Standardized video counts of Southeast U.S. Atlantic red grouper (*Epinephelus morio*) from the Southeast Reef Fish Survey

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Standardized video counts of Southeast U.S. Atlantic red grouper (*Epinephelus morio*) from the Southeast Reef Fish Survey

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Abstract

Standardized video counts of red grouper were generated from video cameras deployed by the Southeast Reef Fish Survey during 2011–2015. The analysis included samples taken between Cape Hatteras, North Carolina and St. Lucie Inlet, Florida. The index is meant to describe population trends of red grouper in the region. A zero-inflated negative binomial model was used to standardize video count data by a variety of predictor variables that could influence abundance and video counts. The 2015 index value and its uncertainty included a calibration factor to account for a change in camera type.

Background

The Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program has conducted most of the historical fishery-independent sampling in the U.S. South Atlantic (North Carolina to Florida). MARMAP has used a variety of gears over time, but chevron traps are one of the primary gears used to monitor reef fish species and have been deployed since the late 1980s. In 2009, MARMAP began receiving additional funding to monitor reef fish through the SEAMAP-SA program. In 2010, the SouthEast Fishery-Independent Survey (SEFIS) was initiated by NMFS to work collaboratively with MARMAP/SEAMAP-SA using identical methods to collect additional fishery-independent samples in the region. Together, these three programs are now called the Southeast Reef Fish Survey (SERFS). In 2010, video cameras were attached to some traps deployed by SERFS, and beginning in 2011 all traps included video cameras (Figure 1).

The SERFS currently samples between Cape Hatteras, North Carolina and St. Lucie Inlet, Florida. This survey targets hardbottom habitats between approximately 15 and 100 meters deep. SERFS began affixing high-definition video cameras to chevron traps on a limited basis in 2010 (Georgia and Florida only), but since 2011 has attached cameras to all chevron traps as part of their normal monitoring efforts. In 2015, the video cameras were changed from Canon to GoPro, to implement a wider field of view and thus observe more fish. A calibration study (detailed below) with both camera types used simultaneously was undertaken to account for differences in fish counts.

Hard-bottom sampling stations were selected for sampling in one of three ways. First, most sites were randomly selected from the SERFS sampling frame that consisted of approximately 3,000 sampling stations on or very near hard bottom habitat. Second, some stations in the sampling frame were sampled opportunistically even though they were not randomly selected for sampling in a given year. Third, new hard-bottom stations were added during the study period through the use of information from various sources including fishermen, charts, and historical surveys. These new locations were investigated using a vessel echosounder or drop cameras and sampled if hard bottom was detected. Only those new stations landing on hardbottom habitat were included in the analyses. All sampling for this study occurred during daylight hours between April and October on the R/V *Savannah*, R/V *Palmetto*, NOAA Ship *Nancy Foster*, or the NOAA Ship *Pisces* using identical methodologies as described below. Samples were intentionally spread out spatially on each cruise (see Figure 2 in Bacheler and Carmichael 2014).

Chevron fish traps with attached video cameras were deployed at each station sampled in our study (Figure 1). Chevron traps were constructed from plastic-coated, galvanized 2-mm diameter wire (mesh size = 3.4 cm2) and measured 1.7 m × 1.5 m × 0.6 m, with a total volume of 0.91 m^3. Trap mouth openings were shaped like a teardrop and measured approximately 18 cm wide and 45 cm high. Each trap was baited with 24 menhaden (*Brevoortia* spp.). Traps were typically deployed in groups of six, and each trap in a set was deployed at least 200 m (usually > 400 m) from all other traps to provide some measure of independence between traps. A soak time of 90 minutes was targeted for each trap deployed.

Canon Vixia HFS-200 high-definition video cameras in Gates underwater housings were attached to chevron traps in 2011–2014, facing outward over the mouth (Figure 1). In 2015, Canon cameras were replaced with GoPro Hero 4 cameras over the trap mouth. Fish were counted exclusively using cameras over the trap mouth. A second high-definition GoPro Hero video or Nikon Coolpix S210/S220 still camera was attached over the nose of most traps in an underwater housing, and was used to quantify microhabitat features in the opposite direction. Cameras were turned on and set to record before traps were deployed, and were turned off after trap retrieval. Trap-video samples were excluded from our analysis if videos were unreadable for any reason (e.g., too dark, camera out of focus, files corrupt) or the traps did not fish properly (e.g., bouncing or dragging due to waves or current, trap mouth was obstructed).

In advance of the switch to GoPro cameras exclusively in 2015, we conducted a calibration study in the summer of 2014 where Canon and GoPro cameras were attached to traps side-by-side and fish were counted at the same time. A total of 143 side-by-side comparisons were recorded, but only 66 pairs had sufficient numbers of priority species to be included in the calibration analyses. Only four pairs of samples observed red grouper, so we instead calculated a calibration factor for this analysis using all species observed in those 66 pairs of videos.

Relative abundance of reef fish on video has been estimated using the *MeanCount* approach (Conn 2011; Schobernd et al. 2014). *MeanCount* was calculated as the mean number of individuals of each species over a number of video frames in the video sample. Video reading time was limited to an interval of 20 total minutes, commencing 10 minutes after the trap landed on the bottom to allow time for the trap to settle. One-second snapshots were read every 30 seconds for the 20-minute time interval, totaling 41 snapshots read for each video. The mean number of individuals for each target species in the 41 snapshots is the *MeanCount* for that species in each video sample. Zero-inflated modeling approaches described below require count data instead of continuous data like *MeanCount*. Therefore, these analyses used a response variable called *SumCount*, which was simply the sum of all individuals seen across all video frames. *SumCount* and *MeanCount* track exactly linearly with one another when the same numbers of video frames are used in their calculation (Bacheler and Carmichael 2014). Therefore, *SumCount* values were only used from videos where 41 frames were read (~93% of all samples).

SERFS employed video readers to count fish on videos. There was an extensive training period for each video reader, and all videos from new readers were re-read by fish video reading experts until they were very high quality. After that point, 10% or 15 videos (whichever was larger) were re-read annually by fish video reading experts. Video readers also quantified microhabitat features (percent of bottom that was hardbottom, maximum substrate relief, substrate size, coverage of attached biota, predominant biotic type, and maximum biotic height), in order to standardize for habitat types sampled over time. Water clarity was also scored for each sample as poor, fair, or good. If bottom substrate could not be seen, then water clarity was considered poor, and if bottom habitat could be seen but the horizon was not visible, water clarity was considered fair. If the horizon could be seen in the distance, water clarity was considered to be good. Including water clarity in index models allowed for a standardization of fish counts based on variable water clarities over time and across the study area. A CTD cast was also taken for each simultaneously deployed group of traps, within 2 m of the bottom, and water temperature from these CTD casts was available for standardization models.

