Using a Censored Regression Modeling Approach to Standardized Catch Per Unit Effort for Red Snapper (*Lutjanus campechanus*) during 1986-2019 from the Southeast Region Headboat Survey in the U.S. Gulf of Mexico

Gulf of Mexico Fisheries Branch, Sustainable Fisheries Division

SEDAR74-DW-21

18 April 2022
Updated: 27 May 2022

Please cite this document as:

Gulf of Mexico Fisheries Branch, Sustainable Fisheries Division. 2022. Using a Censored Regression Modeling Approach to Standardized Catch Per Unit Effort for Red Snapper (Lutjanus campechanus) during 1986-2019 from the Southeast Region Headboat Survey in the U.S. Gulf of Mexico. SEDAR74-DW-21. SEDAR, North Charleston, SC. 28 pp.

Using a Censored Regression Modeling Approach to Standardized Catch Per Unit Effort for Red Snapper (Lutjanus campechanus) during 1986-2019 from the Southeast Region Headboat Survey in the U.S. Gulf of Mexico

Gulf of Mexico Fisheries Branch
Sustainable Fisheries Division
NOAA Fisheries - Southeast Fisheries Science Center
Corresponding Author Email (*latreese.denson@noaa.gov*)

March 27, 2022

Keywords

Catch per unit effort (CPUE), standardization, recreational fisheries, headboat, censoring, generalized linear model, red snapper, bag limit

Abstract

Established methods for trip selection (i.e., Stephens and MacCall 2004) and index standardization with bag limits (i.e., censored lognormal regression) were applied to recreational data from the Southeast Region Headboat Survey. These methods were used to develop indices of abundance for red snapper (*Lutjanus Campechanus*) in the U.S. Gulf of Mexico. Separate indices were developed for the West, Central, and Eastern Gulf of Mexico following updates from the recent Stock ID process. The resulting indices intend to describe population trends of fish in the size range landed by headboat vessels. Index calculation follows procedures similar to those used for SEDAR 31 and SEDAR 52, except the current indices are further truncated to 2007 to account for increasingly restrictive for-hire vessel regulations.

Introduction

In this study, a delta censored lognormal regression approach following the analysis of Saul and Walter III (2012) and Sagarese and Rios (2017) was used to develop standardized indices of abundance from the Southeast Region Headboat Survey (SRHS) for the recreational red snapper (*Lutjanus campechanus*) fishery in the U.S. Gulf of Mexico. The SRHS conducted by NOAA Fisheries has monitored catch and fishing effort from headboats in the U.S. Gulf of Mexico since 1986. The headboat fishery in the Gulf of Mexico includes for-hire vessels.

The censored regression approach to standardizing CPUE was recommended by the Indices Working Group during SEDAR 31 because of its ability to account for the bag limit effect which, if not accounted for, would otherwise give the artificial perception that abundance had decreased unnecessarily over the time series (SEDAR 2013). The implementation of the trip limit has impacted the ability to properly observe the full potential of red snapper that could be caught for a given unit of fishing effort. During SEDAR 31, the inclusion of discards was not recommended to generate an index as anglers may be altering their fishing behavior after catching their limit of red snapper or while fishing outside of the recreational open season, which would bias their discards.

Since SEDAR 31, there have been additional changes to fisher behavior, management, and assessment population structure for which the analyses in this working paper attempt to account for. During SEDAR 52, evidence suggested that headboat targeting has changed since SEDAR 31, where trips tended to be shorter, closer to shore, and multi-species in nature (SEDAR 2018). These findings prompted the Indices Working Group to suggest the truncation of the SRHS index East to 2013. During both SEDAR 31 and SEDAR 52, the substantial reductions in the length of annual recreational fishing seasons have been a topic of concern as it has greatly reduced the data available for modeling CPUE of red snapper. Most recently, the SEDAR 74 Research Track Stock ID working group determined there were two stock boundaries for red snapper in the U.S. Gulf of Mexico: one boundary remaining at the Mississippi outflow and another in the Big Bend area of Northwest Florida (SEDAR 2021).

Materials and Methods

Data Source

The SRHS collects data on the catch and effort for individual headboat trips. Reported information includes landing date and location, vessel identification, the number of anglers, a single fishing area for the entire trip, trip duration and/or type (half/three-quarter/full/multi-day, day/night, morning/afternoon), and catch by species in number and weight. Headboats use hook and line gear and generally target hard bottom reefs as the fishing grounds and multiple species in the snapper-grouper complex.

Catch per unit effort (CPUE) was calculated on an individual trip basis. The CPUE for each trip was estimated as the number of red snapper landed on a trip divided by the fishing effort, where effort was the product of the number of anglers and the total hours fished. To estimate effort for each trip type (i.e., trip duration), the following assumptions were adopted: Half day trip = 5 hours fished; Three-quarter day trip = 7.5 hours fished, and Full day trip = 10 hours fished.

Data Concerns and Exploratory Analyses

There were three major data concerns when using the SRHS dataset to create and index of abundance that accurately represented the changes in the red snapper population in the U.S. Gulf of Mexico. The data concerns are explored graphically using data from trips which caught red snapper during the open season from 1986-2019.

1. There was a lack of positive observations in the East when the trips east of the Mississippi were split to create the new Central and Eastern regions (**Table 1**). The average percent of positive trips in the East was 2.62%, compared to 81.37% in the West and 77.43% in the

Central region. The lack of positive data in the East limits index standardization capabilities.

2. There has been a bag limit in place since 1990 that has decreased from seven to two fish as of 2007. The impact of trip limits on the index was thoroughly explored by Saul and Walter III (2012). Their explorations resulted in the use of the delta censored lognormal modeling approach to address the now censored positive data.

3. The constant decrease in the allotted days for Federal for-hire season and changes to the individual state season likely influences fishery behavior and stability (**Table 2**). These changes in management may decouple trends in observations from the trends in abundance. The Federal for-hire fishery was open all year until 1997, when it was reduced to 330 days. A reduction in days continued until 2000 where there was a constant 194-day season (53% of the year), between April 21st and November 1st, for seven years. In 2008, the open season was again decreased to only 65 days (17% of the year). The federal for-hire season lengths have fluctuated since but have not been open for greater than 75 days (21% of the year).

Data Filtering

The following data preparation and filtering techniques were applied to the 1986-2019 SRHS dataset:

1. Trips were separated into the regions specified by the red snapper Stock ID process (SEDAR 2021). Similar to SEDAR 52, SRHS grid areas 24 through 27 are considered the Western region (30.93% of observations). Unlike SEDAR 52, the SRHS grid areas 23, 28, and 29 are now a part of the newly identified Central region (30.76% of observations), while 18, 21, and 22 are part of the Eastern region (38.31% of observations).

2. Observations were included from half-day trips (34.21%), three-quarter day trips (28.59%), multiday trips (2.15%) and full-day trips (35.04%).

3. Trips with possible errors in catch and effort information were excluded including trips with an unusually large number of target species relative to the observations from the same region.

4. Trips with zero anglers were excluded. This was likely an error.

5. Trips during the closed season for red snapper were excluded. Closed season data were excluded because fishing effort outside of the red snapper fishing season would not have targeted red snapper, and any red snapper caught incidentally would have been discarded and not recorded in the headboat survey.

6. Trips after 2007 and outside of April 21st and November 1st were removed. Exploratory analyses show an influence of season length on fishery stability and fishing behavior. This includes fluctuations in participation by headboat captains and positive catches.

Subsetting Trips: Stephens and MacCall

The Stephens and MacCall approach (Stephens and MacCall 2004) was used to select trips to develop the index since no direct targeting information was available. This is the same approach used previously for red snapper by Saul and Walter III (2012) as well as Sagarese and Rios (2017). This approach uses the species composition of each trip in a logistic regression of species presence/absence to infer if effort on that trip occurred in habitat similar to that of red snapper. If effort on a trip was determined to occur in similar habitat to red snapper, then that trip was used in the analysis (Stephens and MacCall 2004).

