Sex and maturity of black sea bass collected in Massachusetts and Rhode Island waters; preliminary results based on macroscopic staging of gonads with a comparison to survey data

A working paper for SARC 53- Black Sea Bass Data Meeting

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Introduction

Black sea bass (*Centropristis striata*) are protogynous hermaphrodites, with most individuals maturing first as a female before changing sex to male later in life (Wenner et al 1986). This life history characteristic poses unique challenges for management of the species (Shepherd and Nieland 2010), and requires accurate information/understanding of the sex ratios and the size at which sex changes. Several studies have described salient aspects of black sea bass life history, however these have largely been limited to populations in the South Atlantic Bight (SAB) and Gulf of Mexico (Mercer 1978, Wenner et al. 1986, Hood et al. 1994, McGovern et al 2002). Although black sea bass north of Cape Hatteras, NC are considered part of a single fishery management unit, focused life history studies on more northern portions of the population are lacking. Given greater migration distances and larger sizes attained by the northern stock component 'borrowing' of data from southern populations may be inappropriate. To reduce uncertainties in management of this population requires accurate estimate of sex ratios and size at sexual transition for this population. The need for more current and detailed (histology based) life history information for the northern component of the stock is currently being addressed in a cooperative research funded project ('A histology- and otolith-based study of black sea bass (Serranidae: *Centropristis striata*) life history in southern New England', Dr. K. Oliveira, R. Jorgensen UMASS Dartmouth). However, the scheduling of SARC53 necessitates reporting preliminary data to address questions about sex ratios of black sea bass in the northern management unit. Specifically, there is an apparent conflict of this species characterized as a protogynous hermaphrodite but that small and young males are evident in the NEFSC groundfish survey database. Namely, how likely are these small males misspecified by macroscopic methods used in routine survey operations? This working paper documents in detail the macroscopic method of identifying sex and maturity class of black sea bass, and although it does note that criteria for identifying active sex change needs further clarification, it also confirms that small males in survey data are real and should be accounted for in modeling of sex ratios.

Methods

Fish were obtained from two sources; the Massachusetts Division of Marine Fisheries (MA-DMF) inshore trawl survey (spring, May; and fall, September) and Research Set Aside (RSA) funded fishery independent scup survey of hard bottom areas in southern New England waters (MA and RI; June, August and October). Subsamples of fish from both sources were selected to cover the size range encountered, kept on ice, transported to the Woods Hole laboratory and processed the same or following day. A total of 217 black sea bass were processed from May to October, 2010 (Table 1). Fish were measured (total length in mm, total weight in grams, gonad and liver weight) photographed, and the gonads were dissected and photographed on a copy stand. A gonadosomatic index (GSI) was calculated as 100*(gonad weight/gonad free body weight). Gonadal tissue samples were preserved for histological analysis but these aspects of the research are ongoing and not presented here. Scales and otoliths were removed from fish for age determination following procedures outlined in Penttila and Dery (1988).

This working paper describes only the macroscopic maturity staging of these samples. Although the macroscopic staging may be less accurate and/or precise than histology-based determinations, individuals experienced in macroscopic assignment of fish maturity processed these samples in the laboratory. In addition, the authors convened to review the high-resolution photographs taken of each fish. Images were projected on a large screen, examined at higher magnification if necessary, discussed and consensus sex and maturity classifications were assigned. This approach may be considered intermediate to at-sea staging on resource surveys (that cannot be reviewed or revisited) and the more definitive gonad histology based approach currently underway. To accommodate sex change in this protogynous hermaphrodite, we included transitional and unknown classifications for individuals whose sex was ambiguous (Table 2). In the present analysis, transitional and unknown fish are combined into a single sex category, as there are no clear macroscopic criteria for the transitional stage yet. The histological analysis may help resolve the classification of transitional fish; however, this preliminary analysis of macroscopic criteria is applicable during and immediately following the late spring to summer spawning season when sex is more apparent and less likely to be in transition.

The sex ratio (percent male) was modeled as a function of length (or age) using a four parameter logistic regression model.

$$f(Length) = c + \frac{d - c}{\left(1 + \exp\left(b(Length - e)\right)\right)}$$

Where *Length* is fish total length (or age) and the parameter *e* is the length (or age) halfway between the upper (*d*) and lower (*c*) asymptotes, and *b* denotes the slope around *e*. In this model both the upper and lower asymptotes are fitted (not fixed) allowing for estimation of non zero lower asymptote as well as upper asymptote different than 100 percent. All models were fitted using the 'drm' function in the 'drc' add-on package for the language and environment R (R Development Core Team 2004). To evaluate the potential influence of data density and variability, models were fitted to sex ratios binned by 1, 2, 3, and 5 cm length categories. Age classes were not binned beyond annual age.

Sex at length data were summarized for the period 1984-2010 from NEFSC and MADMF trawl surveys. Results of the monthly sampling (below) indicated some uncertainty in determining sex in the fall, therefore we limited our analysis to spring surveys. This survey data was modeled using the same approach as above (four parameter logistic model). Macroscopic determination of sex in small fish is difficult, therefore we limited our analysis to fish > 15 cm. Two models were fit; with percent male binned by either 1 or 2 cm length categories.

Results

A wide range of fish sizes (19-59 cm total length) and maturity stages (developing, ripe, running ripe, spent and resting) were sampled over the six month period (Figs. 1-3). Four individuals analyzed were considered to be immature (19.4, 20.0, 20.6, 27.5 cm TL), and these were all classified as females. Mature male and female black sea bass were easily distinguished macroscopically during the spawning season, when ovaries and testes were developing or ripe and GSI was high (Figs. 1 and 4). Review of the high resolution photographs resulted in changing the sex classification for 10 of the 217 fish examined (4.6%), all associated with changing to or from the transitional class. Nine were initially classified as transitional/unknown but during the review and discussion process we were able to assign an agreed upon sex (4 female, 5 male). One individual was classified as a female during the initial workup, but upon review was changed to transitional/unknown. During the consensus review process, no fish sex classifications were changed from the May and June samples, three individuals collected in August were changed, two in September, and 5 were changed in October. Individuals classified as transitional/unknown had low GSI and occurred from August- October, well after the peak spawning season (Fig. 2).

Across all months, the size distribution of males was greater than that for females, with a large region of overlap (Fig. 3). Small males (<40cm) occurred in all months sampled. Fits of the four parameter logistic model indicated a significant non-zero (c = 19.7-22.9; Appendix 1) percentage male at smaller size classes. The different binning approaches resulted in similar fits, however only the 1 cm bin model had a significant slope parameter (b), possibly due to the abrupt change predicted in the other models. All models had similar estimates for the inflection point (e = 43.4-44.0) and upper limit (d = 100.1-101.2).

Female ages ranged from 1 to 7 years while male ages ranged from 2 to 12 years (Fig. 6). Thus, age classes 2 to 7 were comprised of both sexes, with an increasing percentage male after age 6 or 7. Fits of the four parameter logistic model indicated a significant non-zero (c = 19.9; Appendix 2) percentage male at younger age classes. This model indicated a significant inflection at about age 7 (e = 6.96) and an upper asymptote near 100 percent (d = 104.6).

The spring survey data (NEFSC and MADMF; 1984-2010) showed similar patterns in percentage male vs. length (Fig 7). Although sample size was large for this dataset (1061 males and 2386 females) sample sizes were generally small at for length bins greater than 50 cm. Two models were fit with length data binned at 1 and 2 cm intervals. Fits of the four parameter logistic models indicated a significant non-zero (c = 24.6, 22.8; Appendix 3) percentage male at smaller size classes. The different binning approaches resulted in similar fits, however only the 2 cm bin model had a significant slope parameter (b). Both models had similar estimates for the inflection point (e = 42.8, 45.6). The estimates for the upper limit were variable (d = 81.0, 95.1), influenced by the low data density at larger sizes.

Discussion

Despite being regarded as sequential hermaphrodites, in most cases the sex of black sea bass was readily identifiable macroscopically, and few individuals were reclassified (10 of 217) after reviewing images and consulting others experienced with this and other hermaphroditic species. Of these 'reclassified' fish, most (9 of 10) were initially identified as transitional/unknown, therefore they should not be considered misclassifications. Difficulty in determining sex increased after the spawning season (August – October), when fish had low GSI and sexual transition is thought to occur (Mercer 1978, Wenner 1986).

As in other studies on black sea bass elsewhere, we observed males across the full length range of mature fish analyzed. In the Gulf of Mexico, Hood et al. (1994) estimated close to 20% percent males at smallest mature sizes. Similarly, Wenner et al. (1986) reported the presence of ~3% mature males at small sizes. Both of these populations (GOMEX and SAB) mature at smaller sizes than the northern population studied here that attains greater sizes (Gulf of Mexico, Hood et al. 1994; South Atlantic Bight, Wenner et al. 1986, McGovern et al. 2002). Only four individuals analyzed were considered to be immature (19.4, 20.0, 20.6, 27.5 cm TL), and these were among the smallest individuals analyzed in the present study. The low number of small and immature fish precluded more detailed analysis of size at maturity.

