A model-based index of Yellowtail Snapper, *Ocyurus chrysurus*, for the Northern Florida Reef Tract from Government Cut through Martin County using Reef Fish Visual Census data from 2012-2016

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A model-based index of Yellowtail Snapper, *Ocyurus chrysurus*, for the Northern Florida Reef Tract from Government Cut through Martin County using Reef Fish Visual Census data from 2012-2016.

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Introduction

Personnel from the National Marine Fisheries Service began the Reef Fish Visual Census (RVC) in 1979 surveying fish along the Florida Reef Tract (FRT) from Biscayne Bay to the Florida Keys (Bohnsack and Bannerot 1986; Bohnsack et al. 1999; Ault et al. 2001; and Smith et al. 2011). In 2004, the need for a fishery-independent survey to assess the status of reef fish resources along the northern portion of the FRT (northern Miami-Dade County to the northern border of Martin County) was also identified by a team of marine resource professionals (local, state, regional, and federal) called the Southeast Florida Coral Reef Initiative (SEFCRI). In 2011, the SEFCRI therefore developed and began testing a fishery-independent monitoring program for the northern FRT adapted from the RVC in the Florida Keys. Sampling officially began program-wide in July 2012 from Government Cut in northern Miami-Dade County through Martin County (Kilfoyle et al. 2015). They employed a two-stage stratified random survey design (Cochran 1977; Smith et al. 2011) with sampling frames by habitat that were created by dividing the reefscape into 100 m x 100 m blocks and listing the habitats in each block. Annually (biennially after 2016), blocks were randomly selected by habitat and SCUBA divers (usually two) were deployed at each of two randomly located stations within the blocks. The divers identified and counted fish within an imaginary cylinder with a 7.5 m radius.

In its review of fishery stock assessments, the National Research Council (1998) recommended using fishery-independent indices whenever possible because fishery independent surveys are statistically designed and unaffected by regulatory changes such as changes in size limits or trip or bag limits. The Reef Fish Visual Census is a fishery-independent source that operates in prime habitat for Yellowtail Snapper in the northern FRT of southeast Florida.

Methods

The reef tract was divided into 5 biogeographic subregions previously defined by Walker (2012) and Walker and Gilliam (2013) as ecologically relevant regions (Fig. 1). The RVC data was filtered by omitting samples at stations with underwater visibility less than 7.5 m (the diver's observation radius) and by removing stations that were conducted in sand, seagrass, mud, or artificial habitats because these habitats were not part of the RVC domain. Stations at the deep ridge strata were also omitted because they were not sampled in every year. The basic observation is the mean density of fish observed by divers per station. The final dataset consisted of 1,992 station samples (Fig. 1).

The index was standardized similarly to the approach used by Ingram and Harper (2009) with the delta (hurdle) model which split the process into two generalized linear submodels (Lo *et al.* 1992). The first submodel estimated the proportion of stations where Yellowtail Snapper were observed. This submodel used a binomial distribution with a logit link. A separate submodel with a gamma distribution and a log link was used to estimate the mean number of Yellowtail Snapper caught at positive stations.

The estimated coefficients were then back-calculated from their linearized form used in the modeling steps; for the logit link, the back transform was $prop = \frac{e^{f(x1+x2+..)}}{1+e^{f(x1+x2+...)}}$ and for the gamma (log link), the back transform was $\hat{Y} = e^{g(x1+x2+...)}$ where the *x1, x2,* refer to the explanatory variables included in the final, respective linear submodels. The annual index is the product of the proportion of stations where Yellowtail Snapper were observed (***prop***) and the mean number of Yellowtail Snapper by year estimated from the positive model ($\hat{\boldsymbol{Y}}$).

Potential explanatory variables included year (2012 to 2016), month (June – Oct.), subregions of the reef tract (Broward-Miami, Deerfield, South Palm Beach, North Palm Beach, and Martin), strata (deep ridge complex, inner linear reef, middle linear reef, nearshore ridge shallow, deep outer linear reef, deep aggregated patch reef, and shallow aggregated patch reef), and underwater visibility (2.5m categories with 25 m +). The depth variable was not included in the model because of its correlation with how habitat stratum is constructed. All potential explanatory variables were treated as categorical variables partially to account for non-linearity. Beginning with the null model, forward stepwise selection was used to identify which variables should be included in the final versions of the submodels. To be included in the final submodel, variables had to meet two criteria: the variable must be statistically significant at an alpha level of 0.05 and its inclusion must reduce deviance (a measure of the variability) by at least 0.5%.

