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Indices of abundance for Red Grouper (*Epinephelus morio*) from the Florida Fish and Wildlife Research Institute (FWRI) video survey on the West Florida Shelf

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Introduction:

Reef fishes, including Red Grouper, are targeted commercially and recreationally along the West Florida Shelf (WFS). Historically, the assessment and management of reef fishes in the Gulf of Mexico has relied heavily on data from fisheries-dependent sources, although limitations and biases inherent to these data are admittedly a major source of uncertainty in current stock assessments. Additionally, commercial, headboat, and recreational landings data are restricted to harvestable-sized fish, and thus are highly influenced by regulatory changes (i.e., size limits, recreational bag limits, and seasonal closures). These limitations render it difficult to forecast potential stock recovery associated with strong year classes entering the fishery. There has been a renewed emphasis in recent years to increase the availability of fisheries-independent data on reef fish populations in the Gulf of Mexico because these data reflect the status of fish populations as a whole, rather than just the portion of the population taken in the fishery. To meet this need for fisheries-independent reef fish data, the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWRI) has been working collaboratively with scientists from the National Marine Fisheries Service (NMFS) to expand regional monitoring capabilities and provide timely fisheries-independent data for a variety of state- and federally-managed reef fishes. Results for Red Grouper are summarized from fisheries-independent reef fish surveys conducted by FWRI along the West Florida Shelf.

Survey Design and Sampling Methods:

The FWRI reef fish survey includes a portion of the WFS bounded by 26^{o} and 28^{o} N latitude and depths from 10 – 110 m (Figure 1). The boundaries of the WFS sampling universe were chosen to compliment ongoing NMFS reef-fish surveys. To assure adequate spatial sampling coverage, the WFS survey area was subdivided into four sampling zones comprised of two NMFS statistical zones (Tampa Bay: NMFS statistical zone 5; Charlotte Harbor: NMFS statistical zone 4) and two depth zones (Nearshore: 10 – 37 m; Offshore: 37 – 110 m). Prior to conducting exploratory sampling in 2008, the WFS survey area was subdivided into 1 km x 1 km sampling units. Results from 2008 indicated that the 1 km x 1 km spatial scale was too large in relation to the small-scale habitat features characteristic of the WFS; accordingly, from 2009 onward the WFS survey area was subdivided into 0.1 nm x 0.3 nm sampling units (E/W by N/S). Overall sampling effort (annual goal of 200 sampling units) was proportionally allocated among the four sampling zones (TBN: Tampa Bay Nearshore; TBO: Tampa Bay Offshore; CHN: Charlotte Harbor Nearshore; CHO: Charlotte Harbor Offshore) based on habitat availability, and specific sampling units were selected randomly within each sampling zone.

Very little is known regarding the fine-scale distribution of reef habitat throughout much of the WFS, and due to anticipated cost and time requirements, mapping the entire WFS survey area was not feasible prior to initiating the WFS reef fish survey. For the 2008 reef fish survey, the identification of sampling units with an increased probability of containing reef habitat (and inclusion in the sampling frame for the reef-fish survey) was based on bottom rugosity calculated from 100-m-resolution interpolated bathymetry data. An examination of results from the 2008 survey indicated that a high proportion of sampling effort occurred at sites with no reef habitat (i.e., unconsolidated sediment). Accordingly, the sampling universe was updated in 2009 to include habitat information provided by commercial fishermen as well as published literature. Further, we implemented an adaptive strategy where a three-pass acoustic survey was conducted covering an area of 1 nm to the east and west of the pre-selected sampling unit prior to sampling. In 2009 and part of 2010, the acoustic survey was conducted using the research vessel echo sounder, whereas for part of 2010 and 2011 onward the acoustic survey was conducted using an L3- Klein 3900 side scan sonar. If these acoustic surveys produced evidence of reef habitat in a nearby sampling unit, but not in the pre-selected sampling unit, sampling effort was randomly relocated to the nearby sampling unit.

At each sampling station, 1 – 2 stationary underwater camera arrays (SUCAs) were deployed based on the quantity and distribution of identified reef habitat. SUCA deployments and collection and processing of field data followed established NMFS protocols. Each SUCA consisted of a pair of stereo imaging system (SIS) units positioned at an angle of 180º from one another to maximize the total field of view. Each SIS unit consisted of an underwater housing containing a digital camcorder to record video and a pair of stereo cameras to capture still images at a rate of one per second. Each SUCA was baited (generally Atlantic Mackerel) and deployed for thirty minutes to assure that twenty minutes of continuous video and stereo images were recorded. Video data from one SIS per SUCA deployment were processed to quantify the relative abundance of Red Grouper (MaxN, or the maximum number of Red Grouper observed on a single video frame). When video conditions allowed, individual Red Grouper were measured using stereo still images using Vision Measurement System software (VMS); measurements obtained could best be described as a natural total length (TL). All individual gear deployments were spaced a minimum of 100 m apart. In addition to data on the relative abundance of Red Grouper, geographic coordinates, depth, physiochemical conditions (e.g., temperature, salinity, dissolved oxygen, pH), and time of day were recorded at each sampling site.

Data Treatment and Standardization:

Data Subsetting:

Overall, 1,083 survey videos were evaluated for developing indices of relative abundance for Red Grouper during the six year sampling period (2008-2013). We excluded any videos that were considered unreadable by an analyst, or where predictor variables of interest were not recorded or standardized sampling methods were not followed. Of the 1,083 video surveys considered for inclusion in the modeling analysis, only five were removed based on the data subsetting approach described, leaving 1,078 samples available for Red Grouper video analyses from 2008-2013. Annual video effort varied from 109 – 236 video deployments per year (Table 1; Figures 2 – 7). Red Grouper observed on video ranged from 197 – 889 mm TL, although most were between 250 and 700 mm TL (Figure 8).

Standardization of Response Variable:

For the video index of Red Grouper we modeled the MaxN, or maximum number of Red Grouper observed during an individual frame across the 20 minute video read. MaxN has previously been used as the response variable for estimation of abundance from reef fish video surveys in the Gulf of Mexico.

Explanatory Variables:

We considered 16 explanatory variables in the model analysis: year, month, depth, latitude, temperature, dissolved oxygen, salinity, start time, vertical relief, presence of algal growth, presence of hard corals, presence of soft corals, presence of seagrass, presence of sponge, presence of unknown sessile organisms, presence of rock, and turbidity. Temperature, dissolved oxygen and salinity were immediately dropped from the analysis since these variables were sporadically recorded during the early portion of the sampling time frame, leaving 13 explanatory variables for consideration in the model. Start time was excluded from model formulations due to a linear dependency that prevented the Zero-inflated models from converging.

Year (*Y*) – Year was included since standardized catch rates by year are the objective of the analysis. We modeled data from 2008-2013, annual summaries of data points considered are presented in Table 1.

Month (*M*) – A temporal parameter based on month of sampling (Table 1; Figure 9).

Depth (*D*) – Water depth may be an important component affecting the distribution of Red Grouper and we included all depths sampled (Table 1; Figure 9). Depth was treated as a quantile factor.

Latitude (*Lat*) – The latitude of video samples was included as a spatial parameter in the model (Table 1; Figure 9). Latitude was treated as a quantile factor in the models.

Vertical Relief (*Rel*) – Habitat type and quantity can influence the distribution and abundance of reef fish. As such the presence or absence of vertical relief was included as a binary habitat descriptor in the model.

Algae (*Alg*) - Habitat type and quantity can influence the distribution and abundance of reef fish. As such the presence or absence of benthic algal growth was included as a binary habitat descriptor in the model.

Hard Coral (*Hcor*) - Habitat type and quantity can influence the distribution and abundance of reef fish. As such the presence or absence of hard corals was included as a binary habitat descriptor in the model.

Soft Coral (*Scor*) - Habitat type and quantity can influence the distribution and abundance of reef fish. As such the presence or absence of soft corals was included as a binary habitat descriptor in the model.

Seagrass (*Sgr*) - Habitat type and quantity can influence the distribution and abundance of reef fish. As such the presence or absence of seagrass was included as a binary habitat descriptor in the model.

