Standardized visual indices for Mutton Snapper, *Lutjanus analis*, for the Florida Keys (1997 – 2022), Dry Tortugas (1999-2021), and Southeast Florida (2013-2022)

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Standardized visual indices for Mutton Snapper, *Lutjanus analis*, for the Florida Keys (1997 – 2022), Dry Tortugas (1999-2021), and Southeast Florida (2013-2022)

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Abstract

National Marine Fisheries Service's (NMFS) Reef Visual Census (RVC) began in 1979 with divers identifying and counting fish along Florida's reef track. The program evolved into gridding the entire reef track into 50m x 50m blocks (originally 200m x 200m) that were grouped by stratum, and, after 1997, whether the block was in a Sanctuary Protected Area. Prior to each season's sampling, spatial blocks (primary sampling units, PSU) were randomly selected from the sampling frames by habitat and in turn, two sampling stations (secondary sampling units) were randomly selected within each PSU. At each station, usually two divers identified the species within their cylinder (7.5 m radius). After five minutes of noting the reef species present, the divers relocate those reef species and count their numbers and estimate their lengths. The RVC dataset consists of the mean counts of the two divers by species and length. The Reef Visual Census data were extracted from the NMFS database using the R package 'rvc' and these data were subset for Mutton Snapper, *Lutjanus analis*. Observation rates expressed as the mean number of Mutton Snapper observed per station, were standardized using two methods: a weighted stratified two-stage approach (design model, Smith, et al. 2011) and a hurdle or delta procedure (Lo *et al*. 1992, Cragg 1971). Separate indices were developed for Southeast Florida, the Florida Keys, and the Dry Tortugas because of the lengths of the Mutton Snapper observed in the Dry Tortugas were typically larger and those observed in Southeast Florida were smaller than the lengths from the Florida Keys. Additionally, there were only three years for which sampling occurred in all regions. Variability of the indices was estimated with a Monte Carlo approach that generated 10,000 random estimates based on the annual means and their standard errors. The index for the Florida Keys increased after 2010, the index for the Dry Tortugas increased after 2006, and the index for Southeast Florida, that started in 2013, increased after 2015. The coefficients of variation for the three indices were less than 0.20.

Introduction

The National Research Council (1998), in its review of fishery stock assessments, recommended using fishery-independent indices whenever possible because fishery independent surveys are statistically designed and unaffected by regulatory changes such as changes in seasons, size limits, or trip or bag limits. The National Marine Fisheries Service's Reef Visual Census (RVC) began in 1979, with the objective of monitoring reef species by identifying and counting fish along the Florida reef track from Biscayne Bay through the Florida Keys (Bohnsack and Bannerot 1986; Bohnsack *et al.* 1999; and Ault *et al.* 2001). Instead of linear transects, RVC divers employed an imaginary cylinder with a 7.5 m radius extending from the surface to the bottom and identified the species in that cylinder for a period of five minutes and then relocated those species to count and estimate the fork lengths of the fish that had been previously identified. Later, the site selection process was modified to a two-stage stratified random survey design (Cochran 1977, Smith *et al.* 2011) with sampling frames by habitat that were created by initially gridding the Florida reef track into 200 m x 200 m blocks and listing the habitats in each block. As bottom habitat mapping has improved, the block size has been reduced to improve the spatial resolution and currently is 50 m x 50 m. The reduction of the block size affects the weighting of the index in the design model but does not affect the model-based index. Annually (biennially after 2012), blocks were randomly selected by strata. The RVC sampling protocols have evolved over time but have been stable since 1997 when the Florida Keys National Marine Sanctuary set aside Sanctuary Protected Areas (SPAs). Florida Fish and Wildlife Conservation Commission (FWC) began a similar visual survey in 1999 and the two surveys were combined in 2009. The Coral Reef Initiative in Southeast Florida began a similar survey in 2013.The RVC data are suitable for developing regional fishery independent indices for the Florida Keys, the Dry Tortugas, and for Southeast Florida.

Methods

Data

With the establishment of Sanctuary Protected Areas by the Florida Keys National Marine Sanctuary in 1997 and the revision of the strata definitions in 1999, RVC personnel recommended only using data from 1999 and later for consistency; however, they provided the details such that data from 1997 and 1998 would also be compatible. Annually, primary sampling units (PSU) were randomly selected by stratum and the locations of two stations were randomly selected inside each PSU. Usually, two divers were deployed at each station and the mean counts of the species observed by the divers were determined for each station. Originally, the block size was 200 m x 200 m but that was reduced to 100 m x 100 m in 2014, and further reduced to 50 m x 50 m in 2020. Ault *et al.* (2021) discuss the rationale of the 50 m x 50 m block size. Therefore, I extracted the RVC station data using the R package 'rvc' (Jeremiah Blondeau pers. comm). There was no sampling in 2013, 2015, nor 2017 due to the biennial sampling schedule and no sampling 2020 due to the pandemic; however, sampling resumed in 2021 in some regions.

Filtering of the RVC data for inter-annual comparability included removing the experimental winter surveys that were conducted in 2004/2005 and removing stations in habitats that were not part of the RVC domain (sand, seagrass, mud, or artificial habitats). Three additional habitats in the Florida Keys (continuous high and mid relief, and isolated high relief) were removed because they were just established in 2014. In Southeast Florida, sampling was conducted every year in June – October and there were 3,530 stations that were in depths to 33 m with a median depth of 16 m (Fig. 1a). In the other regions, some months were sampled in only a few years while other months were sampled nearly every year; therefore, only stations in the Florida Keys that were sampled in June through September were included in the final dataset which had 10,135 stations that were in depths to 33 m with a median depth of 7.0 m (Fig. 1b). In the Dry Tortugas, only stations that were sampled in May through July were included in the final dataset resulting in a final dataset that had 6,019 stations in depths to 33 m with a median depth of 16.5 m (Fig.1c).

Analyses

Design model

The design-based index or density of Mutton Snapper was the mean number of Mutton Snapper observed per station, and it was estimated using a two-stage sampling scheme that involved estimating the mean number of Mutton Snapper observed by block (PSU) from the station means (secondary sampling units) and weighting the PSU means by the proportion of PSUs sampled by stratum to the total number of PSUs in the region (Smith *et al.* 2011). Thus, the design index can be thought of as the annual mean numbers observed across stratum and protected status weighted by the proportion of the sampled stratum blocks to the total number of blocks occurring in the region. Smith, *et al.* (2011) gives the equations for calculating the weighted means and variances in their Appendix A. The explanatory variables for the design models were year (Southeast Florida: 2013-2022, Florida Keys:1997-2022, and Dry Tortugas: 1999-2021); stratum (Southeast Florida: deep reef complex, linear reef inner and middle, nearshore ridge, linear reef outer, aggregated patch reef, ridge deep; Florida Keys: forereef deep linear reef, forereef mid-channel linear reef, forereef shallow linear reef, spur and groove, inshore patch-reef, mid-channel patch-reef, and offshore patch-reef; and the Dry Tortugas: continuous high, medium, low relief; isolated high, medium, low relief; Spur and groove high and low relief; and all of these have high and low rugosity); and whether the station occurred in a Sanctuary Protected Area (0, 1); Southeast Florida has no protected areas). The strata from 2021 and later were based on depth and rugosity. The calculations were made with an R script provided by J. Herbig (FWRI, St. Johns, NL).

Hurdle/delta models

Similar to the approach that Ingram and Harper (2009) used for Black Grouper, the index was standardized with the delta or hurdle approach which split the process into two generalized linear submodels (Maunder and Punt 2004, Lo *et al.* 1992, Cragg 1971): a submodel with a binomial distribution and a logit link to estimate the annual proportion of stations where Mutton Snapper were observed and a submodel with either a gamma, Poisson, or log-normal distribution and a log link to estimate the annual mean number of Mutton Snapper observed at a station where Mutton Snapper were observed, i.e., the number of Mutton Snapper observed at a positive station. The annual index is the product of the proportion of positive stations (***Prop***) and the mean number of Mutton Snapper observed at positive stations ($\hat{Y}$) by year after each term had been back-calculated from their linear forms (for the logit link, the transform was $prop = \frac{e^{f(x1+x2+..)}}{1+e^{f(x1+x2+...)}}$ and for the Poisson and gamma distributions (log link) and the log-normal distribution (identity link), the transform was $\hat{Y} = e^{g(x1+x2+...)}$ where the *x1, x2,* refer to the variables included in the final, respective linear submodels).

The submodels used a forward stepwise process starting with the null model to identify which variables could be included in the final versions of the respective submodels. Potential explanatory variables included year (Southeast Florida: 2013 – 2022), month (Southeast Florida: June – October Florida Keys: June – September, and Dry Tortugas: May – July), protected status (1, 0), subregion (Southeast Florida: Broward - Miami, Deerfield, South Palm Beach, North Palm Beach, Martin counties; Florida Keys: Marquesas, Lower Keys, Middle Keys, Upper Keys, Biscayne; and Dry Tortugas: Tortugas Bank. Dry Tortugas National Park, Unmapped Tortugas), habitat (Southeast Florida: deep reef complex, linear reef inner and middle, nearshore ridge, linear reef outer, aggregated patch reef, ridge deep; all of these have high and low rugosity; (Florida Keys: forereef deep linear reef, forereef mid-channel linear reef, forereef shallow linear reef, spur and groove, inshore patch-reef, mid-channel patch-reef, and offshore patch-reef; and Dry Tortugas: continuous high, medium, low relief; isolated high, medium, low relief; Spur and groove high and low relief; depth category (5m to 25 m+ in 5-m categories), Southeast Florida did not include depth because they did not measure depth in 2015) and zone (Southeast Florida does not use zone, Florida Keys: inshore, mid-channel, offshore patch reef, forereef; and Dry Tortugas did not include zone because zone was not recorded in 2008). To be included in the final submodel, potential explanatory variables were evaluated with two criteria: the variable had to be statistically significant at the 0.05 level (the probability of rejecting the null hypothesis) and the inclusion of the potential variable had to reduce the deviance (a measure of the variability) by at least 0.5%. At each step, the variable selected for inclusion in the final model met the statistical criterion and reduced the mean deviance more than the other variables in that step. The stratum variable (STRAT) from the design model could only be included as a potential explanatory variable in the Southeast Florida model because of the redefinition of STRAT beginning in 2021; also, if a component variable of STRAT (habitat or depth) was selected, then STRAT was no longer considered for inclusion in the model. All the potential, explanatory variables were treated as categorical variables partially to account for non-linearity.

