Standardized Reef Visual Census index for Gray Snapper, *Lutjanus griseus*, for the Florida reef track from the Florida Keys and Dry Tortugas for 1997-2018

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Standardized Reef Visual Census index for Gray Snapper, *Lutjanus griseus*, for the Florida reef track from the Florida Keys and Dry Tortugas for 1997-2018.

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Abstract

Reef Fish Visual Census' (RVC) observation rates for Gray Snapper, *Lutjanus griseus*, expressed as the average number of Gray Snapper observed per station, were standardized using a delta or hurdle procedure. Count data from 1999 through 2018 were extracted for the Florida Keys and Dry Tortugas omitting stations north of the Miami-Dade/Monroe County line and the basic data from 1997 and 1998 were copied from the data used in SEDAR 51. The RVC data were additionally filtered to remove those stations with visibility less than 7.5 m, stations from experimental winter surveys, and stations in sand, seagrass, mud, or artificial habitats because these habitats were not part of the RVC domain. The final data set included 13,607 stations.

As before with SEDAR 51, the final variables to include in the model to estimate the annual number of Gray Snapper per station were selected in a forward stepwise manner from the potential explanatory variables that included year (1997 to 2018), season (Apr-Jun, Jul-Sep, Oct-Dec), sub-regions of the reef track (Upper Keys, Middle Keys, Lower Keys, Dry Tortugas Bank, and Dry Tortugas National Park), Sanctuary Protected Area (yes, no), habitat (continuous high, medium, and low relief, isolated high, medium, and low relief, rubble low relief, spur and groove high and low relief), reef zones (inshore, mid-channel, offshore patch reef, forereef, deepwater, lagoon, bank), and depth (2.5m categories with 25 m +). The same five configurations of the estimation model (delta-Poisson, delta-gamma, delta-lognormal, negative binomial , and Poisson) were developed, but this time the models were compared using the Root mean square error based on a simple residual in the original units.

The delta-Poisson model had the lowest Root-Mean-Square-Error (18.83 fish observed per station). The submodel for the proportion of stations that observed Gray Snapper reduced the mean deviance by 14.6% and the submodel for the mean number of Gray Snapper observed at positive stations reduced the deviance by 14.4%. The average number of Gray Snapper observed per station increased until 2005 and then has remained stable although variable since. The index value in 2018 was the second highest in the time series, the highest occurred in 2011. The coefficients of variation were 0.15 or less.

Introduction

Personnel from the National Marine Fisheries Service' Southeast Fisheries Science Center began monitoring the fish populations on the Florida reef track with the Reef Visual Census (RVC) in 1979 counting fish from Biscayne Bay through the Florida Keys (Bohnsack and Bannerot 1986; Bohnsack *et al.* 1999; and Ault *et al.* 2001). Eventually, the RVC evolved into a two-stage stratified random survey design (Cochran 1977, Smith *et al.* 2011) to estimate the abundance of fish along the reef track. Sampling frames by habitat were created by gridding the Florida reef track 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 the spatial resolution. Although the change in the block size changes the abundance estimates, it does not affect the index because the index is a measure of the average number of Gray Snapper observed by the divers at a station. Annually (biennially after 2012), blocks were randomly selected by habitat and usually two SCUBA divers were deployed at each of two randomly located stations within the blocks. The divers identified and counted the 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 (SPA). 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 visual survey in 1999 and the two surveys were merged in 2009.

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. Most of the fishery independent sampling programs used in SEDAR assessments occur in deeper waters than where Gray Snapper occur. The Reef Visual Census is a fishery-independent source that operates in prime habitat for Gray Snapper.

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; therefore, I extracted the RVC station point count data for the Florida Keys and Dry Tortugas for the 1999 through 2018 with the 'rvc' R package developed by Jeremiah Blondeau from NOAA South Florida National Coral Reef Monitoring Program https://grunt.sefsc.noaa.gov/rvc_analysis20/samples/index. There was no sampling in 2013, 2015, 2017, nor 2019 due to the biennial sampling schedule; however, there also was no sampling in 2020 because of the Covid pandemic. The 1997 and 1998 data from SEDAR 51 already had the three additional fields (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) added following the instructions in Jeffrey Renchen's 24 Feb 2017 email. Because SEDAR 75 is a Gulf of Mexico assessment, stations located north of Monroe County were excluded from the analyses. For the reef track, excluding these data meant extending the 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, removing stations that were conducted in sand, seagrass, mud, or artificial habitats because these habitats were not considered part of the RVC domain. Because underwater visibility was not recorded routinely until 2002 and in 2004 in the Dry Tortugas sampling, some of the visibility measurements were in feet instead of meters, visibility was not considered as a potential explanatory variable. Visibility was included in SEDAR 51 because I wasn't aware of the above issues with visibility. The final dataset consisted of 13,607 station samples from the Florida Keys and the Dry Tortugas (Fig. 1).

The analytical approach used in SEDAR 51 and here was similar to what Ingram and Harper (2009) did for Black Grouper, the index was standardized with the delta or hurdle approach which split the process into two generalized linear submodels (Lo *et al.* 1992, Cragg 1971): one submodel to estimate the proportion of stations where Gray Snapper were observed with a binomial distribution that used a logit link. The response variable for this submodel was 1.0 if Gray Snapper were observed at a station or 0.0 if none was observed. The second submodel estimated the mean number of Gray Snapper observed at positive stations with either a gamma or a Poisson distribution with a log link, or a log-normal distribution which used a normal distribution on log transformed numbers of fish and an identity link. Additionally, two models (negative binomial and Poisson) were developed that used single distributions.

