NOAA Technical Memorandum NMFS-SEFSC-617

EXPLORATORY ASSESSMENT OF FOUR STOCKS IN THE U.S. SOUTH ATLANTIC:

BANK SEA BASS (*Centropristis ocyurus*)

GRAY TRIGGERFISH (*Balistes capriscus*)

SAND PERCH (*Diplectrum formosum*)

TOMTATE (*Haemulon aurolineatum*)

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, Florida 33149

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EXECUTIVE SUMMARY

Exploratory stock assessments were completed for four data-poor stocks in the U.S. South Atlantic during the summer of 2010. A review of the fishery independent MARMAP survey database identified bank sea bass, gray triggerfish, sand perch and tomtate as four unassessed, data-poor stocks with good assessment potential due to significant catches in the survey over time. All of the work in this report should be viewed as preliminary due to the amount of time available for its completion.

For bank sea bass, a surplus production model was used to evaluate the stock status using the modeling program ASPIC. Reference points (F/F_{MSY} and B/B_{MSY}) were obtained in order to provide management indicators about the stock. The results from ASPIC indicated that bank sea bass currently have an F/F_{MSY} value above 1.0 indicating the stock is undergoing overfishing, and a B/B_{MSY} value below 0.5, which even under the most conservative estimates of MSST, indicates the stock is overfished. Although, the trend in recent years indicates that the rate of overfishing is decreasing, projections done with ASPIC show that if the current fishing pressure is sustained, the stock biomass may continue to decline. If fishing mortality or landings were eliminated, projections estimate that B/B_{MSY} would reach 1.0 in 2025.

The status of gray triggerfish is highly uncertain. The yield-per-recruit model was very sensitive to natural mortality rate and fraction mature. The fishing mortality rate estimates were relatively uncertain due to the small and variable data set, which estimated the proxy for fishing mortality rate at maximum sustainable yield (via $F_{40\%}$ MSP) to be equal to 0.63. The surplus production model, calculated using ASPIC, was not able to fit the CPUE to a production curve, and produced no usable results. Results are inconclusive regarding whether the stock is currently subject to overfishing.

Yield-per-recruit analysis was performed, using sand perch life history information and the calculated value of M, to approximate fishing pressures that would produce maximum yield. These analyses produced ranges for $F_{0.1}$ and $F_{40\%}$ that were generally above ranges for current estimated fishing pressures (as determined by catch curve analysis). Results of the catch curve analyses and the yield-per-recruit analyses, combined with analysis of available data and life history information, suggest that the current fishing pressures on sand perch are sustainable.

Overall, the surplus production model was the only one of the three analysis methods that provided information on the current status of the tomtate. The surplus production model indicated that the tomtate is likely overfished and currently experiencing overfishing. The indices alone show a generally decreasing trend in the abundance of tomtate; however, the MARMAP index shows a general stabilization of the abundance since 2003 and the headboat index shows a slight increase in abundance since 2007. According to projections, the population is likely to decrease further if current fishing pressure is maintained and would likely take

approximately 20 years to reach B/B_{msy} of one if fishing mortality rate (F) was set to zero. Caution is warranted in interpreting these results as a number of problems were identified with the commercial catch data available for use in the assessment. The analysts recommend that these results be viewed as preliminary and that additional efforts should be made to reconstruct the commercial catch data, both landings and discards, before any future assessment takes place.

Eight students participating in the Population Dynamics Recruiting Program (PDRP) completed the assessments during a six-week summer program. The PDRP is designed to identify outstanding undergraduate students from across the country and recruit them into the discipline of marine resources population dynamics and eventually into jobs with NOAA. The students were under the supervision of NMFS stock assessment scientists and NMFS stock assessment scientists reviewed all of the work published in this report. All of the work in this report should be viewed as preliminary due to the amount of time available for its completion.

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About the Authors

Eight students participating in the Population Dynamics Recruiting Program (PDRP) completed these assessments during a six-week summer program. Currently, there is an insufficient number of stock assessment scientists being trained by universities across the country (DOC and DOE 2008, Berkson et al. 2009b). The PDRP was created by the NMFS Southeast Fisheries Science Center (SEFSC) to identify outstanding undergraduate students from across the country and recruit them into the discipline of stock assessment and eventually into jobs with NMFS. The program first started in 2003 and has proven to be highly effective (Berkson et al. 2009a, Berkson and Tillman 2011).

The eight students are listed below. During the summer of 2010:

- Molly Broome was a freshman at Rollins College, majoring in Marine Biology.

- Danielle Claar was a sophomore at the University of Hawaii at Hilo, majoring in Marine Science.

- Elizabeth Hamman had just graduated from the New College of Florida with a double major in Marine Biology and Applied Math. She is currently a graduate student at the University of Florida.

- Toby Matthews was a sophomore at the University of Maryland, majoring in General Biology.

- Miguel Salazar was a junior at Texas A&M, majoring in Environmental Geosciences.

- Katelin Shugart-Schmidt had just graduated from Randolph College with a major in Environmental Science. She is currently a graduate student at Virginia Tech studying fisheries science and stock assessment.

- Amy Tillman had just graduated from the University of Georgia, majoring in Mathematics. She is currently a graduate student at Virginia Tech studying statistics, fisheries science, and stock assessment.

- Matthew Vincent had just graduated from Coastal Carolina University, double majoring in Marine Science and Biology. He is currently a graduate student at Virginia Tech studying fisheries science and stock assessment.

Dr. Jim Berkson works for the NMFS SEFSC and leads the Recruiting, Training, and Research Unit at Virginia Tech and the PDRP. He maintains faculty status, as an Associate Professor, at Virginia Tech.

Acknowledgements

The four preliminary stock assessments contained in this Technical Memorandum were completed for data-poor stocks in the summer of 2010 as part of the National Marine Fisheries Service Recruitment, Training, and Research Unit at Virginia Tech. For the sake of consistency, sections of the assessments (including parts of the introduction, data collection, and methods) are shared among the four assessments and were written collaboratively by the authors.

Lead analysts for each species were the following: Katelin Shugart-Schmidt and Amy Tillman (bank sea bass); Elizabeth Hamman and Matthew Vincent (gray triggerfish); Molly Broome and Toby Matthews (sand perch); and Danielle Claar and Miguel Salazar (tomtate).

The authors would like to thank Dr. Bonnie Ponwith, Director of the Southeast Fisheries Science Center (SEFSC), for providing the support and funding that made this program possible.

Stock assessment guidance was provided by Dr. Michael Prager, formerly with the SEFSC, and Drs. Erik Williams, Rob Cheshire, and Amy Schueller of the SEFSC.

Data were provided by Dr. Steve Turner, Dr. Rob Cheshire, Dr. Amy Schueller and Mr. Josh Bennett of the SEFSC, and Dr. Marcel Reichert, Dr. Jessica Stephen, and Mr. Joey Ballenger of MARMAP.

Thanks to Dr. Brian Murphy and Dr. Steve McMullin of Virginia Tech for overall program support and instruction.

Thanks to Lynn Hayes and Elizabeth Fillman of Virginia Tech for their tireless efforts to coordinate this program and for providing logistical support.

Drs. Michael Prager, Dr. Amy Schueller, and Alex Chester provided valuable comments on earlier drafts of the individual species' reports.

Finally, we'd like to thank Mr. Duane Harris, Chairman of the South Atlantic Fisheries Management Council, and Mr. John Carmichael, for their expertise and willingness to answer questions.

The Population Dynamics Recruiting Program is supported by a grant from the NMFS Southeast Fisheries Science Center to Virginia Tech.

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Exploratory Assessment of Bank Sea Bass, *Centropristis ocyurus*

Image from www.floridasportfishing.com

Abstract

Bank sea bass, *Centropristis ocyurus*, are small, fast-growing fish found along the Atlantic coast of North America, with a northern limit of Virginia, and in the Gulf of Mexico. The species is hermaphroditic and achieves initial maturity around the age of three. Although the species is caught both commercially and recreationally, the latter catch far outweighs the former. In addition, bank sea bass is occasionally used as a bait fish.

Bank sea bass data were available from a variety of sources, including the MARMAP program, the MRFSS program, and from NMFS landing records. For this assessment, the instantaneous natural mortality (M) of the species was approximated as 0.46 using the Hoenig estimation method, which follows the procedure set in previous SEDAR assessments. Catch curve analysis was used to derive a value for total instantaneous mortality (Z), but was deemed unreliable as the age of full selectivity into the fishery as determined by MARMAP age structure data was found to be inconsistent with that determined from industry data. Fish were selected far earlier in the recreational fishery than in the MARMAP surveys. Values of Z were extremely uncertain, ranging from 0.786 to 1.606.

Yield-per-recruit estimation was conducted using a NMFS Toolbox program, and with life history information. Two main results were examined, $F_{0.1}$ and $F_{40\%}$, although $F_{40\%}$ was ultimately not considered valid due to the hermaphroditic nature of the species. $F_{0.1}$ was found to vary the most with changes to M and was also sensitive to variations on fishing selectivity at age.

Additionally, a surplus production model was used to evaluate the stock status using the modeling program ASPIC. Reference points (F/F_{MSY} and B/B_{MSY}) were obtained in order to provide management indicators about the stock. The results from ASPIC indicated that bank sea bass currently have an F/F_{MSY} value above 1.0 indicating the stock is undergoing overfishing, and a B/B_{MSY} value below 0.5, which even under the most conservative estimates of MSST, indicates the stock is overfished. Although, the trend in recent years indicates that the rate of overfishing is decreasing, projections done with ASPIC show that if the current fishing pressure is sustained, the stock biomass may continue to decline. If fishing mortality or landings were eliminated, projections estimate that B/B_{MSY} would reach 1.0 in 2025. Decreasing yield will cause the stock B/B_{MSY} to rise more quickly when compared to the same proportional decrease in fishing pressure. Additionally, overall yield for the bank sea bass fishery may be easier to manage than regulations based on fishing mortality rate.

More data need to be gathered on the species' age-frequency distribution, sex-change initiators, and vital rates.

Introduction

Evaluating the stock status of all species harvested within the South Atlantic has become increasingly important. In 2007, President Bush signed the Magnuson-Stevens Reauthorization Act, which states that an annual catch limit must be put into place for all stocks undergoing overfishing by January 1, 2010, and for all other stocks by 2011. Out of 72 stocks managed in the South Atlantic Fisheries Management Council's (SAFMC) snapper-grouper complex, only 12 have assessments that have been accepted through a peer-review process (John Carmichael, SAFMC, personal communication). For stocks without assessments, a number of methods may be used, including multiplying a stock's average annual catch by a scalar less than one or using indicator stocks combined with stock complexes. This exploratory assessment, completed as part of the National Marine Fisheries Service (NMFS) – Virginia Tech (VT) Population Dynamics Recruiting Program, aims to provide the scientific information needed to set an annual catch limit for the bank sea bass stock. This assessment provides basic stock information through analysis of vital rates, catch curves, yield-per-recruit methods, and a surplus production model.

Bank sea bass, *Centropristis ocyurus*, are a small, fast-growing fish found along the Atlantic coast of North America, with a northern limit of Virginia, and in the Gulf of Mexico (FishBase 2010). Located in deeper waters along hard bottom surfaces, the species matures quickly (usually by the age of 3) and is hermaphroditic, changing sex from female to male. Bank sea bass are caught both commercially and recreationally, with recreational catch far outweighing commercial catch in terms of biomass. Typically, bank sea bass are caught using Bandit gear (a mechanically assisted fishing reel) in the commercial fishery and with traditional hook and line gear in the recreational fishery.

History of Management Regulations

No regulations have been put into effect to control the recreational or commercial catch of the species (SAFMC 2010).

Stock Structure

Although the bank sea bass ranges from the coast of Virginia to the Gulf of Mexico, no study has been done to determine if the population might be comprised of distinct stocks. Therefore, for the purpose of this study, the population under the jurisdiction of the South Atlantic Fishery Management Council, from North Carolina through the eastern coast of Florida, was considered to be a single stock.

Data Sources

MARMAP Data

MARMAP (Marine Resources Monitoring, Assessment, and Prediction) collects fishery-independent data using random sampling and a variety of gear types. Through this sampling, MARMAP obtains CPUE (catch-per-unit-effort), age, length, and weight data, along with other life history data such as maturity state (Marcel Reichert, South Carolina Department of Natural Resources, personal communication). The program is funded by the National Marine Fisheries Service and implemented by the South Carolina Department of Natural Resources. Sampling occurs at 300 to 500 randomly selected live-bottom sampling sites per year from Cape Fear, North Carolina, to Cape Canaveral, Florida. Life history data gathered from each specimen includes length (standard and total) in millimeters, weight in grams, date caught, sex, and maturity. Otoliths are extracted for ageing. Other data provided included trap soak time, longitude and latitude coordinates of trap set, depth and date of capture, and quantity of bank sea bass caught. MARMAP also provided a small amount of additional life history data (including age information) gathered from fishery-dependent samples.

MARMAP uses a variety of gear types to catch bank sea bass, including hook and line, snapper reels, baited blackfish traps, uncovered minnow traps, various experimental traps, Florida antillean traps, falcon trawls without a turtle exclusion device (TED) and chevron traps. Only the chevron traps provided sufficiently large and consistent enough sample sizes of fish to allow calculation of abundance indices.

Two fishery independent indices were calculated for 1990-2009 using data from the MARMAP chevron trap: an abundance index (Figure 1) and a biomass index (Figure 2). The abundance index was standardized based on the number of fish caught per soaked trap hour, and the biomass index was standardized based on the weight of fish in grams caught per soaked trap hour. The MARMAP program began using chevron traps to collect biological samples in 1988, but because collection was inconsistent for the first two years due to personnel training with the new gear type, MARMAP scientists advised us to not use the corresponding data points in further analysis. Since 1988, only chevron traps have been used exclusively in index calculations to avoid inconsistencies in gear type.

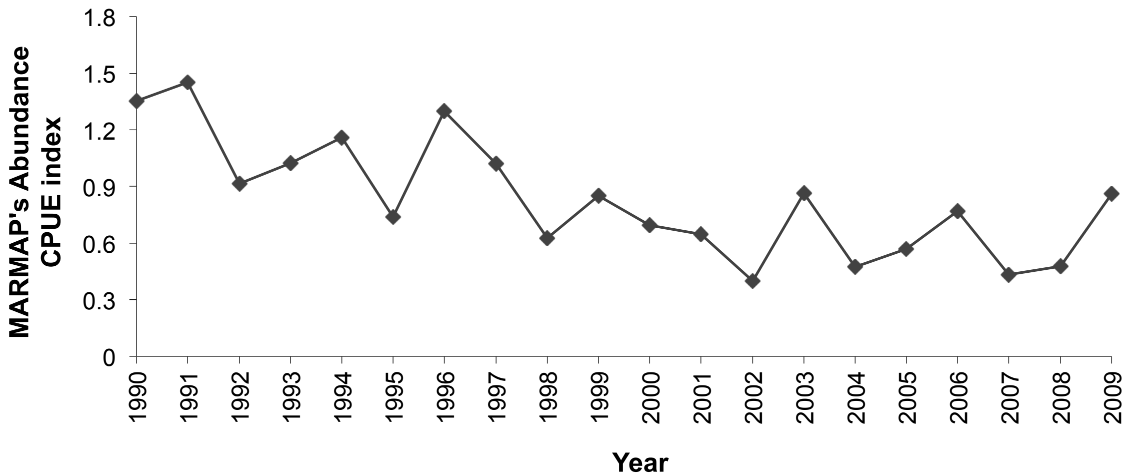


Figure 1. BSB: Abundance CPUE index from 1990-2009 estimated using MARMAP chevron trap data. (The index was standardized based on the number of fish caught per soaked trap hour)

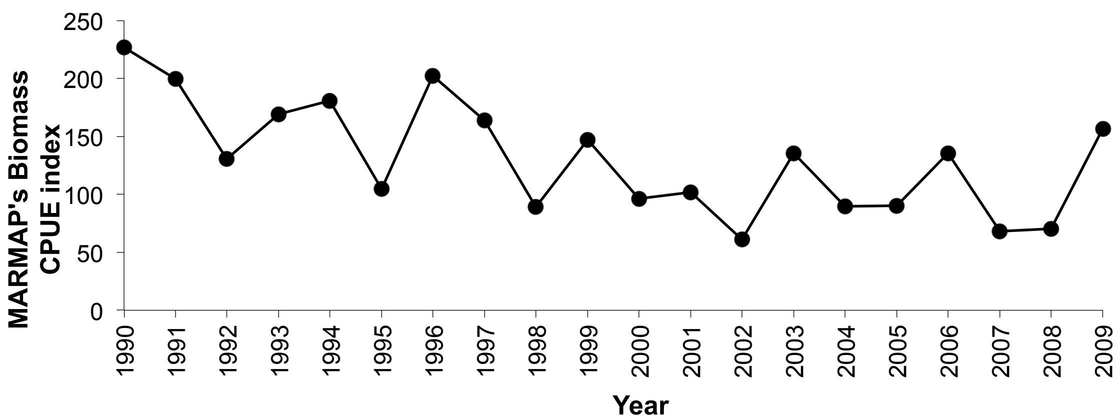


Figure 2. BSB: Biomass CPUE index from 1990-2009 estimated using MARMAP chevron trap data. (The index was standardized based on the weight of fish in grams caught per soaked trap hour.)

Headboat Data

Headboats are for-hire fishing vessels on which individual anglers pay fees. Data were collected from logbooks under the NMFS Headboat Logbook Program, which requires headboat captains to record data in order to maintain boat permits. Information includes catch composition, number of fish and species harvested, bycatch, number of anglers, trip type, and location fished (Cody and Turner 2010). This information is validated by state and federal cooperative headboat sampling programs, which also collect and provide life history data.

A headboat CPUE index was compiled and provided by Dr. Amy Schueller of the Southeast Fisheries Science Center's (SEFSC) Beaufort Laboratory. The index was calculated using a delta-glm with a gamma distribution and units were in number of fish per angler hour (Figure 3). Total effort was estimated using a method described in Stephens and MacCall (2004). Headboat landings were provided to Dr. Jim Berkson (NMFS RTR Unit, Blacksburg, VA) and included in the overall total landings data provided to us.

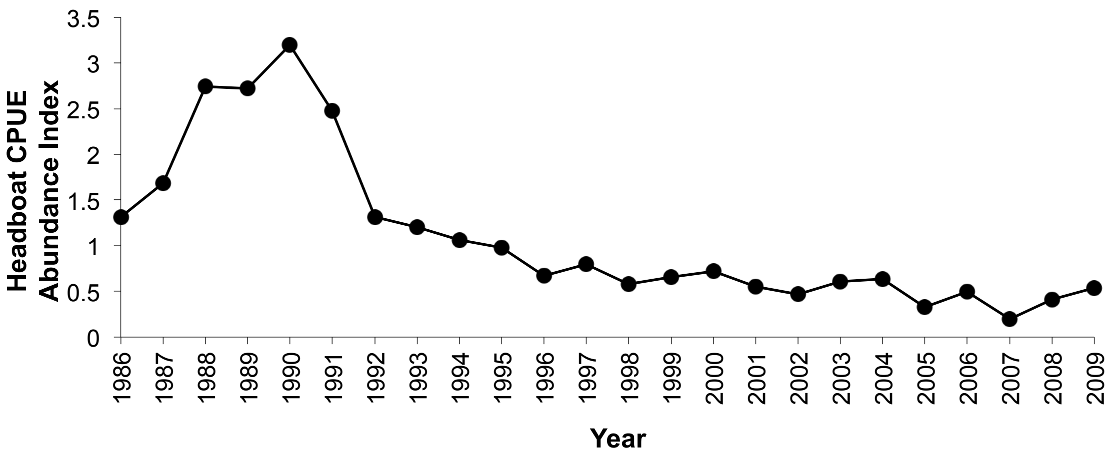


Figure 3. BSB: Headboat CPUE index (number of fish per angler hour) from 1986-2009.

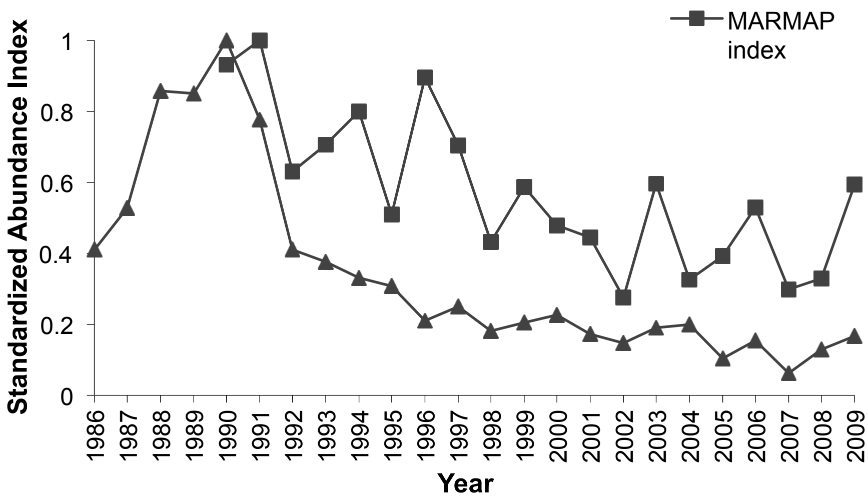


Figure 4. BSB: Standardized headboat and MARMAP CPUE indices.

The headboat and MARMAP indices were standardized, enabling direct comparison between them (Figure 4). The headboat CPUE index displays a clear trend, increasing in the earlier years and decreasing from 1990 on. The MARMAP CPUE has a generally decreasing trend over time with year to year variation. Starting in 1990, both indices seem to correlate, showing a decreasing trend, providing greater assurance that the indices accurately reflect historic changes in the fishery.

MRFSS Data

The Marine Recreational Fishing Statistics Survey (MRFSS), run by NMFS, uses telephone surveys to estimate recreational fishing effort. Recreational fishermen are also surveyed at docks and fishing locations to estimate recreational catch. The two surveys are combined to produce annual estimates of catch in pounds, which were provided to Dr. Berkson for the years 1996-2008 by the SEFSC's Miami Lab. These landings were included in the overall total landings data provided to us.

Commercial Data

Commercial data were collected on both the state and federal levels. Although data collection varies by state, common methods used are the submission of trip-tickets, landing weight reports from seafood dealers, ship logbooks, and sampling of catches conducted both on ships and at docks. Historically almost all data came from seafood dealerships but in recent years there has been a shift towards mandatory trip-ticket reporting (NMFS 2010). Commercial landings data were provided by the SEFSC's Miami laboratory to Dr. Berkson. These data were not provided to the analysts, except in aggregated form, to ensure confidentiality.

Commercial discards were calculated by the SEFSC and provided to Dr. Berkson, but they were received after completion of this assessment. Discards were provided in numbers of fish with no agreed upon method available for converting to weight. Data were not available for years prior to 1993. Data for this stock was considered insufficient (Kevin McCarthy, SEFSC, personal communication), and for that reason, these data were not incorporated into the current assessment.

Total Catch Data

Total catch data from 1986 to 2009, combining commercial, recreational, and headboat catch, as described above, were provided by Dr. Jim Berkson (NMFS RTR Unit, Blacksburg, VA), and were not broken down due to confidentiality issues relating to commercial data. Total landings follow a similar trend in comparison to the CPUE indices (Figure 5). Landings seem to decrease over time similar to the indices, except for the spike in total landings in 1995. The MRFSS landings are estimated by telephone surveys and are highly variable; and therefore, MRFSS landings more than likely contributed to the spike in total landings that year.

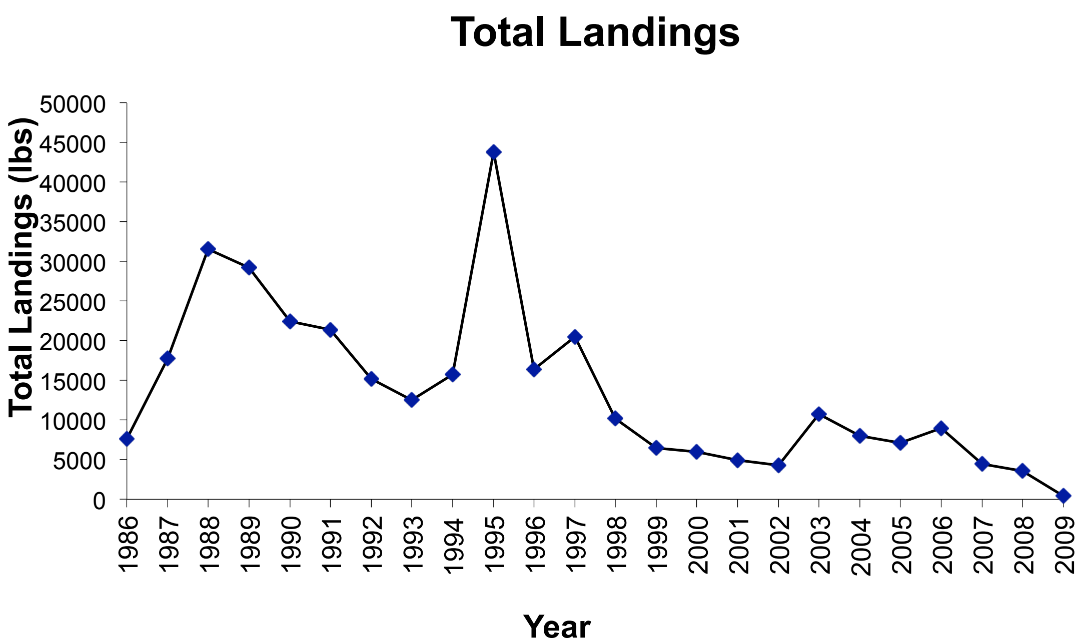


Figure 5. BSB: Total landings from the South Atlantic Region summed over commercial, headboat, and recreational catch.

Vital Rates

As no stock assessment has previously been conducted on bank sea bass, four vital rates (growth, maturity, fecundity, and mortality) were estimated.

Growth

Bank sea bass attain an average weight of 61.2 grams at age one, which was estimated from MARMAP life history data. In order to establish parameters to estimate natural mortality, a von Bertalanffy growth function was fit to length and age data provided by MARMAP (Equation 1), where L_t is the length at time t in millimeters, L_∞ is the average maximum length in millimeters, t_0 is the theoretical length at age zero, and K is a growth rate parameter.

$$L_t = L_\infty (1 - \exp(-K(t - t_0))) \quad \text{(Equation 1)}$$

The resulting function (Figure 6) was

$$L_t = 188.4 (1 - \exp(-0.661 (t + 0.455))) \quad \text{(Equation 2)}$$

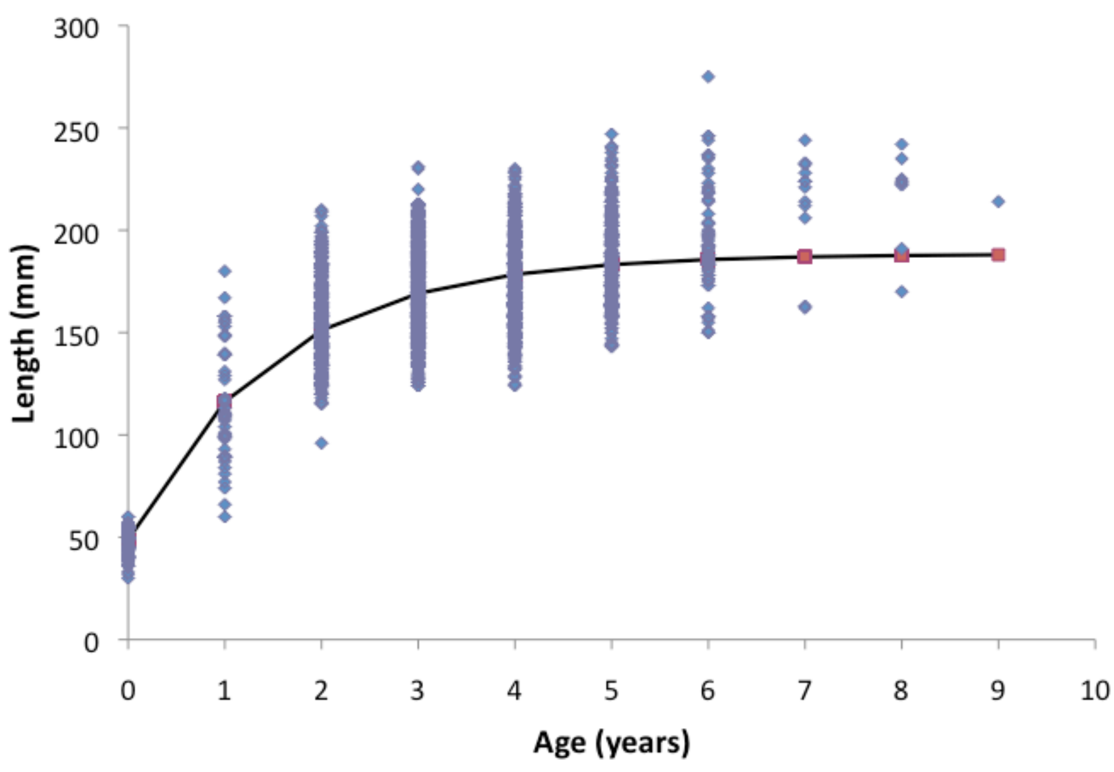


Figure 6. BSB: Fitting from the von Bertalanffy growth function.

This relationship fits the length-age distribution of the data well. Although it would have been beneficial to change the count age (age in whole years) of each sample to an adjusted age (age in fractional years) to ensure a high resolution of understanding into the age structure, there was insufficient data for this to occur, as very few of the examined otoliths had recorded edge and quality indicators (Jessica Stephen, South Carolina DNR, personal communication).

Maturity and Fecundity

The best estimates for bank sea bass age of maturity are between two and three years for all females (SAFMC 2010). Females generally spawn in the early spring months. A four-inch fish spawns an estimated 4,000 eggs, while an eight-inch fish produces up to 30,000 (SAFMC 2010).

Fecundity estimates are complicated for this species because of sequential female to male hermaphrodism, which occurs after a fish has passed through several spawning seasons. There are no known direct triggers for the transformation.

Natural Mortality

For this assessment, the natural mortality rate was estimated using several different methods. Each method uses different parameters in order to estimate the value of natural mortality (M) in a population. These equations use parameters such as estimated values from the von Bertalanffy growth curve (K, L_∞), the maximum observed age (t_{max}), the age at maturity (a_m), water temperature (T, °C), and weight (W, grams) to approximate the natural mortality rate (equations in Table 1). For the Bank Sea Bass, these values were chosen based on the data listed in the growth section of the assessment. Water temperatures were estimated at a range of potential values, with 15 and 20 degrees Celsius listed below (Erik Williams, NMFS Beaufort Lab, personal communication).

Following the procedure established in previous SEDARs (Erik Williams, NMFS Beaufort Lab, personal communication), the Hoenig method of estimation was deemed to be the most reliable, and accordingly the natural mortality rate used in further analysis was 0.468.

Table 1. BSB: Methods available for estimating natural mortality, M.

(using the parameters K and L_∞ from a von Bertalanffy length curve; age at 50% maturity, a_m; maximum age of the fish, t_{max}; mean water temperature in degrees C, T; and average weight (in grams) at age, W.)

Author(s)	**Equation**	**Estimate of M**
Alverson and Carney (1975)	$M = \frac{3*k}{e^{0.38*t_{\max}*k}-1}$	M=0.231
Beverton and Holt (1957)	$M = \frac{3*k}{e^{a_m*k}-1}$	M=0.72
Hoenig (1983)	$M = e^{1.46-1.01*\ln(t_{\max})}$	M=0.468
Pauly (1979)	$M = e^{(-0.0152+0.6543*\ln(k)-0.279*\ln(L_{\inf})+0.4634*\ln(T)}$	M=1.161 for T=15, M=1.327 for T=20
Ralston and Williams (1989)	$M = 0.0189 + 2.06*k$	M=1.380
Lorenzen (1996)	$M = 3.69*W^{-0.305}$	see Table 2

Weight-at-age values used to calculate Lorenzen age-specific natural mortality values appear in Table 2.

Table 2. BSB: Lorenzen weight-at-age variable natural mortality calculations.

Age	Weight-at-age (g)	*M*
0	3	2.56
1	61	1.05
2	123	0.85
3	132	0.83
4	145	0.81
5	196	0.74
6	227	0.71
7	310	0.64
8	368	0.61

Analyses

Catch Curves

Catch curves were used to estimate the total instantaneous mortality rate, *Z*, for bank sea bass. A catch curve analysis is based on the number of fish sampled in each age class. It uses the number of fish present from the modal age (the point at which fish are likely recruited to the fishery) to the oldest age present in the sample. The data are log transformed and a linear regression is fit. The slope of this fit approximates *Z*, (Equation 3; where *M* is the instantaneous natural mortality rate and *F* is the instantaneous fishing mortality rate).

$$Z = M + F \qquad \text{(Equation 3)}$$

Graphing the age *vs.* the number caught for each year revealed a consistent modal age of three and a modal age plus one of four, which is sometimes used as a more conservative estimate. Unfortunately, as no gear selectivity data exist for bank sea bass, it was impossible to accurately compare between the various gear types used by MARMAP. Therefore, only data produced by Chevron traps were utilized to estimate *Z*. Catch curves were generated for each year in the series, and a curve was generated using the total numbers-at-age over all years. An average value of *Z* was calculated based on the *Z* values for each of the individual years. Age frequency data from MARMAP were used for estimating these various *Z* values (Table 3).

Table 3. BSB: Age frequency MARMAP data.

