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Meaghan D. Bryan and Kevin McCarthy

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Standardized catch rates for red grouper from the Unites States Gulf of Mexico vertical line and longline fisheries

Meaghan D. Bryan and Kevin McCarthy
National Marine Fisheries Service, Southeast Fisheries Science Center
Sustainable Fisheries Division, 75 Virginia Beach Drive, Miami, FL, 33149-1099
Meaghan.Bryan@noaa.gov
Kevin.J.McCarthy@noaa.gov
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Introduction

Handline, longline, and fish trap landings and fishing effort of commercial vessels operating in the United States Gulf of Mexico (GOM) have been monitored by the National Marine Fisheries Service (NMFS) through the coastal logbook program. The coastal logbook program in the GOM is conducted by the NMFS Southeast Fisheries Science Center. The program collects landings and effort data by trip from permitted vessels for a number of fisheries managed by the Gulf of Mexico Fisheries Management Council. The GOM coastal logbook program began in 1990 with the objective of a complete census of reef fish fishery permitted vessel activity. Florida was the exception, where a 20% sample of vessels was targeted. Beginning in 1993, the sampling in Florida was increased to require reports from all vessels permitted in the reef fish fishery.

Indices of abundance were developed for the vertical line (handline and electric/hydraulic reel) and longline fleets. The time-series used in the analyses started in 1990 and ended in 2013, the terminal year of the assessment. An index of abundance for the trap fleet was developed during SEDAR 12. This index was not recommended for use at that time. The main concern was that effort was not well defined. The best unit of available effort was number of traps opposed to soak time. In light of this, an updated fish trap index was not developed. Additionally, this fishing mode was prohibited in 2006.

Methods

The logbook database contains a number of variables. They include unique trip identifier, the landing date, fishing gear deployed, areas fished (equivalent to NMFS statistical zones, Figure 1), number of days at sea, number of crew, gear specific fishing effort (e.g. number of lines fished, number of hooks per line and estimated total fishing time in hours), species caught and whole weight of the landings.

Data filtering

The data exclusions made for the longline analysis were as follows:

1. Multiple areas fished may be recorded for a single fishing trip. In such cases, assigning landings and effort to specific locations was not possible; therefore, only trips in which one area fished was reported were included in these analyses.

2. Multiple fishing gears may be recorded for a single fishing trip. In such cases assigning landings and effort to a particular gear type was not possible. Trips fishing multiple gears were excluded in these analyses.

3. Logbook reports submitted 45 days or more after the trip completion data were excluded from these analyses due to the lengthy gap in reporting time.

4. Trips that fell outside the 99th percentile were considered to represent mis-reported data or data entry errors and were excluded from this analysis. The following were excluded from the longline analysis:
a. The number of hooks fished per line < 16 and the number of hooks per line > 3000,
b. The number of lines fished 96,

c. The number of days at sea > 20, and
d. The number of crew members > 5.

Data excluded from the vertical line analysis included trips with reports of:
a. The number of hooks fished per line > 45 (bandit rig) or > 40 (handline),
b. The number of lines fished > 8 (bandit rig) or > 10 (handline),
c. The number of days at sea > 14 (bandit rig and handline), and
d. The number of crew members > 5 (bandit rig) or > 6 (handline).

5. Seasonal closures and regulatory closured have been employed to manage the commercial red grouper fishery. Closures were impleamented on the following dates: November 8, 1990 - December 31, 1990; February 15 – March 15, 1999-2008; November 15, 2004 – December 31, 2004; and October 10, 2005 – December 31, 2005. The dataset was restricted to time periods for which fishing on red grouper was allowed.

6. Approximately 99% of the red grouper commercial longline landings were from statistical zones 1-10. All other statistical zones were excluded from the longline analysis. For the vertical line analysis, commercial data were limited to those taken from logbooks submitted for fishing trips occurring in statistical zones 1-11. Approximately 99.9% of commercial vertical line landings were reported from those statistical zones.

7. The indices are essentially Florida indices. Given that in Florida between 1990-1992 only 20% of vessels were required to report, the years 1990, 1991, and 1992 were excluded from the analysis.

8. Trips fishing more the 24 longline sets per day were excluded from this analysis. Vertical line trips with reported fishing more than 24 hours per day were also excluded.

Identifying trips targeting red grouper

Targeted red grouper trips were identified using the Stephens and MacCall (2004) approach, where trips are subset based upon the reported species composition of the landings. This method is intended to identify trips that fished in locations containing red grouper habitat and, therefore, had the potential of catching red grouper. This was done for the pre-IFQ index. Prior to using Stephens-MacCall, the percentage of longline trips catching red grouper was ~74% on average (Table 1). After implementing Stephens-MacCall, the percentage of longline trips catching red grouper was ~94% on average (Table 2).

The diagnostics used to determine whether the Stephens-MacCall approach described the targeting of red grouper by longline vessels during the pre-IFQ years are shown in Figure 2. False prediction of targeted trips was minimized at a critical value approximately equal to 0.55 (Figure 2a). Strongest species associations were with gag grouper, black grouper, gray snapper, margate, scamp, mutton snapper, and lane snapper (Table 3). Stephens-MacCall was not applied to the longline IFQ-index . The diagnostics shown in Figure 3 indicate that this approach poorly describes targeting of red grouper during the IFQ years. The percentage of trips capturing red grouper ranged between 77% and 87% (Table 4).

The Stephens and MacCall method was also used to identify vertical line trips fishing within presumptive red grouper habitat. Approximately 53% of trips during the period 1993-2009 (pre-IFQ years) reported landings of red grouper (i.e., positive trips). The final data set for use in index construction had 65-90% positive trips per year. Diagnostic plots for the Stephens and MacCall analysis are provided in Figure 4. The critical value for minimizing false prediction of targeted red grouper trips was 0.57 (Figure 4a). The species most highly associated with red grouper in commercial vertical line landings were gag grouper, black grouper, scamp, lane snapper, and mangrove snapper (Figure 5).

During the years 2010-2013 (IFQ years), approximately 57% of all trips reported landings of red grouper. Following application of the Stephens and MacCall data subsetting technique, the final data set for use in index construction had 86-90% positive trips per year. Diagnostic plots for the subsetting analysis are provided in Figure 6. The critical value for minimizing false prediction of targeted red grouper trips was 0.49

(Figure 6a). The species most highly associated with red grouper in commercial vertical line landings were gag grouper, black grouper, grunts (species group), scamp, and margate (Figure 7).

Catch per unit effort

Longline catch rate was calculated in weight of fish per hook fished. For each trip, catch per unit effort was calculated as:
CPUE = pounds of red grouper/(number of longline sets*number of hooks per set)

The data for number of hours fished while using longline gear is unreliable in the coastal logbook program due to misreporting. Calculating CPUE by hook-hour could not be done for the longline data.

Vertical line catch rate was calculated in weight of fish per hook-hour. For each trip, catch per unit effort was calculated as:
CPUE = pounds of red grouper/(number of lines fished*hooks per line*total hours fished)

Standardized indices

Commercial longline indices

The factors that were explored for the commercial longline cpue standardization model development were as follows:

Pre-IFQ commercial longline index

Factor	Levels	Value
Year	16	1993 - 2009
AREA	10	Statistical zones: 1 - 10
Month	12	Month of year

IFQ commercial longline index

Factor	Levels	Value
Year	4	2010-2013
AREA	10	Statistical zones: 1 - 10
Depth closure	2	Open (all months except June, July, and August), Closure (June, July, and August). This corresponds with the management rule that excludes longlines from depths less than 35 fathoms during June, July, and August.
Allocation category	3	Low (1-7237 lbs), mid (7238 – 26302 lbs), and high (26303 – 206249 lbs)allocation

Given the high proportion of positive trips, a GLM assuming a binomial error distribution was inappropriate. A GLM assuming a lognormal error distribution was used to examine the above factors for effects on red grouper CPUE. Factors that significantly affected CPUE were then identified using the GLM assuming lognormal error distribution as described for vertical lines. The index was fit using the Proc Mixed procedure in SAS. All factors were modeled as fixed effects except two-way interaction terms containing YEAR that were modeled as random effects.

Table 5 summarizes the results from the iterative building of the lognormal model for the pre-IFQ commercial longline index. The inclusion of the main effects, area and year, reduced the deviance by 1.21% and 1.08%, respectively and were statistically significant factors. In addition the inclusion of these main effects in the model reduced the likelihood ratio. This further justifies their inclusion in the standardization model. The inclusion of the area-year interaction term reduced the deviance by 2.81%. The likelihood ratio increased with the increase of the area-year interaction term; therefore, the interaction term was not included in the standardization model. The main effect, month, was not included in the model because its inclusion did not reduce the deviance by 1% and month was not a statistically significant factor.

The pre-IFQ index model is as follows:

LN(CPUE) = INTERCEPT + AREA + YEAR

Table 6 summarizes the results from the iterative building of the lognormal model for the IFQ commercial longline index. The inclusion of the main effects, area and year, reduced the deviance by 9.02% and 3.88%, respectively and were statistically significant factors. In addition the inclusion of these main effects in the model reduced the likelihood ratio justifying their inclusion in the standardization model. Including the main effect, depth closure, only reduced the deviance by 0.68%, but it was a statistically significant factor. Its inclusion also reduced the likelihood ratio; therefore, depth closure was included in the standardization model as a main effect. The main effect, alloc_cat (allocation category), was not included in the model because its inclusion did not reduce the deviance by 1% and it was not a statistically significant factor. The inclusion of the area-year interaction term reduced the deviance by 1%. The likelihood ratio increased with the increase of the area-year interaction term; therefore, the interaction term was not included in the standardization model.

The IFQ-index model is as follows (see Table 6):

LN(CPUE) = INTERCEPT + AREA + YEAR + DEPTH_CLOSURE

Pre-IFQ index

The pre-IFQ standardized index is summarized in Table 7 and Figure 8. After an initial decline between 1993 and 1994 the standardized index had an increasing trend until 2005. The standardized index declined in 2006 and 2007, followed by an increase in 2008. Index values in 2008 and 2009 were similar.

The standardized index in 2002 is approximately 30% lower than the nominal (Table 7 and Figure 8). This may be explained by the area effect. More specifically, the nominal cpue in shrimp grid 5 had the greatest number of positive trips and was three times higher, on average, than the nominal cpue in other areas (Figure 9).

The model diagnostics are summarized in Figure 10b)

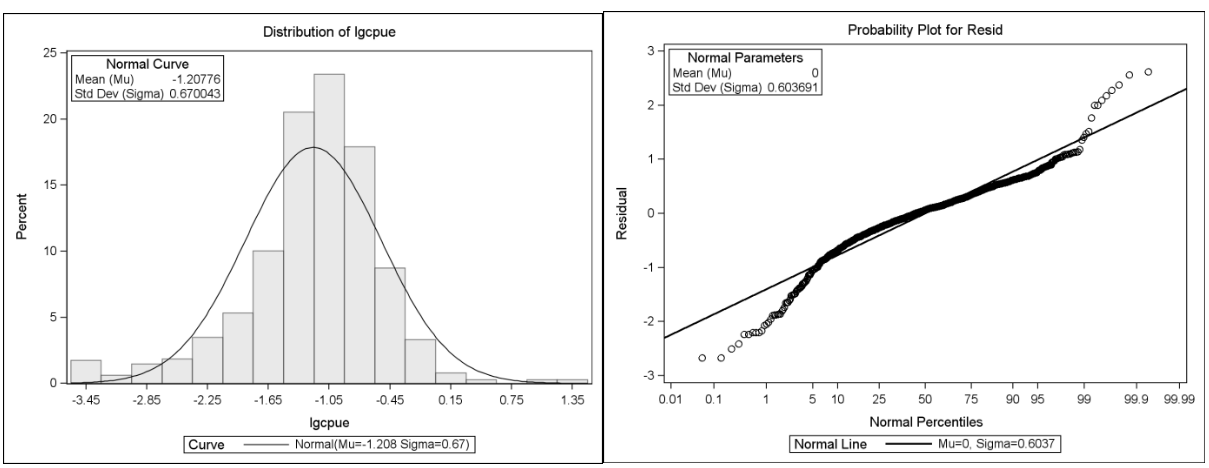

Figure 10a.

