Red Snapper Fishery-Independent Indices of Abundance in US South Atlantic Waters Based on a Chevron Trap Survey

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Marine Resources Research Institute
South Carolina Department of Natural Resources
P.O. Box 12259
Charleston, SC 29412

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Abstract

Fishery-independent measures of catch and effort with standard gear types and deployment strategies are valuable for monitoring the status of stocks, interpreting fisheries landings data, performing stock assessments, and developing regulations for managing fish resources. This report presents a summary of the fishery-independent monitoring of Red Snapper in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS, known collectively as SERFS). Specifically, it presents annual nominal catch per unit effort (CPUE) of Red Snapper in chevron traps from 1990 to 2013. Also included are annual CPUE estimates for chevron trap catches from 1990 to 2013 standardized by a delta-generalized linear model (dGLM) and a zero-inflated negative binomial model (ZINB). The standardized models account for the effects of potential covariates that may affect sampling or abundance, other than year of capture, on annual CPUE estimates. We also include length and age compositions for the chevron trap survey to describe selectivity. The ZINB model fit best to observed catches of Red Snapper. Standardized annual CPUE estimates normalized to the series' average indicated that CPUE was highly variable with little trend through the early 2000s, before declining to series' lows in the mid 2000s. Since approximately 2006, CPUE in the region has been increasing generally.

Introduction

Fishery-independent measures of catch and effort with standard gear types and deployment strategies are valuable for monitoring the status of stocks, interpreting fisheries landings data, performing stock assessments, and developing regulations for managing fish resources. Inevitably, tighter management regulations result in fishery-dependent catches reflecting the demographics of a restricted subset of the population, affecting the utility of fishery-dependent data when assessing the current status of the stock. When fisheries are highly regulated, fishery-independent surveys are often the only method available to adequately characterize population size, age and length compositions, and reproductive parameter distributions, all of which are needed to assess the status of stocks. The Marine Resources Monitoring, Assessment and Prediction (MARMAP) program has conducted fishery-independent research on the continental shelf and shelf edge between Cape Hatteras, North Carolina, and St. Lucie, Florida, for over 40 years to provide information for reliable stock assessments and evaluation of management plans. Housed at the Marine Resources Research Institute (MRRI) at the South Carolina Department of Natural Resources (SCDNR), the overall mission of the MARMAP program has been to determine the distributions, relative abundances, and critical habitats of economically and ecologically important fishes of the SAB, and to relate these features to environmental factors and exploitation activities.

Although the MARMAP program has used various gear types and methods of deployment since its inception, the program has strived to use consistent gears and sampling methodologies throughout extended time periods to allow for analyses of long-term changes in relative abundance, age compositions, length frequencies, and other information. As such, the MARMAP program primarily has used a standard sampling methodology with chevron traps for monitoring purposes on known live-bottom habitats since 1990. The focus of this report is on developing an annual catch per unit effort

(CPUE) or abundance index for Red Snapper (*Lutjanus campechanus*) based on chevron trap catches from 1990 to 2013.

Until recently, the MARMAP program was the only long-term fishery-independent program that collected the data necessary to develop indices of relative abundance for species in the South Atlantic Fisheries Management Council's (SAFMC) snapper-grouper species complex. In 2008, with a first field season occurring in 2009, the Southeast Area Monitoring and Assessment Program's South Atlantic component (SEAMAP-SA) provided funding to complement MARMAP efforts. A particular goal of the SEAMAP-SA Reef Fish complement is to assist with the expansion of the geographical sampling coverage of the current fishery-independent surveys, focusing on either shallow or deep potential live-bottom areas. In addition, the SEAMAP-SA complement funding allowed for expanded sampling in marine protected areas (MPAs).

Beginning in 2010, NOAA Fisheries made funding available to create the Southeast Fisheries Independent Survey (SEFIS) program housed at the Southeast Fisheries Science Center (SEFSC) laboratory in Beaufort, NC. This fishery-independent survey was designed to further complement the historical MARMAP/SEAMAP-SA reef fish monitoring efforts, again aimed at extending the geographical range of the surveys. SEFIS activities were coordinated closely with MARMAP/SEAMAP-SA staff, which trained SEFIS personnel and have participated in SEFIS monitoring cruises. SEFIS uses gear and methodologies identical to MARMAP/SEAMAP-SA to maintain the integrity of the long-term data set. In 2011, for logistical and cost savings reasons and since all programs were using identical sampling methods, it was decided that SEFIS vessels would concentrate sampling efforts in waters off Georgia and Florida, while MARMAP/SEAMAP-SA vessels would concentrate efforts off South Carolina and North Carolina. Given the close coordination and consistent sampling methodology used by each of the fishery-independent sampling programs, it is possible to combine catch, effort, and length data collected by each program for chevron traps for the analyses presented in this report (see **Error! Reference source not found.** for gear deployment summary). The combined efforts of MARMAP, SEAMAP-SA Reef Fish Complement, and SEFIS to conduct fishery-independent reef fish monitoring in the US South Atlantic region are now referred to as the Southeast Reef Fish Survey (SERFS).

Objective

This report presents a summary of the fishery-independent monitoring of Red Snapper in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS, known collectively as SERFS). Specifically, it presents annual nominal catch per unit effort (CPUE) of Red Snapper in chevron traps from 1990 to 2013. Also included are annual CPUE estimates for chevron trap catches from 1990 to 2013 standardized by a delta-generalized linear model (dGLM) and a zero-inflated negative binomial model (ZINB). The standardized models account for the effects of potential covariates that may affect sampling or abundance, other than year of capture, on annual CPUE estimates. Data presented in this report are based on the combined SERFS database accessed in January, 2014 for the dGLM analysis and on July 14, 2014 for the nominal and ZINB analyses, and include data collected through the 2013 sampling season.

Methods

Survey Design and Gear

The standard SERFS sampling area includes waters of the continental shelf and shelf edge between Cape Hatteras, NC, and St. Lucie Inlet, FL, although over the years the majority of sampling has occurred south of Cape Lookout, NC (Figure 1). Throughout this range, we sample stations established on confirmed live bottom (monitoring) from May through September each year, though cruises have occurred prior to and after these months in some years. Traps deployed on suspected live bottom in a given year (reconnaissance) are evaluated based on catch and video or photographic evidence of bottom type for inclusion in the sampling frame the next year.

MARMAP began using chevron traps in 1988 after a commercial fisherman introduced the use of this trap design in the US South Atlantic region (Collins 1990). Subsequently, in 1988 and 1989, chevron traps were used simultaneously with blackfish and Florida Antillean traps to compare the efficiency of the three different trap designs at capturing reef fishes on live-/hard-bottom habitats (Collins 1990). Results indicated that the chevron trap was most effective overall for species of commercial and recreational interest in terms of both total weight and numbers of individuals captured (Collins 1990). Based on these results, the MARMAP program has used chevron traps for reef fish monitoring purposes in the US South Atlantic since 1990, using this single gear to replace both blackfish and Florida Antillean traps. Currently, all three fishery-independent monitoring programs composing SERFS continue to utilize the chevron trap as their primary monitoring gear.

Each year, stations are selected randomly from known live-/hard-bottom stations identified for monitoring via fish traps (low to moderate relief) in that year (currently ~ 3,500 stations are available). Stations are selected randomly in a manner such that no station selected in a given year is closer than 200 m to any other selected station, though the minimum difference typically is closer to 400 m. Chevron traps have been deployed at depths ranging from 13 to 218 m, although the depth of usage generally is less than 100 m. The vast majority of the deeper deployments occurred in 1997.

The chevron trap time series has been continuous from 1990 to present, although the distribution and extent of sampling has changed over time. The spatial coverage of the survey has expanded over the time series as we have added stations and sampling effort in the northern and southern ends of the survey. Figure 1 shows the extent of the survey for all sampling years included in this report and the locations of Red Snapper catches and Table 1 shows changes in the survey with regards to some environmental variables over all years included in this report.

Chevron traps are arrowhead shaped, with a total interior volume of 0.91 m^3 (Figure 2, Collins 1990). Each trap is constructed of 35 x 35 mm square mesh plastic-coated wire (MARMAP 2009). Each trap possesses a single entrance funnel (“horse neck”) and release panel to remove the catch (Collins 1990; MARMAP 2009). Prior to deployment each chevron trap is baited with a combination of whole or cut clupeids (*Brevoortia* or *Alosa* spp., family Clupeidae), with *Brevoortia* spp. most often used. Four whole clupeids on each of four stringers are suspended within the trap and approximately 8 clupeids, with their abdomen sliced open, are placed loose in the trap (Collins 1990; MARMAP 2009). An individual trap is attached to an appropriate length of 8 mm (5/16 in) polypropylene line buoyed to the surface using a polyball buoy. We attach a 10 m trailer line to this polyball buoy, with the end of the trailer line clipped to a Hi-Flyer buoy or another polyball. Generally traps are deployed in sets of six when a sufficient number of stations are available in a given area (MARMAP 2009). Traps are retrieved in chronological order of deployment, using a hydraulic pot hauler, after an approximately 90-minute soak time.

Oceanographic Data

While traps are soaking, oceanographic variables (mainly temperature and salinity) are determined using a CTD. Bottom temperature (°C) as used in this report is defined as the temperature of the deepest recording within 5 m of the bottom.

Data and Treatment

Data and Nominal CPUE Estimation

Data available for use in CPUE estimation for each trap (deployment) included a unique collection number, date of deployment, soak time, latitude, longitude, bottom depth, catch code, number of Red Snapper captured, aggregate weight of Red Snapper captured, and bottom temperature, among other variables. We used numbers, instead of weight, of Red Snapper for all analyses. Estimates of CPUE, or relative abundance, are given as the number of Red Snapper caught per trap per hour soak time (dGLM CPUE) or number per trap (nominal CPUE and ZINB CPUE).

Prior to modeling, a subset of the available SERFS trap data was selected for CPUE estimation based on several criteria:

1) Deployments made via SERFS with a project ID of P05 (MARMAP fishery-independent samples), T59 (SEAMAP-SA Reef Fish Complement fishery-independent samples), and T60 (SEFIS fishery-independent samples)
2) Deployments with catch codes of 0 (no catch), 1 (catch with finfish), 2 (catch without finfish), 9 (recon trap deployment), 90 (recon trap deployment with no catch), 91 (recon trap deployment with finfish), and 92 (recon trap deployment without finfish catch)
    a. For development of the dGLM standardized index (i.e. index presented in the 2013 trends report), all 9, 90, 91, and 92 catch codes were removed from analysis
3) Deployments with station codes of “Random” (randomly-selected live-bottom station), “NonRandom” (non-randomly sampled live-bottom station (a.k.a. haphazard sample)), “ReconConv” (reconnaissance deployments that were subsequently converted into live-bottom stations), and “Is Null” (traps for which there is no station code value – the use of station codes is fairly new since 2010. Historically we used only the catch ID to indicate randomly-selected stations)
4) Deployments with Gear ID equal to 324 (chevron traps)
5) Deployments with Data Source not equal to “Tag-MARMAP”
    a. “Tag-MARMAP” represents special historic MARMAP cruises that were used to tag various species of fish. Because standard sampling procedures were not used (e.g.

not all fish were measured for length frequency) these samples are excluded from CPUE development

6) Deployments at depths between 15 and 74 m
    a. Represents the depth range at which 100% of Red Snapper were collected by any gear used in the SERFS (Ballenger et al. 2012b)
    b. Given previous constraints, this removes 248 traps deployed at <15 m or >74 m of depth and 2 traps for which we are missing depth data
7) Soak times outside of a window between 45 and 150 minutes, which generally indicates deviations from standard protocols
    a. Note, SERFS targets a soak time of 90 minutes for all chevron trap deployments
    b. Removes an additional 192 traps with unusually long or short soak times
8) Deployments made since 1990
    a. Removes an additional 178 traps sampled in 1988 and 1989

Delta-Generalized Linear Model (dGLM) CPUE Standardization

In the MARMAP annual trends report, Red Snapper annual CPUE is calculated using a dGLM method. In this method, CPUE is standardized among years using the "delta-GLM" technique described in Lo et al. (1992). Briefly, the standardized CPUE is the product of fitted values from two generalized linear models (GLMs). The first model examines the effects of factors or "covariates" on the presence or absence of a species using the binomial error distribution. As we assume each gear deployment is independent and identical to all other gear deployments, each gear deployment in effect represents a binomial trial with a sample size of one (n=1). In such cases, we refer to the distribution as a Bernoulli distribution, thus our reference to the Bernoulli sub-model or Bernoulli GLM of the delta-GLM in the remainder of this report. By modeling this presence/absence data using the Bernoulli distribution, we assume that the presence/absence data conform to the Bernoulli distribution density function

$$f(y;\pi) = \binom{1}{y} * \pi^{y} * (1-\pi)^{1-y}.$$

The mean and variance of the Bernoulli distribution are given by

$$E(Y) = \pi \qquad\qquad \mathrm{var}(Y) = \pi * (1-\pi).$$

The second model examines the effects of covariates on the CPUE of positive observations using a second assumed error distribution (e.g. gamma distribution, Gaussian distribution, lognormal distribution, etc.). This model is referred to as the positive GLM or the error distribution identified as "best" modeling the positive data (e.g. gamma sub-model and lognormal sub-model).

In the current report, only the use of the gamma and lognormal distributions were investigated to model the positive data in the dGLM. The gamma distribution is appropriate for use with a continuous response variable *Y* that has positive values (*Y* > 0), and is represented by the probability density function

$$f(y;\mu,\nu) = \frac{1}{\Gamma(\nu)} * \left(\frac{\nu}{\mu}\right)^{\nu} * y^{\nu-1} * e^{\frac{y*\nu}{\mu}} \qquad y > 0 \text{ (Zuur et al. 2009).}$$

Under the gamma distribution, the mean and variance of *Y* are

$$E(Y) = \mu \qquad \text{var}(Y) = \frac{\mu^2}{\nu}.$$

The lognormal distribution is a continuous probability distribution of a response variable *Y* whose logarithm is normally distributed, and is represented by the probability density function

$$f(y;\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} * e^{-\frac{(\ln y-\mu)^2}{2\sigma^2}} \qquad y > 0.$$

Under the lognormal distribution, the mean and variance of *Y* are

$$E(Y) = e^{\mu+\frac{1}{2}\sigma^2} \qquad \text{var}(Y) = \left(e^{\sigma^2} - 1\right) * e^{2\mu+\sigma^2}.$$

Covariates in the initial development of the dGLM CPUE estimates include latitude, depth, bottom temperature, and season. Covariates were defined as categorical variables for this analysis based on the 50% quartiles for distribution of sampling efforts, creating 2 bins for each covariate (Bubley et al. 2014). Selection of the covariates included in the final model (both Bernoulli GLM and positive GLM) was done based on Akaike's information criteria (AIC; Akaike 1973). Year was included as a covariate in both models regardless of the selection outcome based on AIC. Further, we allowed the possibility that different covariates may appear in the Bernoulli GLM and positive GLM. The final dGLM standardized CPUE index is the product of the year effects and any selected covariates from the two models. Coefficients of variation, standard error, and standard deviations were determined by a jackknifing approach.

Zero-Inflated Model CPUE Standardization

CPUE was standardized among years using a zero-inflated count model (ZINB). Given the biological knowledge of Red Snapper and the sampling design of the SERFS chevron trap survey, we compared model fits with the ZINB method to those of the nominal CPUE estimation and dGLM method based on conclusions and recommendations drawn during SEDARs 32 and 36. Investigation of this technique to model CPUE data also was suggested during the Fishery-Independent Survey Independent Review for the South Atlantic (SEFSC 2012). As is the case with many ecological count data sets (Zuur et al. 2009), the observed CPUE data appeared to be zero-inflated based on preliminary analyses (Figure 3), suggesting the appropriateness of zero-inflated count data models.

Briefly, we provide some background information regarding zero-inflated count data models. For a more complete discussion, see Chapter 11 in Zuur et al. (2009). Zeileis et al. (2008) provides a nice overview and comparison of Poisson, negative binomial, and zero-inflated models in R. Some textbooks devoting sections to the discussion of zero-inflated models include Cameron and Trivedi (1998), Hardin and Hilbe (2007), or Hilbe (2007).

The concept of zero inflation derives from the observation that in many ecological, economic, and social studies there are far more zeros in count data than what would be expected for a Poisson or negative binomial distribution. As such, zero inflation means that we have far more zeros than we would expect. Ignoring zero inflation when it exists can have two major consequences, namely the estimated parameters and standard errors may be biased and the excessive number of zeros can cause overdispersion (Zuur et al. 2009).

Zeros due to design and observer errors are called false zeros or false negatives while structural and "animal" zeros are known as positive zeros, true zeros, or true negatives (Zuur et al. 2009). To address these different sources of zeros, two distinctive classes of zero-inflated models have been developed, two-part (hurdle) and mixture models, with the difference between the two classes arising due to differences in how they deal with zeros. Two-part models do not discriminate between the four different types of zeros and simply treat a zero as a zero whereas mixture models account for the type of zero.

Mixture models (zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB)) treat zeros via two different processes: the binomial process and the count process (Zuur et al. 2009). A binomial generalized linear model is used to model the probability of measuring a zero while the count process is modeled by a Poisson or negative binomial GLM. As such, the fundamental difference between hurdle and mixture models is that the count process can produce zeros in mixture models but not in hurdle models (Zuur et al. 2009). In such a setup, the zeros resulting from the count process model represent true zeros, while the binomial GLM models the probability of measuring a false zero versus all other types of data (counts and true zeros; Zuur et al. 2009). In short, the probability functions of a ZINB are:

$$f(y_i = 0) = \pi_i + (1 - \pi_i) * \left(\frac{k}{\mu_i + k}\right)^k$$

$$f(Y_i = y_i | y_i > 0) = (1 - \pi_i) * \frac{\Gamma(y_i + k)}{\Gamma(k) * \Gamma(y_i + 1)} * \left(\frac{k}{\mu_i + k}\right)^k * \left(1 - \frac{k}{\mu_i + k}\right)^k$$

for the binomial component and the non-zero component, respectively. In ZINB, the expected mean and variance are slightly different due to the definition of the probability functions. The mean and variance of a ZINB are:

$$\mathrm{E}(Y_i) = \mu_i * (1 - \pi_i)$$

$$\mathrm{var}(Y_i) = (1 - \pi_i) * \left(\mu_i + \frac{\mu_i^2}{k}\right) + \mu_i^2 * \left(\pi_i^2 + \pi_i\right).$$

If the probability of false zeros is 0, the mean and variance of the negative binomial GLM are equal.

In the development of the ZINB CPUE model for Red Snapper, we modeled CPUE as catch per trap, compared to the traditional method of calculating catch per trap per hour. We included soak time as an offset term instead of creating a catch rate by dividing the catch per trap by the soak time or sample duration. By defining this offset variable we adjust for the amount of opportunity for the gear to capture a fish (e.g. a deployment with a soak time of 120 minutes has twice the opportunity than a deployment with a soak time of 60 minutes).

Similar to dGLM, ZINB models can account for effects of different covariates on observed counts. The same or different covariates can be included in the binomial sub-model and catch sub-model. In initial investigations we considered the following covariates in addition to year:

- Depth – continuous variable
- Bottom temperature – continuous variable
- Longitude – continuous variable
- Latitude – continuous variable
- Day of Year (DOY) – continuous variable

Other covariates in the data set that could have been considered included bottom salinity, month, season, dissolved oxygen concentration, chlorophyll-A concentration, nitrite (NO_2) concentration, nitrate (NO_3) concentration, and phosphate (PO_4) concentration. We didn't consider bottom salinity as a potential covariate due to its general lack of variability in oceanic waters and preliminary investigations suggesting there was little relationship between Red Snapper CPUE and bottom salinity. We didn't consider month or season as a covariate as each is correlated to a high degree with our included covariate DOY. Given DOY gives more temporal resolution, the assumption was made that it would provide greater power in standardizing Red Snapper CPUE with regards to within year day of sampling differences. Finally, we didn't consider the last five potential covariates due to missing values on a large number of trap sets data for these variables, primarily due to the lack of equipment to collect these variables historically.

Prior to inclusion of the considered covariates in the full model, we used preliminary analyses to investigate the possibility of collinearity between any of the variables. A pairs plot of continuous covariates revealed high correlation between latitude and longitude (due to the shape of the survey region), and moderate correlation between bottom temperature and depth and bottom temperature and DOY (Figure 4). Variance inflation factor (VIF) estimates for all considered covariates were all <2, though there was some concern regarding the higher VIF for bottom temperature (Table 2). When bottom temperature is excluded, all VIFs fall to <1.2. Given the weak ecological relationships expected between CPUE and the considered covariates, that bottom temperature was moderately correlated with both latitude and depth, and that we are missing bottom temperature data on numerous stations throughout the history of the SERFS due to CTD failure, we removed bottom temperature from consideration as a potential covariate.

Box plots of the remaining covariates (depth, latitude, and DOY) among years showed no obvious strong collinearity (Figure 5). With regards to sampling depth, sampling throughout the entire period appeared fairly homogenous, with the possible exception of 1992. With regards to latitude, it appears there has been a general expansion at two points during the survey, 1996, and 2010 (Figure 1). Most notable is the expansion in 2010, which corresponds to the first sampling season including SEFIS. Since 2010 the median latitude of sampling has shifted south with an overall broader range of sampling.

1999 was slightly anomalous in that the latitude distribution is restricted compared to surrounding years, with it being more similar to the early years of the survey. Finally, for DOY there does seem to be more year to year variability in days sampled. This is to be expected given the nature of the survey and weather constraints. Most notably, sampling appeared to occur earlier than average in 1990 and 1992 and later than average in 1991 and 2010. Also, sampling in 1999 was restricted temporally compared to other years.

Due to the desire to include continuous variables in the zero-inflated standardization model, we used generalized additive models (GAM) to investigate the relationship of continuous covariates with CPUE. We investigated two sets of GAMs, one looking at the relationship of continuous covariates to the presence/absence of Red Snapper and one looking at the relationship of continuous covariates to Red Snapper catch.

For the presence/absence GAMs, each of the covariates had a non-linear effect on the presence of Red Snapper (Figure 6 and Table 3). Probability of presence of Red Snapper peaked at depths of 25-70 m, declining at shallower and deeper depths. The decline in presence at depths between 40 and 55 m may be explained by a lack of stations in this depth zone at latitudes where red snapper are commonly found relative to other depths. Probability of presence shows two distinct peaks at latitudes of 28-30°N and >34.5°N, with a smaller peak around 32°N. In general, latitude has a greater effect on probability of capture than the other covariates. Finally, the relationship between DOY and probability of presence is either flat or parabolic with highest probabilities of presence occurring at the beginning and end of the sampling season. These peaks could be driven by low sample sizes near the beginning and end of the sampling seasons.

For the catch GAMs, each of the covariates had a non-linear effect on the catch of Red Snapper (Figure 7 and Table 3). Highest catches of Red Snapper occurred at the shallowest depths, generally declining as depth increases. Highest catches of Red Snapper showed a trimodal peak compared to latitude, with similar peaks at around 28.5°N, 31°N, and 33°N. Finally, Red Snapper catch compared to DOY was fairly flat, except for a slight peak around 275 days.

Based on these GAM analyses, in addition to year, we included the continuous covariates depth, latitude and DOY as polynomials in the full ZI model to allow for non-linear effects of these covariates on Red Snapper CPUE. To determine the order of the polynomials, we rounded the GAM effective degrees of freedom (Table 3) to the nearest whole number, letting this number represent the highest polynomial order. Prior to model development, these continuous variables were centered and scaled to improve statistical convergence.

Selection of the covariates included in the final model (both zero-inflation and count sub-models) was done based on Bayesian information criterion (BIC; Schwarz 1978). We allowed the possibility that different covariates may appear in each of the sub-models. All analyses were performed in R (Version 3.1.0; R Development Core Team 2014). The zero-inflated models in R were developed using the function zeroinfl available in the package *pscl* (Jackman 2011; Zeileis et al. 2008).

Chevron Trap Length and Age Composition

Red Snapper lengths were measured following retrieval of each chevron trap set to the nearest centimeter prior to 2010 and to the nearest millimeter from 2010 to 2013. Lengths were measured either as fork length or maximum (pinched) total length at the time of capture. Here, we report length in maximum (pinched) total length and any fork lengths were converted to such based on conversions developed by Ballenger et al. (2012b) from over 1,700 fish. All measurements done in mm were rounded to the nearest whole cm prior to analysis. Length percent compositions were calculated for each year using 1-cm length bins centered on the integer. Although the resolution of the majority of the time series and all analyses were done in cm, length compositions are presented in mm to be consistent with other reports, including life history. Following length measurements, sagittal otoliths were removed from all Red Snapper to serve as the aging structure for Red Snapper. Ages presented here are calendar age based on increment counts, estimated increment formation on July 1st, and edge type (White et al. 2010, SEDAR 24-DW14).

Results

Sampling Summary

A data set for analysis was obtained from a query of the SERFS database on July 14, 2014. Given the constraints mentioned above and removing any collections we are missing covariate data (1 station removed because of missing latitude data), from 1990 to 2013 we made 10,664 chevron trap monitoring deployments (Table 1), averaging 444 collections per year (range: 219-1,331), following standard monitoring station sampling protocol. The average depth for these collections was 37 m, with annual averages ranging from 33 to 41 m. The average latitude was 32.10°N, with annual averages ranging from 31.25°N to 32.79°N. The average DOY was 194, with annual averages ranging from 151 to 222 days.

Nominal CPUE

Nominal catch per trap averaged 0.136 for the entire time series, with annual averages ranging from a low of 0.016 in 1996 to a high of 0.367 in 2012 (Table 4 and Figure 8).

Delta-GLM CPUE

Results of the dGLM standardization reported here were initially reported in an annual report of trends in catch of snapper-grouper species (Bubley et al. 2014) and were not updated for this report. These results are presented here purely for comparative purposes, as the authors felt that a newer approach such as the zero-inflated methods would be more appropriate for the Red Snapper data set.

DGLM-standardized CPUE estimates were variable (range: 0.01 – 0.9; Table 4) with no clear directional trend throughout the time series until the last 4 years (Figure 8). Since 2010, the trend was upward, reaching historically high levels in 2013, topping previous series' high levels in 2011 and 2012. The standardization method reduced variability due to sampling differences among years and reduced the extent of recent years' increase in relative abundance compared to the nominal estimates, suggesting that some of the increase in abundance was due to changes in sampling.

Zero-Inflated CPUE

Preliminary model analyses clearly suggested that a zero-inflated negative binomial model (ZINB) was superior to a Poisson GLM, a negative binomial GLM, or zero-inflated Poisson model (ZIP). Both the best-fit Poisson GLM and best-fit negative binomial GLM, with overdispersions of 3.404 and 1.445, respectively, suggested overdispersion remained given these model structures (Table 5). Continued overdispersion despite these model structures suggests the catch data is zero-inflated and likely should be modeled using a zero-inflated model structure. While the overdispersion for the best-fit negative binomial GLM was mild, this model had a hard time converging and was unstable statistically. Comparing the ZIP and ZINB full models, BIC clearly suggested that a negative binomial error structure for the count model was superior to a Poisson error structure (Table 5), likely due to its ability to better account for the dispersion parameter by estimating theta directly in the model.