Sponges (Spo) - Habitat type and quantity can influence the distribution and abundance of reef fish. As such the presence or absence of sponges was included as a binary habitat descriptor in the model.

Unknown Sessile Organisms (*Usess*) - Habitat type and quantity can influence the distribution and abundance of reef fish. As such the presence or absence of unknown sessile organisms was included as a binary habitat descriptor in the model.

Rock (*Rock*) - Habitat type and quantity can influence the distribution and abundance of reef fish. As such the presence or absence of rock was included as a binary habitat descriptor in the model.

Turbidity (*Turb*) – Due to the effect of turbidity on both species distribution and the ability of our video analysts to process video samples accurately, we included a turbidity factor as a quantile factor in our model.

Model Selection:

Video surveys produce count data that do not conform to assumptions of normality. As such distributions of count data are often modeled using Poisson or negative binomial error distributions. Further, there is evidence that our video data may have a disproportionate number of zero counts that may differ from the standard error distributions used for count data (Figure 10). These data distributions are referred to as "zero-inflated" and are fairly common in ecologically based count data. Zero-inflation is considered a special case of over dispersion that cannot be easily addressed using traditional transformation procedures (Hall 2000). Due to the count nature of the data, and the possibility of inflation of the zero counts we used four different error distribution models to construct preliminary evaluation models (i.e., Poisson, Negative Binomial, Zero-inflated Poisson, Zero-inflated Negative Binomial). The zero inflated approaches model the zero counts using two different processes, a binomial and a count process (Zuur et al. 2009).

Initially, four null models were considered utilizing both a Poisson (P) and Negative binomial (NB) error distribution (1), and both Zero-inflated Poisson (ZIP) and zero inflated Negative Binomial (ZINB) formulations (2).

(1) $MaxN = Y + M + D + Lat + Rel + Alg + Hcor + Scor + Sgr + Spo + Usess + Rock + Turb$

and

(2) $MaxN = Y + M + D + Lat + Rel + Alg + Hcor + Scor + Sgr + Spo + Usess + Rock + Turb \mid Y + M + D + Lat + Rel + Alg + Hcor + Scor + Sgr + Spo + Usess + Rock + Turb$

We compared the variance structure of each model formulation using likelihood ratio tests (Zuur et al. 2009) and Aikaike's information theoretic criterion (AIC; Zuur et al. 2009) to determine the most appropriate model formulation for the development of a video index for Red Grouper in the Eastern

Gulf of Mexico. The likelihood ratio tests (Table 2) showed strong support for application of a ZIP or ZINB formulation. The ZIP and ZINB formulations were nearly identical (Figure 11), therefore the decision to use a ZIP model was chosen based on parsimony, since the ZINB model requires the estimation of an additional parameter (theta).

A backwards step-wise model selection procedure was used to exclude unnecessary parameters from the null model (2) formulation. The optimum Red Grouper model formulation (3) was determined using a combination of AIC and likelihood ratio tests (Zuur et al. 2009) and excluded month, depth, vertical relief, algal growth, hard coral, soft coral, seagrass, sponge, unknown sessile organisms, rock and turbidity from the count portion of the model and excluded month, depth, hard coral, seagrass, unknown sessile organisms and turbidity from the binomial component of the model (Table 3).

(3) $MaxN = Y + Lat \mid Y + Lat + Rel + Alg + Scor + Spo + Usess + Rock$

Model diagnostics showed no discernible patterns of association between Pearson residuals and fitted values or the fitted values and the original data (Figure 12). An examination of residuals for the spatial and environmental model parameters (Figure 13) showed no clear patterns of association, indicating correspondence to underlying model assumptions (Zuur et al. 2009). Lastly, a comparison of predicted values against original data distribution (Figure 14) indicates a good fit between the model and original data.

All data manipulation and analysis was conducted using R version 3.0.2 (R Core Team 2014). Modeling was conducted using the zeroinfl function of the pscl package (Jackman 2008), available from the Comprehensive R Archive Network (CRAN).

Results:

Annual standardized index values for Red Grouper in the Eastern Gulf of Mexico, including coefficients of variation are presented in Table 4. The relative nominal video counts for Red Grouper varied somewhat from the standardized index of abundance with only the 2011 and 2013 nominal values falling outside the 2.5% and 97.5% confidence intervals of the standardized index (Figure 15). The standardized index doe increase estimates of abundance from 2008-2010 while slightly decreasing estimates of abundance from 2011-2013. Due to a somewhat short temporal extent of the index, limited inferences can be discerned concerning patterns of Red Grouper abundance, nevertheless the index does indicate an increasing trend in relative video counts from 2008-2013 with relative stability between 2011 and 2013.

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Table 1. Annual total number of video samples included in the analysis and range of spatial and environmental variables included.

Year	# of video samples	Depth Range (m)	Latitude Range	Month Range
2008	109	12 - 106	26.028 – 27.746	July - August
2009	180	12 - 105	25.999 – 27.990	June – Sept.
2010	151	11 - 102	26.025 – 27.986	July – August
2011	221	12 - 84	26.064 – 27.984	June – Sept.
2012	236	11 - 104	26.020 – 27.975	June – Sept.
2013	181	7 - 93	26.010 – 27.996	July – Oct.

Table 2. Preliminary model formulation comparisons.

	df	Likelihood	*df*	χ^2	*p*-value
Poisson	27	-728.29			
Negative Binomial	28	-728.21	1	0.170	0.679
ZIP	54	-692.23			
ZINB	55	-692.23	1	0	0.998

Table 3. Model selection results for Zero-Inflated Poisson model of Red Grouper observed during FWRI video surveys on the West Florida Shelf, 2008-2013

	Removed Term						
Step	Count Process	Binomial Process	*df*	AIC	χ^2	*df*	*p* - value
Null	<none>	<none>	54	1492.46			
1	M	<none>	50	1488.01	3.539	4	0.472
2	M, D	<none>	47	1487.59	5.591	3	0.133
3	M, D, Scor	<none>	46	1485.71	0.112	1	0.738
4	M, D, Scor, Alg	<none>	45	1484.00	0.296	1	0.587
5	M, D, Scor, Alg, Rock	<none>	44	1482.32	0.313	1	0.576
6	M, D, Scor, Alg, Rock, Turb	<none>	40	1477.84	3.522	4	0.475
7	M, D, Scor, Alg, Rock, Turb, Sgr	<none>	39	1476.89	1.057	1	0.304
8	M, D, Scor, Alg, Rock, Turb, Sgr, Hcor	<none>	38	1476.01	1.117	1	0.291
9	M, D, Scor, Alg, Rock, Turb, Sgr, Hcor, Rel	<none>	37	1475.94	1.927	1	0.165
10	M, D, Scor, Alg, Rock, Turb, Sgr, Hcor, Rel, Spo	<none>	36	1476.68	2.742	1	0.098
11	<none>	D	33	1471.38	3.438	4	0.487
12	<none>	D, Sgr	32	1469.41	0.033	1	0.855
13	<none>	D, Sgr, Usess	31	1467.41	0.004	1	0.984
14	<none>	D, Sgr, Usess, Hcor	30	1466.51	1.099	1	0.294
15	<none>	D, Sgr, Usess, Hcor, Turb	27	1467.47	6.956	3	0.073
16	<none>	D, Sgr, Usess, Hcor, Turb, M	23	1467.89	8.425	4	0.077

Table 4. Relative nominal MaxN, number of stations sampled (N), proportion of positive sets, standardized index, and CV for FWRI Red Grouper video index of the West Florida Shelf, 2008-2013.

