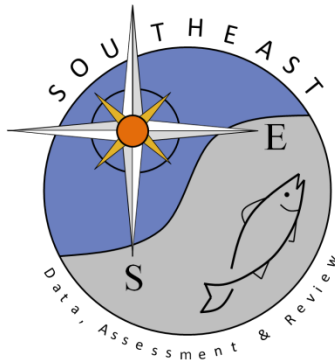


Standardized Reef Visual Census indices for Hogfish, *Lachnolaimus maximus*, for Southeast Florida (2013 - 2024), the Florida Keys (1997 – 2024), and Dry Tortugas (1999 - 2024)

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Standardized Reef Visual Census indices for Hogfish, *Lachnolaimus maximus*, for Southeast Florida (2013 - 2024), the Florida Keys (1997 – 2024), and Dry Tortugas (1999 - 2024)

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Abstract

National Marine Fisheries Service's (NMFS) Reef Visual Census (RVC) began in 1979 with the intent of monitoring reef fish populations 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. The program expanded to the Dry Tortugas in 1999 and the Coral Reef Initiative in Southeast Florida (SEFCRI) began a similar survey in 2013. Prior to region's sampling, sites are randomly selected from the regional gridded sampling frames by habitat from depths of 30 m or less. Separate indices were developed for Southeast Florida, the Florida Keys, and the Dry Tortugas because the lengths of the Hogfish observed in the Dry Tortugas were typically larger than those observed in Southeast Florida and the Florida Keys. Additionally, there were only four years for which sampling occurred in all three 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 Southeast Florida, that started in 2013, generally increased with the highest value in 2024, the index for the Florida Keys increased until 2016 and then declined and then increased with the index value in 2024 being the highest in the series, the index for the Dry Tortugas was variable but stable at a 0.4 level until 2018 when it increased and the index in 2023 was the highest in the time series. None of the coefficients of variation for the three indices exceeded 0.22.

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 fishing 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 imaginary cylinders 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 sampling 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 (Ault *et al.* 2021). 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). The 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 (SEFCRI) began a similar survey in 2013. The RVC data are suitable for developing regional fishery independent indices for Southeast Florida, the Florida Keys, and the Dry Tortugas.

Methods

Data

Within each selected primary_sample_unit (PSU) grid, two sampling stations (secondary sampling units) were randomly selected. At each station, usually two divers separate and then identify the species within their imaginary cylinders (7.5 m radii) as they descend. After five minutes of noting the reef species present, the divers count and estimate the fork lengths of the previously identified reef species. Divers also record water visibility, depth and rugosity (vertical relief).

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 could also be made compatible. Annually, PSUs 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., the RVC data was extracted 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.

The extracted RVC data prior to 2021 do not contain the most recent STRAT variables nor the information (depth and rugosity) needed to apply the current STRAT definitions. However, the current RVC sampling universe, describing station depth and rugosity, is defined within a geodatabase. Using the R package, 'sp', observations for each region were spatially joined to the appropriate regional sampling universe shapefile. An observation was matched to a sampling universe station if its latitude and longitude fell within the spatial bounds of the primary_sample_unit's polygon. Once joined, observations then had the corresponding data to assign depth and rugosity classes and then assign the new STRAT value based on the definitions given in Table 1 by region.

The RVC dataset by station consists of the mean species-counts by length from the divers. Observation rates expressed as the mean number of Hogfish observed per station, were standardized using three methods: a weighted stratified two-stage approach (design model, Smith, et al. 2011), a hurdle or delta procedure (Lo *et al.* 1992, Cragg 1971) or fitting directly to either a Poisson distribution or a negative binomial distribution. The model with the lowest root mean square error was selected for the index.

RVC data were filtered to enhance inter-annual comparability. For example, stations in habitats that were not part of the RVC domain (sand, seagrass, mud, or artificial habitats) were removed. In Southeast Florida (Fig. 1a), data were filtered to include observations from June – October and four additional habitats were removed (aggregated patch reef shallow, scattered coral, rock and sand, and Other); there were 3,809 stations that were in depths to 33 m with a median depth of 16.3 m. The Florida Keys (Fig. 1b) data were filtered to only include observations from June -- September; five habitats (continuous high relief, continuous moderate relief, isolated high relief, rubble moderate-relief, and spur-and-groove moderate relief), stations with depth unknown and rugosity unknown were removed. After filtering the Florida Keys, there were 9,716 stations spanning from 1997 to 2024 in depths to 29 m with a median depth of 6.7 m. In the Dry Tortugas (Fig.1c), only stations that were sampled in months other than May -- July were removed as were stations with unknown rugosity resulting in a final dataset that had 6,379 stations in depths to 33 m with a median depth of 16.5 m.

Analyses

Design model

The design-based index or density of Hogfish was the mean number of Hogfish observed per station by year, and it was estimated using a two-stage sampling scheme that involved estimating the mean number of Hogfish 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 by stratum 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: 2013-2024, Florida Keys: 1997-2024, and Dry Tortugas: 1999-2024); stratum (Southeast Florida: aggregated patch reef deep, colonized pavement deep, colonized pavement shallow, deep ridge complex, linear reef inner and middle, patch reef, linear reef outer, ridge deep, ridge shallow, and spur and groove; Florida Keys: continuous high relief, continuous moderate relief, isolated high relief, rubble moderate-relief, and spur-and-groove moderate relief; 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 STRAT variable from 2020 and later as provided by the rvc function were based on depth and rugosity; thus, depth and rugosity for the earlier years had to be retrieved from the sampling frames as explained previously. The calculations for the design model 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 (Potts and Elith 2006, 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 Hogfish were observed and a submodel with either a gamma or a Poisson with a log link, or log-normal distribution and an identity link to estimate the annual mean number of Hogfish observed at a station where Hogfish were observed, i.e., the number of Hogfish observed at a positive station. The annual index is the product of the proportion of positive stations (**Prop**) and the mean number of Hogfish 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 $prop = \frac{e^{f(x_1+x_2+\dots)}}{1 + e^{f(x_1+x_2+\dots)}}$ and for the Poisson and gamma

distributions (log link) and the log-normal distribution (identity link), the transform was $\hat{Y} = e^{g(x_1+x_2+\dots)}$ where the $x_1, x_2,$ refer to the variables included in the corresponding final, 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: 2013–2024, Florida Keys: 1997–2024, Dry Tortugas: 1999–2024); month (Southeast Florida: June–October; Florida Keys: June–September; and Dry Tortugas: May–July); protected status (1, 0), subregion (Southeast Florida: Miami-Dade, Broward–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); 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_class (< 12 m, 22 – 22 m, > 22 m). Underwater visibility was not considered because of missing years of data. 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 mean 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 any other variable 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 in the other two regions; 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.

Single distribution models

In addition to the three hurdle configurations, the number of Hogfish observed were also fit with negative binomial and Poisson distributions. 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 Hogfish observed per station directly with a single distribution.

Variability

The variability in the estimated annual index values by either the hurdle models or the single distribution models 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 ($\mu=0$, $\sigma=1$). 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 Hogfish came from the binomial distribution and for the stations where Hogfish were observed the predicted values came from the positive 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 Hogfish index was the model configuration with the lowest RMSE.

Lengths and selectivities

Given the tail shape of Hogfish, fork length was the preferred length measurement. The RVC divers estimate fork lengths to the nearest cm *in situ*, however there is a lot of 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.). All the regions used the same

equations to convert any different measurements to fork lengths. Only the lengths from the RVC stations after the data were filtered were used in the length frequencies and selectivities.

Selectivities of the indices were estimated from binned Hogfish lengths after being weighted by the regional indices. If fish of all lengths were visible to the divers, then a flat-topped selectivity would be reasonable. The logistic equation was:

$$sel = \frac{1}{1 + \exp((L50 - L)/slope)} \quad (1)$$

where *sel* was selectivity, *L50* was the length at which 50% of the fish were selected (inflection point, *L* was the length, and the *slope* was a shape coefficient. If only some of the lengths were visible to the divers, then a dome-shaped selectivity would be appropriate. The dome shape would be appropriate if larger fish occurred in depths greater than the 30 m sampling limit. The double logistic equation was

$$sel = \left(\frac{1}{1 + \exp((L50_1 - L)/slope_1)} \right) * \left(1 - \frac{1}{1 + \exp((L50_2 - L)/slope_2)} \right) \quad (2)$$

where *sel* was selectivity, *L50₁* was the ascending length at which 50% of the fish were selected and *L50₂* was the corresponding descending length, *slope₁* and *slope₂* were shape coefficients, and *L* was the fork length in cm. Non-linear regressions were used to estimate the coefficients.

Results and Discussion

Hogfish were not an abundant species on the Florida Keys reef track. Table 2 provides a data summary by region and year of the number of stations; the number of positive stations; the proportion of positive stations; the nominal mean catch rate and its standard deviation (SD), and coefficient of variation (CV); the standardized index and its standard deviation (SD), coefficient of variation (CV), and upper and lower 95% confidence limits; and the standardized index scaled to its mean and its scaled upper and lower 95% confidence limits.

Southeast Florida

From 2013 through 2024, there were a total of 3,809 stations in Southeast Florida and divers observed Hogfish at 1,243 stations or 33% of the stations. The maximum number of Hogfish observed at a single station was 17.5 fish but the 99th percentile of number of Hogfish observed at a station was 5.5 fish and the median was 0.0 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 Hogfish but the other diver did not, the number observed at that station would be recorded as 0.5 Hogfish.

While the six model configurations had similar trends in Southeast Florida, a general increase (Fig. 2a), the model configuration with the lowest RMSE was the hurdle model with the Poisson distribution for the positive stations (RMSE = 0.9052, df = 3378, Table 3a). Diagnostic plots for the probability of seeing a Hogfish at a station submodel are shown in Fig. 3 a, c, and e. The binomial submodel for the hurdle models reduced the mean deviance of the probability of observing at least one Hogfish by 21.3%. The variables selected for the binomial submodel were subregion, habitat, and year. The submodel with the Poisson distribution for estimating the number of Hogfish observed at successful stations reduced the mean deviance by 16.9%. The variables selected

in the final Poisson submodel were habitat, subregion, year, month, depth class, and rugosity class (Table 4a) and the diagnostic plots are in Fig.3 b, d, and f. There were 27 stations (2.2%) that were considered outliers, i.e., stations with mean numbers of Hogfish greater than 5.25 fish.

The Southeast Florida visual index for Hogfish was low, around 0.1 Hogfish per station from 2013- 2016 and then increased in 2018 and has been stable although variable since then with the index in 2024 being the highest (0.33 fish, Table 2a, Fig. 5a). The coefficients of variation were reasonable ranging from 0.13 to 0.18. The standardized index had a similar shape to the nominal index, but the values were lower (Fig. 6a).

The range of weighted fork lengths (FL) of Hogfish estimated by divers in situ was from 3 to 77 cm FL (Fig. 7a). The median size of the Hogfish ($n = 1,801$ fish) was 24 cm FL, and the interquartile range was 20 to 30 cm FL. McBride et al. (2008) estimated the length at which 50% of the female Hogfish are mature at FL 19.2 cm FL; therefore, more than 79% of the observed Hogfish were at least the size of 50% maturity. Given the 99-percentile length of 45.5 cm FL and maximum length of 77 cm FL, 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, 15.6 cm (SE = 0.18 cm) FL, the ascending slope, 1.66 cm (SE = 0.13 cm) FL, the descending inflection point, 32.3 cm (SE = 0.22 cm) FL, and the descending slope, 3.15 cm (SE = 0.19 cm) FL.

Florida Keys

In the Florida Keys after data filtering, Hogfish were observed at 5,302 stations out of 9,616 stations sampled (55%). The maximum mean number of Hogfish observed at a single station in the Florida Keys was 30 fish and the 99th percentile of number of Hogfish observed at a station was 2.5 fish and the median was 0.5 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 = 1.5756, $df = 9,686$, Table 3b). The submodel estimating the probability that at least one diver observed a Hogfish at a station (binomial distribution) reduced the mean deviance by 10.6% and the variables in the final submodel, listed in decreasing order of importance, included habitat, year, and rugosity class (Table 4c). The Poisson model estimating the number of Hogfish observed reduced the deviance by 9.9% and the variables in the final model, listed in decreasing order of importance, included habitat, year, rugosity class (Table, 4d). Diagnostic plots for the probability of observing a Hogfish at a station model are shown in Fig. 4 a, c, and e. There were 73 stations (0.7%) that were considered outliers, i.e., stations with mean numbers observed greater than 1.5 Hogfish.

The Reef Fish Visual Census index for Hogfish observed in the Florida Keys generally increased until 2008 then declined in 2009 until 2012 then the increase resumed. There was a drop in 2018 and 2022 followed by the index's highest value in 2024, the terminal year (1.71 fish observed, Table 2b, Fig. 5b). The coefficients of variation were reasonable, ranging from 0.05 to 0.22. The standardized RVC index had a similar shape to the nominal index although lower except for the 2024 index value (Fig. 6b).

