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A proposed, tested, and applied adjustment to account for bias in growth parameter estimates due to selectivity

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ABSTRACT

Growth information is important for stock assessments because it gives an indication of spawning stock biomass in the form of weight or fecundity, which is an important indicator of stock status, as well as being important if fitting to length composition data. Sampling for growth characteristics should include all ages and sizes in the population, but data are often only available from fishery-dependent sampling, which can lead to biased estimates of true underlying population growth parameters because of selectivity, which includes both gear selectivity and availability. Two stock assessments with the potential for biased growth because of dome-shaped selectivity and lack of fishery-independent age data are the Gulf and Atlantic menhaden assessments. The objectives of our study were (1) to develop and test a method to estimate unbiased growth parameters regardless of the selectivity of the gear used to sample ages and lengths and (2) to apply the proposed method to fit unbiased population growth parameters for Gulf and Atlantic menhaden. We propose a method to adjust for the bias in the growth curve parameters and account for missing samples at smaller and larger lengths. The proposed method was tested on simulated data and applied to data for Gulf and Atlantic menhaden. Use of the adjustments was robust and resulted in reduced bias in the growth parameter estimates with accuracy being affected by both sample size and variability in mean length at age. Increasing the sample sizes increased the accuracy of the adjustments (i.e., as the coefficient of variation (CV) for length at age increased, the accuracy of the estimates decreased). For Gulf menhaden, the parameters estimated for the unadjusted growth curve were $L_\infty = 240.8$, $k = 0.38$, $t_0 = -1.14$, and CV of length at age = 0.06 (assumed constant) with a total sample size of 366,710 from 1977 to 2011. For Atlantic menhaden, the parameters estimated for the unadjusted growth curve were $L_\infty = 350.9$, $k = 0.32$, $t_0 = -0.83$, and CV of length at age = 0.12 (assumed constant) with a total sample size of 480,668 from 1955 to 2011. The adjustment for a maximum length of capture had a large impact on the overall growth parameters for both species, while the adjustment for a minimum length of capture had less impact. Bias in the growth curve parameter estimates can be reduced by using the method outlined to account for selectivity.

1. Introduction

Selectivity is important in stock assessments as it defines what ages or lengths are being represented by an index or harvested from a fishery (Quinn and Deriso, 1999). The concept of selectivity includes a combination of fishery targeting, capture by the gear, size limits, and spatial distribution of the fish population by age and size (Quinn and Deriso, 1999; Sampson and Scott, 2011). Selectivity can also have an impact on the estimates of model parameters used to describe life history characteristics for a stock assessment because often samples come from fishery-dependent sampling. Ideally, information on growth for assessment models comes from fishery-independent and -dependent sampling and includes all ages and sizes in the population. However, in reality, often the only age samples available are those from the fishery-dependent sampling. If the fishery selects for only certain size classes, then estimates of growth can be biased (Ricker, 1969).

Growth information, such as the parameters of the von Bertalanffy growth curve, is important for stock assessments because it is important when fitting to length composition data and is generally used to give an indication of spawning stock biomass in the form of weight or fecundity, which is an important stock status indicator for harvested species (von Bertalanffy, 1957; Restrepo et al., 1998). For some stock assessments, parameter k or the size-at-age information from the growth curve is used to derive other important life history characteristics (Williams and Shertzer, 2003; Charnov et al., 2012). While estimates of growth curve parameters have

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been adjusted because of minimum length limits (McGarvey and Fowler, 2002) and selectivity (Troynikov, 1999; Taylor et al., 2005; Troynikov and Koopman, 2009), growth curve parameter estimates are generally unadjusted for maximum length limits or dome-shaped selectivity and few studies have tested proposed methods with simulated data. Gwinn et al. (2010) explored the bias in the methods that account for dome-shaped selectivity including fixing L_∞. However, when good data are unavailable to provide an estimate of L_∞, fixing it is inappropriate. Alternately, one could use the variance observed in fully selected age classes to assume a variance at non-fully selected ages to provide information about the approximate scale of the L_∞ value. Two stock assessments with the potential for biased growth because of dome-shaped selectivity and lack of fishery-independent age data are assessments for Gulf menhaden *Brevoortia patronus* and Atlantic menhaden *B. tyrannus*.