To estimate variability in the annual index values, a Monte Carlo simulation approach was used with 10,000 iterations using the least-squares mean estimates and their standard errors from the two generalized linear submodels. Each iteration used the annual least-squares mean estimate on the log 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, these values were transformed back from their linear scales prior to being multiplied together and the index derived was the product of the probability of observing a Yellowtail Snapper during surveys and the annual average number of Yellowtail Snapper counted at sites where this species was encountered. The nominal index is a yearly average of habitat-stratified mean densities of fish per station.

Results and Discussion

The binomial submodel estimating the probability that one of the divers observed at least one Yellowtail Snapper at a station reduced the deviance by 18.04%. The variables in this final submodel, listed in decreasing order of importance, included habitat strata, month, and visibility (Table 1). Diagnostic plots for the binomial submodel are shown in Figure 2. The submodel with the gamma distribution for estimating the number of Yellowtail Snapper observed at successful stations reduced the deviance by 34.80%. Three variables were selected for this final submodel, listed in decreasing order of importance, included habitat strata, subregion, year, and month (Table 2). The maximum mean number of Yellowtail Snapper observed at a single station was 200 fish.

The Southeast Coral Reef Initiative Reef Fish Visual Census (SEFCRI-RVC) index for Yellowtail Snapper decreased from 2012 (1.23 fish per station) to 2014 (0.55 fish per station), increased in 2015 (1.13 fish per station), then decreased again in 2016 (0.70 fish per station; Table 3, Fig. 3). The coefficients of variation ranged from 0.171 to 0.179. When scaled to their respective means, the nominal index had a similar shape as the standardized SEFCRI-RVC index (Fig. 4).

Based on 2,846 diver-observed fish, the median size of the Yellowtail Snapper in the northern Florida Reef Tract *in situ* was 19 cm FL and the interquartile range was 15 to 25 cm FL (Fig. 5). The largest Yellowtail Snapper estimated by divers *in situ* was 45 cm FL.

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Table 1. Stepwise selection of variables for their inclusion in the binomial submodel (binomial distribution and logit link) estimating the probability of observing a Yellowtail Snapper at a Reef Fish Visual Census station along the northern Florida Reef Tract (shaded lines). The fields include the variable, degrees of freedom, deviance, mean deviance, Chi-square degrees of freedom, Chi-square value, probability of a greater chi-square value, percent reduction in deviance, whether the model converged, and the cumulative percent reduction in deviance.

Explanatory variable	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of a greater chi-square value	Percent reduction in deviance	Converged	Cumulative percent reduction in mean deviance
Null	1991	2276.93	1.144	.	.	.	.	Conv	
Strata	1979	1886.85	0.953	12	390.07	0	16.63	Conv	16.63
Visibility	1982	2188.15	1.104	9	88.78	0	3.46	Conv	
Subregion	1987	2217.22	1.116	4	59.71	0	2.43	Conv	
Month	1987	2244.16	1.129	4	32.76	<0.0001	1.24	Conv	
Year	1987	2258.16	1.136	4	18.76	0.0009	0.62	Conv	
Strata Month	1975	1862.16	0.943	4	24.70	0.0001	0.93	Conv	17.56
Strata Year	1975	1866.05	0.945	4	20.80	0.0003	0.75	Conv	
Strata Visibility	1970	1867.50	0.948	9	19.35	0.0224	0.48	Conv	
Strata Subregion	1975	1876.27	0.950	4	10.59	0.0316	0.30	Conv	
Strata Month Visibility	1966	1842.75	0.937	9	19.40	0.0220	0.49	Conv	18.04
Strata Month Year	1971	1848.22	0.938	4	13.94	0.0075	0.45	Conv	
Strata Month Subregion	1971	1850.57	0.939	4	11.59	0.0207	0.35	Conv	