IFQ index

The IFQ standardized index is summarized in Table 8 **and Figure 11. The lowest catch rate was in 2010 followed by an increase in 2011 and 2012 and a decline in 2013. Model diagnostics are summarized in Figure 10**b)

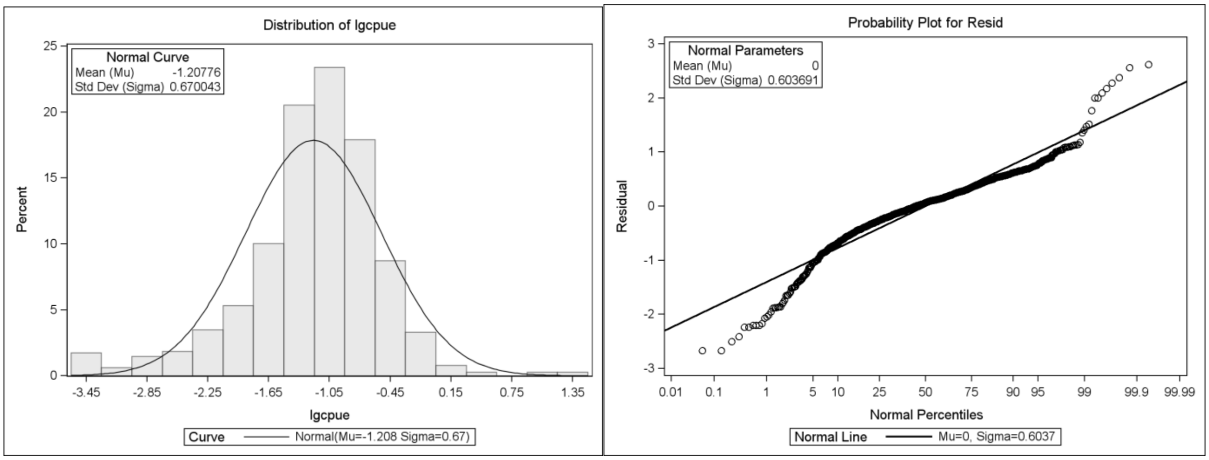

Figure 10b.

Commercial vertical line indices

For the pre-IFQ index construction (including data from the years 1993-2009), five factors were considered as possible influences on the proportion of trips that landed red grouper and on the catch rate of red grouper. An additional factor, number of hook hours fished, was examined for its effect on the proportion of positive trips. In order to develop a well balanced sample design it was necessary to define categories within some of the factors examined:

Factor	Levels	Value
YEAR	17	1993-2009
AREA	4	Gulf of Mexico statistical areas 1-5, 6, 7, and 8-11
DAYS	3	1 day at sea, 2-3 days at sea, 5 or more days at sea
MONTH	12	Month of the year
CREW	3	1, 2, 3 or more crew members
Hook hours fished*	4	<33, 33-96, 97-294, and 295 or more hook hours fished

*Hook hours tested for inclusion in the proportion positive (binominal) model

In addition to the factors listed above, an IFQ allocation factor, was examined when constructing the IFQ index (included data from the years 2010-2013). Total red grouper IFQ allocation was assumed to be the sum of red grouper, red grouper multi, and gag grouper multi allocation available to a vessel on a fishing trip. In cases where vessel owners/IFQ shareholders had multiple IFQ accounts, the sum of all red grouper allocation, as defined above, was assigned to trips reported by each vessel owned by that IFQ shareholder. Assigning the sum of red grouper IFQ allocation from all vessels owned by a shareholder to each vessel owned by that shareholder was done because each of the vessels had the potential to land that maximum available allocation. That potential for landings may have influenced the fishing behavior of the captain. Allocation categories were:

No allocation
1-1,166 pounds of allocation
1,167-3,716 pounds of allocation
3,717-10,300 pounds of allocation
10,301 pounds or more of allocation

Standardization

The delta lognormal modelling procedure (Lo et al. 1992) was used to construct the vertical line standardized indices of abundance. Parameterization of each model was accomplished using a GLM analysis (GENMOD; Version 8.02 of the SAS System for Windows © 2000. SAS Institute Inc., Cary, NC, USA). For each GLM analysis of proportion positive trips, a type-3 model was fit, a binomial error distribution was assumed, and the logit link was selected. The response variable was proportion successful trips. During the analysis of catch rates on successful trips, a type-3 model assuming lognormal error distribution was examined. The linking function selected was “normal”, and the response variable was log(CPUE) where log(CPUE)=ln(pounds of red grouper/hook hours fished). All 2-way interactions among significant main effects were examined. Higher order interaction terms were not examined.

A forward stepwise regression procedure was used to determine the set of fixed factors (listed above) and interaction terms that explained a significant portion of the observed variability. Each potential factor was added to the null model sequentially and the resulting reduction in deviance per degree of freedom was examined. The factor that caused the greatest reduction in deviance per degree of freedom was added to the base model if the factor was significant based upon a Chi-Square test ($p<0.05$), and the reduction in deviance per degree of freedom was ≥1%. This model then became the base model, and the process was repeated, adding factors and interactions individually until no factor or interaction met the criteria for incorporation into the final model.

Once a set of fixed factors was identified, the influence of the YEAR*FACTOR interactions were examined. YEAR*FACTOR interaction terms were included in the model as random effects. Selection of the final mixed model was based on the Akaike’s Information Criterion (AIC), Schwarz’s Bayesian Criterion (BIC), and a chi-square test of the difference between the –2 log likelihood statistics between successive model formulations (Littell et al. 1996).

The final delta-lognormal models were fit using the SAS GLIMMIX macro (Russ Wolfinger, SAS Institute). To facilitate visual comparison, relative indices and relative nominal CPUE series were calculated by dividing each value in the series by the mean cpue of the series.

Vertical line analyses results

The final model of the pre-IFQ years (1993-2009) data set for the binomial on proportion positive trips (PPT) and the lognormal on CPUE of successful trips for each species were:

PPT = Days + Area + Year + Hook hours fished + Year*Area + Area*Hook hours

LOG(CPUE) = Area + Year + Crew + Month + Year*Area + Year*Month + Area*Month

The final models of the IFQ years (2010-2013) data set were:

PPT = IFQ Allocation + Area + Days + Year[1]

LOG(CPUE) = Area + Crew + IFQ Allocation + Days + Year + Area*Crew + IFQ allocation*Days + Crew*Days

[1]Year did not meet the inclusion criteria for the binomial model, but was included to allow for yearly mean cpue to be calculated

The linear regression statistics for fixed effects and the analyses of the pre-IFQ mixed model formulations of the final models are summarized in Table 9. Table 10 contains the linear regression statistics of the IFQ final models.

Relative nominal CPUE, number of trips, proportion positive trips, and relative abundance indices are provided in Table 11 for the red grouper vertical line pre-IFQ analysis. Yearly standardized catch rates of the index ranged from a low of 0.49 in 1996 to approximately 1.5 in 2008. Coefficients of variation (CV) for the per-IFQ index were fairly low (0.29-0.31) for all years. The delta-lognormal abundance index constructed for the pre-IFQ years (1993-2009), along with 95% confidence intervals, is shown in Figure 12. Plots of chi_square residuals of main effects in the binomial component of the pre-IFQ model are provided in Figure 13. Diagnostic plots for the lognormal component of the pre-IFQ model are provided in Figures 14 and 15.

Red grouper standardized catch rates for commercial vertical line vessels prior to IFQ implementation were generally higher during 2001-2009 compared to the period 1993-2000. Confidence intervals around those yearly mean rates were large, however. As with any fishery dependent index of abundance, changes in catchability may mask true trends in population abundance.

No final index of abundance was constructed from commercial vertical line data reported during the period 2010-2013 (IFQ years). The distribution of log-transformed cpue was not normal (an assumption of the delta-lognormal analysis), as seen in Figure 16. In addition, the distribution of log cpue varied among trips with different amounts of IFQ allocation (Figure 17). Those trips with the highest amount of red grouper IFQ allocation had an approximately normal distribution of log transformed cpue (although with a long tail of low cpues). Distributions of log transformed cpues reported from vessels with lower amounts of allocation were bimodal with a mode log transformed cpues of 1-2 and a secondary mode at log transformed cpues of -3 to -2. Vessels with the lowest amount of IFQ allocation reported approximately equal numbers trips over a broad range of cpues. Such a violation of one of the assumptions of the analysis would invalidate the results and therefore, no vertical line index for the period 2010-2013 was constructed.

Literature cited

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Tables

Table 1. The total number of trips, the number of trips catching red grouper (positive trips), and the proportion of positive trips by year for the pre-IFQ (1993-2009) commercial longline index before implementing the Stephens-MacCall approach.

Year	Total number of trips	Number of positive trips	Proportion of positive trips
1993	525	467	0.8895
1994	834	641	0.7686
1995	781	585	0.749
1996	775	531	0.6852
1997	1178	857	0.7275
1998	1081	803	0.7428
1999	1099	848	0.7716
2000	1055	722	0.6844
2001	1057	771	0.7294
2002	989	674	0.6815
2003	1068	753	0.7051
2004	1021	799	0.7826
2005	950	735	0.7737
2006	1097	822	0.7493
2007	752	557	0.7407
2008	694	563	0.8112
2009	339	222	0.6549
Mean			0.7439

Table 2. The total number of trips, the number of trips catching red grouper (positive trips), and the proportion of positive trips by year for the pre-IFQ (1993-2009) commercial longline index after implementing the Stephens-MacCall approach.

Year	Total number of trips	Number of positive trips	Proportion of positive trips
1993	480	453	0.9438
1994	700	612	0.8743
1995	634	550	0.8675
1996	540	501	0.9278
1997	853	815	0.9555
1998	794	763	0.961
1999	842	808	0.9596
2000	709	661	0.9323
2001	763	731	0.9581
2002	678	638	0.941
2003	774	721	0.9315
2004	792	763	0.9634
2005	728	699	0.9602
2006	826	784	0.9492
2007	564	535	0.9486
2008	567	552	0.9735
2009	227	215	0.9471
Mean			0.9408

Table 3. Species associations from Stephens-MacCall for the pre-IFQ vertical line index.

Species	**Coefficient**
Cusk eel	-1.4798
Queen snapper	-1.3677
Snappers, unclassified	-1.3543
Queen triggerfish	-1.2042
Yellowedge grouper	-1.1902
Red hind	-1.1776
Blacktip shark	-0.8844
Rock hind	-0.8132
Bearded brotula	-0.7202
Atlantic, red & white hake	-0.6943
Speckled hind	-0.6092
Bull shark	-0.5538
Lesser amberjack	-0.5537
Yellowfin grouper	-0.5340
Tilefish	-0.5287
Atlantic sharpnose shark	-0.4596
Snowy grouper	-0.3789
Warsaw grouper	-0.3771
Sandbar shark, fins	-0.3713
Misty grouper	-0.3658
Bar jack	-0.3402
Greater amberjack	-0.3347
Finfishes, unclassified for food	-0.3183
Hammerhead shark	-0.2301
Blackfin tuna	-0.2095
Lemon shark	-0.1318
Dog snapper	-0.1181
Almaco jack	-0.1130
Red porgy, large	-0.1113
Scorpionfish	-0.1053
Vermillion snapper	-0.0615
Mako shark, unclassified	-0.0456
King mackerel	-0.0283
Wahoo	0.0150
Dolphinfish	0.0387
Whitebone porgy	0.0700
Jolthead progy	0.1654
Grunts	0.1776
Silk snapper	0.1885
Blackfin snapper	0.2060
Shark, unclassified, fins	0.2450

Table 3. continued.

