Trends in relative abundance of gray triggerfish in waters off the SE US based on fishery-independent surveys

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Summary of Nominal and Delta-GLM Standardized CPUE Based on SAB Reef Fish Surveys (MARMAP, SEAMAP-SA, and SEFIS) Using Blackfish Traps (1981 – 1987), Florida Traps (1981 – 1987), and Chevron Traps (1990-2011)

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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 lack of adequate fishery-independent survey observations can create several issues when considering both the consequences of management actions, such as large closed areas and harvest moratoria, and the ability to evaluate such actions. If fishery-independent data are lacking, the potential impacts on stock assessments include: an increase in assessment uncertainty, which is often used to challenge the need for management actions, a greater dependence on fishery-dependent measures of abundance that are in turn affected by management actions (e.g. large-scaled closed areas that drastically alter effort patterns), an inability to separate a population level response from changes in fishery behavior, and an inability to evaluate if management actions are eliciting the desired population response (Williams and Carmichael 2009).

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. Specifically, MARMAP's current main objectives are to:

1) sample fishes in the SAFMC snapper-grouper complex using a variety of gears in live bottom, rocky outcrop, high relief, and mud bottom habitats,
2) collect data for time series descriptions of reef fish species for the development of annual length and age compositions and the development of relative abundance indices,
3) investigate population characteristics on fish species of interest through life history analysis, including age, growth, sex ratio, size/age of sexual maturation/transition, spawning season, fecundity, and diet,
4) collect hydrographic data for comparison to and inclusion in the development of relative abundance indices , and
5) expand the geographical extent of sampling coverage of live bottom habitats, particularly in areas off of North Carolina and elsewhere and waters deeper and shallower than traditionally sampled, by identifying new live bottom areas using underwater video, trap cameras, and fathometers.

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. The focus of this paper is on gears that historically or currently have been used for monitoring purposes and have captured gray triggerfish (*Balistes capriscus*) in sufficient quantity to warrant an investigation of the development of a CPUE index based on the observed annual CPUE. Specific gears investigated for the development of CPUE indices include blackfish traps, Florida snapper (i.e., Antillean) traps, chevron traps, and short bottom longlines.

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. As is the case with MARMAP, this program is housed at the MRRI at the SCDNR. A particular goal of the SEAMAP-SA complement is to assist with the expansion of the geographical sampling coverage of the current MARMAP program (Objective 5, above). 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 (Figure 1). In addition, the SEAMAP-SA complement funding allowed for expanded sampling in marine protected areas (MPAs). In 2009 and 2010, we concentrated most of the new SEAMAP-SA Reef Fish survey efforts on surveying new bottom and sampling MPA's. In 2011, we increasingly concentrated SEAMAP-SA Reef Fish survey efforts on sampling monitoring stations identified in previous years as containing live bottom habitat. This increased monitoring station sampling effort contributes to the expanded range of monitoring station sampling in 2011 (Figure 1). 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) laboratory in Beaufort, NC. This fishery-independent survey was designed to further complement the historical MARMAP/SEAMAP-SA reef fish monitoring efforts. SEFIS activities were closely coordinated 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 introduced video as a new sampling gear to develop new indices of relative abundance. In 2010, SEFIS program sampling mostly concentrated on identifying 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 (Figure 1).

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). Specifically, it presents annual catch per unit effort (CPUE) of gray triggerfish from three monitoring gears: two historical gears (blackfish and Florida traps) and one monitoring gear currently in use (chevron trap). Included here are nominal CPUE estimates for all gears over the range of years in which each specific gear was employed for monitoring purposes. In addition, standardized CPUE estimates were developed through the use of a delta-GLM model. The delta-GLM models accounted 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 December, 2012. Data only through the 2011 sample season was included to be consistent with the SEDAR 32 terminal year, though we had 2012 data available.

Methods

Sample Collection

As outlined above, current reef fish monitoring in the US South Atlantic region is accomplished via the combined efforts of three different fishery-independent survey programs, those being the MARMAP program, the SEAMAP-SA Reef Fish Survey, and the SEFIS program. Henceforth, we will refer to the combined efforts of these three different fishery-independent survey programs 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 most commonly found 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). With regards to gray triggerfish, early monitoring gears that routinely captured gray triggerfish included blackfish and Florida traps. Subsequently, beginning in 1990 the MARMAP program began primarily using chevron traps for monitoring purposes, which catch a diverse array of sizes and species of fish, including gray triggerfish. Though the MARMAP program did begin using two additional hook-and-line gears for monitoring purposes in 1996 (short bottom longlines and long bottom longlines), neither of these gears capture gray triggerfish in sufficient numbers to warrant the development of a CPUE index.

In recent years, the SEAMAP-SA Reef Fish Survey and the SEFIS program have adopted chevron trap 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). 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 ($N0_3$). When a CTD cast was associated with a specific monitoring gear set, in general a single CTD deployment was made, with its water column variables then being associated with all monitoring gear deployed during that given set. A set is composed of one to six (generally six) pieces of gear (blackfish trap, Florida trap, chevron trap) deployed at the same time in the same geographic area. We made the single CTD cast to be associated with the set of monitoring gear during the period of time between the deployment of the last piece of gear in the set and retrieval of the first piece of gear.

Both of the additional funding sources made available to enhance the fishery-independent monitoring of reef fish in the SAB have funded programs designed to complement the traditional MARMAP survey program as currently designed. Thus, both the SEAMAP-SA Reef Fish survey and the SEFIS program have sampling methodologies for monitoring stations that mirror those employed by MARMAP since 1990. As such, the SEAMAP-SA Reef Fish survey and the SEFIS program are only sampling monitoring stations for inclusion in CPUE and additional analyses in this report using chevron traps. Given the close coordination between 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 the analyses presented in this report. We present a summary of the number of gear deployments for each of the three gears used for analysis in this report made by the SAB Reef Fish Survey in Table 1.

Blackfish Trap

Blackfish traps are a traditional commercial fishing gear, utilized by fishermen in the US South Atlantic to target black sea bass on live/hard bottom reef habitats. As such, the gear is still used by commercial fishermen to this day (Williams and Carmichael 2009). Given its use in the commercial fishery to target black sea bass, a common reef fish species, the MARMAP program utilized blackfish traps as a primary sampling gear from 1977 through 1989 to sample reef fish species found in live/hard bottom habitats. During this period, the MARMAP program generally set blackfish traps in sets of six on live bottom reef areas found in depths of less than 50 m. During this period, we deployed the traps at 13 inshore study areas with known live-bottom and/or rocky ridges. However, the time series used for annual CPUE and mean length analyses only spanned from 1981-1987 (Table 1), as this is the only period when we used a standardized sampling protocol. From 1977 to 1980, traps were deployed two per buoy, with each trap being separated by a 30.5 m line. From 1988 to 1989, all traps were anchored to a research vessel while fished (see Collins 1990 for a full description).

We provide a schematic of a standard blackfish trap in Figure 2. These traps are nearly cubic (0.6 m x 0.6 m x 0.5 m) in shape with a total interior volume of 0.16 m^3 (Collins 1990; MARMAP 2009). We constructed each trap with 38 mm (1.5 inch) octagonal mesh wire, commonly referred to as chicken wire in the agricultural industry (MARMAP 2009). Each trap consisted of two entrances (0.13 m diameter, 0.09 m length) and one bait well (0.10 m diameter, 0.25 m length) (Collins 1990; MARMAP 2009).

Prior to deployment, MARMAP program staff baited blackfish traps with cut herrings (*Brevoortia* or *Alosa* spp., family Clupeidae), placing 12 cut clupeids in the bait well (Collins 1990; MARMAP 2009). Subsequently, using a brommel hook we attached the trap to an appropriate length of 8 mm (5/16 in) polypropylene line buoyed to the surface using a polyball buoy. Each trap soaked for approximately 90 minutes, before being retrieved using a hydraulic pot hauler (MARMAP 2009).

Florida Trap

Florida traps, which are also known as Florid Antillean traps, Florida snapper traps, and snapper traps, were a fish trap design used by the MARMAP program to sample reef fish in live/hard bottom habitats of the US South Atlantic from 1980 through 1989. The MARMAP program discontinued the use of Florida traps as a primary trap gear for the sampling of reef fish in the SAB in 1990 based on the results of Collins (1990),who compared the species captured via blackfish traps, Florida traps, and chevron traps. During the period of use for monitoring purposes (1980-1989), the MARMAP program generally set Florida traps in sets of six at 12 study areas with known live bottom and/or rocky ridge reef areas distributed from Onslow Bay, NC to off Fernandina Beach, FL (SEDAR 2008). However, we removed the years 1988 and 1989 from all analyses as all traps were anchored to a research vessel while fished during these years (see Collins 1990 for a full description). In addition, we removed the year 1980 from all analyses due to insufficient sample size and limited geographical coverage of Florida trap deployments in this year. Thus, we only used data from the years 1981-1987 (Table 1) in the development of annual CPUE and mean length analyses, as this is the only period when we used a standardized sampling protocol.

We provide a schematic of a standard Florida trap in Figure 2. These traps are rectangular (0.9 m x 1.1 m x 0.6 m) in shape with a total interior volume of 0.59 m^3 (Collins 1990; MARMAP 2009). We constructed each trap with 38 x 51 mm (1.5 x 2.0 inch) plastic-coated wire mesh (MARMAP 2009). Each trap possessed a single entrance funnel and bait well, with the bait well having a diameter of 0.13 m and a length of 0.6 m (Collins 1990; MARMAP 2009).

Prior to deployment, MARMAP program staff baited Florida traps with cut herrings (*Brevoortia* or *Alosa* spp., family Clupeidae), placing 24 cut clupeids in the bait well (Collins 1990; MARMAP 2009). Subsequently, using a brommel hook we attached the trap to an appropriate length of 8 mm (5/16 in) polypropylene line buoyed to the surface using a Hi-Flyer buoy. Each trap soaked between 90 and 120 minutes, after which it was retrieved with a hydraulic pot hauler (MARMAP 2009). During 1981 to 1987, Florida traps baited with cut clupeids were soaked for approximately two hours during daylight at 13 inshore study areas with known live bottom and/or rocky ridges. We also sampled four shelf edge areas off SC (50-60 m depth) with Florida traps.

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 Antillean traps. Currently, all three fishery-independent monitoring programs continue to utilize the chevron trap as their primary monitoring gear.

Each year sampling stations are selected randomly form 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.

A schematic of a standard chevron trap is provided in Figure 2. These 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* species 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.

Oceanographic Data

While traps are soaking, oceanographic variables (mainly temperature and salinity) were determined using a CTD. From 1987 through 1992 an Applied Microsystem's STD-12 model CTD was employed which also collected dissolved oxygen values. From 1993 through the current sampling year

(2011) 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.

Data and Treatment

Data and Nominal CPUE Estimation

Available data for each trap fished included a unique collection number, date of deployment, soak time (provided in minutes), latitude, longitude, bottom depth (m), catch code, number of gray triggerfish captured, and collective weight of gray triggerfish. For chevron trap collections, additional information regarding the bottom temperature (^{o}C) in the sampling area was available from the oceanographic data collected via the CTD. We used numbers, instead of weight, of gray triggerfish for all analyses. Estimates of relative abundance, or catch per unit effort (CPUE), were standardized to the number of gray triggerfish 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 (45 and 195 minutes for Florida traps) 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 was 10-94 m, determined by the depth range at which 100% of individual gray triggerfish was collected. This was done to reduce the number of zero catches from locations outside the normal depth range of gray triggerfish. To visually assess whether this depth range was appropriate a plot of the sampling density of all chevron trap collections across the 10-94 m depth range and gray triggerfish positive chevron trap collections across the 10-94 m depth range is provided in Figure 3. The collections under these constraints/criteria were included in the analyses and referred to as "included traps" below.

Annual nominal mean CPUE in the included traps was calculated by determining the numbers of individual gray triggerfish caught per trap per hour soak time, divided by the total number of traps deployed during that year:

$$Annual\ CPUE = \sum \frac{\#\ of\ fish\ caught * 60\ minutes}{deployment\ duration\ (minutes)} / \#\ gear\ deployments.$$

CPUE Standardization

CPUE was standardized among years using the "delta-GLM" technique described in Dick (2004). 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:

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

The mean and variance of the Bernoulli distribution are given by:

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

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.). We refer to this model as the positive GLM, and generally will name the sub-model for the positive GLM based upon the error distribution identified as "best" modeling the positive data (e.g. gamma sub-model and lognormal sub-model).

In the current report, we only investigated the use of the gamma and lognormal distributions to model the positive data in the delta-GLM model. 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:

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

Under the gamma distribution, the mean and variance of Y are given by:

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

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:

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

Under the lognormal distribution, the mean and variance of Y are given by:

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

Regardless of distribution, the response variable considered in this report is CPUE.

Selection of the covariates included in the final model (both Bernoulli GLM and positive GLM) and the error distribution for the positive model was done based on Akaike's information criterion (AIC; Akaike 1973). We include year 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 delta-GLM 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 for each delta-GLM analysis were determined by a jackknifing approach.

All analyses were performed in R, based primarily on code adapted from Dick (2004). Data presented in this report are based on the combined MARMAP/SEAMAP-SA/SEFIS database accessed in December, 2012.

Results

Blackfish Trap

Data Summary

From 1981 to 1987, we made 2373 blackfish trap gear deployments (Table 1), averaging 339 (range: 180-530) collections per year. Of these collections, we have included catch data from monitoring stations for 2,302 (97.0%), or on average from 329 (range: 180-527) collections per year (Table 2). We were unable to use data from 71 collections (3.0%) due to soak times either being less than 45 minutes or greater than 150 minutes.

The length composition of gray triggerfish captured in blackfish traps from 1981 to 1987 is shown in Figure 5. A total of 92 gray triggerfish were captured in blackfish traps during this time period, ranging in size from 14 to 37 cm fork length (FL), with an average size of 25.9 cm FL. The mean size of gray triggerfish captured in blackfish traps was smaller than the mean size gray triggerfish captured in Florida or chevron traps. This suggests different selectivity's among the three different trap types.

Nominal CPUE

Nominal CPUE ranged from a high of 0.073 fish*trap^{-1}*hr^{-1} to a low of 0.003 fish*trap^{-1}*hr^{-1} in 1982 and 1986, respectively (Table 2 and Figure 4A). Annual coefficients of variations ranged from 0.25 to 1.00 (Table 2). Nominal CPUE estimates normalized to the series average indicates that CPUE exhibited a general decreasing trend through 1987 (Figure 4B).

Delta-GLM CPUE

Explanatory Variables

For the delta-GLM analysis, in addition to year we considered the covariates depth (m), latitude (^{o}N), and season. Year was necessarily included because standardized CPUE by year is the desired response variable of the delta-GLM model. For depth, we binned the available data in to five different depth zones: <20 m, 20-24 m, 25-29 m, 30-34 m, and ≥35 m. The total number of traps deployed in each depth zone, the proportion of blackfish traps with positive catch, and the nominal CPUE within each depth zone is provided in Figure 6. For latitude, the latitudes reported in the MARMAP database were first rounded to the nearest whole degree of latitude, after which the data were pooled into two latitude bins for the delta-GLM analysis: ≤32^{o}N and ≥33^{o}N. The total number of traps deployed in each latitude zone, the proportion of blackfish traps with positive catch, and the nominal CPUE within each latitude zone is provided in Figure 7. Finally, for season, based on the date of capture we pooled the data into two seasons: spring (June and earlier) and summer (July and later). The total number of traps deployed in each season, the proportion of blackfish traps with positive catch, and the nominal CPUE within each season is provided in Figure 8.

No covariate data was missing from any of the collections included in the delta-GLM analysis. However, in 1986 there was less than two positive blackfish trap collections for gray triggerfish. This necessitated the removal of this year of data from the delta-GLM analysis. This is a constraint of the delta-GLM model as currently implemented because the jackknifing technique used to estimate annual coefficients of variations requires that two or more positive collections occur in a given year. This resulted in the removal of 252 blackfish trap collections that were used in nominal CPUE calculations, leading to a total of 2050 blackfish trap collections being used in the delta-GLM analysis (Table 3).

During the model selection process for the final delta-GLM model, AIC selection suggested the removal of the covariates depth and season from the Bernoulli sub-model and the covariates latitude and season from the positive sub-model (Table 4). AIC also suggested that the lognormal error structure was most appropriate to model the positive catch. Thus, our best delta-GLM model contained the covariate latitude for the Bernoulli sub-model and the covariate depth and a lognormal error distribution for the positive sub-model. Based on analysis of deviance tables (Table 5), all variables, including year, were significant in the Bernoulli sub-model of the delta GLM, while only the variable year was significant in the lognormal sub-model. Diagnostics suggested reasonable fits to the Bernoulli (Figure 9) and lognormal sub-models (Figure 10 and Figure 11).

Standardized CPUE

Standardization by the delta-GLM model generally had a negligible effect on annual CV estimates compared to nominal CPUE CV estimates (Table 2 and Table 3). The annual CV for the delta-GLM model ranged from a low of 0.30 to a high of 0.73 in 1982 and 1987, respectively (Table 3). This suggested that the inclusion of these extra covariates and the formal statistical modeling of CPUE using the delta-GLM approach didn't explain a large proportion of the variation in individual trap catches.

Standardized CPUE estimates normalized to the series average indicates that CPUE exhibited a general decreasing trend through1987 (Figure 4B). This pattern was echoed in the normalized nominal CPUE annual estimates. CPUE was below the series average for all years from 1983-1987 (Table 2, Table 3, and Figure 4B).

Florida Trap

Data Summary

From 1981 to 1987, we made 1494 Florida trap gear deployments (Table 1), averaging 213 (range: 119-340) collections per year. Of these collections, we have included catch data from monitoring stations for 1,392 (93.2%), or on average from 199 (range: 119-334) collections per year (Table 6). We were unable to use data from 101 collections (6.8%) due to soak times either being less than 45 minutes or greater than 195 minutes. Additionally, 1 (0.07%) additional collection was removed from analysis due to the sampling depth being outside the normal depth range of gray triggerfish.

The length composition of gray triggerfish captured in Florida traps from 1981 to 1987 is shown in Figure 5. A total of 88 gray triggerfish were captured in Florida traps during this time period, ranging in size from 21 to 51 cm fork length (FL), with an average size of 36.7 cm FL. The mean size of gray triggerfish captured in Florida traps was larger than the mean size gray triggerfish captured in blackfish (25.9 cm FL) or chevron traps (32.2 cm FL). This suggests different selectivity's among the three different trap types.

Nominal CPUE

Nominal CPUE ranged from a high of 0.071 fish*trap^{-1}*hr^{-1} to a low of 0.005 fish*trap^{-1}*hr^{-1} in 1982 and 1986, respectively (Table 6 and Figure 12A). Annual coefficients of variations ranged from 0.27 to 0.78 (Table 6). Nominal CPUE estimates normalized to the series average indicates that CPUE exhibited a general decreasing trend through 1987 (Figure 12B).

Delta-GLM CPUE

Explanatory Variables

For the delta-GLM analysis, in addition to year we considered the covariates depth (m), latitude (^{o}N), and season. Year was necessarily included because standardized CPUE by year is the desired response variable of the delta-GLM model. For depth, we binned the available data into three different depth zones: <30 m, 30-44 m, and ≥45 m. The total number of traps deployed in each depth zone, the proportion of Florida traps with positive catch, and the nominal CPUE within each depth zone is provided in Figure 13. For latitude, the latitudes reported in the MARMAP database were first rounded to the nearest whole degree of latitude, after which the data were pooled into two latitude bins for the delta-GLM analysis: ≤32^{o}N and ≥33^{o}N. The total number of traps deployed in each latitude zone, the proportion of Florida traps with positive catch, and the nominal CPUE within each latitude zone is provided in Figure 14. Finally, for season, based on the date of capture we pooled the data into two seasons: spring (June and earlier) and summer (July and later). The total number of traps deployed in each season, the proportion of Florida traps with positive catch, and the nominal CPUE within each season is provided in Figure 15.

No covariate data was missing from any of the collections included in the delta-GLM analysis. As such, data from the same 1,392 collections used in the development of the nominal CPUE estimate was used in the delta-GLM analysis (Table 7).

During the model selection process for the final delta-GLM model, AIC selection suggested the removal of the covariate season from the Bernoulli sub-model and the covariates depth, latitude and season from the positive sub-model (Table 8). However, because as currently implemented the delta-GLM function constructed for R requires the inclusion of at least one extra covariate, in addition to year, for each component of the delta-GLM model, we retained season in the positive sub-model. From Table 8, it can be seen that the AIC score between the positive sub-model containing and excluding season are extremely similar, thus the inclusion of season does not likely affect model results. AIC also suggested that the lognormal error structure was most appropriate to model the positive catch. Thus, for modeling CPUE, our delta-GLM model contained the covariates depth and latitude for the Bernoulli sub-model and the covariate season and a lognormal error distribution for the positive sub-model. Based on analysis of deviance tables (Table 9), all variables, including year, were significant in the Bernoulli sub-model of the delta GLM. Conversely, no variable was significant in the lognormal sub-model. Note that year was not an important factor in explaining the CPUE of Florida traps that were positive for gray triggerfish. This suggests that sampling year helps determine whether a Florida trap will catch a gray triggerfish, but does not explain how many gray triggerfish will be captured if a trap caught a gray triggerfish. The general inability of covariates to explain the number of gray triggerfish captured if a trap catch is positive probably stems from the observation that we captured only a single gray triggerfish in 45 of 60 positive Florida traps (75%) with three or less gray triggerfish being captured in all Florida trap collections. Diagnostics suggested reasonable fits to the Bernoulli (Figure 16) and lognormal sub-models (Figure 17 and Figure 18).

Standardized CPUE

Standardization by the delta-GLM model generally had a negligible effect or slightly increased annual CV estimates compared to nominal CPUE CV estimates (Table 6 and Table 7). The annual CV for the delta-GLM model ranged from a low of 0.27 to a high of 0.78 in 1984 and 1987, respectively (Table 7). This suggested that the inclusion of these extra covariates and the formal statistical modeling of CPUE using the delta-GLM approach didn't explain a large proportion of the variation in individual trap catches.

Standardized CPUE estimates normalized to the series average indicates that CPUE exhibited a general decreasing trend through1987 (Figure 12B). This pattern was echoed in the normalized nominal CPUE annual estimates. CPUE was below the series average for all years from 1985-1987 (Table 6, Table 7, and Figure 12B).

Chevron Trap

Data Summary

From 1990 to 2011, we made 10,175 Chevron trap gear deployments (Table 1 and Table 10), averaging 463 (range: 286-1051) collections per year. Of these collections, we have included catch data from monitoring stations for 8,083 (79.4%), or on average from 367 (range: 218-628) collections per year (Table 10 and Table 11). Of the collections not used in the development of annual CPUE estimates, the majority (n=1602 or 15.7%) were reconnaissance trap deployments used to investigate potential new live bottom habitats. In addition, we removed 490 collections (4.8%) from CPUE calculations due to excluded soak times (<45 or >150 minutes, n=358; 3.5%), damage or loss of the gear (n=100, 1.0%) and sampling depth (<10 or >94 m, n=32, 0.3%). In addition, note that 1990 was the first year after hurricane Hugo struck the area. During that year, the spatial coverage and sampling season was limited as a logistical consequence of this storm.

The length composition of gray triggerfish captured in chevron traps from 1990 to 2011 is shown in Figure 5. A total of 8,706 gray triggerfish were captured in chevron traps during this time period, ranging in size from 10 to 61 cm fork length (FL), with an average size of 32.2 cm FL. The mean size of gray triggerfish captured in chevron traps was larger than the mean size gray triggerfish captured in blackfish traps (25.9 cm FL), but smaller than the mean size captured in Florida traps (36.7 cm FL). This suggests different selectivity's among the three different trap types.

Nominal CPUE

Nominal CPUE ranged from a low of 0.122 fish*trap^{-1}*hr^{-1} to a high of 0.961 fish*trap^{-1}*hr^{-1} in 1990 and 1997, respectively (Table 11 and Figure 19A). Annual coefficients of variations ranged from 0.10 to 0.23 (Table 11). Nominal CPUE estimates normalized to the series average indicates that CPUE exhibited a general decreasing trend from the early 1990s through 2011 (Figure 19B).