These were the same five configurations that were developed in SEDAR 51 but not mentioned. The selection of the distribution in the final hurdle configuration was based on the extent of the reduction in the mean deviance. The annual index was the product of the proportion of positive stations (***Prop***) and the mean number of Gray Snapper ($\hat{Y}$) by year after they each have been back calculated to their original units from their linear forms. For the logit link, the back transform was

$$Prop = \exp(f(x1 + x2+\ldots)+\sigma^2/2)/[1 + \exp(f(x1 + x2+\ldots)+\sigma^2/2)] \qquad \text{Eq. 1.}$$

where the *x1, x2,* refer to the variables included in the final, linear submodel and the $\sigma^2/2$) is the offset of the mean from the mode. For the Poisson and gamma distributions (log link) the back transform was

$$\hat{Y} = \exp(f(x1 + x2+\ldots)+\sigma^2/2) \qquad \text{Eq. 2.}$$

Where $\hat{Y}$ is the annual mean number of Gray Snapper observed at a station and the other symbols have the same meaning as above. The back-transform of the log-normal distribution that used an identity link was the same as for the gamma or the Poisson distributions because the response variable in the model was the logarithm of the number of fish observed.

$$Index = Prop * \hat{Y} \qquad \text{Eq. 3.}$$

The two models that used single distributions also used a log link and hence the index was back transformed using eq. 2.

Potential explanatory variables included year (1997 to 2018); season (Apr-Jun, Jul-Sep, Oct-Dec); sub-regions of the reef track (Upper Keys, Middle Keys, Lower Keys, Dry Tortugas Bank, Dry Tortugas National Park); Sanctuary Protected Area (yes, no; stations located in the Dry Tortugas National Park were all considered protected); habitat (continuous high, medium, and low relief, isolated high, medium, and low relief, rubble low relief, spur and groove high and low relief); reef zones (inshore, mid-channel, offshore patch reef, forereef, deepwater, lagoon, bank); and depth (2.5m categories with 25 m +). As noted above, underwater visibility was not included in the analyses. All the potential explanatory variables were treated as categorical variables which partially accounts for possible non-linearity. The submodels used a forward stepwise process starting with the null model to identify which variables should be included in the final versions of the respective submodels. To be included in the final submodel, variables had to meet two criteria: the variable had to be statistically significant at the 0.05 level (the probability of rejecting the null hypothesis) and its inclusion in the model had to reduce the deviance (a measure of the variability) by at least 0.5%.

The variability in the annual index values was estimated with 10,000 iterations of a Monte Carlo simulation that used the least-squares mean estimates and their standard errors from the two GLIM submodels. Each iteration used the annual least-squares mean estimate on the linear scale and uncertainty was added by multiplying the annual least-squares mean estimate's standard error by a random normal deviate (μ=0, σ=1; Eq. 1 and 2). As described above, these values were transformed back from their linear scales and multiplied together (Eq. 3).

To compare all the models, the Root-Mean-Square-Error (RMSE), using the back transformed estimates, was calculated for each of the five candidate models and the residual was the observed number of fish – predicted number of fish. For the hurdle models, the predicted number of fish from the positive data was multiplied by the probability of observing a Gray Snapper. The final model was the model with the lowest RMSE.

Results and Discussion

Figure 2 shows nominal mean numbers of Gray Snappers observed per station per year. Twenty-two-point five percent of the stations (3744 of the 13,607 stations) observed Gray Snappers; the mean number per station on a day ranged from 0 to 1605 fish although divers on 90% of the stations that observed Gray Snappers observed 3 or fewer. The index pattern is stable but variable. The large error bars (CV > 0.30) in 2004, 2008, and 2011 were due to a total of six stations, two stations per year (numbers of fish: 350, 625, 505, 1605, 450, and 500). A possible explanation for these high counts is that these stations were sampled during the spawning season and the divers witnessed spawning aggregations of Gray Snapper.

Table 1 lists the different model configurations and their fits based on the root mean-square error (RMSE) and of the different configurations, the delta- Poisson submodel had the lowest RMSE (18.83 fish) which was the same configuration as in SEDAR 51. This model also reduced the deviance the most (14.4%). The hurdle models all used the same submodel for the proportion of stations that observed Gray Snapper. That submodel used a binomial distribution because the observations only had two possible values zero or one. The variables selected for the final binomial submodel were habitat, reef zone, depth category, and year and they reduced the deviance by 14.6% (Table 2). The standardized residuals were centered on zero and were mostly distributed between 1.0 and -1.0 (Fig. 3 a and c). Table 3 shows the stepwise process in selecting the variables to be included the final Poisson submodel and the variables selected for the final submodel for the number of Gray Snapper observed at a station included reef zone, subregion of the Keys, habitat. depth category, and year. There were 23 outliers with this submodel, and the outlier stations all had mean counts of 130 Gray Snapper or more observed. The plots of standardized residuals show the influence of the outliers (Fig.3 b, d, f). However, they are not errors but probably just reflect spawning aggregations.

The Reef Fish Visual Census index for Gray Snapper increased from 1997 until 2005 and then was stable but variable with the 2018 value (4.07 fish per station) was the second highest in the time series (Table 4, Fig.4). The coefficients of variation were reasonable ranging from 0.092 to 0.152. The standardized RVC index had a similar shape as the nominal index especially in recent years, 2014 - 2018 (Fig. 5). A comparison of the standardized RVC index with the previous RVC index from SEDAR 51 (Fig. 6) shows lower values for the 1997-2002 which may be due to including visibility as a potential explanatory variable in the earlier index. Also, the current index has lower values for 2014 and 2016 which are in line with the values from 2002 to 2012 where the 2014 value in the earlier index was quite high and the value for 2016 was lower but still high.