Year	Relative Nominal MaxN	N	Proportion positive	Standardized Index	CV
2008	0.105	109	0.036	0.454	0.459
2009	0.207	180	0.066	0.321	0.285
2010	0.704	151	0.191	0.929	0.149
2011	1.767	221	0.457	1.504	0.089
2012	1.534	236	0.384	1.357	0.096
2013	1.682	181	0.419	1.435	0.109

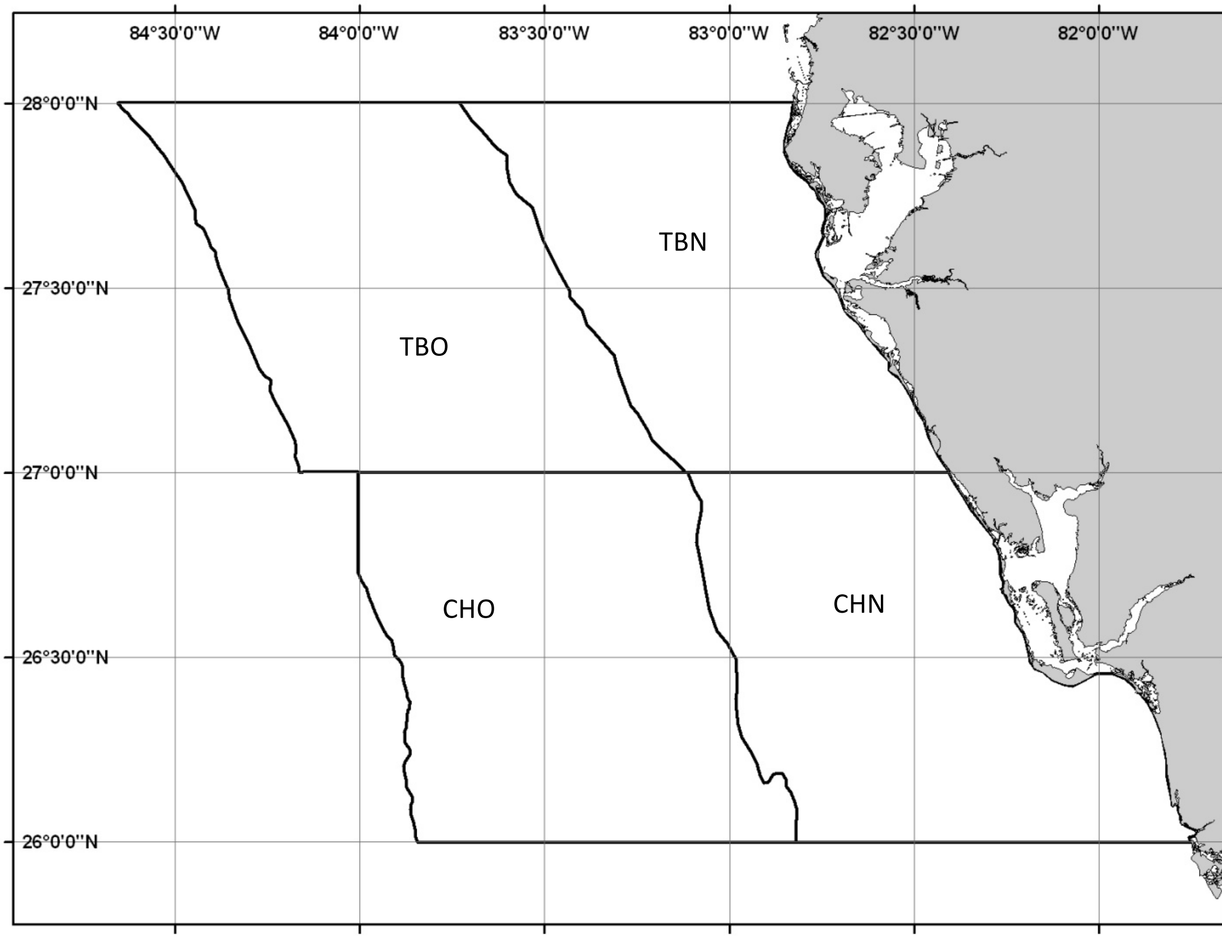

Figure 1. The West Florida Shelf survey area. The 20fa (37m) contour separates nearshore (i.e., TBN and CHN) and offshore (TBO and CHO) sampling zones. The sampling area includes waters 10m – 110m.

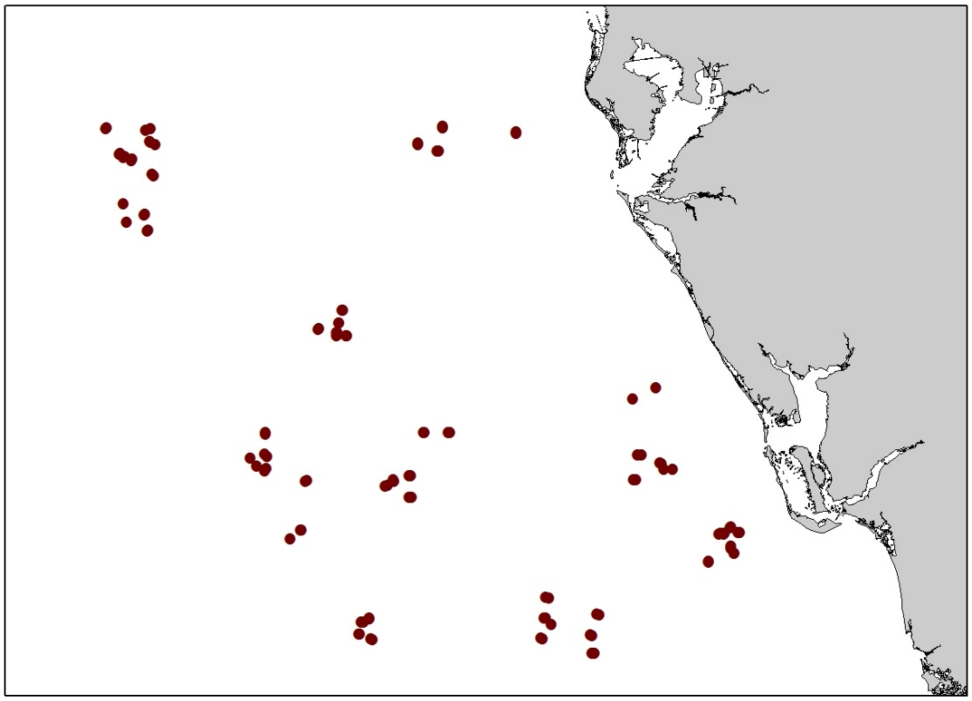

Figure 2. Map of sampling locations where SUCAs were deployed in 2008.

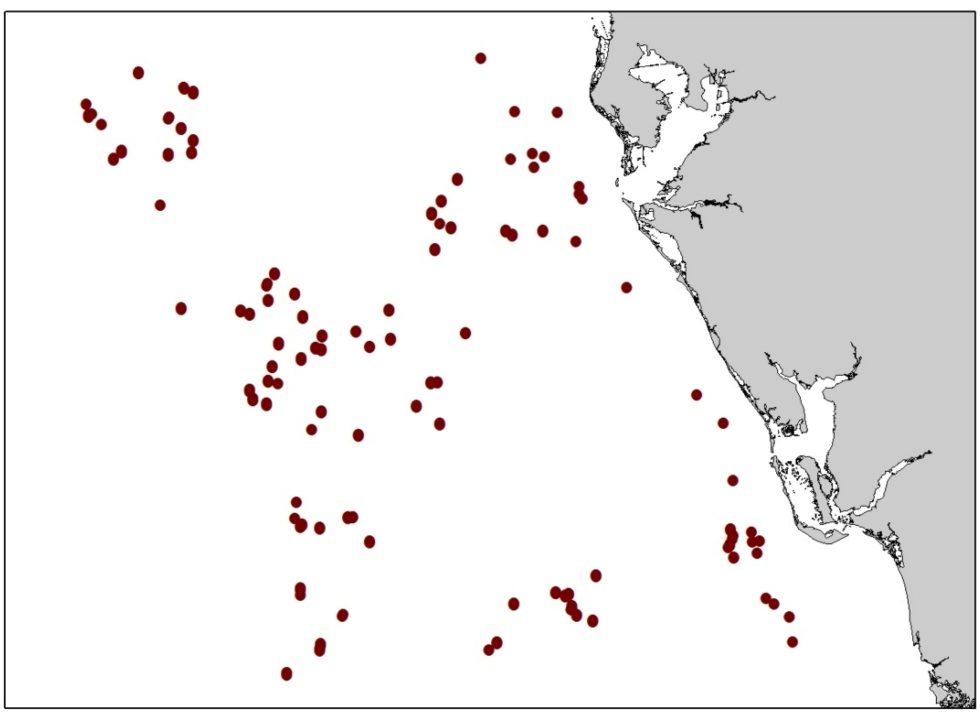

Figure 3. Map of sampling locations where SUCAs were deployed in 2009.

