Standardized Catch Rates of Mutton Snapper (*Lutjanus analis*) from the Marine Recreational Information Program (MRIP) in Southeast Florida and the Florida Keys, 1981-2022

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SEDAR 79

Introduction

Mutton snapper are caught by recreational anglers primarily in South Florida from Indian River to Monroe County. The Marine Recreational Fisheries Statistics Survey (MRFSS) was initiated in 1981 to collect catch, effort, and participation estimates from the recreational sector. MRFSS consists of a telephone survey of fishing effort and an access point angler intercept survey (APAIS) of angler catch. Intercepts are conducted at public marine fishing access points (boat ramps, piers, beaches, marinas, etc.) to collect individual catch data including number of each species landed (i.e., harvested), number discarded, length, and weight. Access points are selected by a proportional random selection process in order to sample high activity sites most often. From these intercept data, the number of fish harvested or caught (fish harvested and released) per trip can be calculated for each species encountered. These catch rates can provide an indication of population trends over time and are combined with the effort estimates from the telephone survey to produce total catch and harvest estimates.

In 1991, MRFSS made several improvements to the survey and one of which was the linking together of separate intercepts of anglers that fished on the same trip and recording the total number of anglers in the party. In 2008, the Marine Recreational Information Program (MRIP) officially replaced MRFSS as a more precise and accurate method for estimating recreational catch and effort. In 2013 the APAIS was implemented to remove bias from the sampling process and in 2015 the Fishing Effort Survey (FES, a mail survey) was launched to improve estimates for those fishing via the private boat and shore effort modes. In 2018, the MRIP data were re-calibrated to account for the transition away from the Coastal Household Telephone Survey (CHTS) towards the new FES. The calibration model was peer reviewed by reviewers appointed by the Center for Independent Experts (https://www.fisheries.noaa.gov/event/fishing-effort-survey-calibration-model-peer-review).

Methods

Prior to analyzing MRIP total catch per unit effort (CPUE), landings per unit effort (LPUE), or releases per unit effort (RPUE), the number of mutton snapper landed and released through time are compared among fishing modes (charter [CH], private [PR], and shore [SH]) and regions. These comparisons will guide the development of standardized indices. Figures 1 and 2 show that the vast majority of removals occur in Southeast FL (SE FL; includes Indian River, Saint Lucie, Martin, Palm Beach, Broward, and Miami-Dade Counties) and the Florida Keys (FL Keys; includes Monroe County). Also, releases far outnumber landings in most years, particularly since 2013 in SE FL. The private mode accounts for the majority of landings and releases. However, relatively high removals also occur in the shore mode, particularly in 1981-1983, 2008, 2015, and 2016, while the charter mode accounts for minimal removals. Since most landings and discards occur in the private mode in SE FL and the FL Keys, this mode and regions will be the focus of index development. Another reason to only consider landings and discards from the private mode is the differences in retention (the length of landed fish) among fishing modes (Figure 3).

Area Descriptions

Two standardized MRIP total catch rate (landings plus releases, CPUE) indices were generated.

1. A private mode catch rate index for Southeast Florida (SE FL) – Counties: Indian River, Saint Lucie, Martin, Palm Beach, Broward, Miami-Dade
2. A private mode catch rate index for the Florida Keys (FL Keys) – Monroe County

Publicly available MRIP data were used to construct standardized indices (https://www.fisheries.noaa.gov/recreational-fishing-data/recreational-fishing-data-downloads). Standardized catch rates were generated by adding the trip catches (number landed plus released; A + B1 + B2) after all forthcoming filtering and clustering steps had been applied to each area-specific dataset.

Data Preparation and Filtering

Prior to identifying directed effort (i.e., 'mutton snapper trips') through species clustering, individual angler trips (identified by ID_CODE) are grouped by fishing party to the extent possible. This is to account for non-independence of catches due to fishing at the same or nearby sites. For boat modes (i.e., private or charter modes) fishing trips cannot be identified prior to 1991, only grouped catch (i.e., those identified by LEADER) and there can be multiple grouped catches on a fishing trip.

From 1991 to present, PRT_CODE is used to group angler-trips by fishing party. Prior to 1991, PRT_CODE is equal to ID_CODE for boat modes (i.e., Charter and Private), indicating that PRT_CODE is the angler-trip identifier prior to 1991. It was confirmed that there are instances of multiple PRT_CODEs for a single LEADER code mainly prior to 1991 and multiple LEADER codes for a single PRT_CODE only after 1990. For simplicity, the term 'fishing party' will apply to data prior to 1991 even though these data are at the 'grouped catch' level.

The proportion of boat mode trips after 1990 (i.e., identified by PRT_CODE) with multiple grouped catches (i.e., multiple LEADER codes per PRT_CODE) is approximately 50% in most years meaning that grouped catches within a trip are quite common and identifying a fishing trip by LEADER requires caution.

Some fishing parties were associated with multiple angler-trip characteristics (e.g., multiple gears, modes, counties fished, areas fished, number in fishing party). In these instances (1,815 records), only the first non-NA value was used to characterize all angler-trips within a fishing party. Then, the MRIP angler-trip data was aggregated to trip-level data by summing landings and releases of each species, and then calculating the number of interviews, the number of contributors to the catch, median avidity (median number of days fished in the last two months), and median hours fished among anglers on the same trip.

Data were initially filtered following these steps:

1. Data in the Gulf of Mexico and South Atlantic were limited to interviews that took place in Southeast Florida and the Florida Keys (i.e., Monroe County) during wave 2, 1981 through wave 6, 2022.
2. Only interviews associated with the private fishing mode fishing hook and line gear were retained.
3. Interviews that reached bag limits for mutton snapper were retained.
4. Data were not adjusted to account for size limits or closed seasons.
5. 439 angler-trip records with NA unadjusted catch
6. 842,614 angler-trip records with 0 unadjusted catch

<u>Species Clustering</u>

To elucidate trends in relative abundance, directed mutton snapper trips must first be identified. Ideally, these trips have a positive chance of encountering a mutton snapper, regardless of whether a mutton snapper was encountered. They presumably occur in favorable mutton snapper habitat and during the time of day/year when mutton snapper are available, while using a gear that can successfully catch mutton snapper.

Without fine-scale spatial and temporal information on fishing locations and associated habitat, clustering methods are used to identify suite of co-occurring species to serve as a proxy for favorable mutton snapper conditions (Shertzer and Williams 2008). A structural zero would then be a trip that did not encounter a mutton snapper but did encounter a species within the mutton snapper cluster. A non-structural zero, which would be removed prior to developing a CPUE index, would be a trip that did not encounter a mutton snapper nor a species within the cluster.

Legrendre and Legrendre (1998) distinguish methods to determine the resemblance between either the objects under study (i.e., sites) or the variables describing them (species or other descriptors). Measuring the association between sites is termed *Q mode*, whereas measuring the association between species is *R mode* (also referred to as inverse analysis). Thus, *R mode* analysis is used to identify the suite of co-occurring species (hereafter, species clusters).

To start *R mode* analysis, the data matrix of abundances (or biomass, area cover, etc.) has rows indicating species and columns indicating samples (or sites) and the similarity between any pair of species is measured (Clarke et al. 2014). Similarities between rare species have little meaning and including them may distort inferred patterns. Field et al. (1982) suggest retaining species that have at least an arbitrary percentage dominance at any one station that results in retaining around 50-60 species. For this analysis, only species that are present in more than 1% of trips are retained. For the FL Keys, this results in 51 retained species and 39 species in SE FL, both of which are within or near the recommended range.

Agglomerative hierarchical cluster analysis was performed with average linkage on the Bray-Curtis similarity measure applied to catch/abundance data for each species (i.e., total unadjusted catch [landed+released] of a species per trip). Several transformations (square root, fourth root, log(x+1)) of catches were considered, as well as standardized catches, and transformed then standardized catches as recommended by Clarke et al (2014). Species catches were standardized across species as a percentage of the total species catch at all trips (i.e., if a species is found in only one trip, its standardized catch there is 100%). Standardizing catches account for the typically large overall abundance differences between species.

Then, a clustering algorithm is applied to a dendrogram (distance/dissimilarity matrix) to partition species into clusters. There are many clustering algorithms to choose from (see Ezugwu et al. 2022), however this analysis selects clusters based on maximizing the average silhouette widths using the *find_k* function within the dendextend package in R. In short, the larger the silhouette width is, the better the object is clustered. Negative values suggest that the corresponding objects may have been placed in the wrong cluster. In addition, an ordination method, nonmetric multidimensional scaling (NMDS), is used to confirm and visualize the separation of clusters.

CPUE Standardization

To standardize total catch per unit effort (CPUE) time series, trips were first removed if none of the species in the cluster were encountered. Trips were also removed if median hours fished, number of contributors, or median avidity were not available, and in addition if median hours fished exceeded 24 hours. In the FL Keys, there were very few inshore fishing trips (area_x=5), so these were also removed. Years with 5 or less positive observations were removed, which removed years 1983-1985, 1988, 2000, 2001, 2004, 2005, and 2011 from the FL Keys data and 1981 from SE FL data. After all filtering, 14,839 trips remained for SE_FL (3,019 positive trips) and 5,003 trips in the Florida Keys (614 positive trips).

CPUE was modeled using the delta-glm approach (Dick 2004; Lo et al. 1992; Maunder and Punt 2004). This approach calculates an index as the product of the indices from binomial (probability of catching a mutton snapper) and positive (trips that caught at least one mutton snapper) sub-models.

Six explanatory variables were evaluated for the binomial model. These included:

Year – factor with levels 1981 to 2022 (not including years that were removed with 5 or less positive observations).

Contributors – The number of contributors to the combined trip catches (total catch of the entire trip); factor with four levels (1- 4+)

Season – factor with two levels; Summer (including waves 3-5 or months May-October) and Other (including waves 6-2 or months November-April)

Waters – waters fished; factor, two or three levels depending on the region (inshore [area_x=5 in SE FL], nearshore [area_x=1 or 3 in the FL Keys], offshore [area_x=2 or 4 in the FL Keys])

Median Hours Fished – median hours fished among anglers; factor, four levels (.5-2, 3-5, 6+)

Median Avidity – median days fished in the last two months among anglers; factor, four levels (0-2, 3-5, 6-9, 10+)

Positive log(CPUE) of mutton snapper was modeled as a normal distribution. To normalize and reduce patterns in residuals, CPUE was defined as the log of the average number of mutton snapper caught per contributor (number of mutton snapper caught per trip [A+B1+B2] divided by the number of contributors to the catch). Several other CPUE definitions and error distributions were explored (e.g., negative binomial, zero inflated poisson, delta gamma) but diagnostic plots indicated poor fits to the data. The same explanatory variables for the positive model were explored as with the binomial model with the exception of the number of contributors to the catch. Sample size tables were produced with the number of positive trips per year for each level of each covariate. Additionally, interaction terms with year were graphically explored.

The stats::glm package in R was used to produce positive and binomial sub-models. For both the positive and binomial sub-models, explanatory variables were selected using stepwise forward selection based a reduction in mean deviance by at least 0.5% (via the step function and a custom function in R). The goal of stepwise selection is to produce a model (overall model) that contains the optimal combination of explanatory variables (which explain a significant amount of variation in the response variable) while also being most parsimonious. Stepwise forward selection starts with a null model that includes only an intercept term. At the first step, additional covariates are added to a null model so that there are n unique models (n = number of covariates). The lowest deviance of the unique models is compared to that of the null model; if it is lower than the deviance of the null model by at least 0.5% the unique model becomes the new base model. This process repeats itself until no additional covariate sufficiently reduces the deviance.

Index Generation and Evaluation

Confidence intervals and annual means were estimated by simulating the distribution of the predicted means using 10,000 randomly generated residuals; each residual was a random normal deviate times the standard error for its predicted mean which was then added to the least squared means for the year factor in either log scale (for the positive model) or the logit scale (for the binomial model). Lastly, these estimates were back-transformed and multiplied together to estimate a distribution of the number per contributor and the distribution was described in terms of percentiles and a mean. This method allows for the transformation of the response variable from log space back to CPUE without applying an approximate bias correction.

Results

Species Clustering

The cluster results that apply to mutton snapper caught off the FL Keys from hook and line gear in the private mode vary among data transformations. The highest silhouette width for mutton snapper occurs when maximizing silhouette width for standardized (i.e., percent) LN(catch + 1), resulting in a silhouette width of 0.058 and an average silhouette width for the cluster of 0.027. This cluster includes yellowtail snapper, gray snapper, lane snapper, black grouper, red grouper, bluestriped grunt, white grunt, grunt family, porgy family, sea bass family, blue runner, requiem shark family, and Spanish mackerel along with mutton snapper. However, negative silhouette widths for Spanish mackerel, requiem shark family, and black grouper suggest these species may have been placed in the wrong cluster (Figure 4). Additionally, blue runner, Spanish mackerel, and requiem shark family are placed on a different branch in the dendrogram (Figure 5).

The top ten co-occurring species with mutton snapper on private mode trips in the FL Keys fishing hook and line gear are presented in Table 1. Yellowtail snapper and gray snapper have the highest percent of co-occurrence (52% and 33%, respectively). On the other hand, the percent of co-occurrence with Spanish mackerel and the requiem shark family is 5% or less.

Nonmetric multidimensional scaling (NMDS) using standardized LN(catch + 1) resulted in relatively low stress value (0.203) so there is a fairly clear delineation of clusters. For many species, the NDMS of standardized LN(catch + 1) aligns with the cluster results, but Spanish mackerel, requiem shark family, and gray snapper are farther away from the rest of the cluster also suggesting these species may not align with the rest of the cluster (Figure 6).

Considering that the proportion of trips with Spanish mackerel, requiem shark family, and black grouper are all very low (Figure 7 and 8), these additional species should not affect an index of abundance. These plots of the proportion of angler-trips that encountered a species within the identified cluster also show a few changes over time. Angler trips that caught a mutton snapper have increased slightly through time. One anomaly is the high proportion of interviews that encountered bluestriped grunt from 1996 to 1999. After 1999, the proportion of interviews that encountered bluestriped grunt is nearly zero. Additionally, some species have been encountered less through time - those being red grouper, black grouper, and white grunt, while requiem shark family, spanish mackerel, sea bass family and grunt family have increased.

For SE FL (hook and line, private mode), the highest silhouette width for mutton snapper occurs when maximizing silhouette width using the fourth root of catch, resulting in a silhouette width of 0.071 and an average silhouette width for the cluster of 0.043. This cluster includes yellowtail snapper, lane snapper, red grouper, bluestriped grunt, white grunt, grunt family, blue runner, gag grouper, and gray triggerfish, along with mutton snapper (Figure 9 and 10). NMDS results suggest that bluestriped grunt could be misplaced (Figure 11), however Figures 12 and 13 show that bluestriped grunt are only present on a very small proportion of trips. These figures also illustrate that the proportion of trips encountering mutton snapper have increased over time and the proportion of trips encountering white grunt, red grouper, and gag have declined.

The top ten co-occurring species with mutton snapper on private mode trips in SE FL fishing hook and line gear are presented in Table 2. Again, yellowtail snapper and gray snapper top the list (both with 26% co-occurrence), yet gray snapper is instead clustered with primarily inshore species (e.g., sheepshead, spotted seatrout). Similarly, pelagic species such as little tunny, king mackerel and a habitat generalist (crevalle jack) are also included on this list but are not included in the mutton snapper cluster.