Step-wise selection using BIC starting with the full model removed a number of covariate polynomials from both the zero-inflation and count sub-models (Table 5). The only constraint on this selection was that the variable "Year" must be retained in the count sub-model of ZINB model. The resulting final model had the following form:

Zero-Inflation Sub-Model

$$\begin{aligned}\mathrm{Abund}^* = {} & \mathit{offset}(\ln(\text{soak time})) + \mathrm{Depth}^2 + \mathrm{Depth}^7 + \mathrm{Latitude} + \mathrm{Latitude}^2 + \mathrm{Latitude}^3 \\ & + \mathrm{Latitude}^4 + \mathrm{Latitude}^6 + \mathrm{Latitude}^8 + \mathrm{DOY} + \mathrm{DOY}^2\end{aligned}$$

Count Sub-Model

$$\begin{aligned}\mathrm{Abund} = {} & \mathit{offset}(\ln(\text{soak time})) + \mathrm{Year} + \mathrm{Depth}^2 + \mathrm{Depth}^3 + \mathrm{Depth}^4 + \mathrm{Depth}^5 + \mathrm{Depth}^6 + \mathrm{Depth}^7 \\ & + \mathrm{Depth}^9 + \mathrm{Latitude}^2 + \mathrm{DOY}^3\end{aligned}$$

where Abund* represents the catch data transformed to presence/absence data and Abund represents the observed catch data.

Standardized annual CPUE estimates normalized to the series average indicates that CPUE was highly variable with little trend through the early 2000s, before declining to series' lows in the mid 2000s (Figure 9). Since approximately 2006, CPUE in the region has been increasing generally (Figure 9). This is similar to the pattern observed for CPUE estimates based upon the dGLM (Figure 8; Bubley et al. 2014).

Plots of annual variance and coefficient of variation (CV) estimates indicate that 10,000 bootstraps were sufficient for these measures to stabilize (Figure 11). Standardization using the ZINB resulted in annual CV estimates of approximately 45%. Individual year CV estimates ranged from a low of 20% to a high of 138% in 2011 and 2003, respectively (Table 4). Though not directly comparable due to different measures of CPUE used and the different criteria used to include collections in the dGLM, it appears that annual CVs estimated using the ZINB are similar to those estimated using the dGLM standardization (Table 4).

A plot of the observed and predicted number of Red Snapper caught suggests that the ZINB was moderately successful at capturing the observed catch pattern (Figure 11). While the ZINB does a fair job predicting the number of traps that had 0 catch, it does a poor job predicting the number of Red Snapper captured given a trap is positive for Red Snapper. In this case it predicts many more traps would catch only a single Red Snapper than observed. Further, it predicts at most only 3 Red Snapper would be caught in any given trap, though we have observed as many as 28 Red Snapper in an individual trap.

Residual diagnostics suggest that there were some outlier observations in the dataset represented by large Pearson residuals (in excess of 30; Figure 12), though overall there is no strong indication of a pattern in the residuals or heteroscedascity when the residuals are plotted against included covariates (Figures 13 and 14). When Pearson residuals are compared to several potential covariates excluded from the final model (Chlorophyll-A concentration, dissolved oxygen concentration, Event (all traps included in a given trap set), longitude, month, salinity, season, and bottom temperature), first glance suggests there is no strong indication of a pattern to the residuals or heteroscedascity, which indicates that no excluded covariates are critical to the model (Figures 15 and 16). The mean Pearson residuals versus dissolved oxygen and bottom temperature show patterns to the residuals that cause some concern (Figure 16). For dissolved oxygen the long string of mainly negative residuals at higher dissolved oxygen concentrations (Figure 16) suggests that Red Snapper catch may be related to dissolved oxygen concentrations. However, we are missing dissolved oxygen measurements from a large number of stations, particularly in earlier years, making the use of this variable as a covariate difficult. For bottom temperature the mean of the residuals indicate a long string of negative residuals at either end (low temperatures (particularly) and high temperatures; Figure 16) that causes some concern. Finally, looking at the spatial distribution of positive and negative Pearson residuals suggests no obvious spatial patterning of the residuals (Figure 17). The one concern may be the group of negative residuals (blue dots) occurring near the northern end of our sampling range north of about 34^{o}N latitude. This lack of spatial structure to the residuals also is supported by the sample variogram, which doesn't show any indication of spatial correlation in trap catches closer than 10 km to each other (Figure 18).

The final ZINB model suggests highly non-linear relationships among Red Snapper catch and included covariates (depth, latitude, and day of year; Figure 19). For depth, as originally suggested, Red Snapper catch peaks at depths between 35 and 40 m, with smaller peaks around 23 and 55 m. For latitude, we see a generally bimodal distribution with catch peaking at around 28-29^{o}N and then again north of approximately 34.5^{o}N. There is a much smaller peak at around 31.5^{o}N. Finally, DOY tends to have little effect on Red Snapper catch until late in the season, after approximately day 250 when Red Snapper catch tends to increase.

Addendum 1

A Zero-Inflated Model of CPUE of Red Snapper in US South Atlantic Waters Based on Fishery-Independent Chevron Trap Surveys

Joseph C. Ballenger, Walter J. Bubley, Tracey I. Smart, and Marcel J. M. Reichert

Marine Resources Research Institute
South Carolina Department of Natural Resources
P.O. Box 12259
Charleston, SC 29412

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Objective

This report presents a summary of the fishery-independent monitoring of gray triggerfish in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS, known collectively as the Southeast Reef Fish Survey (SERFS)). Specifically, it presents annual catch per unit effort (CPUE) of gray triggerfish from chevron traps. Included here are annual CPUE estimates for chevron trap catches standardized by a zero-inflated statistical model for the years 1990-2013. The zero-inflated model accounts for the effects of potential covariates, other than year of capture, on annual CPUE estimates. Data presented in this report are based on the combined SERFS database accessed on July 14, 2012, and include data collected through the 2013 sampling season. The original report above presents a nominal index, a delta-GLM standardized index, and a zero-inflated standardized index based on the same chevron trap catches. The difference between the two zero-inflated indices presented (original in above report and current model reported here) is how the covariates are treated in the model with the former treating the covariates as continuous variables that are modeled using polynomials in the model and the latter treating the covariates as categorical variables.

Methods

Survey Design and Gear

See the original report above for a description of the sample collection methods

Oceanographic Data

See the original report above for details regarding the collection of oceanographic data via a CTD.

Data and Treatment

Data and Nominal CPUE Estimation

Data available for use in CPUE estimation for each trap (deployment) included a unique collection number, date of deployment, soak time, latitude, longitude, bottom depth, catch code, number of Red Snapper captured, aggregate weight of Red Snapper captured, and bottom temperature, among other variables. We used numbers, instead of weight, of Red Snapper for all analyses. Estimates of CPUE, or relative abundance, are given as the number of Red Snapper caught per trap.

Prior to modeling, a subset of the available SERFS trap data was selected for CPUE estimation based on several criteria:

9) Deployments made via SERFS with a project ID of P05 (MARMAP fishery-independent samples), T59 (SEAMAP-SA Reef Fish Complement fishery-independent samples), and T60 (SEFIS fishery-independent samples)
10) Deployments with catch codes of 0 (no catch), 1 (catch with finfish), 2 (catch without finfish), 9 (recon trap deployment), 90 (recon trap deployment with no catch), 91 (recon trap deployment with finfish), and 92 (recon trap deployment without finfish catch)

   a. For development of the dGLM standardized index (i.e. index presented in the 2013 trends report), all 9, 90, 91, and 92 catch codes were removed from analysis

11) Deployments with station codes of “Random” (randomly-selected live-bottom station), “NonRandom” (non-randomly sampled live-bottom station (a.k.a. haphazard sample)), “ReconConv” (reconnaissance deployments that were subsequently converted into live-bottom stations), and “Is Null” (traps for which there is no station code value – the use of station codes is fairly new since 2010. Historically we used only the catch ID to indicate randomly-selected stations)
12) Deployments with Gear ID equal to 324 (chevron traps)
13) Deployments with Data Source not equal to “Tag-MARMAP”
    a. “Tag-MARMAP” represents special historic MARMAP cruises that were used to tag various species of fish. Because standard sampling procedures were not used (e.g. not all fish were measured for length frequency) these samples are excluded from CPUE development
14) Deployments at depths between 15 and 74 m
    a. Represents the depth range at which 100% of Red Snapper were collected by any gear used in the SERFS (Ballenger et al. 2012b)
    b. Given previous constraints, this removes 248 traps deployed at <15 m or >74 m of depth and 2 traps for which we are missing depth data
15) Soak times outside of a window between 45 and 150 minutes, which generally indicates deviations from standard protocols
    a. Note, SERFS targets a soak time of 90 minutes for all chevron trap deployments
    b. Removes an additional 192 traps with unusually long or short soak times
16) Deployments made since 2010
    a. Removes an additional 6754 traps sampled in 1988-2009 – prior to this period sampling was somewhat limited in the heart of Red Snapper habitat off northern Florida and southern Georgia. Only since has the percent positive samples for Red Snapper in chevron traps exceeded 5%.
    b. Exclusion of early years was made via consensus within the SEDAR 41 Index Working Group and during a SEDAR 41 Data Workshop plenary session.

Zero-Inflated Model CPUE Standardization

CPUE was standardized among years using a zero-inflated count model (ZINB). Given the biological knowledge of Red Snapper and the sampling design of the SERFS chevron trap survey, we compared model fits with the ZINB method to those of the nominal CPUE estimation and dGLM method based on conclusions and recommendations drawn during SEDARs 32 and 36. Investigation of this technique to model CPUE data also was suggested during the Fishery-Independent Survey Independent Review for the South Atlantic (SEFSC 2012). As is the case with many ecological count data sets (Zuur et al. 2009), the observed CPUE data appeared to be zero-inflated based on preliminary analyses (Figure 3), suggesting the appropriateness of zero-inflated count data models.

Briefly, we provide some background information regarding zero-inflated count data models. For a more complete discussion, see Chapter 11 in Zuur et al. (2009). Zeileis et al. (2008) provides a nice overview and comparison of Poisson, negative binomial, and zero-inflated models in R. Some textbooks devoting sections to the discussion of zero-inflated models include Cameron and Trivedi (1998), Hardin and Hilbe (2007), or Hilbe (2007).

The concept of zero inflation derives from the observation that in many ecological, economic, and social studies there are far more zeros in count data than what would be expected for a Poisson or negative binomial distribution. As such, zero inflation means that we have far more zeros than we would expect. Ignoring zero inflation when it exists can have two major consequences, namely the estimated parameters and standard errors may be biased and the excessive number of zeros can cause overdispersion (Zuur et al. 2009).

Zeros due to design and observer errors are called false zeros or false negatives while structural and "animal" zeros are known as positive zeros, true zeros, or true negatives (Zuur et al. 2009). To address these different sources of zeros, two distinctive classes of zero-inflated models have been developed, two-part (hurdle) and mixture models, with the difference between the two classes arising due to differences in how they deal with zeros. Two-part models do not discriminate between the four different types of zeros and simply treat a zero as a zero whereas mixture models account for the type of zero.

Mixture models (zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB)) treat zeros via two different processes: the binomial process and the count process (Zuur et al. 2009). A binomial generalized linear model is used to model the probability of measuring a zero while the count process is modeled by a Poisson or negative binomial GLM. As such, the fundamental difference between hurdle and mixture models is that the count process can produce zeros in mixture models but not in hurdle models (Zuur et al. 2009). In such a setup, the zeros resulting from the count process model represent true zeros, while the binomial GLM models the probability of measuring a false zero versus all other types of data (counts and true zeros; Zuur et al. 2009). In short, the probability functions of a ZINB are:

$$f(y_i = 0) = \pi_i + (1 - \pi_i) * \left(\frac{k}{\mu_i + k}\right)^k$$

$$f(Y_i = y_i | y_i > 0) = (1 - \pi_i) * \frac{\Gamma(y_i + k)}{\Gamma(k) * \Gamma(y_i + 1)} * \left(\frac{k}{\mu_i + k}\right)^k * \left(1 - \frac{k}{\mu_i + k}\right)^k$$

for the binomial component and the non-zero component, respectively. In ZINB, the expected mean and variance are slightly different due to the definition of the probability functions. The mean and variance of a ZINB are:

$$\mathrm{E}(Y_i) = \mu_i * (1 - \pi_i)$$

$$\mathrm{var}(Y_i) = (1-\pi_i) * \left(\mu_i + \frac{\mu_i^2}{k}\right) + \mu_i^2 * \left(\pi_i^2 + \pi_i\right).$$

If the probability of false zeros is 0, the mean and variance of the negative binomial GLM are equal.

In the development of the ZINB CPUE model for Red Snapper, we modeled CPUE as catch per trap, compared to the traditional method of calculating catch per trap per hour. We included soak time as an offset term instead of creating a catch rate by dividing the catch per trap by the soak time or sample duration. By defining this offset variable we adjust for the amount of opportunity for the gear to capture a fish (e.g. a deployment with a soak time of 120 minutes has twice the opportunity than a deployment with a soak time of 60 minutes).

Similar to dGLM, ZINB models can account for effects of different covariates on observed counts. The same or different covariates can be included in the binomial sub-model and catch sub-model. In initial investigations we considered the following covariates in addition to year:

- Depth – categorical variable
- Bottom temperature – categorical variable
- Longitude – categorical variable
- Latitude – categorical variable
- Day of Year (DOY) – categorical variable

Other covariates in the data set that could have been considered included bottom salinity, month, season, dissolved oxygen concentration, chlorophyll-A concentration, nitrite (NO_2) concentration, nitrate (NO_3) concentration, and phosphate (PO_4) concentration. We didn't consider bottom salinity as a potential covariate due to its general lack of variability in oceanic waters and preliminary investigations suggesting there was little relationship between Red Snapper CPUE and bottom salinity. We didn't consider month or season as a covariate as each is correlated to a high degree with our included covariate DOY. Given DOY gives more temporal resolution, the assumption was made that it would provide greater power in standardizing Red Snapper CPUE with regards to within year day of sampling differences. Finally, we didn't consider the last five potential covariates due to missing values on a large number of trap sets data for these variables, primarily due to the lack of equipment to collect these variables historically.

Prior to inclusion of the considered covariates in the full model, we used preliminary analyses to investigate the possibility of collinearity between any of the variables. A pairs plot of continuous covariates revealed high correlation between latitude and longitude (due to the shape of the survey region), and moderate correlation between bottom temperature and depth and bottom temperature and DOY (Figure 4). Variance inflation factor (VIF) estimates for all considered covariates were all <2 (Table 2).

Box plots of the covariates (depth, latitude, bottom temperature, and DOY) among years showed no obvious strong collinearity (Figure 20). With regards to sampling depth, sampling throughout the entire period appeared fairly homogenous. With regards to latitude, it appears that the sampling distribution has been fairly homogenous, though there is a slight indication of more northern sampling in 2012. For bottom temperature, sampling throughout the entire period appeared fairly homogenous. Finally, for DOY while the overall range of DOY sampled annually was similar, there is some indication that the median DOY sampled in 2010 was later than in the other three years.

Due to the desire to inform the binning structure of covariates in the zero-inflated standardization model, we used generalized additive models (GAM) to investigate the relationship of each covariate with CPUE. We investigated two sets of GAMs, one looking at the relationship of continuous covariates to the presence/absence of Red Snapper and one looking at the relationship of continuous covariates to Red Snapper catch.

For the presence/absence GAMs, all covariates except bottom temperature had a non-linear effect on the presence of Red Snapper (Figure 20 and Table 8). Probability of presence of Red Snapper peaked at depths of 25-70 m, declining at shallower and deeper depths. The decline in presence at depths between 40 and 55 m may be explained by a lack of stations in this depth zone at latitudes where red snapper are commonly found relative to other depths. Probability of presence shows two distinct peaks at latitudes of 28-30^{o}N and >34.5^{o}N, with a smaller peak around 32^{o}N. In general, latitude has a greater effect on probability of capture than the other covariates. Probability of presence shows no discernible trend with respect to bottom temperature. Finally, the relationship between DOY and probability of presence is either flat or parabolic with highest probabilities of presence occurring at the beginning and end of the sampling season. These peaks could be driven by low sample sizes near the beginning and end of the sampling seasons.

For the catch GAMs, each of the covariates had a non-linear effect on the catch of Red Snapper (Figure 21 and Table 8). Catch of red snapper shows three distinct peaks at depths of 20-25 m, 35-40 m, and 50-60 m, though some of this high frequency variability is likely driven by station distribution. There is a marked decrease in the catch of red snapper at depths shallower than 20 m and deeper than 60 m. Highest catches of Red Snapper occurred at the shallowest depths, generally declining as depth increases. Catches of Red Snapper clearly peaked at around 29^{o}N, with smaller peaks occurring at 32^{o}N and >34^{o}N. With regards to bottom temperature, catch of Red Snapper generally increased as temperature increased through approximately 27^{o}C. At higher temperatures, catch of Red Snapper appeared to rapidly decline though sample size at these high temperatures is small. Finally, Red Snapper catch compared to DOY showed the same trend as the presence/absence data, with highest catches occurring at the beginning and end of the sampling seasons.

Based on these GAM analyses, in addition to year, we decided to include the categorical covariates depth, latitude, bottom temperature and DOY in the full ZI model (Table 8). To inform the bin structure, we used the GAM analyses relating catch of Red Snapper to each covariate (Figures 21 and 22) to identify periods or relatively homogenous catch of Red Snapper with respect to the covariate. This resulted in 4, 5, 3, and 4 bins for the covariates depth, latitude, bottom temperature, and DOY, respectively (Table 8). Members of the SEDAR 41 Index Working Group provided guidance on the number of bins and potential bin break points during the SEDAR 41 data workshop.

Selection of the covariates included in the final model (both zero-inflation and count sub-models) was done based on Akaike's information criterion (AIC; Akaike 1973). We allowed the possibility that different covariates may appear in each of the sub-models. All analyses were performed in R (Version 3.1.0; R Development Core Team 2014). The zero-inflated models in R were developed using the function zeroinfl available in the package *pscl* (Jackman 2011; Zeileis et al. 2008).

Results

Sampling Summary

A data set for analysis was obtained from a query of the SERFS database on July 14, 2014. Given the constraints mentioned above and removing any collections we are missing covariate data (410 stations removed because of missing bottom temperature data), from 2010 to 2013 we made 3,679 chevron trap monitoring deployments (Table 9), averaging 920 collections per year (range: 610-1,304), following standard monitoring station sampling protocol. The average depth for these collections was 38 m, with annual averages ranging from 37 to 40 m. The average latitude was 31.39°N, with annual averages ranging from 30.84°N to 31.80°N. The average bottom temperature was 21.9^{o}C, with annual averages ranging from 21.1 to 22.2^{o}C. The average DOY was 200, with annual averages ranging from 194 to 222 days. Please note that due to missing bottom temperature data and the desire of SEDAR 41 index working group panelists to include bottom temperature as a covariate, we removed greater than 10% of available collections for the years 2010 and 2011 (Table 10).

Zero-Inflated CPUE

Step-wise forward selection using AIC add the covariates depth, latitude, and bottom temperature to both the zero-inflation and count sub-models (Table 11). In addition, the covariate year was added to the zero-inflation sub-model. The covariate DOY was not added to either sub-model. The only constraint on this selection was that the variable "Year" must be retained in the count sub-model of ZINB model. The resulting final model had the following form:

Zero-Inflation and Count Sub-Model

$$\text{Abund} = offset(\ln(\text{soak time})) + \text{Year} + \text{Depth} + \text{Latitude} + \text{Temperature}$$

where Abund represents the catch data transformed to presence/absence data in the zero-inflation model and the observed catch data in the count model.

Standardized annual CPUE estimates normalized to the series average indicates that CPUE was below average in 2010 and 2011 and above average in 2012 and 2013 (Figure 23).

In the bootstrap to estimate variability in the annual relative abundance index we observed a convergence rate of 57.6%, resulting in 2880 individual bootstraps being used in variability estimation. For each of these bootstraps we calculated an observed relative index based on the bootstrap sampling (Figure 24), with those giving the same overall pattern of relative abundance observed in the base model. Plots of annual variance and coefficient of variation (CV) estimates indicate that 2,880 bootstraps were sufficient for these measures to stabilize (Figure 25). Standardization using the ZINB resulted in annual CV estimates of approximately 18%. Individual year CV estimates ranged from a low of 11% to a high of 23% in 2012 and 2010, respectively (Table 12).

A plot of the observed and predicted number of Red Snapper caught suggests that the ZINB was moderately successful at capturing the observed catch pattern (Figure 26). While the ZINB does a fair job predicting the number of traps that had 0 catch, it does a poor job predicting the number of Red Snapper captured given a trap is positive for Red Snapper. In this case it predicts many more traps would catch only a single Red Snapper than observed. Further, it predicts at most only 3 Red Snapper would be caught in any given trap, though we have observed as many as 28 Red Snapper in an individual trap.

Residual diagnostics suggest that there were some outlier observations in the dataset represented by large Pearson residuals (in excess of 20; Figure 27), though overall there is no strong indication of a pattern in the residuals or heteroscedascity when the residuals are plotted against included covariates (Figures 28 and 29). When Pearson residuals are compared to several potential covariates excluded from the final model (Chlorophyll-A concentration, dissolved oxygen concentration, Event (all traps included in a given trap set), longitude, month, salinity, season, and bottom temperature), first glance suggests there is no strong indication of a pattern to the residuals or heteroscedascity, which indicates that no excluded covariates are critical to the model (Figures 30 and 31). Finally, looking at the spatial distribution of positive and negative Pearson residuals suggests no obvious spatial patterning of the residuals (Figure 32). This lack of spatial structure to the residuals also is supported by the sample variogram, which doesn't show any indication of spatial correlation in trap catches closer than 10 km to each other (Figure 33).

The final ZINB model suggests non-linear relationships among Red Snapper catch and depth and latitude, a linear relationship between Red Snapper catch and bottom temperature, and no effect of DOY on Red Snapper catch (Figure 34). For depth, as originally suggested, Red Snapper catch peaks in bin 2, which corresponds to depths between at depths between 30 and 44 m. For latitude, we see a generally bimodal distribution with catch peaking in bins 2 (28-29.99^{o}N) and 5 (>=34^{o}N). For bottom temperature, the catch of Red Snapper increases as bottom temperature increases. Finally, because DOY is excluded from the final ZINB model, there is no predicted effect of DOY on the catch of Red Snapper.

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Tables

Table 1: Number of chevron trap deployments on live/hard-bottom areas and information associated with chevron trap deployments included in nominal and standardized catch per unit effort (CPUE) calculations for Red Snapper.

		Depth (m)				Latitude (°N)				Day of Year			
			Range				Range				Range		
Year	**Collections**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**
1990	345	33	17	62	0.55	32.55	30.42	33.86	0.0347	151	114	222	1.51
1991	296	34	17	57	0.63	32.62	30.42	34.61	0.0481	216	163	268	2.02
1992	315	34	17	62	0.57	32.79	30.42	34.32	0.0393	155	92	227	2.47
1993	406	35	16	60	0.61	32.39	30.43	34.32	0.0387	176	131	226	1.46
1994	429	36	16	64	0.61	32.27	30.74	33.82	0.0310	185	130	300	2.35
1995	386	33	16	60	0.70	32.09	29.94	33.75	0.0406	203	124	299	2.73
1996	375	38	15	74	0.65	32.23	27.92	34.33	0.0600	190	121	261	2.25
1997	420	38	15	74	0.65	31.98	27.87	34.59	0.0757	196	126	273	1.51
1998	463	41	15	74	0.70	32.04	27.44	34.59	0.0687	182	126	231	1.78
1999	236	36	15	71	0.83	31.94	27.27	34.59	0.1188	199	153	272	1.82
2000	295	36	15	73	0.71	32.37	28.95	34.28	0.0652	196	138	294	2.40
2001	255	37	15	67	0.82	32.32	27.87	34.28	0.0693	206	144	298	2.27
2002	238	37	15	70	0.84	31.87	27.86	33.95	0.0874	207	169	268	1.94
2003	219	38	16	62	0.79	32.07	27.43	34.33	0.1113	202	155	266	2.15
2004	280	39	15	74	0.88	32.27	29.00	33.97	0.0636	177	127	303	2.16
2005	303	38	15	69	0.74	32.08	27.33	34.32	0.0842	191	124	273	2.84
2006	292	37	15	69	0.76	32.30	27.27	34.39	0.0874	203	158	272	1.97
2007	330	37	15	73	0.75	32.18	27.33	34.33	0.0795	200	142	268	2.08
2008	297	37	15	70	0.70	32.16	27.27	34.59	0.0858	193	127	274	2.57
2009	395	35	15	70	0.68	32.23	27.27	34.60	0.0824	202	127	282	2.41
2010	760	38	15	71	0.49	31.37	27.34	34.59	0.0596	222	125	301	1.95
2011	849	38	15	73	0.46	31.25	27.23	34.54	0.0645	202	124	299	1.63
2012	1149	39	15	74	0.41	31.84	27.23	35.02	0.0629	191	116	285	1.35
2013	1331	37	15	73	0.35	31.26	27.23	35.01	0.0544	197	115	278	1.27

Table 2. Variance inflation factor (VIF) estimates and degrees of freedom (df) for all considered covariates.

	Including Temp.		Excluding Temp.	
Variable	**VIF**	**df**	**VIF**	**df**
Year	1.470	23	1.234	23
Depth	1.295	1	1.048	1
Bottom Temperature	1.920	1		
Latitude	1.220	1	1.106	1
Day of Year	1.467	1	1.126	1

Table 3. Generalized Additive Model (GAM) results and full model polynomial order for the zero inflation sub-model (ZI) and count sub-model (Count) for the zero-inflated index model. EDF = effective degrees of freedom of smoothed spline.

	Presence/Absence GAM		Catch GAM					
			Including 0 Catches		Excluding 0 Catches		Polynomials	
Variable	**EDF**	**p-value**	**EDF**	**p-value**	**EDF**	**p-value**	**ZI**	**Count**
Depth	8.7	<0.0001	8.62	<0.0001	8.42	<0.0001	9	9
Latitude	8.33	<0.0001	8.89	<0.0001	8.21	<0.0001	8	9
Day of Year	2.76	0.0001	8.12	<0.0001	7.87	<0.0001	3	8

Table 4. Red Snapper nominal catch per unit effort (CPUE), delta-GLM (dGLM) standardized CPUE*, and zero-inflated negative binomial (ZINB) standardized CPUE for chevron traps. N = number of included traps, positive = proportion of included collections positive for Red Snapper, fish = number of individuals captured, CV = coefficient of variation, and normalized = annual index value normalized to its long-term mean to give relative abundance over time. *From Bubley et al. (2014) – note the number of stations used annually (and thus # positive and % positive) for this model is different due to the exclusion of all "ReconConv" stations from this analysis and earlier database access date.