Delta-GLM CPUE

Explanatory Variables

For the delta-GLM analysis, in addition to year we considered the covariates depth (m), latitude (°N), bottom temperature (°C), and season. Year was necessarily included because standardized CPUE by year are the desired response variable of the delta-GLM model. For latitude, the latitudes reported in the MARMAP database were rounded to the nearest whole degree of latitude prior to binning. For season, based on the date of capture we pooled the data into two seasons: spring (June and earlier) and summer (July and later). Table 13 provides a summary of the bins used for each of the covariates in the delta-GLM analysis. Missing covariate data related to latitude and temperature resulted in the removal of 9 and 1030 chevron trap collections, respectively, or 0.1% and 12.7% of the data included in the nominal CPUE analysis. This resulted in a total of 7,044 included collections retained in the delta-GLM analysis, ranging from 184 to 458 per year (Table 12). Please note that due to missing bottom temperature and latitude data, we removed greater than 20% of available collections for the years 1995, 1996, 1999, 2000, and 2011 (Table 14). Because of the high encounter rate of gray triggerfish in the chevron traps, exclusion of this data likely does not affect annual CPUE significantly. The total number of traps deployed, the proportion of chevron traps with positive catch, and the nominal CPUE for the various depth, latitude, temperature, and season bins can be found in Figure 20 through Figure 23, respectively.

During the model selection process for the final delta-GLM model, AIC selection suggested that we retain all covariates in both the Bernoulli and positive components (Table 15) and model the positive component with a lognormal error distribution. Thus, our best-fit delta-GLM model contained all possible covariates considered and modeled the positive component using a lognormal error distribution. Based on analysis of deviance tables (Table 16), all variables, including year, were highly significant in both the Bernoulli and lognormal sub-model of the delta GLM. Diagnostics suggested reasonable fits to the Bernoulli (Figure 24) and lognormal sub-models (Figure 25 and Figure 26).

Standardized CPUE

Standardization by the delta-GLM model generally had a negligible effect on annual CV estimates compared to nominal CPUE CV estimates (Table 11 and Table 12). The annual CV for the delta-GLM model ranged from a low of 0.12 to a high of 0.23 in 1997 and 2003, respectively (Table 12).

Compared to the nominal CPUE, the delta-GLM tended to reduce annual variability in CPUE, particularly over the period 2004-2011 (Figure 19B). Please note the low estimate of CPUE in 1990 may have been influenced by both the direct effect that Hurricane Hugo had on the reef fish communities of the SAB, as well as the effect it had on the temporal and spatial extent of samples collected as part of the MARMAP sampling season in 1990. Standardized CPUE estimates normalized to the series average indicates that CPUE was somewhat variable through the mid- to late-1990's, before exhibiting a general decreasing trend through 2011 (Table 12 and Figure 19), with an almost linear decline in annual CPUE from 2004-2011 (Figure 19).

Addendum 1

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

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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). 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 1990-2011. 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 December, 2012, and include data collected through the 2011 sampling season. Data only through the 2011 sample season was included to be consistent with the SEDAR 32 terminal year, though we had 2012 data available. The original report above presents nominal and delta-GLM standardized CPUE estimates based on the same chevron trap catches.

Methods

Sample Collection

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

Chevron Trap

See the original report above for a description of the chevron trap

Oceanographic Data

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

Data and Treatment

Data

Available data for each trap fished included a unique collection number, date of deployment, soak time (provided in minutes), latitude, longitude, bottom depth (m), catch code, number of gray triggerfish captured, and collective weight of gray triggerfish. For chevron trap collections, additional information regarding the bottom temperature (^{o}C) in the sampling area was available from the oceanographic data collected via the CTD. We used numbers, instead of weight, of gray triggerfish for all analyses. Estimates of relative abundance, or catch per unit effort (CPUE), were standardized to the number of gray triggerfish 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 was 10-94 m, determined by the depth range at which 100% of individual gray triggerfish was collected. This was done to reduce the number of zero catches from locations outside the normal depth range of gray triggerfish. To visually assess whether this depth range was appropriate a plot of the sampling density of all chevron trap collections across the 10-94 m depth range and gray triggerfish positive chevron trap collections across the 10-94 m depth range is provided in Figure 27. The collections under these constraints/criteria were included in the analyses and referred to as "included traps" 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 due to the poor fit to the observed data using a lognormal error distribution for the positive component of the delta-GLM model (Figure 25). Investigation of this technique to model CPUE data was also suggested during the Fishery-Independent Survey Independent Review (Massey et al. 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 (Figure 27) suggesting the appropriateness of zero-inflated count data models.

Briefly, I will provide some background information regarding zero-inflated count data models. For a more complete discussion see Chapter 11 in Zuur et al. (2009) and 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. 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 beyond what would be expected if you assumed a Poisson or negative binomial distribution, 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. Another example, your using a gear for which the detection

probability of the gear is less than one, i.e., gray triggerfish occupy a site, but the trap does not catch them. This is probably an important source of zeros in the chevron trap survey.

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 gray triggerfish and the sampling design of the SAB Reef Fish Survey, SEDAR 32 data workshop index working group panelists *a priori* determined that zero-inflated mixture models were more appropriate than zero-inflated hurdle models for modeling CPUE of gray triggerfish from chevron trap catches. The merits and assumptions of both classes of zero-inflation models were considered, but given that we expect true zeros to be present in the data set, mixture models appeared most appropriate. Based on this assumption, we only investigated ZIP and ZINB models for the development of the standardized index of relative abundance.

Mathematics of ZIP and ZINB Models

To understand the math underlying ZIP and ZINB models, one must 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

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

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:

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

Now the question becomes "how do we model the count process?". The answer: assume that the counts follow a Poisson or negative binomial (geometric distribution special case of negative binomial). This assumption gives rise to the terms zero-inflated *Poisson* (ZIP) and zero-inflated *negative binomial* (ZINB).

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

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

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

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

Substituting Equation 4 into Equation 2 we have

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

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

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

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 μ_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 X represents 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

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

where the symbol Z represents each covariate (possibly the same or different covariates included in the Poisson GLM) and the regression coefficients to be estimated are represented by the symbols v (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 ZIP and ZINB Models

In a Poisson GLM, we have $\mathrm{E}(Y_i) = \mu_i$ and $\mathrm{var}(Y_i) = \mu_i$, whereas 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 ZIP and 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 ZIP are

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

$$\mathrm{var}(Y_i) = (1 - \pi_i) * (\mu_i + \pi_i * \mu_i^2). \quad (11)$$

If the probability of false zeros is zero, that is $\pi_i = 0$, we obtain the mean and variance equations from the Poisson GLM. If $\pi_i > 0$, then the variance is larger than the mean; hence, excessive number of zeros causes overdispersion.

The mean and variance of a ZINB are

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

$$\mathrm{var}(Y_i) = (1 - \pi_i) * \left(\mu_i + \frac{\mu_i^2}{k}\right) + \mu_i^2 * \left(\pi_i^2 + \pi_i\right). \tag{12}$$

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 gray triggerfish we modeled CPUE as catch per trap. This deviates from how fishery-independent indices for the SEDAR process have traditionally calculated CPUE. Traditionally, fishery-independent indices were modeled as catch per trap per hour. The difference between these two formulations is whether you take soak time (or sample duration) into account when calculating the CPUE for a given trap. In the current model formulation, instead of dividing the catch per trap 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 trap to capture a gray triggerfish, therefore a trap with a soak time of 120 minutes is twice as likely to catch a gray triggerfish as a trap 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, ZIP and 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 season in addition to year. Year is necessary to include because standardized CPUE estimates by year are the desired response variable of the model. The latitudes and bottom temperatures reported in the SAB Reef Fish Survey database were rounded to the nearest whole degree of latitude and whole degree Centigrade, respectively, prior to binning. For season, we pooled the data into two seasons based on the date of capture: spring (June and earlier) and summer (July and later). Bins for sampling depth and latitude were determined based on the quartiles of their distribution such that each bin represented 25% of the available data. 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 17 provides a summary of the bins used for each of the covariates in the analysis.

We provide a method for estimating the annual index of abundance (i.e., the year effect) and associated uncertainty measures. In this procedure, to extract the annual abundance index we obtain the predicted CPUE from the model at all possible combinations of the covariates. Then the annual index of abundance is simply the mean of the predicted values within each year. These values are normalized to the series mean to obtain a normalized relative abundance index where a value of 1 suggests normal (with respect to the time series) CPUE. To obtain estimates of the uncertainty about these point estimates, a bootstrap technique is used. A total of 7500 bootstraps were ran, with the annual coefficient of variation (CV) being calculated as the standard deviation of the bootstrap results within a given year divided by the predicted annual abundance index value.

Selection of the covariates included in the final model (both binomial and count sub-models) and the error distribution (Poisson or negative binomial) for the count sub-model 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

Data Summary

From 1990 to 2011 the SAB reef fish survey made 10,175 chevron trap gear deployments (Table 10), averaging 463 collections per year (range: 286-1051). Of these collections, we included catch data from monitoring stations for 8,083 (79.4%), or on average 367 collections per year (range: 218-628; Table 10). Of the collections not used in the development of annual CPUE estimates, the majority (n=1602 or 15.7%) were reconnaissance trap deployments used to investigate potential new live bottom habitats. In addition, we removed 490 collections (4.8%) from CPUE calculations due to excluded soak times (<45 or >150 minutes, n=358; 3.5%), damage or loss of the gear (n=100, 1.0%), and sampling depth (<10 or >94 m, n=32, 0.3%).

For development of the zero-inflated model, missing covariate data related to latitude and temperature resulted in the removal of 9 and 1030 chevron trap collections, respectively, or 0.1% and 12.7% of the data included in the nominal CPUE analysis (see Ballenger et al. 2013). This resulted in a total of 7,044 included collections retained in the analysis, ranging from 184 to 454 per year. Please note that due to missing bottom temperature and latitude data, we removed greater than 20% of available collections for the years 1995, 1996, 1999, 2000, and 2011 (Table 14). Because of the high encounter rate of gray triggerfish in the chevron traps, exclusion of this data likely does not affect annual CPUE significantly.

Zero-Inflated CPUE

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 gray triggerfish CPUE than the Poisson error distribution (negative binomial AIC = 14,936 vs. Poisson AIC = 17,790). A step-wise backward selection routine using AIC dropped the depth term from the binomial component of the ZINB (Table 18). No covariates were dropped from the negative binomial component by step-wise backward selection. A plot of the observed and predicted number of gray triggerfish caught in included chevron trap collections suggests the ZINB model was successful at capturing the observed catch pattern (Figure 28 and Figure 29). The total number of traps deployed, the proportion of chevron traps with positive catch, and the nominal CPUE for the various depth, latitude, bottom temperature, and season bins can be found in Figure 30, Figure 31, Figure 22 and Figure 23, respectively.

Standardized annual CPUE estimates normalized to the series average indicates that CPUE has been highly variable throughout the time series, though there has been a general decreasing trend since the mid- to late-1990s (Table 19 and Figure 32). This is similar to the pattern observed for CPUE estimates based upon the delta-GLM model (Figure 33). Also presented in Figure 33 are results of an updated delta-GLM model for gray triggerfish using the latitude and depth covariate bins as defined for the ZINB model. Please note the low estimate of CPUE in 1990 may have been influenced by both the direct effect that Hurricane Hugo had on the reef fish communities in the SAB and the indirect effect it had on the temporal and spatial extent of sampling by MARMAP in 1990. Particularly striking during 1990 (and 1992) is the shift in average sampling date, being approximately a month or more earlier in that year than in all other years in the time series (Table 12). More work is needed to investigate the effect that a shift in average sampling date may have had on CPUE estimates during these two years.

In the bootstrap to estimate variability in the annual relative abundance index we observed a convergence rate of 74.2%, resulting in 5563 individual bootstraps being used in variability estimation. For each of these bootstraps we calculated an observed relative abundance index based on the bootstrap sample (Figure 34), with those giving the same overall pattern of relative abundance observed in the base model. Investigation of annual variance and CV estimates at different boostrap sample sizes suggested that the variance and CV for all years converged by 5000 bootstraps (Figure 35), thus we do not expect a further increase in the bootstrap sample size to affect annual variance estimates. Standardization using the ZINB model resulted in annual coefficient of variation (CV) estimates averaging 16.8%, with a median value of 15.7% (Figure 36). Individual year CV estimates ranged from as low as 10.8% to as high as 29.3% (Table 19).

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Tables

Table 1: Number of gear deployments, by year and gear type, during fishery-independent sampling of live/hard bottom areas. This includes both randomly selected monitoring stations ("included" collections) and reconnaissance stations.

Year	Blackfish Trap	Florida Trap	Chevron Trap	Total
1977	21*	–	–	21
1978	90*	–	–	90
1979	312*	–	–	312
1980	298*	7*	–	305
1981	348	121	–	469
1982	259	130	–	389
1983	432	165	–	597
1984	530	260	–	790
1985	372	260	–	632
1986	252	228	–	480
1987	180	354	–	534
1988	105*	105	105*	315
1989	80*	80	80*	240
1990	–	–	354	354
1991	–	–	305	305
1992	–	–	324	324
1993	–	–	542	542
1994	–	–	468	468
1995	–	–	545	545
1996	–	–	642	642
1997	–	–	532	532
1998	–	–	523	523
1999	–	–	347	347
2000	–	–	383	383
2001	–	–	325	325
2002	–	–	336	336
2003	–	–	286	286
2004	–	–	319	319
2005	–	–	357	357
2006	–	–	333	333
2007	–	–	361	361
2008	–	–	354	354
2009	–	–	464	464
2010	–	–	1051	1051
2011	–	–	1024	1024
Total	3279	1710	10360	15349

* – years were not included in summaries, as the MARMAP program did not use a consistent gear deployment strategy

Table 2: Blackfish trap nominal CPUE for gray triggerfish. Included Collections = number of collections between depths of 10-94 m with a duration of 45-150 minutes and catch code of 0 (nothing caught in trap), 1 (catch with finfish, but not necessarily selected species), and 2 (catch without finfish), n = number of individuals captured, Normalized = CPUE normalized to its mean value over the time series, and Nominal CPUE (#s) = mean number of individual fish*trap^{-1}*hr^{-1}.

			Nominal CPUE (#s)		
Year	Included Collections	n	CPUE	CV	Normalized
1981	317	29	0.070	0.35	2.22
1982	239	19	0.073	0.30	2.33
1983	415	16	0.031	0.38	0.99
1984	527	5	0.006	0.45	0.19
1985	372	16	0.030	0.25	0.95
1986	252	1	0.003	1.00	0.10
1987	180	2	0.007	0.71	0.23

Table 3: Blackfish trap delta-GLM standardized CPUE and information associated with blackfish trap sets included in standardized CPUE calculation. Included collections = defined as in Table 6 plus the removal of any collections for which an included covariate in the final delta-GLM model is missing data, Positive = proportion of included collections positive for the species of interest, n = number of positive traps, and Normalized = delta-GLM standardized CPUE (number of fish*trap^{-1}*hr^{-1}) normalized to its mean value over the time series.

		Depth (m)		Latitude (°N)		Date				Delta-GLM Standardized CPUE				
Year	**Included Collections**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg. Date**	**Range**			**Positive**	**n**	**CPUE**	**CV**	**Normalized**
1981	317	28.2	16 - 44	32.91	31.67 - 34.28	08/02/81	04/23/90	-	09/13/81	5.05%	16	0.0521	0.32	1.83
1982	239	25.1	16 - 33	32.68	31.68 - 33.48	06/23/82	06/08/82	-	07/14/82	5.86%	14	0.0657	0.30	2.30
1983	415	24.8	15 - 42	32.99	31.68 - 34.33	05/02/83	04/13/83	-	05/18/83	2.65%	11	0.0273	0.34	0.96
1984	527	28.3	15 - 62	32.80	31.69 - 34.39	08/06/84	07/12/84	-	08/30/84	0.95%	5	0.0042	0.46	0.15
1985	372	27.8	16 - 42	32.68	30.74 - 34.32	06/07/85	05/11/85	-	08/14/85	4.30%	16	0.0192	0.32	0.67
1986*	0	–	–	–	–	–		–		–	–	–	–	–
1987	180	28.6	15 - 42	32.31	31.68 - 32.79	04/10/87	04/07/87	-	04/13/87	1.11%	2	0.0028	0.73	0.10

* – Year excluded from delta-GLM standardization of annual CPUE due to insufficient positive gear deployments (n<2)

Table 4: Model selection results from the delta-GLM model for gray triggerfish caught in MARMAP blackfish traps, 1981-1987.

Removed	df	Deviance	AIC
	Bernoulli Sub-Model		
Depth and Season	5	466.546	480.546
Depth	4	465.396	481.396
Season	1	463.307	485.307
<none>	–	461.797	485.797
Latitude	1	489.202	511.202
Depth and Latitude	5	543.240	557.240
Depth, Season and Latitude	6	545.416	557.416
	Lognormal Sub-Model		
Latitude and Season	2	11.7259	95.0109
Latitude, Season and Depth	6	13.3600	95.3606
Latitude	1	11.6942	96.8377
Latitude and Depth	5	13.2920	97.0338

Table 5: Analysis of deviance tables for the delta-GLM model for gray triggerfish caught in MARMAP blackfish traps, 1981-1987. Bernoulli sub-model p-value represents results of a Chi-squared Test. Lognormal sub-model p-value represents results of an F test.

Factor	df	Deviance	Residual df	Residual Deviance	p-value
			Bernoulli Sub-Model		
Null			2049	569.72	
Year	5	24.3039	2044	545.416	0.0002
Latitude	1	78.8702	2043	466.546	<0.0001
			Lognormal Sub-Model		
Null			63	16.5476	
Year	5	3.18758	58	13.36	0.020435
Depth	4	1.6341	54	11.7259	0.127024

Table 6: Florida trap nominal CPUE for gray triggerfish. Included Collections = number of collections between depths of 10-94 m with a duration of 45-195 minutes and catch code of 0 (nothing caught in trap), 1 (catch with finfish, but not necessarily selected species), and 2 (catch without finfish), n = number of individuals captured, Normalized = CPUE normalized to its mean value over the time series, and Nominal CPUE (#s) = mean number of individual fish*trap^{-1}*hr^{-1}.

			Nominal CPUE (#s)		
Year	**Included Collections**	**n**	**CPUE**	**CV**	**Normalized**
1981	119	10	0.047	0.37	1.32
1982	122	12	0.071	0.31	1.97
1983	137	8	0.040	0.44	1.10
1984	225	23	0.045	0.27	1.24
1985	227	16	0.028	0.35	0.78
1986	228	7	0.017	0.39	0.46
1987	334	3	0.005	0.78	0.13

Table 7: Florida trap delta-GLM standardized CPUE and information associated with Florida trap sets included in standardized CPUE calculation. Included collections = defined as in Table 6 plus the removal of any collections for which an included covariate in the final delta-GLM model is missing data, Positive = proportion of included collections positive for the species of interest, n = number of positive traps, and Normalized = delta-GLM standardized CPUE (number of fish*trap^{-1}*hr^{-1}) normalized to its mean value over the time series.

		Depth (m)		Latitude (^{o}N)		Date				Delta-GLM Standardized CPUE				
Year	**Included Collections**	**Avg.**	**Range**	**Avg.**	**Range**	**Avg. Date**	**Range**			**Positive**	**n**	**CPUE**	**CV**	**Normalized**
1981	119	28.2	16 - 44	32.87	31.68 - 34.28	07/31/81	04/23/90	-	09/13/81	6.72%	8	0.0613	0.39	2.09
1982	122	31.4	17 - 49	32.60	31.69 - 33.48	06/20/82	06/08/82	-	07/14/82	8.20%	10	0.0752	0.34	2.56
1983	137	40.3	20 - 73	32.66	31.68 - 34.33	06/09/83	04/13/83	-	08/14/83	5.11%	7	0.0169	0.48	0.58
1984	225	34.6	15 - 59	32.73	31.68 - 34.39	07/11/84	05/02/84	-	08/30/84	7.56%	17	0.0315	0.37	1.08
1985	227	38.9	16 - 57	32.57	30.74 - 34.32	06/14/85	05/11/85	-	07/18/85	3.96%	9	0.0117	0.44	0.40
1986	228	41.5	16 - 60	32.25	30.89 - 33.28	05/31/86	04/12/86	-	06/22/86	3.07%	7	0.0072	0.50	0.25
1987	334	46.3	15 - 64	32.21	30.42 - 32.87	05/29/87	02/19/87	-	08/20/87	0.60%	2	0.0014	0.77	0.05

Table 8: Model selection results from the delta-GLM model for gray triggerfish caught in MARMAP Florida traps, 1981-1987.

Removed	df	Deviance	AIC
Bernoulli Sub-Model			
Season	1	423.196	443.196
Season and Depth	3	428.420	444.420
<none>		422.815	444.815
Depth	2	428.130	446.130
Season and Latitude	1	453.963	471.963
Latitude	1	453.935	473.935
Lognormal Sub-Model			
Depth, Latitude and Season	4	10.5481	81.9689
Depth and Latitude*	3	10.2518	82.2594
Depth and Season	3	10.4122	83.1904
Depth	2	10.1427	83.6174
Latitude	1	10.0202	84.8879
Season	1	10.1588	85.7123
<none>		9.9608	86.5312

* – This model was assumed for the delta-GLM analysis. As currently implemented, the delta-GLM function constructed for R requires the inclusion of one extra covariate (in addition to year) in both components of the delta-GLM model.

Table 9: Analysis of deviance tables for the delta-GLM model for gray triggerfish caught in MARMAP Florida traps, 1981-1987. Bernoulli sub-model p-value represents results of a Chi-squared Test. Lognormal sub-model p-value represents results of an F test.

Factor	df	Deviance	Residual df	Residual Deviance	p-value
Bernoulli Sub-Model					
Null			1391	494.674	
Year	6	28.3223	1385	466.352	<0.0001
Depth	2	12.3886	1383	453.963	0.0020
Latitude	1	30.7669	1382	423.196	<0.0001
Lognormal Sub-Model					
Null			59	12.1499	
Year	6	1.60177	53	10.5481	0.25064
Season	1	0.296294	52	10.2518	0.22575

Table 10: Annual total number of chevron trap collections made by fishery-independent survey, and the number of included collections made at monitoring stations. 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 10 and 94 m as included collections. Please note that the SEAMAP-SA Reef Fish and SEFIS fishery-independent research projects did not begin until 2009 and 2010, respectively.

	MARMAP		SEAMAP-SA Reef Fish		SEFIS		Total	
Year	**All**	**Included**	**All**	**Included**	**All**	**Included**	**All**	**Included**
1988	105	0	–	–	–	–	105	0
1989	80	0	–	–	–	–	80	0
1990	354	350	–	–	–	–	354	350
1991	305	298	–	–	–	–	305	298
1992	324	315	–	–	–	–	324	315
1993	542	410	–	–	–	–	542	410
1994	468	454	–	–	–	–	468	454
1995	545	523	–	–	–	–	545	523
1996	642	451	–	–	–	–	642	451
1997	532	439	–	–	–	–	532	439
1998	523	518	–	–	–	–	523	518
1999	347	253	–	–	–	–	347	253
2000	383	319	–	–	–	–	383	319
2001	325	248	–	–	–	–	325	248
2002	336	240	–	–	–	–	336	240
2003	286	218	–	–	–	–	286	218
2004	319	271	–	–	–	–	319	271
2005	357	325	–	–	–	–	357	325
2006	333	296	–	–	–	–	333	296
2007	361	325	–	–	–	–	361	325
2008	354	303	–	–	–	–	354	303
2009	452	402	12	0	–	–	464	402
2010	459	368	108	2	484	127	1051	497
2011	410	308	68	0	546	320	1024	628

Table 11: Chevron trap nominal CPUE for gray triggerfish. Included Collections = number of collections between depths of 10-94 m with a duration of 45-150 minutes and catch code of 0 (nothing caught in trap), 1 (catch with finfish, but not necessarily selected species), and 2 (catch without finfish), n = number of individuals captured, Normalized = CPUE normalized to its mean value over the time series, and Nominal CPUE (#s) = mean number of individual fish*trap^{-1}*hr^{-1}.