CPUE Standardization

Histograms of mutton snapper unadjusted catch per trip including zeros exhibit zero inflation and overdispersion in both regions (Figures 14 and 15). For positive trips, the CPUE definition that most closely resembles a normal distribution is log(unadjusted catch per contributor) in both regions (Figures 14 and 15). Diagnostic plots of residuals also confirmed that unadjusted catch per contributor resulted in less biased residuals compared to log(unadjusted catch per trip) or log(unadjusted catch per median hours fished).

A comparison of mean nominal unadjusted catch per contributor among regions (Figure 16) shows that nominal rates are generally much higher in SE FL compared to the FL Keys, especially in recent years. Mean nominal catch rates in the FL Keys after 2015 have stayed around 0.1, while mean nominal catch rates in SE FL during that time have increased and range from approximately 0.4 to 0.7. This increase is driven by mean nominal discard rates, whereas mean nominal landings rates in SE FL have remained mostly stable, with a slight decline from 2010 to 2020 followed by an increase thereafter.

The number of trips that encountered at least one mutton snapper by year for each level of each covariate are presented in Table 3 for the FL Keys and Table 4 for SE FL. Interaction plots for each covariate and year are presented in Figures 17 and 18 for the FL Keys and SE FL, respectively. Since 2016 mean nominal catch rates in nearshore waters in the FL Keys and non-summer months have been slightly elevated. While in SE FL, mean nominal catch rates have increased the most in inshore waters since 2013 and during non-summer months since 2019 (Figure 18). These plots suggest that inshore or nearshore waters and non-summer months may have an outsized influence on mean nominal catch rates in recent years. The following analysis does not account for interaction terms, and therefore assumes a constant effect of all covariates over time.

The final positive and binomial sub-models were:

<u>FL_Keys</u>

Pos: log(catch per contributor) = year + waters fished (Table 5)

Bin: Presence = year + contributors + median hours fished (Table 6)

<u>SE_FL</u>

Pos: log(catch per contributor) = year + median avidity + waters fished (Table 7)

Bin: Presence = year + median avidity (Table 8)

To evaluate residuals of the binomial model randomization was introduced to produce continuous normal residuals using the 'qres.binom' function of the 'statmod' package in R. Randomized quantile residuals for both binomial sub-models were normally distributed and showed no pattern across predictor variables (Figures 19 and 21). Residuals from the positive sub-models were close to normal but exhibited some patterns across predictor variables (Figures 20 and 22). For the FL Keys positive sub-model, catch rates in nearshore waters are overall slightly overestimated but there are few successive years with over or under estimation (Figure 20). Similarly for the positive sub-model for SE FL, catch rates in inshore waters are overall slightly overestimated and there are some successive years of over or under estimation (Figure 22). An interaction term between year and waters fished would likely resolve some of these patterns. Diagnostic plots of the positive sub-models indicate that residuals are close to normality, variance is homoscedastic, and there are no influential outliers in the dataset (Figures S1 and S2).

The observed annual mean CPUE and modeled CPUE are provided in Tables 9 and 10 and plotted in Figures 23 and 24 alongside the index used in the previous assessment (SEDAR 15AU). Trends in both standardized indices (CPUE scaled to the mean) are very similar to the scaled nominal mean. The standardized index used in SEDAR 15AU was developed using data from all regions combined and most closely aligns with the SE FL index.

The standardized index for the FL Keys is variable but generally stable around the mean (i.e., 1), but there is a slight increase after 2012 (Figure 23). The standardized index for SE FL is also variable but stable through 2012, however after this time the index significantly increases (Figure 24). As illustrated in Figure 16, this increase is mostly attributed to an increase in discards per unit effort (i.e., contributor) in SE FL. Additionally, interaction plots in Figure 18 suggest that the increase is mostly occurring in inshore waters.

To further understand the differences among these two regions, an exploratory spatial temporal analysis of CPUE by year and interview location shows that in recent years the highest CPUE occurs in the southern Indian River Lagoon, off Jupiter, FL, and in Biscayne Bay (Figure S3). For this analysis, waters fished was assumed to be a proxy for longitude.

Recommendations

As with any fishery dependent CPUE, caution is needed when inferring trends in abundance as changes in angler targeting behavior, fishing techniques, and regulation changes can lead to changes in CPUE that are not reflective of changes in abundance.

If MRIP CPUE indices are to be inputs in a stock assessment model, it is recommended to use the indices from 1991-2022 since a trip (i.e., fishing party) indicator is available only after 1990. Additionally, while there is increased sampling effort after 1990 in both regions, the sampling effort in the FL Keys is reduced from 2000-2012 (Figures 8 and 13).

The increase in CPUE in Southeast FL appears to be driven by discards per unit effort (Figure 16), however length information on discards is sparse and originates from other boat modes (i.e., headboat and charter) that exhibit different retention patterns compared to the private mode. In addition, discards are self-reported by anglers and are not validated. An index of landings only (LPUE) may alleviate these concerns and will likely be stable over time (Figure 16), but indices that rely on landings-only data are even more sensitive to management changes (e.g., minimum size limits, bag limits, closed seasons, etc.). Also changes in retention of an

LPUE index over time (e.g., from changes in the minimum size limit) would need to be accounted for.

Therefore, it is prudent to evaluate the need for any fishery dependent index relative to fishery independent indices designed to monitor changes in abundance. The Reef Fish Census (RVC) fish survey, for instance, could offer an alternative to an MRIP CPUE as it may have similar spatial coverage; however, in Southeast FL the SEFCRI RVC survey was only initiated in 2013 and includes years 2013-2016, 2018, 2021, and 2022.

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Tables

Table 1. Top 10 co-occurring species with mutton snapper on private mode trips in the FL Keys fishing hook and line gear.

Common Name	Number of Trips	Proportion of Trips
Yellowtail Snapper	332	0.52
Gray Snapper	211	0.33
Lane Snapper	153	0.24
Red Grouper	139	0.22
White Grunt	129	0.20
Grunt Family	127	0.20
Blue Runner	78	0.12
Sea Bass Family	73	0.11
Black Grouper	62	0.10
Jolthead Porgy	62	0.10

Table 2. Top 10 co-occurring species with mutton snapper on private mode trips in SE FL fishing hook and line gear.

Common Name	Num Trips	Proportion of Trips
Gray Snapper	789	0.26
Yellowtail Snapper	773	0.26
Blue Runner	588	0.19
Little Tunny	426	0.14
King Mackerel	422	0.14
Gray Triggerfish	352	0.12
White Grunt	348	0.12
Crevalle Jack	334	0.11
Lane Snapper	314	0.10
Red Grouper	295	0.10

Table 3. Number of positive trips per year and covariate for the FL Keys area model. Highlighted years were removed.

Year	Waters Fished		Median Hours Fished			Median Avidity				Number of Contributors				Season	
	Nearshore	Offshore	[0.5,2]	(2,5]	(5,24]	[0,2]	(2,5]	(5,9]	(9,60]	1	2	3	4+	Other	Summer
1981	4	3	NA	5	2	NA	1	2	4	3	2	1	1	4	3
1982	9	NA	1	2	6	2	4	1	2	4	2	2	1	5	4
1983	2	NA	NA	NA	2	NA	1	NA	1	2	NA	NA	NA	2	NA
1984	4	1	NA	5	NA	2	NA	2	1	4	NA	1	NA	3	2
1986	8	3	2	6	3	5	1	2	3	6	1	2	2	8	3
1987	12	6	NA	11	7	6	3	3	6	10	2	3	3	14	4
1988	2	NA	NA	2	NA	NA	NA	NA	2	2	NA	NA	NA	2	NA
1989	5	2	3	1	3	NA	2	NA	5	4	2	1	NA	4	3
1990	5	1	1	3	2	2	1	1	2	3	NA	3	NA	5	1
1991	10	6	NA	10	6	8	3	2	3	1	7	3	5	9	7
1992	10	6	1	7	8	4	3	2	7	5	6	2	3	4	12
1993	20	5	2	16	7	5	6	2	12	5	6	8	6	18	7
1994	18	1	3	12	4	6	3	2	8	1	7	8	3	12	7
1995	11	6	1	10	6	3	2	4	8	NA	6	6	5	10	7
1996	11	4	NA	5	10	2	4	4	5	1	3	6	5	9	6
1997	18	2	1	14	5	4	5	2	9	1	8	6	5	15	5
1998	17	1	4	11	3	10	2	NA	6	2	8	4	4	16	2
1999	10	4	2	8	4	3	4	2	5	3	5	4	2	10	4
2000	NA	2	NA	1	1	NA	1	NA	1	NA	NA	NA	2	NA	2
2001	3	NA	NA	1	2	1	1	1	NA	1	1	NA	1	2	1
2002	3	5	4	2	2	3	1	1	3	3	1	2	2	7	1
2003	8	10	1	9	8	5	6	3	4	1	11	5	1	11	7
2004	2	2	NA	2	2	1	1	1	1	1	2	NA	1	2	2
2005	2	1	1	1	1	2	NA	NA	1	NA	NA	NA	3	3	NA
2006	4	3	2	2	3	2	1	2	2	NA	3	3	1	6	1
2007	6	11	3	10	4	5	3	6	3	4	3	5	5	5	12
2008	7	13	4	12	4	9	4	3	4	3	9	3	5	11	9
2009	3	4	1	6	NA	2	2	1	2	NA	6	NA	1	5	2
2010	3	3	NA	4	2	2	NA	1	3	1	1	3	1	2	4
2011	2	2	NA	2	2	2	2	NA	NA	2	1	NA	1	3	1
2012	4	4	3	4	1	4	NA	3	1	1	3	1	3	5	3
2013	16	11	6	16	5	7	3	5	12	4	16	5	2	10	17
2014	22	13	3	23	9	12	6	4	13	5	7	12	11	20	15
2015	17	12	3	15	11	8	8	6	7	5	10	11	3	21	8
2016	17	16	3	22	8	3	10	8	12	11	11	8	3	21	12
2017	24	13	6	19	12	16	7	6	8	12	13	10	2	21	16
2018	21	7	5	19	4	12	6	5	5	2	10	9	7	16	12
2019	28	7	3	22	10	9	7	6	13	8	16	4	7	29	6
2020	18	13	5	18	8	5	8	7	11	7	11	4	9	21	10
2021	19	10	7	14	8	12	7	2	8	9	13	2	5	12	17
2022	15	6	4	11	6	10	7	2	2	8	8	4	1	8	13

Table 4. Number of positive trips per year and covariate for the SE FL area model. Highlighted years were removed.

Year	Waters Fished			Median Hours Fished			Median Avidity				Number of Contributors				Season	
	Inshore	Nearshore	Offshore	[0.5,2]	(2,5]	(5,24]	[0,2]	(2,5]	(5,9]	(9,60]	1	2	3	4+	Other	Summer
1981	2	2	1	NA	3	2	2	2	NA	1	4	NA	1	NA	1	4
1982	2	7	5	2	11	1	3	2	NA	9	6	6	2	NA	2	12
1983	5	2	5	NA	3	9	2	1	5	4	7	2	3	NA	NA	12
1984	2	4	4	3	3	4	3	NA	4	3	3	4	3	NA	9	1
1985	5	NA	1	NA	4	2	NA	NA	2	4	6	NA	NA	NA	5	1
1986	5	11	11	6	17	4	5	5	6	11	27	NA	NA	NA	13	14
1987	7	5	10	4	12	6	4	5	8	5	19	1	NA	2	9	13
1988	NA	6	4	NA	6	4	4	2	3	1	10	NA	NA	NA	5	5
1989	4	14	18	5	19	12	5	4	9	18	36	NA	NA	NA	10	26
1990	4	15	9	2	19	7	5	3	13	7	25	1	1	1	12	16
1991	3	14	11	3	15	10	6	6	8	8	9	12	6	1	9	19
1992	15	36	14	13	34	18	16	15	18	16	21	29	13	2	26	39
1993	20	35	12	3	41	23	15	12	20	20	25	25	14	3	29	38
1994	16	20	15	6	27	18	13	10	10	18	16	26	6	3	25	26
1995	2	12	13	5	12	10	8	5	12	2	11	9	7	NA	15	12
1996	11	12	8	2	22	7	9	12	5	5	4	17	7	3	18	13
1997	13	10	16	3	22	14	8	9	11	11	7	23	6	3	17	22
1998	34	23	17	8	47	19	13	23	20	18	25	27	15	7	32	42
1999	20	32	13	4	34	27	11	20	19	15	20	24	18	3	36	29
2000	10	33	33	9	43	24	12	17	26	21	32	27	11	6	44	32
2001	12	31	26	5	43	21	16	7	21	25	22	26	12	9	20	49
2002	32	59	41	6	85	41	30	32	33	37	29	57	35	11	47	85
2003	18	37	16	6	36	29	17	17	11	26	16	32	14	9	34	37
2004	17	46	17	8	49	23	30	17	14	19	14	33	17	16	43	37
2005	23	72	23	10	79	29	29	23	25	41	26	43	30	19	46	72
2006	51	77	29	16	105	36	44	39	25	49	29	60	41	27	69	88
2007	55	84	21	20	104	36	31	32	54	43	28	76	33	23	90	70
2008	40	87	29	12	103	41	41	43	42	30	32	65	43	16	58	98
2009	33	58	17	7	66	35	22	29	44	13	13	58	23	14	50	58
2010	17	62	13	7	67	18	11	16	33	32	15	35	30	12	32	60
2011	12	27	5	3	28	13	7	10	16	11	11	23	7	3	20	24
2012	25	28	17	3	40	27	25	19	16	10	13	33	17	7	35	35
2013	37	39	12	12	46	30	20	25	22	21	16	39	24	9	36	52
2014	37	51	25	9	57	47	26	33	26	28	27	48	29	9	52	61
2015	44	56	23	9	71	43	35	35	22	31	26	53	24	20	48	75
2016	31	29	29	5	49	35	34	25	15	15	23	40	16	10	36	53
2017	32	33	27	10	60	22	33	23	22	14	26	45	16	5	35	57
2018	16	33	17	4	39	23	24	17	11	14	12	29	17	8	16	50
2019	26	33	24	7	51	25	41	14	16	12	27	32	19	5	32	51
2020	21	30	14	6	41	18	13	17	14	21	25	26	11	3	40	25
2021	39	48	37	11	69	44	39	31	26	28	46	47	20	11	58	66
2022	51	64	56	13	88	70	48	48	42	33	65	74	26	6	70	101

Table 5. Deviance table for the final positive sub-model for the FL Keys area model.

Factor	Df	Resid. Df	Resid. Dev	Deviance	% Deviance Reduced	Family	Dispersion
NULL	1	613	566.52	566.52	-		
year	32	581	515.87	50.66	3.93		
waters	1	580	509.46	6.41	1.03	Gaussian	0.88

Table 6. Deviance table for the final binomial sub-model for the FL Keys area model

Factor	Df	Resid. Df	Resid. Dev	Deviance	% Deviance Reduced	Family	Dispersion
NULL	1	5002	3725.46	3725.46	-		
Year	32	4970	3657.76	67.69	1.18		
Contributors	3	4967	3626.15	31.61	0.79		
Median Hours Fished	2	4965	3602.74	23.41	0.59	Binomial	1

Table 7. Deviance table for the final positive sub-model for the SE_FL area model.

Factor	Df	Resid. Df	Resid. Dev	Deviance	% Deviance Reduced	Family	Dispersion
NULL	1	2958	2031.06	2031.06	-		
Year	40	2918	1940.81	90.25	3.13		
Median Avidity	3	2915	1922.53	18.28	0.81		
Waters	2	2913	1907.02	15.51	0.71	Gaussian	0.65

Table 8. Deviance table for the final binomial sub-model for the SE_FL area model.

