# Using a Censored Regression Modeling Approach to Standardize Red Snapper Catch per Unit Effort Using Recreational Fishery Data Affected by a Bag Limit

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# Using a Censored Regression Modeling Approach to Standardize Red Snapper Catch per Unit Effort Using Recreational Fishery Data Affected by a Bag Limit

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## Keywords

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

## Abstract

In this paper we apply a censored regression approach previously used for red snapper to statistically calculate an unbiased standardized index of abundance using data collected from a fishery with trip limits. A delta censored lognormal regression approach is applied to catch and effort data from the recreational fishery for red snapper (*Lutjanus campechanus*) in the Gulf of Mexico. Indices are calculated for the headboat and private/for hire sectors using data through 2016 following the same procedures as SEDAR31.

## Introduction

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, 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 (Table 1) have greatly reduced the data available for modeling CPUE of red snapper in recent years.

## Methodology

*Data*

The recreational fisheries in the Gulf of Mexico are surveyed by three programs:

- Marine Recreational Fishery Statistics Survey (MRFSS) conducted by the NOAA Fisheries (NMFS);
- Texas Marine Sport-Harvest Monitoring Program by the Texas Parks and Wildlife Department (TPWD);
- Headboat Survey (HBS) conducted by NMFS, Southeast Fisheries Science Center, Beaufort, NC.

These three surveys together provide information on catch in numbers, fishing effort, and length and weight samples. The MRFSS and the TPWD survey are both sampling-based, while the Headboat Survey is a census of headboats using logbooks provided to all headboats to report total landings per trip and fishing effort. MRFSS was conducted in TX through 1985, after which the Texas Parks and Wildlife Department covered surveying efforts. In addition, starting in 1986, MRFSS no longer covered headboats in the Gulf of Mexico and instead this sector of the recreational fishery was covered by the Headboat Survey. MRFSS provides 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) and 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 MRFSS on fish landed whole and observed by the interviewers, fish reported as killed by the fishers and fish reported as released alive by the fishers. Similar to MRFSS, the Texas Parks and Wildlife survey also, provides information on participation, effort and species-specific landings however no discards are reported in this dataset.[1]

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

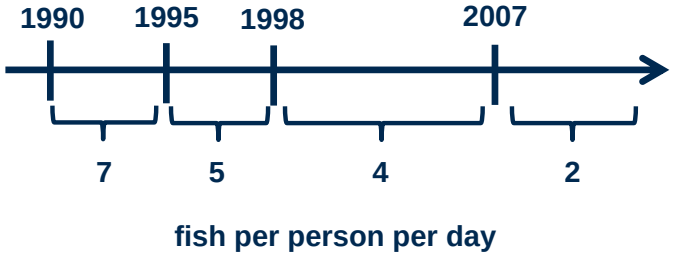


**Figure 1**: Red snapper recreational bag limit history.

[1] General overview of the recreational surveys from the following: Recreational Survey Data for Gag and Black Grouper in the Gulf of Mexico. Patty Phares, Vivian Matter, and Steve Turner. National Marine Fisheries Service, Southeast Fisheries Science Center, Sustainable Fisheries Division, January, 2006. Sustainable Fisheries Division Contribution No. SFD-2006-008.

As in Saul and Walter III (2012), only the landings information from the MRFSS dataset was used to construct an index, and the MRFSS data were combined with the TPWD survey in order to develop indices for the private/for hire sector that geographically cover the entire U.S. coastline in the Gulf of Mexico. The MRFSS/Texas and Headboat Survey data sets were looked at across different strata to assess the sample size of total trips and positive trips within each of the strata. In order to avoid double counting, any data from Texas, present in the MRFSS dataset between the years 1981 through 1985, were removed from the MRFSS data because the State of Texas has its own survey. In addition, data from the headboat mode in MRFSS, also present in the years 1981 through 1985, were removed because this information was covered by the Headboat Survey program. The shore mode was removed from the MRFSS data as well as trips taken in inshore waters because less than 0.1 percent of such trips caught red snapper. Datasets were partitioned at the Mississippi River and separate Eastern and Western indices were estimated. Effort was measured as the number of anglers times the hours fished, while catch was measured as the number of fish caught.

*Trip Selection*

After comparing multiple approaches for subsetting recreational data, Saul and Walter III (2012) determined that the three trip selection approaches perform very similarly to one another, and the Stephens and MacCall approach (Stephens and MacCall 2004) was recommended for use in SEDAR31 since it is the convention accepted by SEDAR. The Stephens and MacCall approach was used to identify trips that could have caught red snapper. 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 red snapper habitat. 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).

For the headboat survey, the data were subset such that only data collected during red snapper open seasons were used in the analysis. 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.

*Continuity CPUE Indices*

An eastern and western continuity index was estimated in the same manner as the indices constructed in SEDAR31 for continuity purposes.

*Censored Delta Lognormal Modeling Approach*

The censored Delta lognormal modeling 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.

The following factors were examined as possible influences on the proportion of positive trips, and the catch rates on positive trips for the MRFSS data:

| | |
|---|---|
| Year (36) | 1981-2016 |
| State (3, 2) | East: FL, AL, MS |
| | West: LA, TX |
| Area (4) | < 3 miles, > 3 miles, <10 miles, > 10 miles |
| Season (2) | Open, Closed |
| Wave (6) | Jan-Feb, Mar-Apr, May-Jun, Jul-Aug, Sep-Oct, Nov-Dev |
| Mode (2) | Charter, Private |
| Anglers (10) | 1,2,3,4,5,6,7,8,9,10+ |

Number of anglers was only explored as a factor for modeling success.

The following factors were examined as possible influences on the proportion of positive trips, and the catch rates on positive trips for the Headboat data:

| | |
|---|---|
| Year (31) | 1986-2016 |
| Area (2,3) | East: Florida Panhandle, FL West Coast |
| | West: LA & Northeast TX, Central TX, South TX |
| Anglers (10) | 0-9, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89, 90+ |

Number of anglers was only explored as a factor for modeling success.

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 was repeated adding 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 in order 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, 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**

*MRFSS East*

The private/for hire mode indices for the eastern Gulf of Mexico contain strictly MRFSS data. Table 2 summarizes the standardized index and corresponding coefficients of variation, upper confidence limits, lower confidence limits, and nominal CPUE. The final deviance table contains a list of the factors that were included in each model in the order in which they were added, and the resulting AIC of the model when that factor was added (Table 4). The standardized index, with 95% confidence intervals, is shown in Figure 1. Appendix A provides the number of observations, the number of positive observations, and the proportion of positive observations by year before and after trip selection. Figure 2 provides a comparison of the private/for hire index that resulted from the current analysis to the index used during the SEDAR31 Update. Differences in the index trend at the end of the time series are due to a slight change in the coded regulations.

*MRFSS West*

The private/for hire mode indices for the western Gulf of Mexico contain a combination of MRFSS data (to cover Louisiana) and data from the Texas Parks and Wildlife Survey. Table 2 summarizes the standardized index and corresponding coefficients of variation, upper confidence limits, lower confidence limits, and nominal CPUE. The final deviance table contains a list of the factors that were included in each model in the order in which they were added, and the resulting AIC of the model when that factor was added (Table 5). The standardized index, with 95% confidence intervals, is shown in Figure 3. Appendix B provides the number of observations, the number of positive observations, and the proportion of positive observations by year before and after trip selection. Figure 4 provides a comparison of the private/for hire index that resulted from the current analysis to the index used during the SEDAR31 Update, which are nearly identical in trend.

*Headboat East*

The headboat mode indices for each region of the Gulf of Mexico were estimated from the NMFS Headboat Survey. Table 3 summarizes the standardized index and corresponding coefficients of variation, upper confidence limits, lower confidence limits, and nominal CPUE. The final deviance table contains a list of the factors that were included in each model in the order in which they were added, and the resulting AIC of the model when that factor was added (Table 6). The standardized index, with 95% confidence intervals, is shown in Figure 5. Appendix C provides the number of observations, the number of positive observations, and the proportion of positive observations by year before and after trip selection. Figure 6 provides a comparison of the headboat index that resulted from the current analysis to the index used during the SEDAR31 Update. An important note is the lack of an index value during 2011 due to all positive trips (100% proportion positive) which prevented the binomial component of the delta model to fit. Although this was not an issue during the SEDAR31 Update, year 2011 had a proportion positive of 99.74% due to only 3 trips included within the Stephens and MacCall subset that did not catch red snapper.

*Headboat West*

The headboat mode indices for each region of the Gulf of Mexico were estimated from the NMFS Headboat Survey. Table 3 summarizes the standardized index and corresponding coefficients of variation, upper confidence limits, lower confidence limits, and nominal CPUE. The final deviance table contains a list of the factors that were included in each model in the order in which they were added, and the resulting AIC of the model when that factor was added (Table 7). The standardized index, with 95% confidence intervals, is shown in Figure 7. Appendix D provides the number of observations, the number of positive observations, and the proportion of positive observations by year and factor. Figure 8 provides a comparison of the headboat index that resulted from the current analysis to the index used during the SEDAR31 Update, which were generally similar in trend.

## Conclusions and Recommendations

Future research will simulation test the censored regression technique in order to better understand the utility and limitations of the algorithm.

