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A model-based index of Yellowtail Snapper, *Ocyurus chrysurus*, for the Florida Reef Tract from Card Sound through the Florida Keys using Reef Fish Visual Census data from 1997-2016.

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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). 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 Florida Reef Tract into 200 m x 200 m blocks and listing the habitats in each block. The block size later was reduced to 100 m x 100 m in 2014 to improve spatial resolution. The change in the block size does not affect the index because the index is a measure of the average number of Yellowtail Snapper observed by the divers at a station. Annually (biennially after 2012), 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. 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). Since 1997, the divers record whether the station being sampled was in a SPA or not. The Florida Fish and Wildlife Conservation Commission (FWC) began a similar reef fish visual survey in 1999 using different methodology but discontinued that survey after 2008 to direct more manpower in support of the RVC.

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 a prime habitat for Yellowtail Snapper in the Florida Keys.

Methods

With the establishment of Sanctuary Protected Areas by the Florida Keys National Marine Sanctuary in 1997, the RVC personnel recommended only using data from 1997 and later for consistency with their revised and improved sampling design; we, therefore, extracted the RVC station point count data for the Florida Keys from 1997 through 2016; there was no sampling in 2013, 2015, nor 2017 due to a change in survey timing to a biennial sampling schedule. For Yellowtail Snapper, the boundary between the Gulf of Mexico and South Atlantic waters is the line between Miami-Dade County and Monroe County. For the reef tract, this meant extending that county line east from the middle of the channel between Swan Key and Palo Alto Key (just north of Key Largo, 25.342941 N, 80.250626 W) and removing stations north of this line. Additional filtering of the RVC data included deleting the experimental winter surveys that were conducted in 2004/2005, omitting samples at stations with underwater visibility less than 7.5 m (the diver's observation radius), omitting the inshore patch reef stratum where comparably low numbers of Yellowtail Snapper were observed, and removing stations that were conducted in sand, seagrass, mud, or artificial habitats because these habitats were not part

of the RVC domain. The 1997 and 1998 data lacked three fields when compared to the later data (whether the dive location was in a SPA; the stratum being sampled based on zone, depth, and habitat; and region which was based on the subregion of the Florida Keys), but these fields could be constructed from other reported information. The basic observation is the mean density of fish observed by divers per station. The final dataset consisted of 6,394 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 (***$\hat{Y}$***).

Potential explanatory variables included year (1997 to 2016), month (June – Sept.), subregions of the reef tract (Upper Keys, Middle Keys, Lower Keys), Sanctuary Protected Area (yes, no), strata (mid-channel patch reef, offshore patch reef, high relief reef, shallow forereef, mid-depth forereef, deep forereef), 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 submodel with the binomial distribution estimating the probability that one of the divers observed at least one Yellowtail Snapper at a station reduced the deviance by 13.97%. The variables in this final submodel, listed in decreasing order of importance, included habitat strata, year, protected area, visibility category, month, and subregion (Table 1). Diagnostic plots for the binomial submodel are shown in Fig. 2. The submodel with the gamma distribution for estimating the number of Yellowtail

Snapper observed at successful stations reduced the deviance by 10.32%. Four variables were selected for this final submodel, listed in decreasing order of importance, included protected area, year, habitat strata, and subregion (Table 2). The maximum mean number of Yellowtail Snapper observed at a single station was 600 fish.

The Reef Fish Visual Census index for Yellowtail Snapper initially decreased to a timeseries low in 1998 (2.51 fish per station) but recovered by 2000 (Table 3, Fig. 3). The index varied without trend through 2016 with high years in 2002 (9.11 fish per station), 2005 (11.07 fish per station), and 2008 (9.22 fish per station). The coefficients of variation ranged from 0.063 to 0.150. When scaled to their respective means, the nominal index had a similar shape as the standardized RVC index (Fig. 4).