Standardization: Delta Censored Lognormal Modeling Approach

The delta censored lognormal regression approach combines separate generalized linear model (GLM) analyses of the proportion of successful trips (trips that landed red snapper) and the catch rates on successful trips to construct a single standardized CPUE index (Lo et al. 1992, Hinton and Maunder 2004, Maunder and Punt 2004). For each GLM procedure of proportion positive trips, a type-3 model was fit, a binomial error distribution was assumed, and the logit link was selected. In this analysis, catch rates on successful trips are assumed to follow a censored lognormal error distribution. For the censored lognormal models, the response variable, ln(*CPUE*), was calculated as:

ln(CPUE) = ln(Catch) / (anglers x hours fished)

Variable Selection

The following factors were treated as fixed effects and were examined as possible influences on the proportion of positive trips and the catch rates of positive trips:

Factor	Factor Levels	Details
Year	21	1986 – 2007
Area	4	West: Louisiana, Northeast Texas, Port Aransas, TX, Port Isabel, TX
	3	Central: Alabama, Mississippi, Northwest Florida and Alabama
	3	East: Dry Tortugas, Florida Middle Grounds, Southwest Florida
Season	4	Dec-Feb, Mar-May, June-Aug, Sep-Nov
Anglers*	10	0-9, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89, 90+
Trip Type*	4	Full Day, Half Day, Three Quarter Day, Multiday

*Only explored as factors for modeling success because these factors were confounded with effort for the CPUE response variable in the lognormal model.

A stepwise approach was used to quantify the relative importance of the explanatory factors. First, a GLM model was fit to the null model (only the intercept) and the AIC, deviance and degrees of freedom were calculated. Next, a suite of models was tested, where each potential explanatory factor was added to the null model. Again, the AIC, deviance, and degrees of freedom were calculated. The model with the factor that had the lowest AIC became the new base model, and the process repeatedly added factors individually, until either the AIC was no longer further reduced or all the factors were added to the model. In addition to screening using

AIC, factors were also screened and not added to the model if the reduction in deviance per degree of freedom was less than one percent. This screening was implemented to fit a more parsimonious model, given the fact that factors which reduce the deviance by so little exert little influence on the index trend. Two-way interactions among significant main effects were not examined because many of these interactions were confounded with one another (such as the interaction of year and month confounding with the regulatory season factor). The final censored lognormal model was fit using the SAS procedure "proc lifereg" (SAS Institute Inc. 1999).

This algorithm fits parametric models to failure time data that can be uncensored, right censored, left censored, or interval censored. The model for the response variable is a linear effect composed of the covariates and a random disturbance term, which is from the lognormal distribution for this work. The model for the response variable is:

$$\boldsymbol{y = X\beta + \sigma\epsilon}$$

where y is the vector of response values, X is the design matrix, β is a vector of unknown regression parameters, σ is an unknown scale parameter, and ϵ is a vector of errors assumed to come from a lognormal distribution. The procedure estimates the parameters of this model using maximum likelihood with a Newton-Raphson algorithm (SAS 9.22 User's Guide 2010; Scott Long 1997, Allison 2010). Martingale-type residuals are used to assess model fit (Barros et al. 2010).

Results and Discussion

Exploratory Analyses

In the Western U.S. Gulf of Mexico and Central U.S. Gulf of Mexico as the number of vessels increased in the fishery, the average number of positive trips also increased. The simultaneous increase in vessels and positive trips indicated some stability in the fishery until the year 2000, when the Federal for-hire season length decreased to 194 days. Another change in the stability of the fishery occurs in 2008 and beyond, when the season length was reduced further to 65 days. In the Eastern U.S. Gulf of Mexico, there was no stable pattern at any point in the time series as the population in this region was likely depleted and beginning to rebuild (**Figure 1**). When standardized indices from 1986 to 2019 for the Western and Central U.S. Gulf of Mexico were compared to federal for-hire season length, there was an increase in CPUE after 2008 (**Figure 2**). The Western U.S. Gulf of Mexico experienced a sharp increase in CPUE while increases in the Central U.S. Gulf of Mexico were moderate. As the season length was shortened, it is likely that headboat captains in the Central region were aware of where to go for red snapper and were increasing their effort within the shortened season, thus artificially increasing the index of abundance post 2007. **Figure 1** and **Figure 2** indicate that changes in management influenced fishery behavior and possibly decoupled the relationship between CPUE and relative population abundance. In an effort to produce an index which accurately reflected the changes in red snapper relative abundance in the U.S. Gulf of Mexico, the remaining results are provided using data from 1986-2007 only, as the season length changed dramatically post-2007.

Species Associations - Stephens and MacCall (2004) Approach - Western U.S. Gulf of Mexico

The minimum difference between the predicted and the observed number of trips that reported red snapper occurred at the probability threshold of 0.44 (**Figure 3C**). Predicted trips were similar to the observed for most of the time series. Predictions were slightly underestimated early in the time series and overestimated at the end of the time series (**Figure 3C**). Trips with a predicted probability greater than the critical threshold probability were considered trips that targeted red snapper (**Figure 3C**). Nominal CPUE was relatively similar before and after applying the Stephens and MacCall (2004) approach, with the exception of the late-1980s and the early-2000s. The Nominal CPUE experienced a dip in 1990 which is when trip limits were initiated, likely affecting the reporting of catch (**Figure 3D**). This method retained 75.6% of the total trips and 92.2% of trips that reported red snapper. Prior to trip selection, there were 38,003 trips, and the proportion positive was 0.76. After selection, there were 28,724 trips, and the proportion positive was 0.92.

The Stephens and MacCall (2004) trip subsetting approach identified 34 fish species which were captured with red snapper in the West. Vermilion Snapper, Gray Triggerfish, Gag, Gray Snapper, and Lane Snapper were highly positively correlated to red snapper whereas Red Porgy, King Mackerel, Little Tunny, and Crevalle Jack were greatly negatively correlated.

Species Associations - Stephens and MacCall (2004) Approach - Central U.S. Gulf of Mexico

The minimum difference between the predicted and the observed number of trips that reported red snapper occurred at the probability threshold of 0.61 (**Figure 4A**). The trends in predicted and observed trips were very similar, with both gradually increasing throughout the time series and with a drop in trips in 1999 that were similar to the Western U.S. Gulf of Mexico (**Figure 4B**). Nominal CPUE was relatively similar before and after applying the Stephens and MacCall (2004) approach (**Figure 4D**). This method retained 73.1% of the total trips and 84.3% of trips that reported Red Snapper. Prior to trip selection, there were 35,145 trips, and the proportion positive was 0.73. After selection, there were 25,695 trips, and the proportion positive was 0.84. The Stephens and MacCall (2004) trip subsetting approach identified 39 fish species which were captured with red Snapper in the Central region. Gulf Flounder, Gag, Red Grouper, Gray Snapper, and Gray Triggerfish were highly positively correlated to Red Snapper whereas Bank Sea Bass, Red Porgy, Rock Sea Bass, and Dusky Flounder were extremely negatively correlated.

Species Associations - Stephens and MacCall (2004) Approach - East U.S. Gulf of Mexico

Due to the lack of positive trips in the Eastern U.S. Gulf of Mexico, a minimum difference between the predicted and the observed number of trips that reported red snapper was difficult to determine but occurred at the probability threshold of 0.25 (**Figure 5A**). There was no constant pattern of over- or underestimation between predicted and observed trips over the time series. The changes were sporadic-- in the early 1990's there appeared to be some over estimation with slight underestimation in the mid-2000's (**Figure 5B**). Nominal CPUE was relatively similar before and after applying the Stephens and MacCall (2004) approach, with the exception of 1986, 2006, and 2007. The Nominal CPUE was also relatively flat until approximately 1998 where it appears to increase until the end of the time series (**Figure 5D**). This method retained 1.4% of the total trips and 57.6% of trips that reported Red Snapper. Prior to trip selection, there were 34,571 trips, and the proportion positive was 0.01. After selection, there were 486 trips, and the proportion positive was 0.58. The trips that were selected from this approach were dominated by those that caught red snapper whether they were the actual target of the trip or not.