The configuration with the lowest RMSE was the hurdle model with the Poisson distribution, however, the hurdle Gamma model was within 0.002. Figure 2b shows the similarity of the indices estimated by the different configurations using the same data. The model configurations agree that the 2024 index was the Florida Keys' highest value.

Three variables (year, habitat, and rugosity class) were selected in every configuration except the design model (Table 1b) which only considers the STRAT variable and whether the site is situated in a protected area of the

Sanctuary in addition to year. Being included in so many Florida Keys configurations is not surprising because the depths at RVC stations where Hogfish were observed in the Florida Keys typically were deeper (mean = 8.4 m, SD = 4.34 m) than the depths at stations where Hogfish were not observed (mean = 6.9 m, SD = 4.20 m, Two sample Kolmogorov-Smirnov test, $t = 8.31$, $df = 9715$, $P = 1.10e-16$). Figure 1b shows the stations where Hogfish were observed, and these were the more seaward or deeper stations and Fig. 11b compares the cumulative proportions by depth.

The range of fork lengths (FL) of Hogfish estimated by divers *in situ* was from 2.0 to 85.0 cm FL (Fig. 7). The median length of the Hogfish in the Florida Keys ($n = 14,435$ fish) was 23cm FL, and the interquartile range was 18 to 29 cm FL. The estimated length at which 50% of the Hogfish are mature was 19.2 cm FL (McBride et al. 2008); therefore, approximately 72% of the observed Hogfish were at least the size of 50% females maturity. Annual length frequencies are shown in Fig. 8b.

The shape of the selectivity curve for Hogfish or the ability to see the lengths of Hogfish depends upon whether all sizes of Hogfish 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 = 21.6 cm FL and a slope of 4.41 cm FL (Excel Solver solution) would be appropriate (Fig. 9c) but if few larger fish are available to the observers then a dome-shaped curve would be appropriate (ascending inflection = 13.8 cm (SE = 0.20 cm) FL, ascending slope = 1.21 cm (SE = 0.16 cm) FL, descending inflection = 32.6 cm (SE = 0.25 cm) FL and the descending slope = 3.89 cm (SE = 0.22 cm FL)) would be more appropriate (Fig. 9d). Choosing the appropriate selectivity pattern for this region will be a discussion topic throughout the assessment process.

Dry Tortugas

In the Dry Tortugas after data filtering, Hogfish were observed at 2874 out of 6,379 stations (47%). The maximum mean number of Hogfish observed at a single station in the Dry Tortugas was 11 fish but the 99th percentile of number of Hogfish observed at a station was 4.0 fish and the median was 0.0 fish observed per station.

The hurdle Gamma and Poisson configurations had the same fit (RMSE = 0.7030, $df = 6,379$, Table 3c). The binomial submodel of the probability of observing a Hogfish reduced the mean deviance by only 2.9% The Gamma distribution explained more of the mean deviance, 2.0%, as compared to 1.7%. Both submodels included year and habitat and the binomial submodel included year, protected status, and rugosity class 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 Hogfish were observed had a mean depth of 16.0 m which was similar to the mean depth of the stations where Hogfish were not observed (17.1 m). There were 31 stations with means greater than 6.5 Hogfish per station (1.1% outliers).

The RVC index for Hogfish observed in the Dry Tortugas has been increasing since 2006 although variable, the index value for 2023 was the highest of the time series (Table 2c, Fig. 5c). The coefficients of variation were reasonable ranging from 0.053 to 0.089. Not surprising, given the low reduction in deviance by the model, the nominal index had a similar shape although higher values than the standardized RVC index (Fig.6c).

The median size of the Hogfish observed in the Dry Tortugas as estimated by the divers *in situ* was 32 cm FL ($n = 3,645$ fish) with an interquartile range of 24 to 42 cm FL (Fig. 7c). The mean length at which 50% of the Hogfish

are mature was 19.2 cm FL (McBride et al. 2008); thus approximately 88% of the observed Hogfish in the Dry Tortugas were at least the size of 50% female maturity.

Because so many larger fish were observed in the Dry Tortugas, a flat-topped selectivity curve (inflection = 32.8 cm FL and a slope of 8.01 cm FL 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 = 18.5 cm (SE = 0.38 cm) FL, ascending slope = 3.78 cm (SE = 0.35 cm) FL, descending inflection = 49.6 cm (SE = 0.52 cm) FL and the descending slope = 7.22 cm (SE = 0.48 cm) FL) would be more appropriate (Fig. 8f).

Regional Comparisons

The RVC Hogfish indices in the three regions are similar in showing a generally increasing trend in recent years (Fig.5). Trends in the Florida Keys index diverged the most from the Dry Tortugas index in 1999, 2008, 2014, 2016, and 2024 (Fig. 10a). Fish that were observed in Southeast Florida and the Florida Keys were smaller than the fish in the Dry Tortugas (Fig. 10b).

Although there were more shallow water stations (< 15 m) in the Florida Keys than in the other two regions (Fig. 10c), divers at shallower stations in the Florida Keys and In Southeast Florida observed fewer Hogfish than at the deeper stations in those regions (Fig. 11 a and b). While chances of observing a Hogfish 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.

Literature cited

- Ault, J.S., S.G. Smith, J. Luo, J. 2021. Refinement of the southern Florida reef tract benthic habitat map with habitat use patterns of reef fish species. Final CRCP Report 31242.
- Ault, J.S., S.G. Smith, G.A. Meester, J. Luo, J. and A. Bohnsack. 2001. Site Characterization for Biscayne National Park: assessment of fisheries resources and habitats. NOAA Technical Memorandum NMFS-SEFSC-468. 165 pp.
- Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41. 15 pp.
- Bohnsack, J.A., D.B. McClellan, D.E. Harper, G.S. Davenport, G.J. Konoval, A-M. Eklund, J.P. Contillo, S.K. Bolden, P.C. Fishel, G.S. Sandorf, J.C. Javech, M. W. White, M.H. Oickett, M.W. Hulsbeck, J.L. Tobias, J.S. Ault, G. A. Meester, S.G. Smith, and Jiangang Luo. 1999. Baseline data for evaluating reef fish populations in the Florida Keys, 1979-1998. NOAA Technical Memorandum NMFS-SEFSC-427. 63 pp.
- Cochran, W.G. 1977. Sampling techniques. John Wiley and Sons, New York. 428 pp.
- Cragg, J. G. 1971. Some statistical models for limited dependent variables with application to the demand for durable goods. *Econometrica* 39(5):829-844.
- Ingram, Jr., G.W. and D.E. Harper. 2009. Patterns of annual abundance of black grouper and red grouper in the Florida Keys and Dry Tortugas based on reef fish visual census conducted by NOAA NMFS. SEDAR 19-DW-11. SEDAR. North Charleston, SC. 85 pp.
- Lo, N.C.N, L.D. Jacobson, and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on Delta-Lognormal models. *Canadian Journal of Fishery and Aquatic Science* 49:2515-2526.
- Lowerre-Barbieri, S. and C. Friess. 2023. Mutton Snapper reproduction. SEDAR 79 DW 12 SEDAR, North Charleston, SC. 21 pp.
- Maunder, M.N. and A.E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. *Fisheries Research* 70:141 – 159.
- McBride, R>S>, P.E. Thurman, and L.H. Bullock.. 2008. Regional variations of Hogfish (*Lachnolaimus naximus*) life history: consequences for spawning biomass and egg production models. *Journal of Northwest Atlantic Fishery Science* 41: 1–12.
- National Research Council. 1998. Improving fish stock assessments. National Academy Press. Washington, D.C. 177 pp.
- Potts, J. M. and J. Elith. 2006. Comparing species-abundance models. *Ecological Modeling* 199:153-163.
- Smith, S. G., J. S. Ault, J. A. Bohnsack, D. E. Harper, Luo, J, and D. B. McClellan. 2011. Multispecies survey design for assessing reef-fish stocks, spatially explicit management performance, and ecosystem condition. *Fisheries Research* 109:25-41.

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2	Nominal and design-based (i.e., density) mean numbers of Hogfish observed per station by year and region compared to the five model configurations.
3	Diagnostic plots of standardized residuals for the probability of observing a Hogfish 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 positive number of observed Hogfish per station at a station (b, d, and f).
4	Diagnostic plots of standardized residuals for the number of Hogfish observed in the Florida Keys fit with a Poisson distribution (a, c, and e) and the Dry Tortugas (b, d, and f) fit with a Gamma distribution.
5	Box-whisker plots of the visual Hogfish regional indices (mean number observed per station) by region and year.
6	Comparing nominal catch rates (solid line) to model-based mean number of Hogfish observed per station and their confidence intervals (index: blue dots and vertical line: 95% confidence interval) by year and region.
7	Weighted distributions of fork lengths in cm of Hogfish estimated <i>in situ</i> by divers along the Florida reef track from 1997 to 2024 by region (a. Southeast Florida, c. Florida Keys, and e. Dry Tortugas) and the corresponding weighted fork length (FL) in 5-cm bins (b. Southeast Florida, d. Florida Keys, and f. Dry Tortugas).
8	Annual RVC length frequencies from Southeast Florida (a), the Florida Keys (b), and the Dry Tortugas (c).
9	Flat-topped (a - c) and dome-shaped (d - f) selectivities estimated from fork lengths weighted by the regional index of Hogfish observed <i>in situ</i> in an imaginary cylinder with a 7.5 m radius.
10	Comparing the regional indices scaled to their means (a), comparing the cumulative proportions of Hogfish lengths sampled by region (b) and the cumulative proportions of depths sampled (c).
11	Comparing the cumulative proportions of station depths sampled by region.

Table 1. Current STRAT definitions by region.

a. Southeast Florida

Depth Class	Definition
D1	depth<12m
D2	12m<=depth<22m
D3	22m<=depth<33m
Rugosity Class	
R1	substrate average vertical relief<0.15 m
R2	0.15m<=vertical relief<0.26m
R3	0.26m<=vertical relief<0.4m
R4	vertical relief>=0.4 m
RU	vertical relief unknown
Subregion	
13	Broward-Miami
14	Deerfield
15	South Palm Beach
16	North Palm Beach
17	Martin

Final Strat	Subregion	Depth Class	Rugosity Class
NSE01	16 & 17	D1	R1 & R2
NSE02	16 & 17	D1	R3 & R4
NSE03	16 & 17	D2	R1 & R2
NSE04	16 & 17	D2	R3 & R4
NSE05	16 & 17	D3	R1 & R2
NSE06	16 & 17	D3	R3 & R4
SSE01	13 & 14 & 15	D1	R1 & R2
SSE02	13 & 14 & 15	D1	R3 & R4
SSE03	13 & 14 & 15	D2	R1 & R2
SSE04	13 & 14 & 15	D2	R3 & R4
SSE05	13 & 14 & 15	D3	R1 & R2
SSE06	13 & 14 & 15	D3	R3 & R4

Table 1 continued. Current STRAT definitions by region.

b. FL Keys

Depth Class	Definition		
NA	zone_nr=1, 2, 3; all depths		
D1	forereef (zone_nr=4), depth<12m		
D2	forereef, 12m<=depth<22m		
D3	forereef, 22m<=depth<33m		
Rugosity Class			
R1	substrate average vertical relief<0.15 m		
R2	0.15m<=vertical relief<0.26m		
R3	0.26m<=vertical relief<0.4m		
R4	vertical relief>=0.4 m		
RU	vertical relief unknown		
Final Strat	Zone	Depth Class	Rugosity Class
FK01	1	NA	all
FK02	2	NA	all
FK03	3	NA	all
FK04	4	D1	R1 & R2
FK05	4	D1	R3 & R4
FK06	4	D2	R1 & R2
FK07	4	D2	R3 & R4
FK08	4	D2	RU
FK09	4	D3	all

Table 1 continued. Current STRAT definitions by region.

c. Dry Tortugas

Depth Class	Definition
D1	depth<12m
D2	12m<=depth<22m
D3	22m<=depth<33m
Rugosity Class	
R1	substrate average vertical relief<0.15 m
R2	0.15m<=vertical relief<0.26m
R3	0.26m<=vertical relief<0.4m
R4	vertical relief>=0.4 m
RU	vertical relief unknown

Final Strat	Depth Class	Rugosity Class
DT01	D1	R1 & R2
DT02	D1	R3 & R4
DT03	D1	RU
DT04	D2	R1 & R2
DT05	D2	R3 & R4
DT06	D2	RU
DT07	D3	R1 & R2
DT08	D3	R3 & R4
DT09	D3	RU

Table 2. The number of stations, number of positive stations, proportion positive, nominal and standardized indices and their standard deviations (SD) and coefficients of variation (CV), and the standardized index for Hogfish scaled to its mean by year and region.

