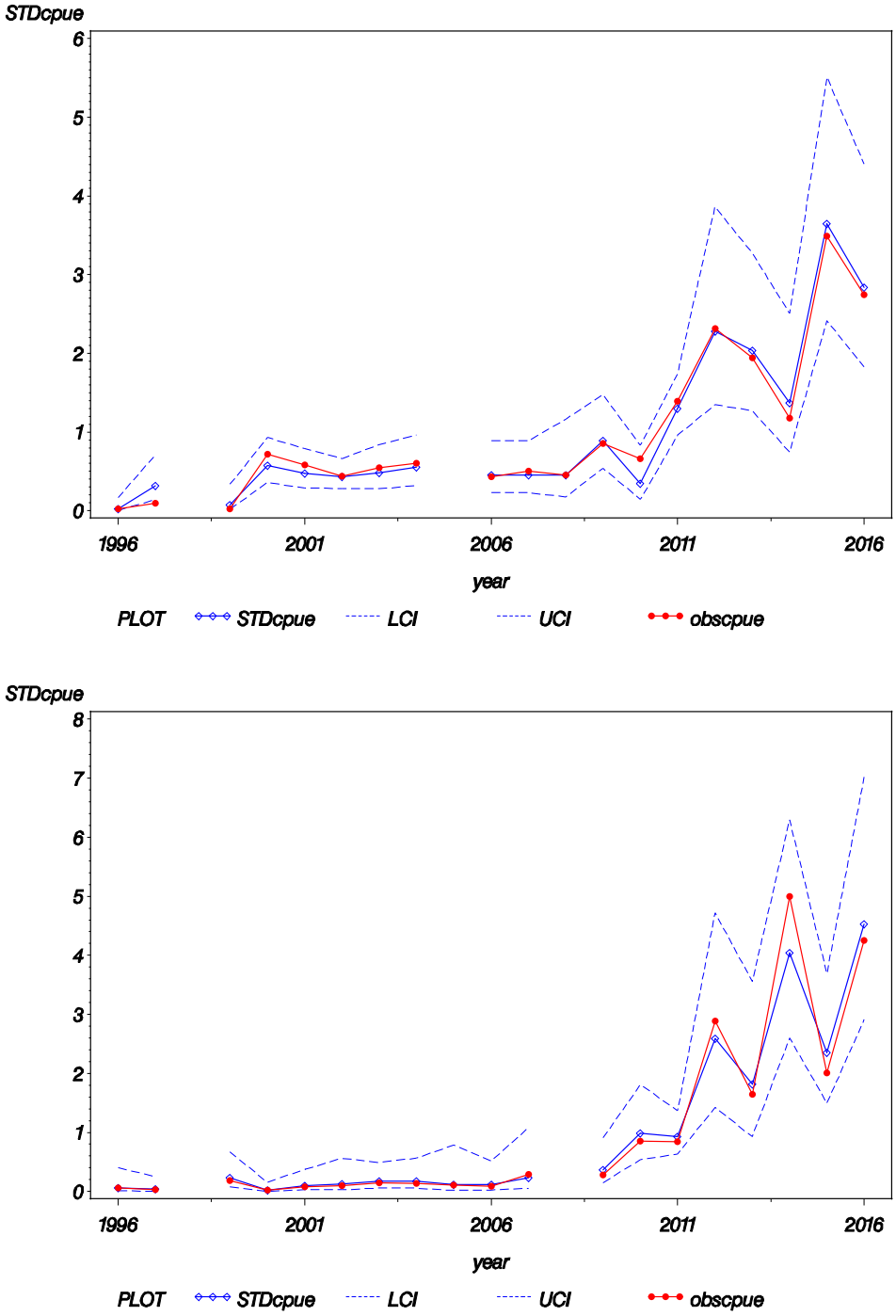


Figure 4. Continuity indices of abundance for the western (top) and eastern (bottom) Gulf of Mexico for Red Snapper from the NMFS Bottom Longline Surveys from 1996 – 2016.

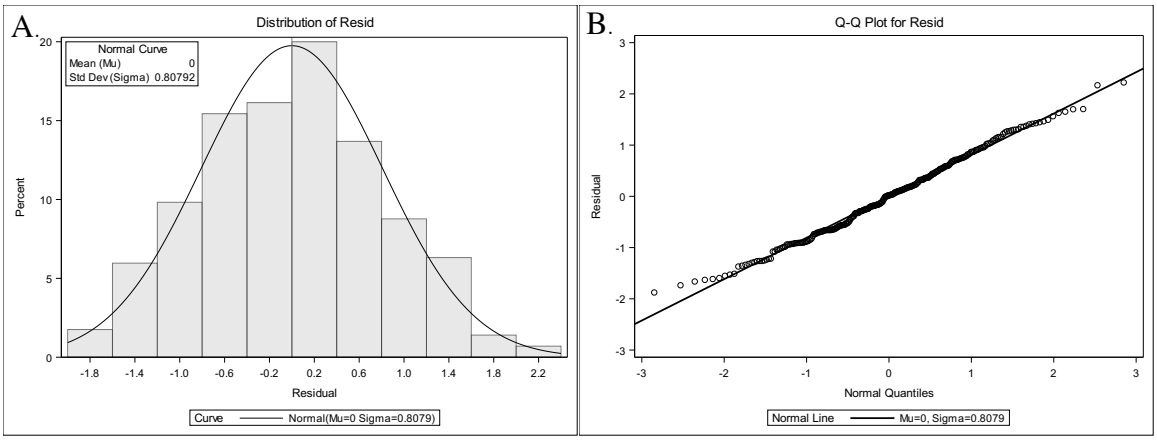


Figure 5. Diagnostic plots for lognormal component of the Red Snapper western Gulf of Mexico NMFS Bottom Longline Surveys model: **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