Species	Coefficient
Red snapper	0.2952
Spinycheek scorpionfish	0.3000
Groupers	0.3193
Unclassified shark	0.3553
Barracuda	0.3607
Blacknose, shark	0.4159
Yellowtail snapper	0.4453
Blueline tilefish	0.5996
Gray triggerfish	0.6121
Cobia	0.7158
Knobbed porgy	0.7783
Lane snapper	1.0341
Mutton snapper	1.1431
Scamp	1.2260
Margate	1.4418
Gray (at mangrove) snapper	1.5480
Black grouper	2.1677
Gag grouper	2.3326

Table 4. The total number of trips, the number of trips catching red grouper (positive trips), and the proportion of positive trips by year for the IFQ (2010-2013) commercial longline index without implementing the Stephens-MacCall approach.

Year	Total number of trips	Number of positive trips	Proportion of positive trips
2010	271	209	0.7712
2011	430	376	0.8744
2012	360	287	0.7972
2013	320	274	0.8562

Table 5. Deviance table from the iterative model building for the pre-IFQ (1993-2009) commercial longline index.

Lognormal								
Factor	**DF**	**Deviance**	**Residual Df**	**Residual Deviance**	**AIC**	**% Deviance Reduced**	**log likelihood**	**Likelihood Ratio Test**
Null	1	14299.6	11469	14299.6	35079.60	-	-17539.8	-
Null+Area	9	14115.9	11460	183.7	34931.20	1.21%	-17465.6	148.4
Null+Area+year	20	13943.5	11444	172.4	34790.40	1.08%	-17395.2	140.8
Null+Area+year+ Area*year	180	13388.1	11306	555.4	34324.00	2.81%	-17162.0	466.4

Table 6. Deviance table from the iterative model building for the IFQ (2010-2013) commercial longline index.

Lognormal								
	DF	**Deviance**	**Residual Df**	**Residual Deviance**	**AIC**	**% Deviance Reduced**	**log likelihood**	**Likelihood Ratio Test**
Null	1	1138.6	1380	1138.6	3652.62	-	-1826.3	-
Null + AREA	9	1029.2	1371	109.4	3513.06	9.02%	-1756.5	139.6
Null + AREA + year	3	987.1	1368	42.1	3455.44	3.88%	-1727.7	57.6
Null + AREA + year + depth_closure	1	979.7	1367	7.5	3444.98	0.68%	-1722.5	10.5
Null + AREA + year + depth_closure + year*AREA	27	953.6	1344	26.1	3407.70	1.00%	-1703.9	37.3

Table 7. The standardized annual commercial longline index and CV for red grouper captured in statistical zones 1-10 in the Gulf of Mexico from 1993 until 2009. The annual nominal and standardized index (Index) values were normalized to an average value of one.

Year	Nominal	Index	CV	Percent difference
1993	0.8361	0.9785	0.0535	17.03
1994	0.7738	0.7235	0.0474	-6.49
1995	0.9213	0.7742	0.0491	-15.96
1996	0.8176	1.0397	0.0513	27.17
1997	0.8575	0.9069	0.0428	5.76
1998	1.0451	0.9552	0.0441	-8.60
1999	0.9176	0.9968	0.0438	8.64
2000	1.0476	0.8980	0.0465	-14.28
2001	0.9860	1.0563	0.0447	7.13
2002	1.5153	1.0600	0.0471	-30.05
2003	1.0506	0.9284	0.0453	-11.64
2004	1.1543	1.1124	0.0440	-3.63
2005	1.3755	1.4437	0.0455	4.95
2006	0.9931	1.0927	0.0435	10.03
2007	0.7466	0.7796	0.0502	4.42
2008	1.0455	1.1811	0.0496	12.97
2009	0.9165	1.0731	0.0731	17.08

Table 8. The standardized annual commercial longline index and CV for red grouper captured in statistical zones 1-10 in the Gulf of Mexico from 2010 - 2013. The annual nominal and standardized index (Index) values were normalized to an average value of one.

Year	Nominal	Index	CV	Percent difference
2010	0.7335	0.6282	0.0866	-14.35
2011	1.1028	1.0556	0.0784	-4.27
2012	1.1362	1.2680	0.0823	11.60
2013	1.0275	1.0481	0.0820	2.00

Table 9. Linear regression statistics for the pre-IFQ GLM models on proportion positive trips (**A**) and catch rates on positive trips (**B**) of red grouper for vessels reporting vertical line gear landings. Analysis of the mixed model formulations of the proportion positive model (**C**) and the positive trip model (**D**). The likelihood ratio was used to test the difference of –2 REM log likelihood between two nested proportion positive models. The final model is indicated with gray shading. See text for factor (effect) definitions.

A.

Type 3 Tests of Fixed Effects

Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	16	48	89.46	5.59	<.0001	<.0001
days	2	684	632.80	316.40	<.0001	<.0001
area	3	48	142.28	47.43	<.0001	<.0001
hook hours	3	684	299.86	99.95	<.0001	<.0001
*area*hook hours*	9	684	197.76	21.97	<.0001	<.0001

B.

Type 3 Tests of Fixed Effects

Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	16	48	27.09	1.69	0.0405	0.0810
area	3	48	159.21	53.07	<.0001	<.0001
crew	2	43E3	2129.19	1064.59	<.0001	<.0001
month	11	173	78.70	7.15	<.0001	<.0001
*area*month*	33	43E3	512.04	15.52	<.0001	<.0001

C.

Proportion Positive Trips	*-2 REM Log likelihood*	*Akaike's Information Criterion*	*Schwartz's Bayesian Criterion*	*Likelihood Ratio Test*	*P*
days + area + year +hook hours	2405.5	2407.5	2412.1		
days + area + year +hook hours + year*area	2264.9	2268.9	2273.3	140.6	<0.0001
days + area + year +hook hours + year*area + area*hook hours	2146.7	2150.7	2155.1	118.2	<0.0001

D.

Catch Rates on Positive Trips	*-2 REM Log likelihood*	*Akaike's Information Criterion*	*Schwartz's Bayesian Criterion*	*Likelihood Ratio Test*	*P*
area + year + crew + month	150617.7	150619.7	150628.3	-	-
area + year + crew + month + year*area	148596.6	148600.6	148605.0	2021.1	<0.0001
area + year + crew + month + year*area + year*month	148166.2	148172.2	148178.8	430.4	<0.0001
area + year + crew + month + year*area + year*month + area*month	147774.1	147780.1	147786.8	392.1	<0.0001

Table 10. Linear regression statistics for the IFQ GLM models on proportion positive trips (**A**) and catch rates on positive trips (**B**) of red grouper for vessels reporting vertical line gear landings.

A.

Type 3 Tests of Fixed Effects						
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	3	240	13.40	4.47	0.0039	0.0045
IFQ allocation	3	240	114.38	38.13	<.0001	<.0001
area	3	240	137.34	45.78	<.0001	<.0001
days	3	240	131.76	43.92	<.0001	<.0001

B.

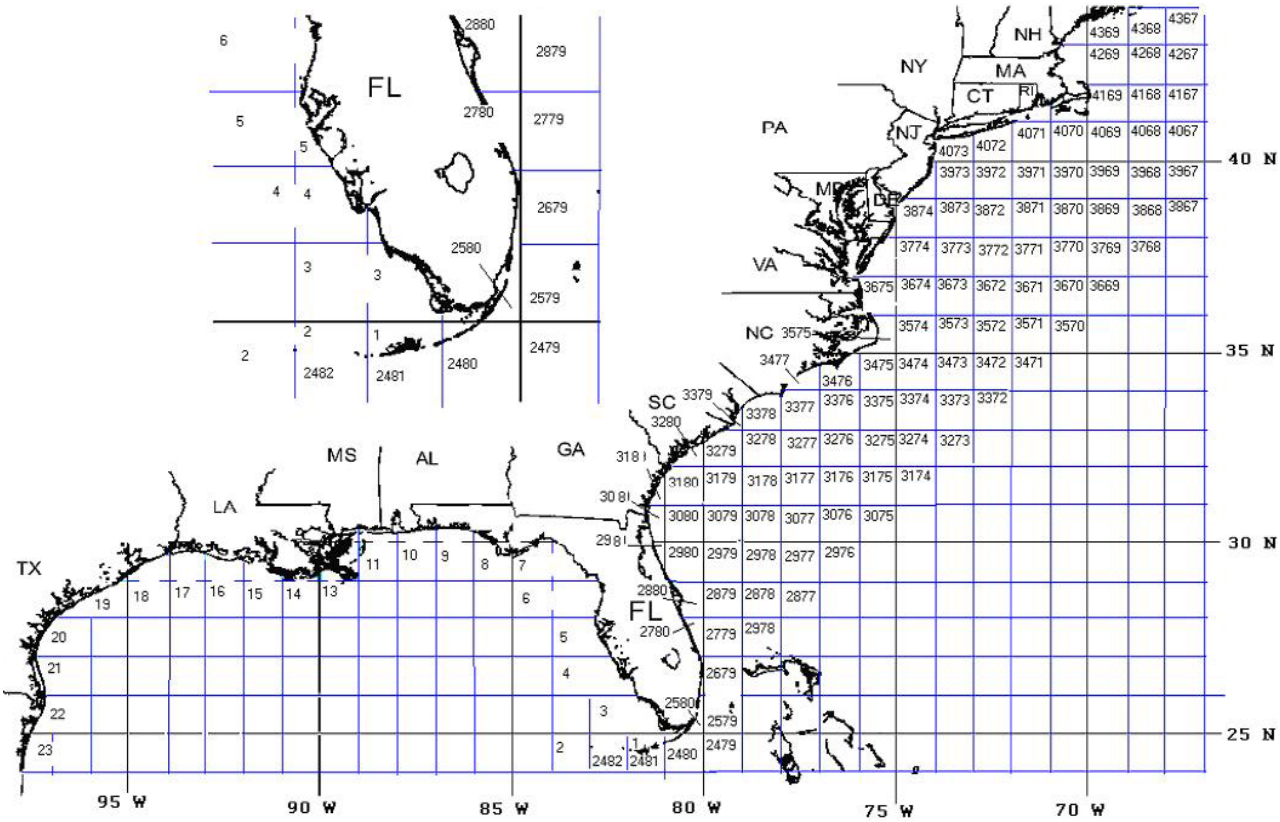
Type 3 Tests of Fixed Effects						
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	3	6900	210.80	70.27	<.0001	<.0001
area	3	6900	4753.23	1584.41	<.0001	<.0001
crew	1	6900	676.78	676.78	<.0001	<.0001
IFQ allocation	3	6900	539.31	179.77	<.0001	<.0001
days	3	6900	177.31	59.10	<.0001	<.0001
*area*crew*	3	6900	150.74	50.25	<.0001	<.0001
*IFQ allocation*days*	9	6900	121.20	13.47	<.0001	<.0001
*crew*away*	3	6900	81.90	27.30	<.0001	<.0001

Table 11. Pre-IFQ index relative nominal CPUE, number of trips, proportion positive trips, and standardized abundance index for red grouper constructed using commercial vertical line data.

