Snowy Grouper Fishery-Independent Indices of Abundance in US South Atlantic Waters Based on Chevron Trap and Short-bottom Longline Surveys

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Snowy Grouper Fishery-Independent Indices of Abundance in US South Atlantic Waters Based on Chevron Trap and Short-bottom Longline Surveys

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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, length frequencies, and other information. As such, the MARMAP program has primarily used a standard sampling methodology with chevron traps for monitoring purposes since 1990 and short-bottom longlines since 1996. The focus of this report is on developing an annual CPUE index for snowy grouper (*Hyporthodus niveatus*) based on chevron trap catches from 1996 to 2012 and short-bottom longline catches from 1996 to 2011.

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, Assessment and Prediction, South Atlantic Region (SEAMAP-SA) program provided funding to complement MARMAP efforts. A particular goal of the SEAMAP-SA complement is to assist with the expansion of the geographical sampling coverage of the current MARMAP program. Upon the identification of previously un-sampled live bottom habitat, appropriate sites were added to the list of available monitoring stations used in the development of annual relative abundance indices (see Ballenger et al. 2013a, Figure 1). In addition, the SEAMAP-SA complement funding allowed for expanded sampling in marine protected areas (MPAs). Sampling efforts originating from SCDNR are now referred to as the MARMAP/SEAMAP-SA Reef Fish Survey.

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) in Beaufort, NC. This fishery-independent survey was designed to further complement the historical

MARMAP/SEAMAP-SA reef fish monitoring efforts. SEFIS activities were coordinated closely with MARMAP/SEAMAP-SA Reef Fish Survey staff. To this effect, MARMAP/SEAMAP-SA Reef Fish Survey staff trained SEFIS personnel and have been participating in SEFIS monitoring cruises. SEFIS has used gear and methodologies identical to MARMAP/SEAMAP-SA Reef Fish Survey to maintain the integrity of the long-term data set. In addition to expanding the sampling efforts geographically, SEFIS also allowed the introduction of video as a new sampling gear to develop new indices of relative abundance. In 2010, SEFIS program sampling was designed almost exclusively to identify previously un-sampled live bottom areas off Florida and Georgia. In 2011, for logistical and cost-savings reasons and since all programs were using identical sampling methods, it was decided that the SEFIS program would concentrate sampling efforts in waters off Georgia and Florida, while the MARMAP/SEAMAP-SA Reef Fish survey would concentrate its efforts off South Carolina and North Carolina. Each program also would continue efforts to investigate new live bottom habitat. In combination, the addition of the SEAMAP-SA complement and the SEFIS program to the MARMAP survey allowed for the expanded range and increase in monitoring station samples observed in 2011 and 2012 (see Figure 1).

Objective

This report presents a summary of the fishery-independent monitoring of snowy grouper in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS). Specifically, it presents annual nominal catch per unit effort (CPUE) of snowy grouper from chevron traps and short-bottom longlines. Also included are annual CPUE estimates for chevron trap catches from 1996 to 2012 and for short-bottom longlines from 1996 to 2011 standardized by a zero-inflated statistical model. 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 MARMAP/SEAMAP-SA/SEFIS database accessed in January, 2013, and include data collected through the 2012 sampling season.

Methods

Sample Collection

As the current fishery-independent reef fish monitoring in the US South Atlantic region is accomplished via the combined efforts of MARMAP / SEAMAP-SA Reef Fish Survey and SEFIS we refer to these efforts as the “SAB Reef Fish Survey”.

The MARMAP program is the first and longest running of these efforts, first conducting sampling of demersal fish assemblages of the US South Atlantic region in 1972. Early on, the sampling strategy changed such that research efforts became more focused on economically important reef fishes (e.g. sea basses, snappers, groupers, porgies, tilefishes, and grunts), which are found most commonly in live/hard bottom habitats of the continental shelf and shelf edge. To target these economically important reef fishes, the MARMAP program used a variety of gears in the early years (MARMAP 2009). Beginning in 1990 the MARMAP program began using primarily chevron traps for monitoring purposes, which catch a diverse array of sizes and species of fish, including snowy grouper. Subsequently, beginning in 1996 the MARMAP program began using a short-bottom longline to target reef fish species commonly occurring on high relief hard-bottom habitats associated with the continental shelf break.

In recent years, SEAMAP-SA Reef Fish Survey and SEFIS have adopted chevron trap and short-bottom longline sampling methodologies identical to those established by MARMAP. 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 Table 1 for gear deployment summary).

The standard SAB Reef Fish Survey sampling area includes waters of the continental shelf and shelf edge between Cape Hatteras, NC, and St. Lucie Inlet, FL, though over the years the majority of sampling has occurred between Cape Lookout, NC, and Ft. Pierce, FL (Figure 1 and Figure 2). Throughout this range, we sample monitoring stations from May through September each year, though we have conducted some additional surveys prior to and after these months in some years.

In conjunction with reef fish sampling, the SAB Reef Fish Survey collects oceanographic data using a CTD. Standard CTD cast data include geographic location, water depth, temperature and salinity. At times, additional water quality variables also have been measured, including the concentrations of dissolved oxygen, chlorophyll-A, phosphate ($P0_4$), nitrite ($N0_2$) and nitrate ($N0_3$). In general, a CTD cast is conducted during the soak time for a given monitoring gear set, where water column variables then are associated with all monitoring gear deployments during that given set. A set is composed of one to six (generally six) traps or longlines deployed at the same time in the same geographic area.

Chevron Trap

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 traps to compare the efficiency of the three different trap designs at capturing reef fishes on live/hard bottom habitats (Collins 1990). During this study, each trap design was deployed simultaneously on reef habitat while anchoring all traps to the research vessel. 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 traps. Currently, all three fishery-independent monitoring programs continue to utilize the chevron trap as their primary monitoring gear.

Each year, between 500 and 700 stations are selected from a database of approximately 2,200 known live/hard bottom areas identified for monitoring via fish traps. Annually, we choose the selected stations in a manner such that no station sampled in a given year is closer than 200 m to any other selected station, though the minimum difference between stations sampled annually is closer to 400 m on average. Traditionally, chevron traps have been deployed at depths ranging from 13 to 218 m, although the depth of usage generally is restricted to less than 100 m. The vast majority of the deeper deployments occurred in 1997.

Chevron traps are arrowhead shaped, with a total interior volume of 0.91 m^3 (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 sp.* most often used. Four whole clupeids on each of four stringers are suspended within the trap and approximately 8 additional loose clupeids, with their abdomen sliced open, are placed loose in the trap (Collins 1990; MARMAP 2009). Subsequently, we attach an individual trap using a brommel hook 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 using a brommel hook, with the end of the trailer line clipped to a Hi-Flyer buoy. Generally traps are deployed in sets of six with a minimum distance between sampling stations of 200 m (MARMAP 2009). Traps are retrieved in chronological order of deployment, using a hydraulic pot hauler, after an approximately 90-minute soak time.

Although the chevron trap time series has been continuous from 1990 to present, the decision was made to truncate the time series for SEDAR 36 during a pre-data deadline webinar for two reasons. First, snowy grouper are primarily a deep-water species. The majority of samples collected in the first 5 years of the SAB Reef Fish Survey were shallow relative to the rest of the time series. For many of the species collected by chevron traps, this is not a concern due to their availability to the gear in shallow water but for deep-water species such as snowy grouper this caused a high number of zero catches. Second, several of the early years of the time series had either no catches or very low catches of snowy grouper (1991, 1992, 1995), most likely due to the shallow nature of the survey in those years. Standardization techniques, including the delta-Generalize Linear Model and Zero-Inflated Negative Binomial model cannot standardize annual CPUE in years with no catches of the species of interest. In a deviation from SEDAR 4, we present chevron trap data from 1996 to the terminal year of the assessment 2012 rather than the full time series.

Short-bottom Longline

In 1996, MARMAP initiated longline gear deployments to monitor the snapper-grouper complex in areas chevron traps cannot sample adequately, such as depths greater than 90 m and with high vertical relief. Although there were some trial deployments in 1979 and 1987, the short-bottom longline (SBLL) survey has been deployed in its current configuration since 1996 to meet this objective. This gear replaced the previously used Kali pole longline gear for sampling reef fishes in these habitats (Russell et al. 1988). In previous reports, the MARMAP program referred to this gear as a “vertical longline” since it was commonly draped over vertical relief. This name was changed to SBLL in 2009, following the Southeast Area Fisheries Independent Survey Workshop (Williams and Carmichael 2009) to avoid confusion with “true” vertical longlines that fish with hooks off the bottom in the water column.

Similar to the chevron traps, SBLL stations are chosen randomly from a database of approximately 300 previously identified SBLL monitoring stations each year. Criteria employed are that stations must be more than 200 m apart and contain high-relief live bottom. The majority of SBLL deployments have been made by MARMAP / SEAMAP-SA on board the *R/V Palmetto*, although SEFIS deployed fewer than 20 SBLLs on board the *R/V Savannah* in 2010.

The SBLL groundline is 25.6 m (~84 ft) of 6.4-mm diameter treated solid braid Dacron (polyester) ground line dipped in green copper naphthenate. Twenty gangions with non-offset circle hooks (almost exclusively #5 Eagle claw size, but in some years some #7 were used) are placed 1.2 m (~4 ft) apart on the groundline, which is tethered to the surface using an 8-mm (5/16 in) polypropylene line attached to a polyball buoy. The gangions consist of an AK snap, 0.5 m of 90 kg monofilament and a tuna circle hook, and are baited (double hooked) with a whole squid (*Illex* sp. or *Loligo* sp.). The polyball buoy is attached to a Hi-Flyer buoy using a 10-m trailer line composed of 8-mm (5/16 in) polypropylene line. Ten to 11 kg weights are attached at each end of the groundline. Soak time is approximately 90 minutes, and the gear is retrieved by a pot hauler. Up to six SBLLs are deployed at one time, with a minimum distance between sampling stations of 200 meters.

In the terminal year of the assessment, 2012, the standard SAB Reef Fish Survey SBLL component was halted due to significant reductions in funding and sea days. Two cruises did deploy the SBLL, however, these deployments deviated from the standard procedure in that the sampling locations were not determined randomly but rather were sampled opportunistically when travel time and day length prevented the ship from reaching chevron trap monitoring stations on that same day. As such, in this report we present short-bottom longline data from 1996 to 2011 when sampling and station selection followed the standard protocols rather than the full time series which would have included 2012 data collected in a non-standard method.

Oceanographic Data

While traps are soaking, oceanographic variables (mainly temperature and salinity) were determined using a CTD. From 1993 through the most recent sampling year (2012) we used Sea-Bird models SBE-19 or SBE-25 CTDs. The SBE-19 measured pressure, temperature, depth, and salinity, while the SBE-25 model was fitted with additional sensors for detecting dissolved oxygen and chlorophyll A. All CTD's are calibrated by authorized dealers/personnel according to the manufacturer's guidelines. Bottom temperature (°C) is the temperature of the deepest recording within 5 m of the bottom.

Data and Treatment

Data and Nominal CPUE Estimation

Available data for each trap or longline fished (deployment) included a unique collection number, date of deployment, soak time (provided in minutes), latitude, longitude, bottom depth (m), catch code, number of snowy grouper captured, aggregate weight of snowy grouper, and bottom temperature. We used numbers, instead of weight, of snowy grouper for all analyses. Estimates of relative abundance, or catch per unit effort (CPUE), were standardized to the number of snowy grouper caught per trap.

Prior to modeling, a subset of the trap data was selected for CPUE analysis based on several criteria. First, only the monitoring stations that had a soak time between 45 and 150 minutes were retained. Second, no data from reconnaissance collections were included (traps not conducted on confirmed live-bottom habitat). Third, if a gear malfunctioned or the catch was mixed among collections that collection was not included. As such, only trap collections with catch codes of 0 (no catch), 1 (catch with finfish), and 2 (catch with no finfish) were used. Finally, the traps retained for CPUE analysis were further delineated by bottom depth. The depths retained for analysis were 35-229 m, determined by the depth range at which 100% of snowy grouper were collected by any gear used by the survey. This was done to reduce the number of zero catches from locations outside the normal depth range of snowy grouper. To visually assess whether this depth range was appropriate a plot of the sampling density of all chevron trap (Figure 3) and short-bottom longline (Figure 4) collections across the 35-229 m depth range and snowy grouper positive collections for each gear across the 35-229 m depth range is provided. The collections under these constraints/criteria were included in the analyses and referred to as "included collections" below.

Zero-Inflated Model CPUE Standardization

CPUE was standardized among years using a zero-inflated count data model. Such a treatment of the data was suggested at the SEDAR 32 data workshop for gray triggerfish CPUE due to the poor fit to the observed data using a lognormal error distribution for the positive component of the delta-GLM model (see Ballenger et al. 2013a, Figure 9). A similar issue was apparent during preliminary evaluation of the data using a delta-GLM model for snowy grouper CPUE in both chevron traps and short bottom longlines. Investigation of this technique to model CPUE data was also suggested during the Fishery-Independent Survey Independent Review (SEFSC 2012) held in 2012. Finally, as is the case with many ecological count data sets (Zuur et al. 2009), the observed CPUE data appeared to be zero-inflated (Figures 5-8) 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). Most of the following discussion is based upon that work. 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).

How to Deal with Excess Zeros?

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).