Factor	Df	Resid. Df	Resid. Dev	Deviance	% Deviance Reduced	Family	Dispersion
NULL	1	14495	14671.93	14671.93	-		
Year	40	14455	14208.21	463.72	2.89		
Median Avidity	3	14452	14093.70	114.51	0.76	Binomial	1

Table 9. Nominal mean CPUE and final modeled index for the FL Keys area model.

Year	Num Trips	Num Pos	Prop Positive	Nominal Mean	Nominal CV	Standardized Index	Index CV
1981	48	7	0.146	0.321	3.445	1.844	0.524
1982	97	9	0.093	0.142	4.2	0.849	0.477
1986	67	11	0.164	0.234	2.986	1.584	0.41
1987	182	18	0.099	0.355	5.362	1.538	0.324
1989	101	7	0.069	0.175	5.13	1.071	0.525
1990	91	6	0.066	0.106	4.926	0.696	0.595
1991	118	16	0.136	0.271	3.977	1.048	0.343
1992	173	16	0.092	0.22	5.92	1.01	0.343
1993	247	25	0.101	0.214	4.873	0.918	0.272
1994	225	19	0.084	0.094	5.112	0.451	0.32
1995	148	17	0.115	0.163	5.433	0.689	0.333
1996	220	15	0.068	0.114	4.907	0.497	0.355
1997	222	20	0.09	0.24	6.618	0.689	0.315
1998	154	18	0.117	0.461	4.65	1.553	0.321
1999	160	14	0.088	0.206	4.925	0.903	0.376
2002	58	8	0.138	0.099	2.688	0.803	0.48
2003	108	18	0.167	0.18	3.367	0.964	0.32
2006	64	7	0.109	0.227	4.23	1.102	0.522
2007	93	17	0.183	0.185	2.83	1.079	0.323
2008	96	20	0.208	0.177	2.502	1.14	0.3
2009	52	7	0.135	0.111	3.017	0.757	0.524
2010	48	6	0.125	0.057	3.106	0.428	0.575
2012	82	8	0.098	0.092	4.157	0.581	0.492
2013	150	27	0.18	0.453	4.439	1.546	0.255
2014	296	35	0.118	0.116	3.954	0.62	0.225
2015	334	29	0.087	0.093	4.592	0.543	0.256
2016	225	33	0.147	0.247	4.66	1.209	0.235
2017	205	37	0.18	0.22	2.777	1.354	0.217
2018	169	28	0.166	0.15	3.552	0.765	0.256
2019	171	35	0.205	0.292	2.738	1.515	0.224
2020	209	31	0.148	0.264	4.372	1.247	0.238
2021	200	29	0.145	0.255	4.303	1.148	0.25
2022	190	21	0.111	0.167	4.458	0.857	0.295

Table 10. Nominal mean CPUE and final modeled index for the SE FL area model.

Year	Num Trips	Num Pos	Prop Positive	Nominal Mean	Nominal CV	Standardized Index	Index CV
1982	107	14	0.131	0.148	3.080	0.654	0.332
1983	110	12	0.109	0.136	3.783	0.583	0.365
1984	133	10	0.075	0.122	4.030	0.578	0.413
1985	103	6	0.058	0.136	4.377	0.588	0.547
1986	216	27	0.125	0.157	2.959	0.755	0.242
1987	254	22	0.087	0.120	4.276	0.537	0.268
1988	56	10	0.179	0.232	2.463	1.297	0.387
1989	271	36	0.133	0.203	3.469	0.831	0.209
1990	231	28	0.121	0.148	3.109	0.664	0.240
1991	238	28	0.118	0.139	3.503	0.588	0.238
1992	355	65	0.183	0.272	5.497	0.821	0.154
1993	347	67	0.193	0.360	3.616	1.211	0.147
1994	280	51	0.182	0.250	3.395	0.887	0.170
1995	239	27	0.113	0.165	4.058	0.613	0.244
1996	266	31	0.117	0.125	3.297	0.537	0.221
1997	294	39	0.133	0.173	3.559	0.628	0.200
1998	400	74	0.185	0.254	3.359	0.877	0.143
1999	591	65	0.110	0.124	3.795	0.492	0.156
2000	409	76	0.186	0.293	3.090	1.039	0.139
2001	391	69	0.176	0.220	3.165	0.851	0.145
2002	538	132	0.245	0.330	4.118	1.034	0.103
2003	562	71	0.126	0.135	3.523	0.517	0.148
2004	487	80	0.164	0.156	2.986	0.659	0.136
2005	462	118	0.255	0.367	2.993	1.242	0.110
2006	657	157	0.239	0.283	3.106	0.912	0.095
2007	626	160	0.256	0.367	3.737	1.171	0.095
2008	602	156	0.259	0.478	4.188	1.429	0.095
2009	461	108	0.234	0.295	2.988	1.034	0.114
2010	402	92	0.229	0.246	2.818	0.851	0.126
2011	319	44	0.138	0.141	4.938	0.502	0.188
2012	455	70	0.154	0.129	3.148	0.573	0.146
2013	376	88	0.234	0.272	3.686	0.927	0.127
2014	572	113	0.198	0.305	3.738	0.973	0.113
2015	526	123	0.234	0.313	3.083	1.044	0.108
2016	333	89	0.267	0.434	3.187	1.622	0.125
2017	311	92	0.296	0.388	2.302	1.556	0.121
2018	241	66	0.274	0.312	2.424	1.262	0.145
2019	204	83	0.407	0.767	2.972	2.215	0.122
2020	216	65	0.301	0.589	3.044	1.916	0.144
2021	380	124	0.326	0.606	2.480	2.139	0.102
2022	475	171	0.360	0.679	2.476	2.392	0.087

Figures

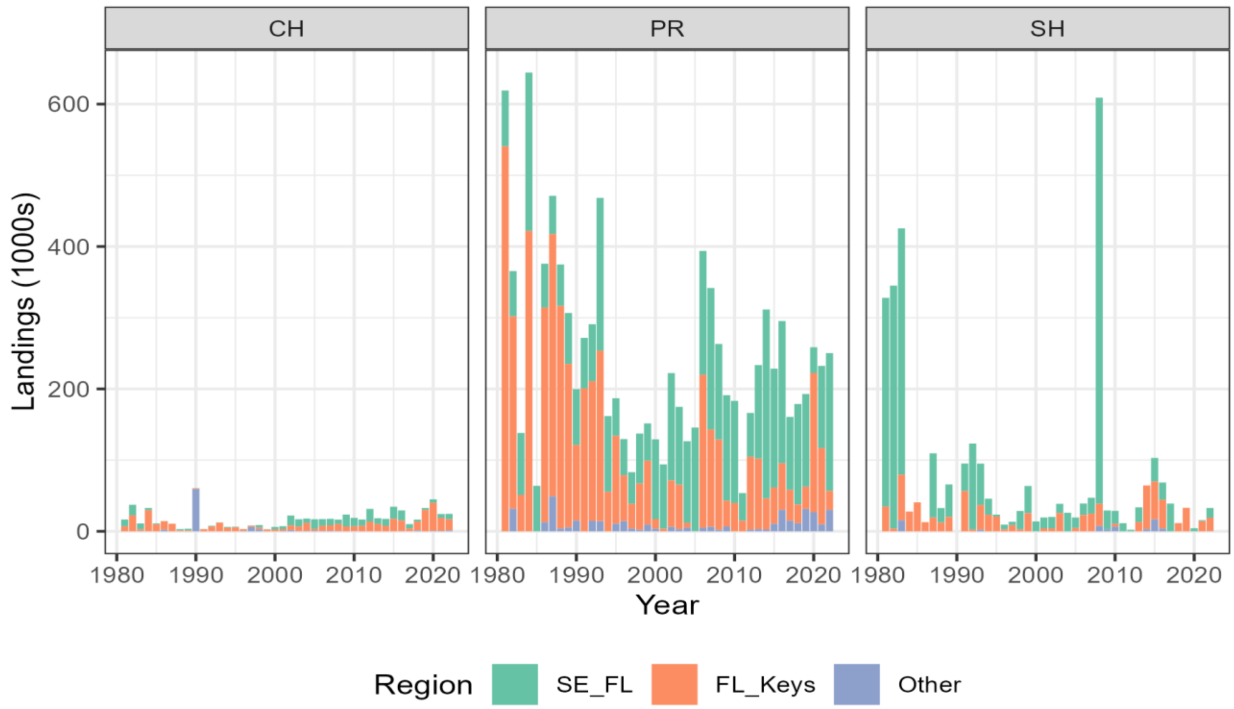

Figure 1. Landings (in 1000s) of Mutton Snapper by fishing mode (Private [PR], Shore [SH], and Charter [CH]) for each year and region.

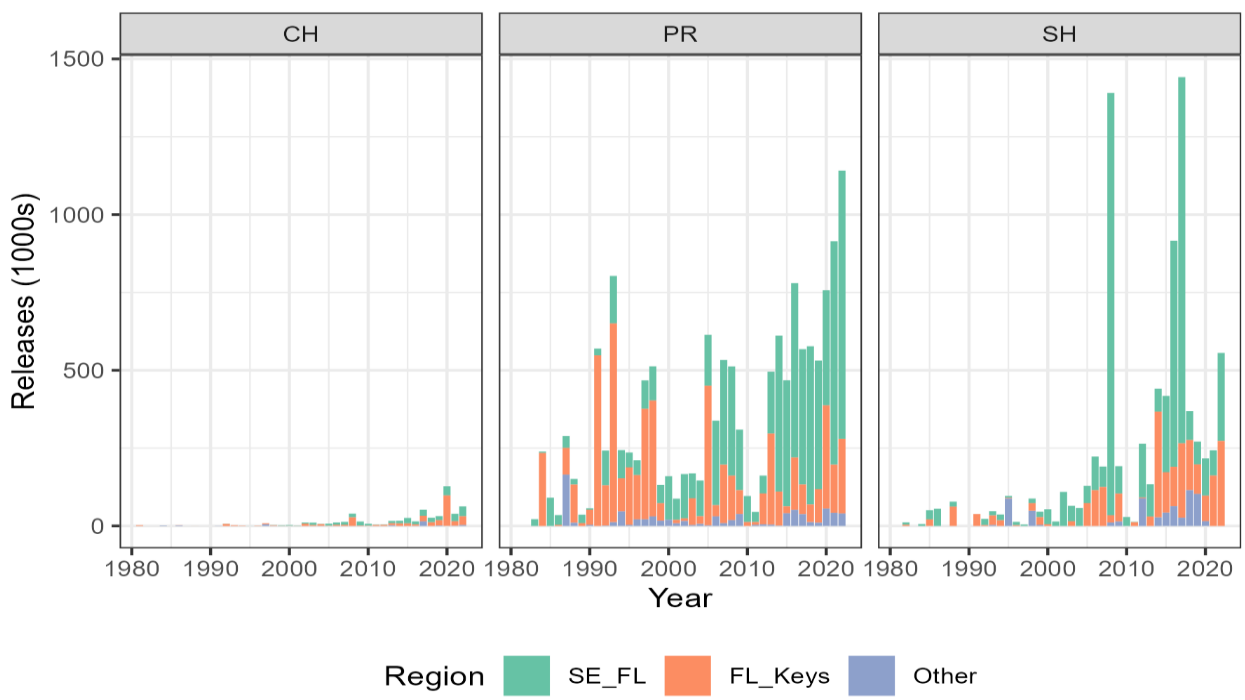

Figure 2. Releases (in 1000s) of Mutton Snapper by year and region by fishing mode (Private [PR], Shore [SH], and Charter [CH]).

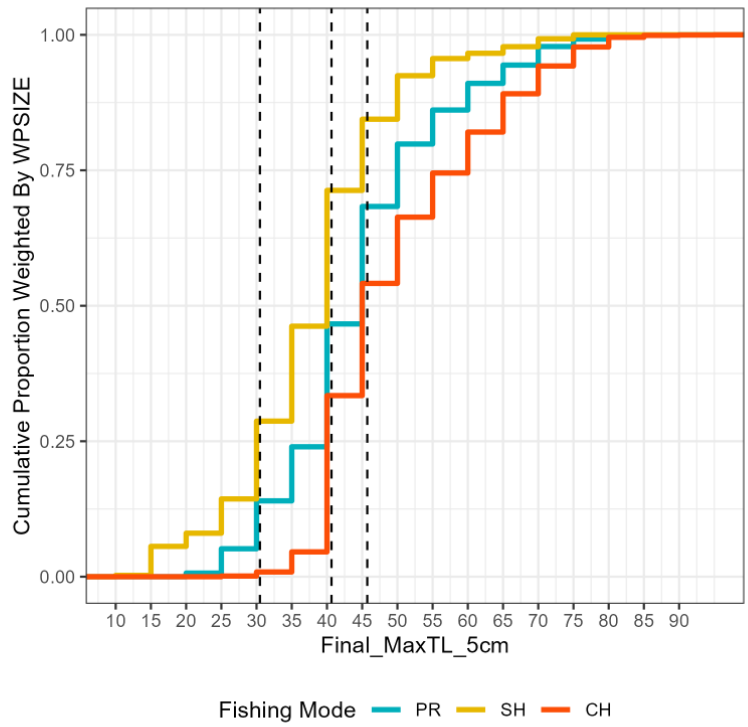

Figure 3. Maximum total lengths in 5 cm bins of landed Mutton Snapper weighted by survey design weights (i.e., WPSIZE) among fishing modes (Private [PR], Shore [SH], and Charter [CH]). Black dotted lines denote minimum size limits in federal waters of the South Atlantic (SAFMC) enacted in 1992 (12 in.), 1995 (16 in.), and 2018 (18 in.).

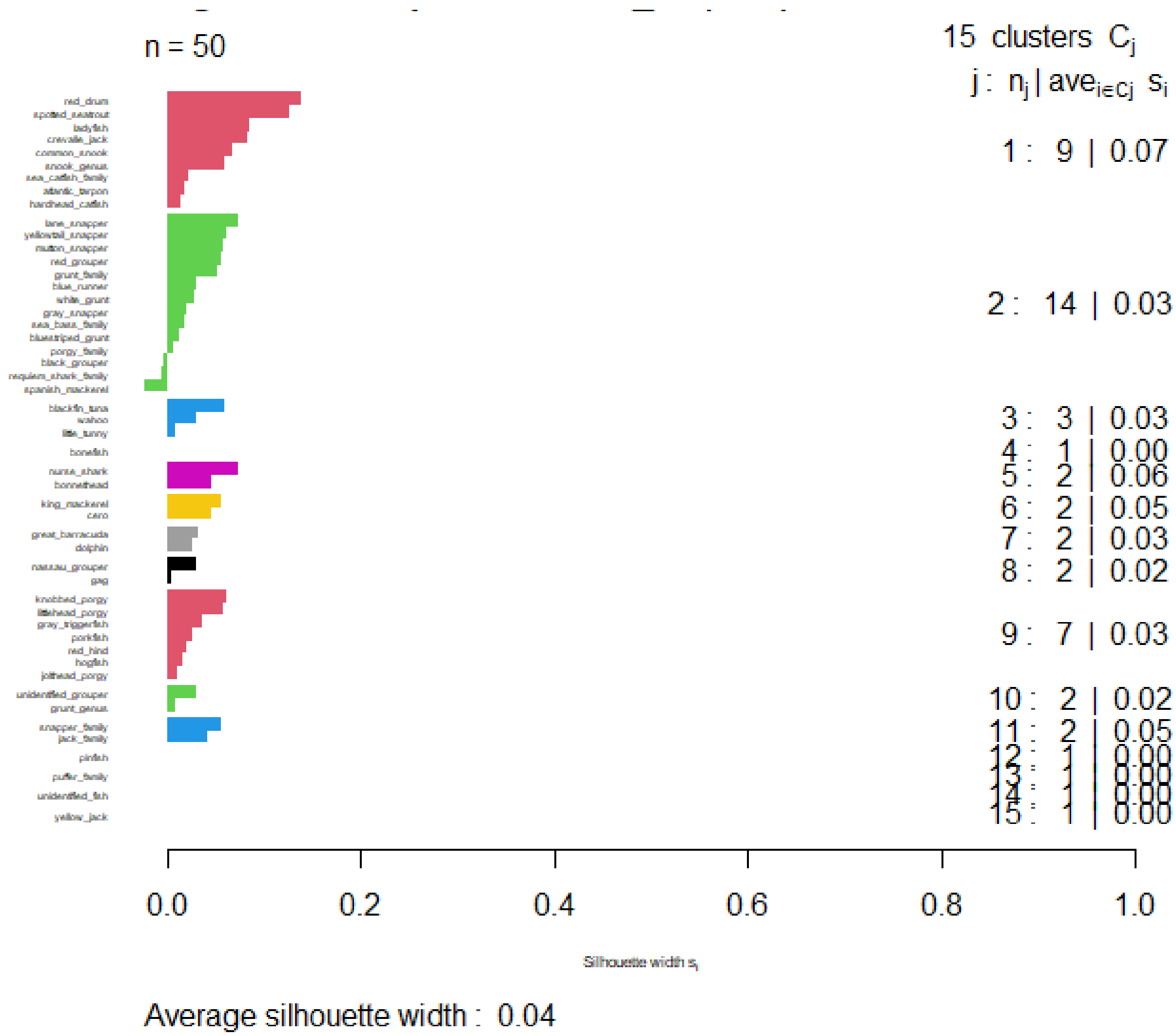

Figure 4. Silhouette widths when maximize average silhouette width of standardized LN(catch + 1) in the FL Keys (private mode, hook and line gear). The cluster identified with Mutton Snapper includes 14 species (green).

