Description of age and growth for blueline tilefish, *Caulolatilus microps*, caught north and south of Cape Hatteras, NC

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SEDAR50-DW07

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Abstract

Age and total length were measured for blueline tilefish, *Caulolatilus microps*, caught off the US Atlantic coast from Florida through Virginia. Fish caught north of Cape Hatteras, NC, were sampled primarily from the recreational fishery (n=1737), while fish caught south of Cape Hatteras were sampled primarily from the commercial fishery (n=2627). Weighted Von Bertalanffy growth models were estimated for fish caught north and south of Cape Hatteras, NC, and had parameter estimates of: [L_∞ = 839 mm TL, κ = 0.11, t_0 = -2.31] (north) and [L_∞ = 739 mm TL, κ = 0.19, t_0 = -1.85] (south). Growth models were compared using likelihood ratio tests and were significantly different with respect to parameters L_∞ ($P < 0.0001$) and κ ($P < 0.0001$). An adjustment applied to the model regressions showed that parameter estimates are not significantly biased due to differences in fishery selectivity between regions.

Introduction

The blueline tilefish (*Caulolatilus microps*) is a demersal teleost that inhabits the North American outer continental shelf, shelf break, and slope at depths ranging from 48 to 236 m (Dooley, 1978; Ross and Hunstman, 1982; Harris et al., 2004). Although once thought to range from Cape Charles, Virginia, to Campeche, Mexico (Dooley, 1978), more recent data show that blueline tilefish have been commercially caught in waters further north off the Mid-Atlantic region of the United States (from Virginia through New York; hereinafter: US Mid-Atlantic) and landed as far north as Massachusetts (Personal communication from the National Marine Fisheries Service (NMFS), Fisheries Statistics Division. [06/02/2016]; hereinafter: NMFS, 2016).

Historical landings derived almost entirely from the commercial fishery off the South Atlantic region of the United States (from the Atlantic coast of Florida through North Carolina; hereinafter: US South Atlantic). Similar to other deepwater reef fisheries in this area, annual landings peaked during the 1980s (Parker and Mays, 1998; SEDAR, 2013). However, proportions of commercial landings have shifted northward since 1985, with increasing proportions of commercial landings coming from North Carolina and states further north in the US Mid-Atlantic (NMFS, 2016). Though increasing since the early 2000s, annual US Mid-Atlantic commercial catches were relatively modest until 2014, when they suddenly increased to nearly ten times the average from the previous ten years (NMFS, 2016). This increase coincided with stricter catch regulations in the US South Atlantic resulting from the 2013 benchmark stock assessment that reported overfished and overfishing statuses for the fishery in that region (SEDAR, 2013).

Little is known about the Mid-Atlantic portion of the stock, including whether the fishery in this area is newly exploiting a pre-existing resource or a new resource introduced through a shift in the stock's range. Stock differences among other demersal species that span the biophysical boundary created by movement of the Gulf Stream offshore at Cape Hatteras, North Carolina, such as black sea bass (*Centropristis striata*) (SEDAR, 2011; NEFSC, 2012) and golden tilefish (*Lopholatilus chamaeleonticeps*) (NEFSC, 2014; SEDAR, 2011), discourage assumptions of uniformity throughout the Atlantic stock of blueline tilefish.

Studies of life history characteristics provide vital information for stock assessment models, such as individual growth model parameter estimates, and can assist in defining stocks or structure within a stock (Ihssen et al., 1981; Begg et al., 1999; McBride, 2014). Spatial variation in growth parameters can have strong impacts on management, even in the absence of genetic differences, by producing different biological reference points (Law, 2000; Heino et al., 2013; Maunder et al., 2016). Previous research on blueline tilefish life history has focused on the populations from the South Atlantic and suggests blueline tilefish are long-lived and slow growing, with observed ages of up to 43 years and low Brody growth parameter estimates of approximately 0.1 (Ross and Huntsman, 1982; Harris et al., 2004). Current databases of age and size information for fish in this region are maintained by the NOAA Southeast Fisheries Science Center and the South Carolina Department of Natural Resources. This study will characterize the age and growth of blueline tilefish off the coast of Virginia, in the southern portion of the US Mid-Atlantic, and compare them with growth of blueline tilefish from the US South Atlantic.

Methods

Sample collection and processing

Blueline tilefish specimens caught off the Virginia coast were collected by the Old Dominion University Center for Quantitative Fisheries Ecology (CQFE) from 2009-2012. Collection methods included purchases of whole fish from commercial fishermen, donations of whole fish or carcasses from recreational anglers, and quasi-fishery independent sample collections by scientists from the Virginia Marine Resources Commission (VMRC) and CQFE aboard recreational charter and head boat vessels (hereinafter referred to as “special charters” because while all fish caught during these collections were kept, regardless of size or any other characteristic, fishing locations were representative of the recreational fishery and not selected randomly).

