Estimated von Bertalanffy growth curves for King Mackerel stocks in the Atlantic and Gulf of Mexico

Elizabeth N. Brooks
and
Mauricio Ortiz
Southeast Fishery Science Center
75 Virginia Beach Drive
Miami, FL 33149

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SUMMARY: As recommended by the 2004 SEDAR Mackerel Data Workshop, otolith data aged by SEFSC-Panama City Laboratory personnel were analyzed to estimate stock- and sex-specific von Bertalanffy growth curves. The estimated growth curves for the Atlantic (12,159 otoliths) and Gulf of Mexico (17,813 otoliths) were compared to previous work by Collins et al. (1989; 683 otoliths in Atlantic) and Manooch et al. (1987; 210 otoliths in Gulf of Mexico). For the Atlantic, the approximate 95% confidence interval for predicted length at age contained the previous growth curve of Collins et al. (1986) for both female and combined sex growth curves. The male growth curve of Collins et al. (1987) falls below the 95% confidence interval for ages 0-5, with the difference ranging from about 29 to 3 mm forklength. For the Gulf of Mexico, the approximate 95% confidence interval for predicted length at age contained the combined sex growth curve of Manooch et al. (1987); however, the predicted length at age 0 for the female growth curve of Manooch et al. (1987) was 10 mm below the lower 95% confidence interval, and for males the predicted length at age 0 was 100 mm less and at age 1 was 40 mm less than the lower 95% confidence interval. The impact of applying updated growth models on estimated catch at age for king mackerel was examined. The result was a shift towards greater numbers of the youngest age classes (ages 0-2) and a decrease of about one year in the age of full selectivity. The presence of significant year effects was tested but results were inconclusive.

Methods

Otoliths collected from North Carolina to Texas for the period 1986-2002 were analyzed. The protocol and methodology for ageing of otoliths is described in DeVries and Grimes (1997). Altogether, 29,972 otoliths were available, of which 12,159 came from the Atlantic and 17,813 came from the Gulf of Mexico. Of the Atlantic otoliths, 7477 were from female fish and 4682 were from males. In the Gulf of Mexico, 12,083 were otoliths from females and 5730 were from males. The Gulf of Mexico was further divided into East and West, where East included the west coast of Florida as well as Mississippi, Alabama, and Louisiana. The western Gulf of Mexico included only Texas. The eastern Gulf of Mexico accounted for 15,514 of the otoliths (10,624 female, 4890 male), while only 2299 otoliths were from Texas in the western Gulf of Mexico (1459 female, 840 male). The data were subsetted and analyzed as follows: Atlantic Females, Atlantic Males, Atlantic Males+Females, Gulf Females, Gulf Males, Gulf Females+Males, Eastern Gulf Females, Eastern Gulf Males, Eastern Gulf Males+Females, Western Gulf Females, Western Gulf Males, Western Gulf Males+Females. These data subsets and samples sizes are summarized in Table 1.

A von Bertalanffy growth curve was fit to all 12 data sets using PROC NLIN and specifying the Marquardt method in SAS (SAS Institute Inc. 1999). An additive error structure was assumed, i.e. constant variance in length at age:

$$L_i = L_\infty(1 - e^{-K(t_i - t0)}) + \varepsilon_i$$

Results

Parameter estimates and 95% confidence interval for von Bertalanffy parameters are given in Table 2 for Atlantic, Table 3 for Gulf, Table 4 for Eastern Gulf, and Table 5 for Western Gulf data sets.

Scatterplots of each dataset and overlayed predicted length at age with 95% confidence intervals are given in Figure 1. An examination of the residual plots (Fig. 2) and the probability plots (Fig. 3) show fairly good agreement with the assumption of normally distributed error. Exceptions are primarily the upper tails of the male growth curves. All 12 growth models were re-fit assuming a multiplicative error structure but it was found the model fit less well in the lower tail in addition to the upper tails still departing from the assumed error distribution. A comparison of predicted length at age for the two error structures shows very negligible differences (Fig. 4), therefore the assumption of additive error structure was retained.

The overlay of Atlantic growth curves in Figure 5 shows that, although the estimates of mean length at age for each sex are consistently higher for this study than the Collins et al. (1989) study, the mean length predicted by Collins et al. (1989) still falls within a 95% confidence interval for females. The male growth curve of Collins et al. (1989) falls below the 95% confidence interval for ages 0 through 5, although the difference is less than 30 mm for ages 0 and 1, and less than 20 mm for ages 2 through 5. In the study by Collins et al. (1989), ages 5 and 10 were the most dominant ages in their female samples, while the present study was dominated by ages 2-4 (Fig. 6). For the male samples, Collins et al. (1989) had proportionally more samples at age 1 and ages 7+, while male samples in the present study were dominated by ages 2-4 (Fig. 6).

Similar overlays for the Gulf (Figure 7) revealed that the sex-specific curves of Manooch et al. (1987) were just outside of the 95% confidence interval for ages 0 (females and males) and age 1 (males only). The difference is greatest for males (95 mm less at age 0, and 35 mm less at age 1). The age composition of the Manooch et al. (1987) samples were dominated by ages 1-3, 98% of the samples were age 9 or less, and the oldest age sampled was 14 for females and 11 for males (Fig. 8). By comparison, the present study, while dominated by ages 1-4, sampled more older individuals (Fig. 8). The oldest age sampled in the present study was 24 for female and 23 for male in the Gulf of Mexico.

When the sex-specific curves from the Atlantic and Gulf are overlayed (Figure 9), there does not appear to be a difference in the estimated growth curves. The predicted mean lengths at age are close between Atlantic and Gulf models, and confidence intervals for one model include the mean prediction of the other model.

There was some discussion at the 2004 King Mackerel data workshop as to whether separate East and West Gulf of Mexico growth curves would be more appropriate than using a single Gulf-wide growth curve. The plot in Figure 10 shows that there is no discernible difference between the sex-specific Gulf-wide growth curves versus the East and West sex-specific growth curves.

The effect on estimated catch at age (CAA) using the von Bertalanffy growth parameters from this study was a net positive shift in the proportional representation of the youngest two age groups (Fig. 11). Likewise, plotting CAA shows a shift in selectivity by about 1 year (Figure 12). These figures show only the years when the stochastic method was used exclusively. Analyzing the slope of the natural logarithm of catch at age in these years allowed a comparison of estimated total instantaneous mortality (Z) between the two sets of growth parameters (those from this study, and those from either Manooch et al. (1987) in the Gulf or Collins et al. (1989) in the Atlantic). Table 6 summarizes the age of full selectivity used in the estimation of Z, the estimate of Z, and R^2 for the regression of ln(Catch at age) versus age. In the Gulf of Mexico, using the growth parameters estimated in the present study typically led to a lower estimate of Z compared to Manooch et al. (1987), while in the Atlantic the estimate of Z was different between this study and Collins et al. (1989) but without any consistent trend.

Following a method discussed in Schaalje et al. (2002), the existence of year effects on growth was examined using SAS proc NLMIXED (SAS Institute Inc. 1999). An initial run was made with no random effects to verify that the same solution could be obtained. During this validation step, it was noted that the model tended to give unstable, and occasionally unrealistic solutions unless the von Bertalanffy parameters were constrained. After the introduction of reasonable bounds, a solution was obtained that matched that produced earlier using proc NLIN (SAS Institute Inc. 1999). Next, year was added to the model as a normally distributed random effect with a mean of 0 and an estimated variance. The significance of year as a random effect depended on the initial conditions.

