A model-based index of Yellowtail Snapper, *Ocyurus chrysurus*, in the Dry Tortugas using Reef Fish Visual Census data from 1999-2016

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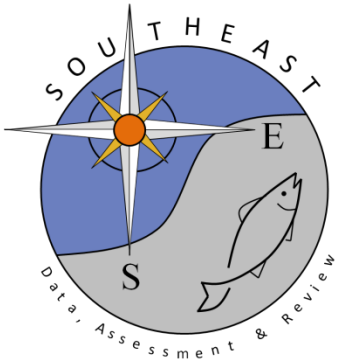

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A model-based index of Yellowtail Snapper, *Ocyurus chrysurus*, in the Dry Tortugas using Reef Fish Visual Census data from 1999-2016.

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Introduction

The Dry Tortugas region is a coral reef ecosystem located in the westernmost portion of the Florida Keys National Marine Sanctuary (FKNMS) approximately 120 km west of Key West, FL. As a result of growing concerns about unsustainable fishing intensities and coral reef stressors in the region, several spatial controls were implemented between 1997 and 2007 (Ault et al. 2006; Ault et al. 2013). In 2001, two areas were established as no take marine reserves (NTMR). The northern portion of Tortugas Bank and northern waters became part of the Tortugas North Ecological Reserve (TNER), leaving the southern half of Tortugas Bank open to recreational and commercial fishing (TBO). Riley's Hump and the waters south became part of the Tortugas South Ecological Reserve (TSER). In 2007, another NTMR in the western half of the Dry Tortugas National Park (DRTO) was established as the Research Natural Area (DRTO RNA). The eastern half of the DRTO remained open only to recreational hook and line fishing (DRTO Open). Commercial fishing has been prohibited in the DRTO since 1935 when the area was first designated as a national monument (Ault et al. 2006). The DRTO contains 7 small keys arranged in an elliptical atoll-like formation (Schmidt et al. 1999).

Personnel from the National Marine Fisheries Service began the Reef Fish Visual Census (RVC) in 1979 by surveying fish along the Florida Reef Tract 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 1999, surveying was extended to the Dry Tortugas region to collect baseline data before the no take marine reserves were established. 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 200 m x 200 m blocks and listing the habitats in each block. 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 Dry Tortugas region.

Methods

The study sites were located within two primary areas of the Tortugas region: the Tortugas Bank and the Dry Tortugas National Park. Sites were further characterized according to their location within the spatial control zones of the Tortugas region: TNER, TBO, DRTO Open, and DRTO RNA (Fig. 1). Sampling was conducted in 1999 and 2000 to collect baseline data before the no take marine reserves

were established and was resumed in 2004 to monitor the response of the fish populations inside and outside the protected areas (see Ault et al. 2006). Monitoring then continued on a biennial schedule through 2016. 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 conducted in sand, seagrass, mud, or artificial habitats as these habitats were not part of the RVC domain. The basic observation is the mean density of fish observed by divers per station. The final dataset consisted of 4,706 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 (1999 to 2016), month (May – July), spatial control zones (zone) within the Dry Tortugas region (TNER, TBO, DRTO Open, and DRTO RNA), strata (contiguous reef with high relief, contiguous reef with medium relief, contiguous reef with low relief, isolated patch reef with high relief, isolated patch reef with medium relief, isolated patch reef with low relief, spur and groove reef with high relief, and spur and groove reef with low relief), and depth (5m categories with 25m +). The subregion variable was not evaluated in the model because of its correlation with the protected or non-protected areas and underwater visibility was not included as it was not reliably measured in years 1999 and 2000. 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 17.18%. The variables in this final submodel, listed in decreasing order of importance, included habitat strata, spatial control zone, year, and depth (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 18.04%. Three variables were selected for this final submodel, listed in decreasing order of importance, included habitat strata, year, and depth (Table 2). The maximum mean number of Yellowtail Snapper observed at a single station was 685 fish.

The Dry Tortugas Reef Fish Visual Census (DRTO-RVC) index for Yellowtail Snapper generally increased in trend throughout the timeseries from 6.43 fish per station in 1999 to 15.71 fish per station in 2016 (Table 3, Fig. 3). In 2006, the index dropped to 7.22 fish per station but recovered in 2008 to 12.63 fish per station. The coefficients of variation ranged from 0.049 to 0.078. When scaled to their respective means, the nominal index had a similar shape as the standardized DRTO-RVC index except in 2000 when the standardized index increased while the nominal index decreased (Fig. 4).