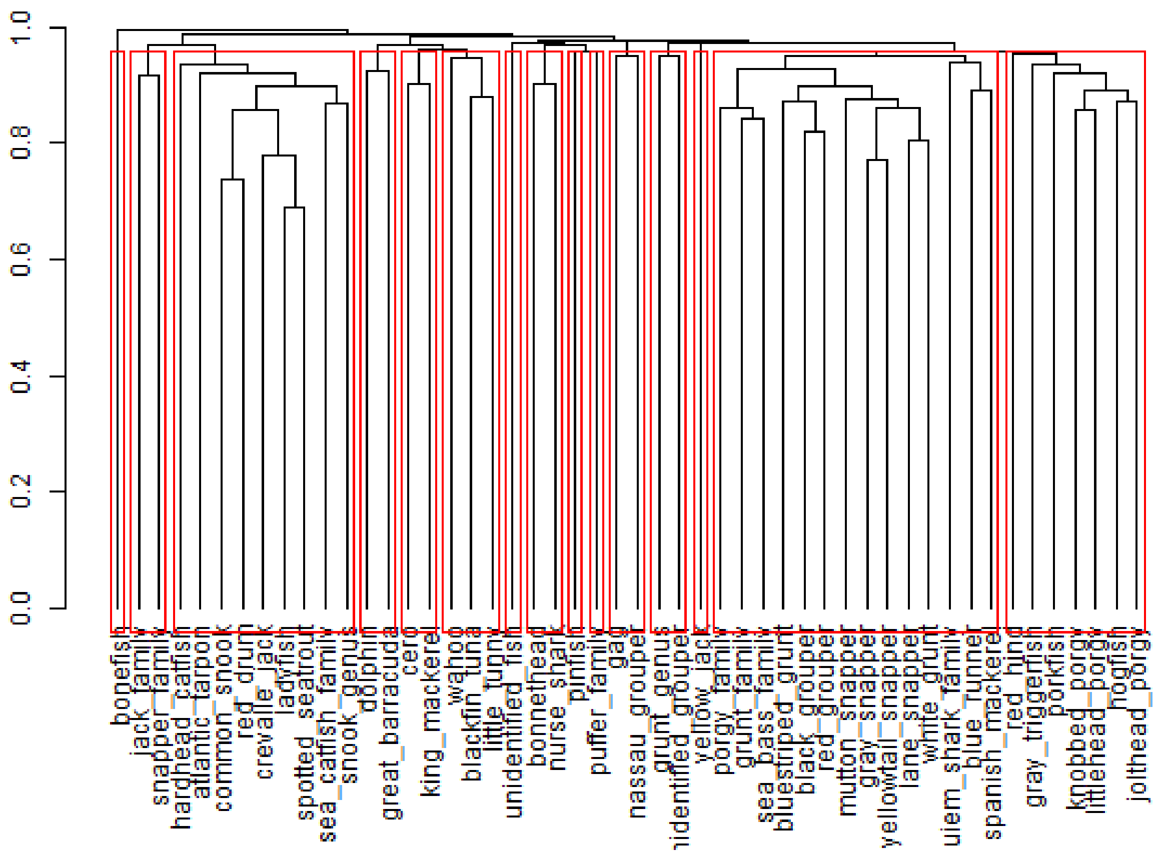

Figure 5. Dendrogram and resulting clusters that maximize average silhouette width of standardized LN(catch + 1) in the FL Keys (private mode, hook and line gear).

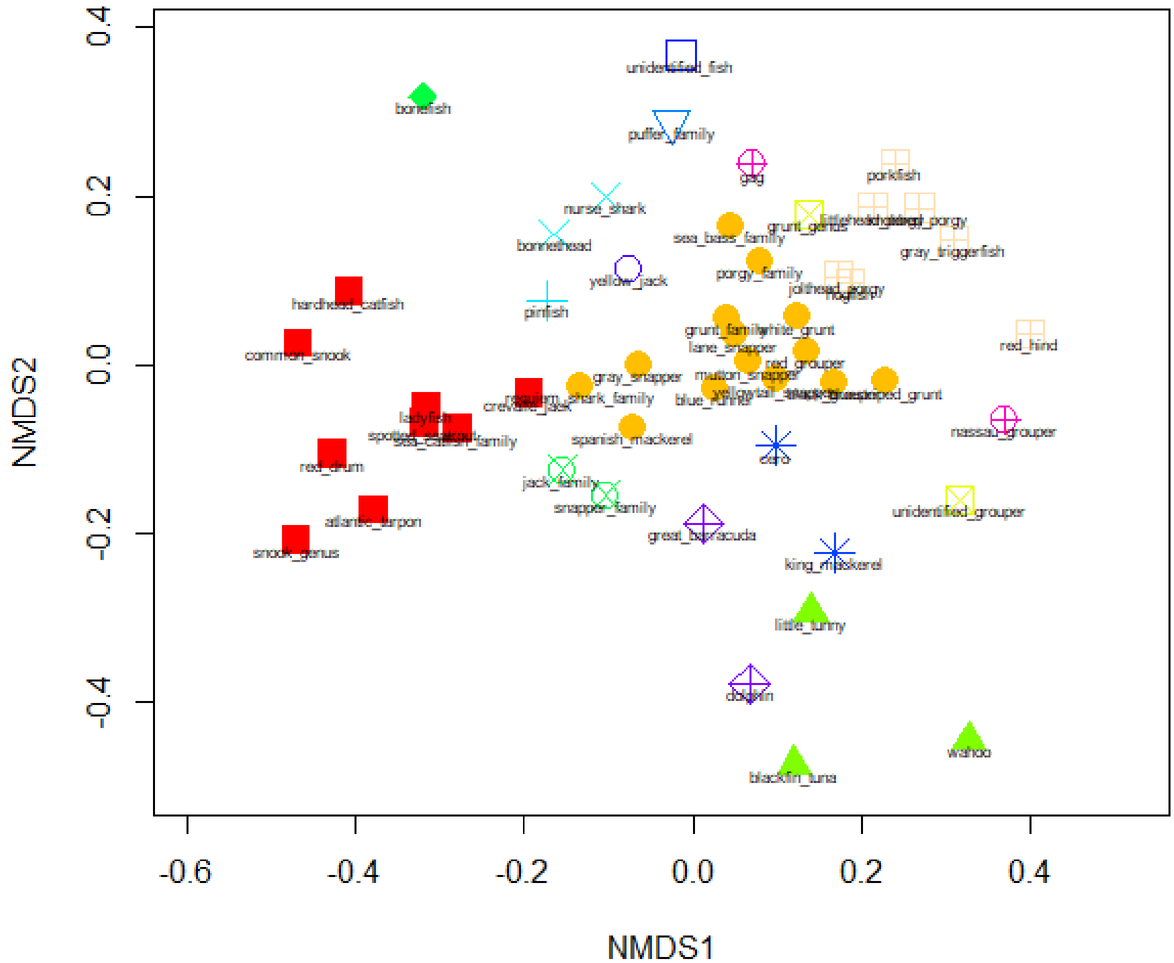

Figure 6. Non-metric Multi-dimensional scaling (NMDS) ordination plot. Point type and color identify clusters resulting in the maximum average silhouette width of standardized LN(catch + 1) in the FL Keys (private mode, hook and line gear).

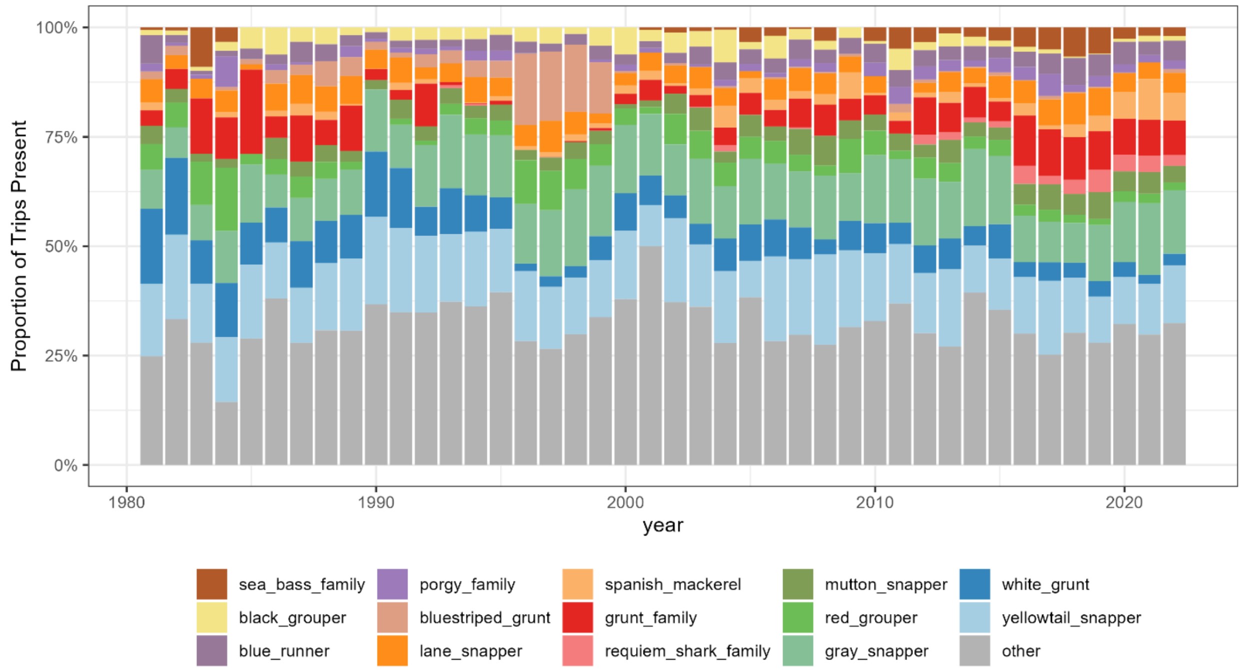

Figure 7. Proportion of trips with species present identified by the clustering method in the FL Keys (private mode, hook and line gear) in addition to all other species ('other').

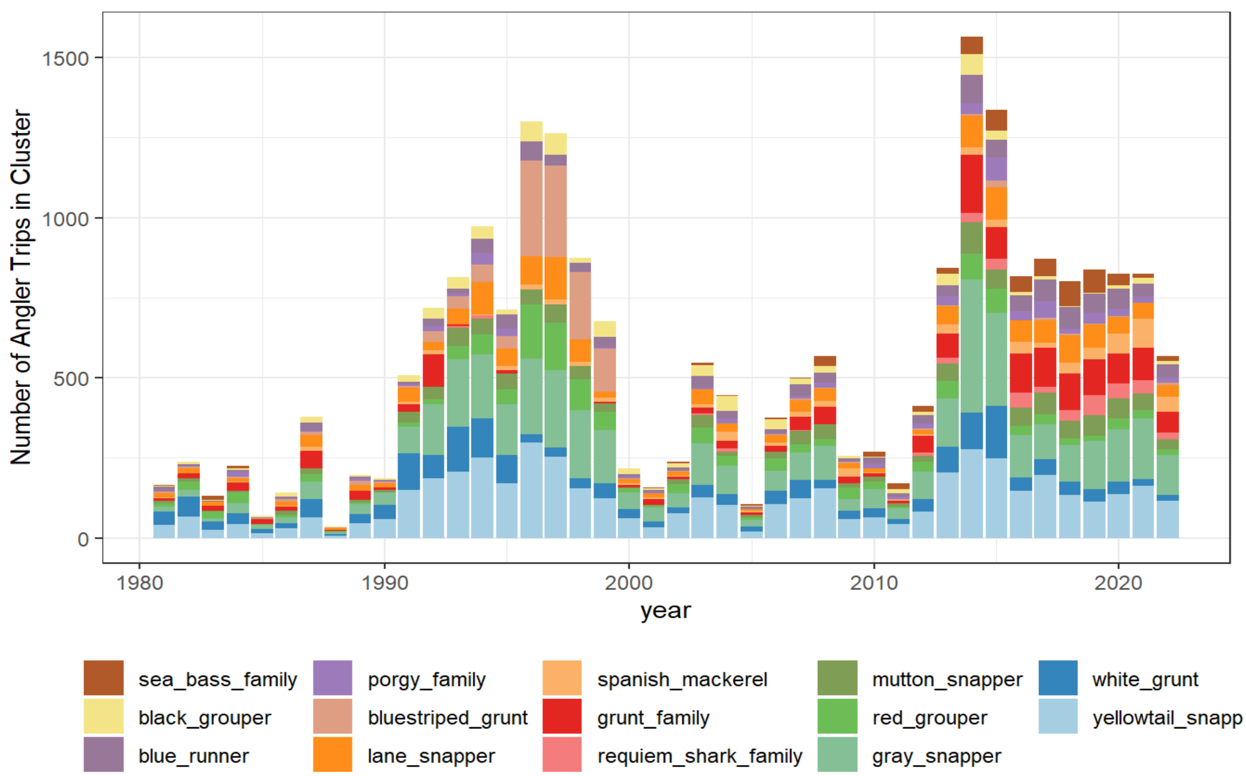

Figure 8. Number of angler trips by species that encountered at least one species identified by the clustering method in the FL Keys (private mode, hook and line gear).