Given this excess in the number of zeros, the question arises why there are extra zeros. Zuur et al. (2009) suggests there are four different potential sources for zeros in a count data set:

1) Structural zeros (a.k.a. naughty naughts or bad zeros) – zeros due to sampling outside the habitat range that an animal lives in. To minimize zeros arising from this source in our analysis we employed the depth constraint to restrict our analysis to only those depths where we have a reasonable chance of catching gray triggerfish.
2) Design error, where poor experimental design or sampling practices are thought to be the reason – for example you are working with a migratory species and you only sampled when they would not be expected to be present because of their migratory nature. This type of zero is not likely for gray triggerfish as we do not think they are highly migratory or use different habitats at different times of the year.
3) Observer error – inability of an observer to distinguish between species. This is not a likely source of zeros in the fishery-independent data set as gray triggerfish are readily identifiable.
4) The "animal" error – the habitat is suitable, but the site is not used by the species.

The zeros due to design and observer errors are also called false zeros or false negatives (in a perfect world we should not have them) 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 and mixture models, with the difference between the two classes arising due to differences in how they deal with zeros.

So called two-part (or hurdle) models consist of two parts:

1) Data are considered as zeros versus non-zeros and a binomial model is used to model the probability that a zero value is observed with covariates potentially included in the binomial model and
2) Non-zero observations are modeled with a zero-truncated Poisson (ZAP) or zero-truncated negative binomial (ZANB) model, and a (potentially different) set of covariates can be used (Zuur et al. 2009).

These models do not discriminate between the four different types of zeros and simply treat a zero as a zero. In this concept, the name hurdle comes from the idea that whatever mechanism is causing the presence of gray triggerfish, it has to cross a hurdle before values become non-zero.

Mixture models (zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB)) models work rather differently, with the zeros being modeled via two different processes: the binomial process and the count process (Zuur et al. 2009). Once again, a binomial generalized linear model (GLM, with the inclusion of potential covariates) is used to model the probability of measuring a zero while the count process is modeled by a Poisson (ZIP) or negative binomial (ZINB) GLM. As such, the fundamental difference between mixture and hurdle models is that the count process can produce zeros in mixture 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 positive versus all other types of data (counts and true zeros; Zuur et al. 2009).

Given the biological knowledge of snowy grouper and the sampling design of the SAB Reef Fish Survey, we compared model fits with the ZINB method to those of the nominal CPUE estimation and delta-GLM method based on conclusions drawn during SEDAR 32 and recommendations of SEDAR 36 data providers and assessment scientists.

Mathematics of ZINB Models

To understand the math underlying ZINB models, one most understand how the question "what is the probability that you have zero counts?" is answered. Let $P(Y_i)$ be the probability that we catch a gray triggerfish at site *i*. The answer to the question is

$$P(Y_i = 0) = P(\text{False Zeros}) + \big(1 - P(\text{False zeroes})\big) * P(\text{Count process gives a zero}) \quad (1)$$

In this manner we divide the data into two imaginary groups: the first group contains only zeros (the false zeros) and the second group is the count data, which may produce zeros (true zeros) as well as values larger than zero. From the data, we do not know which of the observations with zeros belong to a specific group. All we know is that the non-zeros (the counts) are in group 2.

To predict the probability of obtaining a false zero, we assume that the probability that Y_i is a false zero is binomially distributed with probability π_i. The probability that Y_i is not a false zero is equal to $1 - \pi_i$. Substituting into Equation 1:

$$P(Y_i = 0) = \pi_i + (1 - \pi_i) * P(\text{Count process at site } i \text{ gives a zero}). \quad (2)$$

Now the question becomes "how we model the count process?". The answer: assume that the counts follow a Poisson or negative binomial (geometric distribution special case of negative binomial) distribution which gives rise to the terms zero-inflated *Poisson* (ZIP) and zero-inflated *negative binomial* (ZINB), in our case ZINB is more appropriate as the negative binomial error distribution allows for overdispersion from the non-zero counts.

Let us assume for simplicity that the count Y_i follows a Poisson distribution with expectation μ_i. The probability function of count Y_i is

$$f(y_i; \mu_i | y_i \geq 0) = \frac{\mu^{y_i} * e^{-\mu_i}}{y_i!}. \quad (3)$$

The solution to this probability function for $P(Y_i = 0) = P(\text{Count process at site } i \text{ gives a zero})$ is

$$f(y_i = 0; \mu_i | y_i \geq 0) = \frac{\mu^0 * e^{-\mu_i}}{0!} = e^{-\mu_i}. \quad (4)$$

Substituting Equation 4 into Equation 2 we have

$$P(y_i = 0) = \pi_i + (1 - \pi_i) * e^{-\mu_i}. \quad (5)$$

The probability that we measure a 0 is equal to the probability of a false zero, plus the probability that it is not a false zero multiplied by the probability that we measure a true zero.

To determine the probability that Y_i is a non-zero count, we use the probability equation

$$P(Y_i = y_i | y_i > 0) = (1 - \pi_i) * \frac{\mu^{y_i} {}_* e^{-\mu_i}}{y_i!}. \quad (6)$$

Hence, the probability functions for a ZIP model becomes:

$$f(y_i = 0) = \pi_i + (1 - \pi_i) * e^{-\mu_i}$$

$$f(Y_i = y_i | y_i > 0) = (1 - \pi_i) * \frac{\mu^{y_i} {}_* e^{-\mu_i}}{y_i!}. \quad (7)$$

Just as in a Poisson GLM including extra covariates, we model the mean $\mu_i$of the positive count data based on covariates as

$$\mu_i = e^{\alpha + \beta_1 X_{i1} + \cdots + \beta_q X_{iq}} \quad (8)$$

where the symbol Xrepresents each covariate and the regression coefficients to be estimated are represented by the symbols α (intercept) and β. For the binomial model with covariates, we model the probability of having a false zero, π_i, as

$$\pi_i = \frac{e^{\upsilon + \gamma_1 Z_{i1} + \cdots + \gamma_q Z_{iq}}}{1 + e^{\upsilon + \gamma_1 Z_{i1} + \cdots + \gamma_q Z_{iq}}} \quad (9)$$

where the symbol Z represents each covariate (possibly the same or different covariates include in the Poisson GLM) and the regression coefficients to be estimated are represented by the symbols υ (intercept) and γ. It is now a matter of formulating the likelihood equation based on the probability functions in Equation 7; take the logarithm, get derivatives, set them to zero, and use an optimization routine to get parameter estimates and standard errors.

The only difference between a ZIP and ZINB is that the Poisson distribution for the count data is replaced by the negative binomial distribution. This allows for overdispersion from the non-zero counts. The probability functions of a ZINB are

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

$$f(Y_i = y_i | y_i > 0) = (1 - \pi_i) * \frac{\Gamma(y_i + k)}{\Gamma(k) * \Gamma(y_i + 1)} * \left(\frac{k}{\mu_i + k}\right)^k * \left(1 - \frac{k}{\mu_i + k}\right)^k. \quad (10)$$

Mean and Variance in ZINB Models

In a negative binomial GLM we have $\mathrm{E}(Y_i) = \mu_i$ and $\mathrm{var}(Y_i) = \mu_i + \mu_i^2/k$. In ZINB, the expected mean and variance are slightly different due to the definition of the probability functions in Equations (7) and (10).

The mean and variance of a ZINB are

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

$$\mathrm{var}(Y_i) = (1-\pi_i) * \left(\mu_i + \frac{\mu_i^2}{k}\right) + \mu_i^2 * \left(\pi_i^2 + \pi_i\right). \tag{11}$$

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

Application

In the development of the zero-inflated CPUE model for snowy grouper, we modeled CPUE as catch per trap and catch per longline. This deviates from how fishery-independent indices for the SEDAR process have traditionally calculated CPUE. Traditionally, fishery-independent indices were modeled as catch per gear deployment (trap or longline) per hour. The difference between these two formulations is how you employ soak time (or sample duration) for calculating the CPUE for a given deployment. In the current model formulation, instead of dividing the catch per deployment by the soak time (in hours), creating a catch rate, we included soak time as an offset term in both the binomial and catch model portion of the zero-inflated model. In this manner, soak time is treated as an offset term with its parameter estimate constrained to 1. What this means theoretically is that by defining an offset variable you are adjusting for the amount of opportunity for the gear to capture a snowy grouper, therefore a deployment with a soak time of 120 minutes is more likely to catch a snowy grouper than a deployment with a soak time of 60 minutes. Such a treatment of the catch data was suggested during the Fishery-Independent Survey Independent Review (SEFSC 2012) and by analysts during the SEDAR 32 data workshop. The use of an offset term is a common method to account for the level of "exposure" when modeling count data.

As indicated above, 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 the current analysis, our full model included the covariates sampling depth (m), latitude (^{o}N), bottom temperature (^{o}C), and day of year (DOY) in addition to year. Year is necessary to include because standardized CPUE estimates by year are the desired response variable of the model. Bins for sampling depth, latitude, bottom temperature, and DOY were determined based on the quartiles of their distribution such that each bin represented 50% of the available data. Please note, for model stability concerns, it was necessary to develop bins for the chevron trap based upon the sampling distribution of positive traps with respect to covariates instead of the sampling distribution of all traps. Such a binning procedure for sampling depth and latitude was suggested by the indices working group during the SEDAR 32 data workshop to help achieve a balanced design. Table 2 provides a summary of the bins used for each of the covariates in the analysis. Figures 3 and 9-11 provide plots of the sampling distribution of chevron trap collections and snowy grouper positive chevron trap collections throughout 1996-2012 with respect to each considered covariate. Figures 4 and 12-14 provide plots of the sampling distribution of short-bottom longline collections and snowy grouper positive short-bottom longline collections throughout 1996-2011 with respect to each considered covariate.

Selection of the covariates included in the final model (both binomial 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

2.15.0; R Development Core Team 2012). The zero-inflated models in R were developed using the function zeroinfl available in the package *pscl* (Jackman 2011; Zeileis et al. 2008).

Results

Chevron Traps

From 1990 to 2012 we made 9,400 chevron trap monitoring station deployments, averaging 408 collections per year (range: 249-842). Of these collections, we removed 2,568 collections from 1990 to 1995, 168 due to soak times out of the typical range (<45 or >150 minutes), 3,325 due to sampling depths outside the range for snowy grouper, and 89 due to damage or loss of gear or deviations in catch processing from standard protocols. We included catch data from 3,280 traps for snowy grouper nominal CPUE (range: 84-457 per year; Table 1).

Zero-Inflated CPUE

For development of the zero-inflated model, missing covariate data related to latitude and temperature resulted in the removal of 223 chevron trap collections, or 6.8% of the data included in the nominal CPUE analysis (Table 3). This resulted in a total of 3,057 included collections retained in the analysis, ranging from 84 to 426 per year (Table 1). Please note that due to missing bottom temperature and latitude data, we removed 19% of available collections for the years 1996 and 2011 (Table 3). Because of the low encounter rate of snowy grouper in the chevron traps relative to many other snapper-grouper species, exclusion of this data could affect annual CPUE estimates.

Based on the full model, AIC selection suggested that a negative binomial error distribution that allows for further overdispersion of the data in the count model was more appropriate for modeling snowy grouper CPUE than the Poisson error distribution (negative binomial AIC = 1093.7271 vs.Poisson AIC = 1095.7965). A step-wise backward selection routine using AIC dropped the year term from the binomial component of the ZINB and the latitude and bottom temperature terms from the count model (Table 4). A plot of the observed and predicted number of snowy grouper caught in included chevron trap collections suggests the ZINB model was successful at capturing the observed catch pattern (Figures 5 and 6). The proportion of traps in a sampling year with positive snowy grouper catch is provided in Table 1.

Standardization using the ZINB model resulted in annual coefficient of variation (CV) estimates on the order of approximately 45.4%. Individual year CV estimates ranged from as low as 20.7% to as high as 92.1% (Table 5). These CVs were similar to the CV estimates obtained from the nominal CPUE model (Table 6).

Standardized annual CPUE estimates normalized to the series average indicates that CPUE has been variable throughout the time series, increasing over the period 1996-2002, decreasing from 2002 through 2008, and then showing signs of a slight increase since 2008 (Figure 15). However, depending on the model formulation, the perceived pattern of CPUE of snowy grouper in chevron traps is highly variable (Figure 16). However, the model presented above was chosen as best representing chevron trap CPUE because in attempts to standardize CPUE with respect to environmental variables (in contrast to the nominal index), addresses the poor model fit associated with the delta-GLM model, and exhibited a much higher convergence rate (i.e. more robust; 99.8% in 10,000 bootstraps) than the alternative ZINB configuration (49.3% in 15,000 bootstraps).

Short-bottom Longline

From 1996 to 2012 we made 797 short-bottom longline monitoring deployments, averaging 43 collections per year (range: 15-85). Of these collections, we removed 22 collections from 2012, 17 due to soak times out of the typical range (<45 or >150 minutes), 7 due to sampling depths outside the range for snowy grouper, and 40 due to damage or loss of gear or deviations in catch processing from standard protocols. This left a total of 711 short bottom longline collections being retained for the development of snowy grouper nominal CPUE (range: 15-85 per year; Table 1).

Zero-Inflated CPUE

For development of the zero-inflated model, missing covariate data related to latitude and temperature resulted in the removal of 80 short-bottom longline collections, or 11.3% of the data included in the nominal CPUE analysis (Table 3). This resulted in a total of 626 included collections retained in the analysis, ranging from 12 to 81 per year (Table 1). Please note that due to missing bottom temperature and latitude data, we removed greater than 10% of available collections for the years 1996, 1998, 2001, 2004 and 2011 (Table 3). Because of the already low annual sample sizes for short-bottom longlines in some years, exclusion of this data could affect annual CPUE estimates.