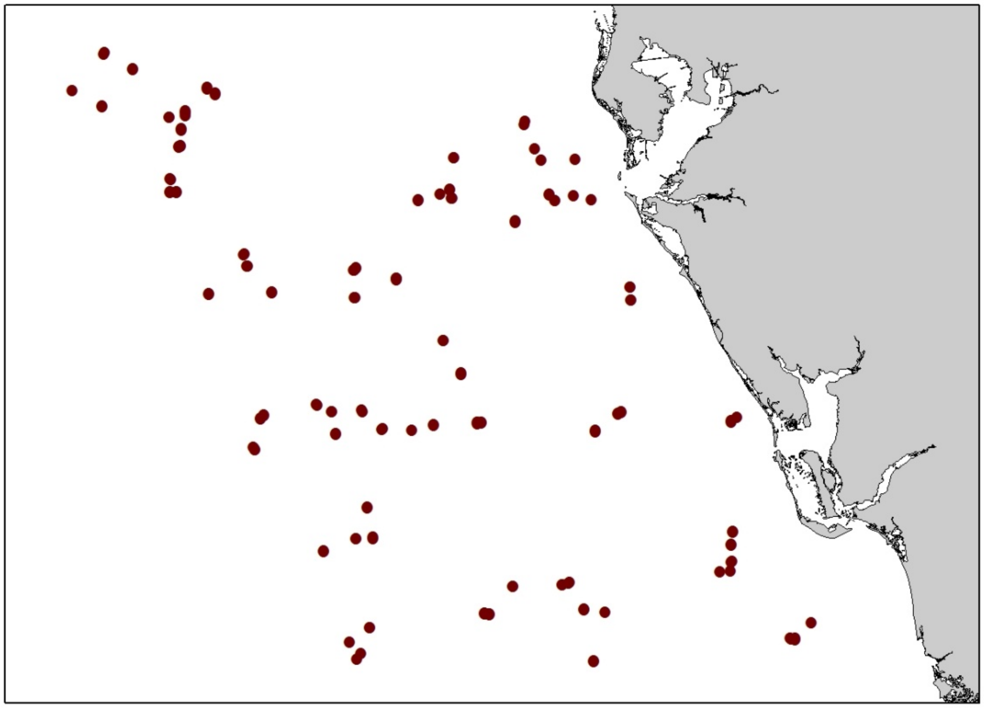

Figure 4. Map of sampling locations where SUCAs were deployed in 2010.

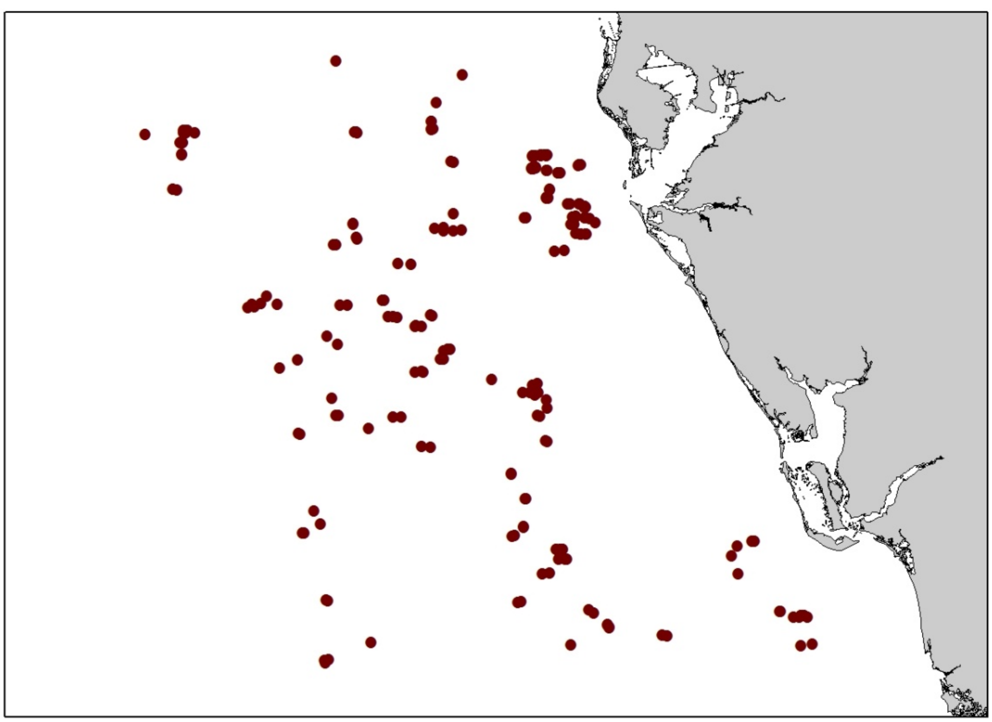

Figure 5. Map of sampling locations where SUCAs were deployed in 2011.

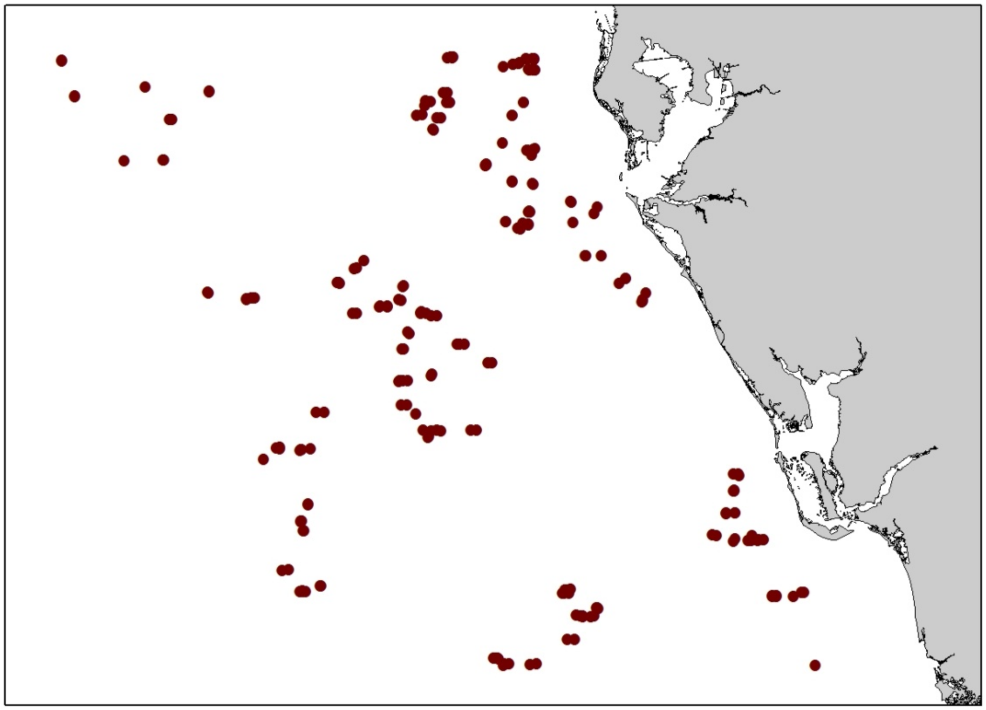

Figure 6. Map of sampling locations where SUCAs were deployed in 2012.

