Catch rates, distribution and size/age composition of red grouper, Epinephelus morio*, collected during NOAA Fisheries Bottom Longline Surveys from the U.S. Gulf of Mexico.*

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Introduction

The Southeast Fisheries Science Center (SEFSC) Mississippi Laboratories has conducted standardized bottom longline surveys in the Gulf of Mexico, Caribbean, and Western North Atlantic since 1995. The objective of these surveys is to provide fisheries independent data for stock assessment purposes for as many species as possible. These surveys are conducted annually in U.S. waters of the Gulf of Mexico (GOM) and/or the Atlantic Ocean (Table 1), and they provide an important source of fisheries independent information on large coastal sharks, snappers and groupers from the GOM and Atlantic. The evolution of these surveys has been the subject of many documents [most recently Ingram *et al*. 2005 (LCS05/06-DW-27)] and was not described again in this document.

Red grouper (*Epinephelus morio*) are an important component of both commercial and recreational fisheries in the GOM. Results from analyses of data collected on red grouper during these surveys are presented below in order to aid in the current assessment of the red grouper stock in the GOM.

Methods and Results

For the SEDAR 12, we used the time series of data between 2000 and 2005 to develop abundance indices for red grouper for the GOM. Due to the use of J-type hooks in early survey years, very few red grouper were captured. With the change to circle-hooks, red grouper catch increased by an order of magnitude (LCS05/06-DW-27). Therefore, only survey years 2000 to 2005, during which circle-hooks were employed, were used (Table 1).

The positions of all stations, within the depth range red grouper were collected (i.e. 13 – 116 m), and positions of stations where red grouper were captured were plotted by year and all years combined (Figures 1-7). No red grouper were collected west of 87° west longitude. Therefore, only stations east of 87° west longitude were plotted. Survey coverage area varied during the time series due to weather or mechanical problems. Only data from stations within the depth range of capture for red grouper and east of 87° west longitude were used in development of annual indices.

The delta-lognormal index of relative abundance (I_y) as described by Lo *et al*. (1992) was estimated as

(1) $I_y = c_y p_y$,

where c_y is the estimate of mean CPUE for positive catches only for year y; p_y is the estimate of mean probability of occurrence during year y. Both c_y and p_y were estimated using generalized linear models. Data used to estimate abundance for positive catches (c) and probability of occurrence (p) were assumed to have a lognormal distribution and a binomial distribution, respectively, and modeled using the following equations:

(2) $$\ln(\mathbf{c}) = \mathbf{X\beta} + \boldsymbol{\varepsilon}$$

and

(3) $$\mathbf{p} = \frac{e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}}{1 + e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}}$$, respectively,

where **c** is a vector of the positive catch data, **p** is a vector of the presence/absence data, **X** is the design matrix for main effects, **β** is the parameter vector for main effects, and **ε** is a vector of independent normally distributed errors with expectation zero and variance σ^2.

We used the GLIMMIX and MIXED procedures in SAS (v. 9.1, 2004) to develop the binomial and lognormal submodels, respectively. Similar covariates were tested for inclusion for both submodels: temperature, salinity, dissolved oxygen concentration, water depth, survey area [eastern GOM divided into three categories: southern survey area (survey area south of 27˚ north latitude); central survey area (survey area between 27˚ and 29˚ north latitude); northern survey area (survey area north of 29˚ north latitude and east of 87˚ west longitude)] and year. A backward selection procedure was used to determine which variables were to be included into each submodel based on type 3 analyses with a level of significance for inclusion of $\alpha = 0.05$. If year was not significant then it was forced into each submodel in order to estimate least-squares means for each year, which are predicted annual population margins (i.e., they estimate the marginal annual means as if over a balanced population). The fit of each of the submodels were evaluated using AIC and residual analyses.

Therefore, c_y and p_y were estimated as least-squares means for each year along with their corresponding standard errors, SE(c_y) and SE(p_y), respectively. From these estimates, I_y was calculated, as in equation (5), and its variance calculated as

(4) $$V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y) + 2c_y p_y \mathrm{Cov}(c, p),$$

where

(5) $$\mathrm{Cov}(c, p) \approx \rho_{c,p}\left[\mathrm{SE}(c_y)\mathrm{SE}(p_y)\right],$$

and $\rho_{c,p}$ denotes correlation of c and p among years.

The backward selection procedure used to develop the delta-lognormal model is summarized in Table 2. For the binomial submodel both salinity and dissolved oxygen effects were dropped based on type 3 analyses, and with each variable removal there was a corresponding decrease in AIC (Table 2). For the lognormal submodel, both salinity and dissolved oxygen variables were dropped from the model, and the year variable was not significant (Table 2). The AIC for model run #3 increased as the salinity was dropped from the model indicating a possible increase in lack-of-fit. However, due to the large *p*-value (0.0931) of the type 3 test for the inclusion of salinity in model run #2 and the small increase in the AIC statistic, we chose to remove this variable. Figure 8 indicates the approximately normal distribution of the residuals of the lognormal submodel.

For red grouper, annual frequencies of occurrence were often less than 0.3 (less then 0.15 for two survey years), indicating a zero-inflated binomial distribution. Therefore, a zero-inflated binomial regression model was employed instead of a binomial model using the methodology of (Ingram *et al*. 2006; Tyre *et al*. 2003). In order to develop the zero-inflated delta-lognormal model to estimate annual indices of abundance, we replaced the regular binomial portion of the delta-lognormal model with a zero-inflated binomial model that takes into account the high proportion of zeros in the abundance data (Ingram *et al*. 2006). The zero-inflated binomial model treats the probability of observing a red grouper as a product of the true probability of the site being occupied (o), and the probability of detection (d) when in fact the site is occupied at the time the sample is taken (Tyre *et al*. 2003; Steventon *et al*. 2005). Multiple samples must be taken at each site in order to estimate d, but the number of samples per site (m) does not have to be equal (Tyre *et al*. 2003). The number of observations of an animal for each site over m samples is denoted as x, and the number of sites sampled as n (Steventon *et al*. 2005).