Based on the full model, AIC selection suggested that a negative binomial error distribution that allows for further overdispersion of the data in the count model was more appropriate for modeling snowy grouper CPUE than the Poisson error distribution (negative binomial AIC = 1327.4253 vs. Poisson AIC = 1362.1071). A step-wise backward selection routine using AIC dropped the latitude term from the binomial component of the ZINB and the year, latitude and depth terms from the count model (Table 7). A plot of the observed and predicted number of snowy grouper caught in included short-bottom longline collections suggests the ZINB model was successful at capturing the observed catch pattern (Figures 7 and 8). The proportion of short-bottom longlines in a sampling year with positive snowy grouper catch is provided in Table 1.

Standardization using the ZINB model resulted in annual CV estimates on the order of approximately 30.0%. Individual year CV estimates ranged from as low as 18.1% to as high as 69.7% (Table 8). These CVs were similar to the CV estimates obtained from the nominal CPUE model (Table 9).

Standardized annual CPUE estimates normalized to the series average indicates that CPUE has been variable throughout the time series, though exhibiting a general increase from the start of the survey through 2009, with a potential decrease in more recent years (Figure 17). However, depending on the model formulation, the perceived pattern of CPUE of snowy grouper in short-bottom longlines is variable (Figure 18). However, the model presented above was chosen as best representing short-bottom longline CPUE because it attempts to standardize CPUE with respect to environmental variables (in contrast to the nominal index) and addresses the poor model fit associated with the delta-GLM model. When choosing between the ZINB models, the model presented above (AIC = 1323.6936) exhibited a much lower AIC score than the one based off the trends report covariate bins (1365.2563) and exhibited a slightly lower AIC score than the best fit models resulting from the ones based on the same covariate bin structure but more simplified full models (ZINB Depth, Temperature and DOY AIC = 1325.8241; ZINB Depth and Temperature AIC = 1326.0029). The convergence rate based on 10,000 bootstrap iterations for the model presented here was still relatively low (57.8%), but higher than all other ZINB models examined (48.0-56.6%).

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Tables

Table 1: Annual total number of fishery-independent collections made by the SAB Reef Fish Survey by survey gear used in the development of nominal and standardized CPUE models as well as the percent of collections used in the development of the standardized models positive for snowy grouper. We only considered those collections that were made at monitoring stations using standard sampling techniques that had a soak time of between 45 and 150 minutes, a catch code of 0 (no catch), 1 (catch with finfish), or 2 (catch without finfish) and a sampling depth of between 35 and 229 m in the formation of nominal CPUE estimates. The number of collections used in the development of standardized CPUE models was equal to or less than that used in the nominal models due to missing covariate data for some collections. Please note that the SEAMAP-SA Reef Fish and SEFIS projects did not begin until 2009 and 2010, respectively.

	Chevron Traps			Short-bottom Longlines		
Year	**Nominal**	**Standardized**	**% Positive**	**Nominal**	**Standardized**	**% Positive**
1996	219	177	6.2%	15	12	33.3%
1997	233	210	7.1%	33	33	42.4%
1998	288	260	3.1%	31	27	44.4%
1999	101	101	3.0%	39	36	36.1%
2000	148	147	1.4%	34	34	50.0%
2001	130	120	10.0%	29	25	52.0%
2002	84	84	6.0%	19	19	52.6%
2003	124	124	5.7%	54	54	46.3%
2004	152	152	5.9%	34	21	19.1%
2005	152	152	2.0%	55	55	32.7%
2006	136	131	6.1%	81	81	16.1%
2007	161	161	3.7%	55	54	9.3%
2008	147	147	1.4%	41	41	48.8%
2009	178	178	2.8%	32	32	15.6%
2010	220	205	4.9%	69	63	46.0%
2011	350	282	3.2%	85	39	25.6%
2012	457	426	4.2%	–	–	–

Table 2: Zero-inflated model covariates (and bins) used in the development of the standardized chevron trap CPUE index for snowy grouper.

Bin #	Latitude (^{o}N)	Depth (m)	Bottom Temperature (^{o}C)	Season
		Chevron Trap		
1	<32.25128	<90	<17.78	<197
2	≥32.25128	≥90	≥17.78	≥197
		Short Bottom Longline		
1	<32.63519	<108	<15.36	<199
2	≥32.63519	≥108	≥15.36	≥199

Table 3: Annual and total exclusion of included monitoring station collections, by gear, from zero-inflated count model analysis due to missing bottom temperature data.

	Chevron Trap			Short-bottom Longline		
Year	**Nominal (n)**	**ZINB (n)**	**% Change**	**Nominal (n)**	**ZINB (n)**	**% Change**
1996	219	177	19.2%	15	12	20.0%
1997	233	210	9.9%	33	33	0.0%
1998	288	260	9.7%	31	27	12.9%
1999	101	101	0.0%	39	36	7.7%
2000	148	147	0.7%	34	34	0.0%
2001	130	120	7.7%	29	25	13.8%
2002	84	84	0.0%	19	19	0.0%
2003	124	124	0.0%	54	54	0.0%
2004	152	152	0.0%	34	21	38.2%
2005	152	152	0.0%	55	55	0.0%
2006	136	131	3.7%	81	81	0.0%
2007	161	161	0.0%	55	54	1.8%
2008	147	147	0.0%	41	41	0.0%
2009	178	178	0.0%	32	32	0.0%
2010	220	205	6.8%	69	63	8.7%
2011	350	282	19.4%	85	39	54.1%
2012	457	426	6.8%	–	–	–
Total	**3280**	**3057**	**6.8%**	**706**	**626**	**11.3%**

Table 4: Results of model selection via backwards selection for the ZINB model of chevron trap CPUE.

Binomial Model	**Count Model**	**AIC**
Year	Latitude + Bottom Temperature	1080.1110
Year	Latitude	1081.5550
Year	Bottom Temperature	1081.7177
Year + Bottom Temperature	Latitude + Bottom Temperature	1083.0305
Year	<none>	1083.2731
Year + Day of Year	Latitude + Bottom Temperature	1084.4793
Year + Bottom Temperature	Latitude	1084.7253
Year + Bottom Temperature	<none>	1086.2172
Year + Day of Year	Latitude	1086.3072
Year + Day of Year	<none>	1087.9202
Year	Latitude + Bottom Temperature + Day of Year	1090.9635
<none>	Latitude	1092.1109
Year	Latitude + Day of Year	1092.8609
<none>	<none>	1093.7271
Day of Year	<none>	1094.0424
Year	Day of Year	1094.4650
Year + Latitude	<none>	1095.8320
Bottom Temperature	<none>	1096.2483
<none>	Day of Year	1096.3593
Year	Latitude + Bottom Temperature + Year	1099.5858
Year + Latitude	Latitude	1100.0826
Year	Latitude + Year	1100.7852
Latitude	<none>	1102.6956
Year	Year	1102.7821
Year + Latitude	Latitude + Bottom Temperature	1103.1307
<none>	Year	1104.0000
Year	Latitude + Depth	1106.3222
Year	Depth	1106.3709
<none>	Depth	1107.2462
Year	Latitude + Bottom Temperature + Depth	1107.2789
Depth	<none>	1151.9840
<none>	Bottom Temperature	1167.1952
Year + Depth	<none>	1196.5259
Year + Depth	Latitude + Bottom Temperature	1198.2518
Year + Depth	Latitude	1199.1314

Table 5: Chevron trap ZINB-standardized CPUE and information associated with chevron trap deployments included in standardized CPUE calculation.

	Depth (m)		Temperature (°C)		Latitude (°N)		Date		ZINB CPUE			
Year	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg.**	**Range**	**Index**	**CV**	**2.5% Quantile**	**97.5% Quantile**
1996	51.5	35-100	20.3	14.2-26.5	31.67	27.92-32.87	7/1	5/2-9/12	0.6972	0.4239	0.3042	1.4402
1997	55.8	35-218	21.8	15.3-27.3	31.51	28.27-34.28	7/15	5/5-9/16	1.0447	0.3311	0.4948	1.8343
1998	52.9	35-92	18.9	9.5-26.8	31.72	28.28-34.23	6/21	3/31-8/18	0.5903	0.3879	0.2586	1.1486
1999	49.0	41-75	21.4	19.0-25.6	31.70	27.27-32.68	7/27	7/13-9/28	1.3620	0.4971	0.0000	2.7168
2000	51.7	35-109	22.8	18.0-26.5	32.2	28.95-33.96	7/6	5/17-9/20	0.1366	0.8148	0.0000	0.4015
2001	50.4	35-91	22.4	17.4-26.1	32.23	30.52-33.97	7/22	5/23-9/20	2.0430	0.2072	1.3777	2.9506
2002	50.3	36-94	22.1	15.2-27.2	31.58	28.95-33.94	7/15	6/18-9/24	3.4960	0.2928	1.6195	5.6662
2003	50.3	35-92	18.4	13.4-21.8	31.71	28.95-32.89	7/21	6/3-8/28	1.0967	0.2735	0.4854	1.6888
2004	50.1	35-91	19.1	16.8-24.0	31.94	29.00-33.96	6/9	5/5-7/21	0.6922	0.5169	0.2501	1.6101
2005	49.4	35-69	23.0	18.0-28.5	31.80	28.95-33.96	7/20	5/3-9/29	1.3643	0.6462	0.0000	3.2924
2006	51.8	36-94	19.7	15.0-23.5	31.84	27.27-32.89	7/13	6/6-9/27	0.7680	0.2929	0.3606	1.2348
2007	51.0	35-92	21.9	16.1-25.4	31.98	28.95-34.28	7/13	5/22-9/12	0.8921	0.5546	0.2687	2.0514
2008	49.9	35-92	21.6	15.2-27.2	31.80	27.27-32.88	7/22	5/6-9/30	0.1487	0.9214	0.0000	0.5041
2009	50.1	35-91	21.7	15.4-27.2	31.79	27.27-33.96	7/21	5/7-9/30	0.4309	0.5355	0.0949	0.9817
2010	51.7	35-92	20.5	12.4-29.4	31.77	28.95-33.97	7/26	5/5-9/25	0.7467	0.3510	0.3405	1.3527
2011	51.8	35-93	20.3	14.8-28.0	30.86	27.27-33.95	7/24	5/21-9/22	0.4562	0.3831	0.1814	0.8554
2012	51.7	35-106	19.8	12.9-26.6	30.89	27.26-33.97	6/27	4/26-10/10	1.0342	0.2798	0.4802	1.6280

Table 6: Alternative models developed to develop an index from chevron trap snowy grouper catch per unit effort estimates. Nominal is an annual geometric mean of CPUE. Delta-GLM Quantile Bins refers to a delta-GLM model developed based upon the depth and temperature bins constructed based on the 25%, 50%, and 75% quantiles of the sampling distribution and latitude and season defined as in the 2012 MARMAP trends report (Ballenger et al. 2013b). ZINB All Covariates by Quantiles refers to a model where all covariates were binned based upon the 50% quantile of the sampling distribution with respect to a given covariate.

	Nominal		**Delta-GLM Quantile Bins**		**ZINB All Covariates By Quantiles**	
Year	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**
1996	2.0351	0.2901	0.8776	0.6276	1.7013	0.4782
1997	1.8995	0.3658	0.8978	0.5976	1.4752	0.6029
1998	0.6472	0.3735	0.6465	0.6264	0.8427	0.9525
1999	0.3447	0.5735	1.0304	0.7708	1.5917	0.5368
2000	0.2381	0.7758	0.3640	1.0895	0.6627	1.8227
2001	3.0471	0.3031	3.8289	0.5990	1.3603	0.4440
2002	2.4157	0.4882	2.8353	0.8396	1.4550	0.6109
2003	1.1215	0.4239	1.7231	0.6252	1.3600	0.5657
2004	1.1695	0.3904	0.5489	0.7072	0.6117	1.1108
2005	0.2700	0.6163	0.9698	0.7955	0.5472	1.8640
2006	0.7439	0.3694	0.2642	0.7536	0.2069	0.4920
2007	0.6841	0.4677	0.5653	0.7763	1.3179	0.7914
2008	0.1371	0.7053	0.3825	0.9345	0.1895	0.8001
2009	0.3327	0.4588	0.2526	0.7773	0.2473	0.8058
2010	0.6341	0.3572	0.5089	0.7108	1.3148	0.6947
2011	0.4987	0.3489	0.5325	0.5810	0.8769	0.5399
2012	0.7811	0.2798	0.7718	0.5562	1.2389	0.7452

Table 7: Results of model selection via backwards selection for the ZINB model of short-bottom longline CPUE. WC = model will not converge.

Binomial Model	Count Model	AIC
Latitude	Day of Year + Latitude	1323.6936
<none>	Day of Year + Latitude + Depth	1323.7191
<none>	Day of Year + Latitude	1324.2347
Latitude	Day of Year + Latitude	1324.3252
Latitude	Day of Year + Latitude + Depth + Bottom Temperature	1324.6267
<none>	Day of Year + Latitude + Depth + Bottom Temperature	1324.6779
Latitude + Bottom Temperature	Day of Year + Latitude	1325.4184
<none>	Day of Year + Depth	1325.7183
Day of Year	Day of Year + Latitude	1325.7426
<none>	Latitude	1325.9336
<none>	Day of Year	1325.9942
Latitude + Day of Year	Day of Year + Latitude	1326.0029
Latitude	Day of Year	1326.3246
<none>	Day of Year + Latitude + Bottom Temperature	1326.5616
Bottom Temperature	Day of Year + Latitude	1326.7219
<none>	Depth	1326.8073
Day of Year	Day of Year + Latitude	1326.8862
<none>	<none>	1327.4253
Day of Year	<none>	1327.7530
Latitude	<none>	1327.8141
<none>	Bottom Temperature	1328.2851
Day of Year	Day of Year	1328.7962
<none>	Day of Year + Latitude + Year	1331.2524
Latitude	Day of Year + Latitude + Depth + Year	1334.2572
<none>	Day of Year + Latitude + Depth + Year	1334.8219
Depth	Day of Year + Latitude	1348.1894
Depth	Day of Year	1349.0962
Depth	<none>	1349.3433
Depth	Day of Year + Latitude	1373.3042
Latitude + Depth	Day of Year + Latitude	1377.7067
Year	Day of Year + Latitude	1382.0280
Year	<none>	1383.5355
Year	Day of Year	1383.5430
Year	Day of Year + Latitude	1384.4776
Latitude + Year	Day of Year + Latitude	1387.1243
<none>	Year	WC
Bottom Temperature	<none>	WC
<none>	Day of Year + Year	WC
<none>	Day of Year + Bottom Temperature	WC
Bottom Temperature	Day of Year	WC
Bottom Temperature	Day of Year + Latitude	WC

Table 8: Short-bottom longline ZINB-standardized CPUE and information associated with short-bottom longline deployments included in standardized CPUE calculation. Positive = proportion of included collections positive for snowy grouper, and Normalized = ZINB standardized CPUE (number of fish*longline^{-1}) normalized to its mean value over the time series.