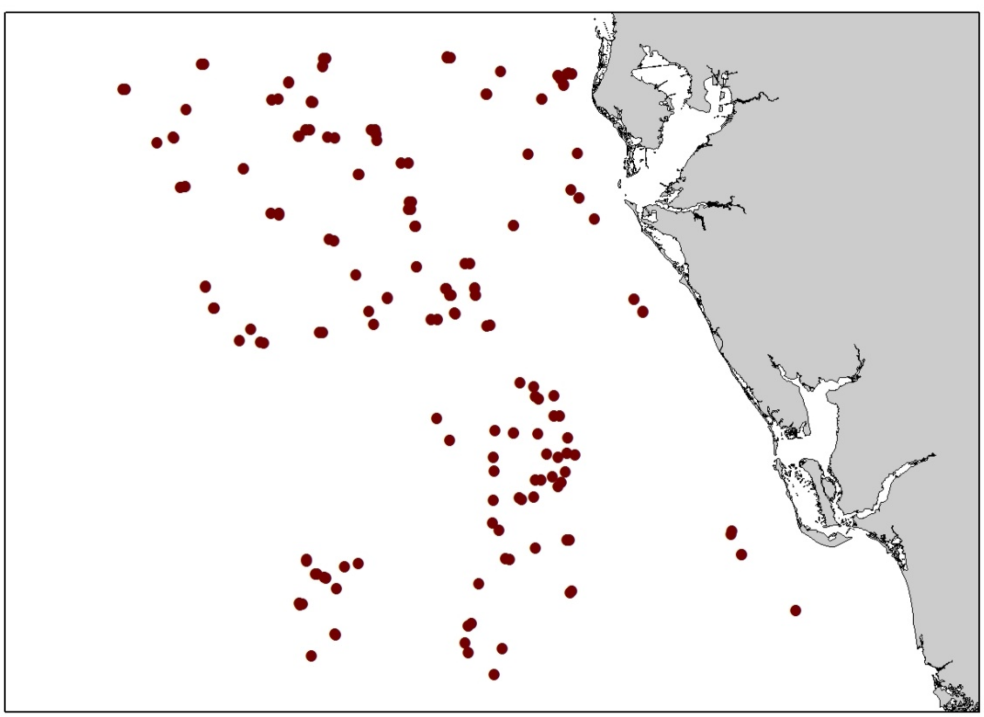

Figure 7. Map of sampling locations where SUCAs were deployed in 2013.

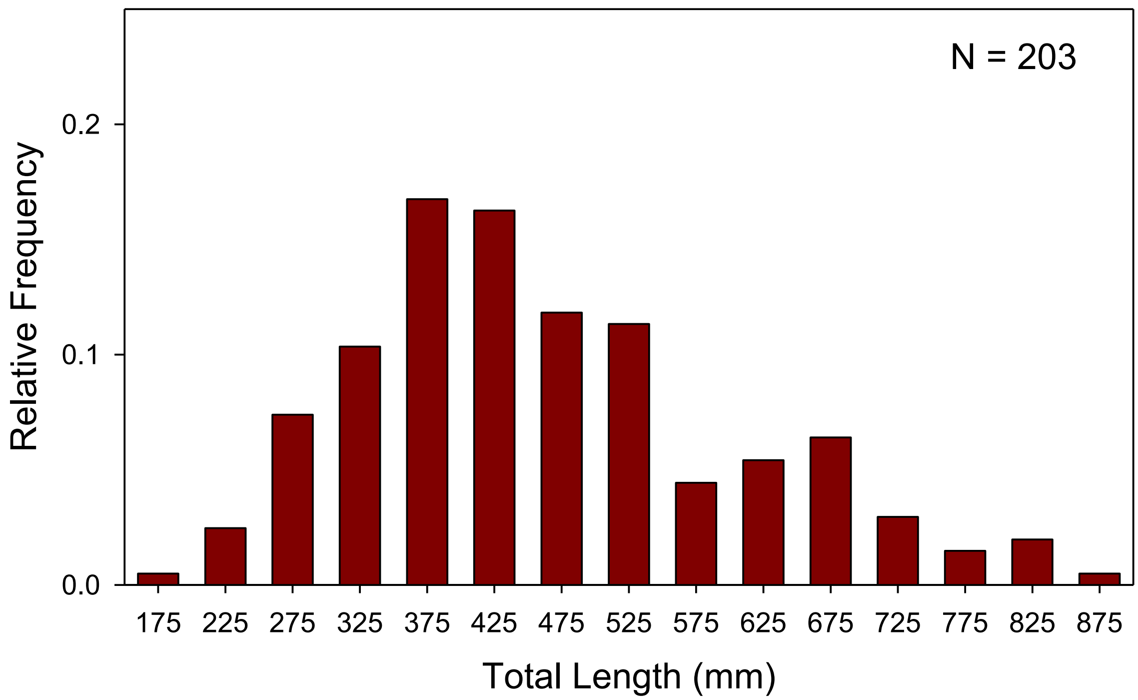

Figure 8. Length frequency distribution of Red Grouper observed on SUCAs and measures using Vision Measurement System software.

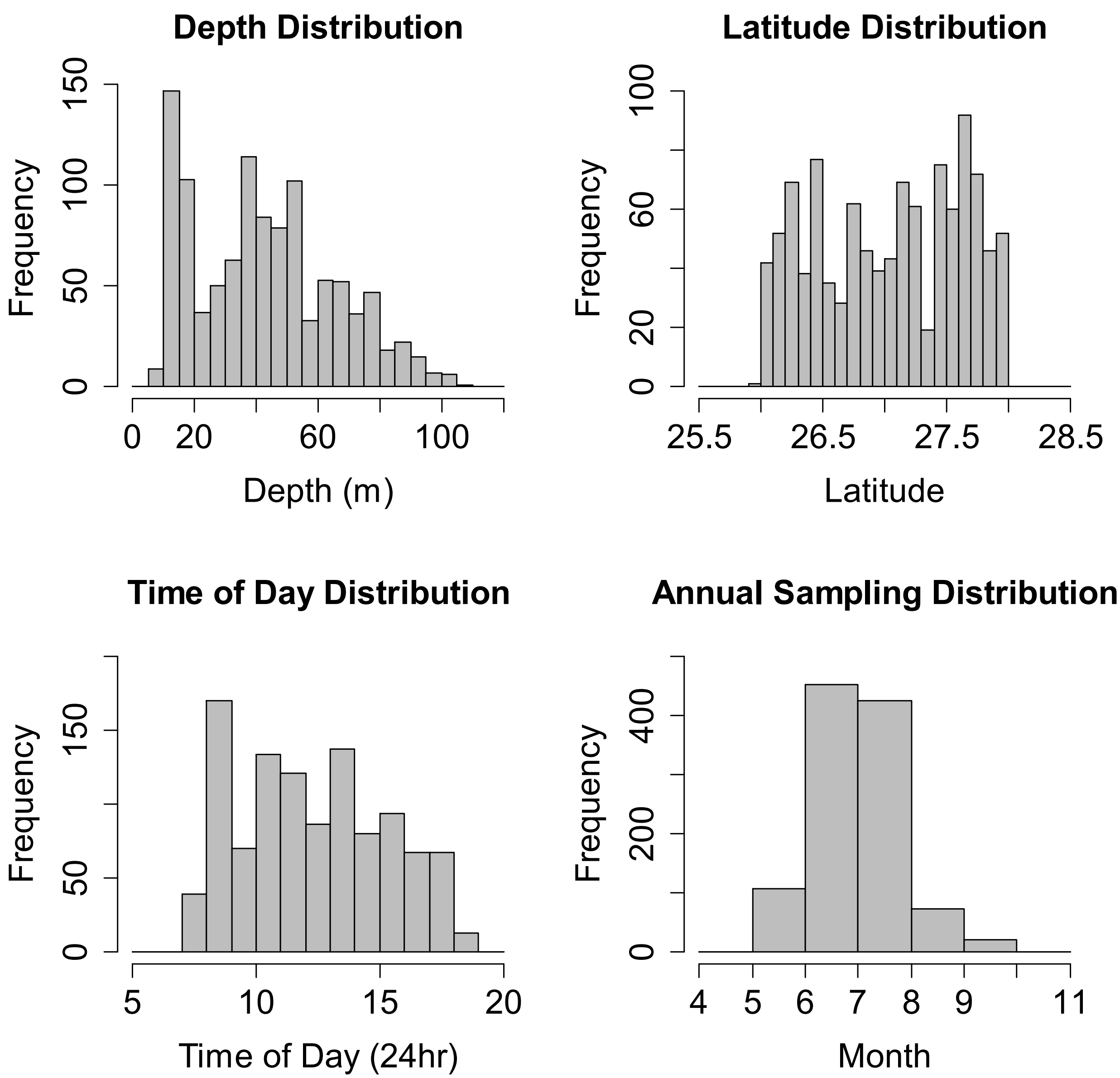

Figure 9. Sample distribution for the original continuous variables.