			Nominal CPUE (#s)		
Year	**Included Collections**	**n**	**CPUE**	**CV**	**Normalized**
1990	350	75	0.122	0.21	0.23
1991	298	394	0.893	0.10	1.70
1992	315	196	0.387	0.15	0.74
1993	410	298	0.443	0.11	0.85
1994	454	446	0.603	0.11	1.15
1995	523	668	0.798	0.13	1.52
1996	451	682	0.893	0.15	1.70
1997	439	714	0.961	0.12	1.83
1998	518	519	0.610	0.13	1.16
1999	253	168	0.404	0.19	0.77
2000	319	245	0.466	0.23	0.89
2001	248	195	0.511	0.13	0.98
2002	240	279	0.675	0.13	1.29
2003	218	53	0.147	0.20	0.28
2004	271	184	0.405	0.15	0.77
2005	325	331	0.588	0.15	1.12
2006	296	146	0.317	0.16	0.60
2007	325	304	0.605	0.18	1.15
2008	303	323	0.668	0.19	1.27
2009	402	257	0.388	0.16	0.74
2010	497	280	0.340	0.15	0.65
2011	628	311	0.312	0.17	0.60

Table 12: Chevron trap delta-GLM standardized CPUE and information associated with chevron trap sets included in standardized CPUE calculation. Included collections = defined as in Table 6 plus the removal of any collections for which an included covariate in the final delta-GLM model is missing data, Positive = proportion of included collections positive for the species of interest, and Normalized = delta-GLM standardized CPUE (number of fish*trap^{-1}*hr^{-1}) normalized to its mean value over the time series.

	Included	Depth (m)		Temperature (°C)		Latitude (°N)		Date				Delta-GLM Standardized CPUE			
Year	Collections	Avg.	Range	Avg.	Range	Avg.	Range	Avg. Date	Range			Positive	CPUE	CV	Normalized
1990	307	33.6	17 - 93	21.9	18.2 - 27.8	32.52	30.42 - 33.82	05/27/90	04/23/90	-	08/09/90	11.07%	0.0634	0.22	0.2467
1991	267	33.3	17 - 93	25.0	15.9 - 27.7	32.65	30.75 - 34.61	08/04/91	06/11/91	-	09/24/91	45.32%	0.3911	0.14	1.5226
1992	288	34.0	17 - 62	21.3	15.3 - 24.5	32.77	30.42 - 34.32	06/02/92	03/31/92	-	08/13/92	28.82%	0.2521	0.15	0.9815
1993	410	35.2	16 - 94	22.8	17.7 - 28.5	32.39	30.43 - 34.32	06/24/93	05/10/93	-	08/13/93	28.78%	0.2194	0.14	0.8542
1994	395	39.1	16 - 93	22.8	18.1 - 26.9	32.34	30.74 - 33.82	06/23/94	05/09/94	-	10/26/94	37.72%	0.2683	0.13	1.0444
1995	359	34.1	16 - 60	24.6	20.2 - 28.3	32.29	29.94 - 33.75	07/16/95	05/03/95	-	10/26/95	40.67%	0.4031	0.13	1.5690
1996	354	38.3	14 - 94	21.8	14.2 - 27	32.19	27.92 - 34.32	07/05/96	04/29/96	-	09/16/96	35.88%	0.4639	0.13	1.8060
1997	390	39.0	15 - 93	22.6	16.8 - 28	32.00	27.87 - 34.59	07/08/97	04/21/97	-	09/29/97	38.72%	0.4207	0.12	1.6378
1998	454	41.6	14 - 92	20.7	9.5 - 28.6	32.11	27.44 - 34.59	06/26/98	03/31/98	-	08/18/98	24.67%	0.3530	0.14	1.3741
1999	184	35.5	15 - 75	22.9	19.5 - 28.8	31.94	27.27 - 34.41	07/19/99	06/02/99	-	09/28/99	24.46%	0.1840	0.20	0.7163
2000	254	36.6	15 - 92	24.1	18 - 28.5	32.17	28.95 - 34.28	07/19/00	05/16/00	-	10/19/00	26.38%	0.1369	0.18	0.5330
2001	229	38.7	14 - 91	23.4	16 - 29.2	32.30	27.87 - 34.28	07/23/01	05/23/01	-	10/24/01	31.44%	0.2253	0.16	0.8769
2002	206	36.0	13 - 94	24.4	15.2 - 28.3	32.05	27.86 - 33.94	07/27/02	06/17/02	-	09/24/02	37.86%	0.3437	0.17	1.3378
2003	212	39.5	16 - 92	18.9	13.4 - 25.1	32.05	27.43 - 34.33	07/22/03	06/03/03	-	09/22/03	13.21%	0.1846	0.23	0.7187
2004	271	39.1	14 - 91	21.1	16.8 - 25.8	32.31	29.99 - 33.97	06/23/04	05/05/04	-	10/28/04	27.31%	0.3320	0.15	1.2923
2005	297	37.4	15 - 69	23.1	18 - 28.5	32.07	27.33 - 34.32	07/16/05	05/03/05	-	10/19/05	30.64%	0.3151	0.15	1.2267
2006	280	38.5	15 - 94	22.4	15 - 26.7	32.21	27.27 - 34.39	07/21/06	06/06/06	-	09/28/06	22.50%	0.1626	0.17	0.6329
2007	319	38.2	15 - 92	23.2	15.3 - 28.9	32.16	27.33 - 34.33	07/20/07	05/21/07	-	09/24/07	30.72%	0.2483	0.14	0.9666
2008	293	38.0	15 - 92	21.9	15.2 - 27.2	32.13	27.27 - 34.59	07/10/08	05/05/08	-	09/30/08	21.84%	0.2194	0.18	0.8543
2009	396	36.4	14 - 91	22.5	15.4 - 27.2	32.25	27.27 - 34.6	07/19/09	05/06/09	-	10/08/09	20.20%	0.1829	0.16	0.7121
2010	447	38.0	14 - 92	21.2	12.4 - 29.4	32.12	27.34 - 34.59	07/17/10	05/04/10	-	10/13/10	19.69%	0.1494	0.16	0.5814
2011	432	42.0	15 - 93	21.4	14.8 - 28.8	31.05	27.23 - 34.32	07/24/11	05/20/11	-	10/25/11	15.97%	0.1322	0.16	0.5145

Table 13: Delta-GLM covariates (and bins) used in the development of standardized chevron trap CPUE indices for gray triggerfish.

Bin #	Latitude (°N)	Depth (m)	Bottom Temperature (°C)	Season
1	<=29	<20	<=20	Spring
2	30	20-24	21-25	Summer
3	31	25-29	>25	–
4	32	30-34	–	–
5	33	35-39	–	–
6	>=34	40-44	–	–
7	–	45-49	–	–
8	–	50-54	–	–
9	–	55-59	–	–
10	–	60-69	–	–
11	–	>=70	–	–

Table 14: Annual and total exclusion of included chevron trap monitoring station collections from delta-GLM/ZINB analysis due to missing bottom temperature data.

	Sample Size		
Year	**Nominal**	**Delta-GLM/ZINB**	**% Change**
1990	350	307	12.29%
1991	298	267	10.40%
1992	315	288	8.57%
1993	410	410	0.00%
1994	454	395	13.00%
1995	523	359	31.36%
1996	451	354	21.51%
1997	439	390	11.16%
1998	518	454	12.36%
1999	253	184	27.27%
2000	319	254	20.38%
2001	248	229	7.66%
2002	240	206	14.17%
2003	218	212	2.75%
2004	271	271	0.00%
2005	325	297	8.62%
2006	296	280	5.41%
2007	325	319	1.85%
2008	303	293	3.30%
2009	402	396	1.49%
2010	497	447	10.06%
2011	628	432	31.21%
Total	**8083**	**7044**	**12.85%**

Table 15: Model selection results from the delta-GLM model for gray triggerfish caught in SAB Reef Fish Survey Chevron traps, 1990-2011.

Removed	df	Deviance	AIC
	Bernoulli Sub-Model		
<none>		7279.52	7359.52
Season	1	7300.97	7378.97
Temperature	2	7416.53	7492.53
Latitude	5	7501.24	7571.24
Depth	10	7588.42	7648.42
	Lognormal Sub-Model		
<none>		1141.13	4581.44
Temperature	2	1153.26	4598.13
Season	1	1164.88	4619.77
Latitude	5	1174.38	4627.67
Depth	10	1187.05	4638.67

Table 16: Analysis of deviance tables for the delta-GLM model for gray triggerfish caught in SAB Reef Fish Survey chevron traps, 1990-2011. Bernoulli sub-model p-value represents results of a Chi-squared Test. Lognormal sub-model p-value represents results of an F test.

Factor	df	Deviance	Residual df	Residual Deviance	p-value
			Bernoulli Sub-Model		
Null			7043	8326.33	
Year	21	281.4049	7022	8044.93	<0.0001
Depth	10	310.4202	7012	7734.51	<0.0001
	1	63.3842	7011	7671.12	<0.0001
Latitude	5	254.5927	7006	7416.53	<0.0001
	2	137.0119	7004	7279.52	<0.0001
			Lognormal Sub-Model		
Null			1957	1352.66	
Year	21	66.4578	1936	1286.2	<0.0001
Depth	10	53.1014	1926	1233.1	<0.0001
Season	1	43.243	1925	1189.86	<0.0001
Latitude	5	36.5997	1920	1153.26	<0.0001
Temperature	2	12.1221	1918	1141.13	<0.0001

Table 17: Zero-inflated model covariates (and bins) used in the development of the standardized chevron trap CPUE index for gray triggerfish.

Bin #	Latitude (°N)	Depth (m)	Bottom Temperature (°C)	Season
1	<31.532905	<26	<=20	Spring
2	31.532905-32.348194	26-32	21-25	Summer
3	32.348195-32.794577	33-48	>25	–
4	32.794578	≥48	–	–

Table 18: Model selection results for the ZINB CPUE model for gray triggerfish caught in SAB Reef Fish Survey chevron traps, 1990-2011. <none> indicates that no terms were removed from that portion of the ZINB model, otherwise the covariate named in that portion of the ZINB model was removed from the analysis.

Removed Terms		
Binomial Model	**Negative Binomial Model**	**AIC**
Depth	<none>	14927.492
Depth and Latitude	<none>	14928.699
Bottom Temperature	<none>	14930.273
Depth and Year	<none>	14932.451
Latitude	<none>	14933.436
<none>	<none>	14935.672
Season	<none>	14935.845
Year	<none>	14937.437
Depth and Season	<none>	14939.974
Depth and Bottom Temperature	<none>	14945.030
Depth	Bottom Temperature	14945.391
<none>	Latitude	14969.309
<none>	Bottom Temperature	14971.580
Depth	Season	14976.541
<none>	Depth	14978.718
Depth	Latitude	14984.323
<none>	Year	15013.100
Depth	Year	15031.564
Depth	Depth	15115.790
<none>	Season	Won't Converge

Table 19: Chevron trap ZINB standardized CPUE. Included collections = defined as in Table 10 plus the removal of any collections for which an included covariate in the ZINB model is missing data, Positive = proportion of included collections positive for gray triggerfish, and Normalized = ZINB standardized CPUE (number of fish*trap^{-1}) normalized to its mean value over the time series.

		ZINB CPUE			
Year	**Included Collections**	**Positive**	**CPUE**	**CV**	**Normalized**
1990	307	11.07%	0.192	0.272	0.238
1991	267	45.32%	0.892	0.128	1.105
1992	288	28.82%	0.742	0.134	0.918
1993	410	28.78%	0.660	0.117	0.817
1994	395	37.72%	0.859	0.111	1.064
1995	359	40.67%	1.280	0.108	1.585
1996	354	35.88%	1.471	0.130	1.821
1997	390	38.72%	1.234	0.112	1.528
1998	454	24.67%	1.621	0.169	2.007
1999	184	24.46%	0.522	0.198	0.646
2000	254	26.38%	0.466	0.206	0.577
2001	229	31.44%	0.556	0.142	0.688
2002	206	37.86%	1.131	0.148	1.400
2003	212	13.21%	0.666	0.293	0.825
2004	271	27.31%	1.080	0.156	1.337
2005	297	30.64%	0.849	0.154	1.051
2006	280	22.50%	0.530	0.171	0.656
2007	319	30.72%	0.784	0.158	0.971
2008	293	21.84%	0.724	0.186	0.897
2009	396	20.20%	0.550	0.189	0.681
2010	447	19.69%	0.562	0.222	0.696
2011	432	15.97%	0.398	0.191	0.493

Figures

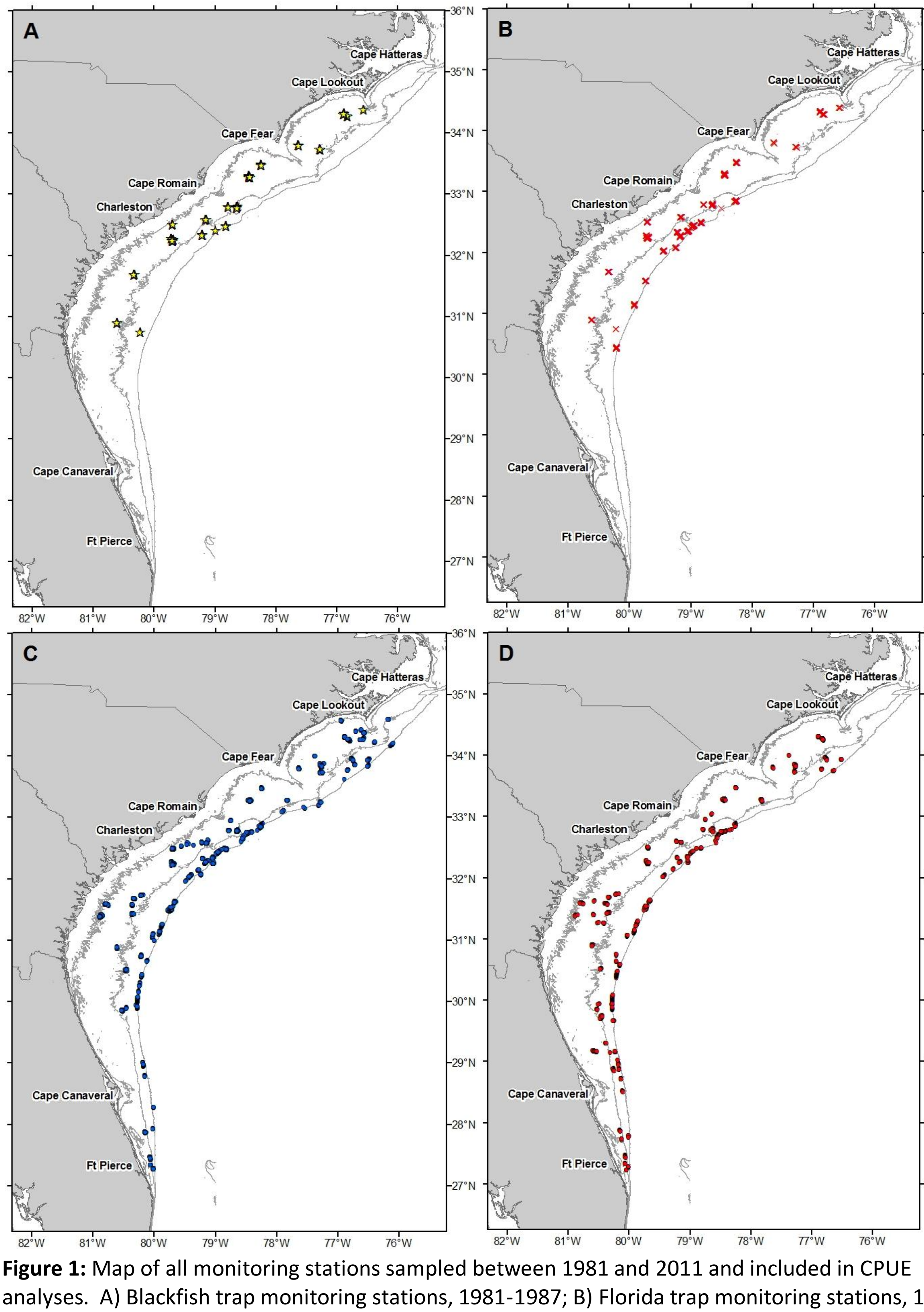


Figure 1: Map of all monitoring stations sampled between 1981 and 2011 and included in CPUE analyses. A) Blackfish trap monitoring stations, 1981-1987; B) Florida trap monitoring stations, 1981-1987, C) Chevron trap monitoring stations, 1990-2010, and D) Chevron trap monitoring stations, 2011.

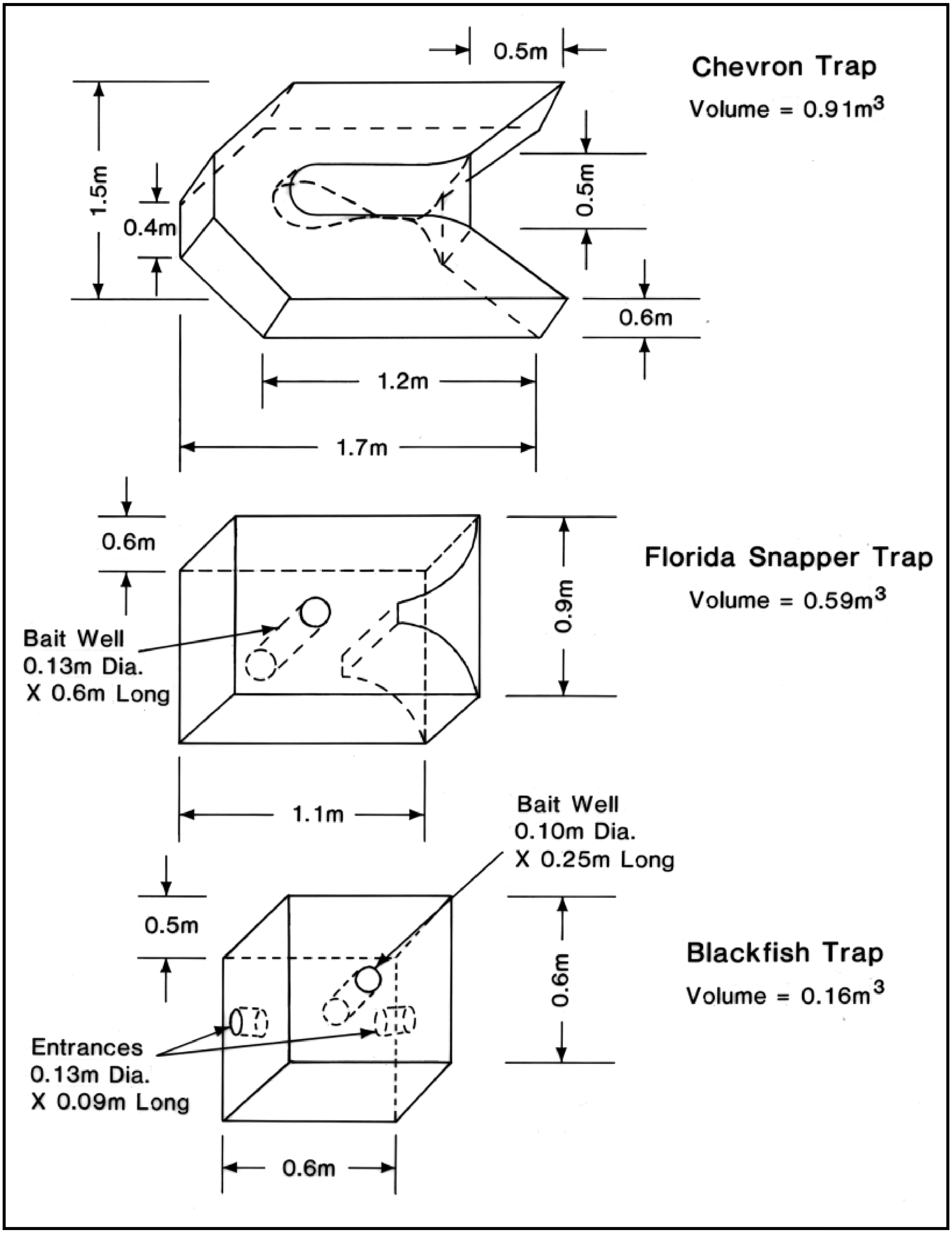


Figure 2: Diagrams of the three trap gears used for monitoring purposes by the SAB Reef Fish Survey from 1981-2011 (from Collins 1990).

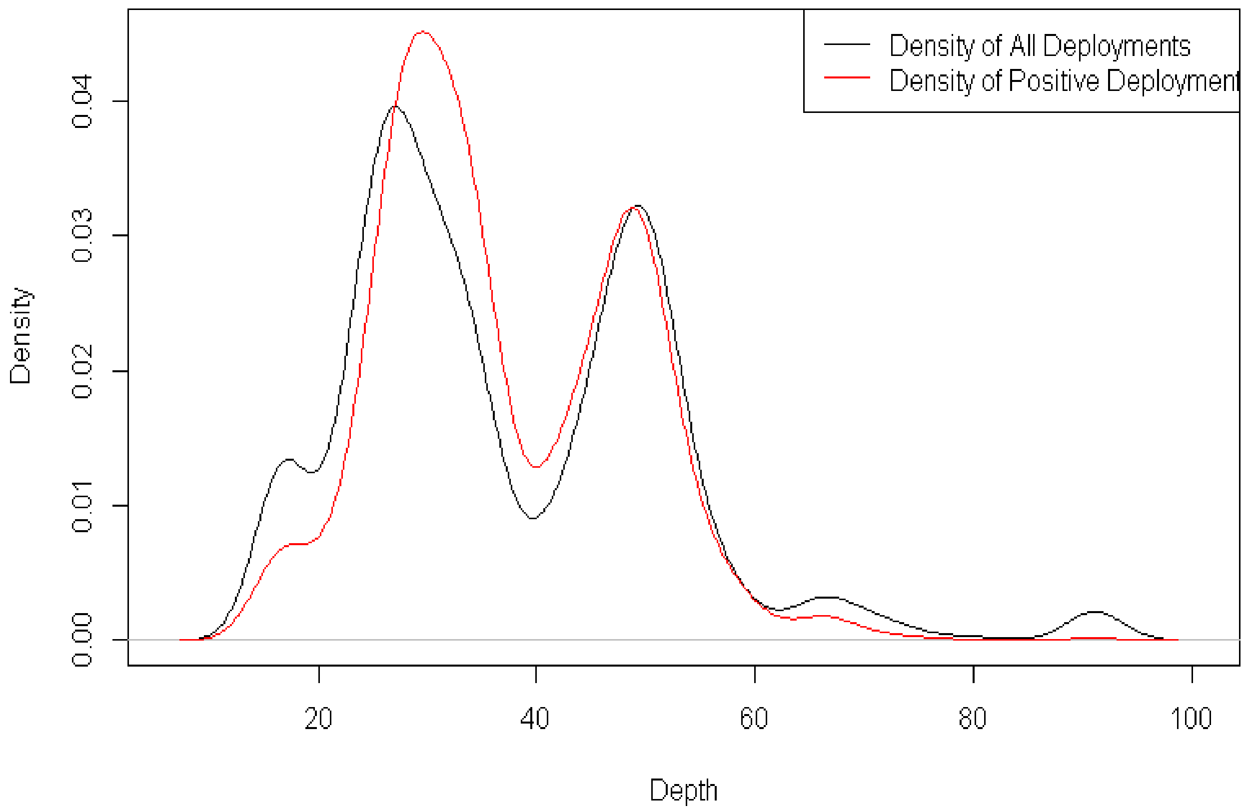


Figure 3: Sampling density plot across depths for chevron trap collections made via the SAB Reef Fish Survey. Illustrated is the density vs. depth for all chevron trap collections (black line) and the density vs depth for gray triggerfish positive chevron trap collections.