	Depth (m)		Temperature (°C)		Latitude (°N)		Date		ZINB CPUE			
Year	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Index	CV	2.5% Quantile	97.5% Quantile
1996	156	73 - 220	14.2	7.9 - 20.8	32.41	32.08 - 32.73	7/23	5/2-8/22	0.4663	0.4162	0.1067	0.8831
1997	193	181 - 209	15.6	14.3 - 16.3	32.64	32.54 - 32.74	9/17	9/16-9/18	0.6982	0.2847	0.3213	1.0858
1998	192	174 - 212	11.1	8.9 - 15.4	32.68	32.54 - 32.87	6/29	5/5-8/19	0.6767	0.3798	0.2620	1.2360
1999	116	59 - 198	18.3	14.5 - 21.2	33.07	29.91 - 34.19	7/12	6/7-9/29	0.9260	0.2741	0.5041	1.4920
2000	160	70 - 198	16.0	12.8 - 23.7	32.95	32.54 - 33.91	7/28	6/20-8/16	0.6959	0.2578	0.3906	1.0945
2001	171	88 - 212	14.7	11.2 - 18.5	33.01	32.53 - 34.24	8/10	6/19-9/20	0.9954	0.2513	0.4777	1.4442
2002	86	71 - 113	17.4	16.4 - 18.6	32.90	32.08 - 33.36	7/11	7/9-7/18	1.3827	0.2942	0.7309	2.3171
2003	161	88 - 210	12.8	10.8 - 17.2	32.73	32.25 - 33.21	8/14	7/16-8/26	0.9700	0.2033	0.6212	1.3941
2004	132	72 - 215	15.5	11.6 - 18.4	32.15	32.08 - 32.26	6/14	5/6-8/5	0.4229	0.6974	0.0948	1.2495
2005	102	46 - 208	18.3	13.6 - 28.0	32.78	30.04 - 33.85	7/8	5/19-9/28	1.0115	0.2323	0.5928	1.5049
2006	115	46 - 219	15.5	9.8 - 21.4	32.54	28.95 - 34.20	7/12	6/6-9/27	0.6721	0.2643	0.2979	0.9840
2007	97	45 - 201	19.6	12.5 - 24.1	33.09	30.04 - 33.86	7/6	6/7-8/23	1.3524	0.2780	0.5004	1.9881
2008	122	45 - 198	19.4	15.1 - 25.8	32.46	32.07 - 32.74	8/21	6/19-9/30	1.7816	0.1809	1.2370	2.4903
2009	108	71 - 200	18.1	12.9 - 24.5	33.12	32.07 - 34.16	8/22	8/4-9/17	2.2397	0.2606	0.9821	3.2909
2010	133	45 - 205	14.4	10.2 - 18.9	32.72	32.07 - 33.83	6/21	5/6-9/22	0.9293	0.1949	0.5839	1.2887
2011	117	45 - 227	14.8	8.6 - 19.9	32.94	32.07 - 34.19	6/29	5/24-8/30	0.7792	0.3350	0.4120	1.4354

Table9: Alternative index models investigated based on short-bottom longline snowy grouper catch per unit effort estimates. Nominal is an annual geometric mean of CPUE. Delta-GLM Quantile Bins refers to a delta-GLM model developed based upon the depth and temperature bins being constructed based on the 50% quantile of the sampling distribution. ZINB Depth, Temperature, & DOY started with a full model that only included the covariates depth, bottom temperature, and day of year. ZINB Depth & Temperature started with a full model that only included the covariates depth and bottom temperature. ZINB Trends Report is a model based on the covariates depth and bottom temperature using the bin structure from the 2012 MARMAP trends report (Ballenger et al. 2013b).

	Nominal		Delta-GLM Quantile Bins		ZINB Depth, Temperature, & DOY		ZINB Depth & Temperature		ZINB Trends Report	
Year	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**	**Index**	**CV**
1996	0.4874	0.3507	0.5615	0.7365	0.4570	0.4563	0.4636	0.4310	0.6767	0.4575
1997	1.0895	0.2822	0.4750	0.4656	0.7041	0.2904	0.6038	0.2581	0.3833	0.4554
1998	0.7999	0.3580	0.5814	0.3950	0.6259	0.4158	0.6974	0.3472	0.3269	0.5085
1999	0.7509	0.3089	1.0476	0.3176	0.8956	0.2852	0.9691	0.2757	1.1162	0.3213
2000	0.9079	0.2906	0.7440	0.2958	0.6799	0.2525	0.6878	0.2228	1.2459	0.3338
2001	1.4226	0.2219	1.2113	0.3176	1.0110	0.2657	1.0299	0.2465	1.1034	0.3902
2002	1.2732	0.3019	2.3523	0.2512	1.3100	0.3510	1.3650	0.2485	2.3552	0.3059
2003	0.8206	0.1783	0.9811	0.2664	0.9565	0.2203	0.9763	0.1610	1.9566	0.2599
2004	0.2931	0.5092	0.5798	0.6677	0.4008	1.0924	0.4189	0.5878	0.6099	0.5969
2005	0.6046	0.2691	1.0797	0.2247	0.9616	0.2504	0.9898	0.2179	0.9870	0.2470
2006	0.3771	0.2970	0.4861	0.3128	0.6330	0.2748	0.7105	0.2449	0.3629	0.3955
2007	0.2430	0.4783	0.5717	0.4413	1.4309	0.3027	1.3115	0.3046	0.5652	0.3698
2008	1.3909	0.2246	1.9423	0.2154	1.8715	0.2076	1.7875	0.1505	1.3111	0.3511
2009	0.5951	0.4860	1.1775	0.4319	2.3704	0.2718	2.1815	0.2289	0.5171	0.4606
2010	1.1119	0.1768	1.2785	0.2026	0.8880	0.2078	0.9984	0.1876	1.6490	0.1987
2011	1.3522	0.1607	0.9301	0.3695	0.8038	0.3643	0.8091	0.2683	0.8336	0.4060

Figures

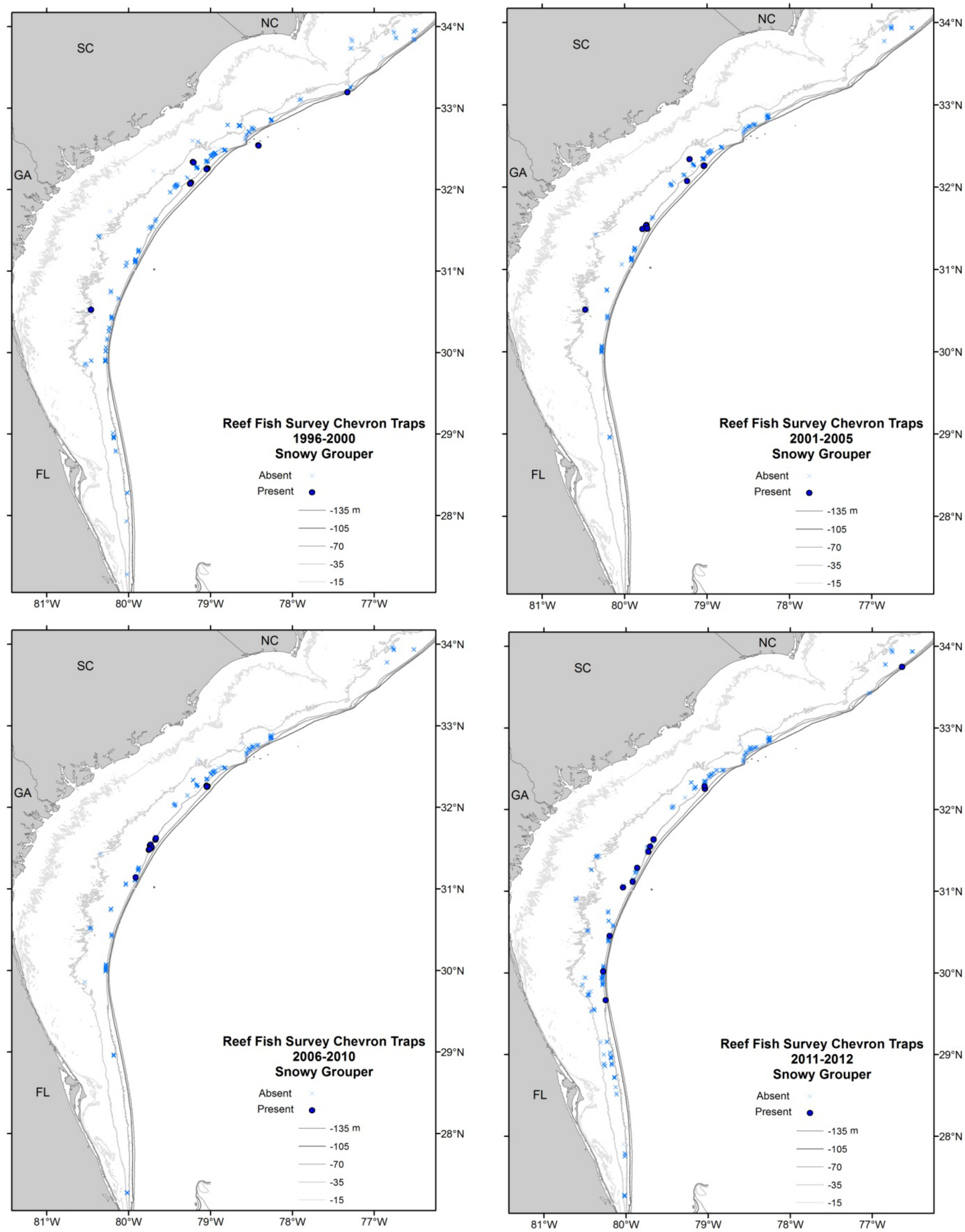

Figure 1: Chevron trap sampling and catches of snowy grouper by the SAB Reef Fish Survey (MARMAP, SEAMAP-SA, SEFIS) included in the nominal CPUE estimate in 1996-2000, 2001-2005, 2006-2010, and 2011-2012.

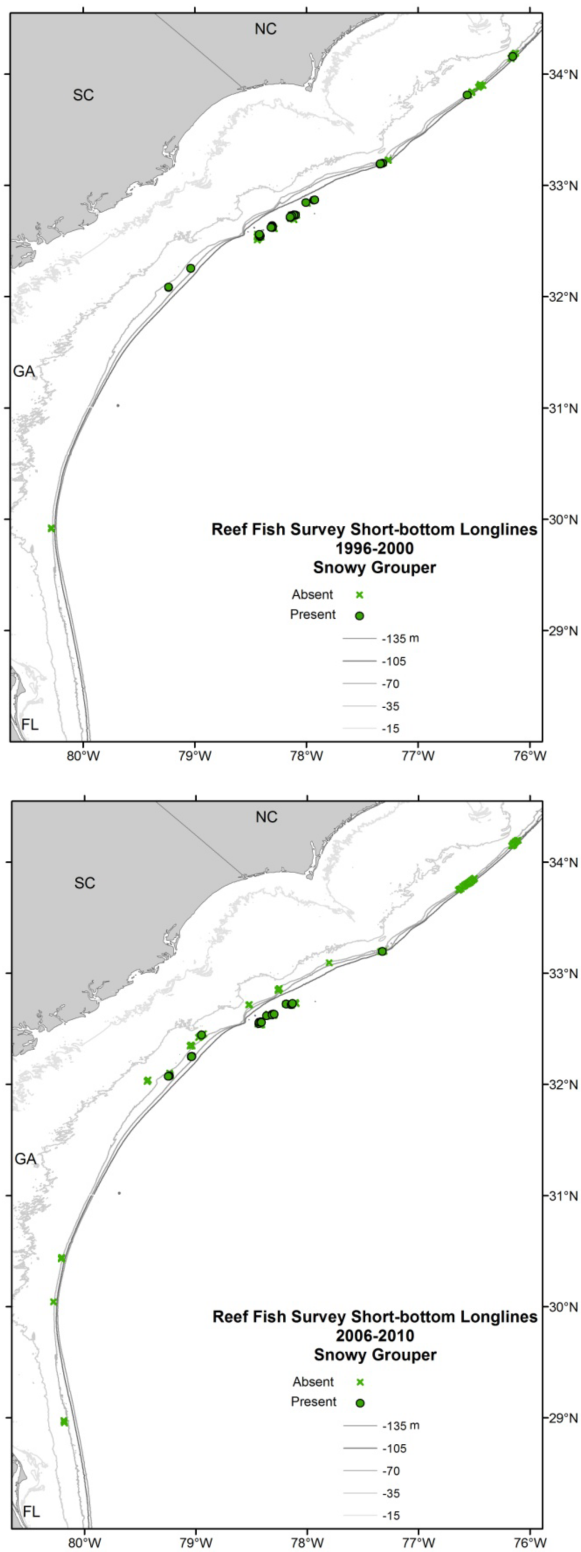

Figure 2: Short-bottom longline sampling and catches of snowy grouper by the SAB Reef Fish Survey (MARMAP, SEAMAP-SA, SEFIS) included in the nominal CPUE estimate in 1996-2000, 2001-2005, 2006-2010, and 2011.

