Standardized Catch Rate Indices for Red Snapper (*Lutjanus campechanus*) during 1981-2019 by the U.S. Gulf of Mexico Charterboat and Private Boat Recreational Fishery

Gulf Fisheries Branch, Sustainable Fisheries Division

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Keywords

Catch, fishing effort, bag limit, catch per unit effort (CPUE), recreational fisheries, Charterboat and Private combined, Red Snapper, censored regression

Abstract

A delta-lognormal index of abundance for the Gulf of Mexico Charterboat and Private combined recreational fishery was constructed for the SEDAR74 Operational Red Snapper stock assessment. The index uses data from the Marine Recreational Information Program, which underwent a substantial modification and peer-review in 2018 following a three year transition period (2015-2018). An index for the Gulf of Mexico for the eastern, central and western regions was developed following the trip selection approach and standardization methodology used for SEDAR52 and SEDAR31. The SEDAR74 eastern region lacked sufficient data to construct an index. The SEDAR74 central standardized index exhibited a similar trend seen in the SEDAR52 eastern region, however there are some notable differences in the start and end of the time series. This is most likely the result of the shift from the MRFSS dataset used in SEDAR52 compared to the updated MRIP dataset used in SEDAR 74. This updated dataset represents the best available science. Data are available up to the terminal year of 2019, however we recommend truncating the SEDAR74 central and west indices in 2007 due to management regulations. Currently, the SEDAR74 west index is truncated in 2014 due to changes in data collection.

Introduction

The recreational fishery in the Gulf of Mexico is surveyed by the Marine Recreational Information Program (MRIP) conducted by NOAA Fisheries (formerly the Marine Recreational Fisheries Statistics Survey, MRFSS), the Texas Marine Sport-Harvest Monitoring Program conducted by the Texas Parks and Wildlife Department (TPWD), and the LA Creel Survey conducted by the Louisiana Department of Wildlife and Fisheries. MRIP/MRFSS has monitored shore based, charterboat and private/rental boat angler fishing in the Gulf of Mexico since 1981.

In this study, a censored regression approach following the analysis of Saul and Walter III (2012) is used to develop standardized indices of abundance from fishery dependent data for the recreational red snapper (*Lutjanus campechanus*) fishery in the Gulf of Mexico, which has experienced increasingly restrictive trip limit regulations. The censored regression approach to standardizing CPUE was recommended by the Indices Working Group during SEDAR31 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 SEDAR31 and SEDAR52, the inclusion of discards was not recommended to generate an index due to the fact that 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. Furthermore, substantial reductions in the length of annual recreational fishing seasons have greatly reduced the data available for modeling CPUE of red snapper in recent years (Sagarese and Rios, 2016). The recreational fishing season has been further reduced since the previous assessment's (SEDAR 52) terminal year of 2016 (**Table 1**), furthermore, states have implemented individual exempted fishing permits for the private fishing mode since 2018.

Materials and Methods

MRIP Transition

The Marine Recreational Information Program completed a three year transition in 2018 (NOAA Fisheries 2018). Estimates of fishing effort for the private and shore modes are now obtained from a Fishing Effort Survey conducted via mail, whereas previously these estimates came from the legacy Coastal Household Telephone Survey. Effort estimates for charter and party boats are still obtained from the For-Hire Telephone Survey and are not affected by the new Fishing Effort Survey. Benchmarking of the Fishing Effort Survey alongside the Coastal Household Telephone Survey for three years allowed for apples-to-apples comparisons between data from the two different surveys and the creation of a peer-reviewed calibration model. The calibration model was peer reviewed by reviewers appointed by the Center for Independent Experts (see Rago et al. (2017)). Additional details can be found at: *https://www.fisheries.noaa.gov/event/fishing-effort-survey-calibration-model-peer-review*. The MRIP transition also accounted for the 2013 design change in the Access Point Angler Intercept Survey (Foster et al. 2018). The MRIP transition resulted in the release of new recreational catch estimates for all species and all modes, including charter mode estimates. As a result, the SEFSC conducted a calibration analysis using the newly released data to correct for this change from the Coastal Household Telephone Survey to the For-Hire Telephone Survey (Dettloff and Matter 2019).

MRIP Data

MRIP collects information on participation, effort, and species-specific catch. Data are collected to provide catch and effort estimates in two-month periods ("waves") for each recreational fishing mode (shore fishing, private/rental boat, charterboat, or headboat/charterboat combined prior to 1986) and for each area of fishing (inshore, state Territorial Seas, U.S. Exclusive Economic Zone), in each Gulf of Mexico state (except Texas). Total catch information is collected by MRIP on fish landed whole and observed by interviewers ("Type A"), fish reported as killed by the fishers ("Type B1") and fish reported as released alive by the fishers ("Type

B2"). Types B1 and B2 were not used in these indices due to concern about changes in angler behavior (Saul and Walter III, 2012).

Data from the MRIP dockside interviews were used to characterize abundance trends of Red Snapper in the Gulf of Mexico. Information on effort included hours fished and number of anglers as reported to the interviewer. The catch per unit effort was calculated on an individual group basis (i.e., by leader) and was equal to the number of fish caught (A) divided by the effort, where effort was the product of the number of anglers and the total hours fished.

Datasets were partitioned as follows: the Eastern index included the Florida regulatory areas 2 and 3, the Central index included the Florida regulatory area 1 (the panhandle), Alabama, and Mississippi and the Western index covered Texas and Louisiana.

Beginning in 2014, the Louisiana Department of Wildlife and Fisheries began conducting the recreational fishing interviews for the LA Creel survey. This survey collects different information than the MRIP interviews and does not include the total hours fished. This creates a break in the effort data and it would be unsuitable to continue the index past 2014 for the West area.

MRIP Data Filtering

Data were filtered following the same steps as SEDAR52:
1. Data in the Gulf of Mexico were limited to interviews that took place in Gulf of Mexico
2. Only interviews associated with Charterboat and Private modes fishing hook and line gear were retained.
3. Interviews that reported shore-based fishing or fishing in inshore waters were excluded.
4. Interviews with possible error in effort information or in catch amount were excluded.

Following Sagarese and Rios (2016) and Saul and Walter III (2012), we use catch and effort observations from MRIP and TPWD to develop standardized catch per unit effort (CPUE) indices of abundance for the private/for hire sector of the recreational fishery. Throughout the time series of the data, various increasingly strict trip limits were imposed on the recreational fishing sector (Figure 1).

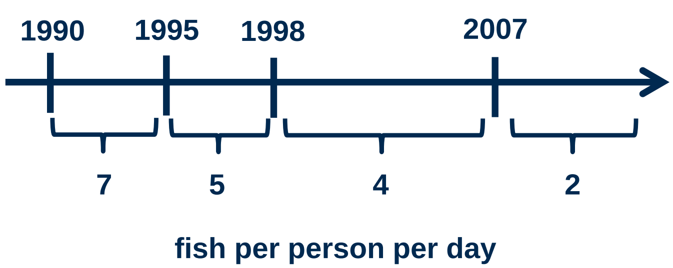

Figure 1: Red snapper recreational bag limit history.

Subsetting Trips: Species Association

A method to infer targeting for each trip was used to develop the index because no direct targeting information was available. The Stephens and MacCall (2004) approach was used to restrict the dataset to trips that likely encountered Red Snapper based on the catch species composition. This approach was applied separately for the East, Central, and West due to potential differences in species compositions between fishing areas.

Variable Selection

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

Name	DF	Details
Year	39	1981-2019
Reg. Season	2	Closed, Open
Mode	2	Charterboat, Private
Area	4	< 3 miles, > 3 miles, <10 miles, > 10 miles
Anglers	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10+
Wave	6	1, 2, 3, 4, 5, 6
State (East)	1	FL
State (Central)	3	FL (FL Reg 1), AL, MS
State (West)	2	LA, TX
FL Reg (East)	2	2 and 3

Standardization

A two-stage censored delta-lognormal approach (GLM; Lo et al. 1992) was used to standardize for variability and non-randomness in CPUE data collection methods not caused by the year effect (i.e., to factor out year to year variations in CPUE not due to changes in abundance). This method combines separate generalized linear models (GLM) analyses of the proportion of leaders that caught at least one Red Snapper (i.e., proportion of positive trips) and the catch rates of the positive leaders to construct a single standardized index of abundance. In the first step, the proportion positive is modeled using a logit regression assuming a binomial distribution of the response variable. In the second step, the logarithm of CPUE on positive trips (those that caught the target species) was used as the response variable assuming a censored lognormal error distribution. The two models were then combined to provide the final standardized index of abundance. Parameterization of each model was accomplished using a GLM procedure. For the lognormal models, the response variable, ln(*CPUE*), was calculated:

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

A forward stepwise regression approach was utilized within the GENMOD procedure of SAS 9.2 (SAS Institute, 2008). In this procedure, factors were added to the base model one at a time based on the percent reduction in deviance per degree of freedom. With each run of the model, the factor that caused the highest reduction in deviance was added to the base model (assuming the factor was significant based on a Chi-Square test with probability ≤ 0.05) until no factor reduced the percent deviance by the pre-specified level of 1%. Once a set of fixed factors was identified, first level interactions were examined. The significance of these interactions was evaluated between nested models using the likelihood ratio test. 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).

Results of the binomial (proportion positive) and censored lognormal (mean CPUE on successful trips) models were then multiplied to attain a single index of abundance based on the year effect. The final delta-lognormal model was fit using the SAS macro GLIMMIX (glmm800MaOB.sas: Russ Wolfinger, SAS Institute). 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, for the model used in this work, is taken from the lognormal distribution. The model for the response variable is

$$y = \mathbf{X\beta} + \boldsymbol{\sigma\varepsilon}$$

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

Species Associations - Stephens and MacCall (2004) Approach - East

The minimum difference between the predicted and the observed number of trips that reported Red Snapper occurred at the probability threshold of 0.1 (**Figure 2A**). Predicted trips showed a general increasing trend throughout the time series, were underestimated early in the time series and at the end of the time-series (**Figure 2B**). Trips with a predicted probability greater than the critical threshold probability were considered as trips that targeted Red Snapper (**Figure 2C**). Nominal CPUE was relatively similar before and after applying the Stephens and MacCall (2004) approach, with the exception of 2012 (**Figure 2D**). This method retained 1.3% of the total trips, and 25.6% of trips that reported Red Snapper. Prior to trip selection, there were 42,384 trips and the proportion positive was 0.01, and after selection there were 564 trips and the proportion positive was 0.57.

