**Title:**

**Trends in the Relative Abundance of Commercially Important Reef Fish Species of the U.S. South Atlantic Region Based on Long-Term Fishery-Independent Surveys**

**Short Title:**

**Trends in Abundance of Reef Fish**

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# Abstract

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# Introduction

The southeastern United States Atlantic continental shelf (a.k.a., the South Atlantic Bight (SAB)), which extends from the straits of Florida to Cape Hatteras, NC, comprises a total area of approximately 90,600 km2 (Fautin, et al., 2010; Menzel, 1993). In 2014, it supported the commercial harvest of 13,200 mt (value of $83 million; personal communication from the National Marine Fisheries Service, Fisheries Statistics Division (April 1, 2016)) of fisheries resources managed by the South Atlantic Fisheries Management Council (SAFMC). While generally exhibiting a subtle slope (~1 m\*km-1), ridges and depressions often lead to localized high relief areas (Fautin, et al., 2010; Menzel, 1993). Geologically, the SAB is dominated by soft-bottom habitat (mud and sand <1 m deep) underlain by carbonate sandstone (Henry, et al., 1981; Riggs, et al., 1996). Secondary to wide expanses of soft-bottom habitat are patchy areas of sand-veneered and rocky outcrop hard-bottom areas (Powles and Barans, 1980; Sedberry and van Dolah, 1984), including hard grounds, reefs and rock outcroppings (Riggs, et al., 1996). Relative to other areas of the SUSLME, hard-bottom is prominent along the shelf break in depths from 45 to 60 m (Fautin, et al., 2010).

The limited hard-bottom areas, which are estimated to cover 4-30% of the total shelf area (Fautin, et al., 2010), are ecologically important resources in that they are necessary to the life history of many ecologically and economically important fish communities (Barans and Henry, 1984; Grimes, et al., 1982; Powles and Barans, 1980). These fish assemblages include economically valuable snappers (Lutjanidae), groupers (Serranidae), grunts (Haemulidae), porgies (Sparidae), as well as a diverse array of tropical fish families such as wrasses (Labridae) and damselfishes (Pomacentridae; Fautin, et al., 2010). Managed as the snapper-grouper complex (SAFMC, 1991), many of these species are or have been recipients of intense fishing pressure and, hence, have been subjected to dynamic fisheries management regulations.

To manage economically important species, measures of catch and effort for the development of relative abundance indices are necessary for monitoring the status of stocks, interpreting fisheries landings data, and providing data for stock assessments. Unfortunately, the use of fishery-dependent (FD) measures of catch and effort is difficult for highly managed fisheries; inevitably tighter management regulations result in FD catches reflecting the demographics of a restricted subset of the population, affecting the utility of FD data when assessing the current status of the entire population (Rudershausen, et al., 2010; Williams and Carmichael, 2009). When fisheries are highly regulated, fishery-independent (FI) surveys are often the only method available to adequately characterize population size, age and length composition, and reproductive parameter distributions, all of which are needed to assess the status of the stocks. This is because FI measures of catch and effort, with standard gear types and deployment strategies, are not constrained by management regulations and are not affected by the vagaries (e.g., intermittent commercial operations, targeting changes, multiple landing sites) of FD data.

Herein, we use FI data derived from the Marine Resources Monitoring, Assessment and Prediction (MARMAP) program and the Southeast Reef Fish Survey (SERFS) chevron trap survey to characterize the change in relative abundance of seven species of reef fish representing five families: Gray Triggerfish, *Balistes capriscus* (Balistidae), White Grunt, *Haemulon plumierii* (Hamulidae), Red Snapper (*Lutjanus campechanus* (Lutjanidae), Vermilion Snapper, *Rhomboplites aurorubens* (Lutjanidae), Black Sea Bass, *Centropristis striata* (Serranidae), Scamp, *Mycteropera phenax* (Serranidae), and Red Porgy, *Pagrus pagrus* (Sparidae). Each of these species differ with regards to exploitation history, fishery desirability, management history and life history while inhabiting the same general habitats (e.g., hard-bottom habitat) and depths. For each species we use a zero-inflated negative binomial (ZINB) generalized linear model (GLM) to standardize for annual vagaries with regards to important abiotic and biotic covariates on the apparent relative abundance of that species.