Table 2. Stepwise selection of variables for their inclusion in the positive submodel (gamma distribution and log link) estimating the number of Yellowtail Snapper observed at positive Reef Fish Visual Census stations along the norther Florida Reef Tract (shaded lines). The fields include the 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 variable	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of a greater chi-square value	Percent reduction in deviance	Converged	Cumulative percent reduction in mean deviance
Null	514	749.13	1.457	.	.	.	.	Conv	
Strata	502	527.98	1.052	12	209.31	0	27.84	Conv	27.84
Subregion	510	562.03	1.102	4	172.48	0	24.39	Conv	
Visibility	505	710.64	1.407	9	32.07	0.0002	3.45	Conv	
Month	510	723.71	1.419	4	21.01	0.0003	2.64	Conv	
Year	510	729.49	1.430	4	16.17	0.0028	1.86	Conv	
Strata Subregion	498	490.61	0.985	4	42.95	0	4.57	Conv	32.41
Strata Year	498	508.67	1.021	4	21.84	0.0002	2.08	Conv	
Strata Month	498	516.17	1.036	4	13.26	0.0101	1.05	Conv	
Strata Visibility	493	518.77	1.052	9	10.32	0.3252	-0.04	Conv	
Strata Subregion Year	494	477.85	0.967	4	15.35	0.0040	1.23	Conv	33.63
Strata Subregion Month	494	480.13	0.972	4	12.58	0.0135	0.91	Conv	
Strata Subregion Visibility	489	480.44	0.982	9	12.21	0.2019	0.18	Conv	
Strata Subregion Year Month	490	465.64	0.950	4	15.04	0.0046	1.17	Conv	34.80
Strata Subregion Year Visibility	485	468.75	0.966	9	11.18	0.2637	0.06	Conv	

Table3. The Southeast Coral Reef Fish Initiative Reef Fish Visual Census (SEFCRI-RVC) index for Yellowtail Snapper, its coefficient of variation, the number of stations sampled, the number of stations in the northern Florida Reef Tract where Yellowtail Snapper were observed, the SEFCRI-RVC index scaled to its mean, nominal index, and the nominal index scaled to its mean.

Year	Mean number per station	Coefficient of variation	Number of stations	Number of stations with Yellowtail Snapper	Index scaled to mean	Nominal index	Nominal index scaled to mean
2012	1.23	0.174	329	101	1.43	1.83	1.50
2013	0.87	0.179	493	100	1.01	1.16	0.95
2014	0.55	0.171	490	121	0.64	0.94	0.77
2015	1.13	0.175	308	99	1.32	1.43	1.17
2016	0.70	0.179	372	94	0.81	0.95	0.78