The approach we used to confirm macroscopic classification of sex, reviewing high resolution images, is intermediate to the more definitive classification possible via gonad histology and the macroscopic classifications made at sea by scientists of varying experience levels whose classifications cannot be reviewed (the fish go overboard and no images are taken). While pictures are less ideal than evaluating the fresh specimen, they provide the opportunity to consult others who may not have been present during the initial processing of samples. Thus, data resulting from a consensus review may be considered to be more precise and accurate than routine macroscopic classifications. The images were of high enough quality to allow us to zoom in on specific regions of the gonad and when reviewed by the entire group we agreed with nearly all of the initial classifications. In addition, we were able to classify difficult samples that were initially classified as unknown. The images also provide a permanent record that can be revisited in the future as needed (if new macroscopic classification schemes are developed). More detailed histological analyses of gonad samples from these and other collections is needed to verify the preliminary conclusions presented here.

Analysis of spring survey data from both NEFSC and MADMF surveys for the period 1984-2010, collected over a broad geographical region showed similar patterns of percentage males at length we estimated from a more localized region in 2010. Models fit to these datasets both indicated about 20 percent male at smaller sizes, and an inflection near 42-45 cm. The slope of the survey time series is more gradual, possibly influenced by differences in size at transition occurring over time. Additionally, this more gradual pattern may be the result of averaging of data over a large region, where transition points differ regionally. Similarly, the estimate of the upper asymptote is likely influenced by averaging across broad geographic scales, since the presence of larger sized females in some portion of the range will pull down the percentage male at large sizes across the entire range.

The results from these datasets of macroscopic sex classifications, one determined by a 'panel' of experienced biologists and the other larger dataset determined by many individuals with varying experience levels (novice-expert) both indicate approximately 20 percent males throughout most of the mature size and age distribution. Similar estimates have been determined from the NEFSC and MADMF spring surveys (Shepherd and Nieland 2010) however, the accuracy of the sex classifications on the surveys was not evaluated. We did not observe any indication of sexual transition in individuals collected during the spawning season. Several caveats should be considered with respect to the estimates of the size at transition (and the estimated inflection point e). First, samples were pooled over a six month period, during which time significant growth occurs. Secondly, the parameter e, represents the halfway point between the two modeled asymptotes and not 50% (i.e. for the 1 cm bin model, the length 43.8 has a percent male halfway between 22.9 and 101.2). The present study provides supporting evidence for the presence of significant numbers of males at small sizes, and demonstrates that sex determination of mature black sea bass by macroscopic examination during the spring is reliable.

Research recommendations

1. Very few immature and age 1 fish were collected in the sampling done in 2010, precluding detailed evaluation of first maturity. A detailed characterization of these sizes and ages, both macroscopically and microscopically (histological) is needed to determine developmental pathways and functionality (or viability) of small males.

2. Although the percentage male appears relatively constant at small sizes and young ages, it is not known whether the rates of transitioning fish and sex-specific mortality rates are constant. A better understanding of the criteria to identify transitioning fish, and an evaluation of when and which individuals change sex is needed to evaluate the proportions transitioning at length and age.

3. Given the latitudinal differences in maximum size attained by black sea bass, the size and age at transition is likely to also differ with latitude. More regional evaluation of sex ratios and the inflection in percent male is warranted.

4. Similarly, given the potential effect of selective fishing on size and age structure, the percentage of small males and the size at transition should be evaluated through time in conjunction with fishing mortality and size regulations.

Acknowledgements

We are grateful for the cooperation by MADMF (especially Jeremy King), and the fishery independent scup survey (especially Dave Borden) who both provided fresh samples in 2010 for this analysis. We thank the many individuals who participated in NEFSC and MADMF surveys over the years and collected some of the data analyzed here. We also thank the Northeast Cooperative Research Program for funding continuing work on life history of black sea bass (Grant # NFFM7230-11-06444).

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Table 1. Summary of black sea bass biological samples collected processed from various sources May-Oct 2010. Sources are; Massachusetts Division of Marine Fisheries (MA-DMF) inshore trawl surveys, Research Set Aside funded fishery independent scup survey (RSA-scup survey).

Date	**Source**	***n***	**Length range (cm)**
5/16/2010	MA-DMF	55	20-42
6/29/2010	RSA-Scup survey	65	30-56
8/2/2010	RSA-Scup survey	50	22-51
9/19/2010	MA-DMF	16	27-38
10/15/2010	RSA-Scup survey	31	19-59

Table 2. Macroscopic maturity staging criteria applied to images of black sea bass gonads; modified from Burnett et al. (1989), and Lyon et al. (2008). TR* not previously used on NEFSC bottom trawl surveys.

Sex/Class	Code	Description
Female		
Immature	I	Ovary paired, tube-like organ, small relative to body cavity; thin, transparent outer membrane; contains colorless to pink jell-like tissue with no visible eggs
Developing	D	Ovaries enlarge; if blood vessels present, they become prominent; ovary has granular appearance as yellow to orange yolked eggs develop
Ripe	R	Enlarged ovary; mixture of yellow to orange yolked eggs and hydrated or "clear" eggs present
Ripe & Running	U	Ripe female with eggs flowing from vent with little or no pressure to abdomen
Spent	S	Ovaries flaccid, sac-like, similar in size to ripe ovary; color red to purple; ovary wall thickening, becoming cloudy and translucent vs. transparent as in ripe ovary; some eggs, either clear or yolked, may still be present, however most adhere to ovary wall; therefore, CUT OPEN OVARY to make sure there is no mass of eggs in center of ovary (as in stages D and R)
Resting	T	Gonad reduced in size relative to ripe ovary, but larger than an immature; interior jell-like with no visible eggs
Transitional	TR*	Gonad contains both female and male tissue; inactive or regressing ovarian tissue with concurrent testicular proliferation
Unknown	UNK	Sex is uncertain
Male		
Immature	I	Testes paired, tube-like organ, small relative to body cavity; thin, translucent, colorless to gray or pinkish
Developing	D	Testes enlarge; color is gray to off-white, outer texture appears smooth; firm with little or no milt
Ripe	R	Enlarged testes; color chalk white, milt (spermatozoa) flows easily when testes is cut
Ripe & Running	U	Before cutting open fish, milt flows easily from vent with little or no pressure on abdomen; once cut open milt flows easily and color is chalk white
Spent	S	Testes flaccid, not as full of milt and robust as in Ripe stage; may contain residual milt; edges or parts of testes starting to turn gray and milt recedes
Resting	T	Testes shrunken in size relative to Ripe stage; color off-white-gray with little or no milt

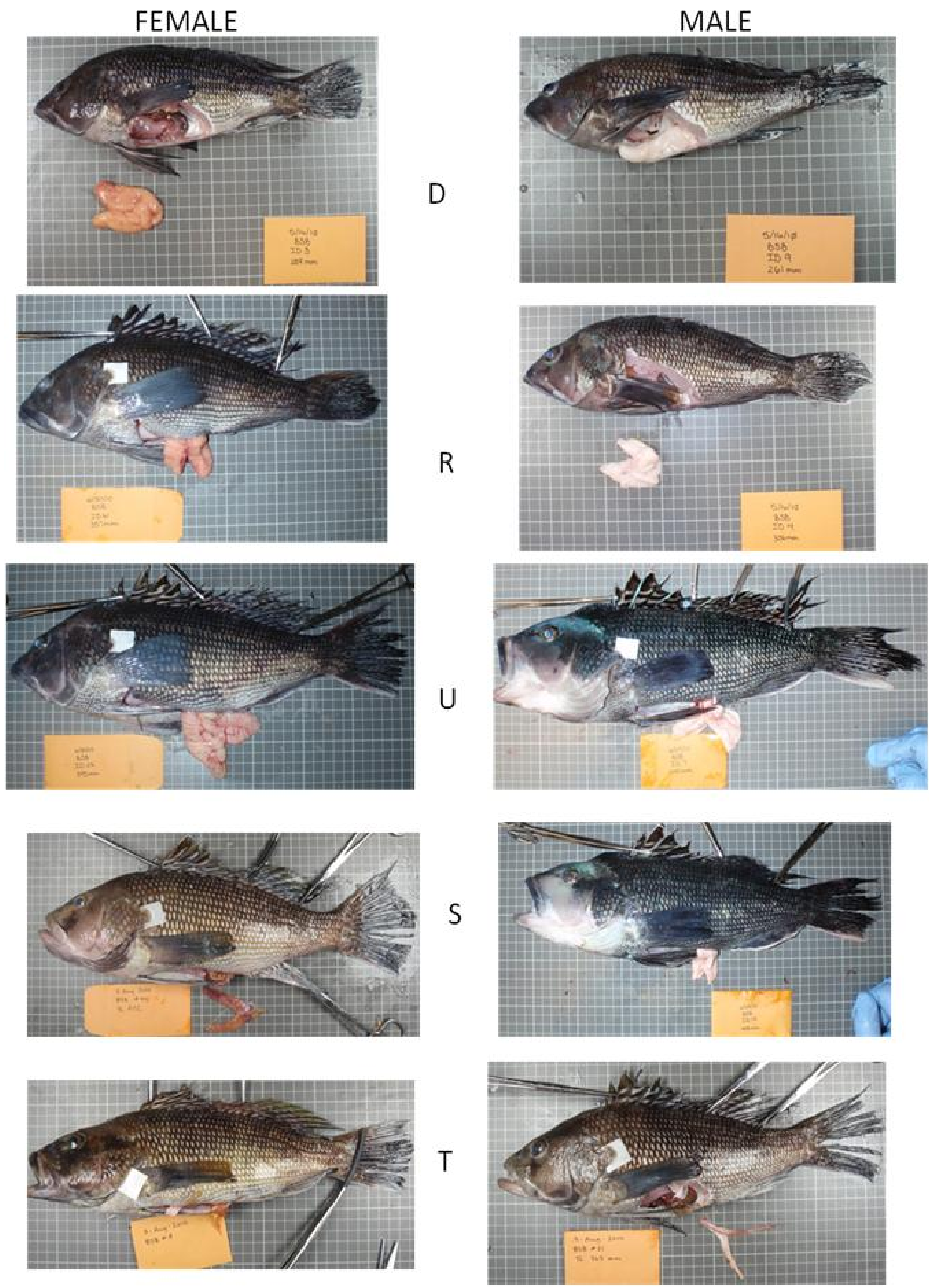

Figure 1. Representative images of black sea bass maturity stages observed in collections over the six month study. D-Developing, R-Ripe, U-Running ripe, S-Spent, T-Resting.