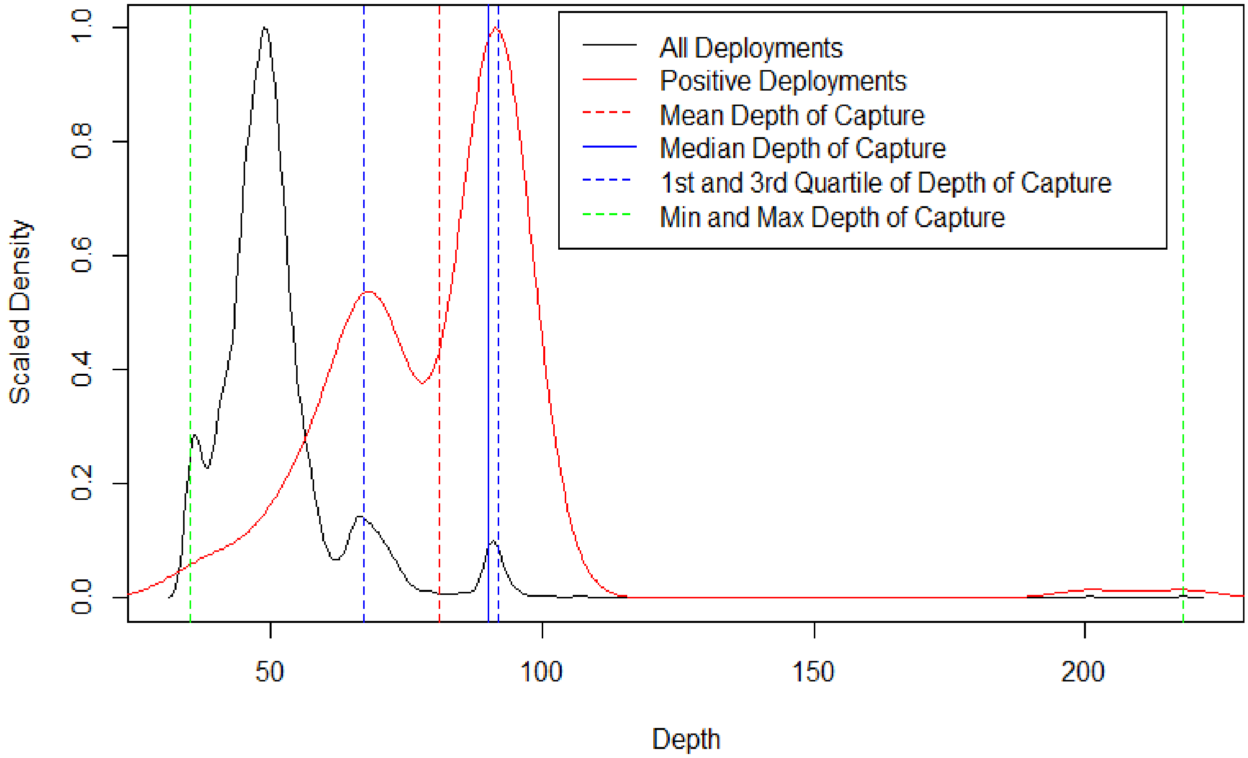

Figure 3: Scaled (to density maximum) sampling density plot across depths for chevron trap collections made by the SAB Reef Fish Survey. Illustrated is the density vs. depth for all chevron trap collections (solid black line) and the density vs. depth for snowy grouper positive chevron trap collections (solid red line) as well as the location of some summary statistics relative to depth of positive chevron traps for snowy grouper.

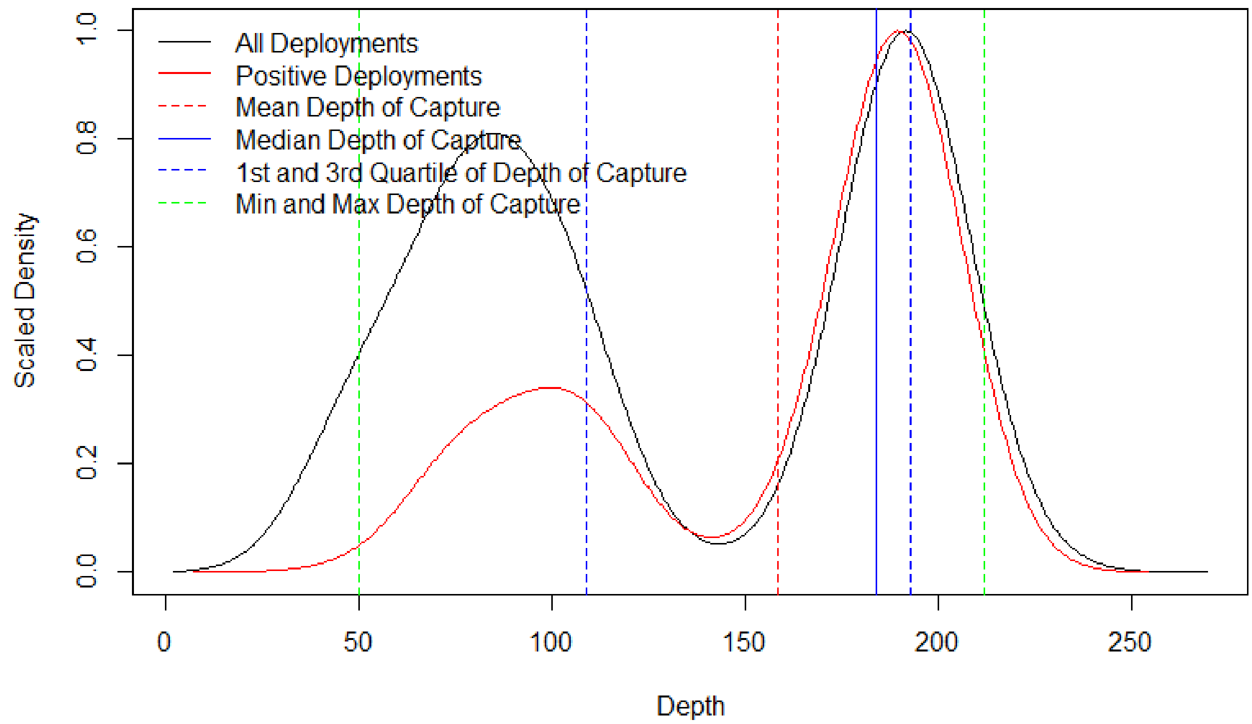

Figure 4: Scaled (to density maximum) sampling density plot across depths for short-bottom longline collections made by the SAB Reef Fish Survey. Illustrated is the density vs. depth for all short-bottom longline collections (solid black line) and the density vs. depth for snowy grouper positive short-bottom longline collections (solid red line) as well as the location of some summary statistics relative to depth of positive short-bottom longlines for snowy grouper.

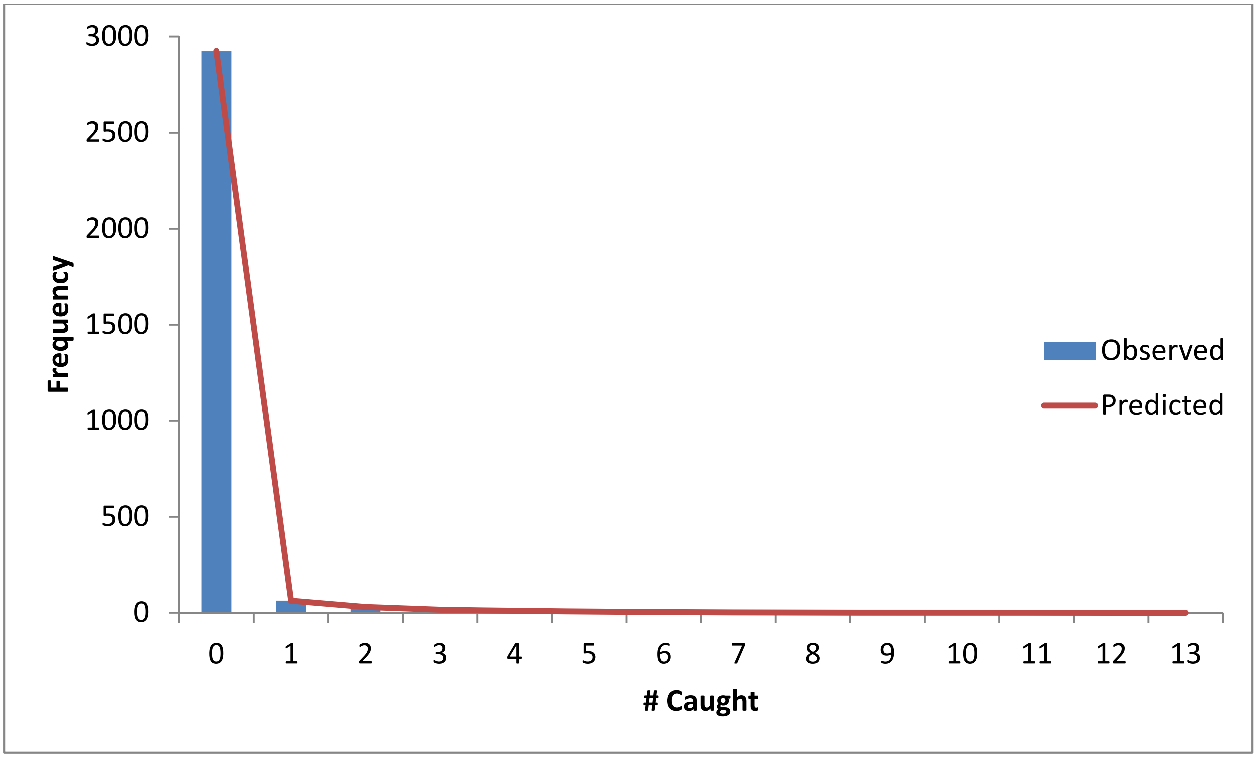

Figure 5: Observed and predicted frequency of traps with a total catch of X snowy grouper, where observed X ranged from 0 to 13 snowy grouper in a single trap.

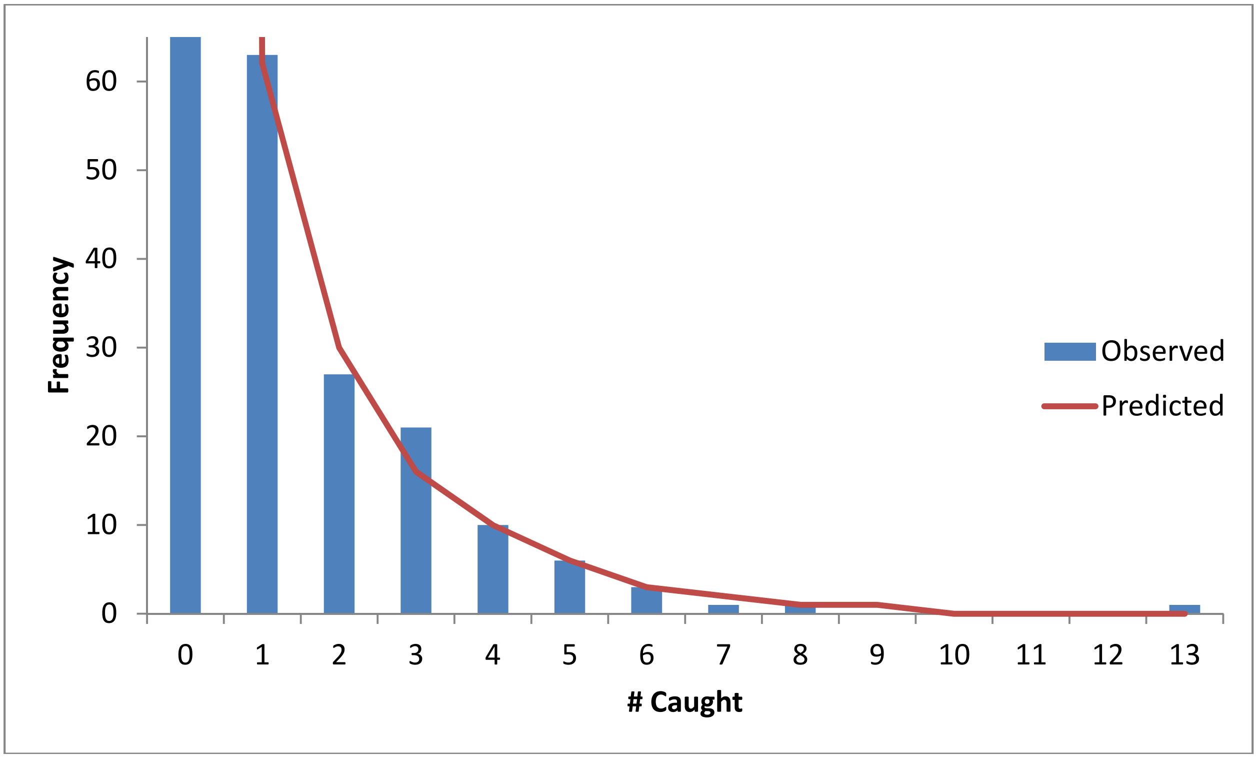

Figure 6: Observed and predicted frequency of traps with a total catch of X snowy grouper. This is the same data presented in Figure 5 with the y-axis scale truncated to a max of 65 to make it easier to see the fit to observed catch for snowy grouper positive chevron traps.