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## Tables

**Table 1**: Recreational season lengths, open/close dates, and references used for modeling red snapper.

| Year | Component | # Days | Open date | Close date | Effective Date | Reference |
|---|---|---|---|---|---|---|
| Pre-1990 | Private/for-hire | 365 | 1-Jan | 31-Dec | | |
| 1990 | " | " | " | " | | |
| 1991 | " | " | " | " | | |
| 1992 | " | " | " | " | | |
| 1993 | " | " | " | " | | |
| 1994 | " | " | " | " | | |
| 1995 | " | " | " | " | | |
| 1996 | " | " | " | " | | |
| 1997 | " | 330 | " | 27-Nov | 11/27/1997 | 62 FR 61700 |
| 1998 | " | 272 | " | 30-Sep | 8/27/1998 | 63 FR 45760 |
| 1999 | " | 240 | " | 29-Aug | 6/4/1999 | 64 FR 30445 |
| 2000 | " | 194 | 21-Apr | 1-Nov | 1/19/2000; 9/18/2000 | 64 FR 71056; 65 FR 50158 |
| 2001 | " | " | " | " | | |
| 2002 | " | " | " | " | | |
| 2003 | " | " | " | " | | |
| 2004 | " | " | " | " | | |
| 2005 | " | " | " | " | | |
| 2006 | " | " | " | " | | |
| 2007 | " | " | " | " | 5/2/2007 | 72 FR 15617 |
| 2008 | " | 65 | 1-Jun | 5-Aug | 8/5/2008 | 73 FR 15674 |
| 2009 | " | 75 | " | 15-Aug | 8/15/2009 | 74 FR 21558 |
| 2010 | " | 53 | " | 24-Jul | 6/2/2010 | 75 FR 23186 |
| 2011 | " | 48 | " | 19-Jul | 9/12/2011 | 76 FR 50143 |
| 2012 | " | 46 | " | 17-Jul | 7/11/2012 | 77 FR 39647 |
| 2013 | " | 42 | 1-Jun; 1-Oct | 29-Jun; 15-Oct | 6/29/2013; 10/1/2013 | 78 FR 34586; 78 FR 57313 |
| 2014 | " | 9 | " | 10-Jun | 5/15/2014 | 79 FR 27768 |
| 2015 | Private | 10 | " | 11-Jun | 6/1/2015 | 80 FR 24832 |
| | For-hire | 44 | " | 15-Jul | 6/1/2015 | 80 FR 24832 |
| 2016 | Private | 11 | " | 12-Jun | 6/10/2016 | 81 FR 38110 |
| | For-hire | 46 | " | 17-Jul | 6/10/2016 | 81 FR 25583 |

**Table 2**: Index values, lower confidence limits, upper confidence limits, and coefficient of variation for the recommended censored regression fit private/for hire mode index for red snapper.

| Year | EASTERN GULF | | | | WESTERN GULF | | | |
|---|---|---|---|---|---|---|---|---|
| | **Index** | **LCI** | **UCI** | **CV** | **Index** | **LCI** | **UCI** | **CV** |
| 1981 | 0.374 | 0.112 | 1.254 | 0.665 | 0.208 | 0.043 | 1.000 | 0.922 |
| 1982 | 0.249 | 0.070 | 0.886 | 0.705 | 0.504 | 0.194 | 1.311 | 0.507 |
| 1983 | 0.893 | 0.273 | 2.922 | 0.649 | 1.084 | 0.604 | 1.943 | 0.298 |
| 1984 | 0.522 | 0.116 | 2.348 | 0.872 | 0.457 | 0.238 | 0.880 | 0.336 |
| 1985 | 0.644 | 0.195 | 2.126 | 0.654 | 0.215 | 0.110 | 0.420 | 0.345 |
| 1986 | 0.274 | 0.086 | 0.877 | 0.633 | 0.430 | 0.227 | 0.816 | 0.328 |
| 1987 | 0.419 | 0.227 | 0.773 | 0.314 | 0.500 | 0.250 | 1.000 | 0.357 |
| 1988 | 0.142 | 0.068 | 0.297 | 0.381 | 0.536 | 0.274 | 1.048 | 0.345 |
| 1989 | 0.089 | 0.041 | 0.192 | 0.401 | 0.498 | 0.243 | 1.022 | 0.371 |
| 1990 | 0.085 | 0.036 | 0.200 | 0.449 | 0.310 | 0.163 | 0.591 | 0.331 |
| 1991 | 0.224 | 0.111 | 0.452 | 0.362 | 0.777 | 0.403 | 1.497 | 0.337 |
| 1992 | 0.475 | 0.277 | 0.814 | 0.274 | 0.812 | 0.472 | 1.396 | 0.276 |
| 1993 | 0.382 | 0.207 | 0.706 | 0.314 | 0.901 | 0.512 | 1.586 | 0.289 |
| 1994 | 0.253 | 0.128 | 0.500 | 0.351 | 0.977 | 0.563 | 1.696 | 0.281 |
| 1995 | 0.256 | 0.122 | 0.537 | 0.383 | 1.146 | 0.696 | 1.885 | 0.253 |
| 1996 | 0.310 | 0.151 | 0.635 | 0.370 | 0.890 | 0.539 | 1.470 | 0.255 |
| 1997 | 0.851 | 0.476 | 1.521 | 0.297 | 0.767 | 0.463 | 1.272 | 0.257 |
| 1998 | 1.358 | 0.902 | 2.045 | 0.207 | 0.841 | 0.507 | 1.396 | 0.257 |
| 1999 | 1.065 | 0.752 | 1.509 | 0.175 | 0.507 | 0.304 | 0.845 | 0.260 |
| 2000 | 1.025 | 0.688 | 1.528 | 0.201 | 0.624 | 0.373 | 1.044 | 0.261 |
| 2001 | 0.857 | 0.560 | 1.311 | 0.215 | 0.609 | 0.356 | 1.040 | 0.273 |
| 2002 | 1.323 | 0.876 | 1.996 | 0.208 | 0.763 | 0.457 | 1.275 | 0.261 |
| 2003 | 1.110 | 0.743 | 1.661 | 0.203 | 0.622 | 0.374 | 1.032 | 0.258 |
| 2004 | 0.935 | 0.654 | 1.336 | 0.180 | 0.577 | 0.350 | 0.950 | 0.254 |
| 2005 | 0.732 | 0.492 | 1.088 | 0.200 | 0.844 | 0.509 | 1.400 | 0.257 |
| 2006 | 0.856 | 0.557 | 1.316 | 0.217 | 0.669 | 0.424 | 1.056 | 0.231 |
| 2007 | 2.335 | 1.478 | 3.687 | 0.232 | 1.822 | 1.110 | 2.989 | 0.251 |
| 2008 | 2.344 | 1.639 | 3.351 | 0.180 | 1.798 | 1.103 | 2.932 | 0.248 |
| 2009 | 1.460 | 0.889 | 2.398 | 0.252 | 2.396 | 1.460 | 3.933 | 0.252 |
| 2010 | 2.405 | 1.454 | 3.978 | 0.256 | 3.175 | 1.712 | 5.887 | 0.316 |
| 2011 | 1.518 | 0.925 | 2.489 | 0.251 | 2.520 | 1.489 | 4.263 | 0.268 |
| 2012 | 2.482 | 1.523 | 4.043 | 0.248 | 1.285 | 0.750 | 2.202 | 0.274 |
| 2013 | 1.624 | 0.933 | 2.827 | 0.283 | 1.553 | 0.942 | 2.561 | 0.254 |
| 2014 | 2.121 | 1.461 | 3.081 | 0.188 | 1.537 | 0.860 | 2.748 | 0.297 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2015 | 2.164 | 1.446 | 3.239 | 0.204 | 1.961 | 1.308 | 2.940 | 0.205 |
| 2016 | 1.843 | 1.306 | 2.601 | 0.174 | 0.885 | 0.509 | 1.537 | 0.281 |

**Table 3**: Index values, upper confidence limits, lower confidence limits, and coefficient of variation for the recommended censored regression fit headboat mode index for red snapper.