Discussion

The observed differences between the growth curves estimated in this study and those of Manooch et al.(1987) and Collins et al. (1989) could be due to ageing method (both used back calculated lengths at age), age composition of the sample, or it could represent a change in the selectivity of the fisheries being sampled. The parameters of the growth model primarily impact the assessment for quarters when the stochastic method (SAR) is applied to catch at size to estimate catch at age. The SAR method is used exclusively for the earliest data (1981-1986), and is used intermittently in the Gulf of Mexico and rarely in the Atlantic for recent years (Fig. 13). An important point to consider is which growth curve is most representative of the selectivity in the fisheries for the years in which the stochastic method is applied. Because the samples used in Manooch et al. (1987) and Collins et al. (1989) came mostly from commercial and recreational catch, and the years represented by their samples are 1980-1985 (Manooch et al.) and 1983-1987 (Collins et al.) those growth curves may be more representative for the early years of the dataset.

During the King Mackerel SEDAR data workshop, participants in the growth sub-group raised the issue of whether growth curves ought to be year-specific. The results of the present study are inconclusive since the analysis indicates that the statistical significance of a year effect depends on the starting position of the search algorithm used for fitting the growth model to the data. It is worth noting that the correlations between the parameter estimates were very high, with asymptotic size being negatively correlated with both K and t0, while the correlation between K and t0 was positive. All correlations were at least 70%, and many were >80-90%. This may be one reason for the instability of solutions encountered while testing for significant year effects. Additional study would be required to help resolve this issue.

Acknowledgements

Otolith data were provided by Doug DeVries at the Panama City Laboratory.

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Table 1. Data sets and sample sizes for which a von Bertalanffy growth curve was estimated.

Data Set	**Sample Size**
Atlantic Female	7477
Atlantic Male	4682
Atlantic Male+Female	12,159
Gulf of Mexico Female	12,083
Gulf of Mexico Male	5730
Gulf of Mexico Male+Female	17,813
Eastern Gulf of Mexico Female	10,624
Eastern Gulf of Mexico Male	4890
Eastern Gulf of Mexico Male+Female	15,514
Western Gulf of Mexico Female	1459
Western Gulf of Mexico Male	840
Western Gulf of Mexico Male+Female	2299

Table 2. Estimates and 95% confidence intervals for parameters of the von Bertalanffy growth curve for Atlantic Females, Atlantic Males, and Atlantic Males+Females, as well as the parameter estimates from Collins et al. (1989).

Parameter	Estimate	L95%	U95%	Collins et al.
Atlantic Females				
L_∞	1293.7	1281.6	1305.7	1208
K	0.1491	0.1431	0.1551	0.1239
t0	-3.4479	-3.6174	-3.2783	-3.7445
Atlantic Males				
L_∞	1011.2	1004.6	1017.8	942
K	0.2126	0.2035	0.2216	0.1915
t0	-3.2177	-3.4026	-3.0327	-2.5006
Atlantic Males+Females				
L_∞	1179	1169.8	1188.1	1277
K	0.1673	0.1609	0.1738	0.0874
t0	-3.4287	-3.5942	-3.2633	-5.6836

Table 3. Estimates and 95% confidence intervals for parameters of the von Bertalanffy growth curve for Gulf of Mexico Females, Gulf of Mexico Males, and Gulf of Mexico Males+Females, as well as the parameter estimates from Manooch et al. (1987).

Parameter	Estimate	L95%	U95%	Manooch et al.
Gulf of Mexico Females				
L_∞	1416	1398.7	1433.3	1417
K	0.136	0.1307	0.1413	0.136
t0	-3.3097	-3.4343	-3.1851	-1.9754
Gulf of Mexico Males				
L_∞	1051	1039.9	1062.1	1113
K	0.1862	0.177	0.1954	0.208
t0	-3.5229	-3.7129	-3.3329	-1.48
Gulf of Mexico Males+Females				
L_∞	1303.2	1288.2	1318.2	1478
K	0.142	0.1364	0.1476	0.1154
t0	-3.5598	-3.6964	-3.4232	-2.3599

Table 4. Estimates and 95% confidence intervals for parameters of the von Bertalanffy growth curve for Eastern Gulf of Mexico Females, Eastern Gulf of Mexico Males, and Eastern Gulf of Mexico Males+Females. (**Note: Manooch et al. parameters applied to the entire Gulf of Mexico**).

Parameter	Estimate	L95%	U95%	Manooch et al.
Eastern Gulf of Mexico Females				
L_∞	1431	1411.5	1450.5	1417
K	0.134	0.1284	0.1396	0.136
t0	-3.3072	-3.4393	-3.1751	-1.9754
Eastern Gulf of Mexico Males				
L_∞	1050.5	1038.6	1062.4	1113
K	0.1898	0.1799	0.1996	0.208
t0	-3.4062	-3.5993	-3.2131	-1.48
Eastern Gulf of Mexico Males+Females				
L_∞	1320.6	1303.9	1337.4	1478
K	0.1403	0.1344	0.1462	0.1154
t0	-3.5092	-3.6505	-3.3679	-2.3599

Table 4. Estimates and 95% confidence intervals for parameters of the von Bertalanffy growth curve for Western Gulf of Mexico Females, Western Gulf of Mexico Males, and Western Gulf of Mexico Males+Females. (**Note: Manooch et al. parameters applied to the entire Gulf of Mexico**).

Parameter	Estimate	L95%	U95%	Manooch et al.
Western Gulf of Mexico Females				
L_∞	1367.9	1326.3	1409.6	1417
K	0.1372	0.1222	0.1522	0.136
t0	-3.5598	-3.9799	-3.1396	-1.9754
Western Gulf of Mexico Males				
L_∞	1079.3	1040	1118.6	1113
K	0.1473	0.1216	0.1729	0.208
t0	-4.9401	-5.821	-4.0593	-1.48
Western Gulf of Mexico Males+Females				
L_∞	1271	1228.1	1313.9	1478
K	0.1292	0.1127	0.1458	0.1154
t0	-4.4687	-5.0331	-3.9043	-2.3599

Table 5. Comparison of age of full selectivity, estimated total instantaneous mortality (Z), and R^2 of the regression of ln(Catch at age) versus age.

	Manooch et al. (1987) Gulf growth parameters			Gulf growth parameters estimated in this study		
Year	Age of Full Selectivity	Estimate of Z	R^2	Age of Full Selectivity	Estimate of Z	R^2
1981	5	0.7266	0.9774	4	0.5618	0.9682
1982	5	0.4157	0.7533	4	0.5184	0.705
1983	5	0.6806	0.9099	2	0.5384	0.9413
1984	5	0.9152	0.9506	4	0.6133	0.8351
1985	5	0.7336	0.9307	5	0.6215	0.9288
1986	5	0.6473	0.9115	3	0.5218	0.977
	Collins et al. (1989) Atlantic growth parameters			Atlantic growth parameters estimated in this study		
Year	Age of Full Selectivity	Estimate of Z	R^2	Age of Full Selectivity	Estimate of Z	R^2
1981	5	0.3163	0.7068	3	0.5761	0.9279
1982	6	1.0469	0.7679	5	0.755	0.9702
1983	8	0.7403	0.9983	5	0.8036	0.8773
1984	7	0.2208	0.6165	4	0.5774	0.933
1985	8	1.194	0.9998	6	0.8202	0.9318
1986	3	0.2445	0.7208	3	0.4619	0.9385