a. Southeast Florida

Year	Num Sampling Events	Num Positive	Prop Positive	Nominal Mean	Nominal SD	Nominal CV	Std Index	Std SD	Std CV	Std Low 95	Std Up 95	Scaled Std Index	Scaled Std Low 95	Scaled Std Up 95
1997														
1998														
1999														
2000														
2001														
2002														
2003														
2004														
2005														
2006														
2007														
2008														
2009														
2010														
2011														
2012														
2013	1050	308	0.293	0.44	0.034	0.078	0.12	0.016	0.130	0.092	0.153	0.82	0.627	1.039
2014	565	160	0.283	0.31	0.027	0.088	0.08	0.012	0.155	0.056	0.102	0.52	0.379	0.692
2015	417	102	0.245	0.34	0.041	0.121	0.10	0.018	0.177	0.069	0.138	0.68	0.472	0.941
2016	462	145	0.314	0.43	0.045	0.104	0.11	0.017	0.155	0.082	0.150	0.77	0.559	1.023
2017														
2018	458	184	0.402	0.62	0.055	0.089	0.24	0.033	0.137	0.183	0.310	1.63	1.242	2.106
2019														
2020														
2021	283	95	0.336	0.42	0.056	0.134	0.15	0.026	0.172	0.105	0.206	1.02	0.714	1.398
2022	293	117	0.399	0.58	0.074	0.128	0.18	0.028	0.158	0.130	0.238	1.21	0.884	1.620
2023														
2024	281	132	0.470	0.9	0.131	0.145	0.33	0.049	0.149	0.242	0.433	2.25	1.647	2.944

Table 2 continued. The number of stations, number of positive stations, nominal and standardized indices and their standard deviations (SD) and coefficients of variation (CV), and the standardized index for Hogfish scaled to its mean by year and region.

b. Florida Keys

Year	Num Sampling Events	Num Positive	Prop Positive	Nominal Mean	Nominal SD	Nominal CV	Std Index	Std SD	Std CV	Std Low 95	Std Up 95	Scaled Std Index	Scaled Std Low 95	Scaled Std Up 95
1997	288	63	0.219	0.21	0.031	0.147	0.17	0.030	0.176	0.119	0.237	0.195	0.135	0.269
1998	213	45	0.211	0.17	0.028	0.163	0.17	0.037	0.217	0.110	0.256	0.195	0.125	0.291
1999	344	89	0.259	0.36	0.044	0.122	0.28	0.038	0.136	0.210	0.357	0.314	0.239	0.406
2000	393	158	0.402	0.69	0.061	0.088	0.54	0.051	0.095	0.451	0.651	0.618	0.512	0.739
2001	587	213	0.363	0.71	0.065	0.091	0.60	0.046	0.077	0.513	0.694	0.681	0.582	0.788
2002	410	227	0.554	0.90	0.095	0.105	0.74	0.056	0.076	0.637	0.860	0.842	0.723	0.976
2003	356	196	0.551	0.93	0.097	0.104	0.87	0.065	0.075	0.748	1.004	0.989	0.850	1.139
2004	187	113	0.604	1.03	0.126	0.122	0.97	0.092	0.095	0.803	1.165	1.107	0.911	1.323
2005	443	244	0.551	1.04	0.090	0.087	0.86	0.059	0.069	0.747	0.981	0.977	0.849	1.113
2006	441	211	0.478	0.85	0.077	0.09	0.75	0.056	0.074	0.642	0.861	0.849	0.729	0.978
2007	571	332	0.581	0.96	0.075	0.078	0.83	0.050	0.06	0.740	0.937	0.947	0.840	1.064
2008	612	410	0.670	1.46	0.082	0.056	1.29	0.062	0.048	1.171	1.411	1.462	1.329	1.602
2009	909	553	0.608	1.11	0.061	0.055	0.92	0.042	0.046	0.843	1.009	1.049	0.957	1.146
2010	494	284	0.575	0.89	0.065	0.073	0.73	0.050	0.068	0.640	0.833	0.832	0.727	0.946
2011	693	418	0.603	0.89	0.049	0.055	0.79	0.043	0.054	0.713	0.881	0.902	0.809	1.001
2012	620	424	0.684	1.19	0.065	0.055	0.97	0.050	0.052	0.875	1.074	1.105	0.993	1.220
2013														
2014	579	341	0.589	1.38	0.101	0.073	1.21	0.063	0.052	1.094	1.341	1.378	1.242	1.522
2015														
2016	526	317	0.603	1.62	0.109	0.067	1.42	0.077	0.054	1.269	1.568	1.607	1.441	1.781
2017														
2018	600	407	0.678	1.09	0.058	0.053	1.06	0.053	0.05	0.960	1.168	1.205	1.090	1.326
2019														
2020														
2021														
2022	201	113	0.562	0.77	0.073	0.095	0.86	0.089	0.103	0.697	1.044	0.978	0.791	1.185
2023														
2024	249	144	0.578	1.21	0.240	0.198	1.71	0.127	0.074	1.478	1.972	1.944	1.678	2.239

Table 2 continued. The number of stations, number of positive stations, nominal and standardized indices and their standard deviations (SD) and coefficients of variation (CV), and the standardized index for Hogfish scaled to its mean by year and region.

c. Dry Tortugas

Year	Num Sampling Events	Num Positive	Prop Positive	Nominal Mean	Nominal SD	Nominal CV	Std Index	Std SD	Std CV	Std Low 95	Std Up 95	Scaled Std Index	Scaled Std Low 95	Scaled Std Up 95
1997														
1998														
1999	312	144	0.462	0.59	0.055	0.092	0.53	0.045	0.084	0.449	0.624	1.20	1.010	1.402
2000	344	146	0.424	0.49	0.051	0.105	0.39	0.034	0.088	0.324	0.456	0.87	0.728	1.024
2001														
2002														
2003														
2004	572	232	0.406	0.48	0.035	0.072	0.40	0.029	0.072	0.348	0.460	0.90	0.782	1.034
2005														
2006	482	173	0.359	0.34	0.029	0.084	0.27	0.023	0.084	0.228	0.316	0.61	0.512	0.711
2007														
2008	653	254	0.389	0.46	0.033	0.071	0.37	0.026	0.070	0.324	0.425	0.84	0.728	0.955
2009														
2010	687	298	0.434	0.47	0.029	0.061	0.39	0.024	0.063	0.340	0.435	0.87	0.765	0.979
2011														
2012	716	383	0.535	0.62	0.033	0.053	0.53	0.028	0.053	0.477	0.587	1.19	1.072	1.320
2013														
2014	692	310	0.448	0.47	0.028	0.059	0.38	0.024	0.062	0.338	0.432	0.86	0.760	0.971
2015														
2016	511	216	0.423	0.46	0.041	0.089	0.37	0.027	0.075	0.315	0.422	0.82	0.707	0.948
2017														
2018	640	354	0.553	0.59	0.030	0.052	0.52	0.028	0.053	0.468	0.576	1.17	1.052	1.295
2019														
2020														
2021	292	164	0.562	0.71	0.059	0.083	0.65	0.050	0.077	0.559	0.755	1.47	1.257	1.697
2022														
2023	299	190	0.635	0.78	0.052	0.066	0.71	0.050	0.070	0.618	0.814	1.60	1.388	1.829
2024	179	110	0.615	0.61	0.055	0.090	0.57	0.051	0.089	0.473	0.671	1.27	1.064	1.509

Table 3. Reef Visual Census assessment model regional selection using the root mean square error.

a. Southeast Florida

Configuration	Variables selected	Number of observations	Model Degrees of freedom	Total Degrees of freedom	Root mean square error
Hurdle Poisson	Year, Month, Subregion_nr, Habitat_cd, Depth_class, and Rugosity class	3809	30	3778	0.9052
Hurdle Gamma	Habitat_cd, Subregion_nr, Year, and Depth_class	3809	23	3785	0.9191
Poisson	Subregion_nr, Habitat_cd, and Year	3809	28	3780	1.0237
Negative binomial	Subregion_nr, Habitat_cd, and Year	3809	24	3784	1.0284
Density	Year, Strat, and Prot	3809	22	3786	1.0831
Hurdle log-normal	Year, Habitat_cd, and Subregion_nr	3809	21	3787	1.2021

b. Florida Keys

Hurdle Poisson	Year and Habitat_cd	9716	29	9686	1.5756
Hurdle Gamma	Year and Habitat_cd	9716	25	9690	1.5774
Density	Year, Strat, and Prot	9716	28	9687	1.7258
Poisson	Habitat_cd, Year, Rugosity_class, and Depth_class	9716	30	9685	1.7456
Negative binomial	Habitat_cd, Year, Rugosity_class, and Depth_class	9716	29	9686	1.7486
Hurdle log-normal	Year and Habitat_cd	9716	28	9687	1.7573

c. Dry Tortugas

Hurdle Gamma	Year and habitat_cd	6379	20	6359	0.7030
Hurdle Poisson	Habitat_cd and year	6379	20	6359	0.7030
Hurdle log-normal	Year and habitat_cd	6379	20	6359	0.7195
Density	Year, strat, and prot	3003	21	2982	0.7630
Poisson	Year, habitat_cd, prot, habitat, and rugosity_class	6379	25	6354	0.8243
Negative binomial	Year, habitat_cd, prot, habitat, and rugosity_class	6379	25	6354	0.8243

Table 4. Stepwise selection of variables for their inclusion in estimating the probability of observing a Hogfish at a Southeast Florida station (shaded lines) with a generalized linear model (binomial distribution with a 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.

a. Southeast Florida Binomial distribution with logit 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	3808	4811.15	1.263	.	.	.	.	Conv	
Subregion_nr	3804	4156.38	1.093	4	654.77	0	13.52	Conv	13.52
Habitat_cd	3798	4272.32	1.125	10	538.83	0	10.97	Conv	
Depth_class	3806	4622.02	1.214	2	189.13	0	3.881	Conv	
Rugosity_class	3805	4640.78	1.220	3	170.37	0	3.465	Conv	
Year	3801	4744.03	1.248	7	67.12	0	1.214	Conv	
Month	3804	4767.35	1.253	4	43.80	0	0.806	Conv	
Subregion_nr and habitat_cd	3794	3855.73	1.016	10	300.65	0	6.044	Conv	19.564
Subregion_nr and depth_class	3802	3906.31	1.027	2	250.07	0	5.161	Conv	
Subregion_nr and rugosity_class	3801	4033.95	1.061	3	122.43	0	2.481	Conv	
Subregion_nr and year	3797	4057.30	1.069	7	99.09	0	1.91	Conv	
Subregion_nr and month	3800	4154.61	1.093	4	1.77	0.778	-0.05	Conv	
Subregion_nr habitat_cd year	3787	3766.74	0.995	7	88.99	0	1.71	Conv	21.28
Subregion_nr habitat_cd rugosity_class	3791	3822.01	1.008	3	33.73	2E-07	0.64	Conv	
Subregion_nr habitat_cd depth_class	3792	3837.32	1.012	2	18.42	0.0001	0.34	Conv	
Subregion_nr habitat_cd month	3790	3849.52	1.016	4	6.22	0.184	0.05	Conv	

Table 4 continued. Stepwise selection of variables for their inclusion in estimating the number of Hogfish observed at a Southeast Florida station (shaded lines) with a generalized linear model (Poisson distribution with a log 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.

b. Southeast Florida 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	1242	1448.67	1.166	.	.	.	.	Conv	
Habitat_cd	1232	1326.4	1.077	10	122.27	0	7.7	Conv	7.7
Subregion_nr	1238	1384.07	1.118	4	64.6	0	4.15	Conv	
Depth_class	1240	1392.82	1.123	2	55.84	0	3.7	Conv	
Rugosity_class	1239	1413.21	1.141	3	35.46	0	2.21	Conv	
Year	1235	1409.1	1.141	7	39.57	0	2.18	Conv	
Month	1238	1425.83	1.152	4	22.84	0.0001	1.26	Conv	
Habitat_cd and subregion_nr	1228	1254.38	1.021	4	72.02	0	4.73	Conv	12.42
Habitat_cd and year	1225	1284.94	1.049	7	41.46	0	2.37	Conv	
Habitat_cd and month	1228	1306.03	1.064	4	20.37	0.0004	1.12	Conv	
Habitat_cd and rugosity_class	1229	1310.54	1.066	3	15.86	0.0012	0.88	Conv	
Habitat_cd and depth_class	1230	1312.72	1.067	2	13.68	0.0011	0.8	Conv	
Habitat_cd, subregion_nr, and year	1221	1212.97	0.993	7	41.41	0	2.41	Conv	14.83
Habitat_cd, subregion_nr, and rugosity_class	1225	1240.19	1.012	3	14.2	0.0027	0.78	Conv	
Habitat_cd, subregion_nr, and month	1224	1240.86	1.014	4	13.52	0.009	0.66	Conv	
Habitat_cd, subregion_nr, and depth_class	1226	1243.11	1.014	2	11.27	0.0036	0.65	Conv	
Habitat_cd, subregion_nr, year, and month	1217	1197.85	0.984	4	15.12	0.0045	0.79	Conv	15.62
Habitat_cd, subregion_nr, year and depth_class	1219	1200.40	0.985	2	12.58	0.0019	0.75	Conv	
Habitat_cd, subregion_nr, year and rugosity_class	1218	1202.02	0.987	3	10.96	0.0120	0.56	Conv	
Habitat_cd, subregion_nr, year, month, and depth_class	1215	1185.47	0.976	2	12.38	0.0020	0.74	Conv	16.36
Habitat_cd, subregion_nr, year, month, and rugosity_class	1214	1187.20	0.978	3	10.65	0.0138	0.54	Conv	
habitat_cd subregion_nr year month depth_class rugosity_class	1212	1175.18	0.970	3	10.29	0.0163	0.52	Conv	16.87