| Year | EASTERN GULF | | | | WESTERN GULF | | | |
|---|---|---|---|---|---|---|---|---|
| | **Index** | **LCI** | **UCI** | **CV** | **Index** | **LCI** | **UCI** | **CV** |
| 1986 | 0.136 | 0.023 | 0.810 | 1.103 | 0.530 | 0.334 | 0.843 | 0.235 |
| 1987 | 0.138 | 0.023 | 0.836 | 1.119 | 0.638 | 0.422 | 0.965 | 0.209 |
| 1988 | 0.172 | 0.030 | 0.988 | 1.069 | 0.761 | 0.507 | 1.141 | 0.205 |
| 1989 | 0.218 | 0.040 | 1.203 | 1.036 | 0.674 | 0.452 | 1.003 | 0.201 |
| 1990 | 0.228 | 0.040 | 1.304 | 1.068 | 0.473 | 0.319 | 0.700 | 0.198 |
| 1991 | 0.290 | 0.051 | 1.662 | 1.068 | 0.787 | 0.510 | 1.215 | 0.220 |
| 1992 | 0.434 | 0.079 | 2.378 | 1.029 | 1.398 | 0.898 | 2.177 | 0.224 |
| 1993 | 0.554 | 0.109 | 2.829 | 0.971 | 1.405 | 0.921 | 2.145 | 0.214 |
| 1994 | 0.435 | 0.080 | 2.375 | 1.028 | 1.094 | 0.738 | 1.624 | 0.199 |
| 1995 | 0.353 | 0.064 | 1.958 | 1.041 | 1.134 | 0.737 | 1.745 | 0.218 |
| 1996 | 0.538 | 0.112 | 2.578 | 0.921 | 1.200 | 0.734 | 1.962 | 0.250 |
| 1997 | 0.925 | 0.213 | 4.013 | 0.844 | 1.267 | 0.819 | 1.958 | 0.221 |
| 1998 | 1.445 | 0.356 | 5.861 | 0.795 | 1.094 | 0.702 | 1.703 | 0.224 |
| 1999 | 1.522 | 0.358 | 6.477 | 0.830 | 0.480 | 0.273 | 0.846 | 0.289 |
| 2000 | 1.368 | 0.316 | 5.911 | 0.842 | 0.457 | 0.289 | 0.722 | 0.232 |
| 2001 | 1.324 | 0.314 | 5.580 | 0.823 | 0.663 | 0.368 | 1.196 | 0.301 |
| 2002 | 1.944 | 0.476 | 7.938 | 0.800 | 0.583 | 0.340 | 1.002 | 0.276 |
| 2003 | 1.752 | 0.425 | 7.219 | 0.807 | 0.500 | 0.303 | 0.825 | 0.254 |
| 2004 | 1.388 | 0.335 | 5.741 | 0.810 | 0.384 | 0.233 | 0.632 | 0.253 |
| 2005 | 1.400 | 0.343 | 5.709 | 0.799 | 0.421 | 0.257 | 0.690 | 0.250 |
| 2006 | 0.820 | 0.200 | 3.366 | 0.804 | 0.495 | 0.285 | 0.861 | 0.282 |
| 2007 | 1.710 | 0.407 | 7.183 | 0.821 | 0.946 | 0.506 | 1.770 | 0.321 |
| 2008 | 2.137 | 0.509 | 8.971 | 0.820 | 0.979 | 0.341 | 2.808 | 0.566 |
| 2009 | 3.031 | 0.650 | 14.127 | 0.899 | 1.048 | 0.555 | 1.979 | 0.326 |
| 2010 | 1.491 | 0.288 | 7.725 | 0.983 | 1.101 | 0.409 | 2.960 | 0.527 |
| 2011 | | | | | 1.122 | 0.384 | 3.277 | 0.577 |
| 2012 | 0.738 | 0.140 | 3.885 | 0.997 | 1.255 | 0.400 | 3.933 | 0.621 |
| 2013 | 1.762 | 0.361 | 8.590 | 0.934 | 1.830 | 0.645 | 5.192 | 0.559 |
| 2014 | 0.076 | 0.014 | 0.409 | 1.014 | 1.397 | 0.304 | 6.424 | 0.888 |
| 2015 | 0.834 | 0.197 | 3.537 | 0.827 | 2.759 | 1.365 | 5.575 | 0.363 |
| 2016 | 0.838 | 0.201 | 3.504 | 0.817 | 2.124 | 0.769 | 5.865 | 0.543 |

**Table 4**: Final deviance table for the recommended eastern Gulf of Mexico censored regression for the private/for hire mode using landings only catch. The table shows the order of the factors as they were added sequentially to the model such that 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 table.

| Factor | Df | Deviance | Residual Df | Residual Deviance | AIC | % Deviance Reduction | Log likelihood | Like ratio |
|---|---|---|---|---|---|---|---|---|
| **BINOMIAL** | | | | | | | | |
| Null | 1 | 20071.82 | 17024 | 20071.82 | 20073.82 | NA | -10035.91 | NA |
| season | 1 | 6709.76 | 17023 | 13362.06 | 13366.06 | 33.43 | -6682.03 | 6707.76 |
| year | 35 | 1354.06 | 16988 | 12008.00 | 12082.00 | 6.75 | -6006.00 | 1352.06 |
| area | 3 | 531.76 | 16985 | 11476.24 | 11556.24 | 2.65 | -5775.12 | 461.76 |
| wave | 5 | 289.54 | 16980 | 11186.70 | 11276.70 | 1.44 | -5633.35 | 283.54 |
| anglers | 9 | 216.28 | 16971 | 10970.42 | 11078.42 | 1.08 | -5530.21 | 206.28 |
| **POSITIVE OBSERVATIONS ONLY** | | | | | | | | |
| Null | 1 | 52478.63 | 12319 | 52478.63 | 17857.92 | NA | -8926.96 | NA |
| year | 35 | 2933.53 | 12285 | 49545.10 | 17219.24 | 5.59 | -8572.62 | 708.68 |
| mode | 1 | 1542.57 | 12319 | 48002.53 | 16831.57 | 2.94 | -8377.78 | 389.68 |
| state | 2 | 2228.21 | 12318 | 45774.32 | 16249.99 | 4.25 | -8085.00 | 585.58 |
| wave | 5 | 801.95 | 12315 | 44972.37 | 16042.24 | 1.53 | -7976.12 | 217.75 |

**Table 5**: Final deviance table for the recommended western Gulf of Mexico censored regression for the private/for hire mode using landings only catch. The table shows the order of the factors as they were added sequentially to the model such that 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 table.

| Factor | Df | Deviance | Residual Df | Residual Deviance | AIC | % Deviance Reduction | Log likelihood | Like ratio |
|---|---|---|---|---|---|---|---|---|
| **BINOMIAL** | | | | | | | | |
| Null | 1 | 11928.20 | 10603 | 11928.20 | 11930.20 | NA | -5964.10 | NA |
| area | 3 | 544.15 | 10600 | 11384.06 | 11392.06 | 4.56 | -5693.03 | 542.15 |
| season | 1 | 343.85 | 10599 | 11040.21 | 11050.21 | 2.88 | -5524.10 | 337.85 |
| year | 35 | 398.49 | 10564 | 10641.72 | 10721.72 | 3.34 | -5325.86 | 396.49 |
| anglers | 9 | 241.01 | 10555 | 10400.71 | 10498.71 | 2.02 | -5240.36 | 171.01 |
| **POSITIVE OBSERVATIONS ONLY** | | | | | | | | |
| Null | 1 | 20719.68 | 7951 | 20719.68 | 7619.32 | NA | -3807.66 | NA |
| year | 35 | 1058.64 | 7917 | 19661.04 | 7272.27 | 5.11 | -3599.14 | 417.04 |
| mode | 1 | 561.37 | 7951 | 19099.67 | 7043.92 | 2.71 | -3483.96 | 230.35 |
| wave | 5 | 286.25 | 7947 | 18813.42 | 6933.84 | 1.38 | -3423.92 | 120.08 |

**Table 6:** Final deviance table for the recommended eastern Gulf of Mexico censored regression for the headboat mode using landings only catch. The table shows the order of the factors as they were added sequentially to the model such that 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 table.

| Factor | Df | Deviance | Residual Df | Residual Deviance | AIC | % Deviance Reduction | Log likelihood | Like ratio |
|---|---|---|---|---|---|---|---|---|
| **BINOMIAL** | | | | | | | | |
| Null | 1 | 41394.04 | 45313 | 41394.04 | 41396.04 | NA | -20697.02 | NA |
| year | 30 | 7124.67 | 45283 | 34269.37 | 34331.37 | 17.21 | -17135.69 | 7122.67 |
| area | 1 | 533.67 | 45282 | 33735.71 | 33799.71 | 1.29 | -16898.85 | 473.67 |
| anglers | 9 | 431.50 | 45273 | 33304.20 | 33386.20 | 1.04 | -16684.10 | 429.50 |
| **POSITIVE OBSERVATIONS ONLY** | | | | | | | | |
| Null | 1 | 12386.15 | 37585 | 12386.15 | -41718.44 | NA | 20861.22 | NA |
| year | 30 | 2408.52 | 37556 | 9977.64 | -49785.77 | 19.45 | 24924.88 | 8127.33 |
| area | 1 | 236.91 | 37585 | 9740.73 | -50686.98 | 1.91 | 25376.49 | 903.21 |

**Table 7**: Final deviance table for the recommended western Gulf of Mexico censored regression for the headboat mode using landings only ("A") catch. The table shows the order of the factors as they were added sequentially to the model such that 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 table.

| Factor | Df | Deviance | Resid. Df | Resid. Dev | AIC | % Deviance Reduction | Log likelihood | Like ratio |
|---|---|---|---|---|---|---|---|---|
| **BINOMIAL** | | | | | | | | |
| Null | 1 | 21557.60 | 44700 | 21557.60 | 21559.60 | NA | -10778.80 | NA |
| anglers | 9 | 880.04 | 44691 | 20677.56 | 20697.56 | 4.08 | -10339.78 | 878.04 |
| area | 2 | 864.26 | 44689 | 19813.30 | 19837.30 | 4.01 | -9916.65 | 846.26 |
| year | 30 | 830.79 | 44659 | 18982.51 | 19066.51 | 3.85 | -9503.25 | 826.79 |
| **POSITIVE OBSERVATIONS ONLY** | | | | | | | | |
| Null | 1 | 181858.99 | 41784 | 181858.99 | 61456.96 | NA | -30726.48 | NA |
| year | 30 | 12763.29 | 41755 | 169095.70 | 58476.40 | 7.02 | -29206.20 | 3040.56 |
| area | 2 | 12731.34 | 41783 | 156364.37 | 55209.64 | 7.00 | -27570.82 | 3270.76 |

