Evaluation of Multiple Survey Indices in Assessment of Black Sea Bass from the U.S. South Atlantic Coast

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*Abstract

The age structure and status of the U.S. southern Atlantic stock of black sea bass were examined using recorded and estimated landings and size frequencies of fish taken from commercial, recreational, and headboat fisheries during 1979-1995. Fishery independent data were obtained from the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program for calibrating virtual population analysis (VPA). MARMAP collected black sea bass with four gear types: hook-and-line (1979-1995), blackfish trap (1979-1989), Florida snapper trap (1980-1989), and chevron trap (1988-1995). Reduced effort with the hook-and-line gear in 1988 coincided with reduced catch per effort (CPE). The size fraction of fish captured with chevron trap was similar to the Florida snapper trap, but dissimilar to the blackfish trap. Hence, an extended time series of CPE was developed combining the Florida snapper and chevron traps. We examined the effect of different combinations of CPE indices (individually and in combination) on estimates of fully recruited fishing mortality, spawning stock biomass, and spawning potential ratio using the FADAPT VPA approach.

*Introduction

Black sea bass, Centropristis striata, also called blackfish, is a serranid that inhabits continental shelf waters in depths of 2-120 m, predominantly between Cape Canaveral, Florida, and Cape Cod, Massachusetts (Mercer 1989). Two populations are thought to occur along the Atlantic coast, separated by Cape Hatteras, North Carolina (Mercer 1989, Shepherd 1991). This study is concerned only with the southern population.

Spawning of black sea bass occurs during January through June along the U.S. southern Atlantic coast, peaking during March to May (Mercer 1989, Wenner et al. 1986). Black sea bass are protogynous hermaphrodites, but mature males occur in all age groups (Vaughan et al. 1995, Table 1). Sex ratios and female maturity schedules were summarized by Vaughan et al. (1995). Because fish undergo sexual transition from female to male during a short period of time (weeks to a few months), the transitional stage was combined with males for calculation of sex ratios used in the analyses that follow.

In this study, we investigated the use of fishery-independent indices from the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program for calibrating virtual population analyses. The MARMAP program collects fishery independent data from the South Atlantic Bight using a stratified random design. Because specific trapping gear types were not consistent over the entire study time period, a greater sampling duration was attained by extending backwards the current trap gear (chevron). We then analyzed the black sea bass catch matrix (from Vaughan et al. 1996) using a calibrated virtual population analytic (VPA) approach with various combinations of the MARMAP gear indices. VPA output included estimates of fully-recruited fishing mortality (ages 4-7), spawning stock biomass (both sexes combined), and spawning potential ratio (SPR). Because black sea bass are protogynous (transforming from females to males) and the effect of changes in population abundance on sex transformations is unknown, spawning potential ratio was based on total mature biomass.

*MARMAP Gear Comparisons

The Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program has collected fishery independent reef fish data off the southeastern U.S. Atlantic coast since 1979. Evolution of the MARMAP sampling design was thoroughly described by Harris and McGovern (1997). Briefly, standard MARMAP sampling was conducted during daylight from May through August between Cape Fear, NC and Cape Canaveral, FL. Gear used included blackfish traps (1979-1989), Florida snapper traps (1980-1989), chevron traps (1988-present), and hook-and-line (1979-present) (Collins and Sedberry 1991). Fishing effort (soak time and bait type/amount for traps; angling time, bait type/amount, and terminal tackle for hook-and-line) was standardized for all gear types. Efficiencies of the three trap types were compared during 1988-1989, and use of blackfish and Florida snapper traps was discontinued in 1990 because the chevron traps sampled a greater species diversity (Collins 1990; design and construction of the traps also presented). Samples were randomly collected from four broad areas of live bottom (identified with underwater TV) during 1979-1987. Since then, sampling has been on a stratified (by latitude) random basis, with 300-600 sites/yr randomly chosen from a data base of over 2,500 known live bottom locations.