Based on 67,842 diver-observed fish, the median size of the Yellowtail Snapper in the Dry Tortugas region *in situ* was 20 cm FL and the interquartile range was 15.5 to 24 cm FL (Fig. 5). The largest Yellowtail Snapper estimated by divers *in situ* was 65 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 Dry Tortugas (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	4705	4262.07	0.906	.	.	.	.	Conv	
Strat	4698	3826.94	0.815	7	435.13	0	10.08	Conv	10.08
Zone	4702	3931.78	0.836	3	330.30	0	7.69	Conv	
Year	4697	4155.62	0.885	8	106.45	0	2.33	Conv	
Month	4703	4230.51	0.900	2	31.56	<0.0001	0.70	Conv	
Depth	4700	4232.74	0.901	5	29.34	<0.0001	0.58	Conv	
Strat Zone	4695	3644.02	0.776	3	182.92	0	4.24	Conv	14.32
Strat Year	4690	3739.53	0.797	8	87.41	0	1.90	Conv	
Strat Depth	4693	3758.19	0.801	5	68.75	0	1.52	Conv	
Strat Month	4696	3795.74	0.808	2	31.20	<0.0001	0.70	Conv	
Strat Zone Year	4687	3550.41	0.758	8	93.61	0	2.06	Conv	16.38
Strat Zone Depth	4690	3598.96	0.767	5	45.06	<0.0001	0.97	Conv	
Strat Zone Month	4693	3632.99	0.774	2	11.03	0.0040	0.22	Conv	
Strat Zone Year Depth	4682	3512.59	0.750	5	37.82	<0.0001	0.80	Conv	17.18
Strat Zone Year Month	4685	3550.04	0.758	2	0.37	0.8305	-0.03	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 in the Dry Tortugas (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	3914	6564.09	1.677	.	.	.	.	Conv	
Strata	3907	5754.04	1.473	7	616.17	0	12.18	Conv	12.18
Year	3906	6179.96	1.582	8	283.30	0	5.66	Conv	
Depth	3909	6409.88	1.640	5	111.93	0	2.22	Conv	
Zone	3911	6441.58	1.647	3	88.73	0	1.79	Conv	
Month	3912	6549.50	1.674	2	10.49	0.0053	0.17	Conv	
Strata Year	3899	5515.06	1.414	8	196.43	0	3.47	Conv	15.65
Strata Depth	3902	5598.02	1.435	5	127.40	0	2.27	Conv	
Strata Zone	3904	5658.59	1.449	3	77.57	0	1.39	Conv	
Strata Month	3905	5750.60	1.473	2	2.77	0.2504	0.01	Conv	
Strata Year Depth	3894	5352.37	1.375	5	138.08	0	2.38	Conv	18.04
Strata Year Zone	3896	5444.19	1.397	3	59.70	0	1.02	Conv	
Strata Year Month	3897	5496.23	1.410	2	15.79	0.0004	0.25	Conv	

Table3. The Dry Tortugas Reef Fish Visual Census (DRTO-RVC) index for Yellowtail Snapper (mean values), its coefficient of variation, the number of stations sampled, the number of stations in the Dry Tortugas where Yellowtail Snapper were observed, the DRTO-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
1999	6.43	0.078	327	242	0.53	6.09	0.46
2000	7.25	0.067	381	304	0.60	5.78	0.43
2001	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-
2004	12.88	0.065	504	374	1.06	13.27	0.99
2005	-	-	-	-	-	-	-
2006	7.22	0.068	416	325	0.60	8.50	0.64
2007	-	-	-	-	-	-	-
2008	12.63	0.051	602	524	1.04	13.19	0.99
2009	-	-	-	-	-	-	-
2010	13.70	0.052	641	530	1.13	14.11	1.06
2011	-	-	-	-	-	-	-
2012	12.66	0.049	726	620	1.04	13.83	1.04
2013	-	-	-	-	-	-	-
2014	15.20	0.050	629	575	1.25	19.48	1.46
2015	-	-	-	-	-	-	-
2016	15.71	0.058	480	421	1.30	19.14	1.43