**Figures**

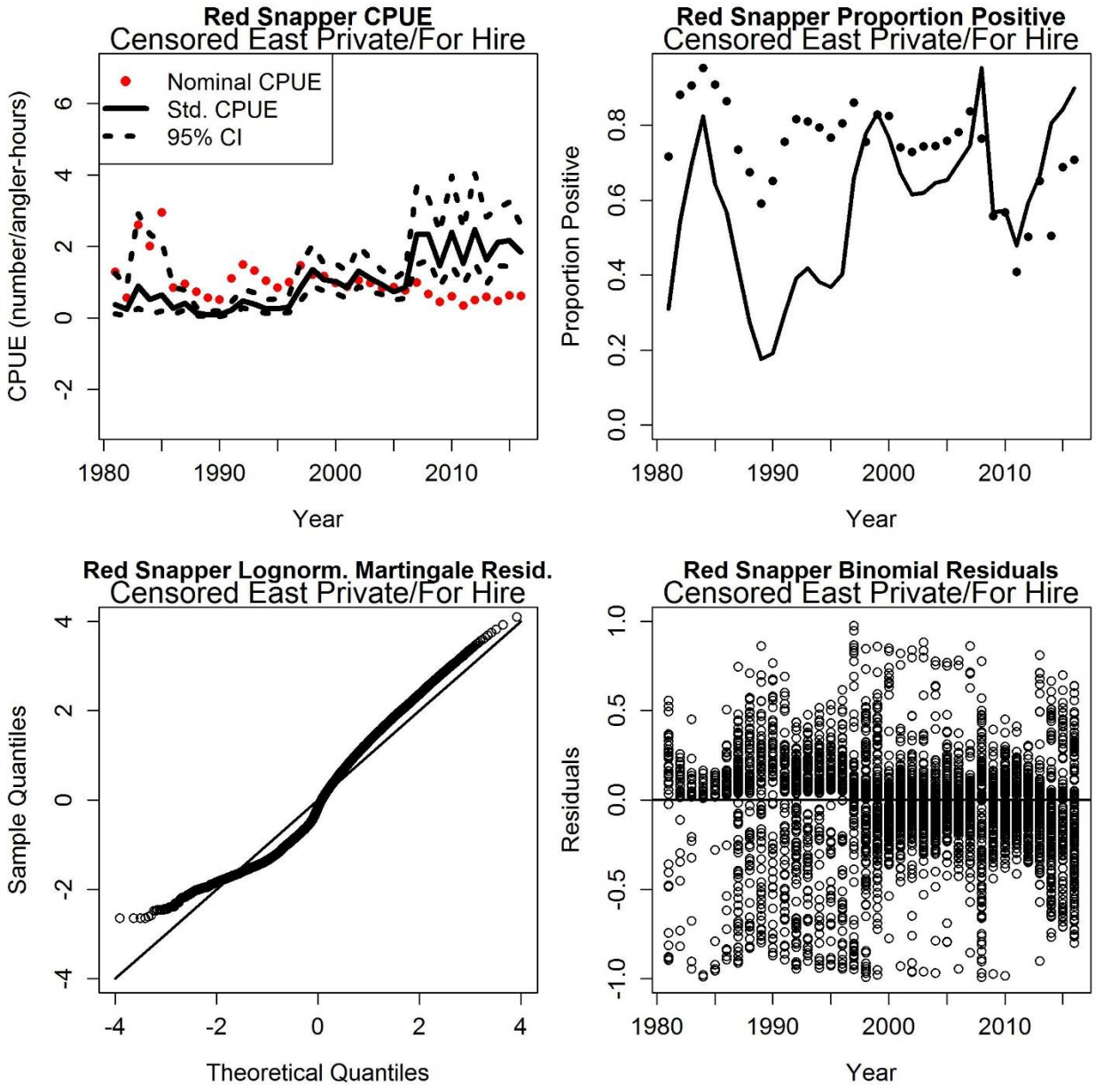


**Figure 1**: Model fit and diagnostics for the recommended eastern Gulf of Mexico censored regression for the private/for hire mode using landings only catch.

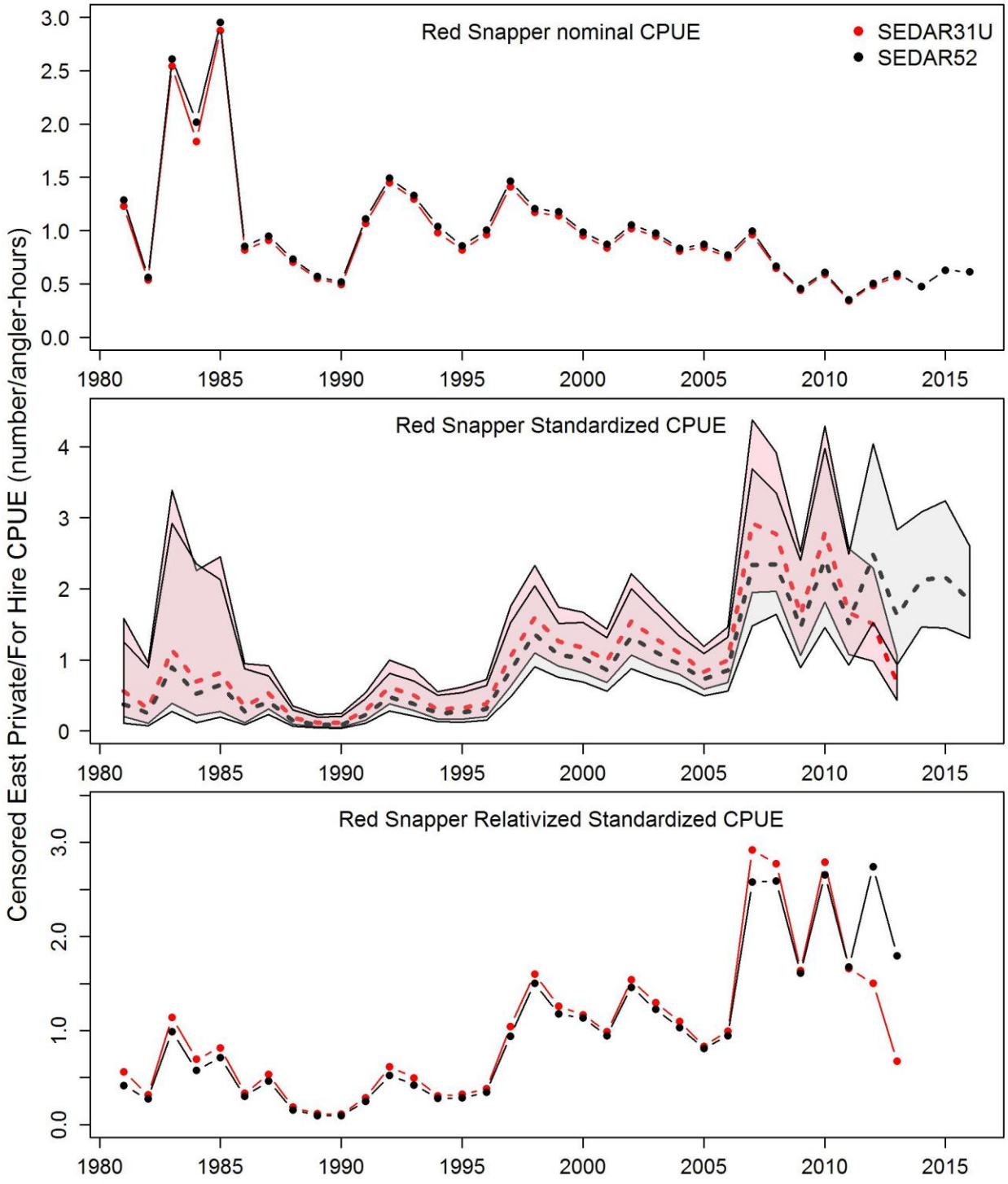


**Figure 2**: Comparison of the recommended eastern Gulf of Mexico censored regression for the private/for hire mode using landings only catch to the index used in the SEDAR31 Update. For comparison, both indices are normalized by their respective means in the bottom panel.