In addition to the three hurdle configurations, the number of Mutton Snapper observed were also fit with negative binomial and Poisson distribution models. The variables for inclusion in these final models were selected by the same forward stepwise process as for the hurdle models. In contrast to the hurdle models, these models fit the mean number of Mutton Snapper observed per station directly.

The variability in the estimated annual index values was estimated using a Monte Carlo simulation approach with 10,000 iterations that used the least-squares mean estimates and their standard errors. Each iteration used the annual least-squares mean estimate on the linear scale and uncertainty was added by multiplying the annual least-squares mean estimate's standard error by a random normal deviate (μ=0, σ=1). As described above, after the two estimates were transformed back from their linear scales, they were multiplied together to form the annual index value. For the design- based model, the negative binomial model, and the Poisson model, the process was simpler because these configurations only involved a single distribution.

The root mean square error (RMSE) from the residuals (the observed values less the predicted values) was used to compare the fits of the six configurations that applied different distributions to the same dataset. With the hurdle models, the predicted values for those stations that did not observe Mutton Snapper came from the binomial distribution and for the stations where Mutton Snapper were observed the predicted values came from the distribution. The degrees of freedom varied depending upon which variables were included in the final submodels. The mean square error was the sum of the squared residuals divided by the total number of observations less the degrees of freedom and the root mean square error was the square root of the mean square error. The final configuration selected for the annual RVC Mutton Snapper index was the model configuration with the lowest RMSE.

Lengths and selectivities

The RVC divers estimate fork lengths to the nearest cm *in situ*, however there is variability in the observed fork lengths (Fig. 7 a, c, and e), necessitating binning the fork lengths in 5 cm bins ([0,5], [5,10], [10,15], etc.). To make length types consistent with management regulations, binned fork lengths are converted to binned maximum total lengths (mTL) by first converting the midpoint of each 5 cm fork length bin to maximum total length in cm using the equation mTL = 1.071*FL + 1.552 (df = 2886, MSE = 35.41, R^2 = 0.998, SEDAR 79). These maximum total lengths are then put into 5 cm mTL bins ([0,5], [5,10], [10,15], etc.). Converting fork lengths to maximum total lengths in this fashion preserves the shape of the distribution of binned fork lengths. Selectivities of the indices were estimated from binned Mutton Snapper lengths without being weighted by the regional indices. All the regions used the same equation to convert the fork lengths. Only the lengths from the RVC stations after the data were filtered were used in this analysis in the length frequencies and selectivities.

Results and Discussion

Southeast Florida

Mutton Snapper were not an abundant species on the Florida Keys reef. In Southeast Florida, after data filtering, Mutton Snapper were observed at 1,218 stations out of 3,530 stations sampled (35%) from 2013 through 2022. The maximum number of Mutton snapper observed at a single station was 15 fish but the 99th percentile of number of Mutton Snapper observed at a station was 5.5 fish and the median was 1.0 fish observed per station. The number of fish observed can be fractional because the number of fish observed at a station is the mean of the numbers observed by the divers at that station. For example, if one diver at a station saw a Mutton Snapper but the other diver did not, the number observed at that station would be 0.5 Mutton Snapper.

While the six model configurations had similar trends in Southeast Florida (Fig. 2a), the model configuration with the lowest RMSE was the hurdle model with the Poisson distribution for the positive stations (RMSE = 0.7943, df = 3509, Table 1a). The submodel estimating the probability that at least one diver observed a Mutton Snapper at a station (binomial distribution) reduced the deviance by 13.6% and the variables in the final submodel, listed in decreasing order of importance, included stratum, year, subregion (geographic subregion), and month (Table 2). Diagnostic plots for the probability of seeing a Mutton Snapper at a station submodel are shown in Fig. 3 a, c, and e. The submodel with the Poison distribution for estimating the number of Mutton Snapper observed at successful stations reduced the deviance by 14.6%. The variables selected in the final Poisson submodel were year and stratum (Table 3) and the diagnostic plots are in Fig.3 b, d, and f. There were 22 stations (1.8%) that were considered outliers, i. e., stations with mean numbers of Mutton Snappers observed greater than 5.0.

The Southeast Florida visual index for Mutton Snapper was low, around 0.2 Mutton Snapper per station from 2013- 2015 and then increased in 2016 and 2018 and has been stable since then (Table 4a, Fig. 5a). The coefficients of variation were reasonable ranging from 0.08 to 0.14. The nominal index had a similar shape as the standardized index (Fig. 6a).

The range of maximum total lengths (mTL) of Mutton Snapper estimated by divers in situ was from 3 to 82 cm mTL (Fig. 7a). The median size of the Mutton Snapper (n = 1,457 fish) was 37 cm mTL and the interquartile range was 33 to 42 cm mTL. Lowerre-Barbieri and Friess (2022) estimated length at which 50% of the Mutton Snapper are mature was 42.2 cm natural TL (43.5 mTL); therefore, 10% of the observed Mutton Snapper were at least the size of 50% maturity. Given the low proportion of mature fish, a dome-shaped selectivity pattern is appropriate (Fig. 8b). The parameters of the dome-shaped selectivity pattern in terms of length were the ascending inflection point, 25.7 cm (SE = 0.65 cm) mTL, the ascending slope, 2.91 cm (SE = 0.60 cm) mTL, the descending inflection point, 40.9 cm (SE = 0.69 cm), and the descending slope, 3.41 cm (SE = 0.66 cm) mTL.

Florida Keys

In the Florida Keys after data filtering, Mutton Snapper were observed at 1,936 stations out of 10,135 stations sampled (19%). The maximum mean number of Mutton Snapper observed at a single station in the Florida Keys was 8.6 fish and the 99th percentile of number of Mutton Snapper observed at a station was 2.5 fish and the median was 0.0 fish observed per station.

As in Southeast Florida, the six model configurations in the Florida Keys all had similar trends (Fig. 2b), the model configuration with the lowest RMSE was the model with the Poisson distribution (RMSE = 0.4777, df = 10,103, Table 1b). The Poisson model reduced the deviance by 18.2% and the variables in the final model, listed in decreasing order of importance, included depth category, subregion, year, and habitat (Table 3b). Diagnostic plots for the probability of seeing a Mutton Snapper at a station model are shown in Fig. 4 a, c, and e. There were 169 stations (1.7%) that were considered outliers, i. e., stations with mean numbers observed greater than 1.5 Mutton Snappers.

The Reef Fish Visual Census index for Mutton Snapper observed in the Florida Keys varied without trend from 2001 until 2006 and then increased in 2007 followed by a decline to lows in 2010 and 2011 and an increase afterward; the highest index value occurred in 2018, the terminal year (Table 4b, Fig. 5b). The coefficients of variation were reasonable ranging from 0.08 to 0.18. The nominal index had a similar shape as the standardized RVC index except for the 2014 – 2018 which had values below the corresponding index values (Fig. 6b).

Although the configuration with the lowest RMSE was the model with the Poisson distribution, three other models had RMSE values within 0.0007 implying that the data had a clear signal. Figure 2b shows the similarity of the indices estimated by the different configuration using the same data. The model configurations agree that the index in the Florida Keys was stable with an increase in 2007 but dropped to a low in 2010-2011 and then has increased afterwards.

Three variables (year, depth, and subregion) were selected in every configuration, the design model (Table 1b) imbedded depth in the STRAT variable, but the subregion of the Florida Keys was not considered in the design model. Depth being included in so many Florida Keys configurations is not surprising because the depths at RVC stations where Mutton Snapper were observed in the Florida Keys typically were deeper (mean = 11.3 m, SD = 6.21 m) than the depths at stations where Mutton Snapper were not observed (mean = 8.0 m, SD = 5.14 m, t = 22.65, df = 8739, P = 1.0). Figure 1b shows the stations where Mutton Snapper were observed, and these were the more seaward or deeper stations. The protected status was fixed in the design model.

The range of maximum total lengths (mTL) of Mutton Snapper estimated by divers in situ was from 3.7 to 87.2 cm mTL (Fig. 7). The median size of the Mutton Snapper in the Florida Keys (n = 1,842 fish) was 44.4 cm mTL and the interquartile range was 35.8 to 49.7 cm mTL. The estimated length at which 50% of the Mutton Snapper are mature was 42.2 cm natural TL (Lowerre-Barbieri and Friess 2022); therefore, approximately 51% of the observed Mutton Snapper were at least the size of 50% maturity.

The shape of the selectivity curve for Mutton Snapper or the ability to see the lengths of Mutton Snapper depends upon whether all sizes of Mutton Snapper occur in the areas and depths that are available to the SCUBA divers. If all lengths are available, then a flat-topped selectivity curve (Inflection = 42.6 cm (SE = 0.26 cm) mTL and a slope of 6.88 cm (SE = 0.23 cm)) mTL would be appropriate (Fig. 8a) but if few larger fish are available to be observed then a dome-shaped curve would be appropriate (ascending inflection = 31.2 cm (SE = 0.60 cm) mTL, ascending slope = 2.86 cm (SE = 0.54 cm) mTL, descending inflection = 56.8 cm (SE = 0.85 cm) mTL and the descending slope = 5.97 cm (SE = 0.78 cm mTL)) would be more appropriate (Fig. 8b). Choosing the appropriate selectivity pattern for this region will be a discussion topic at the data workshop.

Dry Tortugas

In the Dry Tortugas after data filtering, Mutton Snapper were observed at 1,834 out of 6,019 stations (30%). The maximum mean number of Mutton Snapper observed at a single station in the Florida Keys was 14.0 fish but the 99th percentile of number of Mutton Snapper observed at a station was 2.5 fish and the median was 0.0 fish observed per station.

Two configurations, the Poisson and the negative binomial, had the same low RMSE (RMSE = 5812, df =6,006, Table 1c); however, the configuration with the negative binomial distribution reduced the deviance by 8.1% while the configuration with the Poisson distribution reduced the deviance by less7.9%. Both models included year and protected status in the final model. Figure 2c shows the similarity of the indices estimated by the different configuration using the same data.

The diagnostic plots are shown in Fig. 4 b, d, and f. Year was the only variable selected in every configuration. Depth probably was not as important in the Tortugas because the stations where Mutton Snapper were observed had similar depths to the stations where Mutton Snapper were not observed There were 94 stations with means greater than 2.0 Mutton Snapper per station (1.6% outliers).