In the case of this study, a year was treated as a site, since the goal was to develop annual indices of abundance. Therefore, when we considered one year after m samples have been taken (i.e., m bottom longline stations completed), the probability of observing zero red grouper was:

(6) $$P(x=0)=o(1-d)^{m}+(1-o)(1)$$

and the probability of observing exactly x red grouper, where x is greater than zero was:

(7) $$P(x>0)=o\binom{m}{x}d^{x}(1-d)^{m-x}+(1-o)(0)$$

after Tyre *et al*. (2003) and Steventon *et al*. (2005). We then combined these two probabilities to form the likelihood function for a single year y:

(8) $$L(o,d\mid x,m)=\begin{cases} o(1-d)^{m}+(1-o), x=0 \\ o\binom{m}{x}d^{x}(1-d)^{m-x}, x>0 \end{cases}$$

following the methods of Tyre *et al*. (2003).

Steventon *et al*. (2005) expressed the above probability in equation (8) as a generalized Bernoulli distribution, allowing the combination of multiple years into a full likelihood:

$$(9) \qquad L\left(o,d \mid \{x_y, m_y, u_y\}\right) = \prod_{y=1}^{n} \left[o(1-d)^{m_y} + (1-o)\right]^{u_y} \times \left[o\binom{m_y}{x_y} d^{x_y}(1-d)^{m_y-y_y}\right]^{1-u_y}$$

where u_y is an indicator variable: $u_y = 1$ when $x_y = 0$ and $u_y = 0$ when $x_y > 0$. The values of *o* and *d* are not required to be constant, and are usually not over time. These values can be influenced by covariates as follows:

$$(10) \qquad \mathbf{o} = \frac{e^{\mathbf{X\beta+\varepsilon}}}{1+e^{\mathbf{X\beta+\varepsilon}}}$$

and

$$(11) \qquad \mathbf{d} = \frac{e^{\mathbf{X\beta+\varepsilon}}}{1+e^{\mathbf{X\beta+\varepsilon}}},$$

where **o** and **d** are vectors of probability of occupancy and probability of detection, respectively, **X** is the design matrix for main effects, **β** is the parameter vector for main effects, and **ε** is a vector of independent normally distributed errors with expectation zero and variance σ^2. Certain covariates may be common between both the above models, while others may be completely different (Steventon *et al*. 2005).

Therefore, in the case of this study, the estimated probability of collecting a red grouper during a single bottom longline station is

$$(12) \qquad p_{Z1,y} = o \times d$$

and the probability of collecting at least one red grouper after *m* bottom longline stations is

$$(13) \qquad p_{Z,y} = o\left[1-(1-d)^m\right],$$

following the methods of Steventon *et al*. (2005). We then replace p_y in equations (1), (4) and (5) with $p_{Z,y}$ from equation (13) to estimate annual indices of abundance and their corresponding variance using this new zero-inflated approach [$I_{Z,y}$ and $V(I_{Z,y})$, respectively].

The NLMIXED procedure in SAS (v. 9.1, 2004) was employed to model the zero-inflated binomial model. Initial SAS code for this procedure was provided by Steventon *et al*. (2005). We modified this code in order to use dummy variables, which were needed to include categorical variables in the model. The variables used in the model were those retained in the final binomial submodel run for the delta-lognormal model. Variables that were deemed to affect both occurrence and detection of red grouper were split between occurrence and detection submodels (see Equations 10 and 11) contained in the zero-inflated binomial submodel. Model performance was evaluated using AUC (Area Under Curve) methodology presented by Steventon *et al*. (2005).

The same variables that were retained in the model-building process of the binomial submodel for the development of I_y were used in the zero-inflated binomial model: temperature, water depth, survey area, and year. All the variables were used in the occupancy submodel while only the year variable was used in the detection submodel for the zero-inflated binomial model. Table 3 summarizes the parameters used in the zero-inflated binomial model and their significance. The zero-inflated binomial submodel had an AUC = 0.733. This means that in 73 out of 100 instances a station selected at random from those with red grouper had a higher predicted probability of red grouper being present than a station randomly selected from those that had no red grouper.

Table 4 and Figure 9 summarize indices of red grouper developed from using a delta-lognormal model and a zero-inflated delta-lognormal model. All indices and corresponding variabilities were similar when comparing years between the two approaches except for survey year 2005, where the CV of the index developed using the zero-inflated delta-lognormal approach was lower. The high variability around the 2002 index for both approaches resulted from the lack of coverage of the survey area during the 2002 survey year (Figure 4). The use of a zero-inflated delta-lognormal methodology is recommended due to the relatively low frequency of occurrence of red grouper in the Gulf of Mexico.

Finally, we constructed length (N = 352) and age (N = 348) frequency histograms for red grouper collected during this survey in the GOM. The mode of the length frequency distribution was 450-499 mm total length. The mode for the age distribution was 5 years, and the mean age was 6.3 years with age ranging from 2 to 21 years.

Literature Cited

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Table 1. NMFS MS Laboratory longline projects, 1995 - 2005. Shaded rows indicate cruises from which data was used in this document. For surveys that occurred in both the Atlantic and Gulf of Mexico within a single survey, only data from the Gulf was used.