The Stephens and MacCall (2004) trip subsetting approach identified 34 fish species which were captured with Red Snapper. Red Porgy, Gag, Whitebone Porgy, Greater Amberjack, and Knobbed Porgy were positively correlated to red snapper whereas Rainbow Runner, Pinfish, Tomtate, and Spanish Mackerel were negatively correlated.

Trends in Species Associations Between Regions for the Stephens and MacCall (2004) approach

The derived probability threshold was not similar across regions, where the threshold was highest in the Central U.S. Gulf of Mexico and lowest in the East. The proportion positive before applying the Stephens and MacCall (2004) approach was similar in all regions except the Eastern U.S. Gulf of Mexico. Applying the Stephens and MacCall (2004) approach dramatically increased the proportion positive for the East U.S. Gulf of Mexico but greatly reduced the number of overall trips (**Figure 6**).

Annual Abundance Indices

Final deviance tables are included in **Tables 3-5** for their respective regions. The final model components for the binomial (i.e., proportion positive) and censored lognormal (catch rate of positive trips) differed based on the region.

Diagnostics for each component of the GLM are provided in **Figure 7** and **Figure 8** for the Western U.S. Gulf of Mexico and Central U.S. Gulf of Mexico, respectively. Residual analysis of the binomial model showed no extreme pattern in the residuals by year. The censored lognormal model results suggest an acceptable fit to the data. The model fit indicated that the assumption of a censored lognormal distribution for positive catch rates continues to be a reasonable assumption for the data. Residual analysis of the lognormal model also showed no obvious patterns in the residuals by year. Diagnostics are not included for the Eastern U.S. Gulf of Mexico as the model was unable to converge to produce a standardized index.

Tables 6-8 summarize the indices, corresponding lower and upper 95% confidence limits, annual coefficients of variation, nominal CPUE, and number of trips (where applicable). Nominal CPUE values fell within the 95% confidence interval of the standardized index, with the exception of the values in years of the Western U.S. Gulf of Mexico index (**Figure 7**). Relative abundance in the Western U.S. Gulf of Mexico remained greater than the relative abundance in the Central U.S. Gulf of Mexico until 1997 when the Western U.S. Gulf of Mexico region experienced a decrease in relative abundance. The Central U.S. Gulf of Mexico region has experienced an overall increase in relative abundance over the time series, with the exception of a decrease from 2002 until 2006 (**Figure 9**). Compared to the other regions, the nominal CPUE for the Eastern U.S. Gulf of Mexico was relatively flat until 1999 before increases from 2001 to 2005. This was likely a reflection of a rebuilding population in a historically depleted region.

Comments on Adequacy for Assessment

Previous Gulf reef fish assessments have included the SRHS index because it contains one of the longest time series and has widespread spatial coverage compared to other indices. Unfortunately, red snapper are a highly regulated species further biasing the fishery-dependent data collected by the SRHS. Past analyses have attempted to account for regulatory changes by using advanced statistical methodology (i.e. a censored lognormal regression) and time series truncation (SEDAR 2018). As regulations for red snapper are frequently updated, the most risk adverse approach for SEDAR 74 would be to explore the use of the SRHS Western and Central indices as presented in this working paper. Specifically, using these indices truncated to a period where management was relatively consistent, April 21st to November 1st annually from 1986-2007. Given the lack of trips selected for the Eastern U.S. Gulf of Mexico and model convergence issues, the East U.S. Gulf of Mexico index is currently not adequate for consideration in SEDAR 74.

Additional research is needed to explore alternative trip selection approaches which may be more appropriate for the U.S. Gulf of Mexico and South Atlantic recreational fisheries.

Acknowledgements

The authors would like to thank SEFSC Sustainable Fisheries Gulf of Mexico Branch staff, Aydan Rios from the Caribbean Branch, and Erik Fitzpatrick from the Data Assessment and Analysis Services Branch for their assistance with developing the index presented in this work.

References

Allison, P. D. 2010. Survival analysis using SAS: a practical guide. SAS Institute, Cary, NC.

Barros, M., M. Galea, M. González, and V. Leiva. 2010. Influence diagnostics in the tobit censored response model. Statistical Methods & Applications 19:379-397.

Hinton, M. G., and M. N. Maunder. 2004. Methods for standardizing CPUE and how to select among them. Col. Vol. Sci. Pap. ICCAT 56:169-177.

Lo, N. C.-h., L. D. Jacobson, and J. L. Squire. 1992. Indices of Relative Abundance from Fish Spotter Data based on Delta-Lognornial Models. Canadian Journal of Fisheries and Aquatic Sciences 49:2515-2526.

Maunder, M. N., and A. E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research 70:141-159.

Sagarese, S., and A. Rios. 2017. Using a Censored Regression Modeling Approach to Standardize Red Snapper Catch per Unit Effort Using Recreational Fishery Data Affected by a Bag Limit. SEDAR52-WP-13. SEDAR, North Charleston, SC. 27 pp.

Saul, S., and J. F. Walter III. 2012. Using a censored regression modeling approach to standardize red snapper catch per unit effort using recreational fishery data affected by a bag limit. SEDAR, North Charleston, SC. Scott Long, J. 1997. Regression models for categorical and limited dependent variables. Advanced quantitative techniques in the social sciences 7.

SEDAR. 2013. SEDAR 31: Gulf of Mexico Red Snapper Stock Assessment Report. SEDAR, North Charleston, SC. 242 pp.

SEDAR. 2018. SEDAR 52: Stock Assessment of Red Snapper in the Gulf of Mexico. SEDAR, North Charleston, SC. 242 pp.

SEDAR. 2021. SEDAR 74: Gulf of Mexico Red Snapper Stock ID Process Final Report. SEDAR, North Charleston, SC, 87 pp.

SAS Institute Inc. 1997, SAS/STAT Software: Changes and Enhancements through Release 6.12. Cary, NC: Sas Institute Inc., 1997. 1167 pp.

Stephens, A., and A. MacCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. Fish. Res. 70:299-310.

Tables

Table 1. Percentage of positive (PPos.) trips by region, annually. Data in tables are values prior to species association trip selection (Stephens and MacCall 2004) or data filtering.

Year	West Trips	West PPos.	Central Trips	Central PPos.	East Trips	East PPos.
1986	1,626	69.74	451	51.66	2,363	1.82
1987	1,950	68.72	766	50.13	1,858	1.24
1988	2,143	68.18	1,790	52.63	2,329	0.94
1989	2,061	68.70	1,665	51.17	3,162	0.60
1990	2,083	69.52	2,048	51.17	6,176	0.63
1991	1,841	77.02	1,982	54.89	5,244	0.55
1992	2,648	79.34	2,240	60.54	5,352	0.19
1993	2,787	84.71	2,597	62.46	5,340	1.12
1994	3,288	80.69	2,471	56.74	4,899	0.51
1995	3,093	80.73	2,650	55.28	3,254	0.03
1996	2,675	82.65	2,548	66.33	3,216	0.31
1997	2,611	76.60	2,579	79.80	2,874	0.42
1998	2,594	79.84	2,319	84.61	1,815	1.10
1999	1,237	86.10	1,423	86.58	1,427	4.41
2000	1,623	76.65	1,837	83.78	1,118	2.50
2001	1,685	85.10	1,751	85.61	1,045	3.06
2002	1,841	81.75	1,807	92.97	961	2.91
2003	1,684	81.35	1,787	92.22	1,106	2.71
2004	1,773	84.55	1,571	91.92	1,288	3.18
2005	1,693	87.77	1,317	94.15	1,536	4.62
2006	1,719	87.55	1,342	93.59	923	5.53
2007	1,743	90.07	1,372	97.81	1,315	2.21
2008	418	93.54	1,096	96.99	806	6.58
2009	989	87.66	1,532	99.28	1,006	8.85
2010	722	95.01	645	97.05	858	6.41

Year	West Trips	West PPos.	Central Trips	Central PPos.	East Trips	East PPos.
2011	635	95.91	1,198	94.57	609	6.73
2012	686	93.73	1,028	93.58	514	8.75
2013	542	95.20	938	92.86	441	9.30
2014	133	91.73	250	97.20	122	14.75
2015	585	87.18	1,089	89.35	657	7.00
2016	661	95.61	1,255	90.28	723	16.04
2017	758	95.91	1,413	94.83	783	26.44
2018	758	96.04	1,588	92.57	930	19.68
2019	810	98.64	1,463	92.07	959	18.56

Table 2. Recreational for-hire season lengths, and opening and closing dates impacting the Southeast Region Headboat Survey trips.