The Reef Fish Visual Census index for Mutton Snapper observed in the Dry Tortugas has been increasing although variable, the index value for 2021 was the highest of the time series (Table 4c, Fig. 5c). The coefficients of variation were reasonable ranging from 0.068 to 0.212. Not surprising, given the low reduction in deviance by the model, the nominal index had a similar shape as the standardized RVC index (Fig.6c).

The median size of the Mutton Snapper observed in the Dry Tortugas as estimated by the divers *in situ* was 52 cm mTL (n = 1,696 fish) with an interquartile range of 44.4 to 61.5 cm mTL (Fig. 7c). The mean length at which 50% of the Mutton Snapper are mature was 42.2 cm natural TL (43.5 cm mTL); thus approximately 77% of the observed Mutton Snapper in the Dry Tortugas were at least the size of 50% maturity.

Because so many larger fish were observed in the Dry Tortugas, a flat-topped selectivity curve (inflection = 51.5 cm (SE = 0.21 cm) TL and a slope of 7.30 cm (SE = 0.19 cm)) would be appropriate (Fig. 8e) but if it is believed that larger fish are unavailable to the divers then a dome-shaped curve would be appropriate (ascending inflection = 38.4 cm (SE = 0.52 cm), ascending slope = 3.61 cm (SE = 0.47 cm), descending inflection = 68.3 cm (SE = 0.67 cm) and the descending slope = 6.19 cm (SE = 0.62 cm) would be more appropriate (Fig. 8f).

Regional Comparisons

The regions are quite distinct even though the visual Mutton Snapper indices in the three regions have increased in recent years (Fig.5). Fish that were observed in Southeast Florida were smaller and the fish in the Dry Tortugas were larger while the sizes of fish observed in the Florida Keys fish were in between (Fig. 9).

Although there were more shallow water stations (< 15 m) in the Florida Keys than in the other two regions (Fig. 10), divers at shallower stations in the Florida Keys and In Southeast Florida observed fewer Mutton Snapper than at the deeper stations in those regions (Fig. 1 a and b). While chances of observing a Mutton Snapper or not was similar throughout the depth range in the Dry Tortugas (Fig. 11c).

For the assessment, these indices as fishery independent indices will be applied to the population directly and not linked to any fishery.

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Table 1. Model fits to six alternative model configurations by region. For each configuration, the fields include the configuration, the variables selected in the final model, number of stations, model degrees of freedom, total degrees of freedom and the root mean square error term. Note that all three of the hurdle models share the same binomial submodel.

a. Southeast Florida

Configuration	Variables selected	Number of stations	Model Degrees of freedom	Total Degrees of freedom	Root mean square error
Hurdle Poisson	Year and stratum	3530	21	3509	0.7943
Hurdle Gamma	Year and stratum	3530	21	3509	0.7964
Poisson	Year, stratum, subregion, and month	3530	29	3501	0.8145
Negative binomial	Year, stratum, subregion, and month	3531	29	3502	0.8159
Density	Year, stratum, and protected	3530	21	3509	0.9576
Hurdle log-normal	Year and stratum	3530	21	3509	0.9961

b. Florida Keys

Configuration	Variables selected	Number of stations	Model Degrees of freedom	Total Degrees of freedom	Root mean square error
Poisson	Depth, subregion, year, and habitat	10135	31	10103	0.4777
Hurdle Poisson	Year, depth, and subregion	10135	26	10108	0.4780
Negative binomial	Depth, subregion, year, and habitat	10135	31	10103	0.4780
Hurdle Gamma	Year, depth, subregion, and habitat	10135	31	10103	0.4784
Hurdle log-normal	Depth, subregion, year, and habitat	10135	31	10103	0.4932
Density	Year, stratum, and protected	10135	25	10109	0.5282

Table 1 continued. Model fits to six alternative model configurations by region. For each configuration, the fields include the configuration, the variables selected in the final model, number of stations, model degrees of freedom, total degrees of freedom and the root mean square error term. Note that all three of the hurdle models share the same binomial submodel.

c. Dry Tortugas

Configuration	Selected explanatory variables	Number of stations	Model Degrees of freedom	Total Degrees of freedom	Root Mean-square-error
Negative binomial	Year, protected	6019	13	6006	0.5812
Poisson	Year, protected	6019	13	6006	0.5812
Hurdle - Gamma	Year, habitat, and protected	6019	20	5999	0.5878
Hurdle - Poisson	Year	6019	11	6008	0.5883
Density	Year, stratum, and protected	6019	20	5999	0.6485
Hurdle – Log-normal	Year	6019	11	6008	0.8166

Table 2. Stepwise selection of variables for their inclusion in estimating the probability of observing a Mutton Snapper at a Southeast Florida station (shaded lines) with a generalized linear model (binomial distribution and logit link). The fields include the potential explanatory variable, degrees of freedom, deviance, mean deviance, Chi-square degrees of freedom, Chi-square value, probability of the null hypothesis, percent reduction in deviance, whether the model converged, and the cumulative percent reduction in deviance.

Explanatory variables	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of null hypothesis	Percent reduction in deviance	Converged	Cumulative percent reduction in mean deviance
Null	3529	4548.92	1.289	.	.	.	.	Conv	.
Stratum	3515	4243.04	1.207	14	305.88	0	6.353	Conv	6.35
Habitat	3519	4253.28	1.209	10	295.64	0	6.234	Conv	.
Year	3523	4312.94	1.224	6	235.99	0	5.026	Conv	.
Subregion	3525	4465.53	1.267	4	83.40	0	1.722	Conv	.
Month	3525	4521.85	1.283	4	27.08	1.92E-05	0.482	Conv	.
Stratum and year	3509	3974.75	1.133	6	268.29	0	5.771	Conv	12.12
Stratum and subregion	3511	4177.82	1.190	4	65.23	0	1.335	Conv	.
Stratum and month	3511	4219.42	1.202	4	23.63	9.49E-05	0.415	Conv	.
Stratum, and year, and subregion_nr	3505	3930.39	1.121	4	44.36	0	0.882	Conv	13.01
Stratum, and year, and month	3505	3945.64	1.126	4	29.11	7.4E-06	0.544	Conv	
Stratum, and year, subregion, and month	3501	3898.94	1.114	4	31.46	2.5E-06	0.598	Conv	13.60

Table 3. Regional stepwise selection of variables to include in estimating the mean number of Mutton Snapper observed at positive stations by region with Poisson or negative binomial distributions. The fields include the potential explanatory variables, degrees of freedom, deviance, mean deviance, Chi-square degrees of freedom, Chi-square value, probability of the null hypothesis, percent reduction in deviance, whether the model converged, and the cumulative percent reduction in deviance.

a. Southeast Poisson distribution with log link

Explanatory variable	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of null hypothesis	Percent reduction in deviance	Converged	Cumulative percent reduction in mean deviance
Null	1217	932.04	0.766	.	.	.	.	Conv	.
Year	1211	845.79	0.698	6	86.25	0	8.804	Conv	8.80
Stratum	1203	868.47	0.722	14	63.57	0	5.737	Conv	.
Habitat	1207	872.65	0.723	10	59.39	0	5.597	Conv	.
Subregion	1213	913.19	0.753	4	18.85	0.0008	1.699	Conv	.
Month	1213	925.06	0.763	4	6.98	0.1367	0.422	Conv	.
year and stratum	1197	782.65	0.654	14	63.15	0.0000	5.821	Conv	14.63
year and habitat	1201	787.04	0.655	10	58.75	0.0000	5.628	Conv	.
year and subregion	1207	831.27	0.689	4	14.53	0.0058	1.269	Conv	.
year and month	1207	834.84	0.692	4	10.96	0.0271	0.883	Conv	.
Year, stratum, and subregion_nr	1193	773.58	0.648	4	9.07	0.0595	0.706	Conv	.
Year, stratum, and month	1193	777.22	0.651	4	5.43	0.2464	0.308	Conv	.

Table 3 continued. Regional stepwise selection of variables to include in estimating the mean number of Mutton Snapper observed at positive Reef Visual Census stations plus negative binomial and Poisson distributions. The fields include the potential explanatory variables, degrees of freedom, deviance, mean deviance, Chi-square degrees of freedom, Chi-square value, probability of the null hypothesis, percent reduction in deviance, whether the model converged, and the cumulative percent reduction in deviance.

b. Florida Keys — Poisson distribution with a log link

Explanatory variable	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of null hypothesis	Percent reduction in deviance	Converged	Cumulative percent reduction in mean deviance
Null	10134	7030.27	0.694	.	.	.	.	.	.
Year	10116	6803.06	0.673	18	227.21	3.4E-38	3.060	Conv	.
Stratum	10128	6560.29	0.648	6	469.98	2.5E-98	6.630	Conv	.
Protected	10133	7029.74	0.694	1	0.53	4.6E-01	-0.002	Conv	.
Month	10131	7005.31	0.691	3	24.96	1.6E-05	0.326	Conv	.
Habitat	10129	6764.39	0.668	5	265.88	2.1E-55	3.734	Conv	.
Subregion	10131	6639.40	0.655	3	390.87	2.1E-84	5.532	Conv	.
Depth	10129	6418.12	0.634	5	612.16	4.8E-130	8.662	Conv	8.66
Zone	10131	6840.10	0.675	3	190.17	5.6E-41	2.676	Conv	.
Depth and year	10111	6214.71	0.615	18	203.41	2.085E-33	2.737	Conv	.
Depth and protected	10128	6401.20	0.632	1	16.92	3.905E-05	0.232	Conv	.
Depth and month	10126	6394.35	0.631	3	23.77	2.791E-05	0.311	Conv	.
Depth and habitat	10124	6338.96	0.626	5	79.16	1.259E-15	1.082	Conv	.
Depth and subregion	10126	6047.07	0.597	3	371.05	4.125E-80	5.255	Conv	13.92
Depth and zone	10126	6360.26	0.628	3	57.86	1.685E-12	0.797	Conv	.
Depth, subregion, and year	10108	5828.45	0.577	18	218.62	1.835E-36	2.964	Conv	16.88
Depth, subregion, and protected	10125	6041.79	0.597	1	5.27	2.166E-02	0.067	Conv	.
Depth, subregion, and month	10123	6041.38	0.597	3	5.68	1.281E-01	0.055	Conv	.
Depth, subregion, and habitat	10121	5967.82	0.590	5	79.24	1.209E-15	1.086	Conv	.
Depth, subregion, and zone	10123	6030.41	0.596	3	16.66	8.317E-04	0.212	Conv	.