Survey	Date	Location	Depth range (m)	Effort (# sets)	Random station selection description.
OT-95-04 (218)	7/23 - 8/17/95	GOM[1]	18 m - 73 m	82	Stations depth stratified and equally allocated within statistical zones; depth strata 18 m - 37 m, 37 m - 55 m, 55 m - 73 m; J hooks.
RS-95-03 (2)	8/10 - 8/24/95	Atlantic[2]	18 m - 73 m	45	Stations depth stratified and equally allocated within statistical zones; depth strata 18 m - 37 m, 37 m - 55 m, 55 m - 73 m; J hooks.
OT-96-04 (222)	7/31 - 9/13/96	GOM and Atlantic	18 m - 73 m	151	Stations depth stratified and equally allocated within statistical zones; depth strata 18 m - 37 m, 37 m - 55 m, 55 m - 73 m; J hooks.
OT-97-04 (227)	7/25 - 9/24/97	Mexican GOM, GOM and Atlantic	9 m - 55 m	259	Stations not depth stratified but equally allocated within 60 linear n. mile zones or statistical zones; J hooks.
OT-98-02 (231)	7/24 - 9/22/98	Mexican GOM, Cuba [3], GOM	9 m - 413 m	216	Stations not depth stratified but equally allocated within 60 linear n. mile zones or statistical zones; J hooks.
OT-99-02 (233)	2/16 - 3/2/99	Atlantic	9 m - 55 m	29	Stations not depth stratified but equally allocated within statistical zones; J hooks.
FE-99-10 SEF	5/6 - 5/19/99	GOM	64 m - 146 m	60	Station coordinates by random longitude and random depth and equally allocated within 10 linear n. mile contiguous sampling blocks; circle hooks.
CARETTA 99-01	8/4 - 9/28/99	GOM	9 m - 55 m	161	Proportional allocation based on continental shelf width within statistical zones; sampling density experiment; hook comparison experiment with 75% J hooks, 25% circle hooks.
GU-00-03 (8)	6/6 - 6/19/00	GOM	64 m - 146 m	59	Station coordinates by random longitude and random depth and equally allocated within 20 linear n. mile contiguous sampling blocks; hook comparison experiment with 75% circle hooks, 25% J hooks.
OT-00-04 (241)	8/3 - 8/28/00	GOM	9 m - 183 m	137	Proportional allocation based on continental shelf width within statistical zones; sampling density experiment; hook comparison experiment with 75% J hooks, 25% circle hooks.
FE-00-12 (2)	9/6 - 10/16/00	Atlantic	9 m - 183 m	105	Proportional allocation based on continental shelf width within statistical zones; sampling density experiment; hook comparison experiment with 75% J hooks, 25% circle hooks.
OT-00-08 (244)	12/6 - 12/12/00	GOM	55 m - 366 m	41	Station coordinates by random longitude and random depth and equally allocated within 10 linear n. mile contiguous sampling blocks; stations depth stratified with 4 stations each block 55 m - 183 m, 2 stations each block 183 m - 366 m; hook comparison experiment with 75% circle hooks, 25% J hooks.
ONJUKU-01	6/1 - 6/20/01	Mexican GOM[4]	9 m - 50 m	38	Proportional allocation based on continental shelf width within 60 linear n. mile sampling zones; circle hooks, Atlantic bonito for bait.
OT-01-04 (247)	7/31 - 9/30/01	GOM	9 m - 366 m	277	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.
ONJUKU-01	6/28 - 7/5/02	Mexican GOM[4]	18 m - 217 m	30	Proportional allocation based on continental shelf width within 60 linear n. mile sampling zones; circle hooks, Atlantic bonito for bait
OT-02-04 (251)	7/31 - 9/21/02	GOM and Atlantic	9 m - 366 m	212	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.
OT-03-04 (255)	7/29 - 9/29/03	GOM	9 m - 366 m	280	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.
GANDY 72-043	07/25 - 08/28/04	Atlantic	8 m – 34 m	40	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.
OT-04-04 (260)	7/31 - 9/29/04	GOM	9 m - 366 m	232	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.
GANDY 72-044	10/06 - 10/23/04	GOM	7 m – 92 m	17	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.
OT-05-04 (266)	8/5 - 8/25/05	GOM and Atlantic	9 m - 366 m	74	Proportional allocation based on continental shelf width within statistical zones; depth stratified, 50% allocation 9 m - 55 m, 40% allocation 55 m - 183 m, 10% allocation 183 m - 366 m; circle hooks.

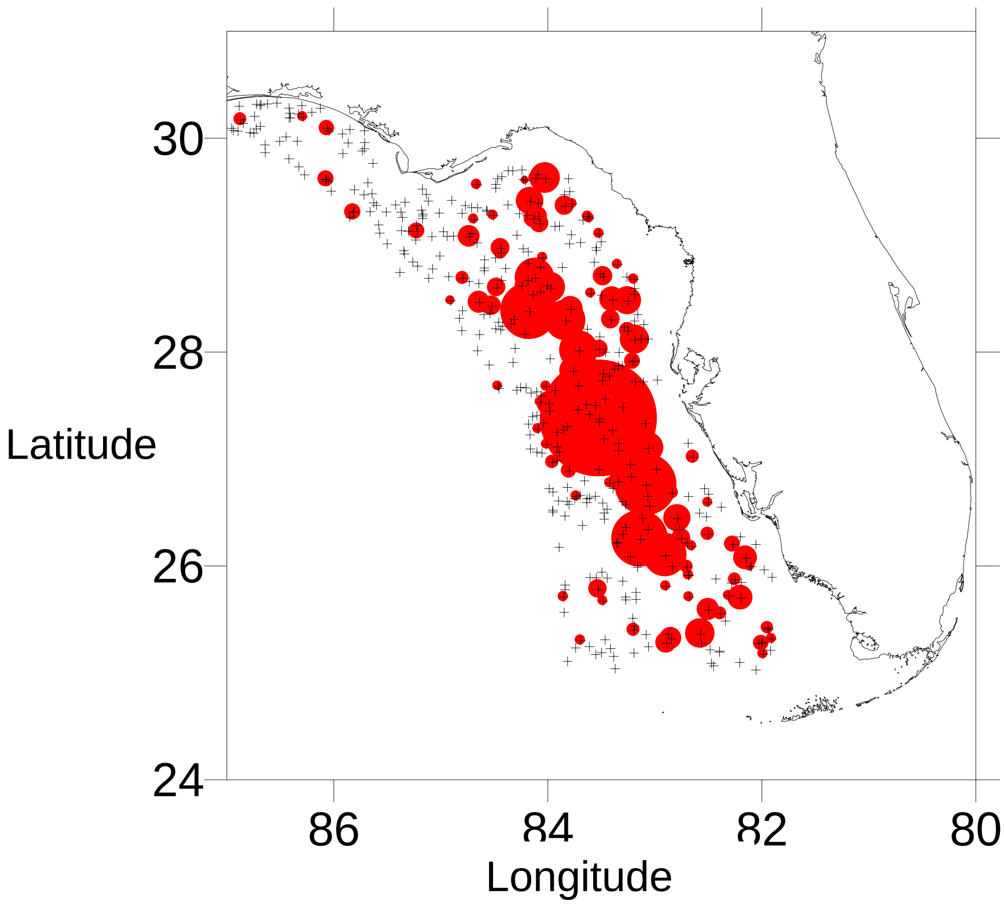

Figure 1. Survey effort and CPUE of red grouper from 2000 through 2005 in the Gulf of Mexico. Crosses indicate effort with no catch. The size of red circles is linearly related to positive CPUE (range: 0.3 – 37.6 red grouper per 100 hook hours). Symbols in the following figures are on the same scale as described for this figure, in order to facilitate direct comparisons.