The unweighted median size of the Gray Snapper in the Florida Keys (*n* = 38,107 fish) as estimated by the divers *in situ* was 24.0 cm TL and the interquartile range was 20.0 to 28.5 cm TL (Fig. 7). The minimum size for keeping Gray Snappers in state waters is 10 in (25.4 cm) and 48% of the Gray Snappers divers observed were 25.4 cm or longer, but the minimum size in federal waters is 12 in (30.5 cm) and 29% of the observed Gray Snappers were 30.5 cm or longer. Fitzhugh *et al.* (2017) found that the length at which 50% of the Gray Snapper are mature was 268 mm TL (253 mm FL) and the 10th percentile length was 152 mm TL (144 mm FL) and the 90^{th} percentile was 384 mm TL (362 mm FL). Therefore, 34% of the observed Gray Snapper were at least the size of 50% maturity.

The RVC divers sample to 30 m; however, the depth range of Gray Snapper extends deeper such that the RVC divers do not sample the full range of Gray Snapper and because of that a dome-shaped selectivity curve is appropriate for the Gray Snapper observed by RVC divers. Figure 8a shows a dome shaped, double logistic selectivity curve

$$Sel = (1+exp((infl1 – L)/slope1)*(1 - (1+exp((infl1 – L)/slope1)) \quad \text{Eq. 4.}$$

where *Sel* is the selectivity, *infl1* is the inflection point on the ascending limb, *L* is the midpoint of the length bin, *slope1* is the shape term for the ascending limb, *infl2* is the inflection point on the descending limb and *slope2* is the shape term for the descending limb. For the RVC index length data, the parameter values are infl1 = 16.13 (SE = 0.38), slope1 = 1.04 (SE = 0.33), infl2 = 29.40 (SE = 0.81), and slope2 = 5.61 (SE 0.80). If it is desired that the dome shaped curve has a maximum value of one, then the selectivities have to be multiplied by a scalar and in this case the scalar is 1.23 (Quinn and Deriso 1999). If the data workshop decides that all sizes of Gray Snapper are available, then the appropriate shape would be a flat-topped selectivity curve (Fig.8b). A simple flat-topped curve is a logistic curve which is just the first term in Eq.4 or

$$Sel = (1+exp((infl – L)/slope) \quad \text{Eq. 5.}$$

and the parameter values are *infl* = 25.16 (SE = 0.13) and *slope* = 4.39 (se = 0.11).

This analysis has benefitted from the extensive review of the RVC data preceding the development of the RVC index for Mutton Snapper (SEDAR 79).

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Table 1. Comparing different assessment configurations using the Root mean squared-error based on a simple residual in the original units that was calculable for all models (residual = observed – predicted). The deviance reduction for the three, delta positive submodels are also included as is the total number of stations.

Model	**Model degrees of freedom**	**Error sum of squares**	**Mean square error**	**Root mean square error**	**Deviance reduction positive data %**
Delta-Poisson	48	5239023	385.05	19.62	14.4
Delta - log normal	30	5437808	399.66	19.99	6.0
Delta-gamma	48	5271088	387.41	19.68	13.1
Negative binomial	38	5547084	407.69	20.19	.
Poisson	48	5352728	393.41	19.83	.

Number of Stations	13607

Table 2. Stepwise selection of variables for their inclusion in estimating the probability of observing a Gray Snapper at a Reef Visual Census station (shaded lines) in the waters of the Florida Keys including the Dry Tortugas with a GLIM (binomial distribution and logit link). 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, and the cumulative percent reduction in deviance. All of the submodels converged.

Explanatory variable	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of null hypothesis	Percent reduction in deviance	Cumulative percent reduction in mean deviance
Null	13606	16010.5	1.18	.	.	.	.	.
Year	13588	15833.6	1.17	18	176.9	0.00	0.97	.
Season	13604	16002.2	1.18	2	8.2	0.02	0.04	.
Subregion	13601	15853.2	1.17	5	157.3	0.00	0.95	.
Protected	13604	15862.9	1.17	2	147.5	0.00	0.91	.
Reef zone	13599	15524.3	1.14	7	486.2	0.00	2.99	.
Habitat	13598	14243.6	1.05	8	1766.8	0.00	10.98	10.98
Depth	13596	15799.3	1.16	10	211.1	0.00	1.25	.
Habitat Year	13580	14130.9	1.04	18	112.7	0.00	0.59	.
Habitat Season	13596	14209.1	1.05	2	34.5	0.00	0.20	.
Habitat Subregion	13593	14015.7	1.03	5	228.0	0.00	1.39	.
Habitat Protected	13596	14196.1	1.04	2	47.6	0.00	0.28	.
Habitat Reef zone	13591	13869.7	1.02	7	373.9	0.00	2.29	13.27
Habitat Depth	13588	14033.2	1.03	10	210.4	0.00	1.25	.
Habitat Reef zone Year	13573	13776.3	1.01	18	93.4	0.00	0.47	.
Habitat Reef zone Season	13589	13853.9	1.02	2	15.8	0.00	0.09	.
Habitat Reef zone Subregion	13586	13819.5	1.02	5	50.2	0.00	0.28	.
Habitat Reef zone Protected	13589	13868.6	1.02	2	1.1	0.58	-0.01	.
Habitat Reef zone Depth	13581	13737.7	1.01	10	132.0	0.00	0.76	14.03

Table 2 continued. Stepwise selection of variables for their inclusion in estimating the probability of observing a Gray Snapper at a Reef Fish Visual Census station (shaded lines) if the Gulf of Mexico waters of the Florida Keys including the Dry Tortugas with a GLM (binomial distribution and logit link). 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, and the cumulative percent reduction in deviance. All of the submodels converged.