Total and fork lengths (mm) were measured for all specimens. Catch locations reported by fishermen were identified within NMFS statistical areas (Figs. 1 and 2). Saggital otoliths were removed and stored in coin envelopes. One otolith from each specimen (randomly selected between left and right) was embedded in epoxy resin. A transverse section (0.4 mm thick) was made through the core using a Buehler Isomet low-speed saw, and sections were mounted on glass slides using Flotexx. Slides were viewed under a microscope at 20-40x magnification using transmitted light.

Aging

Aging was attempted for all specimens collected from 2009-2011. However, to reduce time and costs of processing, the 2009-2011 data was used to proportionally allocate (based on total length) a subsample of the 2012 specimens for age analyses (Quinn and Deriso, 1999). In preparation for SEDAR 32, an aging protocol was established by age readers from CQFE and other agencies throughout the US South Atlantic to ensure consistency of aging methods throughout the Atlantic coast (SEDAR, 2013). Increments consisted of one translucent and one opaque zone and were primarily counted along a ventral axis of the section. Occasionally, the dorsal region of the section was counted if the ventral was unclear, and when possible, both regions were counted and compared for additional age verification. Discontinuous opaque or translucent areas were common, which made aging difficult. When possible, increments were confirmed to extend from the succal groove to the distal edge of the section. Increments were counted independently by two CQFE readers without knowledge of fish size or time of capture.

If independent counts differed, the slide was recounted by both readers until a consensus age could be agreed upon. If no age could be agreed upon, the specimen was discarded from age analyses. Precision between readers was evaluated using bias measurements, bias plots, average percent error (APE), and percent agreement of initial readings. A paired t-test was used to determine whether average biases from initial readings deviated from zero. Ages for a set of otoliths aged by readers from all agencies involved at SEDAR 32, including one reader from the present study, showed no significant bias among agencies (SEDAR, 2013).

Marginal Increment Analysis

Periodicity of increment formation was investigated for the CQFE data set using marginal increment analysis (MIA). Increment widths were measured for a stratified (by month) random sample of the aged dataset. Increment widths were measured from the otolith nucleus to the edge along an axis roughly 45 degrees proximal to the ventral axis. This axis was used because this region of the otolith was where increments were most consistently visible and distinguishable. Increments in other portions of otolith sections often showed splitting or were visibly faded, including along the distal edge, a more common axis for increment measurement. All increments were measured using Image-Pro Plus vers. 6.2.0.424 (Media Cybernetics, Inc.). An index of completion was calculated by multiplying the marginal increment width by 100 and then dividing by the width of the last complete increment (Hyndes et al., 1992). Monthly average indices were calculated and plotted against the calendar year to determine timing and periodicity of increment formation.

Length Conversion

To make comparisons among modern blueline tilefish from different geographical regions, the data collected during our sampling was supplemented by concurrent data collected by the NOAA Beaufort Laboratory from 2003-2011, which included samples caught in waters off Florida through Virginia. Some of these samples only had length measurements for either fork or total length. To use as much data as possible, a linear relationship between fork and total lengths was estimated based on individuals from both (our own and NOAA's) data sets that had both measurements, and missing values were imputed.

Regional Growth Comparison

We compared growth models of blueline tilefish that were caught north and south of Cape Hatteras, NC, from 2003-2012, using the combined CQFE and NOAA data sets. We selected Cape Hatteras as our boundary for comparison under the assumption that connectivity would be more likely to occur on either side of, rather than across, this biophysical boundary. Cape Hatteras is located within NMFS statistical area 635, with increasing numbers to the east and south (Figs. 1 and 2). Therefore, blueline tilefish with reported catch locations were divided into northern (statistical areas less than 635) and southern (statistical areas greater than or equal to 635) groups. Fish with catch location codes that did not correspond to NMFS statistical areas were disregarded from length at age analyses. Length at age was modeled using the von Bertalanffy (VB) growth function (von Bertalanffy, 1938):

$$L_t = L_\infty[1 - e^{-\kappa(t-t_0)}],$$

where L_∞ is the horizontal asymptote representative of the mean maximum length, κ is the Brody growth parameter representative of how quickly maximum length is achieved, and t_0 is the theoretical age at length = 0. VB growth models were regressed upon total lengths at age and compared using likelihood ratio tests (LRT) (Kimura, 1980). To increase the probability of differences among parameters being attributable to true differences in growth rather than sampling variability, significance for regional comparisons was measured at the $\alpha = 0.01$ level.

