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SEDAR74-DW-23

20 April 2022
Updated: 27 April 2022
Updated: 26 May 2022

Please cite this document as:

Thompson, Kevin A., Theodore S. Switzer, Mary C. Christman, Sean F. Keenan, Christopher Gardner, Katherine E. Overly, Matt Campbell. 2022. Indices of abundance for Red Snapper (*Lutjanus campechanus*) on natural reefs in the eastern Gulf of Mexico using combined data from three independent video surveys. SEDAR74-DW-23. SEDAR, North Charleston, SC. 25 pp.

Indices of abundance for Red Snapper (*Lutjanus campechanus*) on natural reefs in the eastern Gulf of Mexico using combined data from three independent video surveys

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Introduction

Historically, three different stationary video surveys were conducted for reef fish in the northern Gulf of Mexico (GOM). The NMFS SEAMAP reef fish video survey (SFRV), carried out by NMFS Mississippi Laboratory, has the longest running time series (1993-1997, 2002, and 2004+), followed by the NMFS Panama City lab survey (PC; 2005+), with the most recent survey being the Florida Fish and Wildlife Research Institute video survey (FWRI, starting year 2010; Table 1). While the surveys use standardized deployment, camera field of view, and fish abundance methods to assess fish abundancies on reef or structured habitat, there are variations in survey design and habitat characteristics collected in addition to the time period and area sampled. Traditionally the surveys have submitted independent indices for each survey, however, combining indices across datasets likely increases predictive capabilities by allowing for the largest possible sample sizes in model fitting and encompassing a greater proportion of the distribution of the stock. Previous research has indicated that combining data across changing spatial areas and surveys and using a year only model, can yield spurious conclusions regarding stock abundance (Campbell 2004; Ye et al. 2004). As such, we used a habitat-based approach to combine relative abundance data for generating annual trends for Red Snapper (*Lutjanus campechanus*) throughout the eastern GOM (eGOM) for the Central and South regions as defined in the Stock ID (SEDAR 2021) process for this assessment.

Survey Comparisons

Survey design

The SFRV survey primarily targets high-relief topographic features along the continental shelf from south Texas to south Florida (Fig. 1). Sites are selected using a stratified, random design with strata determined by region and total proportion of reef area in a sampling block (10 minute latitude X 10 minute longitude blocks). Sites are selected at random from known reef areas identified through habitat mapping (multi-beam and side-scan sonar). Historic indices developed from the survey designate the Mississippi river delta as a geographic feature separating the west and east regions of the GOM (Campbell et al. 2017)

The Panama City video survey targets the inner shelf of the northeast GOM (5-60 m depth) ranging from NMFS, SEFSC statistical zone 6 through 10 (Fig. 1). Survey design has changed through time, but since 2010 a two-stage unequal probability design has been used. Blocks are 5 minutes x 5 minutes in size with sites randomly, proportionally allocated by region, sub-region and depth. Two known reef sites, a minimum of 250 m apart within each selected block are randomly selected. This survey is broken up into eastern and western regions by Cape San Blas in the Florida Panhandle. Sites are described using side-scanning before video deployment (Gardner et al. 2017).

The FWRI survey initially focused on the regions offshore of Tampa Bay and Charlotte Harbor, FL (NMFS statistical zones 4 and 5) with habitats either inshore (10-36 m depth) or offshore (37-110 m depth). The survey has since expanded to also include NMFS, SEFSC statistical zones 9 and 10 off the Florida Panhandle in 2014 with additional sites added in 2016 to cover the entirety of the West Florida Shelf from statistical zones 2-10 (Fig. 1; FWRI/NFWF). Sites are initially randomly selected and mapped using side scan sonar over a 2.1 km^2 area (Switzer et al. 2020). Video deployment sites are then randomly assigned proportionally across region and depth zones (Thompson et al. 2017). Relative contribution of each survey by area and habitat observed is given in Table 2.

Following the funding provided by NOAA RESTORE council, the three surveys were unified into a single site selection with the individual labs each taking a portion of the sites (G-FISHER project; Fig. 1). These data are then the only dataset available from 2020 and moving forward. However, due to Covid restrictions on sampling in the federal system, FWRI was the only institute able to sample in 2020. As such the spatial coverage of the 2020 data was the same as the FWRI post NFWF expansion from 2016 and on, therefore these data were treated as a terminal year of the FWRI-only dataset. Annual distribution for all surveys can be found in Appendix A.

Video reads

All three surveys use paired stereo-imaging cameras at each site. All videos are read to identify the maximum number of individuals of each species viewed in a single frame within a 20-minute time frame (i.e. MaxN, MinCount). Habitat characteristics on video are also noted with the percentage or presence/absence of abiotic and biotic habitat types that may contribute to fish biomass (e.g. sponge, algae, and corals), although some categories are not shared among all labs (Campbell et al. 2017; Gardner et al. 2017; Thompson et al. 2017).

Fish length measurement

Fish length measurements have varied through time for the surveys, starting with the Pascagoula survey in 1995 fish lengths were measured from video using parallel lasers attached on the camera system (Campbell et al. 2017). Panama City survey also used this laser-based approach from 2007 to 2009. However, the frequency of hitting targets with the laser is low and to increase sample size any measurable fish during the video read was measured (i.e. not just at the mincount), and fish could have potentially been measured twice. Subsequent years from (2008 in Pascagoula and 2010 in Panama City) used a stereo-video approach, which is the only method used in the entirety of the FWRI dataset. Vision Measurement System (VMS, Geometrics Inc.) was used to estimate size of fish up to 2014 for all three surveys and all switched to SeaGIS software (SeaGIS Pty. Ltd.) and have used them for the remainder of the timeseries.

Data reduction

For all surveys, video reads were excluded if they were unreadable due to turbidity or deployment errors. For the Pascagoula survey, data included in this index are from 1993 and on, due to different counting methods in 1992. The entire spatial extent of the Panama City data was used from 2006 on with 2005 excluded because of an incomplete survey. For the FWRI data from prior to 2010 was excluded due to the earlier year's not including side-scan geoform as a variable which was determined to be potentially important as an explanatory variable in the analyses. Following discussions at the data workshop, the decision was made to truncate the overall time series for the south region due to very low catch rates in the SFRV survey initially and the small footprint of the PC survey in that region (Fig. 1). Therefore, the south index was limited to 2010-2020. Final sample sizes by survey and year can be found in Table 1 and spatial coverage is shown in Figure 1. Data were separated into Central (zones 7-10) and South (zones 2-6) regions following the stock ID workshop and analyses were completed for each of these regions independently.

Index Construction

Habitat models

To develop a single index of abundance for Red Snapper the data from all three surveys a habitat variable was created that included each of the separate survey individual variables that could be applied to all the data. This was done so final index models can account for changing sampling effort and habitat allocation through time rather than limiting the model to be predicted only by year and survey. We first determined the percentage of sites that occurred on good, fair, or poor (G, F, P) habitats for each survey and region independently. For this we used a categorical regression tree approach (CART) because this method accounts for correlations among variables and allows both continuous and categorical data to be included. It has been previously demonstrated to be a useful tool in fisheries ecology and specifically in describing fish-habitat associations (De'Ath and Fabricus 2000; Yates et al. 2016).

For these initial analyses, MaxN for each site was reduced to a presence and absence variable and was used as the response variable for habitat designations. Predictor variables included the habitat metrics coded on the video reads (reduced to presence/absence), the latitude and longitude of each site and depth for all three survey sets. For FWRI and Panama City's data, side-scan geoform was also included as a landscape-level habitat variable, with values derived using a modified version of the Coastal and Marine Ecological Classification Standard (CMECS) classification approach. Geoform was not included as a predictor variable for the analysis of Pascagoula survey data because the habitat mapping for that survey has primarily been conducted utilizing multibeam sonar. At present, comparable habitat classification between side-scan and multibeam is not possible due to differences in scale and differences in the underlying data itself (particularly for low relief strata). We first used a random forest approach to reduce the number of potential variables to be selected from in the final model for each lab's dataset to reduce redundant or correlated variables used in the final indexing model. For the random forest analysis, each survey was modeled separately for the entirety of that dataset. The random forest analysis fitted 2000 CARTS to the data and then determined each variables importance, a scale-less number used to indicate the number of final models each variable occurred in and its significance therein. An example of output is given in Fig. 2 for the FWRI survey dataset.

From the random forest analysis, approximately 50% of the potential variables were retained for each survey given by the importance values for a final CART model. The final model was created by fitting the presence of Red Snapper at a site to the independent variables for a training dataset of 80% of the data. The remaining 20% of the data were retained in a test dataset to determine misclassification rates for each of the three models. The proportion of sites with positive Red Snapper catches at each terminal node was then evaluated to determine the habitat characteristics defining good, fair or poor habitat. Terminal nodes with double (2X) the overall proportion of positive catches for a dataset were assigned a good habitat code. Poor sites were identified as those determined by proportion positives that were at least half (50%) of the overall proportion positive and were generally approaching zero. The remaining sites were deemed fair and included the range of the overall proportion positive. All analyses were carried out using R version 3.0.2 (R Core Team 2014) and the Party package for CART (Hothorn et al. 2006).