The median size of the Yellowtail Snapper in the Florida Keys (n = 47,616) as estimated by the divers *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 70 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 in the Florida Keys (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	6393	8520.15	1.333	.	.	.	.	Conv	
Strata	6388	7725.78	1.209	5	794.38	0	9.25	Conv	9.25
Protected	6392	8358.36	1.308	1	161.79	0	1.88	Conv	
Year	6376	8352.31	1.310	17	167.84	0	1.71	Conv	
Subregion	6391	8385.25	1.312	2	134.90	0	1.55	Conv	
Visibility	6384	8457.12	1.325	9	63.03	0	0.60	Conv	
Month	6390	8474.95	1.326	3	45.21	0	0.48	Conv	
Strata Year	6371	7546.93	1.185	17	178.85	0	1.86	Conv	11.12
Strata Protected	6387	7651.77	1.198	1	74.00	0	0.86	Conv	
Strata Subregion	6386	7659.36	1.199	2	66.42	0	0.75	Conv	
Strata Visibility	6379	7666.89	1.202	9	58.89	0	0.57	Conv	
Strata Month	6385	7680.44	1.203	3	45.34	0	0.49	Conv	
Strata Year Protected	6370	7466.26	1.172	1	80.67	0	0.94	Conv	12.05
Strata Year Subregion	6369	7480.31	1.174	2	66.62	0	0.76	Conv	
Strata Year Visibility	6362	7473.50	1.175	9	73.43	0	0.74	Conv	
Strata Year Month	6368	7511.22	1.180	3	35.71	<0.0001	0.38	Conv	
Strata Year Protected Visibility	6361	7387.45	1.161	9	78.81	0	0.81	Conv	12.86
Strata Year Protected Subregion	6368	7402.03	1.162	2	64.23	0	0.73	Conv	
Strata Year Protected Month	6367	7425.77	1.166	3	40.49	0	0.44	Conv	
Strata Year Protected Visibility Month	6358	7338.39	1.154	3	49.07	0	0.54	Conv	13.40
Strata Year Protected Visibility Subregion	6359	7345.42	1.155	2	42.04	0	0.47	Conv	
Strata Year Protected Visibility Month Subregion	6356	7287.16	1.147	2	51.22	0	0.58	Conv	13.97

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 in the Florida Keys (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	3934	6521.87	1.658	.	.	.	.	Conv	
Protected	3933	6188.45	1.573	1	247.56	0	5.09	Conv	5.09
Strata	3929	6231.14	1.586	5	215.22	0	4.34	Conv	
Year	3917	6274.31	1.602	17	182.71	0	3.38	Conv	
Visibility	3925	6411.86	1.634	9	80.42	0	1.46	Conv	
Subregion	3932	6429.23	1.635	2	67.65	0	1.37	Conv	
Month	3931	6464.77	1.645	3	41.59	0	0.80	Conv	
Protected Year	3916	6015.10	1.536	17	133.39	0	2.26	Conv	7.35
Protected Strata	3928	6092.46	1.551	5	73.45	0	1.35	Conv	
Protected Subregion	3931	6116.25	1.556	2	55.15	0	1.06	Conv	
Protected Visibility	3924	6113.41	1.558	9	57.33	0	0.94	Conv	
Protected Month	3930	6147.92	1.564	3	30.89	<0.0001	0.55	Conv	
Protected Year Strata	3911	5933.97	1.517	5	63.60	0	1.13	Conv	8.48
Protected Year Subregion	3914	5944.91	1.519	2	54.98	0	1.03	Conv	
Protected Year Visibility	3907	5949.73	1.523	9	51.18	<0.0001	0.80	Conv	
Protected Year Month	3913	5973.29	1.527	3	32.68	<0.0001	0.57	Conv	
Protected Year Strata Subregion	3909	5811.48	1.487	2	97.50	0	1.84	Conv	10.32
Protected Year Strata Visibility	3902	5884.35	1.508	9	39.28	<0.0001	0.56	Conv	
Protected Year Strata Month	3908	5893.59	1.508	3	31.95	<0.0001	0.55	Conv	

Table3. The Reef Fish Visual Census index, its coefficient of variation, the number of stations sampled, the number of stations in the Florida Keys where Yellowtail Snapper were observed, the 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
1997	8.61	0.098	225	194	1.28	11.89	1.73
1998	2.51	0.145	165	115	0.37	5.28	0.77
1999	4.53	0.103	358	211	0.68	6.45	0.94
2000	6.19	0.100	367	205	0.92	7.74	1.13
2001	5.44	0.093	573	308	0.81	7.91	1.15
2002	9.11	0.103	297	159	1.36	8.78	1.28
2003	6.24	0.113	214	130	0.93	6.72	0.98
2004	7.26	0.150	109	70	1.08	6.78	0.99
2005	11.07	0.084	293	207	1.65	11.82	1.72
2006	6.17	0.097	289	167	0.92	6.18	0.90
2007	8.29	0.078	398	252	1.24	8.01	1.17
2008	9.22	0.068	428	314	1.38	8.36	1.22
2009	5.94	0.063	663	407	0.89	4.74	0.69
2010	5.01	0.090	398	208	0.75	4.18	0.61
2011	6.64	0.068	525	325	0.99	5.31	0.77
2012	6.14	0.078	404	248	0.92	4.98	0.72
2013	-	-	-	-	-	-	-
2014	6.11	0.087	409	224	0.91	5.69	0.83
2015	-	-	-	-	-	-	-
2016	7.24	0.088	279	191	1.08	7.01	1.02