Year	Age									Sample
	1	2	3	4	5	6	7	8	9	Size
1988	0	50	112	63	23	6	4	3	1	262
1992	0	20	106	95	12	1	0	0	0	234
2003	1	101	175	28	9	2	1	0	0	316
2007	9	100	103	40	31	5	1	0	0	280

For chevron traps, the age distribution indicates that the bank sea bass is not selected for until age three or four, which fishery-dependent catch-length data indicates is not the case for the recreational fishery. Furthermore, only four years had sufficient sample sizes to justify analysis (1988, 1992, 2003, 2007), per the recommendation of Dr. Erik Williams (NMFS Beaufort Lab, personal communication), who indicated that samples must contain at least 200 individuals for an accurate analysis.

The estimated total instantaneous mortality rate based on catch curve analysis ranged from 0.78 to 2.28 (Table 4). The high variability of *Z* indicated that it was likely an imprecise value, and therefore undermined its value to the assessment. Between the years 1988 and 1992, the catch curves for the modal age indicate that (assuming a constant natural mortality rate) the fishing mortality rate increased from 0.3 to 1.1. If the modal age plus one is used instead, the fishing mortality ranges even more, from 0.3 to 1.8.

Table 4. BSB: Total instantaneous morality, *Z*, for the MARMAP chevron trap age data evaluated at the modal age and the modal age plus one.

Year	Modal age	Modal age + 1
1988	0.786	0.778
1992	1.606	2.277
2003	1.297	1.289
2007	1.135	1.289
Data from all years combined	1.064	1.038
Annual estimates averaged	1.206	1.408

The uncertainty in this analysis may be due to a variety of assumptions. One assumption is that the natural mortality and fishing mortality rates remained constant over time (Haddon, 2001). It is also assumed that the sample distribution remained constant throughout the time series, including constant recruitment and a stable age distribution. Finally, the catch curve analysis relies on a correct estimation of age at full recruitment to the fishery (Shertzer et al., 2008).

Due to disagreement in the results with those from the surplus production model and the limited number of years with available age data, we determined that catch-curves are likely not an accurate predictor of total instantaneous mortality for bank sea bass.

Yield-Per-Recruit Model

Yield-per-recruit (YPR) models approximate the potential yield at reference point fishing pressures for a population through the use of life history parameters. The main goal of YPR analysis is to find the fishing conditions under which maximum yield for the fishery can be obtained. For the purposes of this model, yield refers to the amount of biomass available for harvest. A single recruit is one fish that has become vulnerable to the fishery.

An YPR analysis was performed using the NOAA Fisheries Toolbox (NFT) YPR version 2.7 software, which expands upon the basic model created by Thompson and Bell (1934). The basic inputs for the software are selectivity on fishing mortality, selectivity on natural mortality, stock weights, catch weights, spawning stock weights, the fraction mature at each age, an estimate of the instantaneous natural mortality rate, and percentage of instantaneous total mortality before spawning.

Output values were explored in this assessment for three benchmarks: F_{Max}, $F_{0.1}$, and $F_{40\%}$. F_{Max} is the fishing mortality level that will theoretically maximize yield. It is important to note that F_{Max} gives no notion of sustainability; in many fisheries, exploitation at F_{Max} would lead to population decline. $F_{0.1}$, the fishing mortality at which the slope of the yield-per-recruit curve is one-tenth of the slope at the origin, is a more conservative alternative to F_{Max}. The fishing mortality for $F_{0.1}$ will thus always be lower than that for F_{Max}, though the resultant yield is often only slightly less. However, as with F_{Max}, continued fishing at $F_{0.1}$ may be unsustainable (Haddon 2001). Finally, $F_{40\%}$ is the fishing mortality that corresponds to a spawning potential ratio (SPR) of 0.4. The SPR for a given fishing mortality is the spawning stock biomass per recruit (SSB/R) at that fishing mortality divided by the SSB/R at $F = 0$. An SPR of 0.4 is generally considered to be a sustainable fishing pressure (where $F = F_{40\%}$) for species with life histories similar to bank sea bass (Dr. Erik Williams, NMFS Beaufort Laboratory, personal communication).

One important assumption of the YPR model is that the results are accurate only once the population has reached an age-structured equilibrium. This is rarely true, so caution must be taken in accepting conclusions solely from yield-per-recruit output. Another important assumption is that the input parameters remain constant over time. It is highly plausible that some inputs, such as natural mortality, could change considerably over time. However, both of these issues are relatively minor when compared to the possibility that the parameters have been estimate inaccurately. Thus, again one must be careful in accepting output from the model without performing additional analyses.

Unfortunately, the hermaphroditic nature of bank sea bass only allowed estimation of the $F_{0.1}$ benchmark and not that of $F_{40\%}$, as calculations of $F_{40\%}$ require additional knowledge about the composition of the mature population. Using the MARMAP age frequency data and the headboat catch-length data, ages were estimated from lengths using the von Bertalanffy growth function parameters discussed previously and these conversions were applied to the headboat data. It was determined from this that bank sea bass are likely to be fully selected into the fishery by the age of one, contrary to the catch curve modal age findings. Therefore, the base-run used to examine the model sensitivity assumed selectivity on fishing and natural mortality of 100% at age one (Table 5)

A sensitivity analysis was conducted varying values of selectivity on fishing mortality by age. Results indicate that $F_{0.1}$ decreased as selectivity at younger ages increased (Table 6).

Table 5. BSB: Input values used for the YPR analysis.

Age	Selectivity on Fishing Mortality	Selectivity on Natural Mortality	Stock Weights (g)	Catch Weights (g)	Spawning Stock Weights (g)	Fraction Mature
1	1	1	61	61	61	0
2	1	1	123	123	123	0.5
3	1	1	132	132	132	1
4	1	1	145	145	145	1
5	1	1	196	196	196	1
6	1	1	227	227	227	1
7	1	1	310	310	310	1
8	1	1	368	368	368	1

Table 6. BSB: Variations of selectivity on fishing mortality used for YPR sensitivity analyses.

Selectivity at age:			$F_{0.1}$
1	**2**	**3**	
0	0.5	1	0.765
0	1	1	0.735
0.5	1	1	0.568
0.75	1	1	0.525
1	1	1	0.491

A sensitivity run was conducted on selectivity at age, which revealed that $F_{0.1}$ ranges depending on how soon the fish are considered to be selected into the fishery, from 0.765 (later) to 0.491 (sooner) (Table 6). The estimate of natural mortality was the most sensitive input value for the YPR analysis (Table 7), with a positive or negative change of 20% from the estimated M resulting in a change of $F_{0.1}$ from 0.36 to 0.625. Following SEDAR procedure, the base run used the Hoenig estimate of natural mortality, and the resulting $F_{0.1}$ value was 0.492.

Table 7. BSB: Results of sensitivity analyses, which varied the natural mortality rate, on $F_{0.1}$ using YPR analysis.

Percent change in M_{Hoenig}	***M***	***$F_{0.1}$***
+ 20	0.374	0.36
+10	0.421	0.426
-	**0.468**	**0.492**
-10	0.515	0.559
-20	0.562	0.625

Unfortunately, due to the hermaphroditic nature of bank sea bass, estimates of spawning stock biomass through this YPR model were inconclusive. Even so, minor variations in the fraction mature of ages one through three had very little effect on $F_{40\%}$.

Surplus Production Model

The surplus production model can be an effective assessment tool for data-poor stocks. Surplus production models can supply management reference points and are independent of age-structured data. Some age-structured data were supplied for bank sea bass from MARMAP but were inconsistent from year to year and not comprehensive; therefore a surplus production model was deemed to be the most reliable model for this assessment. The surplus production model is used to estimate the biomass produced beyond replacement levels for a population. This excess biomass is the biomass produced above replacement levels which can be harvested without depleting the population.

The logistic model, described by Schaefer (1954, 1957) allows the combination of many vital rates into a single equation (Equation 4; Haddon 2001). B_t is the biomass at time t, C_t is the catch at time t, r is the intrinsic growth rate, and K is the carrying capacity.

$$B_{t+1} = B_t + r * B_t\left(1 - \frac{B_t}{K}\right) - C_t \qquad \text{(Equation 4)}$$

ASPIC is a modeling program that attempts to fit a non-equilibrium surplus production model to input data in order to analyze stock status and project potential management schemes for the future (Prager 1994). ASPIC estimates a fit to one or more CPUE indices. Initial guesses were made for maximum sustainable yield (*MSY*), carrying capacity (*K*), catchability coefficient (*q*) for each CPUE index, and the ratio of the starting biomass to carrying capacity (B_1/K). Based on these values, total landings data, and CPUE indices, ASPIC attempts to fit a production curve where B_t is the biomass at time t, C_t is the catch at time t, r is the intrinsic growth rate, and K is the carrying capacity (Equation 5; Figure 7; Haddon 2001).

$$Yield = r * B_t\left(1 - \frac{B_t}{K}\right) \qquad \text{(Equation 5)}$$

ASPIC provided estimates of F/F_{msy} and B/B_{msy} in order to determine stock status and to project potential management actions into the future.

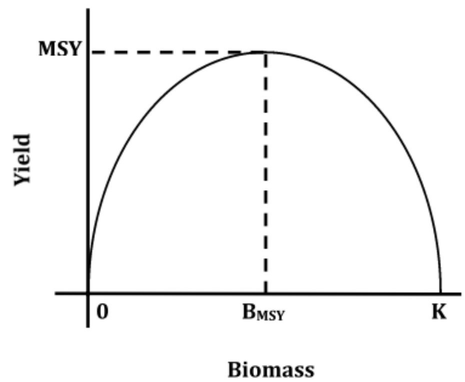


Figure 7. BSB: Production curve as described by Equation 5 where *MSY* is maximum sustainable yield, *K* is carrying capacity, and B_{MSY} is the biomass at maximum sustainable yield (Haddon, 2001).

Input data included both the headboat and MARMAP chevron trap biomass CPUE indices and total landings by year from 1986 to 2009. ASPIC requires total landings data for each year evaluated. Available catch data were converted from pounds to grams for use in ASPIC. The MARMAP biomass CPUE index was paired with total landings and used as the first CPUE time series data set. The headboat CPUE abundance index was the second time series data set. A value of negative one was substituted for missing values for MARMAP's biomass CPUE indices from 1986 to 1989 according to the program manual, and the program estimated these missing values and paired them with the total landings data for 1986-1989.

Initial guesses for *MSY*, *K*, *B1/K*, and *q* for each time series were input, and after running a bootstrap, point estimates were obtained as output (Table 8). A catchability coefficient was estimated for each CPUE index.

Table 8. BSB: Initial input values used for ASPIC and the point estimates after bootstrapping.

	Initial Guesses	Point Estimates
B1/K	5.0E-01	9.8E-01
MSY	6.3E+06	2.8E+06
K	6.3E+07	1.3E+08
q1	4.6E-06	3.0E-06
q2	2.3E-07	1.8E-08

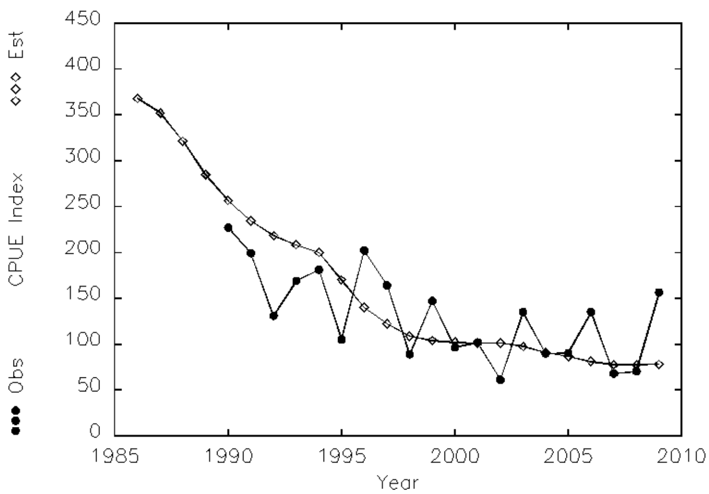
ASPIC fit the CPUE indices relatively well for bank sea bass (Figure 8). The size of the residuals generally decreases with time. Missing values were entered for the MARMAP biomass CPUE index from 1986-1989, and ASPIC estimated initial values for the time series based on index values from 1990 on. Estimating back in time in a time series data set could be viewed as extrapolation, so caution should be used when analyzing the stock status from 1986 to 1989. The estimated fits to the CPUE indices seem to provide a smooth, negative trend from 1986 to 2009 for both indices.

Figure 9 displays reference points B/B_{msy} and F/F_{msy} over time that may be used by scientists and managers in the management process. These points give a rough estimation of when a species may be overfished or currently experiencing overfishing.

Confidence intervals for the bias-corrected reference points (Table 9) were calculated in ASPIC through the use of bootstrapping, the assumption that the residuals were lognormally distributed. The intervals shown in Figure 10 cannot be negative, which explains the asymmetrical shape of the confidence intervals.

In ASPIC, the sum of squares and least absolute value methods are both available to calculate the best fit model conditioned on yield. A sensitivity run comparing the two methods was completed. The sum of squares method is adversely influenced by outliers, more than the least absolute value method. The sum of squares optimization was deemed the most appropriate method for the assessment of bank sea bass because it takes into consideration influential points to a greater degree than the least absolute value method. The sum of squares algorithm seems to be a conservative optimization method for bank sea bass which is important when analyzing a data-poor stock.

(a)



(b)

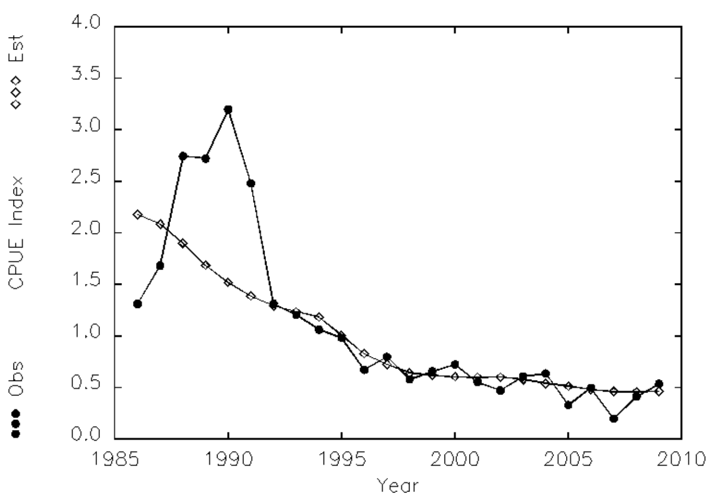


Figure 8. BSB: The fits to (a) the MARMAP biomass CPUE index and (b) the headboat abundance index for bank sea bass in the South Atlantic.

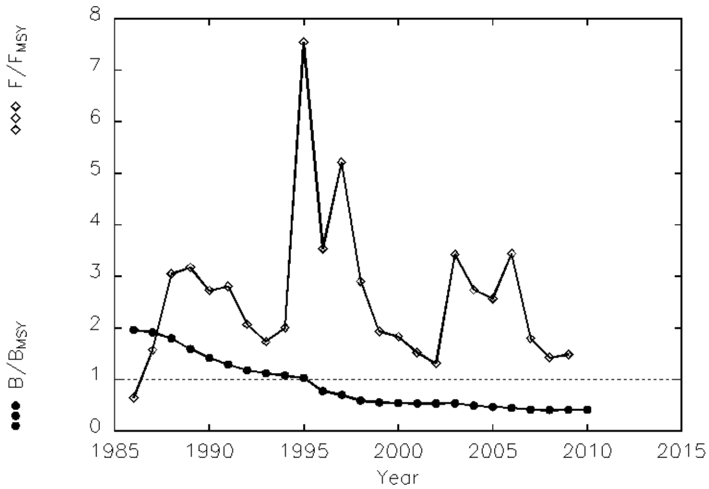
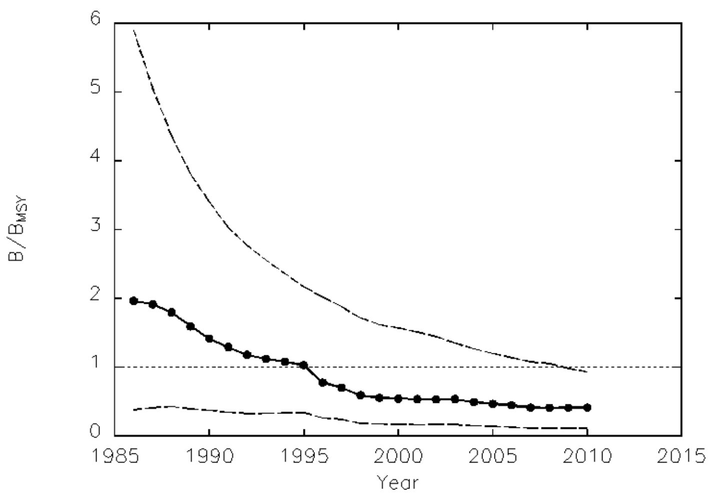


Figure 9. BSB: Reference points B/B_{msy} and F/F_{msy} for bank sea bass based on South Atlantic landings, a MARMAP biomass CPUE index, and a headboat abundance CPUE index.

Table 9. BSB: Bias-corrected (BC) reference point estimates for bank sea bass in the South Atlantic obtained from bootstrapping, along with upper and lower nonparametric 80% confidence bounds.

Reference point	BC estimate	80% LCB	80% UCB
MSY	2,772,000	885,700	6,741,000
B_{2010}/B_{msy}	0.41	0.11	0.93
F_{2009}/F_{msy}	1.48	1.17	4.15

(a)



(b)

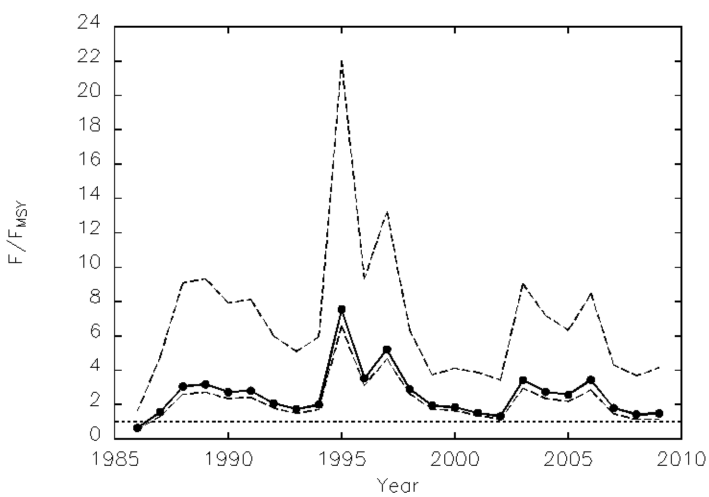


Figure 10. BSB: Reference points within the 80% bias-corrected confidence intervals from ASPIC. (a) B/B_{msy} and (b) F/F_{msy}.

Management Projections

ASPIC can also project the stock status into the future to evaluate the likely effects of specified management regimes. Projections can provide useful information to determine an Allowable Biological Catch (ABC) and Annual Catch Limit (ACL) for bank sea bass. The accuracy in the projections is based on the reference point estimates thus using care when drawing conclusions from the projections is critical.

The following set of projections estimate future population status first based on changes to the fishing mortality rate and later based on changes to yield, both relative to 2009. Projection input values for fishing mortality rates and yield were selected based on a logical progression of values between zero (no fishing mortality or yield) and a 150% increase from 2009 values.

ASPIC projections were based on proportional changes to the 2009 fishing mortality rate relative to F_{2009}/F_{MSY} (Figures 11-17). None of the projected scenarios resulted in B/B_{MSY} increasing to 1.0 in the next ten years. In fact, even with the total elimination of fishing pressure, B/B_{MSY} did not reach 1.0 until 2025.

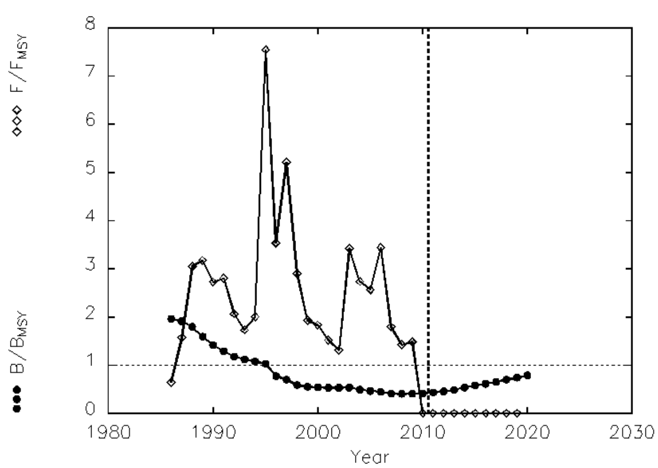


Figure 11. BSB projection: Fishing mortality decreases to zero immediately for 10 years.

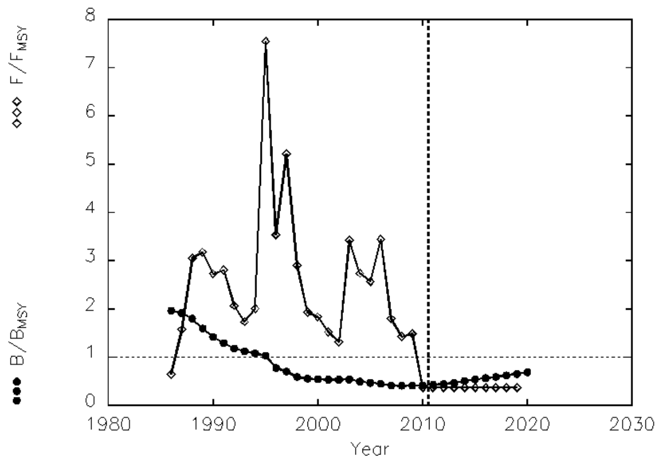


Figure 12. BSB projection: Fishing mortality decreases by 75% for 10 years relative to the F_{2009}/F_{msy} point estimate found from bootstrapping.

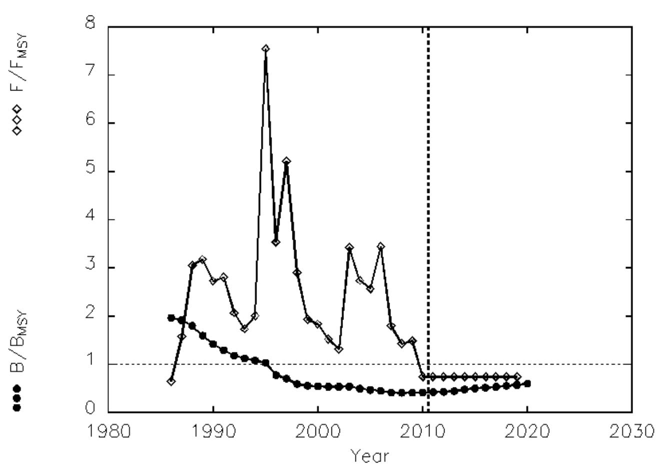


Figure 13. BSB projection: Fishing mortality decreases by 50% for 10 years relative to the F_{2009}/F_{msy} point estimate found from bootstrapping.

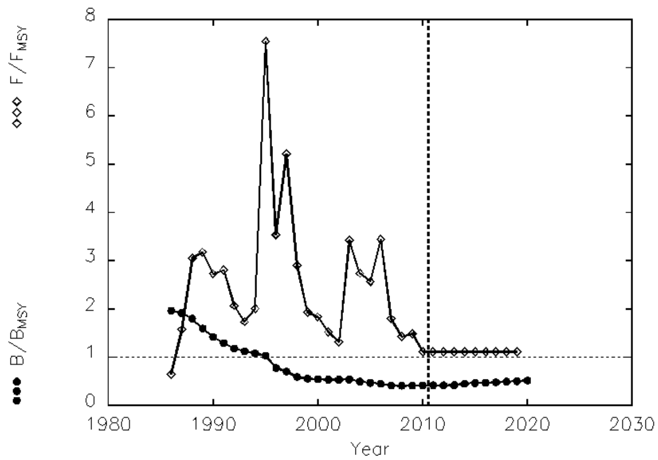


Figure 14. BSB projection: Fishing mortality decreases by 25% for 10 years relative to the F_{2009}/F_{msy} point estimate found from bootstrapping.

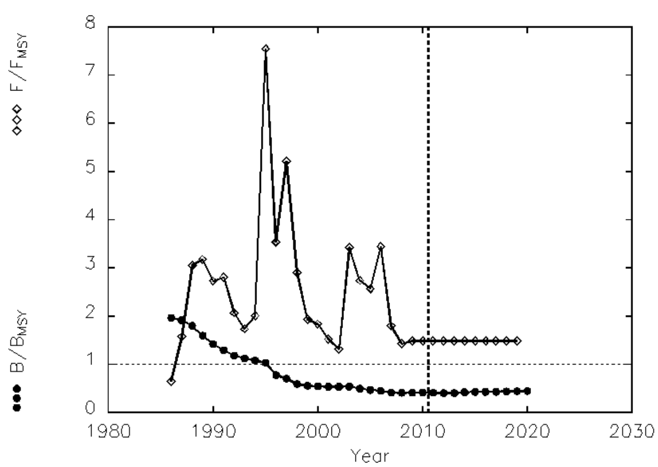


Figure 15. BSB projection: Fishing mortality held constant for 10 years relative to the F_{2009}/F_{msy} point estimate found from bootstrapping.

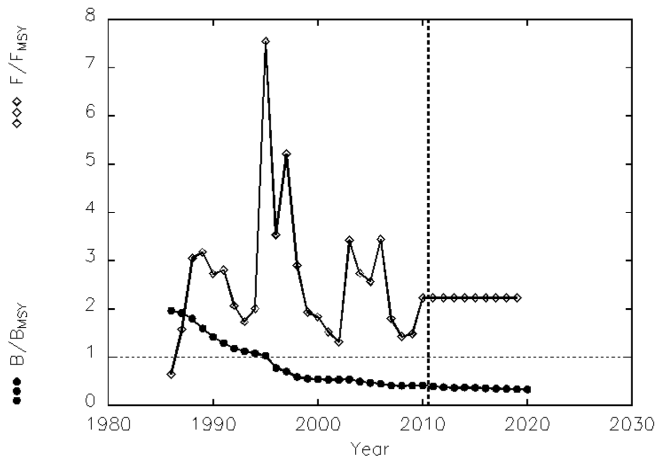


Figure 16. BSB projection: Fishing mortality increases by 150% for 10 years relative to the F_{2009}/F_{msy} point estimate found from bootstrapping.

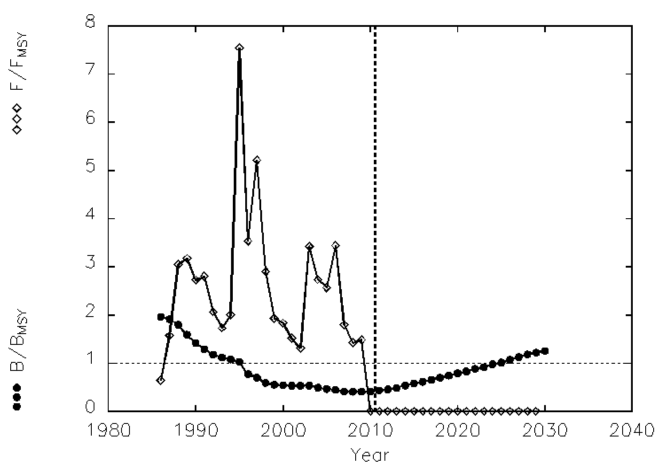


Figure 17. BSB projection: Fishing mortality eliminated for 20 years.

Under no projected circumstances can the B/B_{MSY} rise to 1.0 in the next ten years (Figures 18-24) based on projections with a proportional changes relative to the 2009 total yield. With the total elimination of yield, B/B_{MSY} will not reach 1.0 until 2025. Decreasing yield will cause the stock B/B_{MSY} to rise more quickly when compared to the same proportional decrease in fishing pressure.

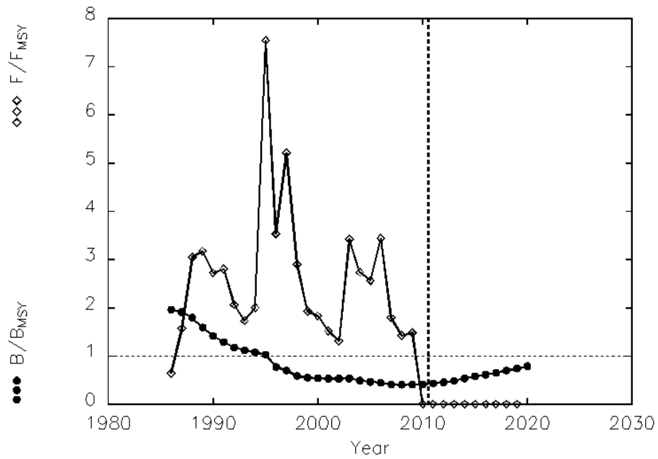


Figure 18. BSB projection: Yield eliminated for 10 years relative to the yield in 2009.

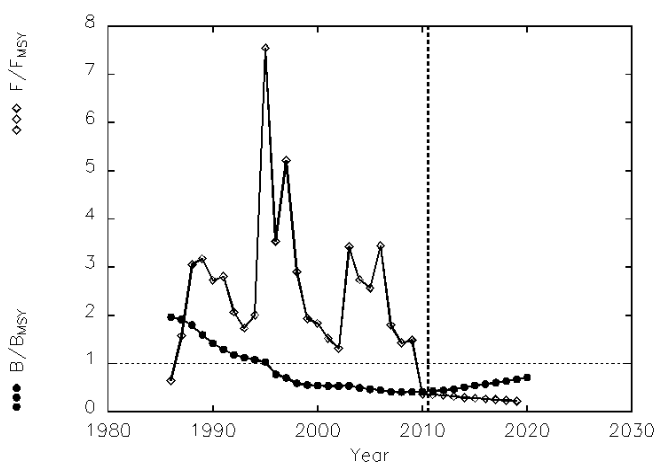


Figure 19. BSB projection: Yield decreased by 75% for 10 years relative to the yield in 2009.

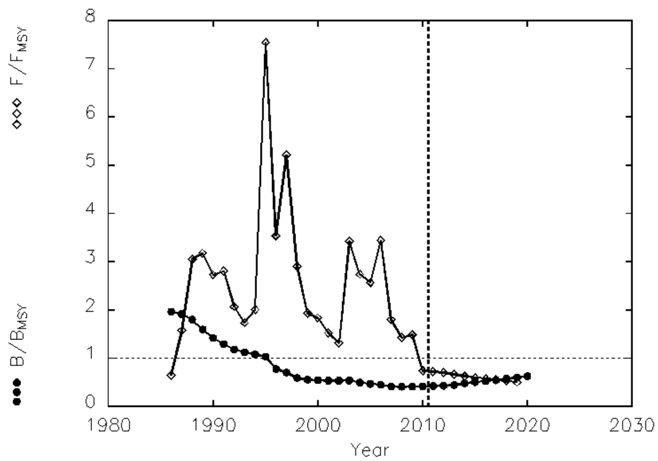


Figure 20. BSB projection: Yield decreased by 50% for 10 years relative to the yield in 2009.

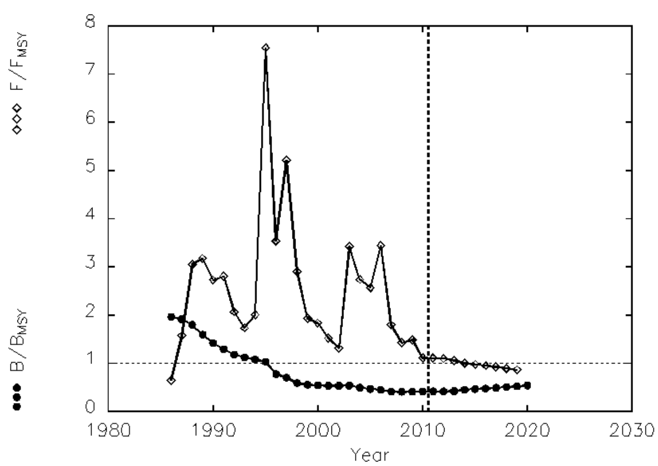


Figure 21. BSB projection: Yield decreased by 25% for 10 years relative to the yield in 2009.

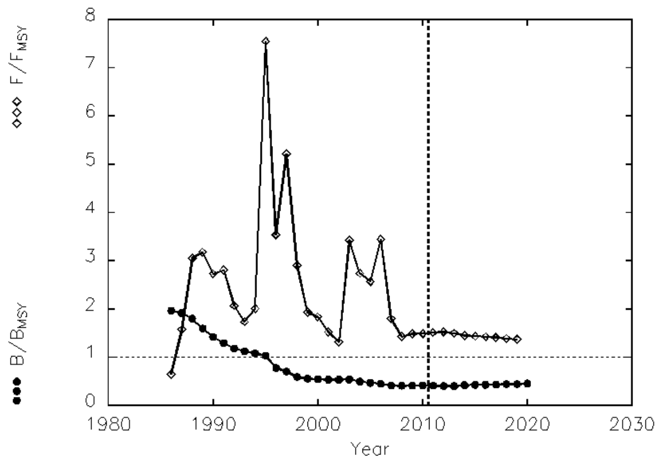


Figure 22. BSB projection: Yield held constant for 10 years relative to the yield in 2009.

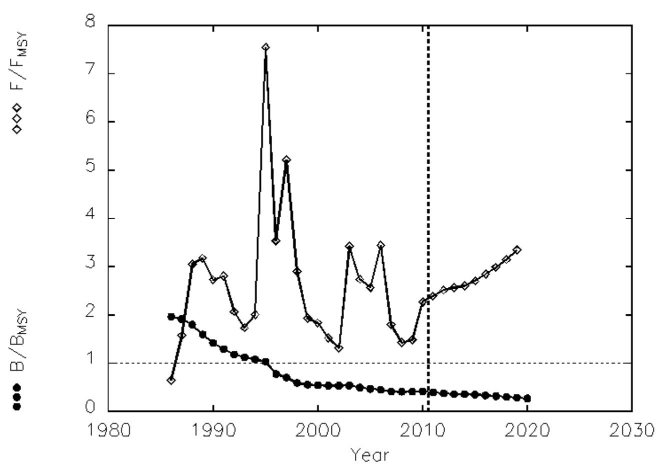


Figure 23. BSB projection: Yield increased by 150% for 10 years relative to the yield in 2009.