Table 3 continued. Regional stepwise selection of variables to include in estimating the mean number of Mutton Snapper observed at positive Reef Visual Census stations plus negative binomial and Poisson distributions. The fields include the potential explanatory variables, degrees of freedom, deviance, mean deviance, Chi-square degrees of freedom, Chi-square value, probability of the null hypothesis, percent reduction in deviance, whether the model converged, and the cumulative percent reduction in deviance.

b. Florida Keys Poisson distribution with a log link

Explanatory variable	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of null hypothesis	Percent reduction in deviance	Converged	Cumulative percent reduction in mean deviance
Depth, subregion, year, and protected	10107	5821.365	0.576	1	7.08	0.0078	0.093	Conv	.
Depth, subregion, year, and month	10105	5826.067	0.577	3	2.38	0.4974	0.009	Conv	.
Depth, subregion, year, and habitat	10103	5734.494	0.568	5	93.95	9.92E-19	1.299	Conv	18.18
Depth, subregion, year, and zone	10105	5808.784	0.575	3	19.66	0.0002	0.256	Conv	.
Depth, subregion, year, habitat, and protected	10102	5707.73	0.565	1	26.76	2.299E-07	0.374	Conv	.
Depth, subregion, year, habitat, and month	10100	5732.98	0.568	3	1.51	0.6800	-0.003	Conv	.
Depth, subregion, year, habitat, and zone	10100	5703.00	0.565	3	31.49	6.701E-07	0.425	Conv	.

Table 3 continued. Regional stepwise selection of variables to include in estimating the mean number of Mutton Snapper observed at positive Reef Visual Census stations plus negative binomial and Poisson distributions. The fields include the potential explanatory variables, degrees of freedom, deviance, mean deviance, Chi-square degrees of freedom, Chi-square value, probability of the null hypothesis, percent reduction in deviance, whether the model converged, and the cumulative percent reduction in deviance.

c. Dry Tortugas Negative binomial distribution with a log link

Explanatory variable	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of null hypothesis	Percent reduction in deviance	Converged	Cumulative percent reduction in mean deviance
Null	6018	4441.54	0.738	0	0	0	0	Conv	0
Year	6008	4111.98	0.684	10	329.57	8.58E-65	7.266	Conv	7.27
Protected	6016	4416.81	0.734	2	24.73	4.26E-06	0.524	Conv	.
Habitat	6011	4409.02	0.733	7	32.53	3.24E-05	0.617	Conv	.
Subregion	6017	4417.06	0.734	1	24.49	7.48E-07	0.535	Conv	.
Depth	6013	4421.22	0.735	5	20.32	0.0011	0.375	Conv	.
Year and protected	6006	4074.55	0.678	2	37.42	7.48E-09	0.813	Conv	8.08
Year and habitat	6001	4086.23	0.681	7	25.75	0.0006	0.473	Conv	.
Year and subregion	6007	4091.72	0.681	1	20.25	6.78E-06	0.441	Conv	.
Year and depth	6003	4093.25	0.682	5	18.73	0.0022	0.345	Conv	.
Year, protected, and habitat	5999	4053.68	0.676	7	20.87	0.0040	0.364	Conv	.
Year, protected, and depth	6001	4057.42	0.676	5	17.14	0.0042	0.310	Conv	.

Note: Strat went out after the first round in the Florida Keys because depth reduced the deviance more. Similarly in the Dry Tortugas, subregion_nr went out after prot (protected or not) because subregion overlapped with the protected status.

Table 4. The number of stations, number of positive stations, nominal and the standardized indices and their coefficients of variation (CV) for Mutton Snapper by year and region. The indices, scaled to their means, are also included.

a. Southeast Florida

Year	Number of stations	Number of positive stations	Nominal index	CV	Hurdle-Poisson standardized index	CV	Standardized index scaled to mean	Nominal index scaled to mean
2013	1050	222	0.19	0.076	0.16	0.105	0.42	0.46
2014	565	164	0.26	0.085	0.23	0.114	0.61	0.62
2015	417	118	0.23	0.098	0.19	0.138	0.50	0.57
2016	462	180	0.49	0.099	0.42	0.097	1.13	1.19
2017	.	.	.	.		.		
2018	459	242	0.80	0.082	0.73	0.076	1.95	1.94
2019	.	.	.	.		.		
2020	.	.	.	.		.		
2021	285	148	0.70	0.086	0.71	0.094	1.88	1.69
2022	292	144	0.77	0.098	0.75	0.093	2.00	1.86

Table 4 continued. The number of Reef Visual Census stations, number of positive stations, nominal and the standardized indices and their coefficients of variation (CV) for Mutton Snapper by region. The indices, scaled to their means, are also included.

b. Florida Keys

Year	Number of stations	Number of positive stations	Nominal index	CV	Poisson standardized index	CV	Standardized index scaled to mean	Nominal index scaled to mean
1997	316	24	0.05	0.225	0.12	0.255	0.59	0.29
1998								
1999	376	29	0.07	0.199	0.10	0.216	0.49	0.35
2000	451	61	0.13	0.148	0.17	0.139	0.85	0.71
2001	643	89	0.12	0.115	0.16	0.123	0.81	0.66
2002	499	85	0.17	0.124	0.15	0.118	0.74	0.92
2003	377	64	0.18	0.141	0.17	0.132	0.85	0.96
2004	199	42	0.22	0.173	0.20	0.160	0.97	1.18
2005	498	86	0.19	0.133	0.19	0.112	0.95	1.02
2006	482	75	0.15	0.134	0.17	0.126	0.83	0.79
2007	606	137	0.26	0.106	0.27	0.093	1.31	1.40
2008	644	152	0.20	0.085	0.23	0.099	1.13	1.10
2009	972	190	0.16	0.078	0.16	0.091	0.82	0.87
2010	530	94	0.14	0.109	0.13	0.127	0.63	0.74
2011	780	130	0.14	0.093	0.13	0.105	0.62	0.75
2012	707	168	0.21	0.087	0.18	0.096	0.87	1.14
2013								
2014	612	124	0.25	0.126	0.27	0.089	1.32	1.35
2015								
2016	559	121	0.26	0.127	0.36	0.097	1.76	1.40
2017								
2018	633	185	0.30	0.081	0.34	0.092	1.66	1.60
2019								
2020								
2021								
2022	251	80	0.30	0.121	0.41	0.121	2.03	1.64

Table 4 continued. The number of Reef Visual Census stations, number of positive stations, nominal and the standardized indices and their coefficients of variation (CV) for Mutton Snapper by region. The indices, scaled to their means, are also included.

c. Dry Tortugas

Year	Number of stations	Number of positive stations	Nominal index	CV	Hurdle-Poisson standardized index	CV	Standardized index scaled to mean	Nominal index scaled to mean
1999	327	29	0.10	0.172	0.07	0.212	0.24	0.34
2000	381	44	0.11	0.163	0.09	0.164	0.34	0.41
2001								
2002								
2003								
2004	576	127	0.21	0.102	0.20	0.094	0.74	0.75
2005								
2006	484	93	0.14	0.105	0.14	0.125	0.51	0.51
2007								
2008	653	181	0.25	0.086	0.23	0.081	0.87	0.87
2009								
2010	689	229	0.34	0.072	0.32	0.071	1.20	1.20
2011								
2012	734	279	0.35	0.058	0.33	0.068	1.23	1.23
2013								
2014	702	223	0.24	0.067	0.22	0.081	0.84	0.85
2015								
2016	535	215	0.46	0.104	0.44	0.069	1.63	1.63
2017								
2018	646	232	0.31	0.063	0.30	0.075	1.13	1.10
2019								
2020								
2021	292	182	0.62	0.064	0.60	0.082	2.24	2.19
2022								

a. Southeast Florida Coral Reef Initiative (2013 – 2013)

b.

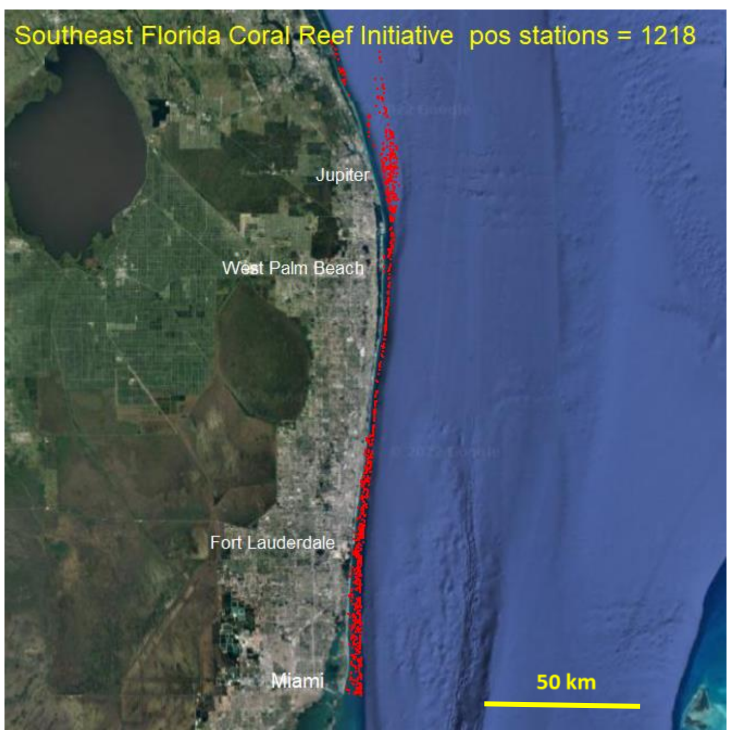
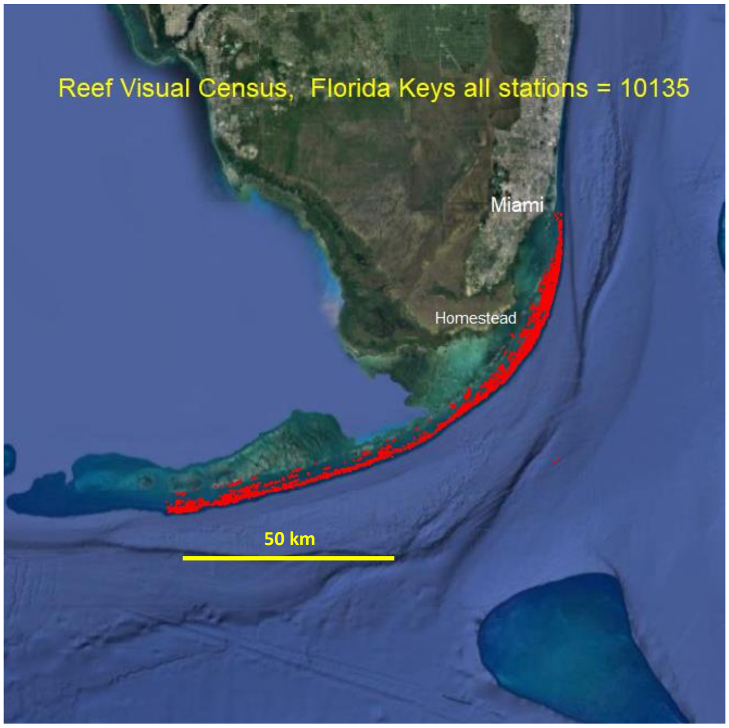


Figure 1. Station locations (red dots) sampled by region (a, c, e) and the stations where Mutton Snapper were observed (b, d, f).

c. Florida Keys (1997 – 2022)



d.