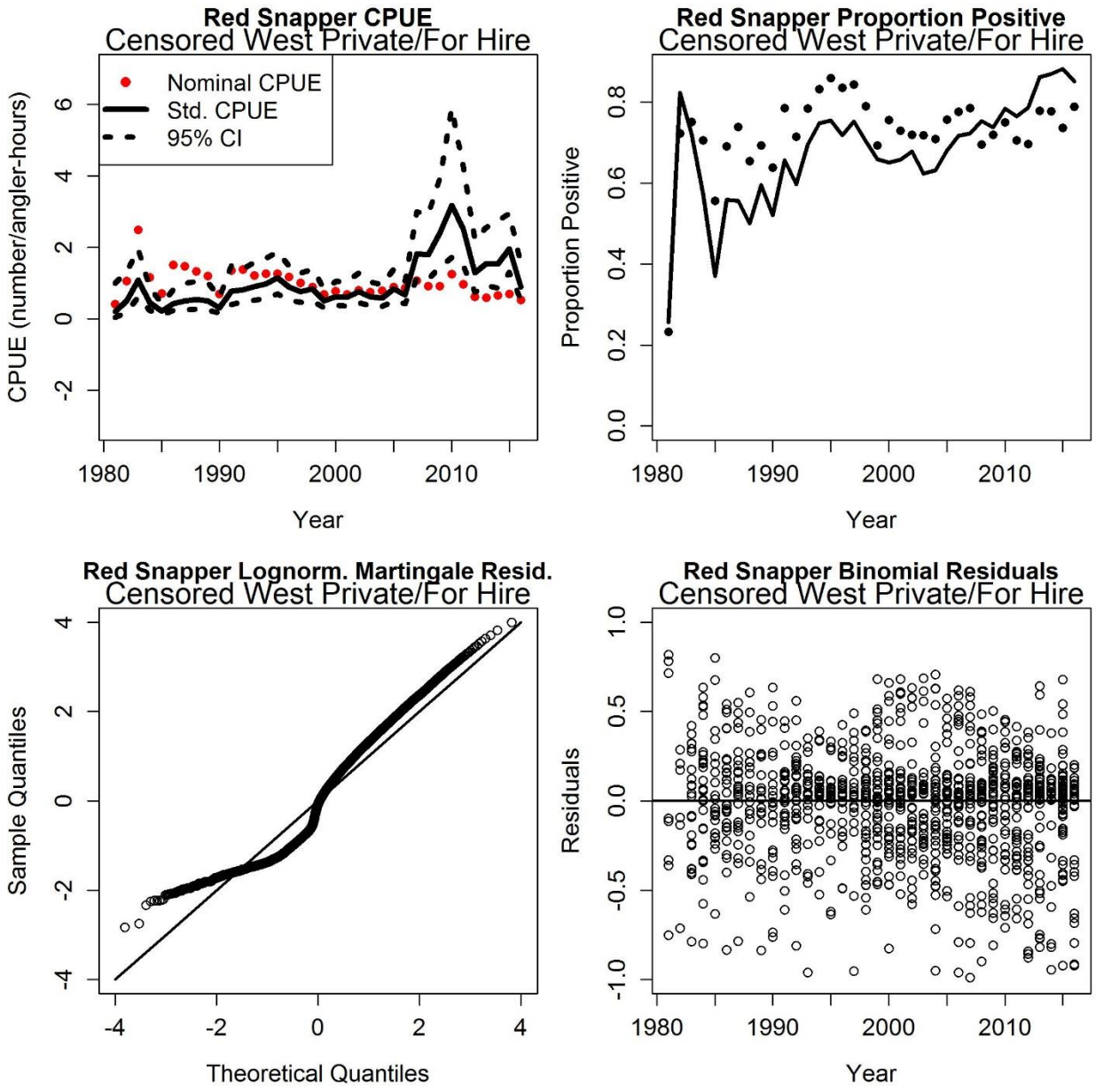


**Figure 3**: Model fit and diagnostics for the recommended western Gulf of Mexico censored regression for the private/for hire mode using landings only catch.

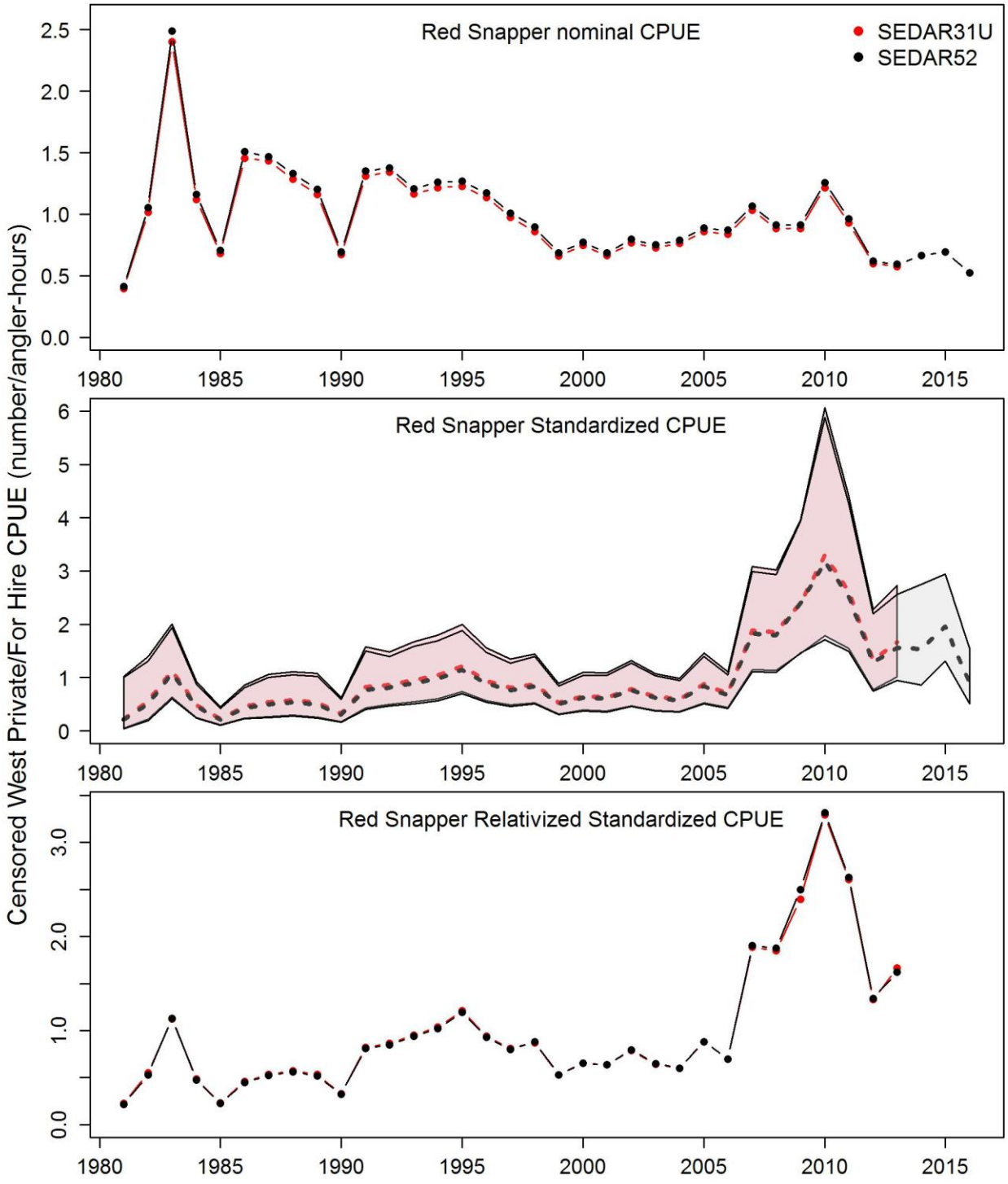


**Figure 4**: Comparison of the recommended western Gulf of Mexico censored regression for the private/for hire mode using landings only catch to the index used in the SEDAR31 Update. For comparison, both indices are normalized by their respective means in the bottom panel.

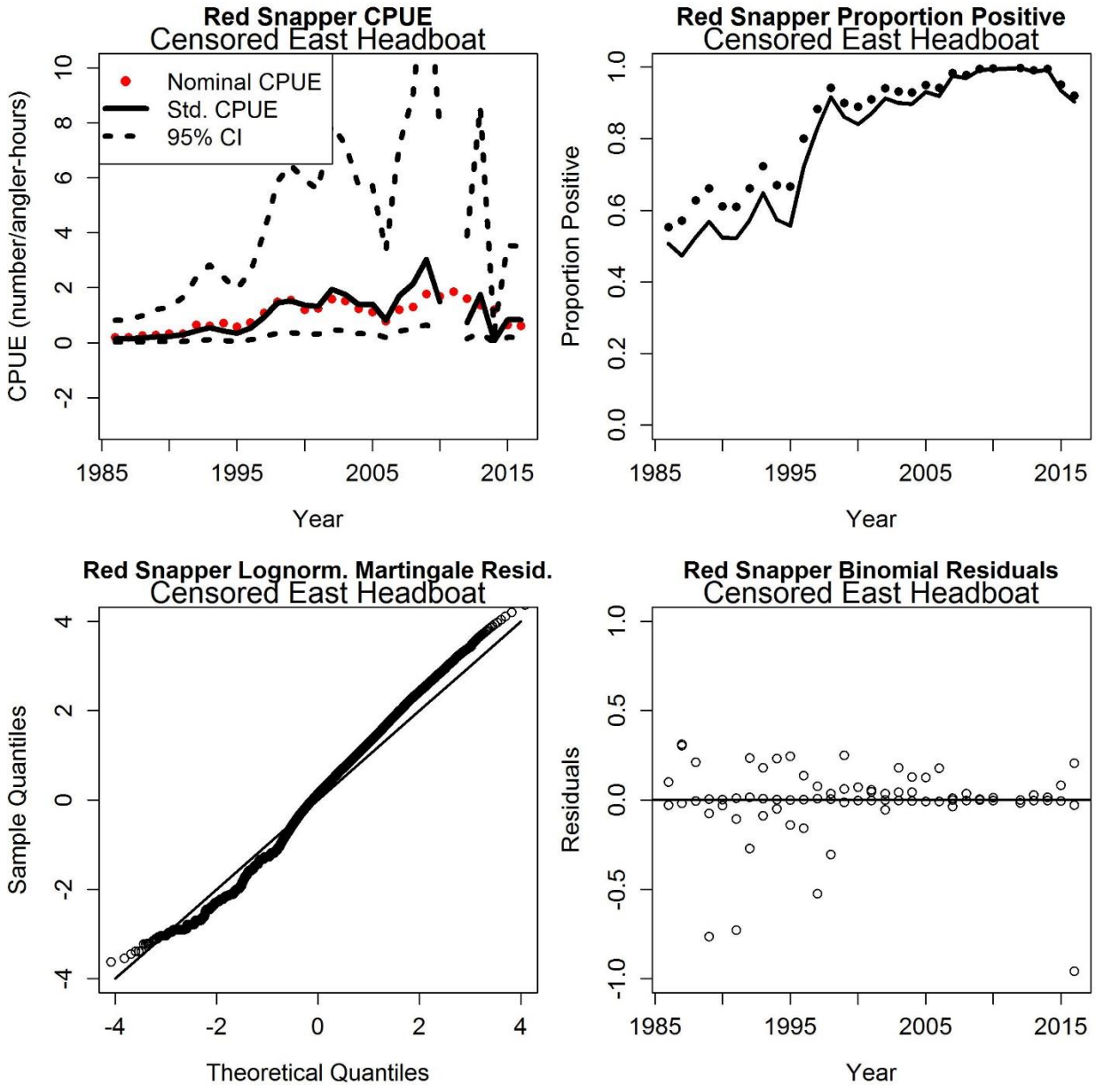


**Figure 5**: Model fit and diagnostics for the recommended eastern Gulf of Mexico censored regression for the headboat using landings only catch.