Both Gulf menhaden and Atlantic menhaden are ubiquitous filter-feeding clupeid species (Ahrenholz, 1991). Gulf menhaden occur in the northern Gulf of Mexico from Florida to Mexico, and Atlantic menhaden are found along the U.S. Atlantic coast from Florida to Maine and into Canada. Both species are schooling, forage fish that are harvested by large, industrial purse-seine fisheries. Gulf menhaden move towards the centre of the species range, off the coast of Louisiana, as they age (Ahrenholz, 1981). Atlantic menhaden migrate north in spring from the spawning grounds off North Carolina through summer and stratify by size and age with older and larger individuals migrating the farthest north (Nicholson, 1971, 1978; Ahrenholz, 1991). Both species exhibit spatial heterogeneity in size and age, and as such, spatial heterogeneity in age occurs on the fishing grounds, which may be responsible for overall dome-shaped selectivity in the fishery (Sampson and Scott, 2011).

The commercial purse-seine fishery is the largest fishery by volume in the Gulf of Mexico and the second largest (along with Atlantic menhaden) in the United States (NOAA, 2012). Currently, there are four processing plants on the Gulf coast, and one plant on the Atlantic coast. Biological samples are collected from vessels at dockside at each of the plants. The 10-fish samples are obtained from the top of a vessel's fish hold (Smith, 1991). Fork length and weight are measured for each specimen sampled, and a scale sample is taken for later age estimation. All scales are sent to the National Marine Fisheries Service (NMFS) Beaufort Laboratory for processing. Scales are used for age estimation because menhaden are short-lived, menhaden otoliths are small and fragile, and the effort needed to process enough otoliths for such a large fishery

Table 1
Run specifications, parameter estimates, and likelihood for runs completed to adjust the growth curve for Gulf menhaden with a minimum adjustment, maximum adjustment, and a minimum and maximum adjustment simultaneously. NA means that the minimum or maximum was not applied. A – indicates a run that did not converge.

Minimum	Maximum	L_∞	k	t_0	CV	Likelihood
100	NA	242.92	0.36	−1.25	0.06	653.09
105	NA	242.97	0.36	−1.26	0.06	650.13
110	NA	243.14	0.36	−1.27	0.06	646.41
115	NA	243.63	0.35	−1.30	0.06	641.37
120	NA	242.97	0.36	−1.28	0.06	636.36
125	NA	240.55	0.38	−1.17	0.06	630.00
130	NA	240.61	0.38	−1.20	0.05	621.63
135	NA	241.23	0.37	−1.26	0.05	612.59
140	NA	242.21	0.36	−1.34	0.05	601.87
145	NA	243.45	0.35	−1.45	0.05	586.78
150	NA	244.53	0.34	−1.53	0.05	568.67
NA	200	–	–	–	–	–
NA	205	–	–	–	–	–
NA	210	–	–	–	–	–
NA	215	–	–	–	–	–
NA	220	314.59	0.20	−1.73	0.07	547.74
NA	225	283.50	0.25	−1.57	0.07	591.00
NA	230	265.94	0.29	−1.44	0.07	624.25
NA	235	253.86	0.32	−1.32	0.07	644.36
NA	240	246.31	0.35	−1.22	0.07	653.93
NA	245	243.17	0.37	−1.17	0.06	660.39
NA	250	242.67	0.37	−1.17	0.06	665.79
100	200	–	–	–	–	–
105	205	–	–	–	–	–
110	210	–	–	–	–	–
115	215	–	–	–	–	–
120	220	–	–	–	–	–
125	225	266.75	0.27	−1.63	0.06	556.14
130	230	257.25	0.30	−1.58	0.06	580.07
135	235	248.18	0.33	−1.45	0.05	590.28
140	240	243.24	0.35	−1.37	0.05	588.23
145	245	242.95	0.35	−1.44	0.05	579.04
150	250	245.21	0.33	−1.56	0.05	566.28
150	200	–	–	–	–	–
145	205	–	–	–	–	–
140	210	–	–	–	–	–
135	215	–	–	–	–	–
130	220	282.69	0.23	−1.86	0.06	506.33
125	225	266.75	0.27	−1.63	0.06	556.14
120	230	264.44	0.27	−1.68	0.06	593.97
115	235	254.70	0.31	−1.52	0.06	618.29
110	240	246.95	0.34	−1.34	0.06	632.47
105	245	244.29	0.35	−1.28	0.06	642.35
100	250	244.30	0.35	−1.28	0.06	650.60