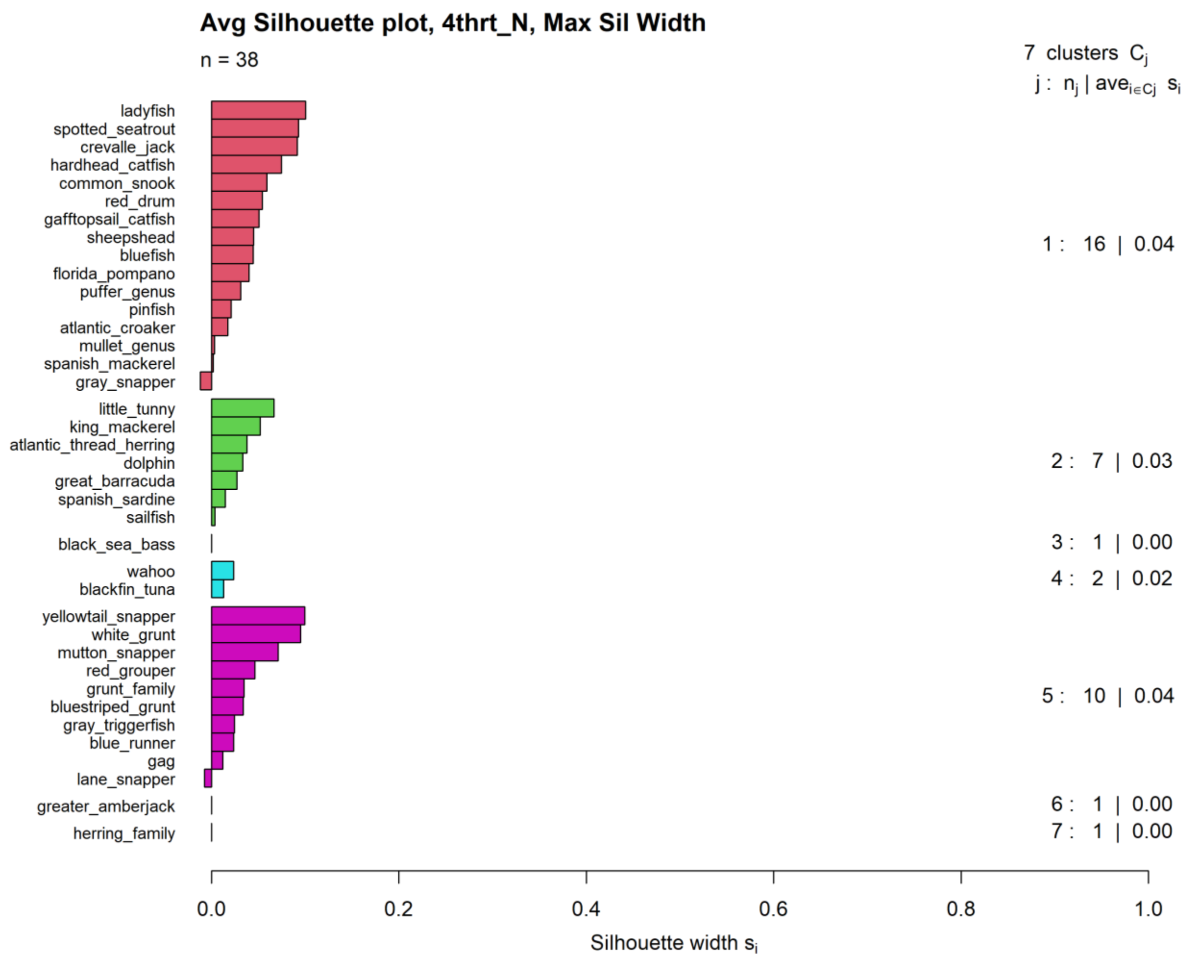

Figure 9. Silhouette widths when maximize average silhouette width of the fourth root of catches (landings + releases) in Southeast FL (private mode, hook and line gear). The cluster identified with Mutton Snapper includes 10 species (purple).

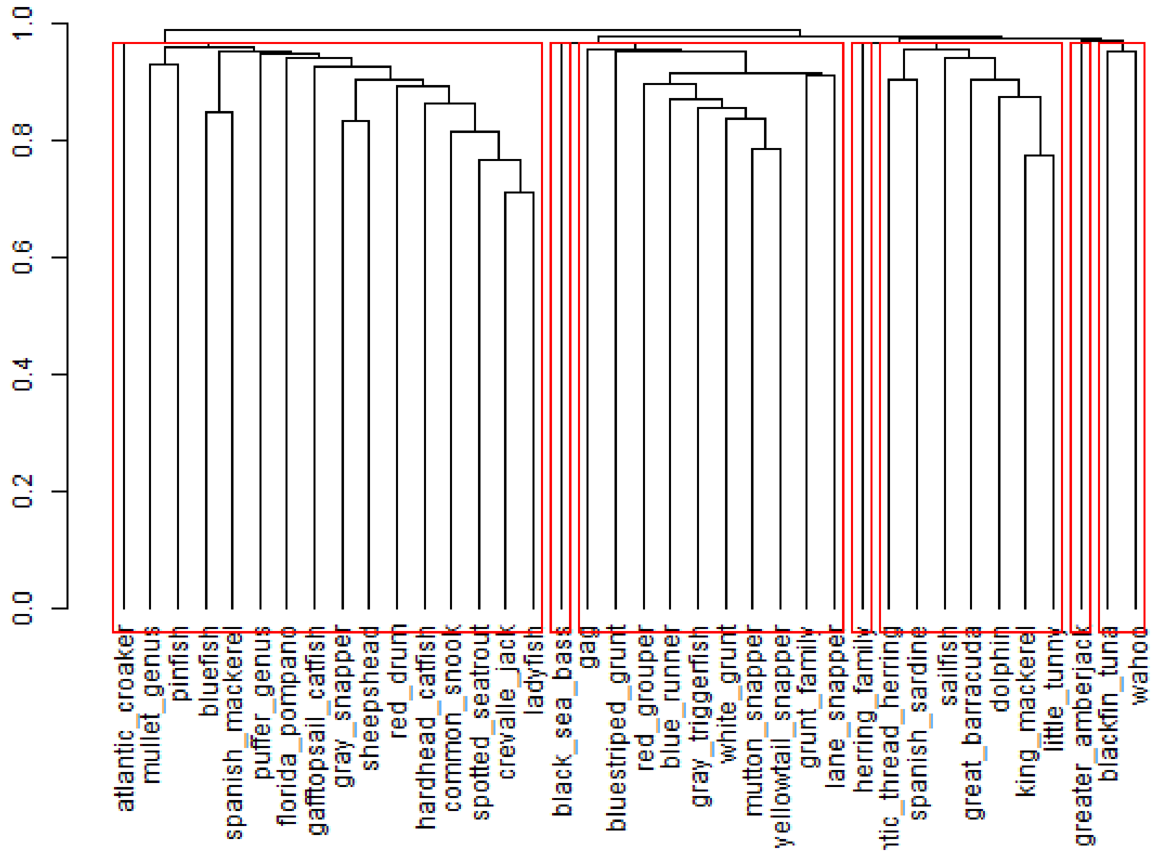

Figure 10. Dendrogram and resulting clusters that maximize average silhouette width of the fourth root of catches (landings + releases) in the Southeast FL (private mode, hook and line ear).

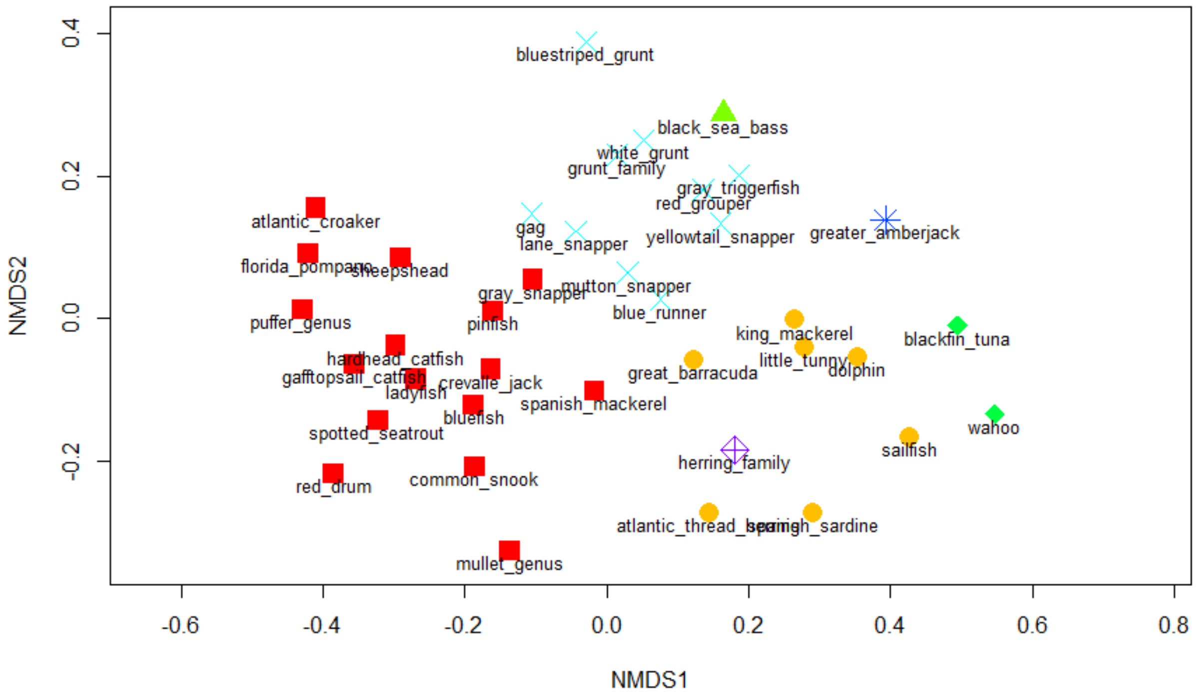

Figure 11. Non-metric Multi-dimensional scaling (NMDS) ordination plot. Point type and color identify clusters resulting in the maximum average silhouette width of fourth root of catches (landings + releases) in Southeast FL (private mode, hook and line gear).

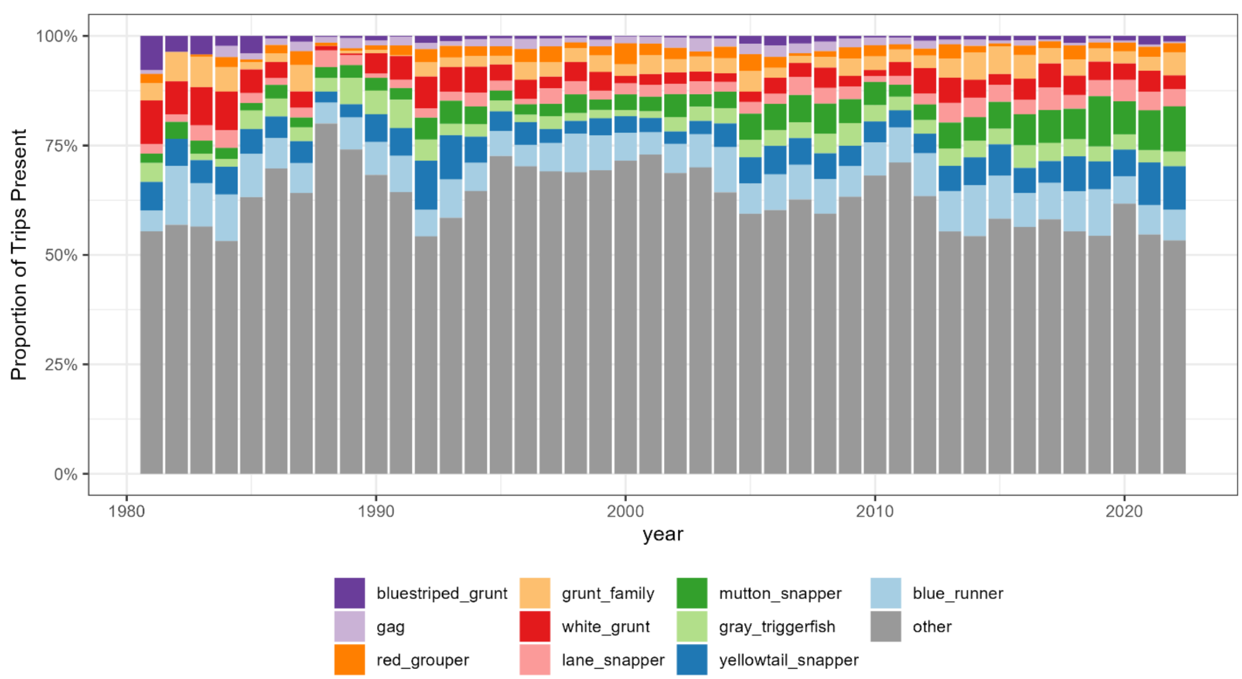

Figure 12. Proportion of trips with species present identified by the clustering method in Southeast FL (private mode, hook and line gear) in addition to all other species (‘other’).

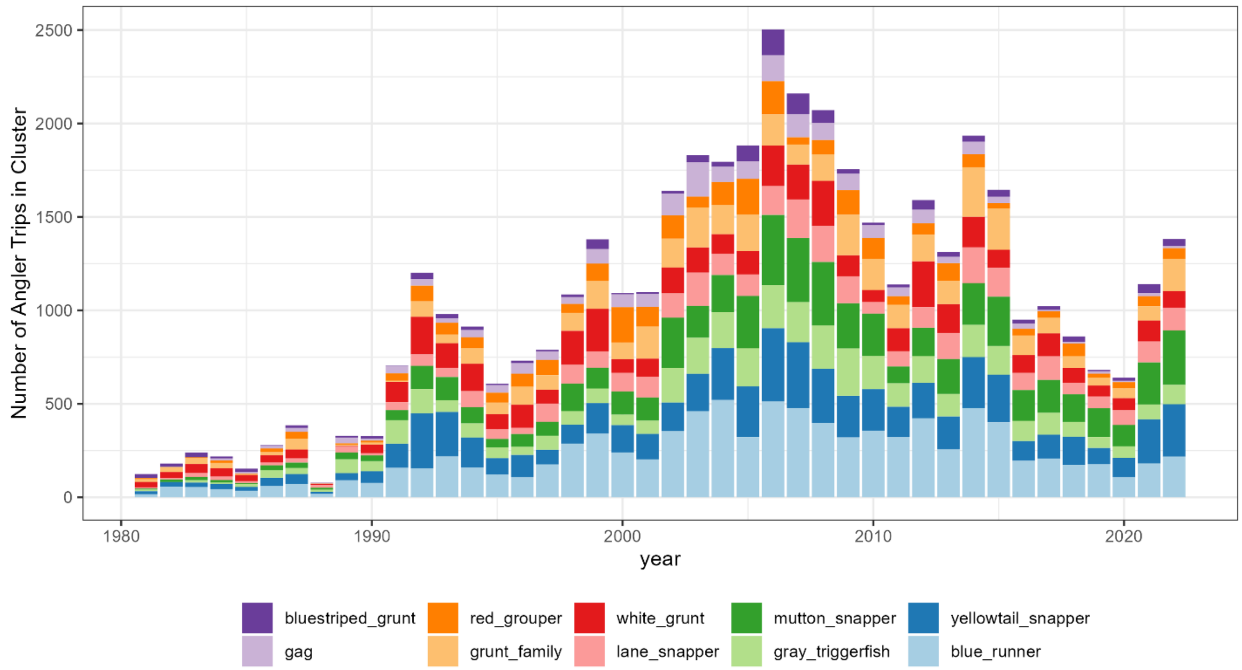

Figure 13. Number of angler trips by species that encountered at least one species identified by the clustering method in Southeast FL (private mode, hook and line gear).