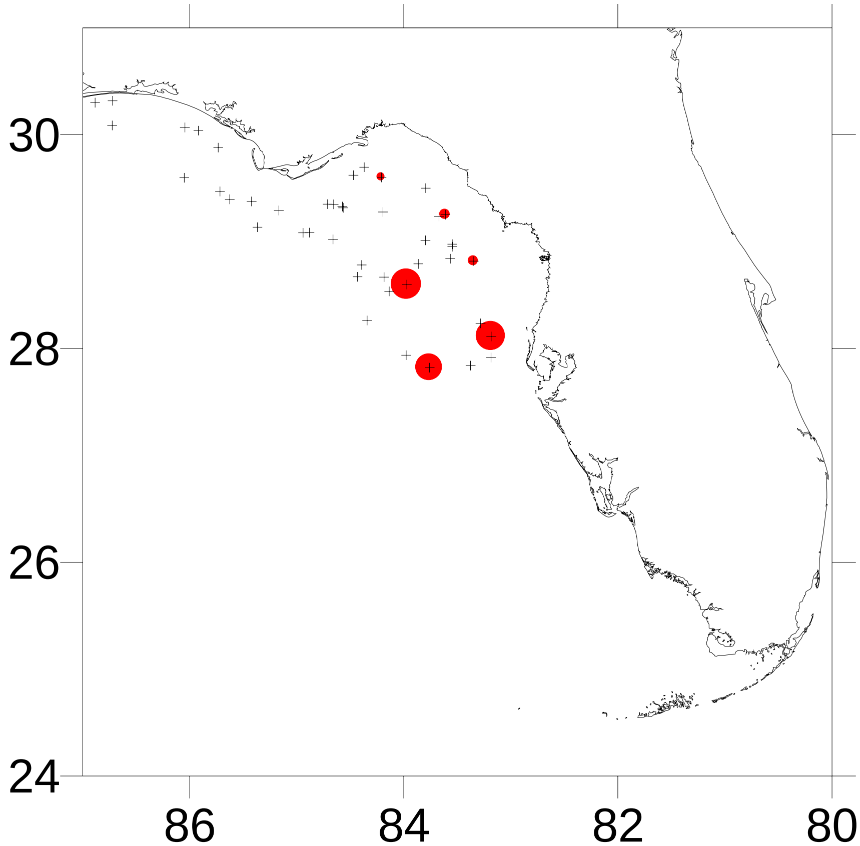

Figure 2. Survey effort and CPUE (range: 0.3 – 7.9 per 100 hook hours) of red grouper for 2000.

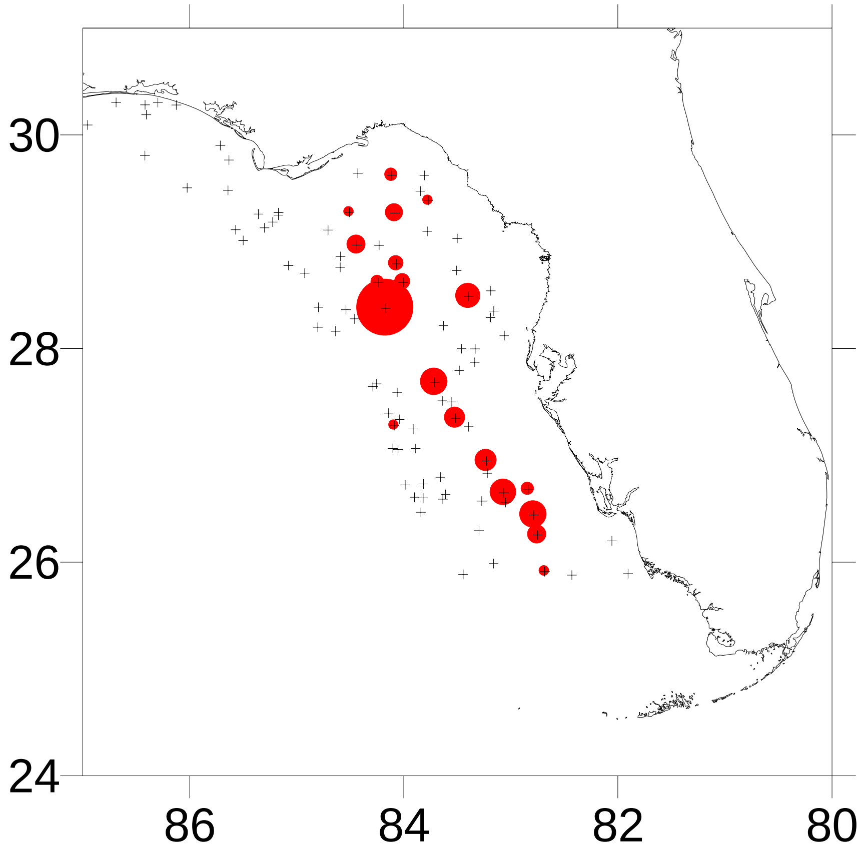

Figure 3. Survey effort and CPUE (range: 1 – 17 per 100 hook hours) of red grouper for 2001.