				Nominal			dGLM Standardized*			ZINB Standardized		
Year	**n**	**Positive**	**% Positive**	**CPUE**	**CV**	**Normalized**	**CPUE**	**CV**	**Normalized**	**CPUE**	**CV**	**Normalized**
1990	345	8	2.32	0.070	0.61	0.78	0.037	0.50	0.82	0.180	0.58	0.74
1991	296	6	2.03	0.057	0.55	0.64	0.062	0.52	1.4	0.288	0.39	1.19
1992	315	9	2.86	0.067	0.40	0.75	0.064	0.44	1.45	0.294	0.49	1.21
1993	406	12	2.96	0.076	0.38	0.85	0.06	0.37	1.36	0.481	0.32	1.98
1994	429	19	4.43	0.105	0.43	1.17	0.053	0.31	1.19	0.340	0.32	1.40
1995	386	7	1.81	0.034	0.43	0.38	0.027	0.44	0.6	0.168	0.44	0.69
1996	375	6	1.60	0.016	0.41	0.18	0.01	0.48	0.23	0.048	0.40	0.20
1997	420	6	1.43	0.057	0.58	0.64	0.021	0.57	0.46	0.145	0.67	0.60
1998	463	8	1.73	0.054	0.57	0.60	0.025	0.47	0.56	0.163	0.49	0.67
1999	236	4	1.69	0.093	0.57	1.04	–	–	–	0.496	0.54	2.04
2000	295	8	2.71	0.058	0.41	0.64	0.045	0.42	1.02	0.253	0.33	1.04
2001	255	7	2.75	0.035	0.40	0.39	0.047	0.42	1.06	0.245	0.40	1.01
2002	238	13	5.46	0.139	0.35	1.55	0.071	0.40	1.6	0.571	0.45	2.35
2003	219	1	0.46	0.032	1.00	0.36	–	–	–	0.114	1.38	0.47
2004	280	4	1.43	0.018	0.53	0.20	0.02	0.61	0.46	0.103	0.52	0.43
2005	303	7	2.31	0.040	0.44	0.44	0.031	0.43	0.7	0.108	0.43	0.45
2006	292	4	1.37	0.017	0.53	0.19	0.014	0.53	0.32	0.073	0.39	0.30
2007	330	8	2.42	0.088	0.70	0.98	0.041	0.48	0.93	0.288	0.54	1.19
2008	297	7	2.36	0.064	0.53	0.72	0.043	0.46	0.97	0.18	0.43	0.77
2009	395	8	2.03	0.025	0.37	0.28	0.021	0.38	0.48	0.097	0.33	0.40
2010	760	69	9.08	0.216	0.18	2.41	0.049	0.31	1.11	0.246	0.22	1.01
2011	849	69	8.13	0.141	0.14	1.58	0.072	0.21	1.63	0.231	0.20	0.95
2012	1149	150	13.05	0.366	0.14	4.10	0.073	0.18	1.65	0.426	0.23	1.76
2013	1331	142	10.67	0.277	0.14	3.10	0.088	0.19	2.00	0.278	0.23	1.14

Table 5. Results of Bayesian information criterion (BIC) selection, including some best-fit preliminary models (RSPoissonSel, RSNBSel, RSZIPAll,RSZINBVisual) based on different model structures from the initial full model mentioned in the report.

Step	Model	Variable	Sub-Model	BIC	Difference
	RSPoissonSel			8824.0	-3055.93
	RSNBSel			5905.0	-136.93
	RSZIPAll			6704.1	-936.04
	RSZINBVisual			6012.8	-244.76
1	ZINB1ab	-Year	Zero Inflation	5951.1	-183.06
2	ZINb2i	-Depth^8	Count	5941.8	-173.78
3	ZINB3z	-DOY^7	Count	5932.6	-164.51
4	ZINB4ak	-Depth^9	Zero Inflation	5923.3	-155.25
5	ZINB5m	-Latitude^3	Count	5914.1	-146.07
6	ZINB6d	-Depth^3	Count	5905.1	-137.00
7	ZINB7r	-Latitude^8	Count	5896.4	-128.36
8	ZINB8p	-Latitude^6	Count	5887.3	-119.28
9	ZINB9av	-DOY^3	Zero Inflation	5878.9	-110.81
10	ZINB10aj	-Depth^8	Zero Inflation	5871.3	-103.25
11	ZINB11s	-Latitude^9	Count	5863.8	-95.77
12	ZINB12k	-Latitude	Count	5856.9	-88.81
13	ZINB13aa	-DOY^8	Count	5850.1	-82.07
14	ZINB14u	-DOY^2	Count	5842.6	-74.57
15	ZINB15y	-DOY^6	Count	5834.6	-66.53
16	ZINB16ag	-Depth^5	Zero Inflation	5828.3	-60.24
17	ZINB17ae	-Depth^3	Zero Inflation	5820.0	-51.89
18	ZINB18w	-DOY^4	Count	5814.5	-46.44
19	ZINB19q	-Latitude^7	Count	5808.5	-40.46
20	ZINB20o	-Latitude^5	Count	5802.0	-33.94
21	ZINB21n	-Latitude^4	Count	5801.8	-33.73
22	ZINB22ac	-Depth	Zero Inflation	5794.9	-26.84
23	ZINB23af	-Depth^4	Zero Inflation	5794.0	-25.97
24	ZINB24ah	-Depth^6	Zero Inflation	5785.3	-17.28

25	ZINB25ap	-Latitude^5	Zero Inflation	5785.2	-17.18
26	ZINB26ar	-Latitude^7	Zero Inflation	5777.1	-9.03
27	ZINB27b	-Depth	Count	5775.7	-7.63
28	ZINB28bb	+Depth^3	Count	5773.9	-5.83
29	ZINB29t	-DOY	Count	5773.9	-5.86
30	ZINB30x	-DOY^5	Count	5768.1	0.00

Table 6. Length composition of Red Snapper collected by chevron trap during the Southeast Reef Fish Survey from 1990 to 2013. Lengths are maximum (pinched) total length in mm (measured or rounded to the nearest 1-cm bin) and composition is in percent of fish in each 1-cm bin of the total for each year.

Length (mm)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
190	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
220	0.0	5.9	0.0	3.2	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	14.3	0.0	0.0	16.7	0.0	3.4	0.0	0.0	0.8	0.5	0.3
230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
240	0.0	11.8	0.0	0.0	2.2	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.6	0.8	0.7	0.8
250	0.0	23.5	0.0	0.0	0.0	0.0	0.0	7.7	0.0	4.5	0.0	0.0	7.5	14.3	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.8	1.4	1.6
260	0.0	5.9	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	2.5	14.3	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	3.7	0.8
270	0.0	5.9	0.0	0.0	0.0	0.0	20.0	11.5	0.0	4.5	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.8
280	0.0	5.9	0.0	0.0	0.0	0.0	10.0	15.4	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	2.6	1.3
290	0.0	29.4	4.8	0.0	0.0	0.0	0.0	3.8	0.0	9.1	0.0	0.0	5.0	14.3	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.8	2.3	1.6
300	0.0	0.0	14.3	3.2	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	3.4	9.1	0.0	0.8	1.4	1.9
310	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.6	0.0	0.7	1.6
320	0.0	5.9	0.0	0.0	0.0	0.0	0.0	3.8	0.0	22.7	0.0	0.0	5.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.8	1.4	2.1
330	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	8.0	9.1	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	3.5
340	0.0	5.9	0.0	0.0	0.0	0.0	0.0	3.8	4.0	4.5	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	1.2	0.0	0.9	4.0
350	8.3	0.0	9.5	0.0	2.2	0.0	0.0	0.0	8.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	0.0	0.0	0.0	1.9	5.3
360	0.0	0.0	9.5	3.2	6.7	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	6.9	0.0	0.6	0.8	3.3	4.3
370	12.5	0.0	4.8	0.0	0.0	0.0	0.0	7.7	4.0	13.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	0.0	0.0	1.2	0.0	3.5	3.5
380	0.0	0.0	0.0	0.0	4.4	0.0	0.0	3.8	8.0	4.5	0.0	11.1	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	2.4
390	8.3	0.0	4.8	0.0	4.4	0.0	0.0	3.8	4.0	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	17.2	9.1	0.0	0.0	4.7	1.3
400	20.8	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	11.8	0.0	0.0	0.0	0.0	0.0	0.0	19.4	0.0	0.0	0.6	0.0	4.4	1.9
410	12.5	0.0	4.8	0.0	4.4	0.0	0.0	0.0	8.0	4.5	5.9	11.1	5.0	0.0	0.0	8.3	0.0	22.6	6.9	0.0	2.9	0.8	3.3	4.0
420	20.8	0.0	0.0	0.0	0.0	0.0	0.0	3.8	12.0	0.0	5.9	11.1	2.5	0.0	0.0	0.0	0.0	9.7	0.0	0.0	1.7	0.0	1.9	1.9
430	4.2	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	11.8	22.2	7.5	0.0	16.7	0.0	0.0	6.5	10.3	0.0	6.4	0.0	2.1	1.6
440	0.0	0.0	0.0	6.5	2.2	7.7	10.0	0.0	0.0	0.0	17.6	11.1	2.5	0.0	0.0	0.0	0.0	3.2	0.0	0.0	5.2	1.7	3.0	0.8
450	0.0	0.0	0.0	3.2	0.0	7.7	0.0	3.8	0.0	0.0	17.6	0.0	0.0	0.0	0.0	0.0	0.0	3.2	10.3	0.0	4.6	4.1	1.6	2.1

460	0.0	0.0	0.0	6.5	2.2	0.0	0.0	0.0	0.0	0.0	5.9	11.1	5.0	0.0	0.0	0.0	0.0	3.2	0.0	9.1	5.8	0.0	0.9	1.6
470	4.2	0.0	0.0	9.7	4.4	0.0	10.0	0.0	0.0	0.0	5.9	0.0	2.5	0.0	0.0	8.3	0.0	0.0	0.0	0.0	2.3	4.1	1.2	1.6
480	0.0	0.0	4.8	6.5	0.0	7.7	0.0	0.0	4.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	3.2	6.9	0.0	3.5	2.5	0.7	2.1
490	4.2	0.0	0.0	19.4	4.4	15.4	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	4.1	0.2	2.1
500	4.2	0.0	4.8	12.9	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	8.3	0.0	0.0	3.4	27.3	6.4	3.3	0.5	1.6
510	0.0	0.0	0.0	3.2	4.4	0.0	0.0	0.0	4.0	0.0	0.0	0.0	2.5	0.0	0.0	8.3	16.7	0.0	10.3	0.0	6.4	1.7	0.2	2.1
520	0.0	0.0	0.0	3.2	2.2	7.7	0.0	0.0	4.0	0.0	0.0	0.0	5.0	0.0	0.0	16.7	0.0	0.0	0.0	9.1	6.4	4.1	0.0	0.8
530	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	4.0	0.0	5.9	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
540	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	4.0	0.0	0.0	11.1	7.5	0.0	0.0	0.0	0.0	0.0	3.4	0.0	5.2	6.6	0.2	0.5
550	0.0	0.0	4.8	3.2	4.4	7.7	0.0	0.0	4.0	0.0	0.0	0.0	5.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	1.7	4.1	0.7	1.3
560	0.0	0.0	4.8	3.2	2.2	7.7	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0	16.7	0.0	0.0	0.0	3.4	0.0	2.9	3.3	0.7	0.3
570	0.0	0.0	0.0	6.5	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	6.6	0.5	0.3
580	0.0	0.0	0.0	3.2	6.7	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	5.8	0.0	0.5
590	0.0	0.0	14.3	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	2.9	2.5	0.9	0.5
600	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	2.3	5.8	0.5	0.3
610	0.0	0.0	0.0	0.0	4.4	7.7	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	4.1	1.6	1.1
620	0.0	0.0	9.5	0.0	6.7	23.1	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	2.5	2.3	0.8
630	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.4	0.5
640	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	2.5	2.1	1.9
650	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	1.7	2.5	1.6	0.3
660	0.0	0.0	0.0	0.0	2.2	7.7	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.7	1.4	0.3
670	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	2.5	1.4	0.0
680	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.7	0.3
690	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	1.6
700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	9.1	1.2	3.3	3.5	0.5
710	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	18.2	0.6	0.8	1.9	2.4
720	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.8	1.2	1.1
730	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	1.2	0.8	2.8	2.7
740	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.5	1.3
750	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	8.3	0.0	0.0	0.0	0.0	0.6	0.8	1.4	1.9
760	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.8	1.9	3.2
770	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.9	2.7

780	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	1.9	1.3
790	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.7	2.1
800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.6
810	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.9	0.5
820	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.7	1.9
830	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.3
840	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
850	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
860	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.7	0.8
870	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8
880	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.8
890	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
900	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
910	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.3
920	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
980	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Fish	24	17	21	31	45	13	10	26	25	22	17	9	40	7	6	12	6	31	29	11	173	121	430	376
Traps	8	6	9	12	19	7	8	7	8	4	8	7	16	1	5	7	5	9	11	9	74	70	155	143

Table 7. Age composition of Red Snapper collected by chevron trap during the Southeast Reef Fish Survey from 1990 to 2013. Ages are calendar age and composition is in percent of fish in each 1-year bin of the total for each year.

Age	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	57.9	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.1	0.0	0.0	66.7	0.0	3.4	0.0	0.6	2.5	3.8	17.7
2	16.7	26.3	10.0	6.9	4.8	0.0	20.0	16.7	36.0	31.6	20.0	42.9	34.2	42.9	40.0	0.0	0.0	96.6	41.4	18.2	6.6	2.5	32.2	23.6
3	41.7	15.8	55.0	20.7	21.4	3.6	10.0	50.0	44.0	36.8	53.3	57.1	52.6	0.0	20.0	33.3	16.7	3.4	51.7	36.4	53.3	8.3	21.4	20.4
4	37.5	0.0	20.0	44.8	42.9	39.3	30.0	20.8	8.0	31.6	20.0	0.0	10.5	0.0	20.0	33.3	16.7	0.0	3.4	36.4	24.6	60.8	3.8	7.1
5	4.2	0.0	5.0	17.2	23.8	28.6	20.0	12.5	4.0	0.0	6.7	0.0	2.6	0.0	20.0	8.3	0.0	0.0	0.0	0.0	12.0	15.8	21.9	6.3
6	0.0	0.0	10.0	3.4	4.8	28.6	20.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	1.2	7.5	8.2	8.4
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.8	4.3	9.5
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	0.0	0.0	1.0	3.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.5	0.5
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.2	0.3
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
12	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.8
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.2	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Fish	24	19	20	29	42	28	10	24	25	19	15	7	38	7	5	12	6	29	29	11	167	120	416	368
Traps	8	8	9	12	19	14	8	6	8	4	8	6	15	1	4	7	5	8	11	9	73	70	148	139

Addendum Tables

Table 8. Generalized Additive Model (GAM) results and full model polynomial order for the zero inflation sub-model (ZI) and count sub-model (Count) for the zero-inflated index model. EDF = effective degrees of freedom of smoothed spline.

	Presence/Absence GAM		Catch GAM		Bins				
Variable	**EDF**	**p-value**	**EDF**	**p-value**	**1**	**2**	**3**	**4**	**5**
Depth (m)	8.60	<0.0001	8.30	<0.0001	<30	30-44	45-59	>=60	
Latitude (°N)	8.76	<0.0001	8.98	<0.0001	<28	28-29.99	30-32.49	32.5-33.99	>=34
Bottom Temperature (°C)	2.46	0.2800	8.79	<0.0001	<15	15-26.99	>=27		
Day of Year	6.92	0.0025	8.51	<0.0001	<150	150-199	200-249	>=250	

Table 9: Number of chevron trap deployments on live/hard-bottom areas and information associated with chevron trap deployments included in standardized catch per unit effort (CPUE) calculations for Red Snapper.

		Depth (m)				Latitude (°N)				Bottom Temperature (°C)				Day of Year			
			Range				Range				Range				Range		
Year	**Collections**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**
2010	610	39	15	71	0.54	31.61	27.34	34.59	0.0675	21.1	12.3	29.4	0.155	210	125	301	2.07
2011	671	40	15	73	0.53	30.84	27.23	34.54	0.0708	21.7	14.8	28.8	0.149	209	140	299	1.74
2012	1094	39	15	74	0.42	31.80	27.23	35.02	0.0654	22.2	12.9	27.8	0.104	194	116	285	1.35
2013	1304	37	15	73	0.36	31.23	27.23	35.01	0.0550	22.1	12.4	28.1	0.085	197	115	278	1.28

Table 10. Annual and total exclusion of chevron trap monitoring station collections from ZINB analysis due to missing bottom temperature data. Excluding and including refers to excluding bottom temperature as a covariate during model construction or including bottom temperature as a covariate during model construction, respectively.

	Sample Size		
Year	**Excluding Temperature**	**Including Temperature**	**% Change**
2010	760	610	19.74%
2011	849	671	20.97%
2012	1149	1094	4.79%
2013	1331	1304	2.03%
Total	**4089**	**3679**	**10.03%**

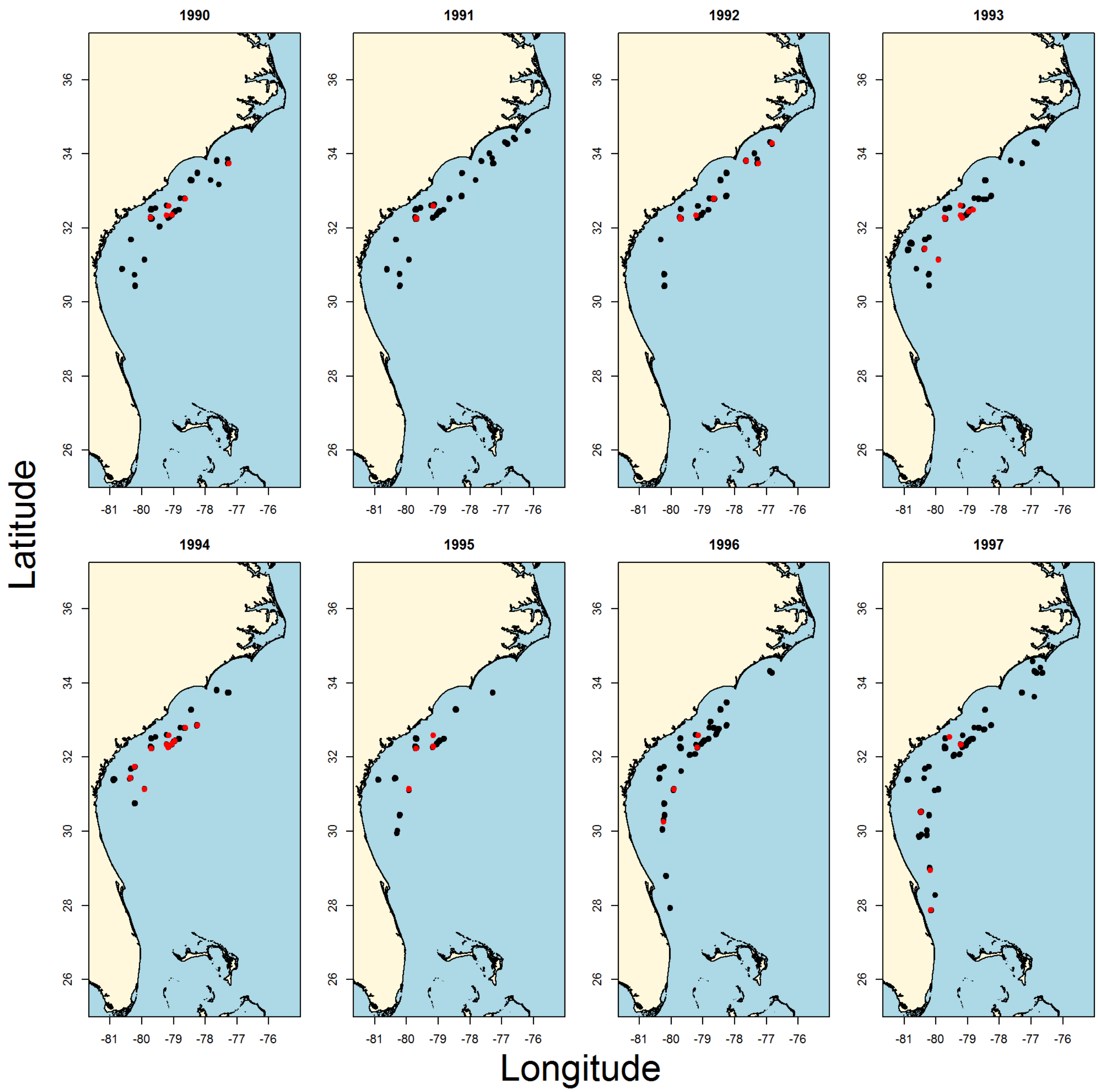
Table 11. Results of AIC selection using forward selection.

Step	Model	Variable	Sub-Model	AIC	Difference
	RSZINB			3707	-337.355
1	ZINB1ZIAdd3	+Latitude	Zero-inflation	3453	-83.544
2	ZINB2ZIAdd2	+Depth	Zero-inflation	3425	-55.439
3	ZINB3CountAdd2	+Latitude	Count	3400	-30.405
4	ZINB4CountAdd2	+Temperature	Count	3393	-23.704
5	ZINB5CountAdd1	+Depth	Count	3378	-9.096
6	ZINB6ZIAdd2	+Temperature	Zero-inflation	3374	-4.534
7	ZINB7ZIAdd1	+Year	Zero-inflation	3369	0.000

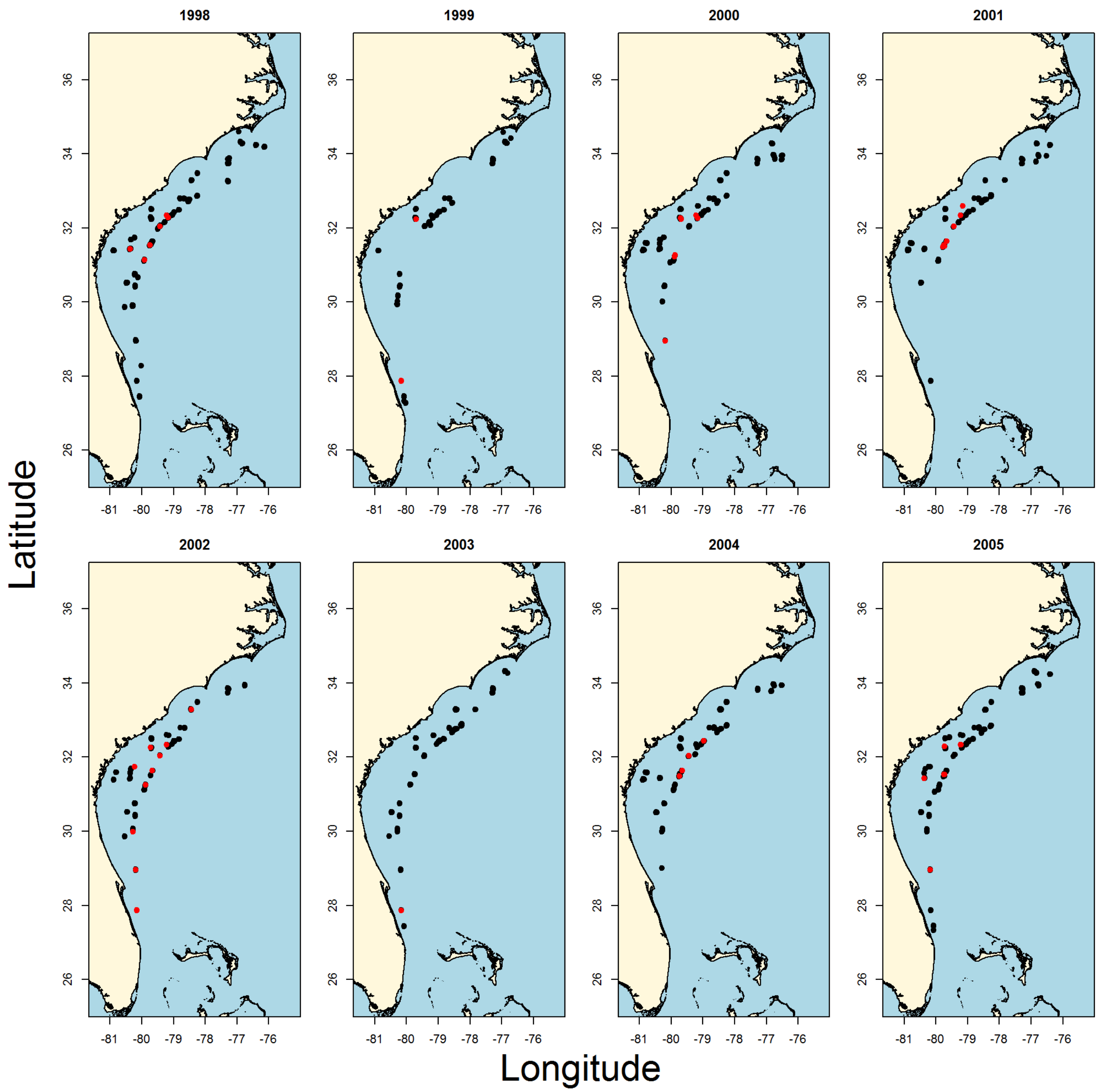
Table 12. Red Snapper nominal catch per unit effort (CPUE) and zero-inflated negative binomial (ZINB) standardized CPUE for chevron traps. N = number of included traps, positive = proportion of included collections positive for Red Snapper, CV = coefficient of variation, and normalized = annual index value normalized to its long-term mean to give relative abundance over time.