Bias Adjustment

A bias in size at age may be introduced by the fact that the majority of blueline tilefish collected during the present study were sampled through donations by recreational fishermen, while the majority of fish collected in the NOAA sample were acquired through samples of the commercial fishery. Discards are minimal for both sectors, reducing potential bias from high grading (SEDAR, 2013). However, gear differences may have some impact on sizes of fish caught in each sector, setting a de facto minimum size limit on the recreational fishery (as this sector is more likely to seek large fish) and maximum size limit on the commercial fishery (as this sector is more likely concerned with total catch weight rather than individual fish size). We used AD Model Builder (Fournier et al., 2012) to address fishery sector and regional selectivity biases, at both small and large sizes, by re-fitting the VB model using a truncated length error distribution and then comparing parameter estimates with and without this adjustment (McGarvey and Fowler, 2002; Schueller et al., 2014). To define ages subject to minimum length truncation due to gear selectivity patterns, we defined the minimum length limit as the minimum length observed for the first age of full selection. For each region, the first age of full section was defined as the age exhibiting maximum numbers-at-age plus one. All non-fully selected age classes were subject to the minimum size limit. The maximum size limit was defined as the smaller of the unadjusted, region specific L_∞ estimates. Once defined, the maximum size limit was applied to all fully selected age classes for the region exhibiting the smaller L_∞ estimate. We only applied the maximum size limit to the region with the smaller unadjusted L_∞ estimate because smaller asymptotic size in a region could be due to bias from reduced selectivity of larger sizes. We make the assumption that such a bias would be less evident in the region with the greater L_∞ estimate.

Results

Sample Collection

A total of 2104 blueline tilefish were collected by CQFE from 2009-2012, with at least 34 fish collected in each month of the calendar year. Blueline tilefish were caught at depths of around 50-200 m, typically in hard-bottomed areas. All fish, except five from a commercial trawl, were caught using rod-and-reel. Specimens were caught in the submarine canyons along the edge of the continental shelf east of the Virginia coast, most often Norfolk Canyon (Fig. 1). The majority of the CQFE sample (n = 1752) came from fishery dependent sampling via donations by recreational anglers. Blueline tilefish collected by special charters (n = 296) constituted 14% of the CQFE sample. CQFE specimens ranged from 283 to 892 mm total length with an overall mean of 538 mm.

Aging

Ages were determined for 967 of 983 fish collected from 2009-2011 and 517 of 1121 fish collected during 2012 by CQFE. Ages ranged from 2 to 40 years with an overall mean of 10 years. Percent agreement between independent readings was 26%, with 60% and 81% of independent readings within 1 and 2 years of each other, respectively. APE between independent readings was 16%. Average bias between independent readings was significantly greater than 0 but significantly less than 1 (0.604; 95% CI: [0.505, 0.703]). Variability among independent and final ages was high, but linear relationships among ages were well approximated as 1:1 (Fig. 3).

Marginal Increment Analysis

Marginal increments for 337 fish collected by CQFE during all months of the year across all years sampled were analyzed to validate periodicity of increment formation. Monthly samples ranged between 25 and 30 otoliths. Monthly mean marginal increments showed a great deal of variability, with the smallest mean indices of completion being observed in February and April (56.6% and 61.2%, respectively) (Fig. 4). The limited range of observed values precludes strong conclusions about increment formation periodicity. However, we do note an overall increasing trend in monthly mean indices throughout a 1 year period, with mean indices at the beginning of that period, February and April, being significantly less than the mean index in the last month, January, according to 95% confidence intervals. Furthermore, the timing of minimum mean indices in February and April coincides with the timing of annual increment formation reported by Ross and Huntsman (1982). Therefore, we continued with age analyses under the assumption of 1 increment formed per year.

Length Conversion

We observed a strong linear relationship between fork and total lengths for blueline tilefish from the combined CQFE and NOAA data sets, collected from 2003-2012 (n=2277, R^2 = 0.998; Fig. 5), and used this relationship to impute missing length measurements.

Regional Growth Comparison

Lengths at age for blueline tilefish from the combined CQFE (n=1481) and NOAA (n=2883) data sets varied between regions north (n=1737) and south (n=2627) of Cape Hatteras, NC. Three CQFE fish were disregarded from length at age analyses, two due to cut tails that prevent measurement of fork or total length and one due to an invalid catch location code. The unweighted regression of the VB model produced an L_∞ estimate for northern fish (936 mm) that was greater than the maximum length observed in that region (913 mm) (Fig. 6a, Table 1), so both regional models were refit to inverse frequency weighted lengths at age. The difference in t_0 estimates for the weighted regressions was less than 0.5 and not significant at the $\alpha = 0.01$ level. Blueline tilefish caught north of Cape Hatteras had significantly greater L_∞ and lesser κ estimates than those caught to the south, resulting in faster growth at young ages (~10 and younger) and earlier attainment of a smaller asymptotic length for fish caught south of Cape Hatteras (Fig. 6, Table 1).