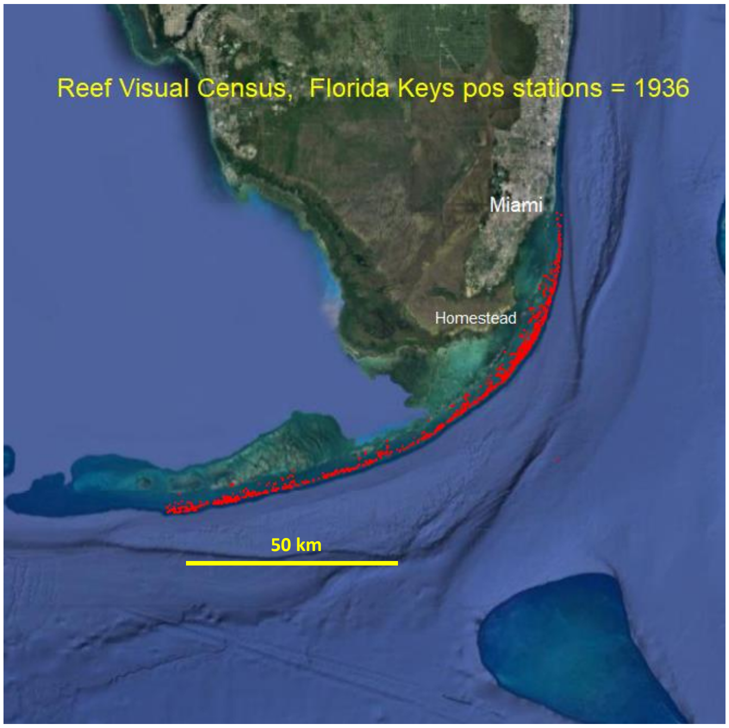
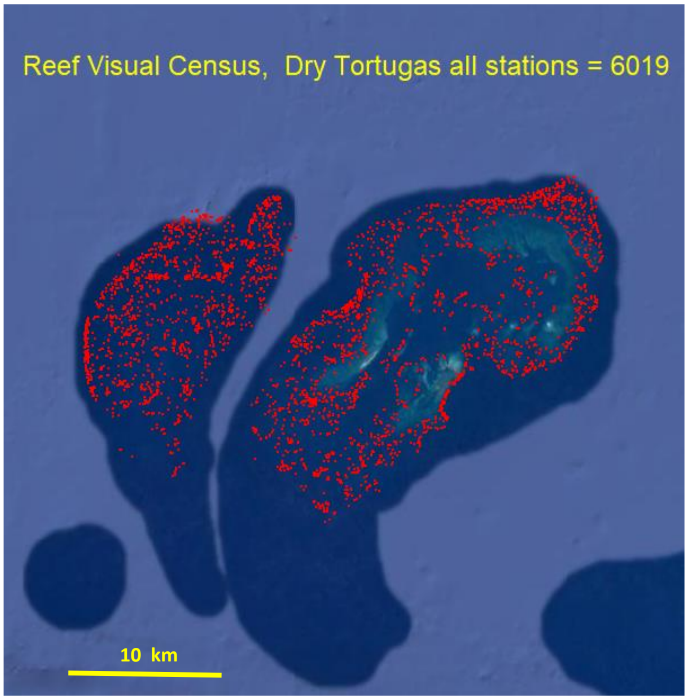
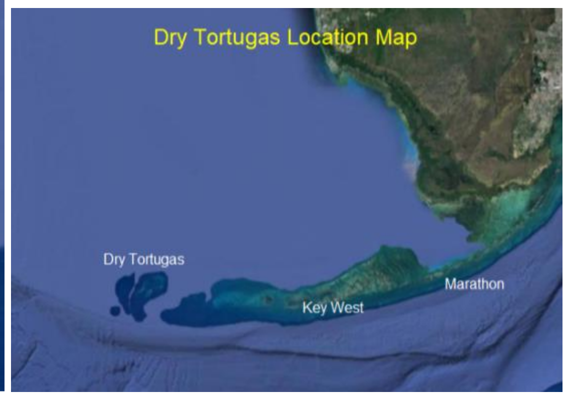


Figure 1 continued. Station locations (red dots) sampled by region (a, c, e) and the stations where Mutton Snapper were observed (b, d, f).

e. Dry Tortugas (1999 – 2021)





f.

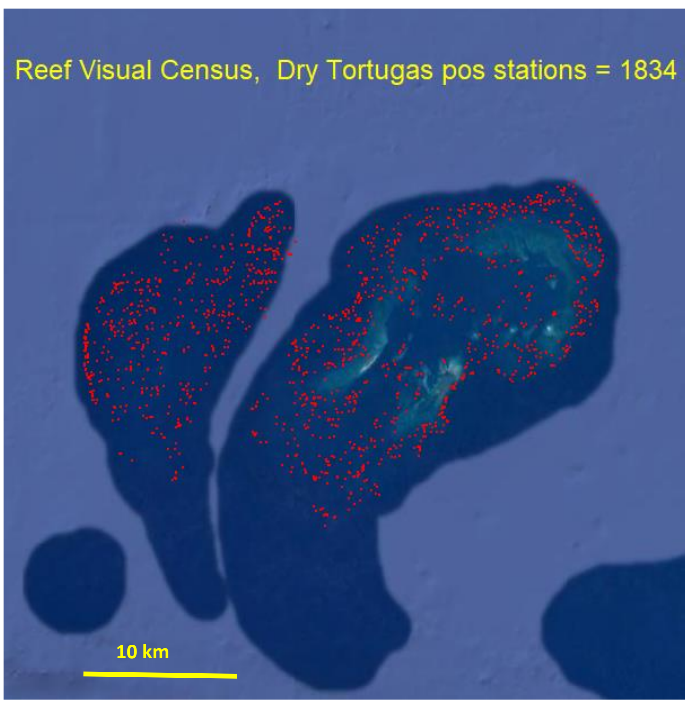
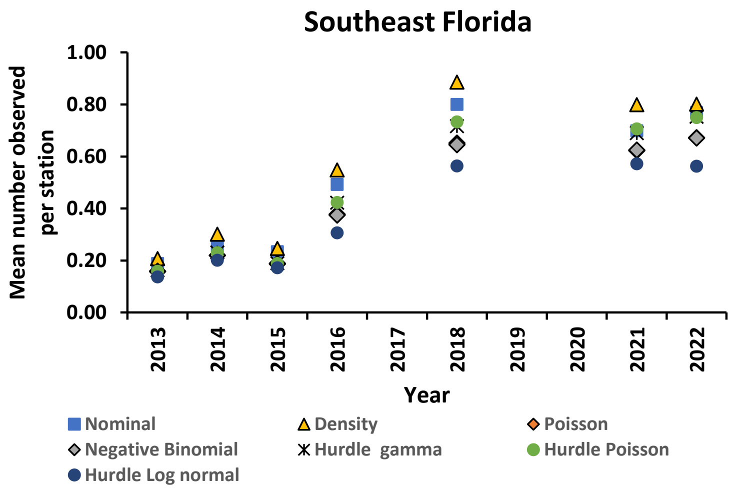
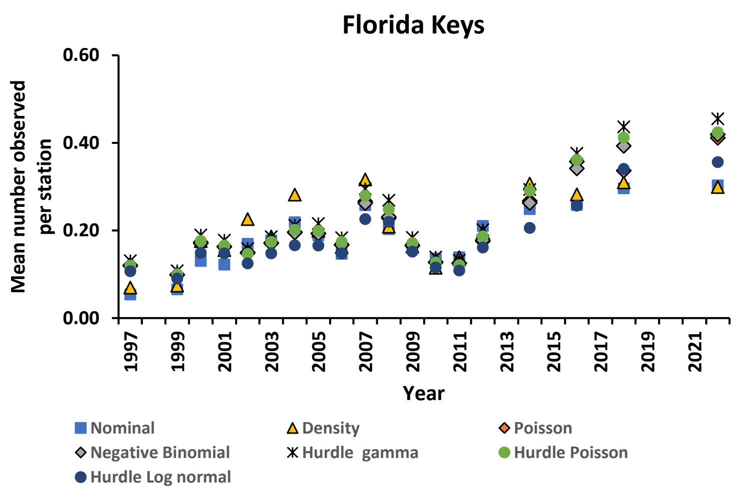


Figure 1 continued. Station locations (red dots) sampled by region (a, c, e) and the stations where Mutton Snapper were observed (b, d, f).

a.



b.



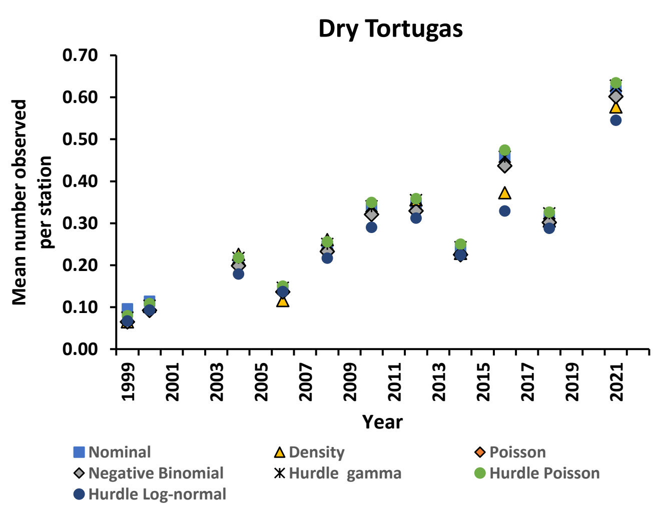


Figure 2. Mean numbers of Mutton Snapper observed per station by year and region: nominal and six model configurations.