The Stephens and MacCall (2004) trip subsetting approach identified 10 species which were captured with Red Snapper (**Table 2)**. Red Grouper, Greater Amberjack, Lane Snapper, Gray Snapper, and Almaco Jack were positively correlated to Red Snapper whereas Red Drum, Spotted Seatrout, Spanish Mackerel, and Cero were negatively correlated.

Species Associations - Stephens and MacCall (2004) Approach - Central

The minimum difference between the predicted and the observed number of trips that reported Red Snapper occurred at the probability threshold of 0.42 (**Figure 3A**). Predicted trips showed a general increasing trend throughout the time series, with an overall match to the observed trips (**Figure 3B**). Trips with a predicted probability greater than the critical threshold probability were considered as trips that targeted Red Snapper (**Figure 2C**). Nominal CPUE was relatively similar before and after applying the Stephens and MacCall (2004) approach, with the exception of the trends seen after 1996 (**Figure 3D**). This method retained 47.2% of the total trips, and 23.6% of trips that reported Red Snapper. Prior to trip selection, there were 24,185 trips and the proportion positive was 0.37, and after selection there were 11,408 trips and the proportion positive was 0.79.

The Stephens and MacCall (2004) trip subsetting approach identified 13 species which were captured with Red Snapper (**Table 3)**. Gray Snapper, Gray Triggerfish, Vermillion and Gag were positively correlated to Red Snapper whereas Spotted Seatrout, Southern Kingfish, and Sheepshead were negatively correlated.

Species Associations - Stephens and MacCall (2004) Approach - West

The minimum difference between the predicted and the observed number of trips that reported Red Snapper occurred at the probability threshold of 0.42 (**Figure 4A**). Predicted trips showed a general increasing trend until 2006 and declined thereafter (**Figure 4B**). Trips with a predicted probability greater than the critical threshold probability were considered as trips that targeted Red Snapper (**Figure 4C**). Nominal CPUE was relatively similar before and after applying the Stephens and MacCall (2004) approach (**Figure 4D**). This method retained 38.2% of the total trips, and 35.3% of trips that reported Red Snapper. Prior to trip selection, there were 24,955 trips and the proportion positive was 0.29, and after selection there were 9,531 trips and the proportion positive was 0.75.

The Stephens and MacCall (2004) trip subsetting approach identified 7 species which were captured with Red Snapper (**Table 4)**. Lane Snapper, Gray Snapper, Gray Triggerfish, and Cobia were positively correlated to Red Snapper whereas Spotted Seatrout, Southern Flounder, and Sheepshead were negatively correlated.

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

Few species were strongly correlated across all three regions. Grey snappers exhibited a high positive correlation with red snapper across all three regions while Spanish mackerel and spotted seatrout exhibited high negative correlations across all three regions (**Figure 5**).

The derived probability threshold and proportion positive before applying the Stephens and MacCall (2004) approach were highest in the central and western areas (**Figure 6**).

Annual Abundance Indices for East

The GLIMMIX process would not converge for the eastern region, as there were insufficient data across the years (**Table 6**).

Annual Abundance Indices for Central

Final deviance tables are included in **Table 7**. The final models for the binomial (i.e., proportion positive) and lognormal (catch rate of positive trips) components were:

$$ProportionPositive = YEAR + REG\_SEASON + CONTB + AREA + WAVE$$

$$ln(CPUE) = YEAR + WAVE + MODE$$

Diagnostics for each component of the GLM are provided in **Figure 7** and **Figure 8**. The binomial model consistently underestimated the proportion of positive trips (**Figure 7A**). The proportion positive ranged from 0.16 to 0.89, and has generally remained between 0.46 and 0.71. Residual analysis of the binomial model showed no obvious patterns in the residuals (**Figure 7B-F**).

The lognormal model results suggest a relatively good fit to the data and indicated that the assumption of a lognormal distribution for positive catch rates was appropriate for the data (**Figure 8A-B**). Residual analysis of the lognormal model also showed no obvious patterns in the residuals (**Figure 8C-G**).

Table 8 summarizes the standardized index, corresponding lower and upper 95% confidence limits, annual coefficients of variation, nominal CPUE, and number of trips. Nominal CPUE values fell within the 95% confidence interval of the standardized index with the exception of the late 2000's (**Figure 9**). Relative abundance remained above the time series mean in the first few years of the index, declined to below the time series mean during most of the 1990s and began to increase slightly in the 2000s.

Annual Abundance Indices for West

Final deviance tables are included in **Table 9**. The final models for the binomial (i.e., proportion positive) and lognormal (catch rate of positive trips) components were:

$$ProportionPositive = YEAR + AREA + CONTB + REGSEASON$$

$$ln(CPUE) = YEAR + WAVE + MODE$$

Diagnostics for each component of the GLM are provided in **Figure 10** and **Figure 11**. The binomial model generally underestimated the proportion of positive trips (**Figure 10A**). The proportion positive ranged from 0.33 to 0.89, and has generally remained between 0.59 and 0.73. Residual analysis of the binomial model showed no obvious patterns in the residuals (**Figure 10B-E**).

The lognormal model results suggest a good fit to the data and indicated that the assumption of a lognormal distribution for positive catch rates was appropriate for the data (**Figure 11A-B**). Residual analysis of the lognormal model also showed no obvious patterns in the residuals (**Figure 11D-G**).

Table 10 summarizes the standardized index, corresponding lower and upper 95% confidence limits, annual coefficients of variation, nominal CPUE, and number of trips. Nominal CPUE values fell within the 95% confidence interval of the standardized index, with the exception of the mid- to late-1980s and after 2008 (**Figure 12**). Relative abundance remained below the time series mean in the first few years of the index, increased to about the time series mean during most of the 1990s and began to increase in the mid 2000s. Relative abundance peaked in 2014, and was at the lowest value in 1985.

Comments on Adequacy for Assessment

The Charterboat and Private combined index presented in this working paper is based on improved methodology compared to the continuity approach for developing indices of abundance for Gulf reef fish stocks from the MRIP. The index for Red Snapper in the central region is associated with moderate variability with a mean CV of 0.41 (range: 0.18 – 0.83), West is associated with moderate variability with a mean CV of 0.26 (range: 0.2 – 0.66) and which is lower compared to other Gulf species (e.g., Red Grouper CV range: 0.49 – 0.8; Sagarese and Rios 2018). Previous Gulf reef fish assessments have included this index because it contains one of the longest time series and has widespread spatial coverage compared to other indices (update).

The implementation of various management actions, most notably the individual state fishing closures beginning in 2017 make the continuation of the index impractical for the private mode. Additionally, the shortened open season in recent years does not allow for the adequate amounts of information to provide an index of abundance. SEDAR 74 is a research track assessment and as such, continuity indices were not necessary. For internal data quality and code checking, a continuity plot of the eastern region used in SEDAR 52 was constructed (**Figure 13**) as was a western index (**Figure 14**). The western continuity was truncated in 2014 due to the lack of hours fished information in LA creel. The large shift in open fishing days from 194 to 65 beginning in 2008 has the potential to bias the index. Examining the trends across the three indices from SEDAR 74, SEDAR 52 and SEDAR 31 with the eastern region demarcated at the Mississippi River shows a clear break after 2007 in the abundance pattern (**Figure 15**). We recommend truncating the central and western indices in 2007 due to the reduction of open fishing days beginning in 2008.

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Tables

Table 1. Recreational season lengths, open/close dates, and references used for modeling red snapper. EFP = Exempted Fishing Permit

Year	Component	# Days	Open date	Close date	Reference
Pre-1990	Private/for-hire	365	1-Jan	31-Dec	
1990	"	"	"	"	
1991	"	"	"	"	
1992	"	"	"	"	
1993	"	"	"	"	
1994	"	"	"	"	
1995	"	"	"	"	
1996	"	"	"	"	
1997	"	330	"	27-Nov	62 FR 61700
1998	"	272	"	30-Sep	63 FR 45760
1999	"	240	"	29-Aug	64 FR 30445
2000	"	194	21-Apr	1-Nov	64 FR 71056; 65 FR 50158
2001	"	"	"	"	
2002	"	"	"	"	
2003	"	"	"	"	
2004	"	"	"	"	
2005	"	"	"	"	
2006	"	"	"	"	
2007	"	"	"	"	72 FR 15617
2008	"	65	1-Jun	5-Aug	73 FR 15674
2009	"	75	"	15-Aug	74 FR 21558
2010	"	53	"	24-Jul	75 FR 23186
2011	"	48	"	19-Jul	76 FR 50143
2012	"	46	"	17-Jul	77 FR 39647
2013	"	42	1-Jun; 1-Oct	29-Jun; 15-Oct	78 FR 34586; 78 FR 57313
2014	"	9	"	10-Jun	79 FR 27768
2015	Private	10	"	11-Jun	80 FR 24832

	For-hire	44	"	15-Jul	80 FR 24832
2016	Private	11	"	12-Jun	81 FR 38110
	For-hire	46	"	17-Jul	81 FR 25583
	Private	42	"	3-Jun	82 FR 21140
2017			16-Jun*	5-Sep	82 FR 27777
			3-Jul	4-Jul	
			4-Sep	5-Sep	
	For-hire	49	"	19-Jul	
2018	Private	EFP	EFP		
	For-hire	51	1-Jun	22-Jul	83 FR 17623
2019	Private	EFP	EFP		84 FR 8825
	For-hire	63	1-Jun	2-Aug	84 FR 8825

*Friday, Saturday and Sunday only

Table 2. Association coefficients of other species with Red Snapper for the eastern Gulf of Mexico. Positive numbers indicate a positive correlation.

Coefficient	Common Name
1.517	Red Grouper
1.220	Greater Amberjack
1.017	Lane Snapper
0.806	Gray Snapper
0.622	Black Grouper
0.456	Gag
0.229	Great Barracuda
0.190	Black Sea Bass
0.178	Wahoo
0.109	Blackfin Tuna
-0.068	King Mackerel
-0.124	Mutton Snapper
-0.162	Little Tunny
-0.381	White Grunt
-0.421	Littlehead Porgy
-0.454	Yellowtail Snapper
-0.474	Dolphin
-0.820	Sheepshead
-1.064	Cero
-1.450	Spanish Mackerel
-2.245	Spotted Seatrout
-2.344	Red Drum

Table 3. Association coefficients of other species with Red Snapper for the central Gulf of Mexico. Positive numbers indicate a positive correlation.

Coefficient	Common Name
1.376	Gray Snapper
1.181	Gray Triggerfish
0.850	Vermilion Snapper
0.828	Gag
0.675	Lane Snapper
0.243	Little Tunny
0.206	Almaco Jack
0.186	Cobia
0.173	Red Grouper
0.153	King Mackerel
0.089	Dolphin
0.050	Scamp
0.015	Greater Amberjack
-0.020	Bluefish
-0.268	Red Porgy
-1.033	Spanish Mackerel
-1.481	Red Drum
-1.706	Black Sea Bass
-1.724	Sand Seatrout
-1.909	Sheepshead
-3.184	Southern Kingfish
-4.595	Spotted Seatrout

Table 4. Association coefficients of other species with Red Snapper for the western Gulf of Mexico. Positive numbers indicate a positive correlation.