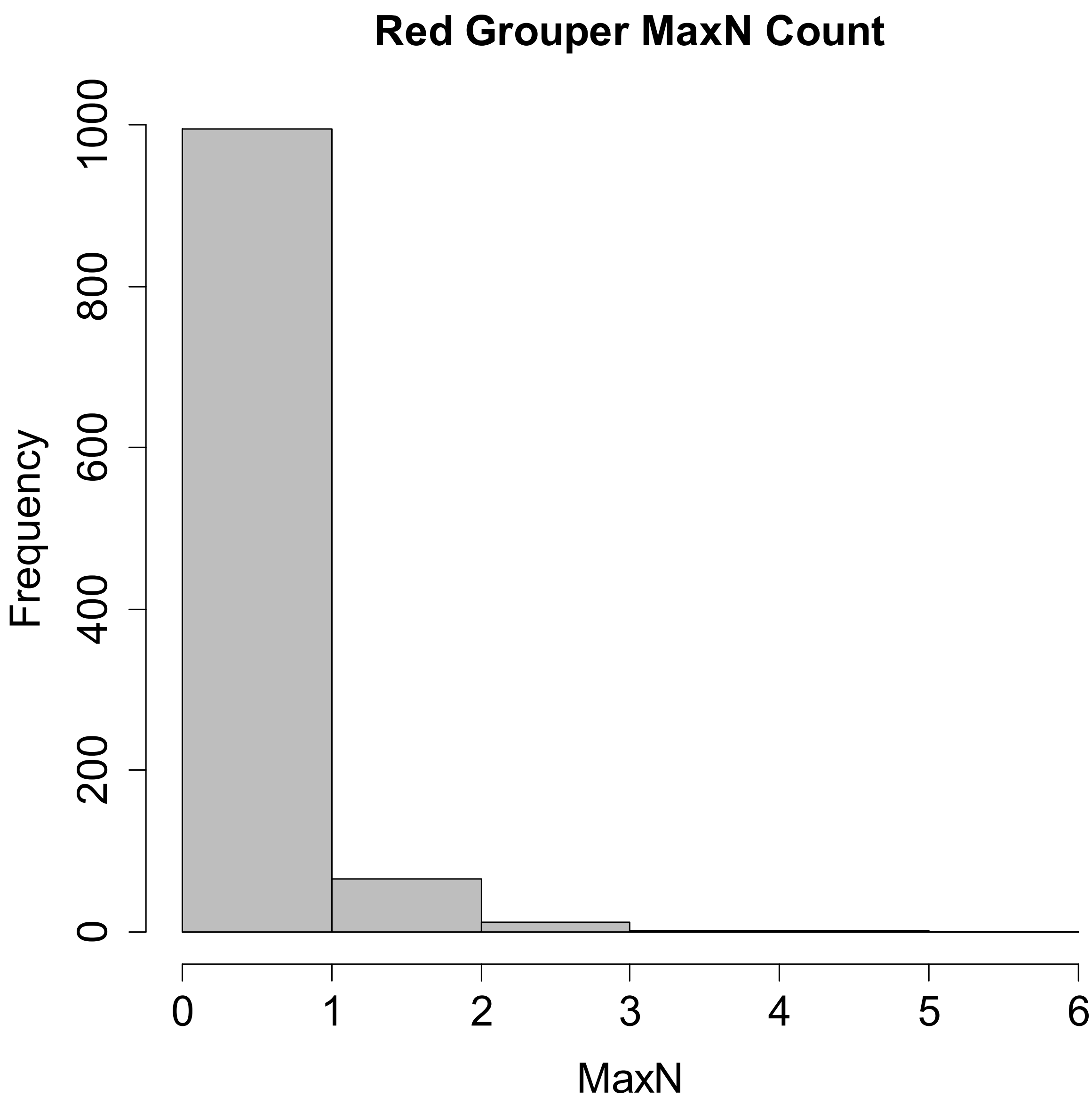

Figure 10. MaxN count distribution for Red Grouper FWRI video surveys on the West Florida Shelf.

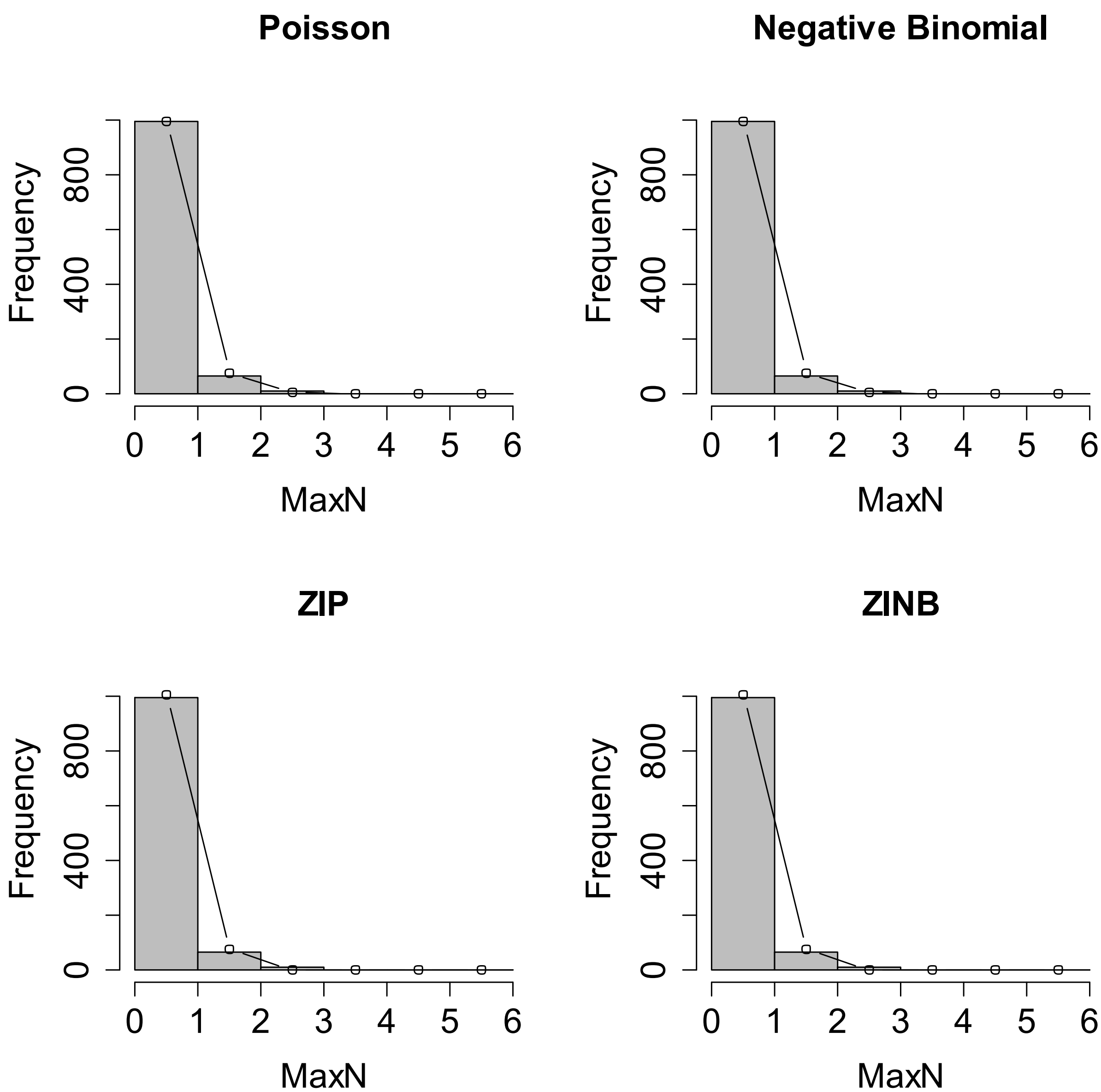

Figure 11. Model formulation comparison, with Poisson (top left), negative binomial (top right), ZIP (bottom left) and ZINB (bottom right) fitted values plotted against the original data distribution.