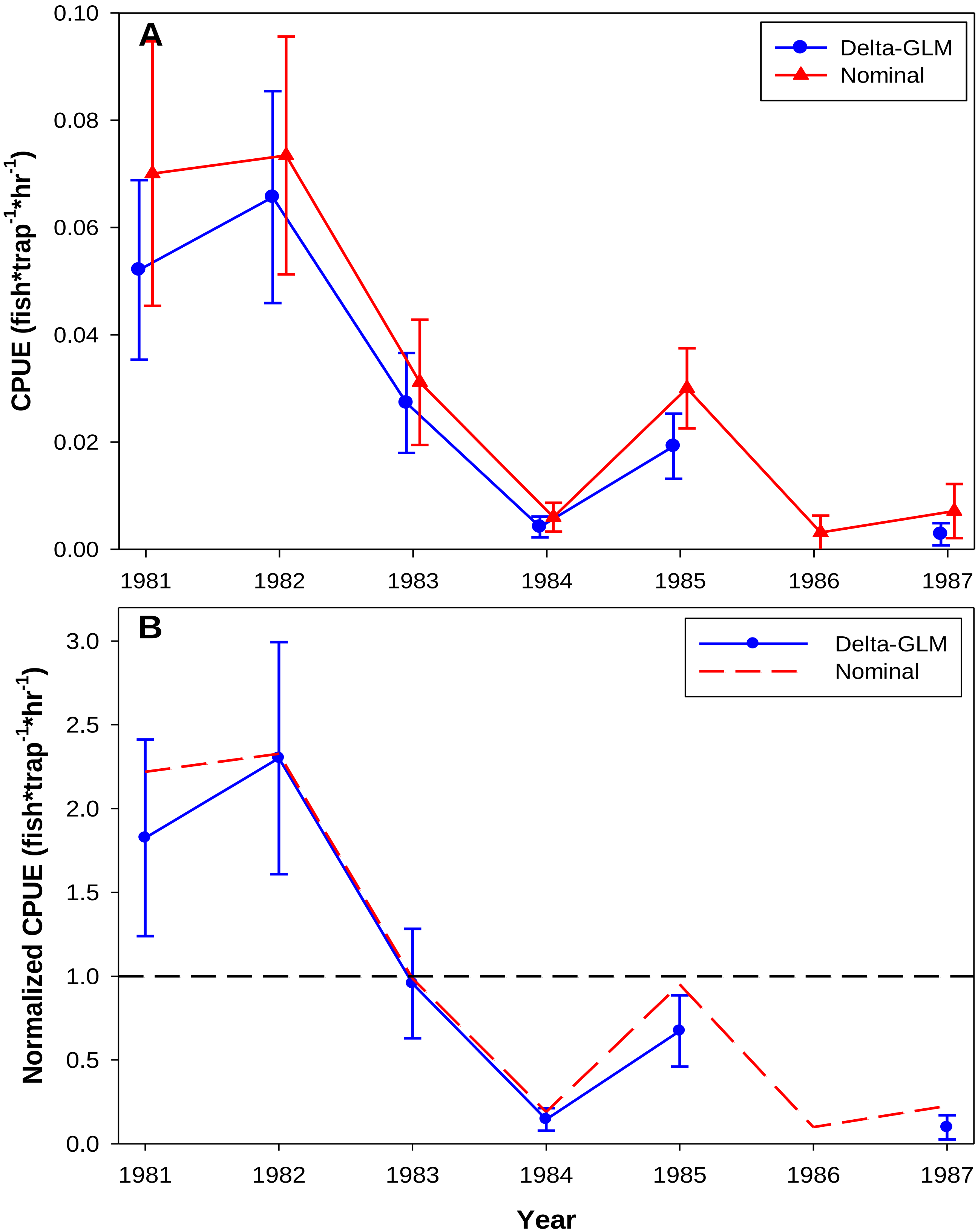


Figure 4: Blackfish trap nominal and delta-GLM standardized CPUE. A) Nominal and delta-GLM standardized CPUE. Please note that the x-axis has been jiggered to allow easier interpretation of the graph. B) Normalized (to the series mean) nominal and delta-GLM standardized CPUE.

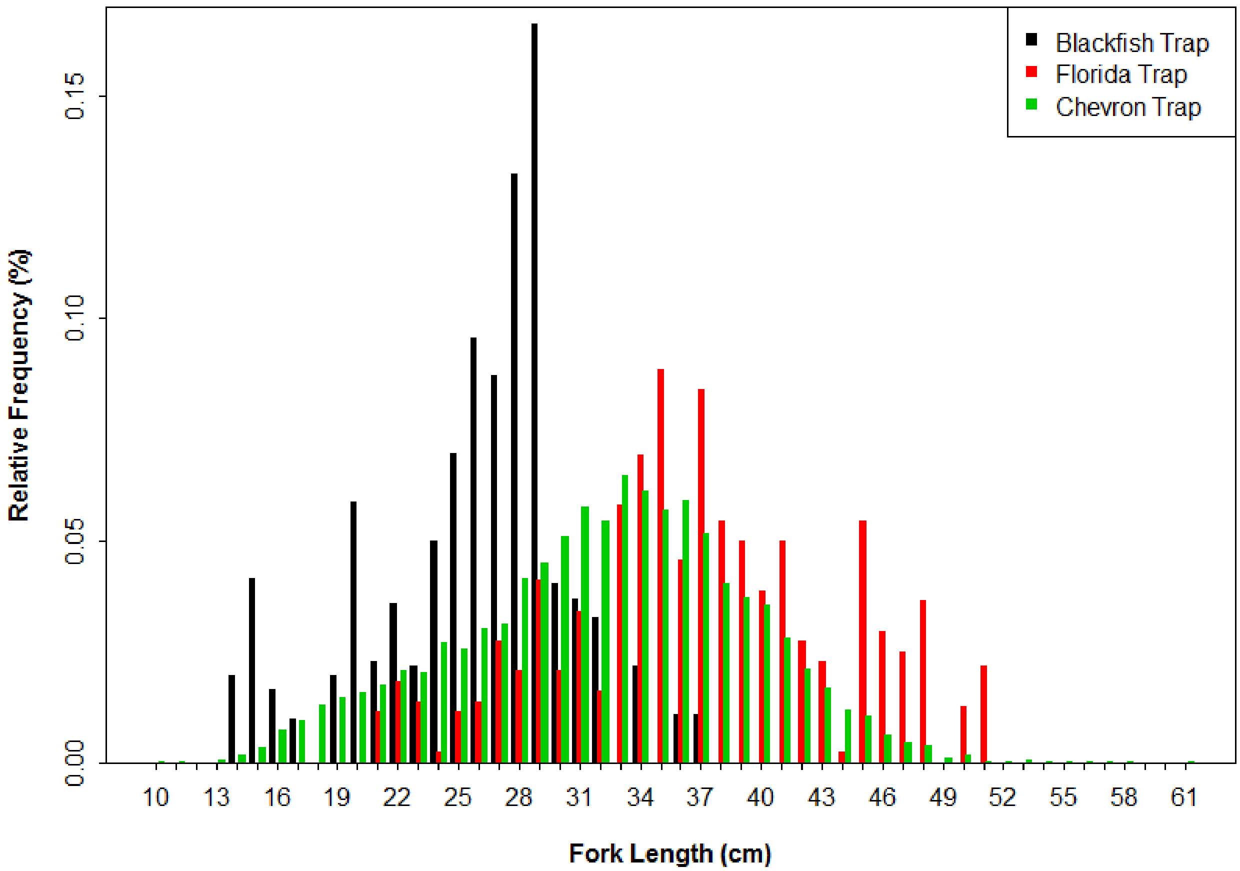


Figure 5: Fork Length (cm) distributions from blackfish (1981-1987; black bars), Florida (1981-1987; red bars) and chevron traps (1990-2011; green bars) deployed by the SAB Reef Fish Survey. A total of 92, 88, and 8706 gray triggerfish were measured from blackfish, Florida, and chevron traps, respectively. All gray triggerfish lengths originally recorded as total lengths were converted to fork lengths using the FL-TL conversion provided in Ballenger et al. (2012).

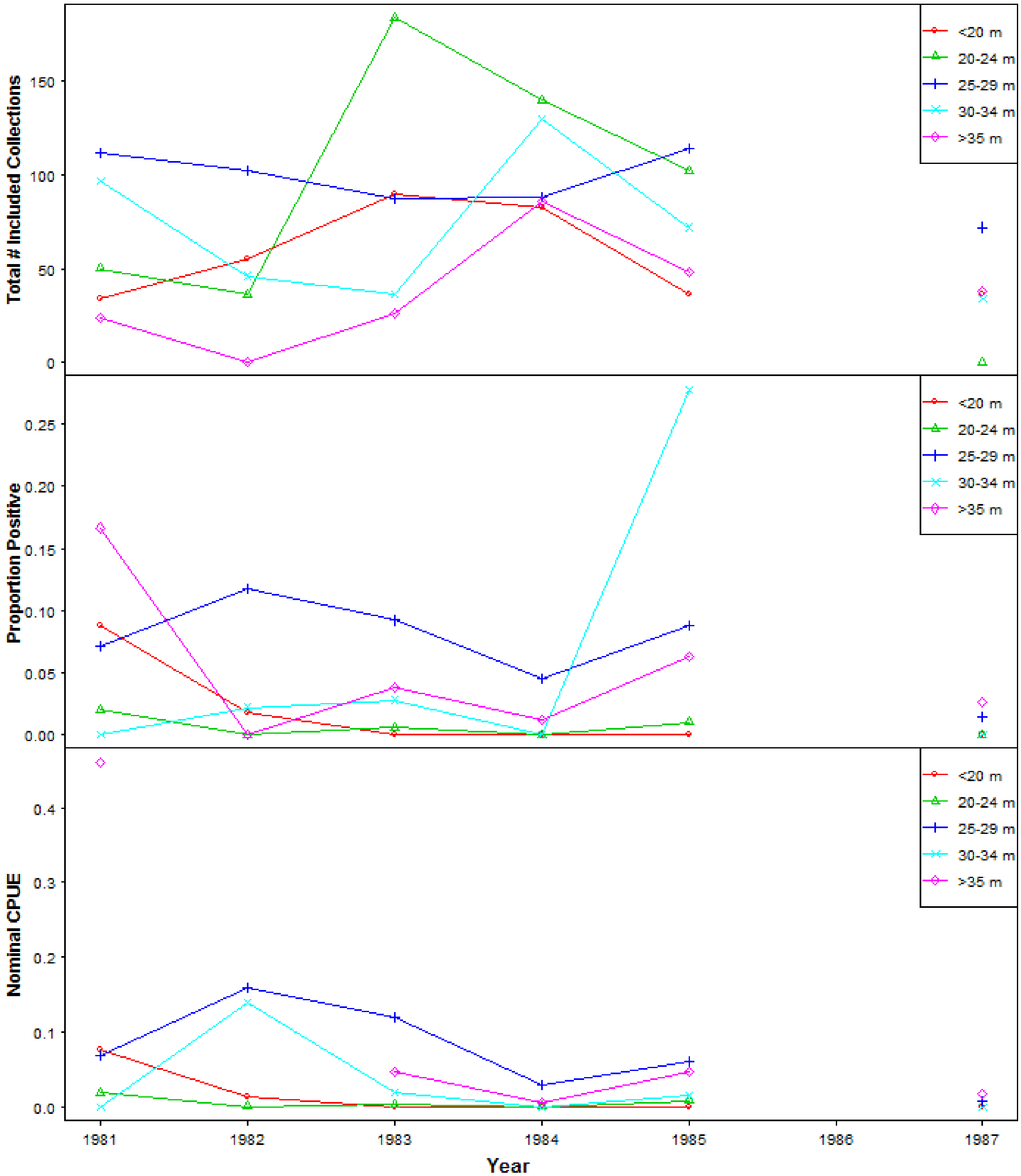


Figure 6: Top panel – the total number of blackfish traps deployed in each depth zone. Middle panel – the proportion of blackfish trap collections with positive gray triggerfish catch in each depth zone. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each depth based on MARMAP blackfish trap catches, 1981-1987. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

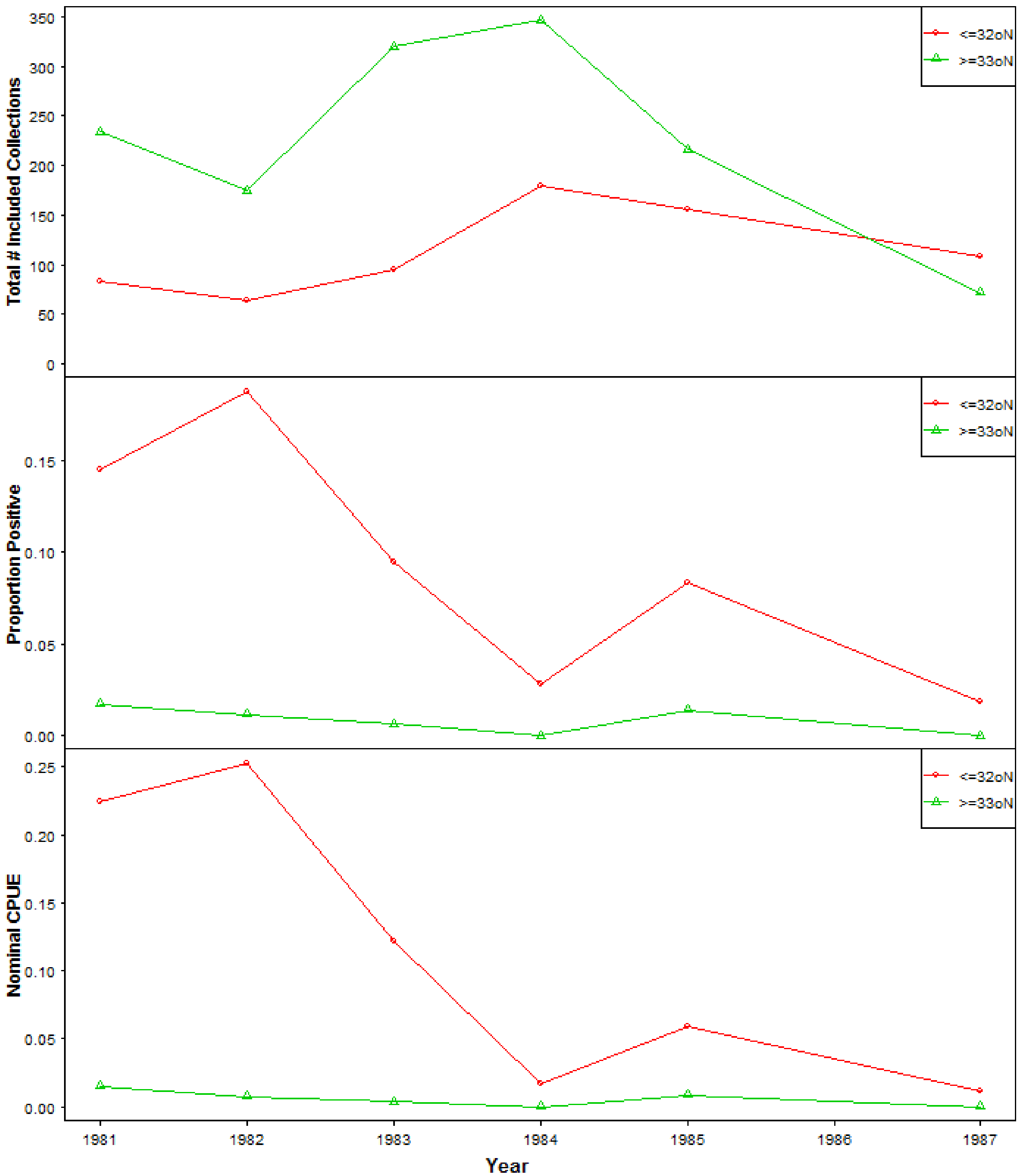


Figure 7: Top panel – the total number of blackfish traps deployed in each latitude zone. Middle panel – the proportion of blackfish trap collections with positive gray triggerfish catch in each latitude zone. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each latitude zone based on MARMAP blackfish trap catches, 1981-1987. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

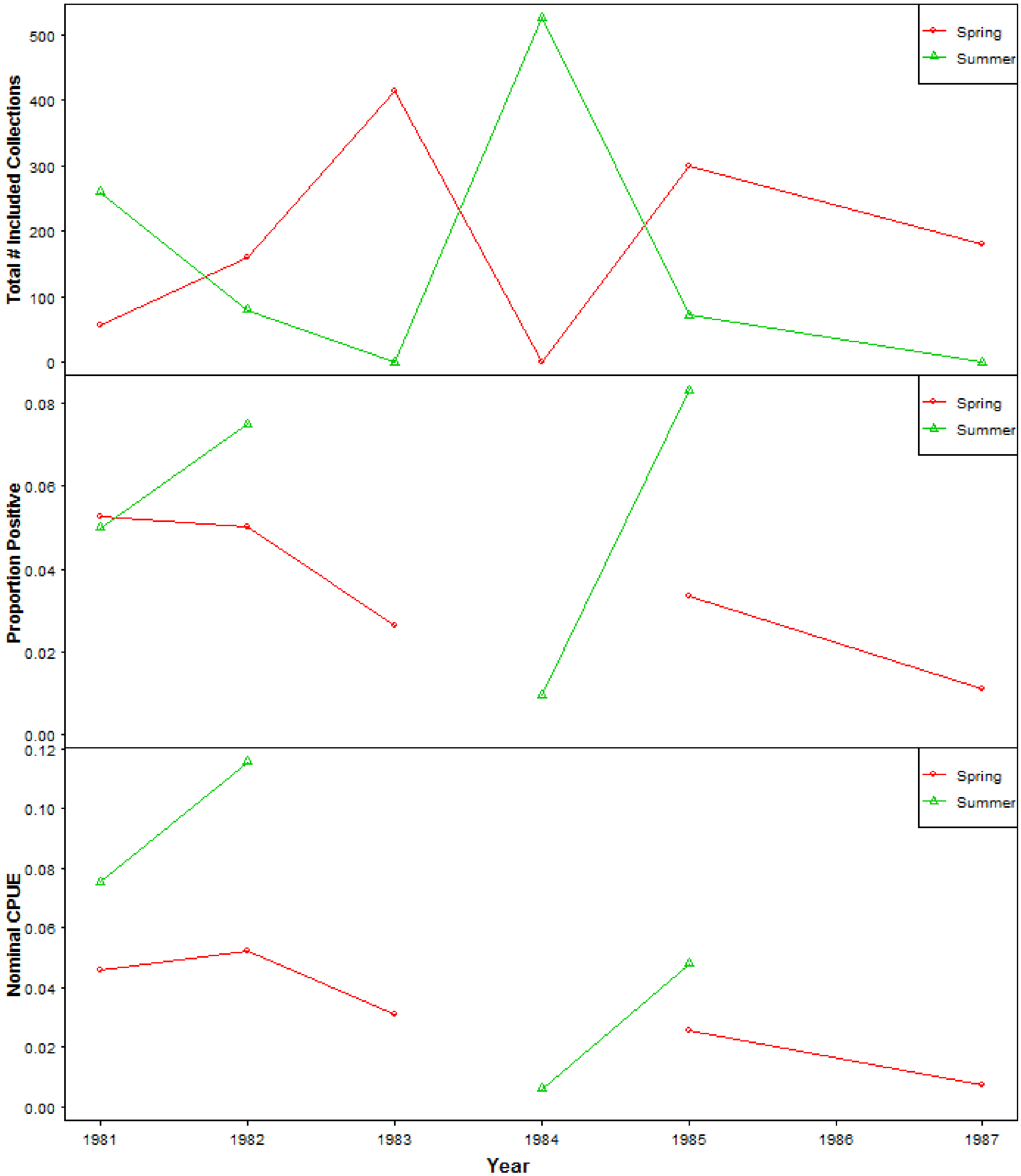


Figure 8: Top panel – the total number of blackfish traps deployed in each season. Middle panel – the proportion of blackfish trap collections with positive gray triggerfish catch in each season. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each season based on MARMAP blackfish trap catches, 1981-1987. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

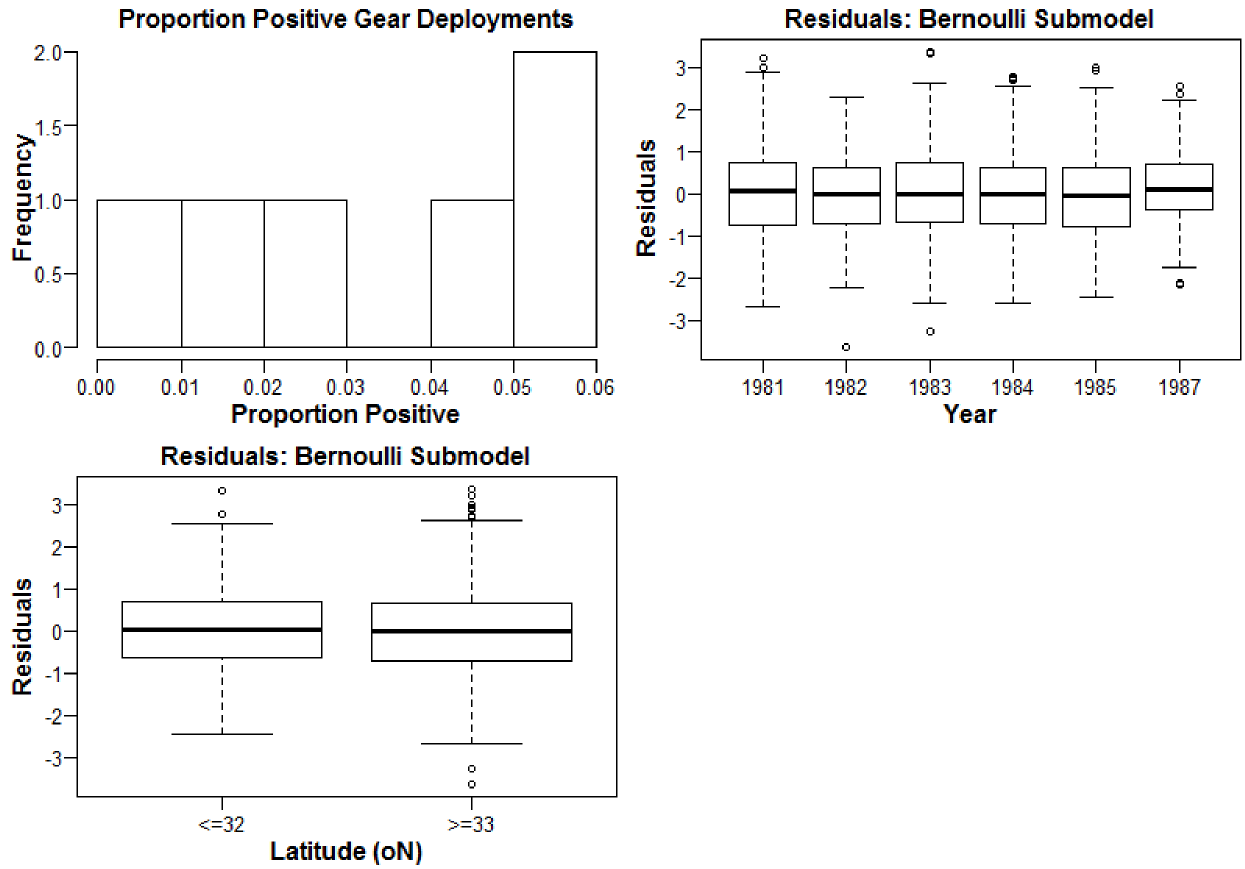


Figure 9: Diagnostics of Bernoulli sub-model fits to positive versus zero gray triggerfish CPUE data from MARMAP blackfish trap collections, 1981-1987. Box-and-whisker plots give first, second (median), and third quartile, as well as limbs that extend approximately one interquartile range beyond the nearest quartile, and outliers (circles beyond the limbs). Residuals are randomized quantile residuals.