		Nominal			ZINB Standardized		
Year	**n**	**CPUE**	**CV**	**Normalized**	**CPUE**	**CV**	**Normalized**
2010	610	0.166	0.24	0.673	0.193	0.23	0.707
2011	671	0.173	0.15	0.703	0.147	0.27	0.536
2012	1094	0.364	0.15	1.479	0.449	0.11	1.642
2013	1304	0.281	0.14	1.144	0.305	0.12	1.115

Figures



1990
1991
1992
1993
1994
1995
1996
1997
Latitude
Longitude


1998
1999
2000
2001
2002
2003
2004
2005
Latitude
Longitude
36
34
32
30
28
26
-81
-80
-79
-78
-77
-76

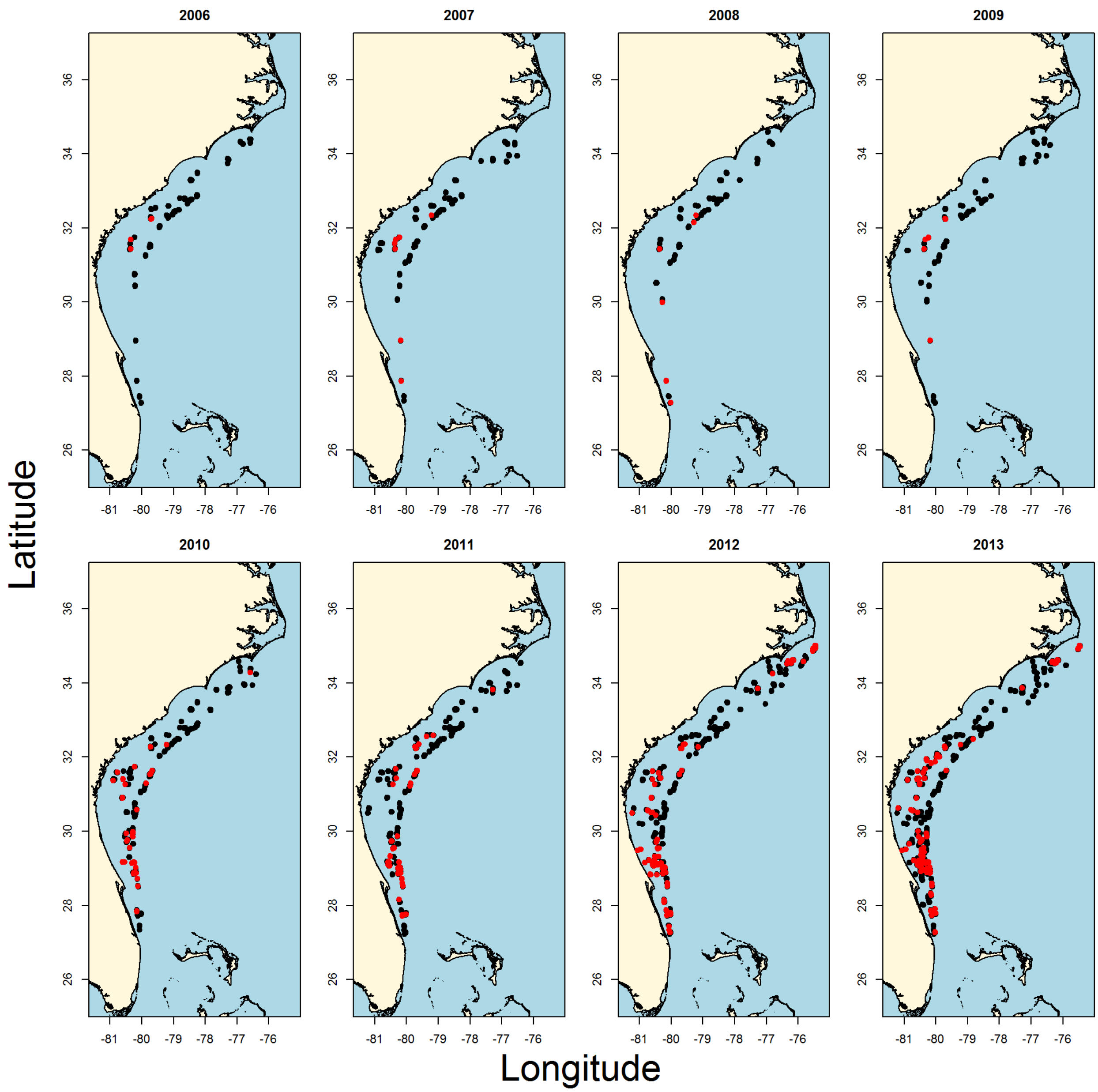


Figure 1: Progression of the spatial coverage of monitoring chevron trap deployments by the Southeast Reef Fish Survey since the initial year using chevron traps to monitor fish on live/hard bottom. Red indicates stations at which Red Snapper were collected in a given year. Note that each symbol may represent multiple sampling events. CTDs were deployed with each trap set, but not pictured here.

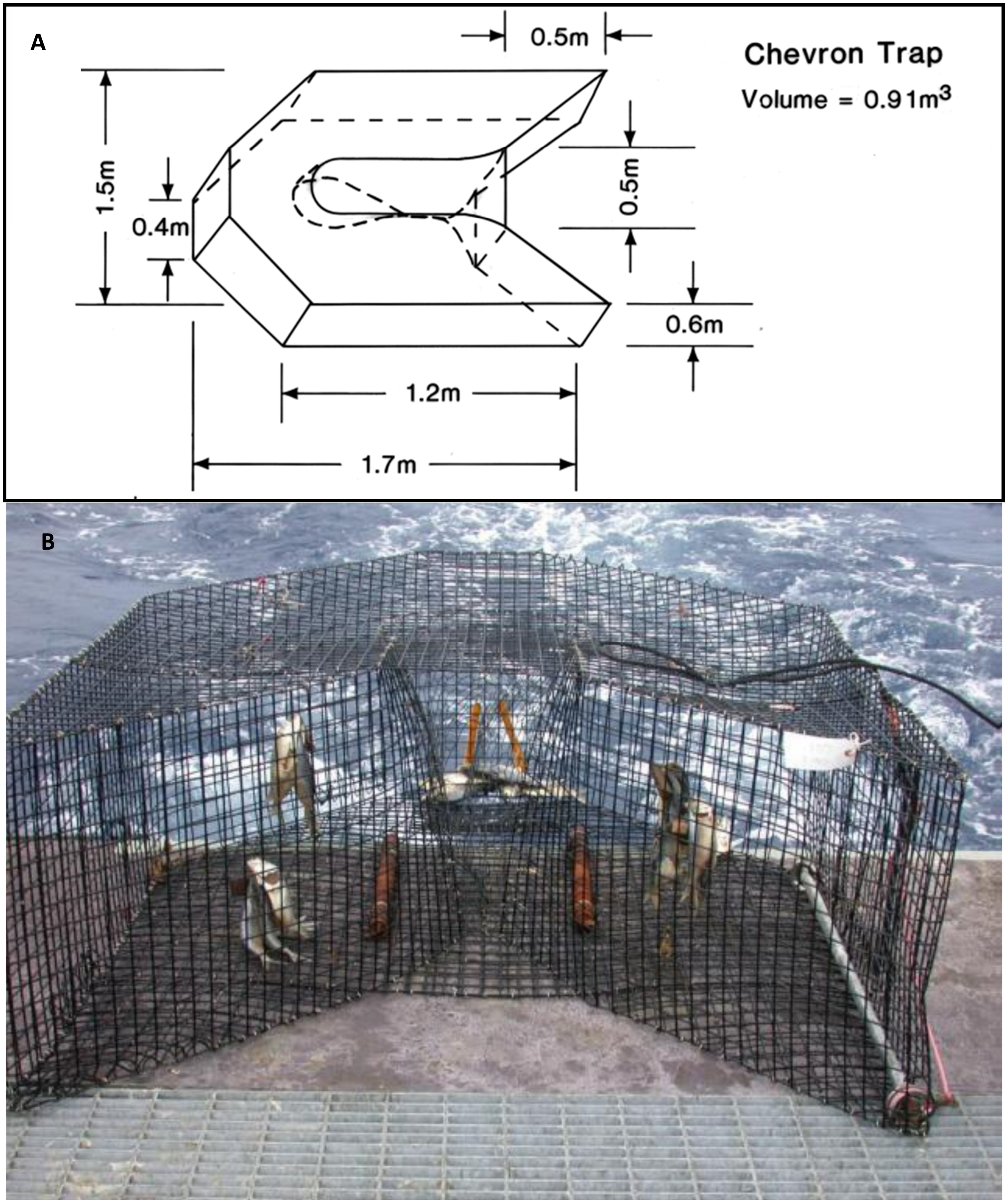


Figure 2. Chevron traps used by SERFS for monitoring reef fish. A. Diagram with dimensions. B. Chevron trap ready for deployment baited with clupeids. Iron sashes attached to the bottom weigh the trap down and help maintain the proper orientation of the trap on the bottom.

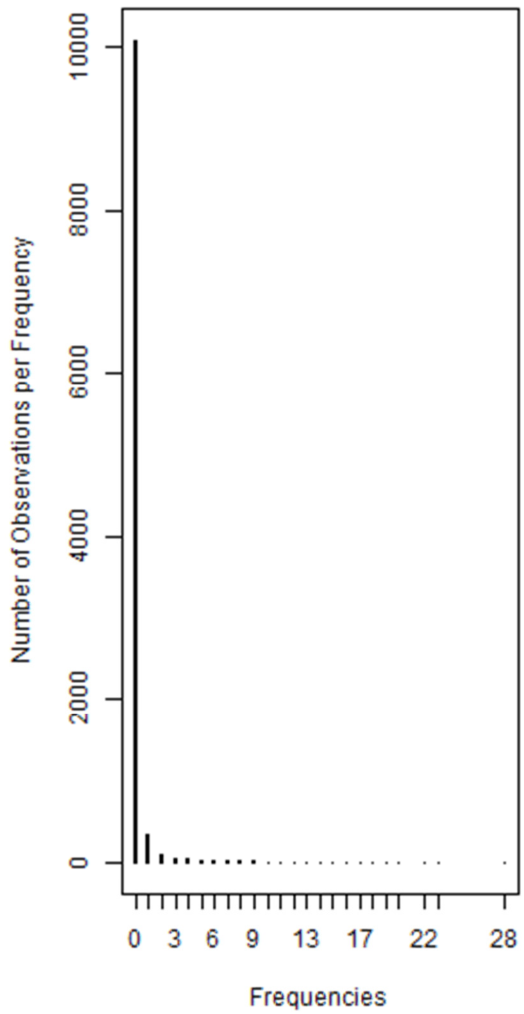


Figure 3. Frequency of occurrence of chevron traps with a given catch of Red Snapper.

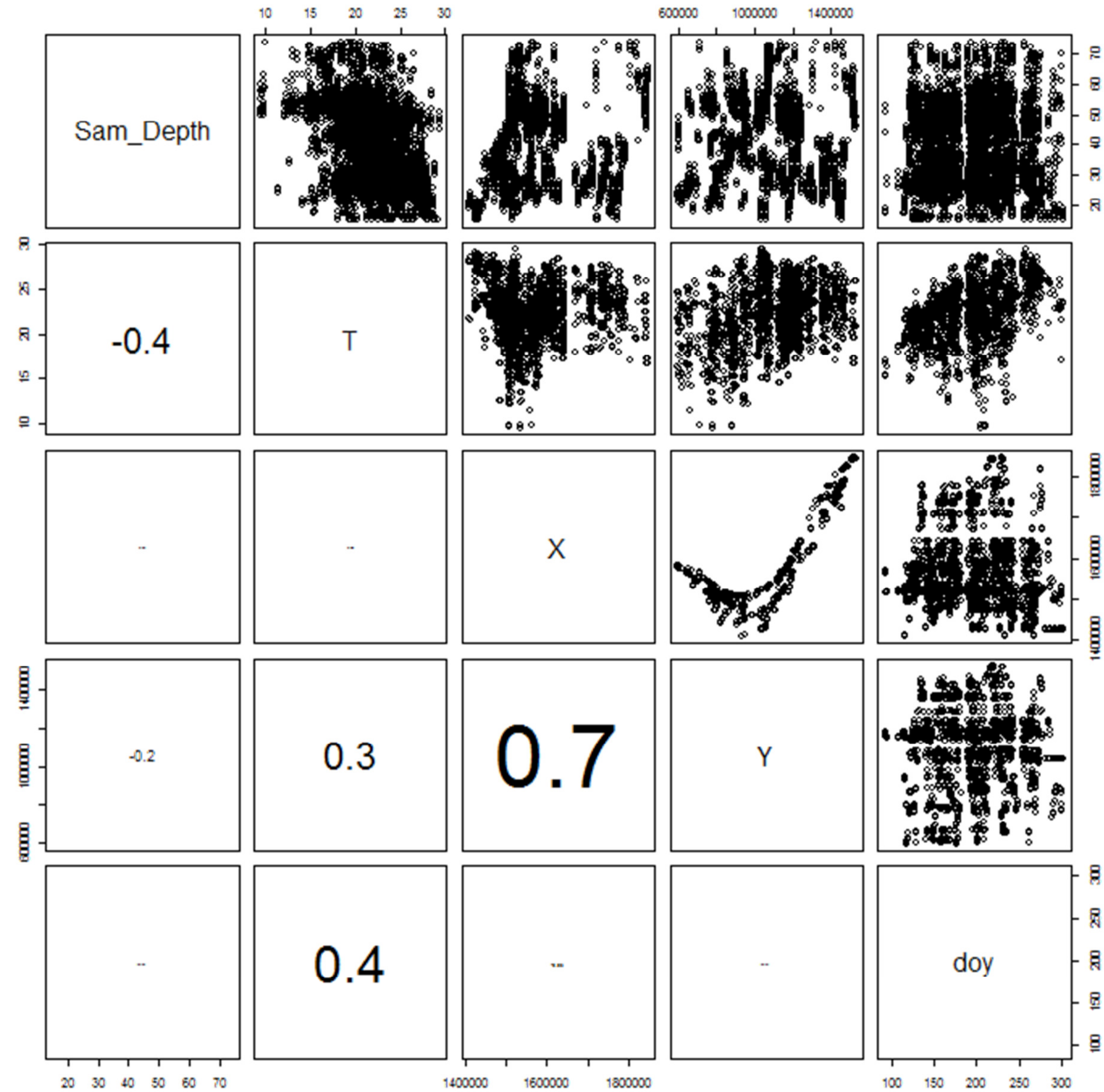


Figure 4. Pairs plot of correlation between considered continuous covariates. Diagonal provides the variable name, lower triangle provides the correlation coefficient estimates, and upper triangle provides scatter plots of the raw data. Sam_Depth=depth in meters; T=bottom temperature in ^{o}C; X=longitude in m, Y=latitude in m; and doy=day of year.

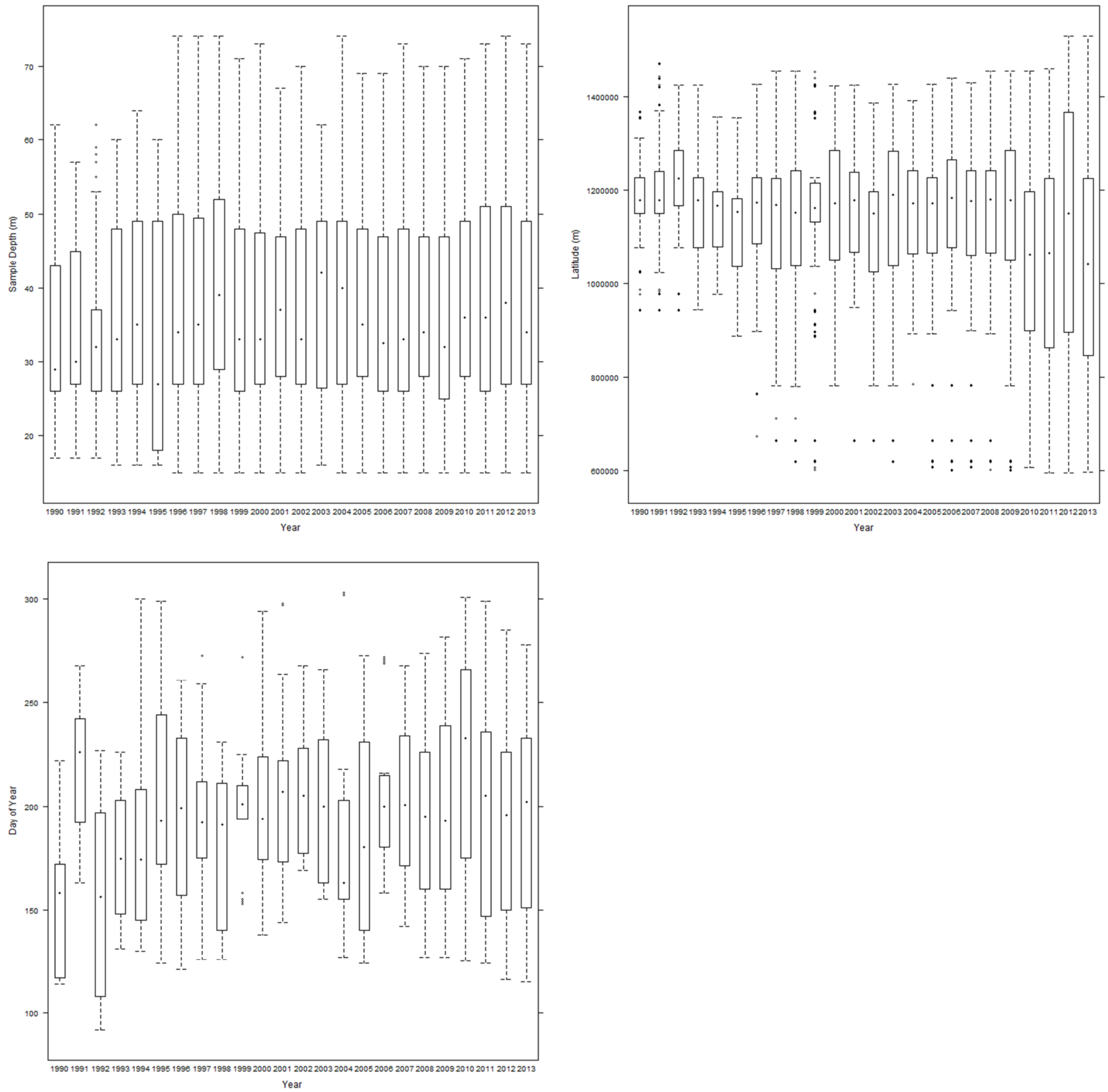


Figure 5. Box plots of depth (top left), latitude (top right), and day of year (bottom left) as a function of year.

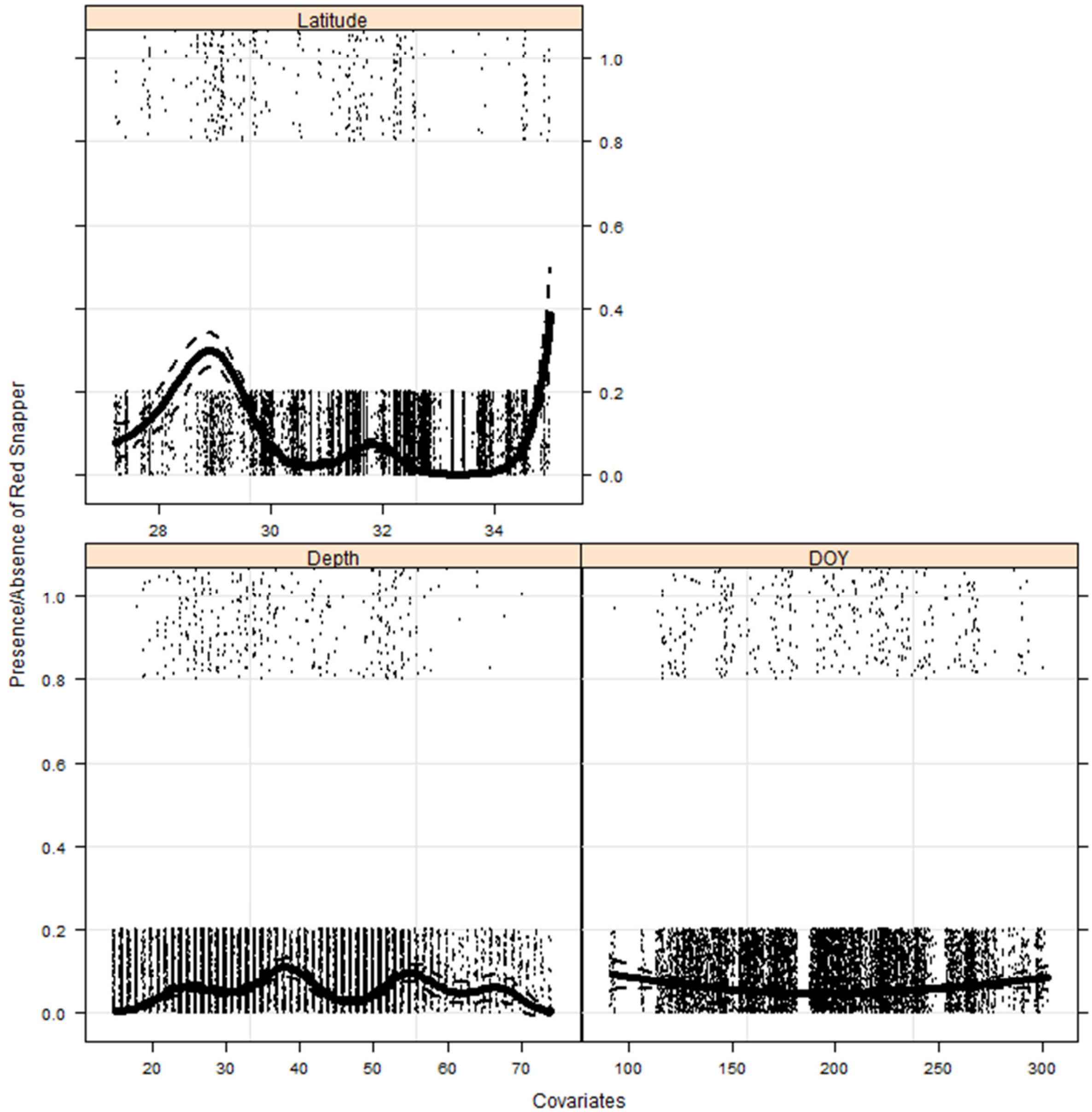


Figure 6. Presence (1) and absence (0) of Red Snapper with respect to the considered covariates, latitude (°N), depth (m), and day of year (DOY). The raw presence/absence data has been jittered in the figure. The solid black line represents a fitted GAM to the presence/absence data with respect to a given covariate. Dashed black lines represent 95% confidence intervals around the GAM fit.

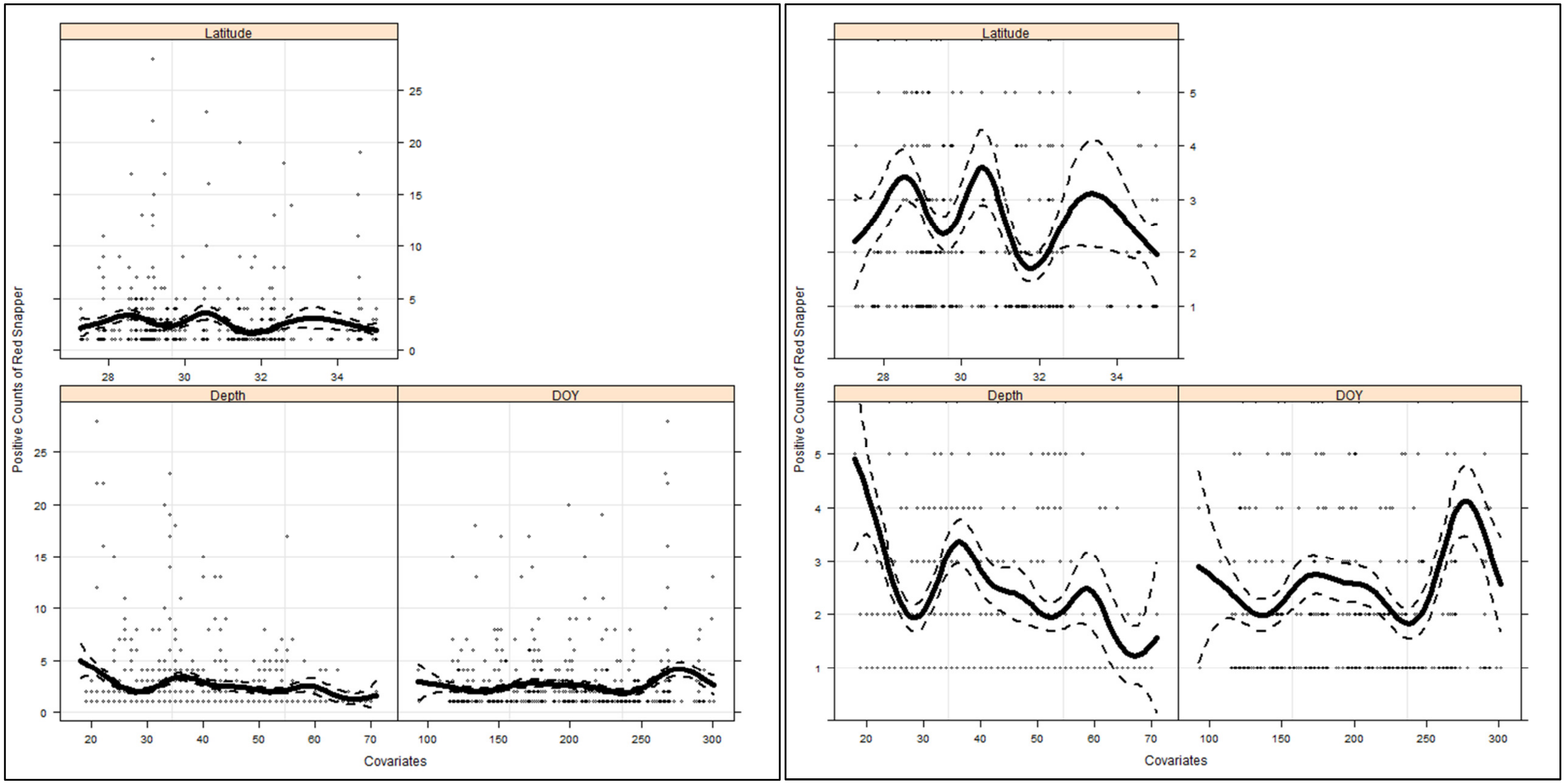


Figure 7. Catch of Red Snapper with respect to the considered covariates, latitude (°N), depth (m), and day of year (DOY). The left panel has an unrestricted y-axis that shows the full catch distribution of Red Snapper. The right panel restricts the y-axis to the range of the GAM model fits to show better detail of the GAM fits. Sold black line represents a fitted GAM to the catch data with respect to a given covariate. Dashed black lines represent 95% confidence intervals about the GAM fit. Only traps that caught Red Snapper were considered for the GAM fits.