Coefficient	Common Name
1.910	Lane Snapper
1.404	Gray Triggerfish
1.110	Gray Snapper
0.925	Cobia
0.924	Bluefish
0.521	Greater Amberjack
0.393	Atlantic Spadefish
-0.140	Sand Seatrout
-0.282	Atlantic Sharpnose Shark
-0.297	Black Drum
-0.306	Little Tunny
-0.372	Dolphin
-0.549	Spanish Mackerel
-0.584	Blacktip Shark
-0.887	Atlantic Croaker
-0.984	King Mackerel
-1.009	Red Drum
-1.097	Sheepshead
-1.243	Southern Flounder
-3.183	Spotted Seatrout

Table 5. Deviance tables for the regression models for Red Snapper in the eastern 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	P_value
Binomial									
Null	1	771	563	771	773		-385		
reg_season	1	63	562	708	712	8.20	-355	61.28	0.000
year	38	120	524	588	668	15.59	-296	118.31	0.000
fl_reg	1	9	523	578	660	1.22	-329	-66.57	1.000
wave	5	17	518	561	653	2.21	-321	15.03	0.000
anglers	12	26	506	534	650	3.46	-313	16.68	0.000
Censored Lognormal									
Null	1	190	319	190	-162		83.29		
year	36	54	284	135	-198	28	137.06	107.54	0.000
mode	1	1	319	132	-202	1	141.41	4.64	0.031
wave	5	4	315	127	-203	2	146.86	10.90	0.001

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 East.

Year	N	Positive N	PPT	Relative Nominal CPUE	Relative Index	Lower 95% CI	Upper 95% CI	CV
1981	4	4	1.000	5.37				
1982	6	2	0.333	0.04				
1983	6	2	0.333	0.45				
1984	5	5	1.000	4.79				
1985	2	2	1.000	0.19				
1986	11	9	0.818	2.20				
1987	10	8	0.800	1.41				
1988	3	2	0.667	1.65				
1989	5	4	0.800	2.41				
1990	5	4	0.800	0.56				
1991	7	2	0.286	0.20				
1992	10	4	0.400	0.58				
1993	4	0	0.000	0.00				
1994	3	0	0.000	0.00				
1995	3	1	0.333	0.15				
1996	8	5	0.625	0.26				
1997	7	6	0.857	2.80				
1998	18	11	0.611	2.66				
1999	18	13	0.722	0.87				
2000	8	4	0.500	0.25				
2001	23	7	0.304	0.26				
2002	12	7	0.583	0.54				
2003	24	10	0.417	0.76				

Year	N	Positive N	PPT	Relative Nominal CPUE	Relative Index	Lower 95% CI	Upper 95% CI	CV
2004	31	8	0.258	0.17				
2005	32	18	0.563	0.53				
2006	15	10	0.667	1.10				
2007	14	5	0.357	0.37				
2008	20	11	0.550	0.44				
2009	9	6	0.667	0.53				
2010	10	5	0.500	0.59				
2011	2	2	1.000	0.95				
2012	9	5	0.556	1.25				
2013	14	6	0.429	0.33				
2014	20	7	0.350	0.57				
2015	15	5	0.333	0.53				
2016	36	18	0.500	0.30				
2017	50	38	0.760	0.92				
2018	40	28	0.700	1.10				
2019	45	36	0.800	0.91				

Table 7. Deviance tables for the regression models for Red Snapper in the central 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	11,644	11,407	11,645	11,646		-5,822	
reg_season	1	3,058	11,406	8,586	8,590	26	-4,294	3,056
anglers	9	573	11,397	8,012	8,034	5	-4,008	572
year	26	467	11,371	7,545	7,619	4	-3,784	449
area	3	246	11,368	7,298	7,378	2	-3,686	195
wave	5	118	11,363	7,180	7,269	1	-3,630	112
Censored Lognormal								
Null	1	34,316	9,042	34,317	12,064		-6,030	
year	26	1,579	9,017	32,737	11,689	5	-5,817	426
wave	5	959	9,038	31,777	11,430	3	-5,682	269
mode	1	711	9,042	31,065	11,227	2	-5,580	205

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 central Gulf of Mexico.

Year	N	Positive N	PPT	Relative Nominal CPUE	Relative Index	Lower 95% CI	Upper 95% CI	CV
1981	39	29	0.744	1.20	0.79	0.23	2.77	0.69
1982	47	43	0.915	0.55	0.50	0.13	1.84	0.73
1983	59	56	0.949	2.68	2.71	0.73	10.02	0.73
1984	38	36	0.947	2.01	1.50	0.35	6.34	0.83
1985	62	57	0.919	2.95	2.40	0.73	7.91	0.65
1986	48	42	0.875	0.78	0.46	0.12	1.74	0.74
1987	228	158	0.693	0.82	0.72	0.38	1.34	0.32
1988	34	26	0.765	0.79	0.29	0.07	1.12	0.77
1989	122	74	0.607	0.52	0.15	0.06	0.35	0.44
1990	100	67	0.670	0.45	0.18	0.07	0.45	0.49
1991	196	147	0.750	0.87	0.45	0.21	0.93	0.38
1992	338	288	0.852	1.12	0.73	0.38	1.38	0.33
1993	251	213	0.849	0.96	0.63	0.32	1.23	0.34
1994	196	162	0.827	0.93	0.55	0.27	1.15	0.38
1995	153	125	0.817	0.84	0.61	0.28	1.35	0.41
1996	172	144	0.837	0.92	0.65	0.30	1.41	0.41
1997	356	326	0.916	0.85	0.92	0.46	1.83	0.35
1998	538	438	0.814	0.91	1.40	0.90	2.18	0.22
1999	938	824	0.878	0.87	1.22	0.83	1.81	0.20
2000	1,058	861	0.814	0.72	1.08	0.73	1.60	0.20
2001	847	654	0.772	0.72	1.08	0.70	1.65	0.22
2002	937	683	0.729	0.82	1.41	0.93	2.14	0.21
2003	946	720	0.761	0.82	1.25	0.83	1.89	0.21
2004	1,191	908	0.762	0.72	1.14	0.79	1.64	0.18

Year	N	Positive N	PPT	Relative Nominal CPUE	Relative Index	Lower 95% CI	Upper 95% CI	CV
2005	955	725	0.759	0.70	0.95	0.64	1.42	0.20
2006	792	603	0.761	0.61	0.95	0.62	1.46	0.22
2007	767	635	0.828	0.90	2.28	1.47	3.54	0.22

Table 9. Deviance tables for the regression models for Red Snapper in the west 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	10,789.	9,549	10,790	10,792		-5,395	
area	3	617	9,546	10,172	10,180	6	-5,087	616
anglers	9	376	9,537	9,795	9,821	4	-4,902	371
reg_season	1	331	9,536	9,464	9,492	3	-4,745	313
year	33	315	9,503	9,149	9,243	3	-4,588	313
Censored Lognormal								
Null	1	12,604.	7,139	12,604	4,062		-2,029	
year	33	515	7,107	12,088	3,829	4	-1,880	298
wave	5	305	7,135	11,783	3,657	2	-1,788	182
mode	1	126	7,139	11,657	3,582	1	-1,750	77

Table 10. 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 Gulf of Mexico.

Year	N	Positive N	PPT	Relative Nominal CPUE	Relative Index	Lower 95% CI	Upper 95% CI	CV
1981	23	7	0.304	0.72	0.70	0.21	2.35	0.66
1982	47	34	0.723	1.40	0.89	0.38	2.09	0.45
1983	262	195	0.744	2.70	1.86	1.14	3.02	0.25
1984	206	140	0.680	1.41	0.68	0.40	1.13	0.26
1985	180	93	0.517	0.70	0.32	0.18	0.56	0.28
1986	189	128	0.677	1.41	0.69	0.40	1.18	0.27
1987	156	112	0.718	1.32	0.71	0.40	1.27	0.30
1988	146	96	0.658	1.24	0.61	0.34	1.10	0.30
1989	128	82	0.641	1.15	0.63	0.34	1.16	0.31
1990	181	111	0.613	0.71	0.38	0.22	0.65	0.28
1991	176	137	0.778	1.46	0.95	0.54	1.68	0.29
1992	273	193	0.707	1.30	1.00	0.62	1.59	0.24
1993	258	200	0.775	1.28	1.08	0.66	1.77	0.25
1994	302	248	0.821	1.24	1.11	0.69	1.81	0.25
1995	472	406	0.860	1.22	1.21	0.78	1.88	0.22
1996	438	365	0.833	1.03	0.93	0.60	1.45	0.22
1997	422	355	0.841	1.01	0.90	0.57	1.40	0.23
1998	399	315	0.789	0.89	0.93	0.60	1.44	0.22
1999	316	221	0.699	0.64	0.56	0.36	0.88	0.22
2000	352	269	0.764	0.72	0.71	0.45	1.10	0.23
2001	318	234	0.736	0.68	0.72	0.45	1.13	0.23
2002	366	263	0.719	0.79	0.91	0.59	1.40	0.22
2003	375	271	0.723	0.75	0.68	0.44	1.04	0.22
2004	366	261	0.713	0.68	0.63	0.41	0.96	0.22

Year	N	Positive N	PPT	Relative Nominal CPUE	Relative Index	Lower 95% CI	Upper 95% CI	CV
2005	377	290	0.769	0.80	0.86	0.56	1.33	0.22
2006	539	414	0.768	0.72	0.67	0.45	0.99	0.20
2007	400	313	0.783	0.77	1.15	0.75	1.76	0.21
2008	314	220	0.701	0.59	0.99	0.65	1.52	0.22
2009	318	232	0.730	0.66	1.36	0.88	2.10	0.22
,010	173	133	0.769	0.86	1.76	1.00	3.11	0.29
2011	267	185	0.693	0.74	1.68	1.06	2.67	0.23
2012	269	190	0.706	0.66	1.49	0.94	2.36	0.23
2013	340	266	0.782	0.80	1.81	1.16	2.82	0.22
2014	202	161	0.797	0.97	2.44	1.44	4.14	0.27