Southeast Florida

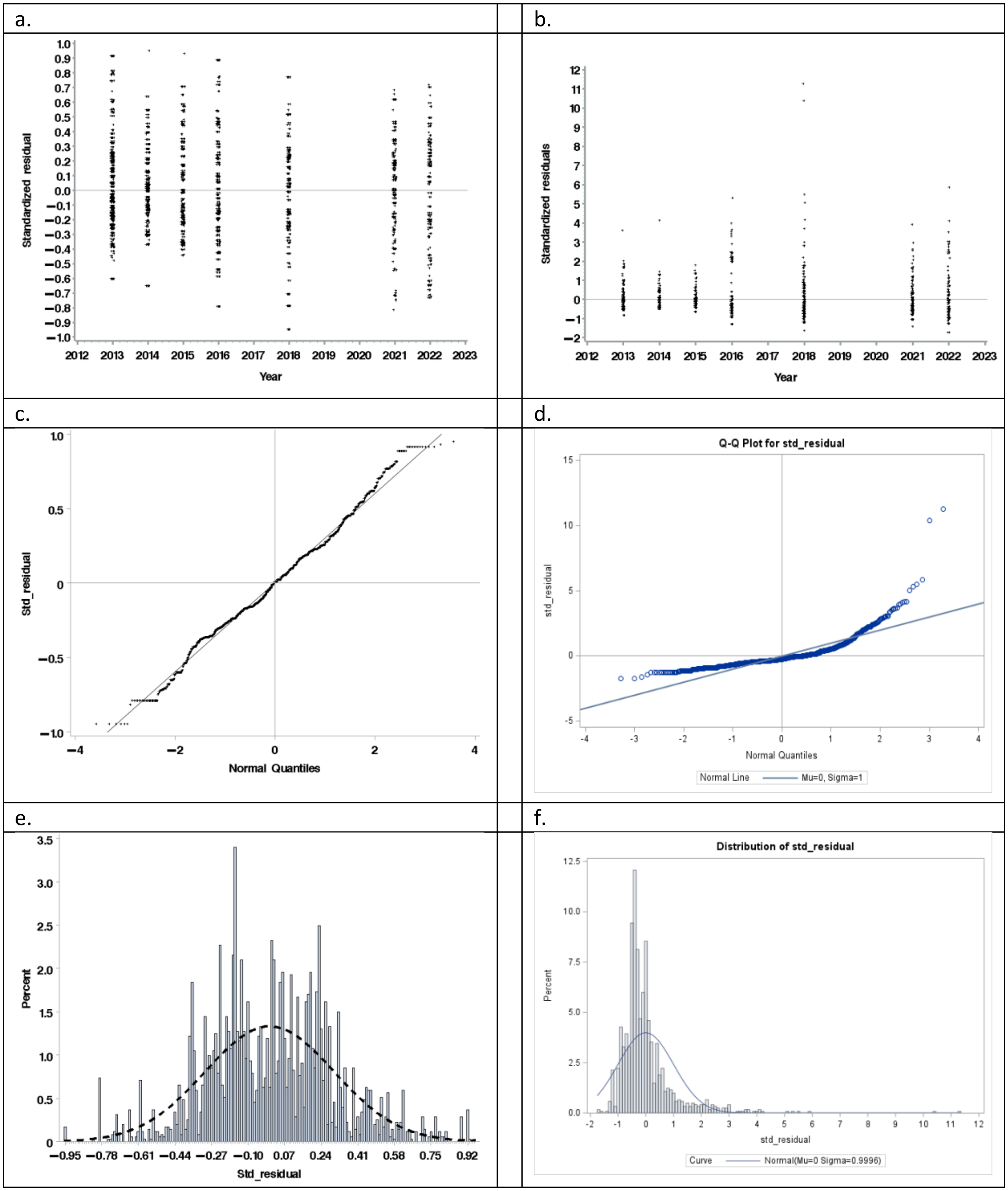


Figure 3. Diagnostic plots of standardized residuals for the probability of observing a Mutton Snapper in Southeast Florida fit using a binomial distribution, (a, c, and e) and diagnostics plots of standardized residuals from a Poisson distribution fit to the number of observed Mutton Snapper per station at a station (b, d, and f).

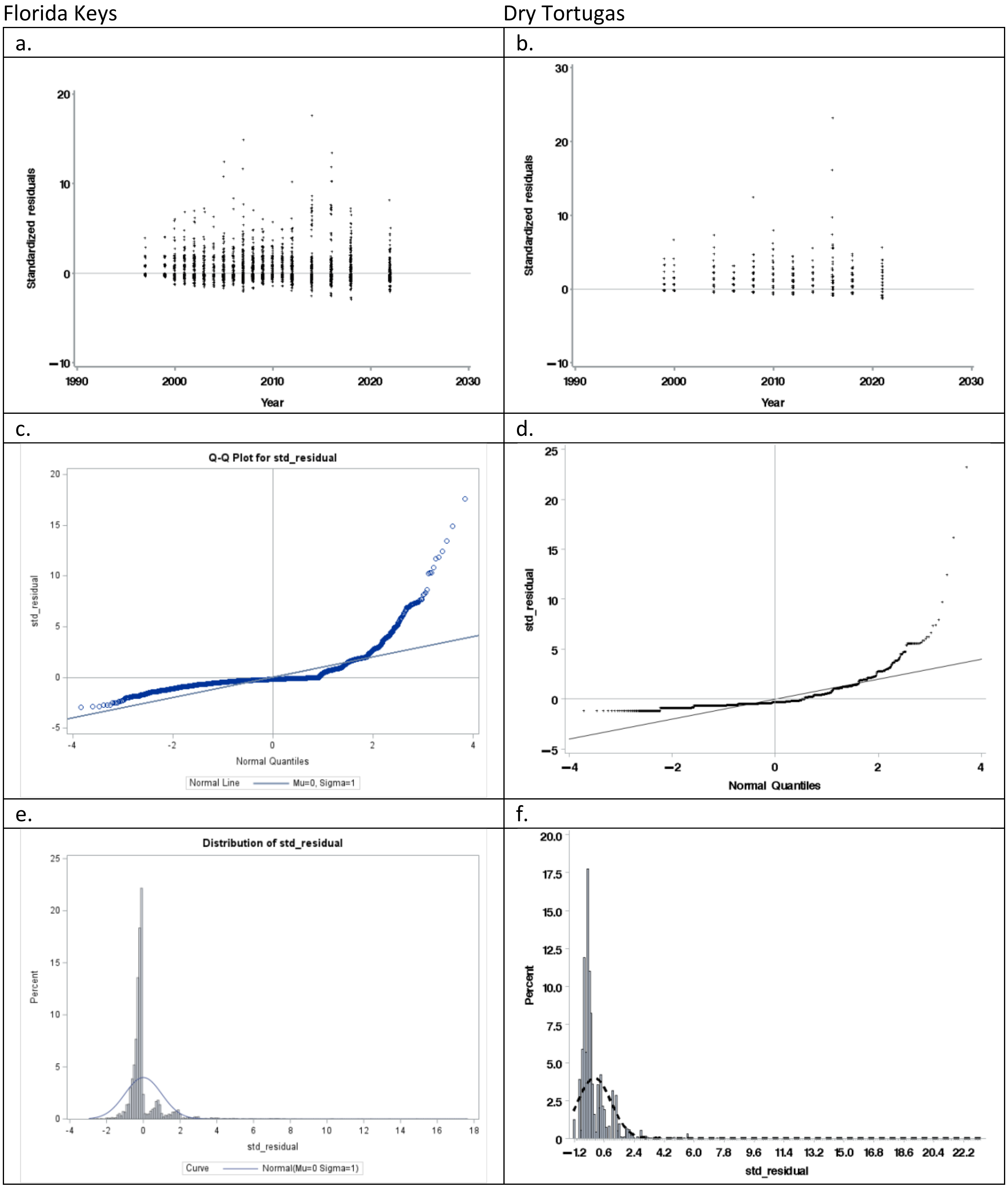
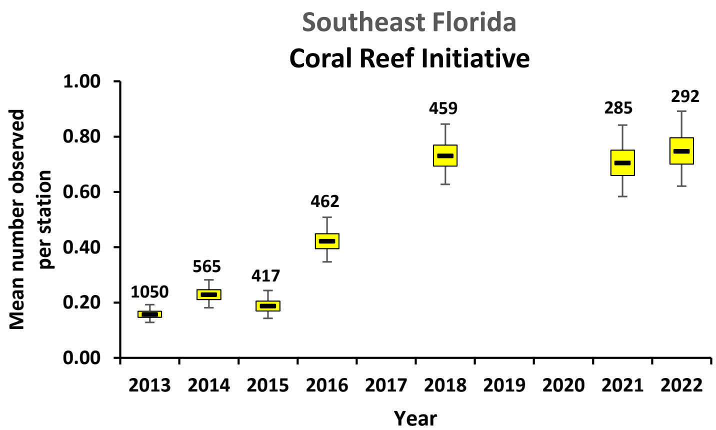
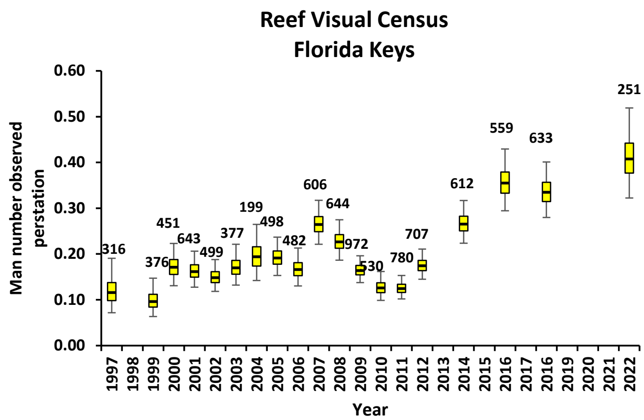


Figure 4. Diagnostic plots of standardized residuals for the number of Mutton Snapper observed in the Florida Keys (a, c, and e) fit with a Poisson distribution and the Dry Tortugas (b, d, and f) fit with a negative binomial distribution.

a.



b.



c.