Data and Treatment

Overall, there were 7001 survey videos with data available covering a period of 5 years (2011-2015). Although data were available from 2010, they were not considered here due to limitations in spatial overlap of the survey area and the core spatial occupancy of red grouper, consistent with recommendations from the Southeast Reef Fish Survey Video Index Development Workshop (Bacheler and Carmichael 2014)). For the years considered, several data filters were applied. We removed any data points in which the survey video was considered unreadable by an analyst (e.g., too dark, corrupt video file), or if the trapping event was flagged for any irregularity that could have affected catch rates (e.g., trap dragged or bounced). Additionally, any survey video for which fewer than 41 video frames were read was removed from the full data set (n =368). Standardizing the number or readable frames for any data point was essential due to our use of *SumCount* as a response variable (see above). We also identified any video sample in which corresponding predictor variable were missing and removed them from the final data set.

Of the 7001 video samples considered for inclusion, 1383 were removed based on the data subsetting guidelines described above, leaving 5618 sampling events for the analysis (Figure 2).

Standardization

Response Variable

We modeled the *SumCount* as the response variable. *SumCount* measures the total number of red grouper observed across all 41 video frames in a sampling event.

Explanatory Variables

We considered 9 explanatory variables: year, season, depth, latitude, water temperature, turbidity, current direction, biotic density, and substrate composition. Although all of these explanatory variables were considered, we included in the final formulation only those that improved model performance.

YEAR (*y*) – Year was included because standardized catch rates by year are the objective of this analysis. We modeled data from 2011-2015. Annual summaries of data points considered are outlined in Table 1.

SEASON (t) – Season is a temporal parameter based on the Julian day of sampling (Figure 3). The season parameter is treated as a factor with days distributed among quartiles.

DEPTH (*d*) – Water depth was treated as a factor with four levels based on quantiles. Annual depth distribution for survey data are outlined in Table 1.

LATITUDE (*lat*)– The latitude of video samples (Figure 3) was divided into 4 levels based on quantiles.

TEMPERATURE (*temp*) – The bottom water temperature was collected from each station and incorporated as a predictor variable. Bottom temperatures ranged from 12.4 to 29.3 degrees Celsius (Figure 3). For the model, temperature was treated as a factor with 4 levels based on quantiles.

TURBIDITY (*wc*) – Turbidity can affect both species distributions and the ability of an analyst to identify species in video survey samples. Turbidity information is recorded during video analysis based on the ability of an analyst to perceive the horizon and surrounding habitat, and it was scored at 3 levels.

CURRENT DIRECTION (*cd*) – This categorical variable describes current direction based on the video point of view. Current direction was included to better account for variability in detection due to the current moving fish away or towards the camera. This variable is assigned one of 4 levels during video processing.

BIOTIC DENSITY (*bd*) – Biotic density is an estimate of the percent cover of attached biota visible during any video. The estimation is made based on percentage cover and ranged from 0 to 98%. For our analysis *bd* was treated as a categorical variable with 4 levels: none (0%), low (1-9%), moderate (10-39%) and high (>40%).

SUBSTRATE COMPOSITION (*sc*) – Substrate composition is an estimate of the proportion of the visible substrate that is hardbottom and is assigned during video processing. This variable was treated as a categorical variable with 4 levels: none, low, moderate, and high.

Zero-Inflated Model

The recommendation of the video index workshop (Bacheler and Carmichael 2014) was to apply a zero-inflated modeling approach to the development of fishery-independent video indices. Zero-inflated models are valuable tools for modeling distributions that do not fit standard error distributions due to excessive number of zeroes. These data distributions are often referred to as "zero-inflated" and are a common condition of count based ecological data. Zero inflation is considered a special case of over-dispersion that is not readily addressed using traditional transformation procedures (Hall 2000). Due to the high proportion of zero counts found in our data set (Figure 4), we used a zero-inflated mixed model approach that accounts for the high occurrence of zero values, as well as the positive counts. The model does so by combining binomial and count processes (Zuur et al. 2009).

The modeling approached used here was similar to that used in SEDAR41 for gray triggerfish and red snapper. As in SEDAR 41, we initially considered a full null model (1) using both a zero-inflated Poisson (ZIP) and a zero-inflated negative binomial (ZINB) formulation,

$$SumCount = y + wc + cd + sc + bd + d + t + lat + temp \mid y + wc + cd + sc + bd + d + t + lat + temp \quad (1)$$

In this formulation, variables to the left of the "|" apply to the count sub-model, and variables to the right apply to the binomial sub-model. Unlike SEDAR 41, in this analysis we favored a simpler null model because of the relatively small proportion of positive counts for red grouper,

$$SumCount = y \mid y \quad (2)$$

which allowed us to add covariates using a step-wise forward selection process (rather than the backward selection of SEDAR 41). However, prior to adding covariates, we compared ZIP and ZINB formulations. We compared the variance structure of each model formulation using AIC and likelihood ratio tests (Zuur et al 2009) to determine the most appropriate model error structure for the development of a red grouper video index. The results of these tests (Table 2) show clear support for the ZINB formulation (similar results were obtained when using the full null model). These results concur with our expectations based on the over dispersion within the video survey data and with the recommendations of the video index development panel (Bacheler and Carmichael 2014). A comparison between the fitted and original data for the ZIP and ZINB model formulations is shown in Figure 5.

We used a step-wise forward model selection procedure to systematically include important covariates in our model formulation. In this procedure, we added each explanatory variable one at a time, alternating between the count (negative binomial) and binomial components. The variable with the largest ΔAIC was added, and the process repeated until no variable resulted in ΔAIC>2. The final red grouper ZINB model formulation (Table 3) included year, current direction, and temperature in the negative binomial component, and year, season, latitude, substrate category, and temperature in the binomial component,

$$SumCount = y + cd + t \mid y + t + lat + sc + t \quad (3)$$

Diagnostics of the final model showed no clear patterns of association between Pearson's residuals and fitted values, or between the fitted values and original data (Figure 6). In addition, an examination of model residuals for the spatio-temporal (Figure 7) and environmental parameters (Figure 8) showed no clear patterns of association, indicating acceptable model choice (Zuur et al 2009). Finally, a comparison of predicted values against the original data distribution (Figure 9) demonstrates how the model fits the original data.