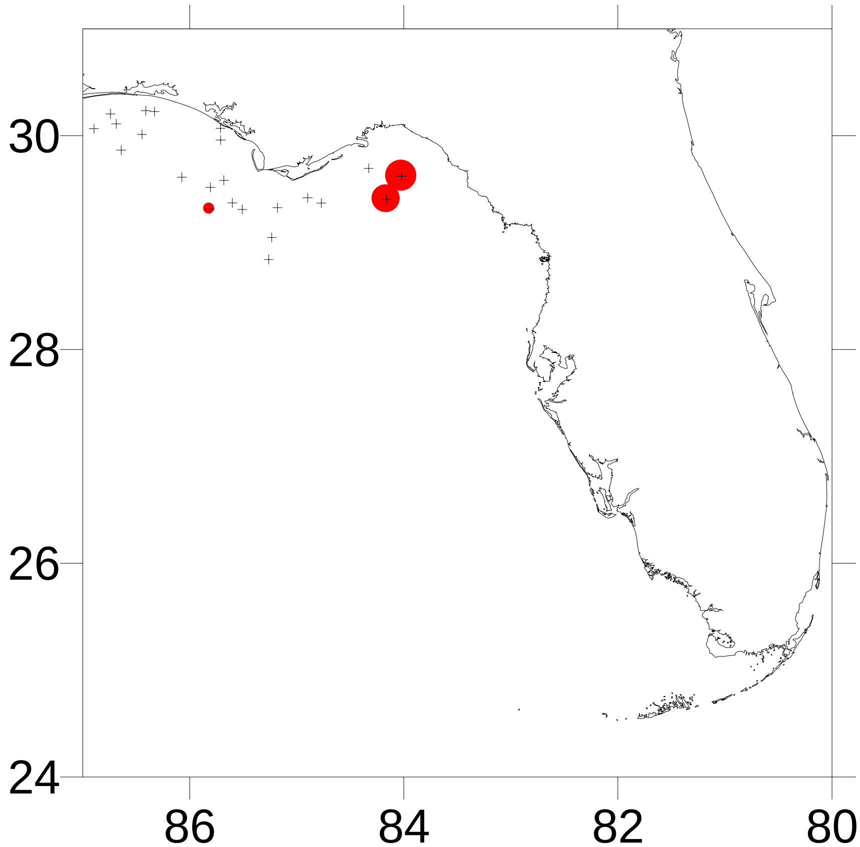

Figure 4. Survey effort and CPUE (range: 1 – 8 per 100 hook hours) of red grouper for 2002.

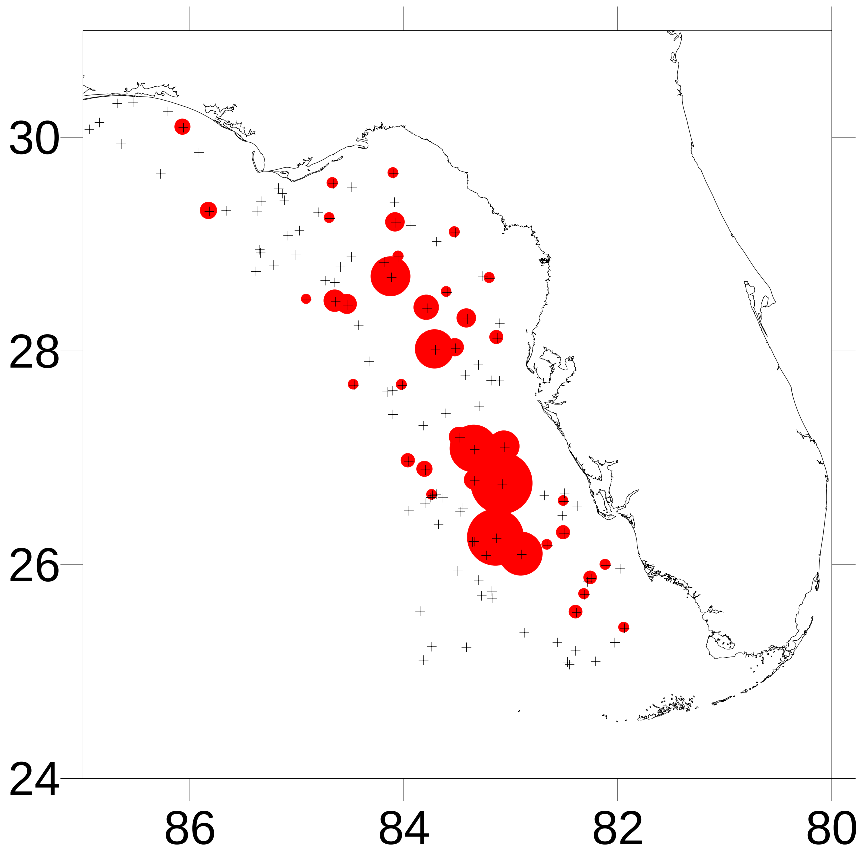

Figure 5. Survey effort and CPUE (range: 0.7 – 18.8 per 100 hook hours) of red grouper for 2003.

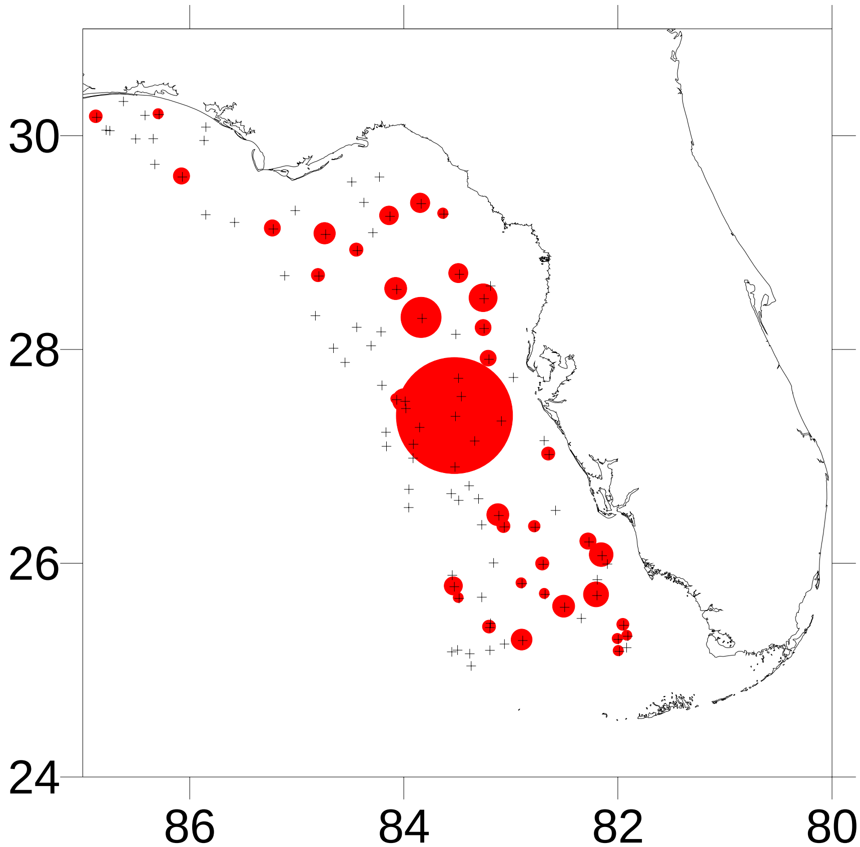

Figure 6. Survey effort and CPUE (range: 0.9 – 37.6 per 100 hook hours) of red grouper for 2004.