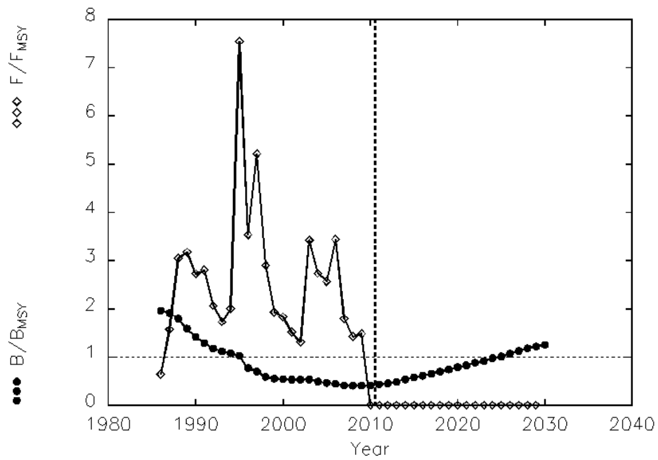


Figure 24. BSB projection: Yield eliminated for 20 years.

As can be seen in Figures 17 and 24, a total elimination of fishing mortality or yield on the stock will lead to the quickest upward biomass trend. ASPIC indicates that such a trend would have to be maintained until 2025 for the stock to reach B/B_{msy}=1.0, and that decreasing yield will have a quicker effect on the stock than decreasing fishing mortality.

Summary of Stock Status

Since neither catch curves nor yield-per-recruit analysis were viable options for this assessment (due to the variability in the calculated Z, issues with modal age selection, and the hermaphroditic nature of the species) the status of the stock was estimated primarily through a production model, fit with the ASPIC program. The overall result is that the south Atlantic bank sea bass stock currently has an F/F_{msy} value above 1.0 indicating the stock is likely undergoing overfishing, and a B/B_{msy} value below 0.5, which even under the most conservative estimates of MSST, indicates the stock is likely overfished. Although fishing pressure seems to have declined in recent years, this trend cannot necessarily guarantee that overfishing will end in the near future.

Research Needs

In order to comprehensively manage this stock, more research needs to be done into the life history and vital rates of the species. Research is needed which targets the hermaphroditic nature of this species, factors involved in sex transformation, and how this change could affect the spawning stock biomass for the population. In addition, more consistent and consecutive age structure data would increase the possibility of meaningful results from the catch curve analysis. Finally, bycatch and bait-use estimates for the commercial industry would increase the accuracy of the landings data.

Having additional data would allow for greater confidence in the assessment of the bank sea bass stock in the South Atlantic.

Exploratory Assessment of Gray Triggerfish, *Balistes capriscus*

picture from www.safmc.net

Abstract

The gray triggerfish, *Balistes capriscus*, is a reef fish found in the United States throughout the South Atlantic and Gulf of Mexico. The fish is caught both recreationally and commercially with landings over the past five years averaging almost 700,000 pounds. Despite its popularity, the gray triggerfish has not previously been assessed in the Atlantic off the southeastern U.S.

This assessment provides basic stock information through analysis of vital rates, catch curves, yield-per-recruit methods, and a surplus production model. The natural mortality rate, *M*, was calculated from multiple equations. Based on precedent in SEDAR assessments, the Hoenig mortality rate of 0.42 was used for further analysis. Catch curves, both regression and Chapman Robson, were used to estimate the total instantaneous mortality rate, *Z.* The total instantaneous mortality rate ranged from 0.64 to 1.15 based on the more accurate Chapman Robson curve (Dunn et al., 2002) using data from 1997. The yield-per-recruit model was very sensitive to natural mortality rate and fraction mature. The fishing mortality rate estimates were relatively uncertain due to the small and variable data set, which estimated the proxy for fishing mortality rate at maximum sustainable yield (via $F_{40\%}$ MSP) to be equal to 0.63. The surplus production model, calculated using ASPIC, was not able to fit the CPUE to a production curve, and produced no usable results.

Based on these results, the status of gray triggerfish in the south Atlantic is highly uncertain. Results are inconclusive regarding whether the stock is currently subject to overfishing. Additional research is needed in the area of maturity at age and gonad weight to produce a more accurate yield-per-recruit model. In addition, the uncertainty in the catch curve results, which provided a wide range of total mortality rate estimates, also strongly contributed to the uncertainty of this stock assessment.

Introduction

The gray triggerfish (*Balistes capriscus*) is caught both commercially and recreationally throughout the southeastern United States and is a favored restaurant catch. Traditionally, the fishery has been larger in the Gulf of Mexico, and the stock there was assessed twice, once by Valle et al. (2001) and once by Porch (2001). The Southeast Data, Assessment and Review (SEDAR) 9 assessment was conducted in 2006 for the Gulf of Mexico population. Many other studies have been conducted on the gray triggerfish in the Gulf of Mexico involving fish assemblages on artificial reefs (Turpin and Bortone 2002), effects of offshore drilling (Grizzle 1986), and marine reserve effectiveness in managing fisheries (Shipp 2003). Several studies off the coast of Brazil and Africa have also been conducted on gray triggerfish, but little research has been done on the species in the South Atlantic.

The gray triggerfish, identified *Balistes capriscus* by Gmelin (1789) is a reef fish approximately 44 cm in length (Figueriredo et al. 2002) with a world record weight of 13 pounds (Szedlmayer 1997). The fish is distributed throughout coastal waters of the Atlantic and the Gulf of Mexico in the United States (Robins et al. 1986). Gray triggerfish is found as far north as Nova Scotia and as far south as Argentina, with an additional population found off the African coast. Gray triggerfish habitat includes reef areas up to depths of 100m (Harmelin-Vivien and Quero 1990), possibly to 128m (Sedberry et al. 2006). Given these depths, gray triggerfish are likely to be vulnerable to barotrauma when caught fish are released, as the risk of this condition increases with depth (Williams 2007). While adult fish inhabit the reef environment, larval and juvenile fish are often found in the sargassum (Wells and Rooker 2004) and recruit to a reef at age one.

Gray triggerfish feed on reef invertebrates. Some of these organisms include bivalves and barnacles identified during a study on artificial reefs (Vose and Nelson 1994), as well as sand dollars (Kurz 1995) and lobsters (Weiss et al. 2008). Very little study has been conducted on the predators of gray triggerfish, possibly due to the effective defense presented by the fish's spine. Probable predators include sharks, tuna, dolphin fish, and sailfish (Bester 2010).

Evaluating the stock status of all species harvested within the South Atlantic has become increasingly important. In 2007, President Bush signed the Magnuson-Stevens Reauthorization Act which states that an annual catch limit must be put into place for all stocks undergoing overfishing by January 1, 2010, and all other stocks by 2011. Out of 72 stocks managed in the South Atlantic Fisheries Management Council's (SAFMC) snapper-grouper complex, only 12 have completed assessments that have been accepted through a peer-reviewed process (John Carmichael, SAFMC, personal communication). For stocks without assessments, a number of methods may be used, including multiplying a stock's average annual catch by a scalar less than one or using indicator stocks combined with stock complexes. This assessment, completed as part of the National Marine Fisheries Service (NMFS) – Virginia Tech (VT) Population Dynamics Recruiting Program, aims to provide the scientific information needed to create an acceptable biological catch (ABC) for the south Atlantic gray triggerfish stock. This assessment provides basic stock information through analysis of vital rates, catch curves, yield-per-recruit methods, and a surplus production model.

Management and Regulations

Gray triggerfish were added to the South Atlantic snapper grouper complex fishery management plan in 1997. In 1995, a NMFS report suggested that a 12" size limit would maintain the spawning stock, and the Florida Fish and Wildlife Conservation Commission adopted the limit. In 1999, the size limit went into effect for all federal waters (Hood 2005), including areas managed by both the South Atlantic Fishery Management Council and the Gulf of Mexico Fishery Management Council.

Stock Structure

Gray triggerfish is widely distributed throughout the Atlantic, including the US. Gray triggerfish are found from North Carolina to Florida in the Atlantic, and throughout the Gulf of Mexico in the United States. The Atlantic and Gulf populations are managed separately and mixing among the populations has not been documented. For the purpose of this assessment, the two populations are assumed to be separate, as assessments and management for the stock in the Gulf of Mexico are independent of those in the South Atlantic.

Data Sources

MARMAP Data

Marine Resources Monitoring, Assessment, and Prediction (MARMAP) is a fishery-independent data collection program that implements random sampling and uses a variety of gear types to obtain CPUE (catch-per-unit-effort), age, length, and weight data, along with other life history data such as maturity state. The program is funded by the National Marine Fisheries Service and implemented by the South Carolina Department of Natural Resources. Sampling occurs at 300 to 500 randomly selected live bottom sampling sites per year from Cape Fear, North Carolina, to Cape Canaveral, Florida. Life history data gathered from each specimen includes length (standard, total and fork) in millimeters, weight in grams, gonad weight in grams, spine annulus count, date caught, sex, and maturity. The dorsal spine was removed and sectioned for aging. The life history data gathered from the samples includes both fishery-independent and fishery-dependent samples. The use of snapper reel was the fishery-dependent gear, while chevron traps were the fisher-independent gear used to collect samples of gray triggerfish. Other data provided include trap soak time, longitude and latitude coordinates of trap set, depth and date of capture, and quantity of gray triggerfish caught.

Two fishery-independent indices were calculated using data from the chevron trap from 1990-2009: an abundance index and a biomass index (Figure 25). The abundance index was standardized based on the number of fish caught per trap hour, and the biomass index was standardized based on the weight of fish in grams caught per trap hour. The use of chevron traps by MARMAP began in 1988 in order to collect biological samples and to develop a fishery-independent index. Because collections using the chevron trap were inconsistent for the first two years due to personnel training with the new gear type, MARMAP scientists advised against using the corresponding data points in further analysis. Since 1988, only chevron traps have been used in index calculations to avoid inconsistencies in gear type.

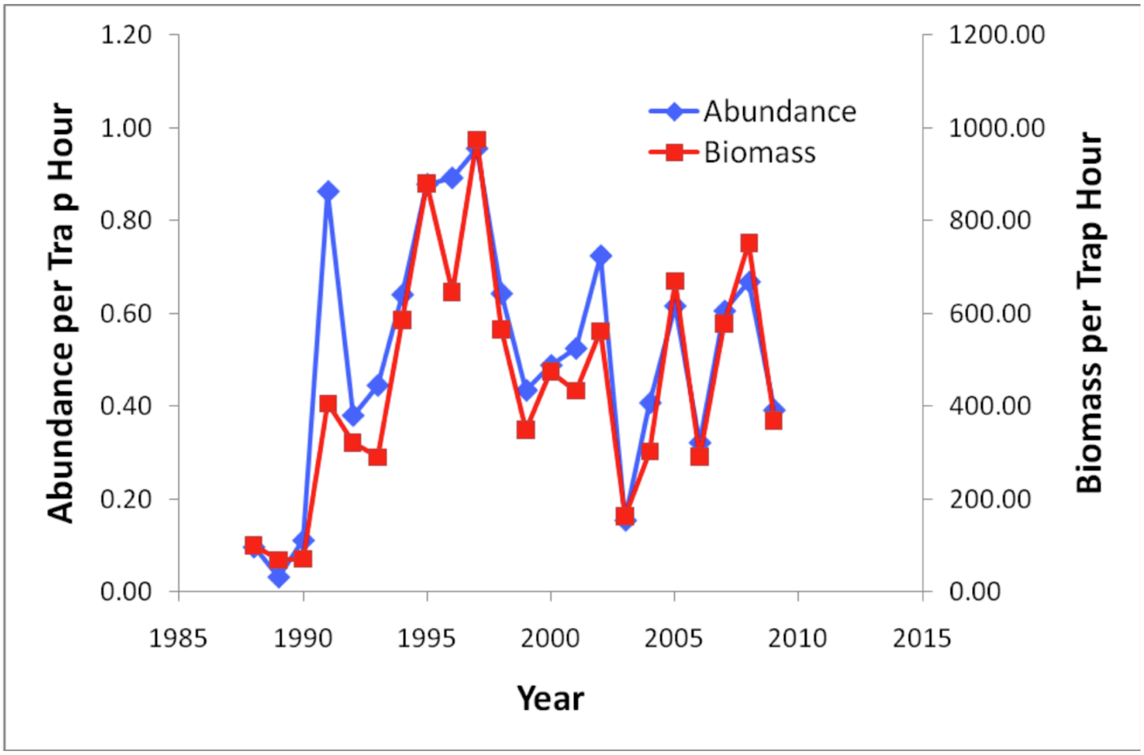


Figure 25. GT: MARMAP abundance and biomass indices calculated using data from chevron traps from 1990 to 2009.

These two indices, as expected, have a similar pattern. The trend in catch per unit effort over time is rather constant during much of the time series.

Headboat Data

Headboats are for-hire fishing vessels on which individual anglers pay fees. Data were collected from logbooks under the National Marine Fisheries Service Headboat Logbook Program, which requires headboat captains to record data in order to maintain boat permits. Information includes catch composition, number of fish and species harvested, bycatch, number of anglers, trip type, and location fished. This information is validated by state and federal cooperative headboat sampling programs, which also collect and provide life history data.

A headboat CPUE index was compiled and provided by Dr. Amy Schueller of the Southeast Fisheries Science Center's Beaufort Laboratory. The index was calculated with a delta-glm using a lognormal distribution and units were in number of fish per angler hour (Figure 26). Total effort was estimated using a method described in Stephens and MacCall (2004). Headboat landings were provided to Dr. Jim Berkson (NMFS RTR Unit, Blacksburg, VA) and included in the overall total landings data.

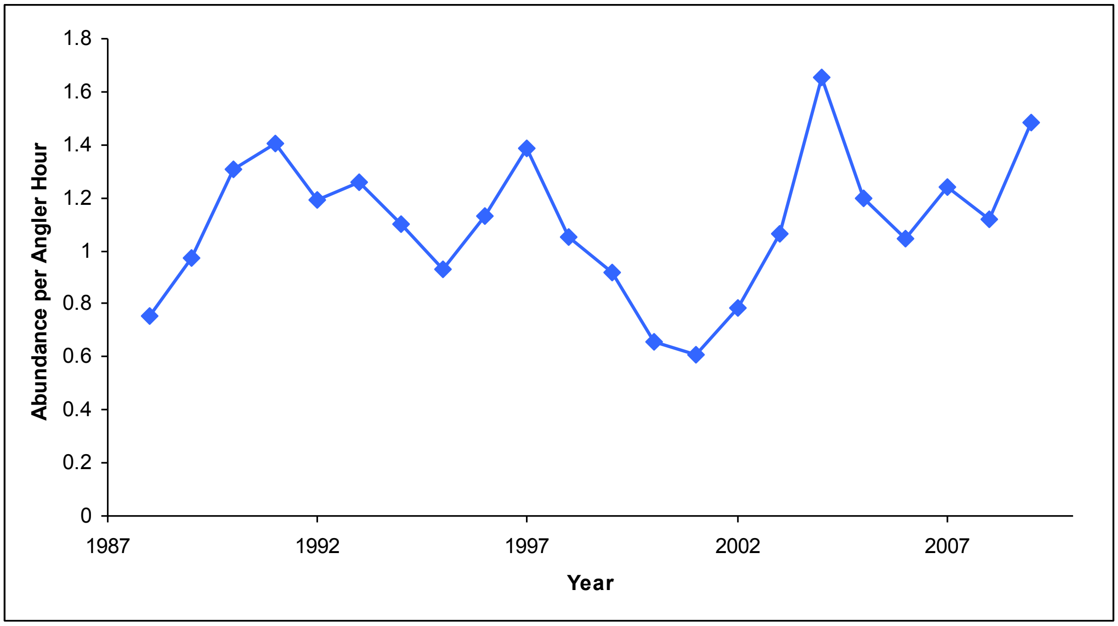


Figure 26. GT: Headboat abundance index estimated from 1986-2009.

Compared to the fishery-independent index based on abundance, the two indices show a similar pattern from the mid-1990s through 2009.

MRFSS Data

The Marine Recreational Fishing Statistics Survey (MRFSS), run by NMFS, uses telephone surveys to estimate recreational fishing effort. Recreational fishermen are also surveyed at docks and fishing locations to estimate recreational catch. The two surveys are combined to produce annual estimates of catch in pounds, which were provided to Dr. Berkson for the years 1996-2008 by the Southeast Fisheries Science Center's Miami Lab. These landings were included in the overall total landings data.

Commercial Data

Commercial data were collected on both the state and federal levels. Although data collection varies by state, common methods include the submission of trip-tickets, landings weight reports from seafood dealers, ship logbooks, and sampling of catches conducted both on ships and at docks. Historically almost all data came from seafood dealerships but in recent years there has been a shift towards mandatory trip-ticket reporting (NMFS 2007). Commercial landings data were provided by the SEFSC's Miami laboratory to Dr. Berkson. These data were not provided to the analysts, except in aggregated form, to ensure confidentiality.

Commercial discards for the years 1993-2009 were calculated by the SEFSC and provided to Dr. Berkson, but they were received after the completion of this assessment. Discards were provided in numbers of fish with no agreed upon method available for converting to weight. Point estimates for the numbers of discards per year averaged 4,181 fish and ranged from a low of 1,053 fish in 2006 to a high of 6,940 fish in 2002. These values were not incorporated into the total catch numbers below because of the problems described.

Total Catch Data

Total catch data from 1986 to 2009, combining commercial, recreational, and headboat catch, as described above, were provided by Dr. Jim Berkson (NMFS RTR Unit, Blacksburg, VA) and were not broken down due to confidentiality issues relating to commercial data. Total landings show two major increases through time, along with a decline from 1997 through 2000 (Figure 27). Overall, from 1988 through 2009, no trend is apparent for the total landings time series.

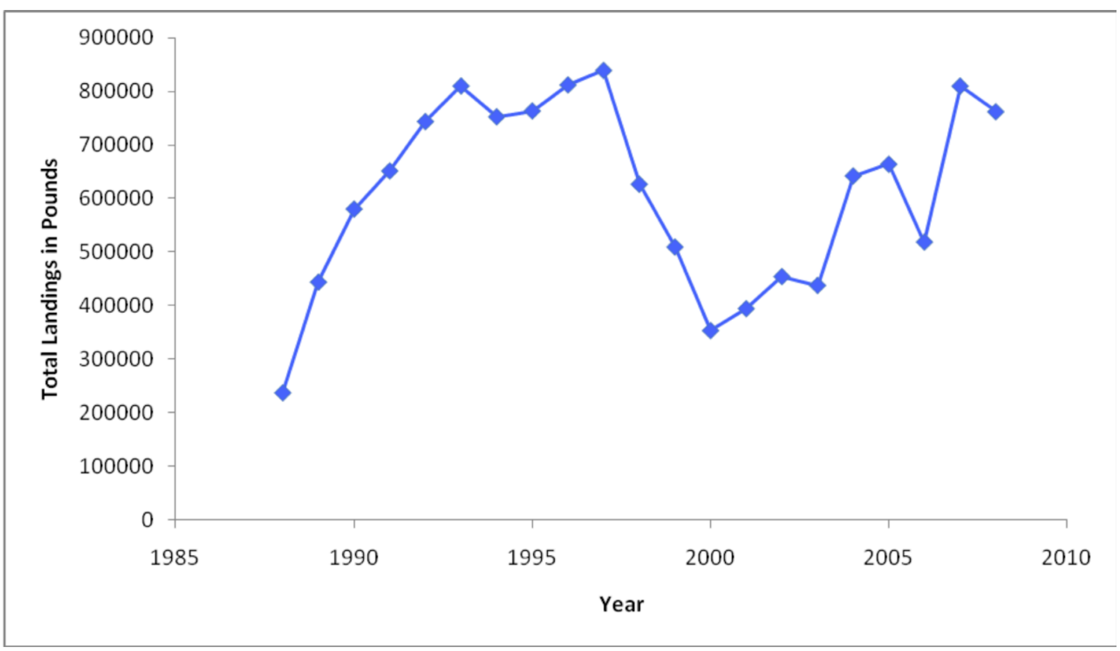


Figure 27. GT: Total catch in pounds from 1988-2009, which includes commercial, recreational, and headboat catches.

Vital Rates

Growth

Age and length data for 2,262 gray triggerfish, collected by fishery-independent and fishery-dependent methods, were provided by MARMAP. Total length, standard length, fork length, weight, and annuli count were provided for gray triggerfish. The annuli count is the number of annuli marks on the dorsal spine of the gray triggerfish. Dorsal spines were sectioned and interpreted, rather than providing an age calculated from an otolith. A minimum length limit of 12 inches was enacted in 1995 for commercial and recreational catch. With a minimum size requirement in place, the harvested gray triggerfish from fishery-dependent sources were expected to not be a true representation of the population and would skew interpretation of the data. For this reason the catch at age of only fishery-dependent data for years 1995 and later were removed for the estimation of the growth function. Fishery-independent data for these years were still used due to their ability to collect samples of all lengths. A von Bertlanffy (1938) growth function (Equation 6)

$$L_t = L_\infty (1 - e^{(-K(t-t_0))}) \qquad \text{(Equation 6)}$$

was fit to the length-at-age data for the combined 1,676 filtered fishery-independent and fishery-dependent gray triggerfish data points provided by MARMAP. The von Bertalanffy growth curve was fit using least sum of squared residuals from each length and age data point. Length-at-age of very young fish was found to be very sparse, so the theoretical age at TL equal to 0, t_0, was constrained to be between 0 and -1. The resulting growth function is shown in Equation 7.

$$L_t = 520.40 * \left(1 - e^{(-0.25(t+1))}\right) \qquad \text{(Equation 7)}$$

The von Bertalanffy growth function appears to describe the growth of gray triggerfish well with reasonable parameter estimates (Figure 28).

A von Bertalanffy weight-at-age growth curve (Equation 8) was fit to the weight in grams and count of annuli for the combined 1,687 filtered fishery-dependent and fishery-independent gray triggerfish data points provided by MARMAP.

$$W_t = W_\infty \left(1 - e^{-K(t-t_0)}\right)^b \qquad \text{(Equation 8)}$$

The weight data for younger fish was found to be insufficient, thus the theoretical age at weight 0 in grams, t_0, was constrained between 0 and -1. The resulting growth function is shown in Equation 9.

$$W_t = 2189.30\left(1 - e^{-0.24(t+1)}\right)^{2.68} \qquad \text{(Equation 9)}$$

The von Bertalanffy growth function fits the raw data with reasonable estimates of parameters (Figure 29).

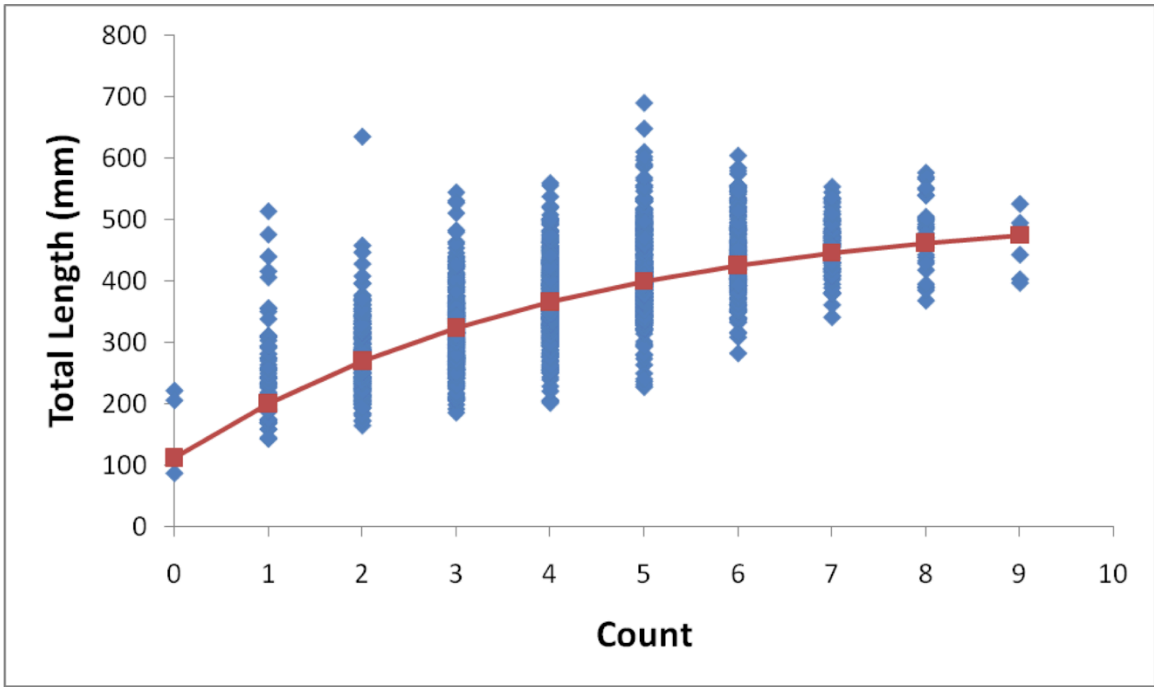


Figure 28. GT: Total length in millimeters plotted against annuli count of 1,676 gray triggerfish from MARMAP with a fitted von Bertalanffy growth equation.

Maturity and Fecundity

The gray triggerfish's spawning habits vary across its distribution temporally, but depth remains consistent at 20-75 m where nests are created in the sediment (Sedberry et al. 2006). Spawning season in the South Atlantic is usually from May through December, with peak spawning occurring from June through July. In Ghana, the peak spawning months are November and December (Ofori-Danson 1990), and for the Gulf of Mexico spawning occurs from June through September (Hood and Johnson 1997).

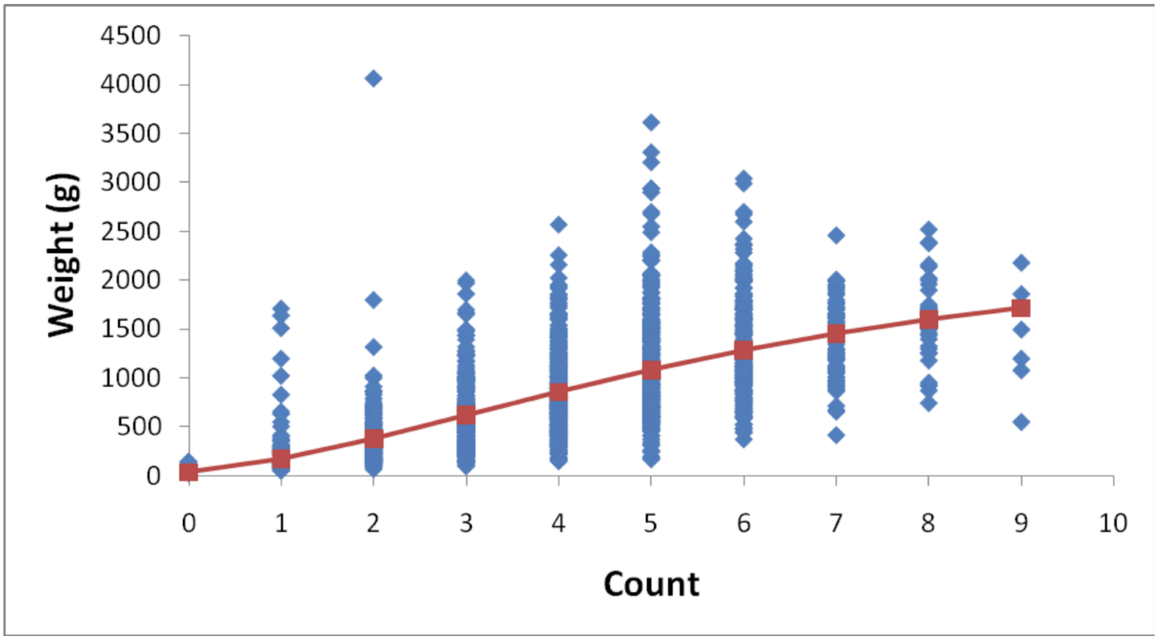


Figure 29. GT: The estimated von Bertalanffy growth function fit to weight in grams and annuli count of 1,687 gray triggerfish from MARMAP.

First time spawners measured around 14 cm and approximately 50-70g in Ghana (Ofori-Danson 1990), but variation is likely between fish found in Ghana and those occurring in the United States. A study done in the Gulf of Mexico by Hood and Johnson (1997) produced inconclusive results on the size and age of maturity due to samples only being collected by the recreational and commercial fisheries. No immature males and very few immature females were sampled; therefore no estimates of 50% maturity in males or females were produced. The study showed that 87.5% of females were mature at age one and only mature males were sampled. These results of high maturity at young age are likely due to skewed fishery-dependent sampling that removes the largest individuals from the population which are more likely to be mature than the smaller individuals of the same age. Fecundity, like maturity, is scarcely studied and understood in gray triggerfish. A study by Simmons (2008) found the mean clutch contains 772,415 eggs.

The weight of gonads in grams and annuli counts were provided for 302 fish from MARMAP sampled using the chevron trap during 1996 and 1997. These data were used to find the average weight of gonads at ages three through seven. An age-specific estimate of gonad weight was desired for ages one through 10; therefore a linear regression and a logarithmic regression were fit to the mean gonad weight at age to estimate the unknown weights. The logarithmic fit was thought to be an underestimation of the gonad weight at ages above 7 because of the large variability seen within the samples collected. Therefore, the linear predictions of gonad-weight-at-age were used in further analysis (Figure 30).

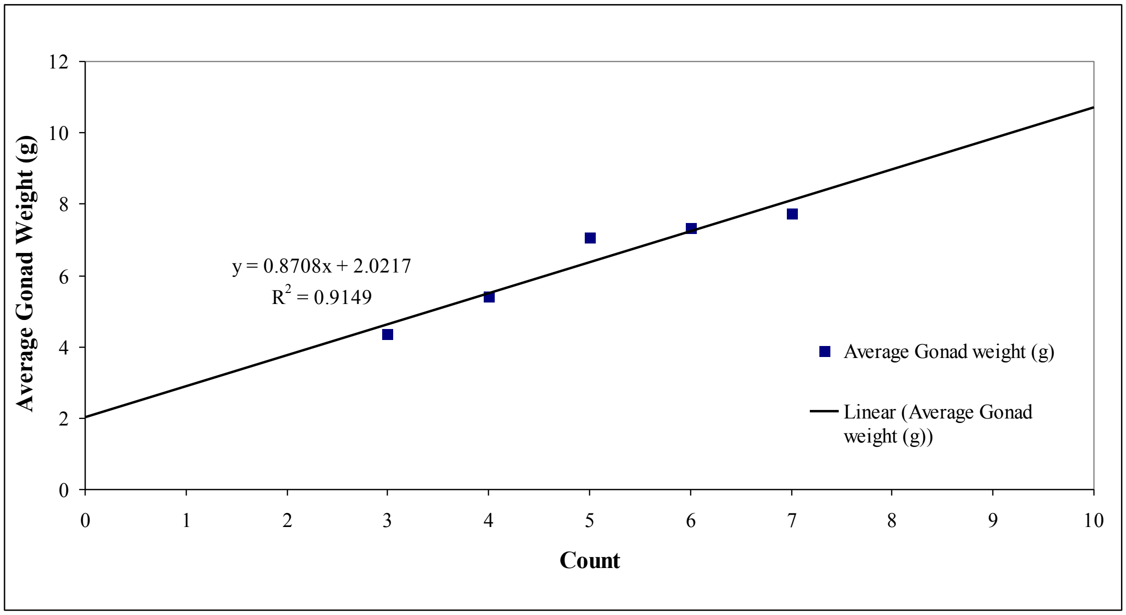


Figure 30. GT: Average gonad weight at age fit to a linear regression.

Natural Mortality

The natural mortality rate was estimated by several different methods (Table 10). Each method uses parameters such as estimated values from the von Bertalanffy growth curve (K=0.253, *Linf*=520.4), the maximum observed age (t_{max}=10), the age when half of the fish are at maturity (a_m=1; Hood and Johnson 1997), water temperature (T, °C), and weight at age(W_a, grams) to approximate the natural mortality rate (Table 10). The maximum age was based upon the maximum count provided by MARMAP aging. One website, www.fishbase.org, listed a maximum age of 13, but the reference could not be verified. The Pauly mortality rate is calculated for both 15°C and 20°C due to the range of observed temperatures. These estimates were suggested based on a stock assessment for similar reef species as suggested by Dr. Erik Williams (NMFS Beaufort Lab, personal communication). Finally, the weight at age was calculated from MARMAP life history data as well as the von Bertalanffy weight equation (Equation 9).

Estimates of natural mortality rate have been calculated for gray triggerfish in the past, but these estimates have been done for areas other than the South Atlantic. The Lorenzen mortality rates for gray triggerfish are shown in Figure 31. Estimates of the natural mortality rate using the Pauly equation (Table 10) ranged from 0.75 in the Caribbean (Garcia and Duarte 2005) to 0.52 in Ghana where the gray triggerfish fishery collapsed (Aggrey-Fynn, 2008). In the Gulf of Mexico, SEDAR 9 found the natural mortality to be 0.27 based on Hoenig's equation and a maximum age of 16.

Table 10. GT: Different methods for estimating the natural mortality rate, *M*.

(The parameters *K* and L_{iinf} are from the von Bertalanffy growth curve; a_m refers to the age at 50% maturity; t_{max} refers to the maximum age of the fish; T refers to the mean water temperature; and *W* refers to average weight-at-age.)