All data manipulation and analysis was conducted using R version 3.3.0 (R Core Team 2016). Modeling was executed using the **zeroinfl** function in the **pscl** package (Jackman 2008), available from the Comprehensive R Archive Network (CRAN).

Calibration of gear

Because camera gear changed in 2015 from Canon to GoPro, index values in 2015 were adjusted to make them comparable to values prior. Ideally, calibration would be done on a species by species basis, however only four red grouper were observed during the calibration study. Thus a data set with all fish observed (n=354) was considered for developing a calibration factor, as well as a trimmed data set to remove the influence of outliers. Trimming was accomplished by removing the smallest and largest 2.5% of counts observed by the GoPro, which left n=345 fish. Using the full and trimmed data sets, *MeanCounts* from Canon cameras were regressed on *MeanCounts* from GoPro cameras to estimate a slope parameter β (Figure 10). For all data, β=0.565 (SE=0.01); for trimmed data, β=0.496 (SE=0.009). The calibration factor from trimmed data was used to adjust the 2015 index value downward, to make it comparable to data from earlier years.

Uncertainty

Uncertainty in the index was computed using a bootstrap procedure with n=1000 replicates. In each replicate, a data set of the original size was created by drawing observations (rows) at random with replacement. This was done by year, to maintain the same annual sample size as in the original data. The model (Equation 3) was fitted to each data set, and uncertainty (CVs) was computed from those fits that converged.

Uncertainty in the 2015 calibration factor was included in the bootstrap procedure by drawing a random value from a normal distribution with a mean of 0.496 and a standard deviation of 0.009 (estimates from the regression using trimmed data). These values, one for each bootstrap replicate, were used to scale the 2015 index estimates. Thus this method accounts for the adjustment, and is also reflected in the estimated 2015 CV.

Results and discussion

Annual standardized index values for red grouper including CVs are presented in Table 4. The relative nominal index fell within the 2.5% and 97.5% confidence intervals of the standardized index and tracked closely with the standardized index (Figure 11).

During 2011-2015, red grouper were observed in a low percentage of video sampling events, about 1-2% annually. For comparison to SEDAR 41 species, gray triggerfish was observed in about 30-35% of sampling events, and red snapper were observed in about 20-25%. With such small sample sizes for red grouper, model convergence was a concern. During model exploration, several covariate combinations resulted in models that did not converge. The final model did converge using the original data set, but in only about 59% of bootstrapped data sets. Although replicates that did not converge were subsequently excluded, the relatively low rate of convergence is a result of the small sample size (positive sampling events), and perhaps an indication that we are asking a lot of this model.

Literature cited

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Table 1: Annual total number of video samples included in the analysis

Year	Number of video samples	Depth range (m)	Latitude range	Date range
2011	576	15-93	27.23-34.54	139-298
2012	1076	15-106	27.22-35.01	115-284
2013	1221	15-100	27.33-35.02	114-277
2014	1381	15-100	27.23-35.02	113-294
2015	1364	16-110	27.26-35.02	111-295

Table 2: Preliminary model error structure comparison

	df	Likelihood	AIC	χ^2	df	*p*-value
ZIP	10	-918.78	1857.57			
ZINB	11	-696.82	1415.65	443.92	1	<0.001

Table 3: Model selection results for Zero-Inflated Negative Binomial model for red grouper observed during SERFS video surveys, 2011-2015. The ΔAIC shows performance improvement from the previous step. Step 1 is compared to the null model, which includes only year effects for both the binomial and negative binomial components.

	Added Term						
Step	**Binomial Model**	**Negative Binomial Model**	***df***	**ΔAIC**	**χ^2**	**df**	***p*-value**
1	<none>	*cd*	13	15.24	19.2	2	<0.001
2	*d*	*cd*	16	22.07	28.1	3	<0.001
3	*d*	*cd + t*	19	5.19	11.19	3	0.01
4	*d+lat*	*cd + t*	22	29.17	35.17	3	<0.001
5	*d+lat+sc*	*cd + t*	22	12.70	18.70	3	<0.001
6	*d+lat+sc+t*	*cd + t*	22	18.32	24.32	3	<0.001

Table 1: The relative nominal *SumCount*, number of stations sampled, proportion positive, standardized index, and CV for the SERFS red grouper video index. The 2015 values shown here reflect the calibration.

Year	Relative nominal (*SumCount*)	N	Proportion positive	Standardized index	CV
2011	0.75	576	0.014	0.66	0.50
2012	0.71	1076	0.019	0.91	0.41
2013	0.88	1221	0.010	0.51	0.53
2014	1.73	1381	0.021	1.85	0.30
2015	0.93	1364	0.015	1.07	0.37