# Methods

## Species

### Balistes capriscus

### Haemulon plumierii

### Lutjanus campechanus

### Rhomboplites aurorubens

### Centropristis striata

### Mycteroperca phenax

### Pagrus pagrus

## Survey Programs

The Marine Resources Monitoring, Assessment and Prediction (MARMAP) program has conducted FI research on the continental shelf and shelf edge between Cape Hatteras, NC, and St. Lucie Inlet, FL, for over 40 years to provide information for reliable stock assessments and evaluation of management plans. The overall mission of the MARMAP program has been to determine the distributions, relative abundances, and critical habitats of economically and ecologically important fishes of the SAB, and to relate these features to environmental factors and exploitation activities. Although the MARMAP program has used various gear types and methods of deployment since its inception, the program has strived to use consistent gears and sampling methodologies through extended time periods to allow for analyses of long-term changes in relative abundance, length frequencies, and other information. Since 1990, the MARMAP program has used a standard sampling methodology with chevron traps for monitoring purposes on known live-bottom habitats.

Until recently, the MARMAP program was the only long-term FI program that collected the data necessary to develop indices of relative abundance for species in the SAFMC snapper-grouper species complex. This began changing in 2009 with the first field season of the Southeast Area Monitoring and Assessment Program’s South Atlantic Component (SEAMAP-SA) Reef Fish Complement Survey. It changed additionally in 2010 with the first field season of the Southeast Fisheries Independent Survey (SEFIS). Both of these newly initiated surveys were designed to complement the traditional MARMAP program with a stated goal of allowing for an expansion of the geographical coverage of fishery-independent reef fish surveys. As all three surveys currently utilize consistent sampling methodologies, collectively we refer to their combined efforts as the Southeast Reef Fish Survey today and use their combined data set for the development of species specific relative abundance indices moving forward.

## Sample Collection

The standard SERFS sampling area includes waters of the continental shelf and shelf edge between Cape Hatteras, NC, and St. Lucie Inlet, FL. Throughout this range, each year MARMAP and SERFS biologists sample stations established on confirmed hard-bottom with chevron traps from May through September, though cruises have occurred prior to and after these months in some years. Currently we have a universe of ~3,500 known hard-bottom stations appropriate for sampling via chevron traps (low to moderate relief). Chevron traps have been deployed at depths ranging from 13 to 218 m, although the depth of usage generally is less than 100 m. Only data derived from confirmed hard-bottom locations are included in the development of subsequent relative abundance indices.

Chevron traps became the primary sampling gear used by MARMAP and SERFS biologists in 1990. MARMAP began using chevron traps for monitoring purposes after a commercial fisherman introduced the use of this design in the U.S. South Atlantic region (Collins, 1990). Chevron traps are arrowhead shaped, with a total interior volume of 0.91 m3 (see Collins, 1990 Figure 1 for diagram). Each trap is constructed of 35 x 35 mm square-mesh plastic-coated wire and possess a single entrance funnel (“horse neck”) and release panel to remove the catch. Prior to deployment each trap is baited with whole clupeids (mostly *Brevoortia spp*., sum *Alosa spp.*, family Clupeidae); four cluepieds on each of four stringers suspended within the trap and approximately 8 clupeids, with their abdomen sliced open, placed loose in the trap. Generally traps are deployed in sets of six when a sufficient number of stations are available in a given areas, with this group of traps referred to as a “set” or “event.” Traps are retrieved in chronological order of deployment, using a hydraulic pot hauler, after an approximately 90-minute soak time. Only traps with soak times of between 45 and 150 minutes are included in subsequent relative abundance analyses.

## Data Collected

### Trap Level Information

From each chevron trap deployment, all fishes are sorted to species, weighed (total weight in grams, per species), and all individual fish are measured to the nearest cm. Additional information recorded includes a unique collection number, date and time of deployment, soak time (in minutes), location (latitude (oN) and longitude (oW) in decimal degrees), bottom depth, catch code, data source and station type. Information regarding trap level catch codes, data source, and station type are used to identify collections that were deployed according to defined fishery-independent chevron trap survey monitoring protocols (see Appendix A, Table 1). Any chevron trap deployments not conforming to standardized protocols are excluded from further relative abundance analyses.