Figures

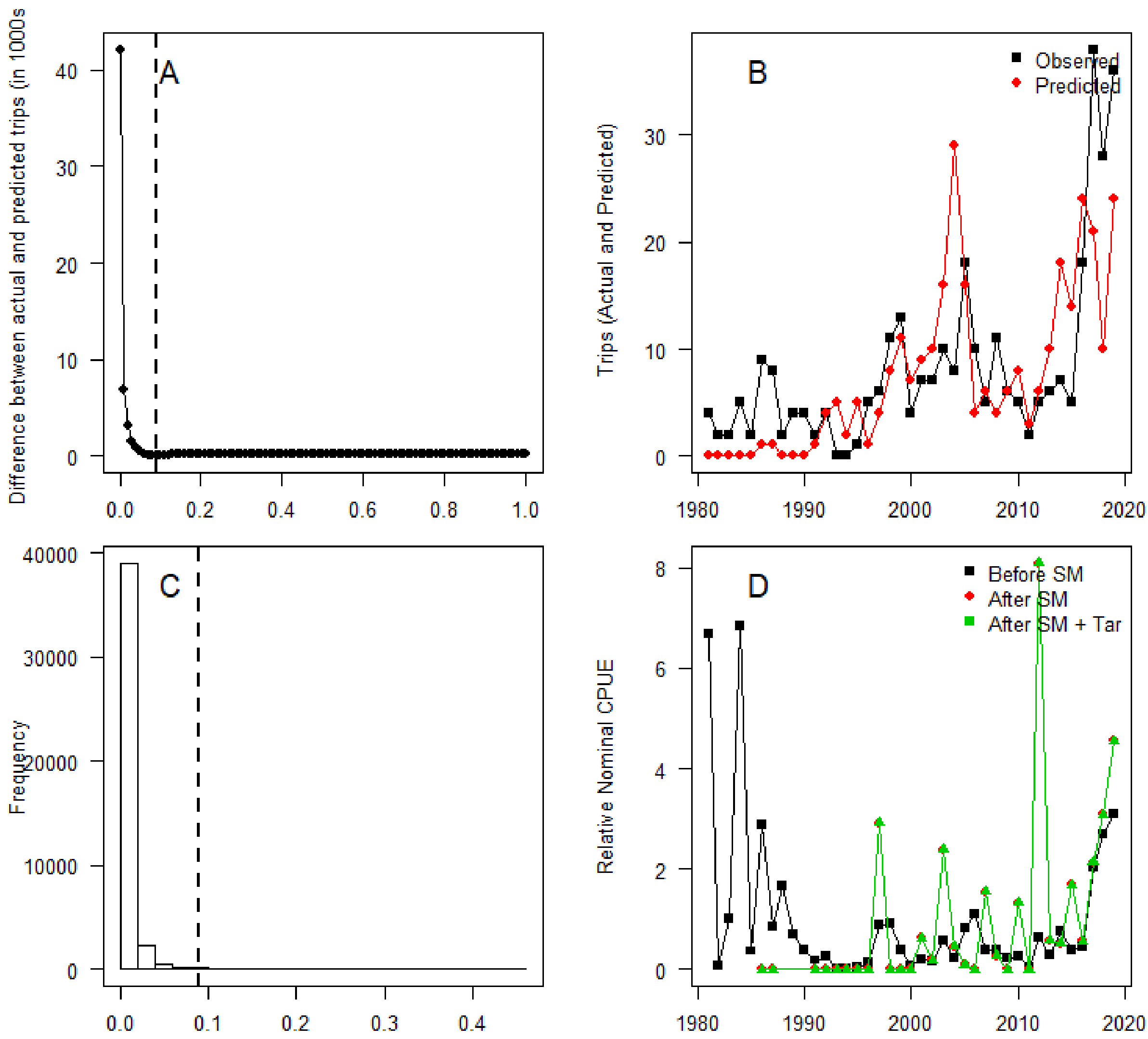

Figure 2. Stephens and MacCall (2004) trip selection diagnostics for the eastern Gulf of Mexico. (A) The difference between the number of records in which Red Snapper are observed and the number in which they are predicted to occur for each probability threshold; (B) the number of actual and predicted trips; (C) Histogram of probabilities generated by the species-based regression; 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.

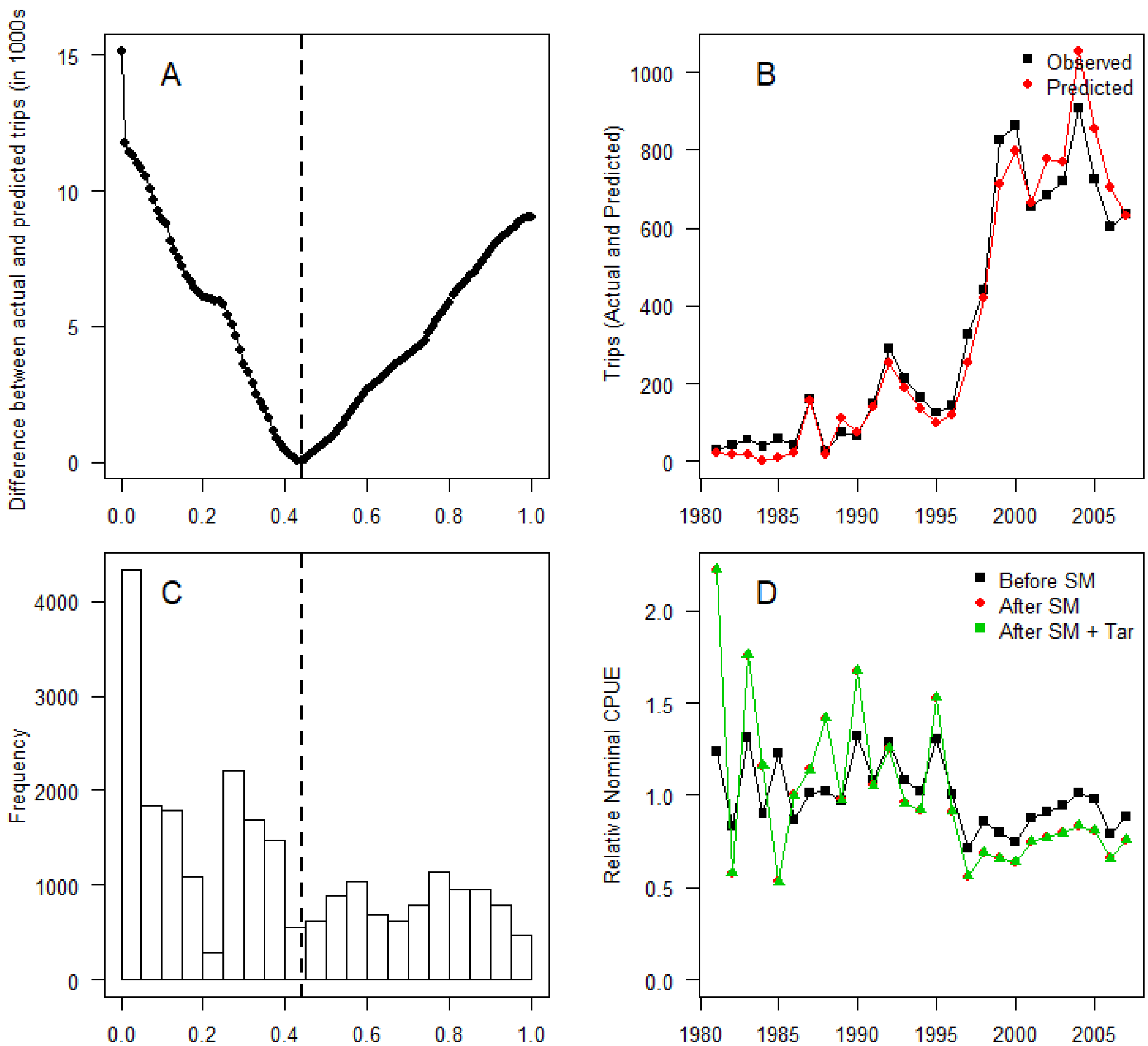

Figure 3. Stephens and MacCall (2004) trip selection diagnostics for the central Gulf of Mexico. (A) The difference between the number of records in which Red Snapper are observed and the number in which they are predicted to occur for each probability threshold; (B) the number of actual and predicted trips; (C) Histogram of probabilities generated by the species-based regression; 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.