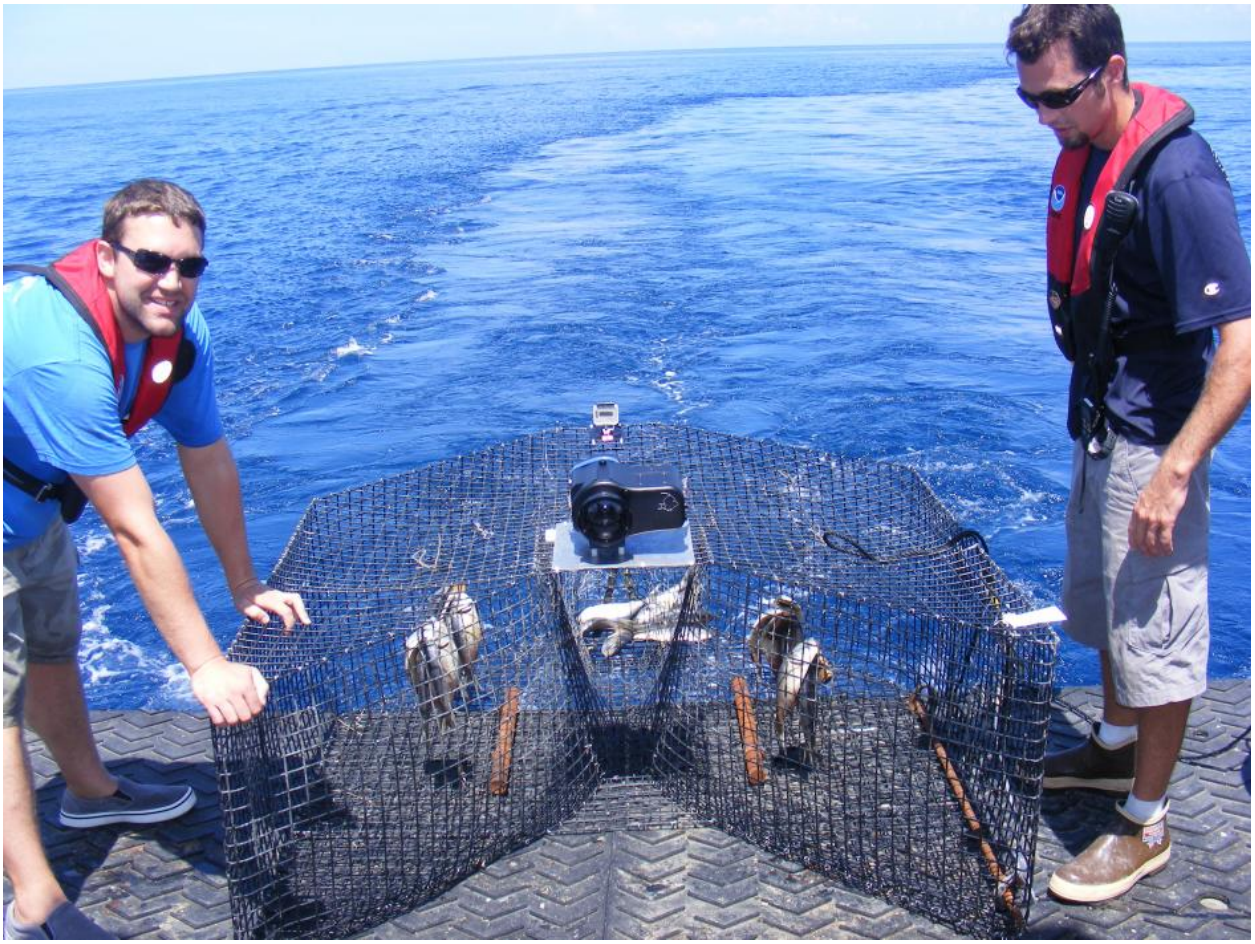


Figure 1: Chevron trap used by SERFS showing the Canon camera over the mouth and GoPro on the trap nose.

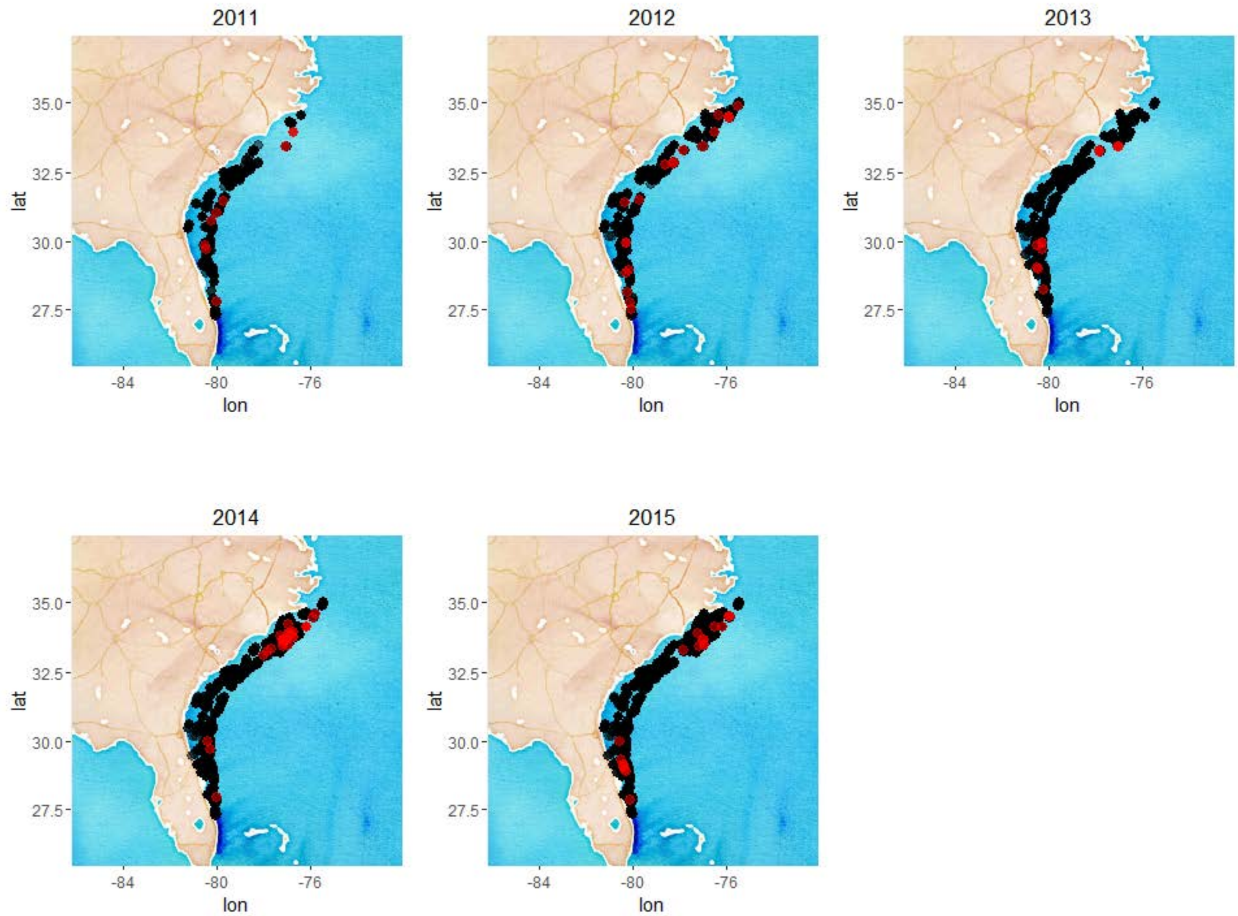


Figure 2: Annual spatial distribution of underwater video samples collected by SERFS in 2011 – 2015. Black points indicate no red grouper were seen on video and red points indicate red grouper were seen on video. Note that red points were overlaid on top of black points, and points may overlap.