Table 4 continued. Stepwise selection of variables for their inclusion in estimating the probability of observing a Hogfish at a Florida Keys station (shaded lines) with a generalized linear model (binomial distribution and logit link). 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. Florida Keys Binomial distribution with a logit 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	9715	13387.96	1.378	.	.	.	.	Conv	
Habitat_cd	9710	12581.55	1.296	5	806.41	0	5.98	Conv	5.98
Year	9695	12746.42	1.315	20	641.55	0	4.60	Conv	
Prot	9714	13160.02	1.355	1	227.94	0	1.69	Conv	
Rugosity_class	9712	13175.54	1.357	3	212.42	0	1.56	Conv	
Depth_class	9714	13301.43	1.369	1	86.53	0	0.64	Conv	
Subregion_nr	9712	13340.27	1.374	3	47.70	0	0.33	Conv	
Month	9712	13380.21	1.378	3	7.75	0.051	0.03	Conv	
Habitat_cd and year	9690	12066.71	1.245	20	514.84	0	3.66	Conv	9.64
Habitat_cd and depth_class	9709	12505.22	1.288	1	76.33	0	0.56	Conv	
Habitat_cd and rugosity_class	9707	12522.94	1.290	3	58.61	0	0.41	Conv	
Habitat_cd and prot	9709	12538.89	1.291	1	42.66	0	0.31	Conv	
Habitat_cd and month	9707	12569.03	1.295	3	12.52	0.006	0.07	Conv	
Habitat_cd and subregion_nr	9707	12571.30	1.295	3	10.25	0.017	0.05	Conv	
Habitat_cd year and rugosity_class	9687	11937.65	1.232	3	129.06	0	0.94	Conv	10.58
Habitat_cd year and prot	9689	12041.61	1.243	1	25.10	5E-07	0.18	Conv	
Habitat_cd year and depth_class	9689	12041.94	1.243	1	24.77	6E-07	0.18	Conv	
Habitat_cd year and month	9687	12045.84	1.244	3	20.87	0.0001	0.13	Conv	
Habitat_cd year and subregion_nr	9687	12046.80	1.244	3	19.91	0.0002	0.12	Conv	

Table 4 continued. Stepwise selection of variables for their inclusion in estimating the number of Hogfish observed at a Florida Keys station (shaded lines) with a generalized linear model (Poisson distribution and log link). 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.

d. 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	5301	7810.40	1.473	.	.	.	.	Conv	
Habitat_cd	5296	7426.88	1.402	5	383.52	0	4.82	Conv	4.82
Year	5281	7458.55	1.412	20	351.85	0	4.14	Conv	
Rugosity_class	5298	7483.30	1.412	3	327.11	0	4.13	Conv	
Subregion_nr	5298	7733.23	1.460	3	77.18	0	0.93	Conv	
Prot	5300	7737.66	1.460	1	72.74	0	0.91	Conv	
Month	5298	7764.91	1.466	3	45.49	0	0.53	Conv	
Depth_class	5300	7809.33	1.473	1	1.07	0.30	-0.01	Conv	
Habitat_cd and year	5276	7118.33	1.349	20	308.55	0	3.61	Conv	8.43
Habitat_cd and rugosity_class	5293	7309.71	1.381	3	117.17	0	1.45	Conv	
Habitat_cd and subregion_nr	5293	7369.61	1.392	3	57.26	0	0.68	Conv	
Habitat_cd and month	5293	7392.71	1.397	3	34.17	2E-07	0.38	Conv	
Habitat_cd and depth_class	5295	7405.05	1.398	1	21.83	0.000	0.26	Conv	
Habitat_cd and prot	5295	7413.39	1.400	1	13.48	0.000	0.16	Conv	
Habitat_cd, year, and rugosity_class	5273	6996.85	1.327	3	121.48	0	1.51	Conv	9.94
Habitat_cd, year, and subregion_nr	5273	7064.02	1.340	3	54.31	0	0.65	Conv	
Habitat_cd, year, and depth_class	5275	7098.00	1.346	1	20.33	6.5E-06	0.24	Conv	
Habitat_cd, year, and month	5273	7099.25	1.346	3	19.08	0.000	0.19	Conv	
Habitat_cd, year, and prot	5275	7108.37	1.348	1	9.95	0.002	0.11	Conv	

Table 4 continued. Stepwise selection of variables for their inclusion in estimating the probability of observing a Hogfish at a Dry Tortugas station (shaded lines) with a generalized linear model (binomial distribution and logit link). 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.

e. Dry Tortugas 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	6113	8436.17	1.380	.	.	.	.	Conv	
Year	6102	8312.02	1.362	11	124.15	0	1.29	Conv	1.29
Habitat_cd	6106	8372.25	1.371	7	63.92	0	0.64	Conv	
Month	6111	8386.44	1.372	2	49.73	0	0.56	Conv	
Subregion_nr	6112	8395.55	1.374	1	40.62	0	0.47	Conv	
Rugosity_class	6110	8399.89	1.375	3	36.28	1E-07	0.38	Conv	
Depth_class	6111	8403.82	1.375	2	32.35	1E-07	0.35	Conv	
Prot	6111	8419.81	1.378	2	16.36	0.0003	0.16	Conv	
Year and prot	6100	8252.53	1.353	2	59.49	0	0.67	Conv	1.97
Year and habitat_cd	6095	8246.20	1.353	7	65.81	0	0.67	Conv	
Year and subregion_nr	6101	8260.69	1.354	1	51.33	0	0.59	Conv	
Year and depth_class	6100	8275.60	1.357	2	36.42	0	0.40	Conv	
Year and rugosity_class	6099	8274.31	1.357	3	37.71	0	0.40	Conv	
Year and month	6100	8307.09	1.362	2	4.93	0.085	0.03	Conv	
Year, prot, and habitat_cd	6093	8197.84	1.345	7	54.69	0	0.54	Conv	2.51
Year, prot, and rugosity_class	6097	8219.21	1.348	3	33.32	3E-07	0.35	Conv	
Year, prot, and depth_class	6098	8241.93	1.352	2	10.61	0.005	0.09	Conv	
Year, prot, and subregion_nr	6099	8247.45	1.352	1	5.09	0.024	0.04	Conv	
Year, prot, and month	6098	8246.34	1.352	2	6.19	0.045	0.04	Conv	

Table 4 continued. Stepwise selection of variables for their inclusion in estimating the number of Hogfish observed at a Dry Tortugas station (shaded lines) with a generalized linear model (Gamma distribution and log link). 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.

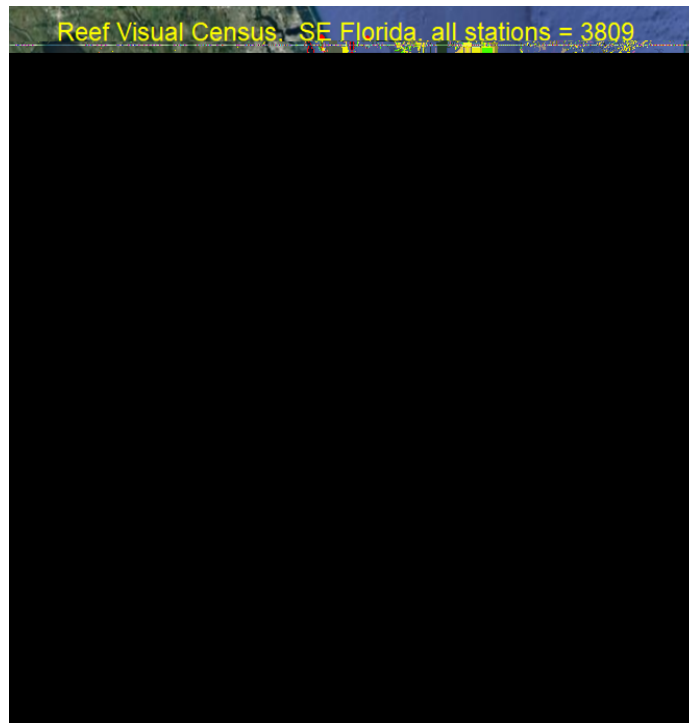
f. Dry Tortugas Gamma distribution with a log link

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	2810	2321.15	0.826	.	.	.	.	Conv	
Year	2799	1993.44	0.712	11	327.71	0	13.78	Conv	13.78
Month	2808	2283.98	0.813	2	37.17	0	1.53	Conv	
Prot	2808	2295.69	0.818	2	25.47	0.000003	1.03	Conv	
Habitat_cd	2803	2292.10	0.818	7	29.06	0.000	1.01	Conv	
Depth_class	2808	2308.02	0.822	2	13.14	0.001	0.50	Conv	
Rugosity_class	2807	2310.38	0.823	3	10.78	0.013	0.36	Conv	
Subregion_nr	2809	2316.56	0.825	1	4.59	0.032	0.16	Conv	
Year and habitat_cd	2792	1964.20	0.704	7	29.24	0.000	1.05	Conv	14.83
Year and depth_class	2797	1984.90	0.710	2	8.54	0.014	0.31	Conv	
Year and subregion_nr	2798	1985.68	0.710	1	7.76	0.005	0.31	Conv	
Year and prot	2797	1988.59	0.711	2	4.85	0.088	0.15	Conv	
Year and month	2797	1989.95	0.711	2	3.49	0.174	0.09	Conv	
Year and rugosity_class	2796	1990.56	0.712	3	2.88	0.411	0.03	Conv	

Table 5. Percent reduction in model mean deviance by the final regional models of the positive observations. The fields include the configuration, the variables selected in the final model include the model degrees of freedom, total degrees of freedom, residual deviance, mean deviance, the percent reduction in deviance, the model configuration and dispersion term.

a. Southeast Florida								
Factor	Df	Resid. Df	Resid. Dev	Mean Deviance	% Deviance Reduced	Family	Dispersion	
NULL	1	1242	1448.67	1.166	-			
Habitat_cd	10	1232	1326.4	1.077	7.70%			
Subregion_nr	4	1228	1254.38	1.021	4.73%	Hurdle	0.849	
Year	7	1221	1212.97	0.993	2.41%	Poisson		
Month	4	1217	1197.85	0.984	0.79%			
Depth_Class	2	1215	1185.47	0.976	0.73%			
Rugosity_Class	3	1212	1175.18	0.970	0.52%			
					16.87%			
Florida Keys								
Factor	Df	Resid. Df	Resid. Dev	Mean Deviance	% Deviance Reduced	Family	Dispersion	
NULL	1	5301	7810.40	1.473	-			
Habitat_cd	5	5296	7426.88	1.402	4.82%	Hurdle	1.273	
Year	20	5276	7118.33	1.349	14.77%	Poisson		
Rugosity Class	3	5273	6996.85	1.327	6.19%			
					25.78%			
Dry Tortugas								
Factor	Df	Resid. Df	Resid. Dev	Mean Deviance	% Deviance Reduced	Family	Dispersion	
NULL	1	2810	2321.15	0.826	-			
Year	11	2799	1993.44	0.712	13.78%	Hurdle		
Habitat_cd	7	2792	1964.20	0.704	1.05%	Poisson	0.711	
					14.83%			

a. Southeast Florida Coral Reef Initiative (2013 – 2024)

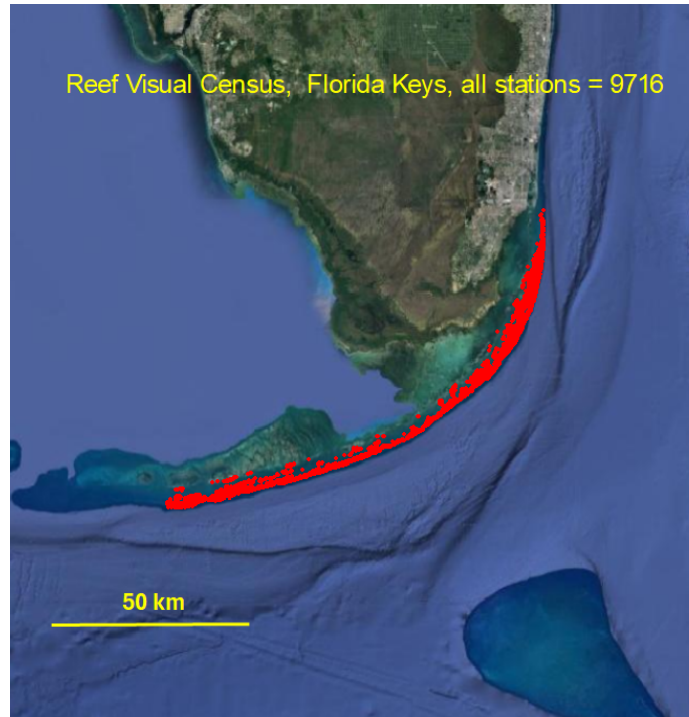


b.