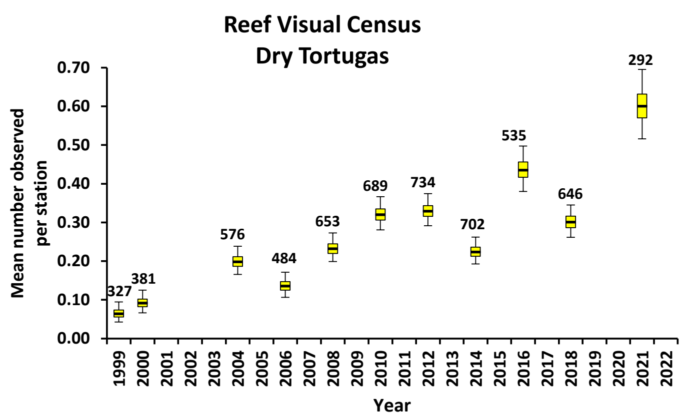
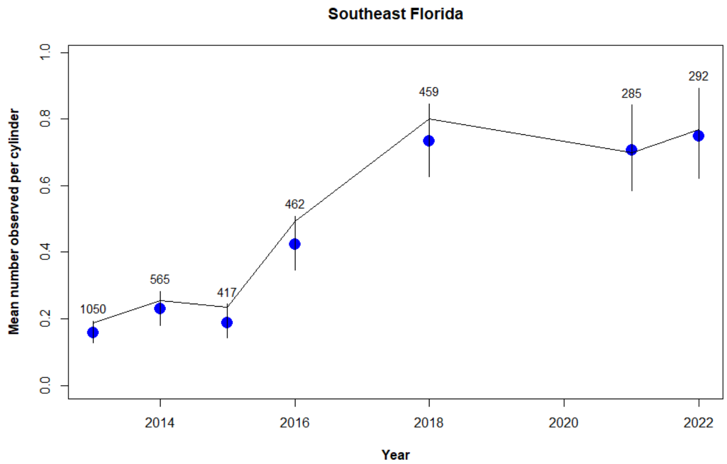
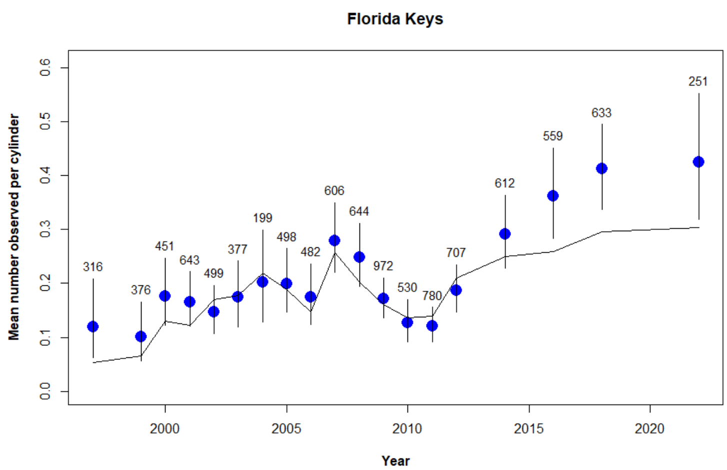


Figure 5. Box-whisker plots of the visual Mutton Snapper regional indices (mean number observed per station) by region and year. The horizontal lines are the median estimate; the boxes are the inter-quartile range, and the vertical lines are the 95% confidence intervals. The numbers of stations sampled each year are shown above the confidence interval.

a.



b.



c.

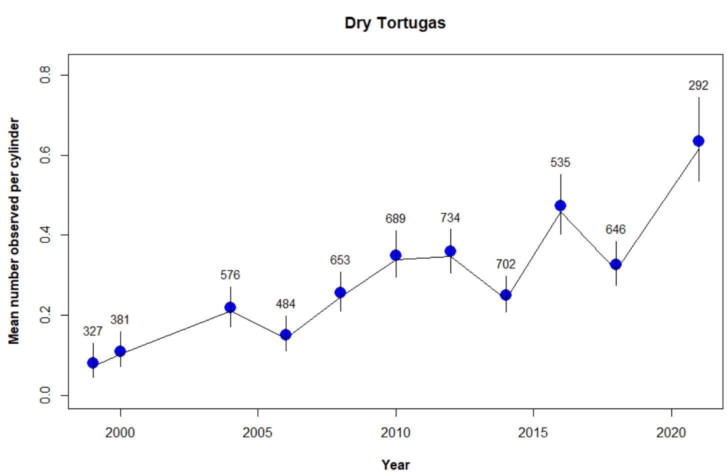


Figure 6. Comparing nominal catch rates (solid line) to standardized (model-based?) mean number of Mutton Snapper observed per station with their confidence intervals (index: blue dots and vertical line: 95% confidence interval) by year and region. The numbers of stations per year are above the symbols.

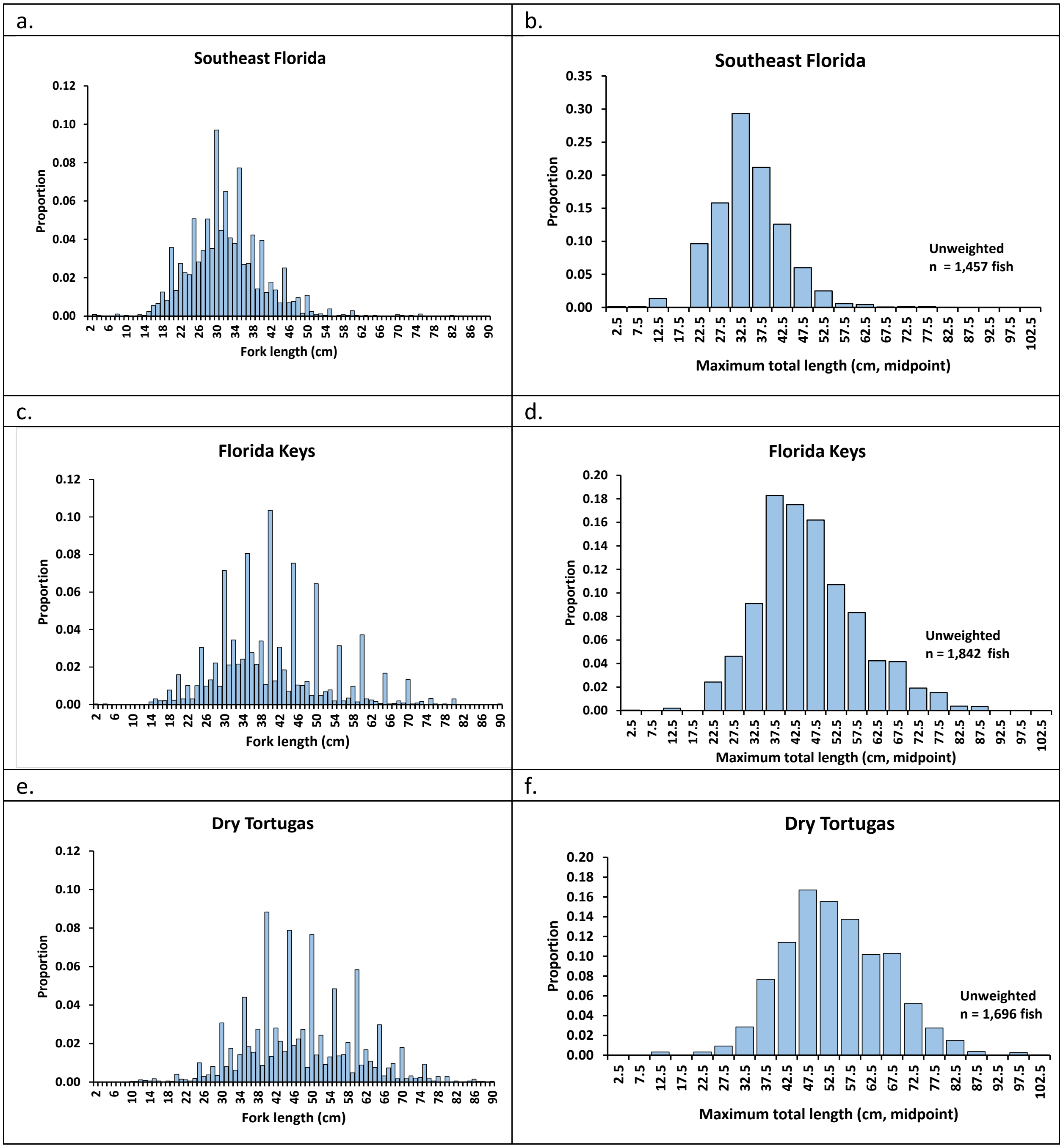


Figure 7. Unweighted distributions of fork lengths in cm of Mutton Snapper estimated *in situ* by divers along the Florida reef track from 1997 to 2022 by region (a. Southeast Florida, c. Florida Keys, and e. Dry Tortugas) and the corresponding unweighted maximum total length (mTL) in 5-cm bins (b. Southeast Florida, d. Florida Keys, and f. Dry Tortugas). The number of fish lengths are included in the mTL figures.