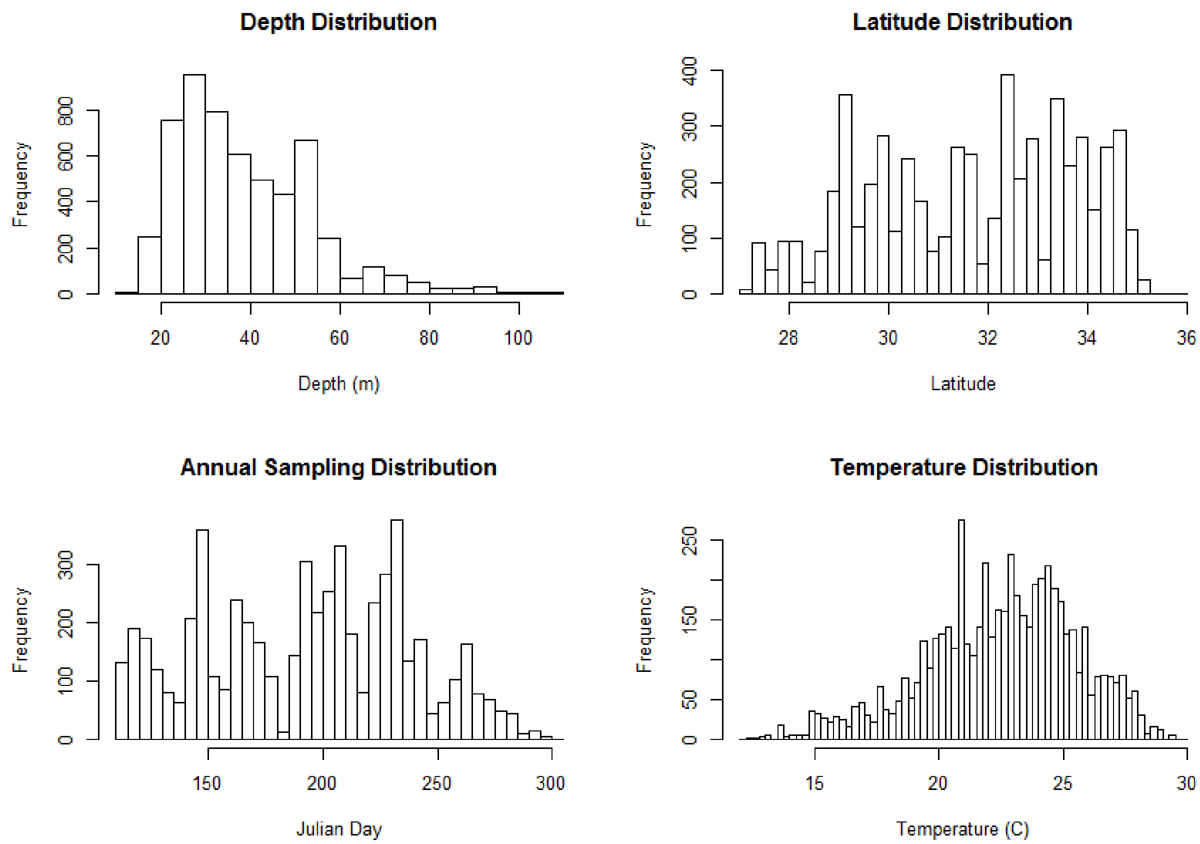


Figure 3: Sample distribution of data collected as continuous variables

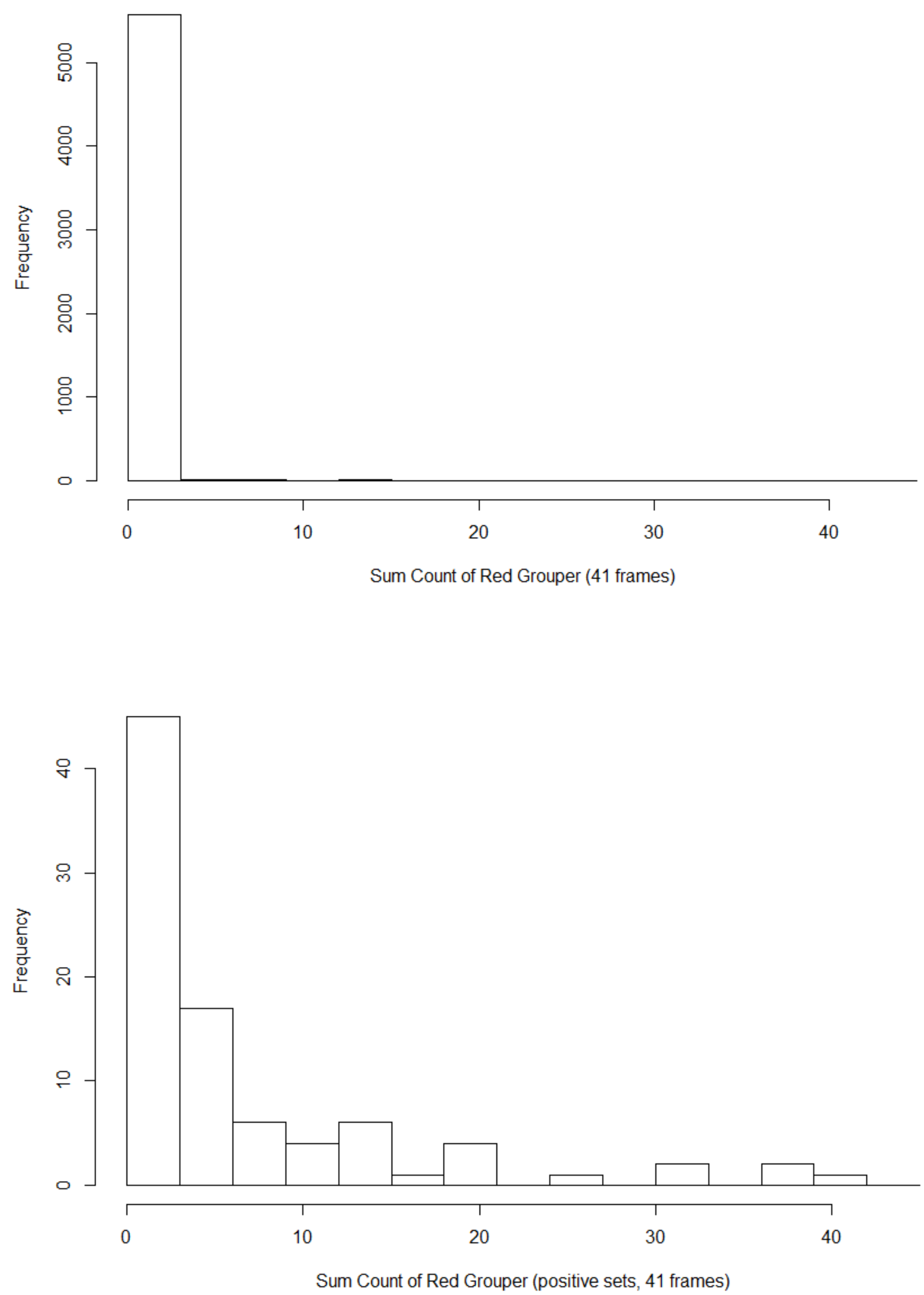


Figure 4: Top panel: *SumCount* distribution of Red Grouper video observations in the South Atlantic. Bottom panel: *SumCount* distribution of Red Grouper video observations, excluding zeros.

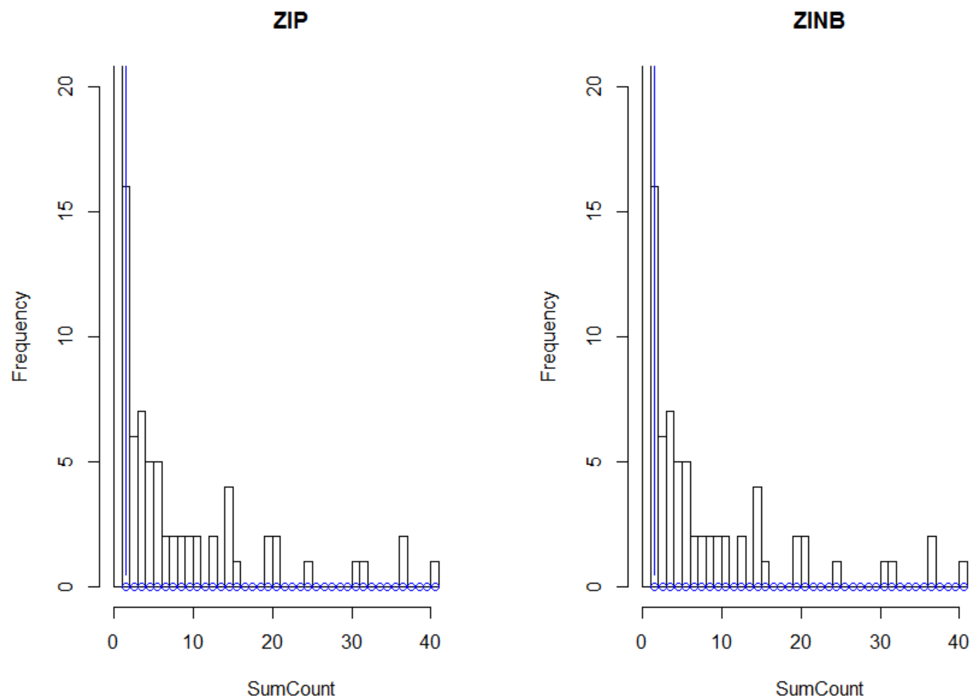