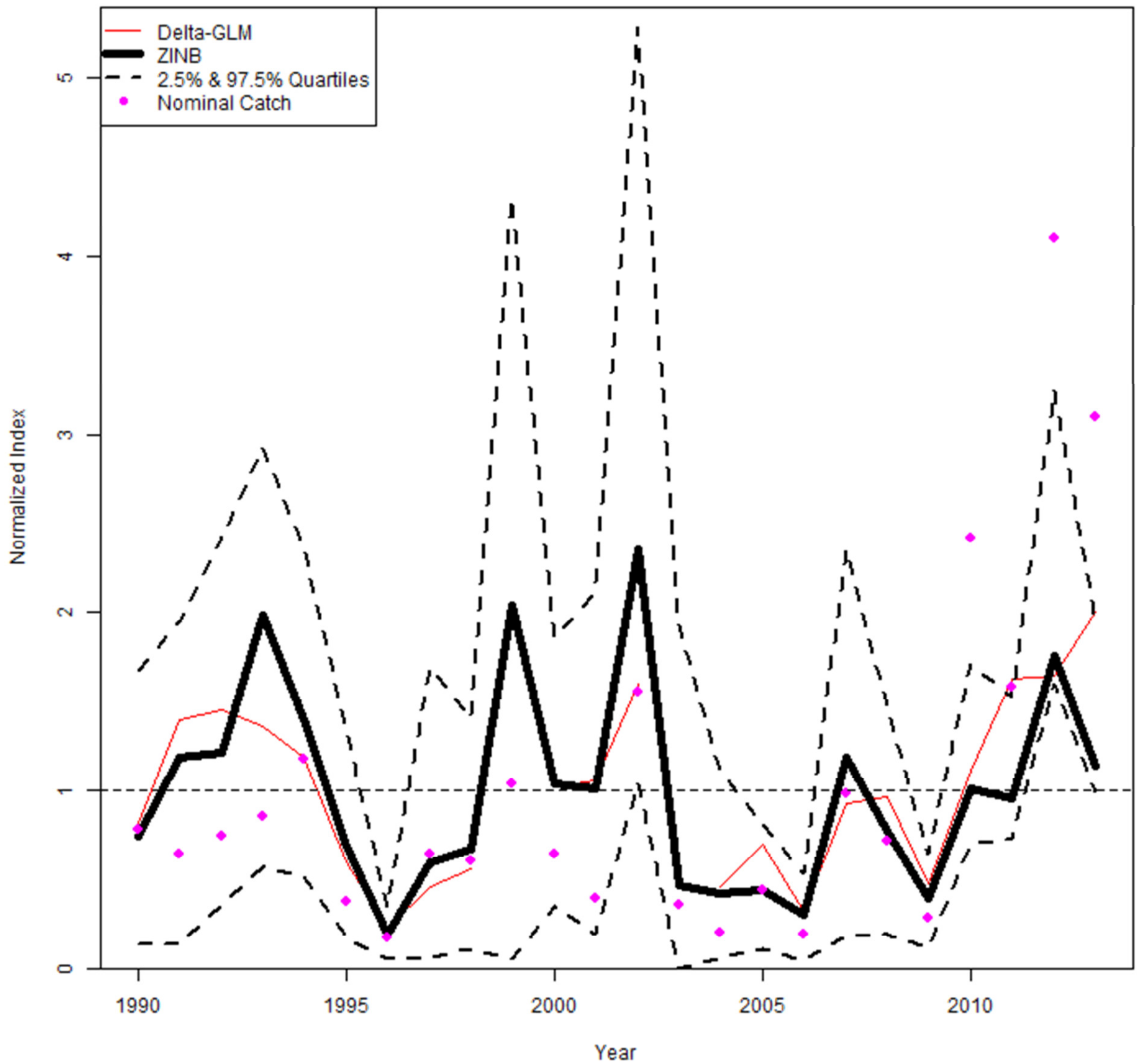


Figure 8. Red Snapper indices of relative abundance for chevron traps. Nominal catch, Delta-GLM standardized CPUE*, and Zero-inflated negative binomial (ZINB) standardized catch normalized to each index's long-term mean to provide relative abundance. *From Bubley et al. (2014).

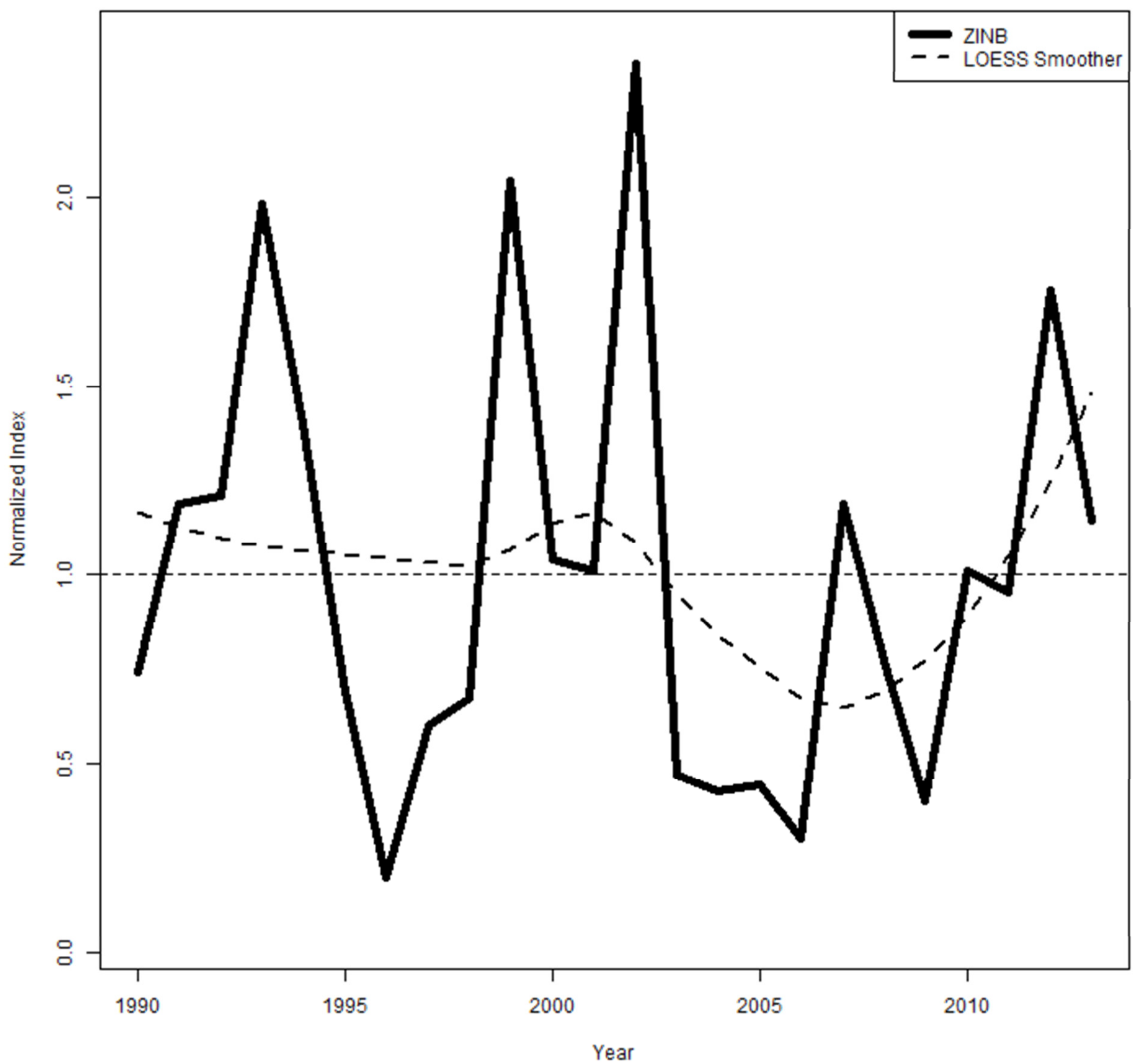


Figure 9. ZINB index of relative abundance for Red Snapper based on the best fit ZINB selected by the Bayesian information criterion (BIC). Heavy dashed-line represents locally-weight scatterplot smoothing (LOESS smoother) that has been added to the plot to aid visual interpretation of the abundance trends. All index values were normalized to the series' mean prior to plotting.

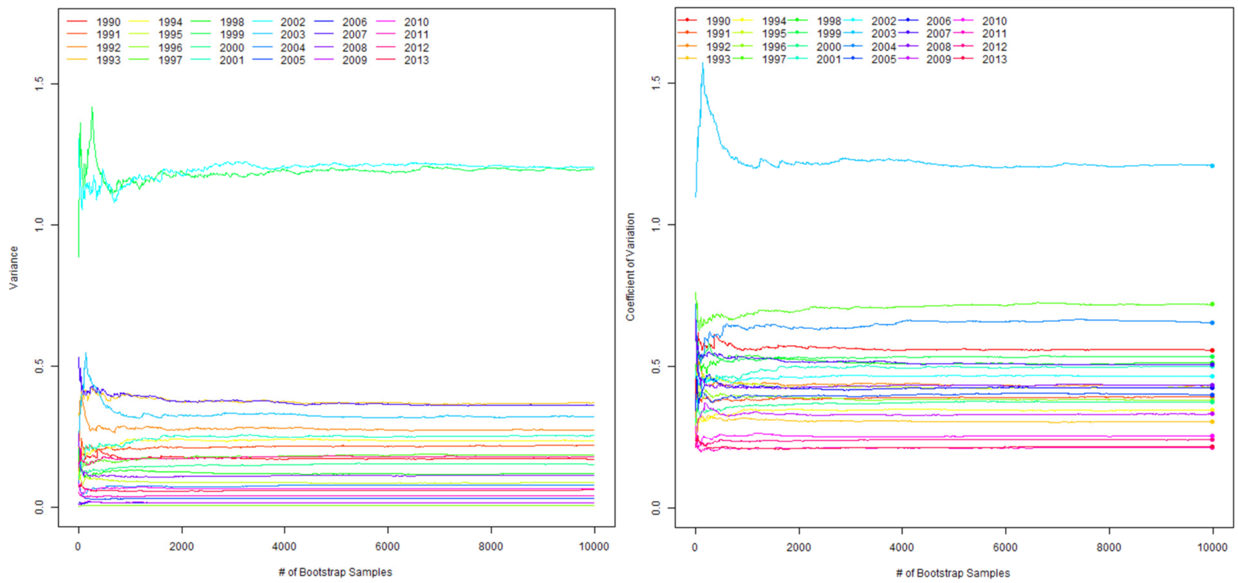


Figure 10. Bootstrap diagnostic plots used to determine if variance (left) and coefficient of variation (CV; right) estimates stabilized over the number of bootstrap iterations run.

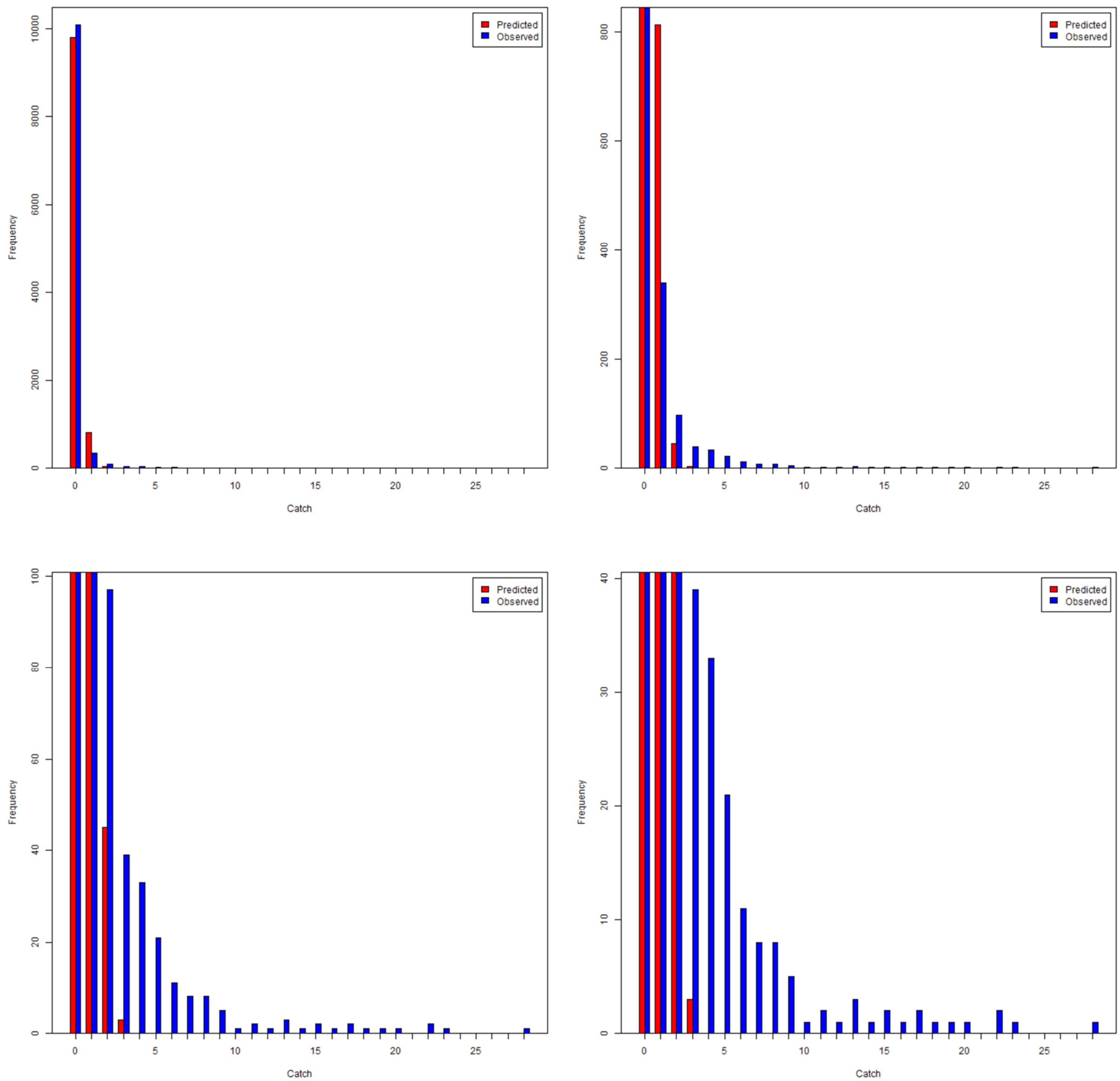


Figure 11. Frequency of traps observed (Observed) with a given catch of Red Snapper or predicted by the ZINB (Predicted). Plots represent the same data, with the y-axis truncated to better resolve low frequencies as one moves clockwise through the plots starting with the top left plot.

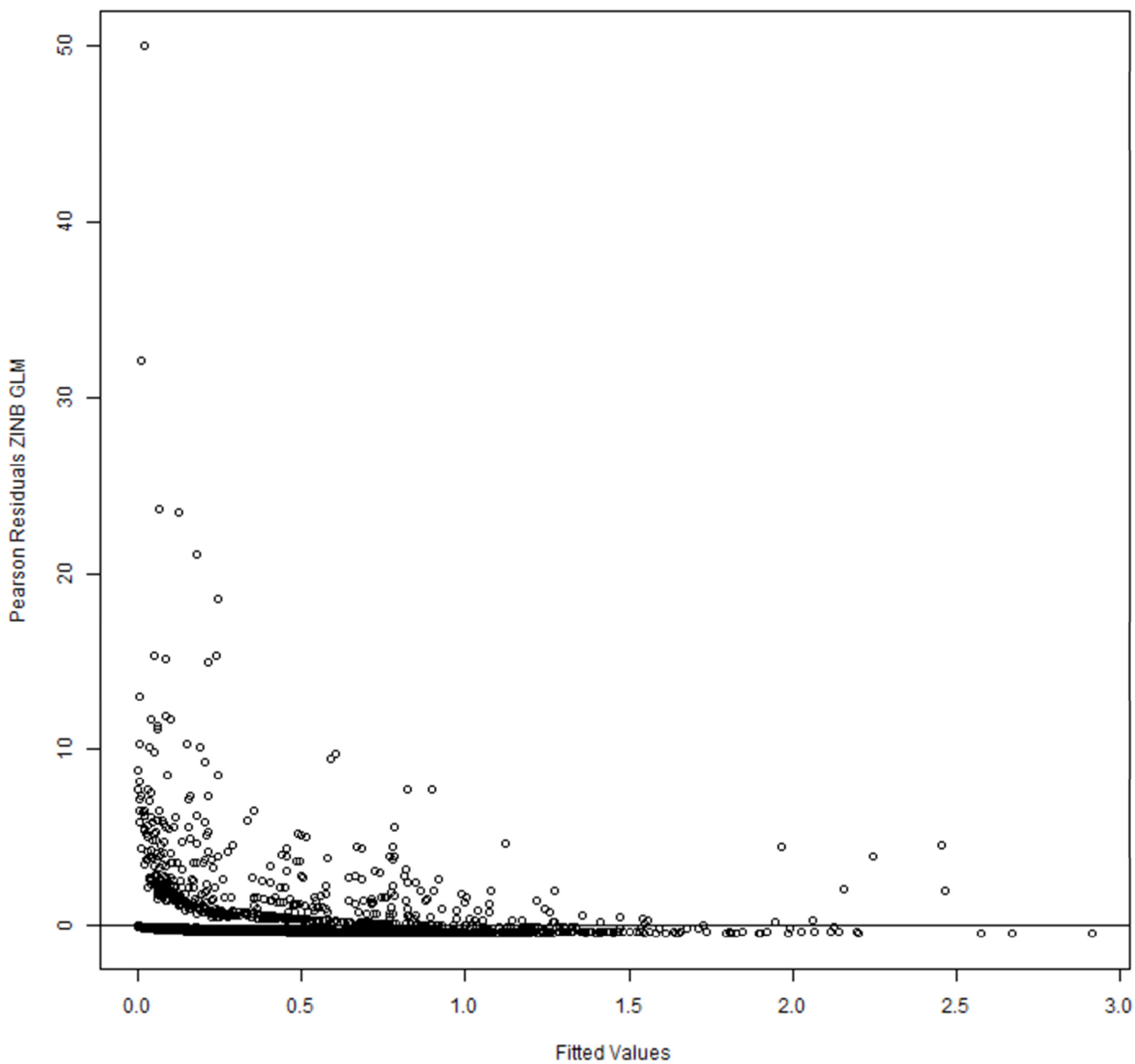


Figure 12. Pearson residuals versus fitted values for the final ZINB model.

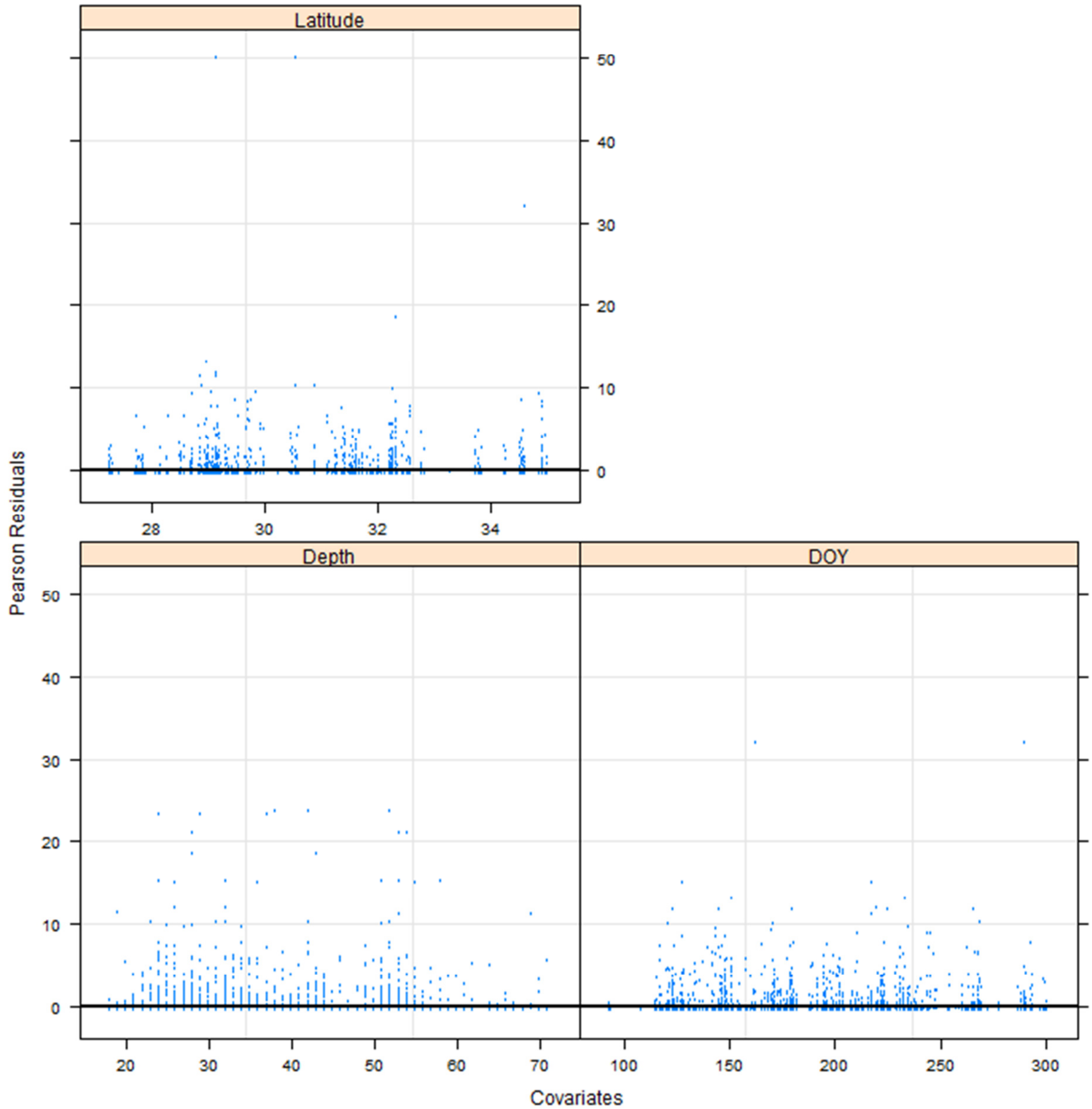


Figure 13. Pearson residuals versus covariates included in the final ZINB model.

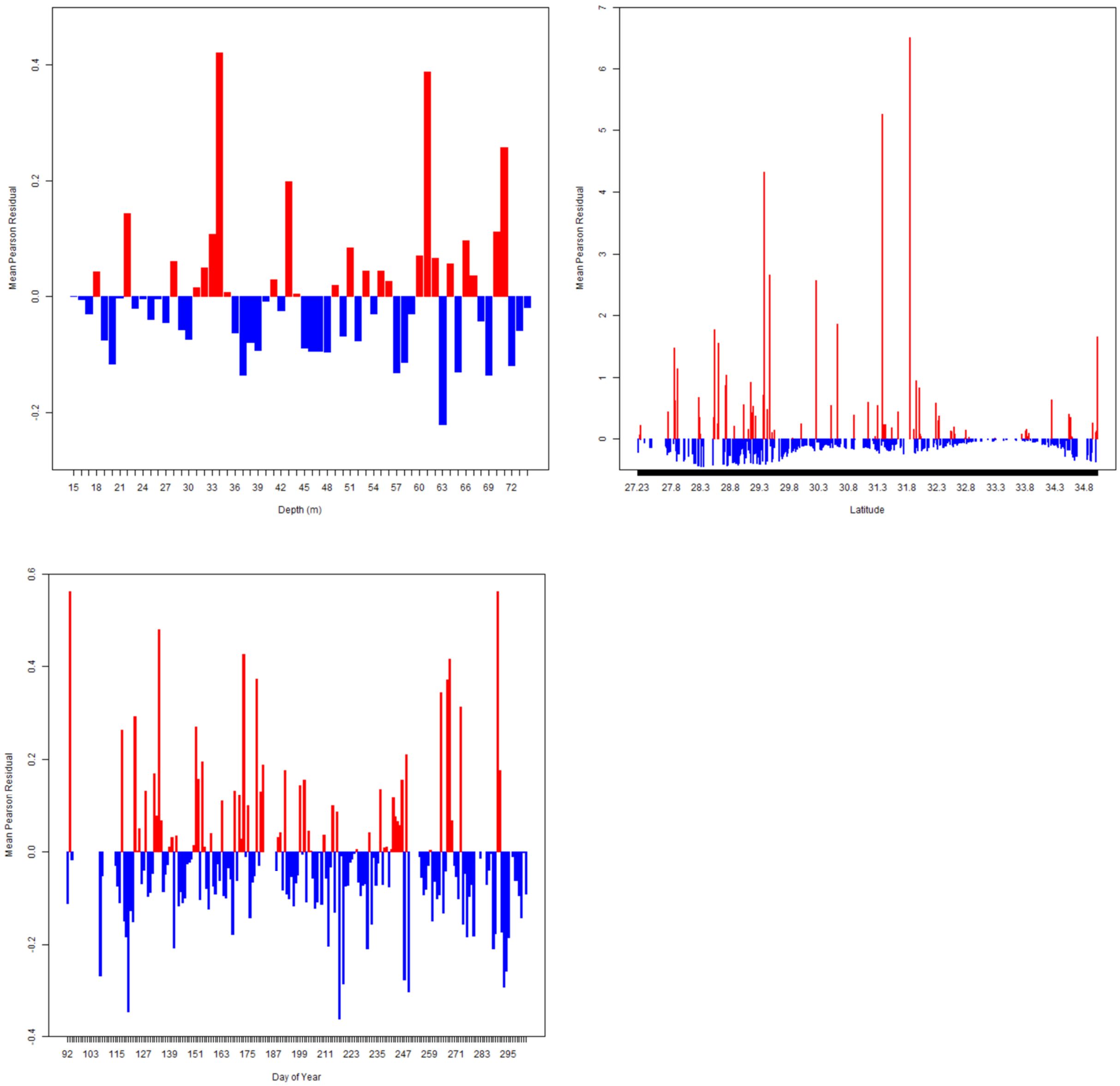


Figure 14. Mean Pearson residual versus included covariates for the final ZINB model.