CART results varied by survey and region with respect to the final variables chosen. Red Snapper habitat models indicated an association with factors commonly attributed to reef or rugose habitats, including rock, relief, soft coral, seawhips, and spatial parameters such as latitude, longitude, and depth (Figs. 3-8). Red Snapper were found to be in a relatively higher proportion of sites in the Central region with occurrence rates of 54% (FWRI), 53% (PC), and 37% (SFRV). Alternatively, the South sites had lower percent positives; 17% (FWRI), 45% (PC), and 7% (SFRV).

The site characteristics that define each node and habitat code were then used to create a habitat variable (i.e., 'hab' and coded as: G or F or P) that was then back applied to each site for each of the three survey datasets. The datasets were then combined for the index model. The final proportion of sites in the three habitat categories for each individual survey set and year are shown in Table 2 and Table 3 for each region.

Index model fitting and diagnostics

The final model used to index abundance was fit using a negative binomial with the formula:

*MaxN = Y*Hab *Survey*

Where Hab is the CART derived habitat code and survey represents the survey that collected the data for each site. Backwards variable selection was used and indicated that the full model performed best, given by AIC, compared to models with only one or two of the potential variables.

The index was fit in SAS using the Proc GLIMMX procedure. To account for the variation in survey area, differences in area mapped with known habitat, and the distribution of Fair, Good, and Poor habitats by survey by year, the estimated MaxN means provided by the GLM were then adjusted. The known potential survey universe for each of the three was first multiplied by the proportion of habitat mapping grids that had reef habitat to provide an area weight. This was then multiplied by each year * Survey * hab combination (up to 12 for the final years with three surveys and three habitat levels), providing a weighting factor for each of the mean estimates. Area weighting factors are provided in Table 4. Weighted index values were then standardized to the grand mean.

Results and Discussion:

Annual standardized index values for Red Snapper in the eGOM, for Central and South regions including coefficients of variation, are presented in Table 5 and Table 6. The model CV's indicate a good model fit, with high values in earlier years but steadily decreasing CV's as additional surveys are added and continue with CV's in the range of ~15% in the final years for both regions. CVs and confidence limits were found to be highest in 1995 and before in the Central model. Biomass trends for Red Snapper in the Central eGOM show low and variable numbers early in the time series, followed by a peak in abundance in 2009 and subsequent decline with recent increases following 2016 (Table 5; Fig. 9). In the South region, relative abundance is low and stable initially in the time series, with a steady increase starting in 2014 through a peak in the population in 2016 and subsequent declines through 2020 (Table 6, Fig. 10).

Overall, combined across all years, the length compositions of Red Snapper in the three surveys are very similar for the Central region (Fig. 11). Length frequencies show more variation across the surveys for the South region, although it the large disparity in sample size, particularly with FWRI samples much higher than the other two should be noted (Fig. 12). The FWRI survey encompasses the more nearshore habitats covered by PC as well as the SRFV deeper sites, and as such when FWRI data are separated by depth zones (nearshore 10-37m and offshore 37m +) the length compositions more match the other respective surveys (Fig. 13).

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Table 1. Summary of sample sizes by year for each of the three included video surveys, Florida Fish and Wildlife Research Institute (FWRI), SEAMAP Reef Fish Video Survey (SRFV), and NMFS Panama City for both the Central (zones 7-10) and South (zones 2-6) regions of the eGOM. No data were available or used from any survey from 1998-2001; 2003.

	Central Region				South Region			
year	FWRI	PC	SFRV	Total	FWRI	PC	SFRV	Total
1993			26	26				
1994			24	24				
1995			13	13				
1996			39	39				
1997			41	41				
2002			46	46				
2004			64	64				
2005			126	126				
2006		89	114	203				
2007		52	160	212				
2008		80	61	141				
2009		101	94	195				
2010		103	110	213	43	32	111	186
2011		127	160	287	205	31	177	413
2012		116	102	218	214	34	179	427
2013		74	74	148	184	11	90	285
2014		141	92	233	276	18	138	432
2015		128	60	188	252	26	92	370
2016	258	121	65	444	461	27	141	629
2017	224	124	58	406	397	25	163	585
2018	228	69	74	371	464	23	139	626
2019	353	84	127	564	546	23	158	727
2020	164			164	585			585
total	1227	1409	1730	4366	3627	250	1388	5265

Table 2. Proportion of sites for each habitat level (Fair, Good, Poor) as determined by individual survey categorical regression trees (CARTs) for Red Snapper presence in the Central region of the eGOM. Note the gap in sampling for the SFRV survey (1998-2002 and 2003).

Central Region

SFRV			
Year	F	G	P
1993	0.769	0.000	0.231
1994	0.500	0.000	0.500
1995	0.769	0.000	0.231
1996	0.692	0.000	0.308
1997	0.610	0.000	0.390
2002	0.848	0.000	0.152
2004	0.703	0.000	0.297
2005	0.627	0.000	0.373
2006	0.570	0.000	0.430
2007	0.563	0.006	0.431
2008	0.525	0.049	0.426
2009	0.628	0.000	0.372
2010	0.582	0.009	0.409
2011	0.669	0.031	0.300
2012	0.500	0.010	0.490
2013	0.568	0.054	0.378
2014	0.576	0.011	0.413
2015	0.450	0.000	0.550
2016	0.646	0.046	0.308
2017	0.672	0.000	0.328
2018	0.392	0.081	0.527
2019	0.433	0.000	0.567

PC			
Year	F	G	P
2006	0.539	0.000	0.461
2007	0.654	0.000	0.346
2008	0.625	0.000	0.375
2009	0.713	0.000	0.287
2010	0.883	0.000	0.117
2011	0.811	0.000	0.189
2012	0.862	0.000	0.138
2013	0.743	0.000	0.257
2014	0.823	0.000	0.177
2015	0.750	0.000	0.250
2016	0.826	0.000	0.174
2017	0.806	0.000	0.194
2018	0.536	0.000	0.464
2019	0.738	0.000	0.262

FWRI			
Year	F	G	P
2016	0.911	0.000	0.089
2017	0.710	0.000	0.290
2018	0.798	0.000	0.202
2019	0.864	0.000	0.136
2020	0.817	0.000	0.183

Table 3. Proportion of sites for each habitat level (Fair, Good, Poor) as determined by individual survey categorical regression trees (CARTs) for Red Snapper presence in the South region of the eGOM.

South Region

SFRV				PC			
Year	F	G	P	Year	F	G	P
2010	0.845	0.000	0.155	2010	0.938	0.000	0.063
2011	0.786	0.006	0.208	2011	1.000	0.000	0.000
2012	0.762	0.014	0.224	2012	0.941	0.000	0.059
2013	0.917	0.000	0.083	2013	1.000	0.000	0.000
2014	0.713	0.000	0.287	2014	1.000	0.000	0.000
2015	0.757	0.000	0.243	2015	1.000	0.000	0.000
2016	0.788	0.000	0.212	2016	0.963	0.000	0.037
2017	0.862	0.014	0.123	2017	1.000	0.000	0.000
2018	0.915	0.000	0.085	2018	0.739	0.000	0.261
2019	0.855	0.000	0.145	2019	0.826	0.000	0.174

FWRI			
Year	F	G	P
2010	0.791	0.000	0.209
2011	0.517	0.000	0.483
2012	0.514	0.000	0.486
2013	0.707	0.000	0.293
2014	0.598	0.000	0.402
2015	0.675	0.000	0.325
2016	0.740	0.000	0.260
2017	0.587	0.000	0.413
2018	0.470	0.000	0.530
2019	0.507	0.000	0.493
2020	0.636	0.000	0.364

Table 4. The habitat weighting used with the annual distribution of Fair, Good, Poor for Red Snapper habitats to adjust estimated model means to account for sampling variation across surveys for the Central and South Regions.

Central Region				
	Survey			
	FWRI (2010-2015)	FWRI (2016+)	PC	SRFV
Total Universe Area (km2)		37767	15757	16824
Area x Proportion of mapped with reef		5856.383	10531.96	12321.72
Time Period Weighting Values				
1993-2005				1
2006-2015			0.46	0.54
2016-2019		0.2	0.37	0.43
2020		1		

South Region				
	Survey			
	FWRI (2010-2015)	FWRI (2016+)	PC	SRFV
Total Universe Area (km2)	46286	106636	6348	14423
Area x Proportion of mapped with reef	10160.648	22083.16	4329.336	11655.26
Time Period Weighting Values				
2010-2015	0.39		0.17	0.45
2016-2019		0.58	0.11	0.31
2020		1		

Table 5. Number of stations sampled (N) by survey and year, proportion of positive sets, standardized index, and CV for the annual Red Snapper combined video index of the Central region of the eGOM.