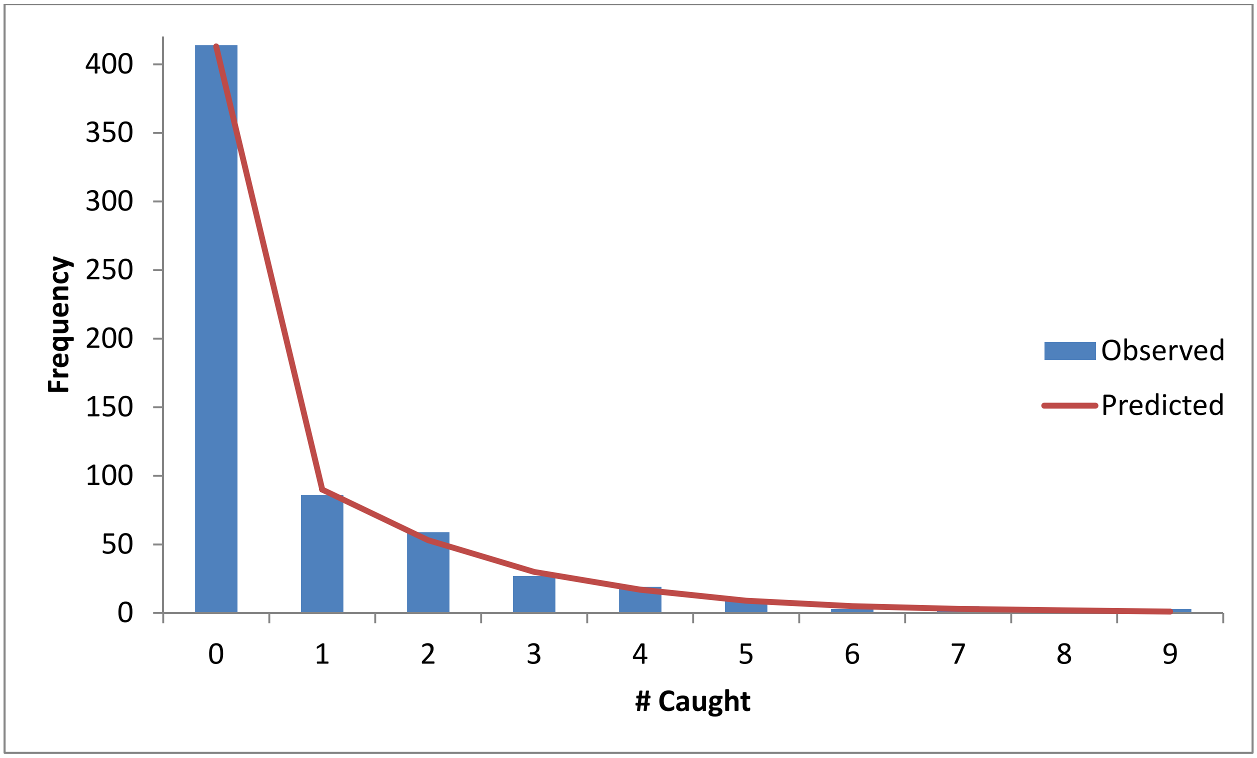

Figure 7: Observed and predicted frequency of short-bottom longlines with a total catch of X snowy grouper, where observed X ranged from 0 to 9 snowy grouper on a single shor-bottom longline.

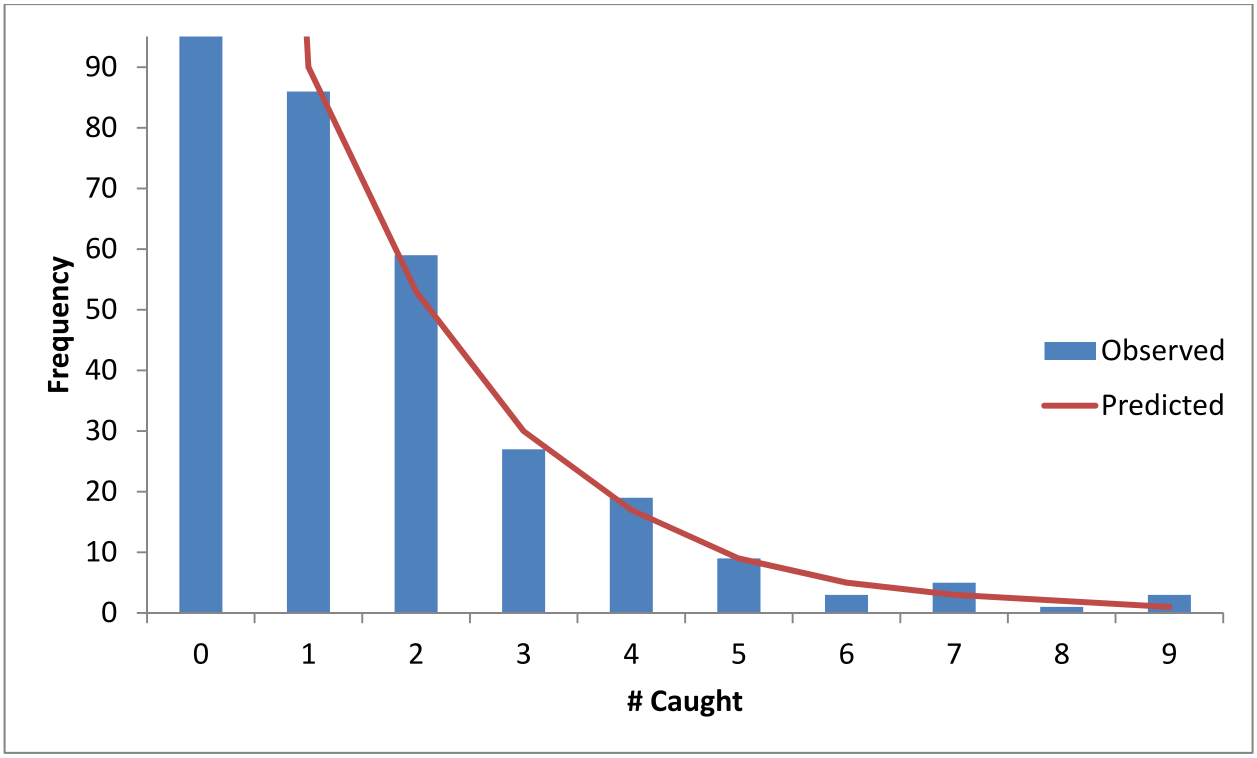

Figure 8: Observed and predicted frequency of short-bottom longlines with a total catch of X snowy grouper. This is the same data presented in Figure 7 with the y-axis scale truncated to a max of 95 to make it easier to see the fit to observed catch for snowy grouper positive short-bottom longlines.

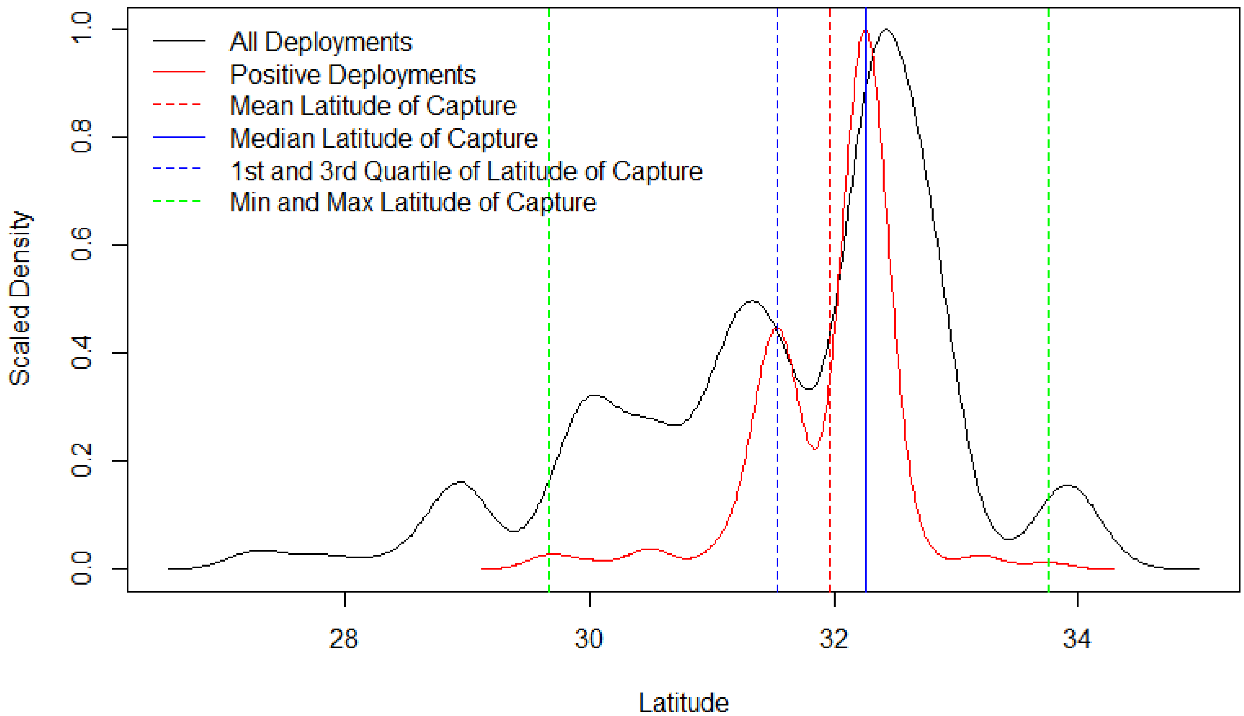

Figure 9: Scaled (to density maximum) sampling density plot across latitudes for chevron trap collections made by the SAB Reef Fish Survey. Illustrated is the density vs. latitude for all chevron trap collections (solid black line) and the density vs. latitude for snowy grouper positive chevron trap collections (solid red line) as well as the location of some summary statistics relative to latitude of positive chevron traps for snowy grouper.

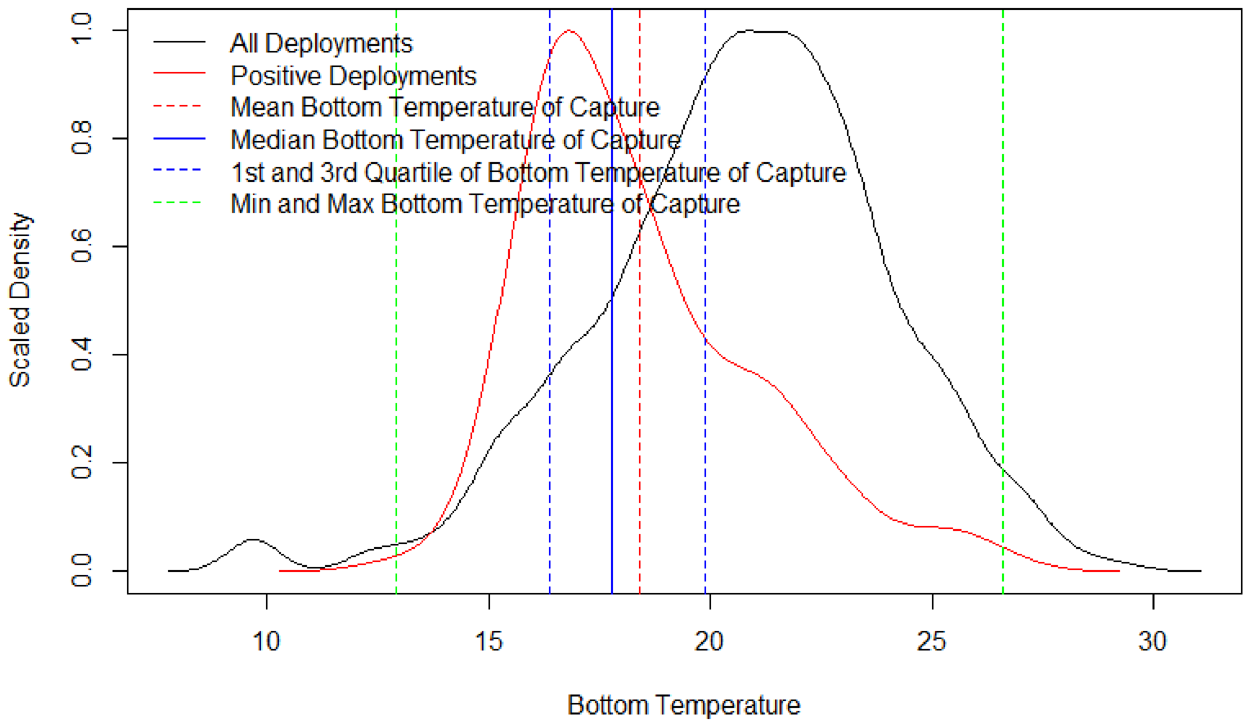

Figure 10: Scaled (to density maximum) sampling density plot across bottom temperatures for chevron trap collections made by the SAB Reef Fish Survey. Illustrated is the density vs. bottom temperature for all chevron trap collections (solid black line) and the density vs. bottom temperature for snowy grouper positive chevron trap collections (solid red line) as well as the location of some summary statistics relative to bottom temperature of positive chevron traps for snowy grouper.