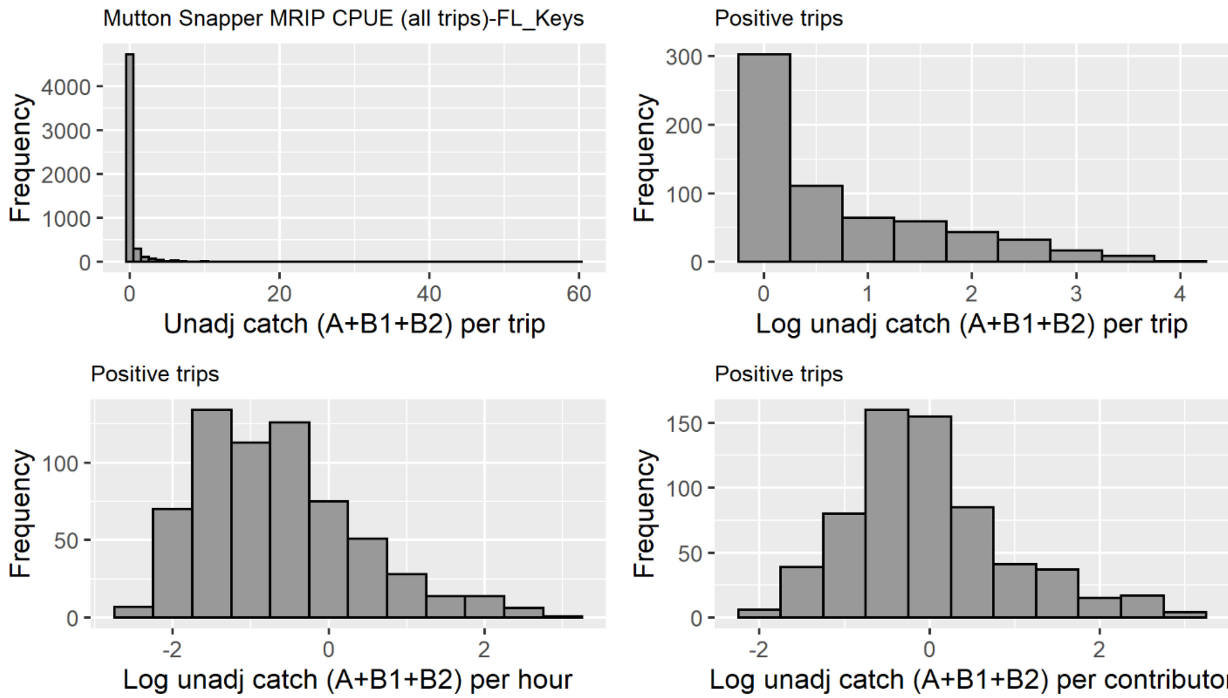

Figure 14. Histograms of mutton snapper unadjusted catch per trip within the species cluster including zeros (top left), log(unadjusted catch per trip) for positive trips (top right), log (unadjusted catch per median hour fished) for positive trips (bottom left), and a histogram of log(unadjusted catch per contributor) for positive trips (bottom right) for the FL Keys (private mode, hook and line gear).

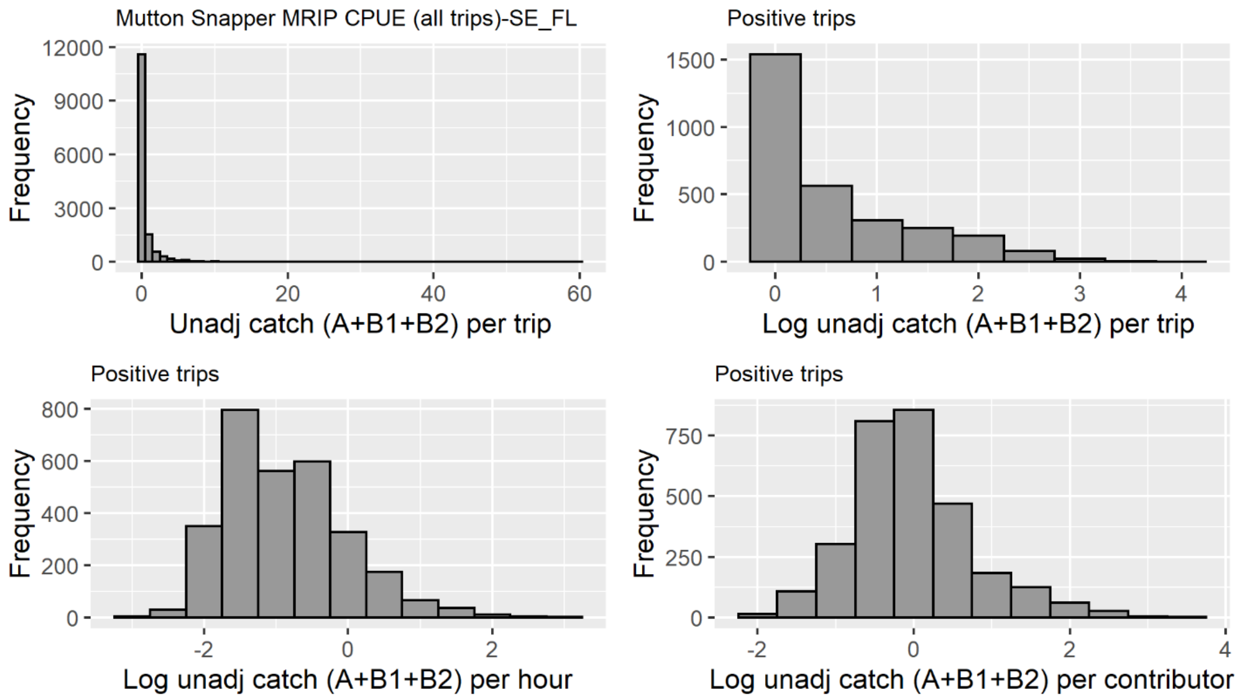

Figure 15. Histograms of mutton snapper unadjusted catch per trip within the species cluster including zeros (top left), log(unadjusted catch per trip) for positive trips (top right), log (unadjusted catch per median hour fished) for positive trips (bottom left), and a histogram of log(unadjusted catch per contributor) for positive trips (bottom right) for Southeast FL (private mode, hook and line gear).

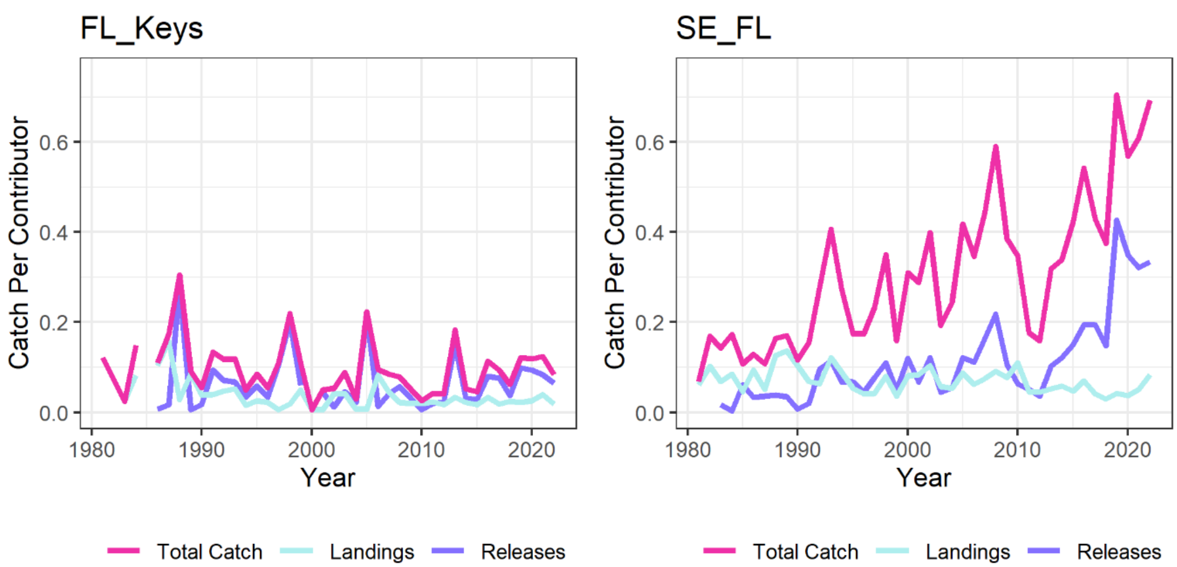

Figure 16. A comparison of mean nominal unadjusted total catch per contributor (magenta), landings per contributor (light blue), and releases per contributor (dark blue) among regions.

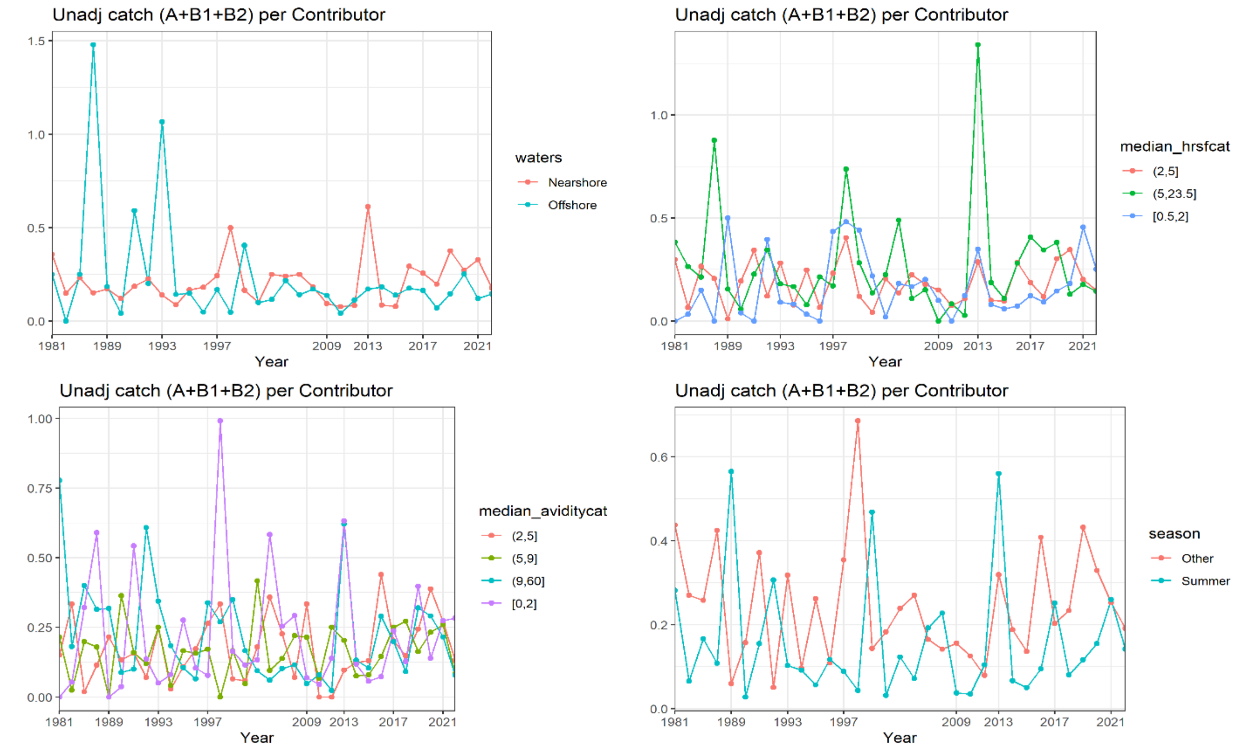

Figure 17. Interaction plots between year and considered covariates for the FL Keys using mean unadjusted catch per contributor.

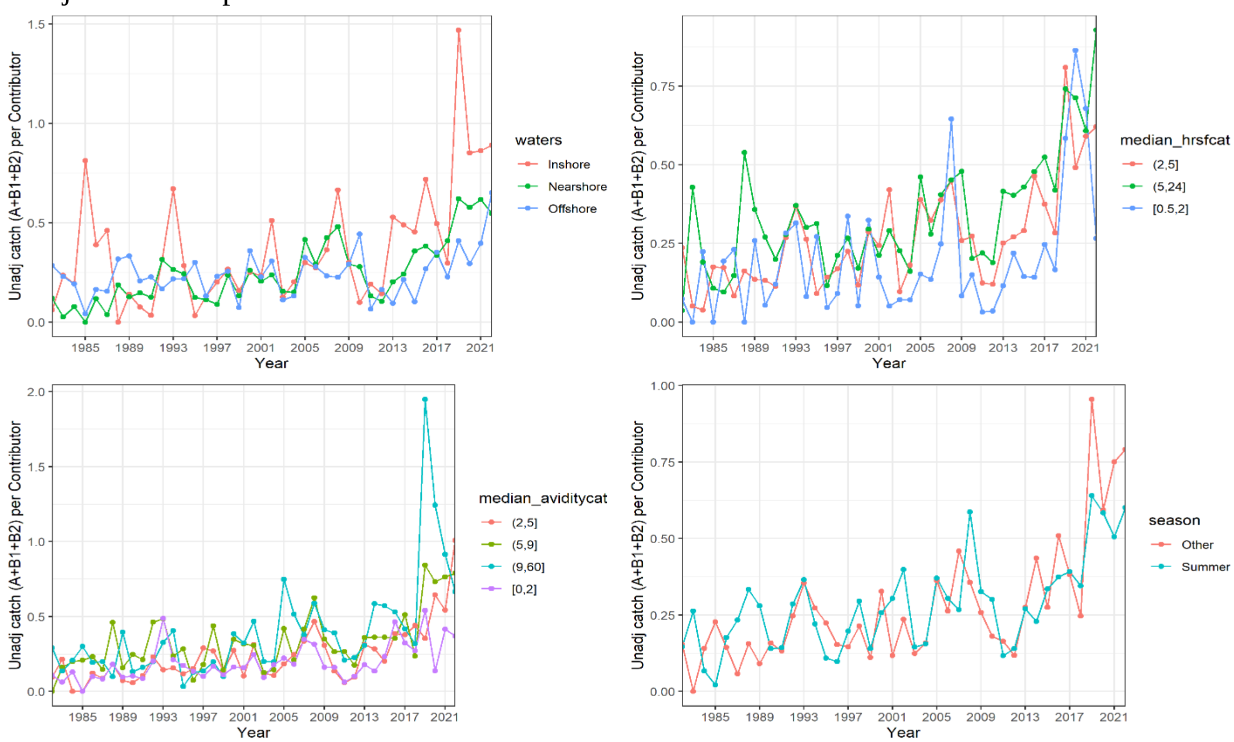

Figure 18. Interaction plots between year and considered covariates for SE FL using mean unadjusted catch per contributor.