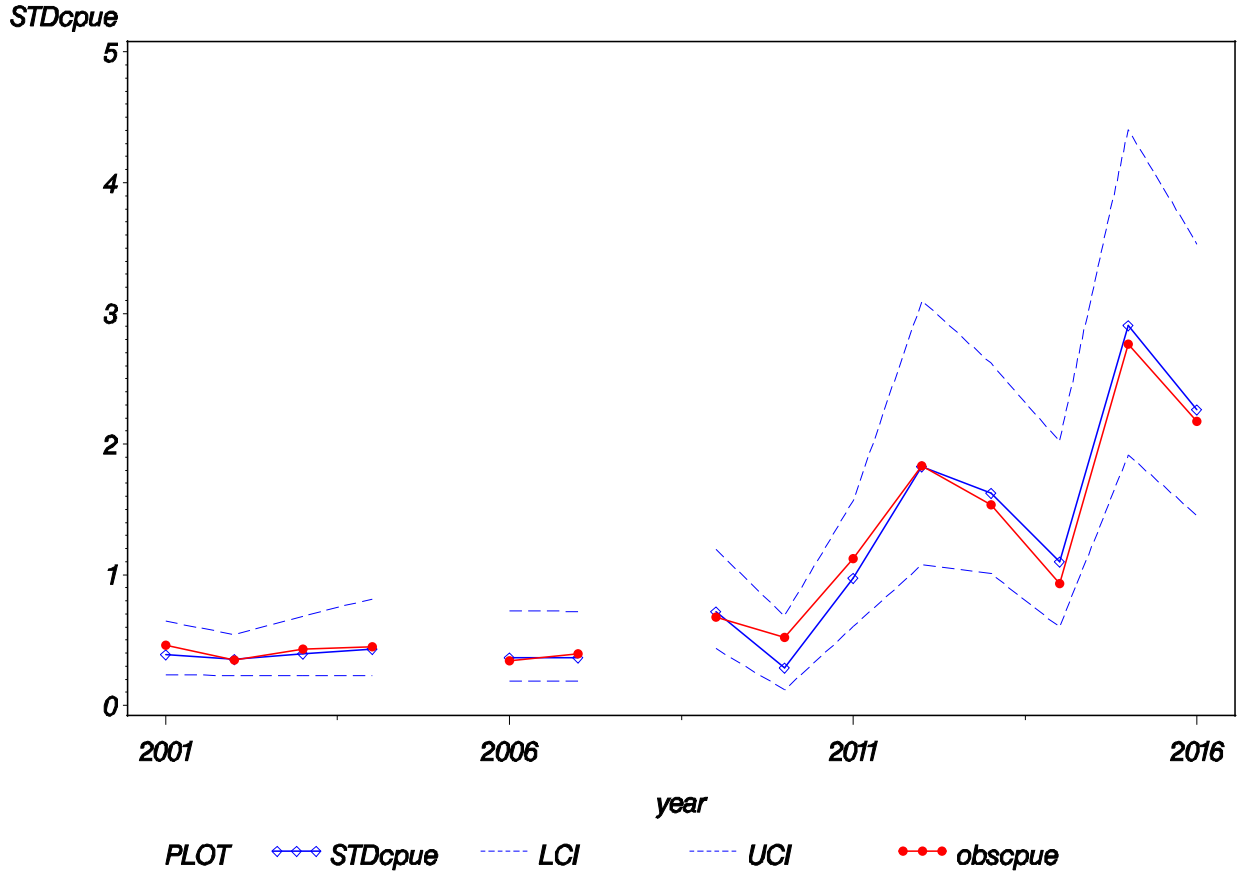


Figure 6. Annual index of abundance for the western Gulf of Mexico for Red Snapper from the NMFS Bottom Longline Surveys from 2001 – 2016.

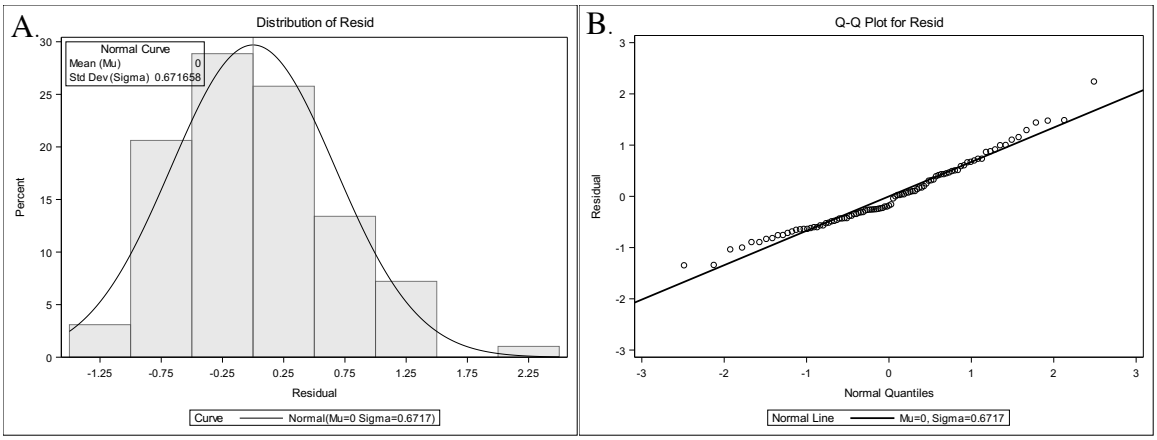


Figure 7. Diagnostic plots for lognormal component of the Red Snapper eastern Gulf of Mexico NMFS Bottom Longline Surveys model: **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

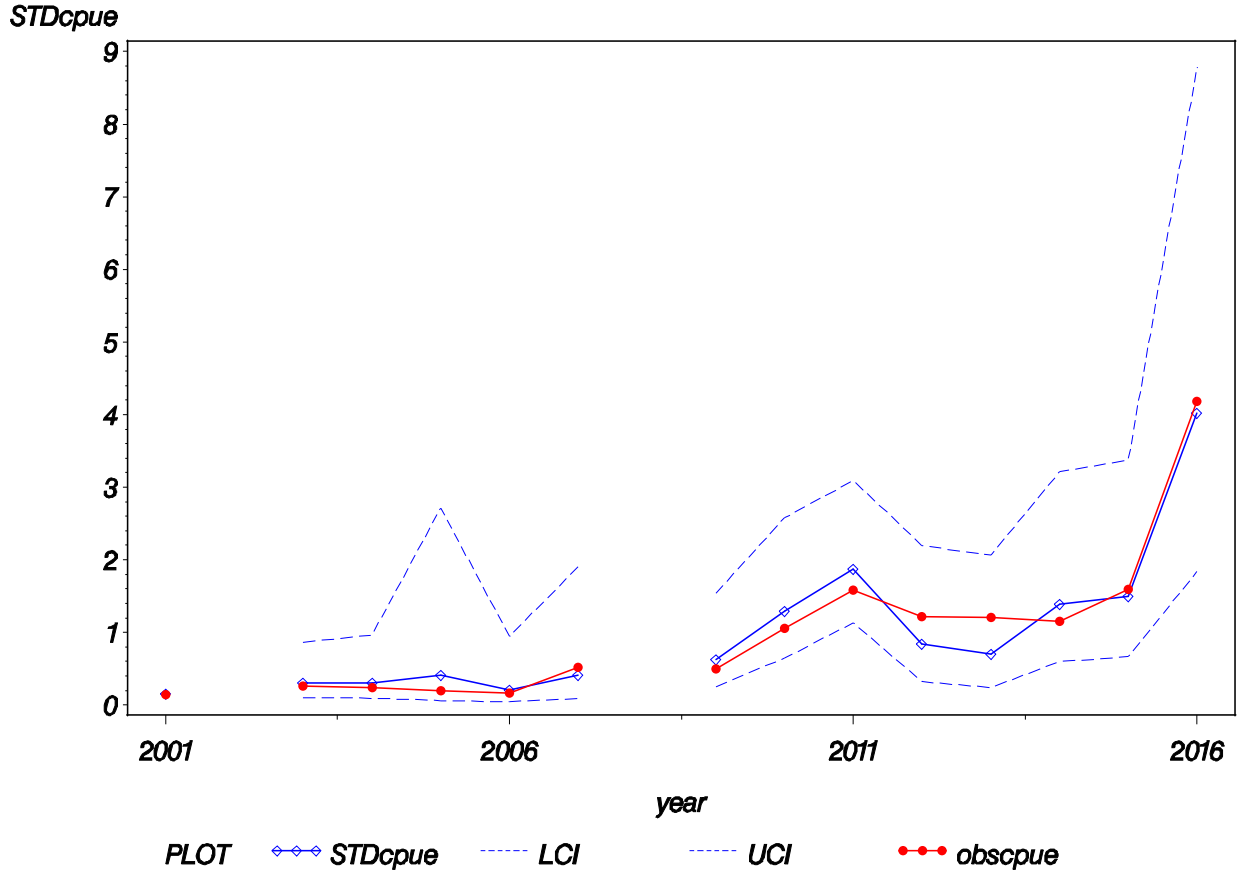


Figure 8. Annual index of abundance for the eastern Gulf of Mexico for Red Snapper from the NMFS Bottom Longline Surveys from 2001 – 2016.