Black sea bass were measured (total and standard lengths), and sagittal otoliths were removed and stored dry. For each year (1979-1995) the commonly sampled sizes (150-259 mm TL) were divided into 10-mm TL classes and 16-26 individuals were randomly subsampled. All individuals larger than 259 mm TL or smaller than 150 mm TL were examined since these individuals were infrequently encountered. The number of black sea bass aged for each year was approximately 400. Otoliths were placed in water and read whole with transmitted light using a Nikon SMZ-2T dissecting microscope. Ageing was done without prior knowledge of the size of the fish or the date of capture. If the two readers disagreed on an age or considered the otolith unreadable, that fish was deleted from analyses. Wenner et al. (1986) used marginal increment analysis to validate the annual nature of increments on black sea bass otoliths.

Declines in catch per effort (CPE) were noted in indices based on MARMAP sampling using hook-and-line and traps (Fig. 1a-b). There was a precipitous decline in hook-and-line CPE during 1987 and 1988, when sample sizes per gear were reduced for comparison sampling while introducing new trapping gear (chevron). Less drastic declines were noted in blackfish trap and Florida snapper trap CPEs during the middle to late 1980's. Unfortunately, both of these indices were discontinued after 1989, while the use of the chevron trap began in 1988. All three trap gear types were fished synoptically during 1988-1989.

Development of an extended trap gear to represent the whole time period was needed for greater comparison of a calibration index with the earlier, converged portion of the virtual population analysis. Recent indices of short duration can have a great impact on VPA estimates, because they occur primarily during the unconverged portion of the VPA (Vaughan et al. 1988). However, without demonstrating some correspondence to the converged portion of the VPA, it is difficult to judge the usefulness of the index as a calibration tool.

The question arises as to which historical trap gear (blackfish or Florida snapper trap) should be used to extend backward the duration of the chevron trap? The cumulative total length frequencies for the two years of overlap (1988-1989) for the three trapping gear types (Fig. 2a-b), showed considerable similarity between the chevron trap and the Florida snapper trap, but not between the chevron trap and the blackfish trap.

Kolmogorov-Smirnov-Type nonparametric tests (Conover 1971) allow comparisons among the maximal difference between cumulative (length) distribution functions. The observed maximal differences among gear types and between years were summarized (Table 1). To compare these differences to the appropriate values of the Smirnov Test Statistic (Table 17 in Conover 1971), it was necessary to apply Bonferroni's correction, because of inflation of α (level of significance) with the conduct of multiple 'independent' tests ($\alpha' = \alpha/n$, where n is the number of independent test). Since seven tests were conducted, an overall Type I error (α) of about 0.035 resulted from seven individual test statistics (α') based on (0.005). The large sample approximation for the Smirnov Test Statistic was $s[(m+n)/mn]^{1/2}$ where s = 1.63 for $\alpha' = 0.005$ and s = 1.22 for $\alpha' = 0.05$. These comparisons suggested that the chevron length frequency was different than the blackfish length frequency for each year, and different from the Florida snapper length frequency during 1988 (Table 1). All between year comparisons (1988-1989) indicated no significant differences within gear types at α=0.005, but at α = 0.05 differences were suggested between years for the Florida snapper trap.

All of the between gear differences may not have been biologically significant when comparing between gear differences to within gear (year-to-year) differences. Relatively large sample sizes available for length frequency comparisons allow one to detect small, but statistically significant differences between length frequency distributions. Analogous to Helser (1996), we used a bootstrap approach to determine whether differences between different gear types exceeded differences from natural variability between the two years for which concurrent data were available. By sampling repeatedly with replacement (1000 bootstrap experiments), we reconstructed the original data sets. The median values of maximal differences from the 1000 bootstrap experiments are summarized (Table 1). A second series of simulations (of 1000 bootstrap experiments) was conducted for which sampling with replacement was from gear data pooled across years, and then randomly resorted between the two years for each gear. Again, the median values of maximal differences from the 1000 bootstrap experiments are summarized (Table 1). We then visually compared the maximal difference between cumulative length distributions between years of the same gear to maximal differences between gear types in the same year (Fig. 3a-b; blackfish-chevron traps and Florida snapper-chevron traps, respectively). We noted a large separation between within gear maximal differences (between years for same gear) and between gear maximal differences when comparing chevron with blackfish trap, suggesting real differences between the sampling properties of these two gears. However, the large overlap among maximal differences when comparing chevron with Florida snapper trap, suggested that differences between years for the FL snapper and chevron traps exceeded differences between the two traps for each year.