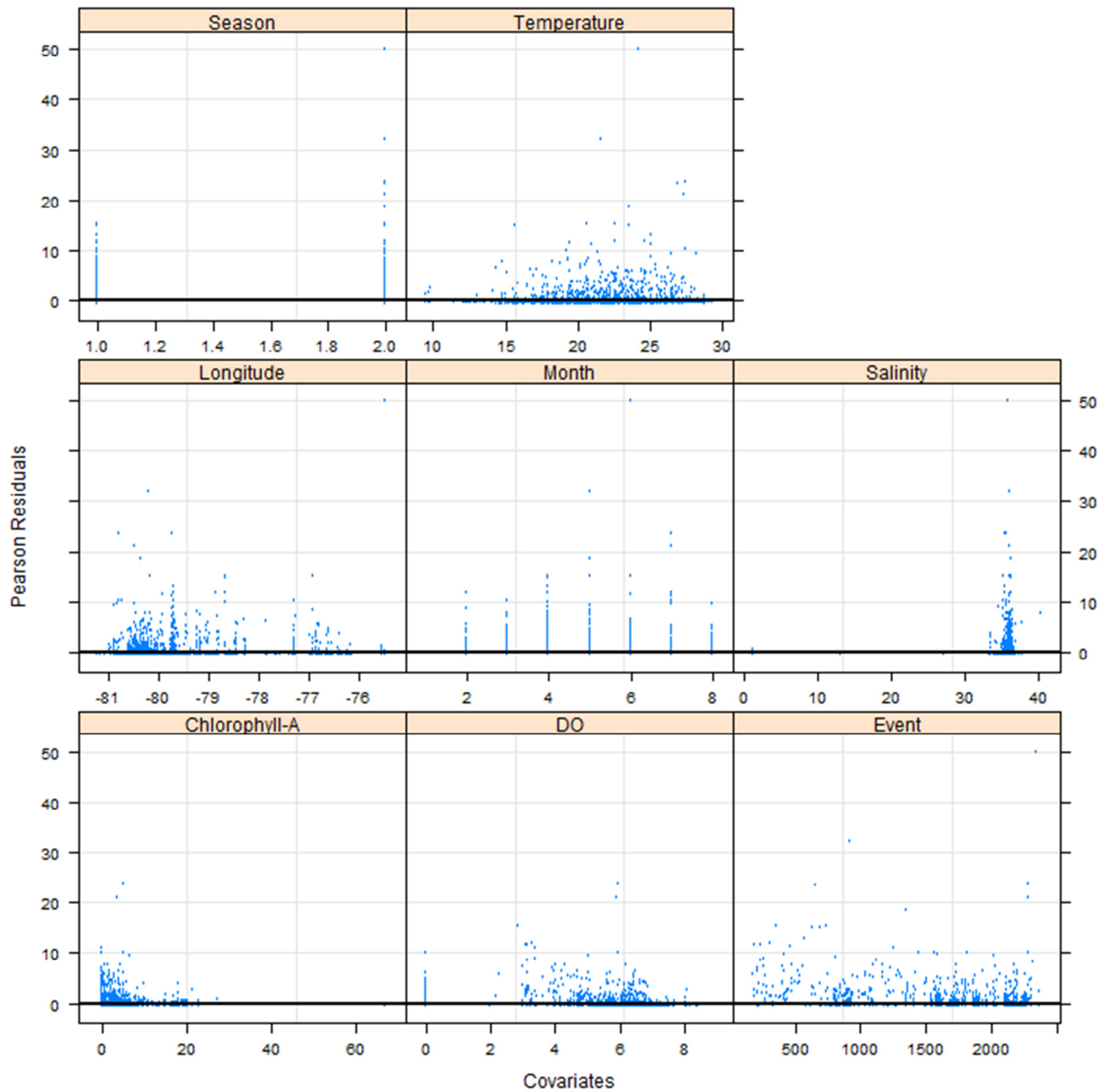


Figure 15. Pearson residuals versus covariates excluded from the final ZINB model.

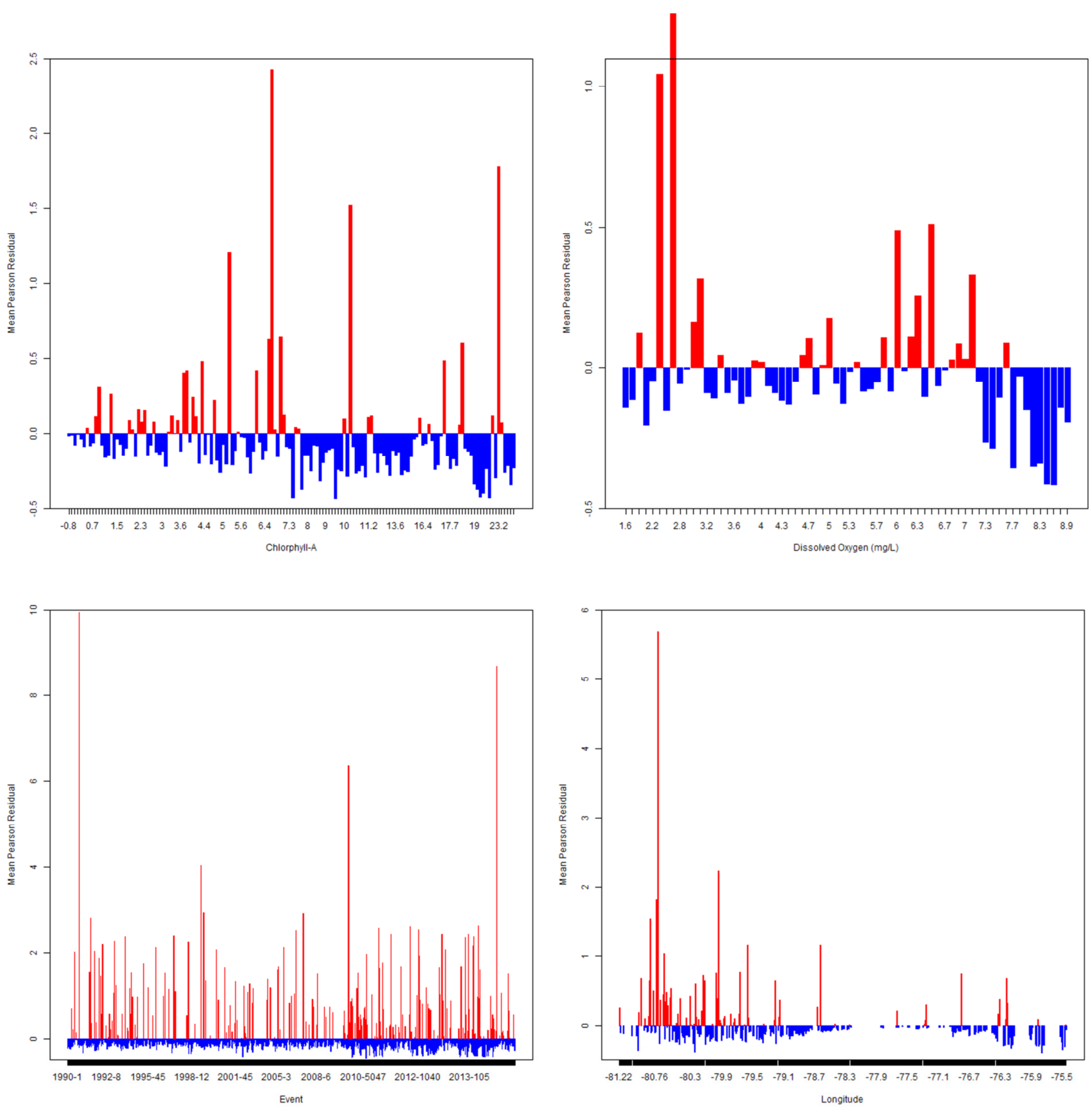


Figure 16. Mean Pearson residuals versus covariates excluded from the final ZINB model.

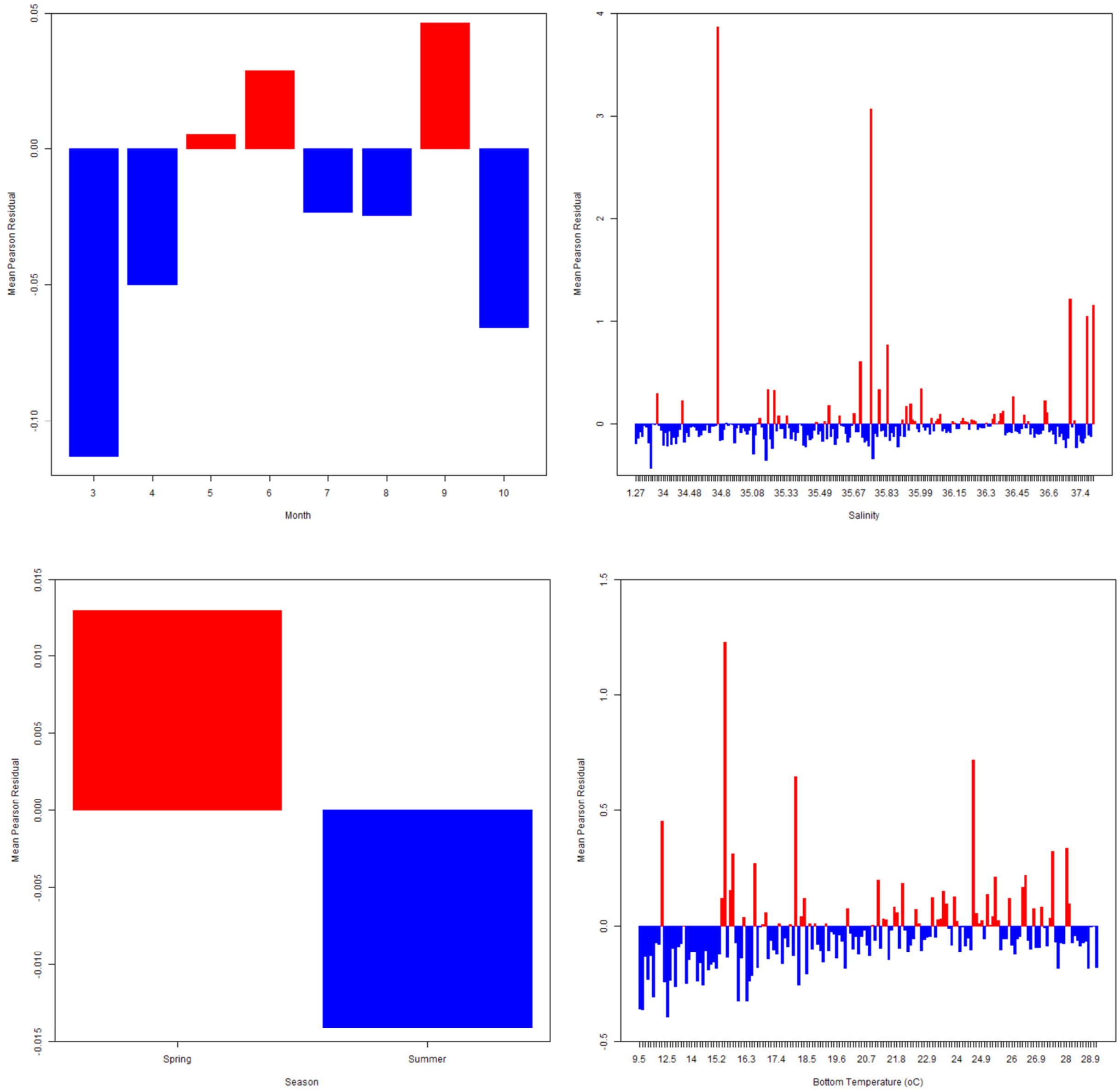


Figure 16 (cont). Mean Pearson residuals versus covariates excluded from the final ZINB model.

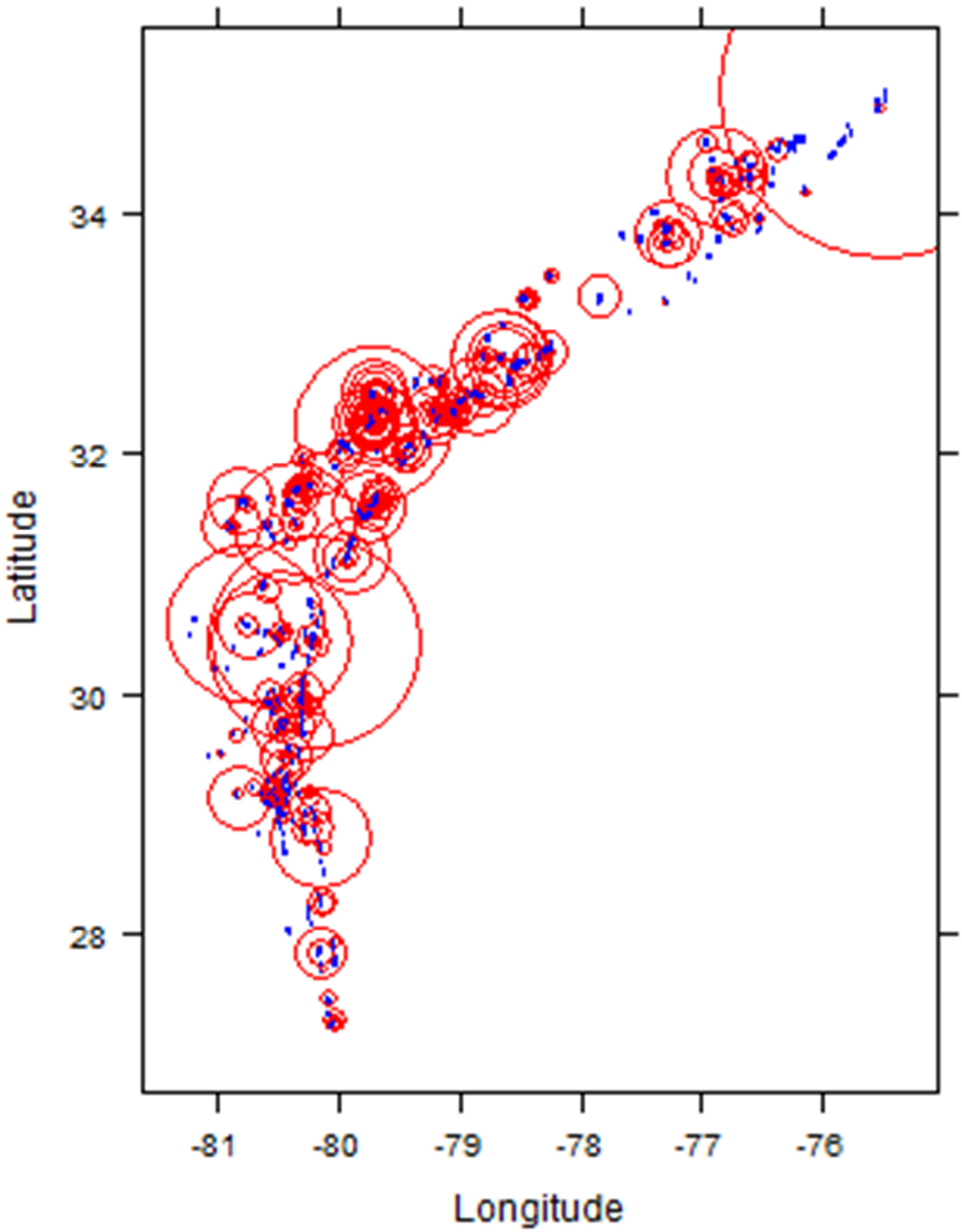


Figure 17. Spatial distribution of Pearson residuals. Red circles indicate positive Pearson residuals and blue circles represent negative Pearson residuals. Size of the circle is indicative of the magnitude of the residual with larger circles corresponding to larger Pearson residual values.

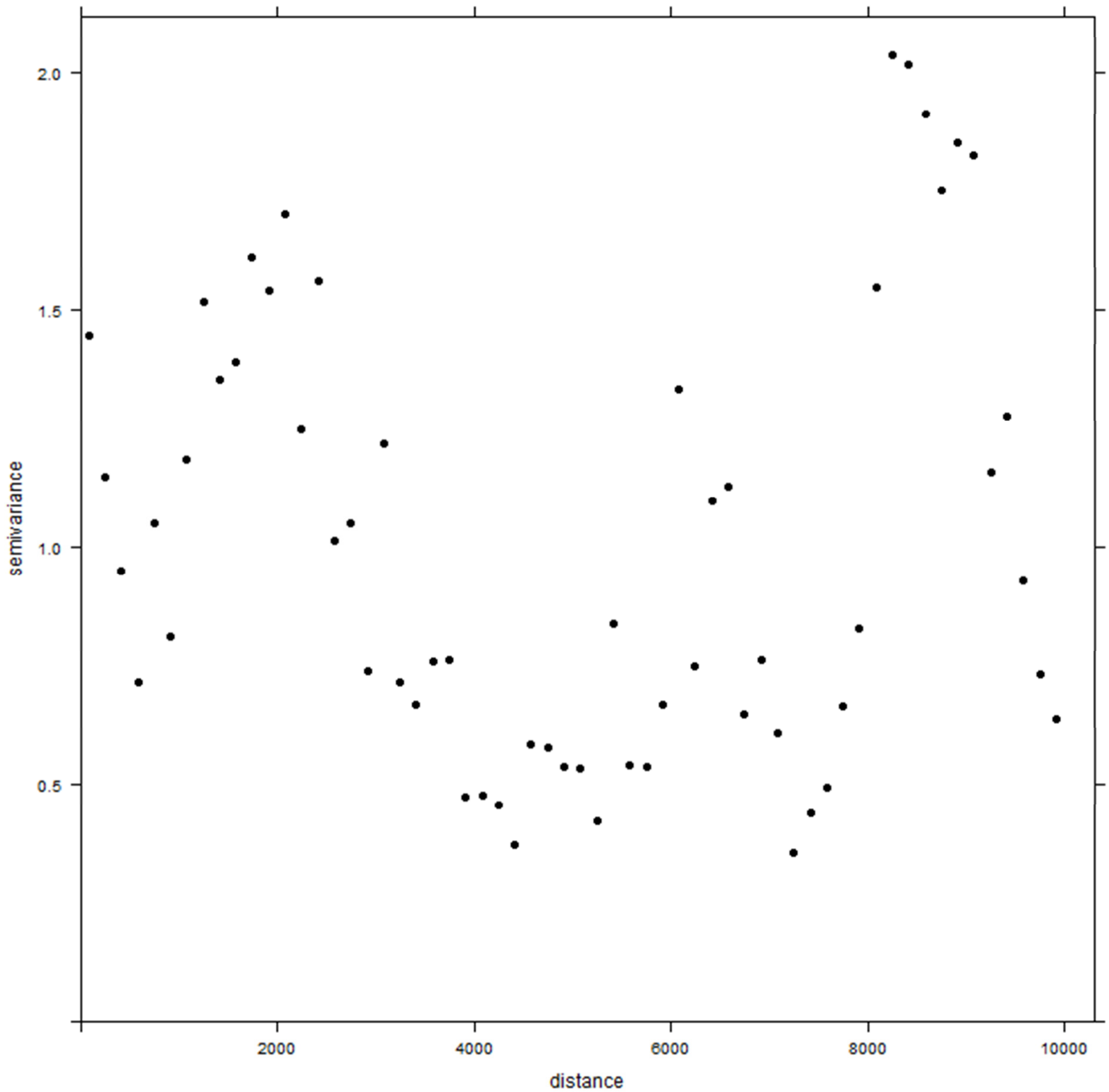


Figure 18. Sample variogram of Pearson residuals. The sample variogram is limited to 10,000 m (10 km).

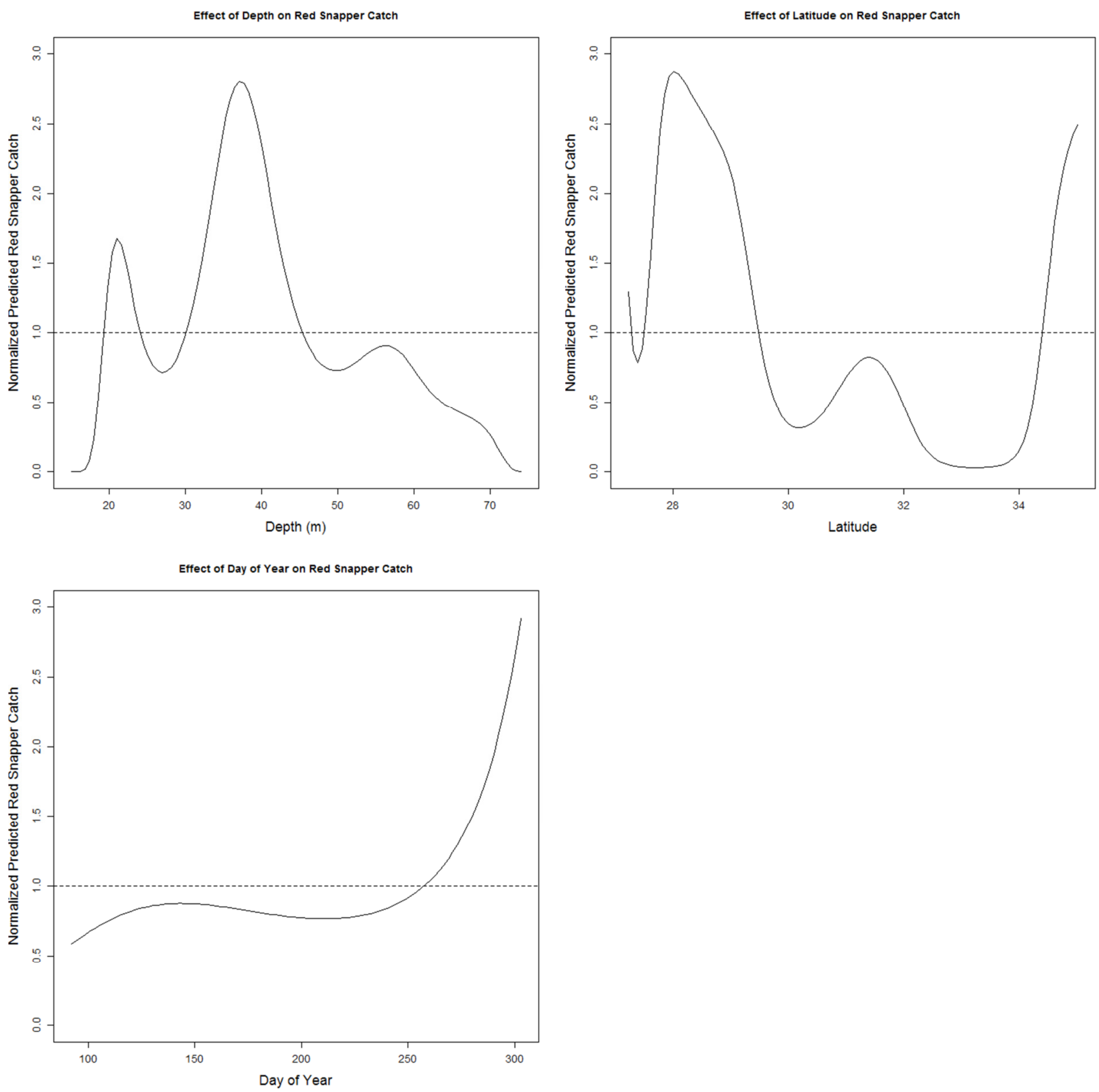


Figure 19. Covariate effects on predicted red snapper catch.

Addendum Figures

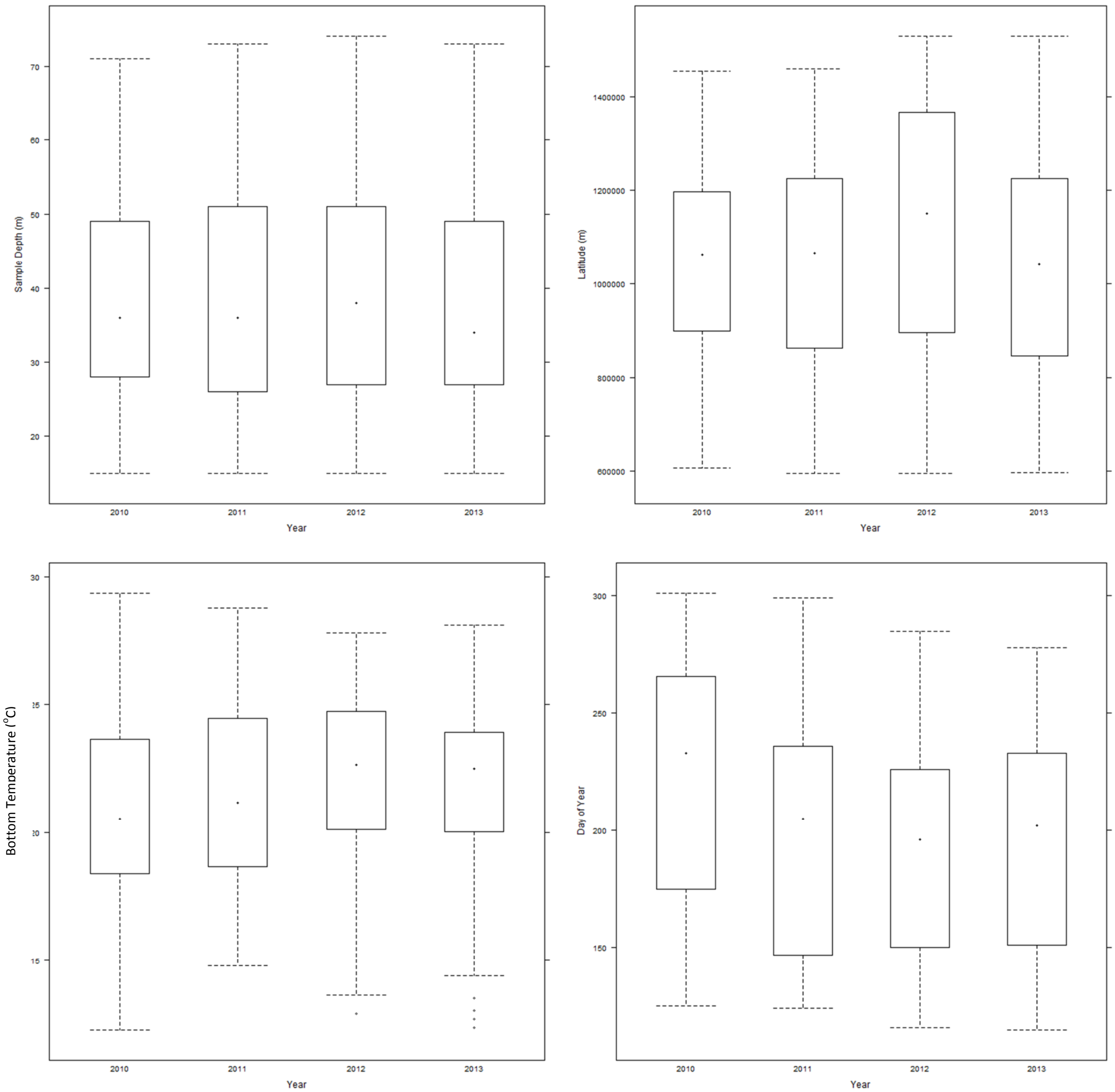


Figure 20. Box plots of depth (top left), latitude (top right), bottom temperature (bottom left), and day of year (bottom right) as a function of year.