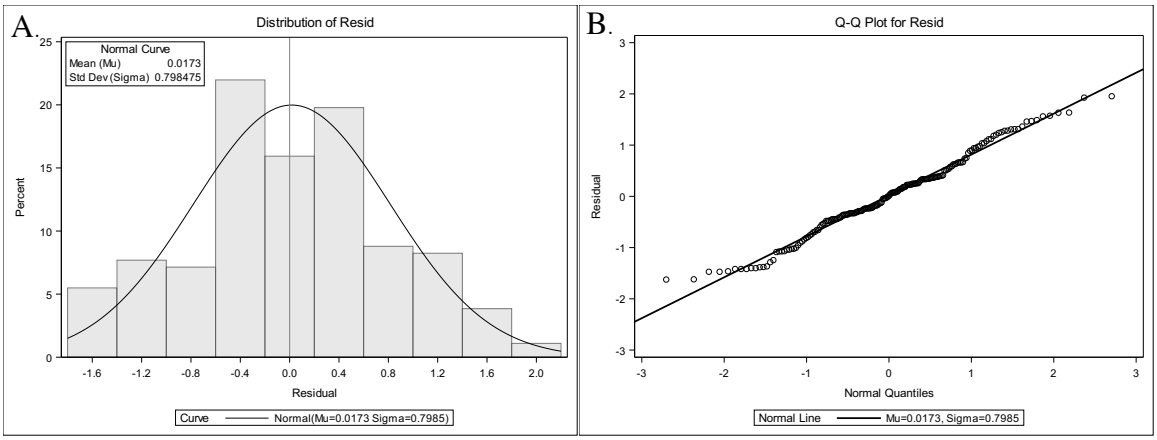


Figure 9. Diagnostic plots for lognormal component of the Red Snapper eastern Gulf of Mexico NMFS Bottom Longline Surveys (with DISL) model: **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

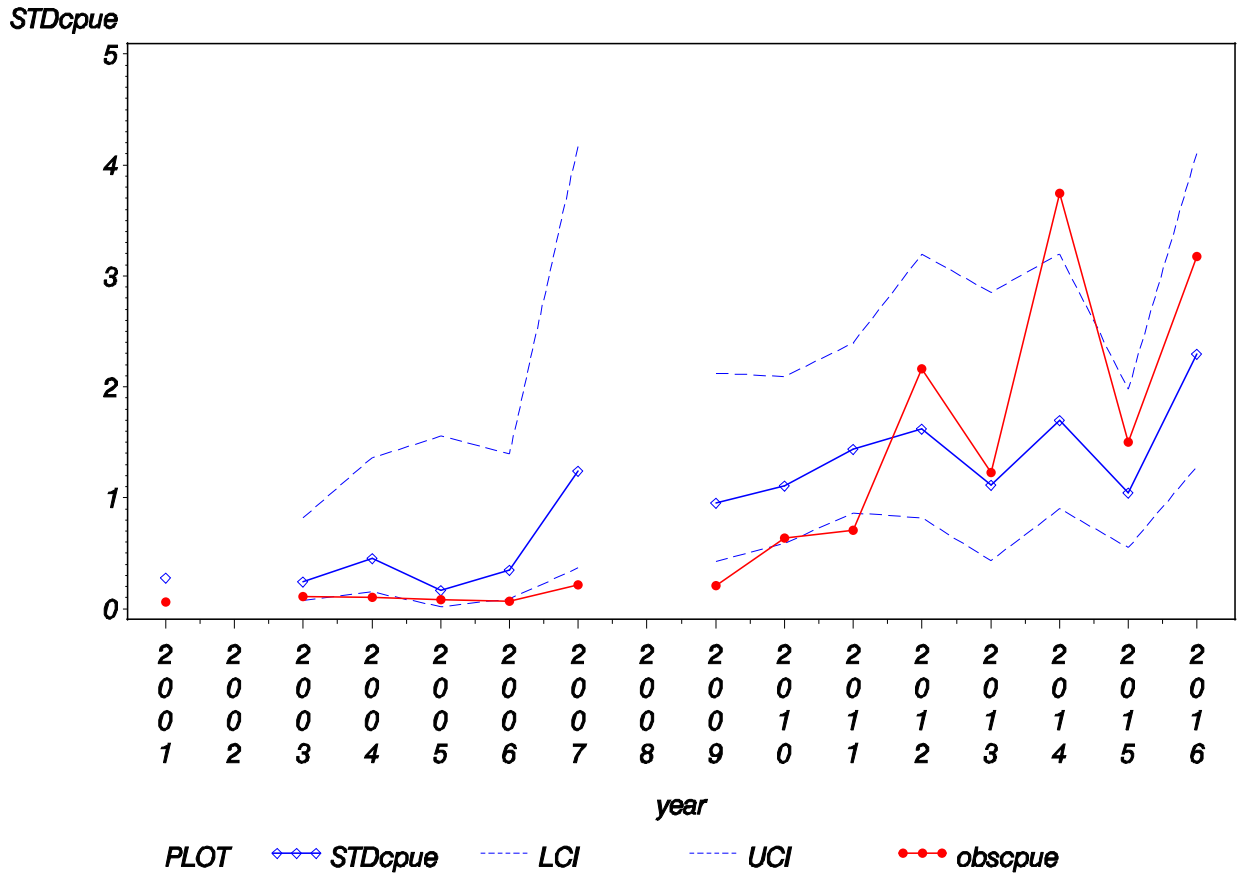


Figure 10. Annual index of abundance for the eastern Gulf of Mexico for Red Snapper from the NMFS Bottom Longline Surveys (with DISL) from 2001 – 2016.

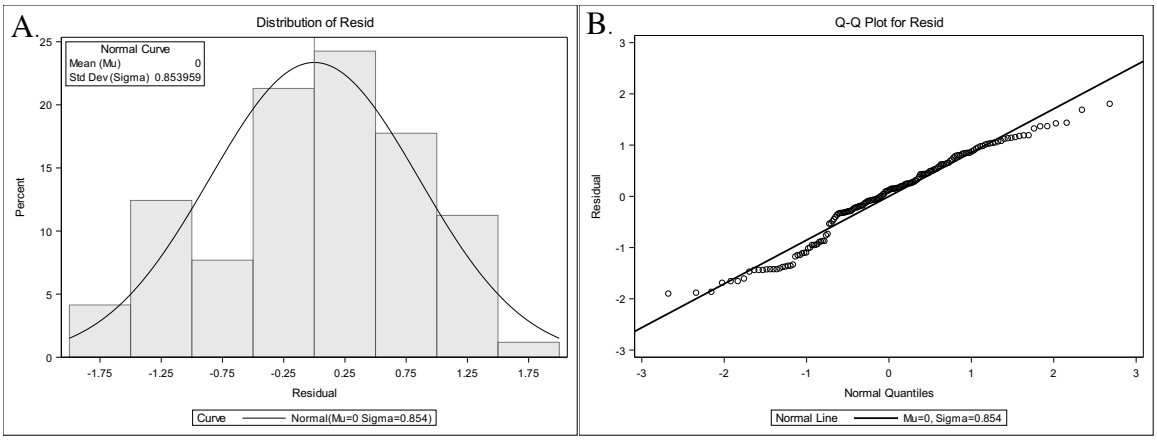


Figure 11. Diagnostic plots for lognormal component of the Red Snapper eastern Gulf of Mexico DISL Bottom Longline Surveys model: **A.** the frequency distribution of log (CPUE) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