Year	N	Prop pos	Std. Nominal	Std. Index	Lower 95% CI	Upper 95% CI	CV
1993	26	0.115	0.077	0.097	-0.075	0.270	0.571
1994	24	0.083	0.062	0.086	-0.102	0.273	0.706
1995	13	0.077	0.038	0.049	-0.116	0.214	1.094
1996	39	0.154	0.102	0.137	-0.052	0.326	0.446
1997	41	0.122	0.206	0.259	-0.011	0.528	0.337
2002	46	0.391	0.476	0.609	0.118	1.100	0.260
2004	64	0.406	0.941	1.186	0.439	1.933	0.204
2005	126	0.373	0.687	0.973	0.451	1.494	0.173
2006	203	0.276	0.721	0.961	0.419	1.503	0.182
2007	212	0.330	0.831	1.561	0.637	2.486	0.191
2008	141	0.397	1.091	1.384	0.739	2.030	0.151
2009	195	0.528	1.537	1.818	1.027	2.609	0.141
2010	213	0.577	1.241	1.646	1.024	2.269	0.122
2011	287	0.540	1.176	1.593	1.075	2.111	0.105
2012	218	0.436	0.644	0.853	0.507	1.200	0.131
2013	148	0.500	0.777	1.042	0.536	1.549	0.157
2014	233	0.481	0.703	0.953	0.414	1.492	0.183
2015	188	0.394	0.670	0.785	0.448	1.121	0.139
2016	444	0.543	1.247	1.372	0.952	1.791	0.099
2017	406	0.544	1.231	1.504	0.989	2.020	0.111
2018	371	0.458	0.974	1.083	0.549	1.618	0.159
2019	564	0.532	1.143	1.504	1.012	1.996	0.106
2020	164	0.537	1.214	1.544	0.899	2.190	0.135

Table 6. Number of stations sampled (N) by survey and year, proportion of positive sets, standardized index, and CV for the annual Red Snapper combined video index of the South region of the eGOM.

Year	N	Prop pos	Std. Nominal	Std. Index	Lower 95% CI	Upper 95% CI	CV
2010	186	0.134	0.461	0.476	0.278	0.675	0.332
2011	413	0.109	0.509	0.625	0.444	0.806	0.231
2012	427	0.091	0.311	0.318	0.225	0.410	0.231
2013	285	0.137	0.767	0.715	0.435	0.996	0.312
2014	432	0.109	0.480	0.402	0.287	0.518	0.228
2015	370	0.157	1.006	1.559	0.738	2.380	0.419
2016	629	0.218	2.228	2.105	1.682	2.527	0.160
2017	585	0.198	1.372	1.507	1.150	1.864	0.188
2018	626	0.198	1.262	1.498	1.120	1.875	0.200
2019	727	0.176	0.882	1.131	0.754	1.509	0.266
2020	585	0.154	0.689	0.664	0.546	0.781	0.141

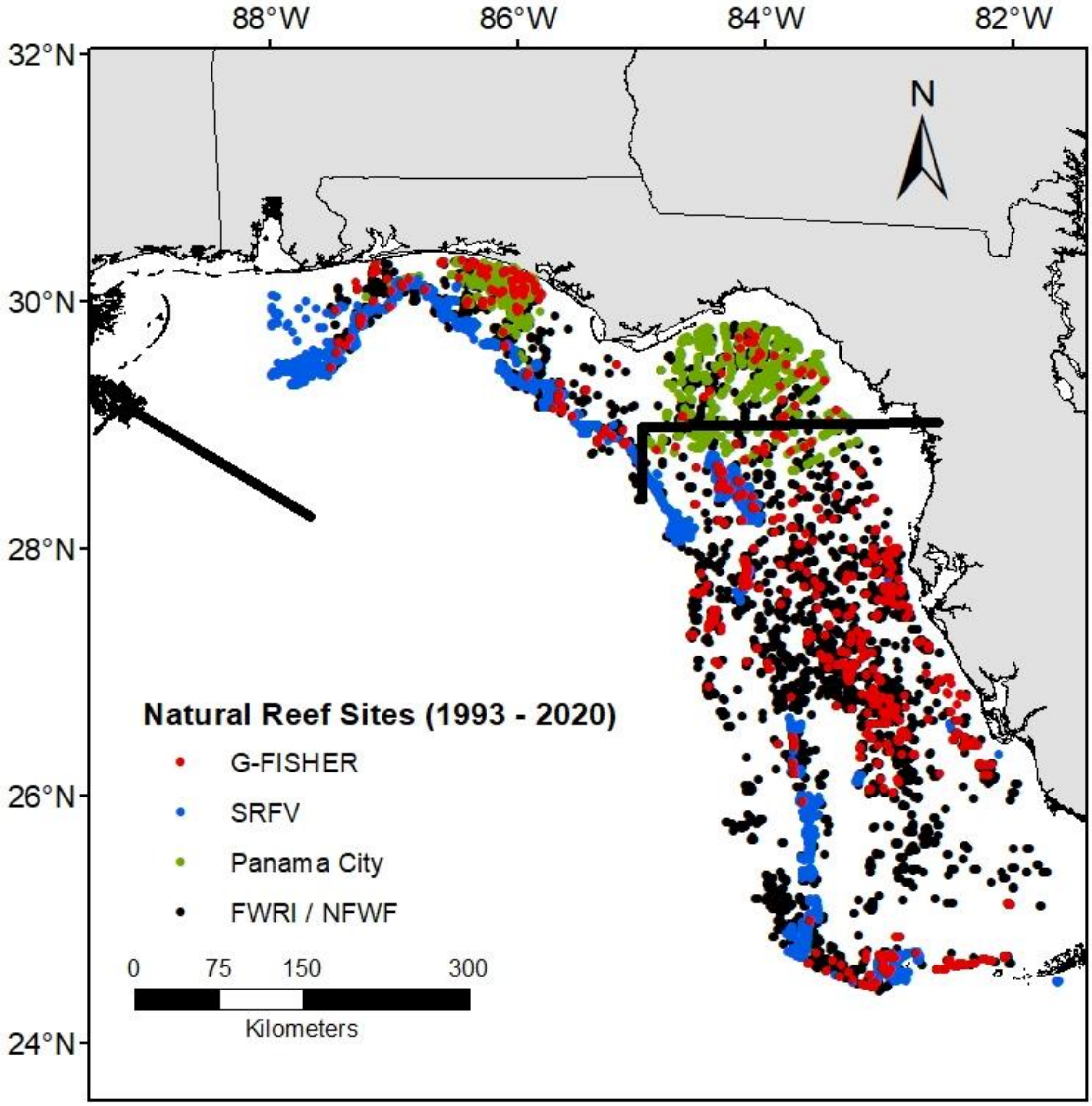

Figure 1. Map of all video sites included in the index for each survey across all years 1993-2020. The break at zone 6/7 is shown to illustrate the Central and South regions for Red Snapper.