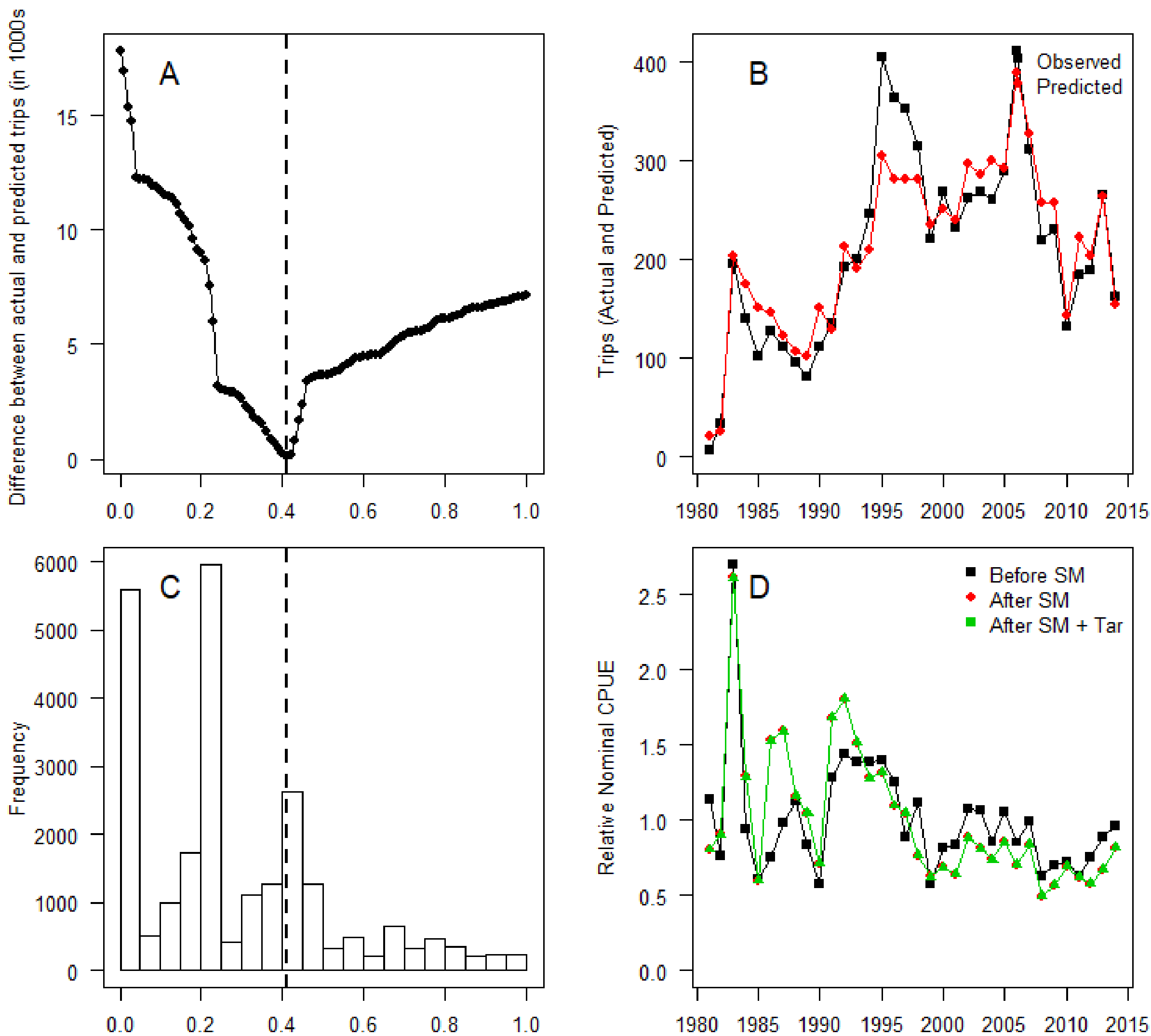

Figure 4. Stephens and MacCall (2004) trip selection diagnostics for the western Gulf of Mexico. (A) The difference between the number of records in which Red Snapper are observed and the number in which they are predicted to occur for each probability threshold; (B) the number of actual and predicted trips; (C) Histogram of probabilities generated by the species-based regression; 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.

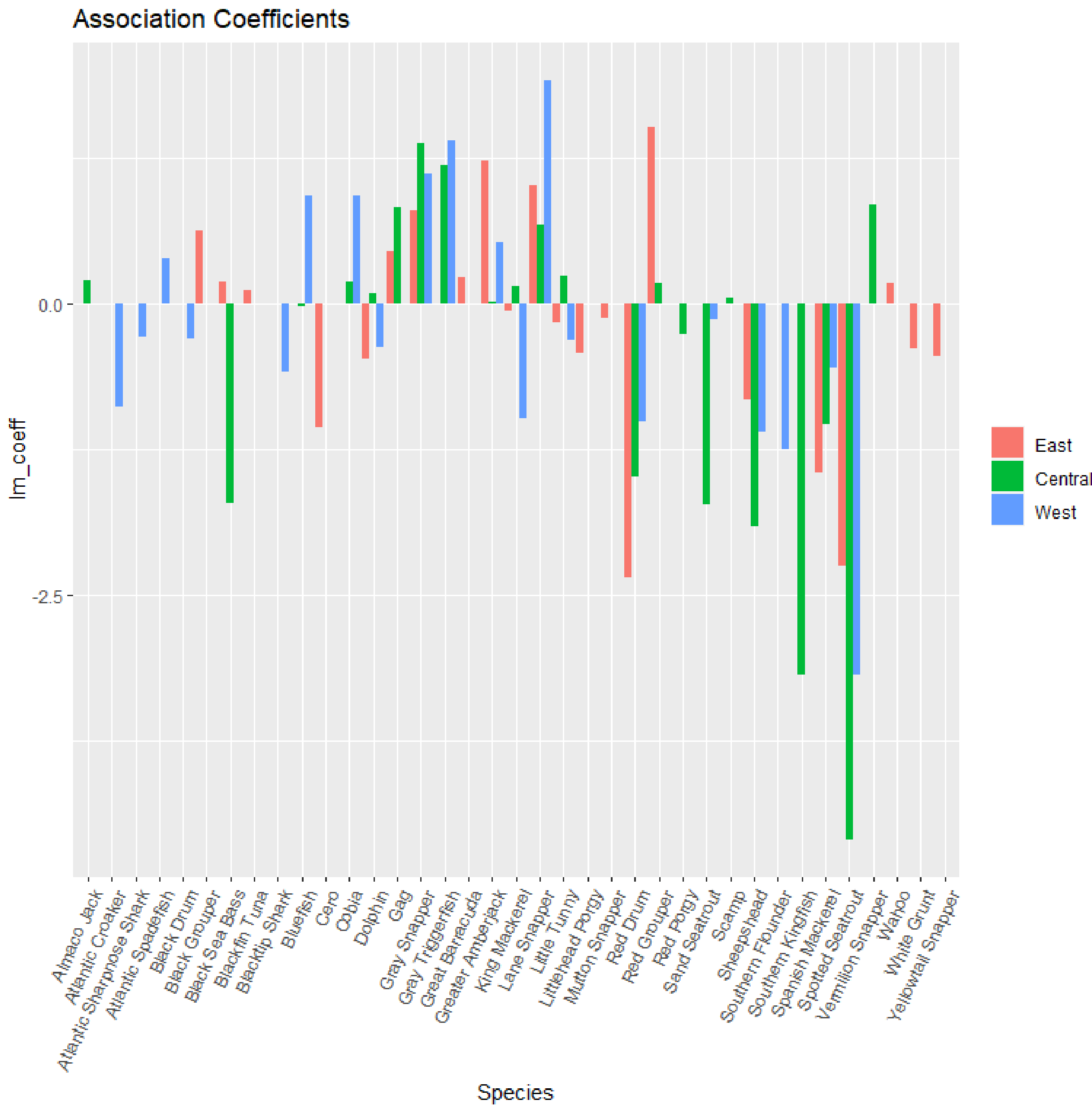

Figure 5. Association coefficients of other species with Red Snapper across regions in the Gulf of Mexico. Positive numbers indicate a positive correlation.

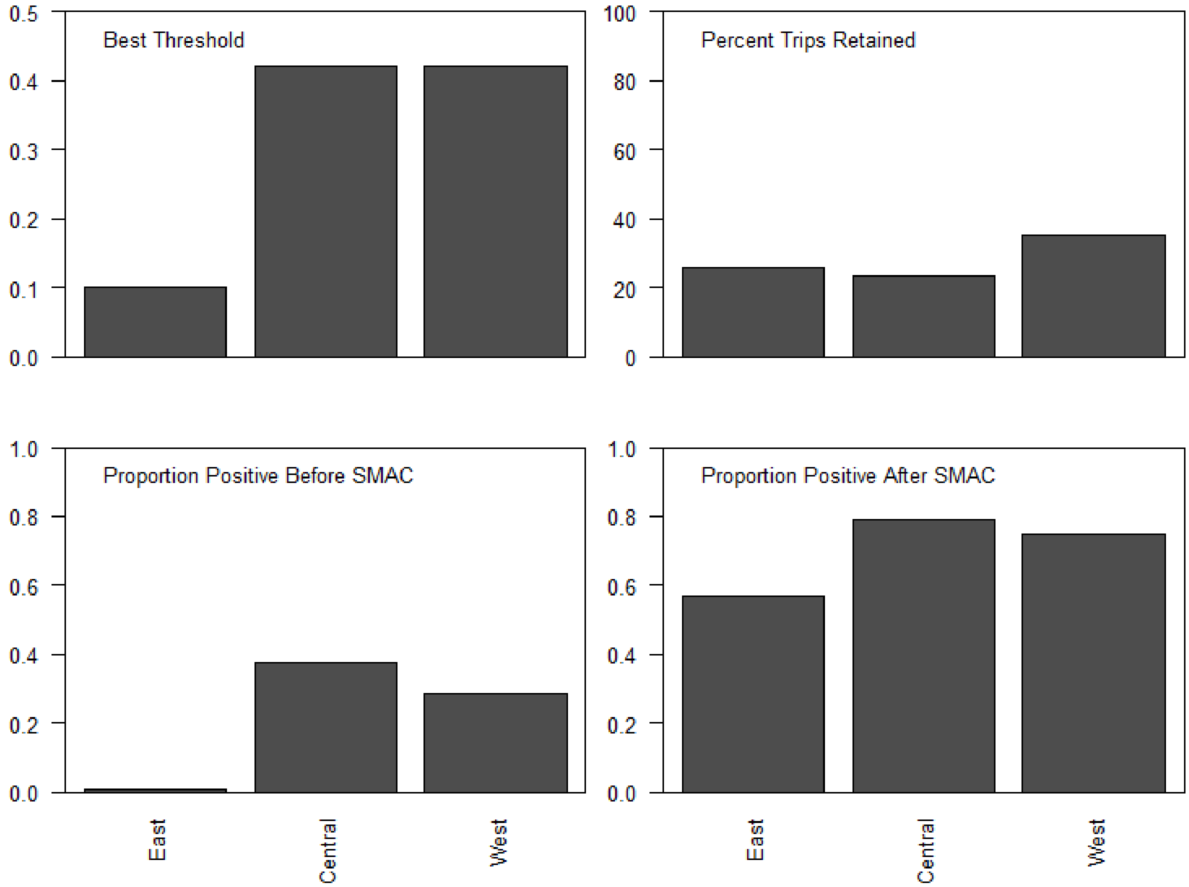

Figure 6. Stephens and MacCall (2004) statistics across regions for associations with Red Snapper.