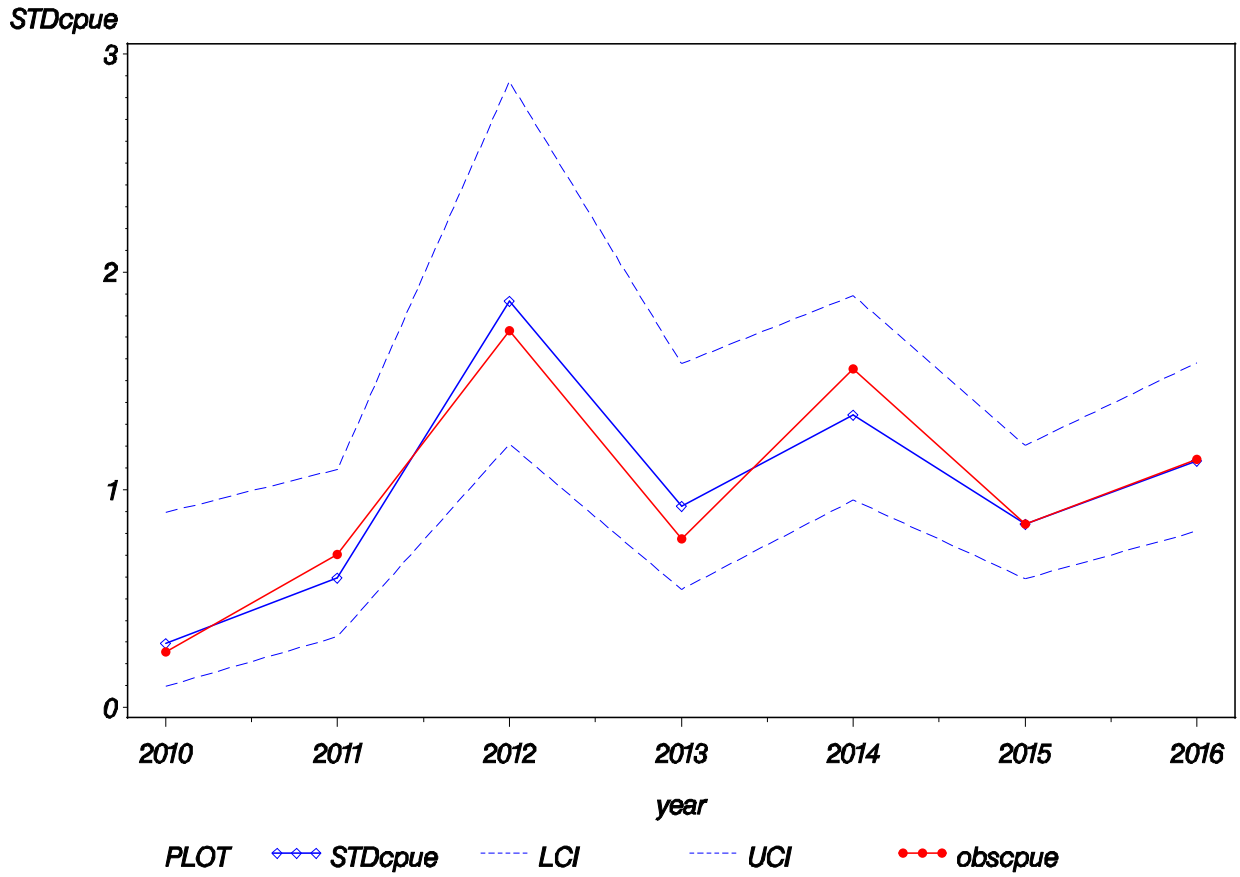


Figure 12. Annual index of abundance for the eastern Gulf of Mexico for Red Snapper from the DISL Bottom Longline Surveys from 2010 – 2016.

Appendix

Appendix Table 1. Summary of the factors used in constructing the Red Snapper abundance index from the NMFS bottom longline survey data for the western Gulf of Mexico. Note that the years 2005 and 2008 were excluded from the index.

Factor	Level	Number of Observations	Number of Positive Observations	Proportion Positive	Mean CPUE
Year	2001	125	25	0.20000	0.65856
Year	2002	150	35	0.23333	0.49510
Year	2003	100	20	0.20000	0.61589
Year	2004	78	15	0.19231	0.63396
Year	2006	71	13	0.18310	0.48715
Year	2007	70	13	0.18571	0.56404
Year	2009	77	23	0.29870	0.95858
Year	2010	48	8	0.16667	0.74235
Year	2011	81	25	0.30864	1.59757
Year	2012	53	19	0.35849	2.60858
Year	2013	65	23	0.35385	2.18252
Year	2014	46	15	0.32609	1.32710
Year	2015	58	27	0.46552	3.93078
Year	2016	50	24	0.48000	3.08816
Area	Louisiana	635	167	0.26299	1.13503
Area	Texas	437	118	0.27002	1.33490
Depth Zone	Mid	446	195	0.43722	2.13314
Depth Zone	Shallow	626	90	0.14377	0.56345

Appendix Table 2. Summary of the factors used in constructing the Red Snapper abundance index from the NMFS bottom longline survey data for the eastern Gulf of Mexico. Note that the years 2002 and 2008 were excluded from the index.

Factor	Level	Number of Observations	Number of Positive Observations	Proportion Positive	Mean CPUE
Year	2001	124	3	0.02419	0.03160
Year	2003	154	5	0.03247	0.05581
Year	2004	133	4	0.03008	0.05241
Year	2005	47	1	0.02128	0.04327
Year	2006	57	2	0.03509	0.03537
Year	2007	63	2	0.03175	0.11386
Year	2009	88	7	0.07955	0.10788
Year	2010	83	12	0.14458	0.23096
Year	2011	161	24	0.14907	0.34398
Year	2012	68	6	0.08824	0.26646
Year	2013	80	5	0.06250	0.26294
Year	2014	56	8	0.14286	0.25166
Year	2015	81	9	0.11111	0.34638
Year	2016	58	9	0.15517	0.91133
Area	Mississippi/Alabama	172	39	0.22674	0.79755
Area	North Florida	469	39	0.08316	0.15207
Area	South Florida	612	19	0.03105	0.06604
Depth Zone	Mid	555	49	0.08829	0.23011
Depth Zone	Shallow	698	48	0.06877	0.17364