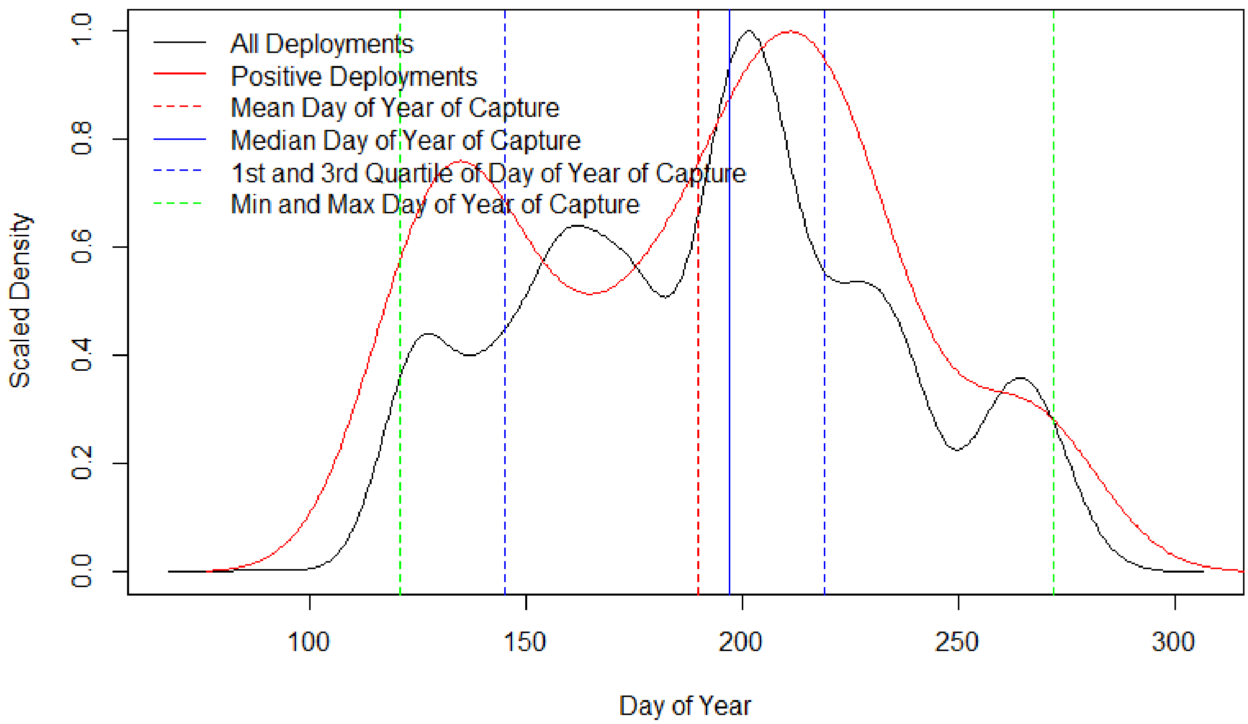

Figure 11: Scaled (to density maximum) sampling density plot across days of year for chevron trap collections made by the SAB Reef Fish Survey. Illustrated is the density vs. day of year for all chevron trap collections (solid black line) and the density vs. day of year for snowy grouper positive chevron trap collections (solid red line) as well as the location of some summary statistics relative to day of year of positive chevron traps for snowy grouper.

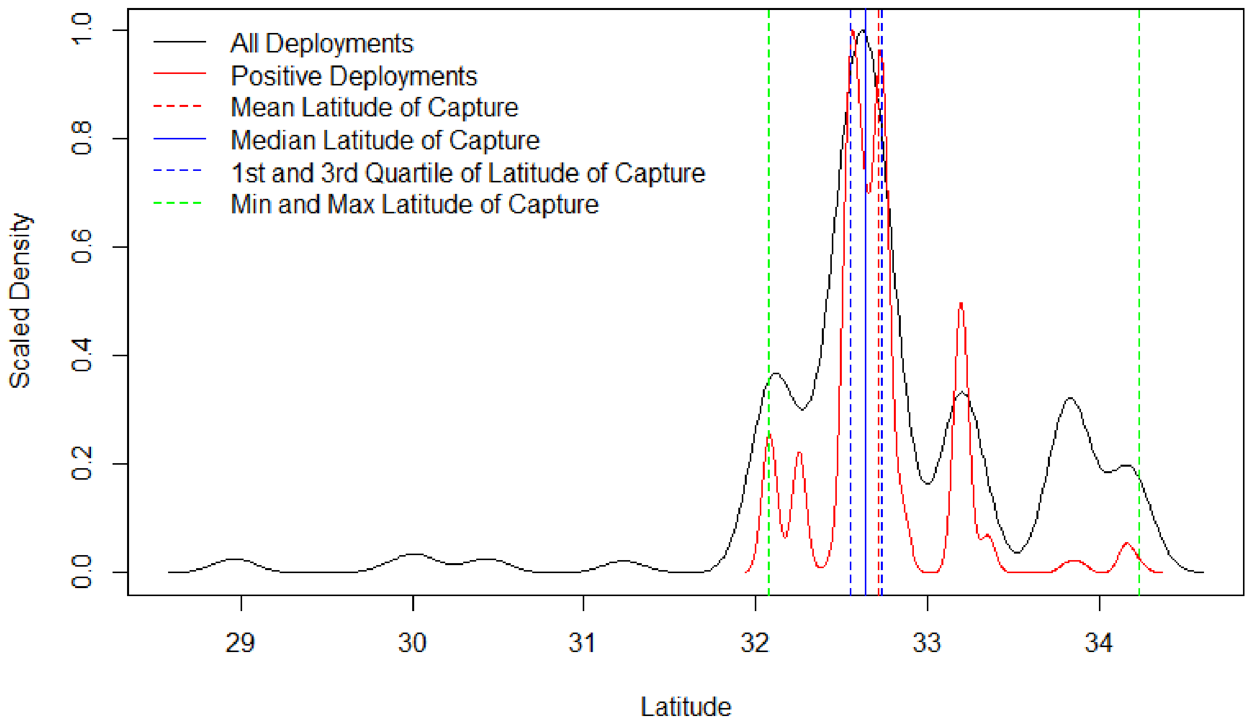

Figure 12: Scaled (to density maximum) sampling density plot across latitudes for short-bottom longline collections made by the SAB Reef Fish Survey. Illustrated is the density vs. latitude for all short-bottom longline collections (solid black line) and the density vs. latitude for snowy grouper positive short-bottom longline collections (solid red line) as well as the location of some summary statistics relative to latitude of positive short-bottom longlines for snowy grouper.

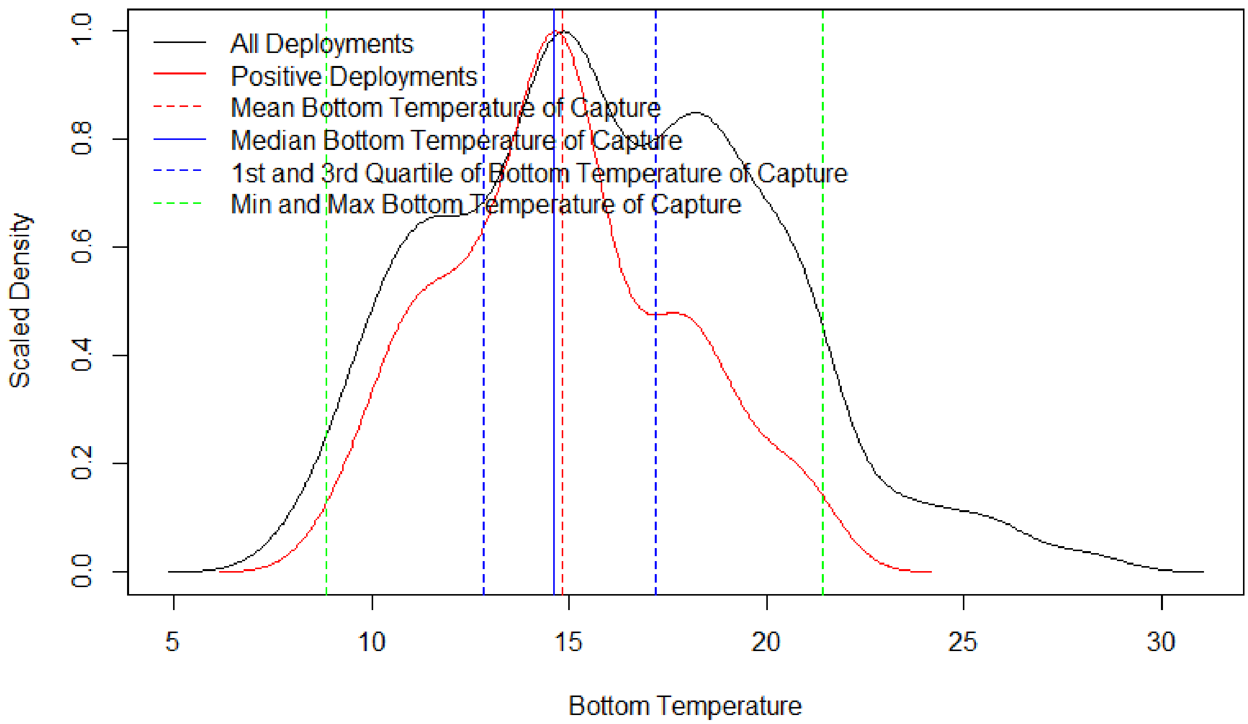

Figure 13: Scaled (to density maximum) sampling density plot across bottom temperatures for short-bottom longline collections made by the SAB Reef Fish Survey. Illustrated is the density vs. bottom temperature for all short-bottom longline collections (solid black line) and the density vs. bottom temperature for snowy grouper positive short-bottom longline collections (solid red line) as well as the location of some summary statistics relative to bottom temperature of positive short-bottom longlines for snowy grouper.

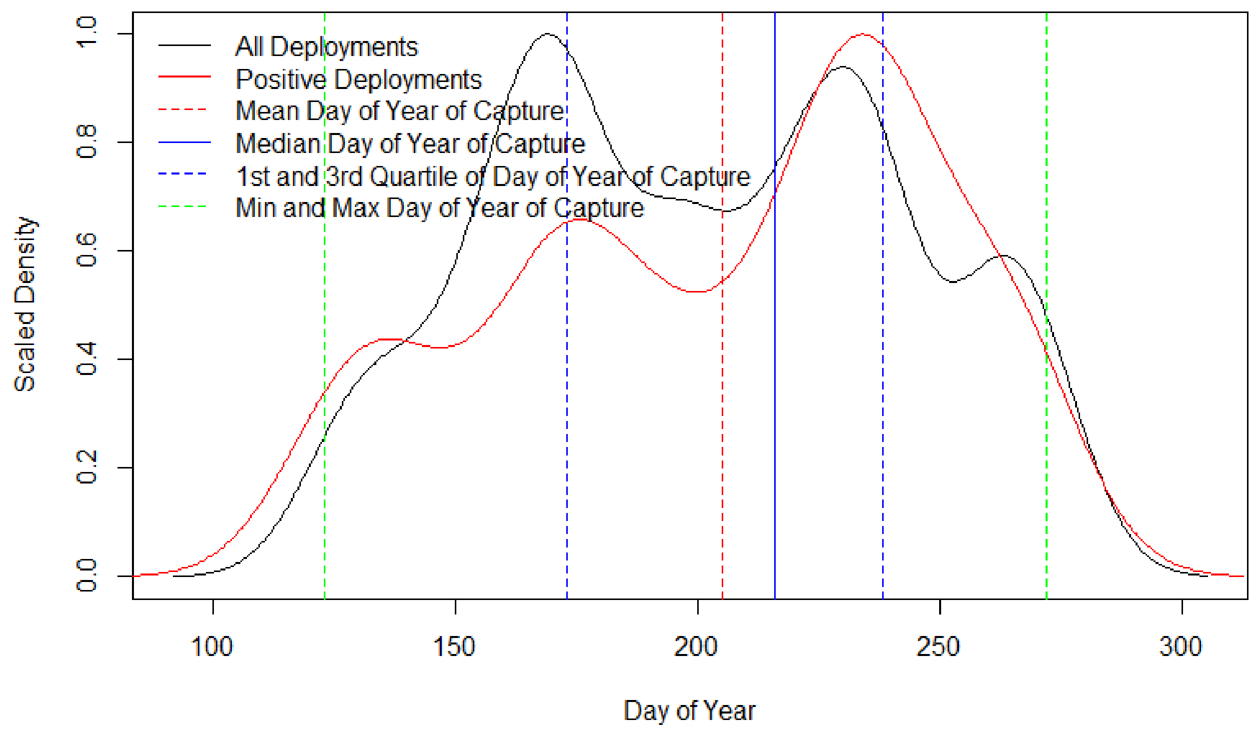

Figure 14: Scaled (to density maximum) sampling density plot across days of year for short-bottom longline collections made by the SAB Reef Fish Survey. Illustrated is the density vs. day of year for all short-bottom longline collections (solid black line) and the density vs. day of year for snowy grouper positive short-bottom longline collections (solid red line) as well as the location of some summary statistics relative to day of year of positive short-bottom longlines for snowy grouper.