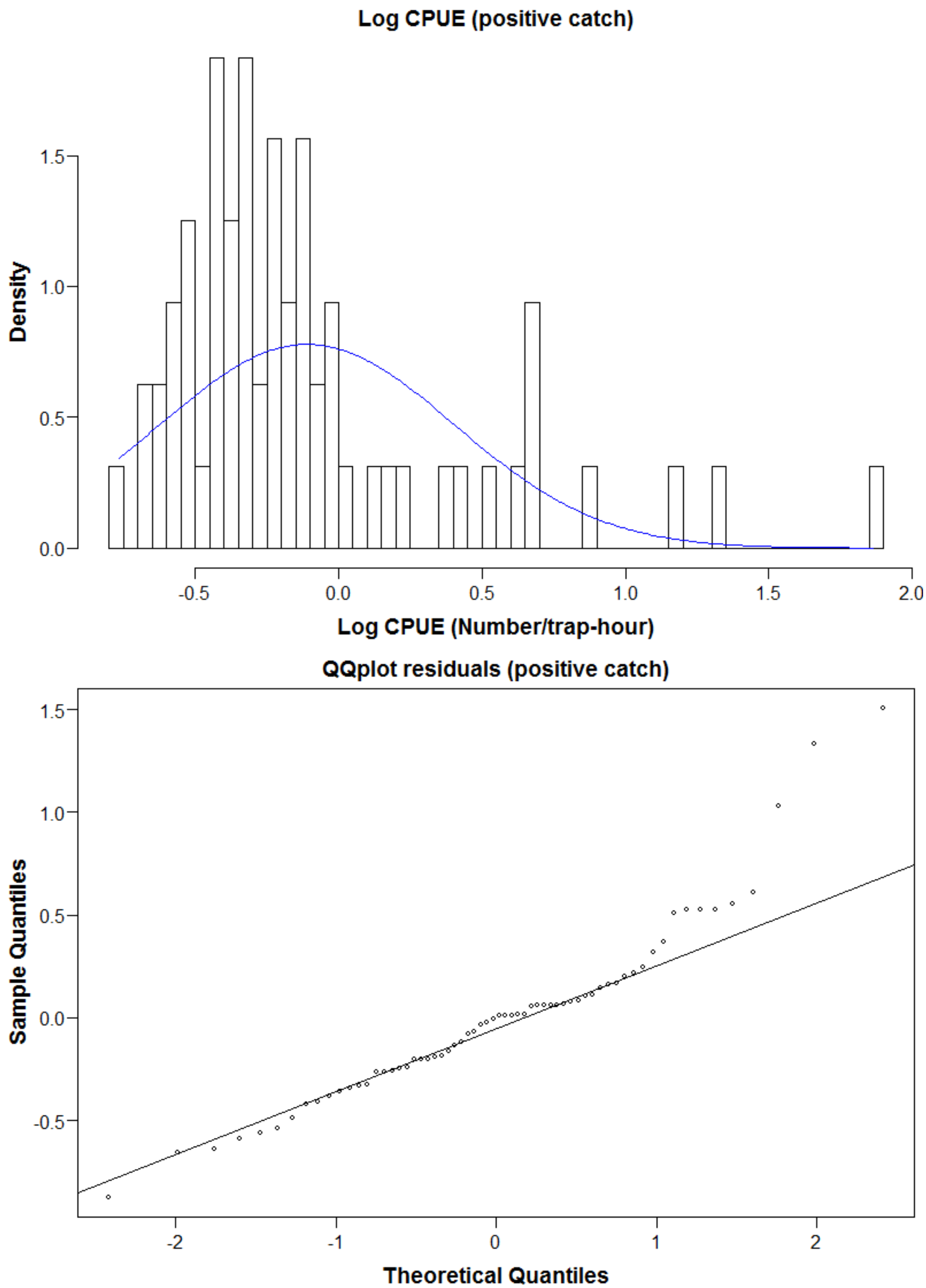


Figure 10: Diagnostics of the lognormal sub-model fit to positive gray triggerfish CPUE data from MARMAP blackfish trap collections. Top panel shows the histogram of CPUE with the lognormal distribution overlaid (line). Bottom panel shows the quantile-quantile plot of positive CPUE data from the fitted model.

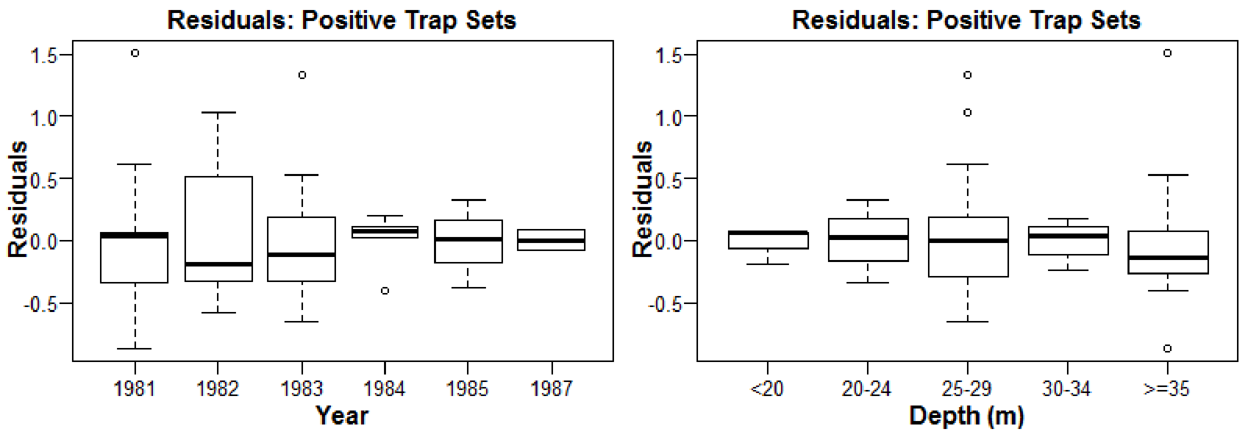


Figure 11: Diagnostics of the lognormal sub-model fit to positive gray triggerfish CPUE data from MARMAP blackfish trap collections. Box-and-whisker plots defined as in Figure 9.

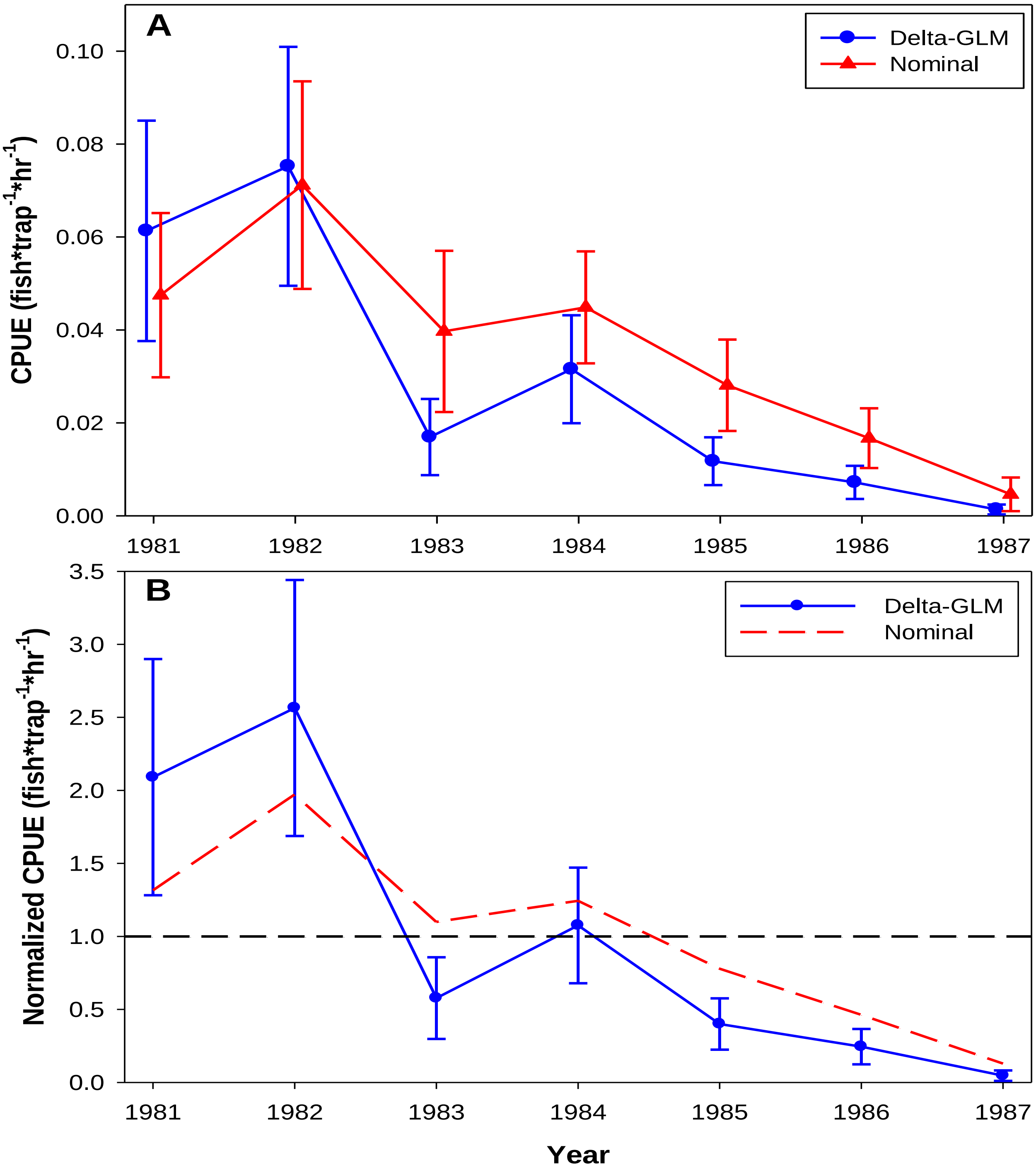


Figure 12: Florida trap nominal and delta-GLM standardized CPUE. A) Nominal and delta-GLM standardized CPUE. Please note that the x-axis has been jiggered to allow easier interpretation of the graph. B) Normalized (to the series mean) nominal and delta-GLM standardized CPUE.

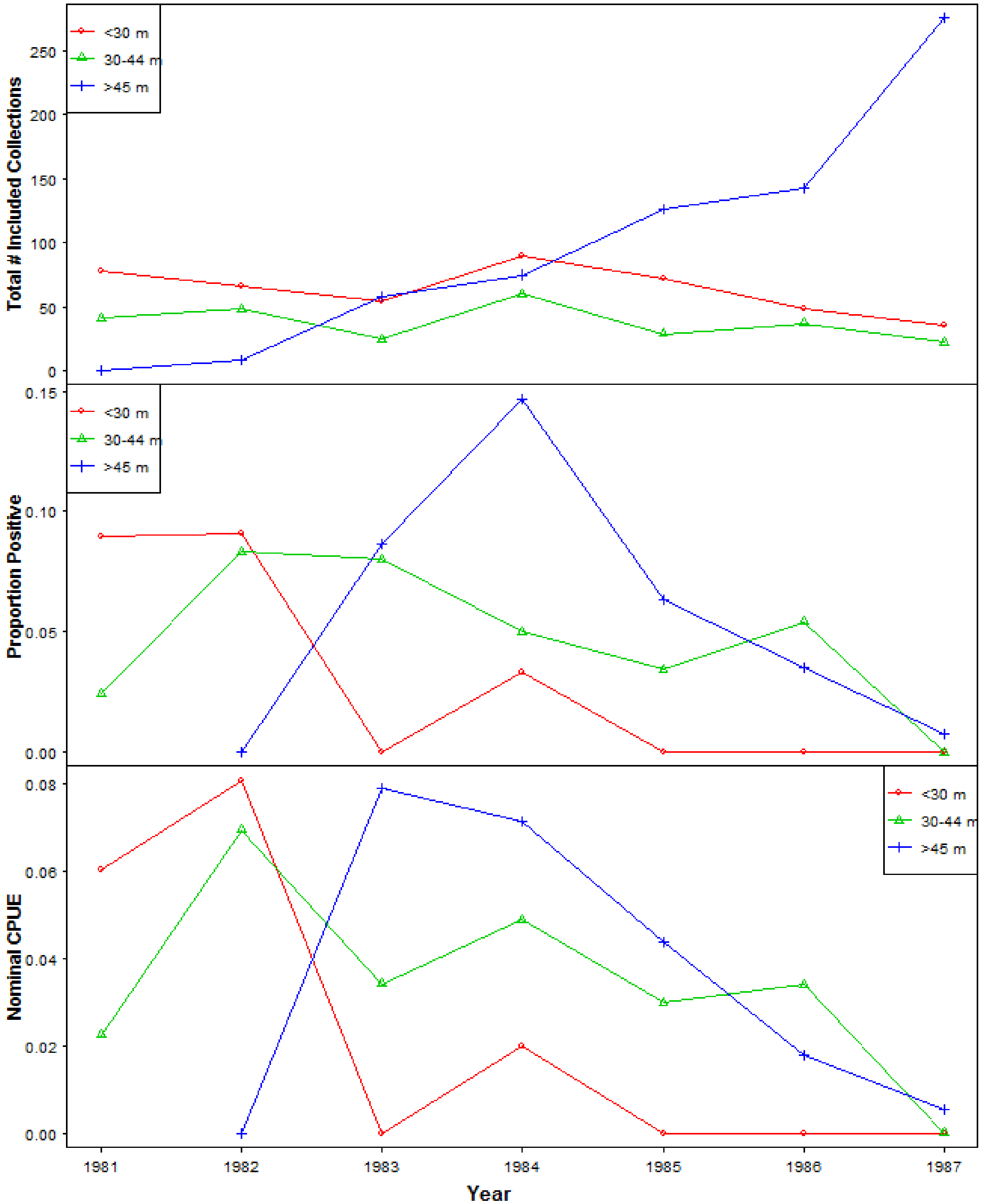


Figure 13: Top panel – the total number of Florida traps deployed in each depth zone. Middle panel – the proportion of Florida trap collections with positive gray triggerfish catch in each depth zone. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each depth based on MARMAP Florida trap catches, 1981-1987. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

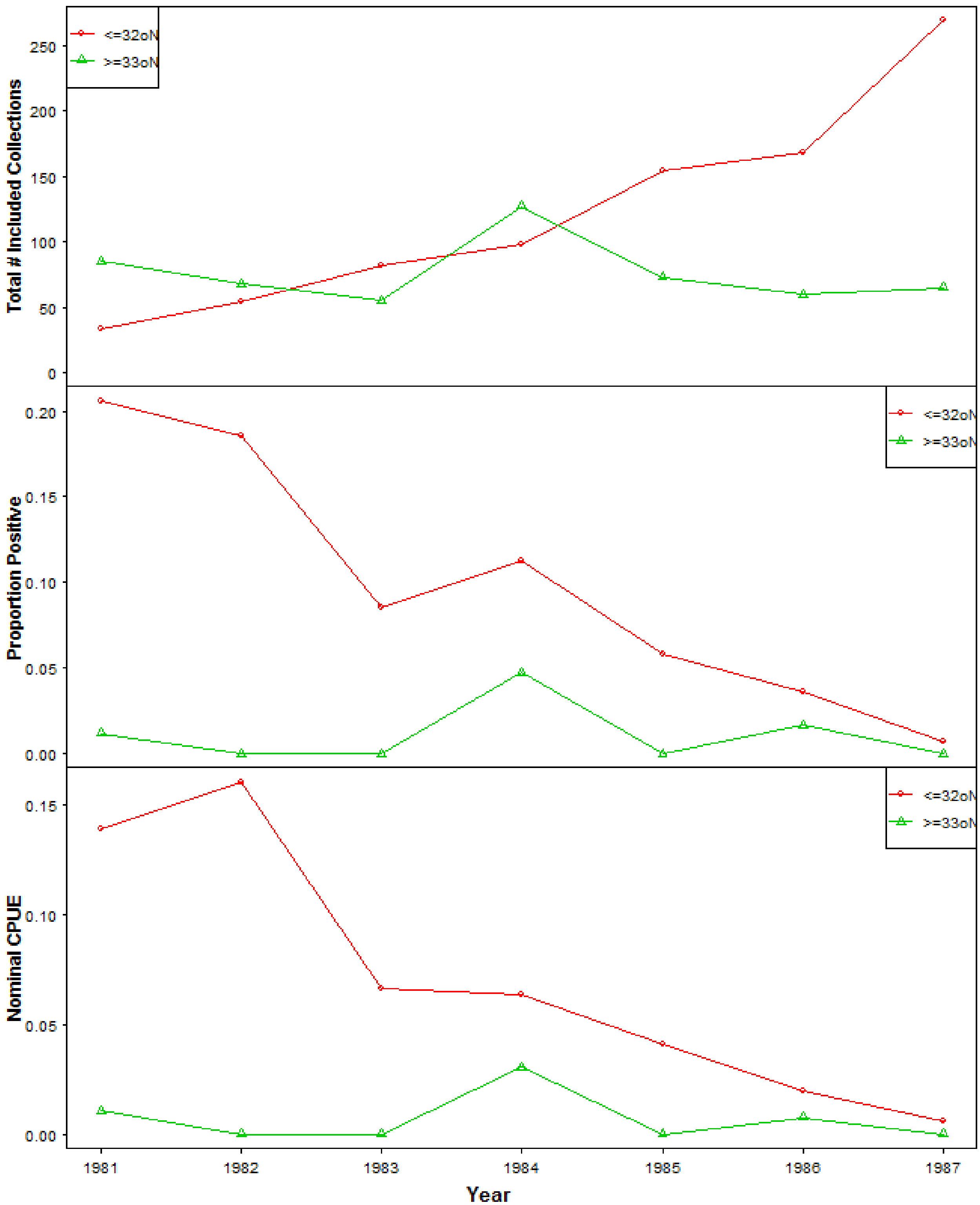


Figure 14: Top panel – the total number of Florida traps deployed in each latitude zone. Middle panel – the proportion of Florida trap collections with positive gray triggerfish catch in each latitude zone. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each latitude zone based on MARMAP Florida trap catches, 1981-1987. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

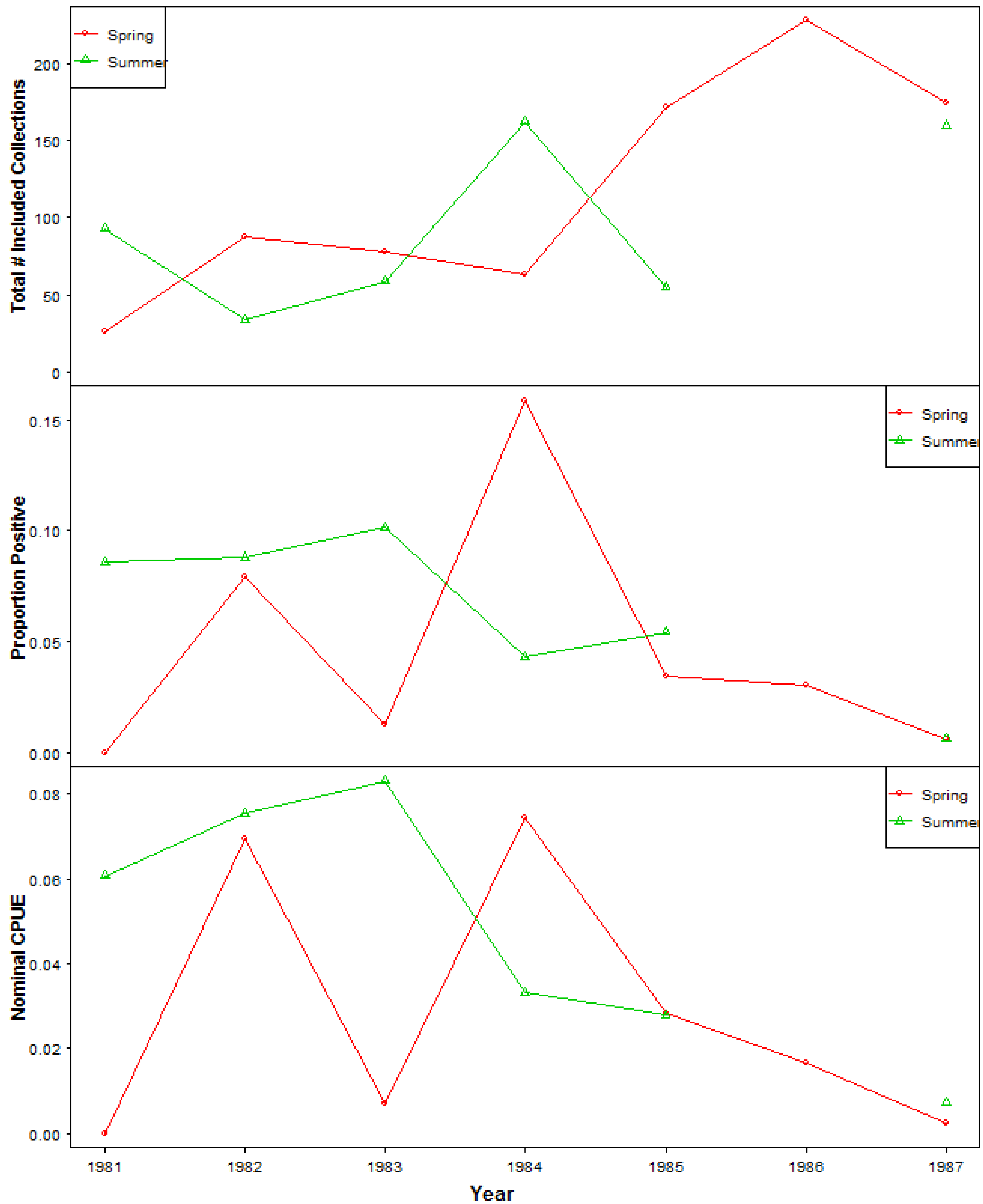


Figure 15: Top panel – the total number of Florida traps deployed in each season. Middle panel – the proportion of Florida trap collections with positive gray triggerfish catch in each season. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each season based on MARMAP Florida trap catches, 1981-1987. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

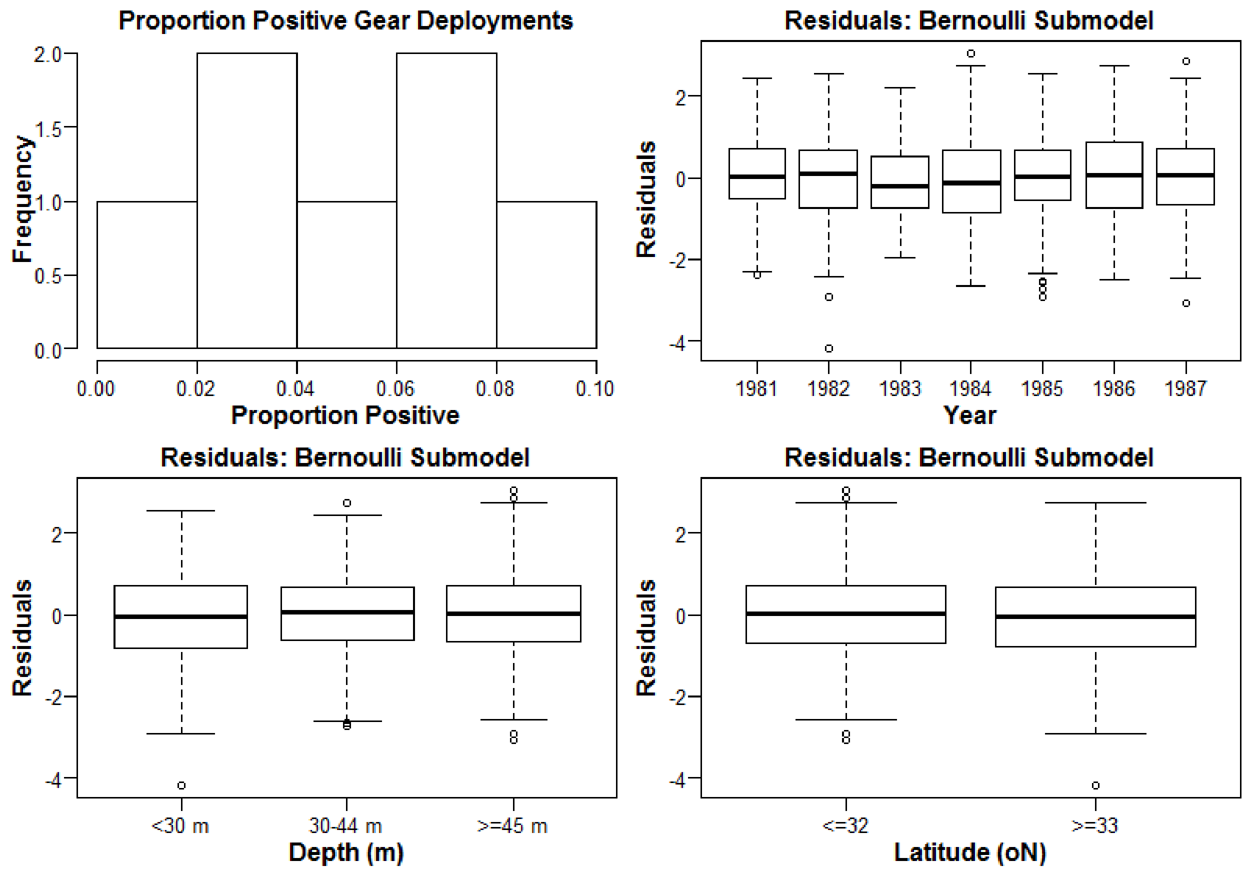


Figure 16: Diagnostics of Bernoulli sub-model fits to positive versus zero gray triggerfish CPUE data from MARMAP Florida trap collections, 1981-1987. Box-and-whisker plots defined as in Figure 9.