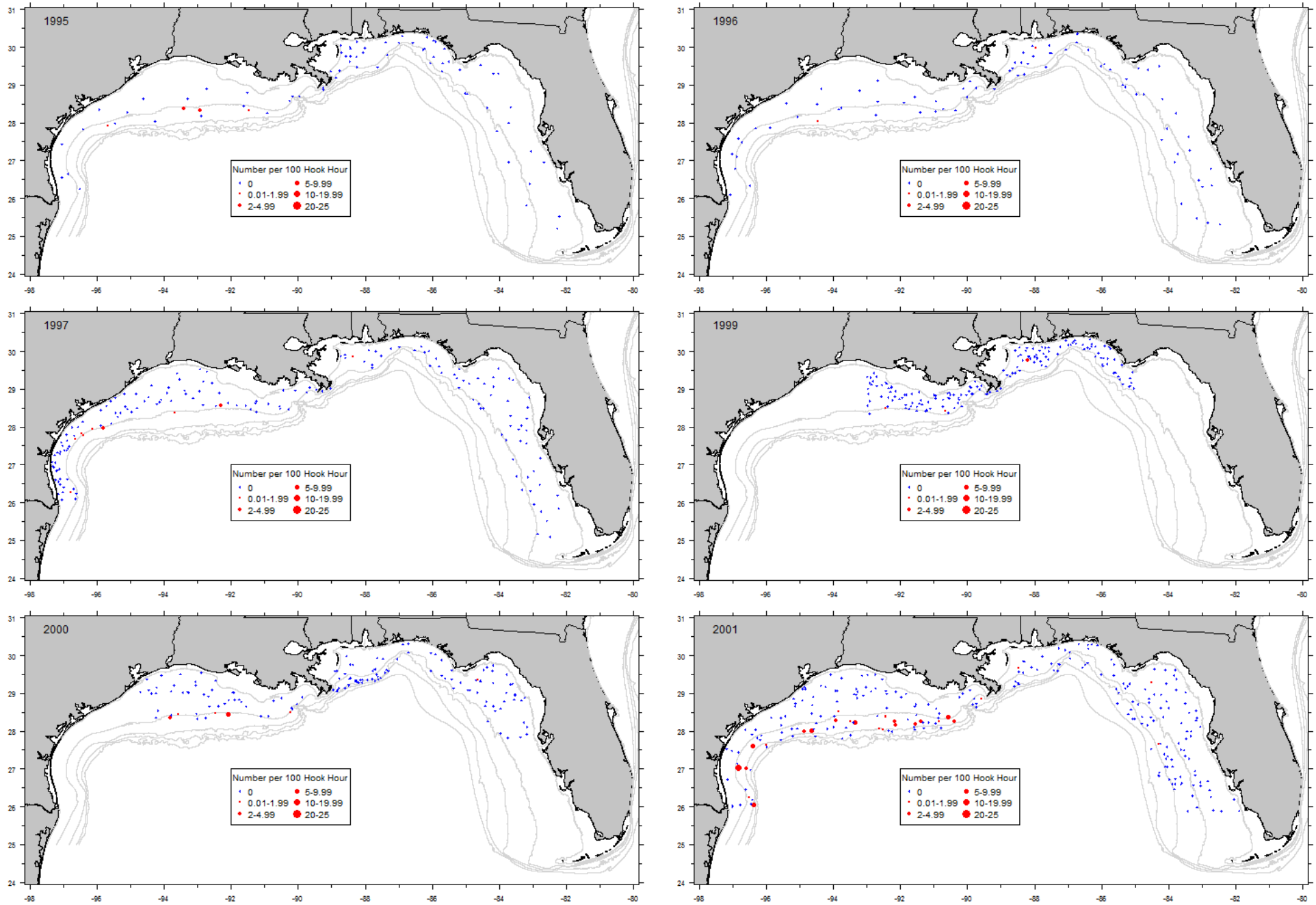
Appendix Table 3. Summary of the factors used in constructing the Red Snapper abundance index from the NMFS bottom longline survey data (with DISL) for the eastern Gulf of Mexico. Note that the years 2002 and 2008 were excluded from the index.

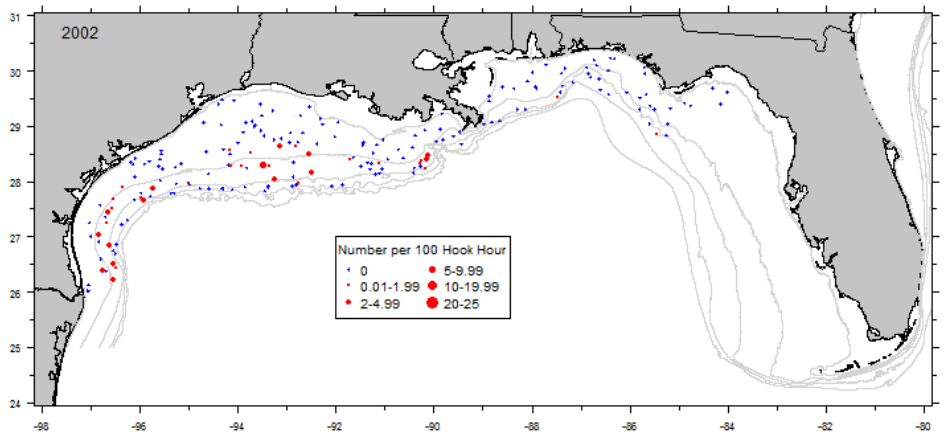
Factor	Level	Number of Observations	Number of Positive Observations	Proportion Positive	Mean CPUE
Year	2001	124	3	0.02419	0.03160
Year	2003	154	5	0.03247	0.05581
Year	2004	133	4	0.03008	0.05241
Year	2005	47	1	0.02128	0.04327
Year	2006	57	2	0.03509	0.03537
Year	2007	63	2	0.03175	0.11386
Year	2009	88	7	0.07955	0.10788
Year	2010	96	16	0.16667	0.33374
Year	2011	170	29	0.17059	0.37294
Year	2012	80	16	0.20000	1.13513
Year	2013	90	13	0.14444	0.64499
Year	2014	87	28	0.32184	1.96321
Year	2015	108	28	0.25926	0.78881
Year	2016	85	28	0.32941	1.66787
Area	Mississippi/Alabama	301	124	0.41196	1.89543
Area	North Florida	469	39	0.08316	0.15207
Area	South Florida	612	19	0.03105	0.06604
Depth Zone	Mid	574	58	0.10105	0.27126
Depth Zone	Shallow	808	124	0.15347	0.65168
Source	DISL	129	85	0.65891	3.35927
Source	NMFS	1253	97	0.07741	0.19865

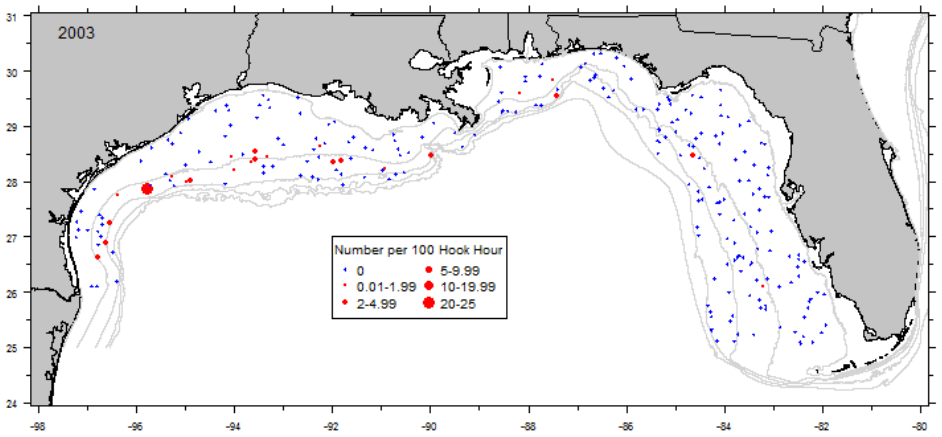
Appendix Table 4. Summary of the factors used in constructing the Red Snapper abundance index from the DISL bottom longline survey data for the eastern Gulf of Mexico.

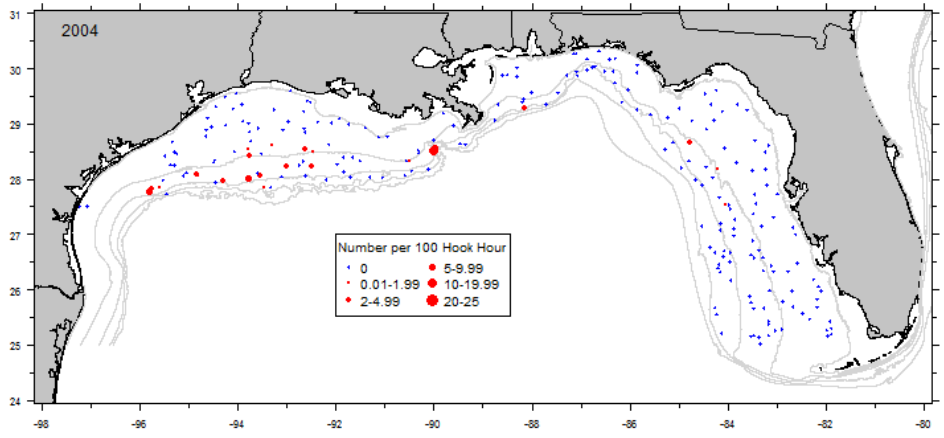
Factor	Level	Number of Observations	Number of Positive Observations	Proportion Positive	Mean CPUE
Year	2010	15	4	0.26667	0.85795
Year	2011	25	13	0.52000	2.37452
Year	2012	30	22	0.73333	5.84211
Year	2013	27	16	0.59259	2.60771
Year	2014	59	39	0.66102	5.25044
Year	2015	54	36	0.66667	2.84753
Year	2016	54	39	0.72222	3.84369
Depth Zone	Deep	46	27	0.58696	2.67315
Depth Zone	Mid	83	63	0.75904	5.86041
Depth Zone	Shallow	135	79	0.58519	2.81205
Season	Spring	135	84	0.62222	4.11600
Season	Summer	129	85	0.65891	3.35927