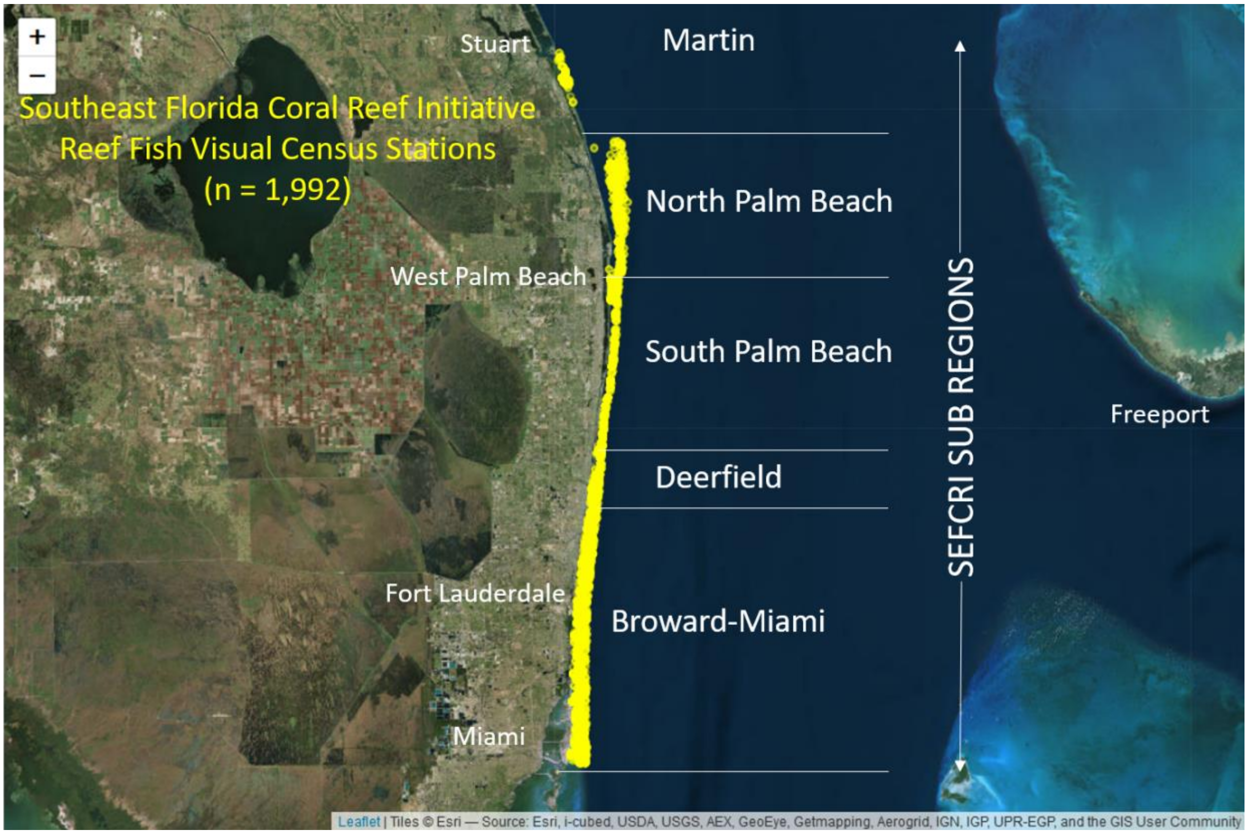

Figure 1. Reef Fish Visual Census station locations sampled in the south Atlantic waters of southeast Florida from 2012 to 2016 by the Southeast Florida Coral Reef Initiative.