Author(s)	Equation	Estimate of M
Alverson and Carney (1975)	$M = \frac{3*k}{e^{0.38*t_{\max}*k} - 1}$	M=0.47
Beverton and Holt (1957)	$M = \frac{3*k}{e^{a_m*k} - 1}$	M=2.64
Hoenig (1983)	$M = e^{1.46-1.01*\ln(t_{\max})}$	M=0.42
Pauly (1979)	$M = e^{(-0.0152+0.6543*\ln(k)-0.279*\ln(L_{\inf})+0.4634*\ln(T)}$	M=0.47 for T=15, M=0.53 for T=20
Ralston and Williams (1989)	$M = 0.0189 + 2.06*k$	M=0.54
Lorenzen (1996)	$M = 3.69*W^{-0.305}$	see Figure 31

Following the precedent established in previous SEDARs, the Hoenig method of estimating natural mortality was adopted, and its resulting estimate of $M = 0.42$ yr^{-1} was used in further analysis.

Analyses

Catch Curves

Catch curve methods were used to estimate total instantaneous mortality, *Z*, for gray triggerfish. Both regression catch curve analysis and Chapman Robson catch curve analysis were used.

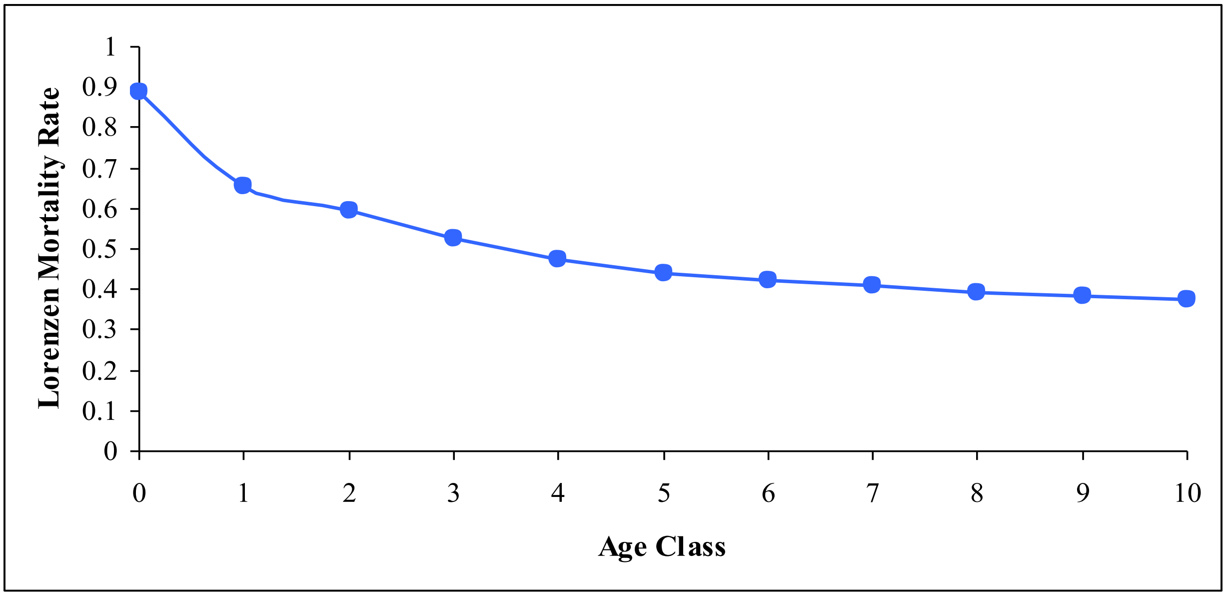


Figure 31. GT: Lorenzen natural mortality rates at age

Regression Catch Curve Analysis. Catch curves were used to estimate total instantaneous mortality, *Z*, for gray triggerfish. Regression catch curves fit a line to the frequency of fish caught in each age class, and the age classes included are the model age (the point at which fish are recruited to the fishery) and older. To do this, the curve is log transformed and a linear regression is fit to the data. The slope of this fit approximates *Z* (Equation 10) for the species, where *M* is the instantaneous natural mortality rate and *F* is the instantaneous fishing mortality rate.

$$Z = M + F \qquad \text{(Equation 10)}$$

The uncertainty in this analysis is due to a variety of assumptions. One assumption is that the natural mortality and fishing mortality rates remain constant over time (Haddon 2001). Sample distributions are assumed to remain constant throughout the time series, including constant recruitment and a stable age distribution. Finally, the catch curve analysis relies on correct estimation of age at full recruitment to the fishery (Shertzer et al. 2008). Due to these assumptions, analysis was performed for each year individually. In addition, *Z* values estimated by year were averaged across years to provide an average value. One additional method was used, which summed the age frequency data by age across years, providing the largest sample size on which to estimate a value for *Z*.

Age frequency data, though not consistently available, were provided for years 1992 through 1997 by MARMAP collected by snapper reel fishery-dependent methods and chevron trap fishery-independent methods (Tables 11 and 12). Regression catch curve analysis was done using the modal age and older and using the modal age plus one and older.

Table 11. GT: Age frequency from snapper reel (fishery-dependent) MARMAP collections for 1992, 1993, 1996, and 1997.

	0	1	2	3	4	5	6	7	8	9	10
1992	-	-	1	12	40	36	13	5	3	-	-
1993	-	-	-	2	15	14	9	5	1	-	-
1996	-	-	-	17	57	84	38	24	3	2	1
1997	-	-	-	5	75	132	83	44	8	1	-

Table 12. GT: Age frequency from chevron trap (fishery-independent) MARMAP collections for 1992-1995 and 1997.

	0	1	2	3	4	5	6	7	8	9	10
1992	2	36	47	34	27	24	7	-	-	-	-
1993	-	27	65	84	44	18	14	1	-	-	-
1994	-	2	18	55	95	50	32	10	9	1	-
1995	1	11	28	53	73	56	35	22	8	2	-
1997	-	4	24	68	152	143	96	35	10	3	-

Regression analysis total instantaneous mortality rates ranged from 0.42 to 1.50 (Tables 13-17). All regression analyses with full selectivity set as the modal plus one had instantaneous mortality rates higher than the regressions using modal age. For snapper reels the average total instantaneous mortality rate at modal age was 0.88 and at modal plus one was 1.04 (Table 17). The average estimated total instantaneous mortality rate for chevron traps at modal age was 0.75 and at modal plus one was 0.87 (Table 17).

Table 13. GT: Estimates of instantaneous total mortality rate using regression catch curve analysis on the snapper reel data for individual years using modal age and modal age plus one.

Year	Ages Used	Regression *Z*
1992	4:8	0.65
1992	5:8	0.84
1993	4:8	0.65
1993	5:8	0.85
1996	5:10	0.95
1996	6:10	0.98
1997	5:9	1.21
1997	6:9	1.50

Table 14. GT: Estimates of instantaneous total mortality rate using regression catch curve analysis on the combined snapper reel data by age across years using modal age and modal age plus one.

	Ages Used	Regression *Z*
Combined by age across years	5:10	1.18
	6:10	1.32

Table 15. GT: Estimates of instantaneous total mortality rate using regression catch curve analysis on the chevron trap data for individual years using modal age and modal age plus one.

Year	Ages Used	Regression *Z*
1992	2:6	0.42
1992	3:6	0.49
1993	3:7	1.00
1993	4:7	1.16
1994	4:9	0.83
1994	5:9	0.91
1995	4:9	0.69
1995	5:9	0.81
1997	4:9	0.82
1997	5:9	1.00

Table 16. GT: Estimates of instantaneous total mortality rate using regression catch curve analysis on the combined chevron trap data by age across years using modal age and modal age plus one.

	Ages Used	Regression *Z*
Combined by age across years	4:9	0.83
	5:9	0.97

Table 17. GT: Total instantaneous mortality rate calculated by averaging individual yearly estimates of total instantaneous mortality for snapper reels and chevron traps using the modal age and modal plus one.

Gear Type	Regression Modal	Regression Modal +1
Snapper reel Average	0.88	1.04
Chevron trap Average	0.75	0.87

To choose the best estimates of total instantaneous mortality rate many factors were taken into account including: sample sizes, the assumptions inherent in each natural mortality method, as well as limitations or biases due to gear type and the presence of a strong cohort in years 1992-1993. The year 1997 was thought to be the best estimate of total instantaneous mortality rate for chevron traps and snapper reel. The year 1997 had by far the most samples, with 883 samples total compared to the 1995 which placed second with 289 samples. These estimates ranged from 0.82 for chevron trap at modal age to 1.50 for snapper reel at modal age plus one. This range of total mortality rate is higher than those estimated for the Gulf of Mexico by Hood and Johnson (1997) of 0.742 to 0.836.

Chapman Robson Catch Curve. The second catch curve method used was the Chapman Robson (1960) catch curve. This catch curve has been found to be more accurate than the regression catch curve (Dunn et al. 2001). Rather than simply calculating a linear regression from the age distribution, the Chapman Robson method uses the minimum variance of a related survival parameter, *S* (Equation 11).

$$S = e^{-Z} \qquad \text{(Equation 11)}$$

In addition to the survival parameter, the mean age (*a*) is also used with the inverse of the sample size (1/*n*; Equation 12).

$$Z = \ln\left(\frac{1 + a - 1/n}{a}\right) \qquad \text{(Equation 12)}$$

Chapman Robson catch curve analysis was performed in R using the function chapman.robson which is part of the FSA package. This analysis was performed for the modal age and the modal plus one. Each estimate of total instantaneous mortality rate estimated by the regression analyses was also estimated using the Chapman Robson analysis.

The modal age was highly variable especially for the chevron trap in years 1992 through 1994. A strong cohort appeared at age 2 in 1992 and could be easily followed to ages 3 and 4 in years 1993 and 1994, respectively (Table 12).The strong cohort violates the assumption of constant recruitment over the years of the time series, thus these estimates were assumed to be inaccurate. This strong cohort was not observed in the same years for the fishery-dependent collections because this method only catches larger and older gray triggerfish. Therefore, the fishery-dependent snapper reel collection method does not appear to violate the assumption of constant recruitment over time for the years 1992 and 1993.

The age at full selectivity to fishery-dependent gear changed from age four to age five during the years 1992 to 1997. This small change may be due to an increase in sample size in 1997 and only a small difference in frequency between the modal age and plus one sample size in 1992. The age at full selectivity to the gear and the subsequent total instantaneous mortality rate estimates for the year 1997 are thought to be most accurate for the snapper reel gear because of the large sample size for this year.

Chapman Robson estimates of *Z* ranged from 0.55 for chevron trap at modal age in 1992 to 1.15 for snapper reel at modal age plus one in 1997 (Tables 18-22). The average total instantaneous morality rate for chevron traps at modal age was 0.67 and at modal age plus one was 0.80 (Table 22). The average total instantaneous mortality rate for snapper reel at modal age was 0.77 and at age plus one was 0.99 (Table 22). Chapman Robson analysis of the combined data by age across years for snapper reel at modal age was 0.88 and at modal plus one was 1.09. Combining data by age across years for chevron traps resulted in an estimated total instantaneous mortality rate at modal age of 0.68 and at modal plus one of 0.86 (Table 21).

Table 18. GT: Estimates of instantaneous total mortality rate using Chapman Robson catch curve analysis on the snapper reel data for individual years using modal age and modal age plus one.

Year	Ages Used	Chapman Robson *Z*
1992	4:8	0.73
1992	5:8	1.01
1993	4:8	0.61
1993	5:8	0.82
1996	5:10	0.87
1996	6:10	0.98
1997	5:9	0.85
1997	6:9	1.15

Table 19. GT: Estimates of instantaneous total mortality rate using Chapman Robson catch curve analysis on the combined snapper reel data by age across years using modal age and modal age plus one.

	Ages Used	Chapman Robson *Z*
Combined by age across years	5:10	0.88
	6:10	1.09

Table 20. GT: Estimates of instantaneous total mortality rate using Chapman Robson catch curve analysis on the chevron trap data for individual years using modal age and modal age plus one.

Year	Ages Used	Chapman Robson *Z*
1992	2:6	0.55
1992	3:6	0.67
1993	3:7	0.82
1993	4:7	0.94
1994	4:9	0.72
1994	5:9	0.80
1995	4:9	0.61
1995	5:9	0.74
1997	4:9	0.64
1997	5:9	0.86

Table 21. GT: Estimates of instantaneous total mortality rate using Chapman Robson catch curve analysis on the combined chevron trap data by age across years using modal age and modal age plus one.

Year	Ages Used	Chapman Robson *Z*
Combined by age across years	4:9	0.68
	5:9	0.86

Table 22. GT: Total mortality rate calculated by averaging individual years' estimates of Chapman Robson catch curve analysis at modal age and modal plus one for chevron traps and snapper reel.

Gear Type	Chapman Robson Modal	Chapman Robson Modal +1
Snapper reel Average	0.77	0.99
Chevron trap Average	0.67	0.80

Total instantaneous mortality rate estimates for snapper reel data were often much higher than those for chevron traps, likely due to a difference in selectivity of the two gear types (Figures 32, 33 and 34). Due to the fishery-dependent nature of the use of snapper reel gear, it is likely the fishermen attempt to catch the largest gray triggerfish. As a result the age at full selectivity to the gear type is slightly higher than the chevron traps which appear to include more younger fish in the samples. Because the fishery-dependent gear catches older fish at a higher frequency, the catch curve becomes steeper and results in a higher total instantaneous mortality rate estimate. This higher estimate of Z is likely due to a higher susceptibility to fishing gear and fisherman preference for larger samples and therefore a higher F.

Similar to the regression analysis, the Chapman Robson analysis estimates with full selectivity at mode plus one were higher than estimates of full selection at the modal age (Figures 32, 33 and 34). The total instantaneous mortality rate estimates by the Chapman Robson analysis were lower than the regression analysis for all years except 1992 for both fishery-dependent snapper reel and fishery-independent chevron traps (Figures 32 and 33).

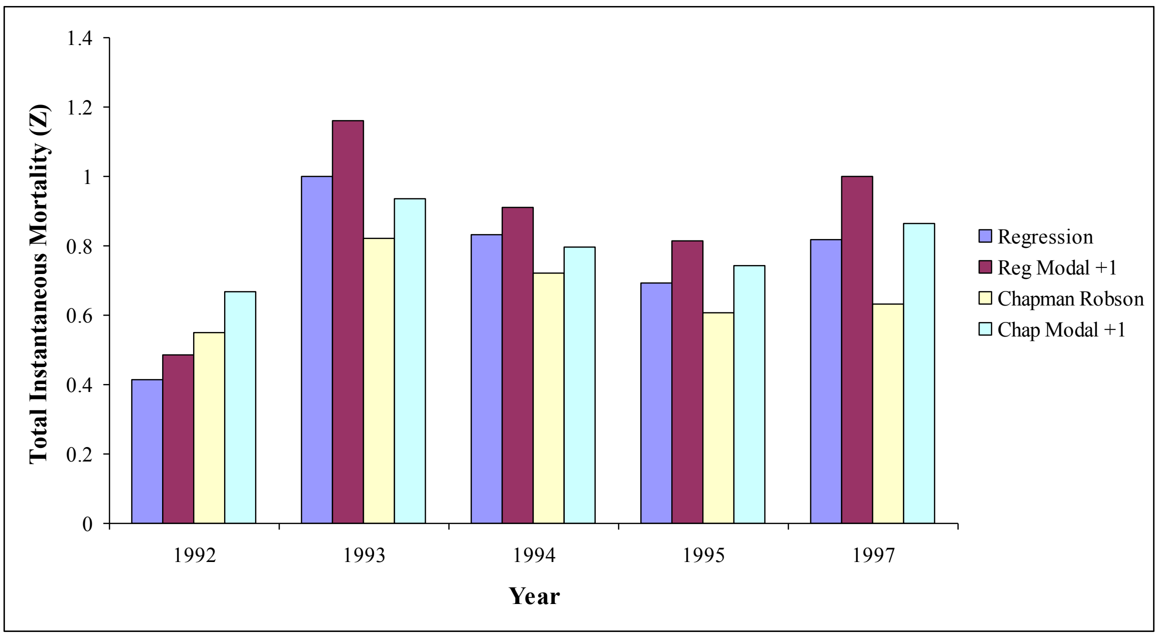


Figure 32. GT: Estimates of total instantaneous mortality rate for chevron traps using regression catch curve analysis and Chapman Robson catch curve analysis.

(Regression analysis at modal age (Regression) and at the age plus one (Reg Modal +1) are presented. Chapman Robson analysis using modal age (Chapman Robson) and at the modal age plus one (Chap Modal +1) are presented.)

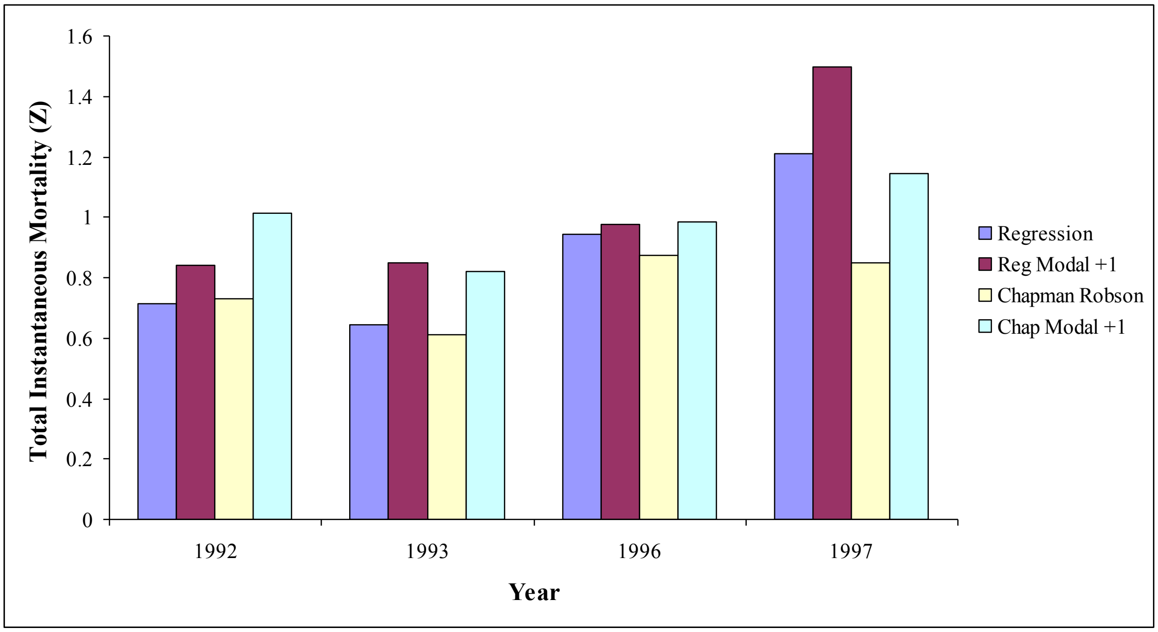


Figure 33. GT: Estimates of total instantaneous mortality rate for snapper reel using regression catch curve analysis and Chapman Robson catch curve analysis.

(Regression analysis at modal age as fully selected (Regression) and at the age plus one (Reg Modal +1) are presented. Chapman Robson analysis at modal age at fully selected (Chapman Robson) and at the age plus one (Chap Modal +1) are presented.)

The 1997 estimates of *Z* were again considered to be the best estimates for both gear types. Chevron trap at modal age gave an estimate of 0.64 and at modal age plus one of 0.86 (Table 20). Snapper reel gave estimates of *Z* as 0.85 at modal age and 1.15 at modal age plus one (Table 18). Our estimated range (0.64-1.15) is larger than the range estimated by Hood and Johnson (1997), which was 0.742-0.836, but does overlap the range of Hood and Johnson (1997). If the average of the years for both gear types separately is used as the estimate of the total instantaneous mortality rate then the range tightens to 0.67-0.99 (Table 22). This average incorporates estimates of *Z* that are inaccurate due to assumption violations and therefore the average is inaccurate. Consequently, the broad range estimated by 1997 is considered the most accurate.

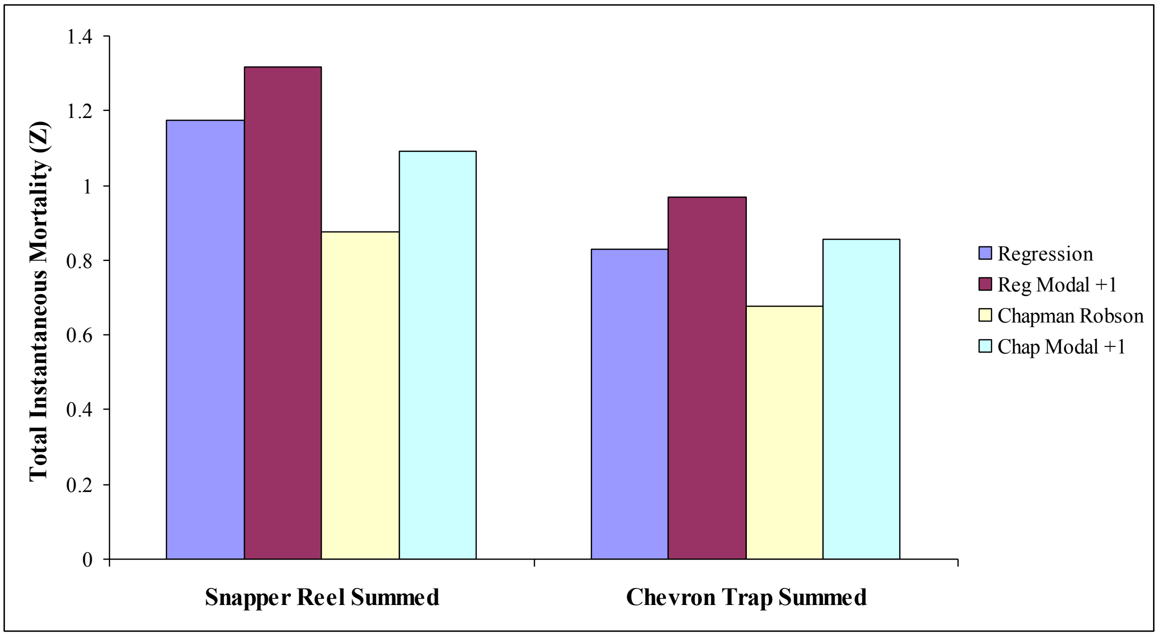


Figure 34. GT: Estimates of total instantaneous mortality rate for snapper reel and chevron trap using data combined by age across years by means of regression catch curve analysis and Chapman Robson catch curve analysis.

(Regression analysis at modal age as fully selected (Regression) and at the age plus one (Reg Modal +1) are presented. Chapman Robson analysis at modal age at fully selected (Chapman Robson) and at the age plus one (Chap Modal +1) are presented.)

Chapman Robson analyses have been shown to be more robust for estimating the total instantaneous mortality rate than regression analyses (Dunn et al. 2001). Therefore, the Chapman Robson estimated range of total instantaneous mortality rate of 0.64 to 1.15 is likely the most accurate for gray triggerfish in the South Atlantic. The estimates of regression catch curve analysis were used as an additional reference to form a more complete understanding of the total instantaneous mortality rate. It is important to note that these values are representative of 1997 and may not be representative of the present.

Yield-Per-Recruit Model

Yield-per-recruit (YPR) models approximate the potential yield at reference point fishing pressures for a population using life history parameters. The main goal of YPR analysis is to find the fishing conditions under which maximum yield for the fishery can be obtained. For the purposes of this model, yield refers the amount of biomass available for harvest. A single recruit is one fish that has become vulnerable to the fishery.

A YPR analysis was performed using the NOAA Fisheries Toolbox (NFT) YPR version 2.7 software (NFT 2008), which expands upon the basic model created by Thompson and Bell (1934). The basic inputs for the software are selectivity on fishing mortality, selectivity on natural mortality, stock weights, catch weights, spawning stock weights, the fraction mature at each age, an estimate of the instantaneous natural mortality rate, and percentage of instantaneous total mortality before spawning.

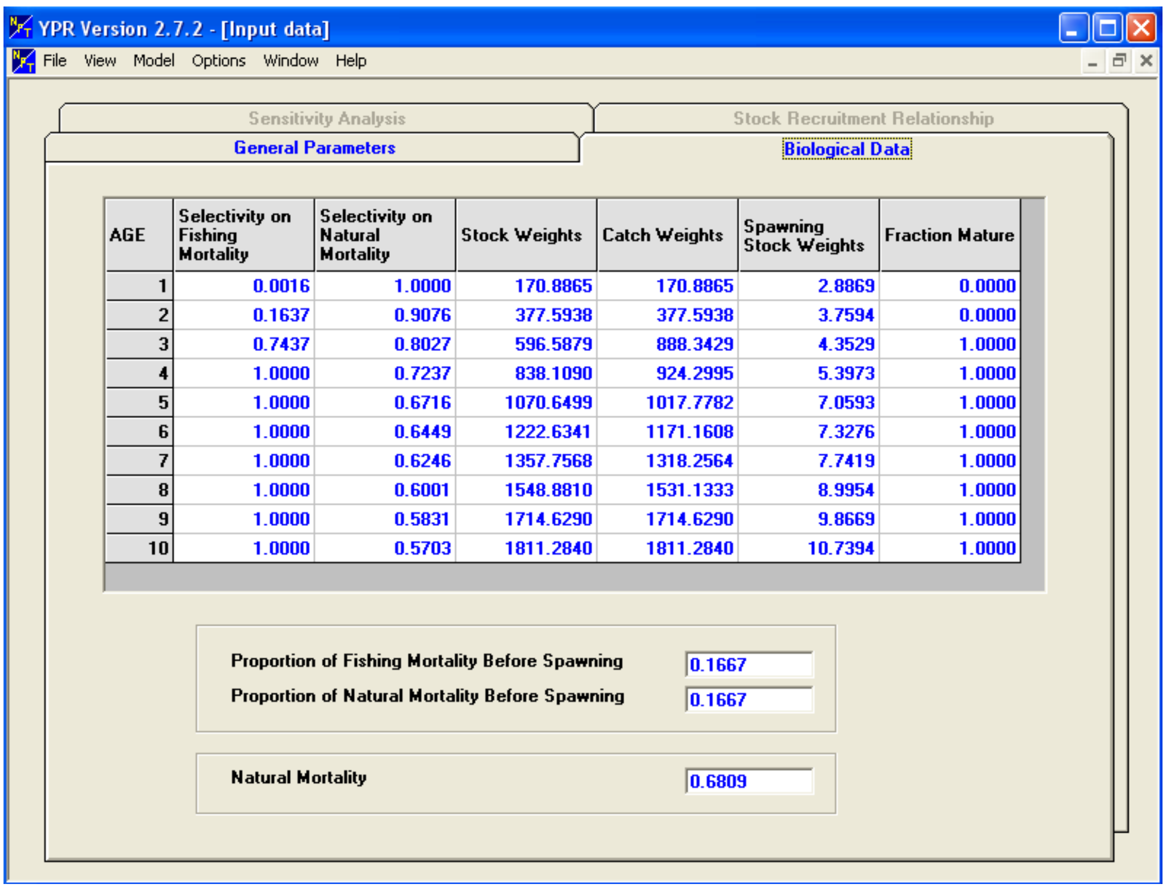
Three output values were of particular importance in this assessment: F_{Max}, $F_{0.1}$, and $F_{40\%}$. F_{Max} is the fishing mortality level that will theoretically maximize yield. F_{Max} does not give any notion of sustainability; in many fisheries, exploitation at F_{Max} would lead to population decline. $F_{0.1}$, the fishing mortality at which the slope of the yield-per-recruit curve is one-tenth of the slope at the origin, is a more conservative alternative to F_{Max}. The fishing mortality rate associated with $F_{0.1}$ will thus always be lower than that for F_{Max}, though the resultant yield is only slightly less. However, as with F_{Max}, continued fishing at $F_{0.1}$ may be unsustainable (Haddon, 2001). Finally, $F_{40\%}$ is the fishing mortality that corresponds to a spawning potential ratio (SPR) of 0.4. The SPR for a given fishing mortality is the spawning stock biomass per recruit (SSB/R) at that fishing mortality divided by the SSB/R at F = 0. An SPR of 0.4 is generally considered to be a sustainable fishing pressure for species with life histories similar to gray triggerfish (Dr. Erik Williams, NMFS Beaufort Lab, personal communication).

One important assumption of the YPR model is that results are accurate only once the population has reached an age-structured equilibrium. This is rarely true, so caution must be taken in accepting conclusions solely from yield-per-recruit output. Another important assumption is that the input parameters remain constant over time. Inputs, such as selectivity on fishing mortality and natural mortality, likely change considerably over time. Thus, again one must be careful in accepting output from the model without performing additional analyses and verifying the inputs and input sensitivities.

Base Run. To calculate selectivity on fishing mortality, fishery-dependent length data were used to identify the frequencies of age classes within the landings. The von Bertalanffy growth curve from the MARMAP data was used to estimate the length-at-age for ages 1 through 10. Full selectivity was determined by the age with the highest frequency and older. For the ages under full selectivity, the percent selectivity at age was calculated by dividing the frequency at catch per age by the highest frequency (Figure 35).

The selectivity on natural mortality was calculated using the Lorenzen equation (Figure 31). The single value for the natural mortality rate was scaled for use with the Lorenzen values.

The stock weights were the mean weight of each age calculated from the MARMAP database, except the weights for ages 1, 2, 9 and 10, which were calculated via a von Bertalanffy curve (Equation 7) because of small sample size. The catch weights were calculated similarly, only using MARMAP fishery-dependent data to include any differences between the average stock weight at age and average weight at age when captured. Spawning stock weights were calculated from average gonad weights for ages 3-7 from the MARMAP data. Others were extrapolated using a linear fit to the average gonad weights (Figure 30). The linear fit was used rather than the logarithmic fit because of literature values suggesting that 87.5% of 1 year olds were mature (Hood and Johnson, 1997). The fraction mature was chosen based on available data, suggesting fish become mature around age 2. This parameter is the most uncertain and sensitivity to this parameter will be explored in section 7.2.



AGE	Selectivity on Fishing Mortality	Selectivity on Natural Mortality	Stock Weights	Catch Weights	Spawning Stock Weights	Fraction Mature
1	0.0016	1.0000	170.8865	170.8865	2.8869	0.0000
2	0.1637	0.9076	377.5938	377.5938	3.7594	0.0000
3	0.7437	0.8027	596.5879	888.3429	4.3529	1.0000
4	1.0000	0.7237	838.1090	924.2995	5.3973	1.0000
5	1.0000	0.6716	1070.6499	1017.7782	7.0593	1.0000
6	1.0000	0.6449	1222.6341	1171.1608	7.3276	1.0000
7	1.0000	0.6246	1357.7568	1318.2564	7.7419	1.0000
8	1.0000	0.6001	1548.8810	1531.1333	8.9954	1.0000
9	1.0000	0.5831	1714.6290	1714.6290	9.8669	1.0000
10	1.0000	0.5703	1811.2840	1811.2840	10.7394	1.0000

Figure 35. GT: Screen shot of input parameters for base run of yield-per-recruit software.

The output of the model, shown in Table 23, show the two reference points, $F_{0.1}$ and $F_{40\%}$ under the conditions of the base run. Increased fishing increased the yield over all fishing mortality rates, thus F_{max} could not be determined (Figure 36).

Table 23. GT: Outputs of base run of yield-per-recruit model for the reference points $F_{0.1}$ and $F_{40\%}$.

Reference Point	F	Yield-per-recruit	SSB per Recruit	Total Biomass per Recruit
$F_{0.1}$	0.79	138.7	1.38	603.3
$F_{40\%}$	0.63	128.1	1.57	634.1

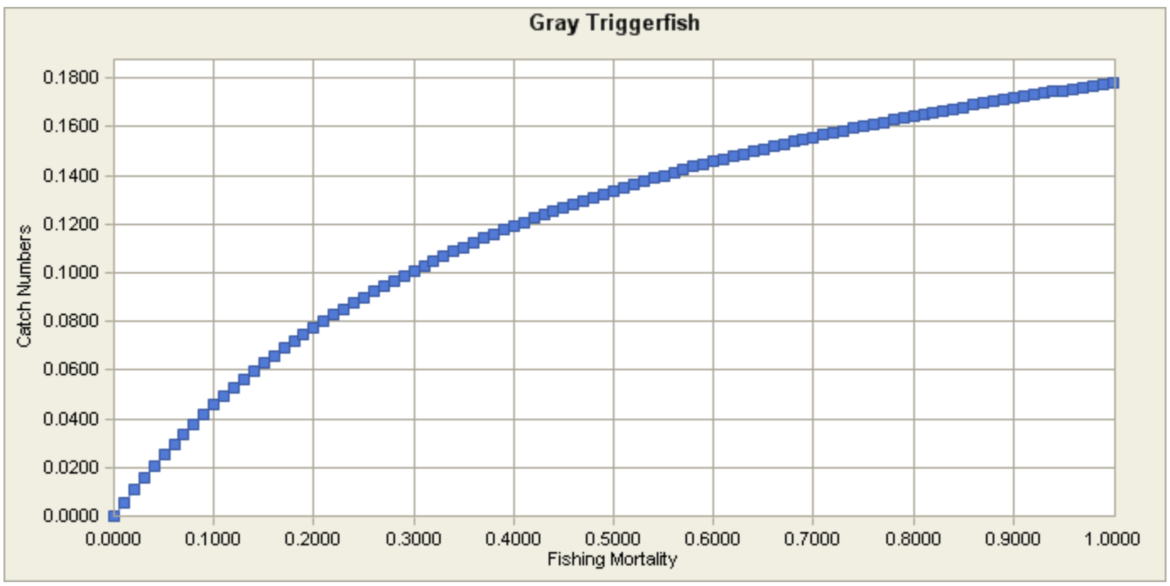


Figure 36. GT: Catch numbers under increasing fishing mortalities from the yield-per-recruit analysis.

The baseline model did not find a maximum fishing mortality rate, F_{max}. When using $F_{0.1}$ as a substitute for F_{max}, fishing mortality is 26% higher than that of $F_{40\%}$, the proxy for F_{MSY}. In comparison, the value of yield-per-recruit is only 8% higher. Because increasing the fishing mortality corresponds to a much smaller increase in the yield, choosing 0.63 as the fishing mortality rate seems to be a reasonable choice.