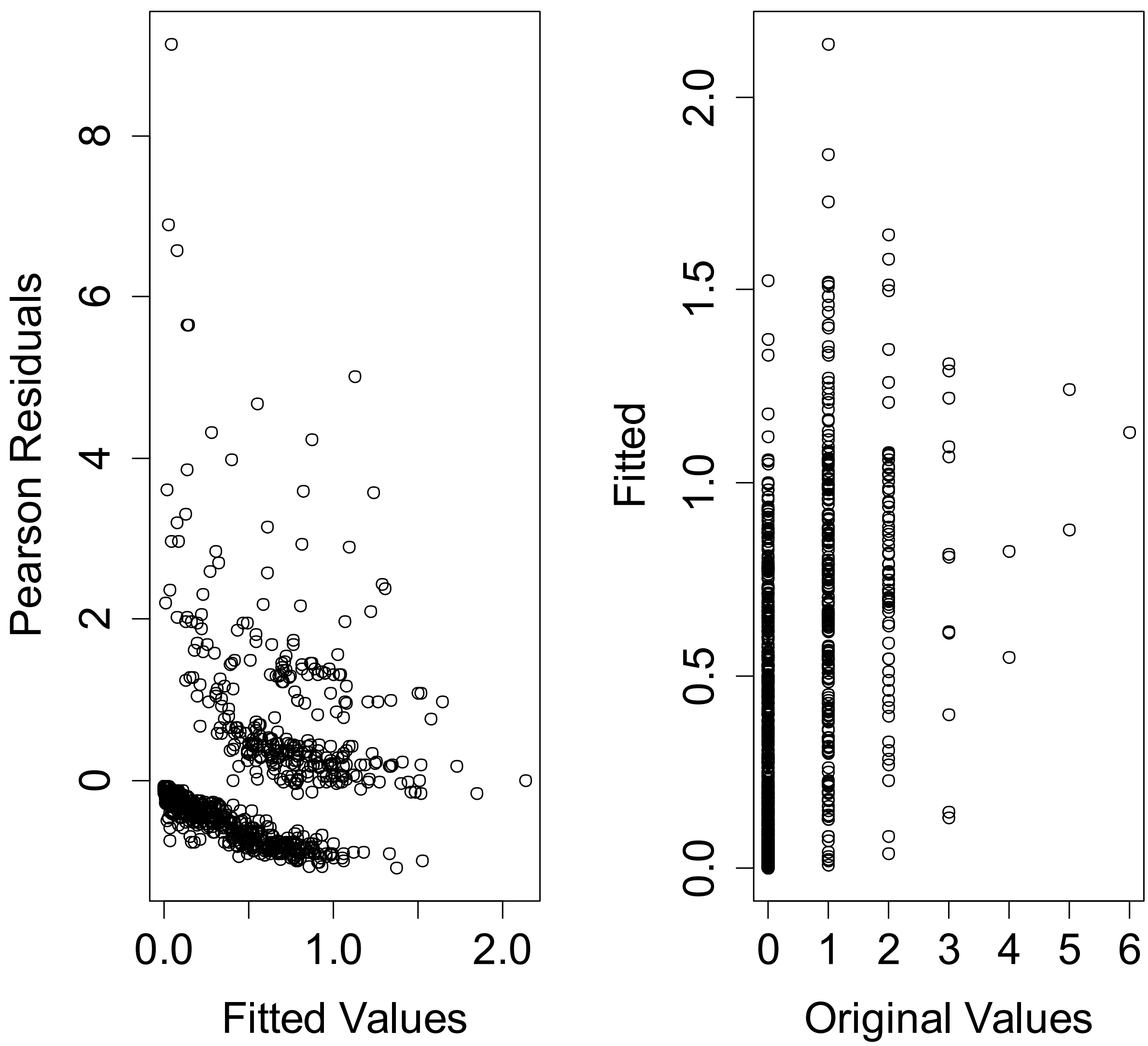

Figure 12. Model diagnostic plots showing fitted model values against Pearson residuals (left panel) and fitted values plotted against original data values (right panel).

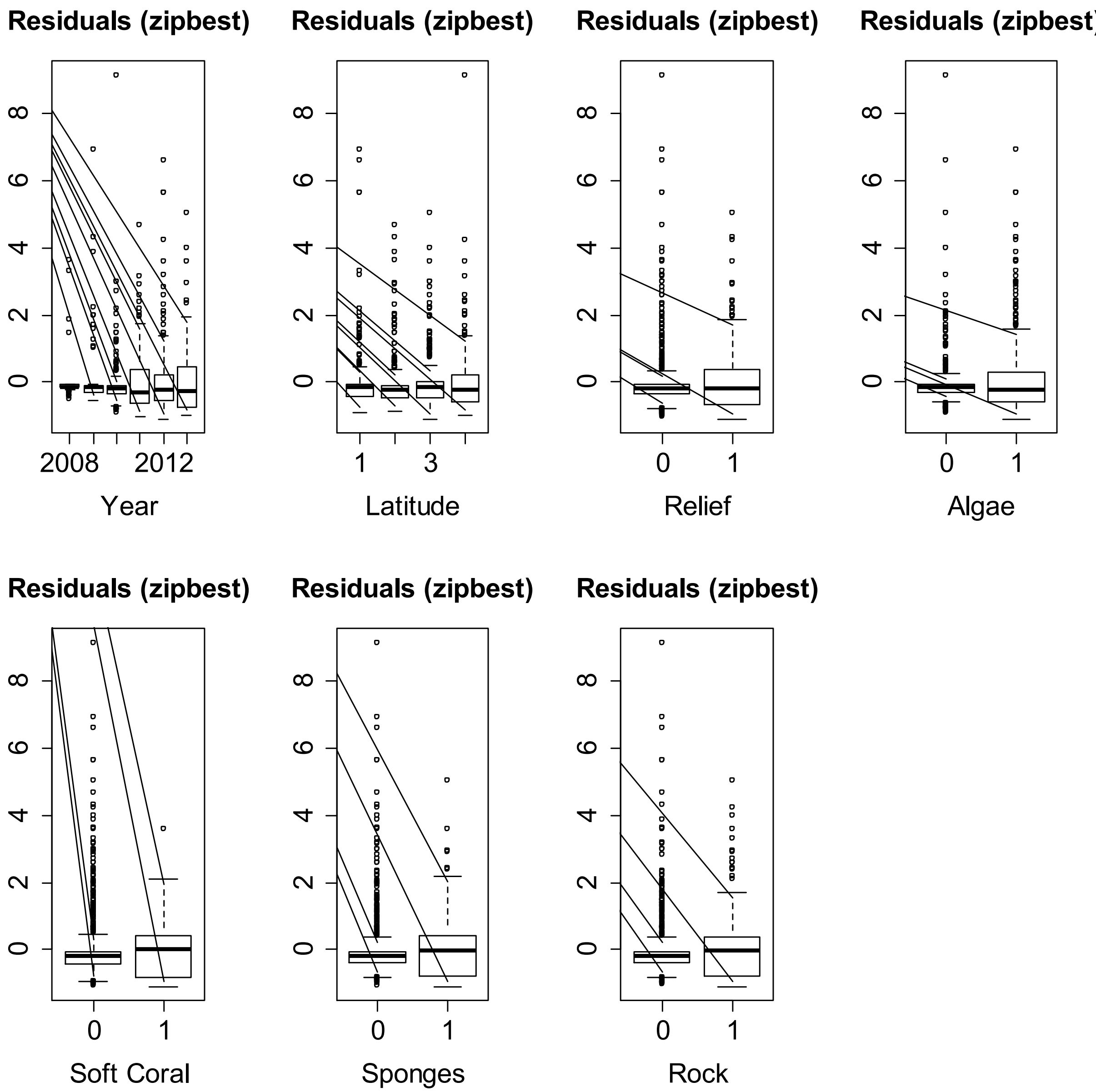

Figure 13. Model diagnostic plots showing Pearson residuals for the final model plotted against spatiotemporal and environmental model parameters.