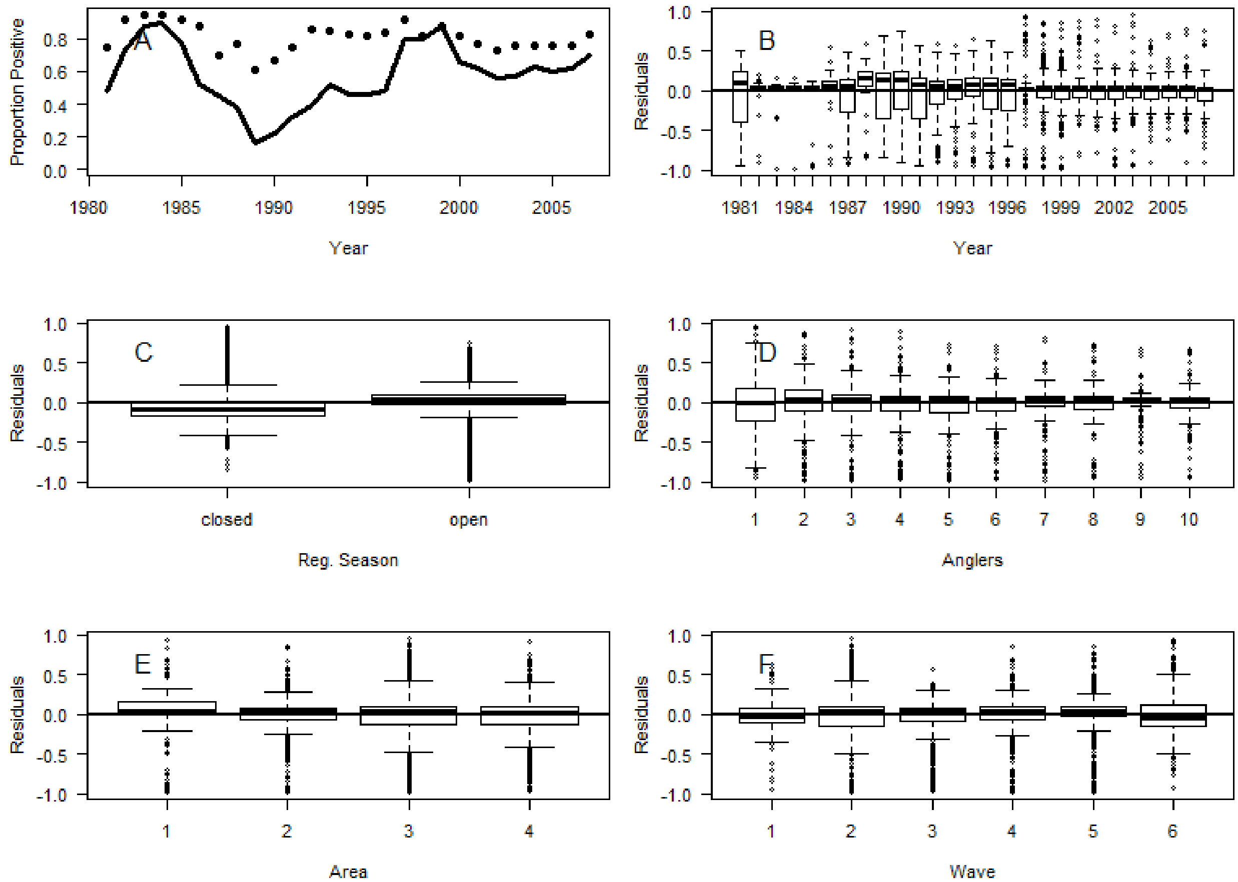

Figure 7. Diagnostic plots for the binomial model for Red Snapper for Central. Shown here are the predicted (solid line) and observed proportion of positive trips by year (A) and the residuals from the binomial model by year (B), regulatory seasons (C), anglers (D), area (E) and wave (F). Note that the observed proportions are below the predicted proportions.

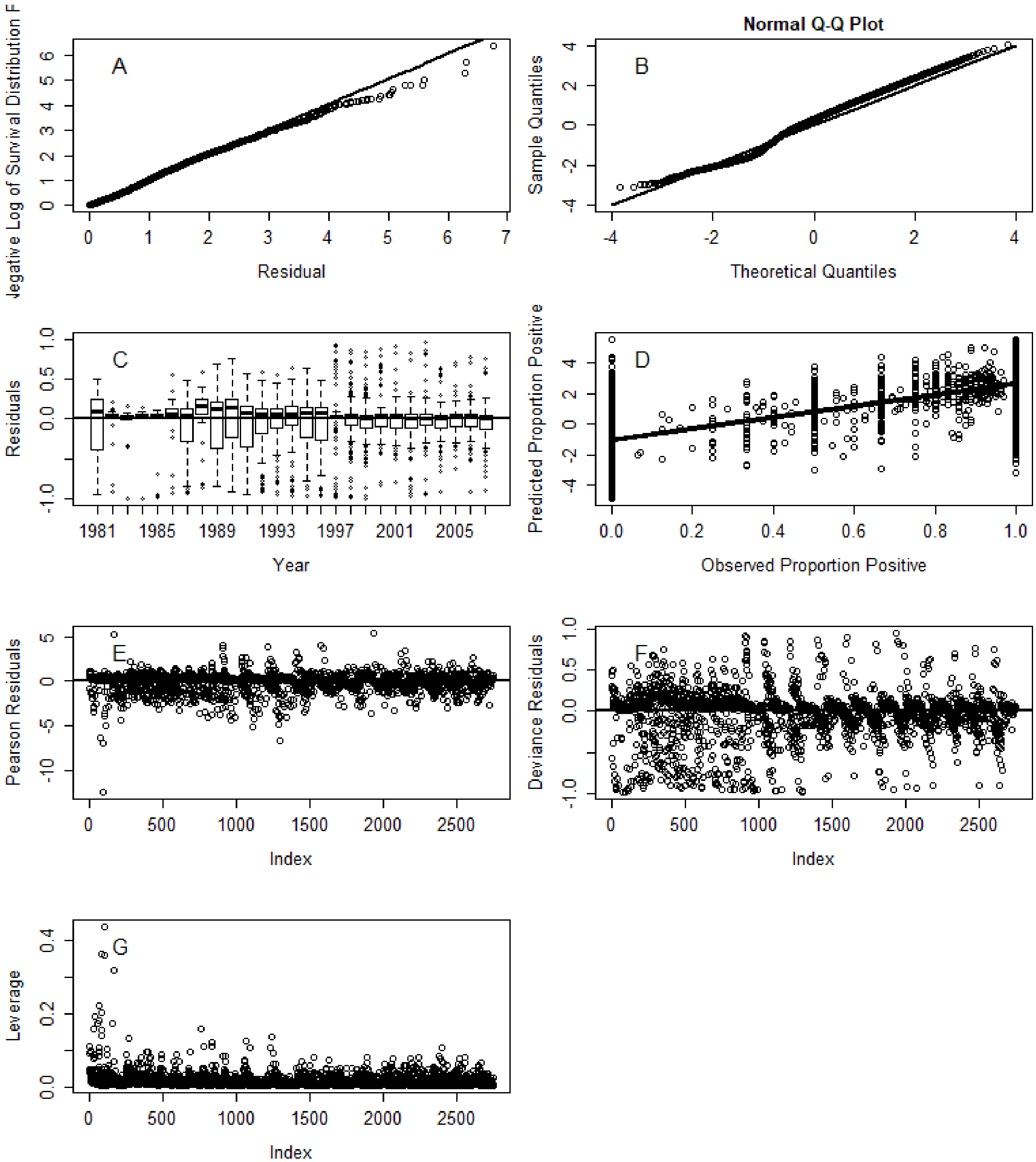

Figure 8. Diagnostic plots for the lognormal model of catch rates on positive trips for Red Snapper for the central Gulf of Mexico. Shown here are the survival distribution residual plot (A), the lognormal residual QQ Martingale plot (B), binomial residuals (C), binomial observed proportion positive (D) binomial Pearson residuals (E), binomial deviance residuals (F) and binomial leverage index (G).

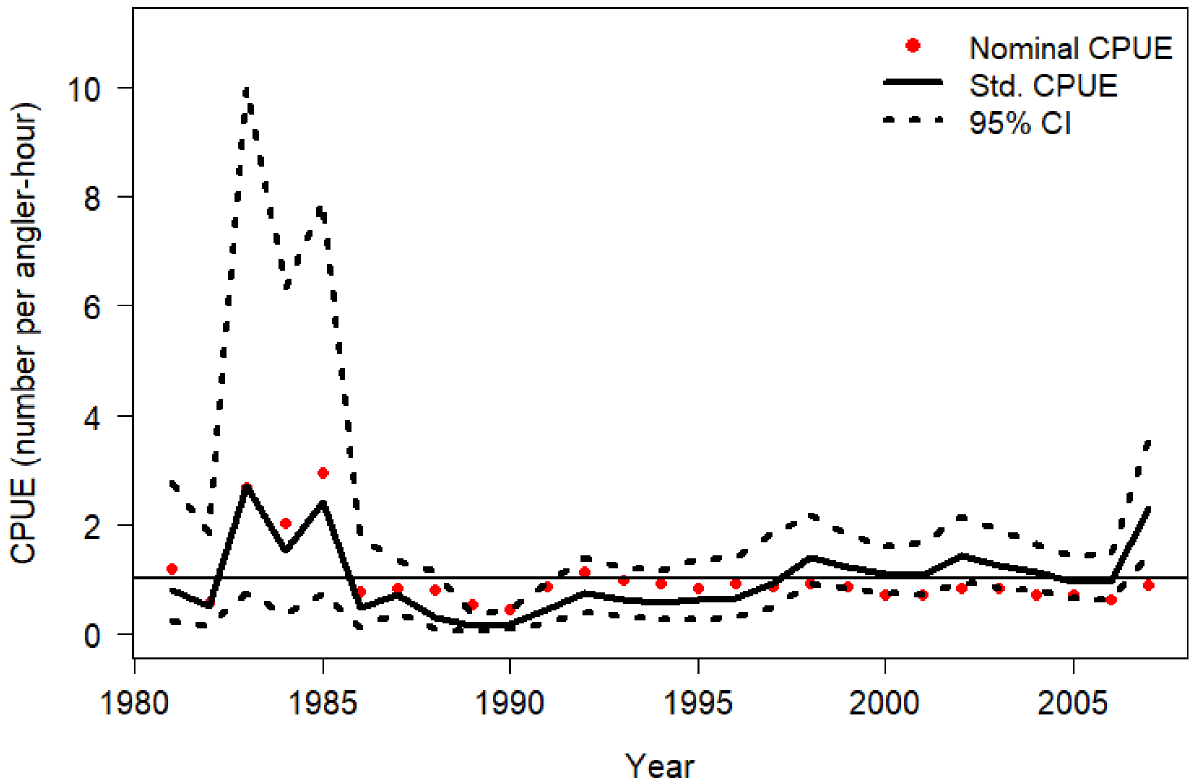

Figure 9. Standardized index with 95% confidence interval, and nominal CPUE for Red Snapper for the central Gulf of Mexico. The index was scaled to the mean value of the entire time series.