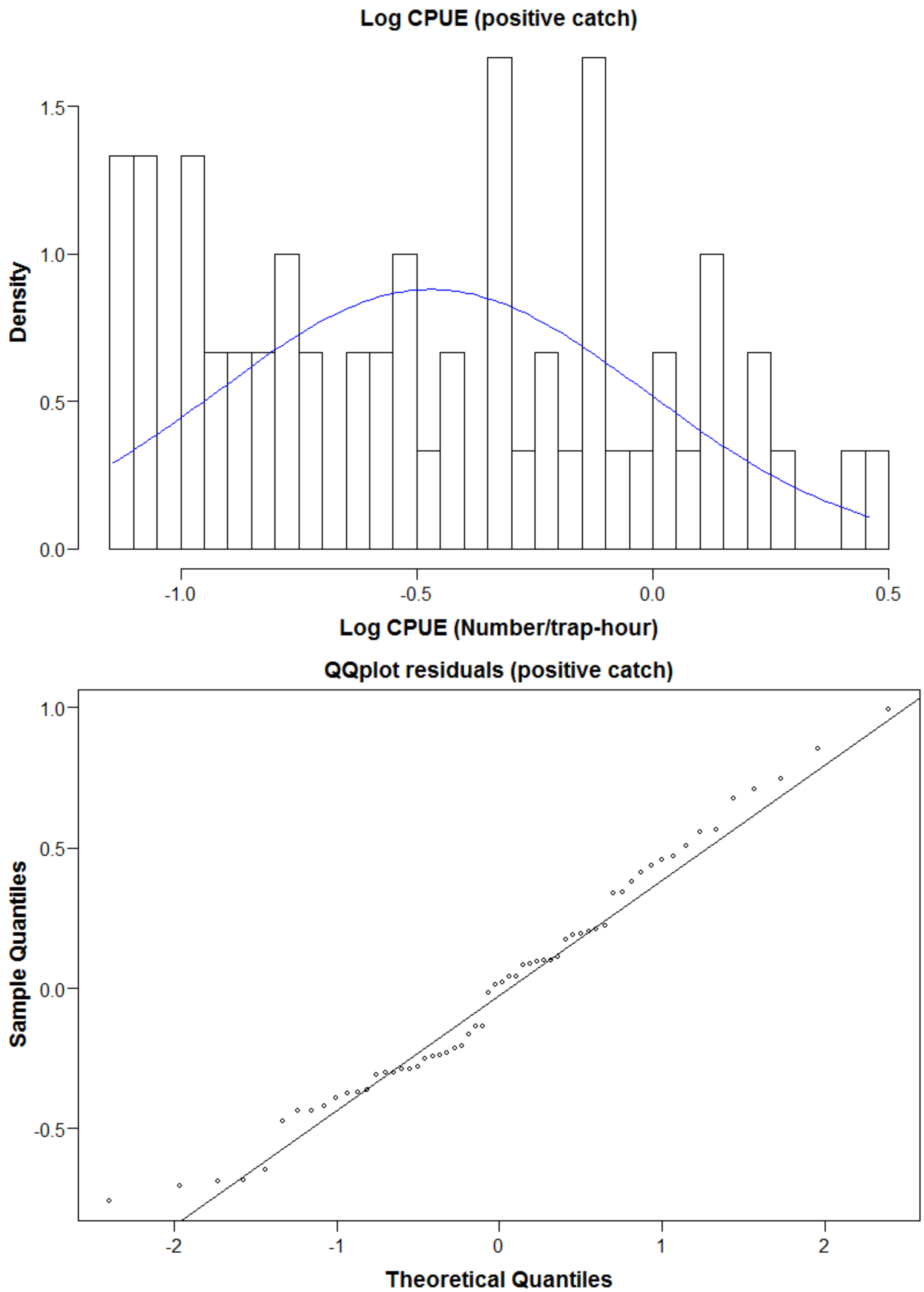


Figure 17: Diagnostics of the lognormal sub-model fit to positive gray triggerfish CPUE data from MARMAP Florida trap collections. Top panel shows the histogram of CPUE with the lognormal distribution overlaid (line). Bottom panel shows the quantile-quantile plot of positive CPUE data from the fitted model.

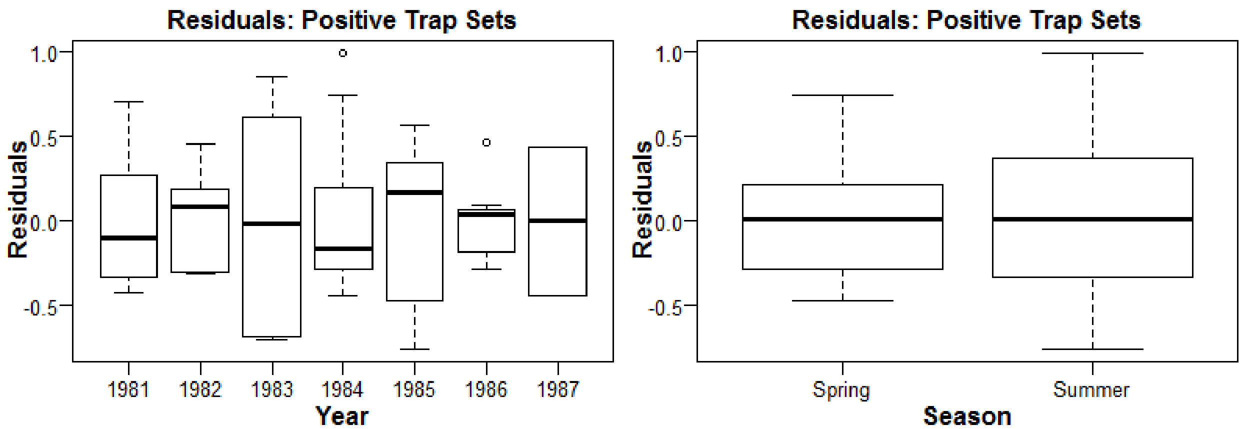


Figure 18: Diagnostics of the lognormal sub-model fit to positive gray triggerfish CPUE data from MARMAP Florida trap collections. Box-and-whisker plots defined as in Figure 9.

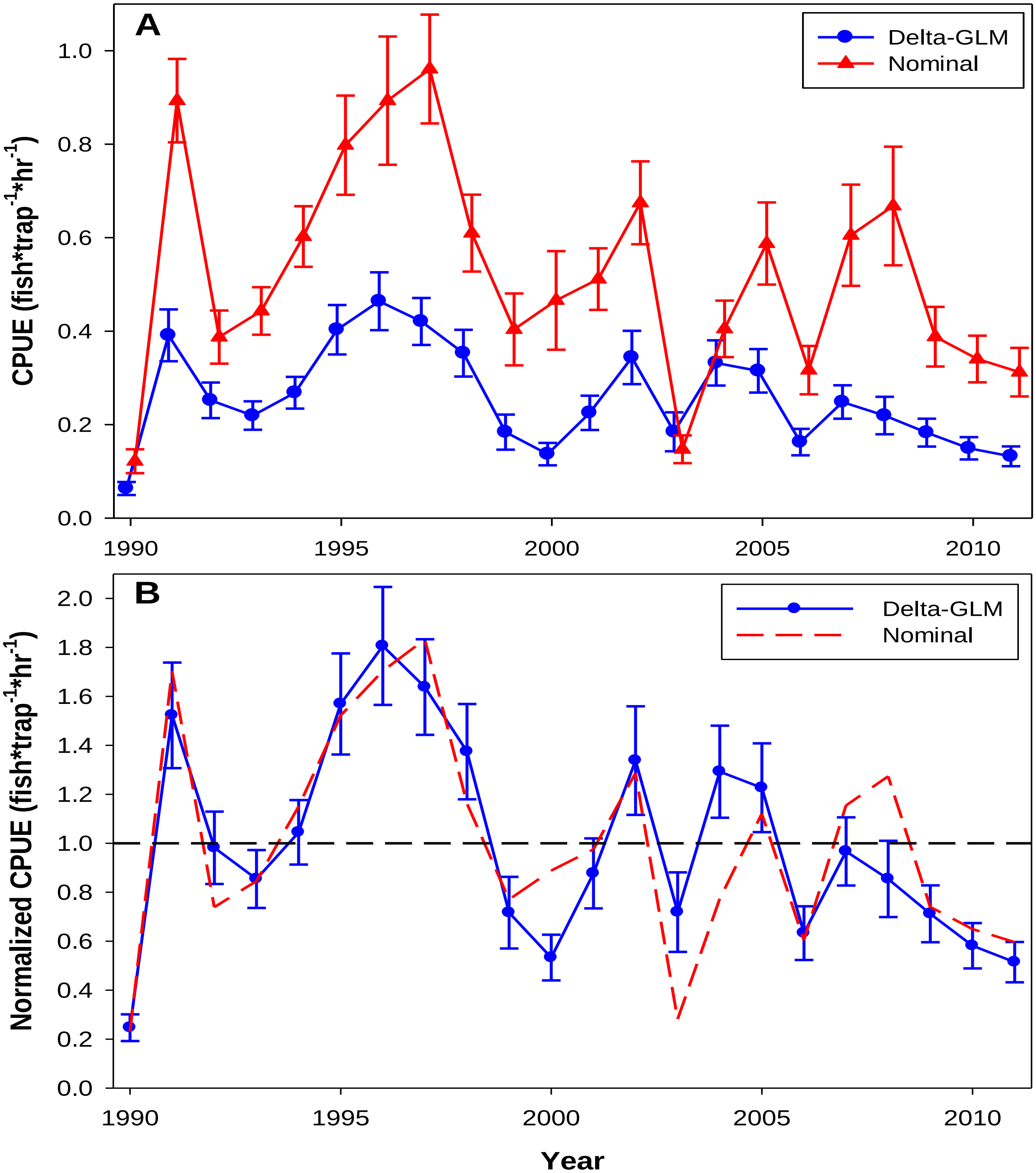


Figure 19: Chevron trap nominal and delta-GLM standardized CPUE. A) Nominal and delta-GLM standardized CPUE. Please note that the x-axis has been jiggered to allow easier interpretation of the graph. B) Normalized (to the series mean) nominal and delta-GLM standardized CPUE.

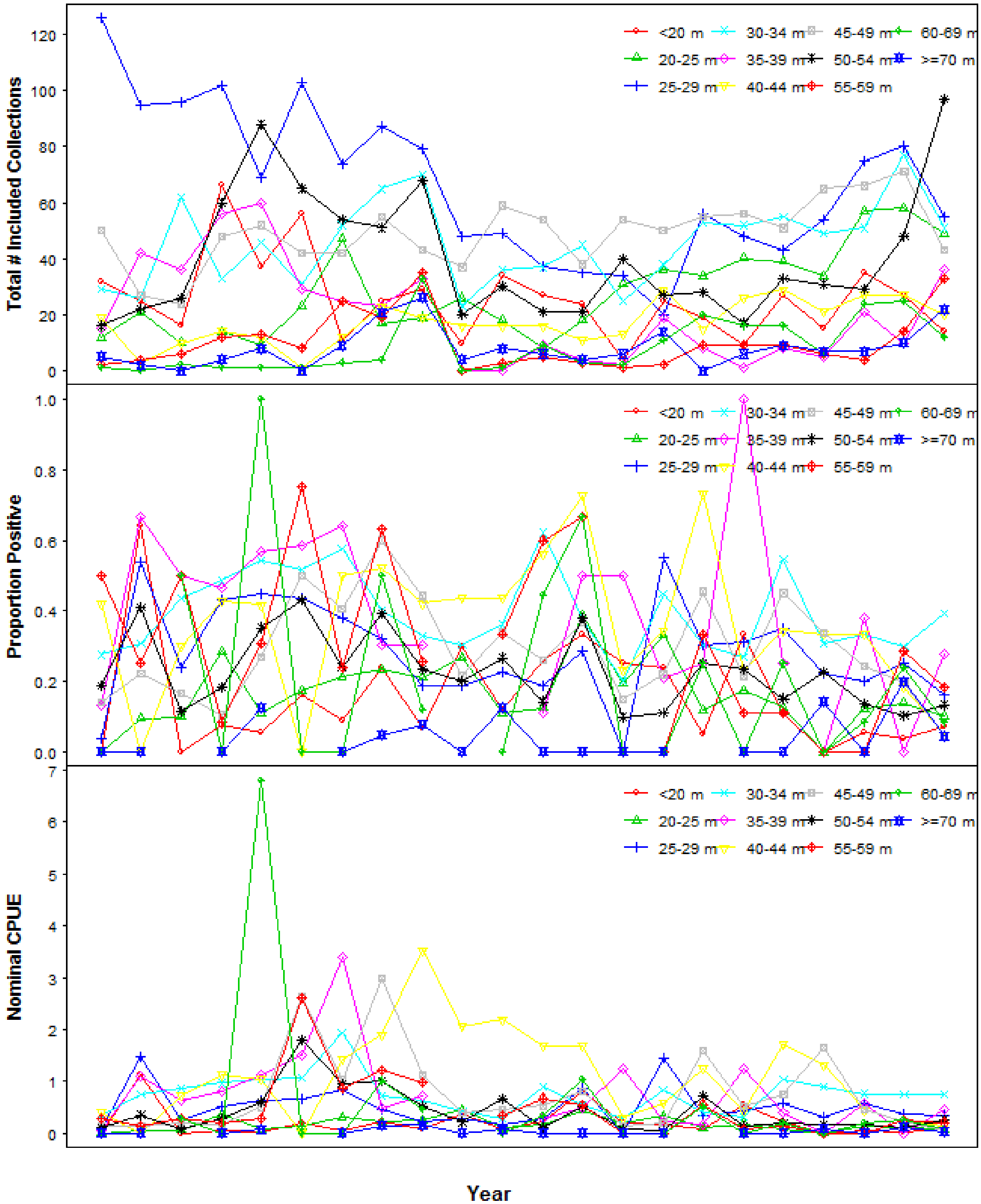


Figure 20: Top panel – the total number of chevron traps deployed in each depth zone. Middle panel – the proportion of chevron trap collections with positive gray triggerfish catch in each depth zone. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each depth based on SAB Reef Fish Survey chevron trap catches, 1990-2011. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

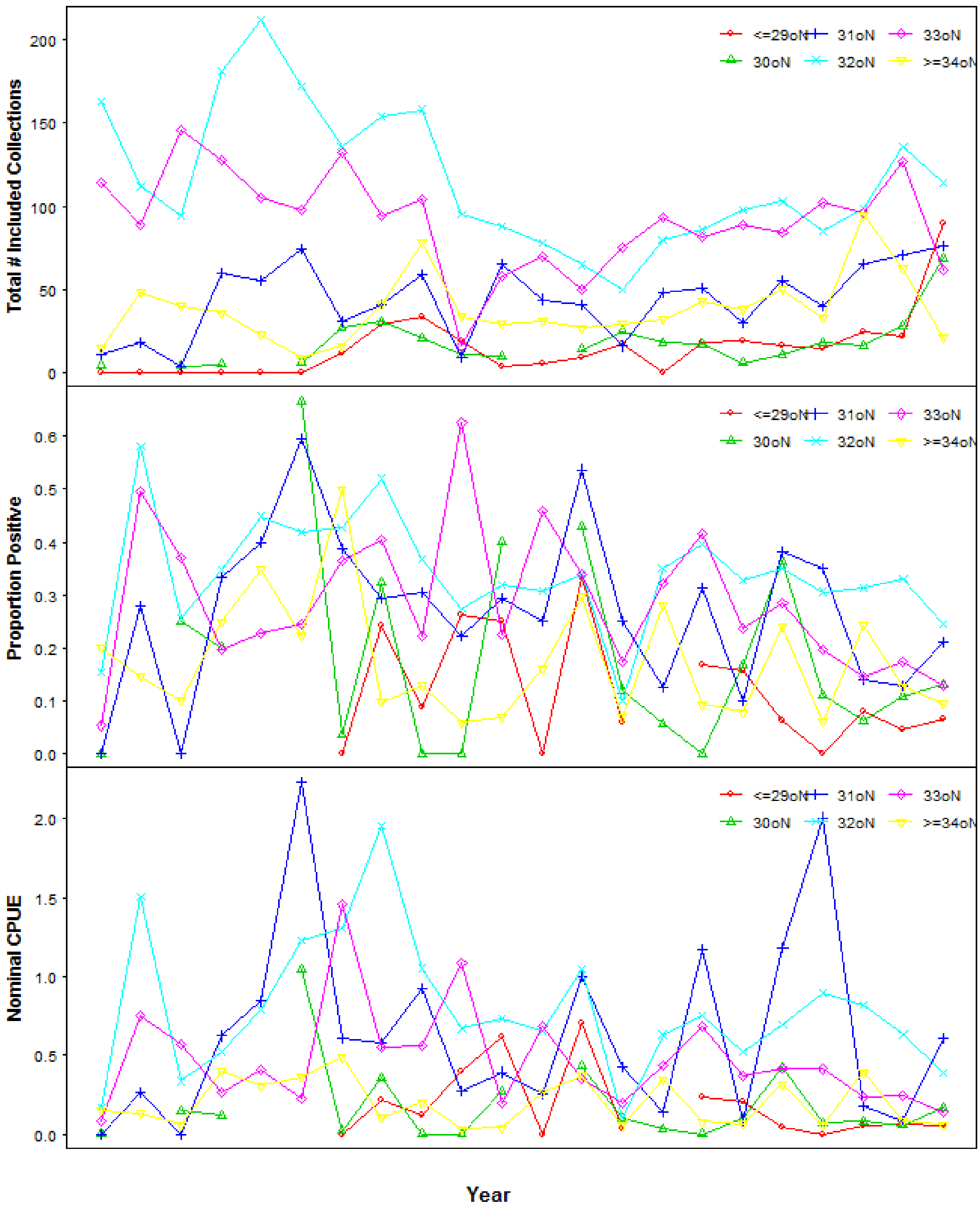


Figure 21: Top panel – the total number of chevron traps deployed in each latitude zone. Middle panel – the proportion of chevron trap collections with positive gray triggerfish catch in each latitude zone. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each latitude based on SAB Reef Fish Survey chevron trap catches, 1990-2011. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

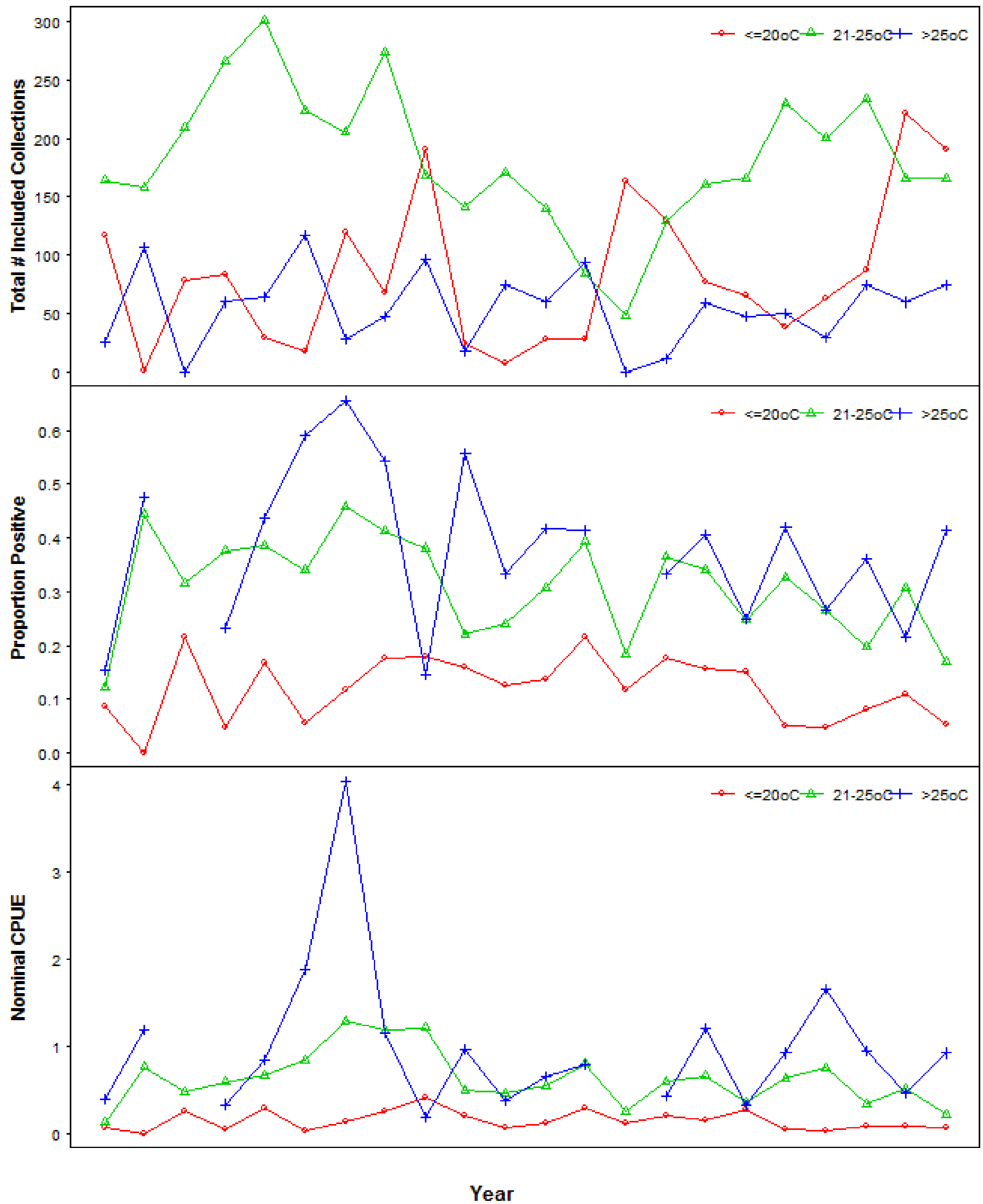


Figure 22: Top panel – the total number of chevron traps deployed in each bottom temperature bin. Middle panel – the proportion of chevron trap collections with positive gray triggerfish catch in each bottom temperature bin. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each bottom temperature bin based on SAB Reef Fish Survey chevron trap catches, 1990-2011. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

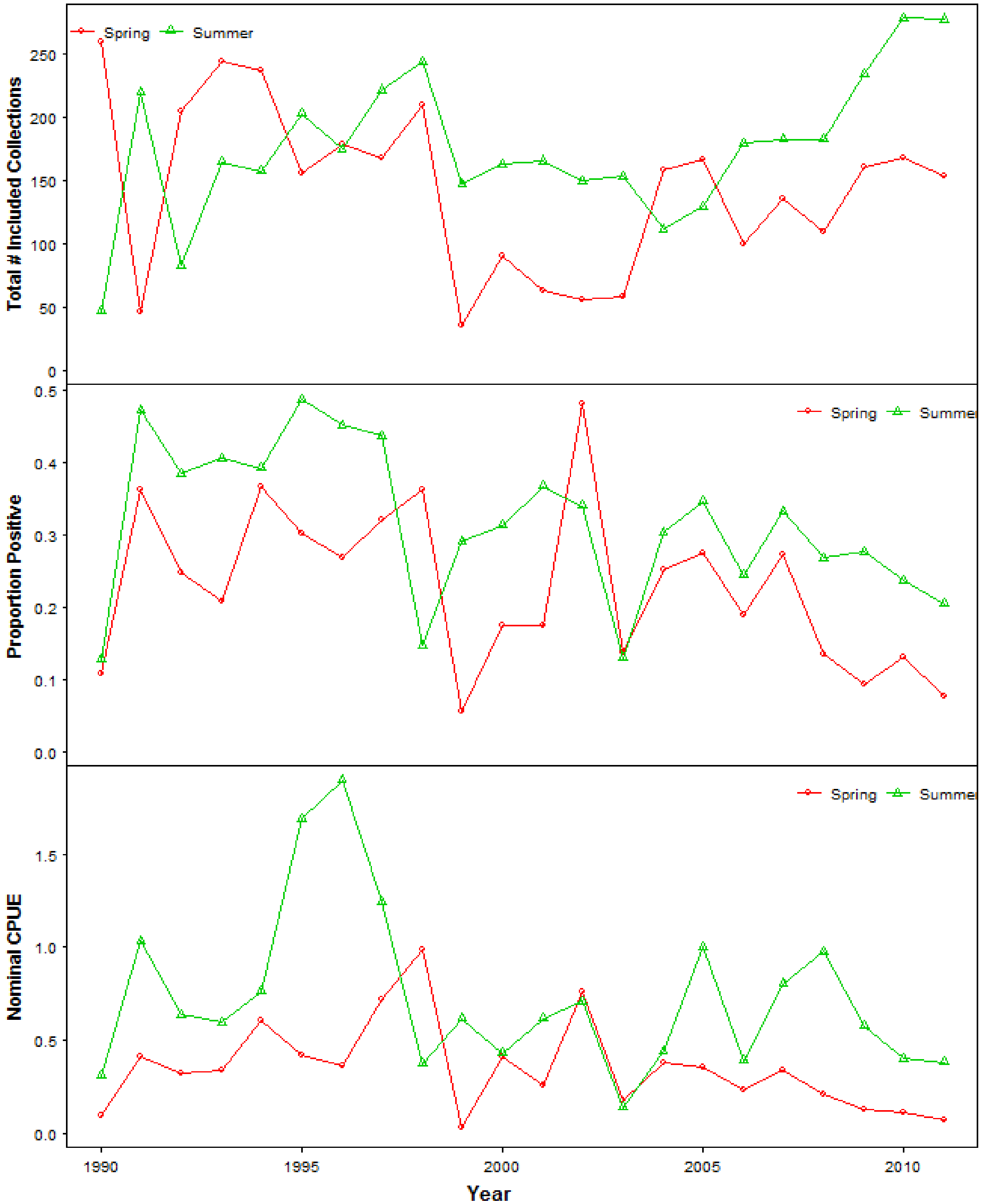


Figure 23: Top panel – the total number of chevron traps deployed in each season. Middle panel – the proportion of chevron trap collections with positive gray triggerfish catch in each season. Bottom panel – the nominal CPUE (fish*trap^{-1}*hr^{-1}) within each season based on SAB Reef Fish Survey chevron trap catches, 1990-2011. Please note the data included in this analysis only includes the data used in the delta-GLM analysis.