TRANS/UNK – Aug

TRANS/UNK – Aug

TRANS/UNK – Sept

Figure 2. Three individual black sea bass collected in August and September that were classified as transitional/unknown.

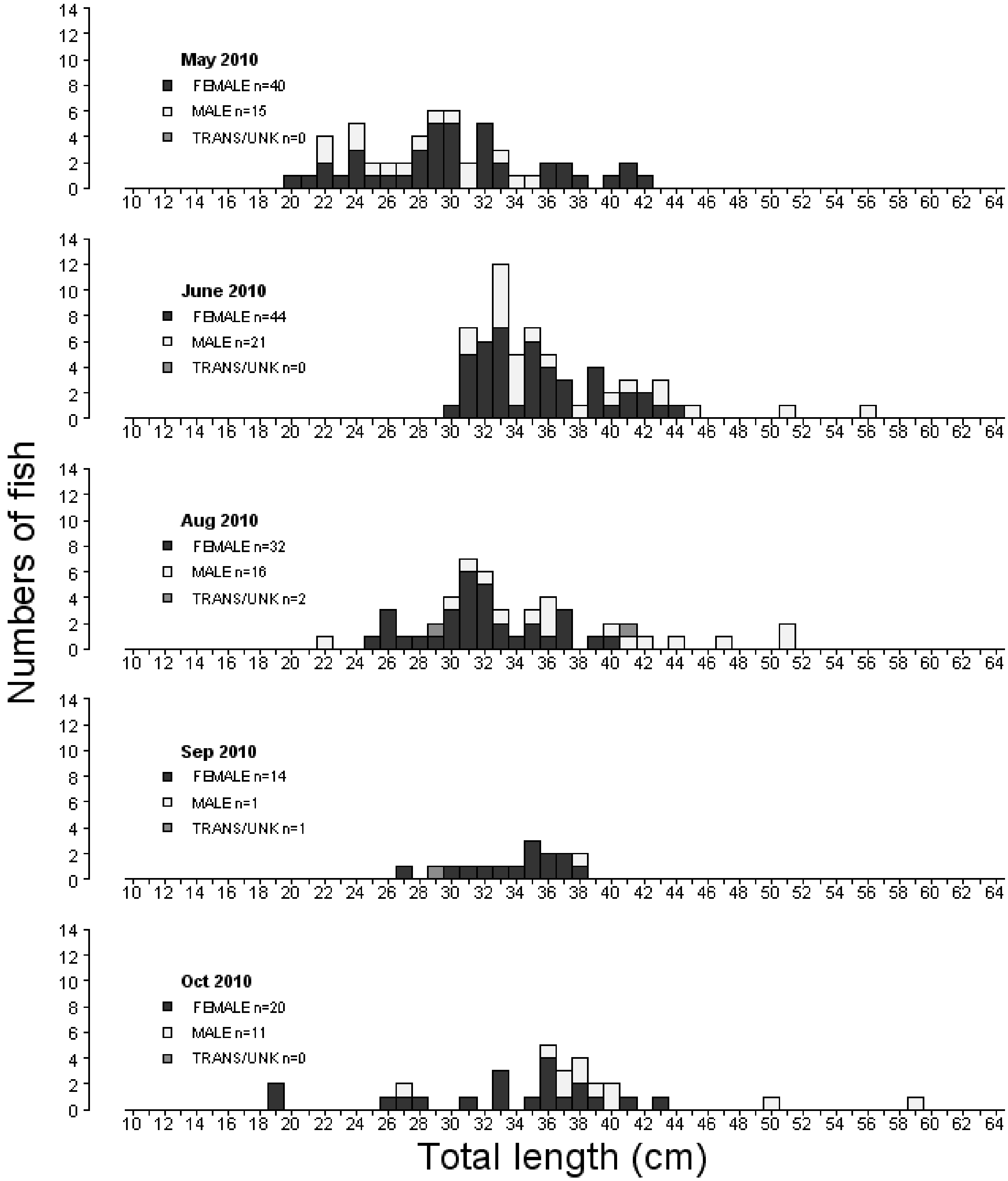

Fig. 3. Size distribution (length frequency) of male, female and transitional black sea bass collected in each month sampled in 2010.

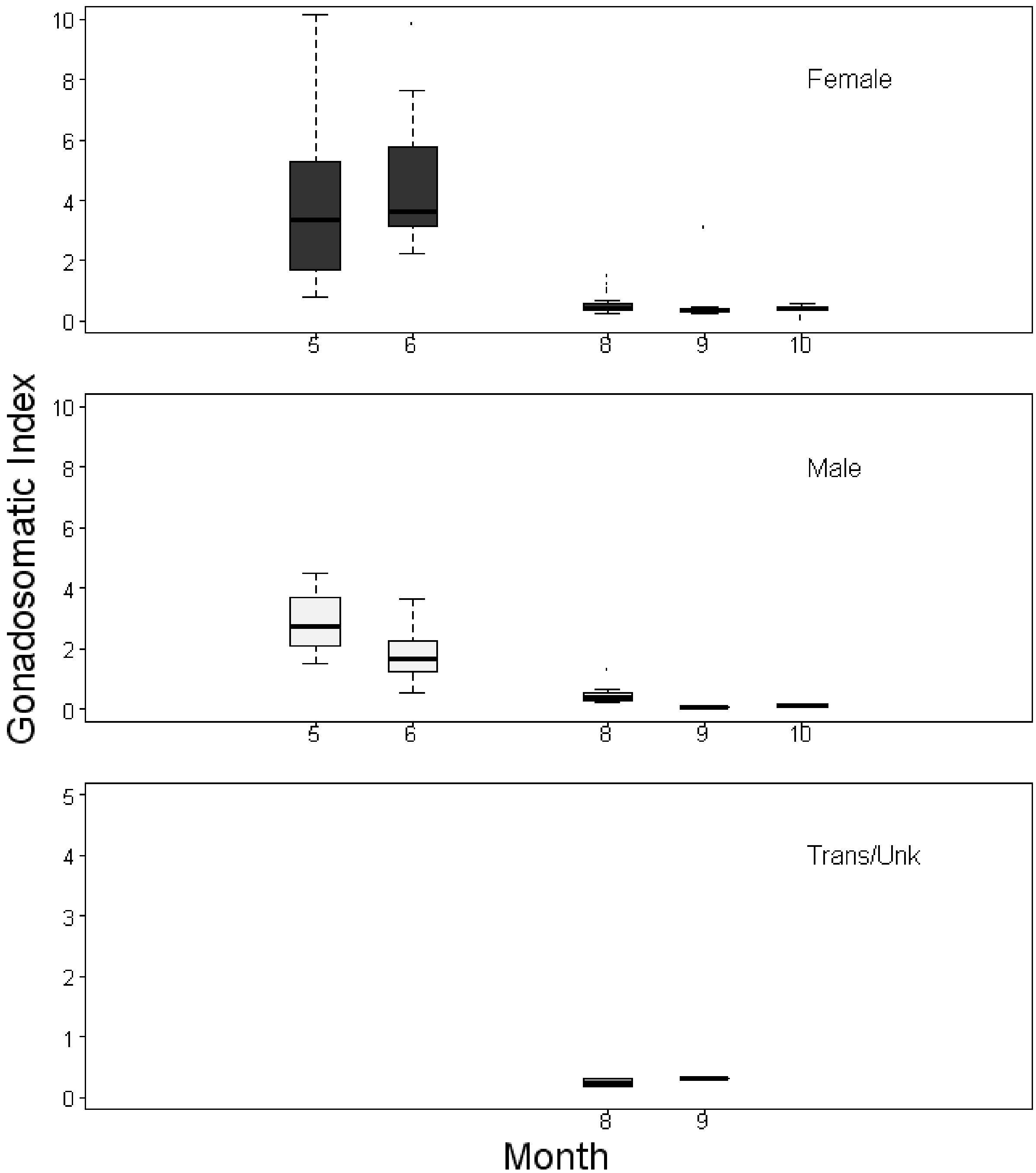

Fig. 4. Gonadosomatic index by month to indicate spawning seasonality. Note different y-axis scales.