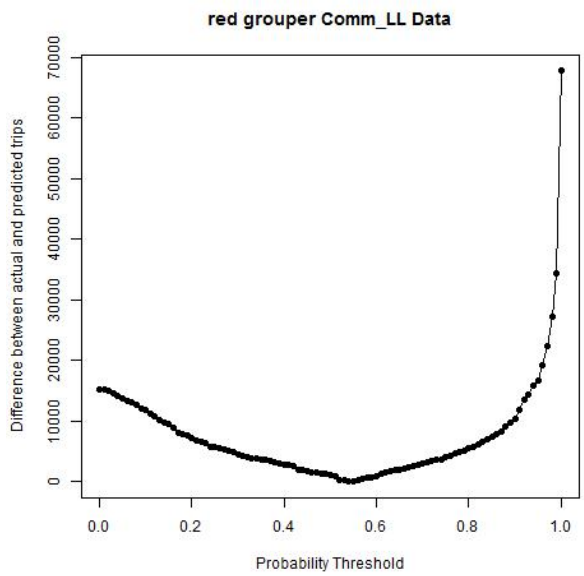
YEAR	Normalized Nominal CPUE	Trips	Proportion Successful Trips	Standardized Index	Lower 95% CI (Index)	Upper 95% CI (Index)	CV (Index)
1993	0.756179	1,670	0.792	0.731148	0.397892	1.343525	0.311394
1994	0.699744	2,239	0.771	0.716001	0.392517	1.306077	0.307467
1995	0.780493	2,281	0.747	0.788638	0.429262	1.448881	0.311289
1996	0.481552	2,256	0.701	0.490723	0.262637	0.916886	0.320343
1997	0.513838	3,318	0.681	0.564737	0.301849	1.056582	0.321058
1998	0.467955	3,874	0.65	0.518547	0.277908	0.967557	0.319611
1999	0.746172	4,244	0.691	0.739924	0.401314	1.364237	0.3132
2000	0.928729	4,210	0.738	0.991072	0.54536	1.801058	0.305457
2001	1.003921	4,120	0.817	1.347042	0.753577	2.40788	0.29665
2002	1.149352	4,192	0.825	1.387094	0.776572	2.477593	0.296246
2003	0.888259	4,068	0.841	0.947107	0.534658	1.67773	0.291835
2004	1.295183	3,732	0.882	1.273959	0.726246	2.234741	0.286637
2005	1.175149	3,064	0.893	1.416903	0.804867	2.494341	0.288524
2006	1.266166	2,768	0.874	1.143482	0.645103	2.026886	0.292174
2007	1.550833	2,595	0.901	1.206628	0.684535	2.126917	0.28921
2008	1.732271	2,701	0.897	1.530894	0.871158	2.690253	0.287586
2009	1.564206	2,606	0.898	1.206101	0.686788	2.118091	0.287235

Figures

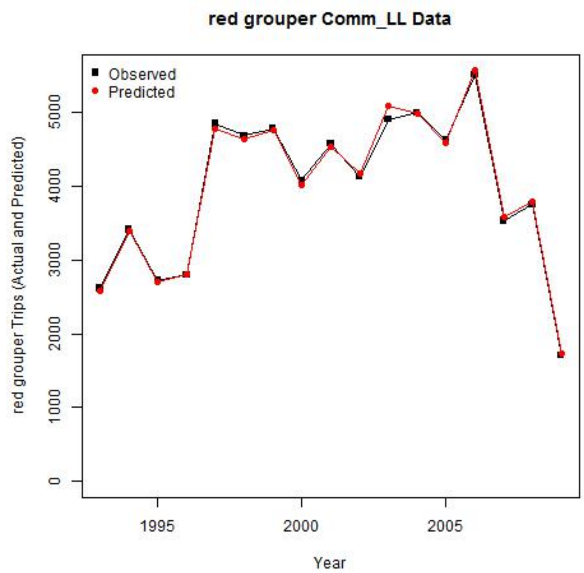
Figure 1. Map of the US commercial fishing statistical (shrimp) grids.



a)



b)



c)

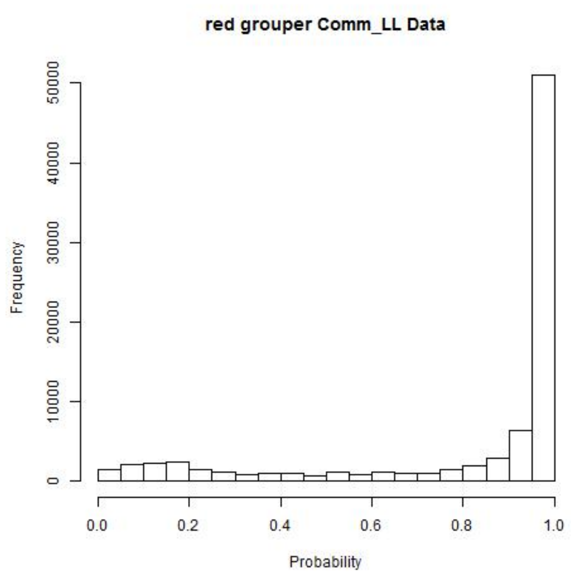
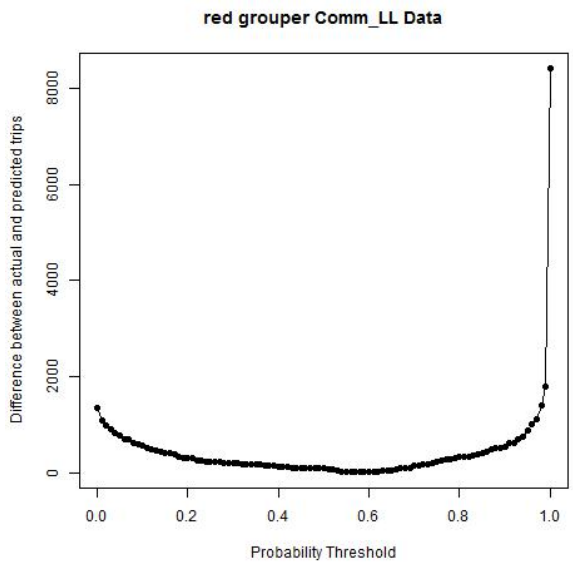
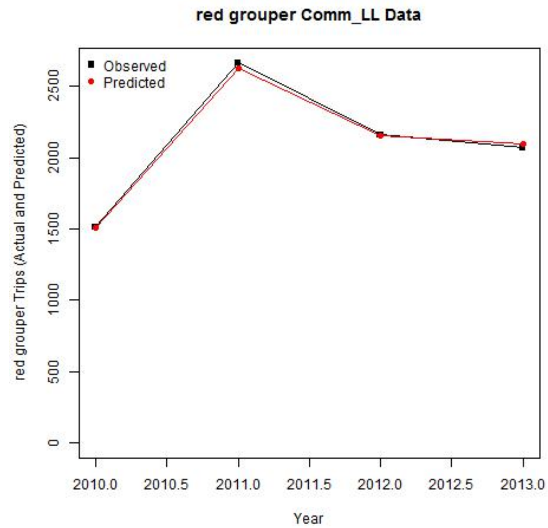


Figure 2. Stephens-MacCall model diagnostics for the pre-IFQ commercial longline index. a) The difference between the number of trips in which red grouper were observed and the number in which they were predicted, b) the number of observed and predicted red grouper trips over time, and c) the frequency of probabilities generated by the species regression.

a)



b)



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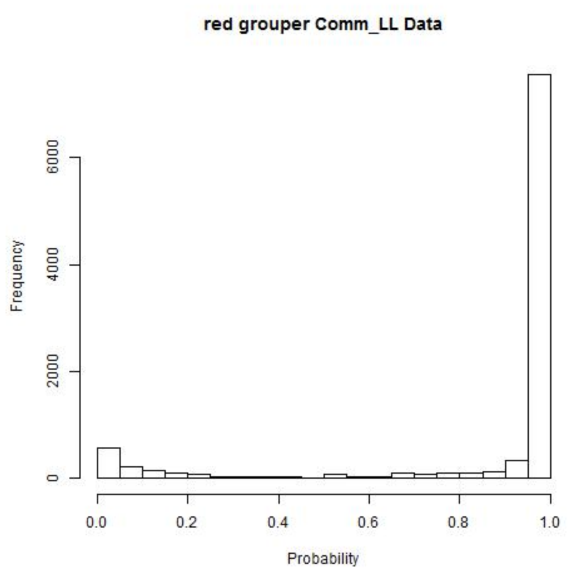
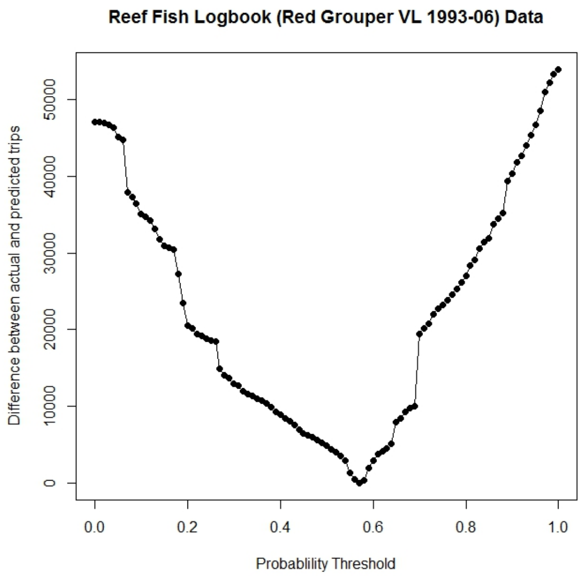
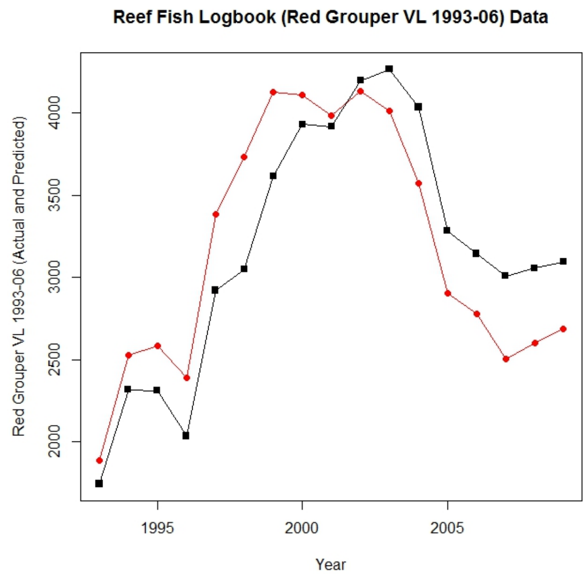


Figure 3. Stephens-MacCall model diagnostics for the IFQ commercial longline index. a) The difference between the number of trips in which red grouper were observed and the number in which they were predicted, b) the number of observed and predicted red grouper trips over time, and c) the frequency of probabilities generated by the species regression.

a)



b)



c)

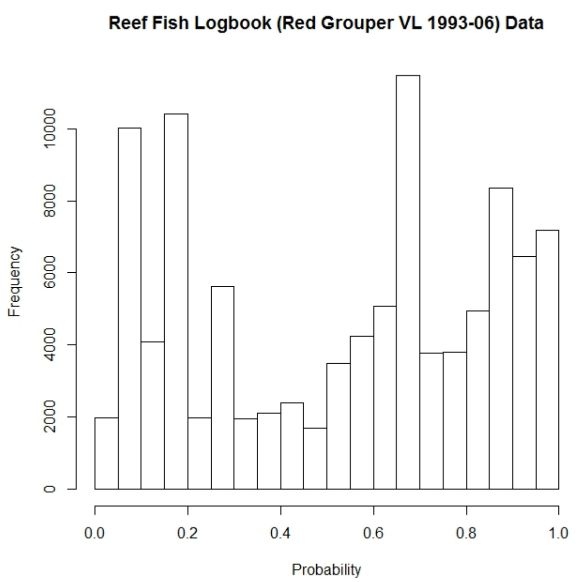


Figure 4. Stephens-MacCall model diagnostics for the pre-IFQ commercial vertical line index. a) The difference between the number of trips in which red grouper were observed and the number in which they were predicted, b) the number of observed and predicted red grouper trips over time, and c) the frequency of probabilities generated by the species regression.