### Trap Set Level Information

For each “set” of chevron traps deployed, hydrographic data is obtained using a conductivity-temperature-depth recorder (CTD). During each CTD cast various hydrographic parameters are recorded, including, but not limited to, water depth (m) and water column temperature profiles (oC). Since 2012, Vemco mini-loggers that are capable of recording water temperature (oC) have also been attached to a sub-sample of deployed chevron traps. A bottom temperature (oC) variable, defined as the temperature value of the deepest point of the CTD cast or as the mean temperature recorded during the soak of a trap as recorded by a Vemco mini-logger, is recorded for each “set” of chevron traps. When information is available from both a CTD cast and mini-loggers for a “set,” bottom temperature is defined using the CTD information. Each chevron trap collection within a given set is assigned the same bottom water temperature value.

## Standardization Model

### Zero-Inflated Negative Binomial GLM

As is the case with many ecological count data sets (Zuur, et al., 2009), the observed catch per trap data from the chevron trap survey appeared to be zero-inflated for each species based on preliminary analyses (see Appendix B, Figure XXX), suggesting the appropriateness of zero-inflated count models (see Cameron and Trivedi, 1998; Hardin and Hilbe, 2007; Hilbe, 2007; Zeileis, et al., 2008; Zuur, et al., 2009 for a full description of zero-inflated models) as a modeling framework for the development of standardized relative abundance indices. Such models are appropriate when 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). See supplementary information and the afore mentioned reference for more background on zero-inflated models.

Herein we used a ZINB GLM to model zeros as being derived from a mixture of two sources: a binomial process and a count process. Such a mixture model is appropriate when zeros can arise due to miss-recorded observations (i.e., due to imperfect detection by the chevron trap) (Cameron and Trivedi, 1998). Zeros derived from the binomial process (i.e., the zero-inflation model) are modeled using a binomial GLM, which is used to model the probability of measuring a zero. Conversely, the count process is modeled using a negative binomial GLM, which allows additional zeros to result from the count process directly (Zuur, et al., 2009). In such a mixture model, the zeros resulting from the count process model represents true zeros, while the binomial GLM models the probability of measuring a false zero versus all other types of data (counts and true zeros; Zuur, et al., 2009).

Mathematically, the probability of obtaining a zero is

. (1)

We assume that the probability that , an observation from an individual chevron trap for the species in questions, is a false zero is binomially distributed with probability ; therefore the probability that is not a false zero is equal to . The probability that the from a negative binomial distribution is zero (i.e. we measure a true zero), which is needed to estimate the is

(2)

where is defined as . The mean and variance of are given by

(3)

where represents the dispersion parameter (smaller , larger the overdispersion). Equation (1) can now be written as

. (4)

Conversely, the probability that is a non-zero count is given by

. (5)

Because we assume a binomial distribution for the binary part of the data and a negative binomial distribution for the count data in a ZINB, equation (5) can be re-written as

. (6)

Re-writing equations (4) and (6) in terms of probability functions f:

(7)

and

(8)

for the zero and the non-zero component, respectively. The mean and variance of a ZINB are

(9)

and

(10)

If, as we do here, covariates are used to model the mean of the positive count data,

, (11)

and the probability of having a false zero, is

. (12)

Here and represent individual covariates for the count and zero-inflation sub-models, respectively, and we have unknown regression parameters .

### Model Structure

For each focal species, we modeled relative abundance (response variable) as catch per trap, including soak time as an offset term (exposure effect) in both the zero-inflation and count sub-models of the ZINB. By defining this offset variable we adjust for the amount of opportunity for the gear to capture a fish (e.g., a deployment with a soak time of 120 minutes has twice the opportunity of a deployment with a soak time of 60 minutes). Our explanatory variable of interest, year, was modeled as a discrete variable such that a “year effect” could be used to represent temporal trends in the relative abundance of the focal species.