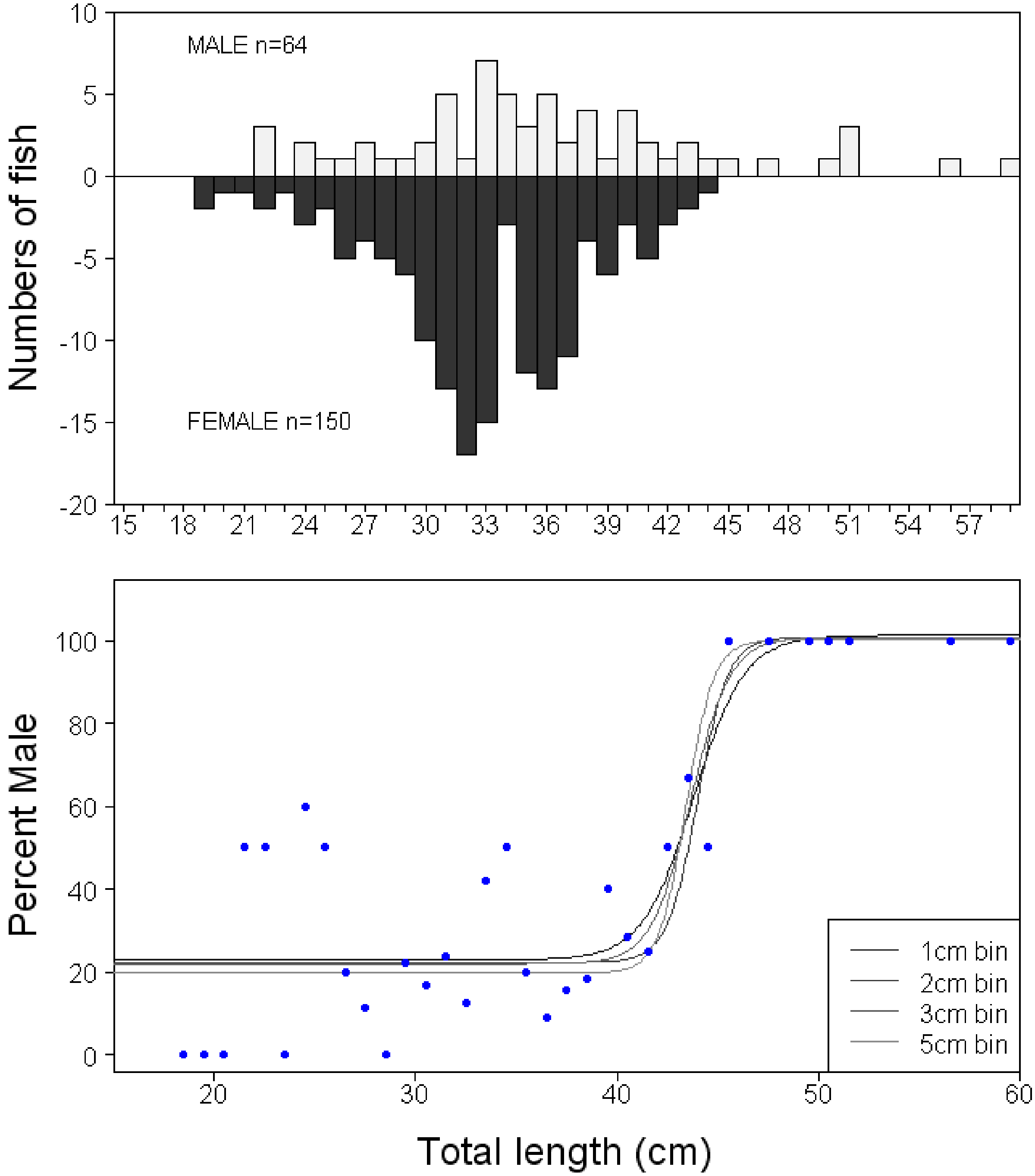

Figure 5. Percent male for black sea bass sampled in 2010 as a function of length. Points represent percentages in each 1 cm length bin. Lines represent the fits of the four parameter logistic model with data binned by 1, 2, 3, and 5cm.

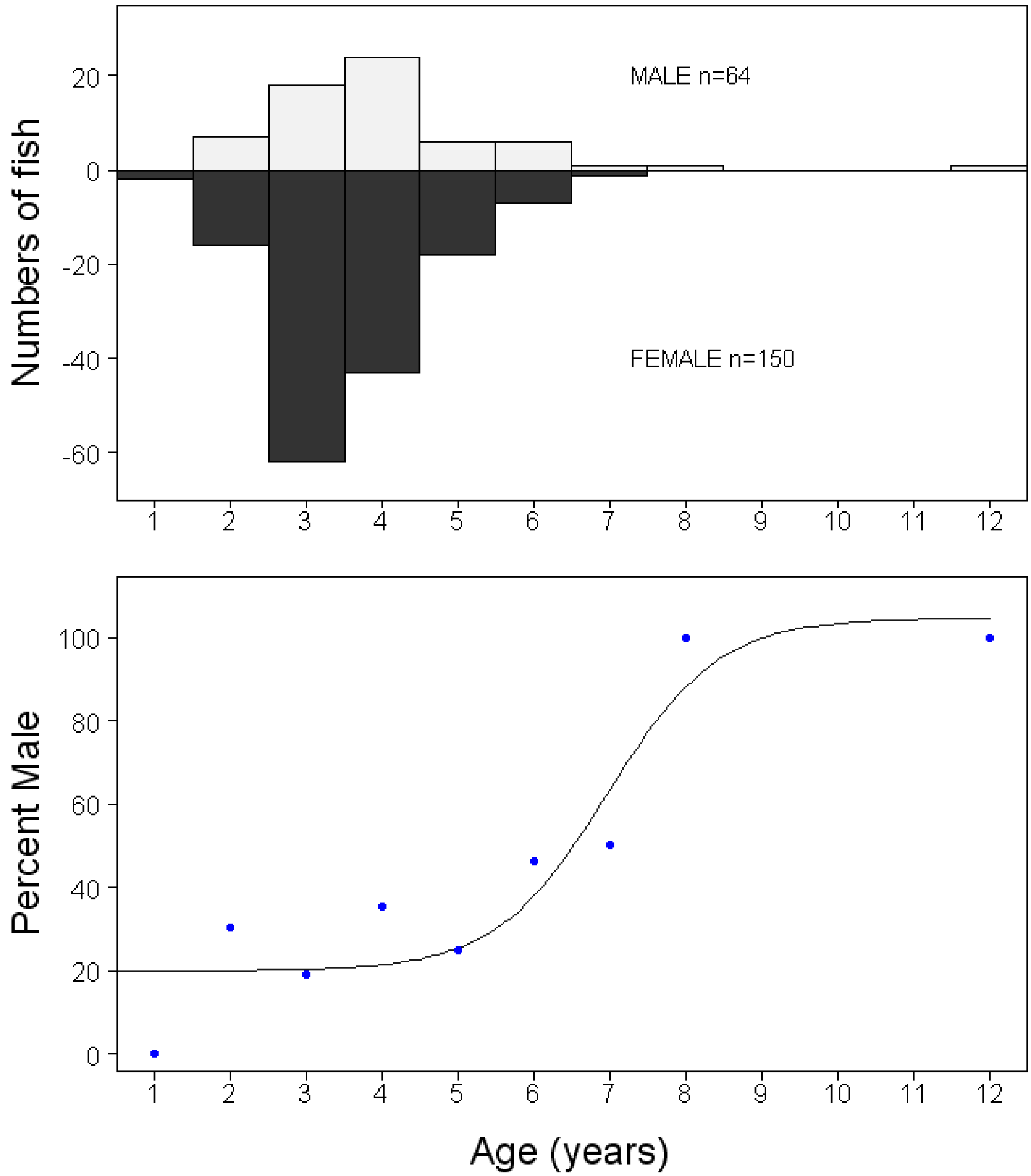

Figure 6. Percent male for black sea bass sampled in 2010 as a function of age. Points represent percentages in each 1 year age bin. Lines represent the fit of the four parameter logistic model.