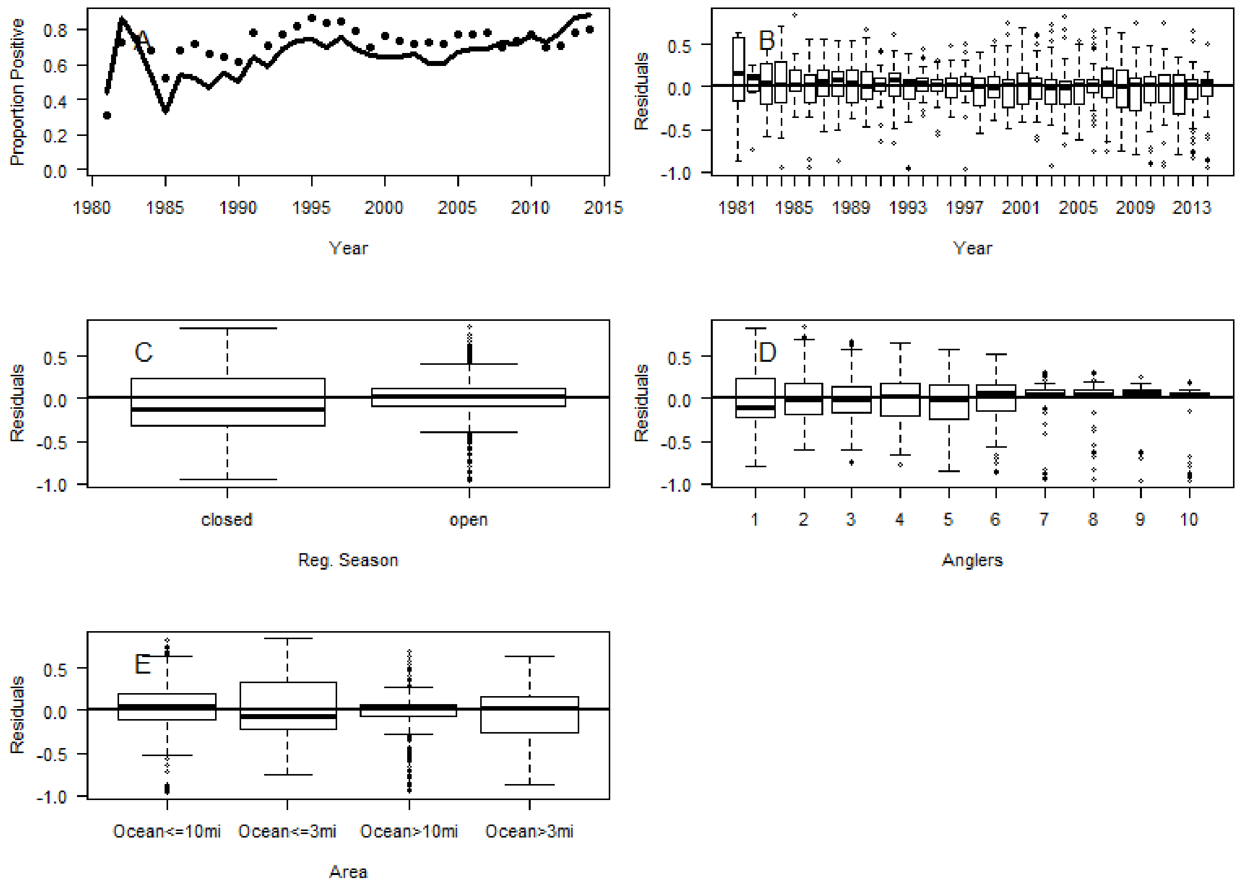

Figure 10. Diagnostic plots for the binomial model for Red Snapper for West. Shown here are the predicted (solid line) and observed proportion of positive trips by year (A) and the residuals from the binomial model by year (B), regulatory season (C), anglers (D), and area (E). Note that the observed proportions are below the predicted proportions.

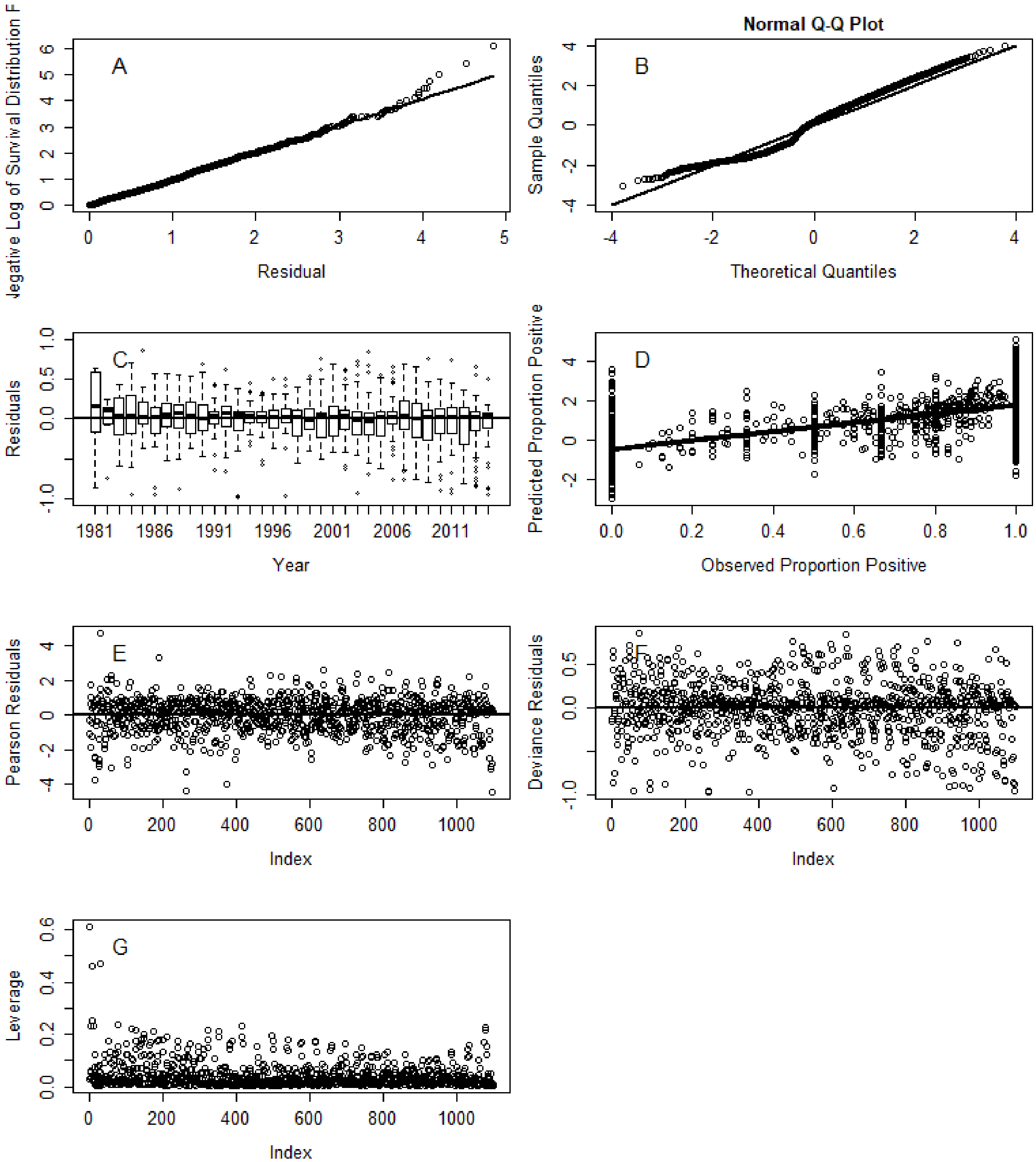

Figure 11. Diagnostic plots for the lognormal model of catch rates on positive trips for Red Snapper for the western Gulf of Mexico. Shown here are the survival distribution residual plot (A), the lognormal residual QQ Martingale plot (B), binomial residuals (C), binomial observed proportion positive (D) binomial Pearson residuals (E), binomial deviance residuals (F) and binomial leverage index (G).

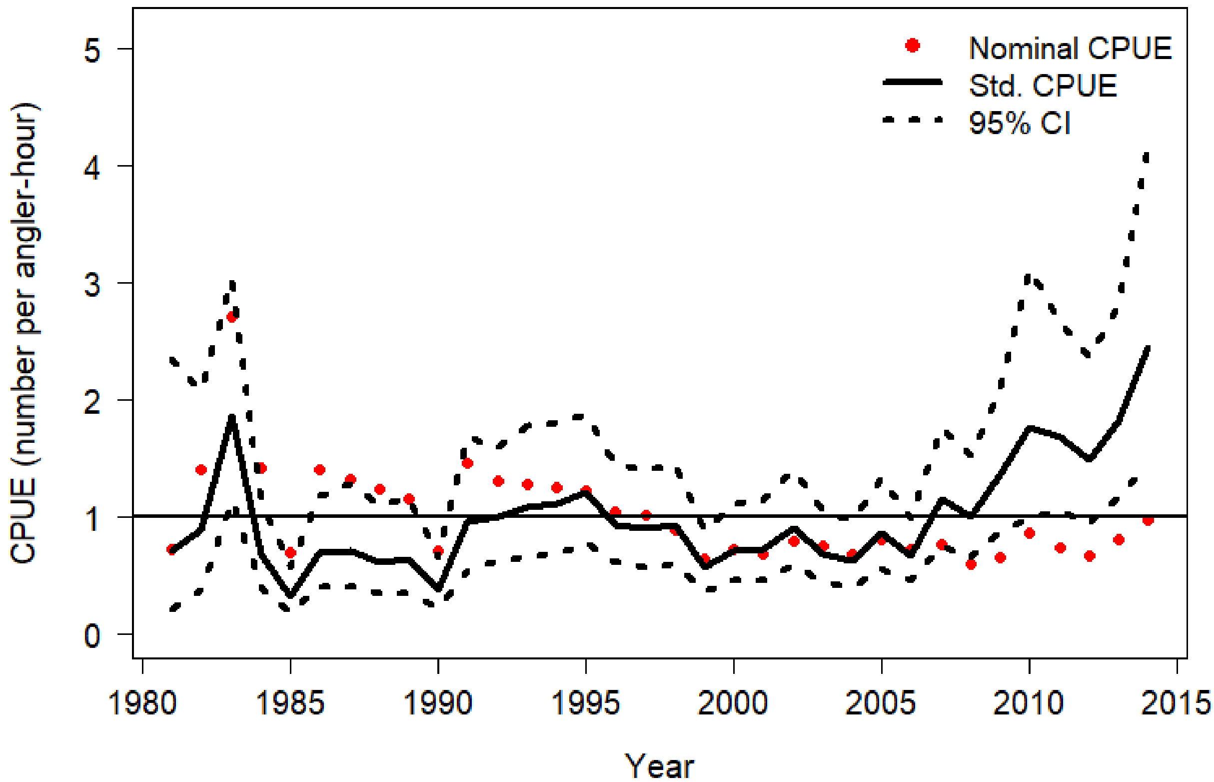

Figure 12. Standardized index with 95% confidence interval, and nominal CPUE for Red Snapper for the western Gulf of Mexico. The index was scaled to the mean value of the entire time series.