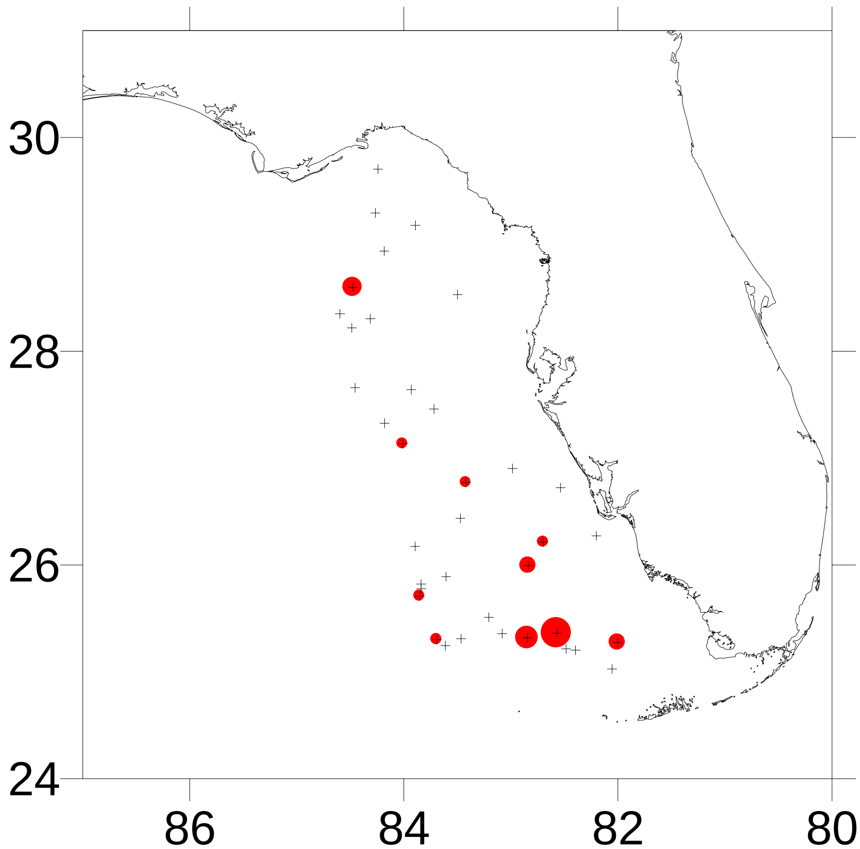

Figure 7. Survey effort and CPUE (range: 1 – 7.6 per 100 hook hours) of red grouper for 2005.

Table 2. Backward selection procedure for building delta-lognormal submodels.

Model Run #1	*Binomial Submodel Type 3 Tests (AIC = 1987.5)*						*Lognormal Submodel Type 3 Tests (AIC = 325.9)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
year	5	150	13.66	2.69	0.0180	0.0233	5	108	0.22	0.9524
area	2	336	6.38	3.19	0.0411	0.0424	2	108	6.02	0.0033
water depth	1	347	16.57	16.57	<.0001	<.0001	1	108	6.96	0.0096
salinity	1	205	1.21	1.21	0.2716	0.2729	1	108	2.42	0.1226
temperature	1	369	3.73	3.73	0.0533	0.0541	1	108	3.22	0.0757
dissolved oxygen	1	332	0.32	0.32	0.5724	0.5728	1	108	0.00	0.9514
Model Run #2	*Binomial Submodel Type 3 Tests (AIC = 1982.7)*						*Lognormal Submodel Type 3 Tests (AIC = 323.4)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
year	5	133	14.35	2.82	0.0136	0.0189	5	109	0.25	0.9388
area	2	341	6.35	3.17	0.0419	0.0431	2	109	6.09	0.0031
water depth	1	349	16.25	16.25	<.0001	<.0001	1	109	7.28	0.0081
salinity	1	215	1.02	1.02	0.3130	0.3141	1	109	2.87	0.0931
temperature	1	371	3.60	3.60	0.0576	0.0584	1	109	3.27	0.0733
dissolved oxygen			dropped					dropped		
Model Run #3	*Binomial Submodel Type 3 Tests (AIC = 1975.2)*						*Lognormal Submodel Type 3 Tests (AIC = 324.8)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
year	5	125	13.55	2.65	0.0188	0.0257	5	110	0.45	0.8150
area	2	337	12.87	6.43	0.0016	0.0018	2	110	7.26	0.0011
water depth	1	355	16.05	16.05	<.0001	<.0001	1	110	6.68	0.0111
salinity			dropped					dropped		
temperature	1	374	4.57	4.57	0.0326	0.0332	1	110	4.97	0.0278
dissolved oxygen			dropped					dropped		