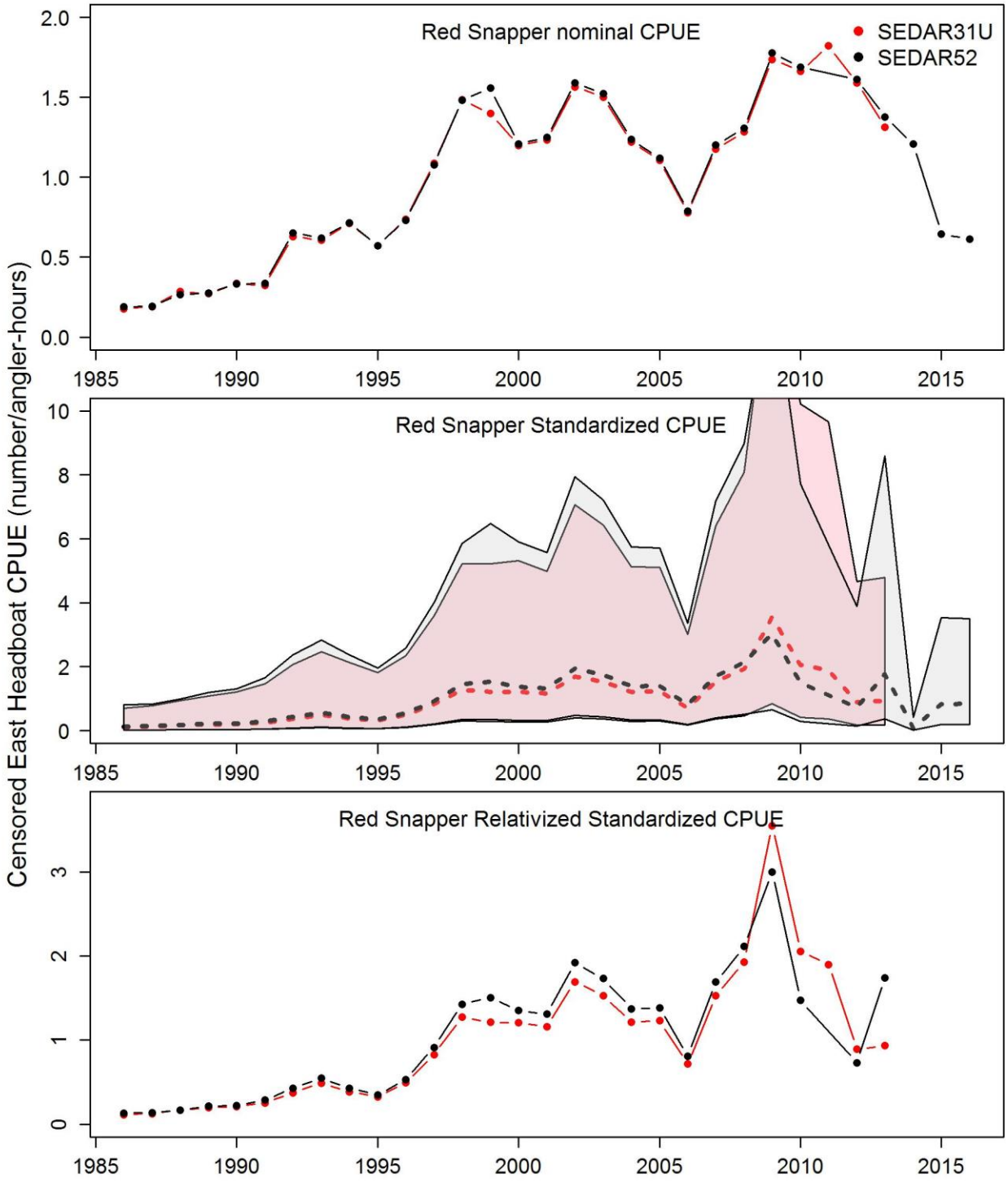


**Figure 6**: Comparison of the recommended eastern Gulf of Mexico censored regression for the headboat using landings only catch to the index used in the SEDAR31 Update. For comparison, both indices are normalized by their respective means in the bottom panel.

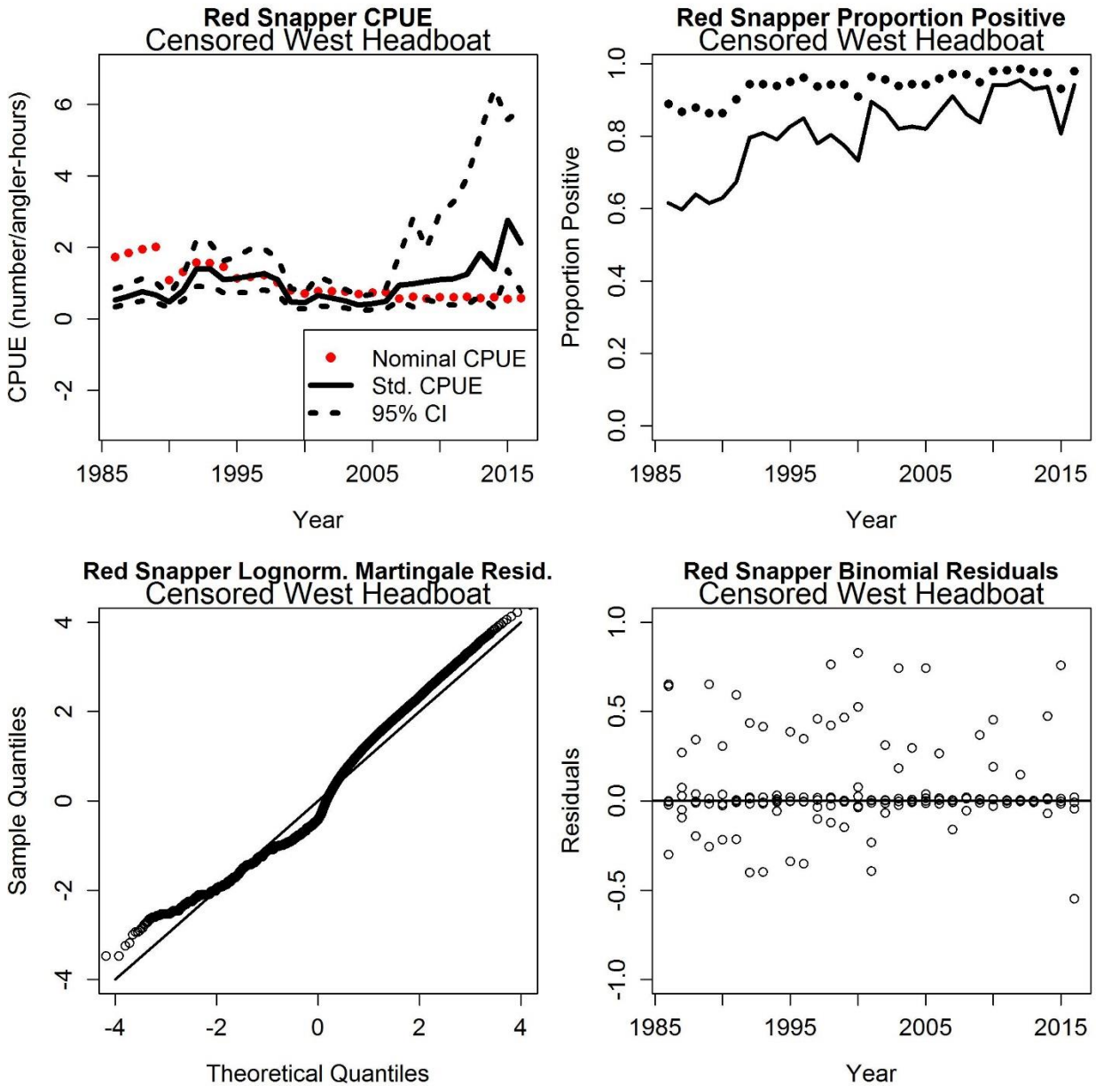


**Figure 7**: Model fit and diagnostics for the recommended western Gulf of Mexico censored regression for the headboat using landings only catch.