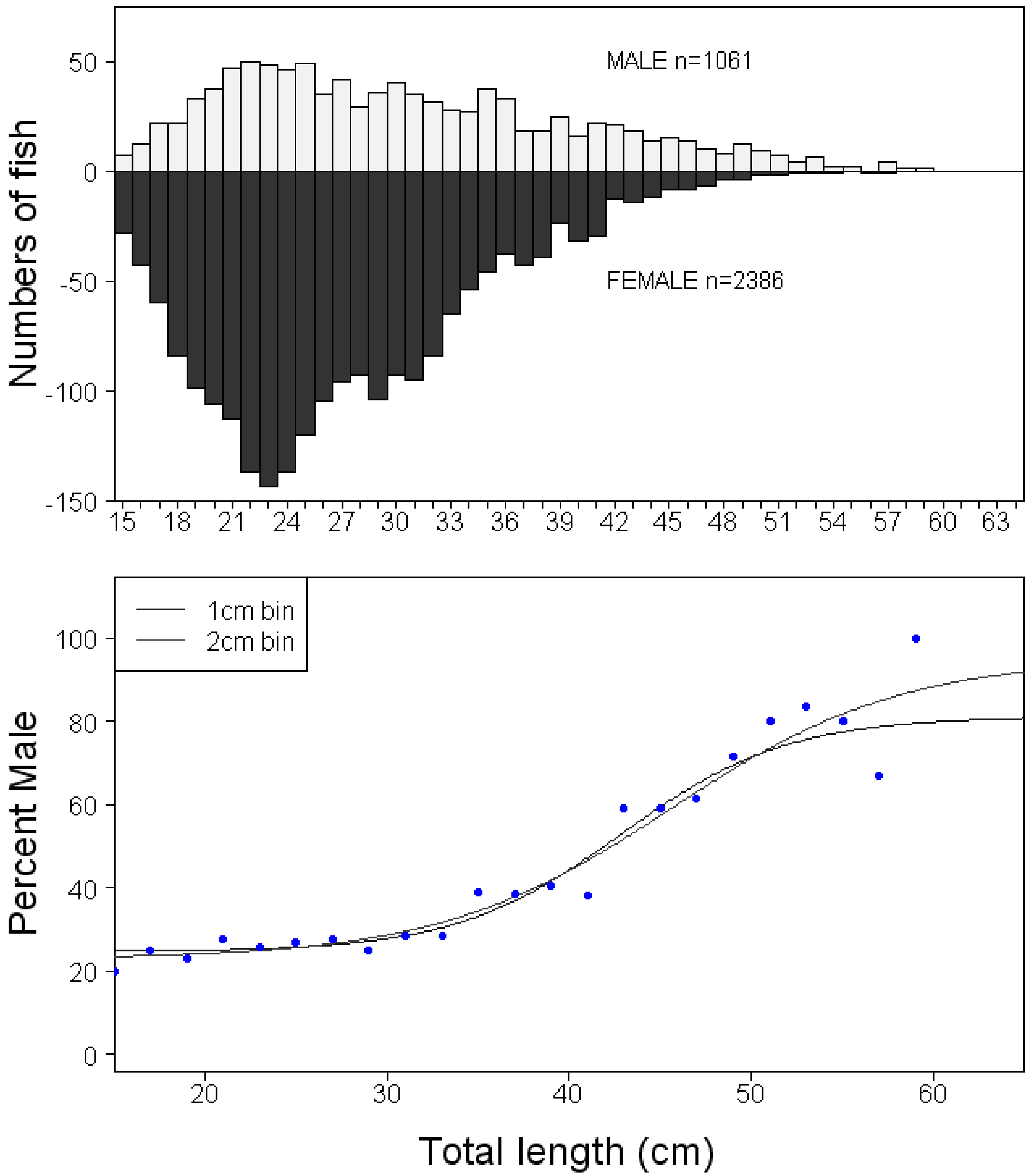

Figure 7. Percent male for black sea bass sampled on NEFSC SBTS and MADMF SBTS (1984-2010) as a function of length. Points represent percentages in each 2 cm length bin. Lines represent the fits of the four parameter logistic model with data binned by 1 and 2 cm.

Appendix 1. Summary of four parameter logistic model fits to the percentage male at length for black sea bass collected in 2010 from various sources (Table 1). See text for model formula and explanation. Four models were fit, with variable size length bins.

Model 1- 1cm binned Length data

```
Model fitted: Logistic (ED50 as parameter) (4 parms)
Parameter estimates:
               Estimate Std. Error   t-value   p-value
b:(Intercept)  -0.78981    0.37082  -2.12993    0.0415
c:(Intercept)  22.87569    3.80002   6.01989 1.319e-06
d:(Intercept) 101.23089    7.55191  13.40467 3.349e-14
e:(Intercept)  43.79021    0.73120  59.88786 4.394e-33
Residual standard error:
 17.38728 (30 degrees of freedom)
```

Model 2- 2cm binned Length data

```
Model fitted: Logistic (ED50 as parameter) (4 parms)
Parameter estimates:
              Estimate Std. Error  t-value   p-value
b:(Intercept)  -1.3346     1.2352  -1.0805     0.296
c:(Intercept)  22.3124     3.9912   5.5904 4.062e-05
d:(Intercept) 100.7394     5.9271  16.9964 1.157e-11
e:(Intercept)  43.9883     0.5388  81.6416 1.063e-22
Residual standard error:
 13.50645 (16 degrees of freedom)
```

Model 3- 3cm binned Length data

```
Model fitted: Logistic (ED50 as parameter) (4 parms)
Parameter estimates:
               Estimate Std. Error   t-value   p-value
b:(Intercept)  -1.01834    0.86342  -1.17943    0.2655
c:(Intercept)  21.95482    4.30140   5.10411    0.0005
d:(Intercept) 100.73393    5.52513  18.23196 5.294e-09
e:(Intercept)  43.64280    0.59727  73.07078 5.587e-15
Residual standard error:
 11.41578 (10 degrees of freedom)
```

Model 4- 5cm binned Length data

```
Model fitted: Logistic (ED50 as parameter) (4 parms)
Parameter estimates:
               Estimate Std. Error   t-value p-value
b:(Intercept)  -1.47008    9.16190  -0.16046  0.8788
c:(Intercept)  19.71305    5.62585   3.50401  0.0172
d:(Intercept) 100.06556    7.86294  12.72623  0.0001
e:(Intercept)  43.41306    5.74844   7.55215  0.0006
Residual standard error:
 12.57344 (5 degrees of freedom)
```

Appendix 2. Summary of four parameter logistic model fits to the percentage male at age for black sea bass collected in 2010 from various sources (Table 1). See text for model formula and explanation. A single model was fit, no age groups were binned.

Model 1- 1 year binned Age data

Model fitted: Logistic (ED50 as parameter) (4 parms)

Parameter estimates:

	Estimate	Std. Error	t-value	p-value
b:(Intercept)	-1.36333	1.03397	-1.31853	0.2445
c:(Intercept)	19.87582	9.30625	2.13575	0.0858
d:(Intercept)	104.61013	13.40348	7.80470	0.0006
e:(Intercept)	6.95768	0.56333	12.35091	0.0001

Residual standard error:

14.62701 (5 degrees of freedom)

Appendix 3. Summary of four parameter logistic model fits to the percentage male at length for black sea bass collected on NEFSC SBTS and MADMF SBTS (1984-2010). See text for model formula and explanation. Two models were fit with different size length bins (1 and 2 cm).

Model 1- 1cm binned Length data

Model fitted: Logistic (ED50 as parameter) (4 parms)

Parameter estimates:

	Estimate	Std. Error	t-value	p-value
b:(Intercept)	-0.22023	0.11726	-1.87813	0.0675
c:(Intercept)	24.58665	4.86670	5.05202	9.486e-06
d:(Intercept)	81.04034	9.06859	8.93638	3.574e-11
e:(Intercept)	42.84653	2.32888	18.39792	1.009e-21

Residual standard error:

14.64586 (41 degrees of freedom)

Model 2- 2cm binned Length data

Model fitted: Logistic (ED50 as parameter) (4 parms)

Parameter estimates:

	Estimate	Std. Error	t-value	p-value
b:(Intercept)	-0.157158	0.054259	-2.896457	0.0093
c:(Intercept)	22.842641	3.720414	6.139811	6.682e-06
d:(Intercept)	95.094550	12.142503	7.831544	2.296e-07
e:(Intercept)	45.576677	2.541987	17.929550	2.299e-13

Residual standard error:

6.162665 (19 degrees of freedom)

Comparing Black Sea Bass Catch and Presence Between Smooth and Structured Habitat in Northeast Fisheries Science Center Spring Bottom Trawl Surveys

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Introduction
The northern stock of black sea bass (*Centropristis striata*) ranges from the southern Gulf of Maine to Cape Hatteras, North Carolina. Black sea bass in this stock are generally located in inshore areas from late spring to autumn and move to offshore areas for overwintering (Kendall 1977; Musick and Mercer 1977; Able et al. 1995; Collette and Klein-MacPhee 2002; Drohan et al. 2007).

The National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey (hereafter called the spring bottom trawl survey) is used to assess black sea bass abundance. Black sea bass may congregate in structured bottom (e.g., near rocks or other substrate), which may not be adequately sampled by the bottom trawls. Consequently, the accuracy of black sea bass abundance estimates from bottom trawl surveys is in question.

The objective of this research is to determine if black sea bass catches or presence in spring bottom trawl surveys is greater in areas with structured bottom than with smooth bottom. To address this objective, we will compare characteristics of black sea bass catches in the spring bottom trawl survey between tows conducted over structured bottom and smooth bottom. We used tows with problems due to hangups, tears, or obstructions as a proxy for having occurred over structured bottom (hereafter called structured tows) and tows without any damage or entanglement as a proxy for having occurred over smooth bottom (hereafter called smooth tows).

Methods
The National Oceanic and Atmospheric Administration (NOAA) Fisheries Toolbox (NFT) program SAGA was used to compile black sea bass catch data from the spring bottom trawl survey during 1968 – 2010. Only data from strata 1 – 12, 25, and 61 – 76 were used, as these are strata where black sea bass are typically located (Figure 1). Strata 8, 9, 12, and 25 were later removed because no black sea bass were caught in these areas. Only data from the following station, haul, and gear (SHG) codes were used: 111, 121, 122, 123, 135, and 136. Other SHG codes were not used because the tow was not from survey trips, the tow was not considered representative, the problem with the tow was caused by a malfunction in the gear instead of structured bottom, or no black sea bass were caught. SHG codes 111 and 121 represent tows without any damage or entanglement and were used as proxies for smooth tows and the other codes were used as proxies for structured tows (Table 1).