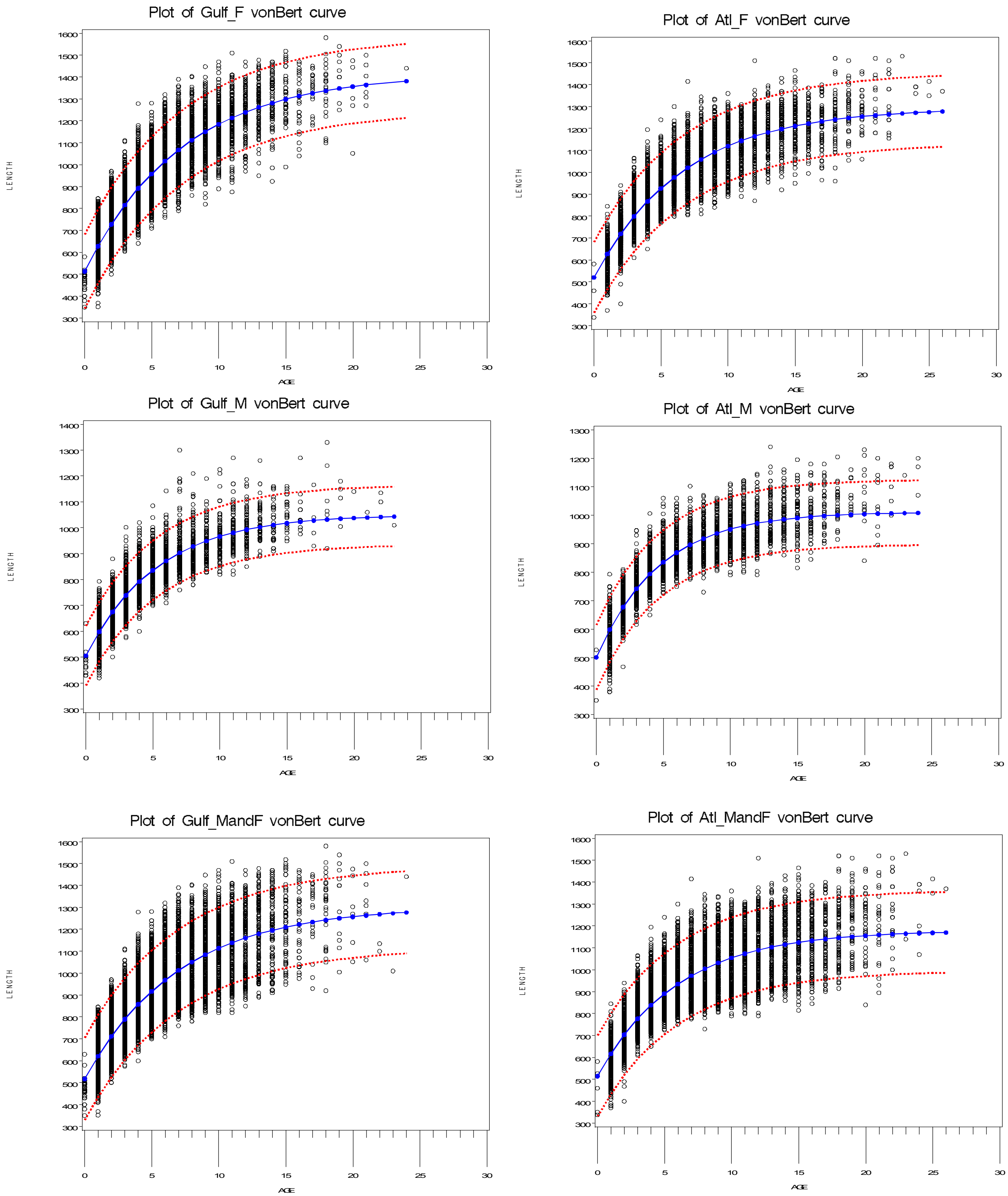
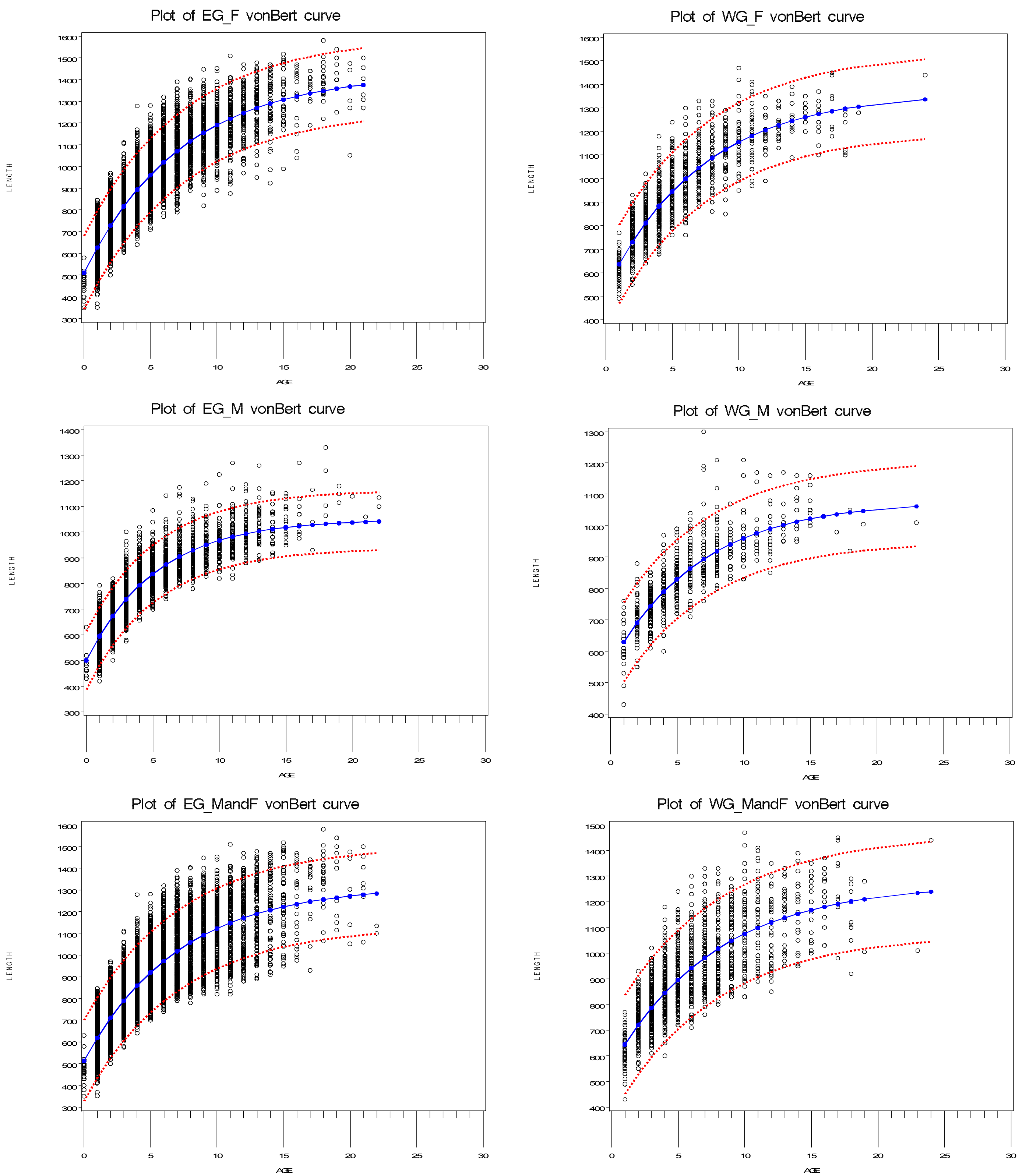


Figure 1. Scatter plots of length at age (mm Forklength) and overlay of predicted length at age with 95% confidence intervals.