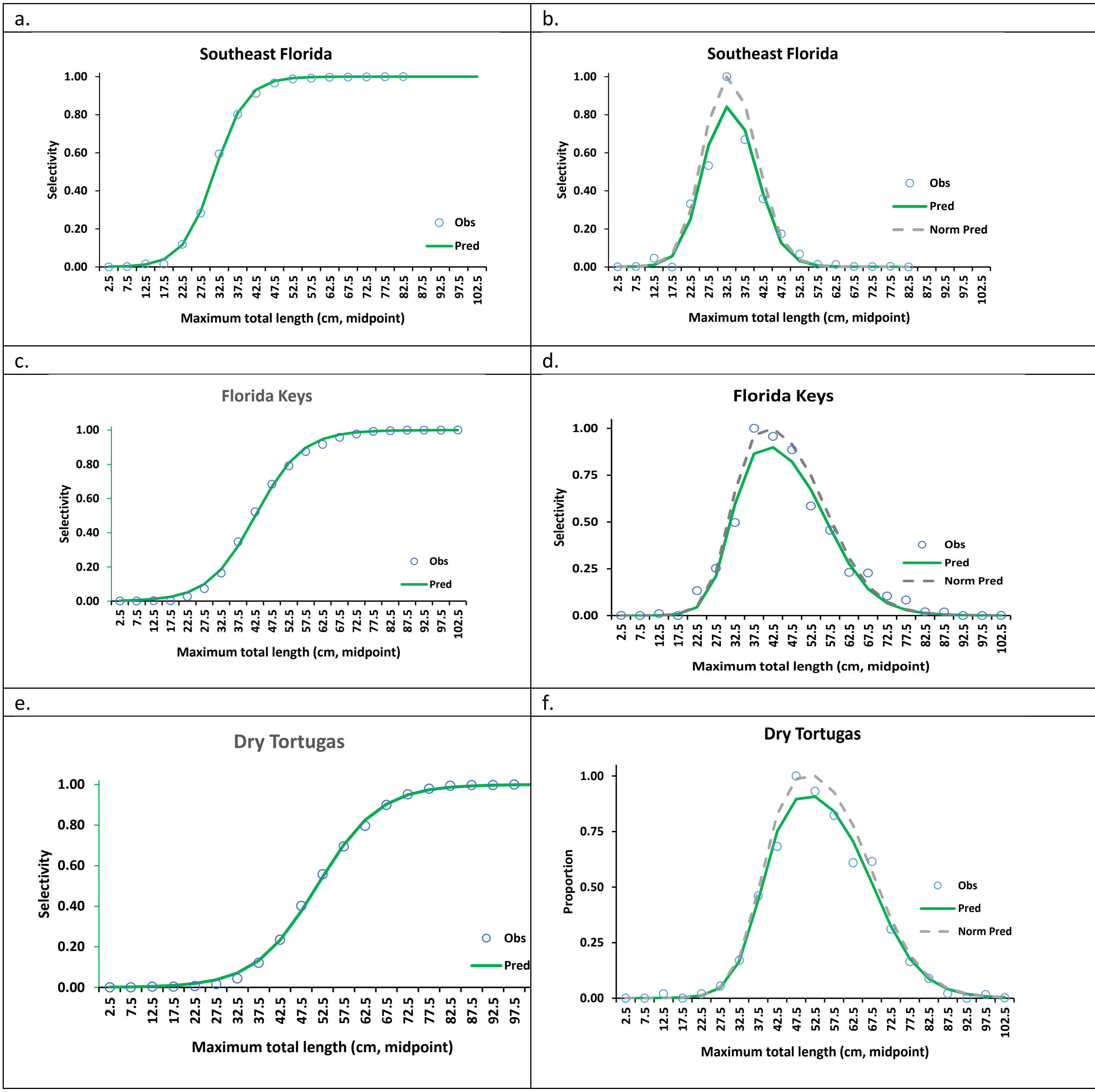


Figure 8. Flat-topped (a - c) and dome-shaped (d - f) selectivities estimated from maximum total length weighted by the regional index of Mutton Snapper observed *in situ* in an imaginary cylinder with a 7.5 m radius. The solid line is the estimated selectivity, the dashed lined is the selectivity normalized to 1.0 and the open circles are the observed values.

a.

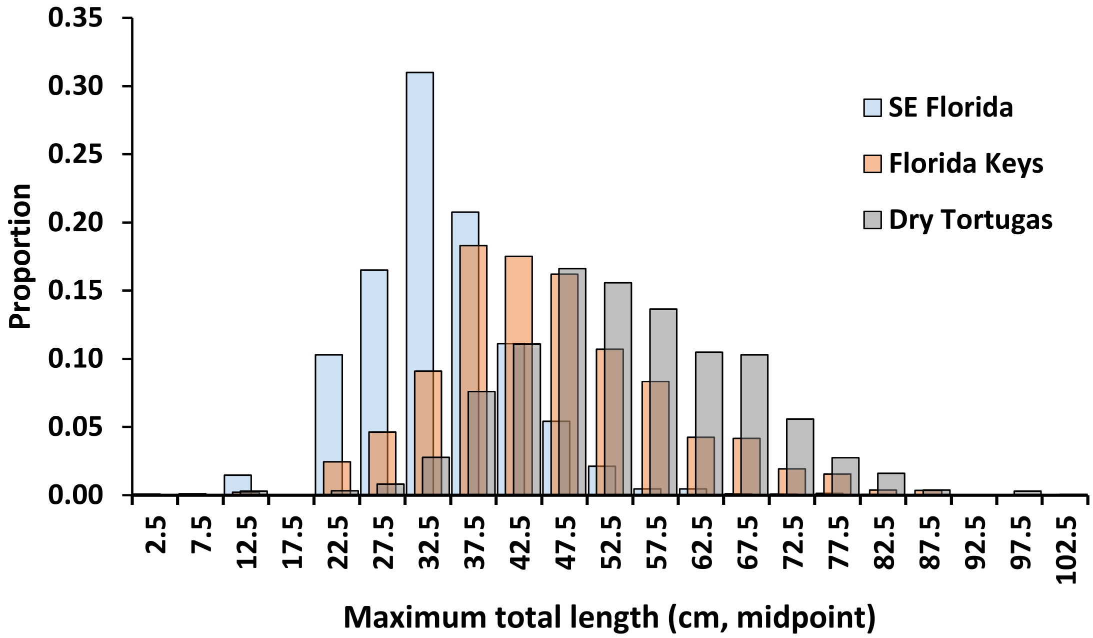


Figure 9. Comparing the diver estimated lengths of Mutton Snapper weighted by regional index.

b.

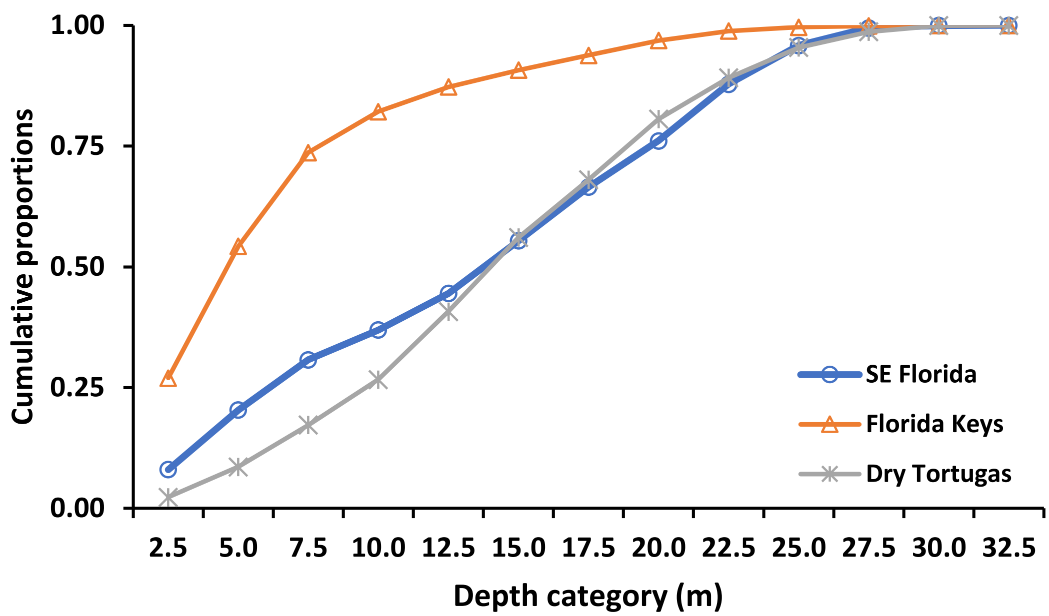
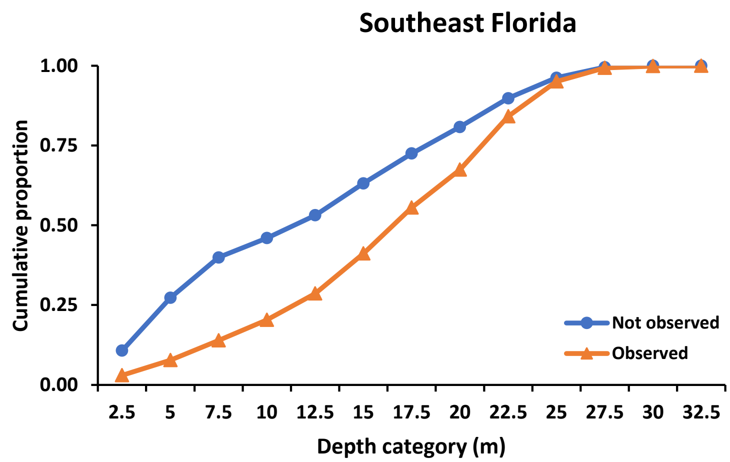
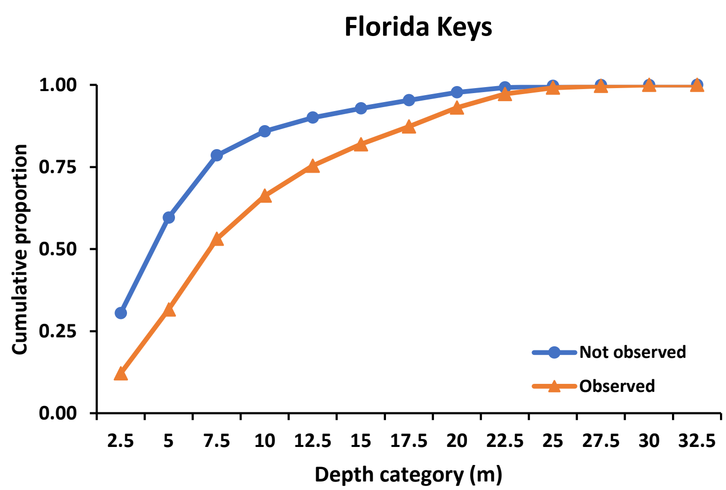


Figure 10. Comparing the proportions of station depths sampled by region.

a. Southeast Florida



b. Florida Keys



c. Dry Tortugas

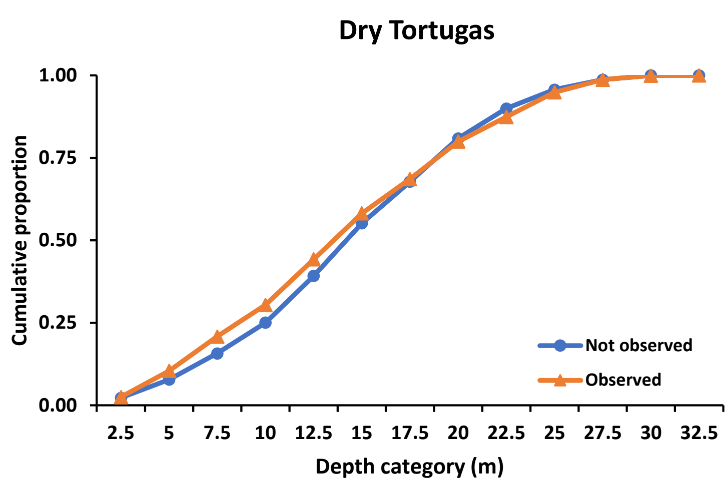


Figure 11. Comparing the depths of stations where Mutton Snapper were observed or not observed by region.