The Mann-Whitney test, a special case of the Wilcoxon rank test, was used to compare the catches of black sea bass (in number and weight) between smooth and structured tows ($\alpha = 0.05$). This non-parametric test was used because the data were distributed in a manner that violated the assumptions of alternative parametric tests (i.e., unequal sample sizes, unequal variances, and non-normal distribution), such as a two-sample t-test. A Mann-Whitney test was also used to compare the proportion of the total catch (of all species) comprised of black sea bass (in number and weight) between smooth and structured tows ($\alpha = 0.05$). If black sea bass congregate near structured bottom, the catches of black sea bass and the proportion of the total catch comprised of black sea bass may be larger in structured tows than smooth tows.

Furthermore, the proportion of smooth tows that caught black sea bass was calculated as the number of smooth tows that caught black sea bass divided by the total number of smooth tows. The proportion of structured tows that caught black sea bass was calculated as the number of structured tows that caught black sea bass divided by the total number of structured tows. If black sea bass congregate near structured bottom, the proportion of structured tows that caught black sea bass may be greater than the proportion of smooth tows that caught black sea bass.

Results

The number of black sea bass caught in smooth tows was significantly greater than the number of black sea bass caught in structured tows (mean smooth = 4.2872; mean structured = 1.4448; W = 575576, P = 0.0243). Similarly, the weight of black sea bass caught in smooth tows was significantly greater than the weight of black sea bass caught in structured tows (mean smooth = 0.9881; mean structured = 0.4635; W = 576742.5, P = 0.0232).

The proportion of the total catch in numbers comprised of black sea bass in smooth tows was significantly greater than the proportion of the total catch in numbers comprised of black sea bass in structured tows (smooth = 0.0046; structured = 0.0022; W = 576465.5, P = 0.0409). Likewise, the proportion of the total catch in weight comprised of black sea bass in smooth tows was significantly greater than the proportion of the total catch in weight comprised of black sea bass in structured tows (smooth = 0.0080; structured = 0.0058; W = 572181, P = 0.0292).

The proportion of smooth tows that caught black sea bass was 0.1922 (Figure 2), and the proportion of structured tows that caught black sea bass was 0.1420 (Figure 3).

Conclusions

More black sea bass (in number and weight) were caught in survey areas with smooth bottom than with structured bottom, which contradicts the assumption that black sea bass congregate in structure while on the continental shelf. This result, however, could be due to our use of entangled or damaged tows as having occurred over structured habitat. If the gear was entangled or damaged, then we would expect fewer black sea bass to have been caught over structure, which would obscure any effect of congregating behavior.

None the less, assuming that any entanglement or damage to the gear affects the catchability of all species equally, if black sea bass do congregate around structured habitat then the proportion of black sea bass caught in structured bottom areas should still be greater than the proportion of black sea bass caught in smooth bottom areas. We found, however, that a greater proportion of the total catch comprised of black sea bass (in number and weight) were caught in survey areas with smooth bottom than with structured bottom. Hence, we found no evidence for black sea bass congregating in structured habitat in a way that would invalidate the use of the spring bottom trawl survey as a method to assess black sea bass abundance.

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Figure 1. NMFS NEFSC spring bottom trawl survey strata. (Figure courtesy of Elizabeth Holmes.)

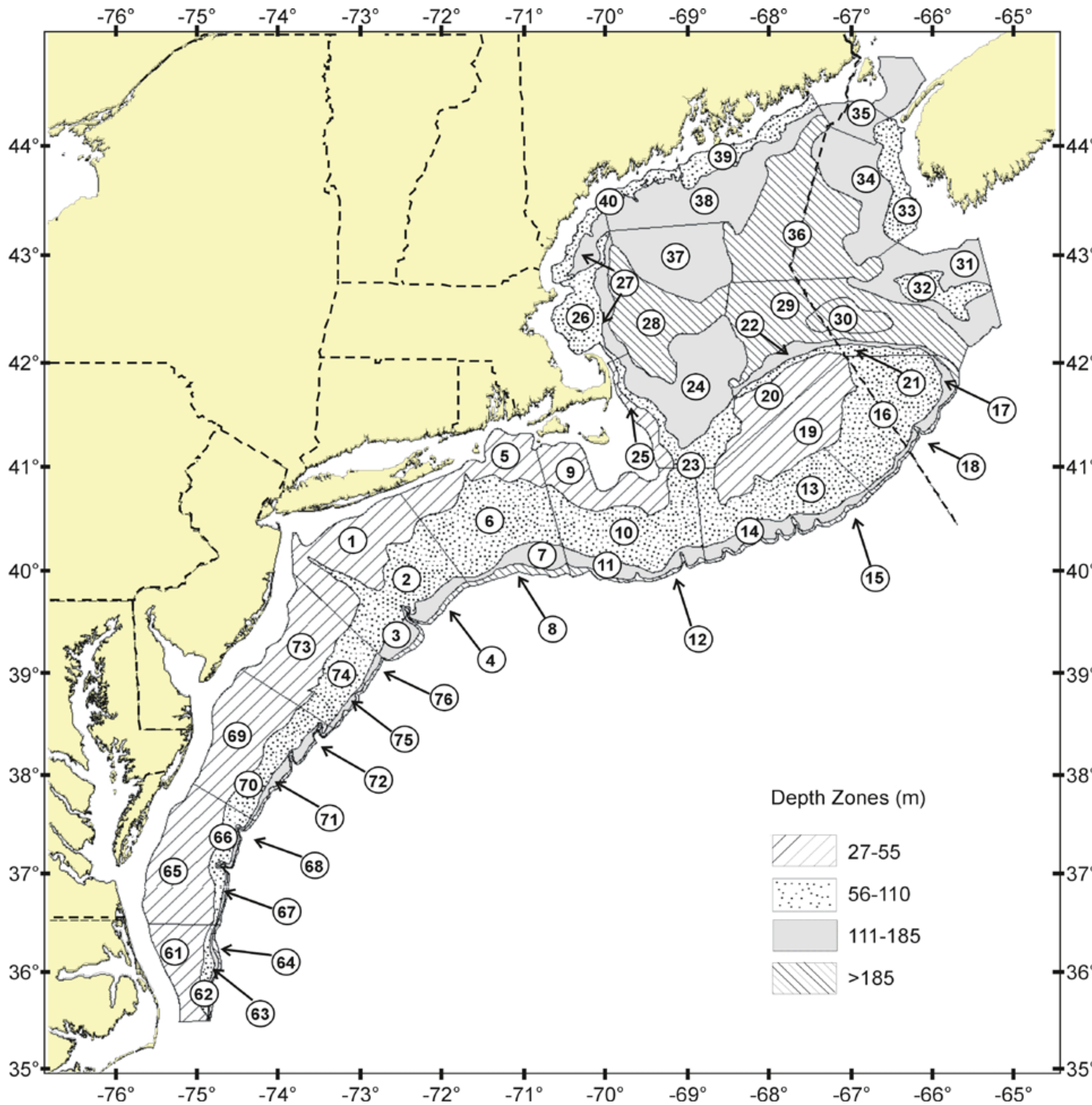

Figure 2. Locations of smooth tows where black sea bass were caught (black circles) and not caught (red circles).