Bias Adjustment

Weighted and unweighted regional models were refit using a truncated normal likelihood for partially selected ages with first age at full selection being defined as 7 years for fish caught south of Cape Hatteras (S) and 8 years for fish caught north of Cape Hatteras (N). Each region’s model was refit several times using all combinations of age at full selection (7 or 8) and minimum total lengths for first age at full selection (Minimum total length at Age 7: 393 mm (S), 340 mm (N); Age 8: 426 mm (S), 380 mm (N)). Maximum length limits were defined as the unadjusted L_{∞} estimates, 711 mm and 740 mm, for unweighted and weighted runs, respectively, and applied to adjusted fits of US South Atlantic models. Adjusted models closely estimated unadjusted models, indicating minimal sampling bias for the original fits (Fig. 7). This minimal bias would not explain differences in the regional growth curves under either weighting scenario. Thus, we conclude that the unadjusted growth curves and comparisons are representative of growth for blueline tilefish north and south of Cape Hatteras.

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Table

Table 1. Parameter estimates for Von Bertalanaffy growth models of unweighted and weighted total lengths at age for blueline tilefish (*Caulolatilus microps*) caught north (n = 1737) and south (n = 2627) of Cape Hatteras, NC, from 2003-2012. When applied, weights were calculated as the inverse of the sample size for a given age and sex. Chi square test statistics and *P*-values resulting from likelihood ratio tests of equality between parameter estimates are shown in the bottom rows. ***Significant difference at $\alpha = 0.01$.

	Unweighted			**Weighted**		
	L_∞	κ	t_0	L_∞	κ	t_0
North	936	0.09	-1.76	839	0.11	-2.31
South	711	0.26	-0.85	739	0.19	-1.85
χ^2	123	128	7.30	262	142	4.64
P	<0.0001***	<0.0001***	0.0069***	<0.0001***	<0.0001***	0.0326

Figures

Figure 1. National Marine Fisheries Service statistical areas north of Cape Hatteras, North Carolina.