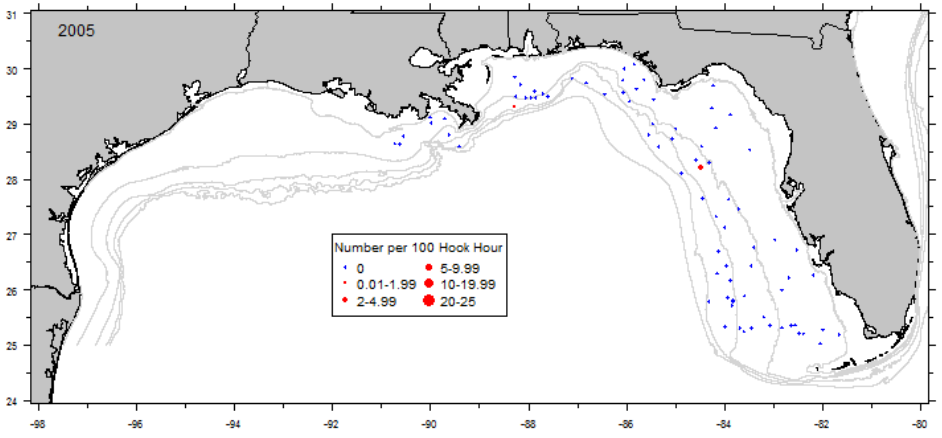
Appendix Figure 1. Annual survey effort and catch of Red Snapper from the NMFS bottom longline survey (1995-2016).