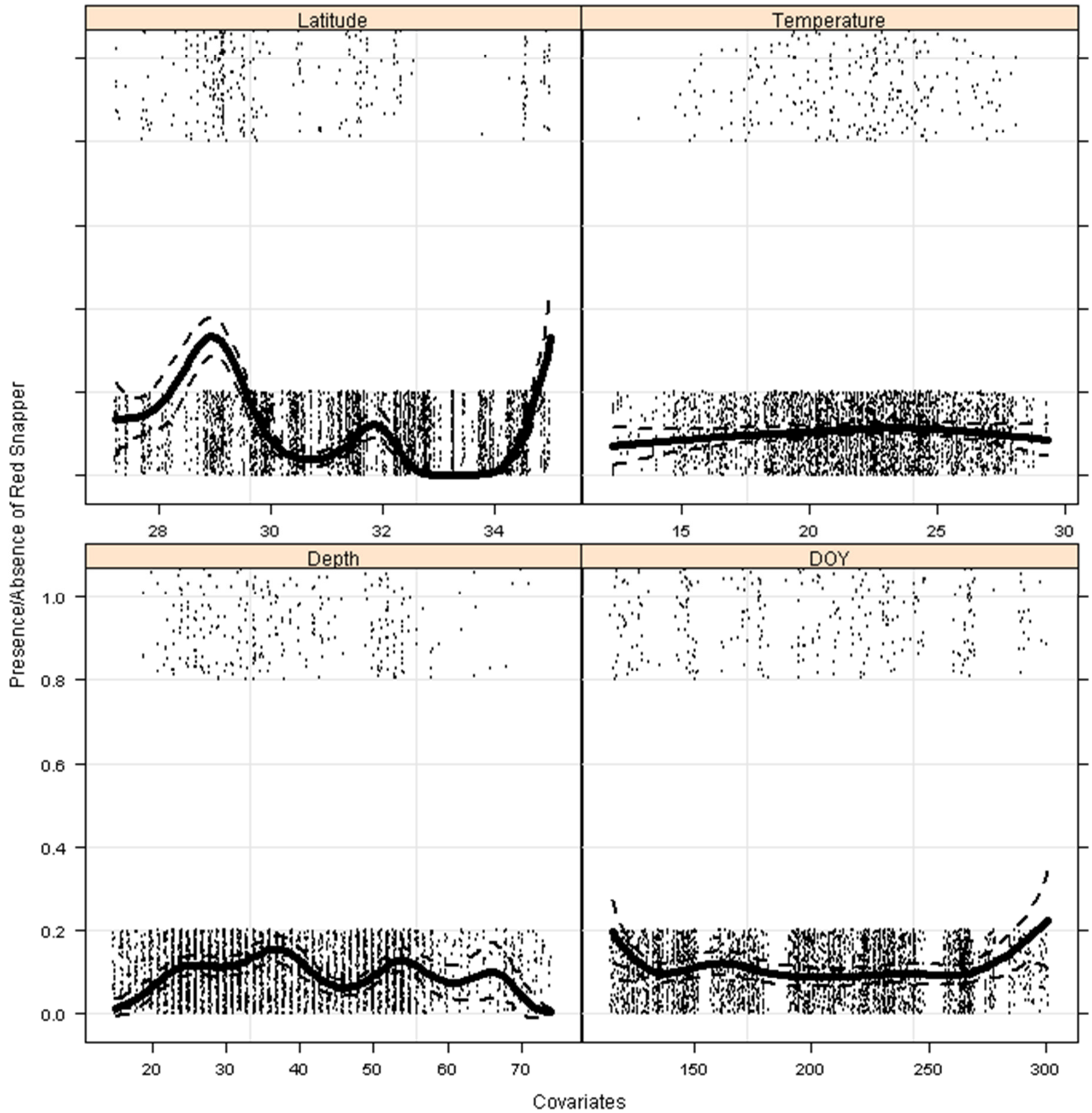


Figure 21. Presence (1) and absence (0) of Red Snapper with respect to the considered covariates, latitude (°N), depth (m), bottom temperature (^{o}C), and day of year (DOY). The raw presence/absence data has been jittered in the figure. The solid black line represents a fitted GAM to the presence/absence data with respect to a given covariate. Dashed black lines represent 95% confidence intervals around the GAM fit.

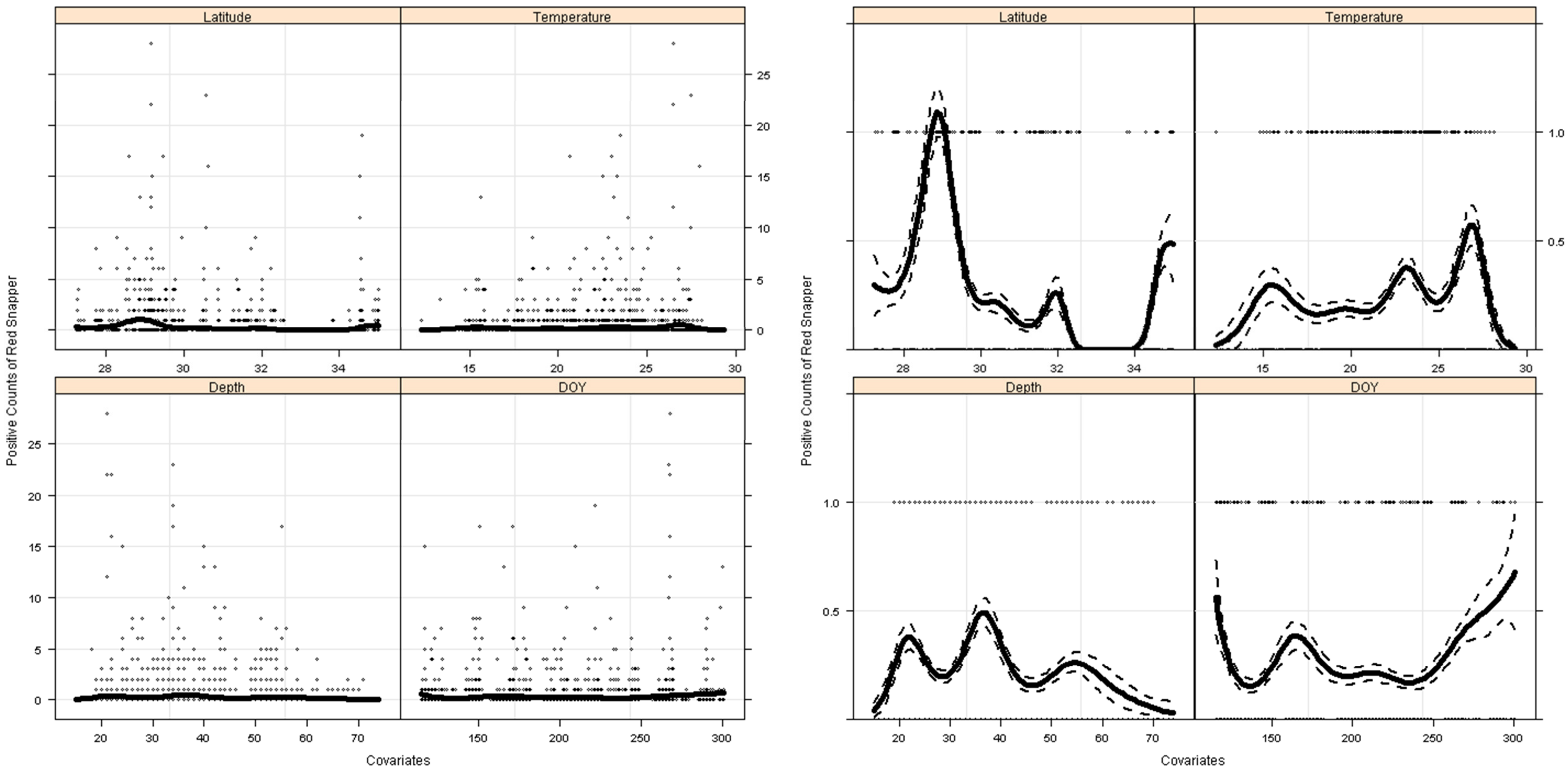


Figure 22. Catch of Red Snapper with respect to the considered covariates, latitude (°N), depth (m), and day of year (DOY). The left panel has an unrestricted y-axis that shows the full catch distribution of Red Snapper. The right panel restricts the y-axis to the range of the GAM model fits to show better detail of the GAM fits. Sold black line represents a fitted GAM to the catch data with respect to a given covariate. Dashed black lines represent 95% confidence intervals about the GAM fit. Only traps that caught Red Snapper were considered for the GAM fits.

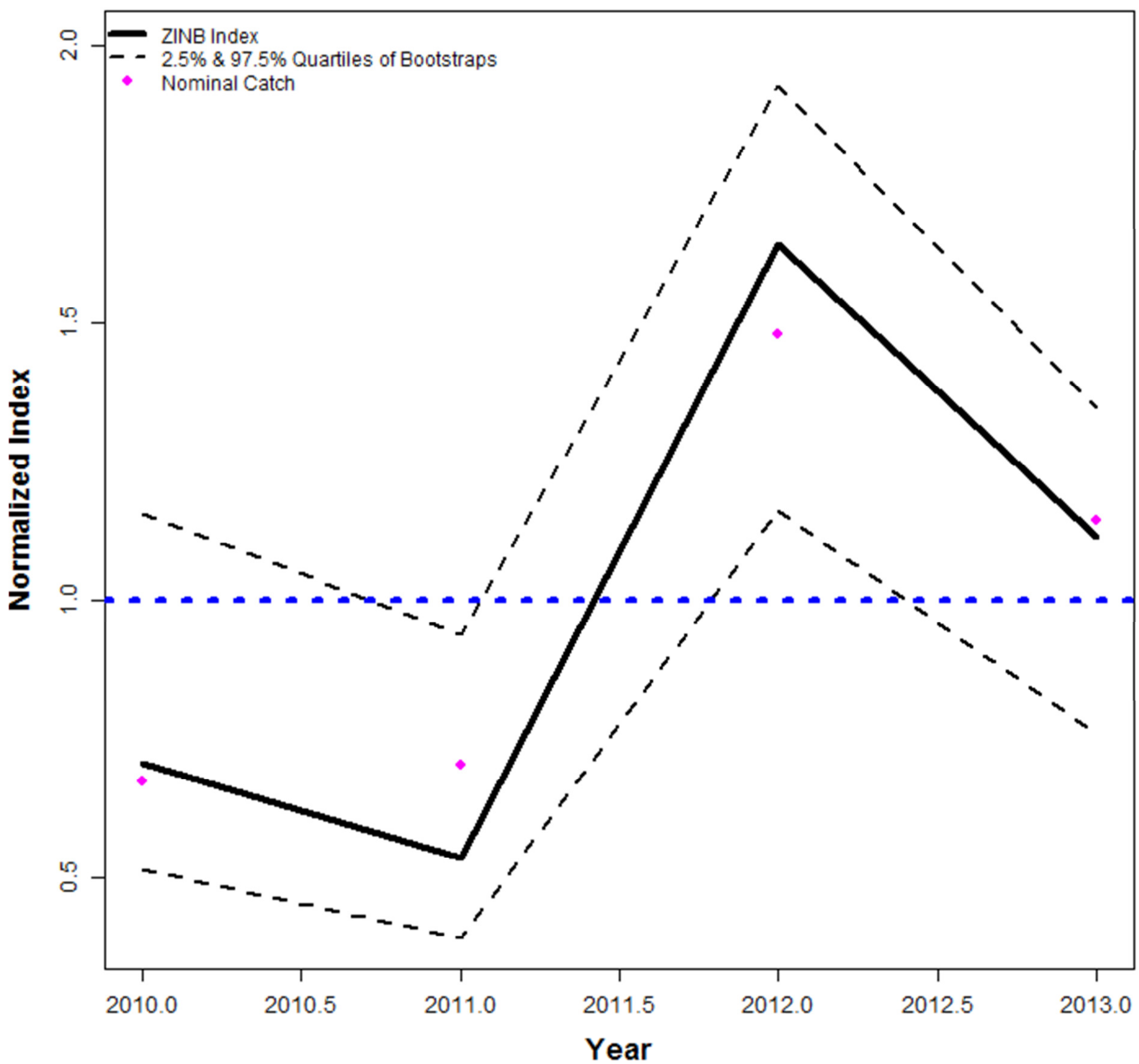


Figure 23. Red Snapper index of relative abundance for chevron traps. Nominal catch and Zero-inflated negative binomial (ZINB) standardized catch normalized to each index's long-term mean to provide relative abundance.

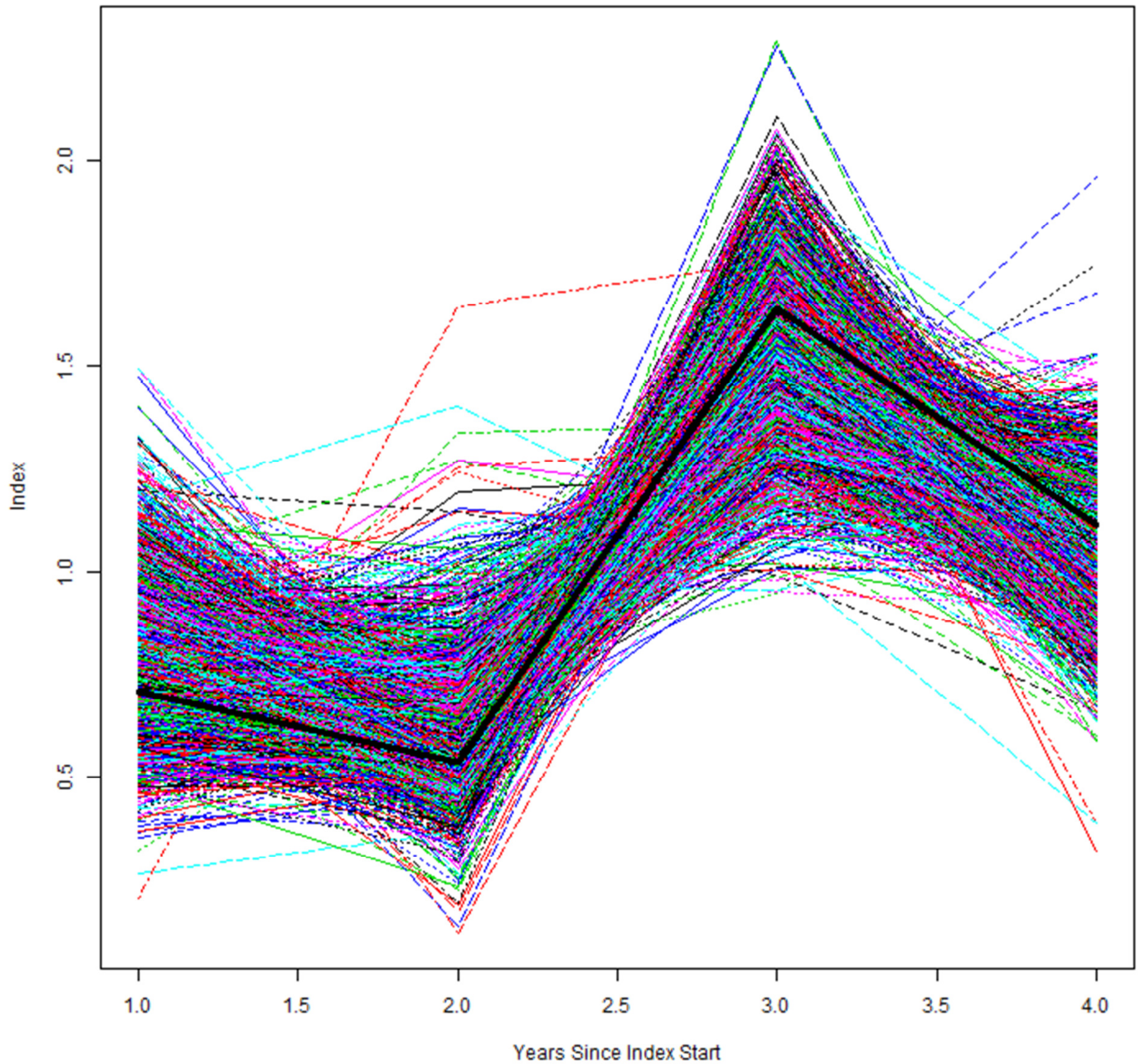


Figure 24. Plot of all individual bootstrap runs normalized annual relative abundance index. Superimposed (black line) is the predicted annual relative abundance index based on the observed catch data.

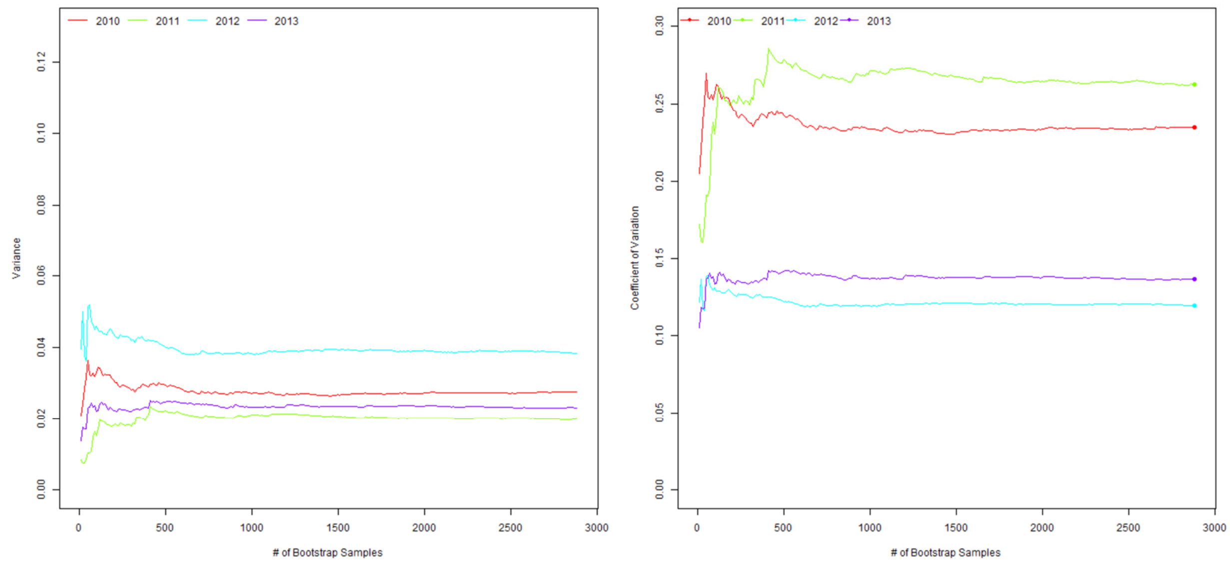


Figure 25. Bootstrap diagnostic plots used to determine if variance (left) and coefficient of variation (CV; right) estimates stabilized over the number of bootstrap iterations run.

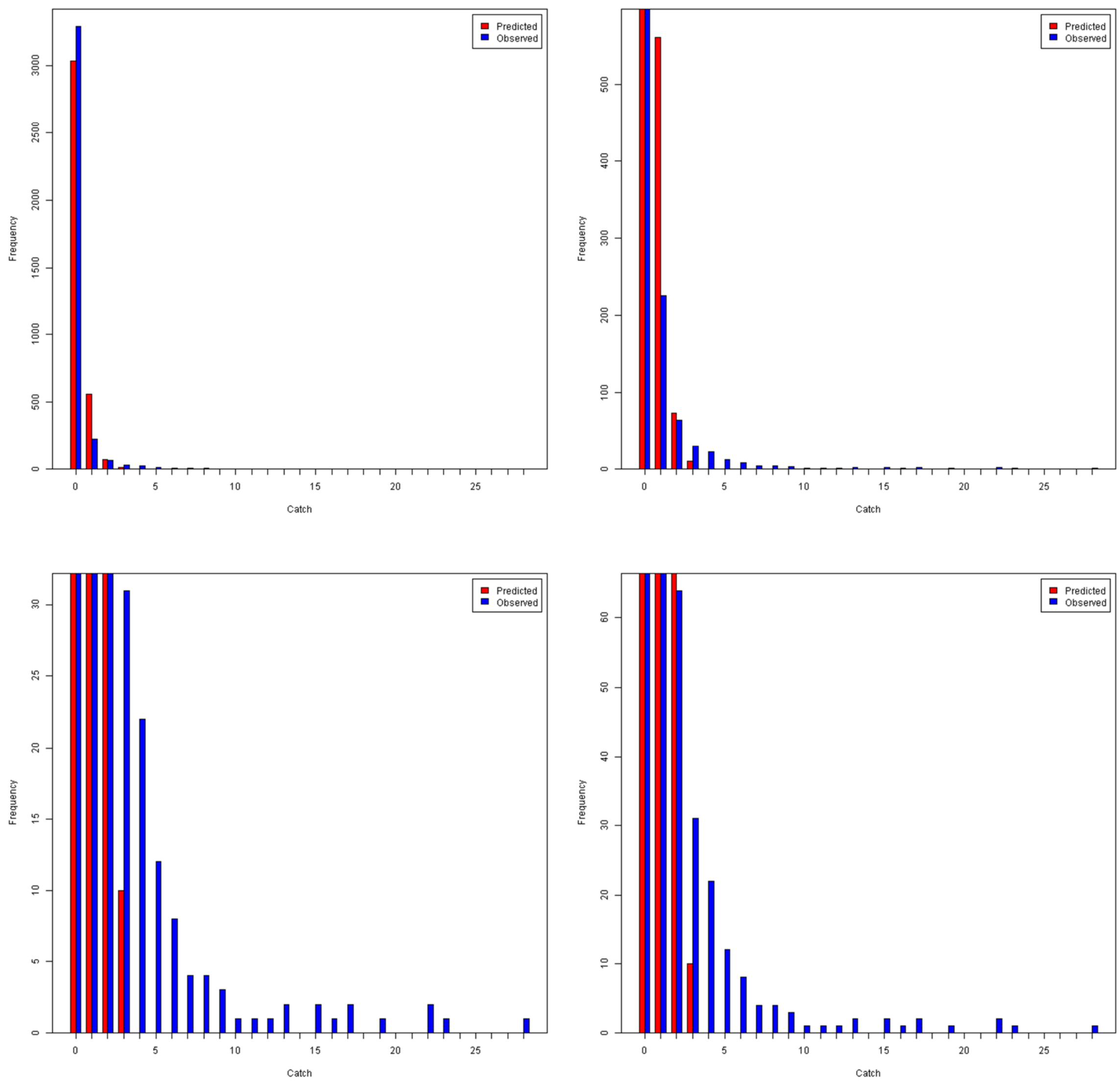


Figure 26. Frequency of traps observed (Observed) with a given catch of Red Snapper or predicted by the ZINB (Predicted). Plots represent the same data, with the y-axis truncated to better resolve low frequencies as one moves clockwise through the plots starting with the top left plot.

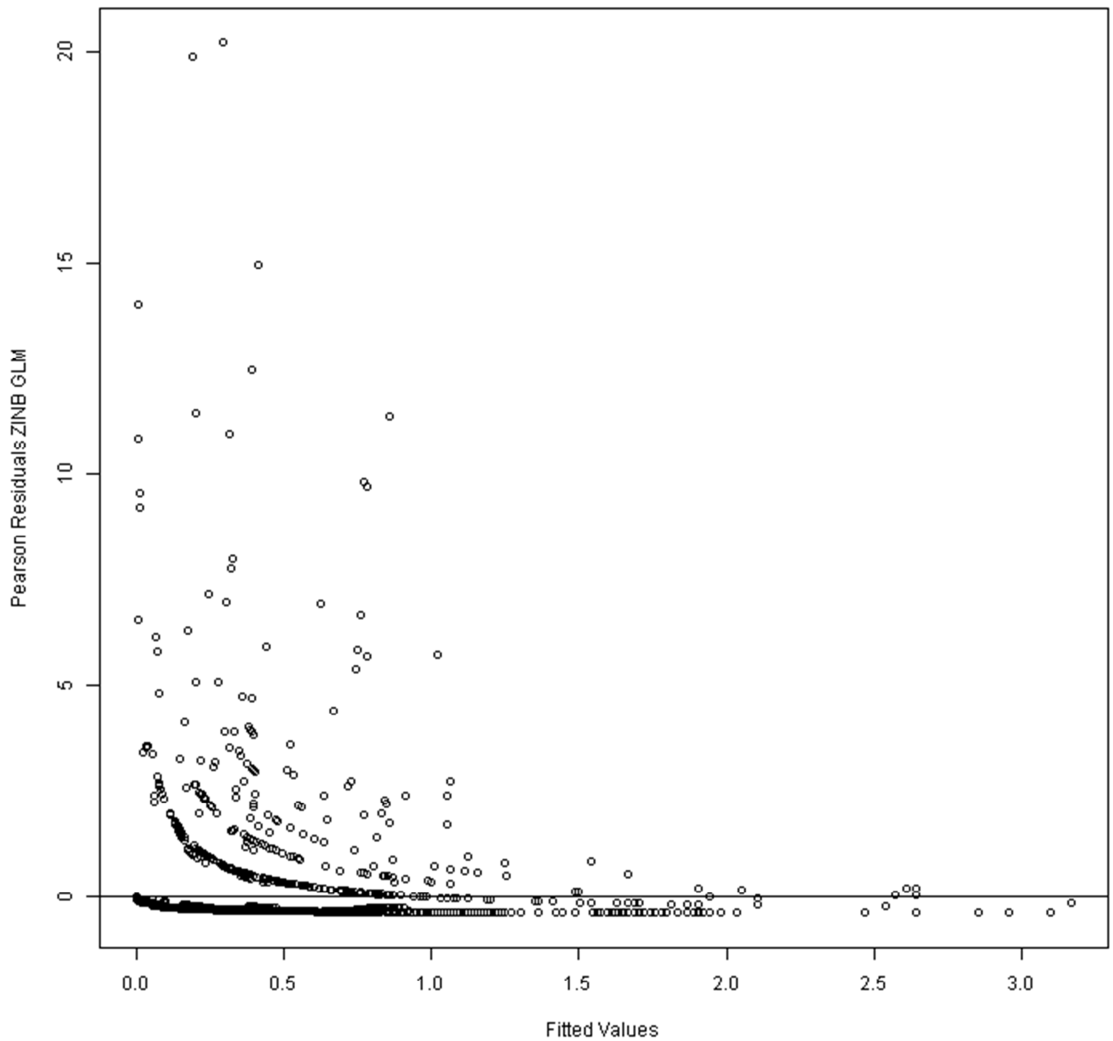


Figure 27. Pearson residuals versus fitted values for the final ZINB model.