Figure 3: Model formulation comparison, with ZIP (left) and ZINB (right) fitted values plotted against the original data distribution. The count data are in whole numbers; fitted values are continuous (in this case, all fitted values are between 0 and 1).

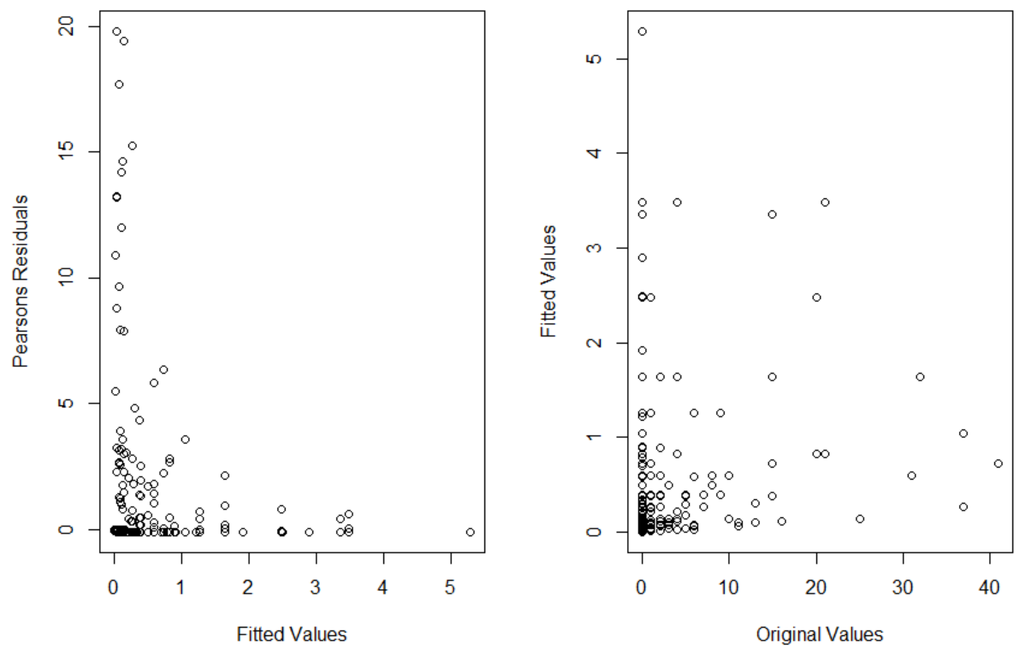


Figure 4: Model diagnostic plot showing fitted model values against Pearson's residuals (left) and fitted values plotted against original data values (right)