Hence, we concluded that the Florida snapper trap CPE could serve as the basis for extending the chevron trap CPE to include the earlier time period of 1980-1987 (Fig. 1b). The conversion was accomplished by multiplying Florida snapper trap CPE in numbers at age by 2.96 (Collins 1990, with additional samples).

*Calibrated Virtual Population Analyses

The catch-at-age matrix was developed from landings (commercial, recreational, and headboat) and corresponding length frequency sampling by fishery and gear for 1979 through 1995 using annual age-length keys developed from MARMAP sampling of similar gear types (traps and hook-and-line) as described in Vaughan et al. (1996) (Table 2).

The analytic program calibrates the virtual population analysis (VPA) to fishery independent indices of abundance (Pope and Shepherd 1985). Specifically, FADAPT [modified from ADAPT (Gavaris 1988) and described in Restrepo (1996)] was the calibration-based VPA program used to analyze the above described catch-at-age matrix with various combinations of the MARMAP CPE indices:

1) Four gear CPE indices,

2) hook-and-line CPE only,

3) three trap CPE indices,

4) chevron trap CPE only,

5) extended chevron trap CPE only, and

6) extended chevron trap and hook-and-line CPE.

The first combination uses all four indices separately in a single run. The second combination considers only the hook-and-line gear, while the following three combinations consider only trap gear. The final combination considers the extended chevron trap gear and hook-and-line together.

Virtual population analysis sequentially estimates population size and fishing mortality rates for younger ages of a cohort from a starting value of fishing mortality for the oldest age. An estimate of natural mortality, usually assumed constant across years and ages, is also required. We used the FORTRAN program for separable virtual population analysis (SVPA) developed by Clay (1990) to estimate the selectivity pattern for recent years to serve as input to the FADAPT runs. For the SVPA runs, starting values of F were based on the mean of the final three year class (1987-1989) estimates of Z (1.0 yr^{-1}) and final F obtained by subtracting M from Z.

The output from the calibrated FADAPT VPA considered in this study (Figs. 4-5) included full F (weighted mean over ages 4-7), spawning stock biomass (SSB), and spawning potential ratio (SPR). Most biological reference points used as targets or overfishing thresholds in fishery management in the United States are based on these variables (Mace and Sissenwine 1993, Mace 1994, Rosenberg et al. 1994).

The age-specific estimates of F for ages 4-7 were weighted by catch in numbers at age to obtain full F. Spawning stock biomass was calculated from mean weight at age by year multiplied by the number of fish and by the percent mature males and females. Spawning potential ratio (SPR) compares spawning stock biomass per recruit with and without fishing. All other life history parameters are usually held constant (e.g., maturity schedule and age-specific sex ratios) in calculating SPR, so the estimate of SPR increases as fishing mortality decreases.

Full F, SSB, and SPR from the FADAPT runs with different sets of CPE indices were compared (Figs. 4-5). As noted above, the starting partial recruitment vector for the FADAPT runs was based on an SVPA run for the period 1990-1995 (this minimized the coefficient of variation based on several SVPA runs of varying duration with final year of 1995).

First, we compared FADAPT runs calibrated to all four indices (hook-and-line and 3 separate unexpanded traps), three separate unexpanded trap indices, and the hook-and-line index only (Fig. 4). The FADAPT run calibrated to the hook-and-line index suggested a considerable increase in full F and moderate decline in SPR in 1995 as compared to FADAPT runs calibrated with the trap indices. Although full F and SPR showed no temporal trend, SSB declined after 1987. The slight increase in SSB in 1992 may have been associated with the introduction of a minimum size limit that year.

Next, we compared FADAPT runs calibrated to the chevron trap indices (unexpanded, expanded, and combined with hook-and-line) (Fig. 5). The FADAPT run calibrated to the unexpanded chevron index suggested much lower full F and higher SPR in 1995 as compared to FADAPT runs calibrated with the expanded chevron trap index (with or without hook-and-line). Again, although full F and SPR showed no temporal trend, SSB declined since 1987.