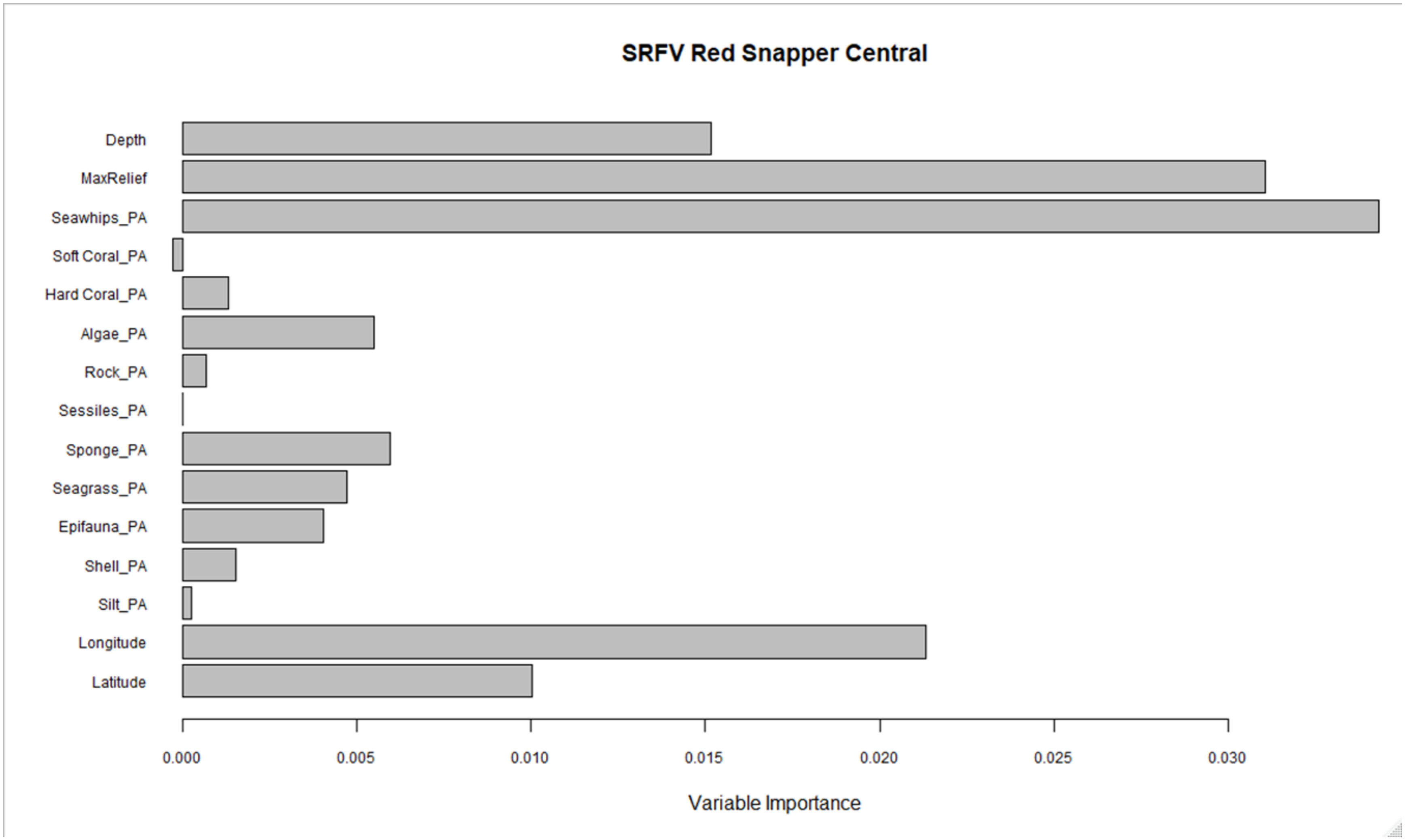

Figure 2. Random Forest generated variable importance for Red Snapper presence using the Central SRFV survey data.

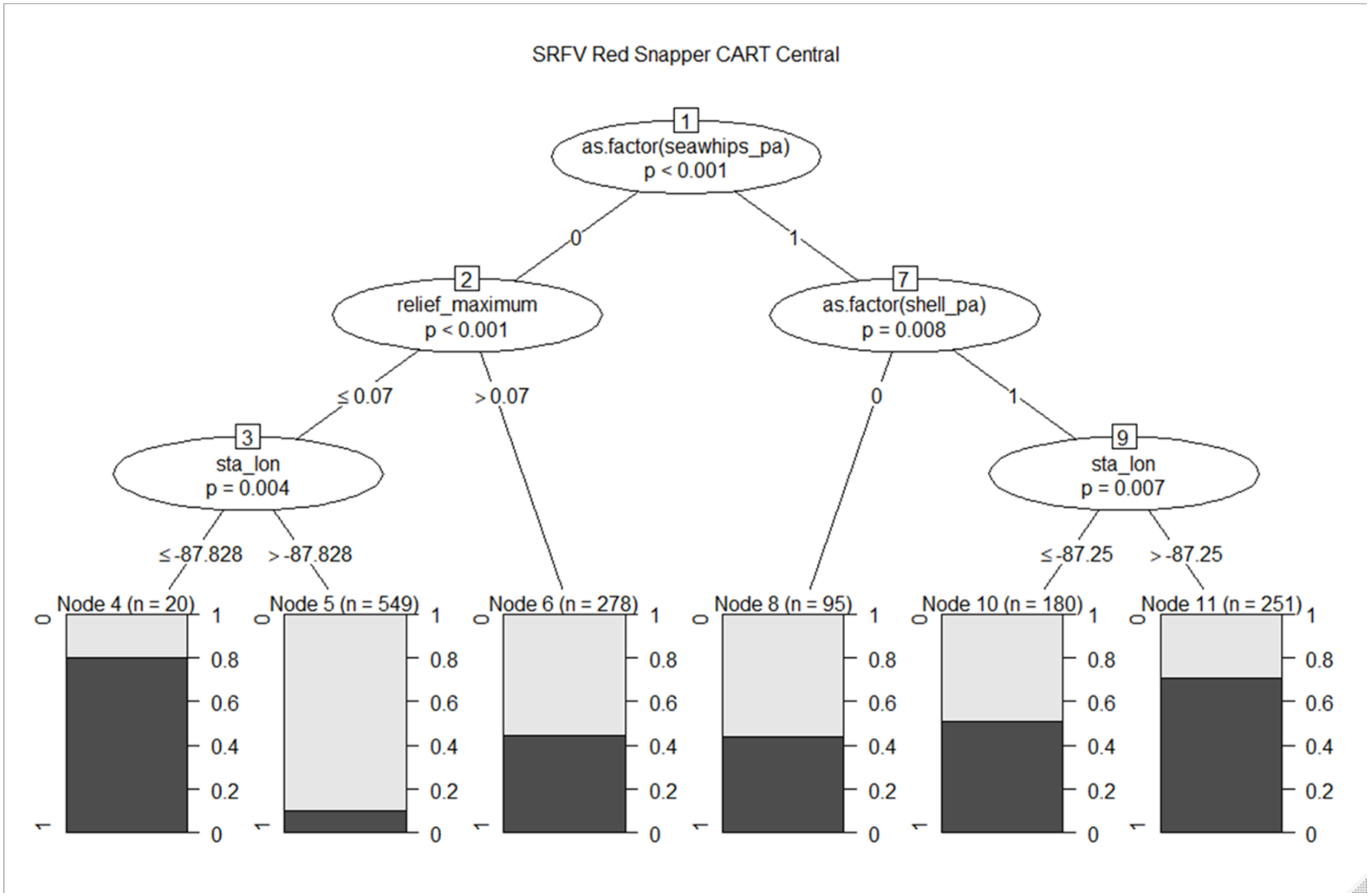

Figure 3. CART results for Red Snapper for SRFV survey for the Central region. Shaded portion of the plots indicate proportion of sites given by a node where Red Snapper were observed.

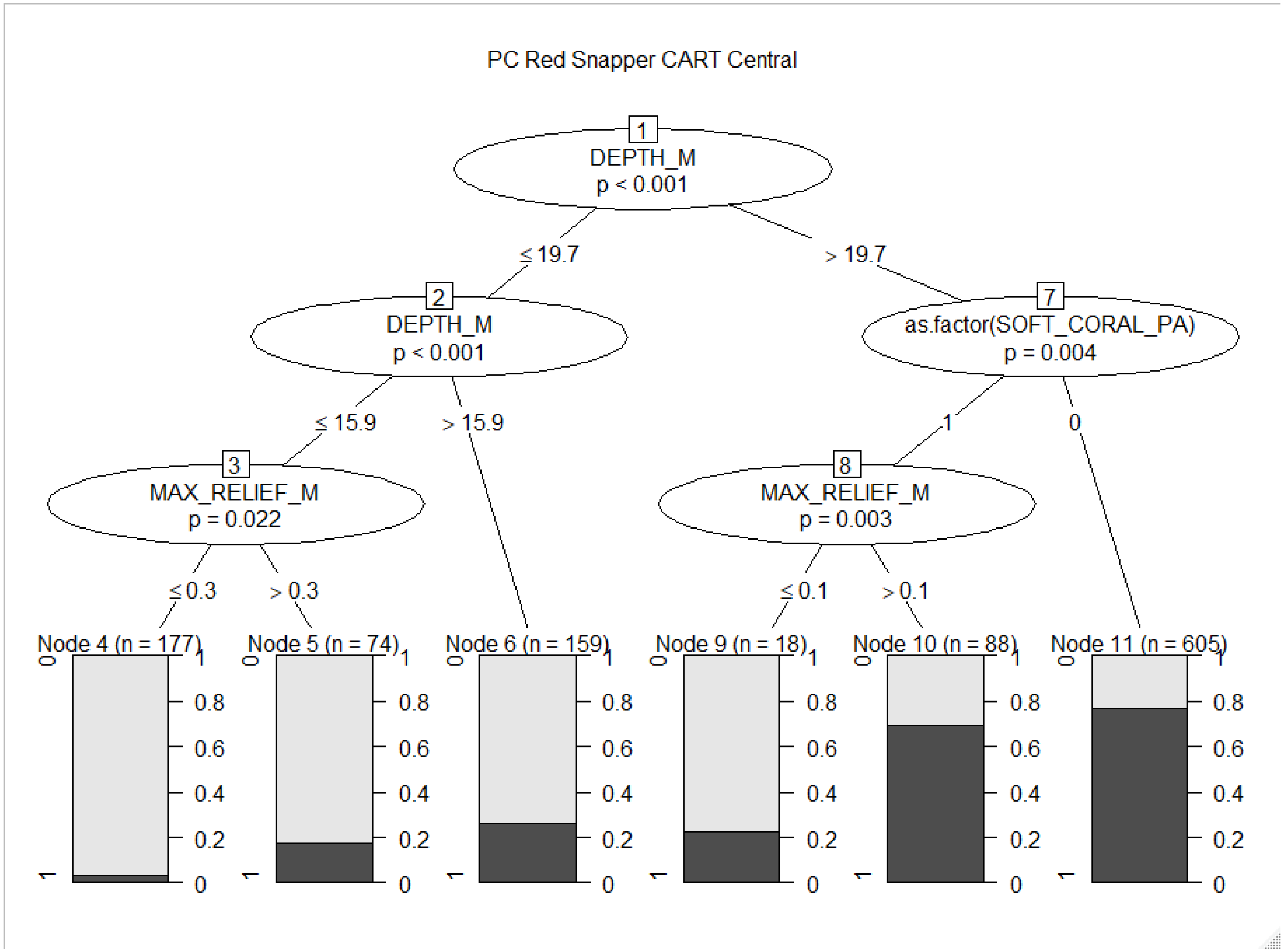

Figure 4. CART results for Red Snapper for PC survey for the Central region. Shaded portion of the plots indicate proportion of sites given by a node where Red Snapper were observed.