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

c. Florida Keys (1997 – 2024)



d.

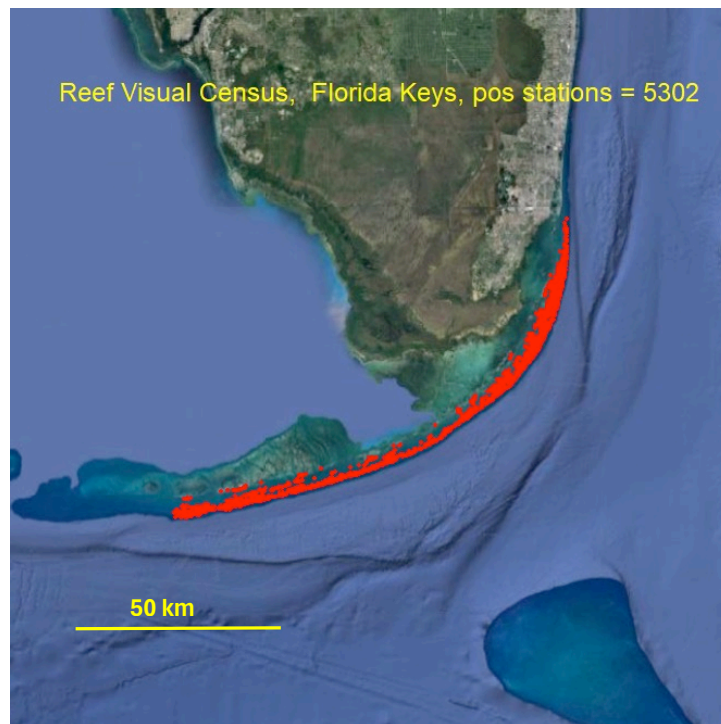
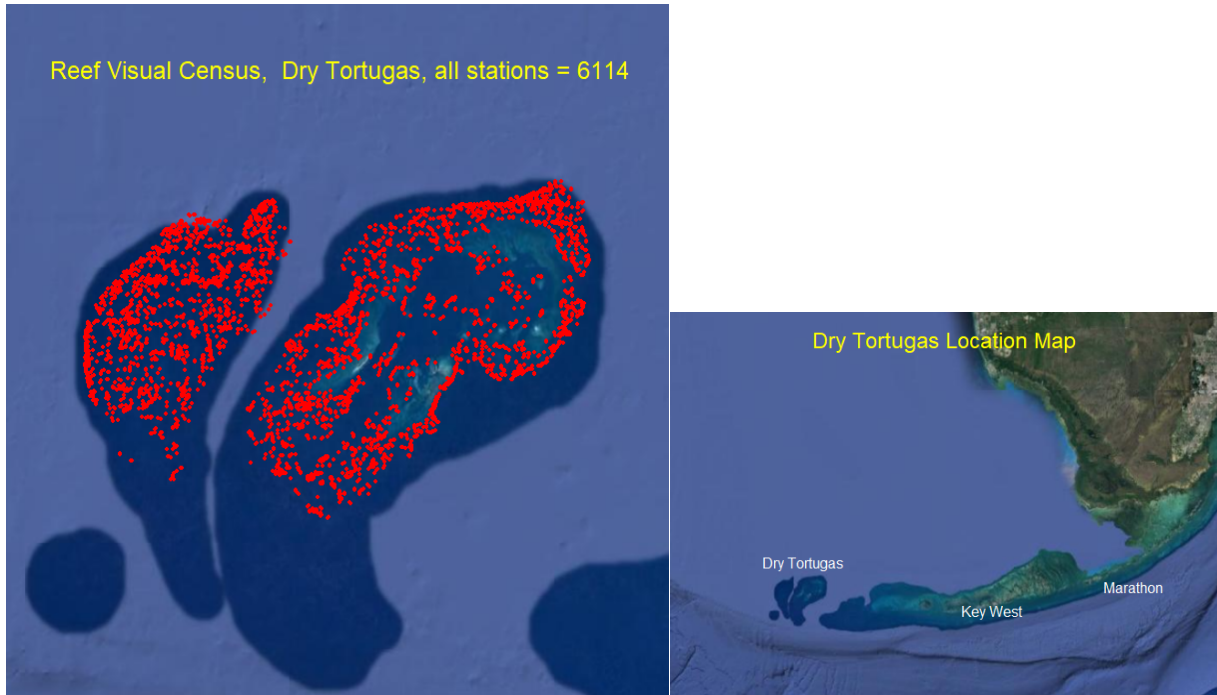


Figure 1 continued. Station locations (red dots) sampled by region (a, c, e) and the stations where divers observed Hogfish (b, d, f).

a. Dry Tortugas (1999 – 2021)



f.

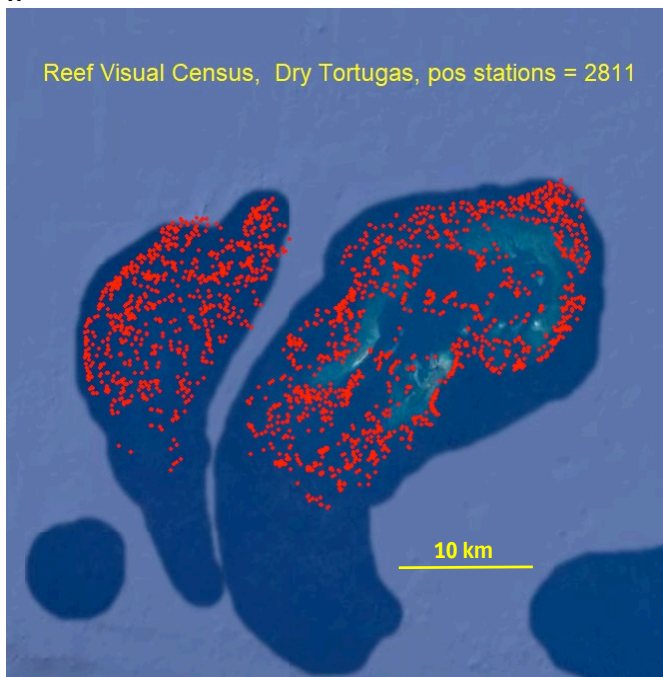
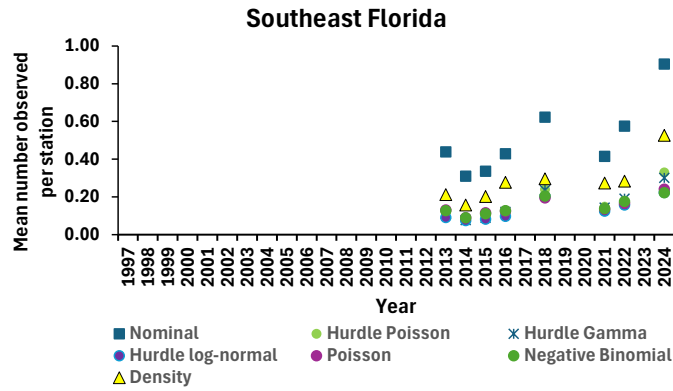
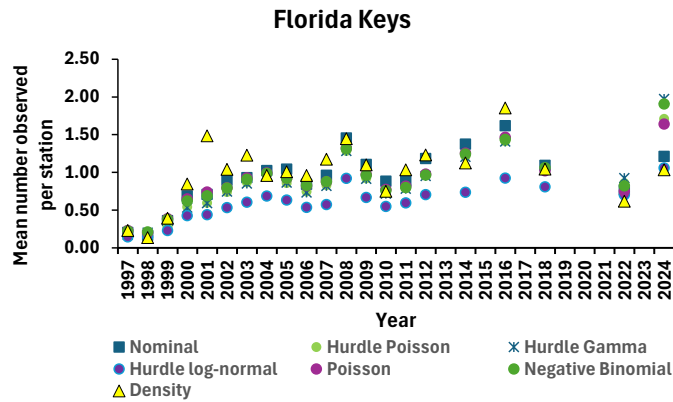


Figure 1 continued. Station locations (red dots) sampled by region (a, c, e) and the stations where divers observed Hogfish (b, d, f).

a.



b.



c.

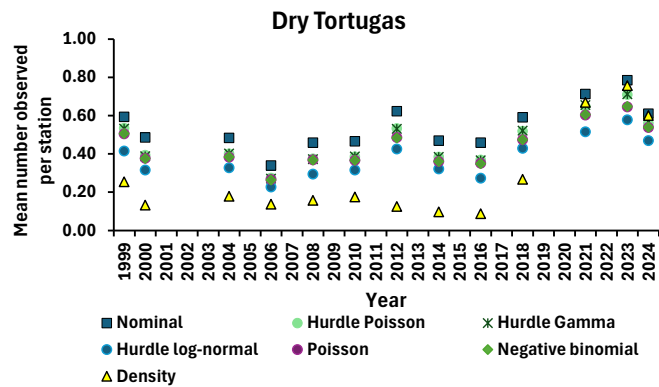


Figure 2. Nominal and design-based (i.e., density) mean numbers of Hogfish observed per station by year and region compared to the five model configurations.

Southeast Florida

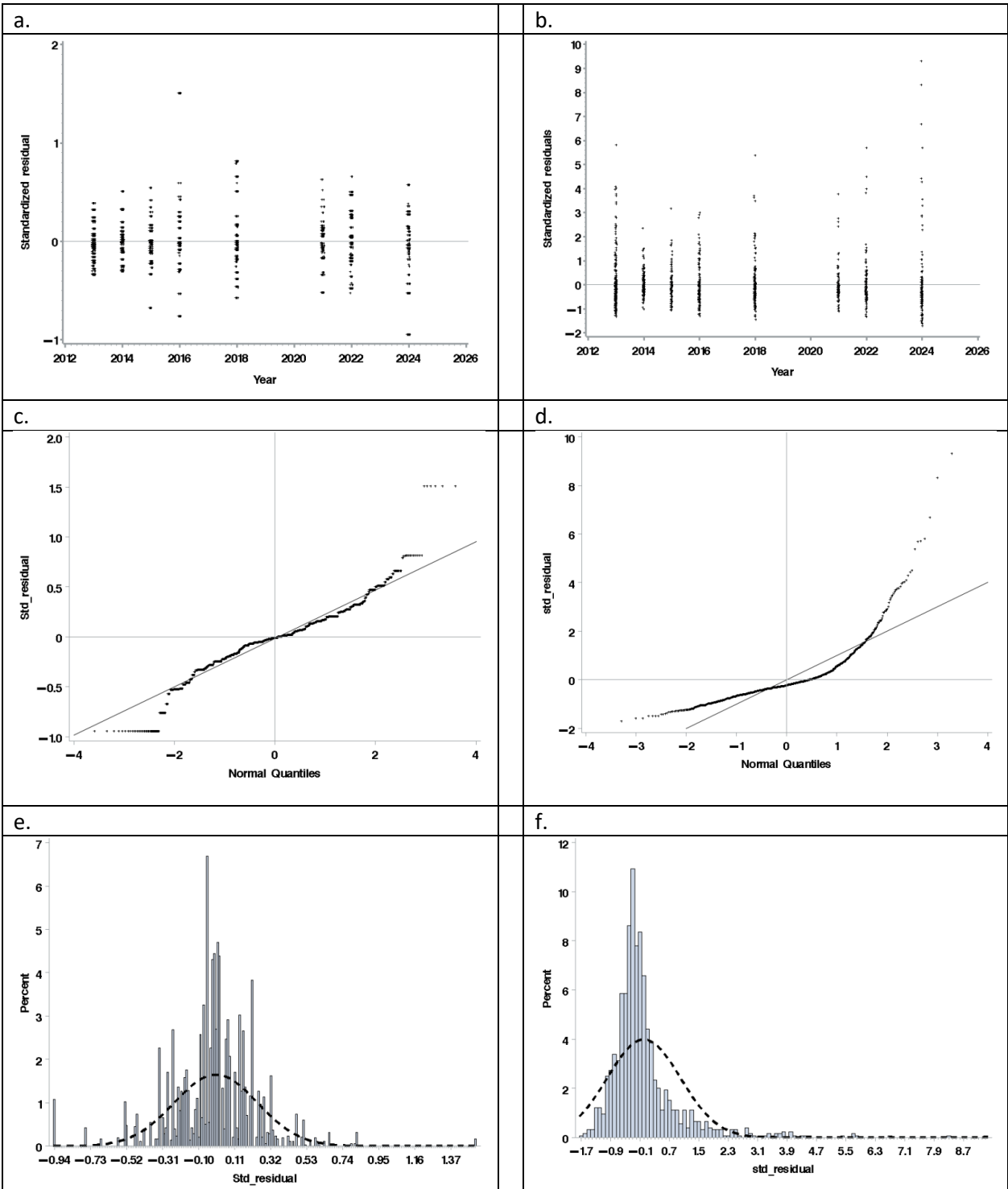


Figure 3. Diagnostic plots of standardized residuals for the probability of observing a Hogfish in Southeast Florida fit using a binomial distribution, (a, c, and e) and diagnostics plots of standardized residuals from a Poisson distribution fit to the positive number of observed Hogfish per station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