Explanatory variable	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of null hypothesis	Percent reduction in deviance	Cumulative percent reduction in mean deviance
Habitat Reef zone Depth Year	13563	13632.3	1.01	18	105.4	0.00	0.55	14.58
Habitat Reef zone Depth Season	13579	13724.5	1.01	2	13.1	0.00	0.07	.
Habitat Reef zone Depth Subregion	13576	13681.2	1.01	5	56.5	0.00	0.32	.
Habitat Reef zone Depth Protected	13579	13724.6	1.01	2	13.0	0.00	0.07	.
Habitat Reef zone Depth Year Season	13561	13623.6	1.00	2	8.7	0.01	0.04	.
Habitat Reef zone Depth Year Subregion	13558	13573.5	1.00	5	58.8	0.00	0.34	.
Habitat Reef zone Depth Year Protected	13561	13618.8	1.00	2	13.5	0.00	0.07	.

Table 3. Stepwise selection of variables to include in estimating the number of Gray Snapper observed at positive Reef Visual Census stations (shaded lines) in the Florida Keys with a GLIM (Poisson distribution and log link). 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, and the cumulative percent reduction in deviance.

Explanatory variable	Degrees of freedom	Deviance	Mean deviance	Chi-square degrees of freedom	Chi-square	Probability of null hypothesis	Percent reduction in deviance	Cumulative percent reduction in mean deviance
Null	3743	90860.6	24.27	.	.	.	.	.
Year	3725	88560.8	23.77	18	2299.8	0.00	2.06	.
Season	3741	90820.0	24.28	2	40.6	0.00	-0.01	.
Subregion	3738	88426.6	23.66	5	2434.0	0.00	2.55	.
Protected	3741	89847.5	24.02	2	1013.1	0.00	1.06	.
Reef zone	3736	86507.9	23.16	7	4352.7	0.00	4.61	4.61
Habitat	3735	87596.6	23.45	8	3264.0	0.00	3.39	.
Depth	3733	87217.8	23.36	10	3642.8	0.00	3.75	.
Reef zone Year	3718	84595.2	22.75	18	1912.7	0.00	1.66	.
Reef zone Season	3734	86317.6	23.12	2	190.2	0.00	0.16	.
Reef zone Subregion	3731	83163.0	22.29	5	3344.9	0.00	3.57	8.18
Reef zone Protected	3734	86073.2	23.05	2	434.7	0.00	0.43	.
Reef zone Habitat	3728	83940.5	22.52	8	2567.4	0.00	2.63	.
Reef zone Depth	3726	83706.5	22.47	10	2801.4	0.00	2.84	.
Reef zone Subregion Year	3713	81379.5	21.92	18	1783.5	0.00	1.53	.
Reef zone Subregion Season	3729	83071.0	22.28	2	92.0	0.00	0.05	.
Reef zone Subregion Protected	3730	82919.9	22.23	1	243.1	0.00	0.24	.
Reef zone Subregion Habitat	3723	80783.8	21.70	8	2379.2	0.00	2.44	10.61
Reef zone Subregion Depth	3721	81124.6	21.80	10	2038.4	0.00	2.01	.

Table 3 continued. Stepwise selection of variables to include in estimating the number of Gray Snapper observed at positive Reef Fish Visual Census stations (shaded lines) with a GLM (Poisson distribution and log link). 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 null hypothesis	Percent reduction in deviance	Cumulative percent reduction in mean deviance
Reef zone Subregion Habitat Year	3705	78789.4	21.27	18	1994.4	0.00	1.78	.
Reef zone Subregion Habitat Season	3721	80655.3	21.68	2	128.5	0.00	0.09	.
Reef zone Subregion Habitat Protected	3722	80639.7	21.67	1	144.1	0.00	0.14	.
Reef zone Subregion Habitat Depth	3713	78806.6	21.22	10	1977.2	0.00	1.95	12.57
Reef zone Subregion Habitat Depth Year	3695	76747.9	20.77	18	2058.7	0.00	1.87	14.43
Reef zone Subregion Habitat Depth Season	3711	78707.9	21.21	2	98.7	0.00	0.06	.
Reef zone Subregion Habitat Depth Protected	3712	78701.0	21.20	1	105.6	0.00	0.09	.
Reef zone Subregion Habitat Depth Year Season	3693	76678.1	20.76	2	69.8	0.00	0.03	.
Reef zone Subregion Habitat Depth Year Protected	3694	76685.0	20.76	1	62.9	0.00	0.05	.

Table 4. The Reef Visual Census index, its coefficient of variation, the number of stations sampled, the number of stations in the Florida Keys where Gray Snapper were observed, the RVC index scaled to its mean, nominal index, and the nominal index scaled to its mean.

Year	Index number per station	Coefficient of variation	Number of stations	Number of stations with Gray Snapper	Index scaled to mean	Nominal index	Nominal index scaled to mean
1997	1.09	0.137	341	116	0.37	1.90	0.66
1998	2.16	0.124	394	168	0.74	4.38	1.53
1999	2.21	0.106	730	221	0.76	2.17	0.76
2000	2.39	0.107	842	229	0.82	2.46	0.86
2001	2.81	0.119	668	178	0.96	3.44	1.20
2002	3.09	0.121	428	116	1.05	2.83	0.98
2003	2.26	0.152	231	60	0.77	2.13	0.74
2004	2.98	0.123	726	170	1.02	3.13	1.09
2005	3.13	0.141	309	73	1.07	2.26	0.79
2006	1.73	0.123	746	153	0.59	1.65	0.58
2007	2.50	0.140	414	81	0.85	1.99	0.69
2008	2.66	0.111	1126	268	0.91	3.83	1.33
2009	3.51	0.112	714	159	1.20	2.61	0.91
2010	2.74	0.099	1116	322	0.94	2.39	0.83
2011	6.05	0.118	552	112	2.07	3.04	1.06
2012	3.42	0.095	1257	378	1.17	3.37	1.17
2013	.	.	.	.	.	.	.
2014	2.79	0.105	1117	291	0.95	2.58	0.90
2015	.	.	.	.	.	.	.
2016	2.67	0.102	845	275	0.91	2.54	0.88
2017	.	.	.	.	.	.	.
2018	4.07	0.092	1051	374	1.39	4.02	1.40