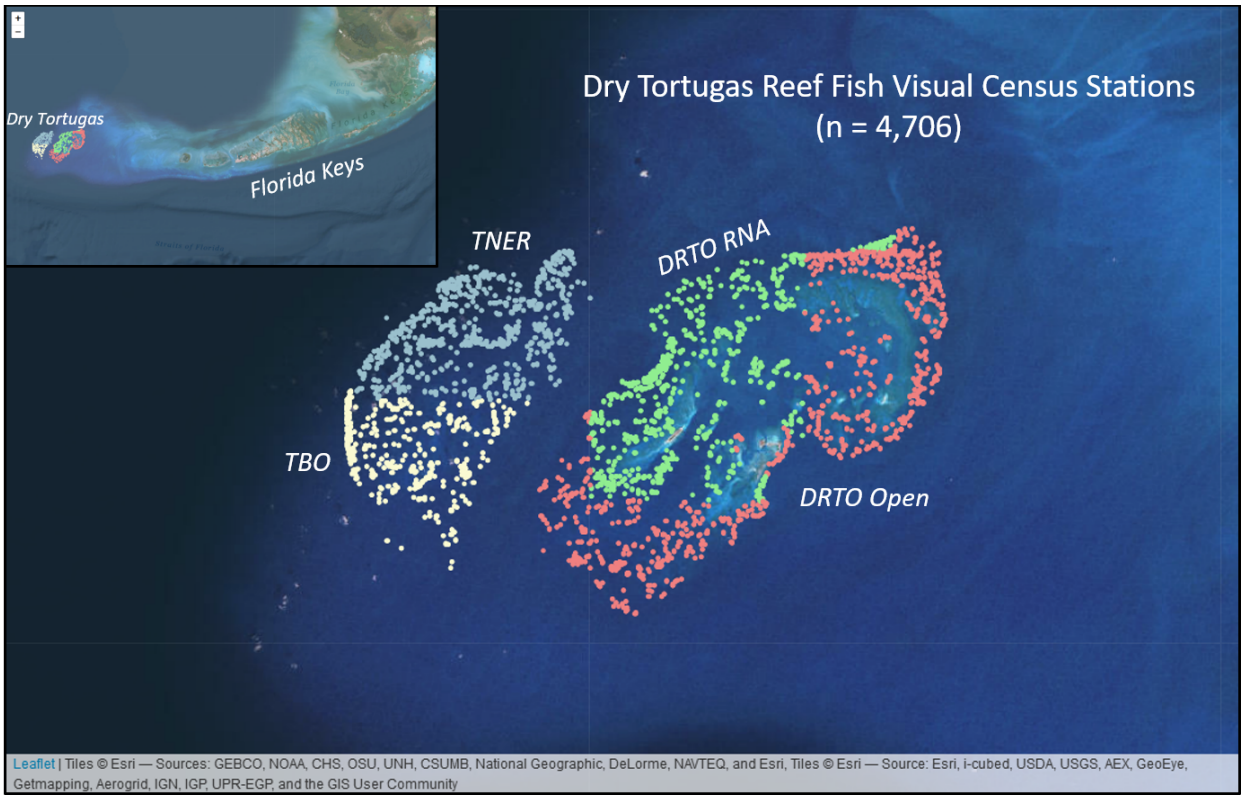

Figure 1. Reef Fish Visual Census station locations in spatial control zones of the Dry Tortugas from 1999 to 2016. DRTO Open (red) is the Dry Tortugas National Park open to recreational hook and line fishing; DRTO RNA (green) is the Research Natural Area (a No Take Marine Reserve within the Dry Tortugas National Park); TNER (blue) is in the Tortugas North Ecological Reserve (a No Take Marine Reserve); and TBO (cream) is the Tortugas Bank Open access to commercial and recreational fishing.