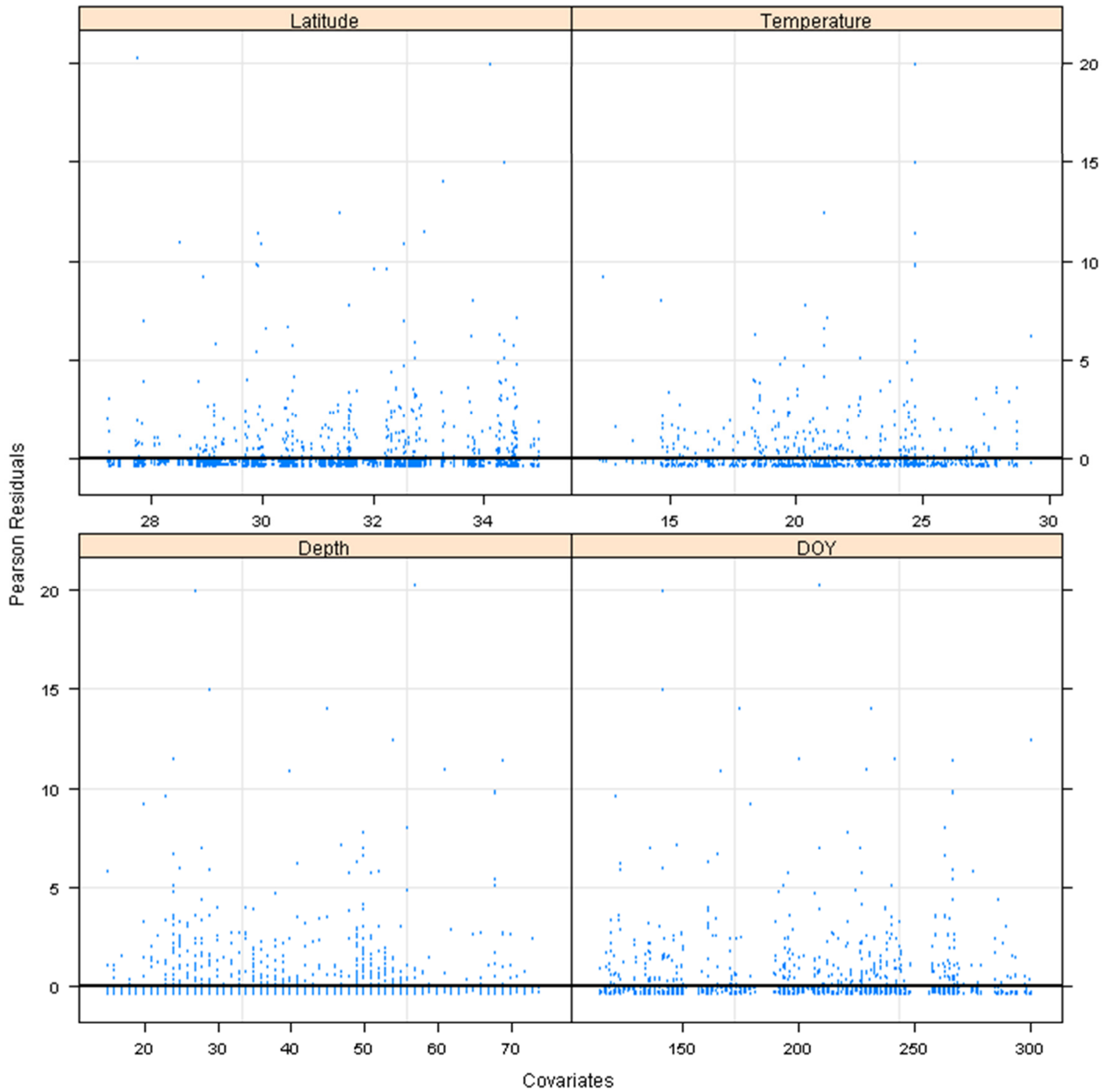


Figure 27. Pearson residuals versus covariates included in the final ZINB model.

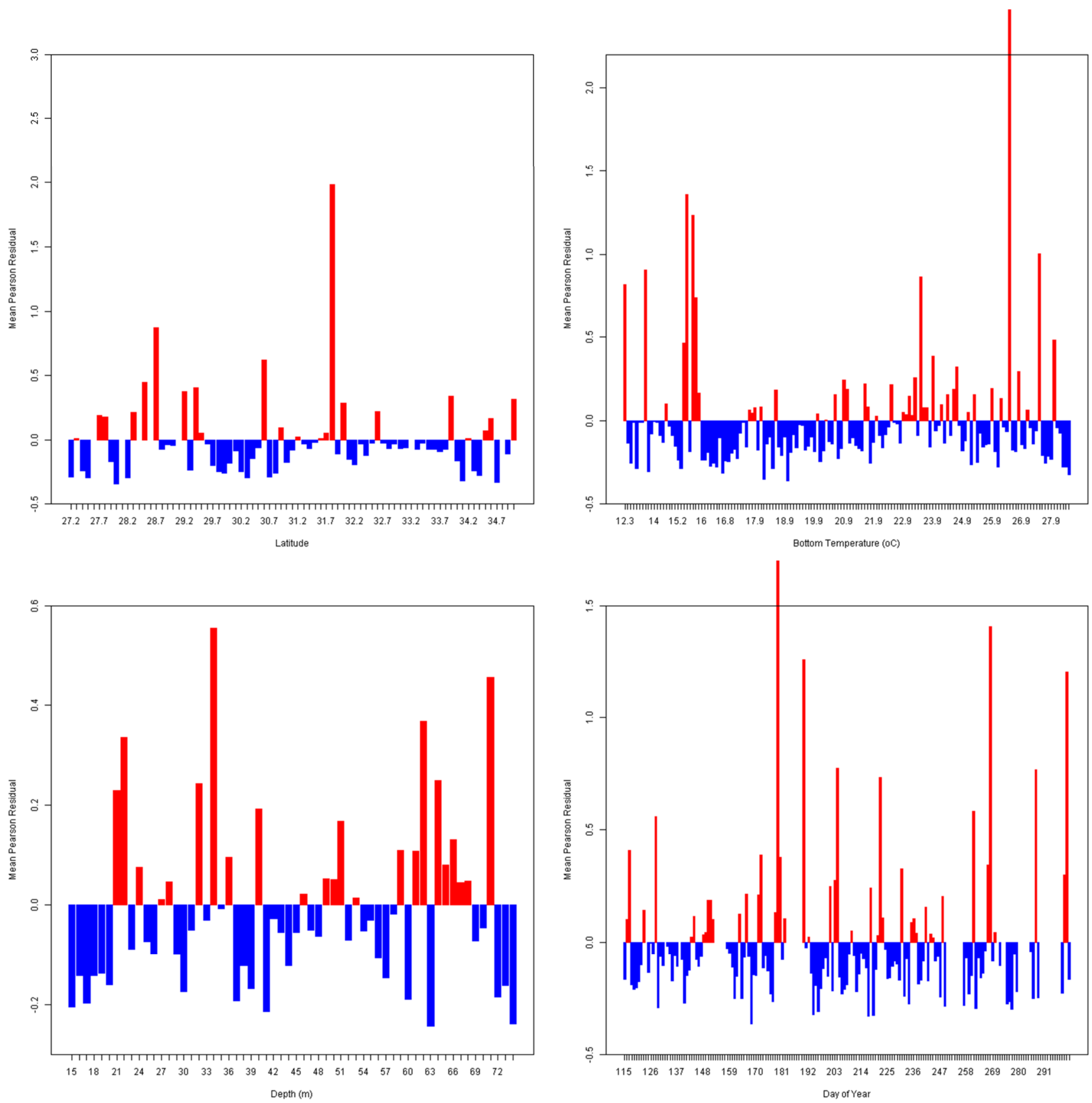


Figure 29. Mean Pearson residual versus included covariates for the final ZINB model.

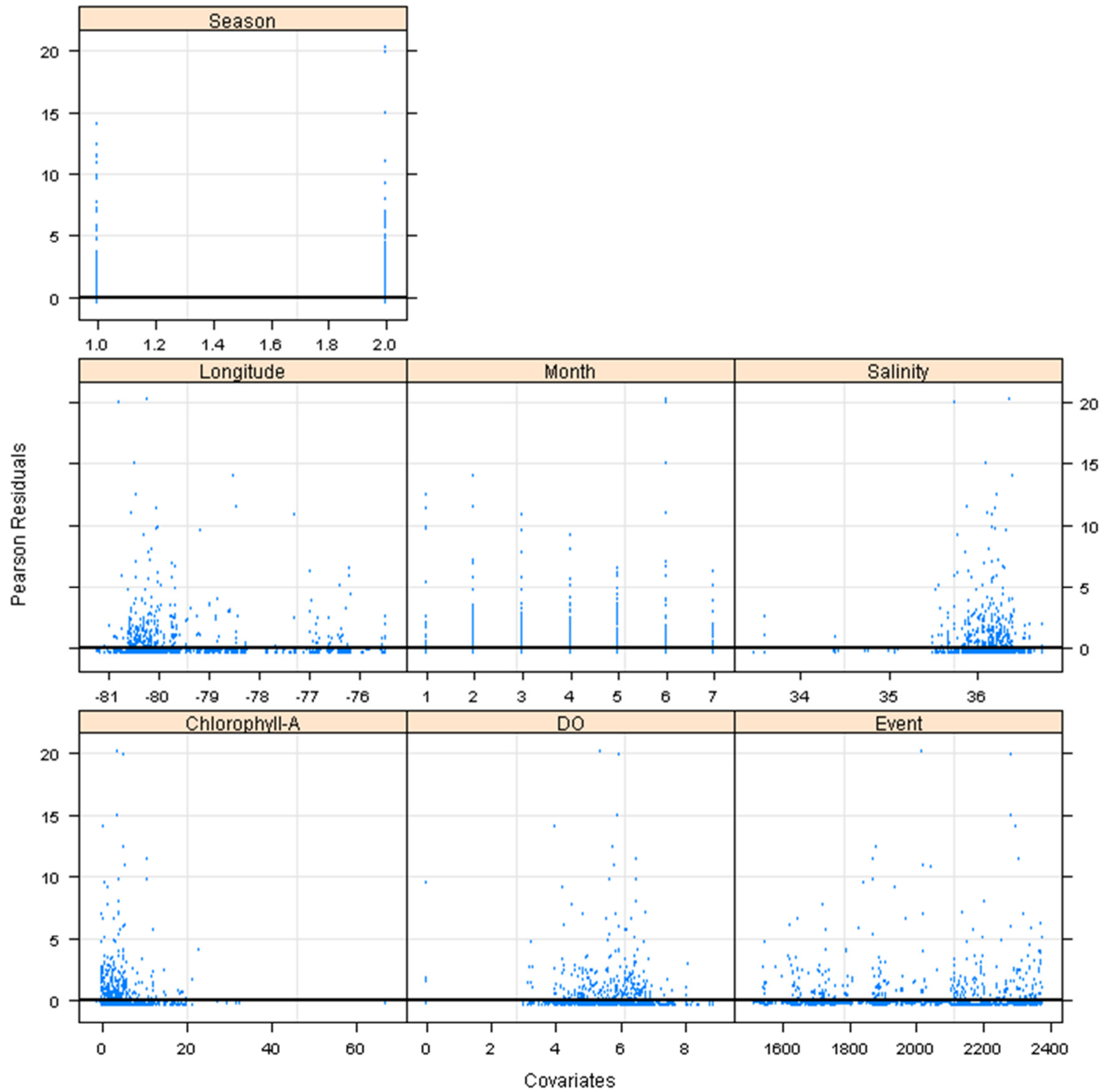


Figure 30. Pearson residuals versus covariates excluded from the final ZINB model.

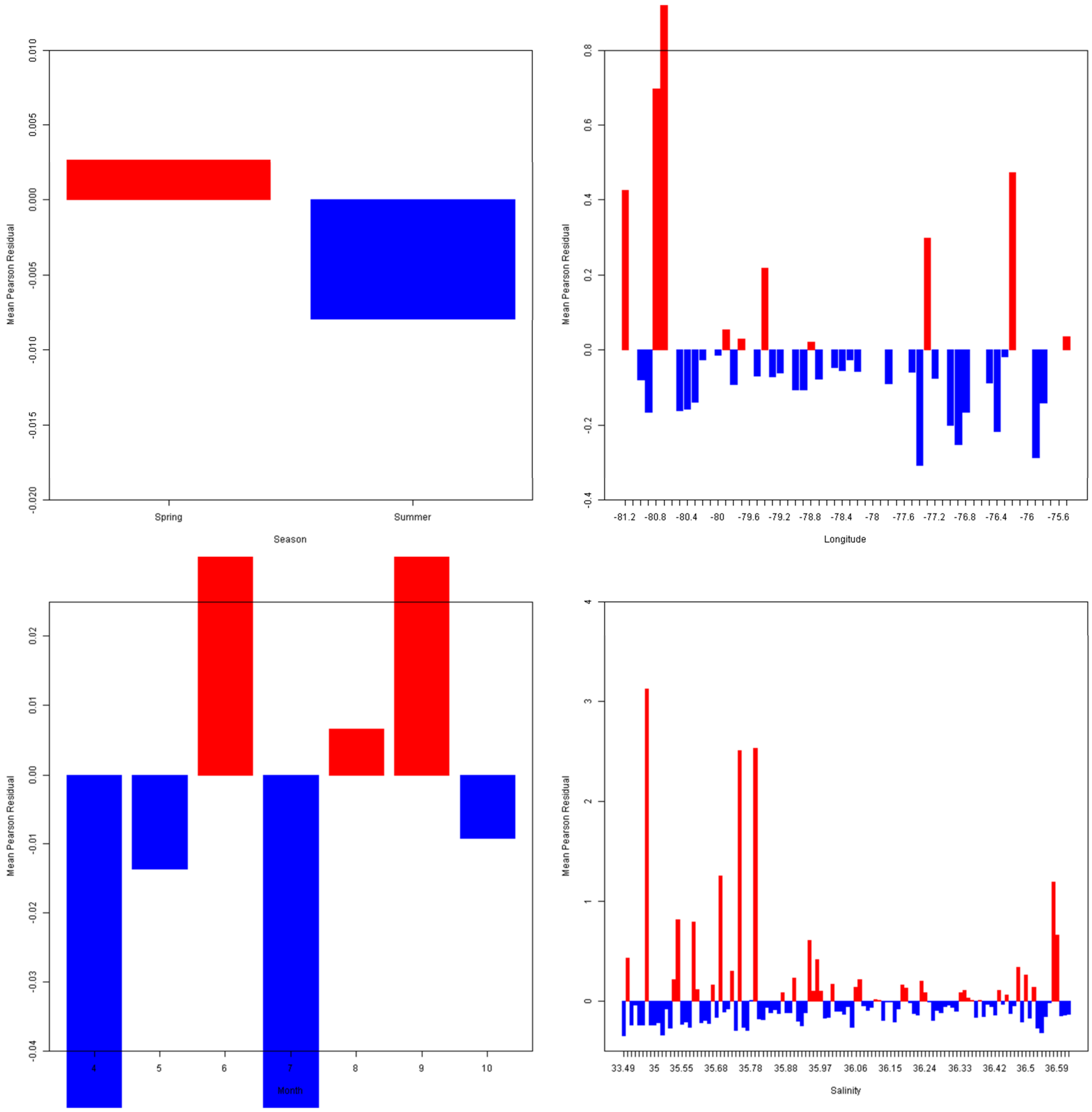


Figure 31. Mean Pearson residuals versus covariates excluded from the final ZINB model.

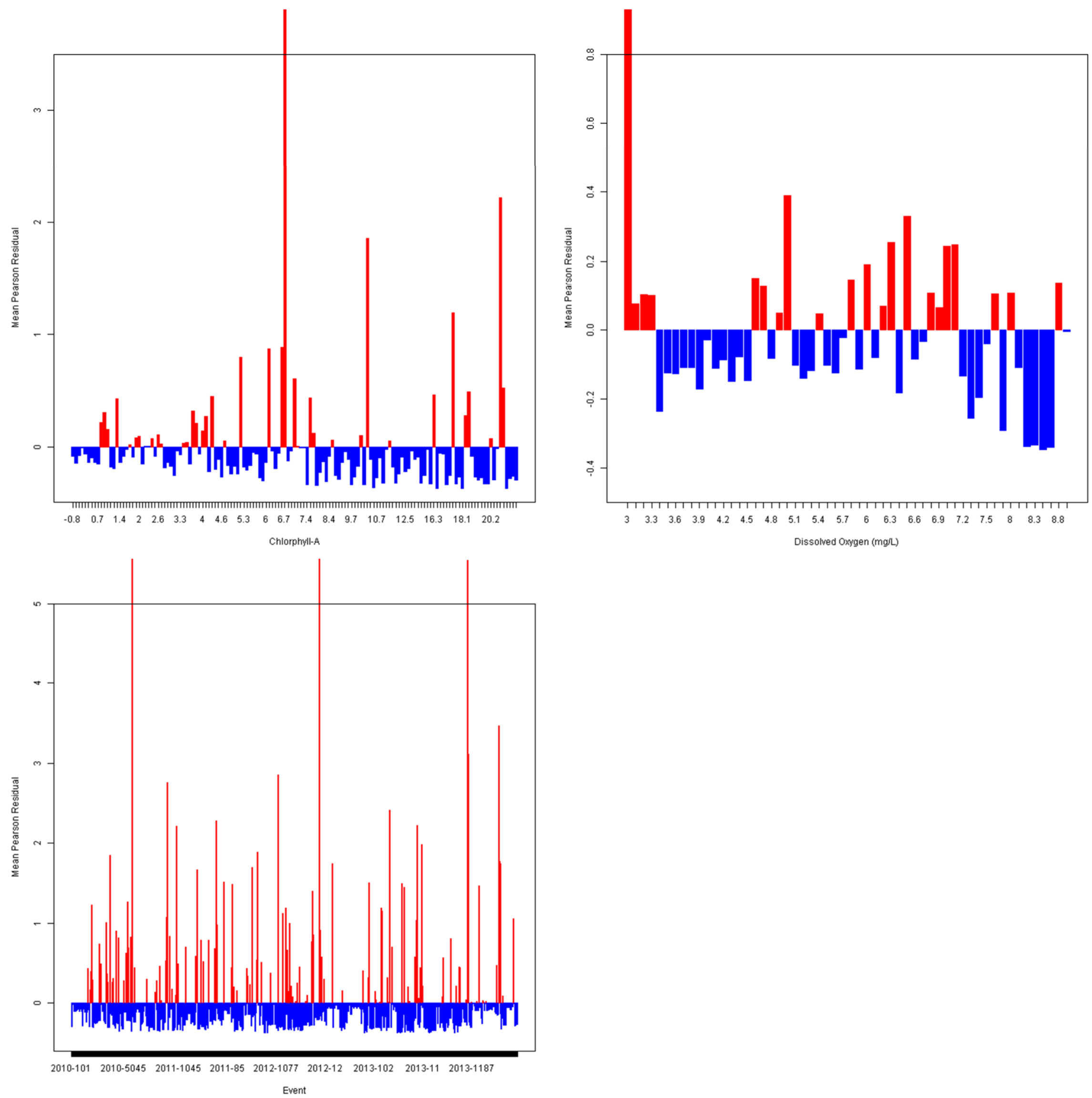


Figure 31 (cont). Mean Pearson residuals versus covariates excluded from the final ZINB model.

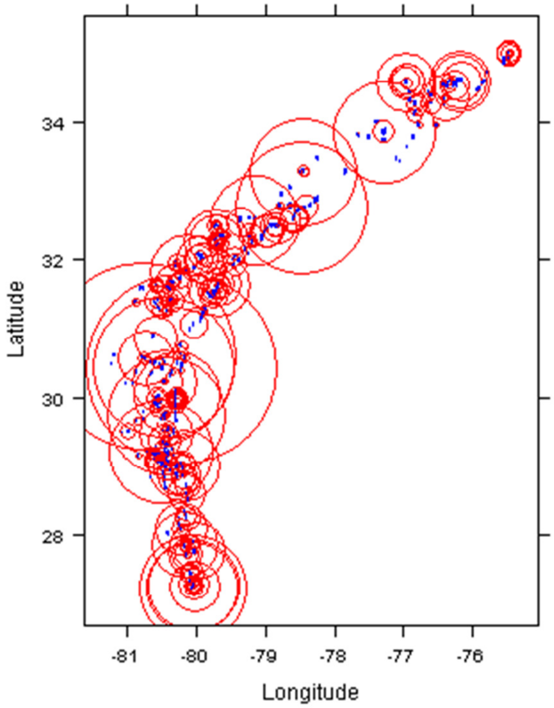


Figure 32. Spatial distribution of Pearson residuals. Red circles indicate positive Pearson residuals and blue circles represent negative Pearson residuals. Size of the circle is indicative of the magnitude of the residual with larger circles corresponding to larger Pearson residual values.

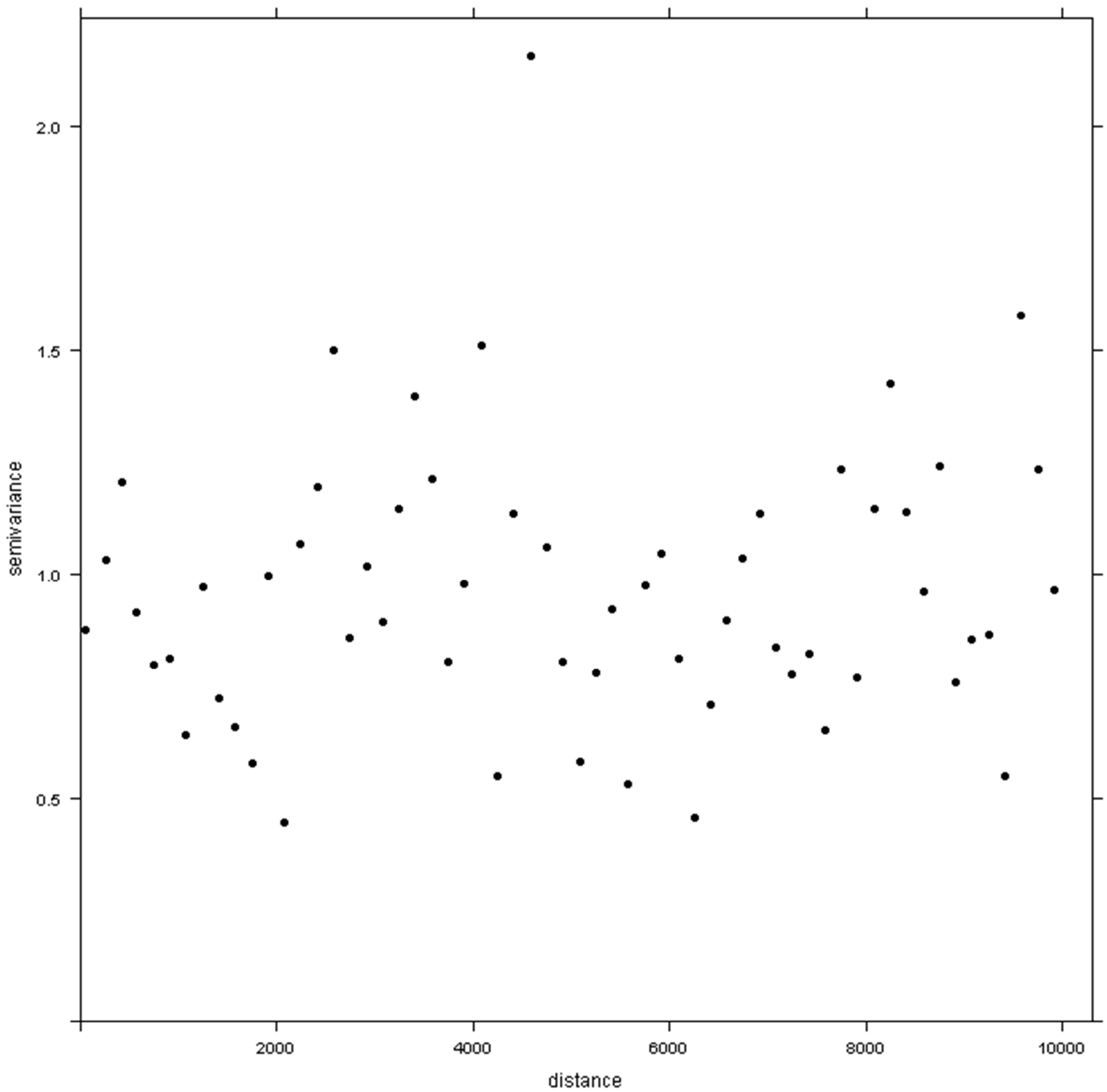


Figure 33. Sample variogram of Pearson residuals. The sample variogram is limited to 10,000 m (10 km).

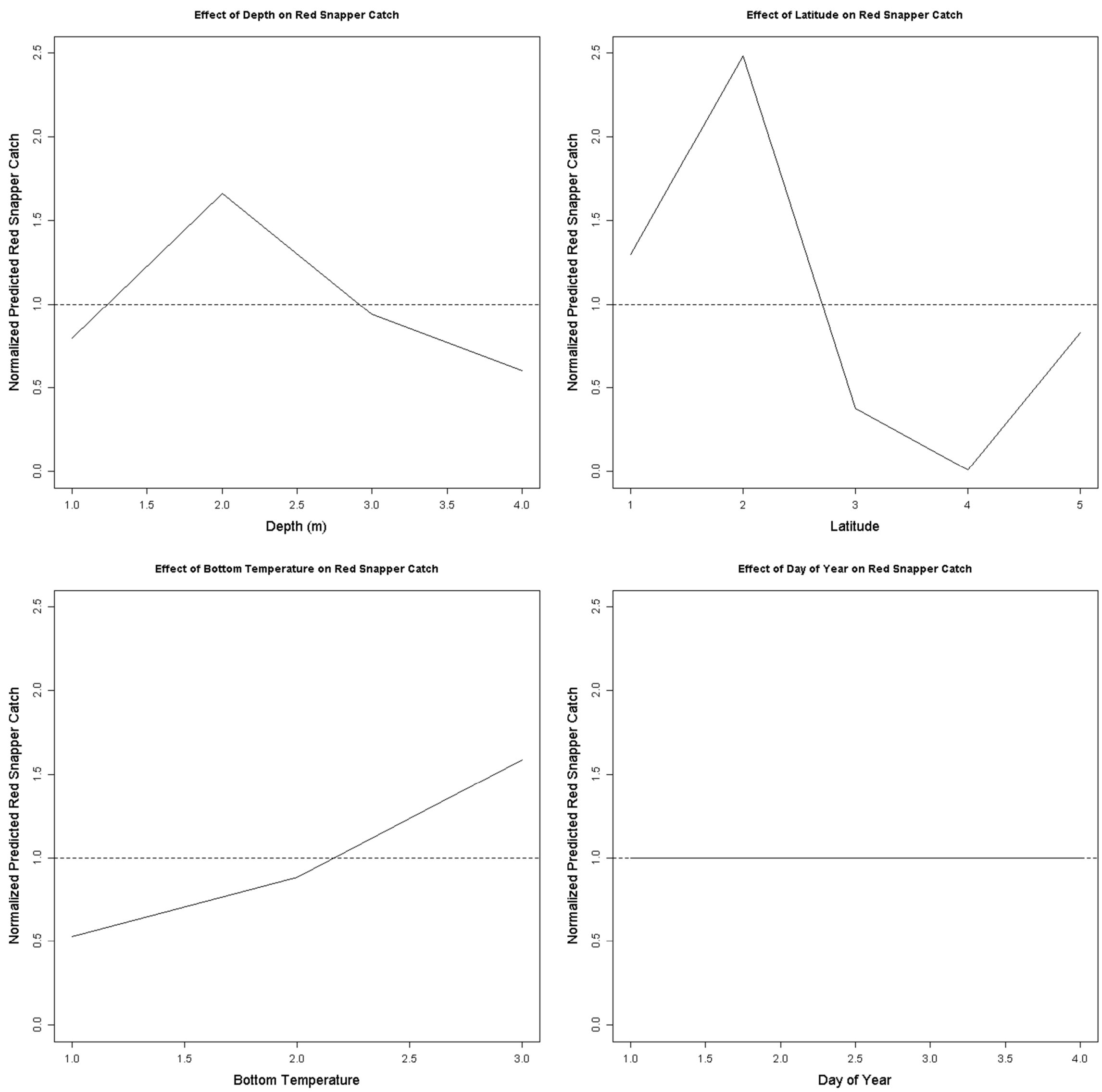


Figure 34. Covariate effects on predicted Red Snapper catch (Day of Year not included in the final model).