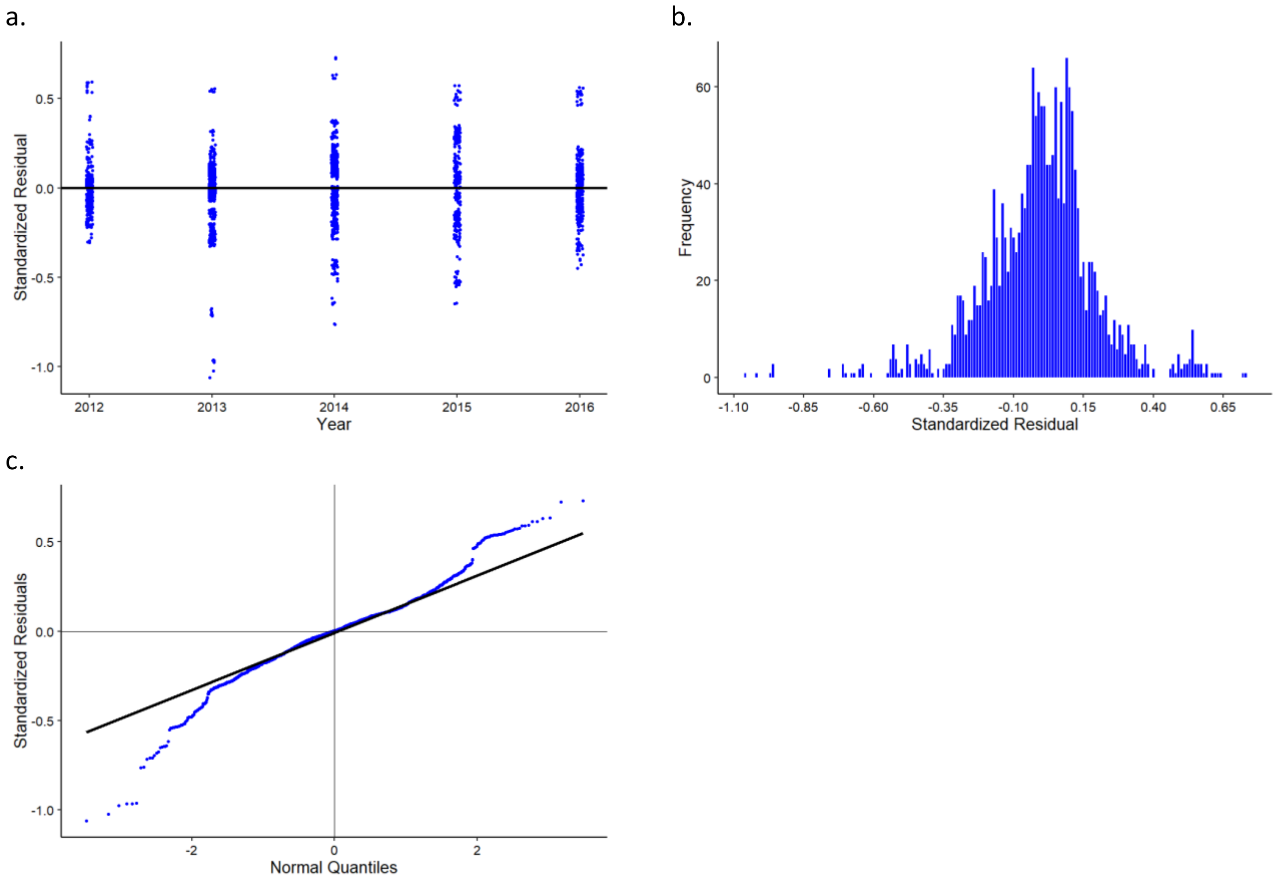

Figure 2. Diagnostic plots for the binomial submodel: a) standardized residuals by year; b) histogram of total standardized residuals; c) q-q plot.

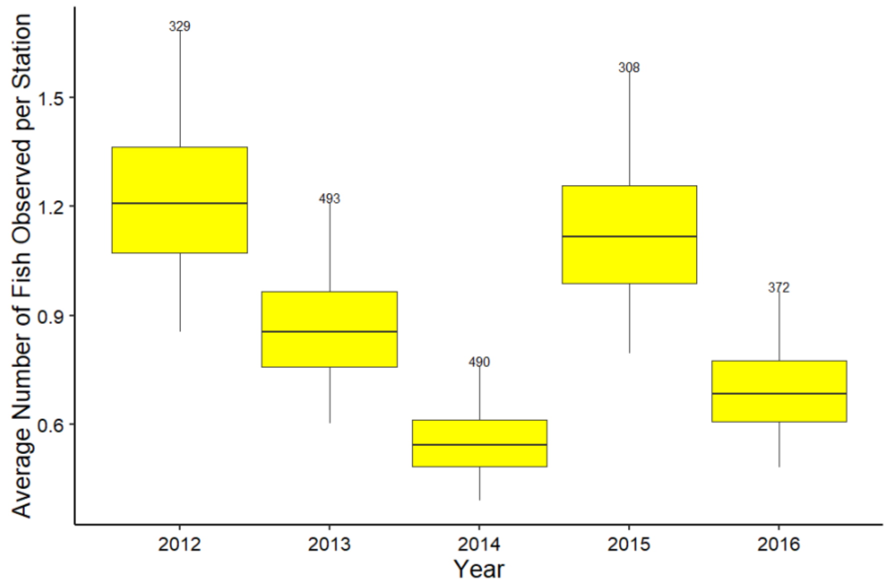

Figure 3. A box-whisker plot of the Southeast Florida Coral Reef Initiative Reef Fish Visual Census (SEFCRI-RVC) index for Yellowtail Snapper by year. The horizontal line is the median estimate; the box is the inter-quartile range, and the vertical line is the 95% confidence interval. The number of stations sampled each year is shown above the confidence interval.