Model error (MSE) from FADAPT was minimized by use of all gear separately (0.067), with similar model error using only trapping gear (0.071) (Table 3). Downweighting by FADAPT of the hook-and-line CPE was apparent when all gear CPEs were used (9.3%) and relatively high weight given to the recent, short chevron CPE (46.6% for all four gears and 52.3% for all three trap gears). Some of the spiky aspect of the Florida snapper trap CPE (Fig. 1) probably resulted in its smaller weighting when all four gear types were used (13.8%) and when all three trap types were used (14.9%). Using only hook-and-line CPE gave highest model error (0.695). As expected, model error was greater for the extended chevron trap CPE (0.317) than for the chevron trap CPE alone (0.133). As the chevron trap CPE was extended backwards using the Florida snapper trap, any lack of agreement with the converged portion of the VPA would tend to increase MSE. Combining the extended chevron trap CPE (68.6%) and hook-and-line CPE (31.4%) in the calibration gave a value for MSE (0.221) less than the two indices used alone, although the residual sum of squares was intermediate.

*Discussion

The blackfish trap CPE was inappropriate for extending the chevron trap CPE, because it had different selectivity properties from the other gear types. Differences in selectivity between the Florida snapper trap CPE and chevron trap CPE were less than or of the same magnitude as annual differences in selectivity by these gear types. Hence, the Florida snapper trap CPE provided a useful surrogate for extending the chevron trap CPE, because it had essentially the same selectivity properties.

The hook-and-line CPE suggested greater full F, and smaller SSB and SPR than indicated by the trap indices. Furthermore, the extended chevron trap CPE (1980-1995) demonstrated greater full F, and smaller SSB and SPR than indicated by the chevron trap CPE (1988-1995). The longer time period for calibration permited better historical comparison between the catch matrix (as represented by the converged portion of the VPA) and the CPE index. The trend in the extended chevron trap CPE agreed well with the trend noted in the hook-and-line CPE, and, in particular, confirming the sharp decline in CPE between 1987 and 1988 noted earlier in the MARMAP hook-and-line CPE index for black sea bass.

Although model error (mean squared error) was lowest for the FADAPT run using all indices separately (without extending chevron trap CPE), it was not necessarily the preferred run. Some of the reduction in model error was obtained by giving greater weighting to the recent, short duration chevron CPE which has fewer years to compare to the converged portion of the VPA. Hence, the true uncertainty associated with the chevron CPE index may have been underestimated. By using the extended chevron CPE with the hook-and-line CPE, uncertainty associated with the longer CPE index better represents the uncertainty inherent with the model fit and the information content of the MARMAP program was more fully used in analyzing the status of the black sea bass stock.

Although no major trends were noted for full F (and hence SPR) in all FADAPT VPA runs with different calibration indices, all FADAPT VPA runs suggested a significant decline in SSB since 1987.

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Table 1. Maximum differences (observed and bootstrap) and Smirnov test statistics for length frequency comparisons among gear (blackfish, Florida snapper, and chevron traps) and between year (1988-89) from MARMAP data. Sample sizes listed in parentheses under comparison variable. Note: * indicates Smirnov test significant at 0.05 level, and ** indicates Smirnov test significant at 0.005 level for individual test.

Gears	Year	Maximum Differences			Smirnov Statistic[c]	
		Observed	Boot[a]	Boot[b]	α=0.005	α=0.05
Blackfish	1988-89 (243,176)	0.060	0.087	0.056	0.161	0.121
Florida Snapper	1988-89 (401,152)	0.135*	0.146*	0.052	0.155	0.116
Chevron	1988-89 (974,669)	0.059	0.062*	0.028	0.082	0.061
Blackfish-Chevron:						
(243,974)	1988	0.371**	0.372**	0.331**	0.117	0.087
(176,669)	1989	0.278**	0.287**	0.331**	0.138	0.103
FL Snapper-Chevron:						
(401,974)	1988	0.105**	0.109**	0.097**	0.097	0.072
(152,669)	1989	0.063	0.083	0.104	0.147	0.110

[a] Median from 1000 bootstrap simulations with years separate.

[b] Median from 1000 bootstrap simulations with years pooled, then reconstructed.

[c] Individual test based on $\alpha = 0.005$, overall test based on seven independent tests (Bonferroni's theorem) is $\alpha = 0.035$.

Table 2. U.S. southern Atlantic black sea bass catch-in-numbers-at-age (in thousands) matrices for ages 1 through 8+ (and total numbers) and years 1979 through 1995. Total catch in weight (thousands of pounds) are also presented. Note that 5% of catch-release recreationally caught fish (type B2 fish from MRFSS) are included in estimates by number (modal age underlined).