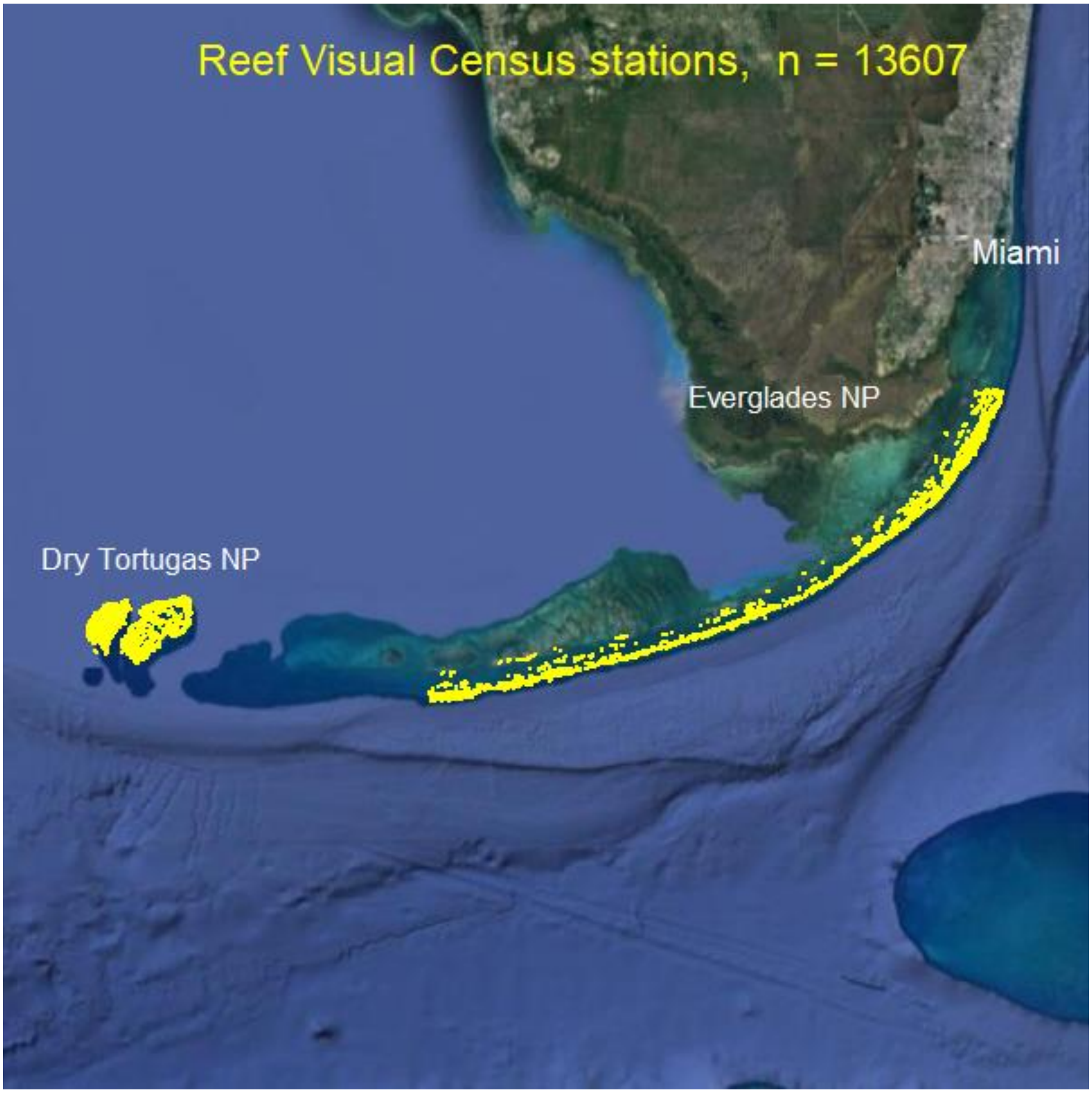


Figure 1. Reef Visual Census station locations sampled in the Florida Keys including the Dry Tortugas from 1997 to 2018.

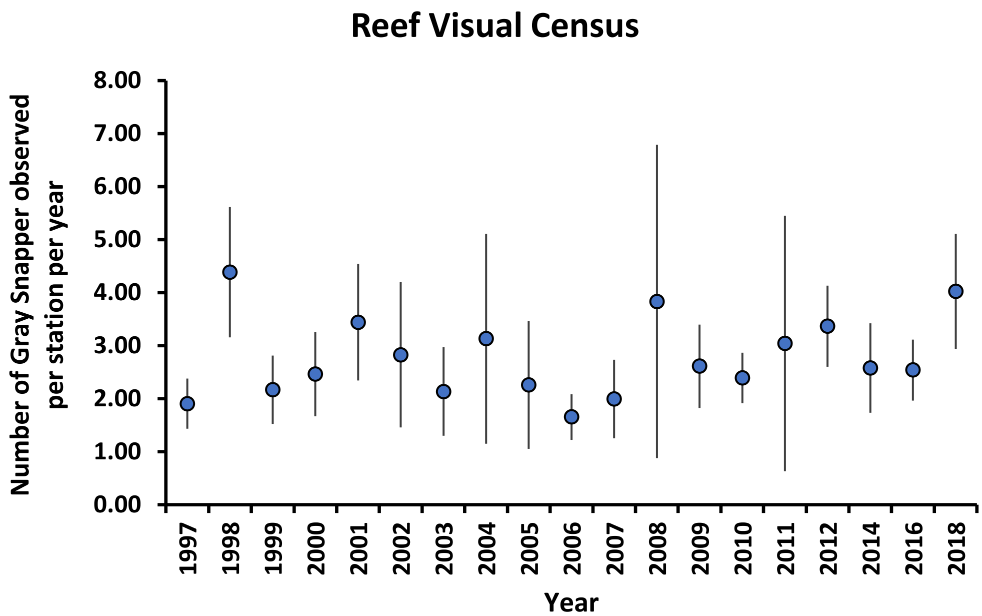


Figure 2. Nominal number of Gray Snapper observed by year and station. The points are the mean estimates, and the vertical lines are the 95% confidence limits.