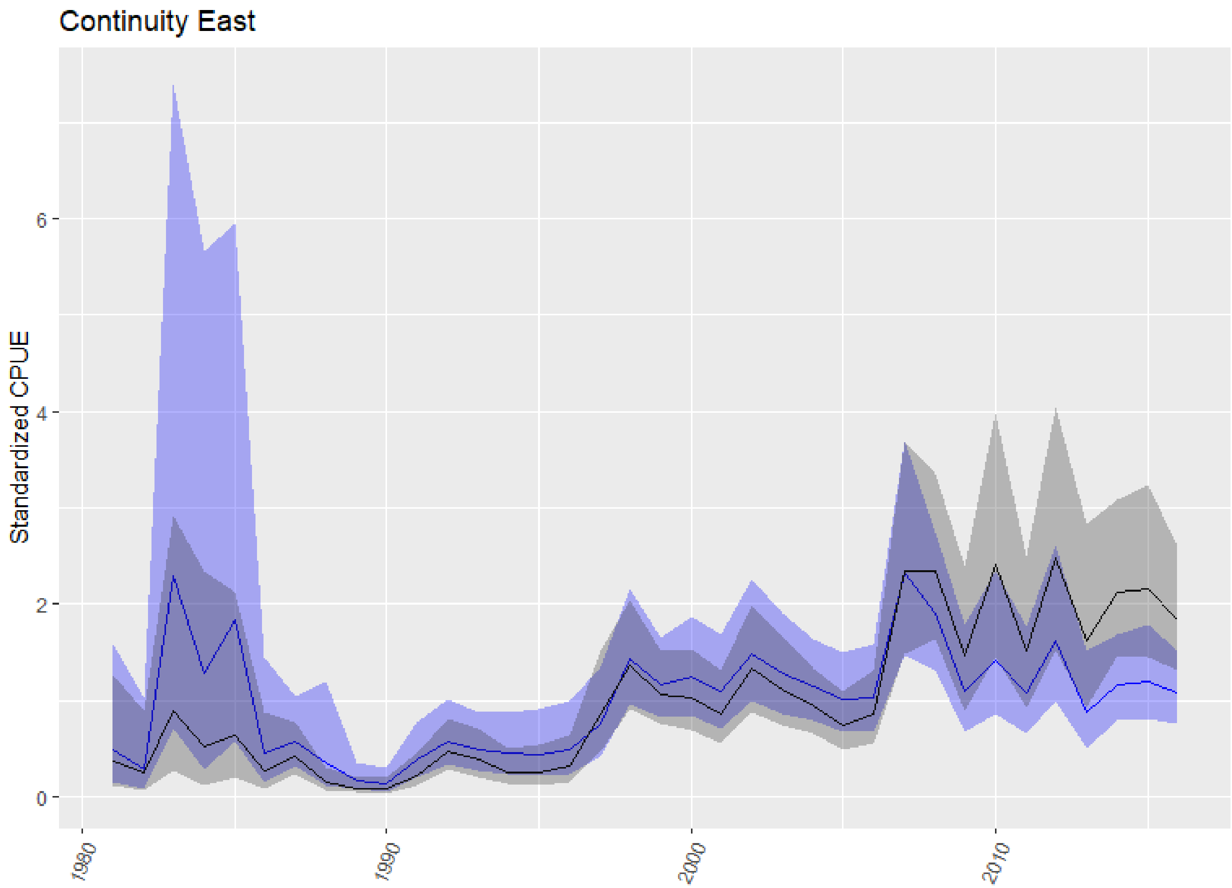

Figure 13. Continuity index for the SEDAR52 east region with updated data (blue) and the SEDAR52 east index (grey) with 95% confidence interval. The index was scaled to the mean value of the entire time series.

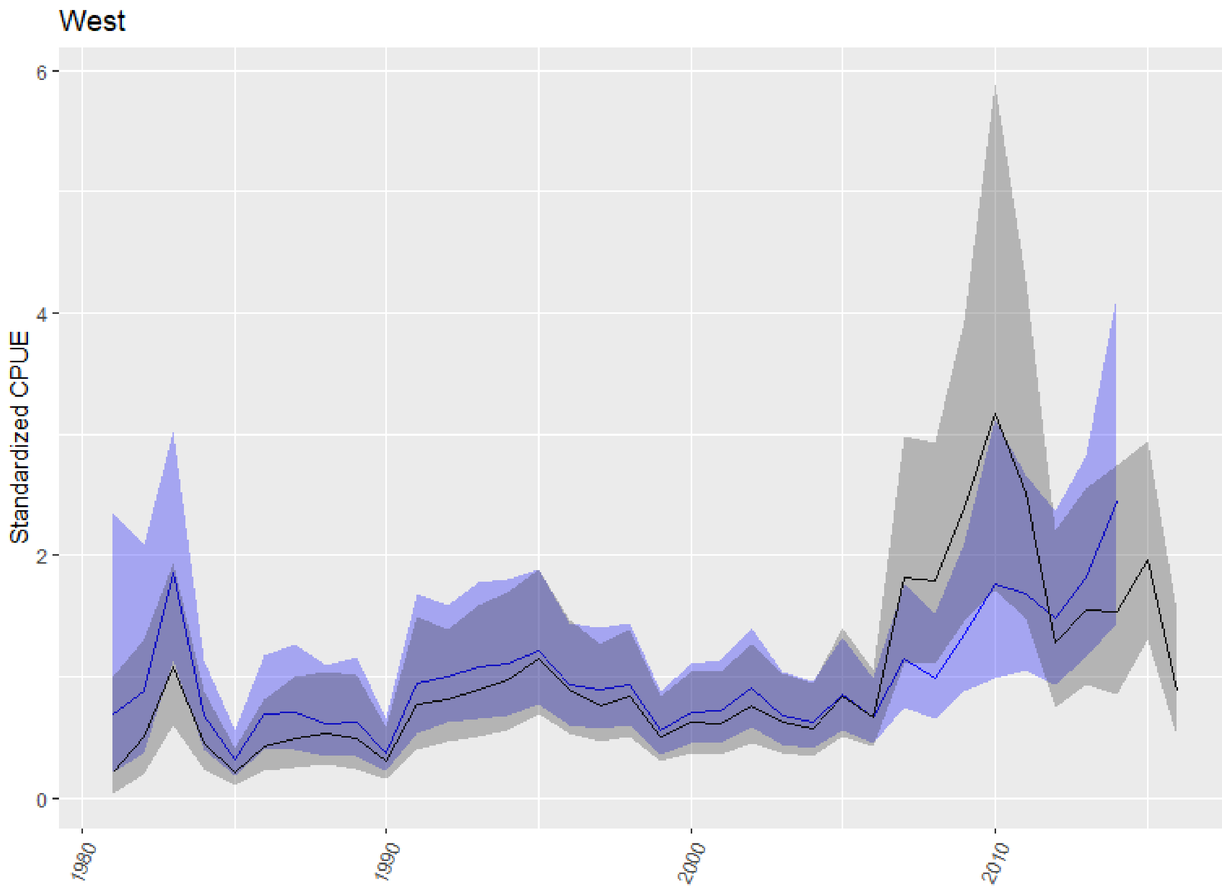

Figure 14. Continuity index for the SEDAR74 western region with updated data (blue) and the SEDAR52 west index (grey) with 95% confidence interval. The index was scaled to the mean value of the entire time series.

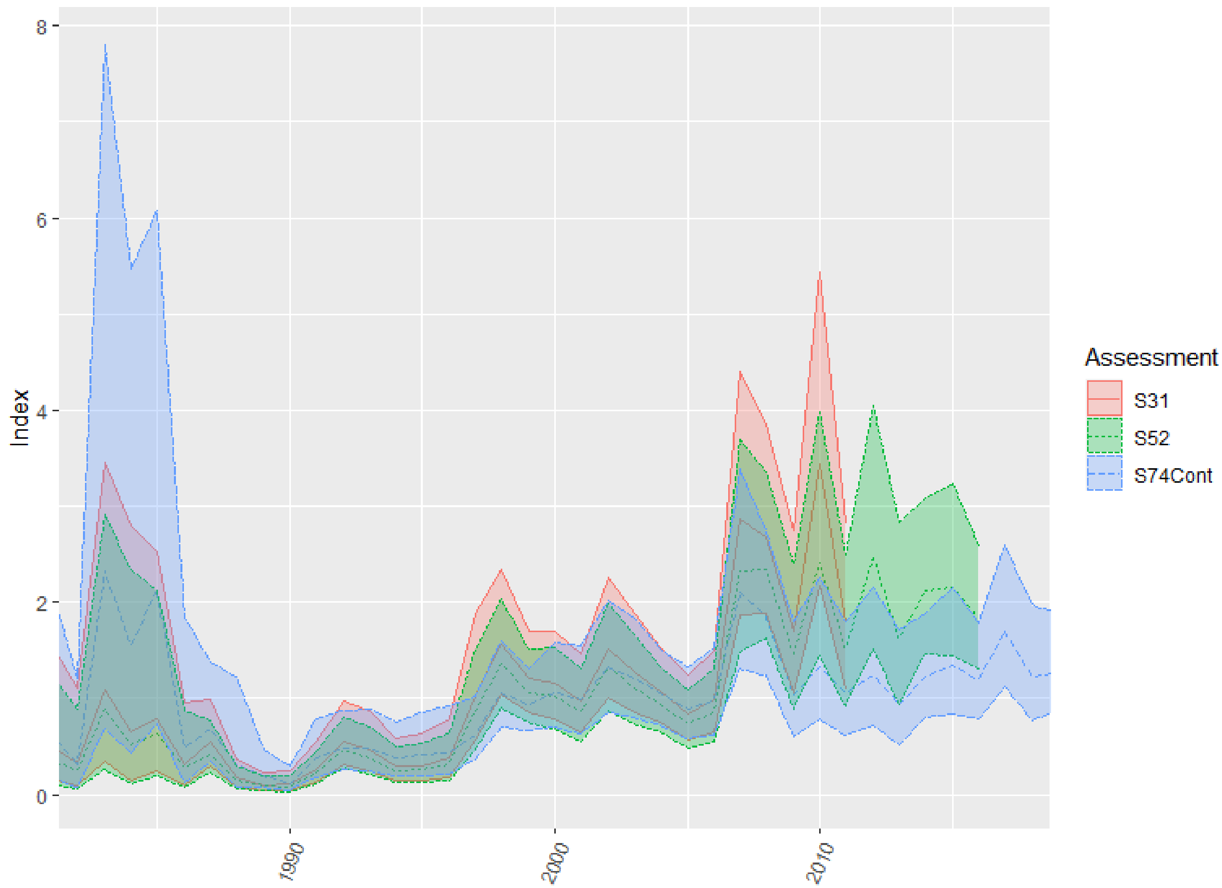

Figure 15. Eastern indices for two previous assessments (SEDAR 31 and SEDAR 52) with the updated data for SEDAR 74 using the previous eastern region boundaries with 95% confidence intervals. The index was scaled to the mean value of the entire time series.