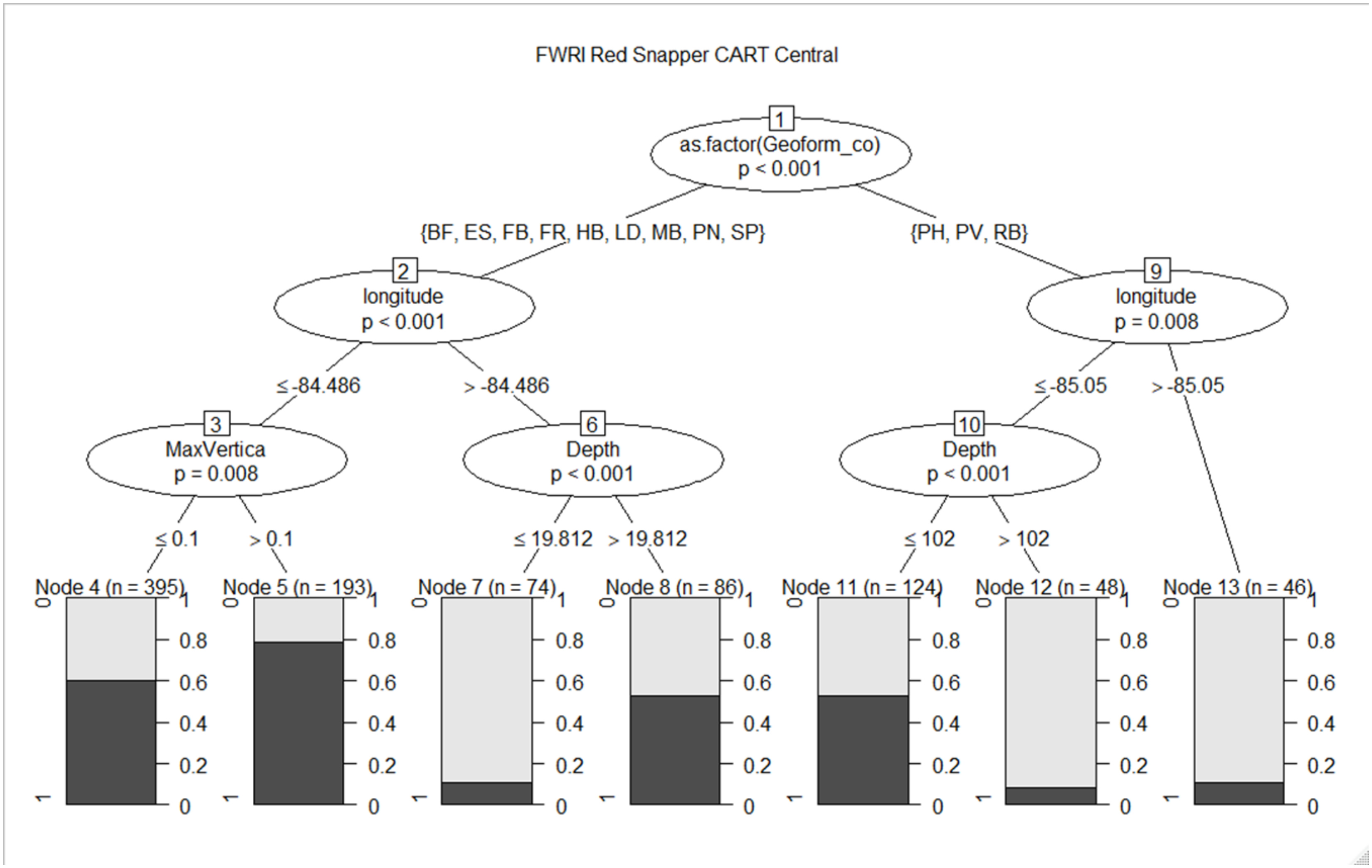

Figure 5. CART results for Red Snapper for FWRI survey for the Central region. Shaded portion of the plots indicate proportion of sites given by a node where Red Snapper were observed.

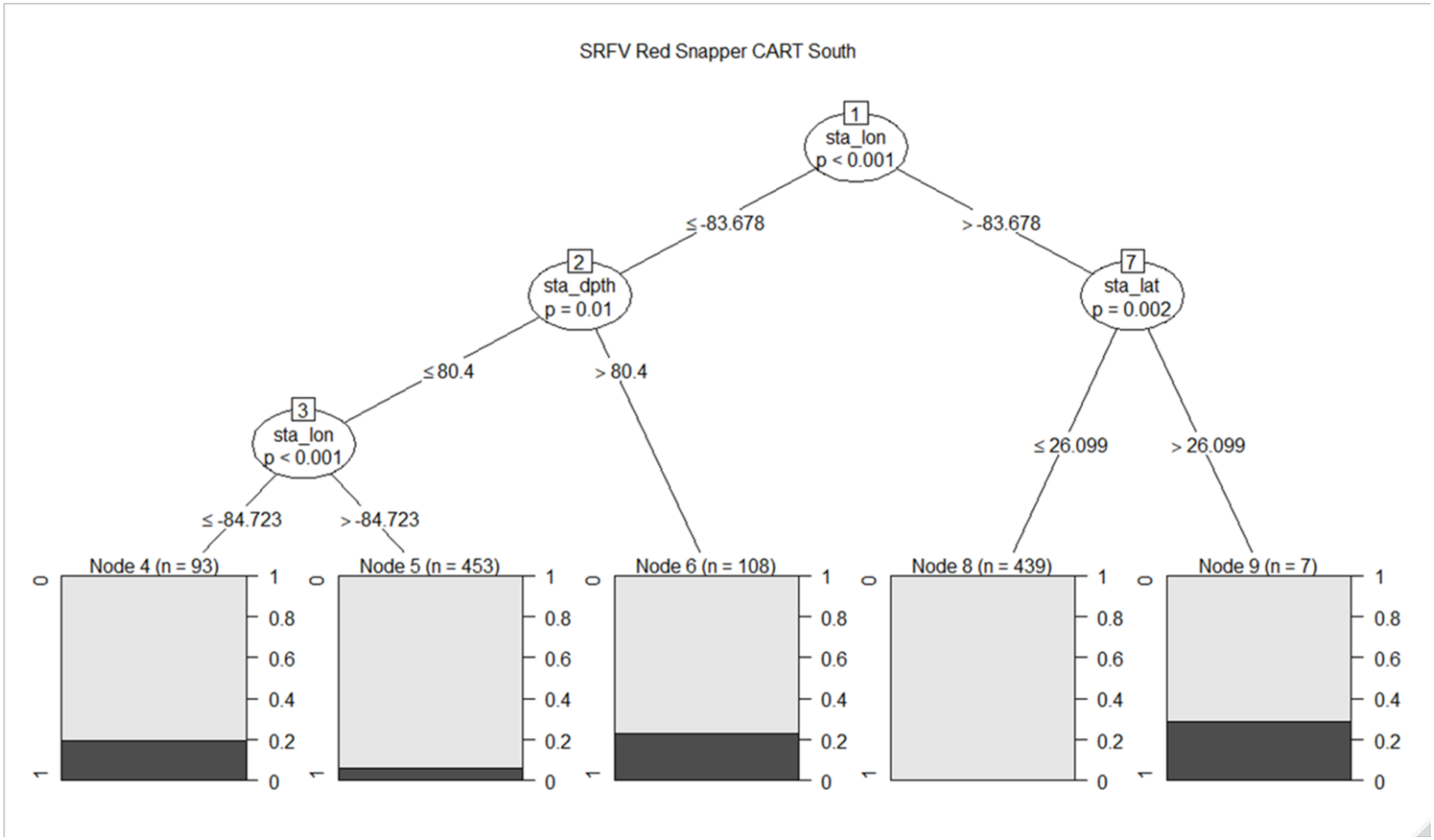

Figure 6. CART results for Red Snapper for SRFV survey for the South region. Shaded portion of the plots indicate proportion of sites given by a node where Red Snapper were observed.