Year	Number of Open Days	Open Date	Close Date
Pre-1990	365	1-Jan	31-Dec
1990	365	"	"
1991	"	"	"
1992	"	"	"
1993	"	"	"
1994	"	"	"
1995	"	"	"
1996	"	"	"
1997	330	"	27-Nov
1998	272	"	30-Sep
1999	240	"	29-Aug
2000	194	21-Apr	1-Nov
2001	"	"	1-Nov
2002	"	"	1-Nov
2003	"	"	1-Nov
2004	"	"	1-Nov
2005	"	"	1-Nov
2006	"	"	1-Nov
2007	"	"	1-Nov
2008	65	1-Jun	5-Aug
2009	75	"	15-Aug
2010	53	"	24-Jul
2011	48	"	19-Jul

Year	Number of Open Days	Open Date	Close Date
2012	46	"	17-Jul
2013	42	1-Jun; 1-Oct	29-June; 15-Oct
2014	9	"	9-Jun
2015	44	"	15-Jul
2016	46	"	17-Jul
2017	49	"	19-Jul
2018	51	1-Jun	22-Jul
2019	48	1-Jun	19-Jul
2020	63	1-Jun	2-Aug

Table 3. Deviance tables for the regression models for red snapper in the Western U.S. Gulf of Mexico. The table shows the order of the factors as they were sequentially added to each model. Fit diagnostics listed for each factor were the diagnostics from a model that included that factor and all of the factors listed above it in the tables below.

Factor	DF	Deviance	Residual DF	Residual Deviance	AIC	Deviance Reduced	Log likelihood	Likelihood Ratio Test
Binomial								
Null	1	15,601	28,723	15,601	15,603		-7,800	
Trip Type	3	1,720	28,720	13,880	13,888	11.03	-6,941	1,718.91
Area	3	1,168	28,717	12,711	12,725	7.49	-6,359	1,162.69
Year	21	523	28,696	12,188	12,244	3.35	-6,101	517.14
Anglers	9	306	28,687	11,882	11,956	1.97	-5,969	264.58
Season	2	276	28,685	11,605	11,683	1.77	-5,839	258.30
Positive Observations								
Null	1	58,547	26,509	58,547	21,008		-10,502	
Year	21	4,483	26,489	54,063	18,938	7.66	-9,446	2,112.04
Area	3	3,702	26,507	50,360	17,063	6.32	-8,505	1,880.81
Season	2	1,675	26,508	48,685	16,170	2.86	-8,057	897.03

Table 4. Deviance tables for the regression models for red snapper in the Central U.S. Gulf of Mexico. The table shows the order of the factors as they were sequentially added to each model. Fit diagnostics listed for each factor were the diagnostics from a model that included that factor and all of the factors listed above it in the tables below.

Factor	DF	Deviance	Residual DF	Residual Deviance	AIC	Deviance Reduced	Log likelihood	Likelihood Ratio Test
Binomial								
Null	1	22,484	25,694	22,484	22,486		-11,242	
Year	21	2,741	25,673	19,742	19,786	12.19	-9,872	2,739.85
Trip Type	3	844	25,670	18,897	18,947	3.76	-9,470	802.74
Positive Observations								
Null	1	2,938	21,616	2,938	-43,131		21,567	
year	21	440	21,596	2,498	-46,602	15.00	23,324	3,512.53
Season	2	124	21,615	2,373	-47,705	4.24	23,877	1,107.06

Table 5. Deviance tables for the regression models for red snapper in the East U.S. Gulf of Mexico. The table shows the order of the factors as they were sequentially added to each model. Fit diagnostics listed for each factor were the diagnostics from a model that included that factor and all of the factors listed above it in the tables below.

Factor	DF	Deviance	Residual DF	Residual Deviance	AIC	Deviance Reduced	Log likelihood	Likelihood Ratio Test
Binomial								
Null	1	661	485	661	663		-330	
Year	20	246	465	414	456	37.31	-208	244.68
Area	2	10	463	404	450	1.55	-223	-29.76
Season	2	6	461	397	447	1.05	-221	2.96
Positive Observations								
Null	1	0	281	0	-1,764		884	
Year	17	0	265	0	-1,918	48.62	978	187.80
Season	2	0	280	0	-1,921	1.41	981	7.85

Table 6. Numbers (N) of total and positive trips, proportion of positive trips (PPT), relative nominal CPUE, and standardized abundance index statistics for Red Snapper in the Western U.S. Gulf of Mexico.

Year	N	Positive N	PPT	Relative Nominal CPUE	Relative Index	Lower 95% CI	Upper 95% CI	CV
1986	970	834	0.86	1.52	0.86	0.57	1.30	0.21
1987	970	834	0.86	1.57	0.89	0.60	1.33	0.20
1988	986	848	0.86	1.62	1.07	0.72	1.58	0.20
1989	1,023	880	0.86	1.80	0.96	0.65	1.42	0.20
1990	1,054	917	0.87	0.85	0.67	0.46	0.99	0.20
1991	1,115	1,015	0.91	1.22	1.27	0.83	1.93	0.21
1992	1,538	1,446	0.94	1.38	1.78	1.17	2.70	0.21
1993	1,671	1,571	0.94	1.35	1.67	1.12	2.50	0.20
1994	1,832	1,685	0.92	1.20	1.23	0.86	1.76	0.18
1995	1,687	1,569	0.93	0.97	1.43	0.97	2.11	0.20
1996	1,494	1,419	0.95	1.04	1.54	0.97	2.43	0.23
1997	1,487	1,368	0.92	1.04	1.58	1.06	2.35	0.20
1998	1,301	1,197	0.92	0.77	1.18	0.79	1.77	0.20
1999	515	479	0.93	0.53	0.39	0.22	0.71	0.30
2000	1,199	1,079	0.90	0.64	0.69	0.46	1.02	0.20
2001	1,356	1,302	0.96	0.70	0.81	0.49	1.34	0.26
2002	1,417	1,346	0.95	0.70	0.71	0.45	1.13	0.24
2003	1,320	1,228	0.93	0.68	0.62	0.40	0.96	0.22
2004	1,457	1,370	0.94	0.62	0.47	0.30	0.73	0.22
2005	1,464	1,376	0.94	0.66	0.53	0.34	0.81	0.22
2006	1,384	1,315	0.95	0.65	0.57	0.35	0.91	0.24
2007	1,484	1,439	0.97	0.51	1.09	0.64	1.84	0.27

Table 7. Numbers (N) of total and positive trips, proportion of positive trips (PPT), relative nominal CPUE, and standardized abundance index statistics for Red Snapper in the Central U.S. Gulf of Mexico.

Year	N	Positive N	PPT	Relative Nominal CPUE	Relative Index	Lower 95% CI	Upper 95% CI	CV
1986	259	155	0.60	0.27	0.17	0.08	0.36	0.38
1987	436	253	0.58	0.26	0.15	0.08	0.27	0.31
1988	713	485	0.68	0.33	0.19	0.12	0.32	0.25
1989	726	465	0.64	0.28	0.22	0.13	0.35	0.25
1990	835	493	0.59	0.44	0.30	0.19	0.48	0.24
1991	971	612	0.63	0.35	0.35	0.23	0.54	0.22
1992	1,066	789	0.74	0.91	0.67	0.43	1.04	0.22
1993	1,179	896	0.76	0.71	0.71	0.46	1.09	0.22
1994	1,183	852	0.72	0.87	0.52	0.34	0.79	0.21
1995	1,392	1,002	0.72	0.74	0.58	0.39	0.87	0.20
1996	1,460	1,212	0.83	0.92	0.72	0.47	1.11	0.22
1997	1,566	1,425	0.91	1.39	1.28	0.76	2.15	0.27
1998	1,399	1,329	0.95	1.50	1.66	0.87	3.15	0.33
1999	834	701	0.84	1.29	1.12	0.64	1.93	0.28
2000	1,537	1,383	0.90	1.48	1.69	1.02	2.81	0.26
2001	1,451	1,335	0.92	1.52	1.62	0.93	2.80	0.28
2002	1,617	1,552	0.96	1.97	2.46	1.28	4.74	0.34
2003	1,721	1,601	0.93	1.78	1.95	1.14	3.36	0.28
2004	1,499	1,394	0.93	1.45	1.57	0.90	2.76	0.29
2005	1,303	1,225	0.94	1.27	1.35	0.70	2.59	0.33
2006	1,310	1,231	0.94	0.88	0.84	0.45	1.55	0.32
2007	1,238	1,213	0.98	1.39	1.90	0.72	4.99	0.51

Table 8. Numbers (N) of total and positive trips, proportion of positive trips (PPT), relative nominal CPUE, and standardized abundance index statistics for Red Snapper in the East U.S. Gulf of Mexico.