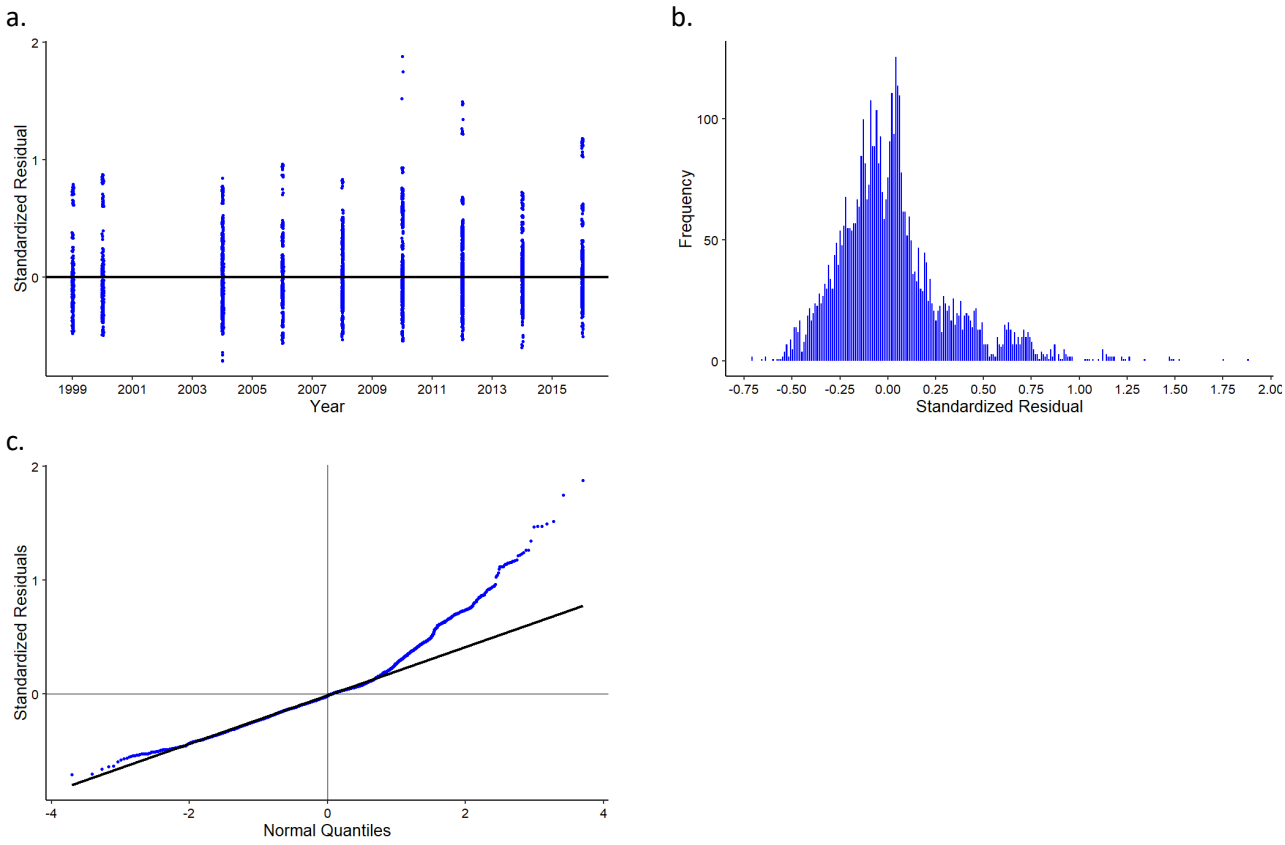

Figure 2. Diagnostic plots for the binomial submodel: a) standardized residuals by year; b) histogram of total standardized residuals; c) q-q plot.

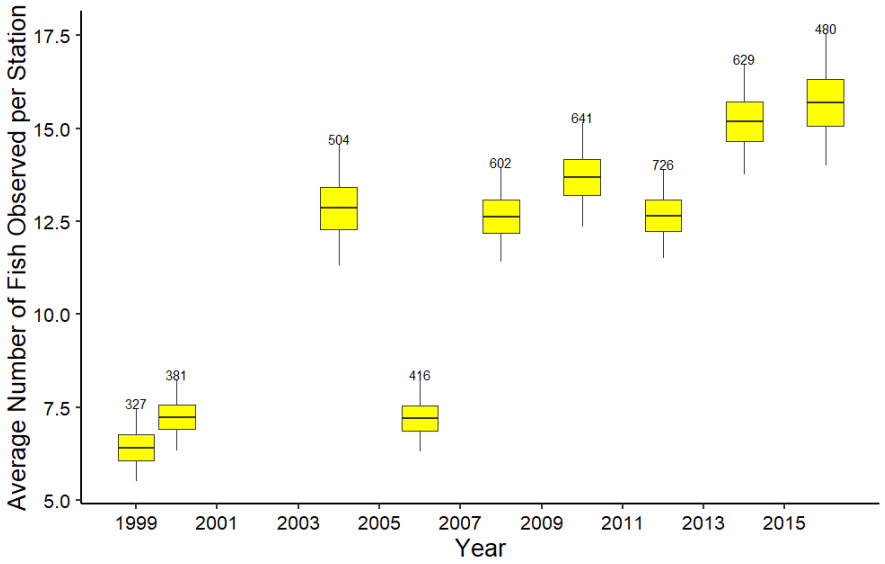

Figure 3. A box-whisker plot of the Dry Tortugas Reef Fish Visual Census (DRTO-RVC) index for Yellowtail Snapper by year. The horizontal line is the median estimate; the box is the inter-quartile range, and the vertical line is the 95% confidence interval. The number of stations sampled each year is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