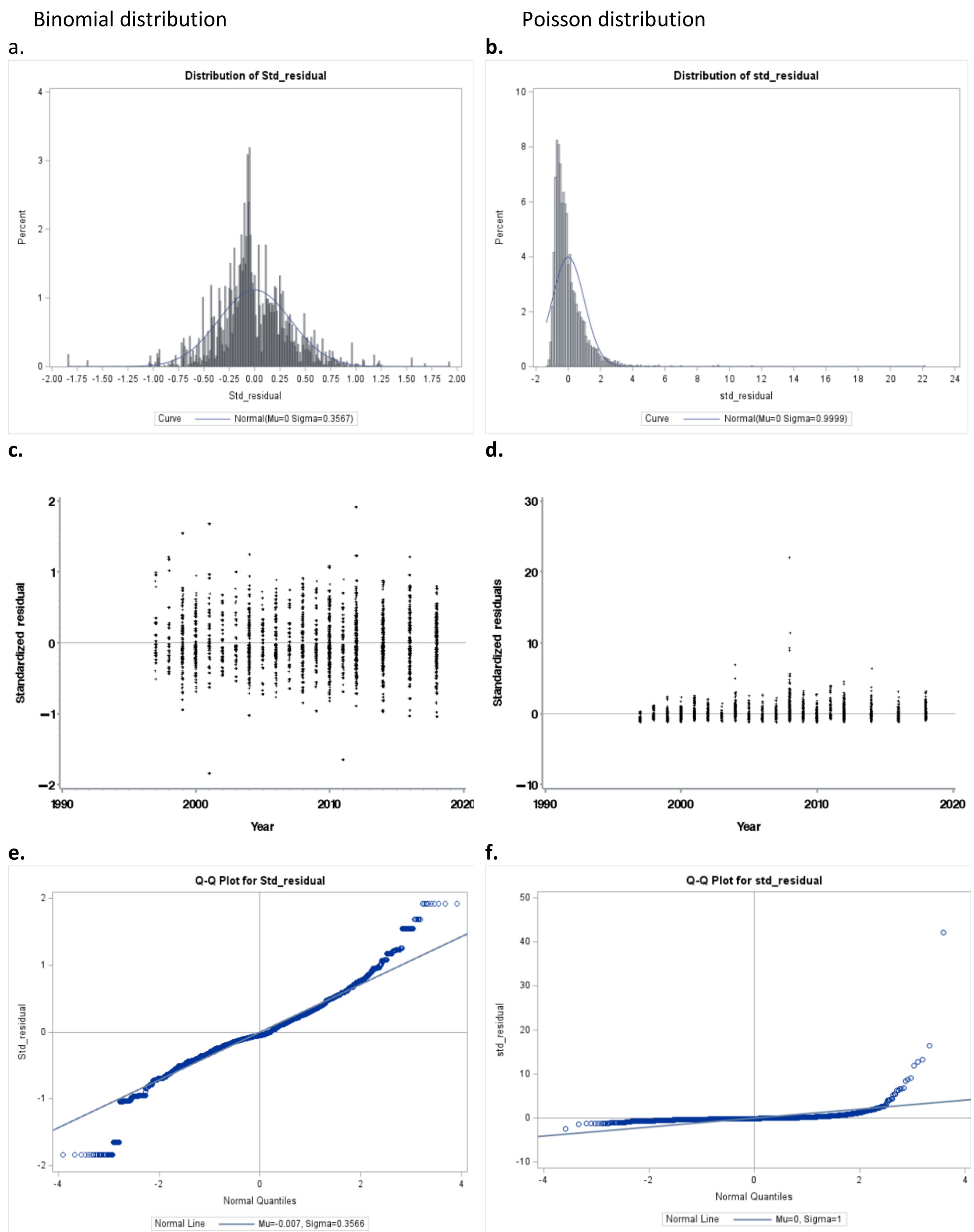


Figure 3. Diagnostic plots of standardized residuals for the probability of observing a Gray Snapper at a station using a binomial distribution (a and c, and q-q plot, e); and plots for the number of Gray Snapper observed at a station using a Poisson distribution, standardized residuals (b and d, and q-q plot, f).