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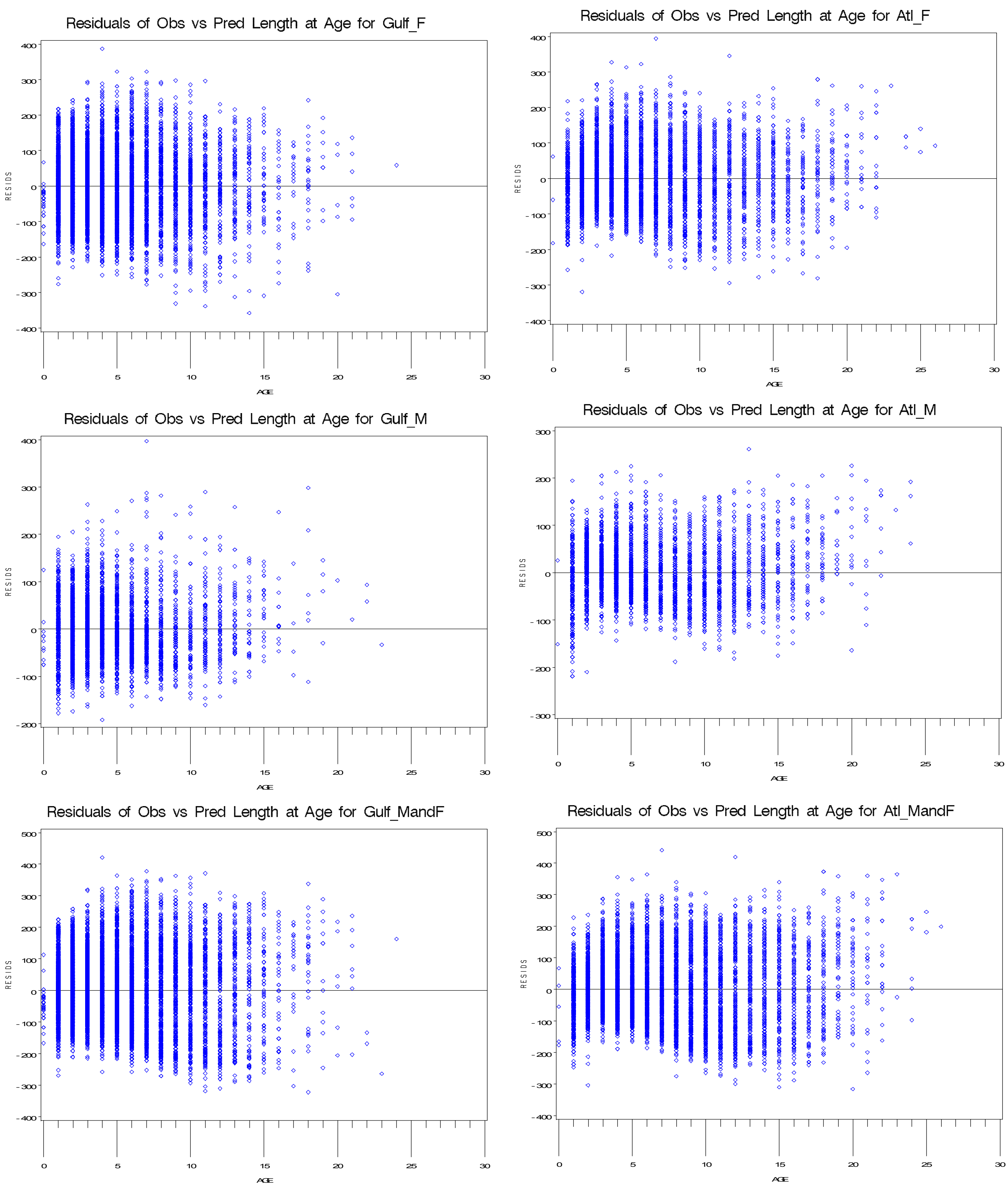
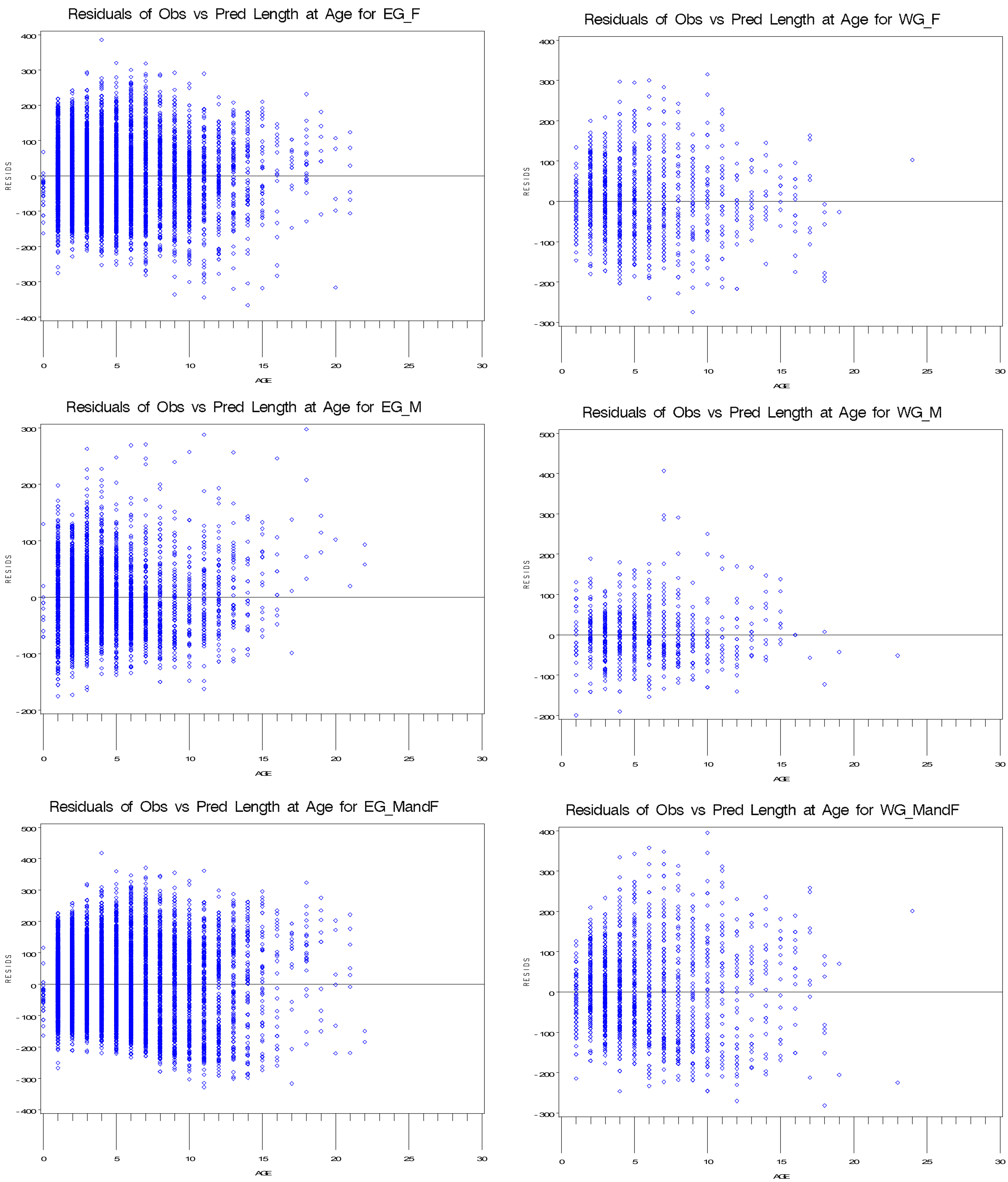


Figure 2. Plots of residuals for predicted length at age.