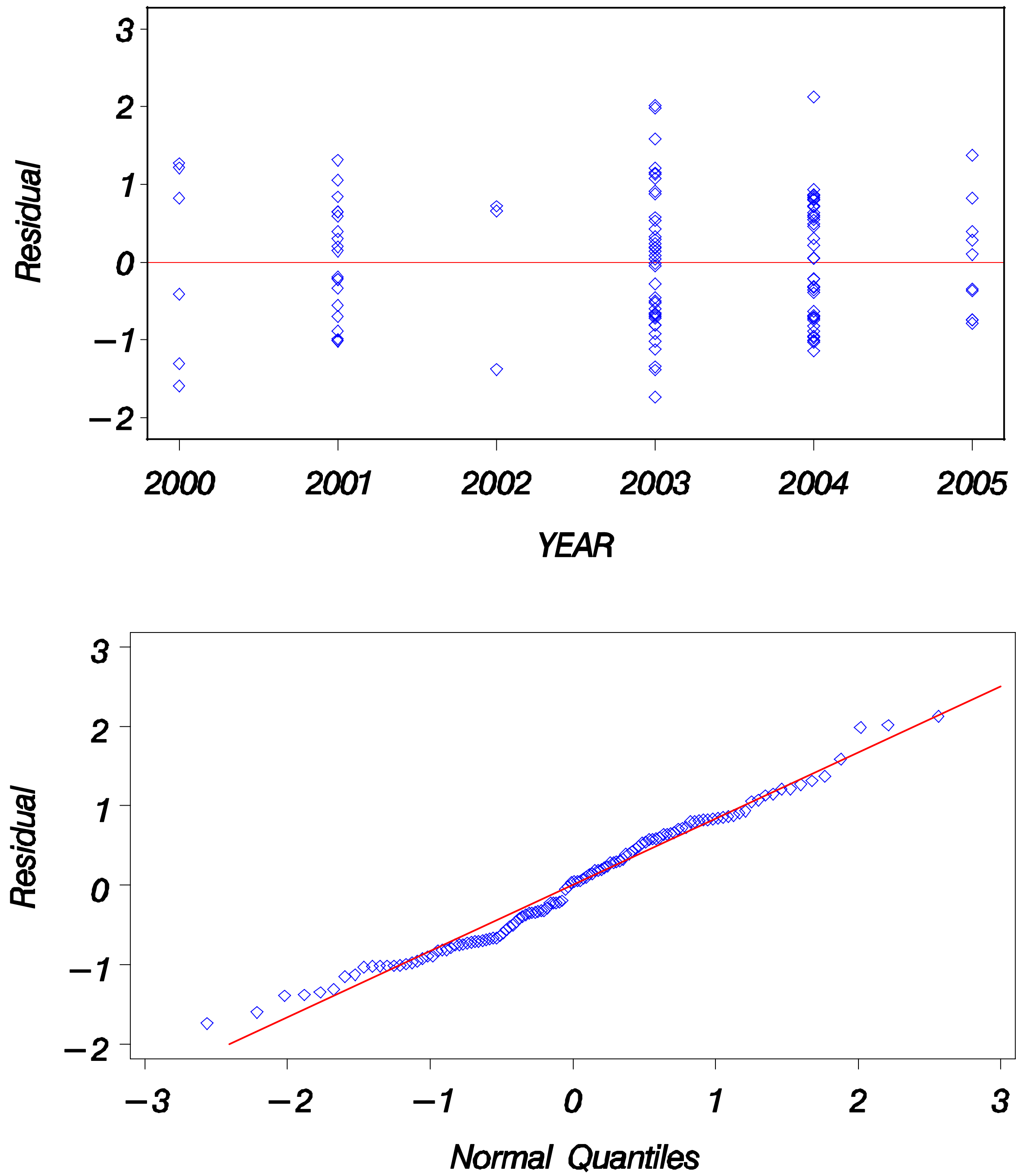

Figure 8. Residual plots of the lognormal submodel. The upper plot is of residuals versus survey year, and the lower is a QQ plot of the residuals.

Table 3. Parameters of the zero-inflated binomial model. The prefix *o* denotes those parameters in the occupancy submodel, while the prefix *d* denotes those parameters in the detection submodel.

Parameter	*Estimate*	*Standard Error*	*DF*	*Pr > |t|*
o_intercept	5.5178	2.4804	410	0.0267
o_depth	-2.4302	0.6301	410	0.0001
o_temperature	-3.9567	1.9009	410	0.0380
o_area_north	-1.0409	0.3378	410	0.0022
o_area_central	0.07433	0.2780	410	0.7893
o_2000	-0.6991	0.6446	410	0.2787
o_2001	-0.3185	0.4831	410	0.5102
o_2002	-0.1143	0.8008	410	0.8865
o_2003	0.2963	0.4458	410	0.5066
o_2004	0.7000	0.4535	410	0.1235
d_intercept	-0.9933	0.1171	410	<.0001
d_2000	-0.8544	0.2150	410	<.0001
d_2001	-0.3015	0.1300	410	0.0209
d_2002	-0.9056	0.4060	410	0.0263
d_2003	0.3514	0.1211	410	0.0039
d_2004	0.6638	0.1214	410	<.0001

Table 4. Indices of red grouper collected during bottom longline surveys (number per 100 hook hours, scaled to a mean of one) developed with delta-lognormal and zero-inflated delta-lognormal models. The total number of samples included in analyses per year, the number of samples containing red grouper per year, and the nominal frequency of occurrence per year are represented by *n*, *m*, and *f*, respectively.

				delta-lognormal model				*zero-inflated delta-lognormal model*			
Survey Year	*n*	*m*	*f*	I_y	*CV*	*LCL*	*UCL*	$I_{Z,y}$	*CV*	*LCL*	*UCL*
2000	44	6	0.13636	0.56464	0.66730	0.16774	1.90065	0.58244	0.67512	0.17099	1.98399
2001	93	20	0.21505	0.65393	0.28887	0.37122	1.15194	0.65565	0.28675	0.37369	1.15036
2002	22	3	0.13636	1.67353	0.81182	0.40330	6.94455	1.73211	0.82704	0.40881	7.33880
2003	116	40	0.34483	1.04199	0.22893	0.66305	1.63750	1.02280	0.22187	0.65976	1.58561
2004	98	41	0.41837	1.39065	0.19250	0.94958	2.03660	1.35232	0.19483	0.91924	1.98944
2005	37	10	0.27027	0.67525	0.58039	0.22986	1.98369	0.65467	0.41195	0.29657	1.44516

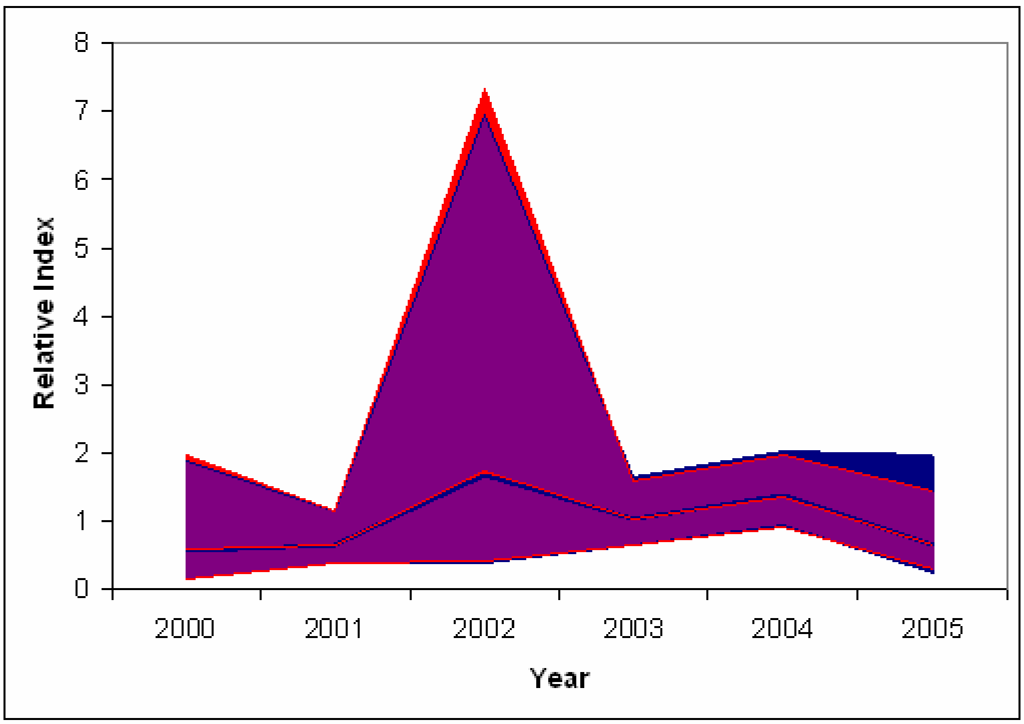

Figure 9. Indices (with 95 % confidence intervals) of red grouper collected during bottom longline surveys (number per 100 hook hours, scaled to a mean of one) developed with delta-lognormal (blue) and zero-inflated delta-lognormal (red) models. The index values are represented by the heavy red and blue lines. The purple area represents where confidence intervals of both index types overlap.