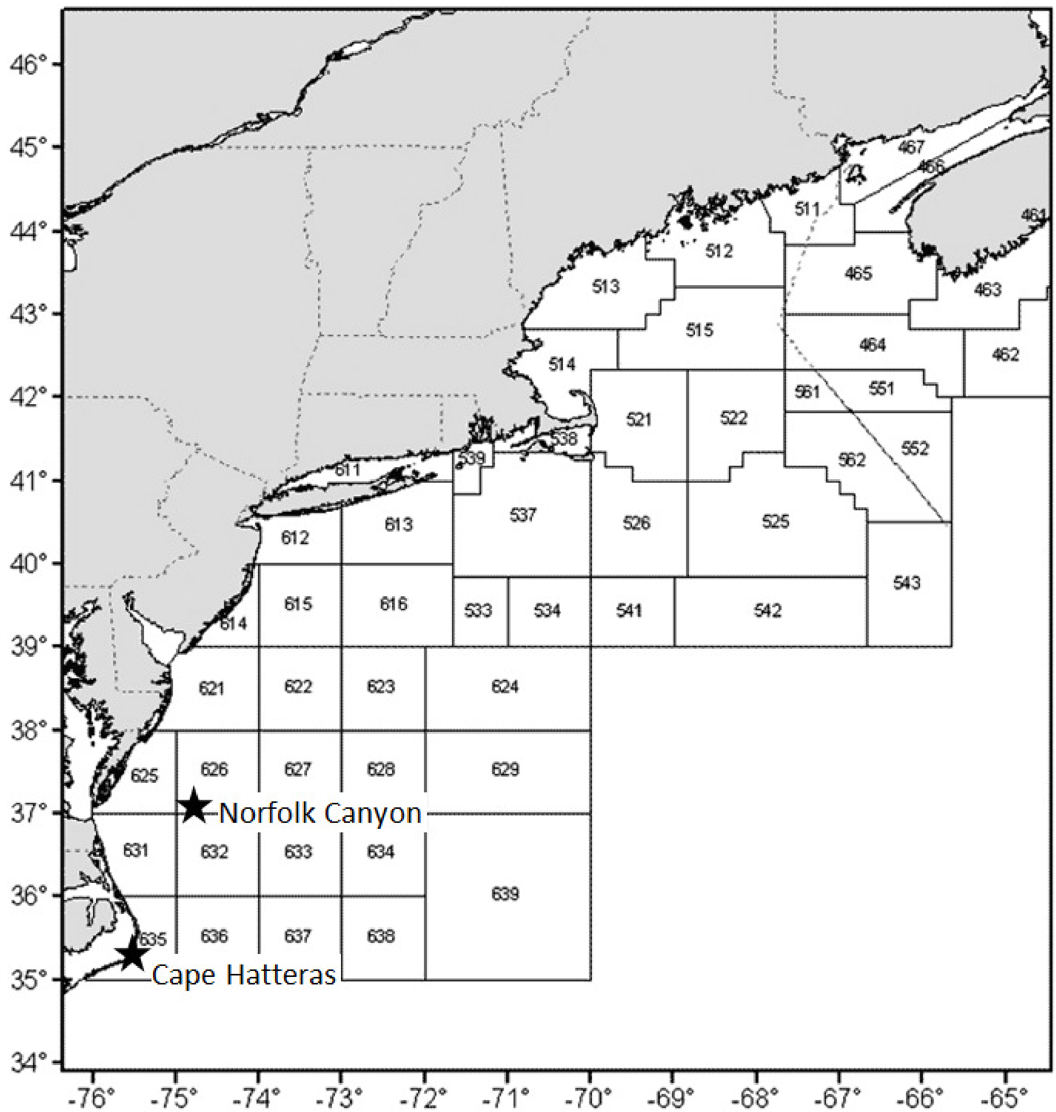

Figure 2. National Marine Fisheries Service statistical areas south of Cape Hatteras, North Carolina.

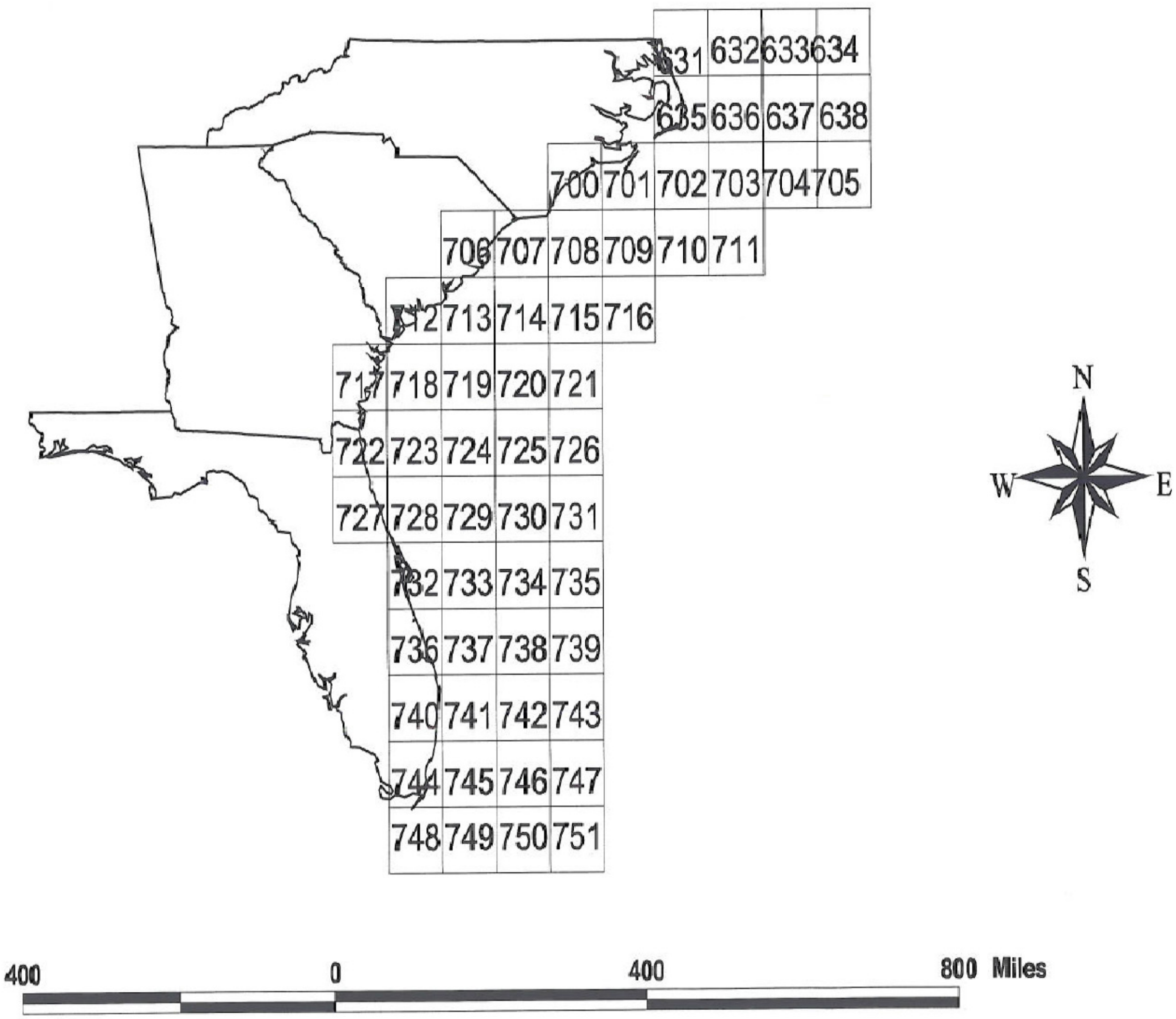

Figure 3. Bias plots of pairwise comparisons for independent and final age readings of blueline tilefish (*Caulolatilus microps*) captured off Virginia from 2009-2012. Error bars represent 95% confidence intervals about mean ages assigned by the read depicted on the y-axis for all fish assigned an age by the read depicted on the x-axis. Lines depict 1:1 relationships between reads. Vertical bars show numbers of fish (n) at age according to the read depicted on the x-axis.