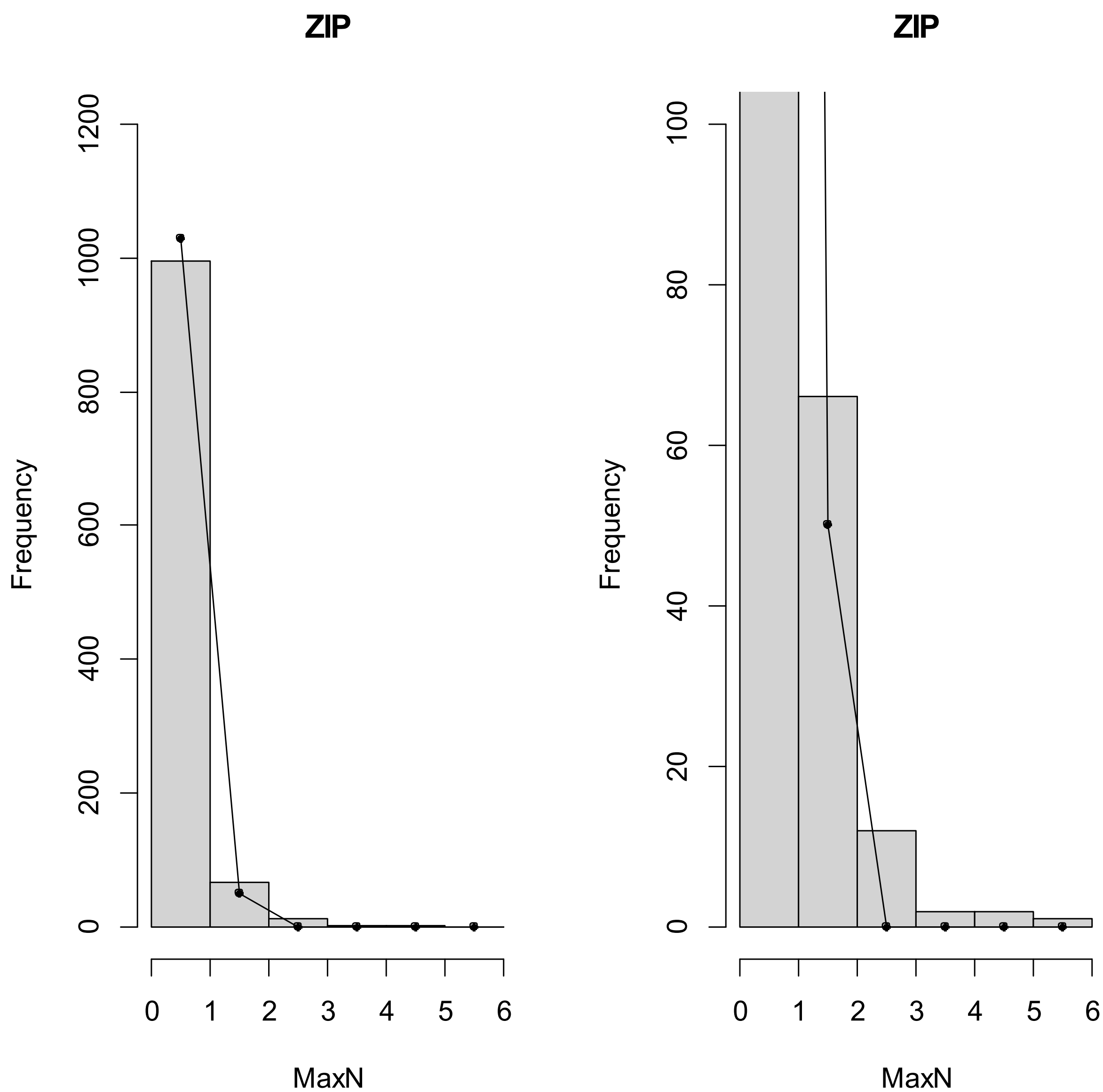

Figure 14. Model diagnostic plots of fitted model values (black line) against the original data distribution. Full distribution view (left panel) and limited y-axis view (right panel).

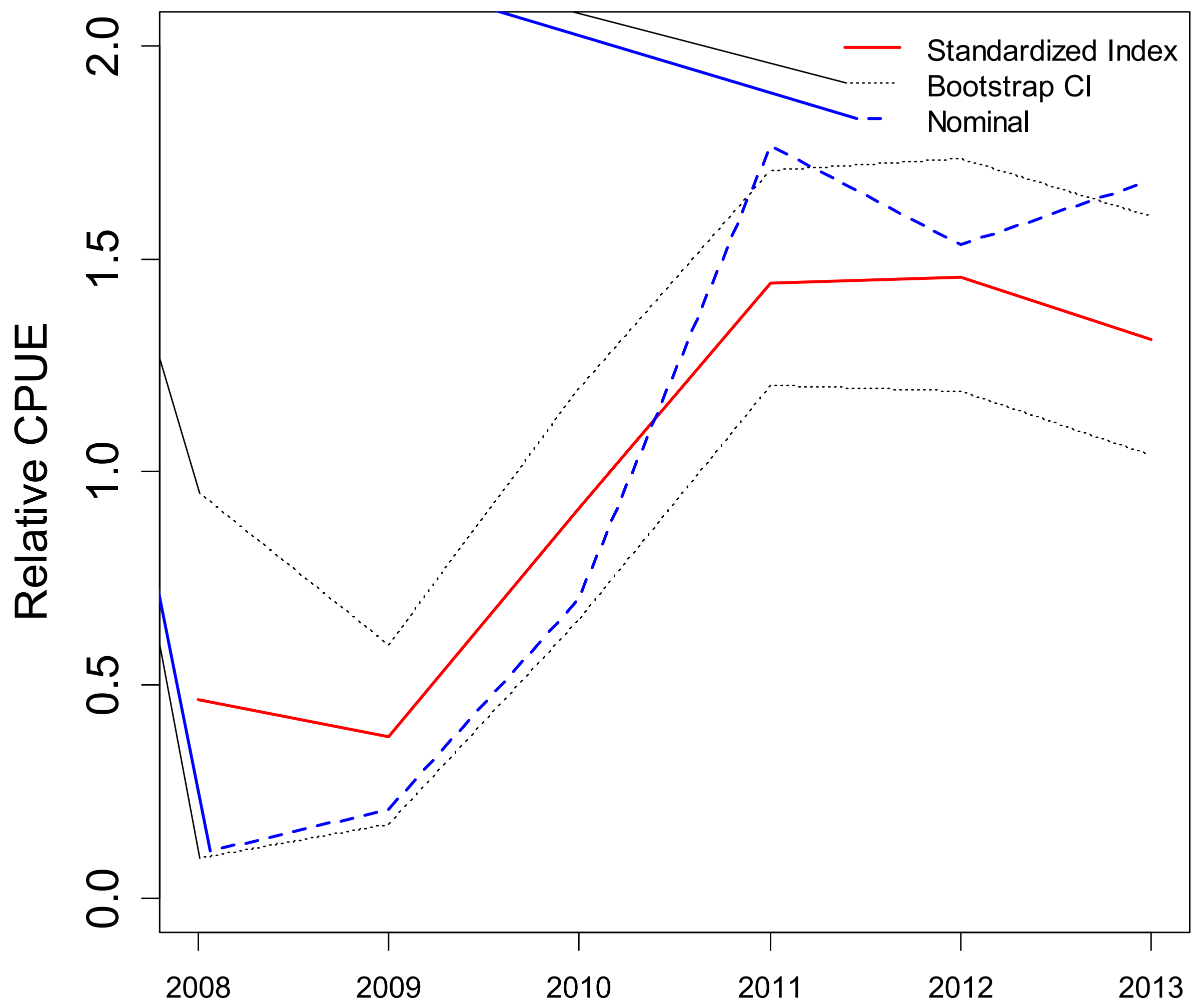

Figure 15. Relative standardized index (solid red line) with 2.5% and 97.5% confidence intervals (black dotted lines) and the relative nominal index (blue hashed line) for Red Grouper CPUE in the FWRI West Florida Shelf Video Survey.