Florida Keys

Dry Tortugas

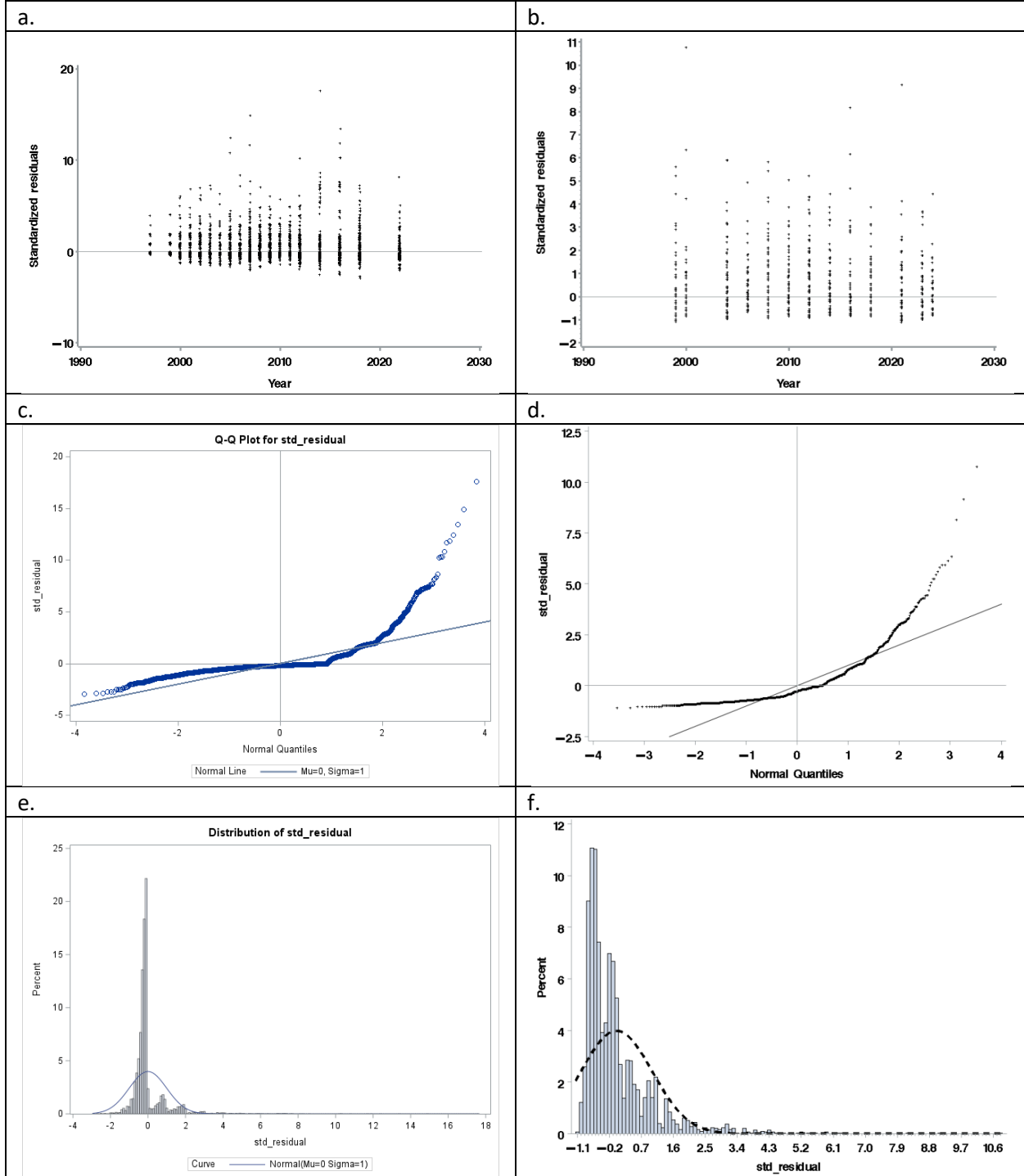
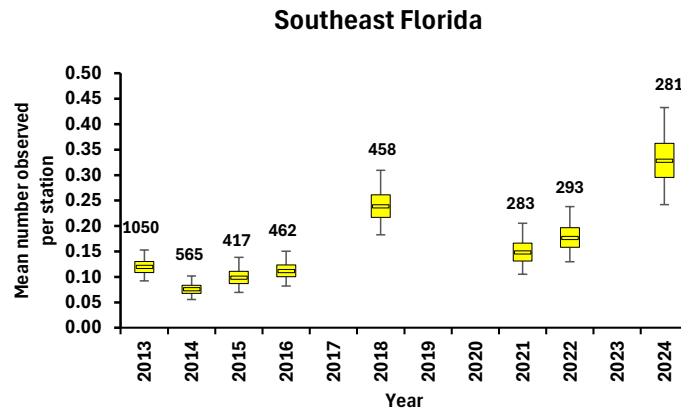
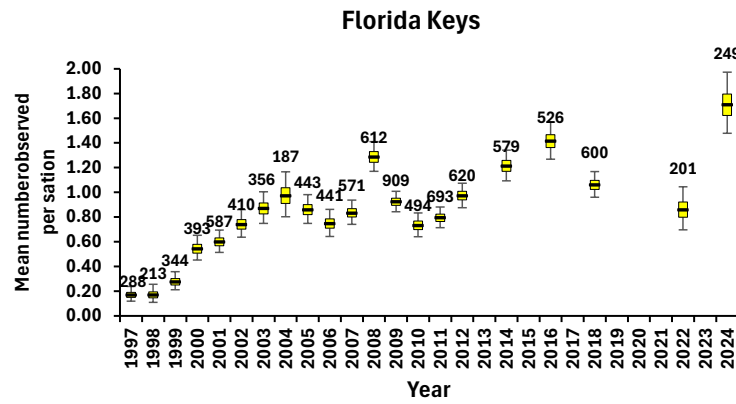


Figure 4. Diagnostic plots of standardized residuals for the number of Hogfish observed in the Florida Keys fit with a Poisson distribution (a, c, and e) and the Dry Tortugas (b, d, and f) fit with a Gamma distribution.

a.



b.



c.

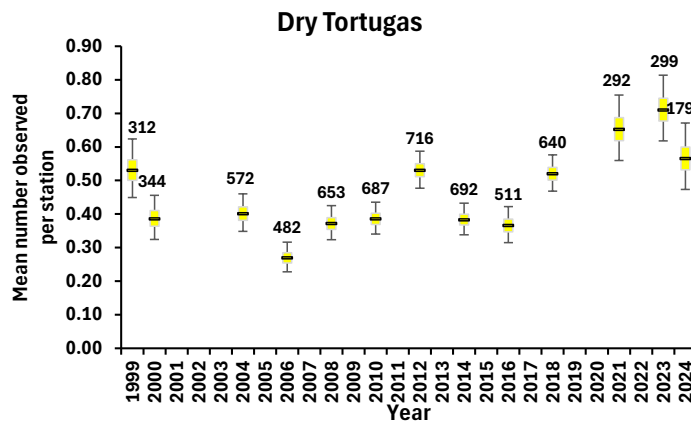
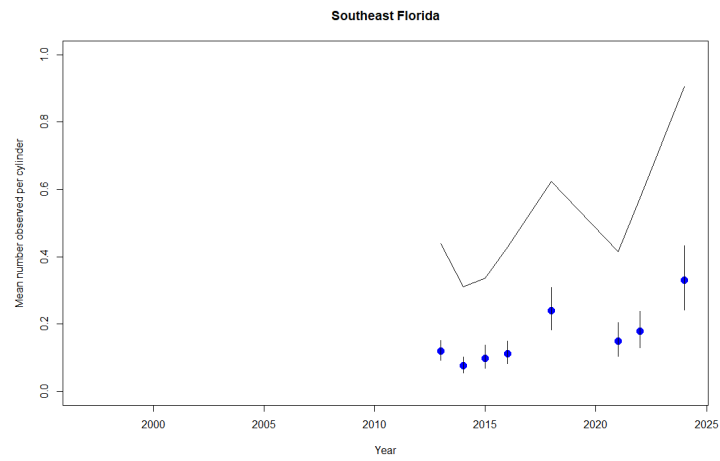
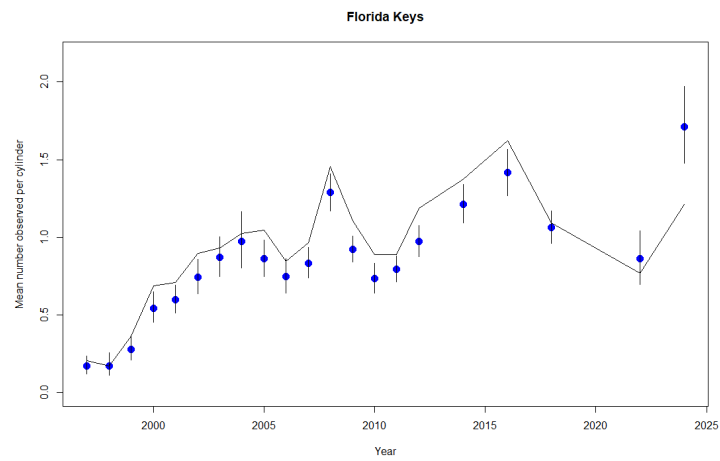


Figure 5. Box-whisker plots of the visual Hogfish regional indices (mean number observed per station) by region and year. The horizontal lines are the median estimate; the boxes are the inter-quartile range, and the vertical lines are the 95% confidence intervals. The numbers of stations sampled each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

a.



b.



c.

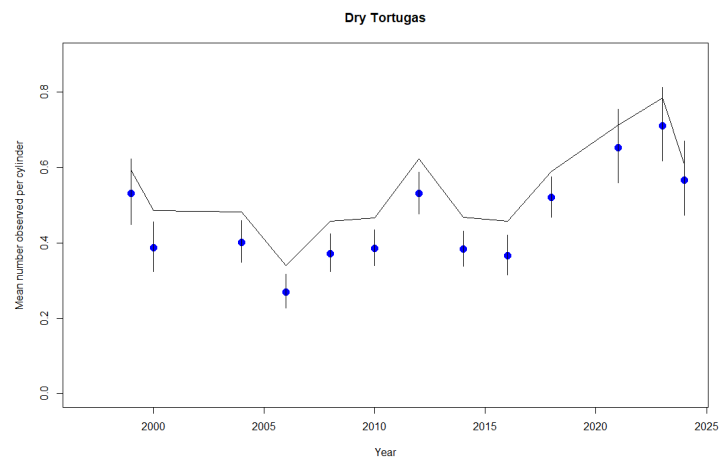


Figure 6. Comparing nominal catch rates (solid line) to model-based mean number of Hogfish observed per station and their confidence intervals (index: blue dots and vertical line: 95% confidence interval) by year and region.