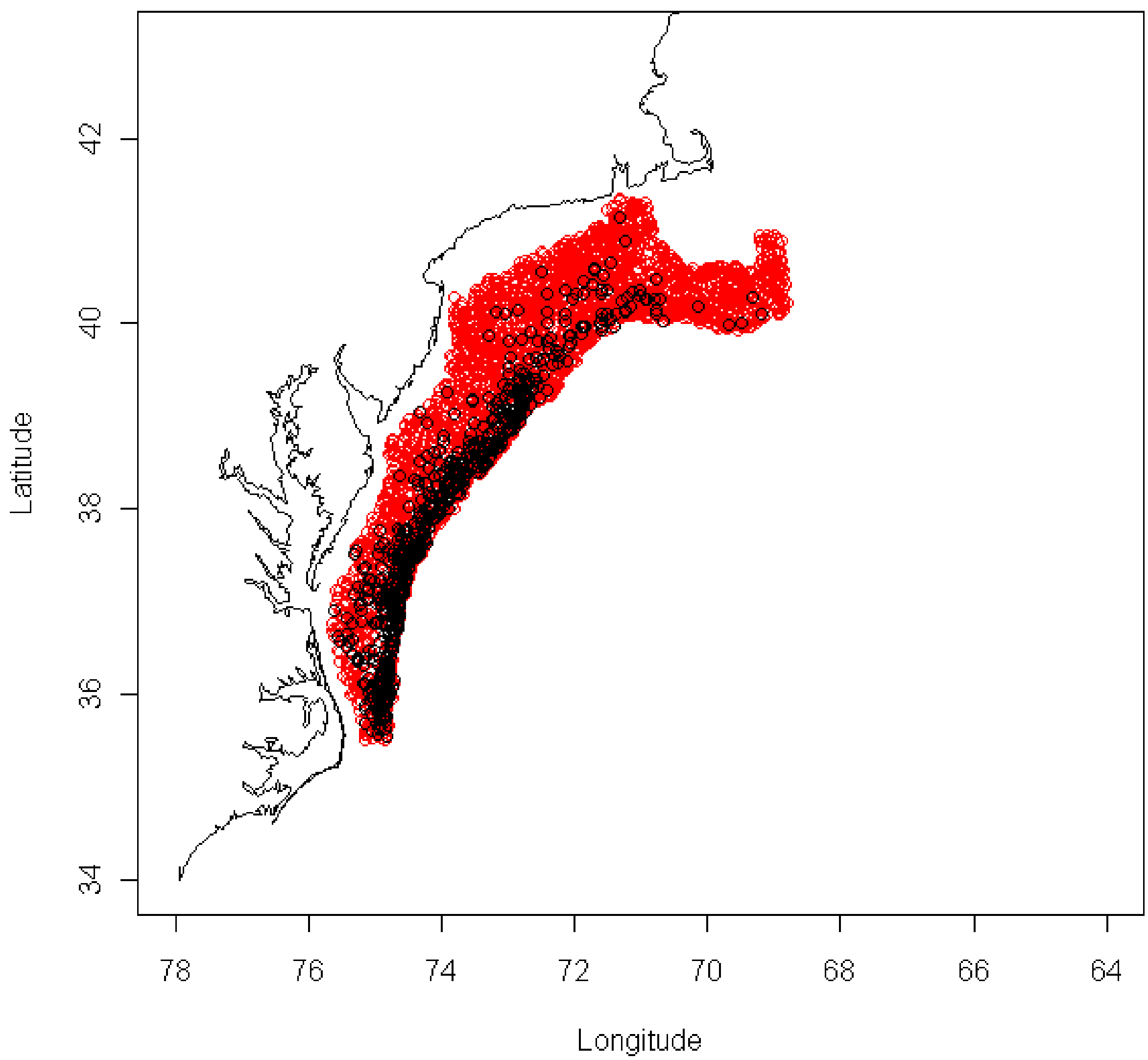

Figure 3. Locations of structured tows where black sea bass were caught (black circles) and not caught (red circles).

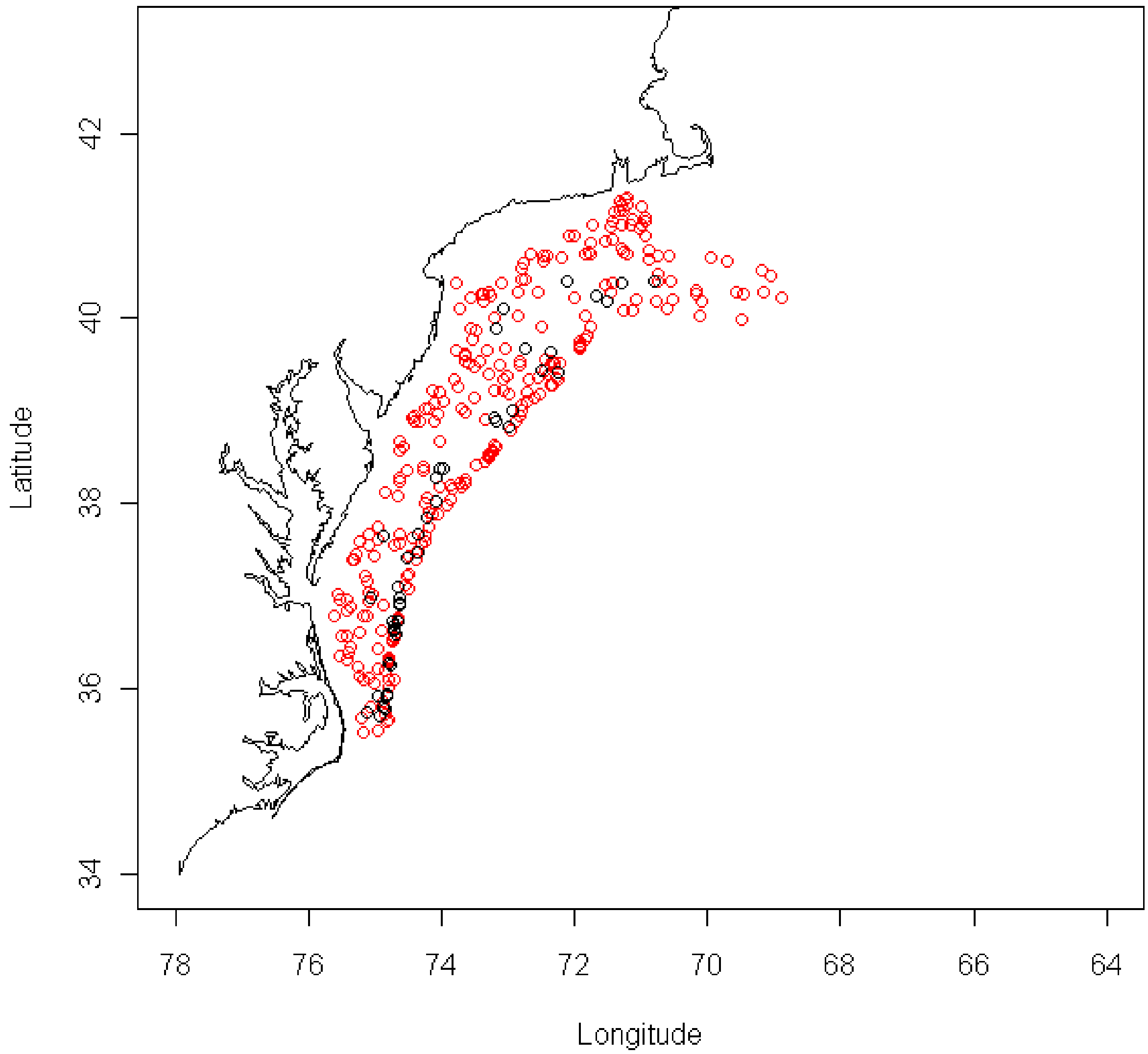

Table 1. Relevant station, haul, and gear (SHG) codes.

Station, Haul, or Gear Code	Description
Station Type	
1	Survey tows.
Haul Type	
1	Good tow. No gear or tow duration problem.
2	Representative, but some problem encountered due to gear or tow duration.
3	Problem tow. May or may not be representative due to gear or tow duration.
Gear Condition	
1	No damage to insignificant damage.
2	Wing twisted or tears in upper or lower wings not exceeding 10 feet; tear in square not exceeding 5 feet; tears not exceeding 3 feet in upper belly, or 6 feet in lower belly; codend or liner with tears not exceeding 2 feet; parted idler; liner hanging out of codend.
3	Hung up with minor damage.
5	Tearup exceeding limits for code 2, but not total.
6	Significant obstruction in trawl, such as fixed gear, rocks, old anchors, timbers, etc. Problem with third wire; unmatched doors; strong current.

Estimating Black Sea Bass Natural Mortality Using Several Methods

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The natural mortality rate, M, of black sea bass was estimated using several methods. The rule-of thumb approach, M_R, was estimated by dividing a constant by the maximum age observed in the stock, $t_{\max}$:

$$M_R = \frac{3}{t_{\max}}.$$

The 3 in this equation implied that 5% of the stock remains alive at $t_{\max}$, and this value was selected arbitrarily (Hewitt and Hoenig 2005). If $t_{\max}$ was selected based on data from an exploited stock, M could also be biased. The Hewitt and Hoenig (2005) approach, M_H, was based on a regression equation rearranged for consistency with the rule-of thumb approach:

$$M_H = \frac{4.22}{t_{\max}}.$$

The 4.22 in this equation implied that 1.5% of the stock remains alive at $t_{\max}$, and this value was estimated based on a meta-analysis of fish stocks. Maximum age, $t_{\max}$, equaled 9 or 12 in both the rule-of-thumb and Hewitt and Hoenig approaches. The Lorenzen (1996) approach modeled natural mortality as a power function of weight (in grams), or in our application, mean weight at age, W_a, to produce natural mortality at age, $M_{L,a}$:

$$M_{L,a} = \alpha W_a^{\beta},$$

where α was the natural mortality rate at unit weight and β was the allometric scaling factor. The values of α and β were set to the estimates for marine species in Lorenzen (1996) and were 3.69 and -0.305, respectively. Mean weight at age was calculated as the average weight during 1984–2010 for ages 1–9 (Table 1). Mean weight for ages 10-12 were predicted from the fitted wt for ages 1 to 9 (wt=4.7155*age^0.2233). A constant value, M_c, was used in the last assessment and was carried forward as an option for the natural mortality rate in this assessment:

$$M_c = 0.4$$

(Figure 1). This value was based on estimates from tagging studies and meta-analyses of mortality rates in other fishes (Miller et al. 2009).

The $M_{L,a}$ values from the Lorenzen approach were also scaled, $\widetilde{M}_{L,a}$, so that the average among ages equaled each of the other methods (i.e., M_R, M_H, and M_c) for calculating natural mortality, M_i:

$$\widetilde{M}_{L,a} = M_{L,a} \frac{M_i}{\overline{M}_{L,a}},$$

where $\overline{M}_{L,a}$ was the average of $M_{L,a}$ over all ages considered (Table 2; Figure 2).