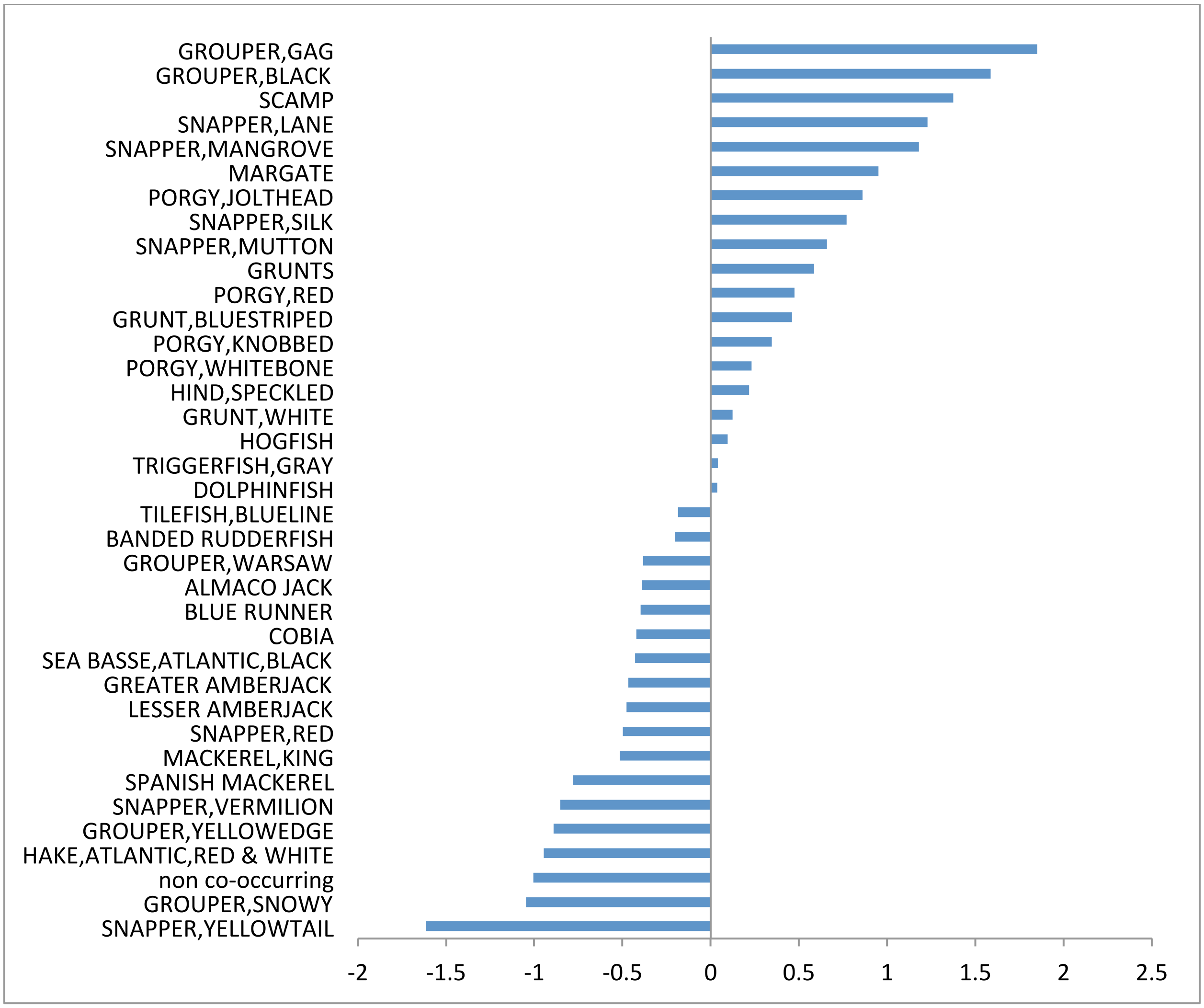
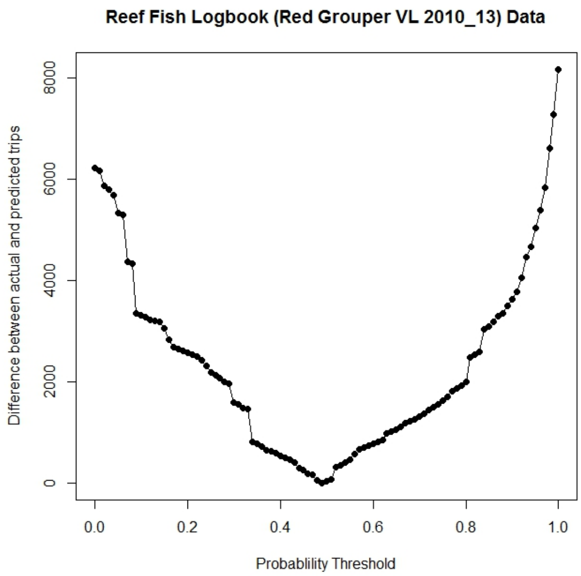
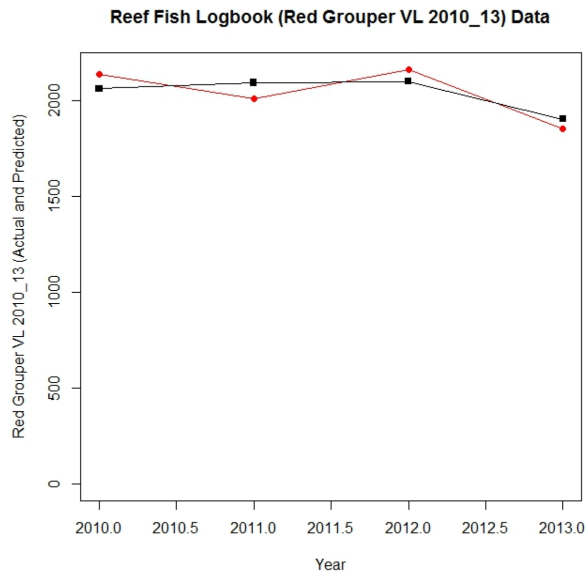


Figure 5. Regression coefficients from the pre-IFQ (1993-2009) Stephens & MacCall analyses of vertical line data. Positive coefficients signify species that had positive associations with the target species. The magnitude of the coefficients indicates the predictive impact of each species. The value for "non co-occurring" is the regression intercept and denotes the probability a trip was fishing in the target species' habitat, but did not report any of the listed species. Species included were reported on at least one percent of vertical line trips in the Gulf of Mexico during 1993-2009.

a)



b)



c)

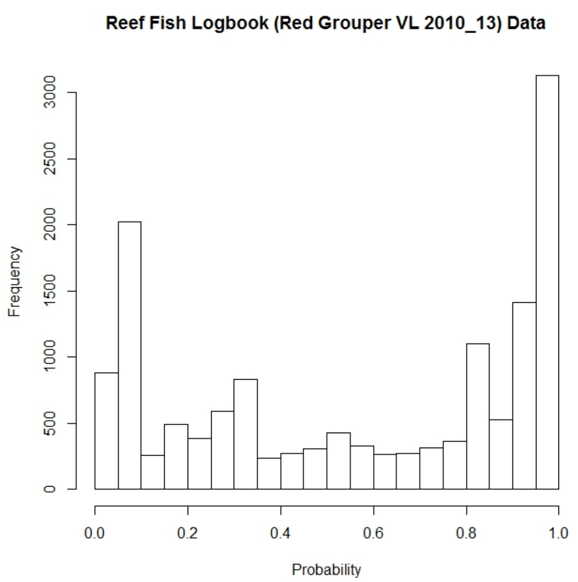


Figure 6. Stephens-MacCall model diagnostics for the IFQ commercial vertical line index. a) The difference between the number of trips in which red grouper were observed and the number in which they were predicted, b) the number of observed and predicted red grouper trips over time, and c) the frequency of probabilities generated by the species regression.

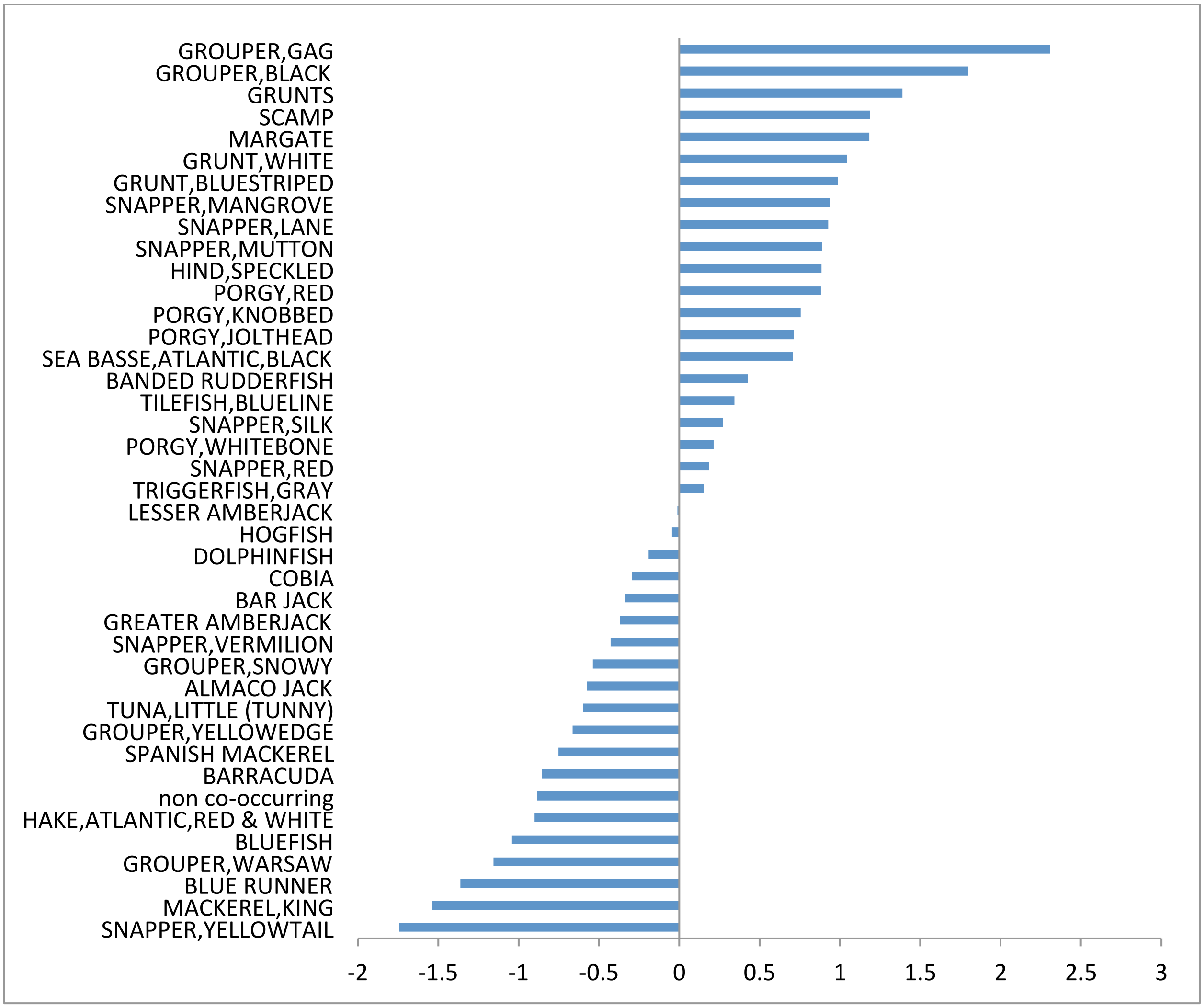


Figure 7. Regression coefficients from the IFQ (2010-2013) Stephens & MacCall analyses of vertical line data. Positive coefficients signify species that had positive associations with the target species. The magnitude of the coefficients indicates the predictive impact of each species. The value for "non co-occurring" is the regression intercept and denotes the probability a trip was fishing in the target species' habitat, but did not report any of the listed species. Species included were reported on at least one percent of vertical line trips in the Gulf of Mexico during 2010-2013.