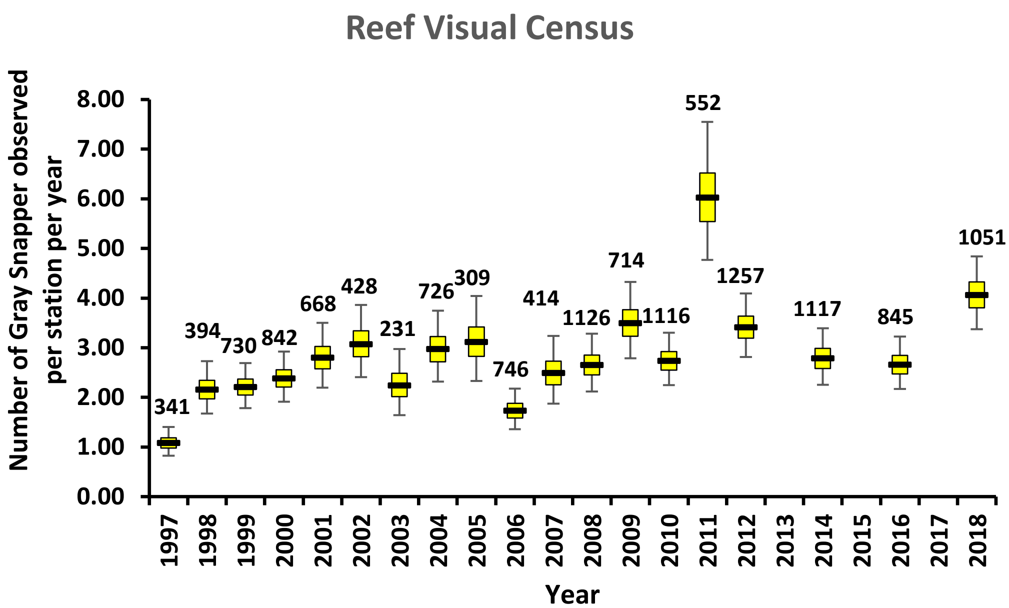


Figure 4. A box-whisker plot of the Reef Visual Census Gray Snapper index by year for the Florida Keys and the Dry Tortugas. The horizontal line is the median estimate; the box is the inter-quartile range, and the vertical line is the 95% confidence interval. The number of stations sampled each year is shown above the confidence interval.

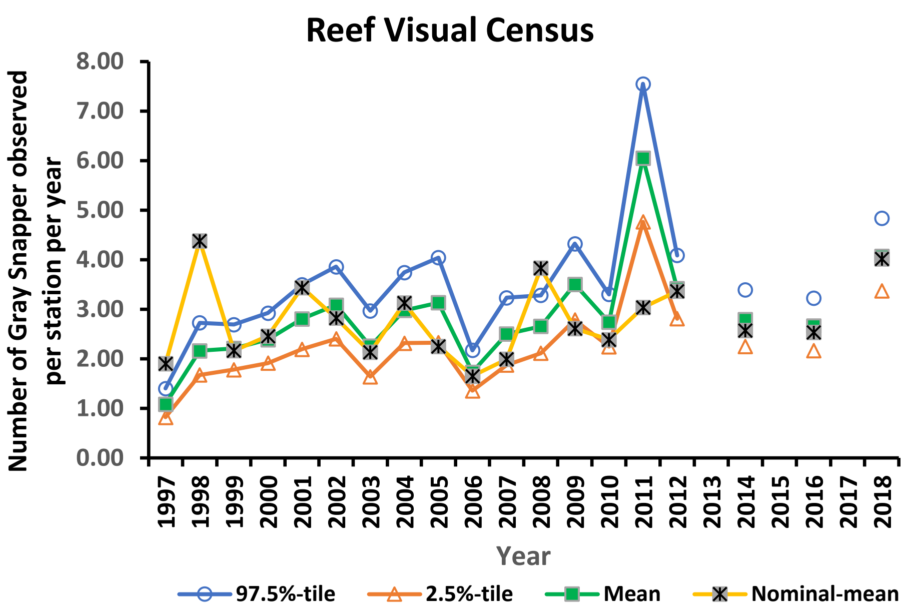


Figure 5. Comparison of the Reef Visual Census Gray Snapper index with their 95% confidence intervals and nominal mean catch rates by year.

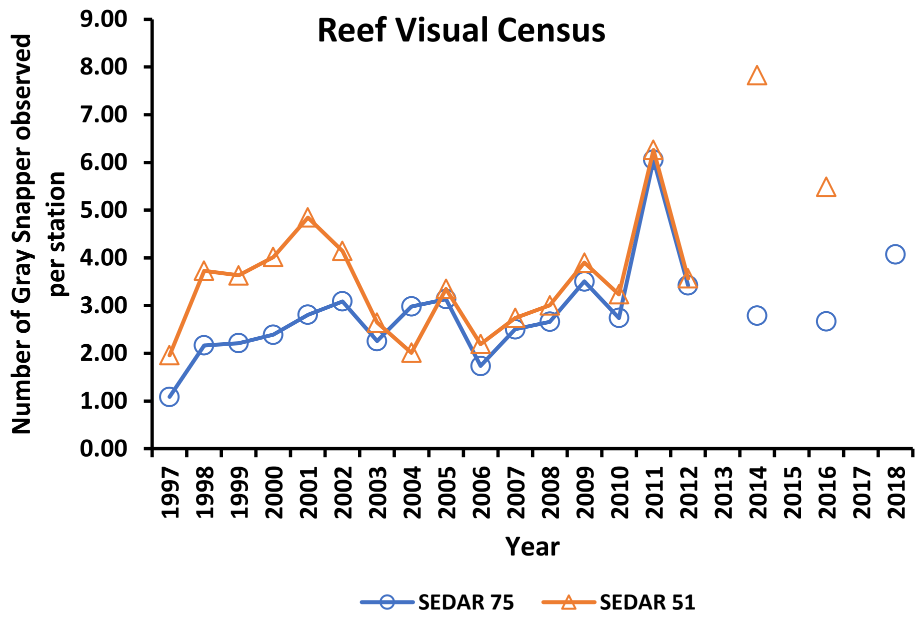


Figure 6. Comparison of the Reef Visual Census Gray Snapper index (open circles) with the earlier RVC index in SEDAR 51 (open triangles).