Sensitivity. The sensitivity of the yield-per-recruit model was analyzed in terms of each input variable. Outputs were most sensitive to the natural mortality rate and fraction mature (Tables 24 and 25).

Table 24. GT: Sensitivity of the yield-per-recruit model to the natural mortality rate.

Natural Mortality Rate	$F_{0.1}$	Yield-per-recruit at $F_{0.1}$	$F_{40\%}$	Yield-per-recruit at $F_{40\%}$
0.749	0.91	123.0	0.72	113.3
0.681	0.79	138.7	0.63	128.1
0.613	0.67	156.9	0.54	145.4

Altering the natural mortality rate by 10% produced some dramatic changes in reference points (Table 24). An increase of 10% to the natural mortality rate led to a 15% increase in $F_{0.1}$, an 11% decrease in yield-per recruit at $F_{0.1}$, a 15% increase in $F_{40\%}$ and a 12% decrease in yield-per-recruit at $F_{40\%}$. In contrast, lowering the natural mortality rate by 10% resulted in a 15% decrease in $F_{0.1}$, a 13% increase in yield-per recruit $F_{0.1}$, a 14% decrease in $F_{40\%}$ and a 14% increase in yield-per-recruit at $F_{40\%}$.

While the natural mortality rate was the most sensitive parameter, the value for fraction mature was also sensitive (Table 25). Because full maturity is reached by 3 years of age, most likely 2 years, the values for ages 1 and 2 were the only ones changed. Only the base run produced a value for $F_{40\%}$; other runs produced a value of "NA" meaning that no fishing mortality rate could force the population to 40% of the unexploited value. In terms of $F_{0.1}$, the model was not sensitive, as maturity had no effect on the maximum fishing effort. Changing the maturity did not change either the $F_{0.1}$ or YPR at $F_{0.1}$ values.

Table 25. GT: Sensitivity of fraction mature, where NA represents an output value where no fishing mortality rate can force the population to 40% of the unexploited value of SSB/R.

Age 1	Age 2	$F_{0.1}$	YPR at $F_{0.1}$	$F_{40\%}$	YPR at $F_{40\%}$
0	**0**	0.790	138.7	0.63	128.08
0	**1**	0.790	138.7	NA	NA
.875	**1**	0.790	138.7	NA	NA
.875	**.950**	0.790	138.7	NA	NA

Because of the large sensitivity to the natural mortality rate and fraction mature, estimating a value of F to serve as a proxy for F_{msy} using a yield-per-recruit model is difficult.

Surplus Production Model

The surplus production model can be an effective assessment tool for data-poor stocks, because they can supply reference points for management and do not require age-structured data. The surplus production model is used to estimate the biomass produced beyond replacement levels for a population, in other words, the biomass that can be harvested without depleting the population.

The logistic model, described by Schaefer (1954, 1957) allows the combination of many vital rates into a single equation (equation 13; Haddon 2001), where B_t is the biomass at time t, C_t is the catch at time t, r is the intrinsic population growth rate, and K is the carrying capacity.

$$B_{t+1} = B_t + r * B_t\left(1 - \frac{B_t}{K}\right) - C_t \qquad \text{(Equation 13)}$$

ASPIC is a modeling program that attempts to fit a non-equilibrium surplus production model to input data in order to understand stock status and evaluate the likely effects of alternative management actions in the future (Prager 1994). ASPIC estimates a fit to one or more CPUE indices. Initial guesses were made for maximum sustainable yield (*MSY*), carrying capacity (K), catchability coefficient (q) for each CPUE index, and the ratio of the starting biomass to carrying capacity (B_1/K). Input data included both the headboat and MARMAP chevron trap CPUE indices and total landings by year from 1990 to 2009. Based on these values, ASPIC attempted to fit a production curve where B_t is the biomass at time t, and K and r are parameters of the logistic growth equation: carrying capacity and intrinsic rate of population growth, respectively (Equation 14; Figure 37).

$$Yield = r * B_t\left(1 - \frac{B_t}{K}\right) \qquad \text{(Equation 14)}$$

ASPIC provided estimates of F/F_{msy} and B/B_{msy} in order to determine stock status and to project potential management actions into the future.

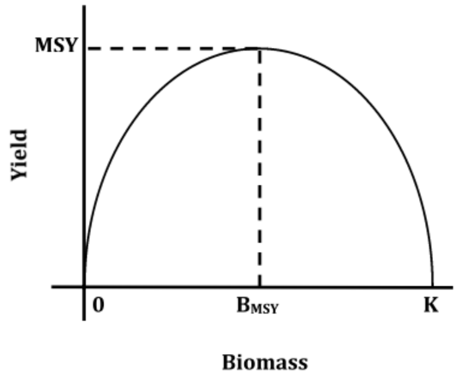


Figure 37. GT: Production curve described by Equation 13, where *MSY* is maximum sustainable yield, *K* is carrying capacity, and B_{MSY} is the biomass at maximum sustainable yield.

Initial runs failed to produce a usable fit. Error messages were unable to be resolved due to the relatively constant nature of the indices. The indices lacked values for large populations with essentially no harvest and for small population sizes where overharvesting has occurred. Therefore, a representative surplus production curve could not be fit to the data from which to create projections. The results from a sample run are shown in Figures 38-40. Because initial runs failed to produce usable results, combinations of initial guesses were fixed in order to attempt to get a useable fit. In addition, we ran the model with each CPUE index separately. These attempts to gain a usable outcome all failed. After consultation with Dr. Michael Prager (SEFSC – retired, personal communication), it was decided that the uninformative CPUE data was likely hindering the fit of a viable production curve.

Summary of Stock Status

As with many data-poor species, the status of south Atlantic gray triggerfish exhibits a great deal of uncertainty. The fishing mortality rate in 1997 was calculated by subtracting the Hoenig natural mortality rate (0.42) from the total mortality rate calculated from the catch curves (0.64 and 1.15). Based on these numbers, the estimated fishing mortality rate was between 0.22 and 0.73 at that time. This represents a wide range of values and may not be representative of current values.

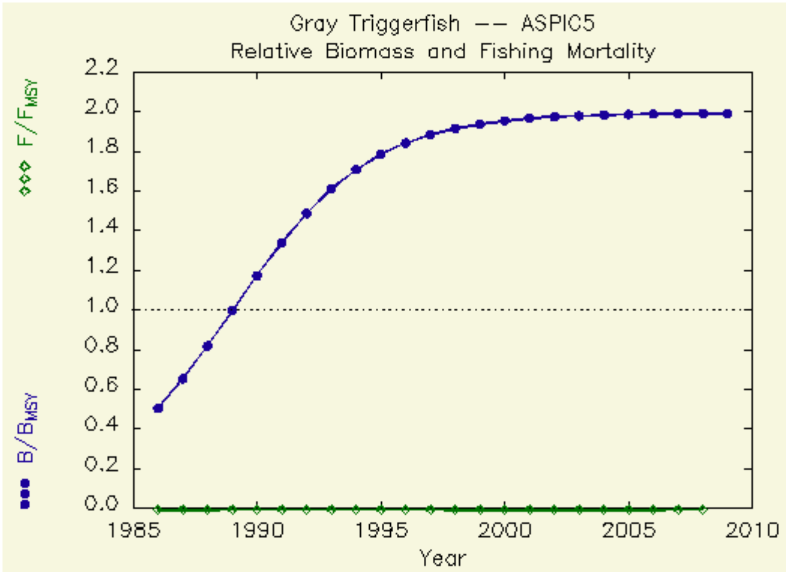


Figure 38. GT: Output values of B/B_{MSY} and F/F_{MSY} using ASPIC illustrating unreasonable results typically expected with uninformative data.

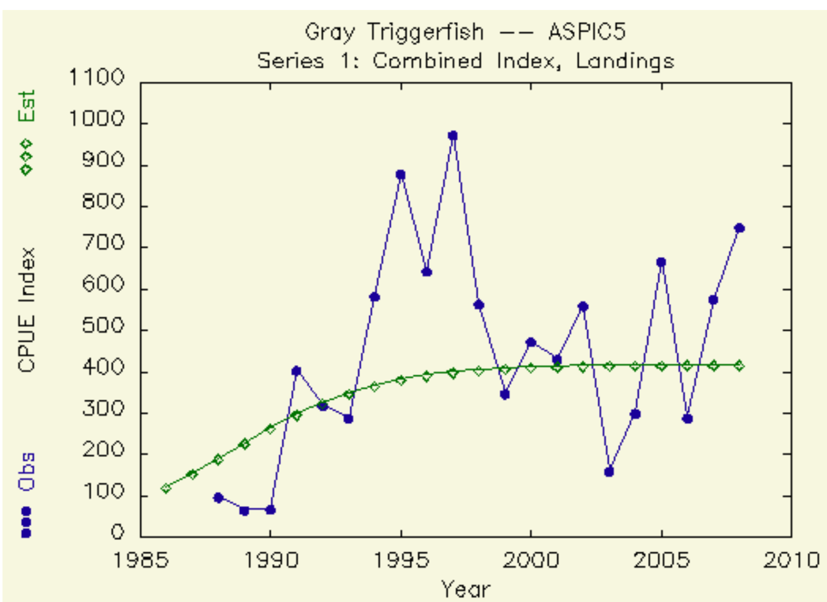


Figure 39. GT: Fit of ASPIC to the MARMAP CPUE index.

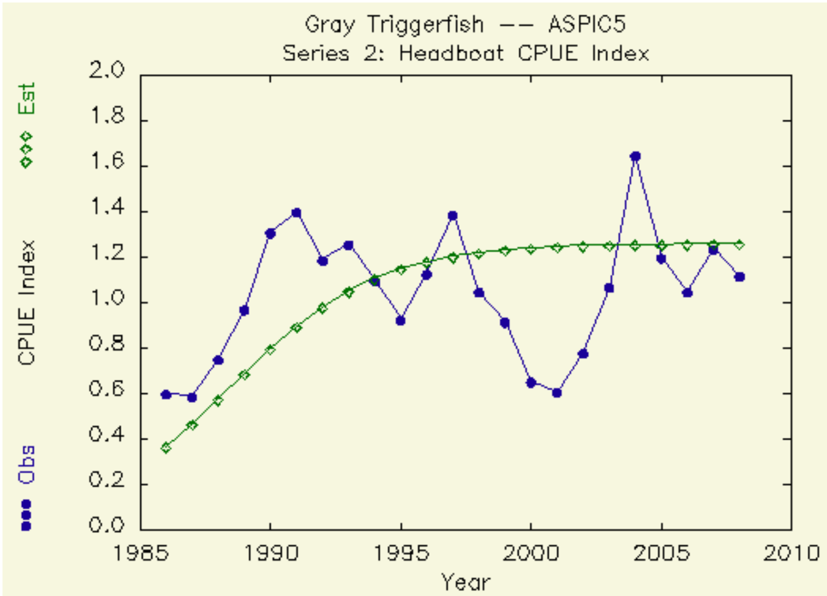


Figure 40. GT: Fit of ASPIC to the headboat CPUE index.

When comparing the lower bound of the of the fishing mortality rate estimates in 1997 (0.22) to the proxy for F_{MSY} ($F_{40\%}$) based on the yield-per-recruit model (0.63) it is possible that the fishing mortality rate at that time was sustainable and the population was not subject to overfishing. Based on the upper bound (0.73), however, it is also possible that the population was subject to overfishing. Due to the uncertainty of the input parameters regarding maturity rates and gonad weights of gray triggerfish, there is a great deal of uncertainty in not only the results of the catch curve analysis, but also the YPR analysis. Most importantly, the results from the catch curve analysis represent the mid to late 1990s and may or may not be representative of current conditions.

Unfortunately, the current status of gray triggerfish in the U.S. South Atlantic is inconclusive, given the limited and uninformative nature of the available data.

Research Needs

Further research is needed in three main areas. The first is updated age information. The aging procedure for gray triggerfish (spine annuli) is more time consuming and difficult than otoliths. Because of these difficulties and a greater time delay in age information, the newest age data is over 13 years old. Updated age frequency data may be beneficial to estimating current mortality rates.

Secondly, as a surplus production model is not a feasible method for analyzing this stock with the available CPUE indices, more descriptive CPUE indices must be made available. With indices that can fit a surplus production model, estimates of historic and current biomass, fishing mortality rate, *MSY*, F_{MSY} and carry capacity can be calculated. These estimates will provide a much clearer estimate of the status of gray triggerfish than currently available.

Finally, maturity data, including age of maturity and gonad weights will be very important in future evaluations of the stock status. The yield-per-recruit model was moderately sensitive to these when estimating $F_{40\%}$, which is the proxy used for fishing mortality at maximum sustainable yield. Further maturity data will help estimate a better value for the fishing mortality rate at the maximum sustainable yield.

Exploratory Assessment of the Sand Perch, *Diplectrum formosum*

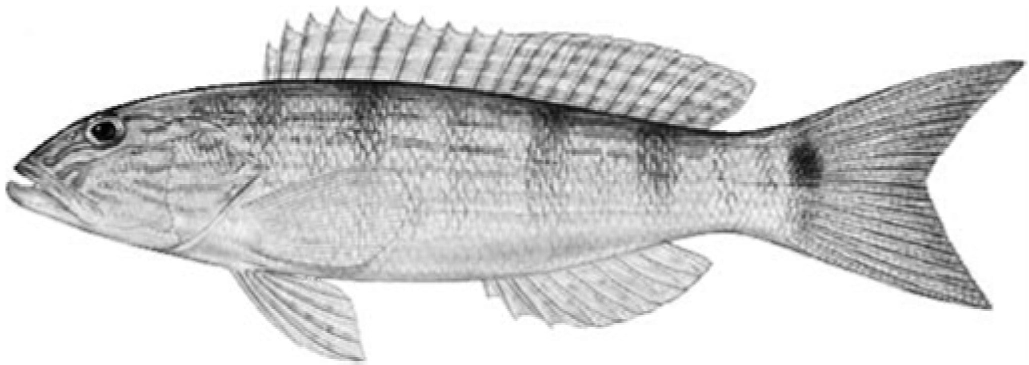


Image from www.floridasportfishing.com

Abstract

The sand perch *Diplectrum formosum* is a relatively small fish found in coastal waters from North Carolina to Uruguay, as well as in the Gulf of Mexico and the Caribbean Sea (Briggs 1958). Sand perch are synchronously hermaphroditic and are generally fully mature between ages two and three (Bortone 1971). Fecundity for sand perch is thought to be relatively high (Houde 1982) but was not used in any specific portion of this assessment. Often, sand perch are not a targeted species, though they appear in commercial bycatch, are sometimes used as bait fish, and are valued as a pan fish. The recreational sector generally comprises the majority of the fishery (Bortone 1977). The southern Atlantic population, from North Carolina to the Florida Keys, was assessed in this report.

The instantaneous natural mortality rate M for sand perch was estimated at approximately 0.53 and was estimated using the Hoenig (1983) method based on previous SEDAR assessments. Catch curve analyses were performed to arrive at an estimated range for the instantaneous total mortality rate Z (Z = 0.68 to 1.04), and a range for the instantaneous fishing rate F was derived from values of Z and M (F = 0.15 to 0.51).

Yield-per-recruit analysis was performed, using life history information and the calculated value of M, to approximate fishing pressures that would produce maximum yield (F_{Max}; in this case $F_{0.1}$ was used as a more conservative estimate of F_{MSY}) from the fishery and to estimate those that are likely to be sustainable (those below $F_{40\%}$). Sensitivity analyses were performed to investigate the effects of differences in input parameters; these analyses produced ranges for $F_{0.1}$ and $F_{40\%}$ that were generally above ranges for current estimated fishing pressures (as determined by catch curve analysis), suggesting that current fishing practices are under-utilizing the fishery and are also likely to be at sustainable levels.

Two types of abundance indices were available for surplus production modeling in this assessment; a fishery-independent CPUE index from MARMAP and a fishery-dependent headboat index (from the NMFS Beaufort, NC lab). The MARMAP index showed considerable noise but generally stable abundance over time. Two versions of the headboat index were provided; both versions showed some decline in abundance over time. However, because the indices showed little contrast in abundance over time, fitting a surplus production model (ASPIC) was not possible with the data available. As a result, discussion of the ASPIC work is included in this report but results were not considered viable.

Results of the catch curve analyses and the yield-per-recruit analyses, combined with analysis of available data and life history information, suggest that the current fishing pressures on sand perch are sustainable. However, this stock is data-poor; therefore, more complete data could yield a different conclusion of stock status. Suggestions for further research and data collection include more thorough fishery-

independent sampling (as well as aging and measurement), more complete catch and bycatch records, and more accurate information on vital rates.

Introduction

Evaluating the stock status of all species harvested within the South Atlantic has become increasingly important. In 2007, President Bush signed the Magnuson-Stevens Reauthorization Act which states that an annual catch limit must be put into place for all stocks undergoing overfishing by January 1, 2010, and all other stocks by 2011. Out of 72 stocks managed in the South Atlantic Fisheries Management Council's (SAFMC) snapper-grouper complex, only 12 have completed assessments that have been accepted through a peer-review process (John Carmichael, SAFMC, personal communication). For stocks without assessment, a variety of methods may be used, including multiplying a stock's average annual catch by a scalar less than one or using indicator stocks combined with stock complexes. This assessment, completed as part of the National Marine Fisheries Service (NMFS) - Virginia Tech (VT) Population Dynamics Recruiting Program, aims to provide the scientific information needed to create an annual catch limit for the sand perch stock. This assessment provides basic stock information through analysis of vital rates, catch curves, yield-per-recruit methods, and a surplus production model.

The sand perch *Diplectrum formosum* is a relatively small fish found in coastal waters from North Carolina to Uruguay, as well as in the Gulf of Mexico and the Caribbean Sea (Briggs 1958). Sand perch generally tolerate water temperatures between 14°C and 34°C (Darcy 1985).

Sand perch are synchronous hermaphrodites; mature fish possess male and female sex organs and produce sperm and eggs (it is unknown whether sand perch can act as both a male and female at the same time, however). Maturation begins around age two and is generally complete by age three (Bortone 1971). Mating occurs year-round, but appears to peak during spring and summer (Darcy 1985). Larvae are planktonic, and older individuals occupy sea bottom habitats at depths of 10-132 m (Barans and Burrell 1976, Avent and Stanton 1979, Wenner et al. 1979a, c, d); in the U.S. South Atlantic, depths of 19-27 meters are most typical (Barans and Burrell 1976, Wenner et al. 1979a, b, c, d). Adults are relatively small (attaining a maximum total length of about 300 millimeters) and consume benthic crustaceans and smaller fish (Darcy 1985).

Due to small size, the sand perch is of little importance to the commercial fishing sector. However, sand perch do compose a portion of commercial by-catch and are sometimes used as a bait fish (Keiser 1977, Siebenaler 1952). On the other hand, sand perch are a common catch for recreational fishermen, though rarely targeted, and are valued as pan fish (Darcy 1985).

Stock Structure

Bortone (1977), as cited by Darcy (1985), proposed that the sand perch *Diplectrum formosum* be divided into two subspecies based on morphological differences. *Diplectrum formosum formosum* inhabits the coastal regions of the Gulf of Mexico and the Atlantic coastal regions from North Carolina to mid-Florida; *Diplectrum formosum radians* inhabits coastal South American waters and the Caribbean Sea (Darcy 1985). This report focuses on *Diplectrum formosum formosum* (henceforth referred to as sand perch), specifically the stock of the southern South Atlantic region.

Data Sources

MARMAP Data

MARMAP (Marine Resources Monitoring, Assessment, and Prediction) is a fishery-independent data collection program that implements random sampling and uses a variety of gear types to obtain CPUE (catch-per-unit-effort), age, length, and weight data, along with other life history data such as maturity state (Marcel Reichert, South Carolina Department of Natural Resources, personal communication). The program is funded by the National Marine Fisheries Service and implemented by the South Carolina Department of Natural Resources. Sampling occurs at 300 to 500 randomly selected live bottom sampling sites per year from Cape Fear, North Carolina to Cape Canaveral, Florida. Life history data gathered from each specimen includes length (standard, total, and fork) in millimeters, weight in grams, gonad weight in grams, otolith annulus count (otoliths are extracted for aging), date caught, sex, and maturity. Other data provided include trap soak time, longitude and latitude coordinates of trap set, depth and date of capture, and quantity of sand perch caught.

Two fishery-independent indices were calculated by MARMAP scientists: an abundance index and a biomass index. The abundance index was calculated based on the number of fish caught per trap soak hour. The biomass index was calculated based on the weight of fish in grams caught per trap soak hour. In 1988, MARMAP began using chevron traps to collect biological samples. Because the collection method was inconsistent for the first two years due to personnel training with the new gear type, MARMAP scientists advised the analysts not to use the corresponding data points in further analysis. Since 1988, only chevron traps have been used in index calculations to avoid inconsistency in gear type.

The MARMAP CPUE indices were based on fishery-independent MARMAP data from 1990 to 2009. The two forms of the index predictably differed in scale, but not trend, which suggests that the average weight per fish caught has not changed significantly throughout the time span of the data. The biomass CPUE index (Figure

41a), rather than the abundance CPUE index (Figure 41b), was utilized for this assessment (see section 7) because catch data were also in terms of biomass.

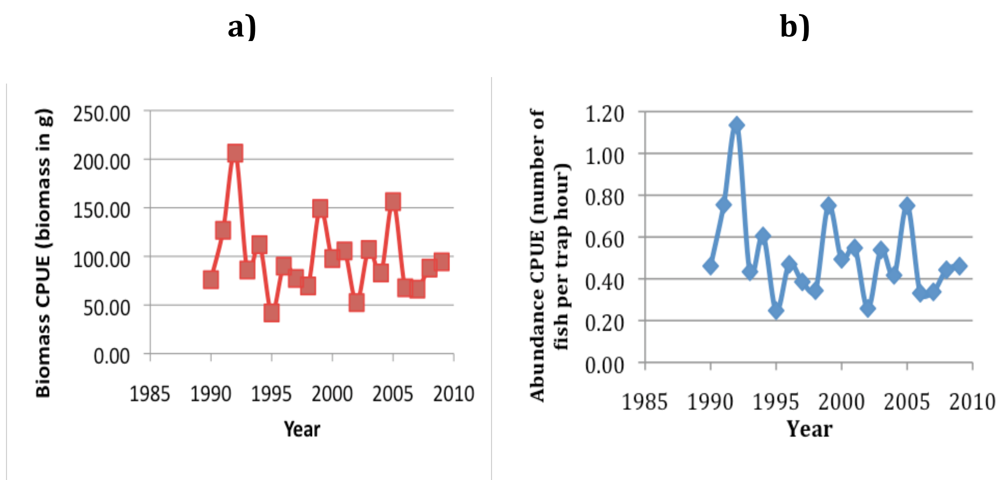


Figure 41. SP: The biomass CPUE index (a) and the abundance CPUE index (b) as provided by MARMAP. The graph shows considerable noise but the general trend suggests a relatively stable abundance over time.

Headboat Data

Headboats are for-hire fishing vessels on which individual anglers pay fees. Data were collected from logbooks under the NMFS Headboat Logbook Program, which requires headboat captains to record data in order to maintain boat permits. Information includes catch composition, number of fish and species harvested, bycatch, number of anglers, trip type, and location fished. This information is validated by state and federal cooperative headboat sampling programs, which also collect and provide life history data.

A pair of headboat indices (Figure 42) was provided for the sand perch stock by Dr. Amy Schueller of the Southeast Fisheries Science Center's Beaufort laboratory. The first headboat index (Figure 42a) utilized a generalized linear model (GLM) and only included trips with positive headboat catches for sand perch from the entire South Atlantic region (North Carolina to southern Florida). The resulting index showed an overall slight decline in the catch per unit effort of sand perch from 1976 to 2009.

The second headboat index (Figure 42b) utilized a delta-lognormal GLM and included headboat catches from North Carolina to near Cape Canaveral, Florida. Effort for this index was determined using the Stephens and MacCall (2004) method, in which effort was calculated by including data from trips targeting associated fish which may result in catch of the fish being studied. Data from southern Florida were not included in this index because the proportion of trips from this region with positive sand perch catch was too small for the Stephens and MacCall selection method to be applied properly (Dr. Amy Schueller, NMFS Beaufort Laboratory, personal communication). This second headboat index included data over a shorter period than the first—from 1984 to 2009—and showed an early spike in CPUE followed by a more precipitous decline than indicated by the first headboat index.

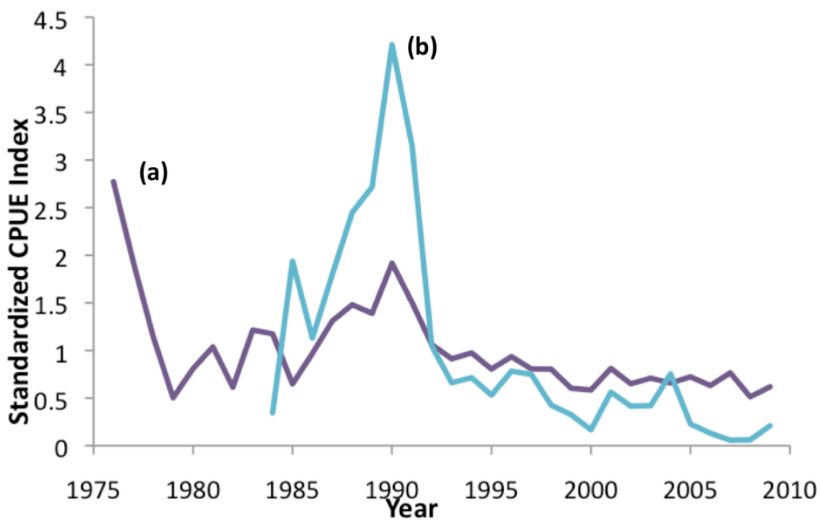


Figure 42. SP: (a) Headboat abundance index using data from the whole South Atlantic region and with effort determined by trips with positive sand perch catch. (b) Headboat abundance index using data from North Carolina to Cape Canaveral, Florida and with effort determined using the Stephens and MacCall method (2004).

MRFSS Data

The Marine Recreational Fishing Statistics Survey (MRFSS), run by NMFS, uses telephone surveys to estimate recreational fishing effort. Recreational fishermen are also surveyed at docks and fishing locations to estimate recreational catch. The two surveys are combined to produce annual estimates of catch in pounds, which were provided to Dr. Berkson for the years 1996-2008 by the Southeast Fisheries Science Center's (SEFSC) Miami laboratory. These landings were included in the overall total landings data provided to the analysts.

Commercial Data

Commercial data are collected on both the state and federal levels. Although data collection varies by state, common methods used are the submission of trip-tickets, landing weight reports from seafood dealers, ship logbooks, and sampling of catches conducted both on ships and at docks. Historically almost all data came from seafood dealerships, but in recent years, a shift has occurred towards mandatory trip-ticket reporting (NMFS 2010). Commercial landings data were provided by the SEFSC's Miami laboratory to Dr. Berkson. These data were not provided to the analysts, except in aggregated form, to ensure confidentiality.

Commercial discards were calculated by the SEFSC and provided to Dr. Berkson, but they were received after completion of this assessment. Discards were provided in numbers of fish with no agreed upon method available for converting to weight. For sand perch, the number of commercial discards never exceeded 18 fish in any given year, and the data were considered to be unreliable (Kevin McCarthy, SEFSC, personal communication).

Total Catch Data

Total catch data from 1962 to 2008, combining commercial, recreational, and headboat landings, were provided by Dr. Jim Berkson (NMFS RTR Unit, Blacksburg, VA)(Figure 43); the data were not separated by fishery type due to confidentiality issues related to the commercial data. The spike in landings for the years 1987 and 1988 seems unusual; misidentification issues may be to blame, as mojarra (fish of the family *Gerridae*) and goatfish (fish of the family *Mullidae*) caught in gill nets have historically been incorrectly classified as sand perch. Gill nets were banned in 1996; therefore, the total catch data from 1997 on should be regarded as the most accurate (Joshua Bennett, SEFSC, personal communication). However, because no evidence is available upon which to disregard the high catches in 1987 and 1988, the catches were considered in analyses.

Vital Rates

No stock assessments have previously been completed on sand perch. This assessment therefore attempted to assign vital rates such as growth, maturity, and mortality to sand perch. Growth rate parameters were used in calculating natural mortality rates and in yield-per-recruit analysis; mortality and maturity rates were essential inputs for the yield-per-recruit model.

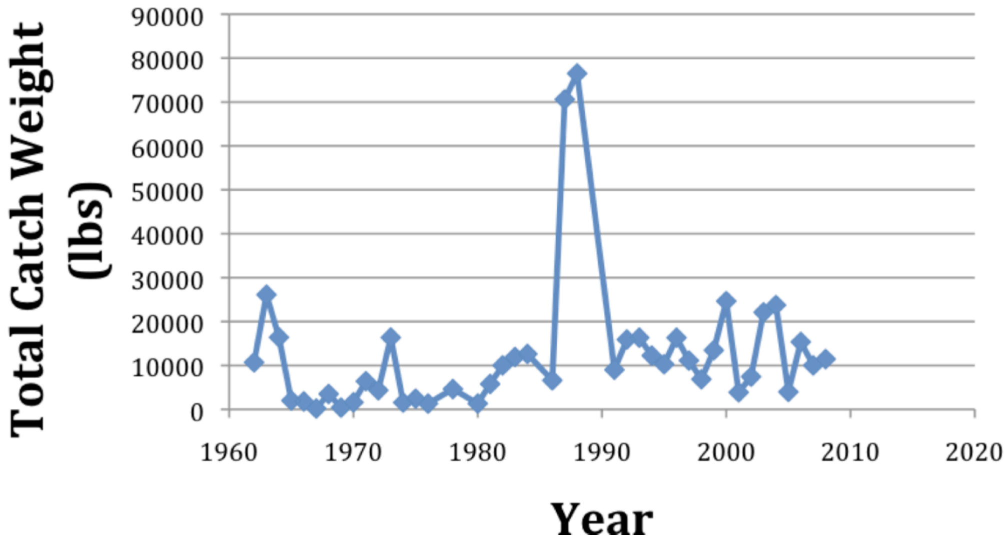


Figure 43. SP: Time series of total catch data (commercial, recreational, and headboat) for the sand perch.

Growth

A von Bertalanffy growth curve (Equation 15) was fitted to MARMAP length and age data (Figure 44). The estimated L_∞ , or asymptotic length, was less than many of the sampled specimens, which created difficulty in calculations. To help the model converge on a reasonable solution, L_∞ in the growth equation was constrained to be the average length of the fish sampled at ages 6, 7, and 8. The variable t_0 was also constrained to be greater than or equal to 1; when the variable was not constrained, estimates of t_0 were unrealistically low. The coefficients from the fitted von Bertalanffy curve were substituted into the von Bertalanffy length growth curve equation to yield the stock-specific equation (Equation 16).

$$L_t = L_\infty\left(1 - e^{-K[t-t_0]}\right) \qquad \textbf{(Equation 15)}$$

$$L_t = 247mm\left(1 - e^{-0.722096[t+1]}\right) \qquad \textbf{(Equation 16)}$$

Maturity

Sand perch are generally fully mature by age 2 or 3 (Bortone (1971). However, no data are available on the fraction mature at each of these two ages.

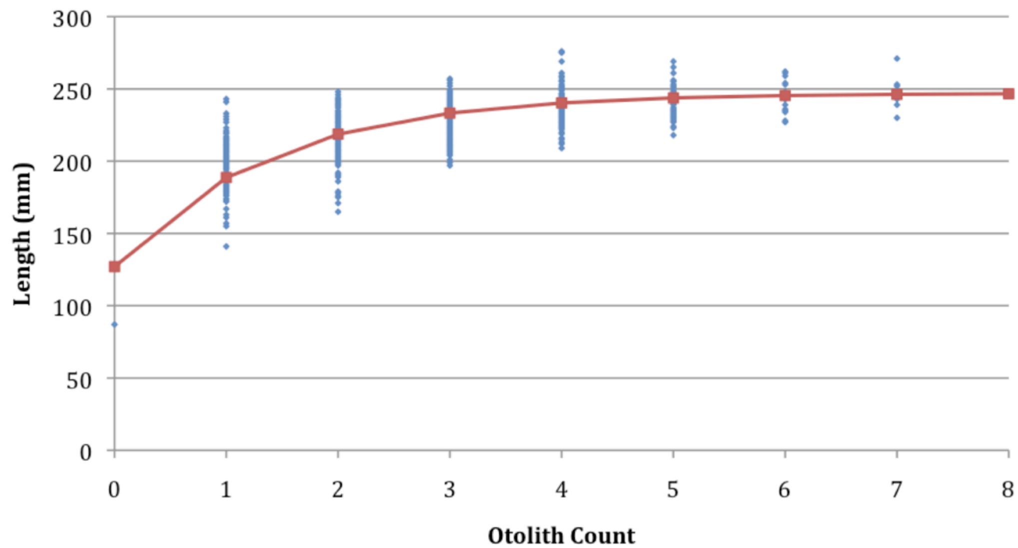


Figure 44. SP: The von Bertalanffy growth curve fit to length and age MARMAP data.

Natural Mortality

For this assessment, natural mortality was estimated with several different methods (Table 26). Each method uses different parameters in order to estimate the value of natural mortality (M) in a population. Parameters used to predict the natural mortality rate include the estimated values from the von Bertalanffy growth curve (K, L_∞), the maximum observed age (t_{max}), the age at maturity (a_m), water temperature (T, °C), and weight (W, grams) (Table 26). Water temperatures of 15 and 20 degrees Celsius were used for the Pauly equation, per the recommendation of Erik Williams (NMFS Beaufort Laboratory, personal communication). Values for M ranged from 0.27 to 1.51. However, following the procedure established in previous SEDARs (Dr. Erik Williams, NMFS Beaufort Laboratory, personal communication), the Hoenig method of estimation was deemed to be the most reliable, and accordingly the natural mortality rate used in further analysis was 0.53.