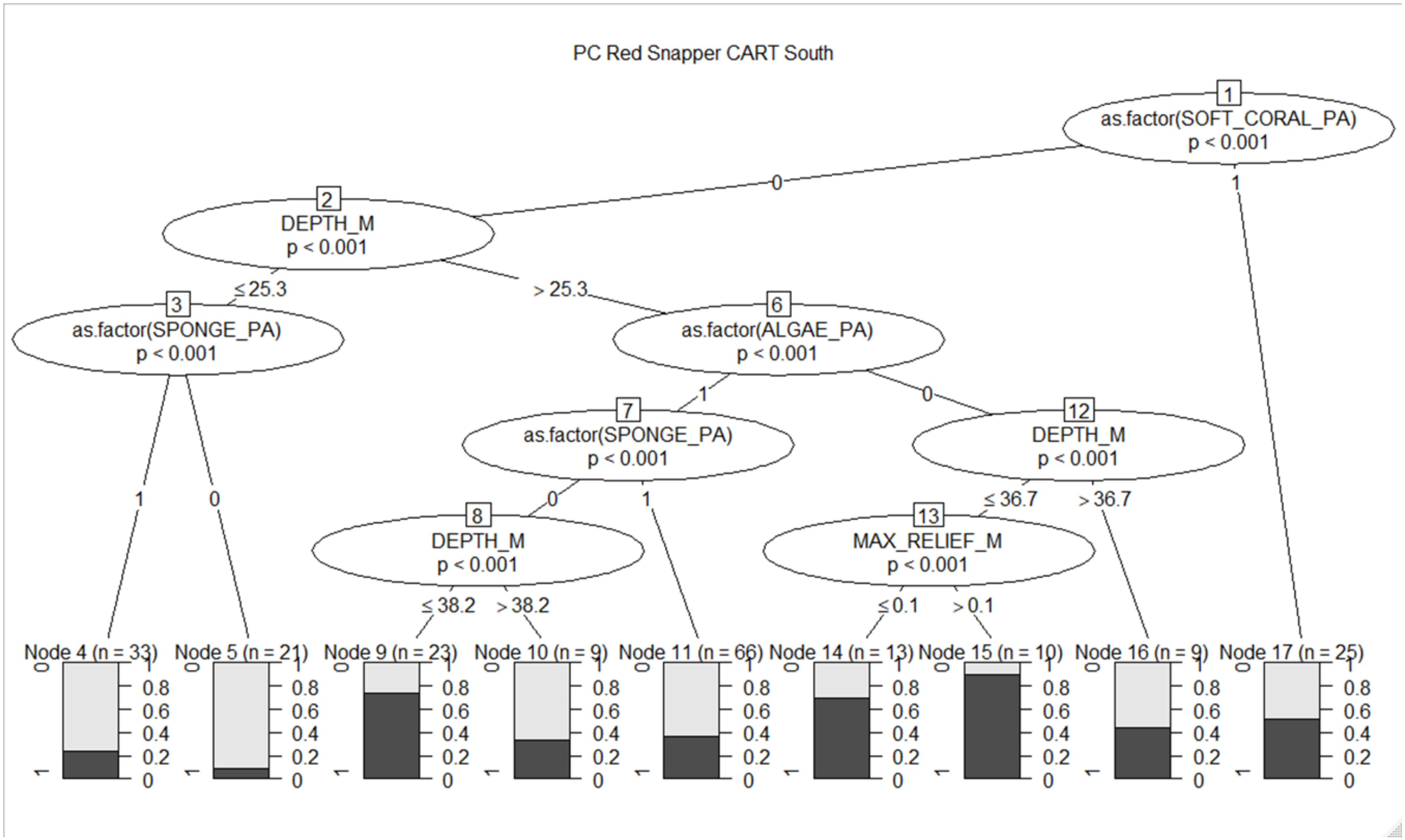

Figure 7. CART results for Red Snapper for PC survey for the South region. Shaded portion of the plots indicate proportion of sites given by a node where Red Snapper were observed.

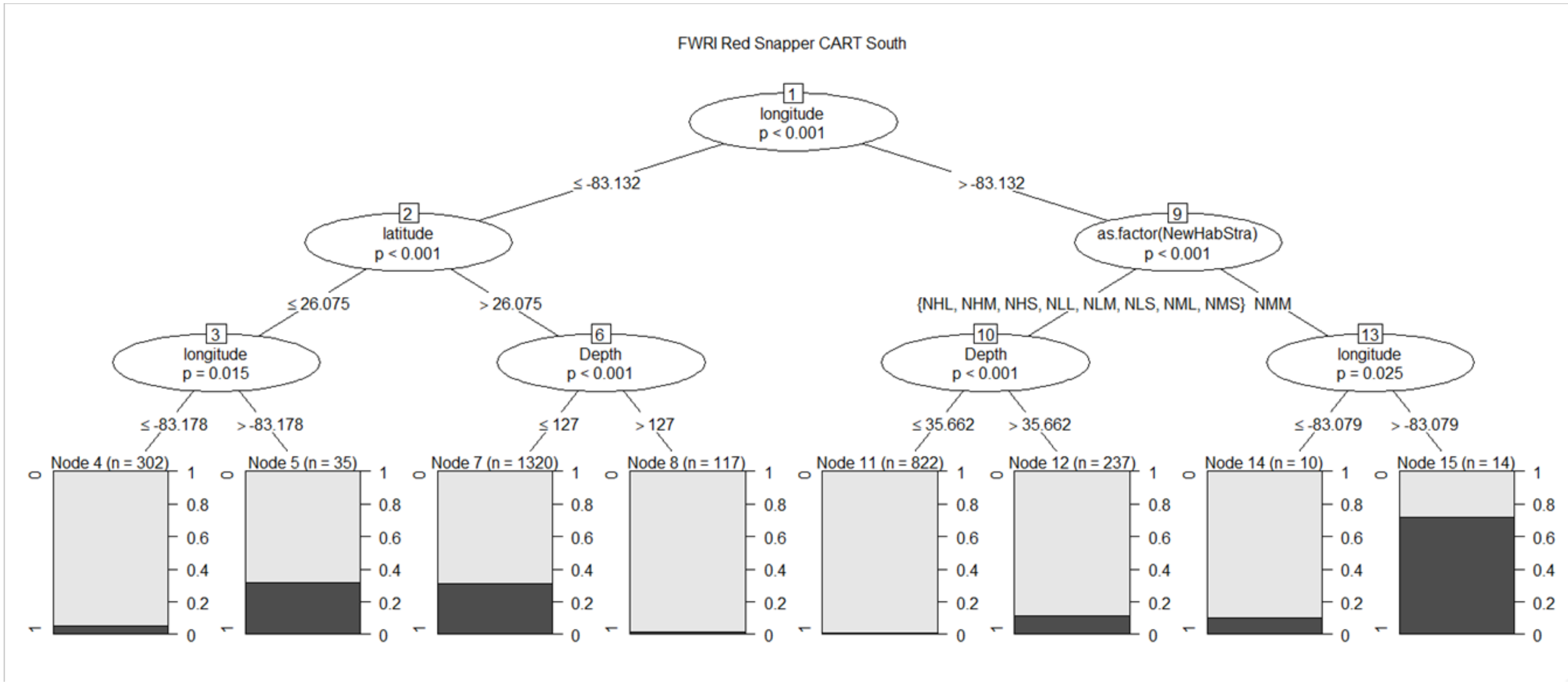

Figure 8. CART results for Red Snapper for FWRI survey for the South region. Shaded portion of the plots indicate proportion of sites given by a node where Red Snapper were observed.