We identified *a priori* a list of available covariates that biologically we could theorize would have an effect on observed counts. These covariates included depth (m), bottom temperature (oC), latitude (oN), and day of year. This is not an exhaustive list of potential covariates one may expect to affect apparent relative abundance annually, but rather a targeted list representing covariates readily available in the data set for the majority of collections since 1990. Each of these were considered continuous variables in the resultant ZINB as they were initially measured on a continuous scale.

### Covariate Treatment

Prior to inclusion of the considered covariates in the full model, we used preliminary analyses to investigate the possibility of collinearity between any of the variables. Pairs plots revealed moderate correlations between bottom temperature and depth and bottom temperature and day of year (Appendix X, Figure XXX). Variance inflation factors (VIF; Appendix X, Table XXX) and box plots of the covariates among years (Appendix X, Figure XXX) indicated minimal collinearity among considered variables. Box plots also indicated subtle differences in the annual distribution of many of the considered covariates, suggesting the need for ZINB standardization of relative abundance trends to account for these annual vagaries with regards to covariate distributions.

Due to the desire to include continuous covariates in the ZINB standardization model, we used generalized additive models as implemented in the R package *mgcv* (Wood, 2000; 2003; 2004; 2006; 2011) to investigate the relationship of continuous covariates with relative abundance. Two sets of GAMs were investigated, one looking at the relationship of continuous covariates to the presence/absence of a focal species and one looking at the relationship of continuous covariates to the catch per trap of a focal species. Effective degrees of freedom, as estimated from these preliminary GAMS were used to inform maximum multi-polynomial order for each covariate considered in the zero-inflation and count sub-models of the full ZINB, respectively.

### Model Development and Selection

Prior to model development, all covariates were centered and scaled to improve statistical convergence. Covariates were included as multiple polynomials in the ZINB using the function “poly” available in the R package *stats* (R\_Core\_Team, 2015). We allowed the possibility that different covariates may appear in each of the sub-models. The only restraint on model structure was that the explanatory variable was forced to be retained in the count sub-model of the ZINB. ZINB were fit using the function “zeroinfl” available in the package *pscl* (Jackman, 2011; Zeileis, et al., 2008). All analyses were performed in R (Version 3.2.3; R\_Core\_Team, 2015).

Selection of the covariates, including multi-polynomial order, included in the final model for each focal species was done based on Bayesian information criterion (BIC; Schwarz, 1978). Model selection was accomplished in a two-step process. In the first step, we removed all covariates from the zero-inflation sub-model (i.e., intercept only zero-inflation sub-model) and optimized the count sub-model of a ZINB for each focal species. In the second step, we fixed the count sub-model to the optimum covariate structure identified during step 1, then optimized the covariate structure of the zero-inflation sub-model.

### Relative Abundance Index Construction

The annual relative abundance (i.e., the year effect) of each focal species was extracted from the selected ZINB using a least squares means approach (Searle 1980). Least squares means are generally used in conjunction with factorial survey designs; given a model design with two or more factors, the marginal means for one factor, in our case that would be the explanatory variable year, are the means for that factor averaged across all levels of the other factor(s). In our case, our standardization covariates are not discrete levels of factors, but rather continuous covariates. Thus, instead of calculating the year effect at all possible combinations of the other factors, we took the average year effect at a series of possible combinations of the other covariates. The series of possible combinations were defined by obtaining 17 evenly spaced values along the range observed for each covariate, subsequently developing a prediction data frame representing every possible combination of year and covariates. Subsequently, using the best fit ZINB model we obtain predicted catch per trap for each combination, using the mean catch per trap, by year, to represent the annual relative abundance of a given focal species.

Uncertainty about the annual relative abundance was estimated using a bootstrapping approach. In our application, 10,000 individual bootstrap samples of the original data with replacement, by year, were obtained. To each individual bootstrap we applied the optimum ZINB selected by BIC, extracting the year effect from each boot using the same procedure outlined above. Variability in individual year effect estimates from the resulting bootstraps were used to obtained annual coefficient of variation estimates and develop confidence intervals about predicted relative abundance annually. The bootstrapping routine was performed using the R function “boot” in the R package *boot* (Canty and Ripley, 2016; Davison and Hinkley, 1997).