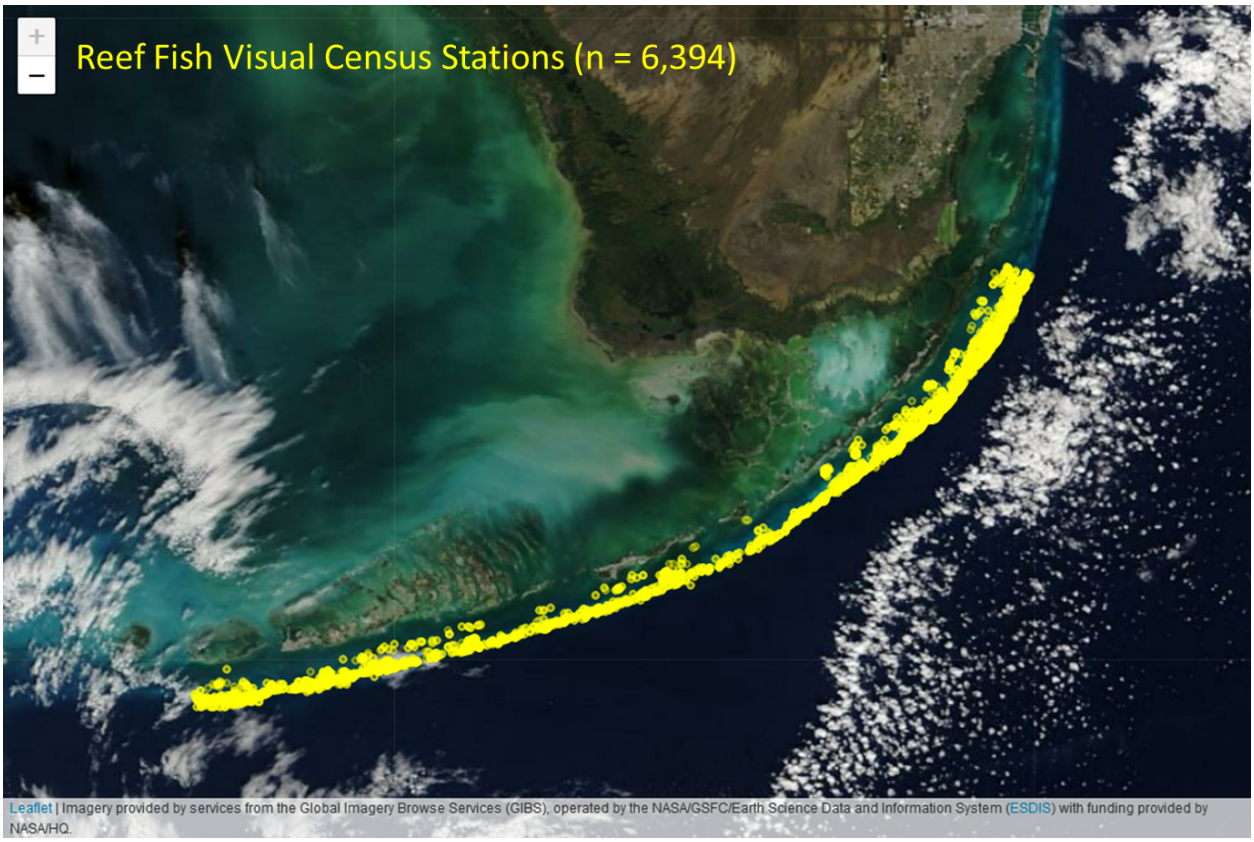

Figure 1. Reef Fish Visual Census station locations sampled in the south Atlantic waters of the Florida Keys from 1997 to 2016.