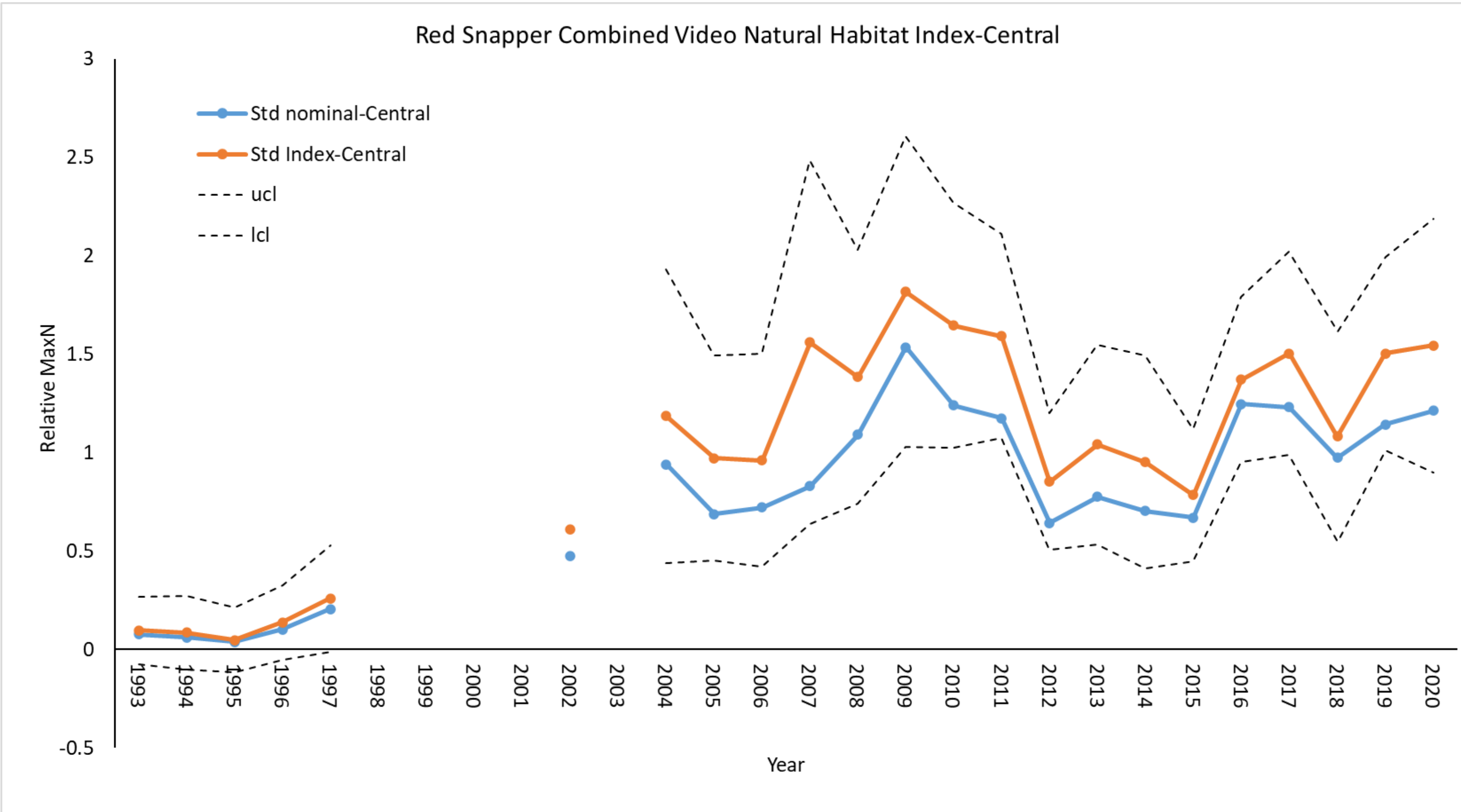

Figure 9. Standardized index with 2.5% and 97.5% confidence intervals and nominal index for relative Red Snapper CPUE (MaxN) using the integrated West Florida Shelf video data for the Central Region.

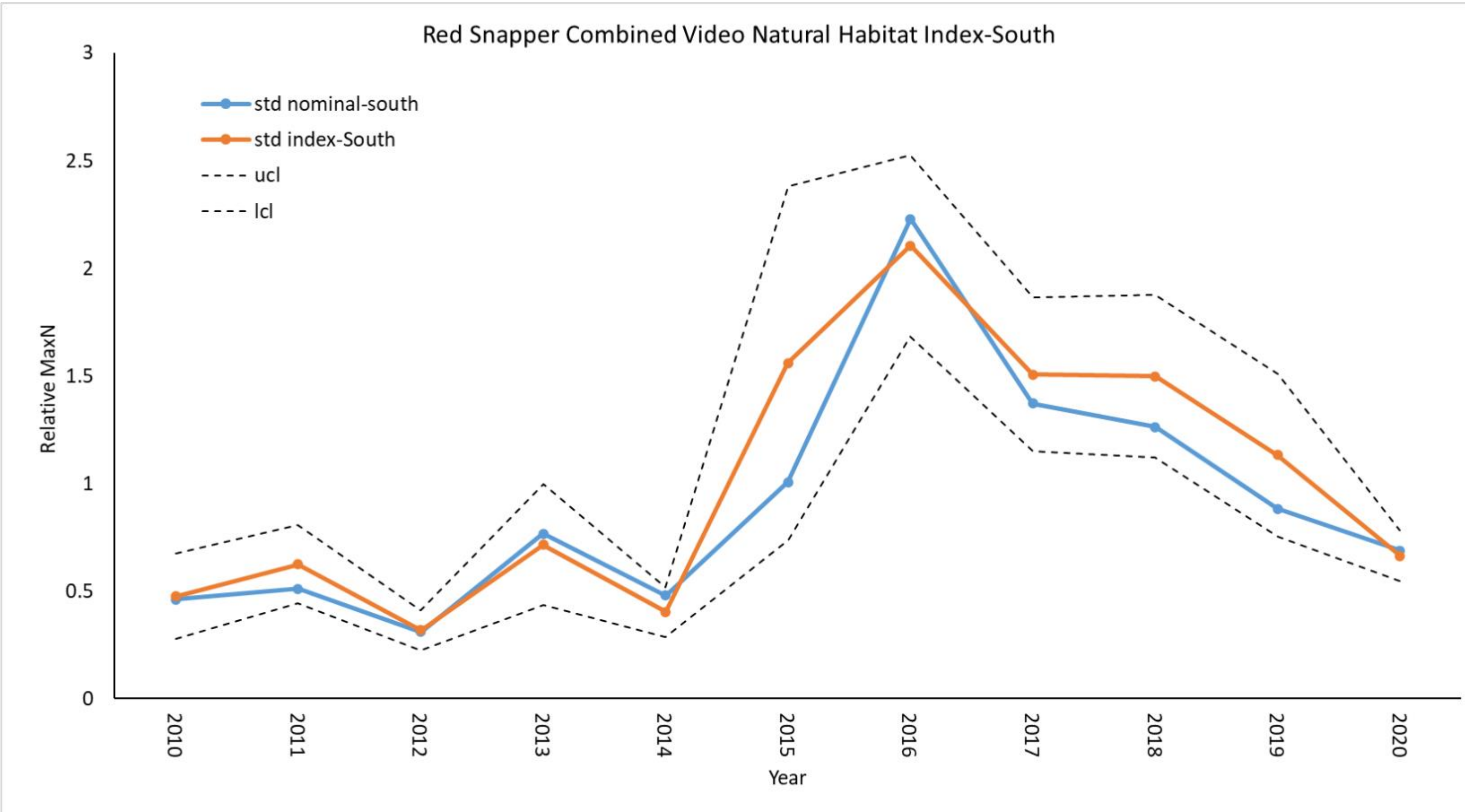

Figure 10. Standardized index with 2.5% and 97.5% confidence intervals and nominal index for relative Red Snapper CPUE (MaxN) using the integrated West Florida Shelf video data for the South Region.