Year	N	Positive N	PPT	Relative Nominal CPUE	Relative Index	Lower 95% CI	Upper 95% CI	CV
1986	15	5	0.33	0.29				
1987	4	0	0.00	0.00				
1988	8	3	0.38	0.36				
1989	5	2	0.40	0.25				
1990	38	13	0.34	0.08				
1991	35	5	0.14	0.42				
1992	33	0	0.00	0.00				
1993	49	25	0.51	0.24				
1994	34	10	0.29	0.11				
1995								
1996	2	0	0.00	0.00				
1997	4	2	0.50	0.35				
1998	11	6	0.54	0.14				
1999	19	18	0.95	2.46				
2000	27	19	0.70	0.56				
2001	39	29	0.74	0.70				
2002	41	28	0.68	0.23				
2003	29	28	0.97	1.35				
2004	35	33	0.94	3.32				
2005	40	40	1.00	4.66				
2006	7	7	1.00	2.92				
2007	11	9	0.82	2.58				

Figures

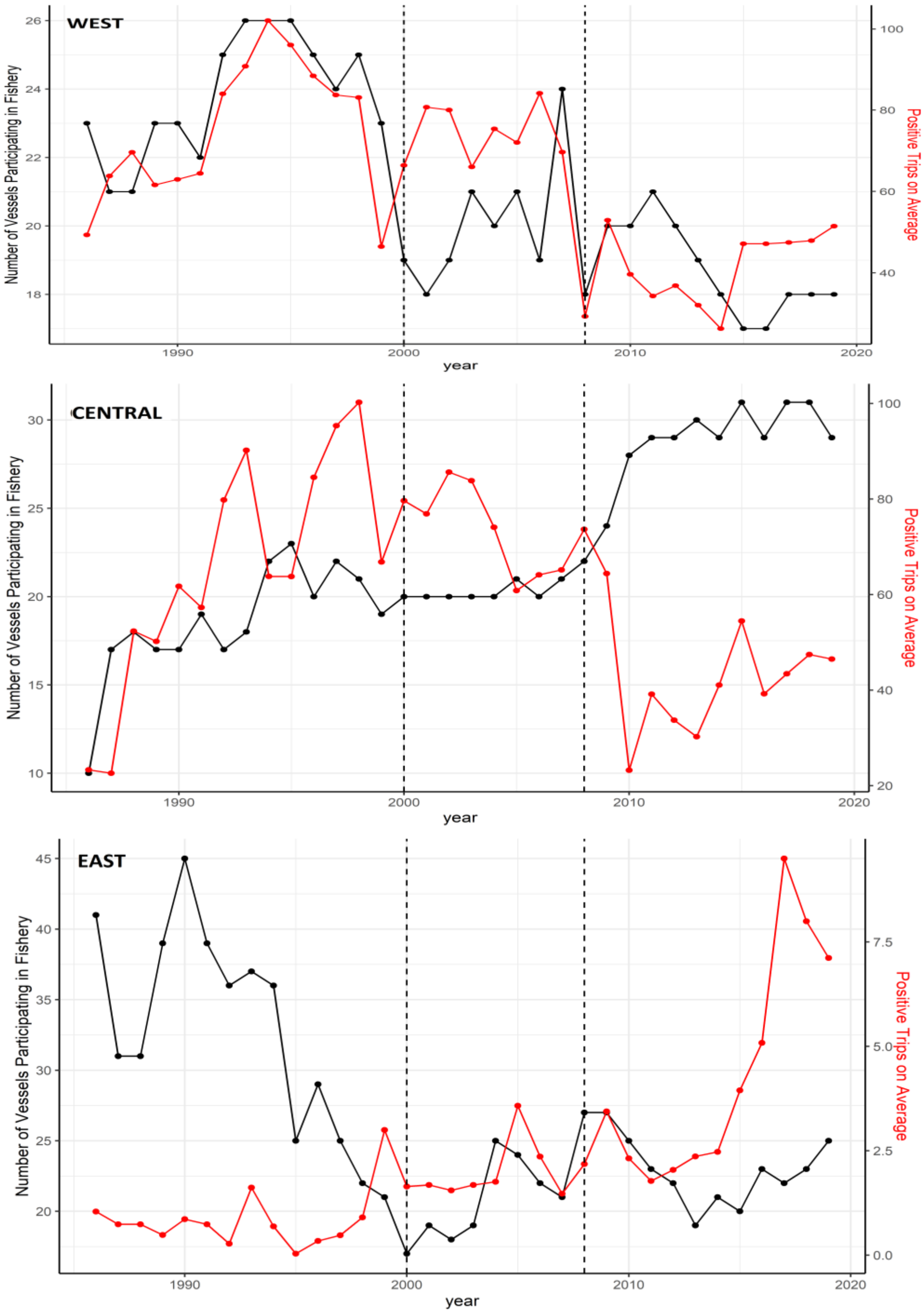

Figure 1. Number of headboat vessels participating in the fishery (black line) relative to the average number of positive trips annually (red line) in each region. Note: regional y-axis are on different scales.

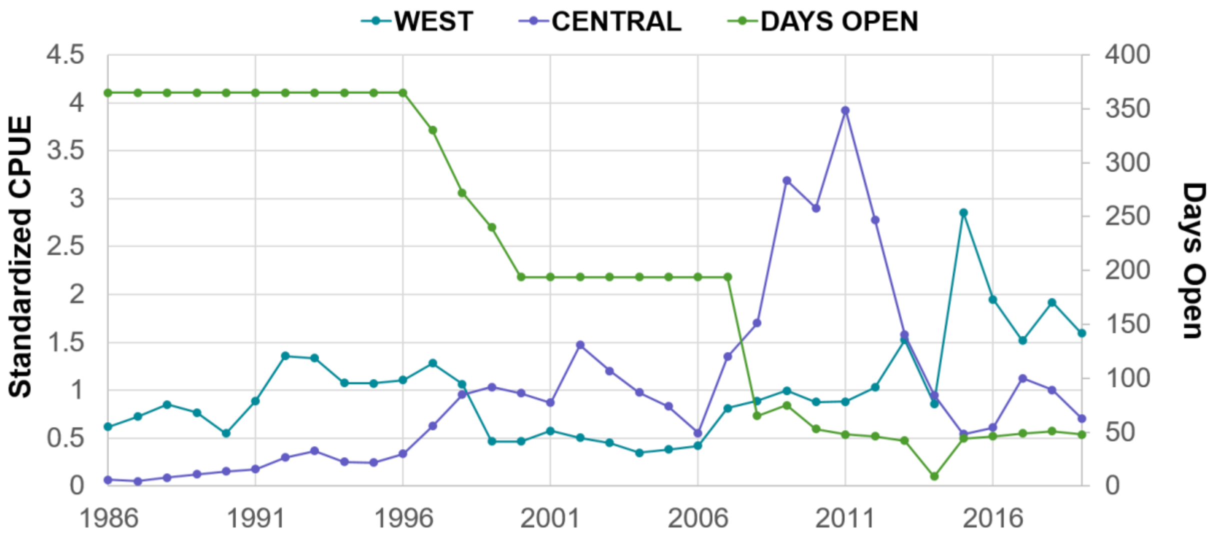

Figure 2. Exploratory analyses of changes in the Western U.S. Gulf of Mexico and Central U.S. Gulf of Mexico indices of relative abundance from 1986 to 2019, in response to the fluctuations in for-hire season length, annually.