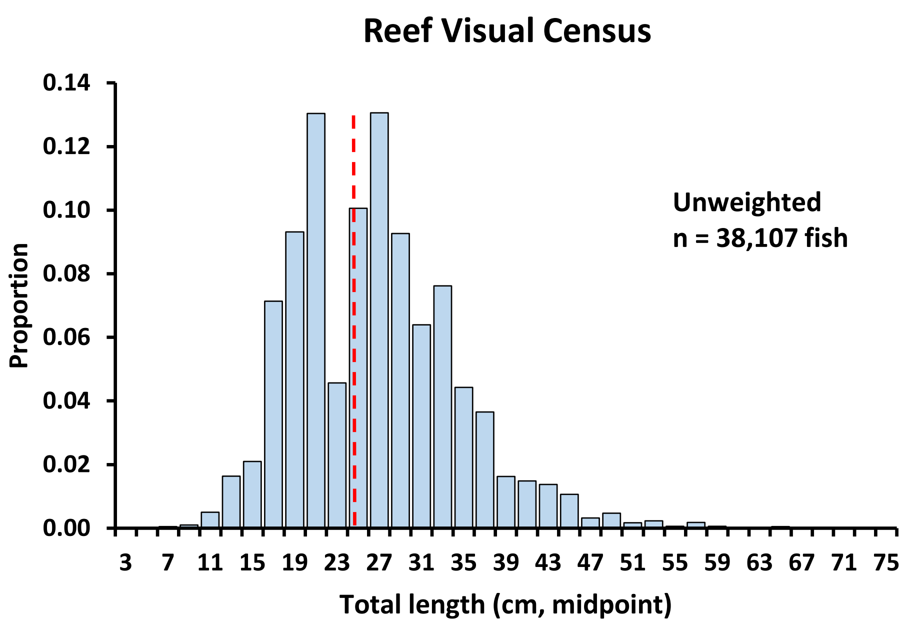
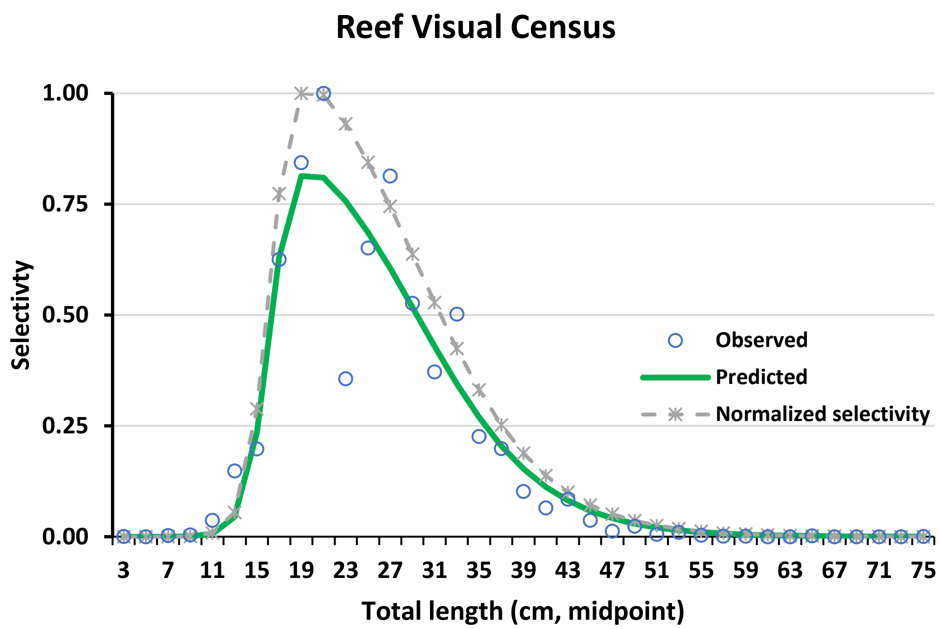


Figure 7. The distribution of total lengths of Gray Snapper estimated *in situ* by Reef Fish Visual Survey divers along the Florida reef track including the Dry Tortugas from 1997 to 2018. The red dashed line is Florida's minimum size limit (10 inches or 25.4 cm).

a.



b.

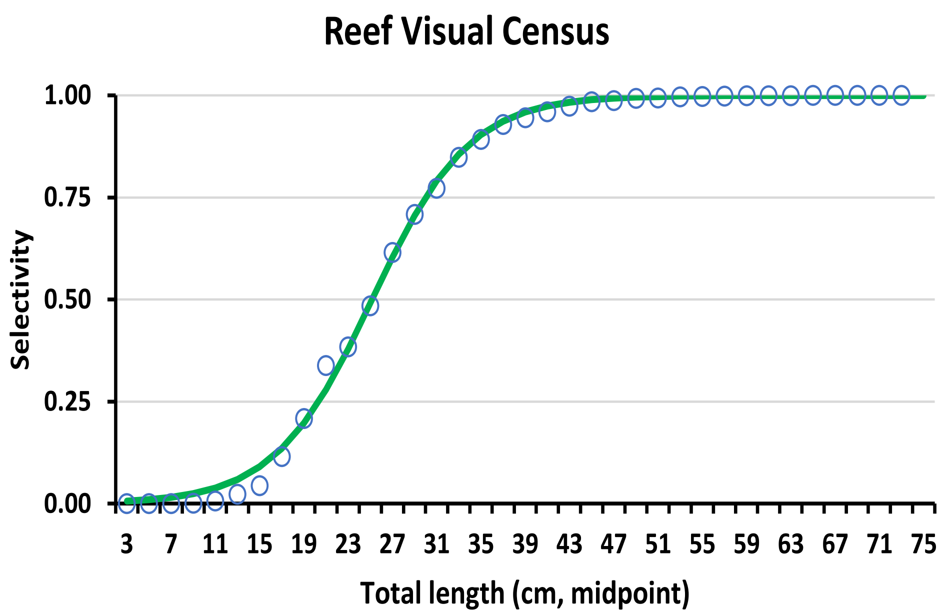


Figure 8. Dome-shaped (a) and flat-topped (b) selectivity of Gray Snapper lengths observed by divers at randomly selected stations in the Florida Keys and Dry Tortugas from 1997-2018.