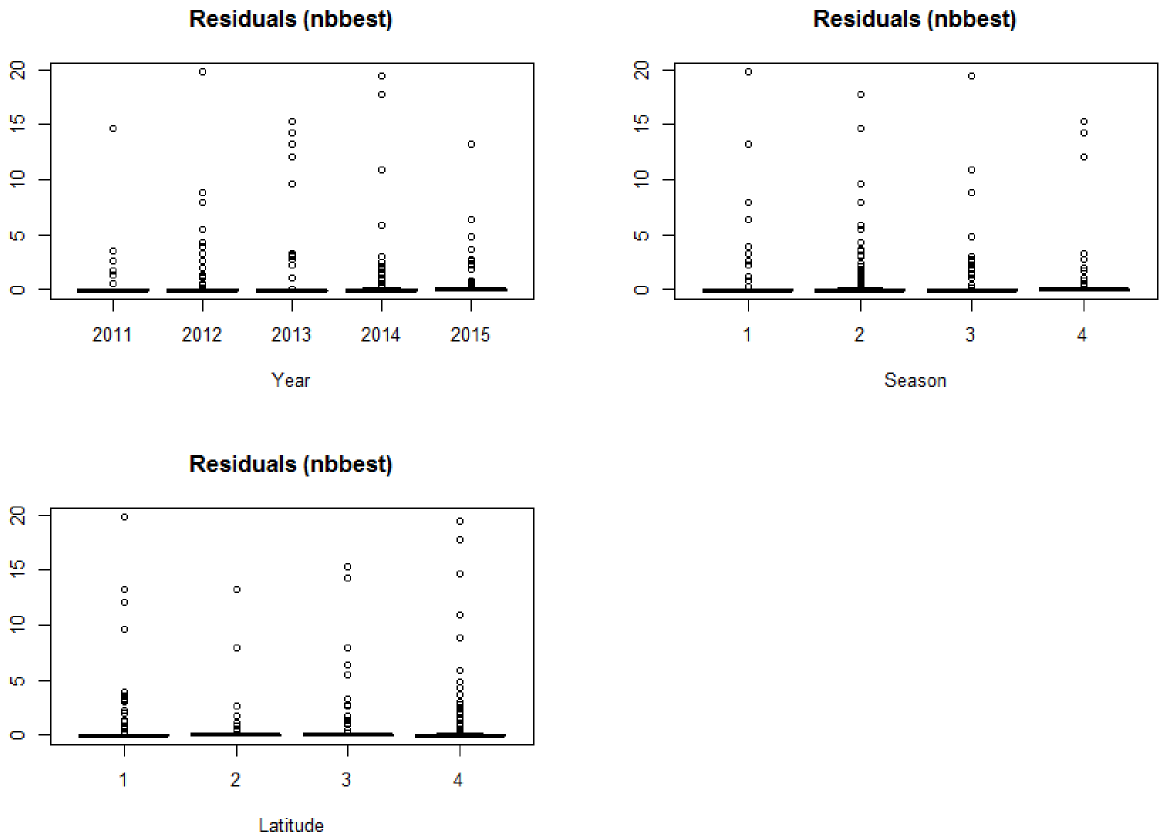


Figure 5: Model diagnostic plot showing Pearson's residuals from the final model plotted against both temporal and spatial model variables

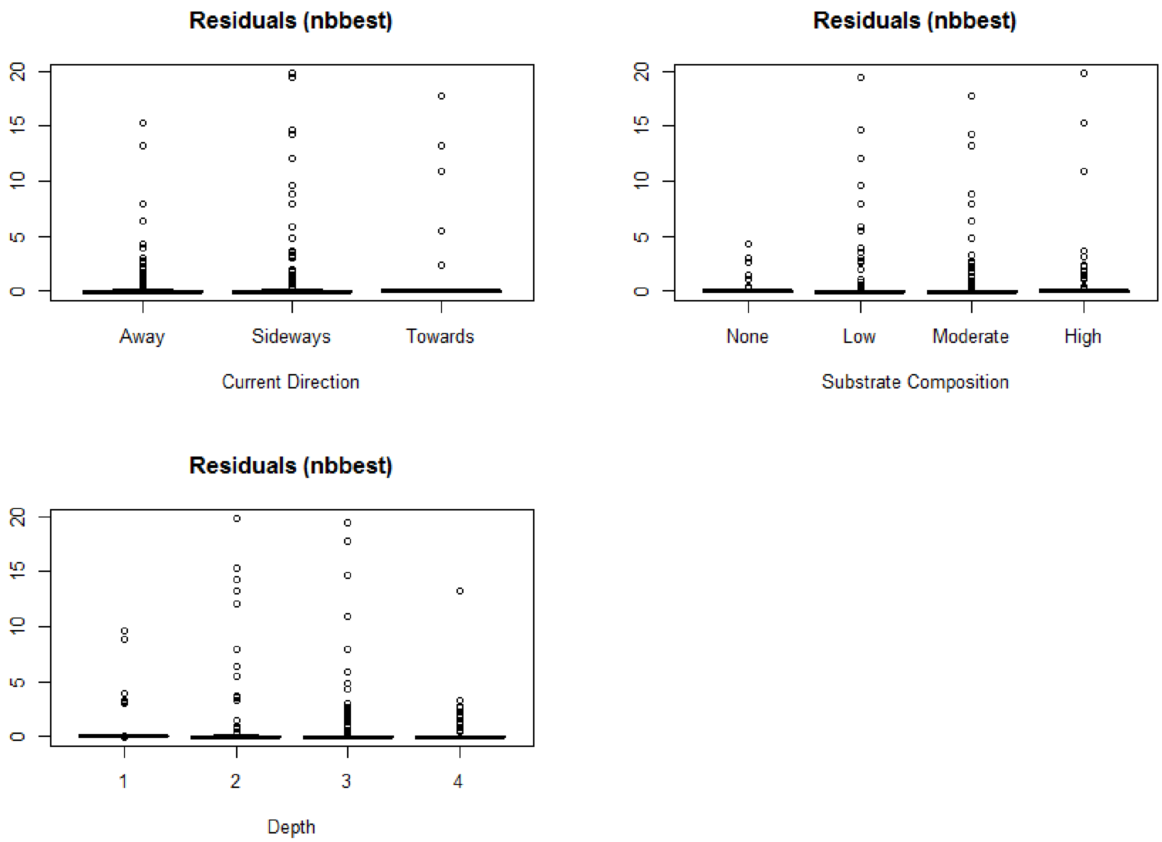


Figure 6: Model diagnostic plots showing Pearson's residuals for the final model plotted against environmental model parameters.