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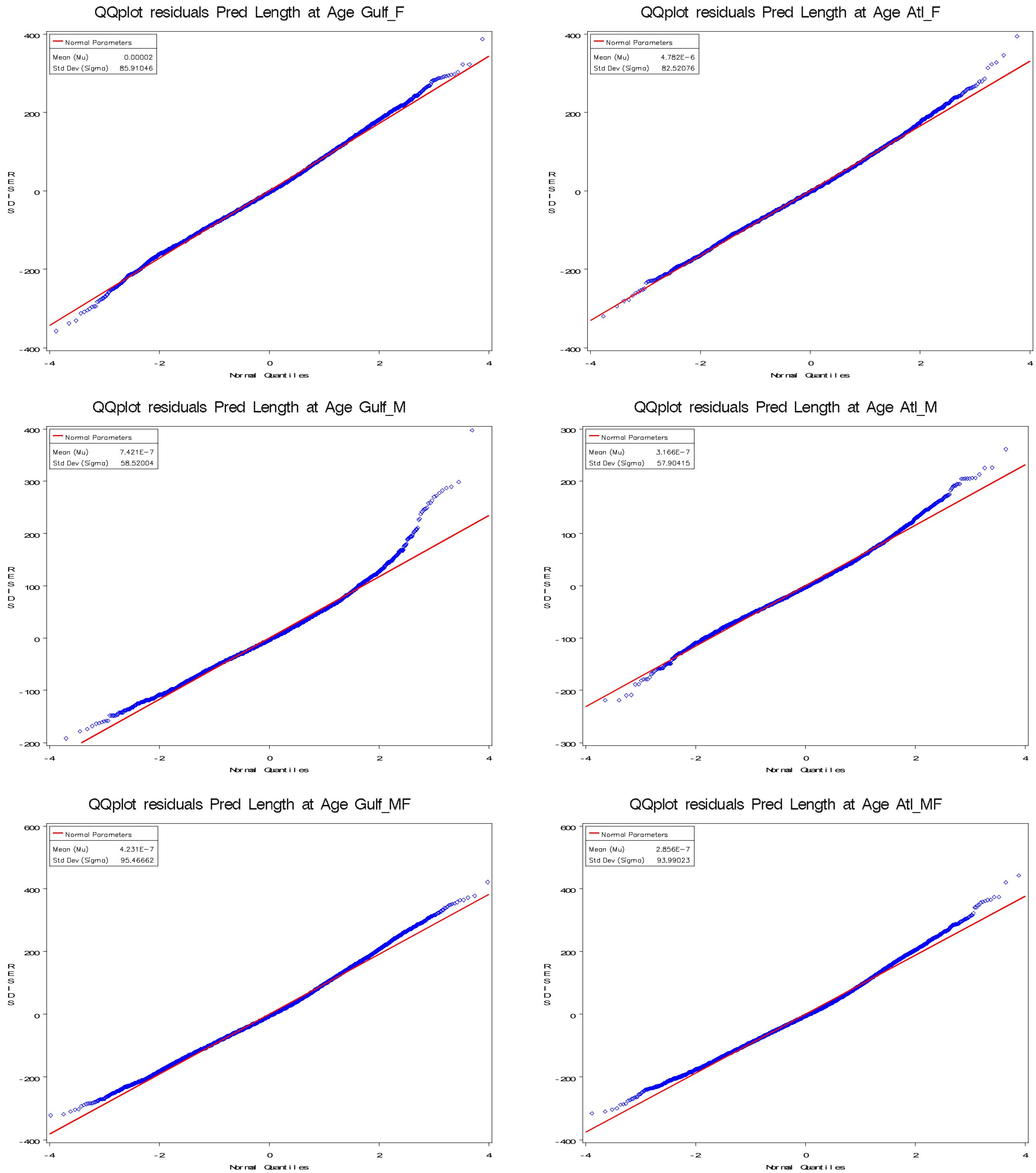


Figure 3. QQ plots of residuals versus a normal distribution.

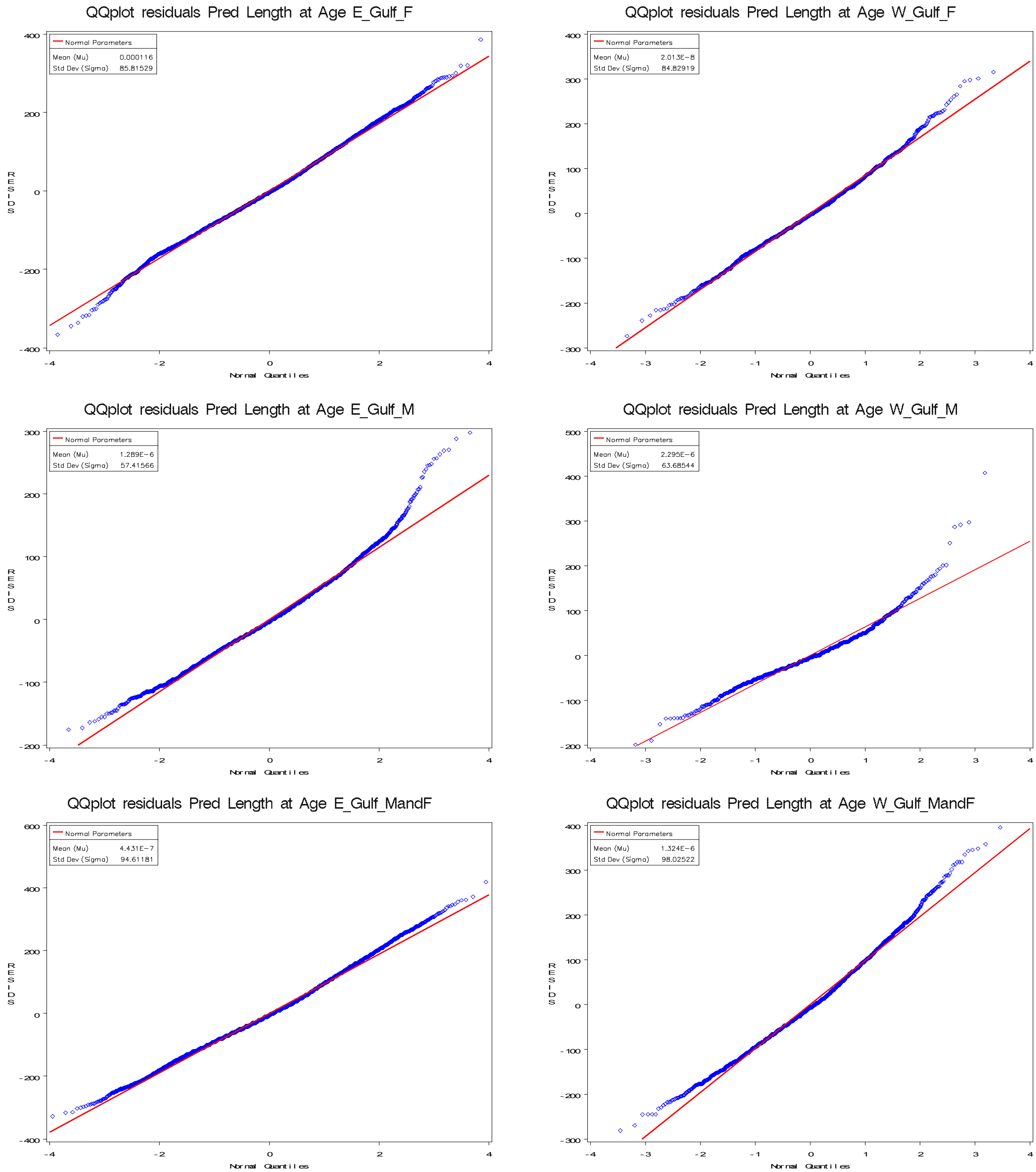


Figure 3 (cont.).