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Table 1. Black sea bass mean weight at age (in grams).

Age	WAA (g)
1	112.92
2	243.19
3	395.48
4	604.69
5	861.95
6	1279.68
7	1542.01
8	1821.36
9	1974.56
10	2658.4
11	3149.8
12	3689.1
Average	

Table 2. Black sea bass natural mortality estimates at age using a constant, the rule-of-thumb approach, the Hewitt and Hoenig approach, the Lorenzen approach, and the Lorenzen approach scaled to each of the other three methods.

Natural Mortality											
Age	**Constant**	**Rule of Thumb[1]**	**Rule of Thumb[2]**	**Hewitt & Hoenig[1]**	**Hewitt & Hoenig[2]**	**Lorenzen**	**Lorenzen Scaled to Constant**	**Lorenzen Scaled to Rule of Thumb[1]**	**Lorenzen Scaled to Hewitt & Hoenig[1]**	**Lorenzen Scaled to Rule of Thumb[2]**	**Lorenzen Scaled to Hewitt & Hoenig[2]**
1	0.40	0.33	0.25	0.47	0.35	0.87	0.67	0.56	0.78	0.50	0.62
2	0.40	0.33	0.25	0.47	0.35	0.69	0.53	0.44	0.62	0.36	0.46
3	0.40	0.33	0.25	0.47	0.35	0.60	0.46	0.38	0.53	0.29	0.38
4	0.40	0.33	0.25	0.47	0.35	0.52	0.40	0.33	0.47	0.24	0.33
5	0.40	0.33	0.25	0.47	0.35	0.47	0.36	0.30	0.42	0.21	0.29
6	0.40	0.33	0.25	0.47	0.35	0.42	0.32	0.27	0.37	0.18	0.25
7	0.40	0.33	0.25	0.47	0.35	0.39	0.30	0.25	0.35	0.16	0.23
8	0.40	0.33	0.25	0.47	0.35	0.37	0.29	0.24	0.34	0.15	0.21
9	0.40	0.33	0.25	0.47	0.35	0.36	0.28	0.23	0.33	0.15	0.21
10	0.40		0.25		0.35	0.33	0.24			0.13	0.19
11	0.40		0.25		0.35	0.32	0.22			0.12	0.17
12	0.40		0.25		0.35	0.30	0.21			0.11	0.16

[1]Maximum age = 9

[2]Maximum age = 12

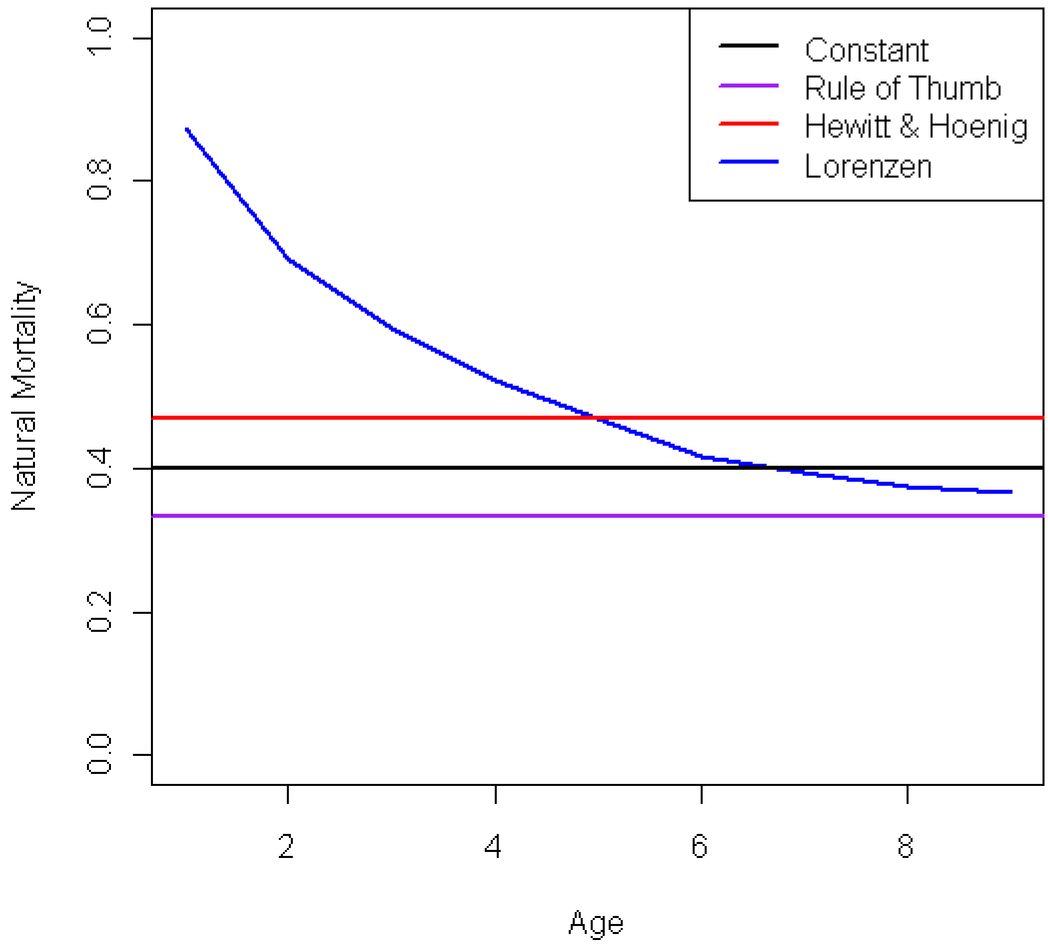

Figure 1. Black sea bass natural mortality estimates at age using a constant, the rule-of thumb approach, the Hewitt and Hoenig approach, and the Lorenzen approach.

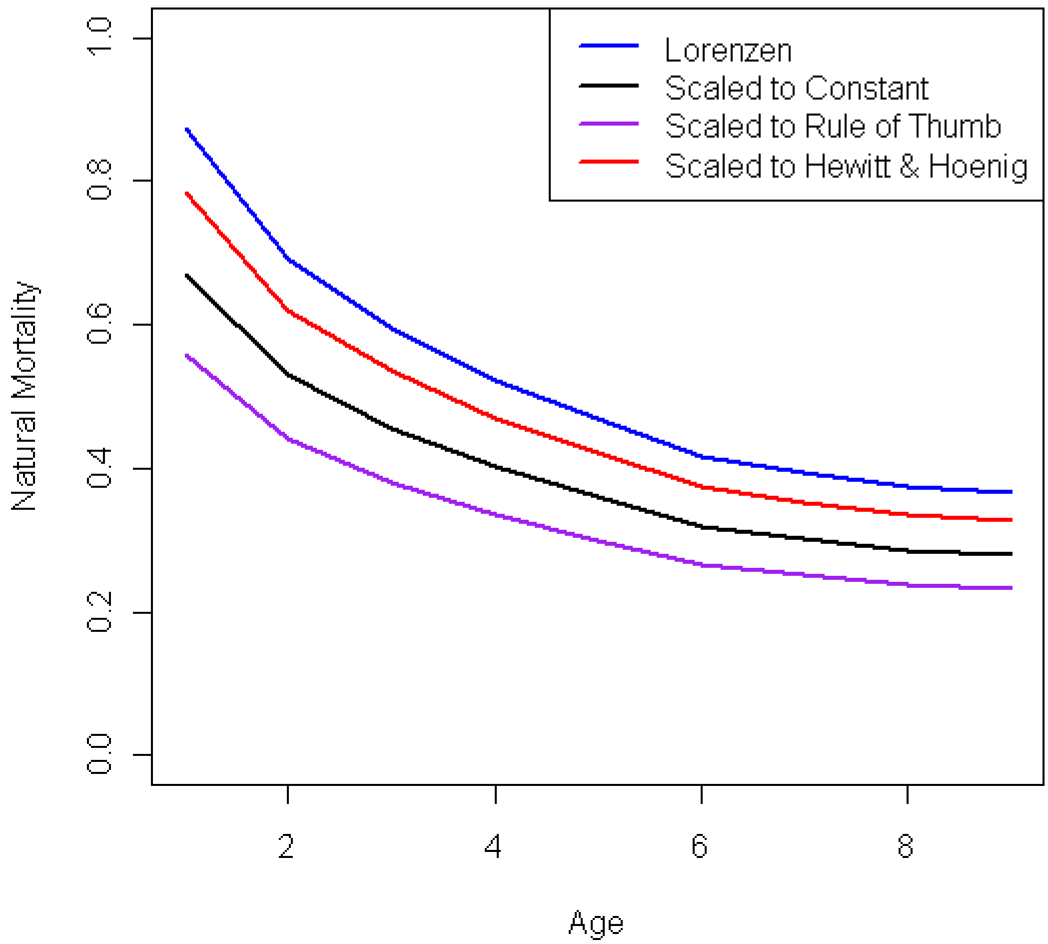

Figure 2. Black sea bass natural mortality estimates at age using the Lorenzen approach, and the Lorenzen approach scaled to the constant, rule-of thumb, and Hewitt and Hoenig approaches.