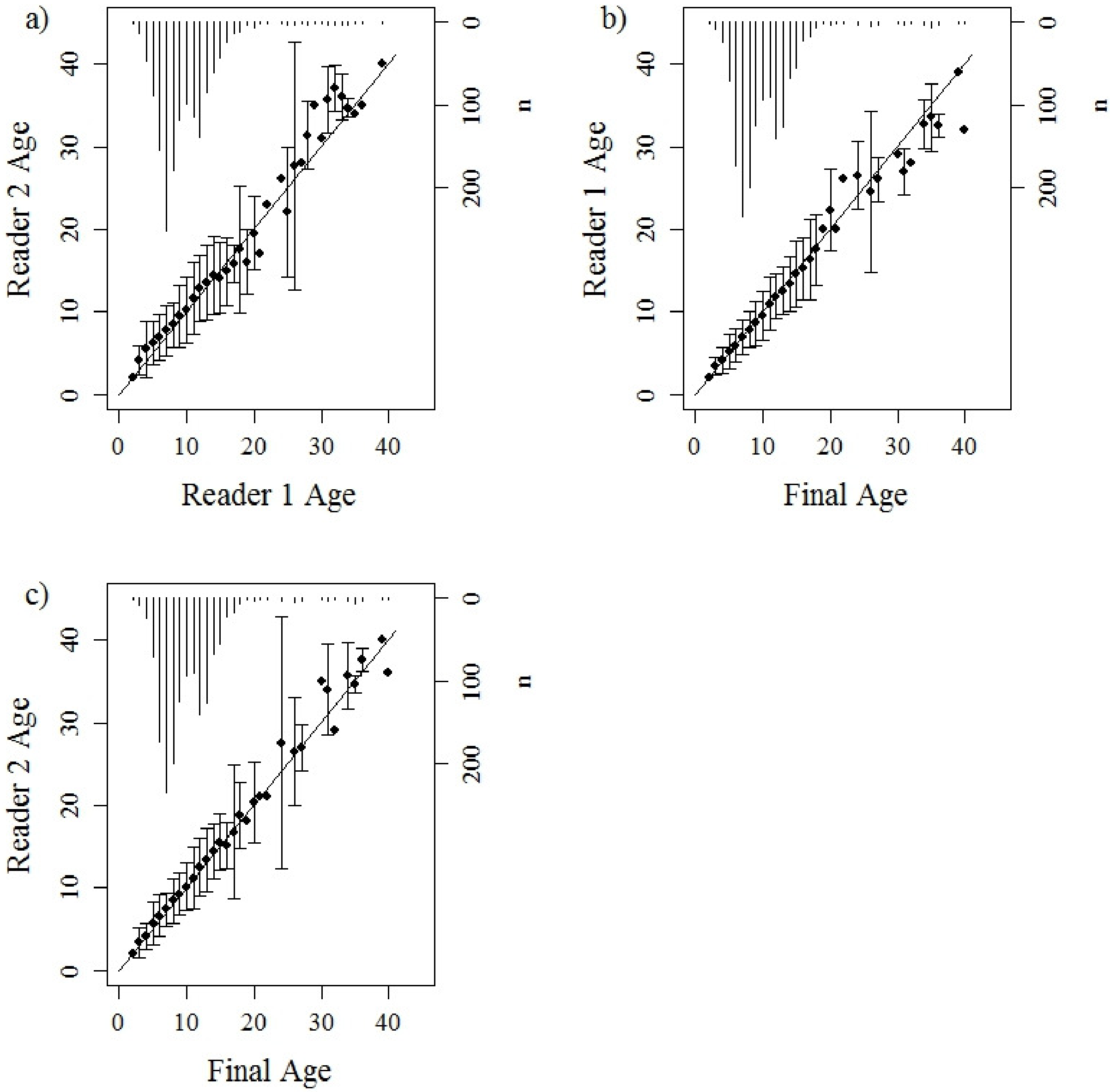

Figure 4. Monthly mean indices of completion with 95% confidence intervals for marginal increments of blueline tilefish (*Caulolatilus microps*) captured off Virginia from 2009-2012, (n = 337).