Table 26. SP: Different methods for estimating the natural mortality rate, *M.*

(The parameters *K* and L_∞ are from a von Bertalanffy length curve; a_m refers to the age at 50% maturity; t_{max} refers to the maximum age of the fish; *T* refers to the mean water temperature in degrees Celsius; and *W* refers to average weight (in grams) at age.)

Author(s)	Equation	Estimate of M
Alverson and Carney (1975)	$M = \frac{3*k}{e^{0.38*t_{\max}*k}-1}$	M=0.271
Beverton and Holt (1957)	$M = \frac{3*k}{e^{a_m*k}-1}$	M=0.669
Hoenig (1983)	$M = e^{1.46-1.01*\ln(t_{\max})}$	M=0.527
Pauly (1979)	$M = e^{(-0.0152+0.6543*\ln(k)-0.279*\ln(L_{\inf})+0.4634*\ln(T)}$	M=1.14 for T=15, M=1.30 for T=20
Ralston and Williams (1989)	$M = 0.0189+2.06*k$	M=1.506
Lorenzen (1996)	$M = 3.69*W^{-0.305}$ s	See Table 29

Analyses

Catch Curves

Two methods of catch curve analysis were used to estimate the total instantaneous mortality rate, *Z*, for sand perch. The Edser (1908) method of catch curve analysis fits a regression to the number of fish per age class from the point at which all fish are recruited to the fishery (the modal age). To do this, the data are log transformed and a linear regression is fit to the data. The slope of this fit approximates *Z* (given in Equation 17), where *M* is the instantaneous natural mortality rate and *F* is the instantaneous fishing mortality rate.

$$Z = M + F \qquad \textbf{(Equation 17)}$$

Catch curve analysis requires a variety of assumptions. One assumption is that the natural mortality and fishing mortality rates remained constant over time (Haddon

2001). Also assumed are a constant sample distribution throughout the time series, as well as constant recruitment and a stable age distribution. Finally, the catch curve analysis relies on a correct estimation of age at full recruitment to the fishery (Shertzer et al. 2008).

For sand perch, MARMAP age distribution data were available for the years 2000-2003 (Table 27). Fish were caught using chevron traps, and the modal age was 2-3. Sufficient otolith edge data were not available, thus ages were denoted by number of annuli rather than by year. Total instantaneous mortality rates were estimated for each year from 2000-2003, as well as for the total numbers-at-age over all four years. An average value of *Z* was also calculated based on the *Z* values for each of the individual years. All catch curve analyses following the Edser method were performed with Microsoft Excel.

The second catch curve method used was the Chapman Robson (1960) method. This method seeks the minimum variance of a survival parameter, *S*, (given in Equation 18) based on the age distribution data rather than by performing linear regression.

$$S = e^{-Z} \quad \textbf{(Equation 18)}$$

In addition to the survival parameter, the mean age (a) is also used with the inverse of the sample size ($1/n$) (Equation 19).

$$Z = \ln\left(\frac{1+a-1/n}{a}\right) \quad \textbf{(Equation 19)}$$

The Chapman Robson method has been found to result in more accurate values for *Z* than the regression catch curve method (Dunn et al. 2001). The Chapman Robson catch curve analyses for this assessment were performed using the program R with the function *chapman.robson*, which is part of the FSA (fisheries stock assessment) package.

Results of Catch Curve Analysis. Total instantaneous mortality rates ranged from 0.68 to 1.04 (Table 28). The range of *Z* values obtained by both methods was rather narrow, which increases confidence in the estimates. The Z values displayed for the Edser method are from the cumulative catch curve results (Figure 45); this curve used the largest sample size and was therefore assumed to be the most indicative of the population. The range of *Z* values can be converted to a range of *F* values using Equation 17 and the Hoenig estimate of *M* (0.53), which results in the estimated values *F* = 0.15 to *F* = 0.51.

Table 27. SP: Age frequency data over a four-year period. Data were from MARMAP fishery-independent chevron traps. Limited data from other years were available, but not used due to very small sample sizes or incomplete fields.

	Age (number of annuli)						
Year	1	2	3	4	5	6	7
2000	12	84	96	28	16	3	3
2001	29	49	57	52	15	5	1
2002	27	44	23	16	15	0	0
2003	18	85	53	22	10	2	1

Table 28. SP: Z values estimated by catch-curve methods.

Year(s) (Chapman Robson)	**Method**	**Modal Age**	**Z (Edser)**	**Z**
2000	individual year	3	0.92	1.03
2001	individual year	3	1.04	0.82
2002	individual year	2	0.81	0.80
2003	individual year	2	0.94	0.80
2000-2003	sum of individual years	2	0.86	0.68
2000-2003	average of individual year	N/A	0.93	0.86

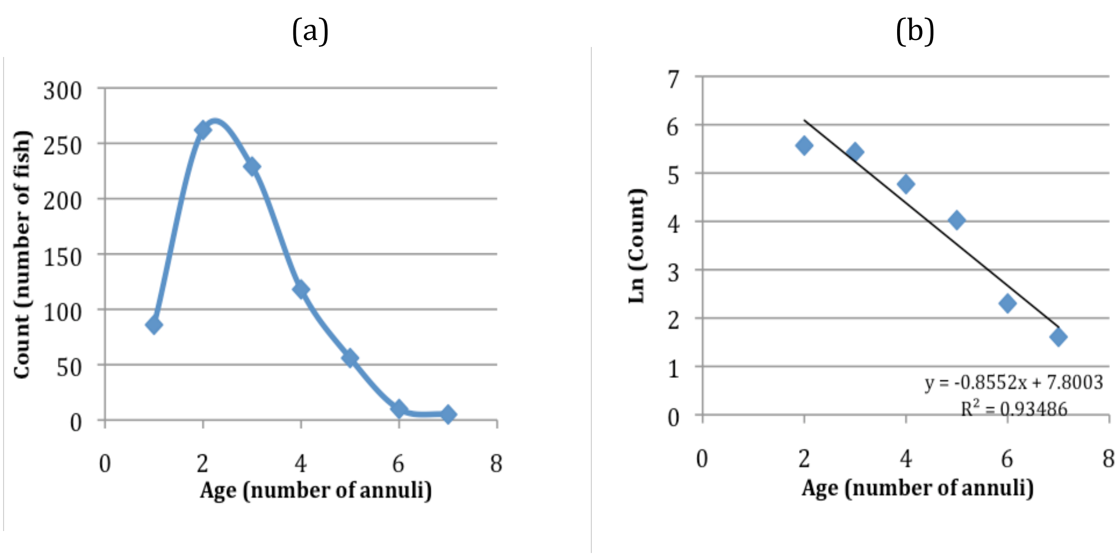


Figure 45. SP: Age frequency (a) and an estimated catch curve (b) for sand perch using the cumulative age frequency data from 2000-2003.

Discussion of Catch Curve Results. Due to the strong assumptions associated with a catch curve analysis, a great deal of uncertainty could be associated with the estimated values of Z and, subsequently, F. For example, the value of Z estimated using data from 2000-2003 may not reflect current levels of Z. However, because catch data and abundance indices for the available years show no strong upward or downward trends, it is likely that mortality and fishing levels have remained relatively constant over the past few decades; this consistency implies that values obtained from the 2000-2003 catch curve analysis should be adequately representative of the larger time period as a whole.

Furthermore, some uncertainty in the value of F may be due to uncertainty in the estimate of M. Some of the variability in the M values for sand perch is likely due to the use of von Bertalanffy coefficients in most of the equations. The analysts attempted to fit a von Bertalanffy length curve to MARMAP life history data, but were met with some difficulty because of limited data for very young fish. Because the value of M is an essential component in Equation 17, it greatly affects the values of F as determined by Z. A point estimate of the fishing mortality rate must be used with extreme caution, so the entire range of fishing mortality rates (0.15 to 0.51) was considered in this assessment.

Yield-Per-Recruit Model

Yield-per-recruit (YPR) models approximate the potential yield at reference point fishing pressures for a population using life history parameters. The main goal of YPR analysis is to find the fishing conditions under which maximum yield for the fishery can be obtained. For the purposes of this model, yield refers to the amount of biomass available for harvest. A single recruit is one fish that has become vulnerable to the fishery.

A YPR analysis was performed using the NOAA Fisheries Toolbox (NFT) YPR version 2.7 software (NFT 2009), which expands upon the basic model created by Thompson and Bell (1934). The basic inputs for the software are selectivity on fishing mortality, selectivity on natural mortality, stock weights, catch weights, spawning stock weights, fraction mature at each age, an estimate of the instantaneous natural mortality rate, and percentage of instantaneous total mortality before spawning.

Three output values were of particular importance in this assessment: F_{Max}, $F_{0.1}$, and $F_{40\%}$. F_{Max} is the fishing mortality level that will theoretically maximize yield. F_{Max} gives no notion of sustainability, and in many fisheries, exploitation at F_{Max} would lead to population decline. $F_{0.1}$, the fishing mortality at which the slope of the yield-per-recruit curve is one-tenth of the slope at the origin, is a more conservative alternative to F_{Max}. The fishing mortality for $F_{0.1}$ will thus always be lower than that for F_{Max}, though the resultant yield is often only slightly less. As with F_{Max}, $F_{0.1}$ gives no notion of sustainability, meaning that continued fishing at $F_{0.1}$ may be unsustainable. Finally, $F_{40\%}$ is the fishing mortality that corresponds to a spawning potential ratio (SPR) of 0.4. The SPR for a given fishing mortality is the spawning stock biomass per recruit (SSB/R) at that fishing mortality divided by the SSB/R at $F = 0$. Goodyear (1993) suggests an SPR of 0.3 as a reasonable first guess for sustainable fishing levels in the northwest Atlantic. For this assessment, a more conservative SPR of 0.4 (i.e., $F = F_{40\%}$) was considered to be a sustainable fishing pressure (Dr. Erik Williams, NMFS Beaufort Laboratory, personal communication).

One important assumption of the YPR analysis is that the population of interest has reached age-structured equilibrium. Another important assumption is that the input parameters remain constant over time. Some inputs, such as natural mortality, could change considerably over time. Even more important than the satisfaction of these two assumptions is the fact that parameters used in the YPR analysis have been estimated accurately. Thus, one must be careful in accepting output from the model without performing additional analyses.

Base Run Inputs. Figure 46 shows a screenshot of the input data for the YPR software as entered for the base run.

AGE	Selectivity on Fishing Mortality	Selectivity on Natural Mortality	Stock Weights	Catch Weights	Spawning Stock Weights	Fraction Mature
1	0	1	140	140	140	0
2	0.2	1	168	168	168	0.5
3	1	1	193	193	193	1
4	1	1	204	204	204	1
5	1	1	221	221	221	1
6	1	1	234	234	234	1
7	1	1	251	251	251	1

Proportion of Fishing Mortality Before Spawning	0.5
Proportion of Natural Mortality Before Spawning	0.5
Natural Mortality	0.53

Figure 46. SP: Input for the base run of the yield per recruit analysis (screenshot of YPR software).

Age-specific selectivity on fishing mortality was estimated based on headboat catch data. To begin, individual sand perch lengths were converted to otolith counts with the von Bertalanffy length growth curve (Equation 16), where *t* was the otolith count (number of annuli) and lengths were in millimeters. It was found that only 1.60% of sand perch caught were less than age 1, 15.5% were less than age 2, and 31.1% were less than age 3. From this it was assumed that all individuals age 3 and older were fully selected into the fishery, while no fish at age 1 and only a portion (set at 20%) of fish at age 2 were selected into the fishery.

Selectivity on natural mortality was initially assumed to be constant across age classes. Age-specific selectivity for natural mortality was calculated using the Lorenzen (1996) equation (Table 29) but was not used because differences in values obtained from the model were very small as compared to using a constant selectivity for natural mortality. Weights by age were calculated from MARMAP life history data and the same values were used for stock weights, catch weights, and spawning stock weights. Maturity values were based on the finding by Bortone (1971) that maturity begins by age 2 and is generally complete by age 3. It was assumed that no fish were mature at age 1, half of the fish at age 2 were mature, and all individuals age 3 or older were mature. Since sand perch spawn throughout the year, a value of 0.5 was used for the proportion of fishing and natural mortality that occurs before spawning. Finally, a natural mortality value of 0.53 was used as derived from the Hoenig equation using a maximum age of 8, which was the highest otolith count obtained in any of the available data (data used in the YPR analysis did not include any age 8 fish; therefore, age 7 was the maximum age for which age-specific selectivity on natural mortality was computed).

Table 29. SP: Age-specific natural mortalities as determined by the Lorenzen equation with weight-at-age data.

Age (number of annuli)	Average Weight (g)	Adjusted *M*	Scaled *M*
1	140	0.818	1
2	168	0.773	0.945
3	193	0.741	0.906
4	204	0.729	0.891
5	221	0.711	0.870
6	234	0.699	0.854
7	251	0.684	0.836

Determining Ranges for $F_{0.1}$ and $F_{40\%}$. In order to calculate possible ranges for the model outputs of $F_{0.1}$ and $F_{40\%}$, high and low values were chosen for the inputs of selectivity on fishing mortality, fraction mature, and natural mortality. These three inputs were thought to have the greatest uncertainty and possible influence on model outputs. The proportion of fish at age 2 selected into the fishery was varied from 0 to 1. Similarly, the age 2 maturity rate was varied from 0.2 to 0.8. Finally, natural mortality values ±10% of the value used in the base run were examined. All eight possible combinations of high and low values for the three input parameters were run through the model, with the highest and lowest values for $F_{0.1}$ and $F_{40\%}$ determining the ranges for the respective model outputs.

Sensitivity Analysis. In order to determine possible effects on the model of slight differences in input, a sensitivity analysis was performed using the same three model input parameters (selectivity on fishing mortality, fraction mature, and natural mortality). The values of $F_{0.1}$ and $F_{40\%}$ were found using the input from the base run except with the fraction of age 2 fish selected, the fraction of age 2 fish at maturity, or the natural mortality altered.

Results of Yield-per-Recruit Analysis. ***Results of Base Run.*** Using the input parameters from the base run, it was determined that $F_{0.1}$ = 1.10, $F_{40\%}$ = 0.939, and an F_{Max} does not exist (Figure 47). The fishing level F was estimated to be between F = 0.15 and F = 0.51 using catch curve analysis (see section 5). Since the value for $F_{0.1}$ is above this range, the current fishing mortality rate appears to be below that required to produce maximum yield. Because the value for $F_{40\%}$ is above the range of F estimated from the catch curves, current fishing levels are thought to be sustainable. No value for F_{Max} was obtained, thus maximum yield for the fishery can theoretically be achieved by simply applying the highest possible fishing pressure. In fact, in all runs no value was obtained for F_{Max}, suggesting that maximum yield will always be obtained by applying maximum fishing effort. Thus, according to values of $F_{0.1}$ and $F_{40\%}$ from the base run, current sand perch fishing practices are not producing maximum yield from the fishery, and they are likely to be at sustainable levels.

Ranges for $F_{0.1}$ and $F_{40\%}$. The analysis resulted in a range of 0.853 to 1.15 for $F_{0.1}$ and a range of 0.375 to 2.96 for $F_{40\%}$. The range for $F_{0.1}$ is entirely above the range of F values obtained from the catch curve analysis, but the range for $F_{40\%}$ does overlap slightly with the range of F values (Figure 48). However, because the size of this overlap is so small compared to the size of the range for $F_{40\%}$, the likelihood that current fishing levels are above $F_{40\%}$ is very small. Fishing mortality would need to be on the upper end of its estimated range, and such low values of $F_{40\%}$ only occurred when 2 year old maturity was low and selectivity of 2 year olds into the fishery was high. Within the estimated ranges for selectivity on fishing mortality, fraction mature, and natural mortality, current practices are likely sustainable and are also producing suboptimal yield.

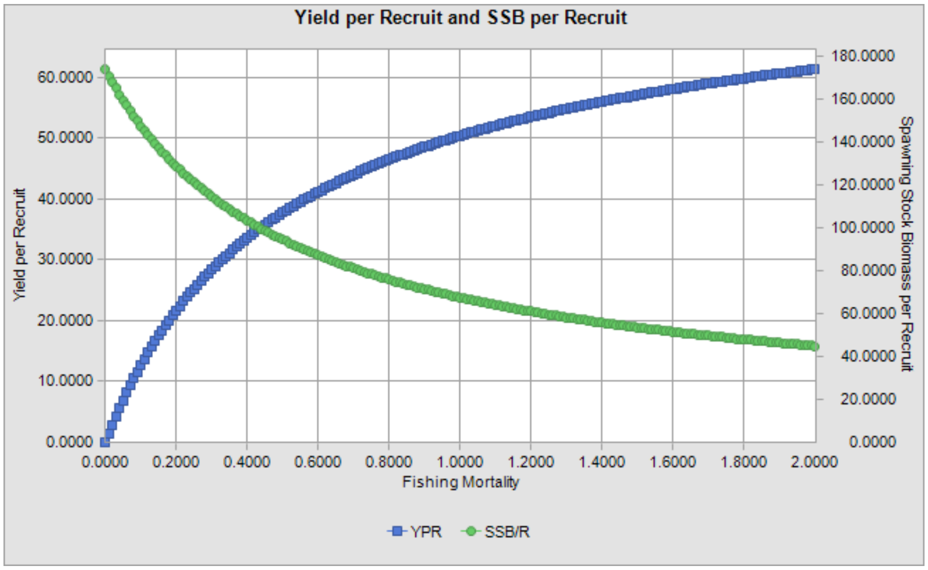


Figure 47. SP: YPR and *SSB*/*R* plot from the base run output.

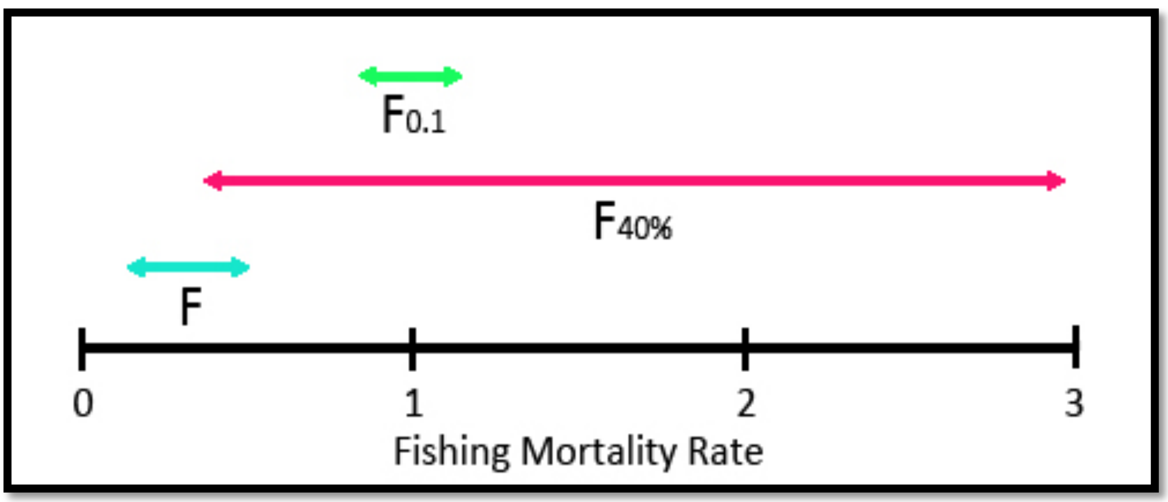


Figure 48. SP: Estimated ranges of *F*, $F_{0.1}$, and $F_{40\%}$. Estimated *F* from catch curves does not overlap range for $F_{0.1}$; it does slightly overlap the range for $F_{40\%}$.

Results of Sensitivity Analysis. The sensitivity of two model outputs, $F_{0.1}$ and $F_{40\%}$, was determined with respect to selectivity on fishing mortality, fraction mature, and natural mortality. Selectivity on fishing mortality had little effect on $F_{0.1}$, but it appeared to have a strong effect on $F_{40\%}$, particularly if it was assumed that low proportions of age 2 fish were selected into the fishery (Figure 49). Since the base run assumed that 20% of the age 2 fish are available to the fishery, small deviances from this value could presumably have noticeable effects on $F_{40\%}$.

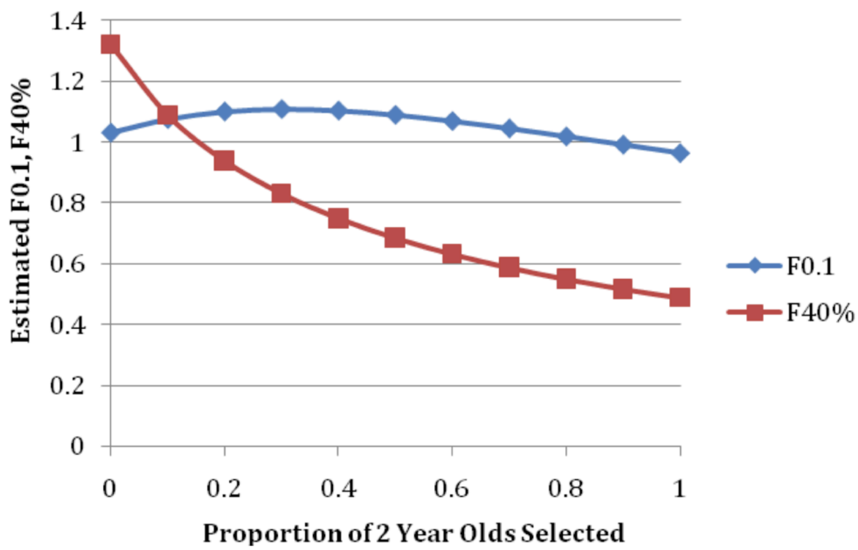


Figure 49. SP: Sensitivity of $F_{0.1}$ and $F_{40\%}$ to the proportion of 2 year olds selected into the fishery.

The fraction mature had no effect on $F_{0.1}$, presumably because maximum yield is obtained by applying maximum fishing pressure on all fish—even immature fish (Figure 50). However, again, there was a noticeable effect on $F_{40\%}$.

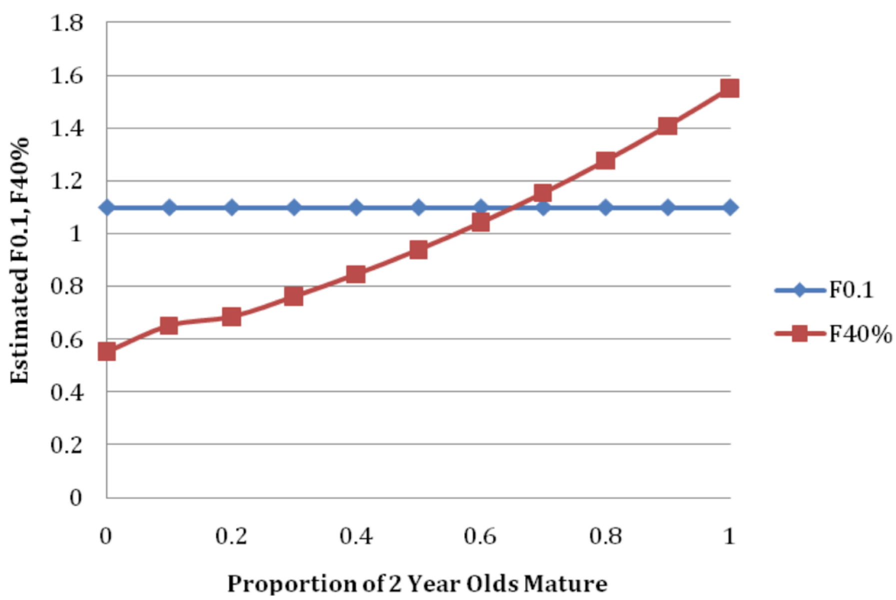


Figure 50. SP: Sensitivity of $F_{0.1}$ and $F_{40\%}$ to the proportion of 2 year olds that have reached maturity.

Finally, altering the natural mortality rate had similar effects on both $F_{0.1}$ and $F_{40\%}$, with both values being approximately linearly related to natural mortality (Figure 51).

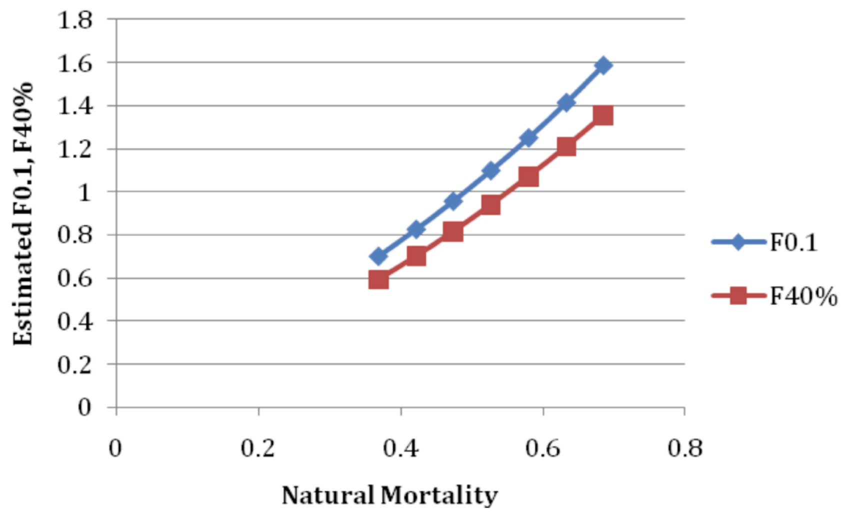


Figure 51. SP: Sensitivity of $F_{0.1}$ and $F_{40\%}$ to natural mortality rate.

Discussion. The base run offers interesting results, with fishing mortality estimated from catch curves being sustainable and yield significantly below maximum yield. However, the range of values obtained for $F_{40\%}$ is very large; the low value, $F_{40\%}$ = 0.375, is within the range of estimated fishing mortality rates, and the high value, $F_{40\%}$ = 2.96, is considerably higher than the highest estimated fishing mortality rates. The sensitivity analysis offers similar insight, with $F_{40\%}$ responding noticeably to changes in selectivity of 2 year olds into the fishery, fraction mature at age 2, and natural mortality. More data, particularly on the fraction of sand perch mature by age 2 and selection of 2 year olds into the fishery, would be very valuable when estimating $F_{40\%}$. Still, if the base run is to be given the most weight, then current practices are likely sustainable, as the base run value for $F_{40\%}$ of 0.939 is well above the range of estimated current F values.

Surplus Production Model

The surplus production model can be an effective assessment tool for data-poor stocks. Surplus production models can supply reference points for management and are not dependent on age-structured data. The surplus production model is used to estimate the biomass produced beyond replacement levels for a population, or excess biomass; in other words, excess biomass is that which can be harvested without depleting the population.

The logistic model, described by Schaefer (1954, 1957) allows the combination of many vital rates into a single equation (Equation 20; Haddon 2001), where B_t is the biomass at time t, C_t is the catch at time t, r is the intrinsic population growth rate, and K is the carrying capacity.

$$\boldsymbol{B_{t+1} = B_t + r * B_t \left(1 - \frac{B_t}{K}\right) - C_t} \qquad \textbf{(Equation 20)}$$

ASPIC is a modeling program that attempts to fit a non-equilibrium surplus production model to input data in order to summarize stock status and evaluate the likely effects of alternative management actions in the future (Prager 2004). ASPIC estimates a fit to one or more CPUE indices. Initial guesses were made for maximum sustainable yield (MSY), carrying capacity (K), catchability coefficient (q) for each CPUE index, and ratio of the starting biomass to carrying capacity (B_1/K). Input data included CPUE indices from MARMAP chevron traps and from headboat data and total landings by year. ASPIC fits a production curve to input data (Equation 21; Figure 52).

$$\boldsymbol{Yield = r * B_t \left(1 - \frac{B_t}{K}\right)} \qquad \textbf{(Equation 21)}$$

ASPIC provides estimates of F/F_{MSY} and B/B_{MSY} in order to determine stock status and to project potential management schemes into the future.

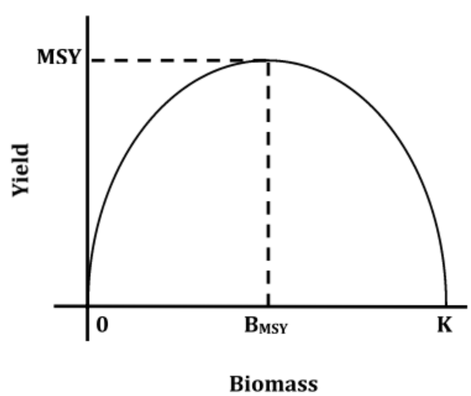


Figure 52. SP: Production curve (Equation 21) where MSY is maximum sustainable yield, K is carrying capacity, and B_{MSY} is the biomass at maximum sustainable yield.

Problems with ASPIC Runs. The available catch indices were used to try to fit a surplus production model with ASPIC. However, there was not enough contrast in the indices over time for the program to give any reliable output, as all three indices were generally flat over the past two decades (Figure 53). Even models fit using only the first available years of the indices, where the most contrast was present, yielded uninformative results. In addition, some pairs of indices were negatively correlated, meaning different indices showed different population trends for the same set of years. Most runs produced results with unrealistically high or low estimates of fishing mortality and biomass (Figure 54), and in all cases the fits to indices were nearly flat (Figure 55). Input values were fixed to try to improve model estimation, but a reliable surplus production model could not be fit with the available indices (Dr. Michael Prager, personal communication).

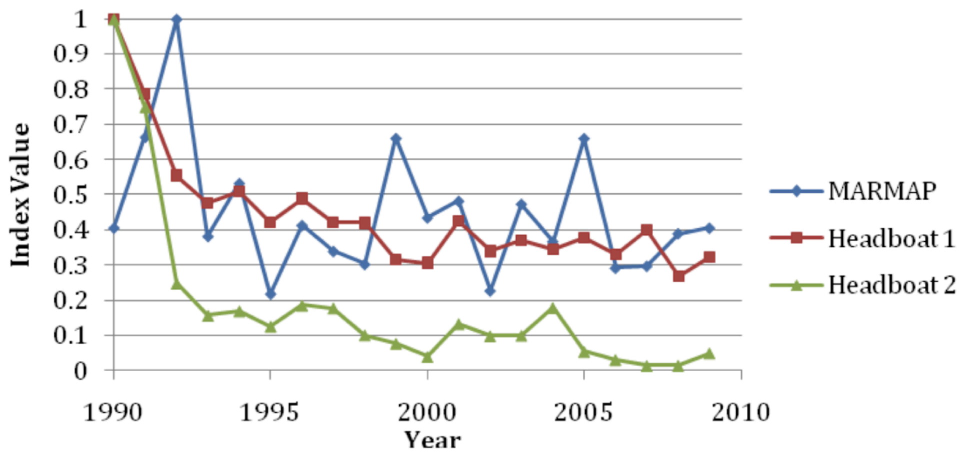


Figure 53. SP: Abundance indices over time. Included are the MARMAP index and two headboat indices, the first which only includes trips in which sand perch were caught and the second which includes any trips that could have caught sand perch but does not include southern Florida. Each index has been scaled to a maximum value of 1.

Summary of Stock Status

Though data on the sand perch are limited, the catch curve and YPR analyses performed indicate that current fishing levels are likely sustainable. The estimated range of fishing mortality values (0.15 to 0.51) is below base run estimates of $F_{0.1}$ and $F_{40\%}$ from the YPR analysis, meaning that the stock is likely under-fished in terms of yield and is being fished sustainably. Though a surplus production model could not be used, the fact that the CPUE indices are relatively constant over time suggests a stable population. Estimates of total mortality from the catch curve analysis and $F_{0.1}$ and $F_{40\%}$ from the YPR analysis are somewhat uncertain, given the available data. As addressed in the next section, more life history data, particularly for younger individuals, could be very valuable in terms of reducing uncertainty in mortality and fishing levels.

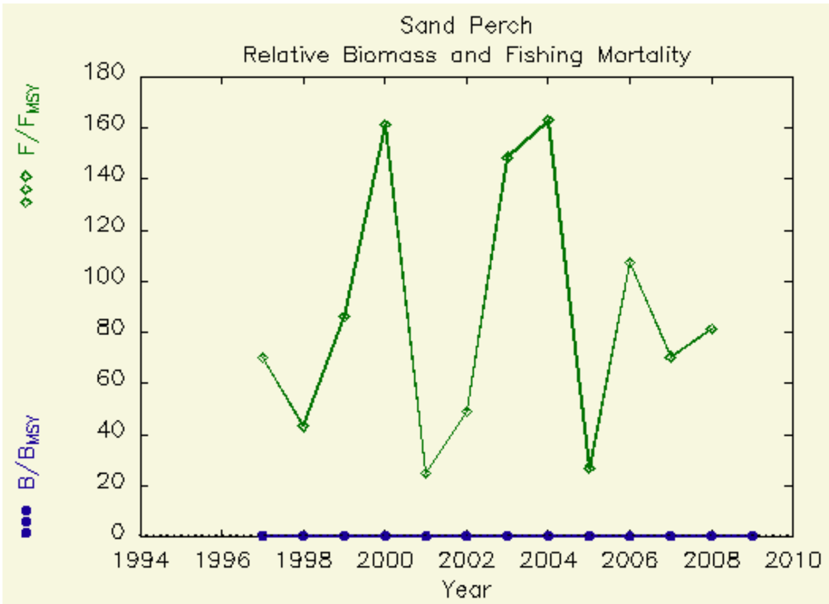


Figure 54. SP: Example output from ASPIC showing unrealistically high estimates of F/F_{MSY}.