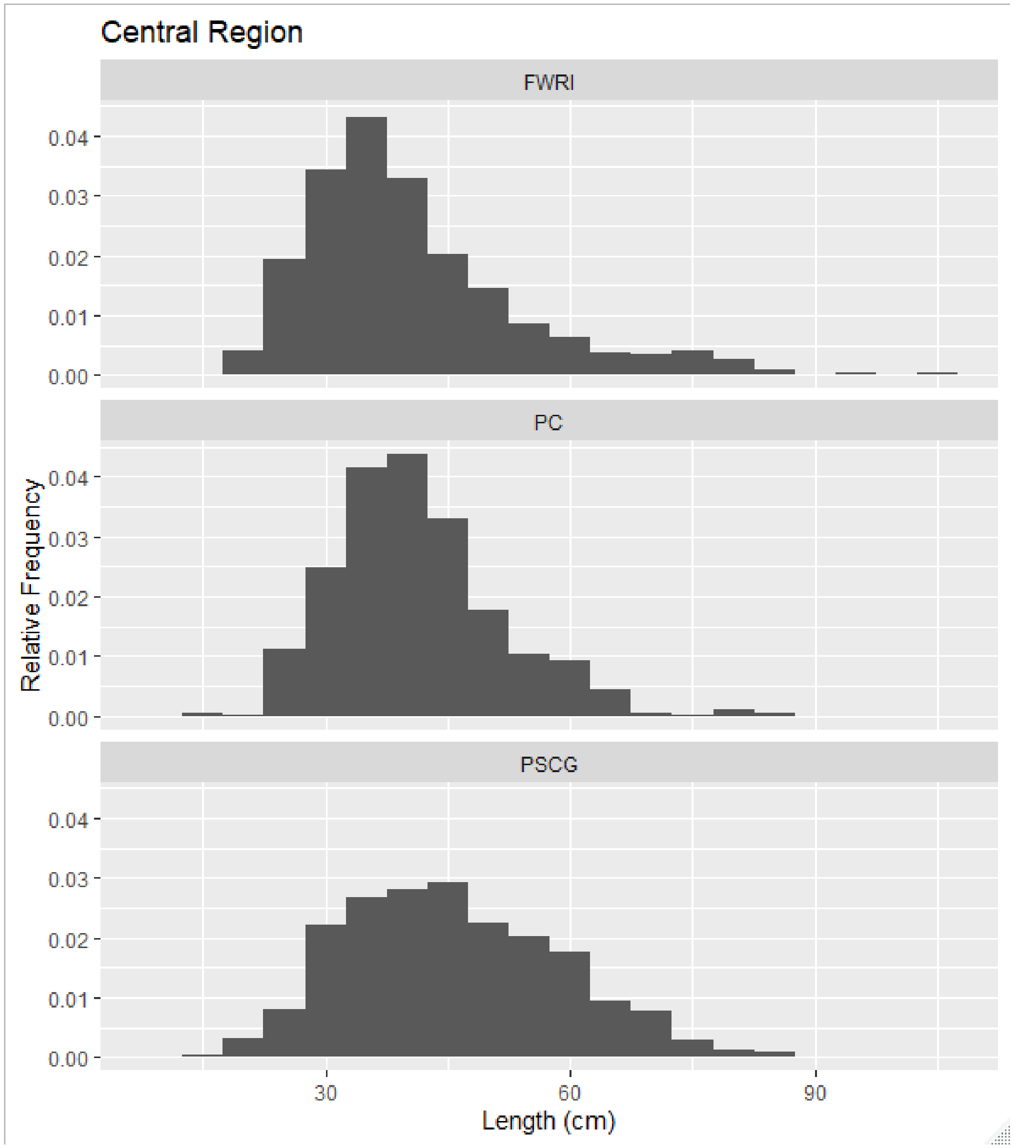

Figure 11. Combined length frequencies of Red Snapper in the Central region by survey for all years sampled.

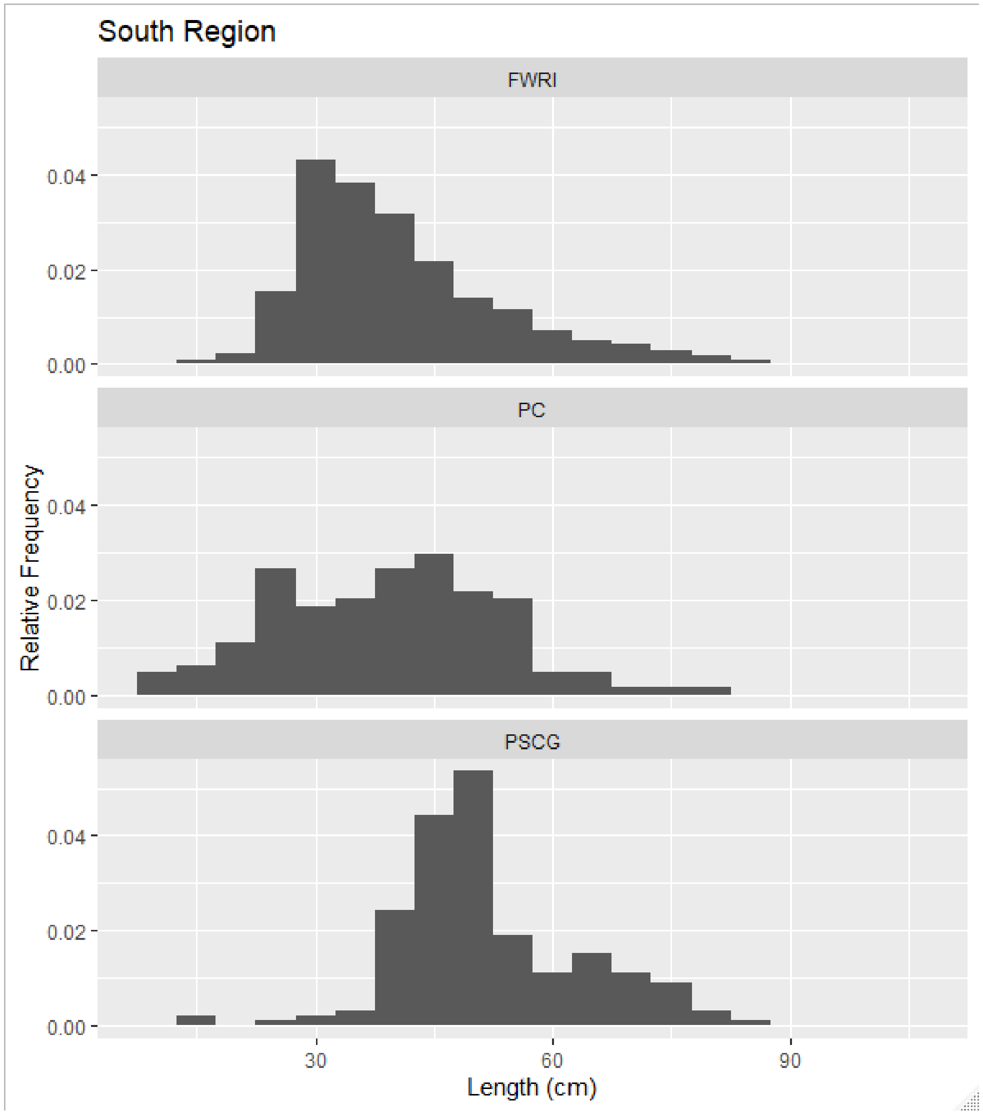

Figure 12. Combined length frequencies of Red Snapper in the South region by survey for all years sampled.

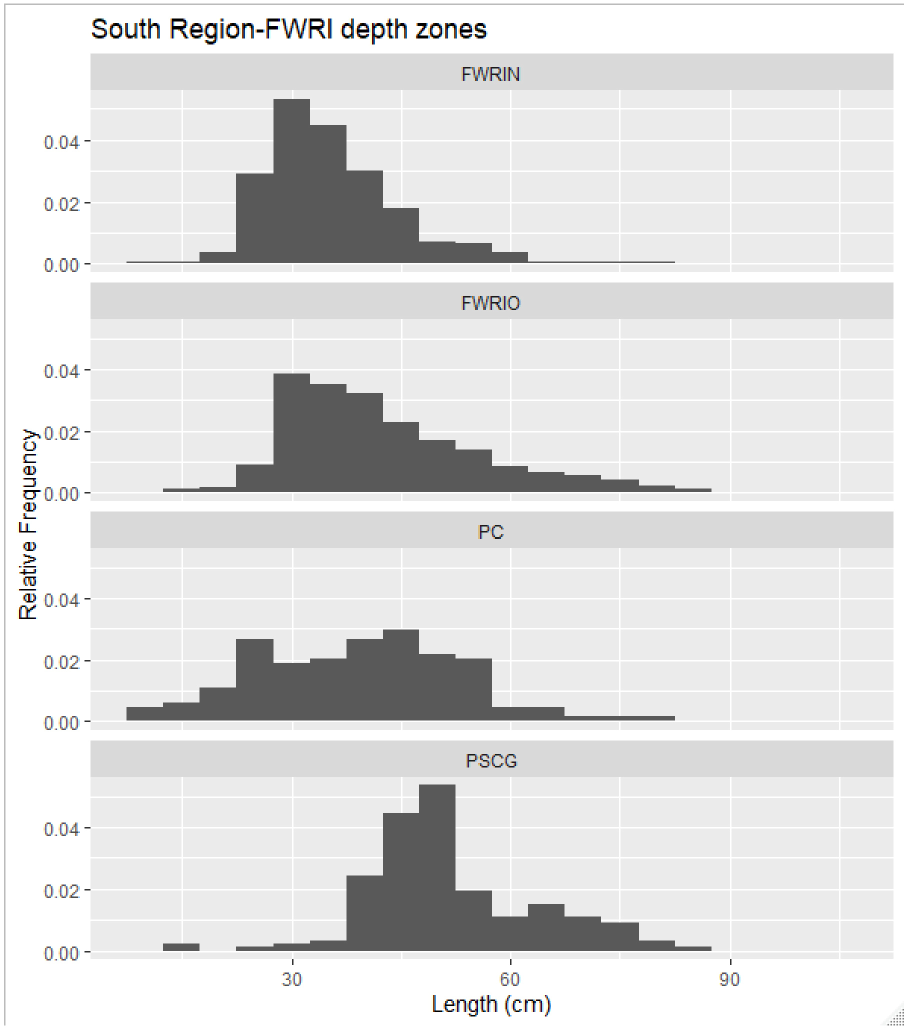

Figure 13. Combined length frequencies of Red Snapper in the South region by survey for all years sampled with FWRI separated into nearshore (N, 10-37m) and offshore zones (O, 37m+) similar to the PC and SFRV surveys, respectively.