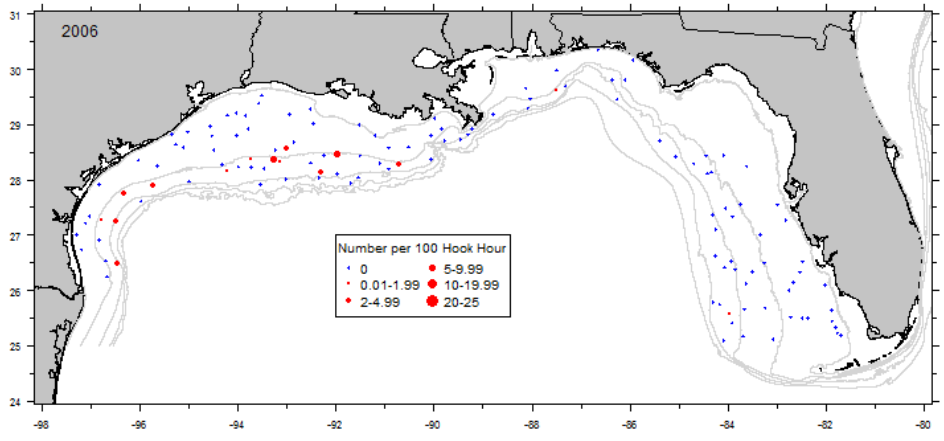


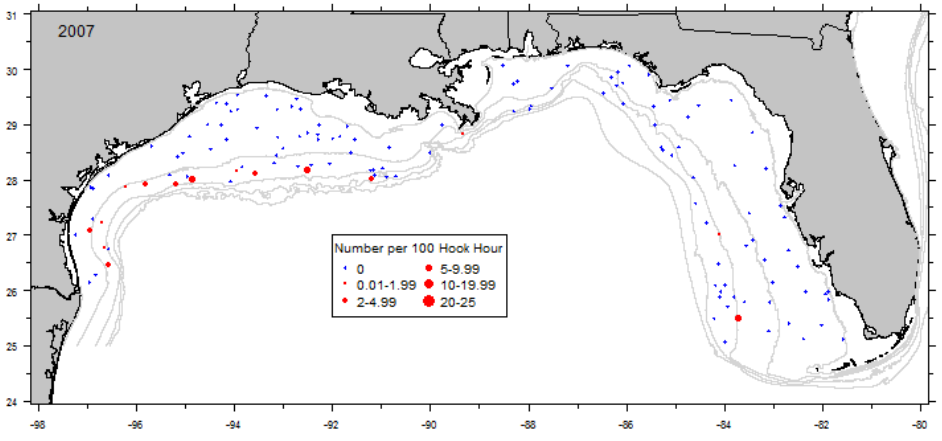

2002
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25

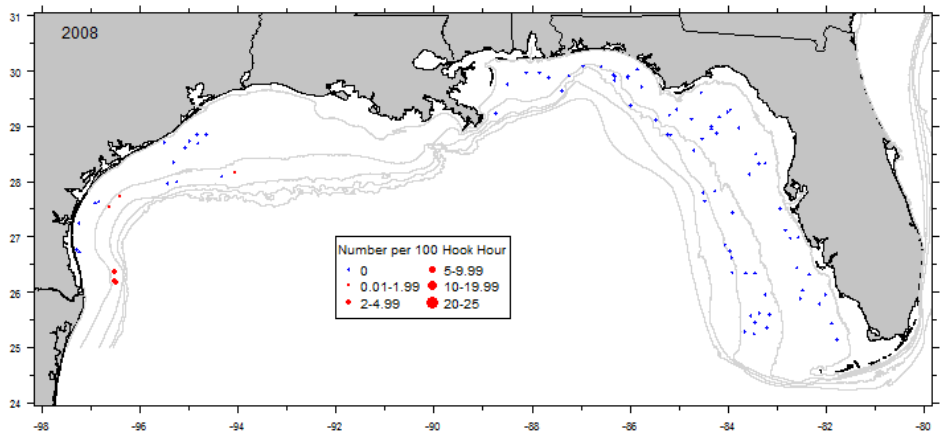

2003
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25


2004
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25


2005
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25


2006
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25


2007
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25


2008
Number per 100 Hook Hour
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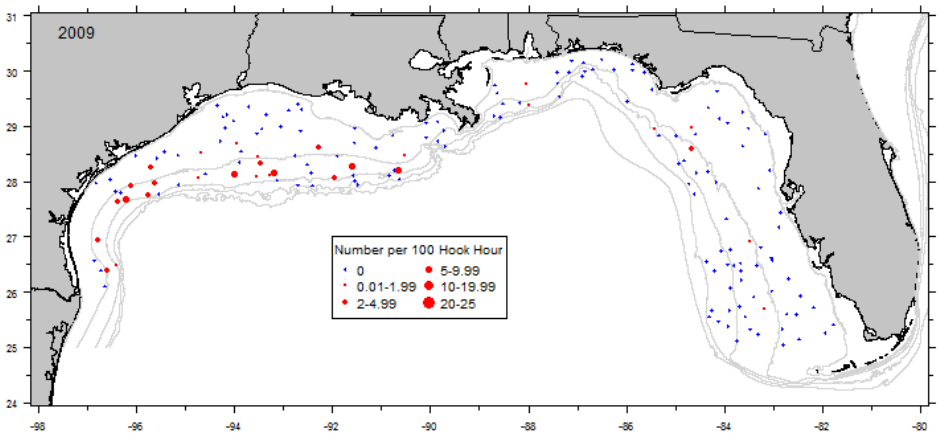
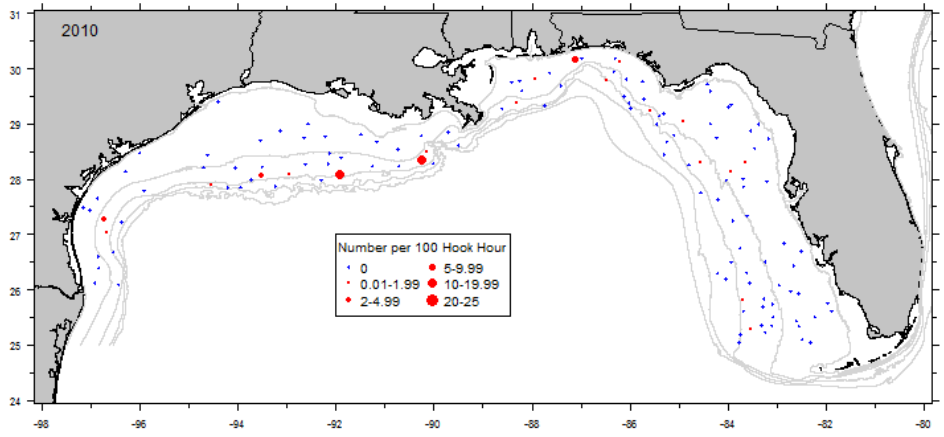
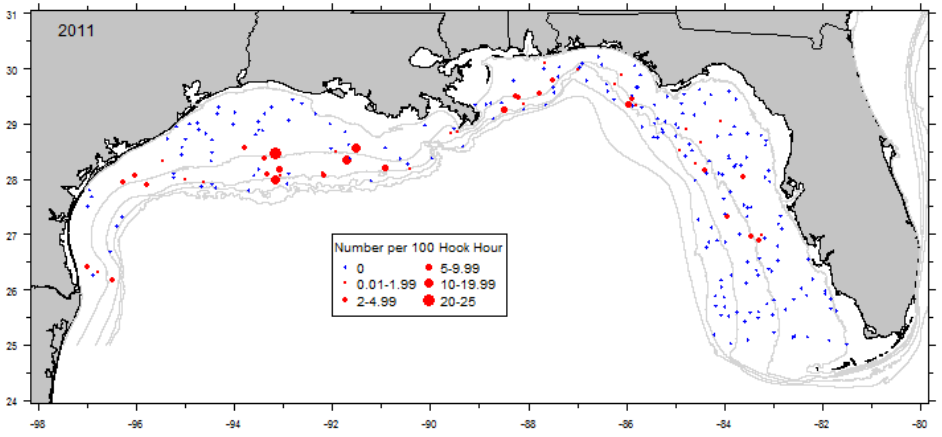
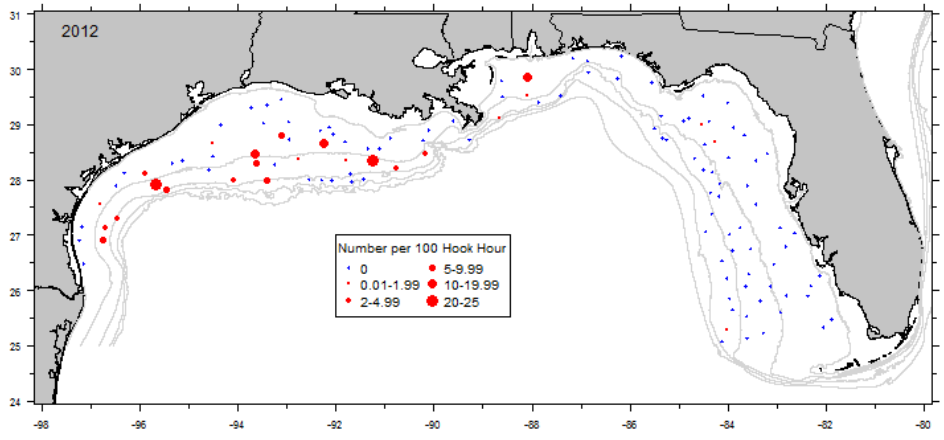
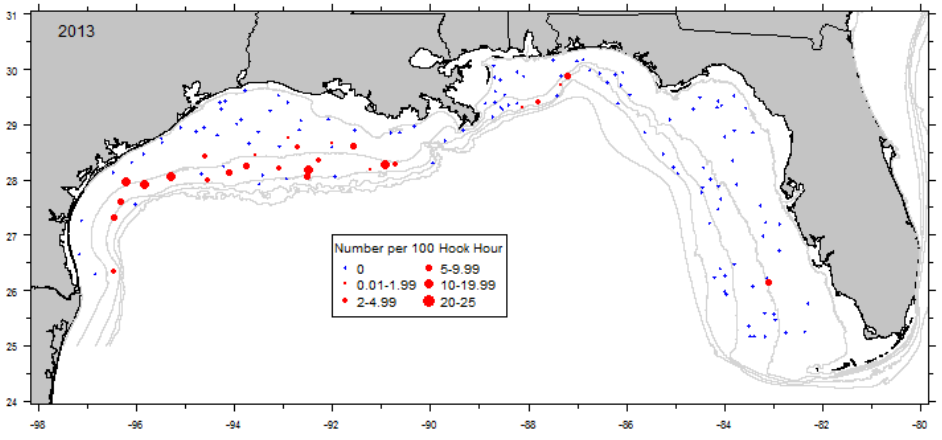
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25