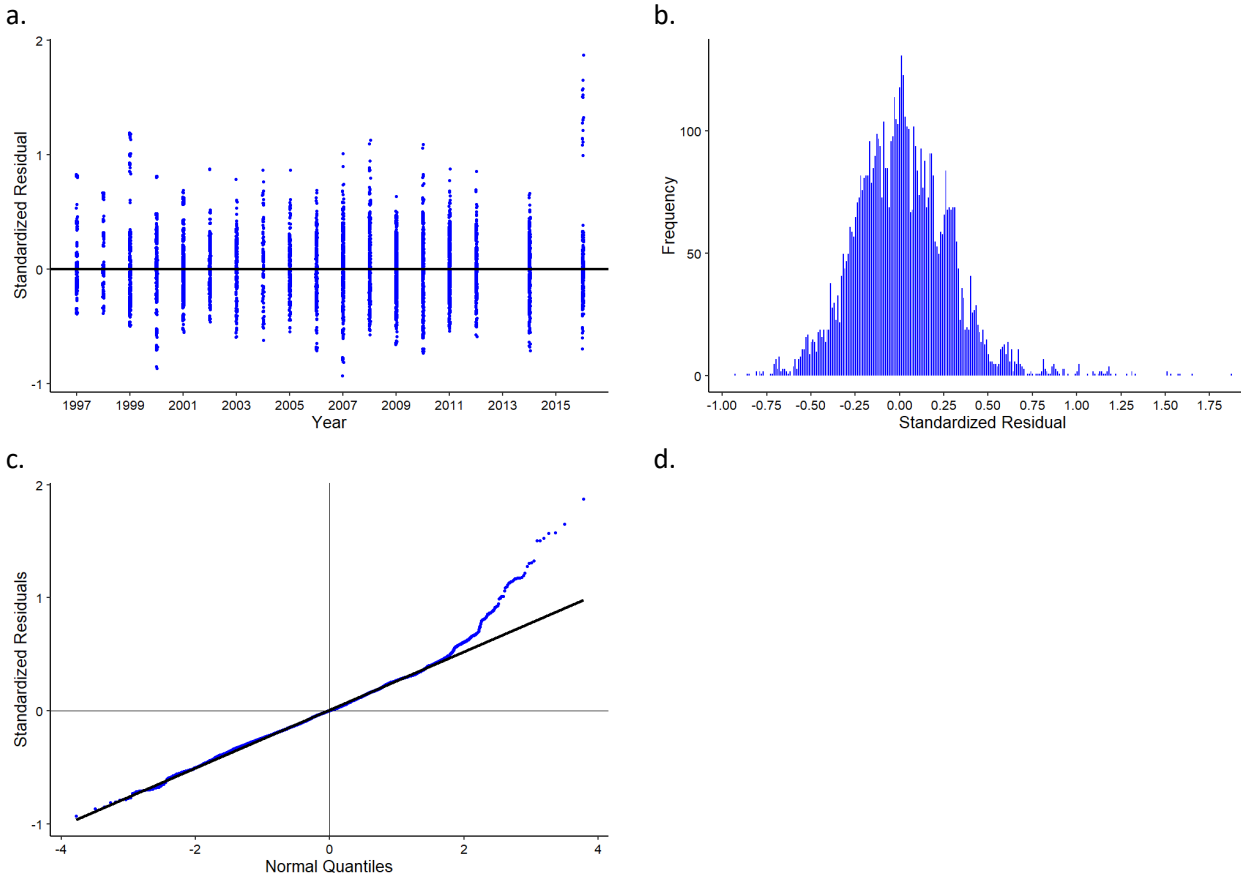

Figure 2. Diagnostic plots for the binomial submodel: a) standardized residuals by year; b) histogram of total standardized residuals; c) q-q plot.

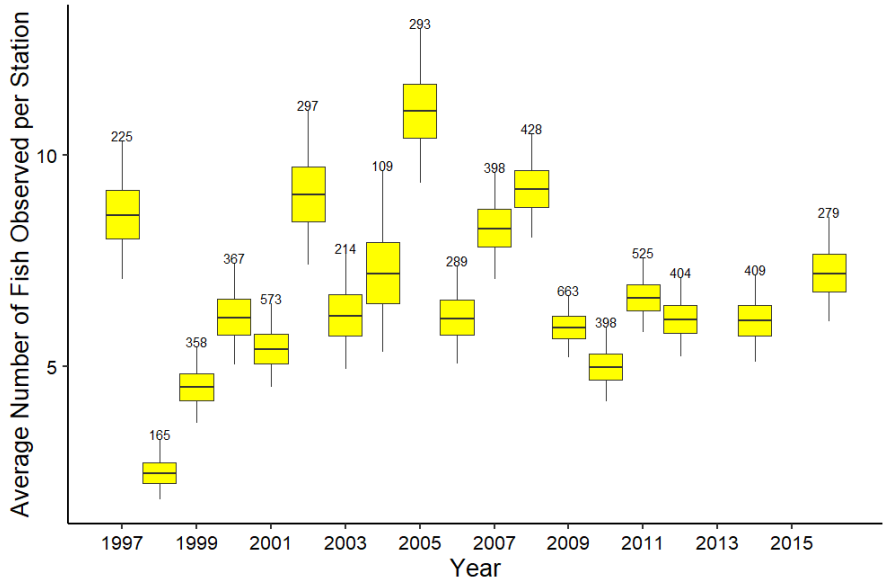

Figure 3. A box-whisker plot of the Reef Fish Visual Census index for Yellowtail Snapper by year. The horizontal line is the median estimate; the box is the inter-quartile range, and the vertical line is the 95% confidence interval. The number of stations sampled each year is shown above the confidence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