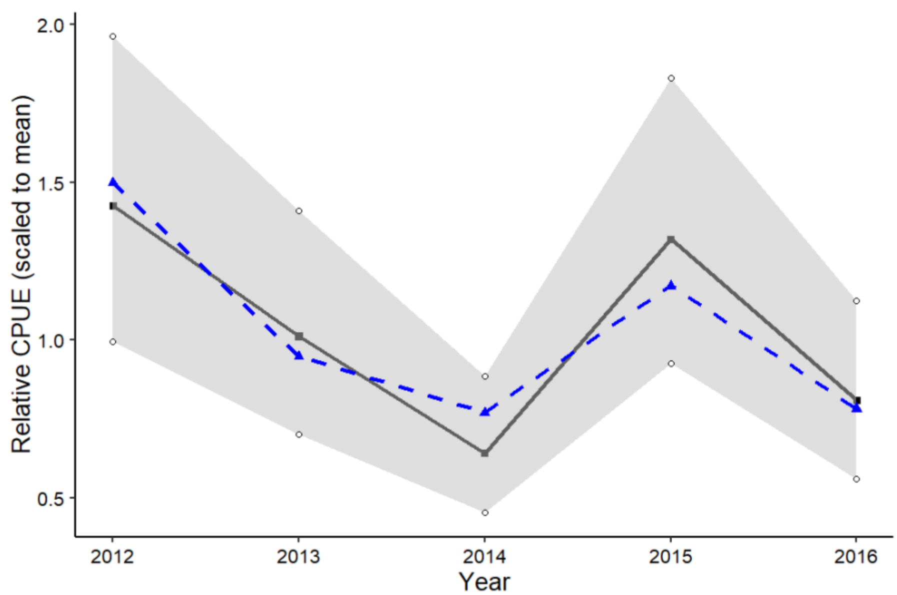

Figure 4. Comparison of the standardized mean values of the Southeast Florida Coral Reef Initiative Reef Fish Visual Census (SEFCRI-RVC) index for Yellowtail Snapper, its confidence intervals, and the nominal index scaled to their means by year. The black squares with the solid black line are the standardized mean values; the gray ribbon with the open circles are the 95% confidence intervals; and the blue triangles with the dashed line are the nominal values.

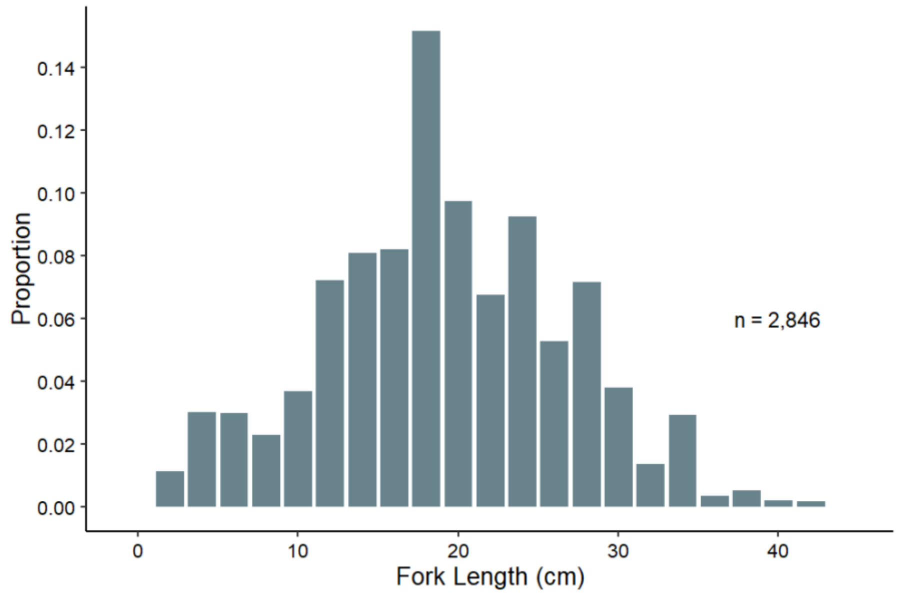

Figure 5. The distribution of total lengths of Yellowtail Snapper estimated *in situ* by Southeast Florida Coral Reef Initiative Reef Fish Visual Census divers along the northern Florida Reef Tract from 2012 to 2016.