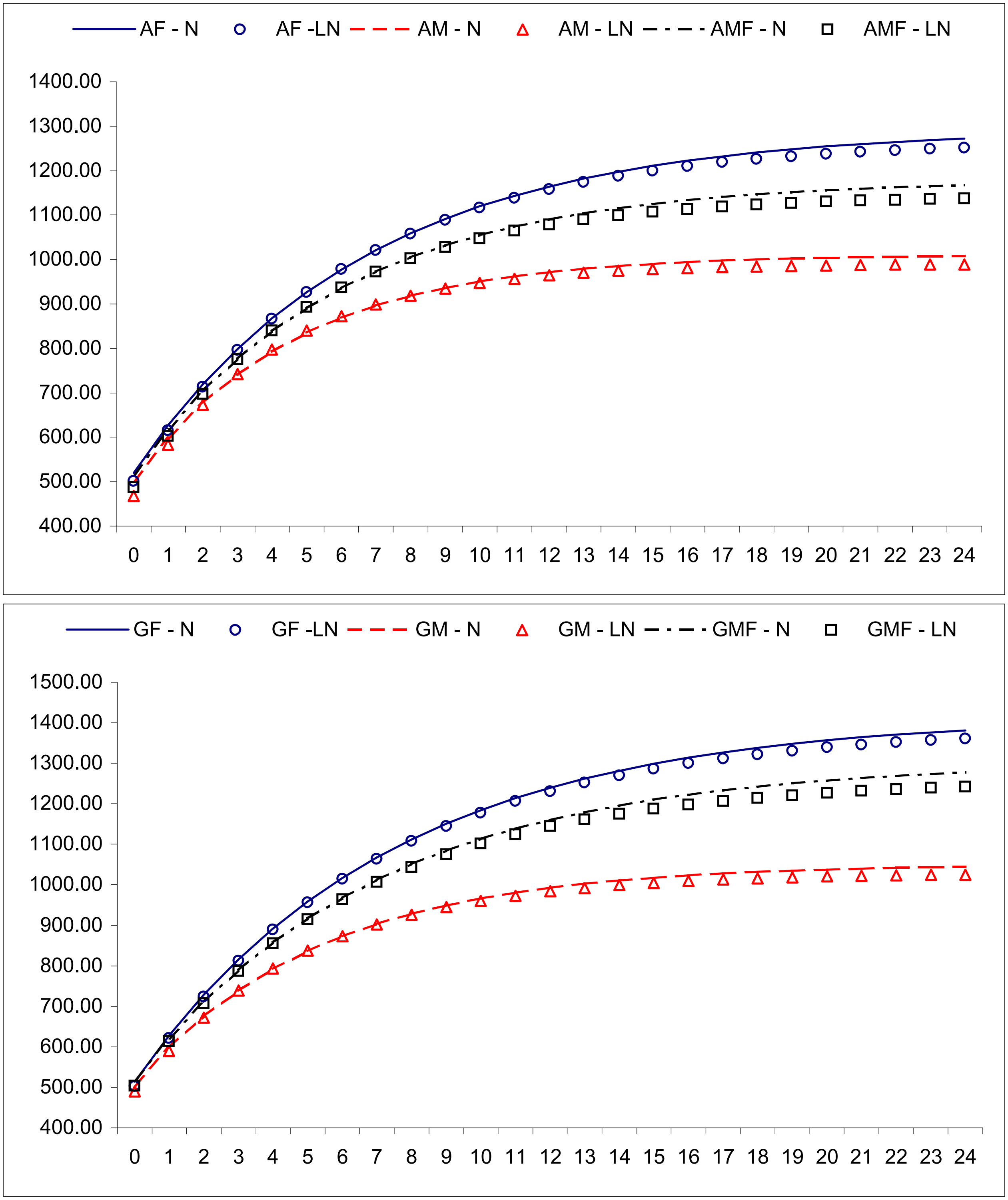


Figure 4. Comparison of addititive versus multiplicative error structure for Atlantic and Gulf of Mexic sex-specific growth curves. In the legend, " - N" refers to the additive model (solid lines) and the " - LN" refers to the multiplicative model (open symbols).