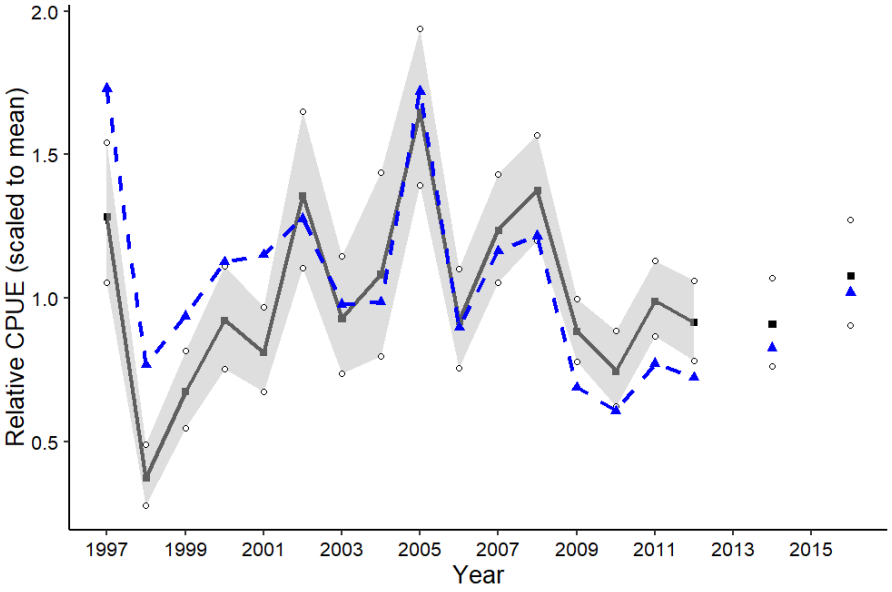

Figure 4. Comparison of the standardized mean values of the Reef Fish Visual Census index for Yellowtail Snapper, its confidence intervals, and the nominal index scaled to their means by year. The black squares with the solid black line are the standardized mean values; the gray ribbon with the open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

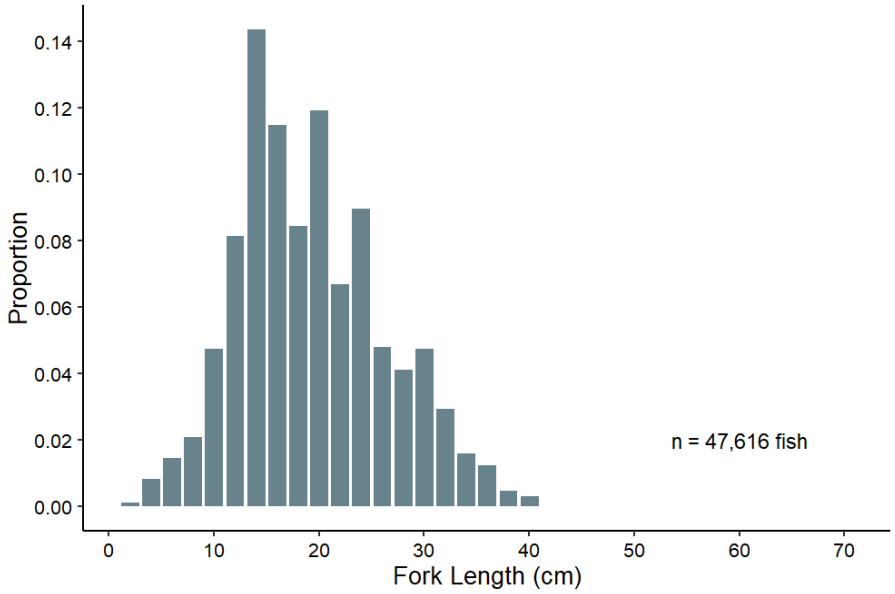

Figure 5. The distribution of total lengths of Yellowtail Snapper estimated *in situ* by Reef Fish Visual Census divers in the Florida Keys from 1997 to 2016.