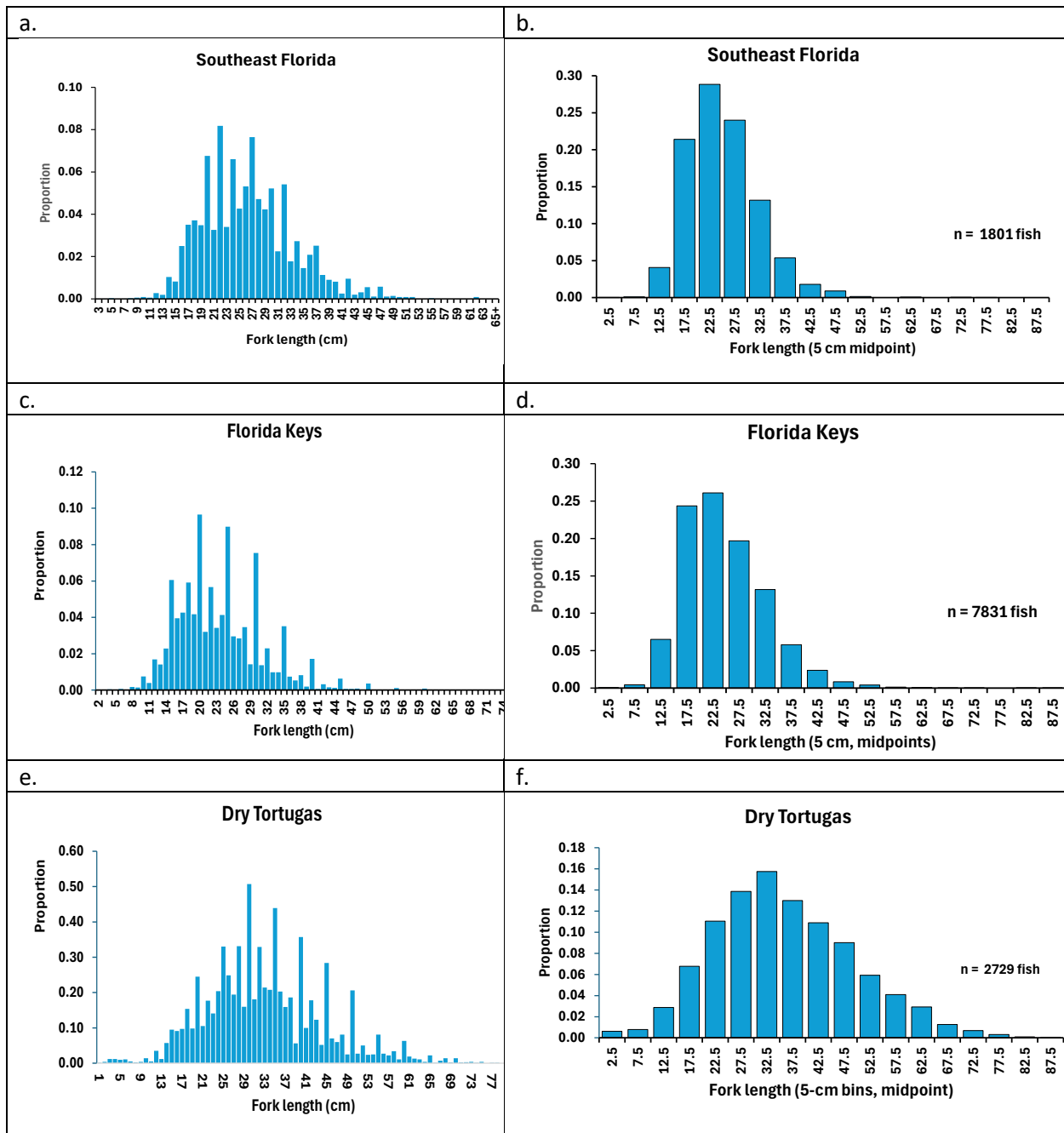


Figure 7. Weighted distributions of fork lengths of Hogfish in 1-cm FL estimated *in situ* by divers along the Florida reef track from 1997 to 2024 by region (a. Southeast Florida, c. Florida Keys, and e. Dry Tortugas) and the corresponding weighted fork length (FL) in 5-cm bins FL (b. Southeast Florida, d. Florida Keys, and f. Dry Tortugas). The number of fish lengths are included in the 5 cm FL figures.

a. Southeast Florida

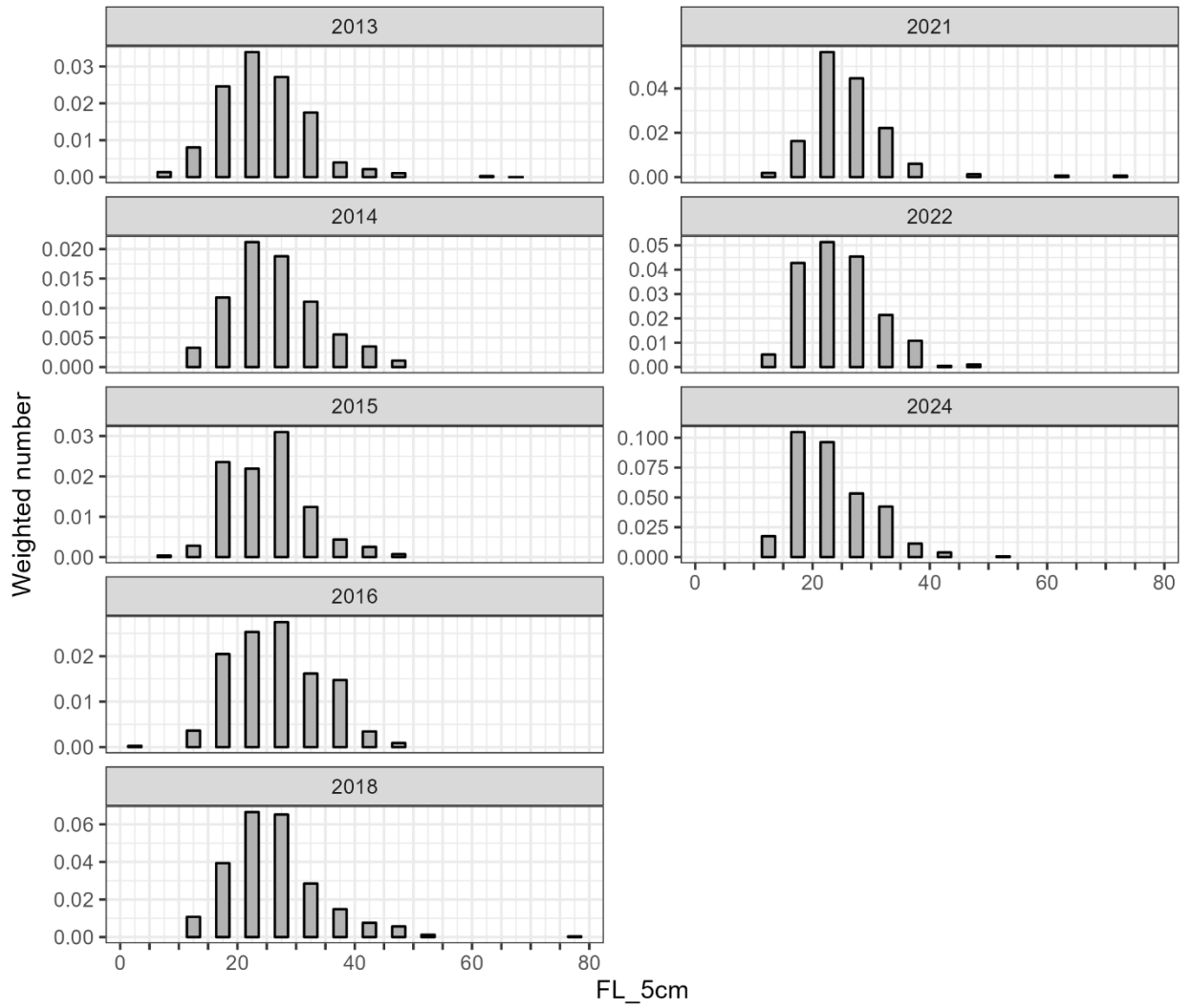


Figure 8. Annual RVC length frequencies from Southeast Florida (a), the Florida Keys (b), and the Dry Tortugas (c).

b. Florida Keys

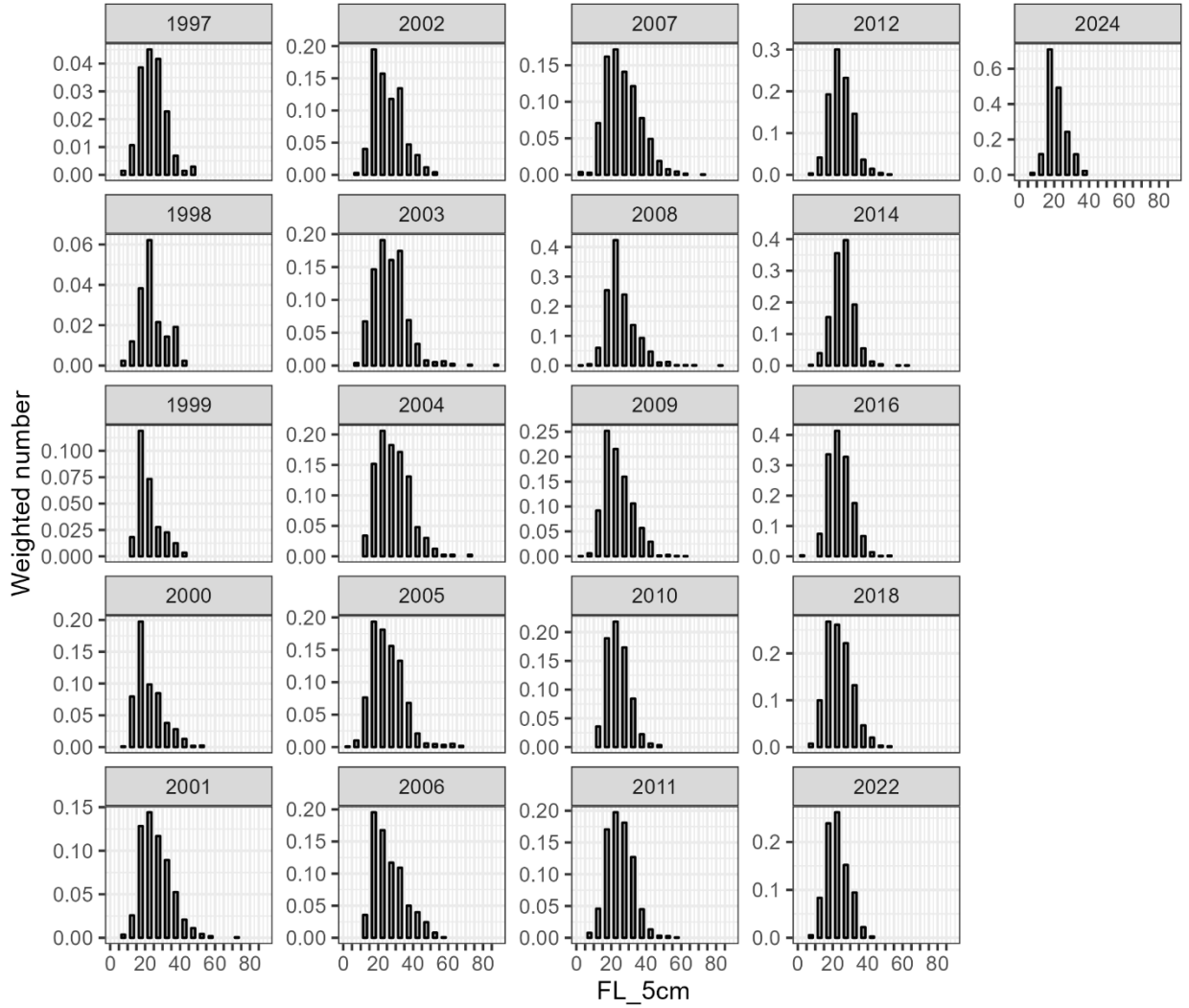


Figure 8 continued. Annual RVC length frequencies Southeast Florida (a), the Florida Keys (b), and the Dry Tortugas (c).