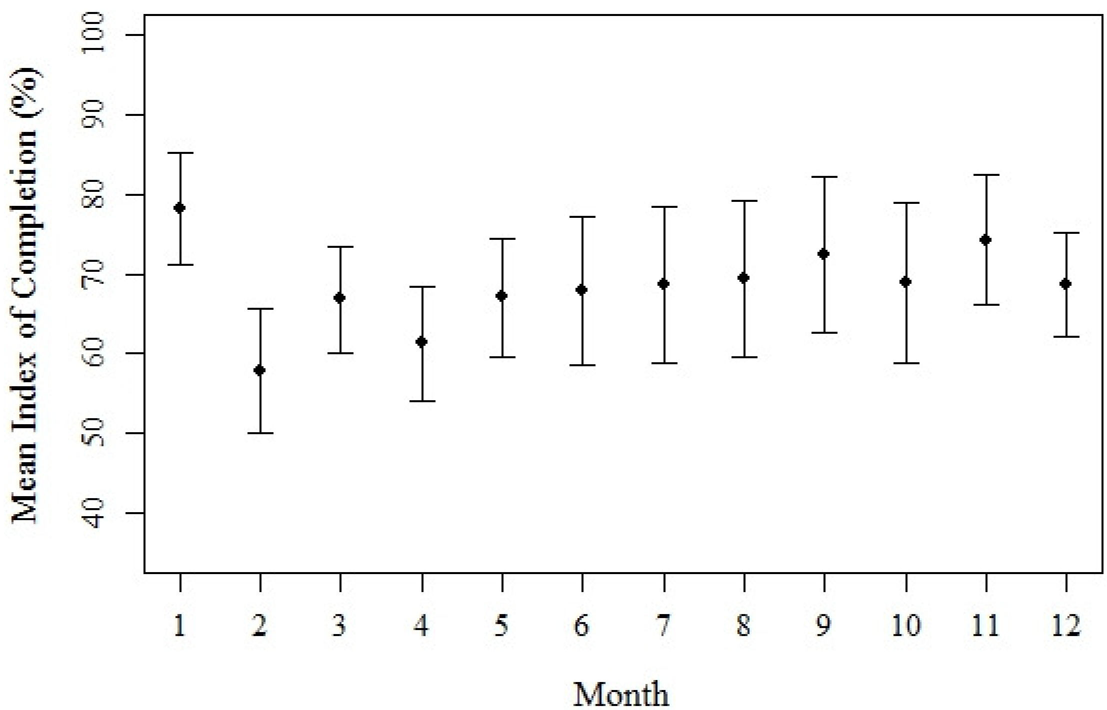

Figure 5. Linear regression of total and fork lengths for blueline tilefish (*Caulolatilus microps*) captured from 2003-2012 (n = 2277).