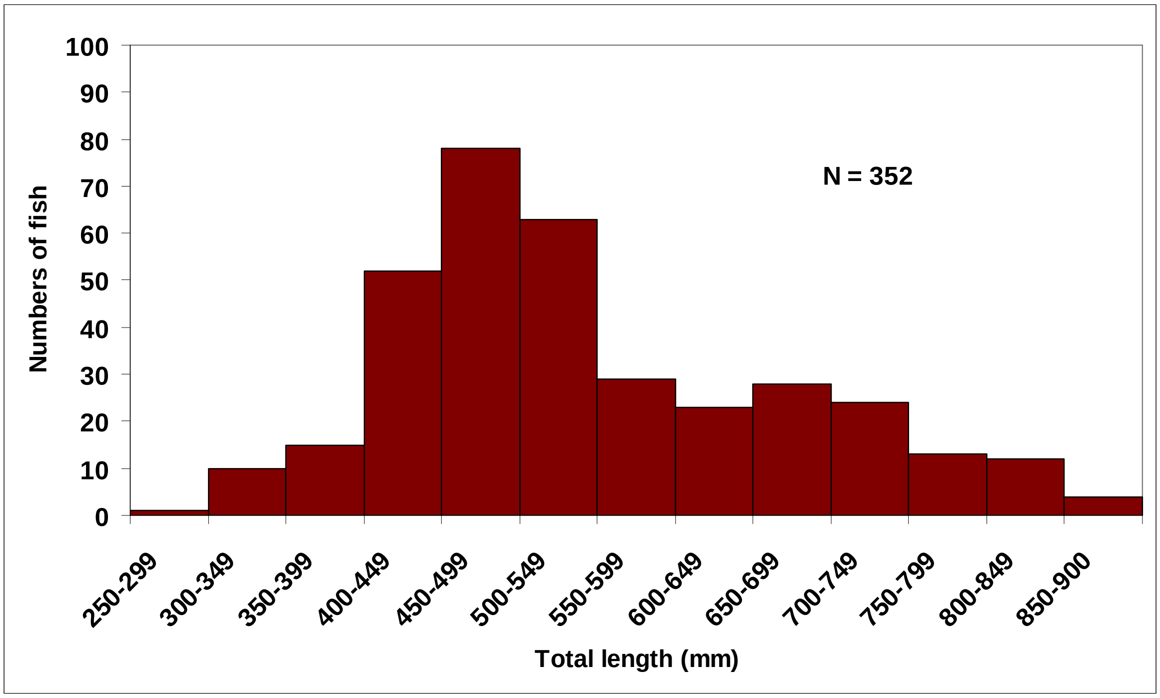

Figure 10. Length frequency histogram of red grouper total lengths collected during bottom longline surveys.

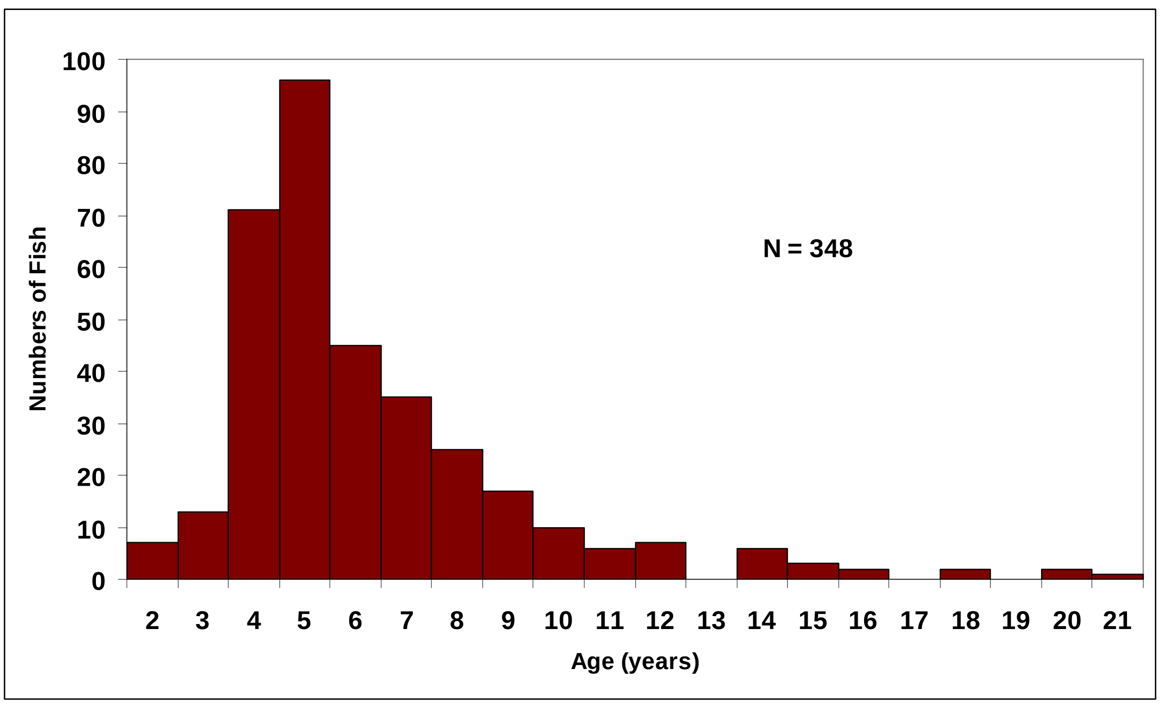

Figure 11. Age frequency histogram of red grouper collected during bottom longline surveys (mean age = 6.30 years).