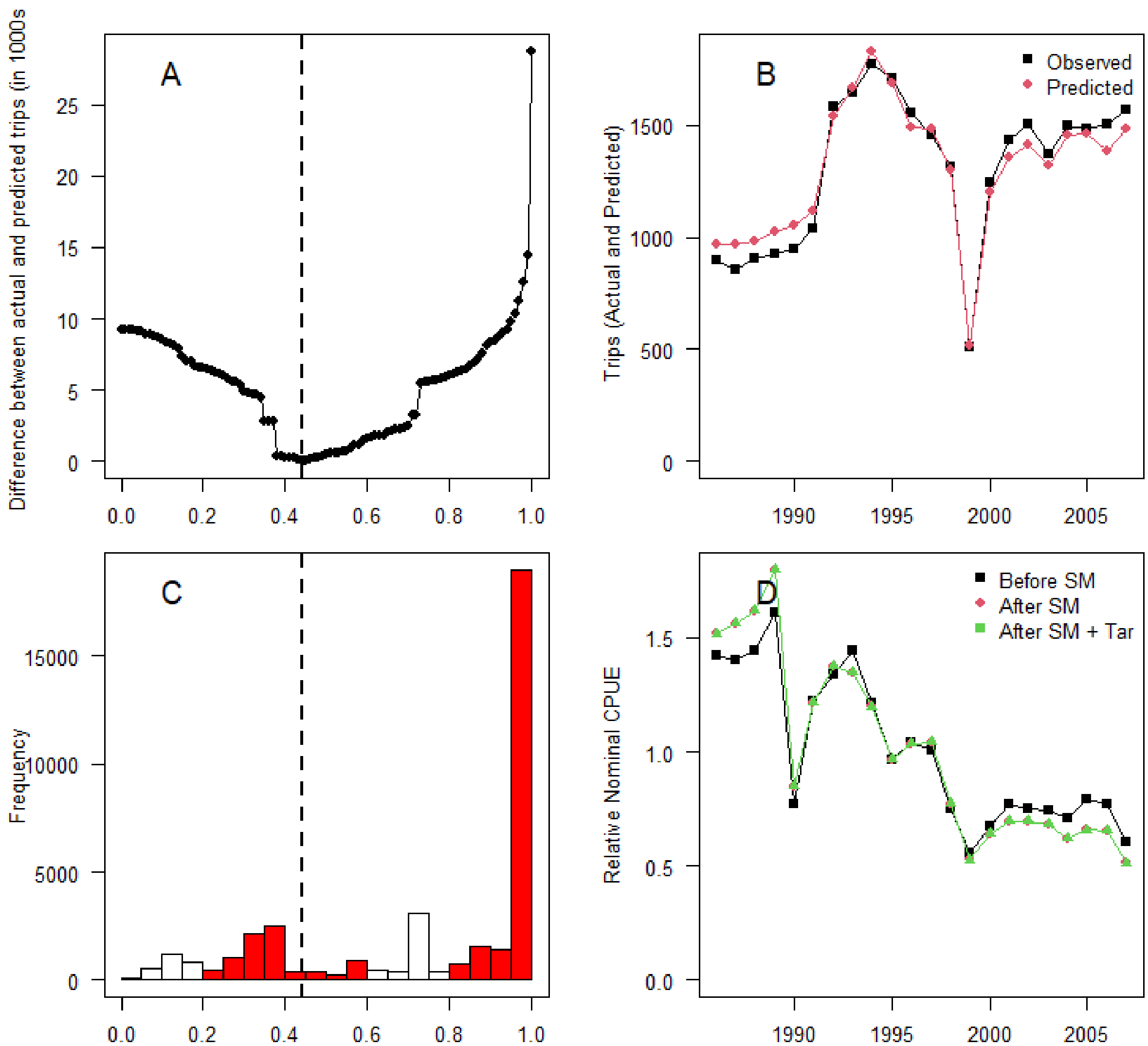

Figure 3. Stephens and MacCall (2004) trip selection diagnostics for the Western U.S. Gulf of Mexico. (A) The difference between the number of records in which Red Snapper are observed and the number in which they are predicted to occur for each probability threshold; (B) the number of actual and predicted trips; (C) Histogram of probabilities generated by the species-based regression (trips that targeted Red Snapper given in red); and (D) Nominal CPUE before ("Before SM") and after ("After SM") Stephens and MacCall (2004) trip selection ("After SM + Tar" = also includes all trips where the target species was caught). The dashed vertical line indicates the critical value where false prediction is minimized.

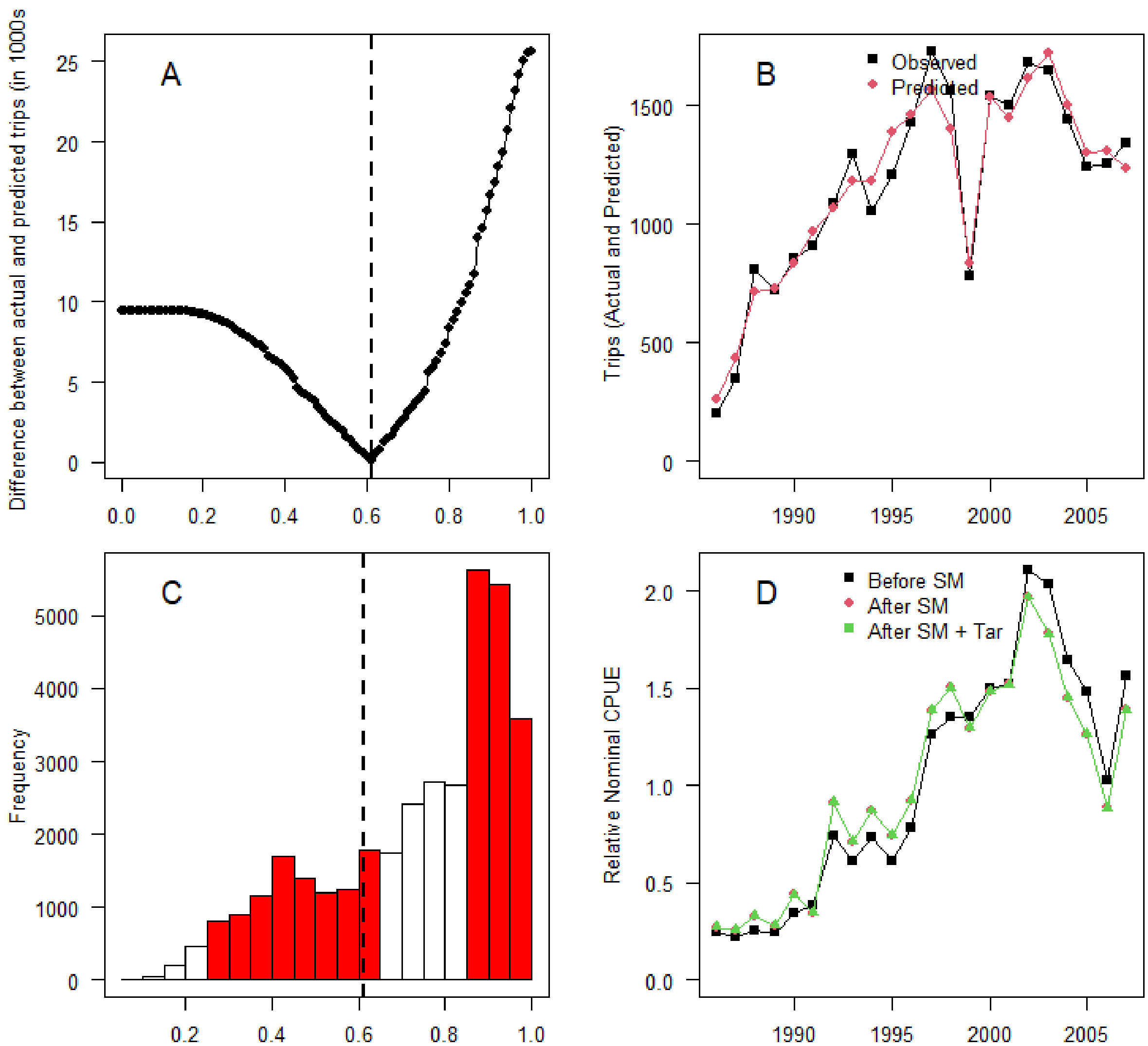

Figure 4. Stephens and MacCall diagnostics for the Central U.S. Gulf of Mexico. (A) The difference between the number of records in which Red Snapper are observed and the number in which they are predicted to occur for each probability threshold; (B) the number of actual and predicted trips; (C) Histogram of probabilities generated by the species-based regression (trips that targeted Red Snapper given in red); and (D) Nominal CPUE before ("Before SM") and after ("After SM") Stephens and MacCall (2004) trip selection ("After SM + Tar" = also includes all trips where the target species was caught). The dashed vertical line indicates the critical value where false prediction is minimized.