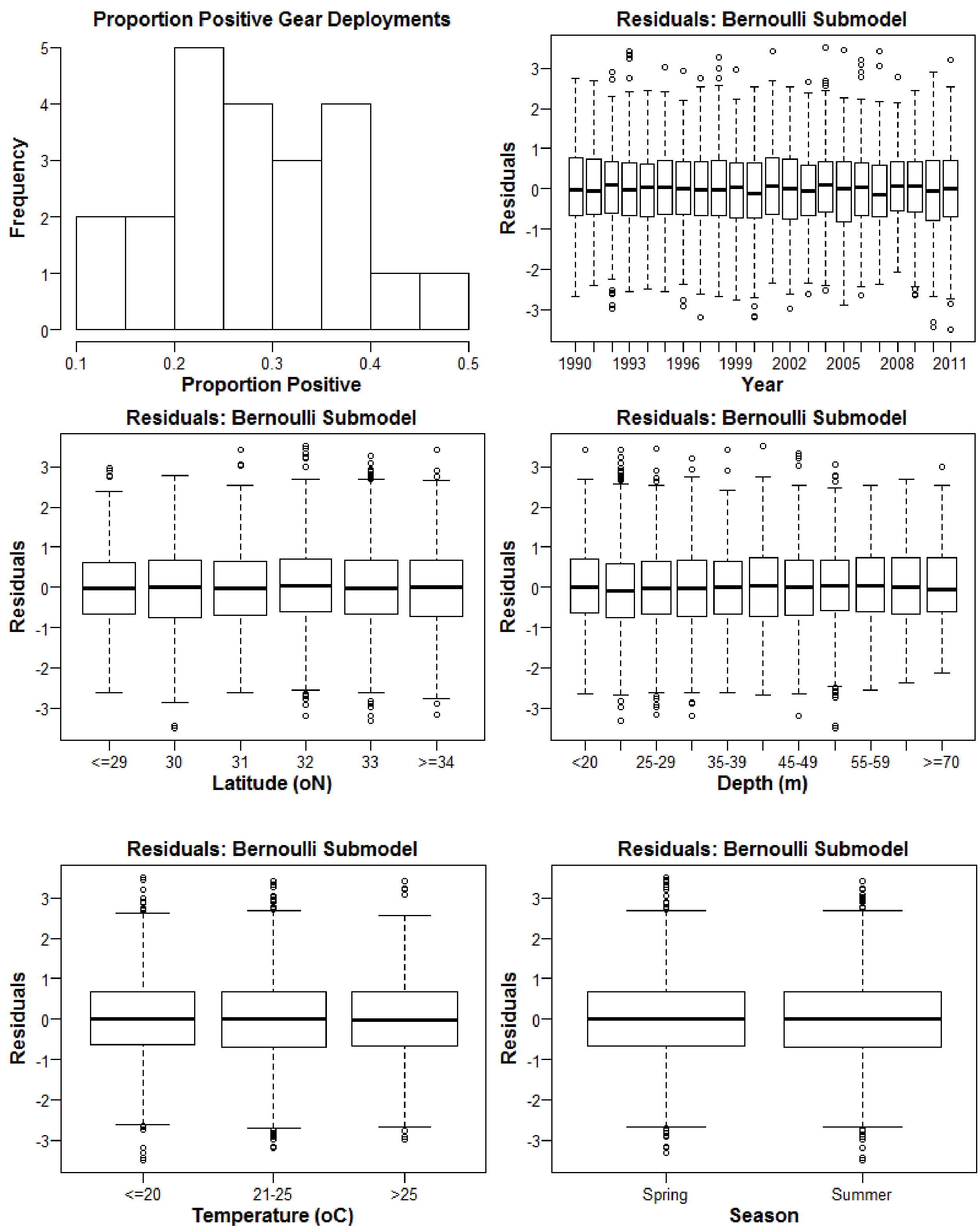
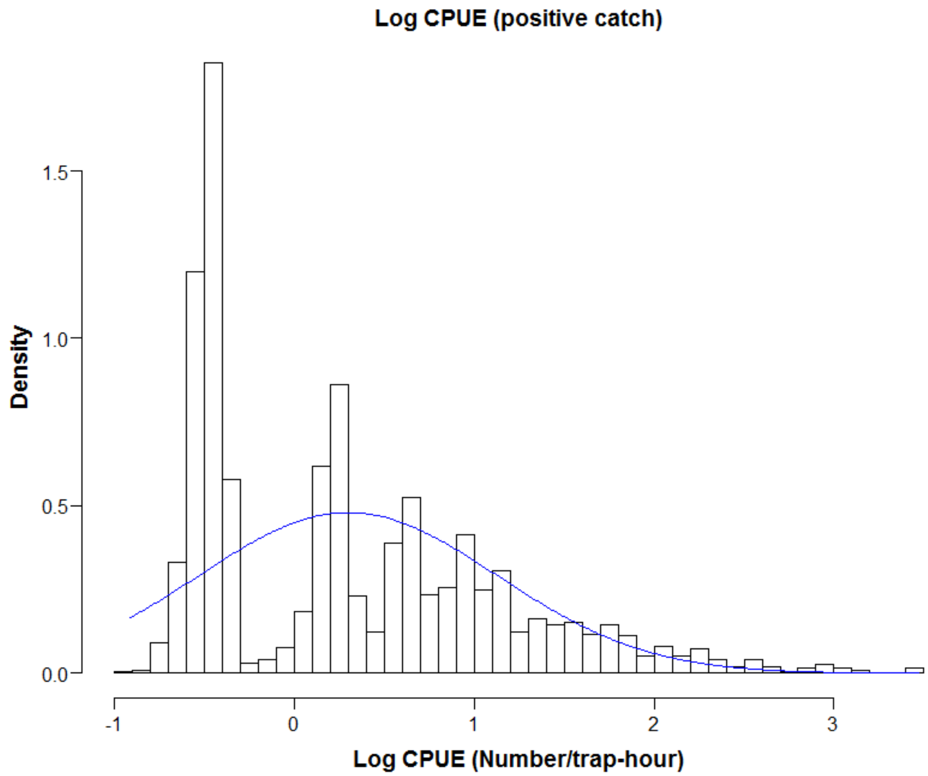


Figure 24: Diagnostics of Bernoulli sub-model fits to positive versus zero gray triggerfish CPUE data from SAB Reef Fish Survey chevron trap collections, 1990-2011. Box-and-whisker plots defined as in Figure 9.



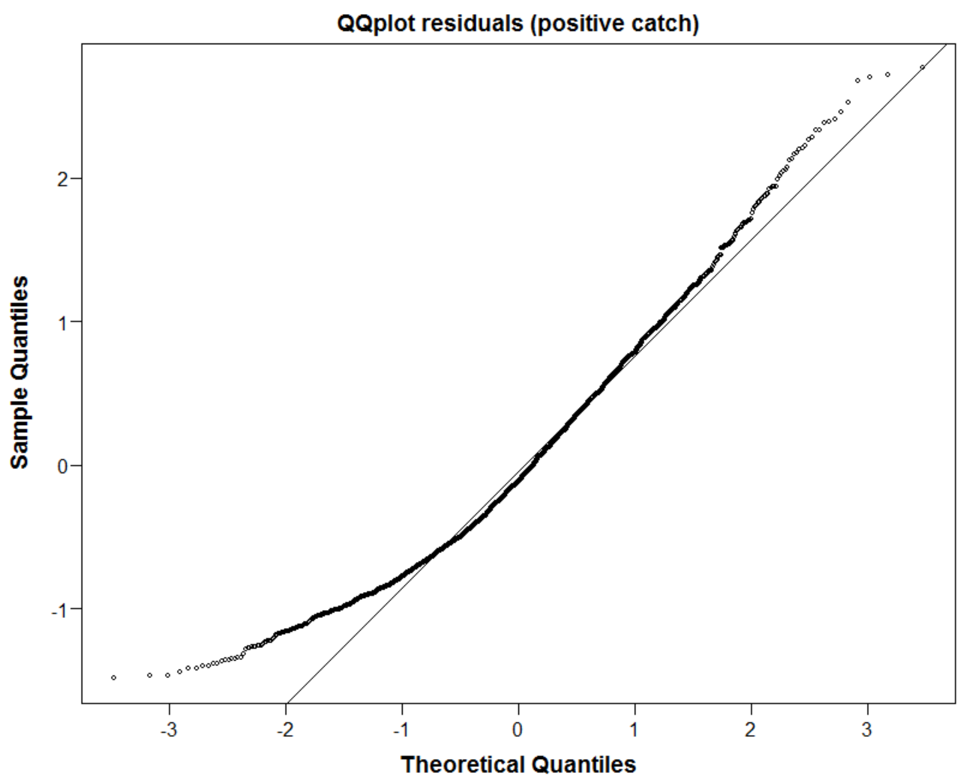


Figure 25: Diagnostics of the lognormal sub-model fit to positive gray triggerfish CPUE data from SAB Reef Fish Survey chevron trap collections. Top panel shows the histogram of CPUE with the lognormal distribution overlaid (line). Bottom panel shows the quantile-quantile plot of positive CPUE data from the fitted model.

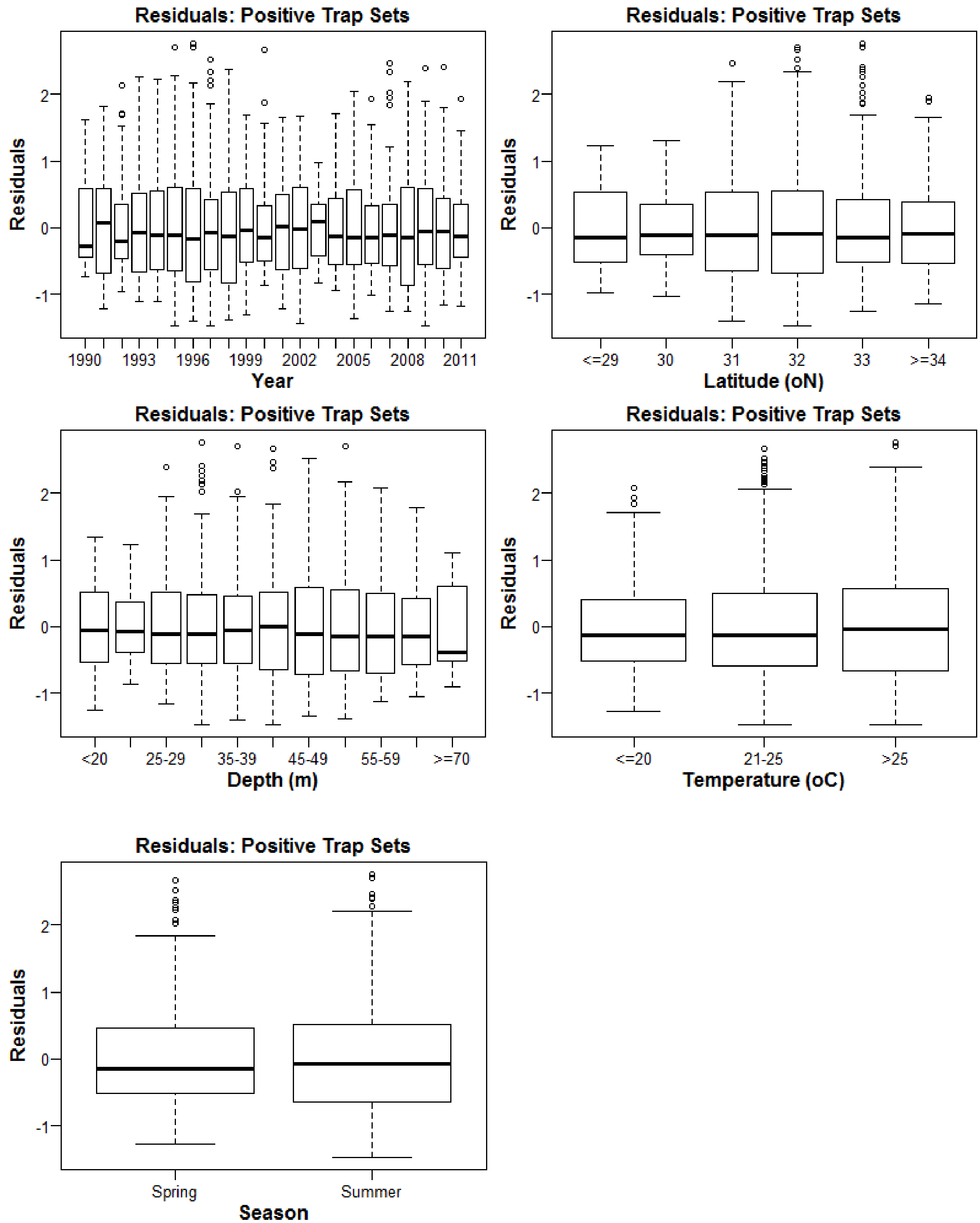


Figure 26: Diagnostics of the lognormal sub-model fit to positive gray triggerfish CPUE data from SAB Reef Fish Survey chevron trap collections, 1990-2011. Box-and-whisker plots defined as in Figure 9.

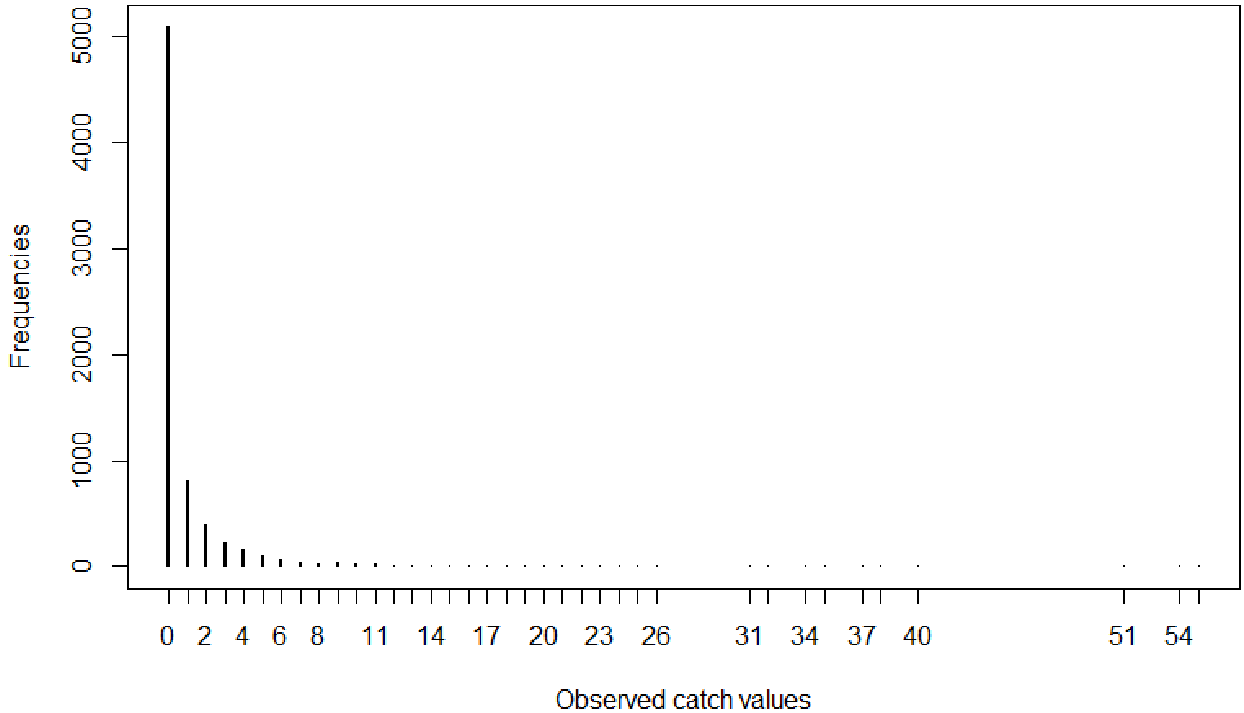


Figure 27: Observed frequency of chevron traps with given total catch of gray triggerfish.

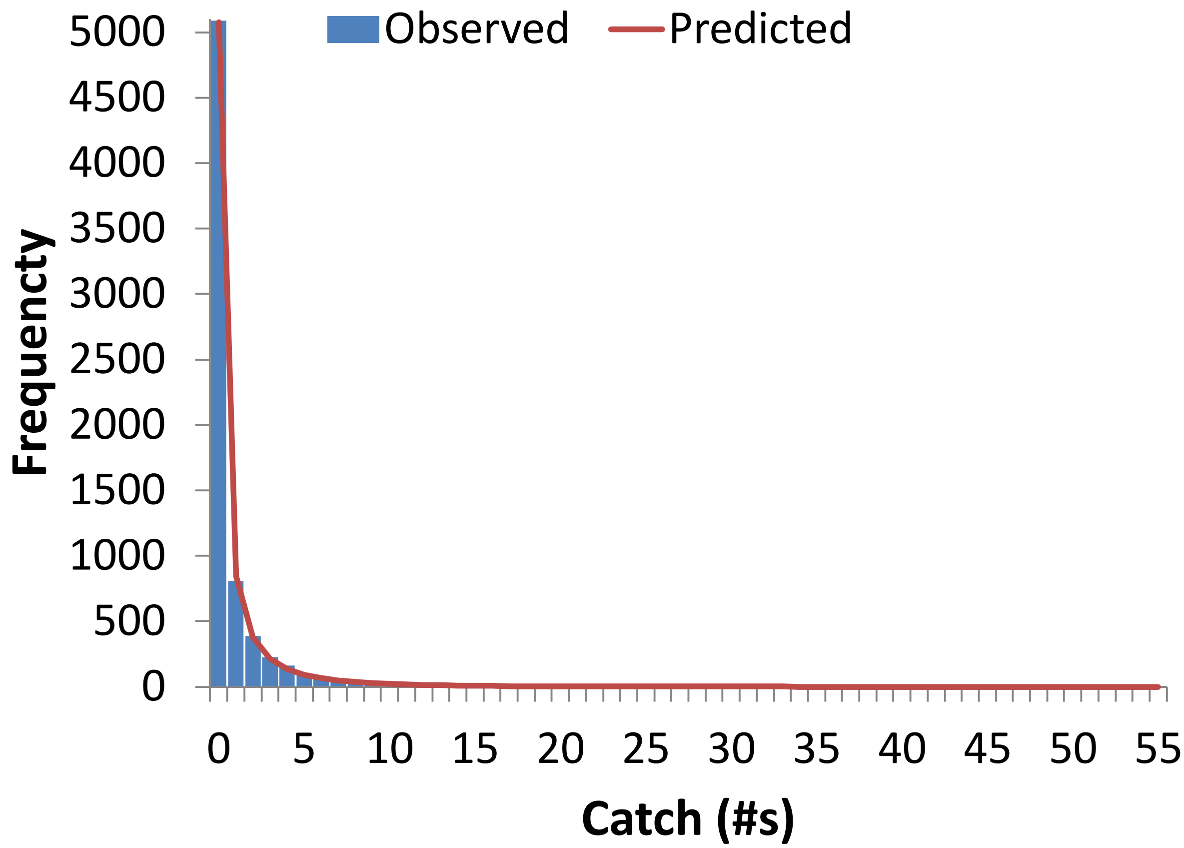


Figure 28: Observed and predicted frequency of traps with a total catch of X gray triggerfish, where observed X ranged from 0 to 55 gray triggerfish in a single trap.

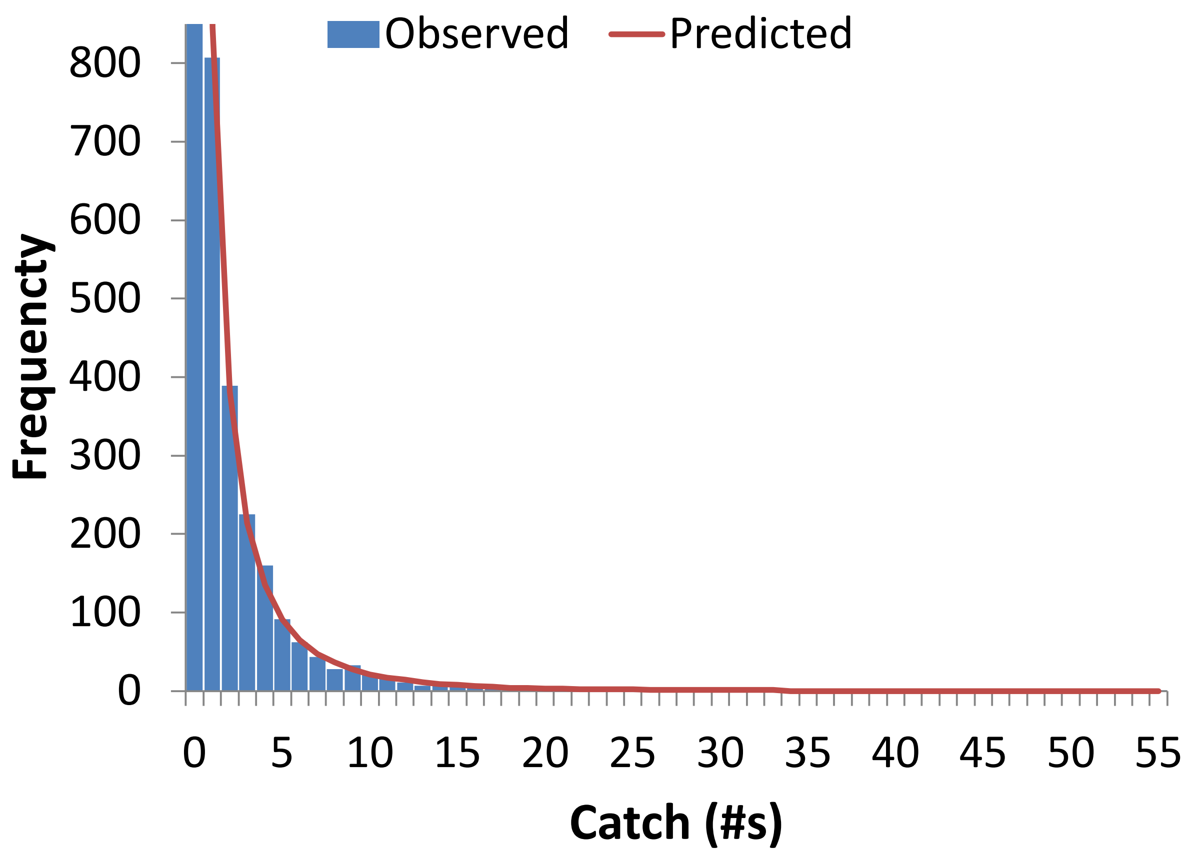


Figure 29: Observed and predicted frequency of traps with a total catch of X gray triggerfish. This is the same data presented in Figure 3, though the y-axis scale has been truncated to a max of 850 to make it easier to see the fit to observed catch for gray triggerfish positive chevron traps.