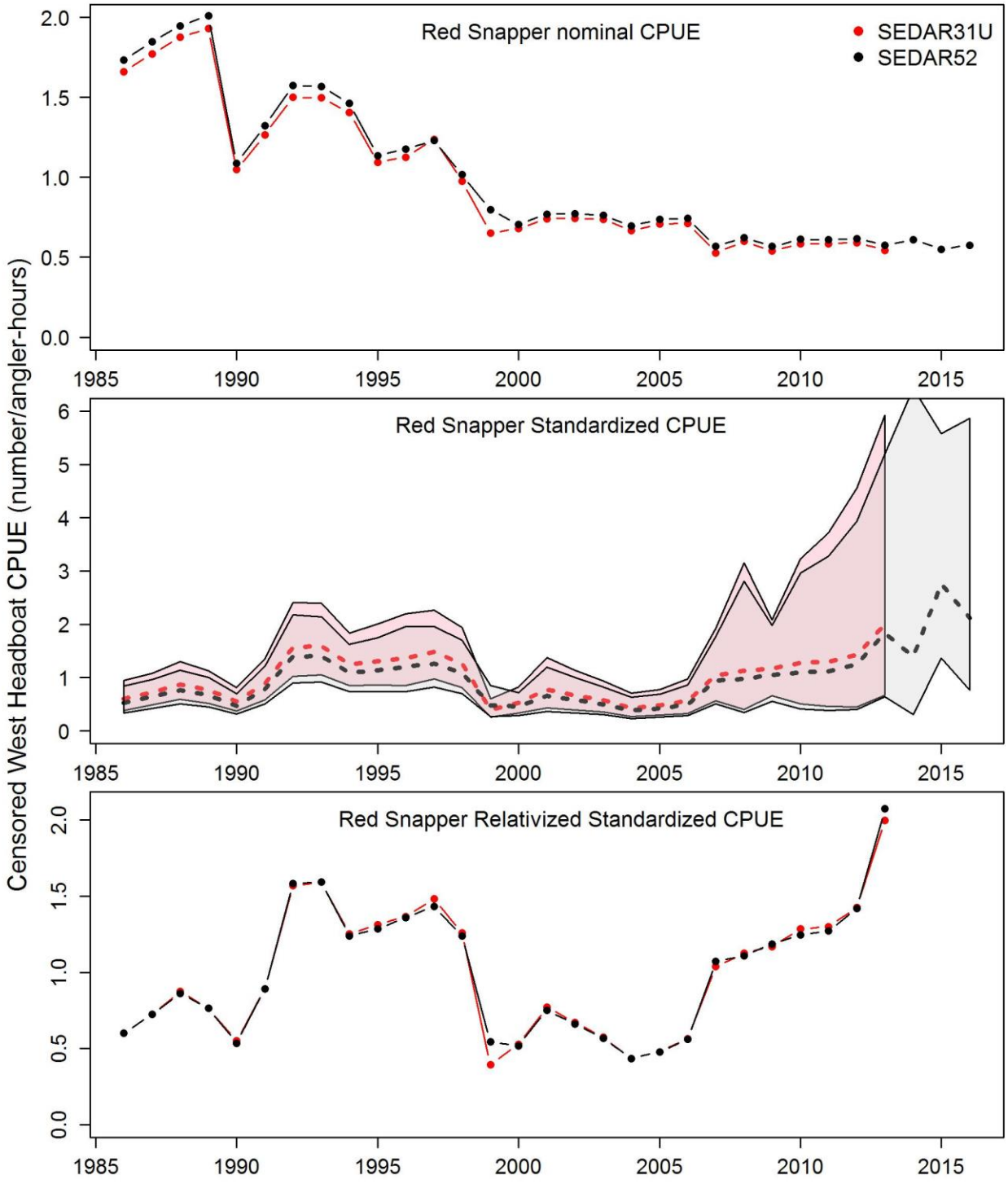


**Figure 8**: Comparison of the recommended western Gulf of Mexico censored regression for the headboat using landings only catch to the index used in the SEDAR31 Update. For comparison, both indices are normalized by their respective means in the bottom panel.

**Appendix A**: Private/for hire sector of the recreational fishery in the eastern Gulf of Mexico

**Table A1**: All trips, positive trips, and percent positive for all data and Stephens and MacCall selected data by year.

| Year | All Data | | | Subset Data | | | Percent Trips Retained |
|---|---|---|---|---|---|---|---|
| | Total Trips | Positive Trips | Proportion Positive | Total Trips | Positive Trips | Proportion Positive | |
| 1981 | 332 | 33 | 9.94 | 46 | 33 | 71.74 | 13.86 |
| 1982 | 727 | 45 | 6.19 | 51 | 45 | 88.24 | 7.02 |
| 1983 | 409 | 58 | 14.18 | 64 | 58 | 90.62 | 15.65 |
| 1984 | 484 | 41 | 8.47 | 43 | 41 | 95.35 | 8.88 |
| 1985 | 374 | 59 | 15.78 | 65 | 59 | 90.77 | 17.38 |
| 1986 | 909 | 51 | 5.61 | 59 | 51 | 86.44 | 6.49 |
| 1987 | 1790 | 166 | 9.27 | 226 | 166 | 73.45 | 12.63 |
| 1988 | 1222 | 102 | 8.35 | 151 | 102 | 67.55 | 12.36 |
| 1989 | 799 | 78 | 9.76 | 132 | 78 | 59.09 | 16.52 |
| 1990 | 814 | 71 | 8.72 | 109 | 71 | 65.14 | 13.39 |
| 1991 | 1002 | 149 | 14.87 | 197 | 149 | 75.63 | 19.66 |
| 1992 | 1940 | 328 | 16.91 | 402 | 328 | 81.59 | 20.72 |
| 1993 | 1285 | 213 | 16.58 | 263 | 213 | 80.99 | 20.47 |
| 1994 | 1411 | 162 | 11.48 | 204 | 162 | 79.41 | 14.46 |
| 1995 | 1353 | 125 | 9.24 | 163 | 125 | 76.69 | 12.05 |
| 1996 | 1486 | 149 | 10.03 | 185 | 149 | 80.54 | 12.45 |
| 1997 | 2017 | 332 | 16.46 | 386 | 332 | 86.01 | 19.14 |
| 1998 | 2816 | 449 | 15.94 | 594 | 449 | 75.59 | 21.09 |
| 1999 | 4312 | 837 | 19.41 | 1010 | 837 | 82.87 | 23.42 |
| 2000 | 4066 | 865 | 21.27 | 1048 | 865 | 82.54 | 25.77 |
| 2001 | 3755 | 661 | 17.60 | 892 | 661 | 74.10 | 23.75 |
| 2002 | 3789 | 690 | 18.21 | 946 | 690 | 72.94 | 24.97 |
| 2003 | 3732 | 730 | 19.56 | 981 | 730 | 74.41 | 26.29 |
| 2004 | 3811 | 927 | 24.32 | 1244 | 927 | 74.52 | 32.64 |
| 2005 | 3286 | 746 | 22.70 | 984 | 746 | 75.81 | 29.95 |
| 2006 | 2760 | 623 | 22.57 | 797 | 623 | 78.17 | 28.88 |
| 2007 | 2725 | 646 | 23.71 | 772 | 646 | 83.68 | 28.33 |
| 2008 | 2764 | 451 | 16.32 | 590 | 451 | 76.44 | 21.35 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2009 | 2281 | 287 | 12.58 | 514 | 287 | 55.84 | 22.53 |
| 2010 | 2185 | 274 | 12.54 | 482 | 274 | 56.85 | 22.06 |
| 2011 | 2554 | 259 | 10.14 | 633 | 259 | 40.92 | 24.78 |
| 2012 | 2657 | 280 | 10.54 | 558 | 280 | 50.18 | 21.00 |
| 2013 | 1794 | 259 | 14.44 | 398 | 259 | 65.08 | 22.19 |
| 2014 | 2725 | 287 | 10.53 | 568 | 287 | 50.53 | 20.84 |
| 2015 | 2678 | 371 | 13.85 | 539 | 371 | 68.83 | 20.13 |
| 2016 | 2739 | 516 | 18.84 | 729 | 516 | 70.78 | 26.62 |

**Appendix B**: Private/for hire sector of the recreational fishery in the western Gulf of Mexico.

**Table B1**: All trips, positive trips, and percent positive for all data and Stephens and MacCall selected data by year.