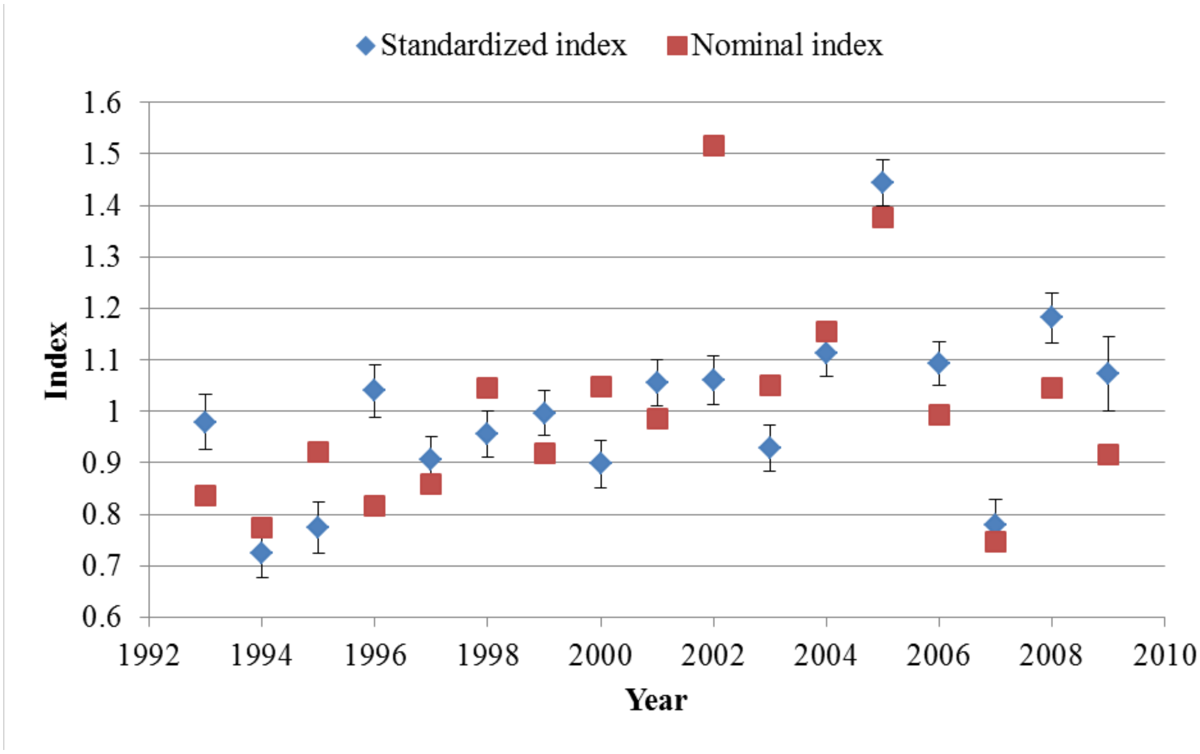


Figure 8. The standardized red grouper commercial longline index for statistical zones 1-10 in the Gulf of Mexico from 1993 until 2009 (years before the implementation of IFQ). The points represent the catch rates normalized to an average of one. The bars represent the CV.

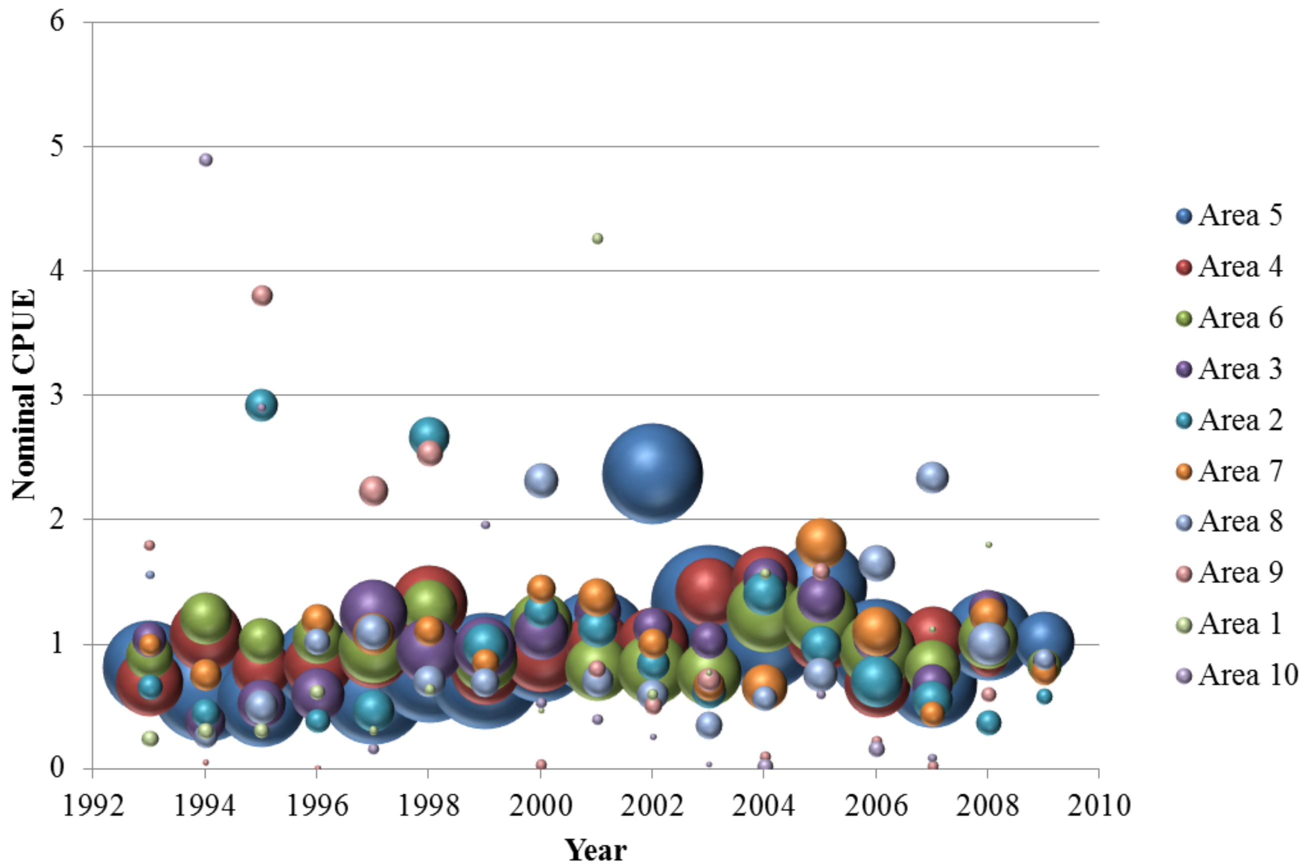
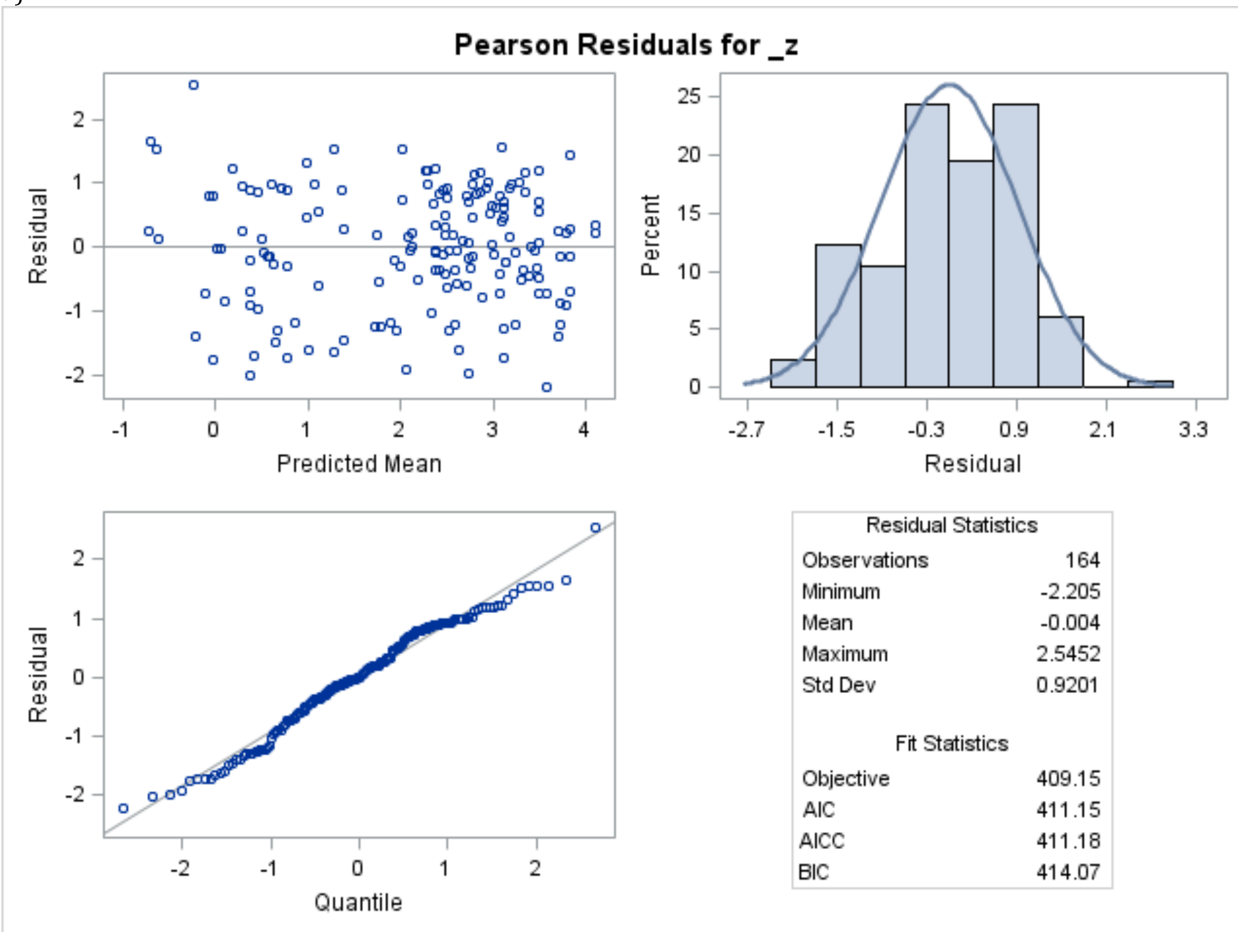


Figure 9. Bubble plot of the pre-IFQ (1993-2009) commercial longline nominal CPUE by year and area. Bubble area represents the number of trips catching red grouper.

a)



b)

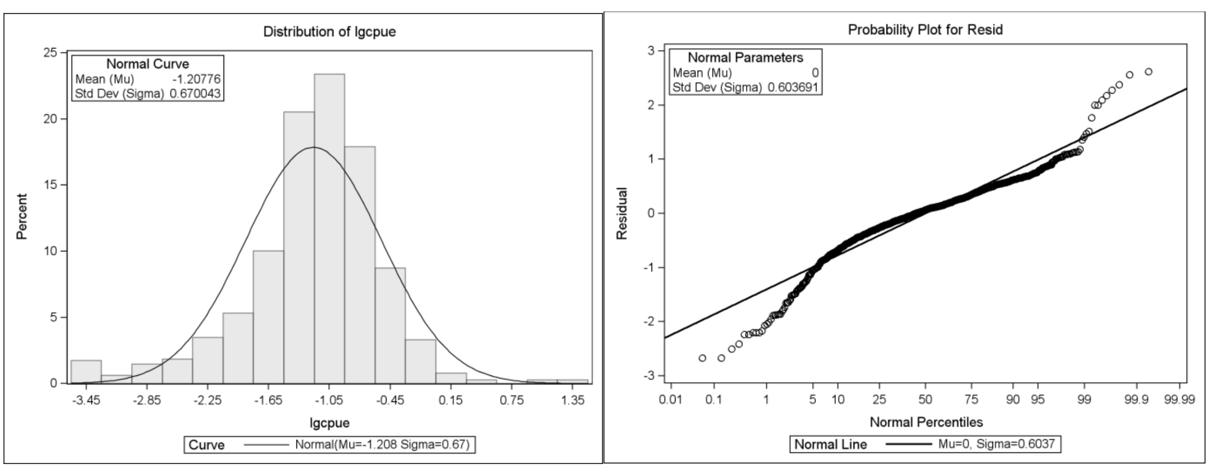


Figure 10. Model diagnostics for the lognormal model fit to the longline a) pre-IFQ (1993-2009) and b) IFQ (2010 – 2013) CPUE data.