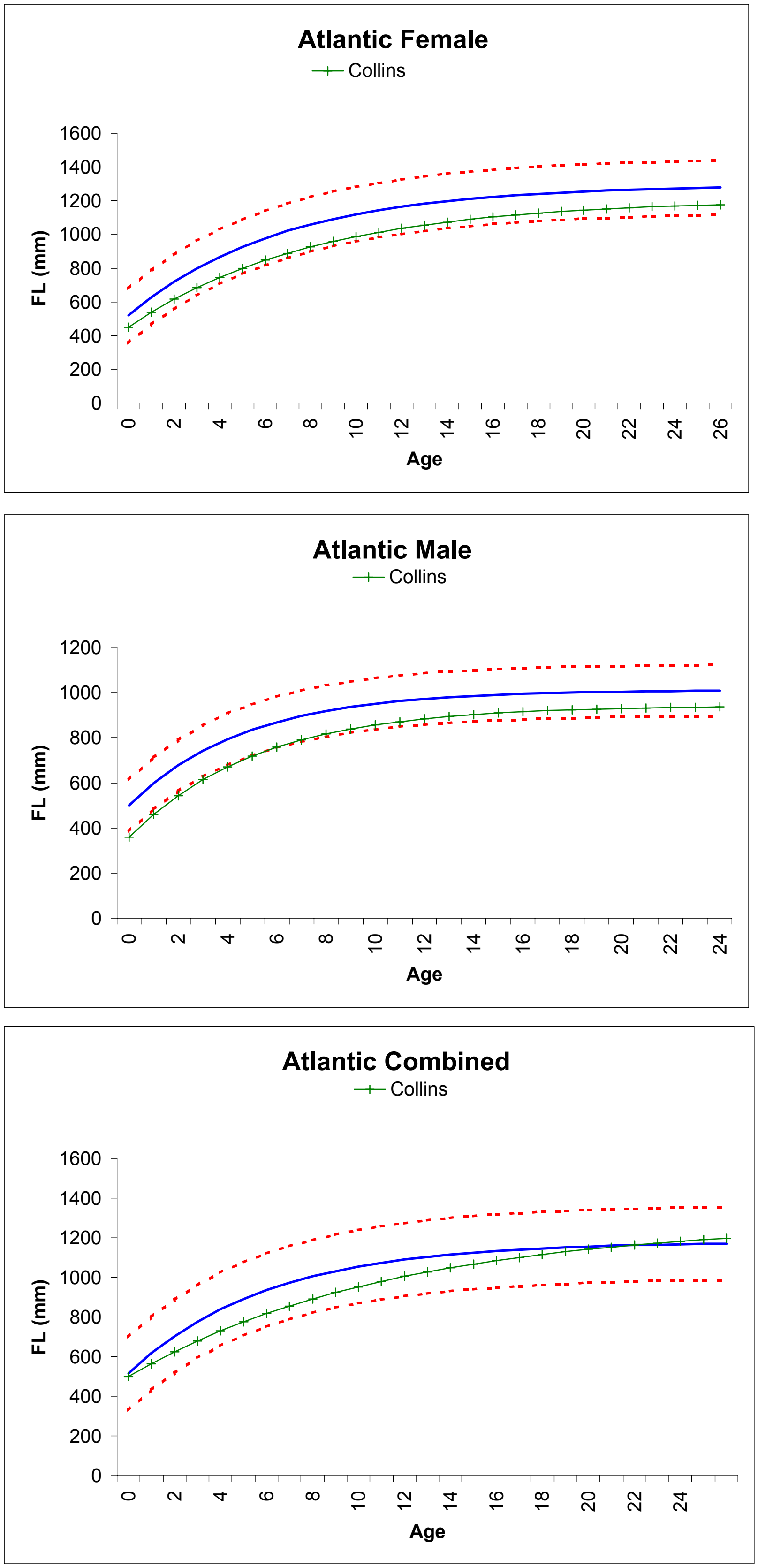
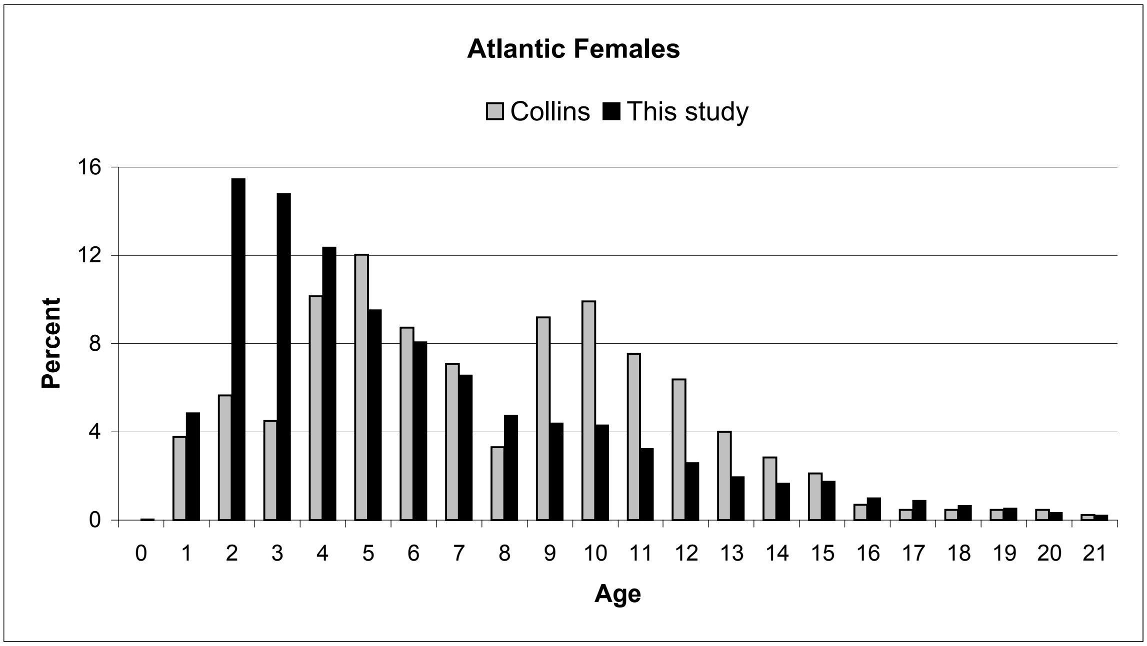


Figure 5. Atlantic growth curves and 95% confidence intervals estimated from this study compared with previous growth curves estimated by Collins et al. (1989).



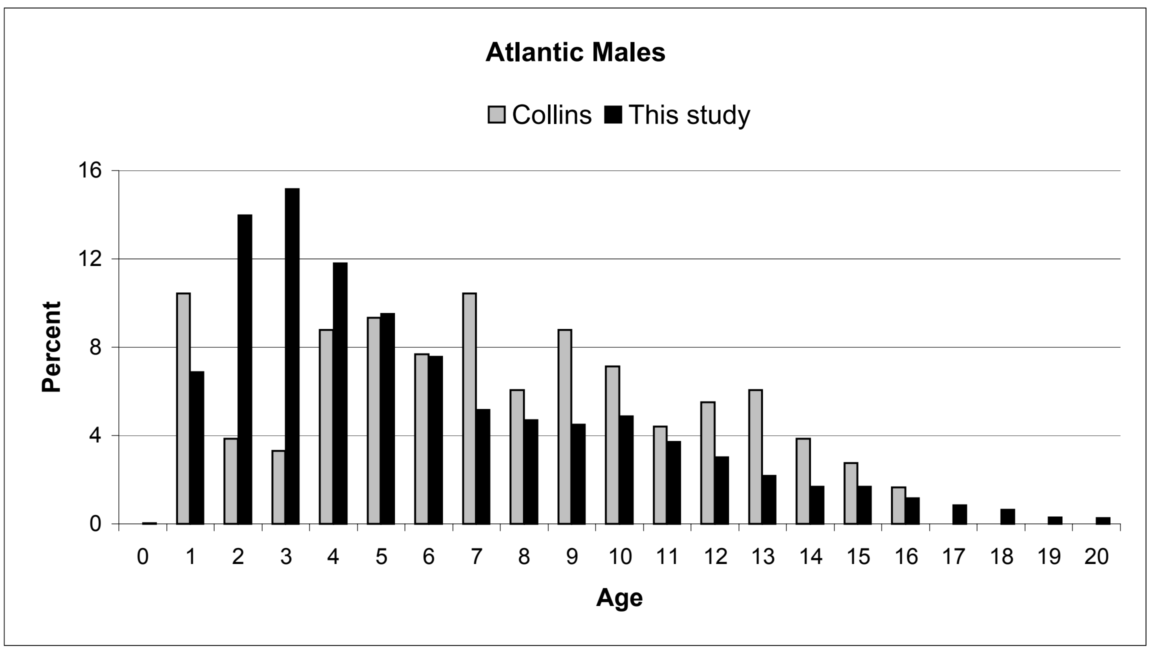
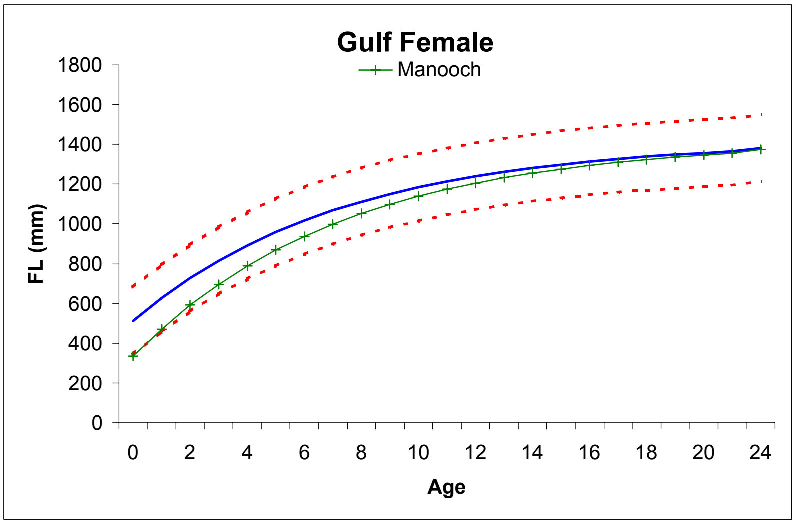
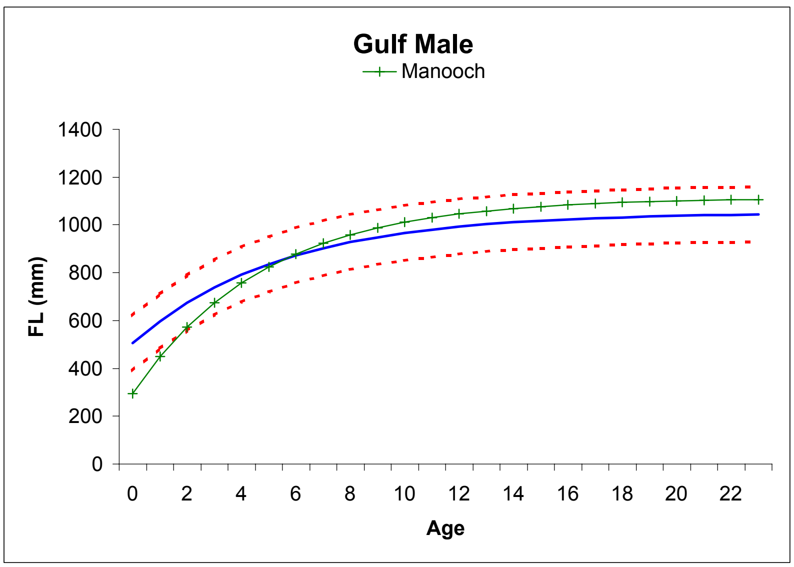