| Year | All Data | | | Subset Data | | | Percent Trips Retained |
|---|---|---|---|---|---|---|---|
| | All | Positive | Proportion Positive | All | Positive | Proportion Positive | |
| 1981 | 100 | 7 | 7.00 | 30 | 7 | 23.33 | 30.00 |
| 1982 | 184 | 34 | 18.48 | 47 | 34 | 72.34 | 25.54 |
| 1983 | 520 | 178 | 34.23 | 237 | 178 | 75.11 | 45.58 |
| 1984 | 666 | 127 | 19.07 | 180 | 127 | 70.56 | 27.03 |
| 1985 | 785 | 104 | 13.25 | 187 | 104 | 55.61 | 23.82 |
| 1986 | 1261 | 134 | 10.63 | 194 | 134 | 69.07 | 15.38 |
| 1987 | 812 | 122 | 15.02 | 165 | 122 | 73.94 | 20.32 |
| 1988 | 637 | 112 | 17.58 | 171 | 112 | 65.50 | 26.84 |
| 1989 | 498 | 95 | 19.08 | 137 | 95 | 69.34 | 27.51 |
| 1990 | 655 | 120 | 18.32 | 188 | 120 | 63.83 | 28.70 |
| 1991 | 761 | 147 | 19.32 | 187 | 147 | 78.61 | 24.57 |
| 1992 | 1015 | 213 | 20.99 | 298 | 213 | 71.48 | 29.36 |
| 1993 | 718 | 218 | 30.36 | 278 | 218 | 78.42 | 38.72 |
| 1994 | 789 | 273 | 34.60 | 328 | 273 | 83.23 | 41.57 |
| 1995 | 1117 | 429 | 38.41 | 499 | 429 | 85.97 | 44.67 |
| 1996 | 951 | 387 | 40.69 | 463 | 387 | 83.59 | 48.69 |
| 1997 | 1242 | 379 | 30.52 | 449 | 379 | 84.41 | 36.15 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1998 | 896 | 327 | 36.50 | 414 | 327 | 78.99 | 46.21 |
| 1999 | 994 | 233 | 23.44 | 336 | 233 | 69.35 | 33.80 |
| 2000 | 801 | 285 | 35.58 | 377 | 285 | 75.60 | 47.07 |
| 2001 | 690 | 238 | 34.49 | 326 | 238 | 73.01 | 47.25 |
| 2002 | 812 | 266 | 32.76 | 370 | 266 | 71.89 | 45.57 |
| 2003 | 762 | 280 | 36.75 | 390 | 280 | 71.79 | 51.18 |
| 2004 | 862 | 275 | 31.90 | 388 | 275 | 70.88 | 45.01 |
| 2005 | 749 | 289 | 38.58 | 382 | 289 | 75.65 | 51.00 |
| 2006 | 1185 | 425 | 35.86 | 548 | 425 | 77.55 | 46.24 |
| 2007 | 832 | 318 | 38.22 | 405 | 318 | 78.52 | 48.68 |
| 2008 | 670 | 223 | 33.28 | 321 | 223 | 69.47 | 47.91 |
| 2009 | 710 | 237 | 33.38 | 329 | 237 | 72.04 | 46.34 |
| 2010 | 399 | 141 | 35.34 | 188 | 141 | 75.00 | 47.12 |
| 2011 | 631 | 197 | 31.22 | 279 | 197 | 70.61 | 44.22 |
| 2012 | 491 | 175 | 35.64 | 251 | 175 | 69.72 | 51.12 |
| 2013 | 569 | 250 | 43.94 | 321 | 250 | 77.88 | 56.41 |
| 2014 | 376 | 151 | 40.16 | 194 | 151 | 77.84 | 51.60 |
| 2015 | 933 | 368 | 39.44 | 500 | 368 | 73.60 | 53.59 |
| 2016 | 533 | 195 | 36.59 | 247 | 195 | 78.95 | 46.34 |

**Appendix C**: Headboat sector of the recreational fishery in the eastern Gulf of Mexico.

**Table C1**: All trips, positive trips, and percent positive for all data and Stephens and MacCall selected data by year.

| Year | All Data | | | Subset Data | | | Percent Trips Retained |
|---|---|---|---|---|---|---|---|
| | Total | Positive | Proportion Positive | Total | Positive | Proportion Positive | |
| 1986 | 2837 | 283 | 9.98 | 512 | 283 | 55.27 | 18.05 |
| 1987 | 2640 | 408 | 15.45 | 714 | 408 | 57.14 | 27.05 |
| 1988 | 4142 | 968 | 23.37 | 1541 | 968 | 62.82 | 37.20 |
| 1989 | 4857 | 878 | 18.08 | 1328 | 878 | 66.11 | 27.34 |
| 1990 | 8253 | 1089 | 13.20 | 1783 | 1089 | 61.08 | 21.60 |
| 1991 | 7261 | 1120 | 15.42 | 1835 | 1120 | 61.04 | 25.27 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1992 | 7623 | 1368 | 17.95 | 2068 | 1368 | 66.15 | 27.13 |
| 1993 | 7967 | 1687 | 21.17 | 2334 | 1687 | 72.28 | 29.30 |
| 1994 | 7404 | 1432 | 19.34 | 2138 | 1432 | 66.98 | 28.88 |
| 1995 | 5906 | 1468 | 24.86 | 2203 | 1468 | 66.64 | 37.30 |
| 1996 | 5764 | 1700 | 29.49 | 2123 | 1700 | 80.08 | 36.83 |
| 1997 | 5453 | 2070 | 37.96 | 2335 | 2062 | 88.31 | 42.82 |
| 1998 | 4138 | 1985 | 47.97 | 2104 | 1985 | 94.34 | 50.85 |
| 1999 | 2851 | 1295 | 45.42 | 1439 | 1295 | 89.99 | 50.47 |
| 2000 | 2957 | 1568 | 53.03 | 1763 | 1568 | 88.94 | 59.62 |
| 2001 | 2798 | 1532 | 54.75 | 1683 | 1532 | 91.03 | 60.15 |
| 2002 | 2768 | 1708 | 61.71 | 1815 | 1708 | 94.10 | 65.57 |
| 2003 | 2894 | 1678 | 57.98 | 1800 | 1678 | 93.22 | 62.20 |
| 2004 | 2860 | 1485 | 51.92 | 1599 | 1485 | 92.87 | 55.91 |
| 2005 | 2853 | 1311 | 45.95 | 1380 | 1311 | 95.00 | 48.37 |
| 2006 | 2265 | 1307 | 57.70 | 1386 | 1307 | 94.30 | 61.19 |
| 2007 | 2687 | 1371 | 51.02 | 1394 | 1371 | 98.35 | 51.88 |
| 2008 | 1902 | 1116 | 58.68 | 1141 | 1116 | 97.81 | 59.99 |
| 2009 | 2538 | 1610 | 63.44 | 1618 | 1610 | 99.51 | 63.75 |
| 2010 | 1473 | 666 | 45.21 | 669 | 666 | 99.55 | 45.42 |
| 2011 | 1722 | 1148 | 66.67 | 1148 | 1148 | 100.00 | 66.67 |
| 2012 | 1459 | 988 | 67.72 | 990 | 988 | 99.80 | 67.85 |
| 2013 | 1055 | 645 | 61.14 | 651 | 645 | 99.08 | 61.71 |
| 2014 | 287 | 181 | 63.07 | 182 | 181 | 99.45 | 63.41 |
| 2015 | 1334 | 682 | 51.12 | 717 | 682 | 95.12 | 53.75 |
| 2016 | 1538 | 847 | 55.07 | 921 | 847 | 91.97 | 59.88 |

**Appendix D**: Headboat sector of the recreational fishery in the western Gulf of Mexico.

**Table D1**: All trips, positive trips, and percent positive for all data and Stephens and MacCall selected data by year.

| Year | All Data | | | Subset Data | | | Percent Trips Retained |
|---|---|---|---|---|---|---|---|
| | Total | Positive | Proportion Positive | Total | Positive | Proportion Positive | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1986 | 1627 | 1134 | 69.70 | 1275 | 1134 | 88.94 | 78.37 |
| 1987 | 1958 | 1340 | 68.44 | 1543 | 1340 | 86.84 | 78.80 |
| 1988 | 2146 | 1463 | 68.17 | 1665 | 1463 | 87.87 | 77.59 |
| 1989 | 2064 | 1417 | 68.65 | 1641 | 1417 | 86.35 | 79.51 |
| 1990 | 2084 | 1448 | 69.48 | 1675 | 1448 | 86.45 | 80.37 |
| 1991 | 1845 | 1418 | 76.86 | 1572 | 1418 | 90.20 | 85.20 |
| 1992 | 2650 | 2102 | 79.32 | 2226 | 2102 | 94.43 | 84.00 |
| 1993 | 2790 | 2362 | 84.66 | 2501 | 2362 | 94.44 | 89.64 |
| 1994 | 3289 | 2654 | 80.69 | 2825 | 2654 | 93.95 | 85.89 |
| 1995 | 3096 | 2498 | 80.68 | 2629 | 2498 | 95.02 | 84.92 |
| 1996 | 2676 | 2212 | 82.66 | 2301 | 2212 | 96.13 | 85.99 |
| 1997 | 2622 | 2010 | 76.66 | 2142 | 2010 | 93.84 | 81.69 |
| 1998 | 2594 | 2071 | 79.84 | 2196 | 2071 | 94.31 | 84.66 |
| 1999 | 1239 | 1067 | 86.12 | 1133 | 1067 | 94.17 | 91.44 |
| 2000 | 1623 | 1244 | 76.65 | 1369 | 1244 | 90.87 | 84.35 |
| 2001 | 1685 | 1434 | 85.10 | 1488 | 1434 | 96.37 | 88.31 |
| 2002 | 1841 | 1505 | 81.75 | 1574 | 1505 | 95.62 | 85.50 |
| 2003 | 1684 | 1370 | 81.35 | 1459 | 1370 | 93.90 | 86.64 |
| 2004 | 1775 | 1501 | 84.56 | 1590 | 1501 | 94.40 | 89.58 |
| 2005 | 1693 | 1486 | 87.77 | 1578 | 1486 | 94.17 | 93.21 |
| 2006 | 1719 | 1505 | 87.55 | 1570 | 1505 | 95.86 | 91.33 |
| 2007 | 1743 | 1570 | 90.07 | 1616 | 1570 | 97.15 | 92.71 |
| 2008 | 418 | 391 | 93.54 | 403 | 391 | 97.02 | 96.41 |
| 2009 | 989 | 867 | 87.66 | 914 | 867 | 94.86 | 92.42 |
| 2010 | 722 | 686 | 95.01 | 700 | 686 | 98.00 | 96.95 |
| 2011 | 635 | 609 | 95.91 | 620 | 609 | 98.23 | 97.64 |
| 2012 | 686 | 643 | 93.73 | 652 | 643 | 98.62 | 95.04 |
| 2013 | 542 | 516 | 95.20 | 528 | 516 | 97.73 | 97.42 |
| 2014 | 133 | 122 | 91.73 | 125 | 122 | 97.60 | 93.98 |
| 2015 | 585 | 510 | 87.18 | 548 | 510 | 93.07 | 93.68 |
| 2016 | 661 | 632 | 95.61 | 645 | 632 | 97.98 | 97.58 |