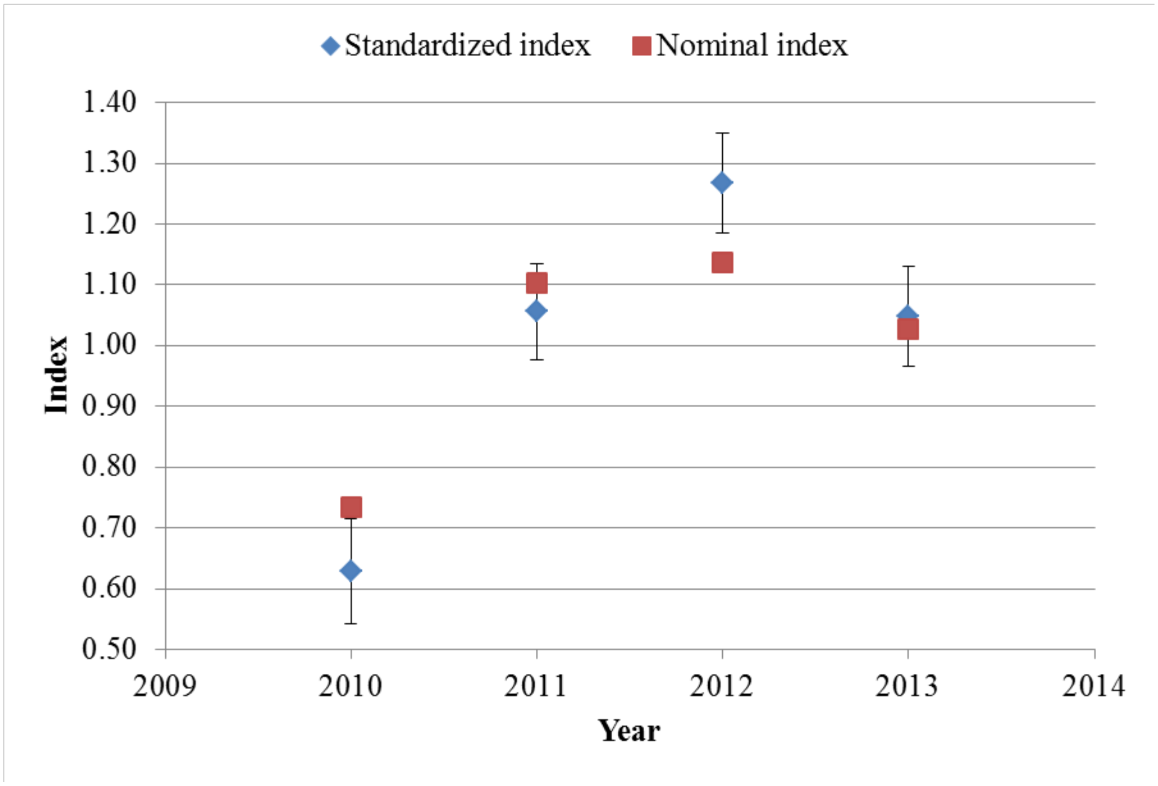


Figure 11. The standardized red grouper commercial longline index for statistical zones 1-10 in the Gulf of Mexico from 2010 until 2013 (years of IFQ program). The points represent the catch rates normalized to an average of one. The bars represent the CV.

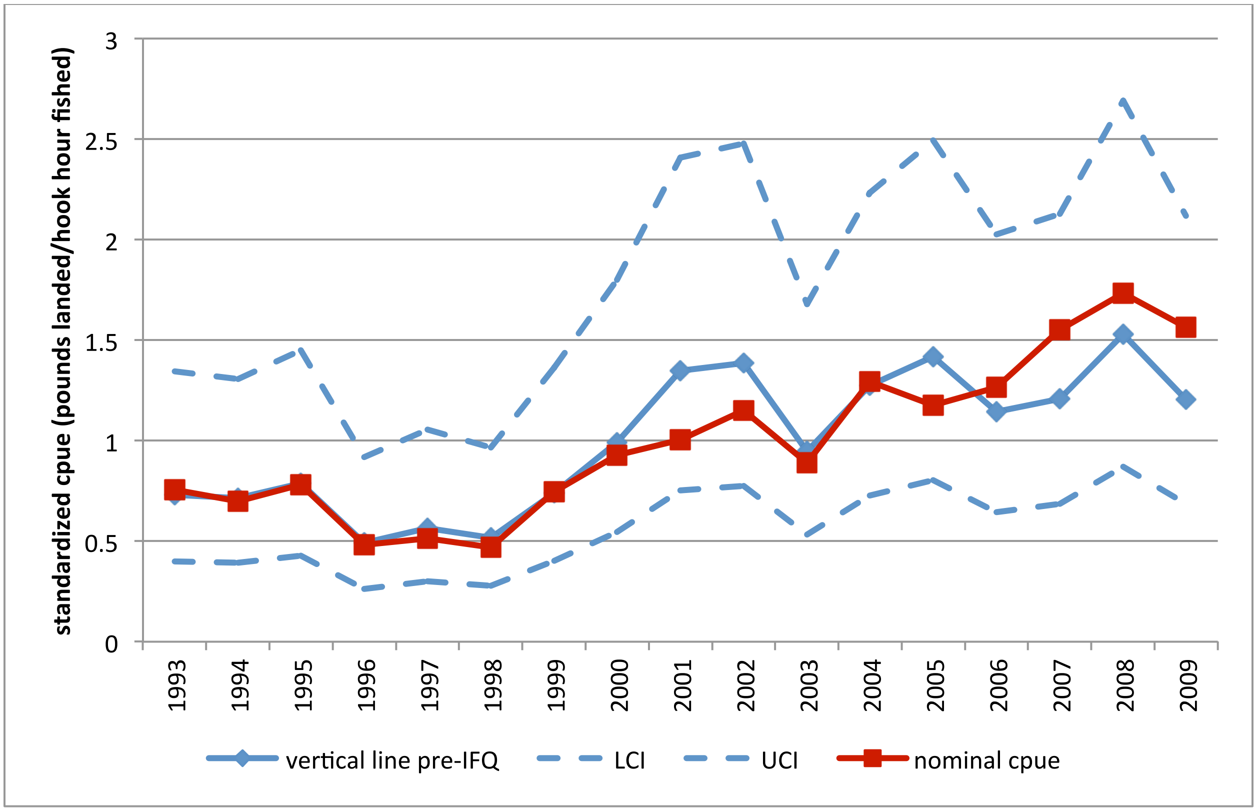
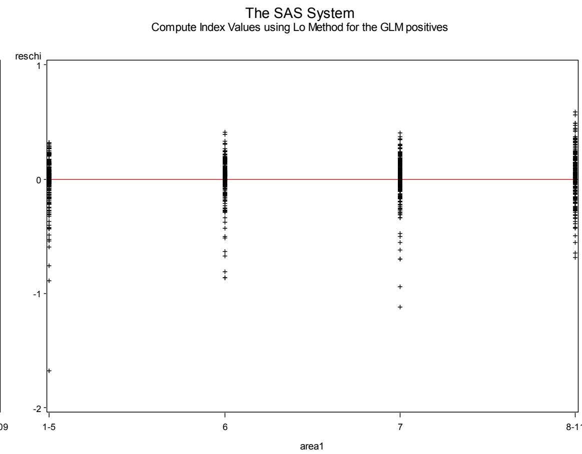


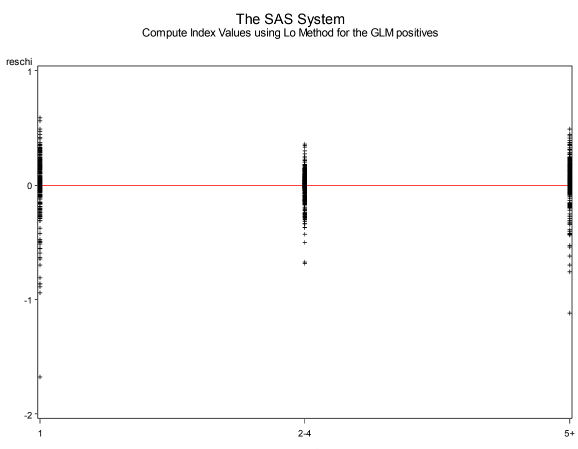
Figure 12. The standardized and nominal red grouper commercial vertical line index for statistical zones 1-11 in the Gulf of Mexico from 1993 until 2009 (years before the implementation of IFQ). The points represent the catch rates normalized to an average of one. The dashed lines represent the upper and lower confidence limits.

A.

B.



C.



D.

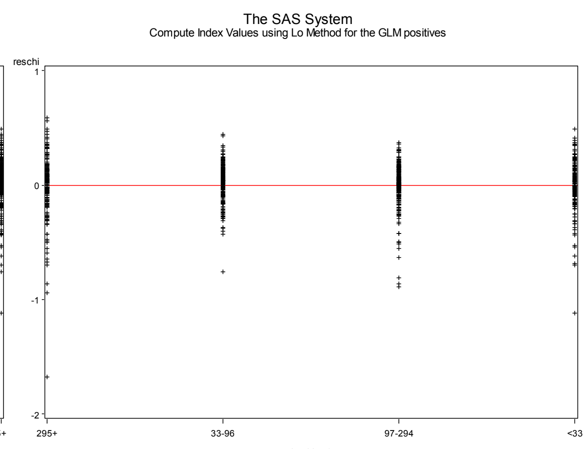


Figure 13. Diagnostic plots for the binomial component of the pre-IFQ (1993-2009) red grouper commercial vertical line gear model: A. the Chi-Square residuals by year; B. the Chi-Square residuals by area fished (labelled area1); C. the Chi-Square residuals by days at sea (labelled away1); and D. the Chi-Square residuals by hook hours fished (labelled hookhrs1).