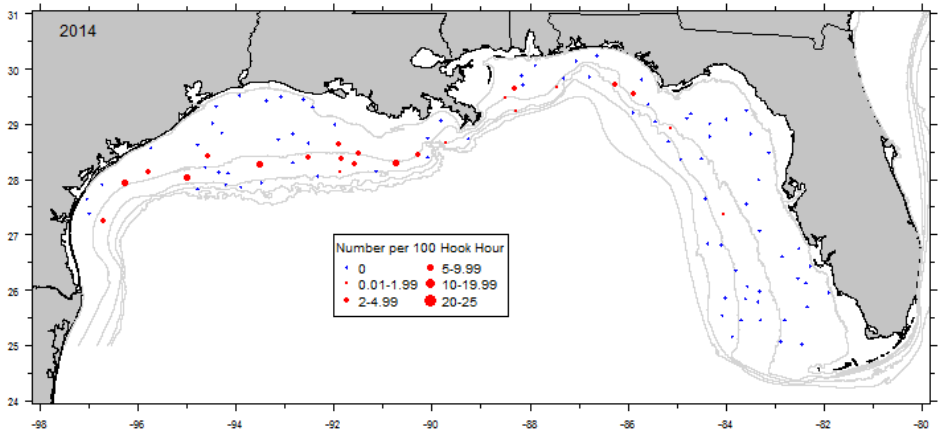

2009
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25

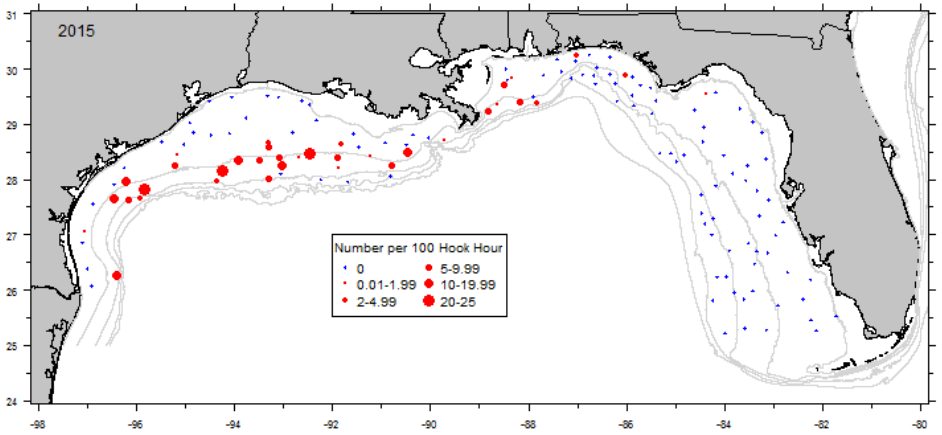

2010
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25

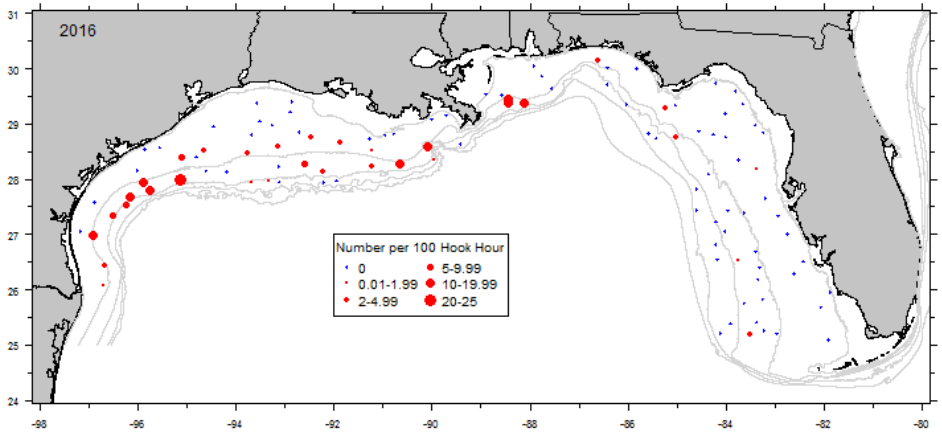

2011
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25


2012
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25

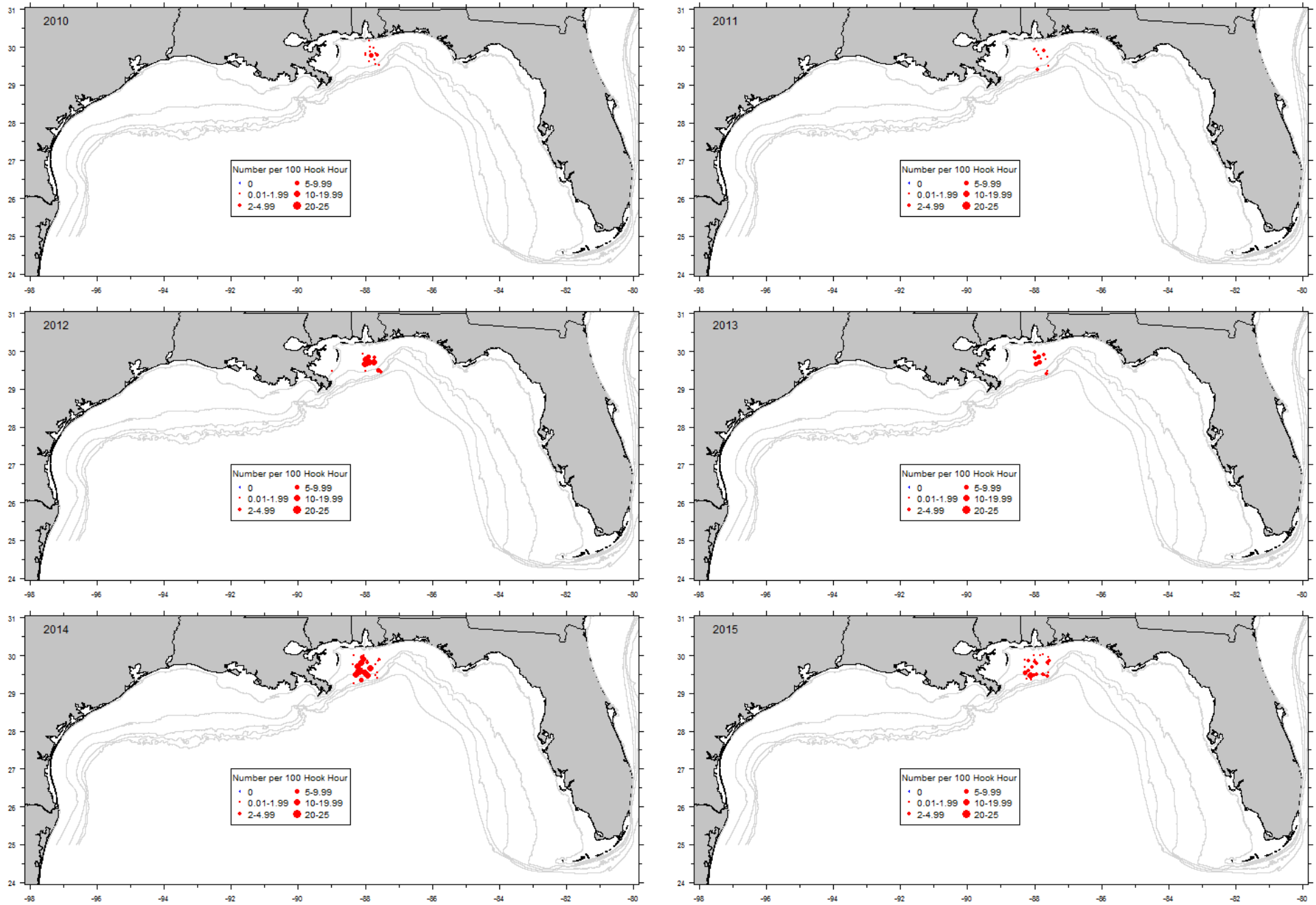

2013
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25

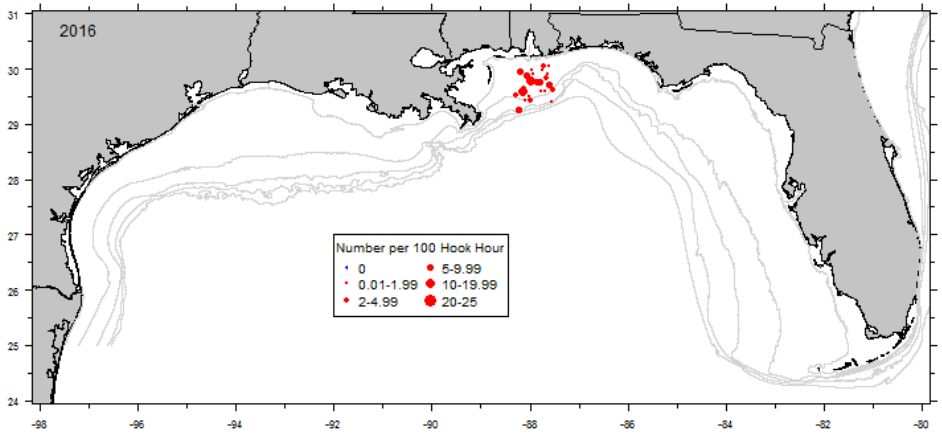

2014
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25


2015
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25


2016
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25

Appendix Figure 2. Annual survey effort and catch of Red Snapper from the DISL bottom longline survey (2010-2016).




2016
Number per 100 Hook Hour
0
0.01-1.99
2-4.99
5-9.99
10-19.99
20-25
31
30
29
28
27
26
25
24
-98
-96
-94
-92
-90
-88
-86
-84
-82
-80