c. Dry Tortugas

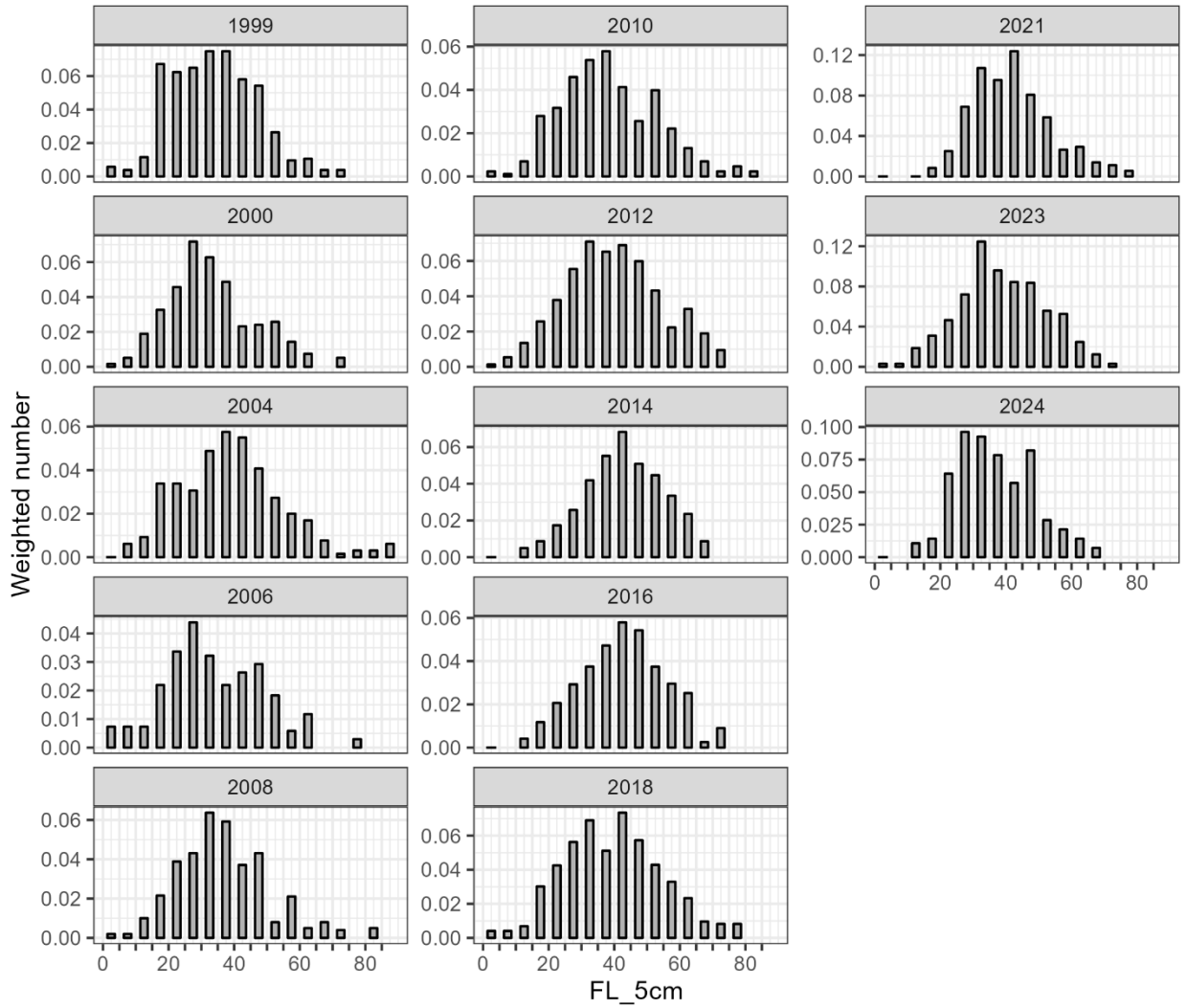


Figure 8 continued. Annual RVC length frequencies from Southeast Florida (a), the Florida Keys (b), and the Dry Tortugas (c).

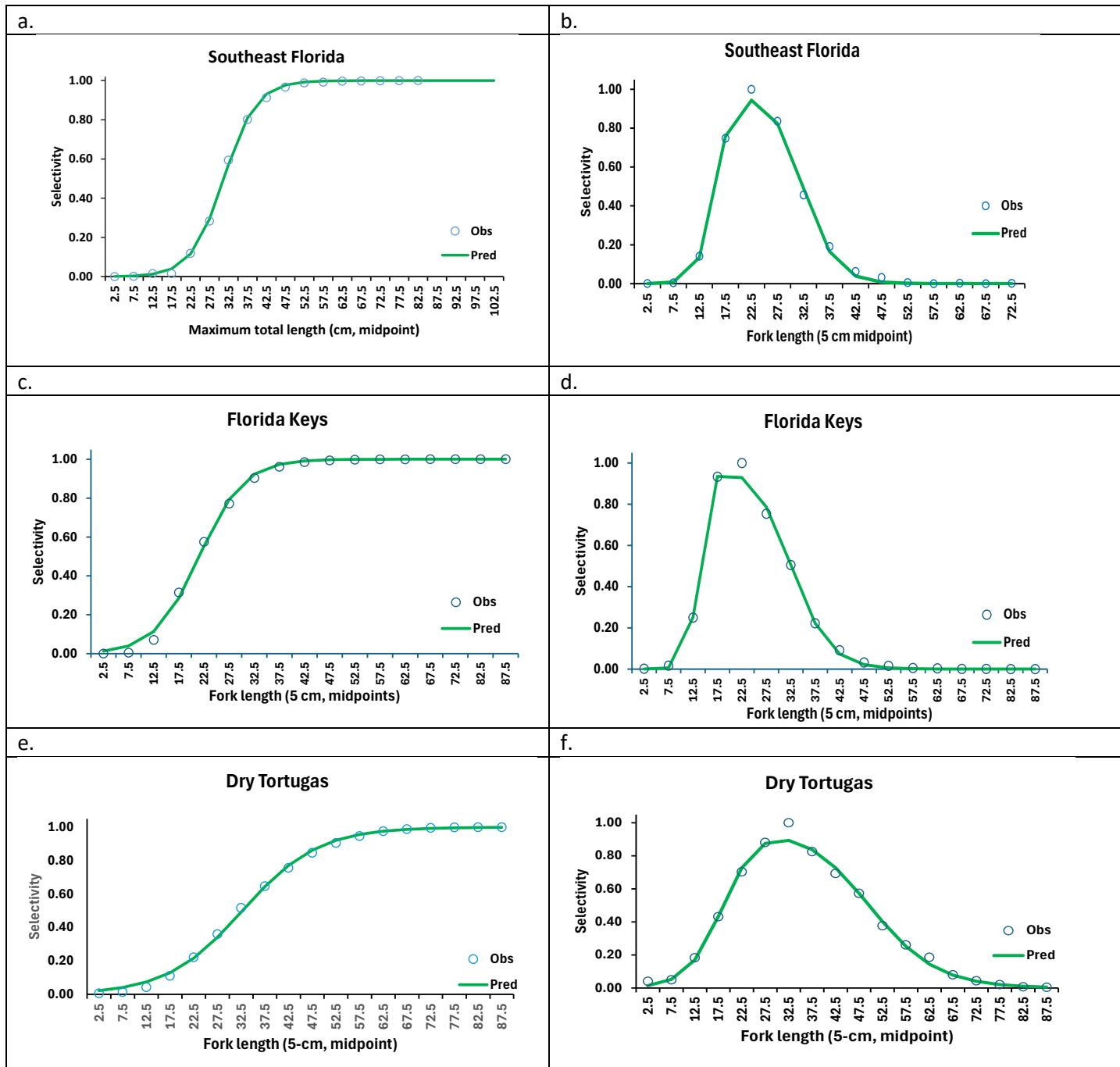
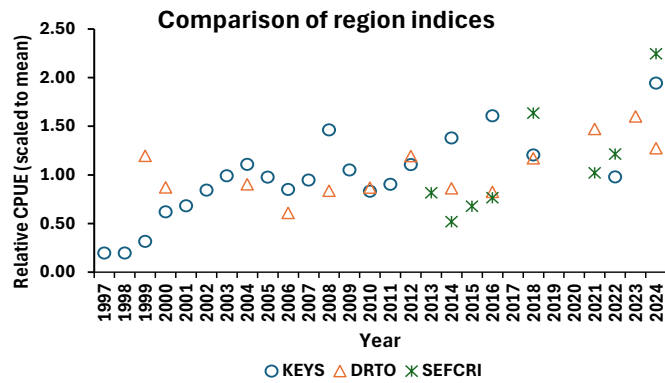
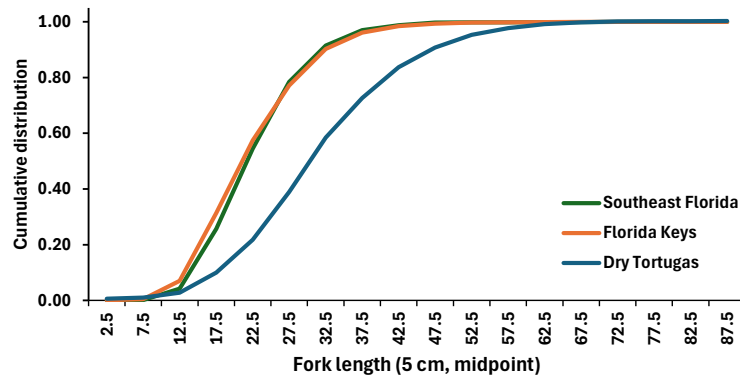


Figure 9. Flat-topped (a - c) and dome-shaped (d - f) selectivities estimated from fork lengths weighted by the regional index of Hogfish observed *in situ* in an imaginary cylinder with a 7.5 m radius. The solid line is the estimated selectivity, and the open circles are the observed values.

a.



b.



c.

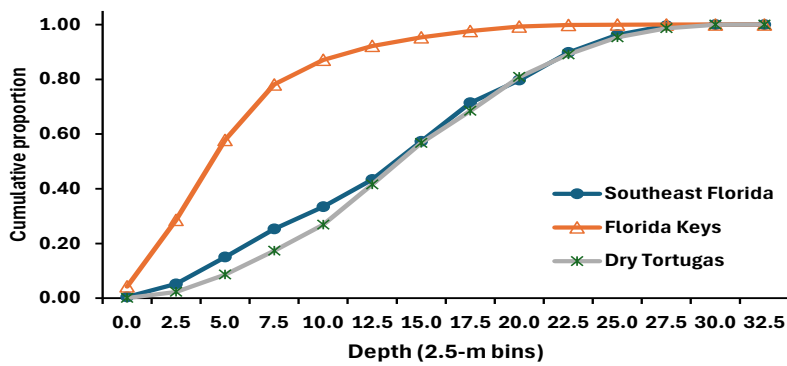
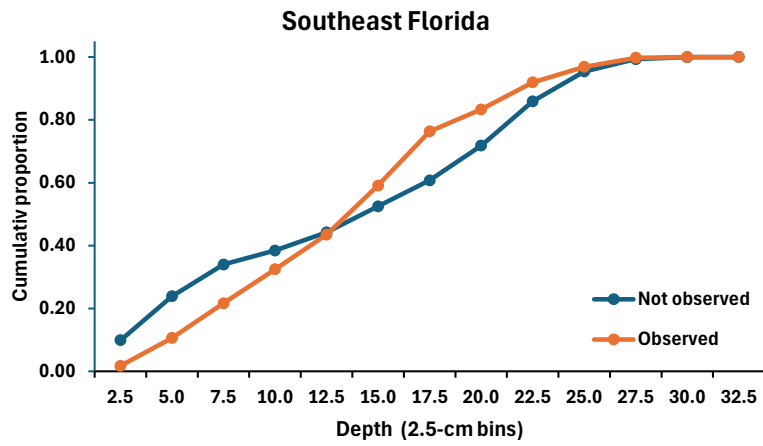
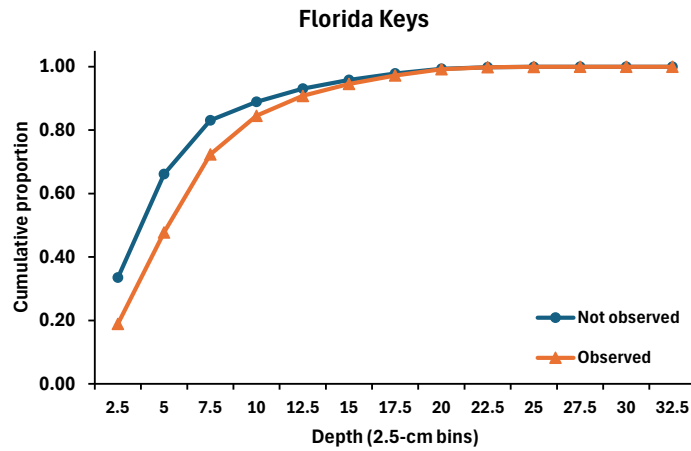


Figure 10. Comparing the regional indices scaled to their means (a), comparing the cumulative proportions of Hogfish lengths sampled by region (b) and the cumulative proportions of depths sampled (c).

a.



b.



c.

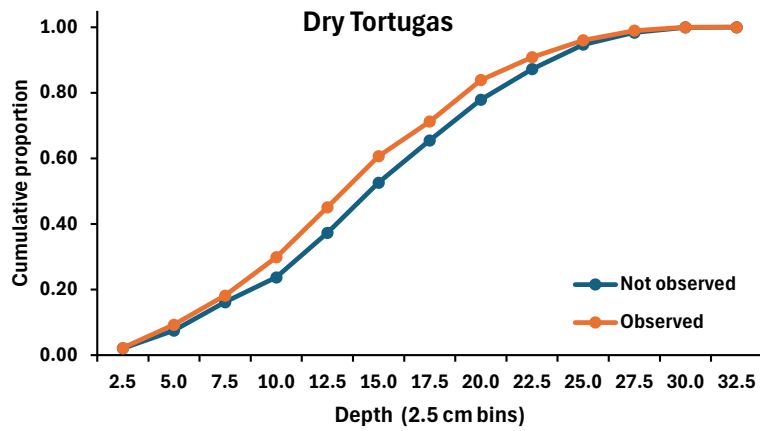


Figure 11. Comparing the depths of stations where Hogfish were observed or not observed by region.