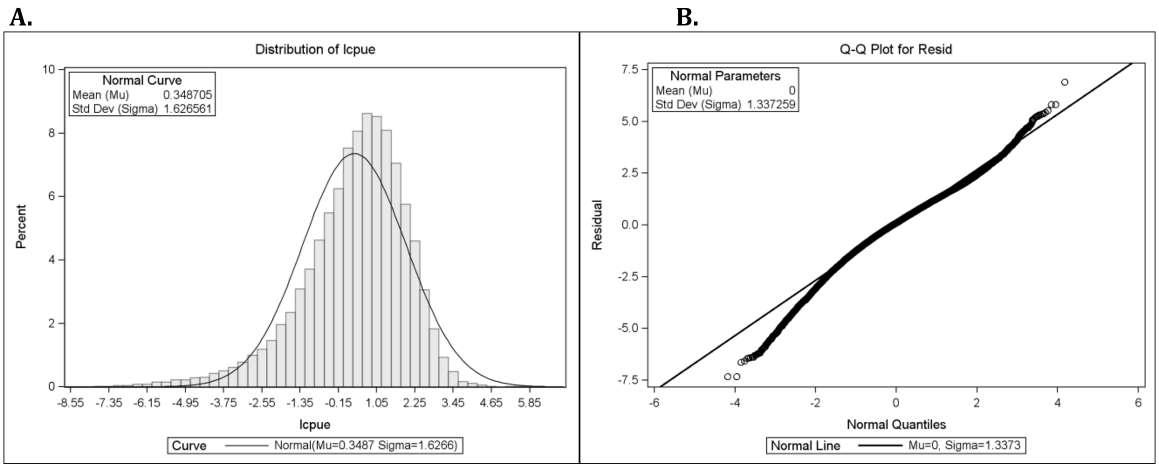


Figure 14. Diagnostic plots for the lognormal component of the pre-IFQ (1993-2009) red grouper commercial vertical line gear model: A. the frequency distribution of log(CPUE) on positive trips, B. the cumulative normalized residuals (QQ-Plot) from the lognormal model. The black lines are the expected normal distribution.

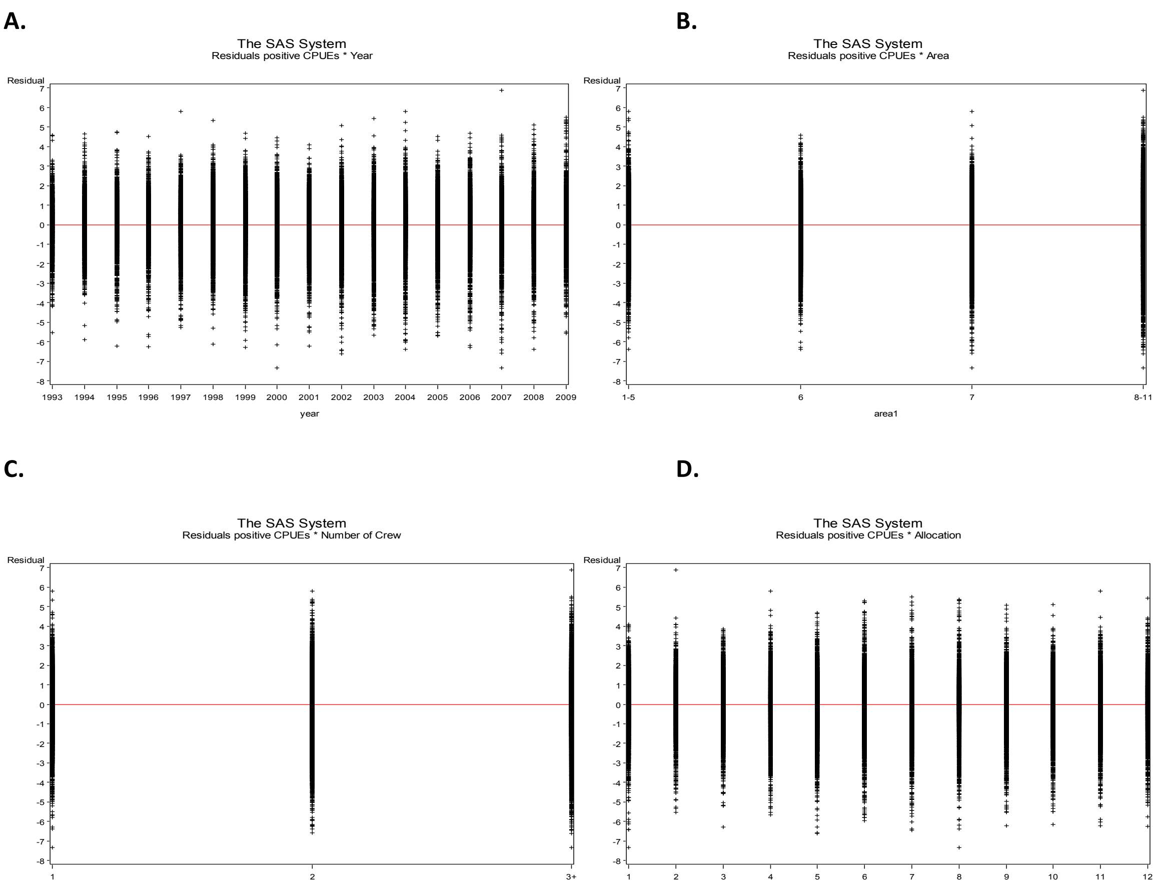


Figure 15. Diagnostic plots for the lognormal component of the pre-IFQ (1993-2009) red grouper commercial vertical line gear model: A. the Chi-Square residuals by year; B. the Chi-Square residuals by area fished (labelled area1); C. the Chi-Square residuals by number of crew (labelled crew1); and D. the Chi-Square residuals by month.

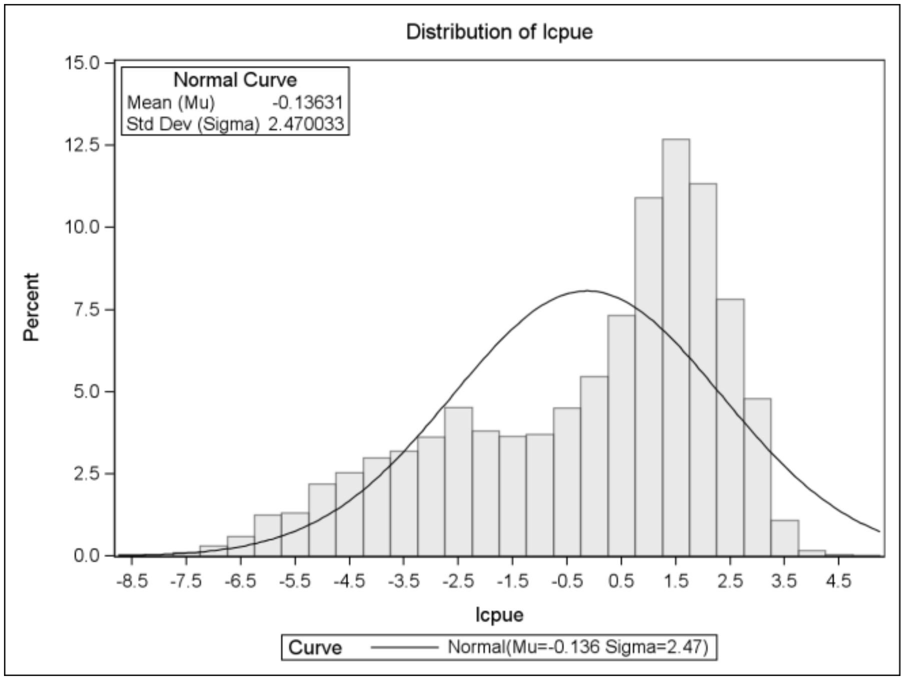


Figure 16. Frequency distribution of log(CPUE) on positive trips from the lognormal portion of the IFQ (2010-2013) red grouper model. The black line is the expected normal distribution.

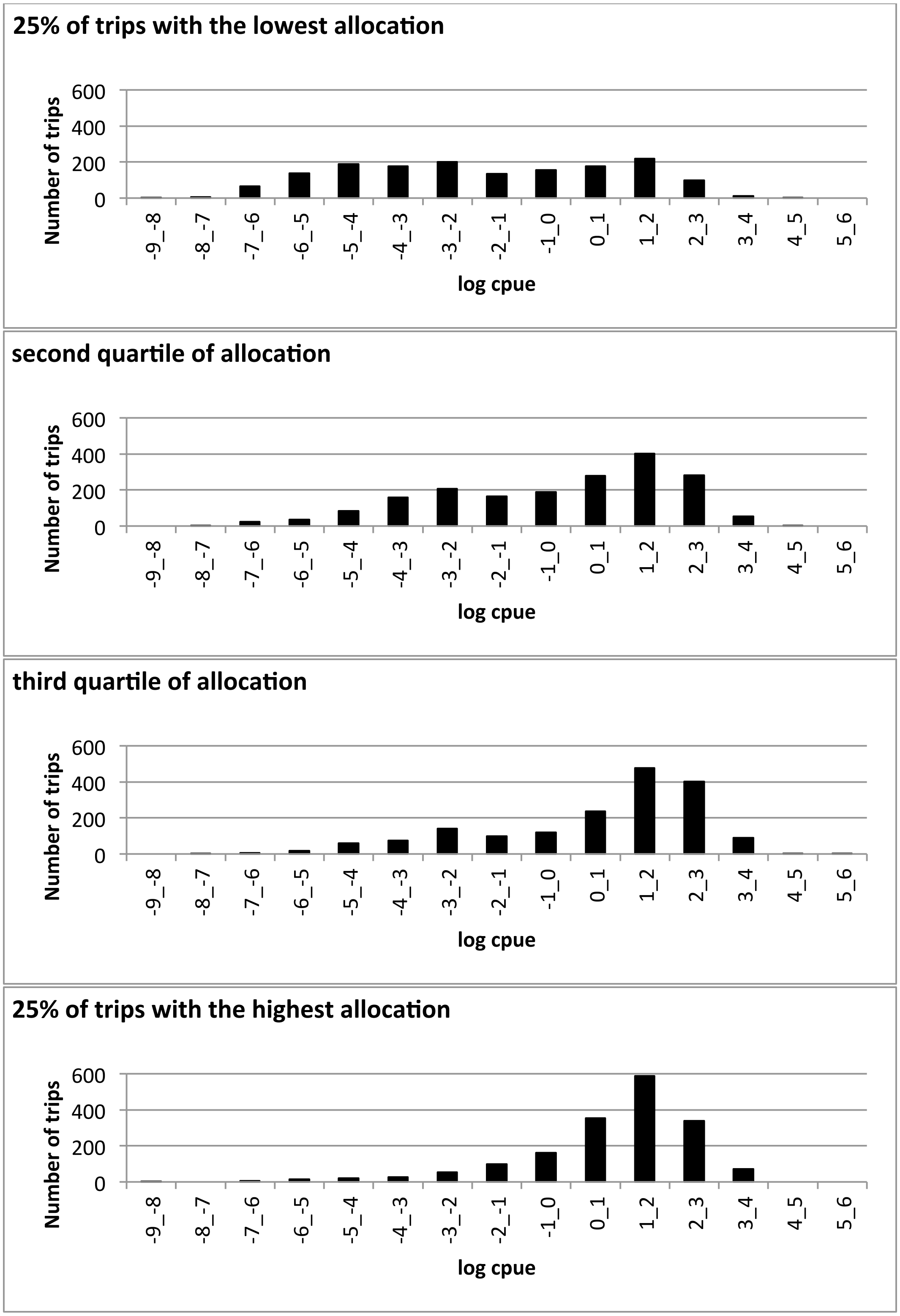


Figure 17. Distribution of the log of cpues calculated from vertical line trips by amount of available red grouper IFQ allocation. Stephens & MacCall selected trips with reported red grouper landings were stratified into four IFQ allocation categories: the 25% of trips with the lowest amount of red grouper IFQ allocation to the 25% of trips with the highest allocation.