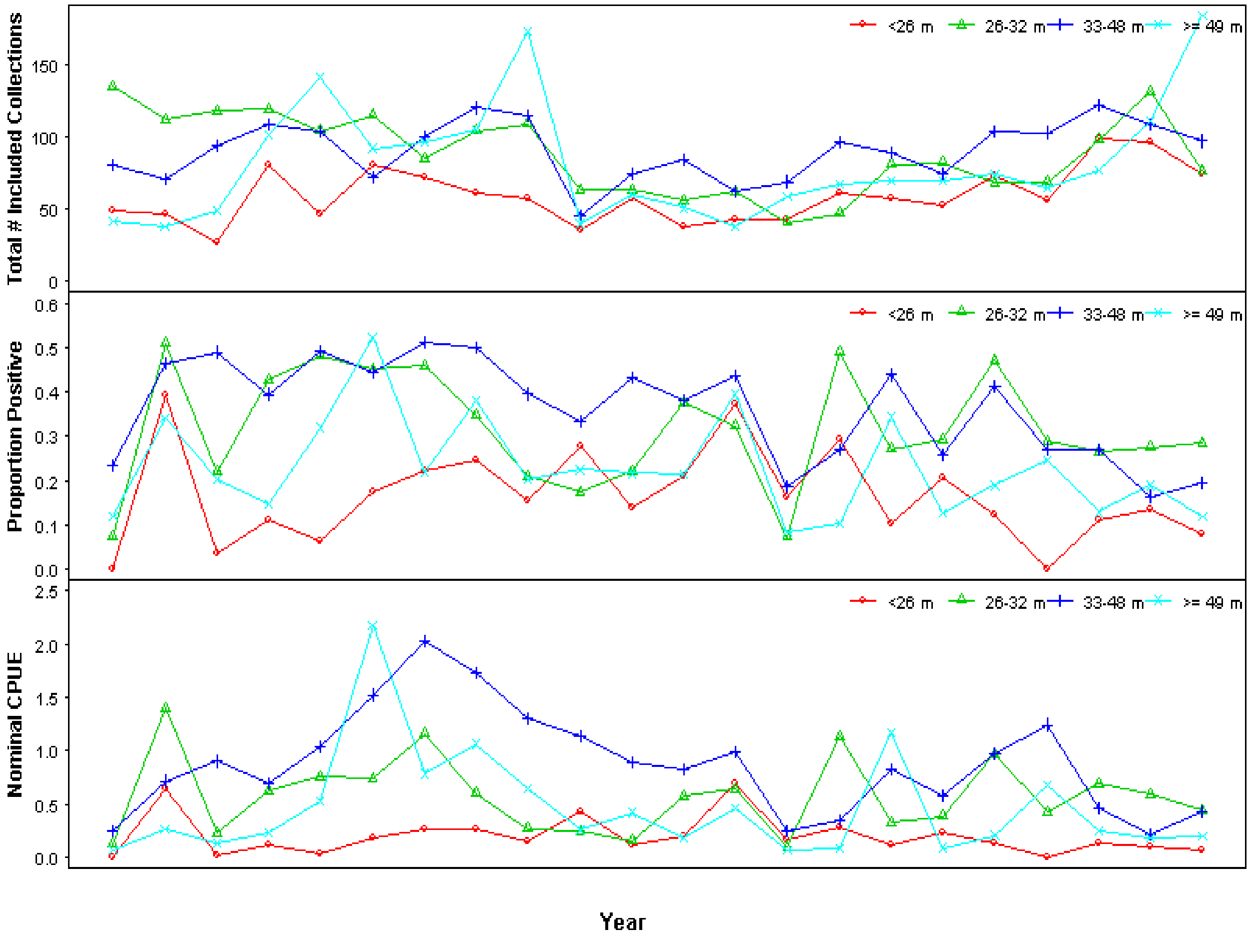


Figure 30: Top panel – the total number of chevron traps included from each depth bin. Middle panel – the proportion of chevron trap collections with positive gray triggerfish catch in each depth bin. Bottom panel – the nominal CPUE (fish*trap^{-1}) within each depth bin based on SAB Reef Fish Survey chevron trap catches, 1990-2011. Please note the data included in this analysis only includes the data used in the ZINB.

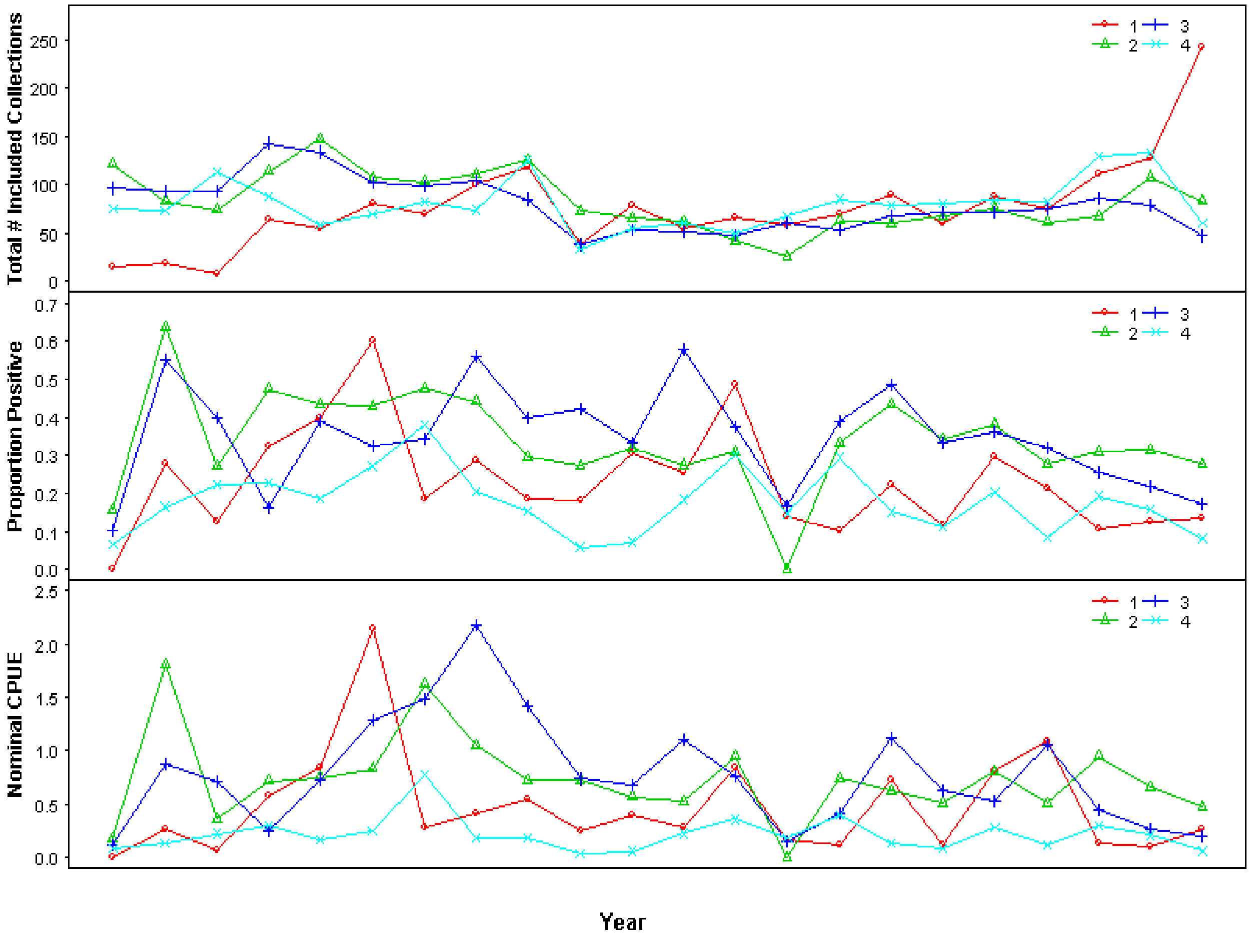


Figure 31: Top panel – the total number of included chevron traps from each latitude bin. Middle panel – the proportion of chevron trap collections with positive gray triggerfish catch in each latitude bin. Bottom panel – the nominal CPUE (fish*trap^{-1}) within each latitude bin based on SAB Reef Fish Survey chevron trap catches, 1990-2011. Please note the data included in this analysis only includes the data used in the ZINB. Legend corresponds to bin number for latitude bins as labeled in Table 17.

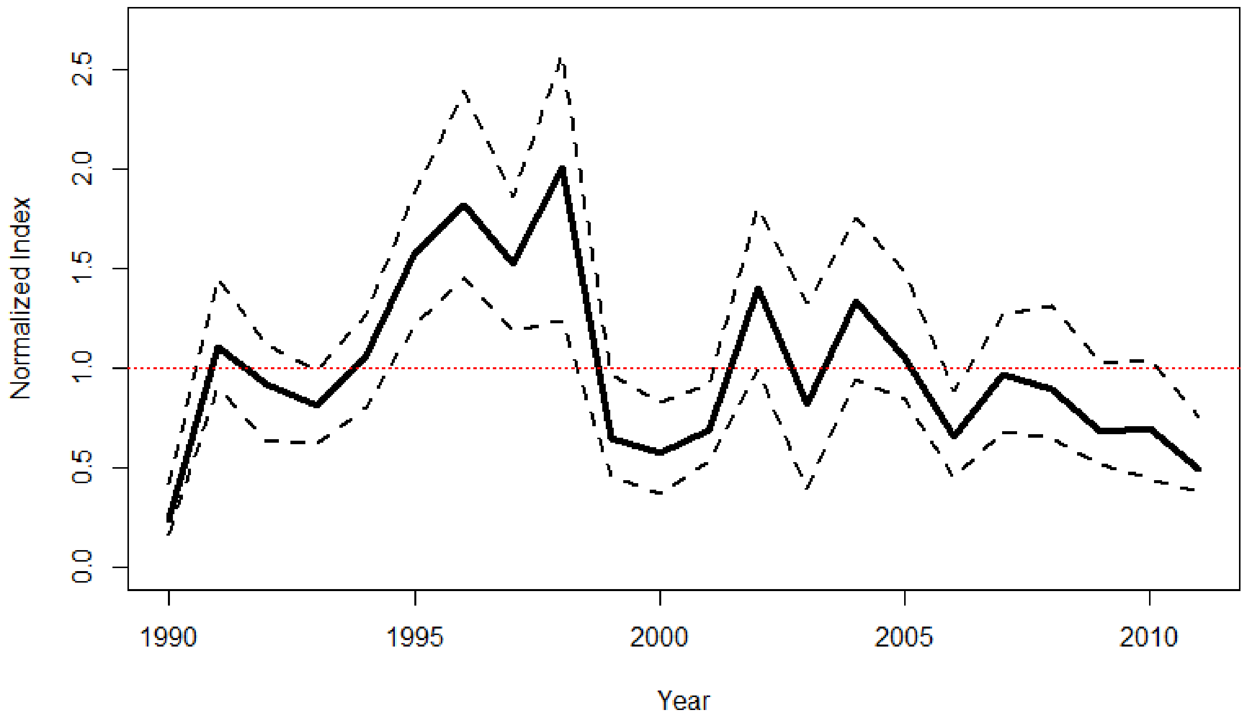


Figure 32: Chevron trap ZINB model standardized CPUE for gray triggerfish normalized to the series mean. Dotted lines represent the 2.5% and 97.5% quantiles of the bootstrap values for each year.

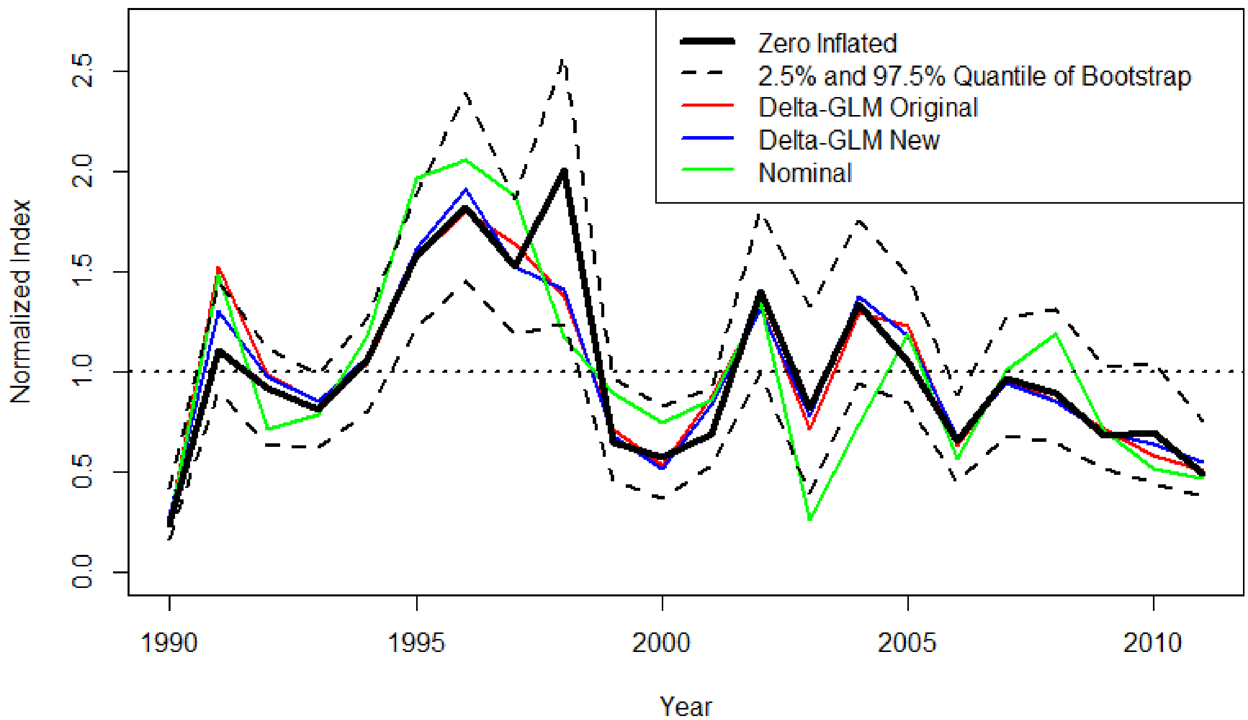


Figure 33: Chevron trap ZINB model standardized CPUE for gray triggerfish normalized to the series mean (heavy black line) presented in this report compared to two delta-GLM standardized CPUE models: Delta-GLM original (red line) which was presented in Table 12 and Delta-GLM New (blue line) which is an updated delta-GLM using the technique detailed for calculating the delta-GLM in the original report but using the covariate bin structure presented for the ZINB model. Also presented is the nominal CPUE (green line). Dotted black lines represent the 2.5% and 97.5% quantiles of the bootstrap values for each year from the ZINB model.

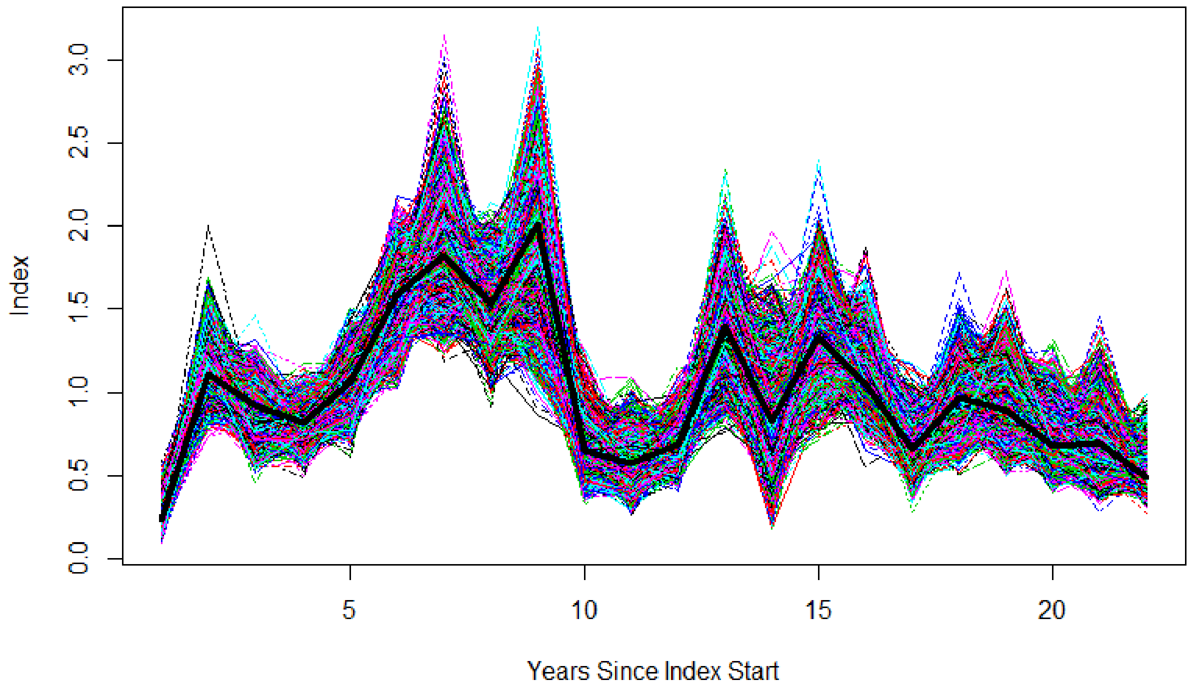


Figure 34: Plot of all individual bootstrap runs normalized annual relative abundance index. Superimposed (black line) is the predicted annual relative abundance index based on the observed catch data.

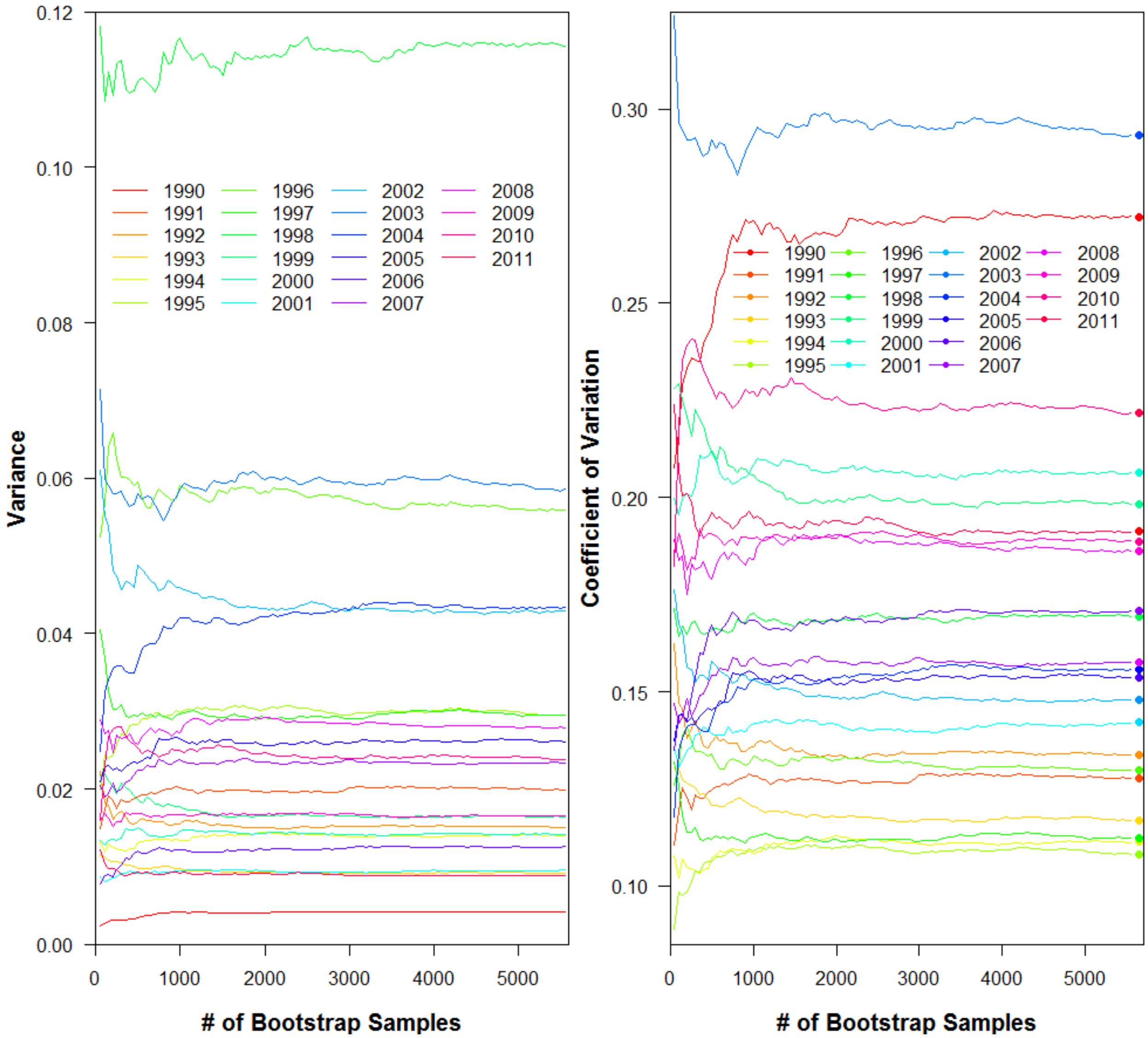


Figure 35: Variance (left panel) and CV (right panel) estimates from bootstraps at various bootstrap sample sizes. Each line in a plot represents the calculated variance and CV for a single year. Dot represents calculated CV for that year. Note that for both variance and CV they have converged for all years by 5000 bootstrap samples. Thus an increase in the number of bootstraps is not expected to affect precision estimates.

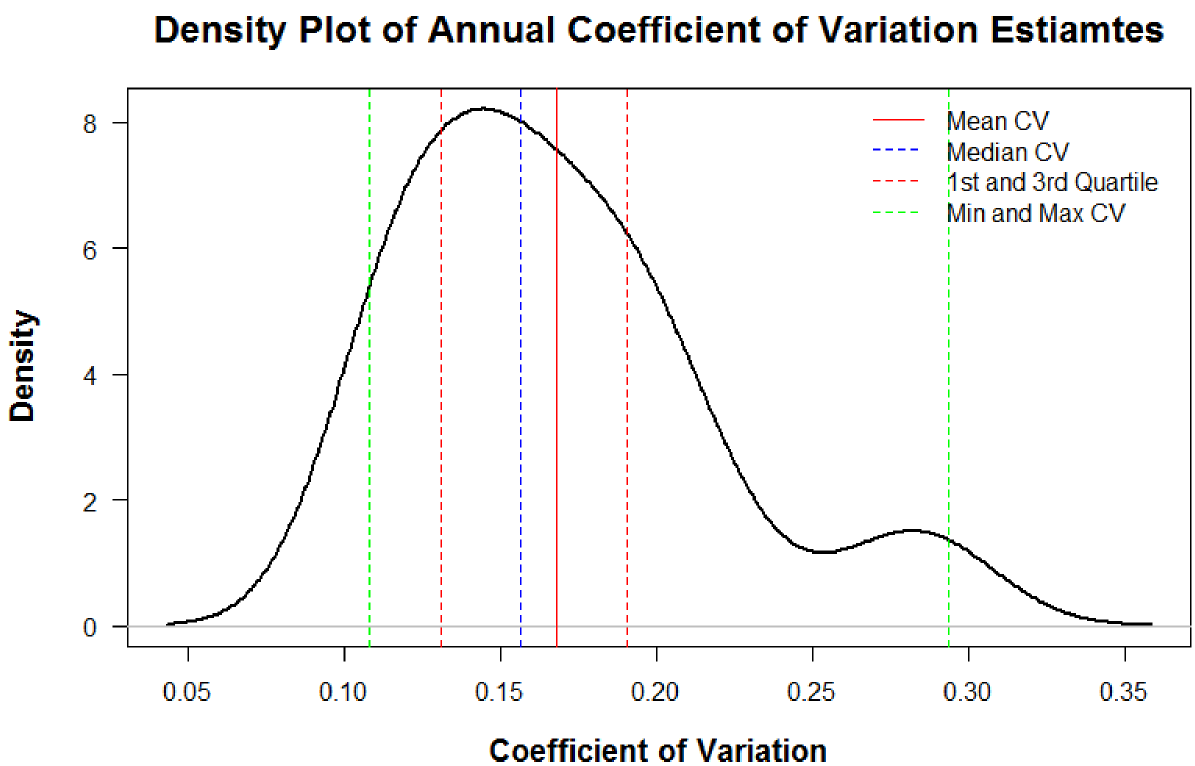


Figure 36: Density plot of CV estimates. See legend for definition of vertical lines.