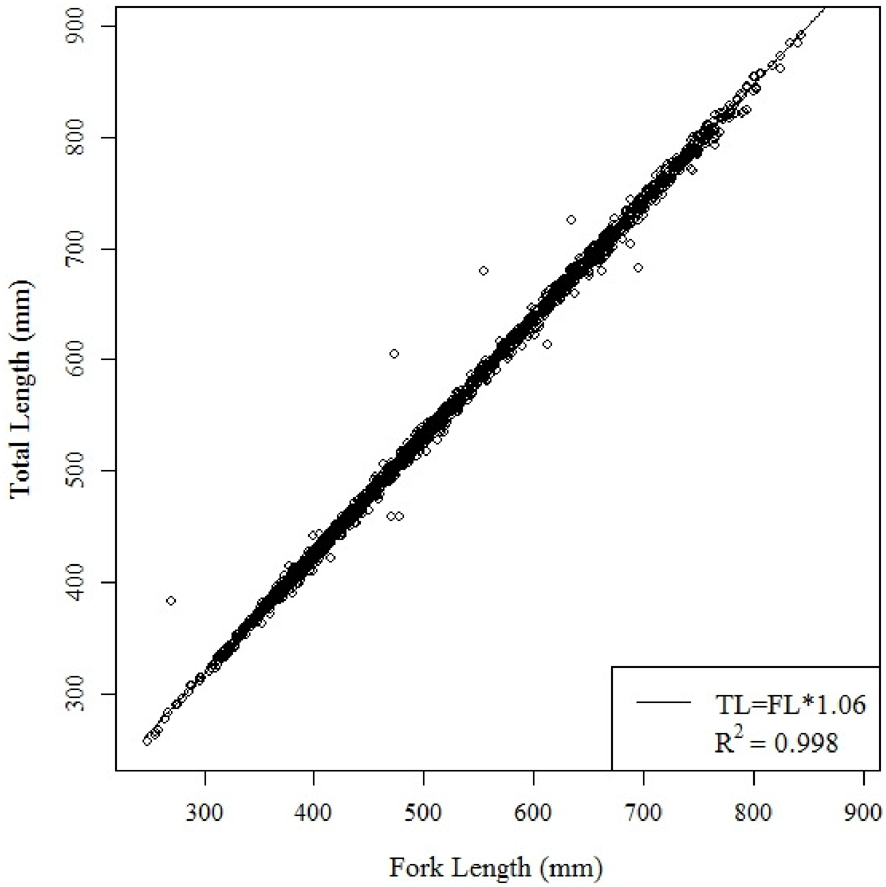

Figure 6. Von Bertalanffy growth curves regressed upon a) unweighted total lengths at age and b) weighted total lengths at age, for blueline tilefish (*Caulolatilus microps*) captured north (n = 1737) and south (n = 2627) of Cape Hatteras, North Carolina. When applied, weights were calculated as the inverse of the sample size for a given age and region.

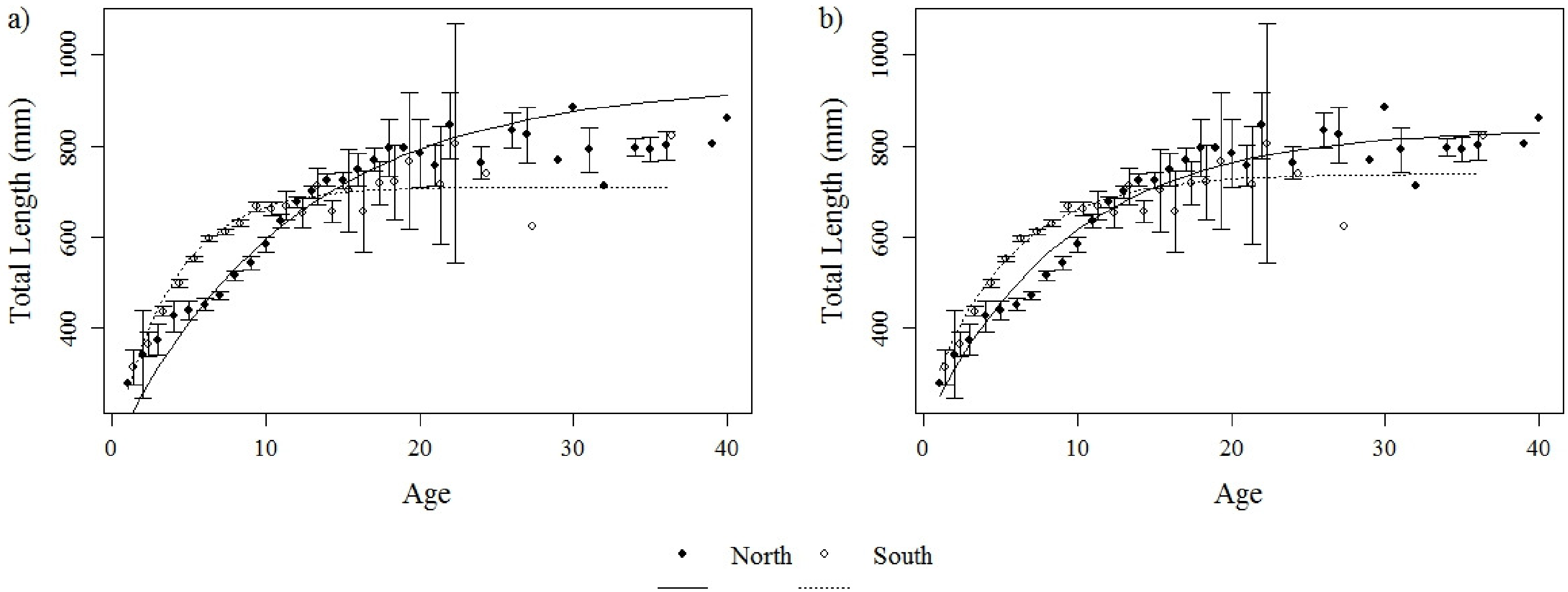

Figure 7. Von Bertalanffy growth curves regressed upon a) unweighted total lengths at age and b) weighted total lengths at age, for blueline tilefish (*Caulolatilus microps*) captured (n = 1737) and south (n = 2627) of Cape Hatteras, North Carolina, with assumed normal (solid line) and truncated-normal (dashed lines) error distributions. When applied, weights were calculated as the inverse of the sample size for a given age and region. Model runs with truncated error distributions for both regions had lower length limits of 393 mm, 340 mm, 426 mm, and 380 mm for fish at least 7, 7, 8, and 8 years old, respectively. Model runs with truncated error distributions for the southern region included runs with and without maximum length limits of a) 711 mm and b) 740 mm.