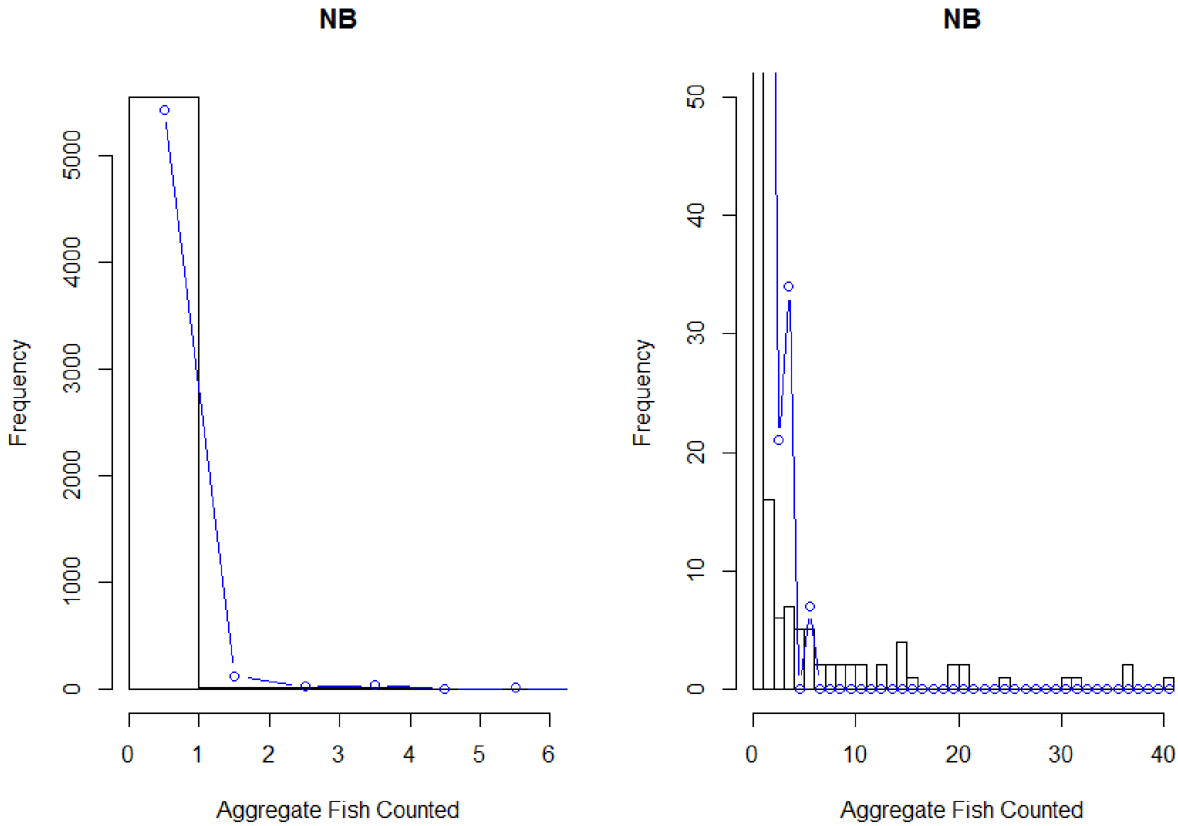
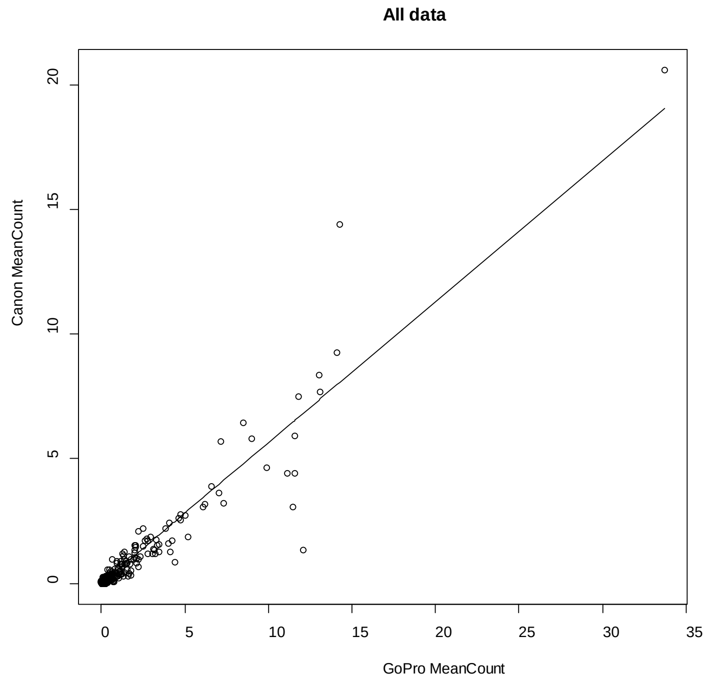


Figure 7: Model diagnostic plots of fitted model values (blue line) against the original data distribution. Limited x-axis distribution view (left); limited y-axis view (right).



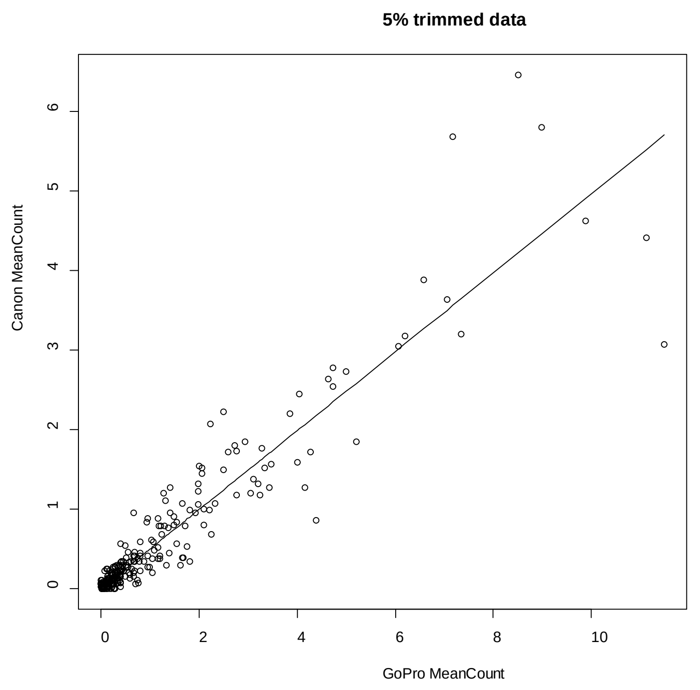


Figure 10: Linear regressions (intercept=0) using all data of the calibration study (top panel) and using 5% trimmed data (bottom panel).

Figure 11: Relative standardized index (solid line) with 2.5% and 97.5% confidence intervals (dashed lines) and the relative nominal index (blue) for red grouper in the SERFS video survey