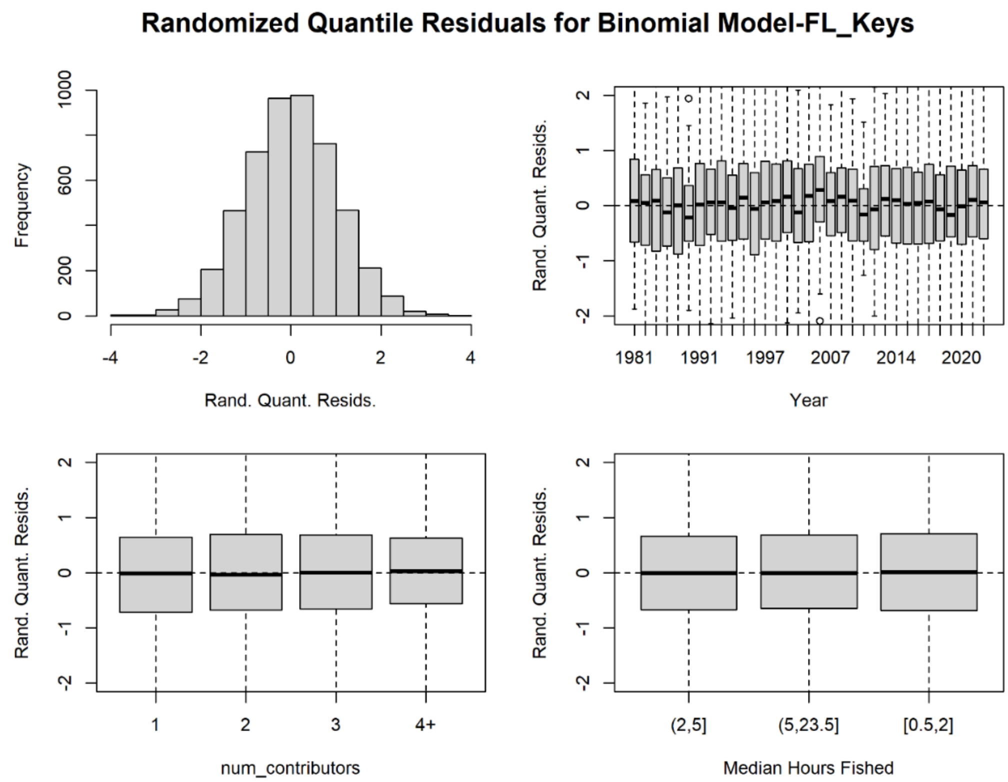

Figure 19. Randomized quantile residuals for the FL Keys Binomial Model.

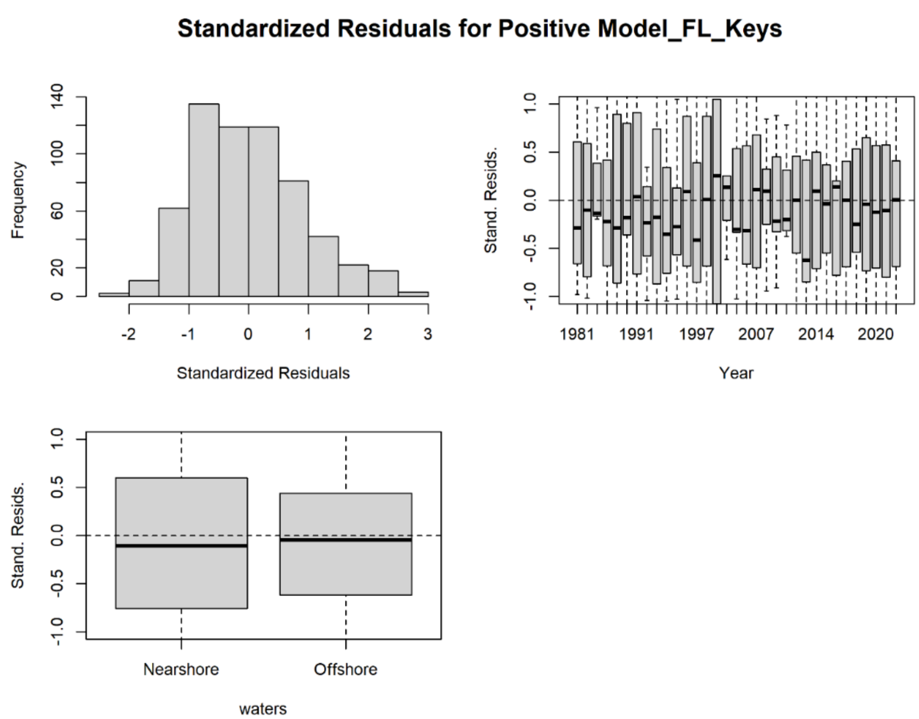

Figure 20. Standardized Pearson residuals for the FL Keys Positive Model.

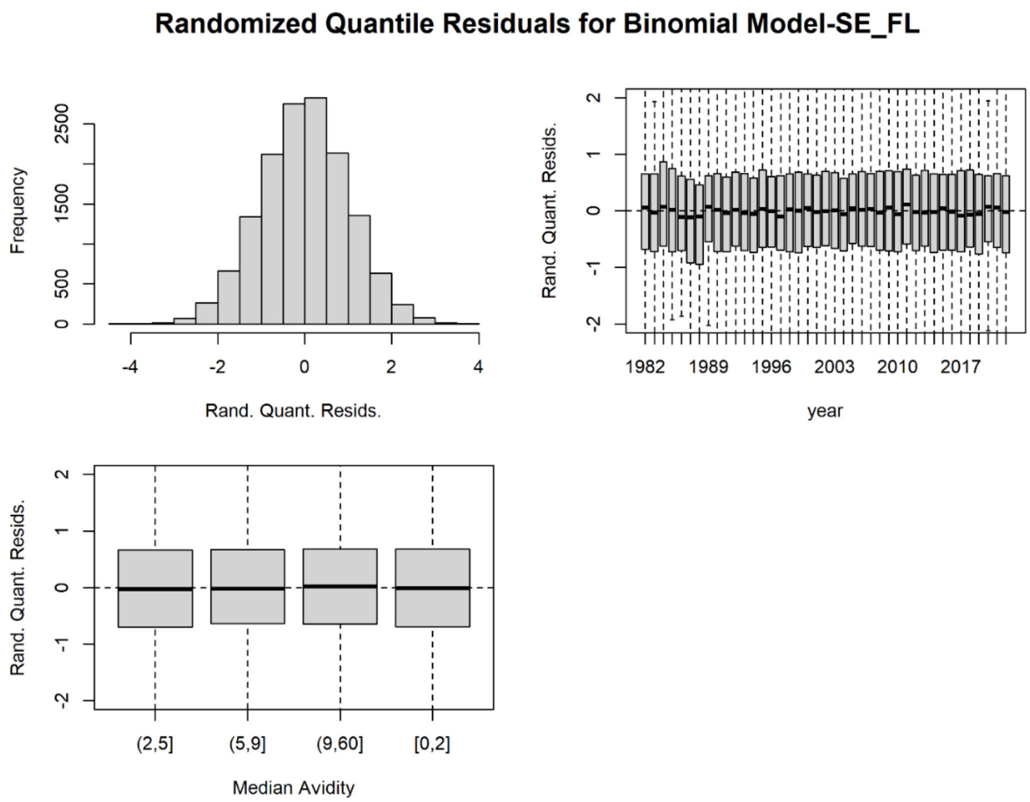

Figure 21. Randomized quantile residuals for the SE FL Binomial Model.

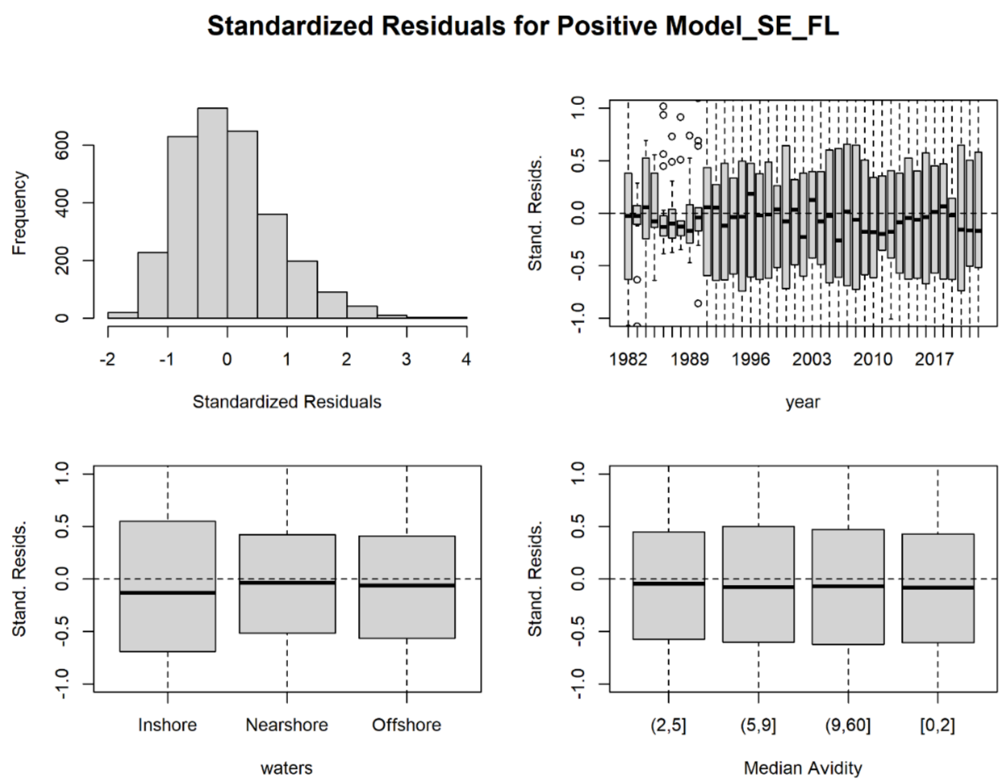

Figure 22. Standardized Pearson residuals for the SE FL Positive Model.

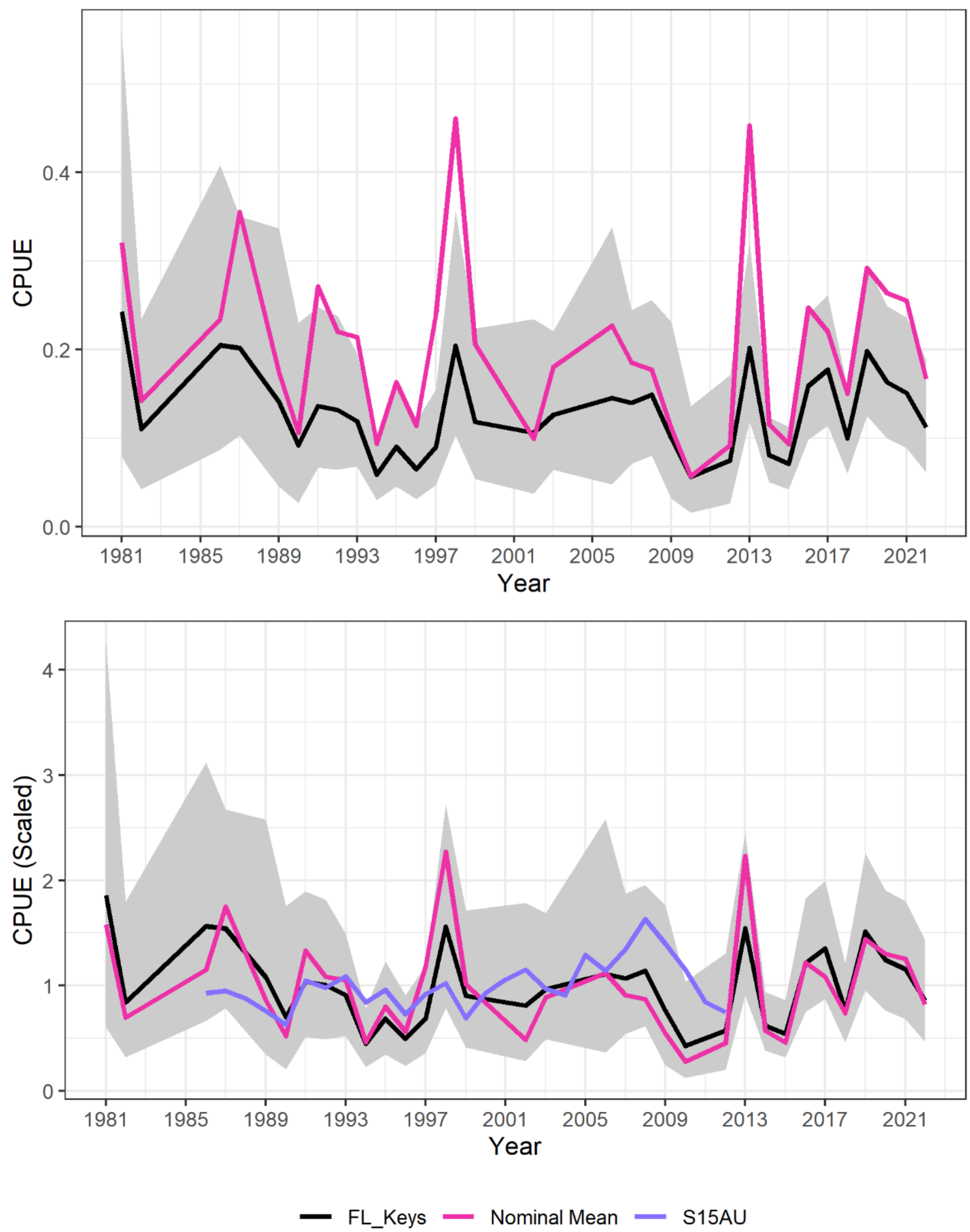

Figure 23. Standardized MRIP catch rate index (black line) of FL Keys mutton snapper with 95% confidence intervals (grey ribbon), along with the nominal CPUE (magenta line) and CPUE from SEDAR 15AU (all regions combined).

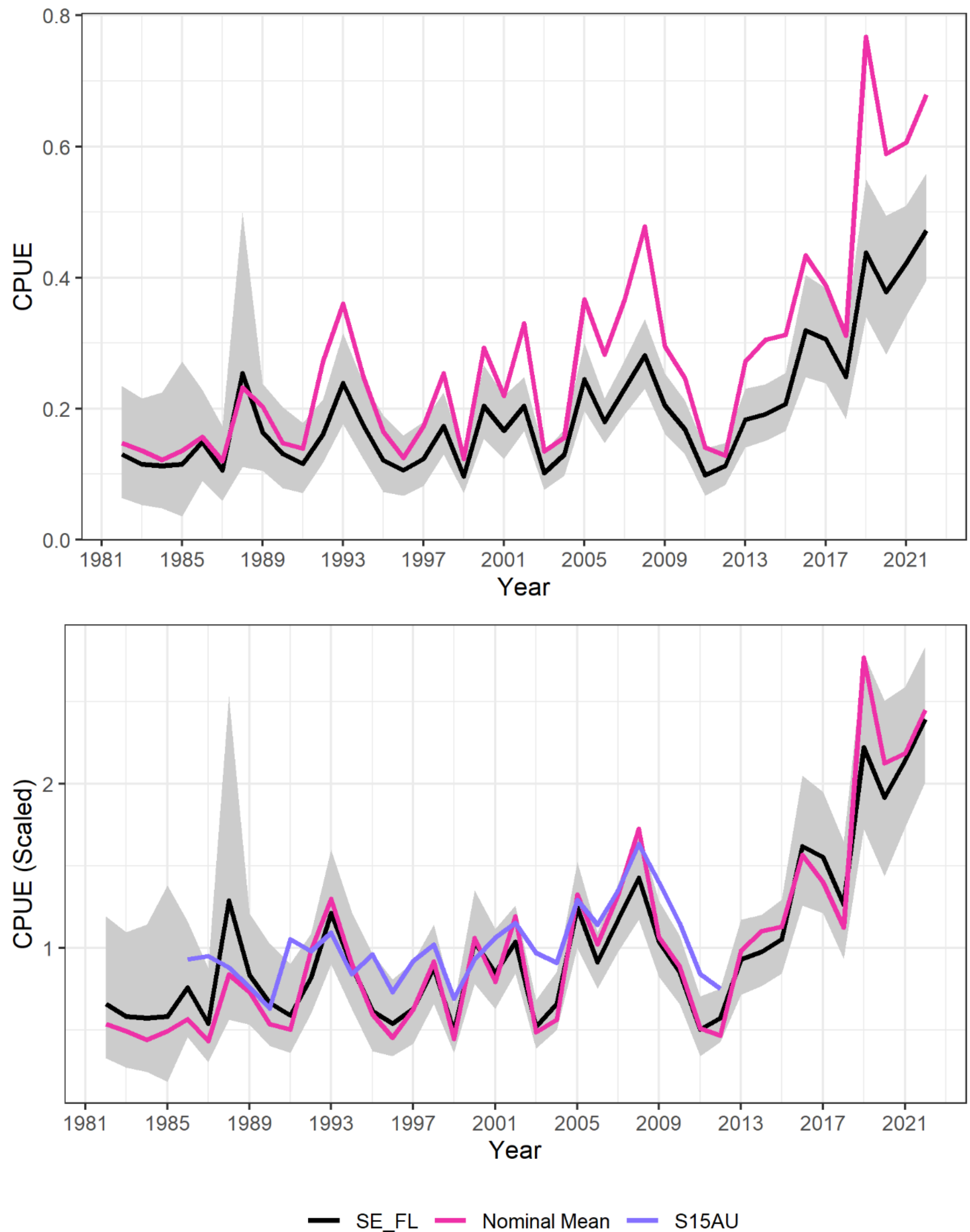

Figure 24. Standardized MRIP catch rate index (black line) of SE FL mutton snapper with 95% confidence intervals (grey ribbon), along with the nominal CPUE (magenta line) and CPUE from SEDAR 15AU (all regions combined).