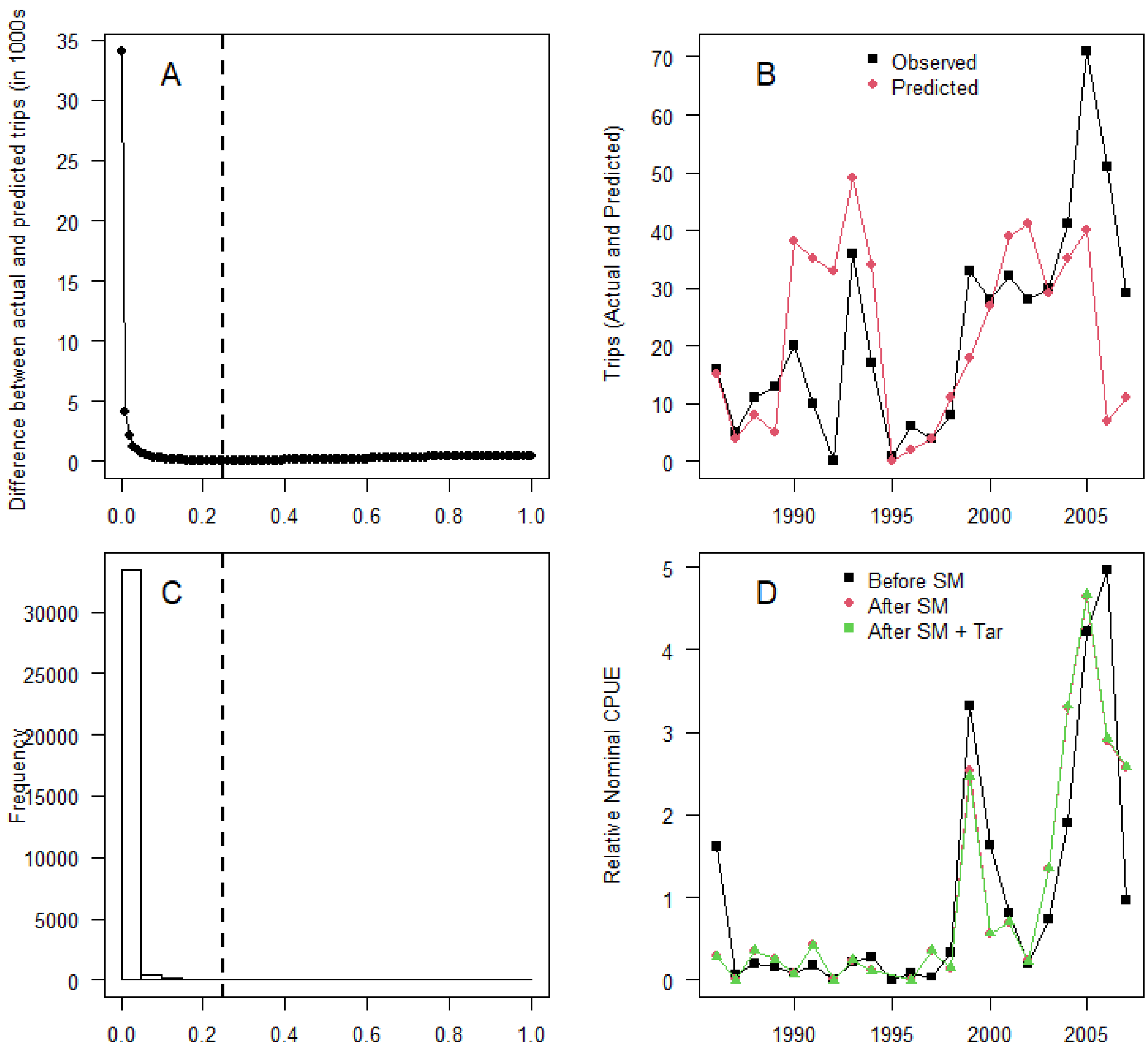

Figure 5. Stephens and MacCall diagnostics for the East U.S. Gulf of Mexico. (A) The difference between the number of records in which Red Snapper are observed and the number in which they are predicted to occur for each probability threshold; (B) the number of actual and predicted trips; (C) Histogram of probabilities generated by the species-based regression (trips that targeted Red Snapper given in red); and (D) Nominal CPUE before (“Before SM”) and after (“After SM”) Stephens and MacCall (2004) trip selection (“After SM + Tar” = also includes all trips where the target species was caught). The dashed vertical line indicates the critical value where false prediction is minimized.

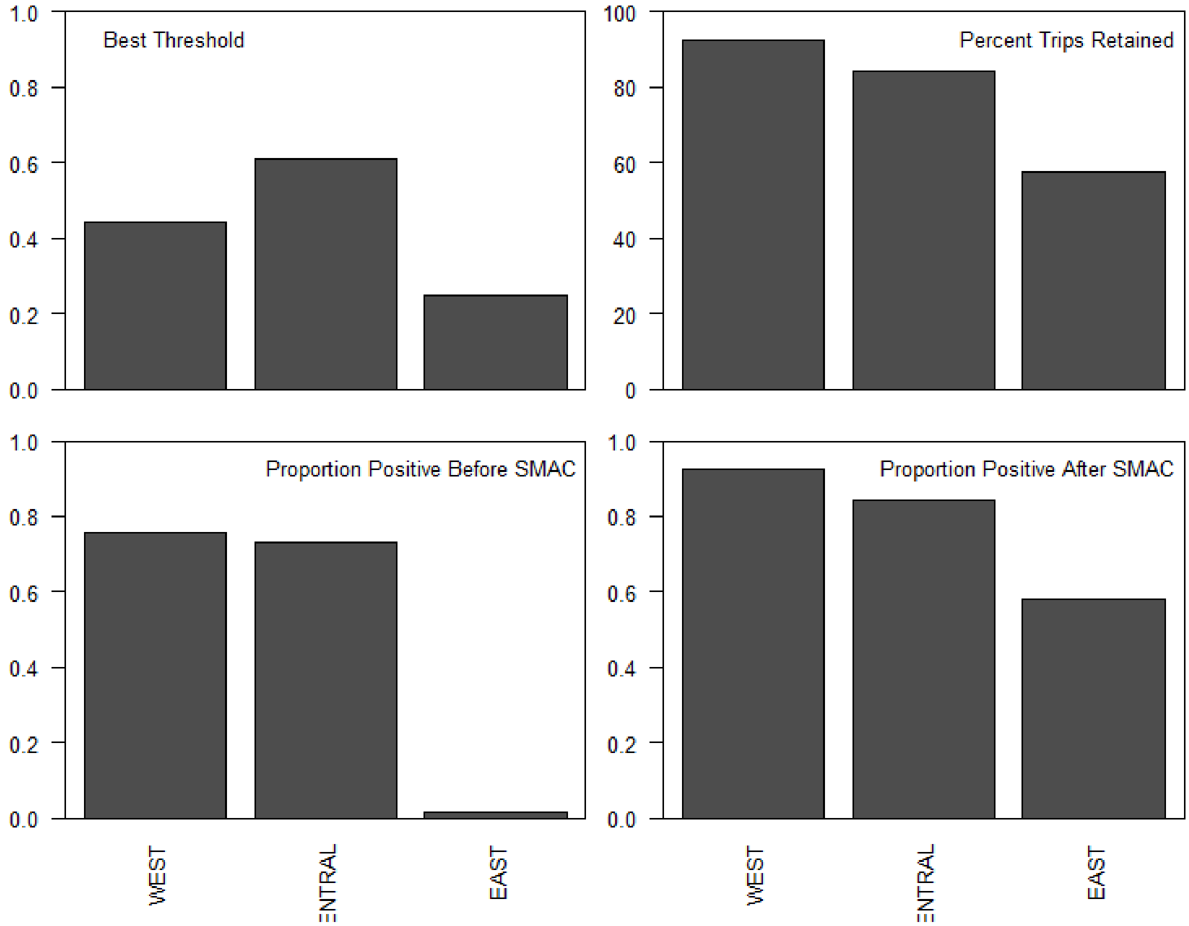

Figure 6. Stephens and MacCall (2004) statistics across regions for associations with red snapper.