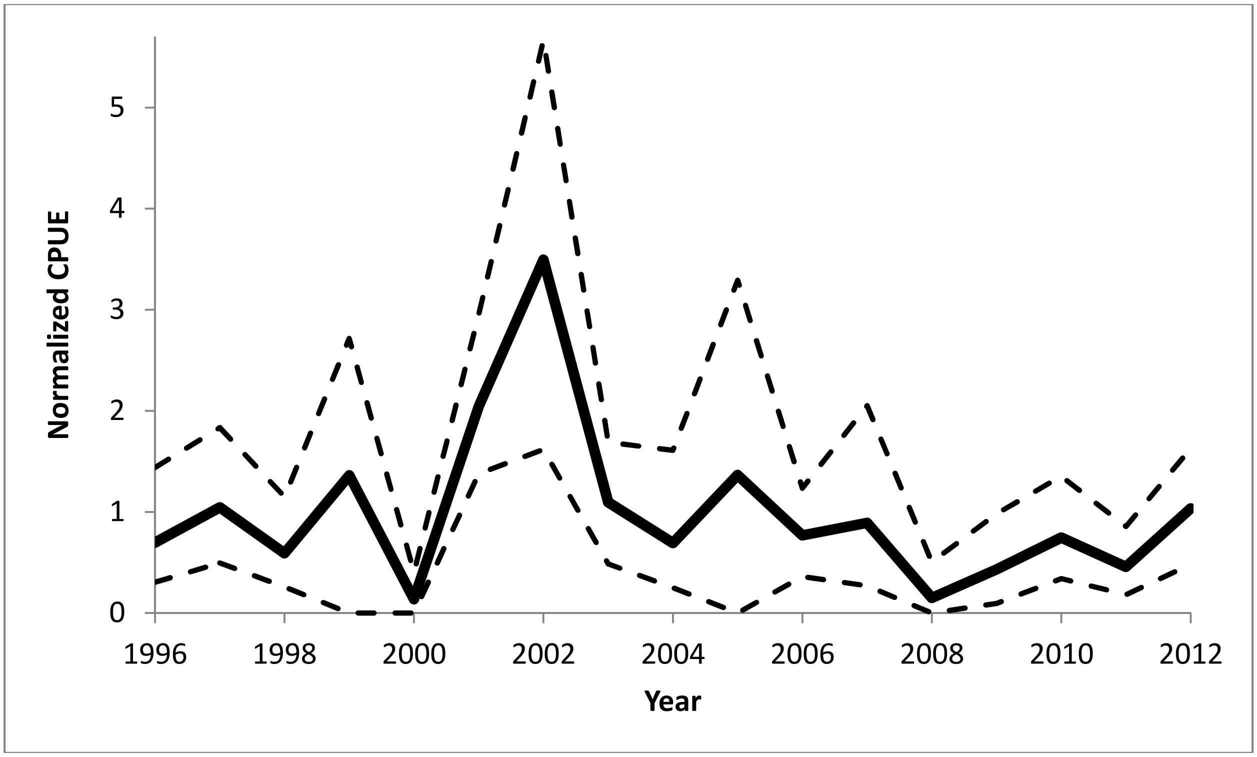

Figure 15: Chevron trap ZINB model standardized CPUE for snowy grouper normalized to the series mean. Error lines represent the 2.5% and 97.5% quantiles of annual CPUE estimated based on 10,000 bootstraps of the raw data.

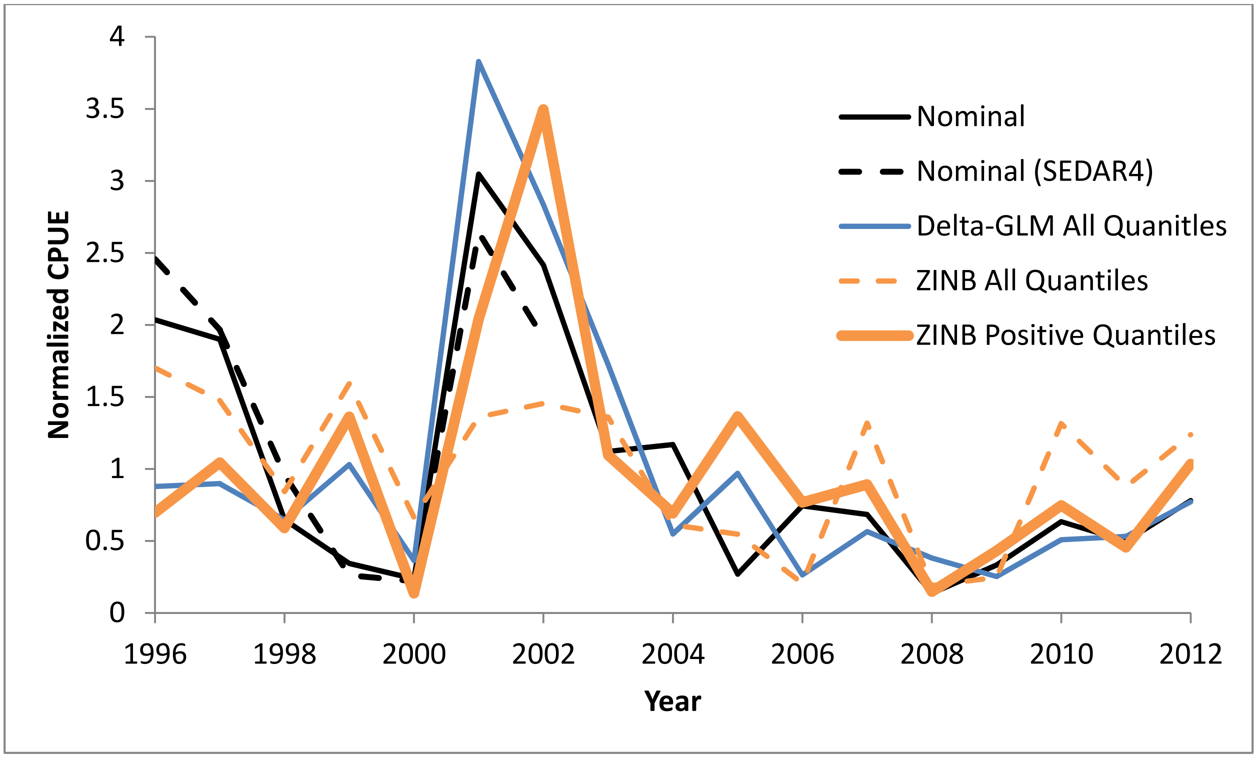

Figure 16: Chevron trap ZINB model standardized CPUE for snowy grouper normalized to the series mean (heavy orange line) presented in this report compared to the nominal CPUE presented in SEDAR 4, the nominal CPUE based upon the updated time series, a delta-GLM standardized CPUE model investigated for model fit, and an alternative structuring of a ZINB model based upon division of covariates into bins based on the overall sampling distribution (in contrast to sampling distribution based upon snowy grouper positive chevron traps) of the chevron trap survey.

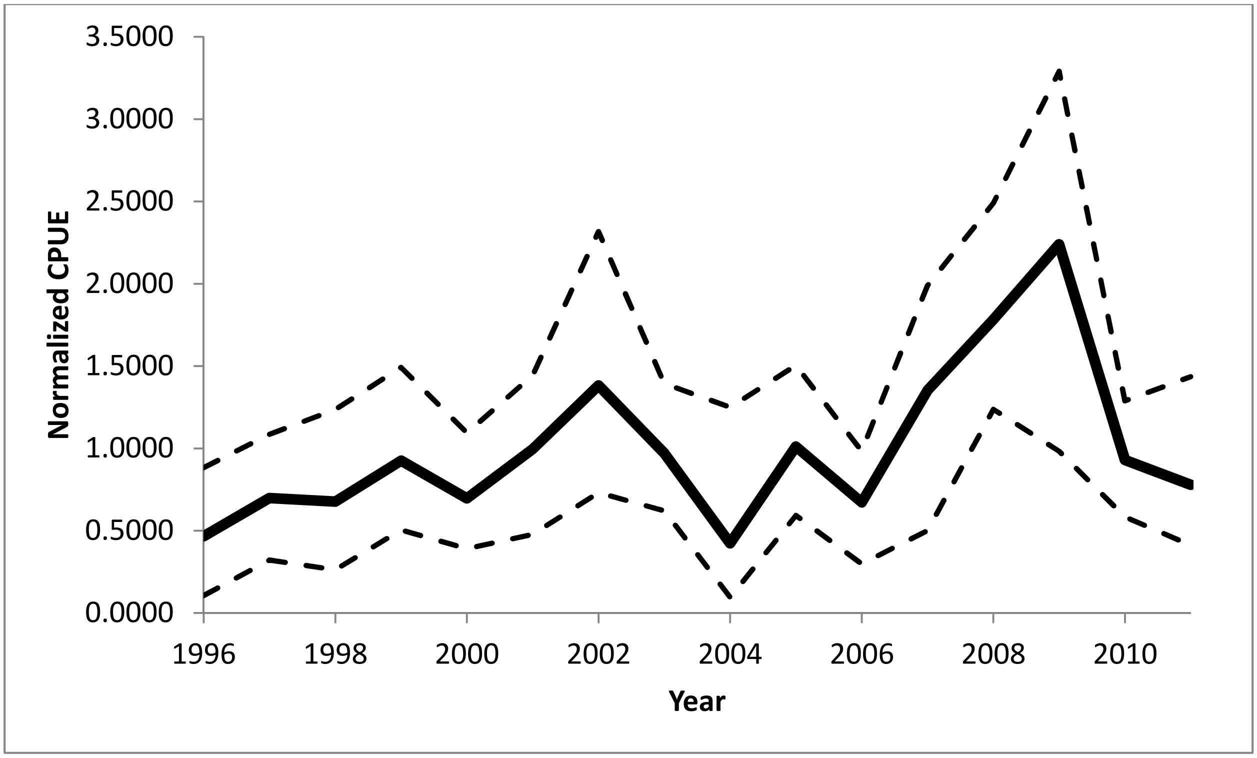

Figure 17: Short-bottom longline ZINB model standardized CPUE for snowy grouper normalized to the series mean. Error lines represent the 2.5% and 97.5% quantiles of annual CPUE estimated based on 10,000 bootstraps of the raw data.

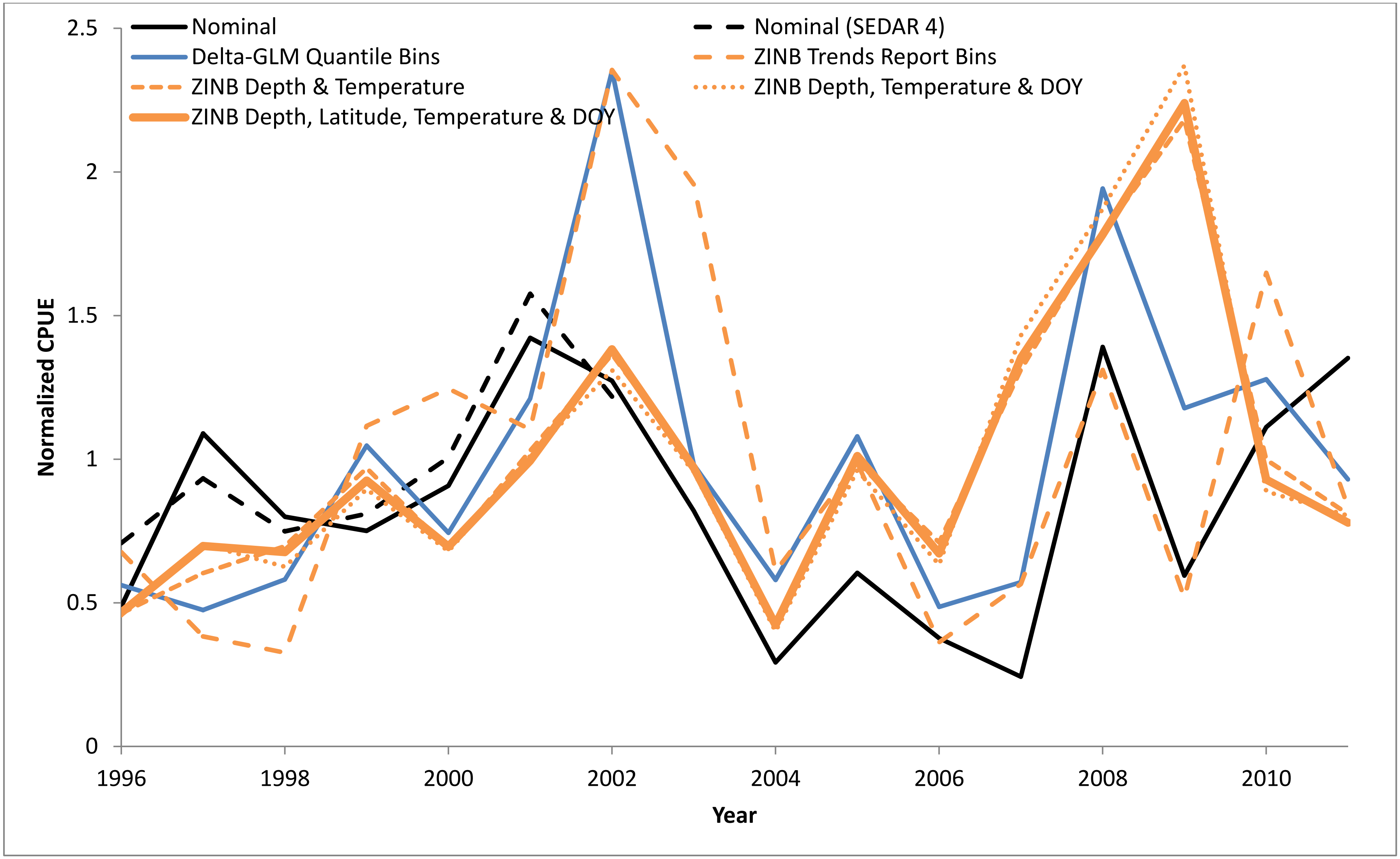

Figure 18: Short-bottom longline ZINB model standardized CPUE for snowy grouper normalized to the series mean (heavy orange line) presented in this report compared to the nominal CPUE presented in SEDAR 4, the nominal CPUE based upon the updated time series, a delta-GLM standardized CPUE model investigated for model fit, and three alternative structures of the ZINB model based on different specifications of the full model.