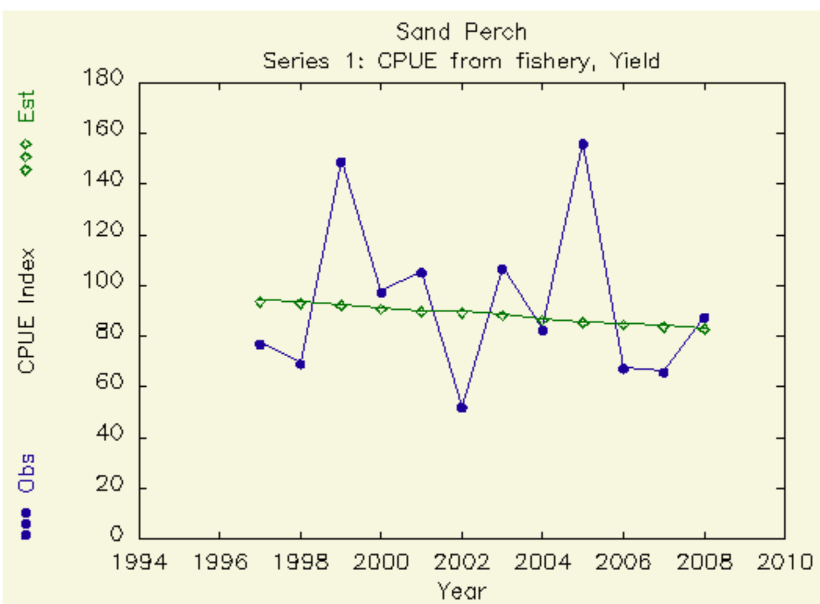


Figure 55. SP: Example output from ASPIC showing the program's fit to the MARMAP index.

Because of low effort, relatively flat indices, and low catch levels, it is likely that the sand perch stock is not overfished. However, reference points of B/B_{MSY} could not be estimated due to difficulties fitting the surplus production model, and it cannot be determined with great certainty that B/B_{MSY} is greater than 1. Still, given the best estimates, the current sand perch stock is most likely sustainable and is not likely to be subject to overfishing.

Recommendations for Further Research

As indicated by the high uncertainty in results from the catch curve and YPR analyses, a great need for additional data on the sand perch exists, particularly in a few key areas. Only four years of data were available for the catch curve analysis and different years gave noticeably different estimates for the total mortality. Since this value is used to estimate fishing mortality and fishing mortality is very important in interpreting the results of the YPR analysis, age frequency data over numerous years could prove very valuable in determining a more accurate estimate of *F*.

In terms of the YPR analysis, accurately determining the selectivities on fishing mortality and the fraction mature-at-age would reduce uncertainty in the estimates. As shown by the sensitivity analyses, the fraction of age 2 fish selected by the fishery has a strong effect on $F_{40\%}$, and the fraction of mature age 2 fish has strong effects on both $F_{0.1}$ and $F_{40\%}$. Thus, more information on these young sand perch would help to limit the ranges of values obtained for $F_{0.1}$ and $F_{40\%}$. This in turn would give a better idea of whether current fishing practices are sustainable and where current yield lies with respect to maximum yield.

Finally, the available data were not sufficient for use in a surplus production model, which would provide much more specific information on how the stock and fishing effort have changed over time and would allow population projections to be explored. However, if the sand perch population remains stable, new indices will still lack the contrast necessary to properly fit an ASPIC model. Should indices exhibit noticeable trends in future years, a surplus production model would be recommended to gain knowledge on the past and possible future states of the stock.

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Exploratory Assessment of Tomtate, *Haemulon aurolineatum*

Image from www.gulfshorefishing.com

Abstract

The tomtate, *Haemulon aurolineatum*, is a small, bottom dwelling fish that belongs to the grunt family. Tomtate typically do not reach fork lengths greater than 25 cm and weights greater than 350 grams. Because of their small size, they are generally not an intentionally targeted species; however, they are still harvested and caught as bycatch.

This assessment was completed as part of the National Marine Fisheries Service (NMFS) – Virginia Tech (VT) Population Dynamics Recruiting Program. Because of the data-poor status of the tomtate stock, relatively simple assessment methods such as catch curves, yield-per-recruit, and surplus production were used to analyze the stock. Natural mortality rate was calculated using a variety of methods, but the resulting value of 0.246 from the Hoenig equation was chosen as the accepted value. Two abundance indices were provided by MARMAP and the NMFS headboat logbook program, and total landings data (combination of commercial, recreational, and headboat data) were provided by Dr. Jim Berkson.

Catch curve analysis allows for a total mortality rate, Z, to be calculated. The fishing mortality rate, F, can be calculated by subtracting the natural mortality rate, M, from the total mortality rate, Z. The catch curve analysis used data from 2000-2003 which was a period that experienced an anomaly in both indices and landings. Therefore, the total mortality rate Z and the calculated F likely represent the conditions only within that time period and cannot help determine conditions after 2003. The yield-per-recruit analysis estimated a $F_{0.1}$ of 0.373 and $F_{40\%}$ of 0.399. The surplus production model indicated that the tomtate is likely overfished and currently experiencing overfishing. These conclusions are based on B/B_{msy} and F/F_{msy} values. The indices alone show a generally decreasing trend in the abundance of tomtate; however, the MARMAP index shows a general stabilization of the abundance since 2003 and the headboat index shows a slight increase in abundance since 2007. According to projections, the population is likely to decrease further if current fishing pressure is maintained and would likely take approximately 20 years to reach B/B_{msy} of one if fishing mortality rate (F) was set to zero. Overall, the surplus production model was the only one of the three analysis methods that provided information on the current status of the tomtate.

Caution is warranted in interpreting these results as a number of problems were identified with the commercial catch data available for use in the assessment. The analysts recommend that these results be viewed as preliminary and that additional efforts should be made to reconstruct the commercial catch data, both landings and discards, before any future assessment takes place.

Further research needs include better estimates of the commercial catch, both landings and discards. Efforts need to be focused on improving the historical catch record before any future assessments are conducted. Improved catch data would likely not change the ultimate outcome of the assessment, as the assessment is likely

driven by the CPUE indices both of which show a sharp decline over time. Increased fishery independent sampling would provide better life history data, such as maturity rates by age, that would help in yield-per-recruit analysis and better age-structured data that would allow for more comprehensive catch curve analyses.

Introduction

Evaluating stock status of all species harvested within the South Atlantic has become increasingly important. In 2007, President Bush signed the Magnuson-Stevens Reauthorization Act which states that an annual catch limit (ACL) must be put into place for all stocks undergoing overfishing by January 1, 2010, and for all other stocks by 2011. Out of 72 stocks managed in the South Atlantic Fisheries Management Council's (SAFMC) snapper-grouper complex, only 12 have assessments that have been accepted through a peer-reviewed process (John Carmichael, SAFMC, personal communication). For stocks without assessments, a number of methods for implementing ACLs may be used, including multiplying a stock's average annual catch by a scalar less than one or using indicator stocks combined with stock complexes. This exploratory assessment, completed as part of the National Marine Fisheries Service (NMFS) – Virginia Tech (VT) Population Dynamics Recruiting Program, aims to provide the scientific information needed to set an annual catch limit for the tomtate stock. The tomtate stock is data-poor and has not been previously assessed. This assessment provides basic stock information through analysis of vital rates, catch curves, yield-per-recruit methods, and a surplus production model.

The tomtate, *Haemulon aurolineatum,* is a small, bottom dwelling fish that belongs to the grunt family. The species is found from Cape Cod, Massachusetts, to Brazil, including the Caribbean, Gulf of Mexico, and Central American coast (Manooch and Barans 1982). Tomtate are found in water depths between 13 and 91 meters and in water temperatures between 10.3 and 28.1°C, although they are typically found in water less than 55 meters deep and temperatures greater than 13°C (Manooch and Barans 1982). Tomtate reside primarily over sponge-coral live bottom environments, but they are also found over sandy bottom environments. Tomtate are thought to occupy live bottom areas during the day, and forage over sandy bottom areas at night, providing an important source of allochthonous nutrients for the reef environment (Sedberry 1985). Tomtate typically do not reach fork lengths greater than 25 centimeters and weights greater than 350 grams. The oldest tomtate on record was aged to 17 years based on otolith increment counts. Other common names for the tomtate include red mouth, ruby lip grunt, and blood mouth.

Although tomtate are not intentionally targeted by recreational fisheries or targeted as a commercially valuable species, a recent study showed that tomtate are commonly caught as bycatch of commercially valuable species (Stephen and Harris 2010). In the Stephen and Harris study (2010), a commercial vessel performed nine fishing trips for vermilion snapper in the U.S. South Atlantic. Tomtate was the fourth most abundant fish captured by numbers during these fishing trips. On these trips, 2% (N=331) of the total catch was tomtate, of which 65% was landed, 24% was discarded, and the remaining 11% was used as bait. Discarded tomtate experienced an immediate release mortality of 72%, most likely as a result of barotraumas (Stephen and Harris 2010).

History of Management and Regulations

The tomtate stock found in the South Atlantic is included in the Snapper-Grouper fishery under the management of the South Atlantic Fishery Management Council (SAFMC). Tomtate is regulated under all general restrictions implemented for snapper-grouper species, including gear restrictions. Historically and currently, tomtate have not been regulated with size limits, trip limits, or catch limits.

Stock Structure

The tomtate stock is continuous from Massachusetts to Brazil, including the Caribbean and the Gulf of Mexico (Manooch and Barans 1982). In this study, only the stock of the U.S. South Atlantic was analyzed for assessment and management purposes. According to Dr. Jim Berkson (NMFS RTR Unit at Virginia Tech, personal communication), a majority of recreational landings of tomtate in the U.S. South Atlantic were centered around the coast of South Carolina and northern Florida. This could indicate that a population of tomtate is present in the south Atlantic that is separate from the Caribbean and Gulf of Mexico stocks, otherwise abundant catches would be present well into southern Florida as well. Tomtate from the south Atlantic have been compared to tomtate from the Campeche Banks, and tomtate from the Campeche Banks have been found to live in shallower depths, have shorter lives, and generally reach smaller maximum lengths (Manooch and Barans 1982). As a consequence, the U.S. South Atlantic tomtate stock is likely separate from the Gulf of Mexico stock. Because there were no reports of a northern stock (north of the U.S. South Atlantic) in the reviewed literature, this report did not look at any potential tomtate stocks that may exist there. However, future assessments should consider tomtate of that northern region.

Data Sources

MARMAP Data

MARMAP is a fishery-independent data collection program that implements random sampling and uses a variety of gear types to obtain CPUE (catch-per-unit-effort), age, length, and weight data, along with other life history data such as maturity state. The program is funded by the National Marine Fisheries Service and implemented by the South Carolina Department of Natural Resources. Sampling occurs at 300 to 500 randomly selected live bottom sites per year from Cape Fear, North Carolina, to Cape Canaveral, Florida. Life history data gathered from each specimen includes length (standard, total and fork) in millimeters, weight in grams, gonad weight in grams, date caught, sex, and maturity. Otoliths are extracted for ageing. Other data provided included trap soak time, longitude and latitude coordinates of trap set, depth and date of capture, and quantity of tomtate caught. Because sampling effort by MARMAP is limited by funding, they supplement their fish life history dataset with fishery dependent data.

Two MARMAP fisheries independent indices, an abundance index and a biomass index, were provided for the years 1988 to 2009. The abundance index was calculated based on the number of fish caught per trap hour, and the biomass index was calculated based on the weight of fish in grams caught per trap hour. For tomtate the biomass and abundance indices were highly correlated. In this assessment, the biomass index was used because the corresponding landings data were provided in terms of biomass (Figure 56). MARMAP began using chevron traps in 1988 for collecting biological samples to put together a fishery independent index. Because the fishery independent collection method was inconsistent for the first two years (1988-1989) due to personnel training with the new gear type, MARMAP scientists advised us to not use the corresponding data points in further analysis.

Headboat Data

Boats that take groups of anglers fishing to various locations are known as headboats. Anglers pay an individual fee to join the boat on its fishing trips. Data were collected from logbooks under the National Marine Fisheries Service Headboat Logbook Program, which requires headboat captains to record data in order to maintain boat permits. Information includes catch composition, number of fish and species harvested, bycatch, number of anglers, trip type, and location fished. This information is validated by state and federal cooperative headboat sampling programs, which also collect and provide life history data. Landings from the headboat data were provided to Dr. Jim Berkson (NMFS RTR Unit, Blacksburg, VA) and were included in the overall total landings data provided for this report.

A headboat CPUE index was compiled and provided by Dr. Amy Schueller of the Southeast Fisheries Science Center's Beaufort Laboratory. The index was calculated using a delta-glm with a gamma distribution, and units were in number of fish per angler hour (Figure 57). Total effort was determined through the Stephens and MacCall method (2004).

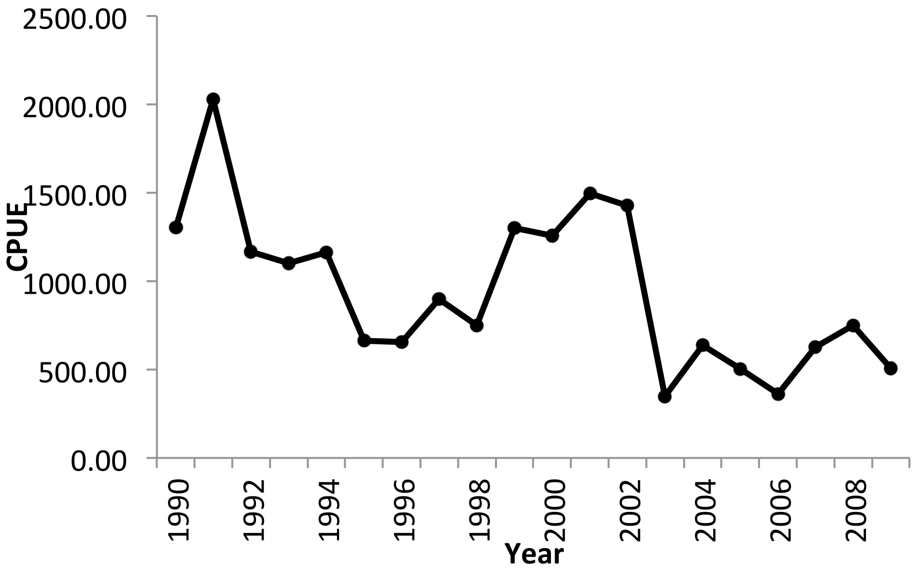

Figure 56. TT: Biomass CPUE index over time calculated from MARMAP chevron traps. CPUE is presented in units of grams of tomtate caught per trap hour.

Although the headboat and MARMAP indices were calculated from two separate data sources, they show the same general population trend over time. In addition, both indices show an increasein the year 2001. This increases confidence that the indices accurately represent the stock status. Both indices show a declining abundance of tomtate in the years used for the analysis (Figure 58).

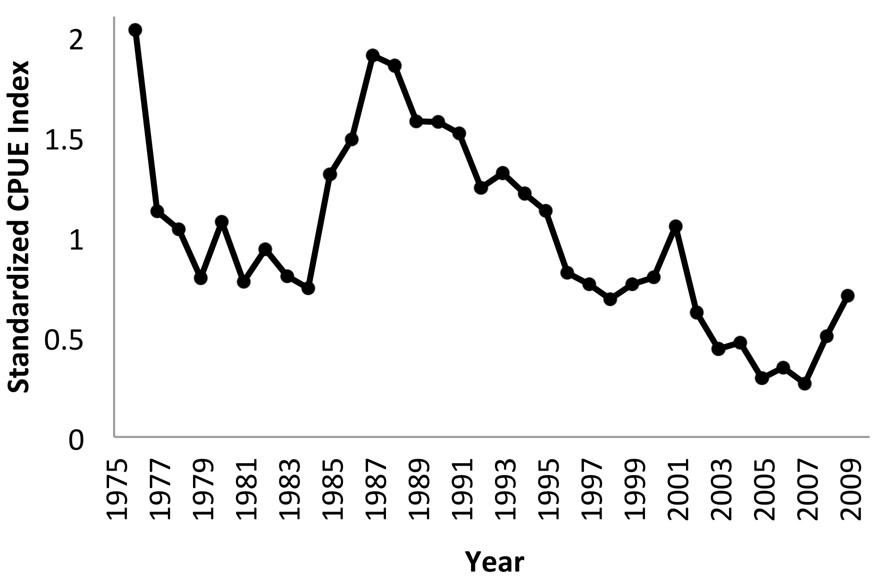

Figure 57. TT: Headboat CPUE index measured in number of fish per angler hour.

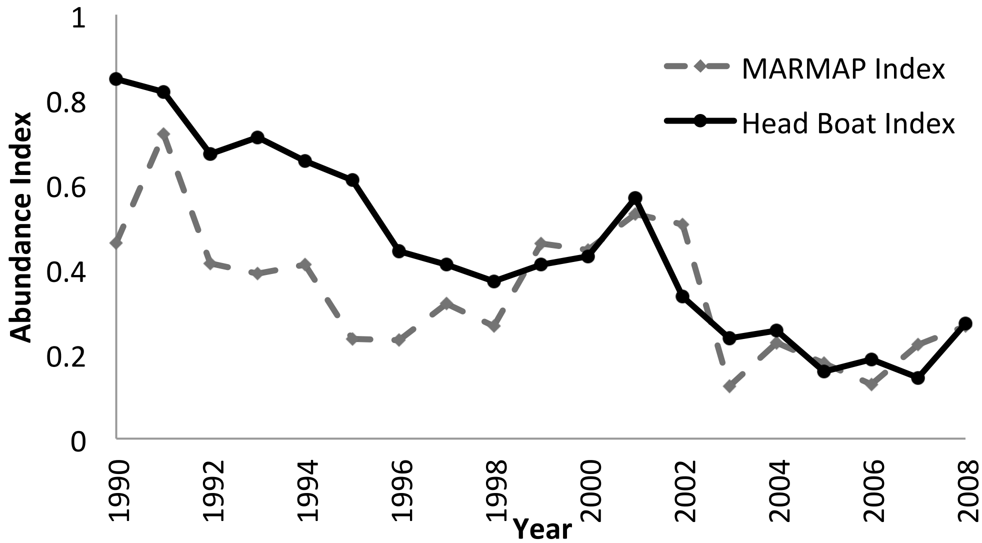

Figure 58. TT: Comparison of the trends between the MARMAP and the Headboat abundance indices from 1990-2008. Both were standardized to 1 for this comparison.

MRFSS Data

The Marine Recreational Fishing Statistics Survey (MRFSS), run by NMFS, uses telephone surveys to estimate recreational fishing effort. Recreational fishermen are also surveyed at docks and other fishing locations to estimate recreational catch. The two surveys are combined to produce annual estimates of catch in pounds. Data for the years 1986-2008 were provided to Dr. Berkson by the Southeast Fisheries Science Center's Miami Laboratory. These landings were included in the overall total landings data provided for this assessment.

Commercial Data

Commercial data were collected on both the state and federal levels. Although data collection varies by state, common methods used include the submission of trip-tickets, landing weight reports from seafood dealers, ship logbooks, and sampling of catches conducted both on ships and at docks. Historically almost all data came from sea food dealers' monthly reports of weight and value of landings by vessel, but in recent years there has been a shift towards mandatory trip-ticket reporting, where both seafood dealers and fishermen must report their landings by species at the conclusion of each fishing trip (NMFS 2010).

In the process of developing estimates of commercial landings, it was discovered that tomtate had been categorized as "unclassified grunts" and "unclassified finfish" in the past. The vast majority of tomtate were thought to be categorized as "unclassified grunts" rather than "unclassified finfish." Over time, fewer entries were entered in these categories, suggesting that species identification has improved.

A method was developed to estimate the pounds of tomtate in the commercial landings. An estimate of the annual percentage of tomtate caught relative to all grunts was calculated using the headboat data, in which tomtate are accurately identified. This percentage was then multiplied by the annual commercial catch of all grunts, including "unclassified grunts" to provide an estimate of the annual commercial catch of tomtate. This approach makes the critical assumption that the percentage of tomtate caught relative to all grunts in the commercial fishery is the same as that of the headboat fishery, an assumption which cannot be verified at the present time. As an alternative, a similar procedure may have been possible using the commercial TIP (Trip Interview Program database to calculate the ratio, rather than the headboat data. This approach would likely have provided a more accurate ratio. The TIP data required to calculate this ratio were not available in time for us to incorporate them into this assessment.

Commercial discards for the years 1993-2009 were calculated by the SEFSC and provided to Dr. Berkson, but they were received after completion of this assessment. Discards were provided in numbers of fish with no agreed upon method available for converting to weight. The average number of discards estimated was 9,576 with a range from 0 in 2004 and 2006 to a high of 35,989 in 2005. Discards were calculated based only on logbook entries specifying tomtate, so actual numbers would likely be higher if tomtate listed as unclassified grunts were to be included. Discard estimates were considered preliminary, and additional work to improve the estimates was recommended before they are incorporated into an assessment (Kevin McCarthy, SEFSC, personal communication). Therefore, commercial discards were not incorporated into the assessment.

A more thorough reconstruction of the historical commercial catch data (both landings and discards) is recommended before any future tomtate assessment takes place.

Total Catch Data

Total catch data from 1986 to 2009, combining commercial, recreational, and headboat catch, as described above, were provided by Dr. Jim Berkson (NMFS RTR Unit, Blacksburg, VA), and were not broken down due to confidentiality (Figure 59).

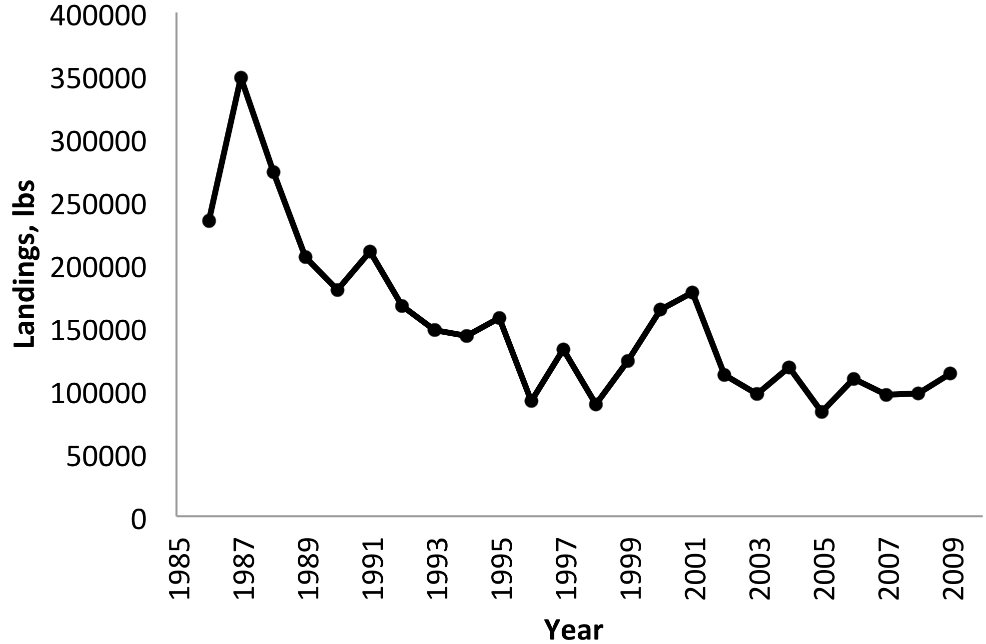

Figure 59. TT: Total catch in pounds combining recreational, headboat, and commercial data for 1986-2009.

Vital Rates

In stock assessments, vital rates can be very useful in understanding potential responses of a stock to a certain level of fishing pressure, at least at a qualitative level. These rates are also utilized as essential inputs in analyses such as the yield per recruit model and the surplus production model.

Growth

In order to quantify the growth rate of tomtate, otolith count and fork length information of 2,544 fish was analyzed. These data were obtained primarily by fishery independent sampling performed by MARMAP, but also included length-at-age data from commercial port sampling. In order to make empirical estimates of mortality rates, a von Bertalanffy curve (Equation 22) was fit to the length-at-age data.

$$L_t = L_\infty(1 - \exp(-K - (t - t_0))) \qquad \text{(Equation 22)}$$

The resulting growth equation for tomtate,

$$L_t = 206(1 - \exp\left(-0.4695 - (t - 1.41)\right))$$ (Equation 23)

appears to estimate the observed values adequately (Figure 60).

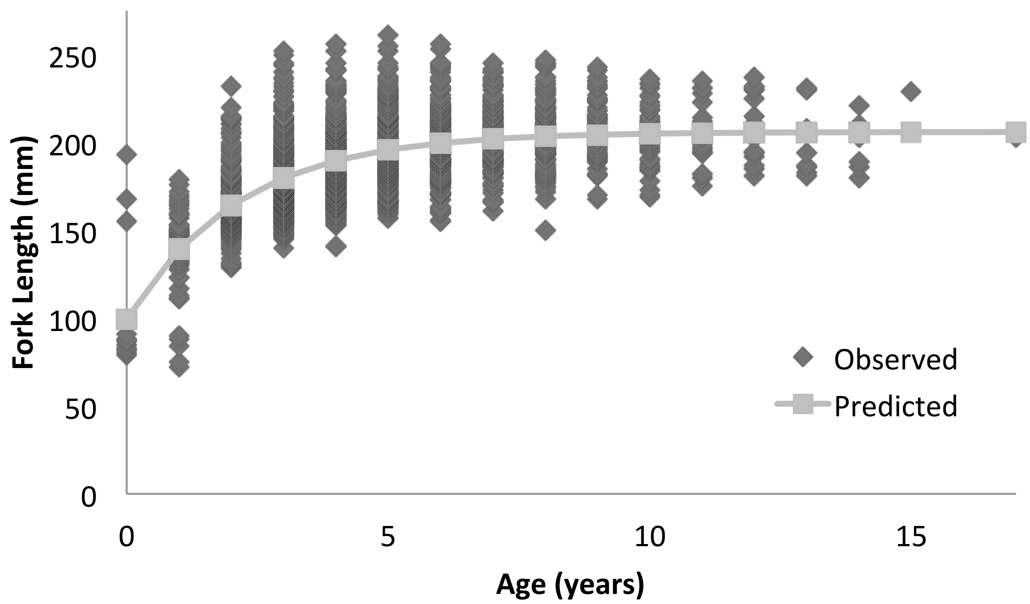

Figure 60. TT: Von Bertalanffy growth curve calculated with MARMAP data.

One previous study was conducted to estimate tomtate growth rates , which compared length and age (otolith and scale) data from 397 fish in order to obtain a von Bertalanffy growth curve (Manooch and Barans 1982). The resulting equation (24),

$$L_t = 310(1 - \exp(-0.22017 - (t - 1.28)))$$ (Equation 24)

differed in slope and maximum length (L_∞) from our calculated curve (Figure 61). In both of these analyses, ages were truncated to one year intervals, without taking into consideration month of collection or growth since last annulus. This limits the precision of the estimated von Bertalanffy growth equation and may bias the value of t_0. However, it should not directly bias estimates of K or L_∞.

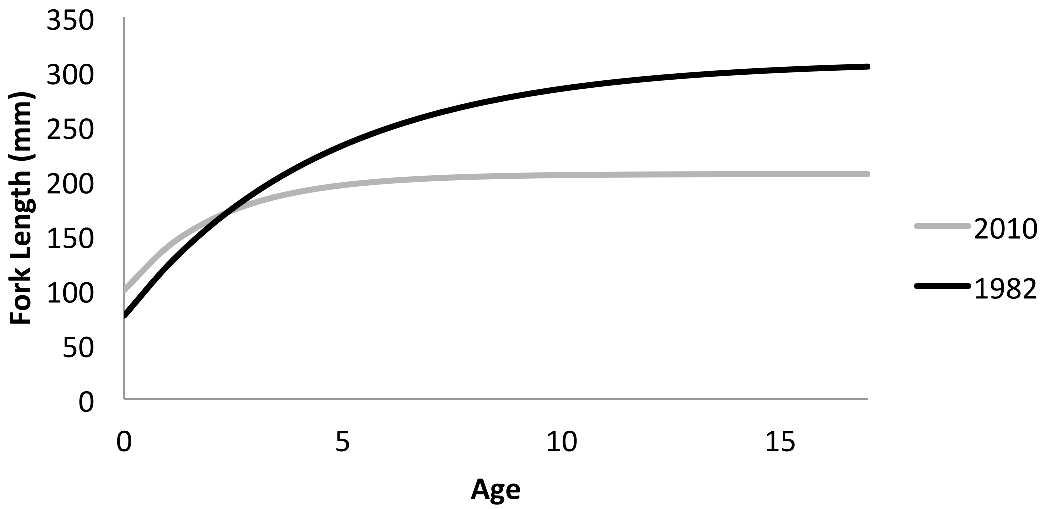

Figure 61. TT: Comparison of von Bertalanffy growth curves calculated in 1982 (n=397; Manooch and Barans 1982) and 2010 (n=2544).

Although the largest fish in the 1982 study and the current study were both about 25 centimeters in length, the L_∞ differed between studies (Figure 61). However, current data nearly doubled the maximum recorded age of tomtate from 9 years to 17 years. Since there are fewer measurements of older fish in the 1982 study, the equation determined probably doesn't do an adequate job of estimating the lengths of older age classes. The older age classes were not present in the sample of that study, most likely as a result of the sample size, and therefore are not represented by the Von Bertelanffy growth equation derived from that data. Alternatively, there is also a possibility that the different shapes of the von Bertalanffy growth curves may be a result of considerably larger sample sizes in the most recent data (n_{1982}=397, n_{2010}=2,544), as the probability of encountering old fish would be less in a smaller sample size. However, if both curves accurately describe the tomtate population at each respective time period, then they may show that a decrease in the maximum size of the species has occurred over time, which could result from a variety of causes.

Maturity and Fecundity

Maturity occurs when tomtate reach a fork length of approximately 15 centimeters for both males and females (Fishbase 2010). According to our data and corresponding von Bertalanffy growth curve, this size is generally reached sometime between ages one and two. Knowledge of tomtate spawning habits is limited to one study analyzing a gonad weight index (Manooch and Barans 1982). This study indicated that tomtate tend to spawn in April and May, but also mentioned that spawning season and duration can be variable throughout their geographic range (Manooch and Barans 1982).

Natural Mortality

For this assessment, natural mortality rate was estimated by several different methods (Table 30). Each method uses different parameters to estimate the value of the natural mortality rate (M) in a population. These equations use parameters such as estimated values from the von Bertalanffy growth curve (K, L_{inf}), the maximum observed age (t_{max}), the age at maturity (a_m), water temperature (T, °C), and weight (W, grams) to approximate the natural mortality rate (Table 30).

A variety of parameters were used in the calculations of natural mortality rates. The growth coefficient, K, and maximum average size, L_{inf}, were taken from the von Bertalanffy growth curve derived in this assessment. The maximum age, t_{max}, was determined based on a maximum otolith count of 17, from the life history data provided by MARMAP. Age at 50% maturity, a_m, was determined to be one year, based on a mature length of 15 centimeters (Fishbase 2010) and the length-age relationship from the von Bertalanffy growth curve. Temperature, T, was chosen to range from 10°C to 28°C (Manooch and Barans 1982). Weight at age, W, was obtained from theoretical weights calculated from weight to age relationship determined from the data provided by MARMAP. This was done with the same process used to determine length to age relationships with the Von Bertalanffy growth curve, however length was substituted by weight.

Although natural mortality rate (M) is a vital stock characteristic, it has not been directly estimated for tomtate. Total mortality rate (Z) was calculated to be 0.887 in Manooch and Barans (1982), using catch curve analysis. The maximum age observed in the 1982 study was 9 years, and no information was given to differentiate Z into natural mortality rate (M) and fishing mortality rate (F). There are not many fish older than age 10, which may explain the absence of older fish in previous studies.

Estimated natural mortality rates for tomtate ranged widely from 0.071 to 2.35. The Lorenzen (1996) model estimated age-specific natural mortality rate to range between 1.23 and 0.754 for increment counts ranging from 0 to 17 (Table 31). The Hoenig (1983) method estimate was M = 0.246, based on a maximum increment count of 17 (Table 30). Following the procedure established in previous SEDARs, the Hoenig method of estimation was deemed to be the most reliable, and accordingly the natural mortality rate used in further analysis was M = 0.246.

Table 30. TT: Different methods for estimating the natural mortality rate, *M.*

(The parameters *K* and L_∞ are from a von Bertalanffy length curve; a_m refers to the age at 50% maturity; t_{max} refers to the maximum age of the fish; *T* refers to the mean water temperature in degrees Celsius; and *W* refers to average weight (in grams) at age.)

Author(s)	**Equation**	**Estimate of *M***
Alverson & Carney (1975)	$M = \frac{3*k}{e^{0.38*t_{\max}*k} - 1}$	0.0713
Beaverton & Holt (1957)	$M = \frac{3*k}{e^{a_m*k} - 1}$	2.35
Hoenig (1983)	$M = e^{1.46-1.01*\ln(t_{max})}$	0.246
Ralston & Williams (1989)	$M = 0.0189 + 2.06*k$	0.986
Pauly (1979)	$M = e^{(-0.0152+0.6543*\ln(k)-0.279*\ln(L_{\inf})+0.463}$	0.751 - 1.21
Lorenzen (1996)	$M = 3.69*W^{-0.305}$	See Table 31

Analyses

Catch Curves

Catch curves were used to estimate the total instantaneous mortality rate, *Z*, for the tomtate. Catch curves fit a line to the number of fish sampled in each age class from the point at which all fish of an age are recruited to the fishery (modal age). To do this, the curve was log transformed and a linear regression was fit to the data. The slope of this fit approximates *Z* (Equation 25), where *M* is the instantaneous natural mortality rate and *F* is the instantaneous fishing mortality rate.

$$Z = M + F \qquad \text{(Equation 25)}$$

Table 31. TT: Lorenzen age-specific- weight was calculated from the von Bertalanffy growth curve.