Supplementary Materials

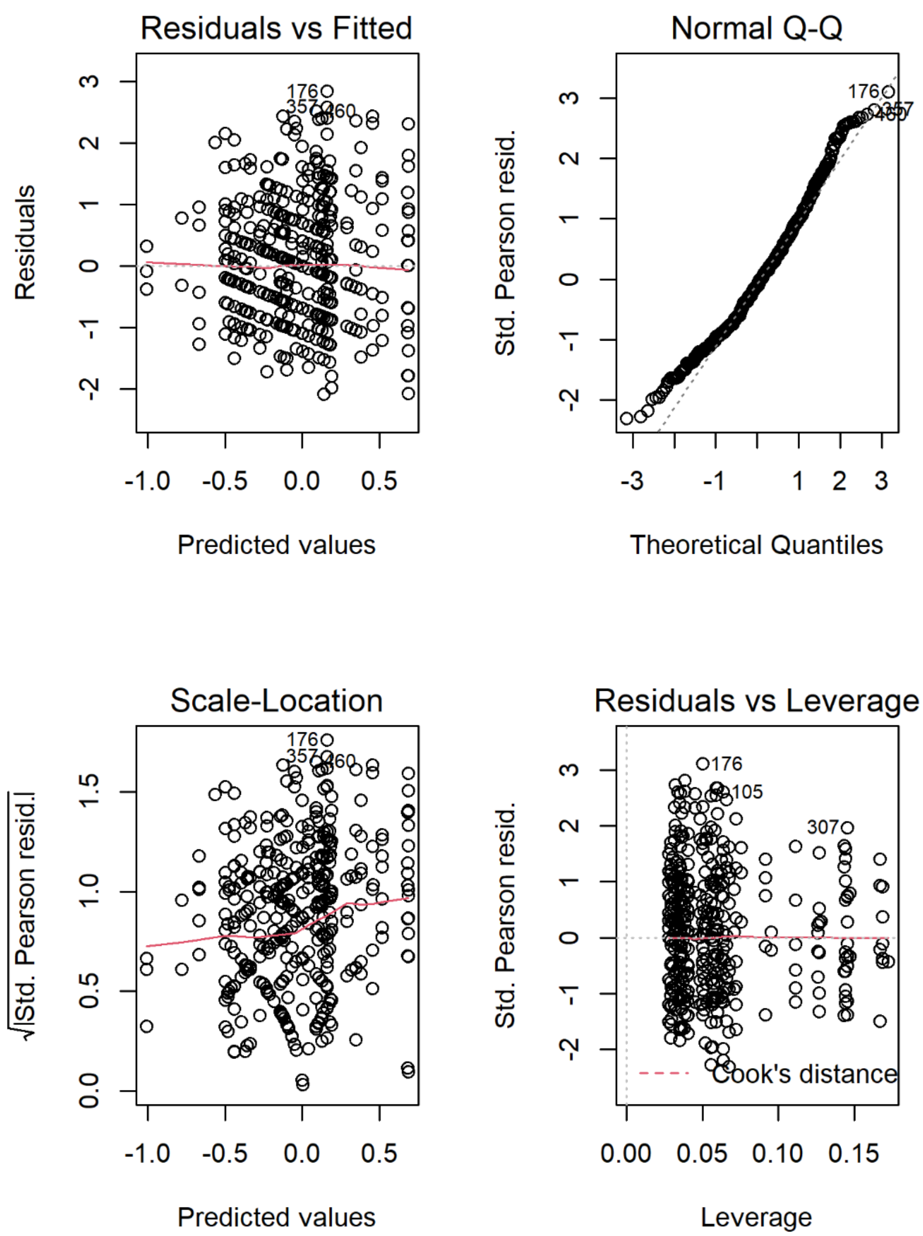

Figure S1. Diagnostic plots for the FL Keys positive model.

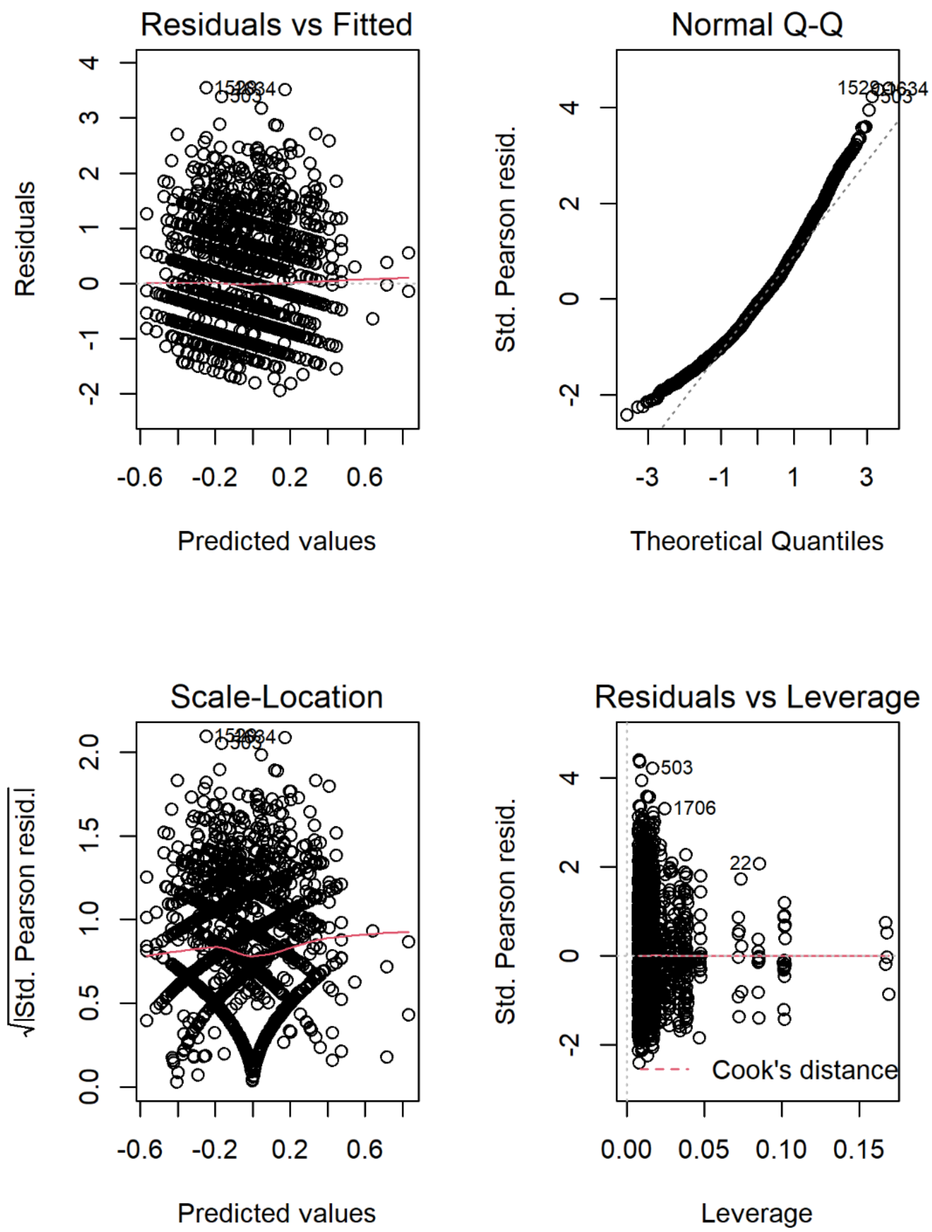

Figure S2. Diagnostic plots for the SE FL positive model.

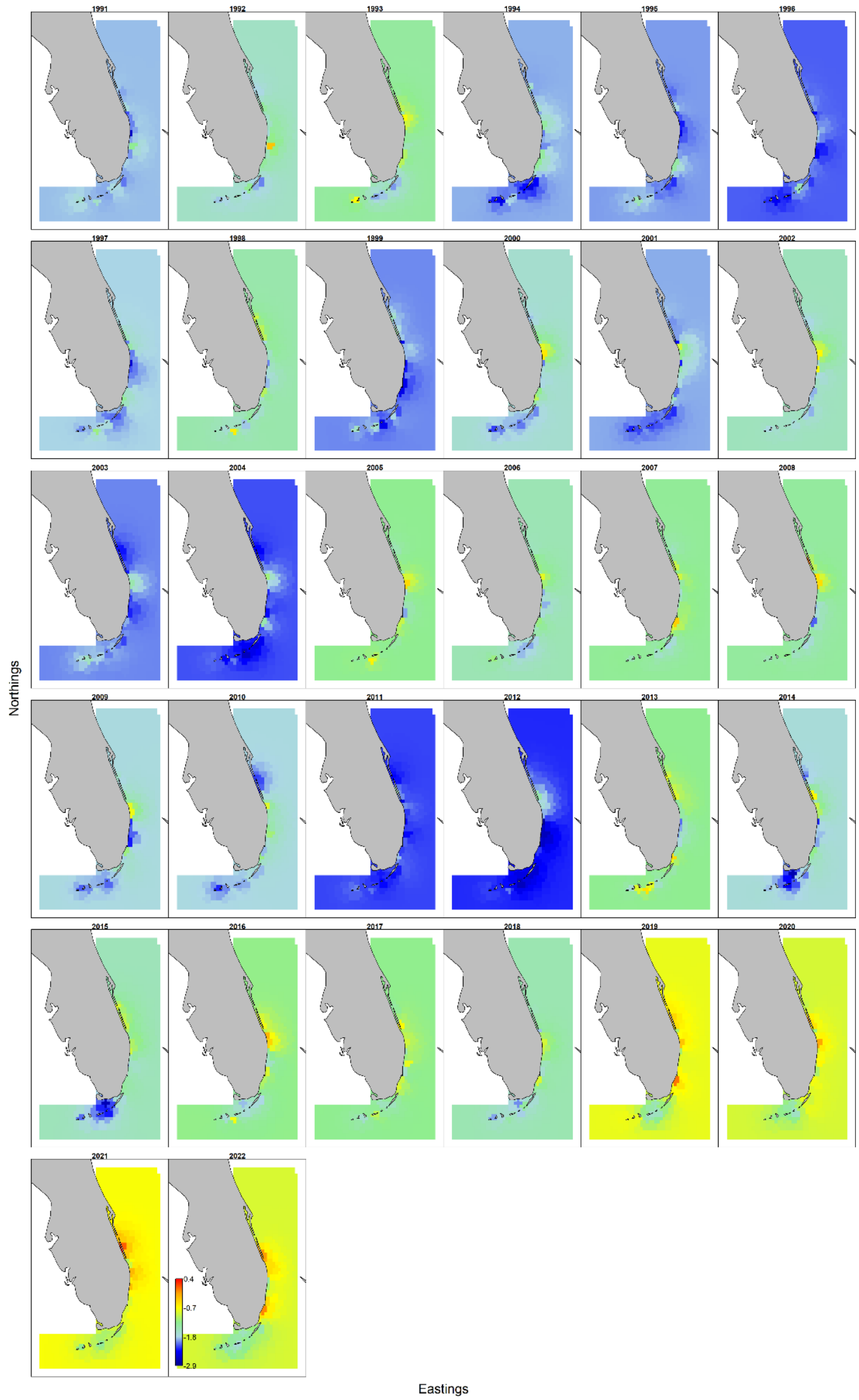

Figure S3. Exploratory analysis of CPUE by year and interview location. Warmer colors (yellow to red) indicate higher CPUE while cooler colors (light blue to dark blue) indicate lower than average CPUE.

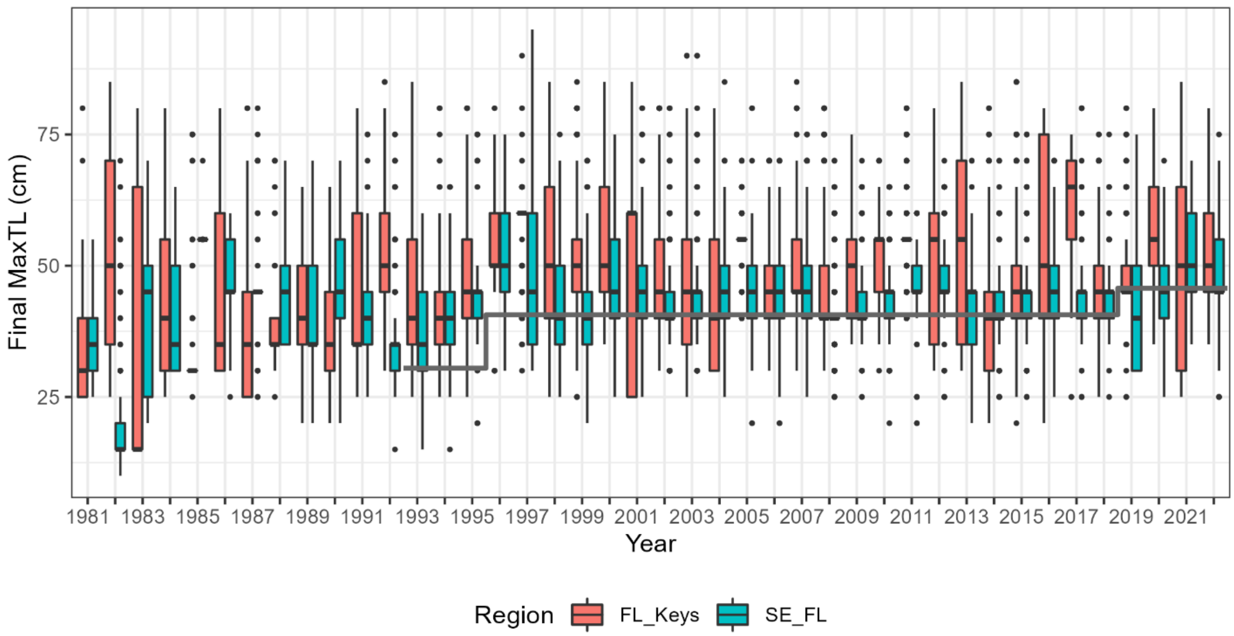

Figure S4. Boxplots of maximum total length (cm) of retained lengths in SE FL and FL Keys. The dark grey line denotes minimum size limits in federal waters of the South Atlantic (SAFMC) enacted in 1992 (12 in.), 1995 (16 in.), and 2018 (18 in.).