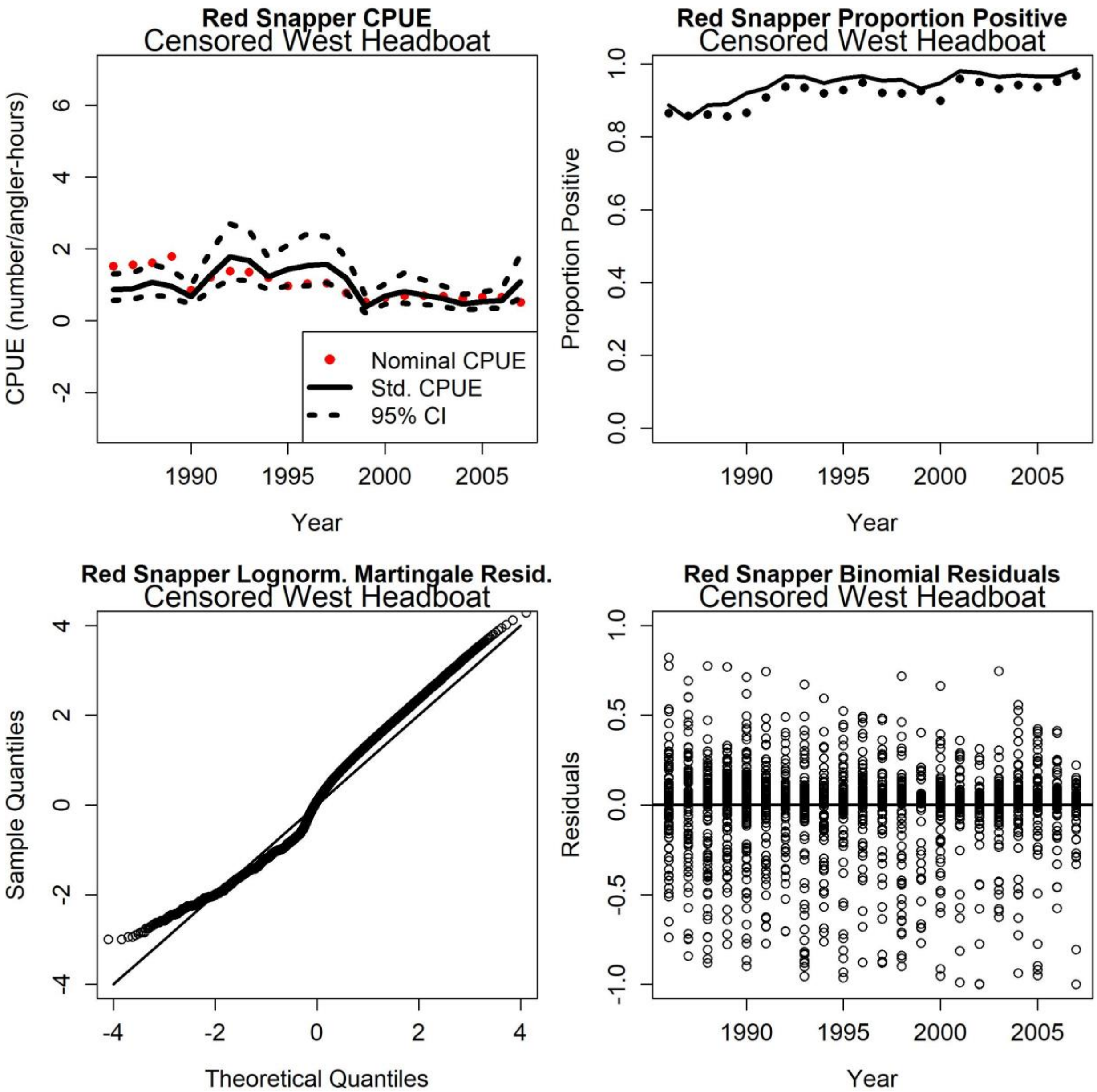

Figure 7. Diagnostic plots for the delta censored lognormal regression for red snapper in the Western U.S. Gulf of Mexico.

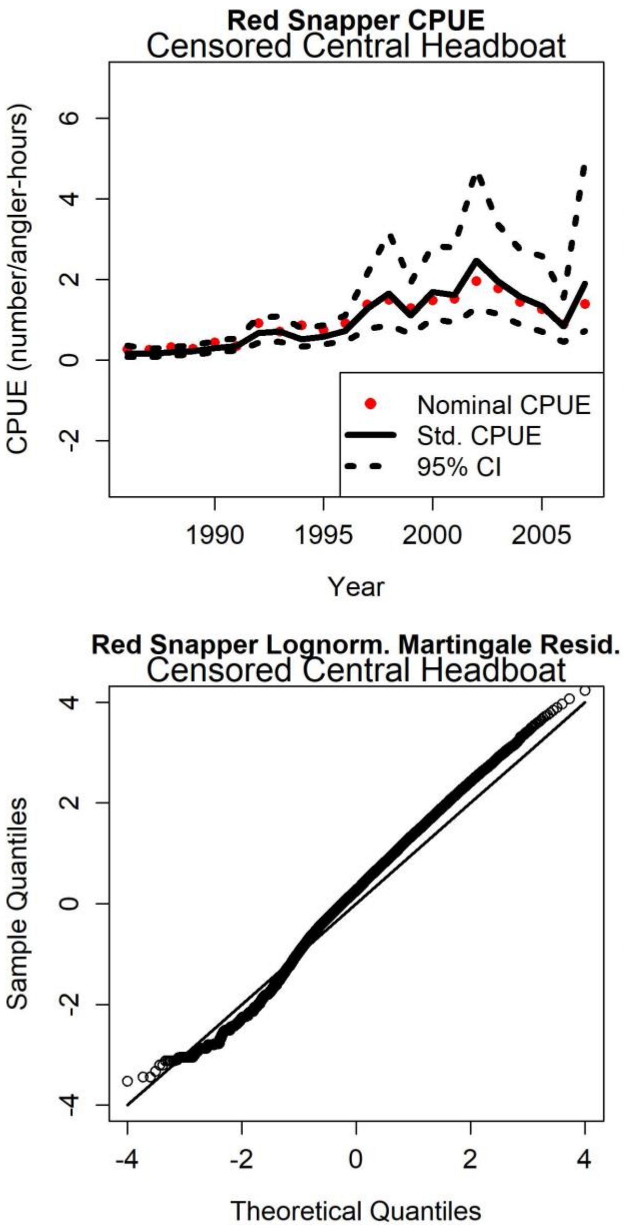

Figure 8. Diagnostic plots for the delta censored lognormal regression for red snapper in the Central U.S. Gulf of Mexico.

Figure 9. Comparison of regional indices from the delta censored lognormal regression for red snapper across the U.S. Gulf of Mexico. Due to the lack of positive trips in the Eastern U.S. Gulf of Mexico, the index was unable to be standardized thus only the nominal CPUE for the East U.S. Gulf of Mexico is presented.