All analyses were performed in R (Version 3.2.3; R\_Core\_Team, 2015).

# Results

# Discussion

# Acknowledgements

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# Tables

# Figures

# Appendix

## Appendix A

Table : Descriptions of codes related to trap level data regarding data source, station type, and catch code. Indicated are whether code identifies whether the chevron trap collection represents a valid sample (conforms to standard SERFS chevron trap sampling protocols) or not. If not representative of a valid sample, a brief description is provided indicating why it is not considered valid

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Levels** | **Description** | **Valid** | **Reason if Not Valid** |
| Data Source | TagMM | Tagging projects |  | Not every species captured were counted and recorded; only data for priority species of the tagging study retained |
| GRR | Gray’s Reef Sample | X |  |
| MARMAP | MARMAP Monitoring Sample | X |  |
| GR | Gray’s | X |  |
| SMRFC | SEAMAP Reef Fish Complement Monitoring Sample | X |  |
| SEFIS | SEFIS Monitoring Sample | X |  |
| Station Type | Recon | Sample on un-verified potential hard bottom |  | Hard-bottom at the location could not be verified |
| Duplicate | Station which was sampled w/in 200 m of another station in a single year |  | Does not confirm to standardized sampling protocol |
| Random | Randomly selected station from chevron trap universe | X |  |
| NonRandom | Station from chevron trap universe that was not randomly selected at beginning of the year, but was sampled opportunistically during the year | X |  |
| Monitoring | Station whose sampling selection (random vs. non-random) is not known, but is part of chevron trap universe | X |  |
| ReconConv | Reconaissance sample for which hard-bottom at station was verified and thus added to chevron trap universe | X |  |
| Catch Code | 0 | No catch | X |  |
|  | 1 | Catch with finfish | X |  |
|  | 2 | Catch without finfish | X |  |
|  | 3 | No catch due to lost trap |  | Lost trap |
|  | 4 | Questionable catch |  | Catch was mixed or lost thus species level abundance data questionable |
|  | 6 | Gear damaged/behaved other than intended |  | Catch questionable due to gear behavior or damage |
|  | 9 | Recon deployment | X\* |  |
|  | 90 | Recon – no catch | X\* |  |
|  | 91 | Recon – catch with finfish | X\* |  |
|  | 92 | Recon – catch without finfish | X\* |  |
|  | 93 | Recon – no catch due to lost trap |  | Lost trap |
|  | 96 | Recon – questionable catch |  | Catch questionable due to gear behavior or damage |

\* – only considered valid if station type = ReconConv

Table : Distribution of “valid” and “non-valid” chevron trap collections, by year. The majority of the non-valid chevron trap deployments are due to reconnaissance trap deployments over un-verified hard-bottom habitat. Note that increase in the number of collections annually since 2010. This is due to the additions of the SEAMAP-SA Reef Fish Complement and the SEFIS to the traditional MARMAP program during recent years.

|  |  |  |
| --- | --- | --- |
|  | **Valid** | |
| **Year** | **Yes** | **No** |
| 1990 | 352 | 2 |
| 1991 | 299 | 6 |
| 1992 | 324 | 0 |
| 1993 | 508 | 34 |
| 1994 | 458 | 10 |
| 1995 | 541 | 4 |
| 1996 | 508 | 134 |
| 1997 | 462 | 71 |
| 1998 | 480 | 43 |
| 1999 | 305 | 42 |
| 2000 | 332 | 51 |
| 2001 | 310 | 15 |
| 2002 | 292 | 44 |
| 2003 | 255 | 31 |
| 2004 | 307 | 34 |
| 2005 | 338 | 19 |
| 2006 | 317 | 15 |
| 2007 | 338 | 23 |
| 2008 | 303 | 51 |
| 2009 | 404 | 60 |
| 2010 | 741 | 310 |
| 2011 | 882 | 132 |
| 2012 | 1217 | 176 |
| 2013 | 1395 | 166 |
| 2014 | 1479 | 41 |
| 2015 | 1520 | 9 |