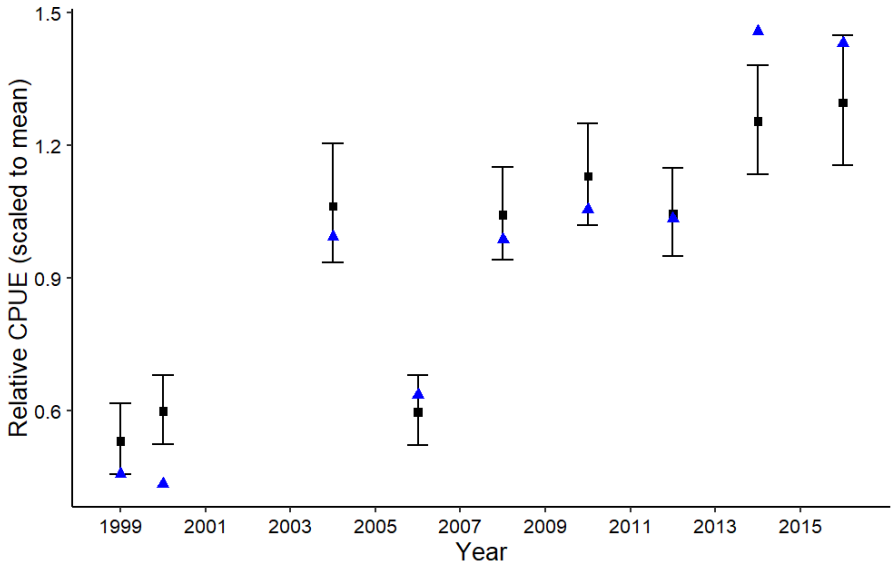

Figure 4. Comparison of the standardized mean values of the Dry Tortugas Reef Fish Visual Census (DRTO-RVC) index for Yellowtail Snapper, its confidence intervals, and the nominal index scaled to their means by year. The black squares are the standardized mean values; the black vertical error bars are the 95% confidence intervals of the standardized mean values; and the blue triangles are the nominal values.

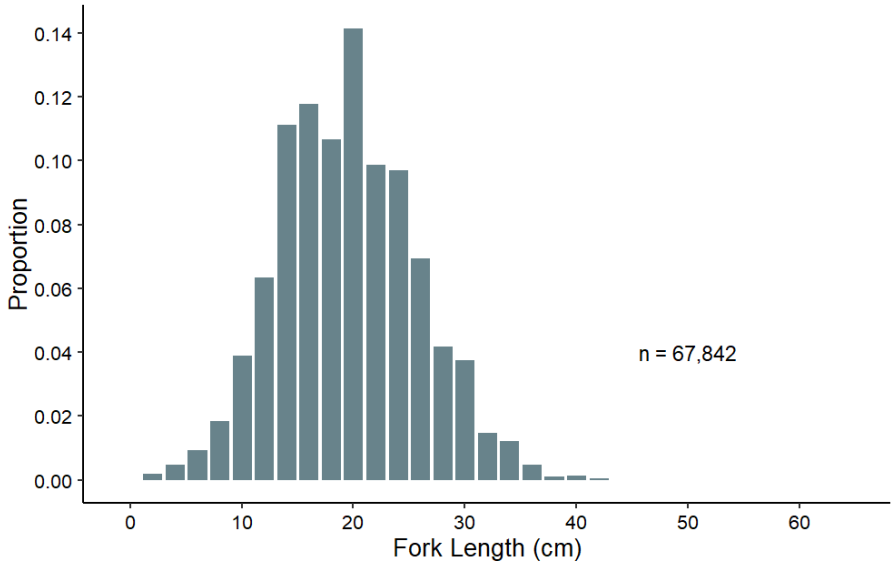

Figure 5. The distribution of total lengths of Yellowtail Snapper estimated *in situ* by Reef Fish Visual Census divers along reef tracts in the Dry Tortugas from 1999 to 2016.