Age	Weight	M
0	36.41	1.23
1	70.30	1.01
2	101.16	0.903
3	125.61	0.845
4	143.59	0.811
5	156.26	0.791
6	164.94	0.778
7	170.80	0.769
8	174.71	0.764
9	177.31	0.761
10	179.03	0.758
11	180.16	0.757
12	180.90	0.756
13	181.38	0.755
14	181.71	0.755
15	181.91	0.755
16	182.03	0.755
17	182.14	0.754

Catch curves require a variety of assumptions. One assumption is that the natural mortality rate and fishing mortality rate remain constant over time (Haddon 2001). Sample distributions are assumed to remain constant throughout the time series, as well as constant recruitment and a stable age distribution. Finally, the catch curve analysis relies on a correct estimation of age at full recruitment to the fishery (Shertzer et al. 2008).

The data used for these catch curve analyses were age frequency data for years 2000-2003 (n=2129, Table 32) from MARMAP chevron traps. All fish collected for age frequency data were caught with chevron traps. For this assessment, two methods were used to analyze catch curves and calculate the value of Z. Excel was used to do the regression catch curve analysis, and R statistical software was used to perform the Chapman Robson (1960) catch curve analysis.

Catch curves were generated for each year in the series, and a curve was generated using the total numbers at age for all four years (Table 33). An average value of *Z* was calculated, based on the *Z* values for each of the individual years.

Table 32. TT: Age-frequency data provided by MARMAP and collected from chevron traps.

Count	2000	2001	2002	2003
0	1	2	0	0
1	17	27	7	6
2	103	51	93	49
3	138	75	109	141
4	83	123	106	50
5	71	76	133	43
6	33	59	80	57
7	28	32	38	27
8	22	29	28	24
9	16	17	19	13
10	10	18	11	5
11	6	9	4	8
12	5	5	4	2
13	1	0	3	3
14	1	4	1	1
15	0	1	0	0
16	0	0	0	0
17	0	1	0	0
Total	535	529	636	429

Table 33. Total instantaneous mortality for each year estimated from data from MARMAP chevron traps. Average *Z* is the average of the calculated *Z* value for each year (2000-2003). Total *Z* was calculated from combining all data by age across years into one set for analysis.

	Total	**2000**	**2001**	**2002**	**2003**	**Average**
Regression	0.487	0.435	0.401	0.451	0.380	0.417
Chapman Robson	0.371	0.406	0.397	0.532	0.399	0.433

The Chapman Robson (1960) catch curve was used in addition to the regression catch curve method (Dunn et al. 2002). Rather than simply calculating a linear regression from the age distribution, the Chapman Robson method uses the minimum variance of a related survival parameter, *S* (Equation 26).

$$S = e^{-Z} \qquad \text{(Equation 26)}$$

In addition to the survival parameter, the mean age (*a*) is also used with the inverse of the sample size (1/*n*; Equation 27).

$$Z = \ln\left(\frac{1 + a - 1/n}{a}\right) \qquad \text{(Equation 27)}$$

Chapman Robson catch curve analysis was performed in R using the function chapman.robson which is part of the Fisheries Stock Assessment package. This analysis was performed for the modal age and older. Each estimate of the total instantaneous mortality calculated using the regression analyses was also calculated using the Chapman Robson analysis.

The total instantaneous mortality estimates by the Chapman Robson analysis were lower than the regression analysis for years 2000, 2001 and total, and higher than the regression analysis for years 2002, 2003, and the average of all 4 years (Table 33).

This catch curve analysis may be influenced by a strong cohort that skewed the age structure data. Evidence of a strong cohort starting with 3 year old fish in 2000 and continuing until 2002 is available (Table 32). Because of the limited number of years available for this analysis, other data anomalies could skew the output. These anomalies should be considered when evaluating the confidence in, and implications derived from the catch curve analysis.

The regression catch curve analysis shows a range of *Z* values from 0.380 for the individual year of 2003 to a value of 0.487 from the combined data from the four years together. The Chapman Robson catch curve analysis shows a range of *Z* values from 0.371 for the combined data from all 4 years to a value of 0.532 for the year 2002. The consistency of the *Z* values between years and analysis methods increases the confidence in the results. However, the *Z* value determined from the average will be considered as the more correct value for *Z* than each year individually, as it represents a longer time series with more data.

Using this value and the estimated natural mortality rate (*M*) from the Hoenig equation, an estimate for a fishing mortality rate (*F*) value can be calculated. Based on equation 4 above, *F* is calculated to be 0.171 for the regression analysis. For the Chapman Robson analysis, *F* is calculated to be 0.187. However, because the catch curve uses data from 2000 to 2003, the fishing mortality rate does not represent the most current conditions. Based on the two indices (Figures 56 and 57) and on the total catch data (Figure 59), the years 2000-2003 appear to be part of a spike that occurred in all three data sets. The conditions in all three data sets have changed since 2004 to the present, with the MARMAP index stabilizing, and total catch slightly increasing. Because conditions have not stayed the same, assuming that the fishing mortality rate from 2000-2003 has remained the same to the present would be unwise. This analysis was helpful to understand past fishing pressure on tomtate, but most likely does not provide an accurate representation of current stock status.

Yield-Per-Recruit Model

Yield-per-recruit (YPR) models approximate the potential yield at reference point fishing pressures for a population using life history parameters. The main goal of YPR analysis is to find the fishing conditions under which maximum yield for the fishery can be obtained. For the purposes of this model, yield refers to the amount of biomass available for harvest. A single recruit is one fish that has become vulnerable to the fishery.

A YPR analysis was performed using the NOAA Fisheries Toolbox (NFT) YPR version 2.7 software (NFT 2007), which expands upon the basic model created by Thompson and Bell (1934). The basic inputs for the software are selectivity on fishing mortality, selectivity on natural mortality rate, stock weights, catch weights, spawning stock weights, the fraction mature at each age, an estimate of the instantaneous natural mortality rate, and percentage of instantaneous total mortality before spawning.

Three output values were of particular importance in this assessment: F_{Max}, $F_{0.1}$, and $F_{40\%}$. F_{Max} is the fishing mortality rate that will theoretically maximize yield. F_{Max} gives no notion of sustainability, and in many fisheries, exploitation at F_{Max} would lead to population decline. $F_{0.1}$, the fishing mortality rate at which the slope of the yield-per-recruit curve is one-tenth of the slope at the origin, may be a more conservative alternative to F_{Max}. The fishing mortality rate for $F_{0.1}$ will thus always be lower than that for F_{Max}, though the resultant yield is often only slightly less. However, as with F_{Max}, continued fishing at $F_{0.1}$ may be unsustainable. Finally, $F_{40\%}$ is the fishing mortality rate that corresponds to a spawning potential ratio (SPR) of 0.4 (i.e., $F = F_{40\%}$). The SPR for a given fishing mortality rate is the spawning stock biomass per recruit (SSB/R) at that fishing mortality rate divided by the SSB/R at $F = 0$. A SPR of 0.4 is generally considered to be a sustainable fishing pressure for species with life histories similar to tomtate (Erik Williams, NMFS Beaufort Laboratory, personal communication).

One important assumption of the YPR model is that results are accurate only once the population has reached an age-structured equilibrium. This is rarely true, so caution must be taken in accepting conclusions solely from yield-per-recruit output. Another important assumption is that the input parameters remain constant over time. Some inputs, such as natural mortality rate, could change considerably over time. Thus, one must be careful in accepting output from the model without performing additional analyses. One important assumption of the YPR model is that results are accurate only once the population has reached an age-structured equilibrium. This is rarely true, so caution must be taken in accepting conclusions solely from yield-per-recruit output. Another assumption is that the input parameters remain constant over time. It is highly plausible that some inputs, such as natural mortality, could change considerably over time. More important to the model is that the input parameters used are accurately estimated to begin with. Thus, one must be careful in accepting output from the model without performing additional analyses.

The parameters that affect the output of the yield-per-recruit model are the proportion of fishing mortality before spawning, natural mortality rate, age at maturity, and selectivity to the fishery. Base parameters were chosen to run a YPR model for our stock, and then sensitivity runs were performed to understand model dependence on parameter inputs. The proportion of fishing mortality before spawning was set at 0.3 to account for the springtime spawning season of the tomtate. The natural mortality rate was set at M=0.246, determined from the Hoenig (1983) equation. Maturity percentages were set at 50% for age one fish, and 100% for age two fish, as tomtate reach maturity between ages one and two. Selectivity to the fishery was determined from the catch curve results. Fish reached a large enough size to enter the fishery between age two and three, with a small possibility of entry at smaller sizes. Selectivity percentages were set as 25% for age one fish, 50% for age two fish, and 100% for age three fish. The weights used for this analysis were derived from the von Bertalanffy growth curve calculated previously.

Results for the base run are shown in Table 34 and Figure 62. F_{max} could not be estimated at M = 0.246 because the YPR curve never reaches a maximum; it continues to increase as the fishing mortality is increased (Figure 62).

Table 34. TT: Yield-per-recruit model base run inputs and results.

<table>
<tr><th>M</th><th>Age</th><th>Selectivity of Fishing Mortality</th><th>Fraction Mature</th><th>$F_{0.1}$</th><th>$F_{40\%}$</th></tr>
<tr><td rowspan="5">0.246</td><td>0</td><td>0</td><td>0</td><td rowspan="5">0.3733</td><td rowspan="5">0.3987</td></tr>
<tr><td>1</td><td>0.25</td><td>0.5</td></tr>
<tr><td>2</td><td>0.5</td><td>1.0</td></tr>
<tr><td>3</td><td>1.0</td><td>1.0</td></tr>
<tr><td>4+</td><td>1.0</td><td>1.0</td></tr>
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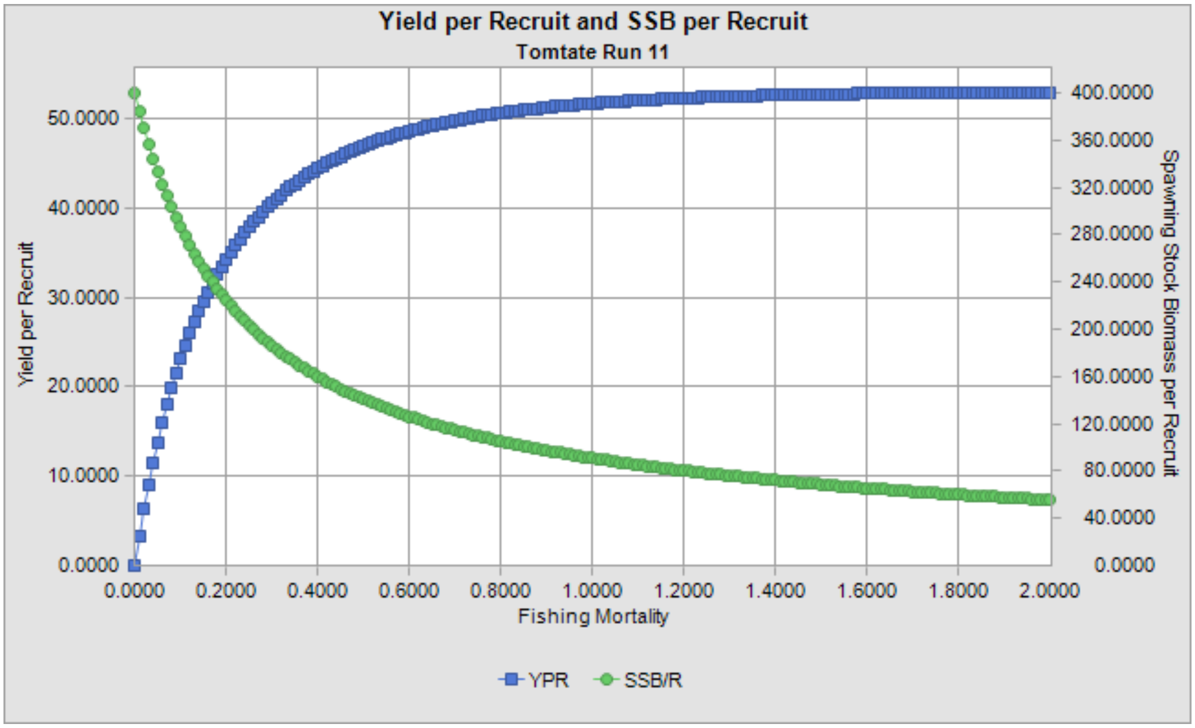


Figure 62. TT: Yield-per-recruit model output that calculated reference points of $F_{0.1}$ and $F_{40\%}$.

Sensitivity analyses were run for the yield-per-recruit model. The most sensitive parameter was the natural mortality rate. Natural mortality rate sensitivity was explored with the input values of 0.1, 0.3, 0.5, and 0.7. The resulting $F_{0.1}$ values ranged from 0.165 to 1.55, and the resulting $F_{40\%}$ values ranged from 0.159 to 1.74. The only input value that produced a viable result for F_{max} (0.5148) was at a natural mortality rate of M = 0.1.

Three sensitivity runs were used to evaluate selectivity on fishing mortality rate (F). Selectivity on F has a minimal effect on the $F_{0.1}$ output values. However, the selectivity of fishing mortality does show a noticeable effect on the $F_{40\%}$ output values (Table 35). The selectivity values used in the sensitivity analysis were determined from headboat length-at-catch data provided by Rob Cheshire of the NMFS Beaufort Laboratory.

Table 35. TT: Effects of changing the input values for fishing mortality rate selectivity on YPR reference point results.

	Trial 1	Trial 2	Trial 3
Age 0	0	0	0
Age 1	0	0	0
Age 2	0.25	0.25	0
Age 3	1	0.5	0.5
Age 4	1	1	1
F0.1	0.4084	0.4350	0.4447
F40%	0.5720	0.7335	1.0741

Age at maturity used in this analysis was derived from length-at-maturity information from previous studies (Fishbase 2010). Length-at-age relationships from the von Bertalanffy growth curve were then used to determine the age at maturity, which was then used in the YPR model. A sensitivity run was performed for a scenario where tomtate mature more slowly (maturity: Age 0: 0%; Age 1: 0%; Age 2: 50%; Age 3: 75%; Age 4: 100%). This analysis showed that $F_{0.1}$ stayed the same, while $F_{40\%}$ decreased from 0.399 to 0.276.

The fishing mortality rate calculated from the catch curve (0.171) is substantially lower than the estimated value of $F_{40\%}$ of 0.399. Because, the value of F represents only four years of data earlier in the decade, comparing that value to the base estimate of $F_{40\%}$ most likely does not lead to any valuable conclusions for the present fishing conditions. The conclusion that can be made if the assumptions of both the catch curve and the YPR analyses held, is that for the years 2000-2003, the fishing effort was below the $F_{40\%}$ level meaning that the species could likely have been fished with more effort to derive a greater sustainable yield. Once again, caution must be used, as the presence of a strong cohort in the data used for the catch curve analysis likely diminishes, if not nullifies, the utility of this portion of the analysis.

Surplus Production Model

The surplus production model can be an effective assessment tool for data-poor stocks. Surplus production models can supply reference points for management and are dependent on age-structured data. The surplus production model is used to estimate the biomass produced beyond replacement levels for a population; in other words, the biomass that can be harvested without depleting the population.

The logistic model, described by Schaefer (1954, 1957) allows the combination of many vital rates into a single equation (Equation 28; Haddon 2001), where B_t is the biomass at time *t*, C_t is the catch at time *t*, *r* is the intrinsic population growth rate, and *K* is the carrying capacity.

$$B_{t+1} = B_t + r * B_t\left(1 - \frac{B_t}{K}\right) - C_t \qquad \text{(Equation 28)}$$

ASPIC is a modeling program that attempts to fit a non-equilibrium surplus production model to input data in order to understand stock status and evaluate the likely effects of alternative management actions in the future (Prager 1994). ASPIC estimates a fit to one or more CPUE indices. Initial guesses were made for maximum sustainable yield (*MSY*), carrying capacity (*K*), catchability coefficient (*q*) for each CPUE index, and the ratio of the starting biomass to carrying capacity (B_1/K). Input data included the headboat CPUE index, the MARMAP CPUE index, and total landings by year. ASPIC fits a production curve to the data (Equation 29; Haddon 2001; Figure 63).

$$Yield = r * B_t\left(1 - \frac{B_t}{K}\right) \qquad \text{(Equation 29)}$$

ASPIC provides estimates of F/F_{msy} and B/B_{msy} in order to determine stock status and to project potential management schemes into the future.

In assessing the tomtate stock, time series data from 1986 to 2009 were used, based on the availability of landings data. The model was fit using total catch data of the tomtate from the U.S. South Atlantic (Figure 59). Two indices were used: a biomass CPUE from MARMAP (Figure 56) and one from the headboat industry (Figure 57). Because the MARMAP index started in 1988 and MARMAP consistently started using chevron traps in 1990, the first four years of the index were entered as missing values that were then estimated by ASPIC. The headboat index included data dating back to 1976, but the early years before 1986 were not used.

The model fit the data relatively well (Figure 64(a) and 64(b)), and the model follows the trend of both indices. The run shown in Figure 64(c) was done by setting B_1/K equal to 1. The model fit the data well only when B_1/K was set to guesses larger than 0.73. At lower values the model failed to produce a good fit, likely due to the large decrease in the beginning of the landings and indices data (Dr. Michael Prager, personal communication). B_1/K represents the biomass at the beginning of the time series, and it is logical that B_1/K cannot start out at a low point if it then experiences the large decrease shown by the abundance indices, i.e. it cannot fall very far if it is already at a low point. In cases where abundance indices drop quickly, surplus production models commonly indicate that the initial population biomass would be near or above K (carrying capacity; Dr. Michael Prager, personal communication).

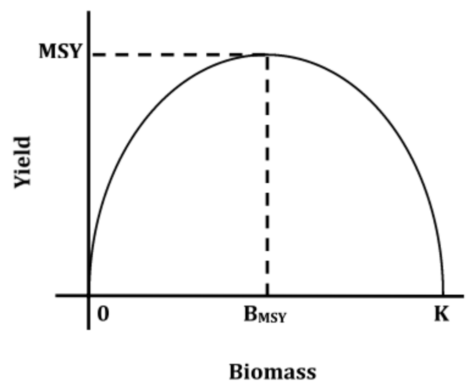


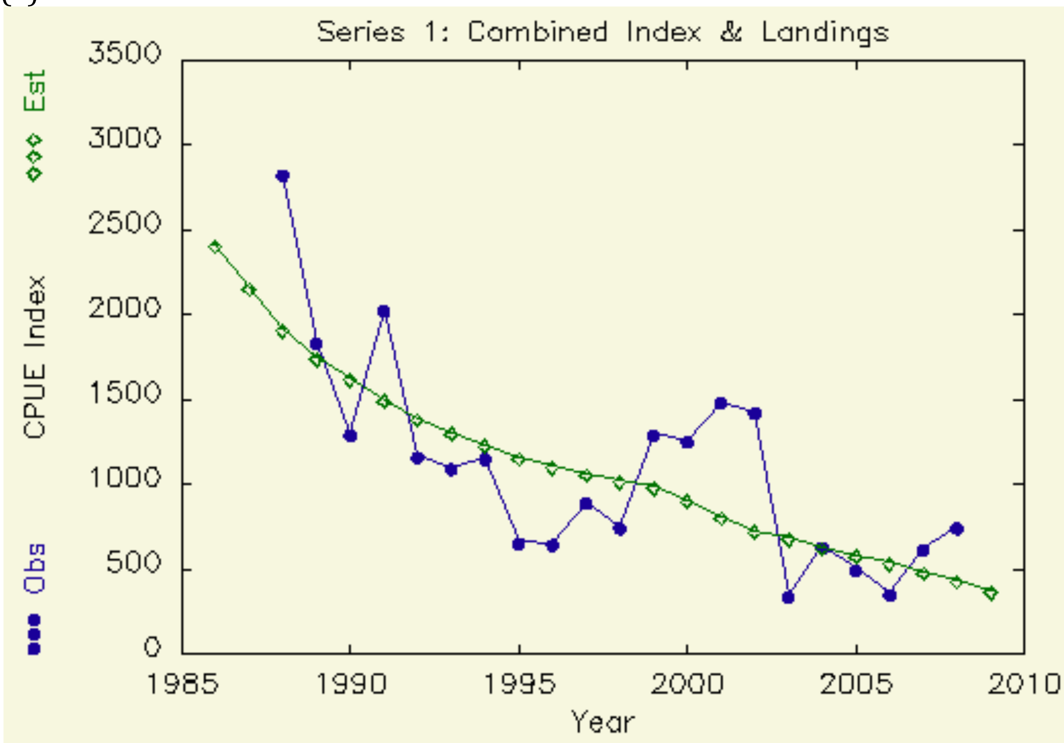
Figure 63. TT: Production curve (Equation 29; Haddon 2001), where *MSY* is maximum sustainable yield, *K* is carrying capacity, and B_{MSY} is the biomass at maximum sustainable yield.

The 80% confidence interval for B_{2009}/B_{MSY} is 0.186 to 0.434 with a bias corrected estimate of 0.268 (Table 36). Even under the most conservative definitions of MSST, the U.S. South Atlantic tomtate population would appear to be overfished. The 80% confidence interval for F_{2008}/F_{MSY} is 3.48 to 16.9 and has a bias corrected estimate of 5.69 (Table 36). Here as well, even at the lower bounds, the value of F/F_{msy} is well above the reference point of F/F_{msy} = 1, meaning that the tomtate is also likely experiencing overfishing.

Table 36. TT: Reference point estimates for the base model run including upper and lower bounds of an 80% confidence interval from the surplus production model of the tomtate from the U.S. South Atlantic.

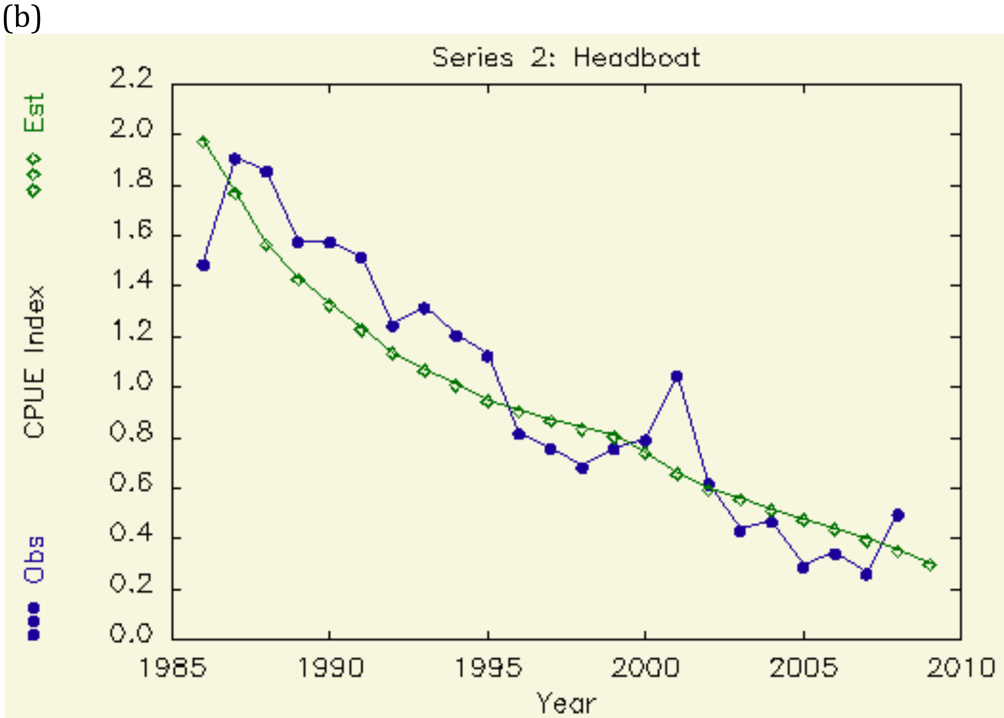
Reference Point	Base Case estimate	80% LCB	80L% UCB
B_{2009}/B_{MSY}	0.268	0.186	0.434
F_{2008}/F_{MSY}	5.69	3.48	16.9

(a)



Series 1: Combined Index & Landings
CPUE Index
Obs
Est
Year
3500
3000
2500
2000
1500
1000
500
0
1985
1990
1995
2000
2005
2010

(b)



Series 2: Headboat
CPUE Index
Obs
Est
Year
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1985
1990
1995
2000
2005
2010

(c)

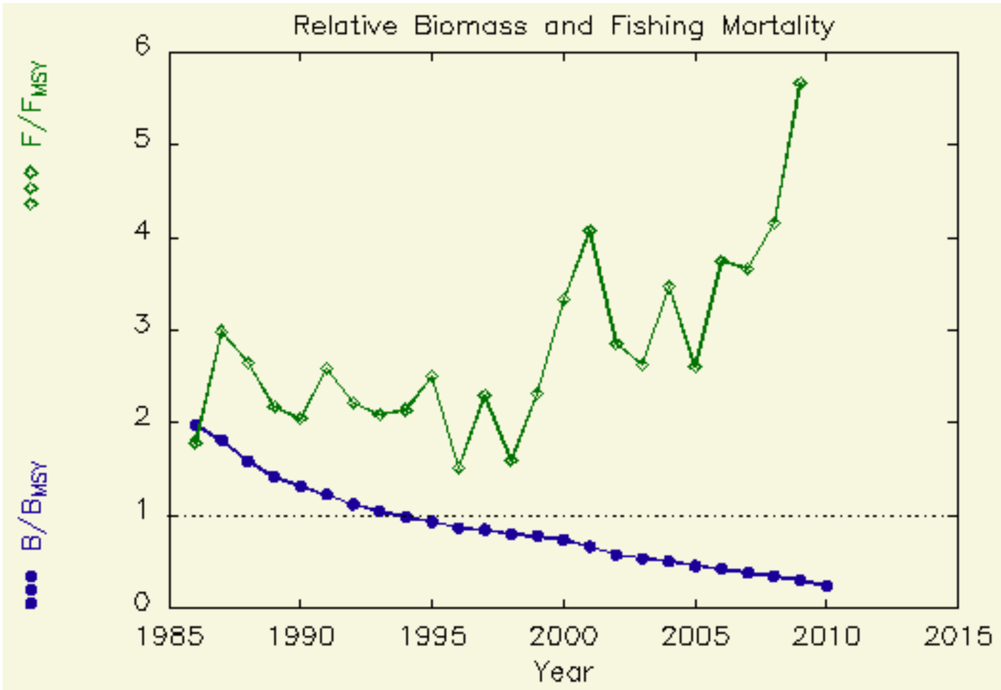
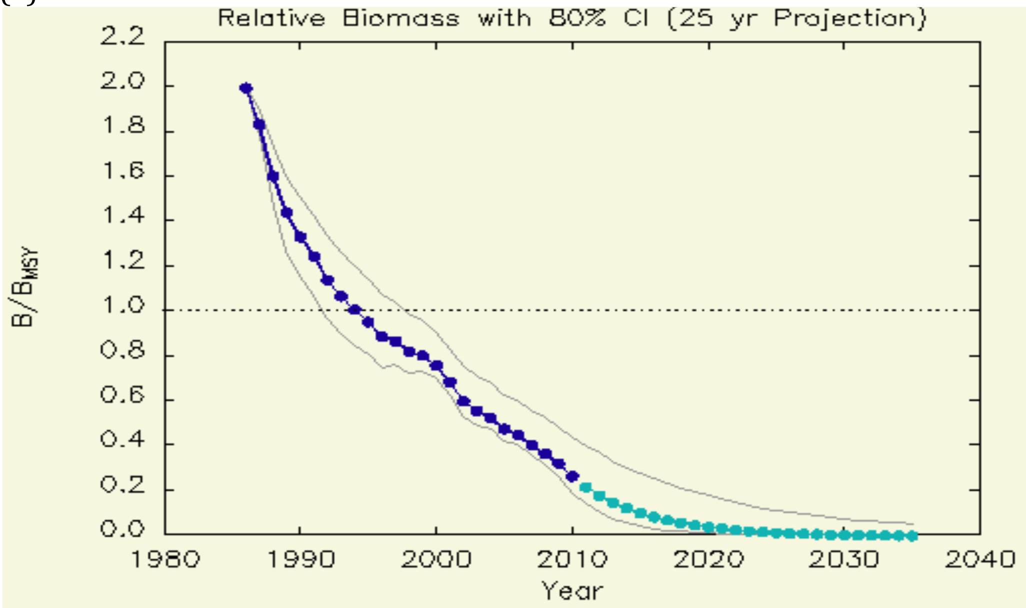


Figure 64. TT: Surplus production model based on US South Atlantic landings, an index from MARMAP, and an additional index from headboat data. (a) Fit of model to MARMAP biomass CPUE index. (b) Fit of model to headboat biomass CPUE index. (c) Estimates of reference points B/B_{msy} and F/F_{msy} from 1986 to 2009.

Management Projections

Projections 25 years into the future under two alternative management scenarios were run using ASPIC. In one case, the goal was to determine how the population would likely react if the fishing pressure present in 2009 was kept constant for the next 25 years. As can be seen in Figure 65 (a), the result of keeping fishing pressure at the 2009 levels, leads the population on a continual decrease to extremely low levels. In the other projection *F* was set to zero for the entire projection simulating a closed fishery. Figure 65 (b) shows that it would likely take the population approximately 20 years to reach a value of B/B_{msy} equal to one.

(a)



(b)

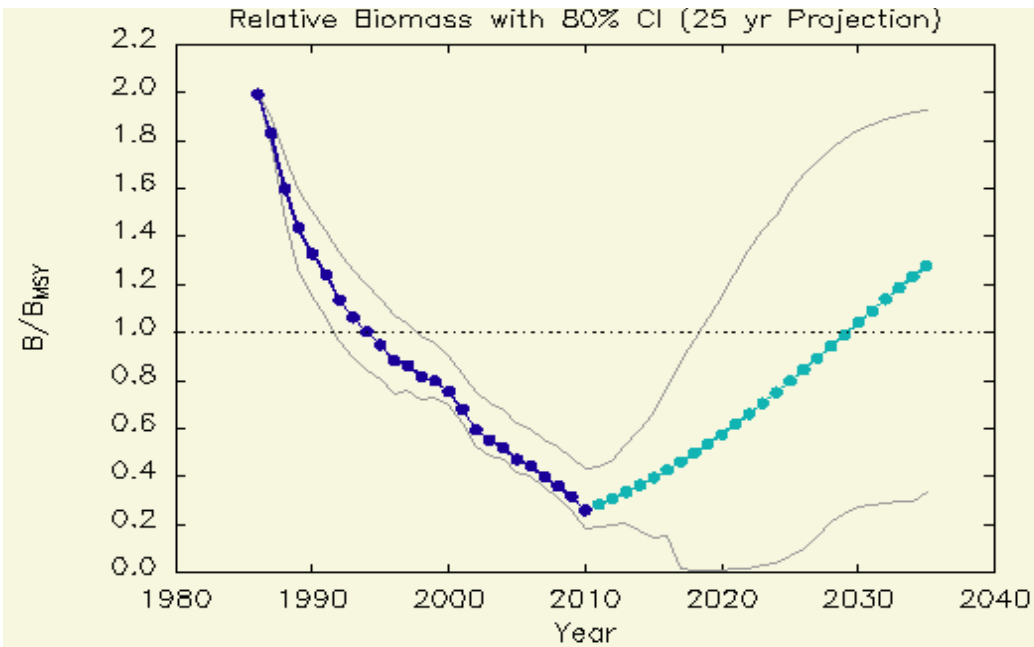


Figure 65. TT: Projections 25 years into the future, including the corresponding 80% confidence intervals. (a) Projection done with *F* kept at the 2009 level for the entire projection. (b) Projection with *F* = 0 for the entire projection.

If we assume the catch data are correct, then it is likely the south Atlantic tomtate population is overfished and currently experiencing overfishing. These results rely on the total catch data input to the model, which is quite uncertain due to the problems with the commercial catch data described above. As a result, these results should be viewed as preliminary until a more thorough reconstruction of the catch data is completed. Nonetheless, if the proportion of catch reported has remained stable, production-model results can still be reliable.

Summary of Stock Status

The catch curve analysis allowed us to calculate a Z value (fishing and natural mortality rates combined). Because only four years were available to create a catch curve and because those years experienced an anomaly in stock conditions, the calculated fishing mortality rate most likely does not represent the current conditions of the stock. As calculated YPR reference points are based on the life history data of the tomtate, their results should still stand in the future.

The surplus production model shows a B/Bmsy value of less than 0.5 and an F/Fmsy of over one. The first implies that even in the most conservative guidelines for determining an overfished species, the tomtate appears to be overfished. The second implies that the species is also likely currently undergoing overfishing. Both the fisheries independent (MARMAP) and the fisheries dependent (headboat) indices show a decreasing trend in catch per unit effort, strongly suggesting the population has seen a substantial decline and likely driving the results of the surplus production model. According to projections, the population is likely to decrease further if current fishing pressure is maintained and would likely take approximately 20 years to reach B/B_{msy} of one if fishing mortality rate (F) was set to zero.

Caution is warranted in interpreting these results as a number of problems were identified with the commercial catch data available for use in the assessment, as described above. The analysts recommend that these results be viewed as preliminary and that additional effort should focus on reconstructing the commercial catch data, both landings and discards, before any future assessment takes place.

Research Needs

This assessment was greatly limited by the availability of data, and the greater the uncertainty in the data, the greater the uncertainty in the result. Fisheries independent data can alleviate some of the uncertainties inherent in population modeling. With more fishery independent data, more can be known about the tomtate's life history such as its maturity for yield-per-recruit analysis and better age structured data for more comprehensive catch curve analysis. Also, a better method for reconstructing the history of tomtate caught in the commercial fishery would allow for a more accurate surplus production analysis of the stock. Species misidentification and misclassification are a large part of that problem. With more data collection and research a complete assessment of the tomtate may be done with more advanced assessment techniques.

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