Year	Age (yr)									Number	Weight
	0	1	2	3	4	5	6	7	8+	(1000)	(1000 lbs)
1979	2.4	303.2	1381.4	1250.2	710.5	360.2	229.2	54.7	19.1	4310.9	2433.2
1980	7.8	160.3	799.1	1715.1	1016.9	321.3	149.5	34.3	30.6	4234.9	3585.6
1981	6.4	232.4	632.2	819.7	729.3	278.2	83.9	29.9	11.6	2823.4	2285.0
1982	6.0	246.8	1213.9	1539.7	1236.1	264.0	95.6	17.5	3.9	4623.6	2888.4
1983	3.0	293.0	795.7	837.5	522.5	206.8	22.6	3.8	1.2	2686.0	1853.5
1984	5.8	54.5	388.6	1098.2	1298.4	436.3	139.7	10.6	1.9	3434.0	2802.1
1985	23.8	350.4	616.7	984.6	791.4	240.7	42.5	3.0	1.0	3054.3	2136.6
1986	0.0	126.5	891.6	547.4	505.4	270.5	52.6	9.2	2.2	2405.4	1746.3
1987	0.0	228.0	686.0	1012.7	512.6	252.3	67.5	23.6	1.9	2784.7	2252.8
1988	3.3	71.8	727.4	1024.1	1122.3	397.4	124.0	47.2	5.1	3522.5	2918.4
1989	4.4	83.0	470.5	1191.6	1010.5	395.5	74.9	17.6	9.1	3257.0	2483.2
1990	0.0	38.9	556.9	1134.3	685.1	329.2	124.8	32.5	6.8	2908.5	2021.9
1991	0.0	52.2	637.9	1001.5	505.6	275.9	72.2	14.0	6.0	2565.1	2002.1
1992	0.0	11.2	489.1	893.9	491.8	316.2	74.7	4.8	8.6	2290.3	1659.5
1993	0.1	25.0	383.0	829.5	344.9	184.4	59.5	6.0	6.8	1839.3	1440.3
1994	0.0	10.4	183.3	397.3	832.8	217.6	116.8	15.8	7.2	1781.3	1567.7
1995	0.0	8.4	219.8	411.5	336.0	309.1	111.8	8.7	5.0	1410.3	1324.6

Table 3. Sample size (n), residual sum of squares (RSS), and mean squared error (MSE) from FADAPT runs for black sea bass with various combinations of calibration indices. Weightings for MARMAP indices estimated by FADAPT: (1) 0.093 for hook-and-line, 0.303 for blackfish trap, 0.138 for Florida snapper trap, and 0.466 for chevron trap; (3) 0.327 for blackfish trap, 0.149 for Florida snapper trap, and 0.523 for chevron trap; and (6) 0.314 for hook-and-line and 0.686 for extended chevron trap.

FADAPT Run	Sample Size	RSS	MSE
1) All Gears	46	3.098	0.067
2) Hook-and-Line Only	17	11.823	0.695
3) All Trap Gears	29	2.072	0.071
4) Chevron Trap Only	8	1.066	0.133
5) Extend Chevron Trap Only	16	5.076	0.317
6) Hook-and-line and Extended Chevron Trap	33	7.295	0.221

*Figure Legends

Figure 1. Comparison of CPE from MARMAP indices of black sea bass abundance from a) trap gears and b) extended chevron trap and hook-and-line gears.

Figure 2. Comparison of black sea bass cumulative length frequency data from MARMAP traps [blackfish (BFT), Florida snapper (FST), and chevron (CHV)] for a) 1988 and b) 1989.

Figure 3. Comparison of bootstrapped maximum differences in black sea bass cumulative length frequency data from MARMAP traps for 1988-89 between a) chevron-blackfish traps, and b) chevron-Florida snapper traps. Year identity is maintained in these bootstraps.

Figure 4. Comparison of full F, SSB, and SPR for black sea bass for MARMAP CPE indices: a) hook & line and 3 individual unexpanded traps, b) 3 individual unexpanded traps, and c) hook & line using FADAPT method.

Figure 5. Comparison of full F, SSB, and SPR for black sea bass for MARMAP CPE indices: a) unextended chevron trap, b) extended chevron trap, and c) hook & line and chevron trap using FADAPT method.