Figure 6. Age distribution of otolith samples from this study versus Collins et al. (1989





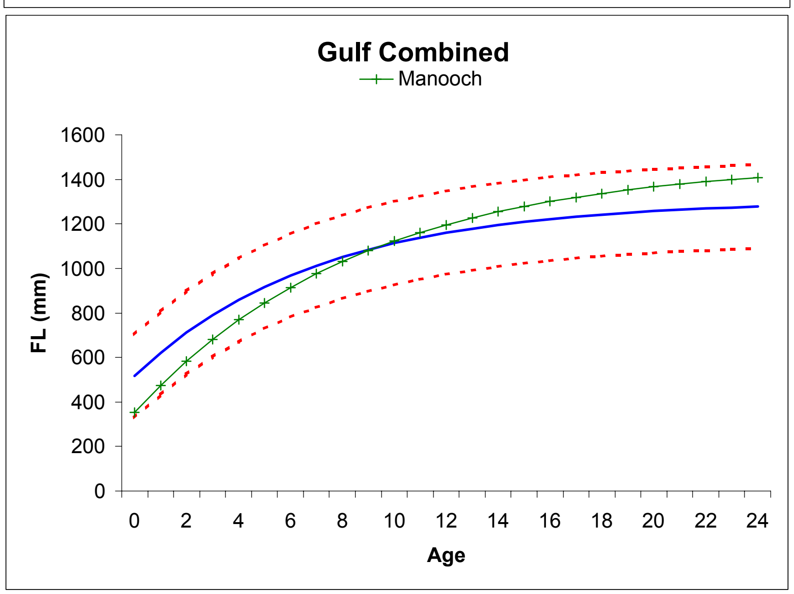
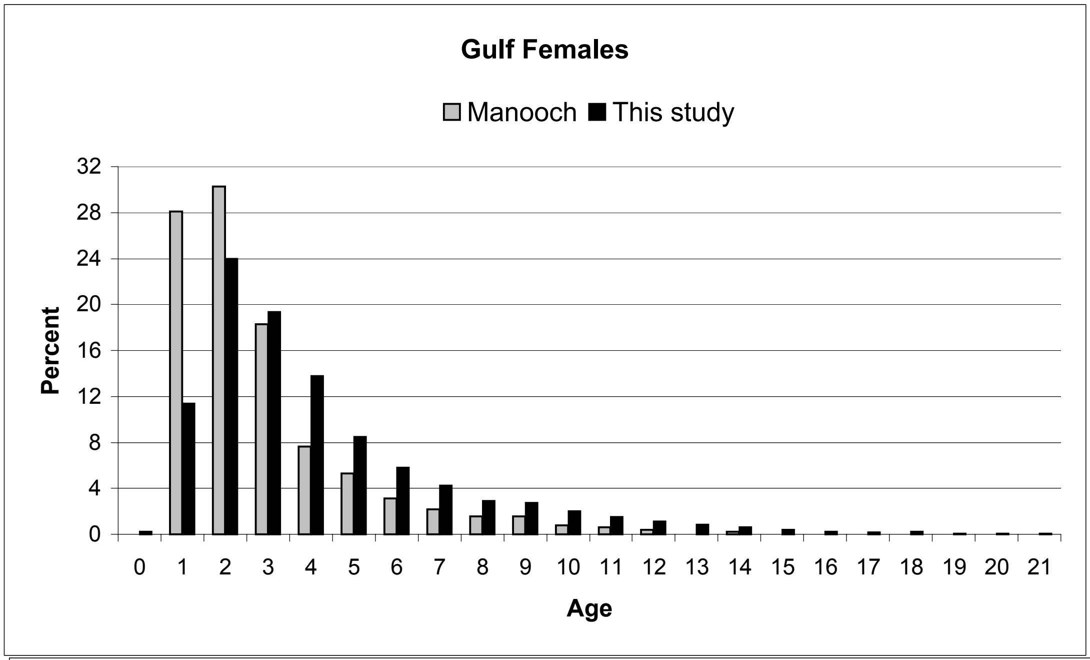


Figure 7. Gulf of Mexico growth curves and 95% confidence intervals estimated from this study compared with previous growth curves estimated by Manooch et al. (1987).



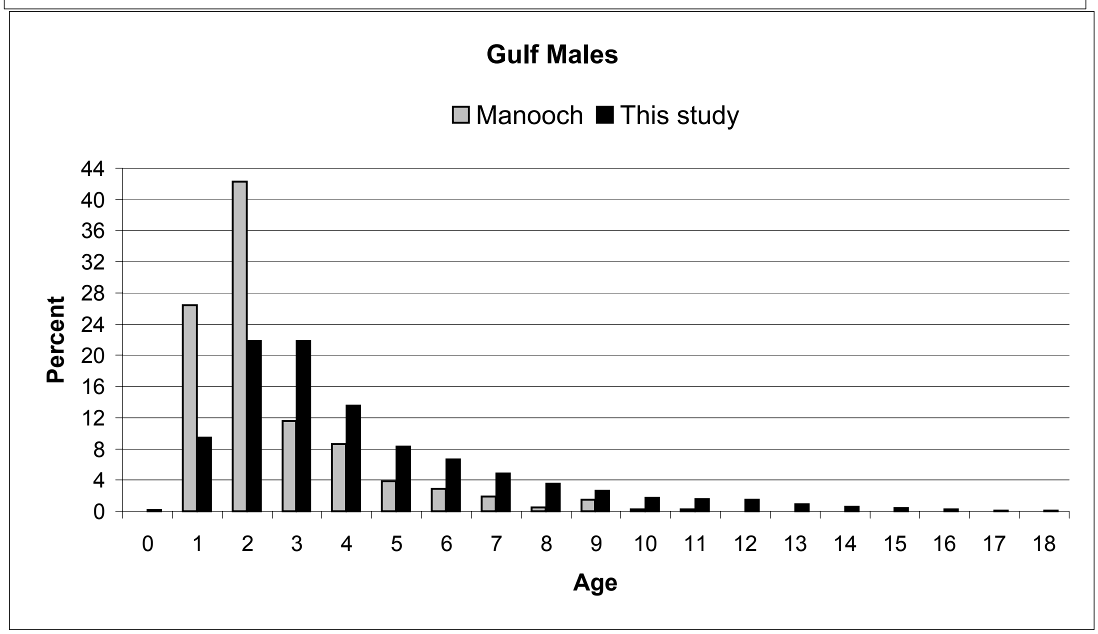
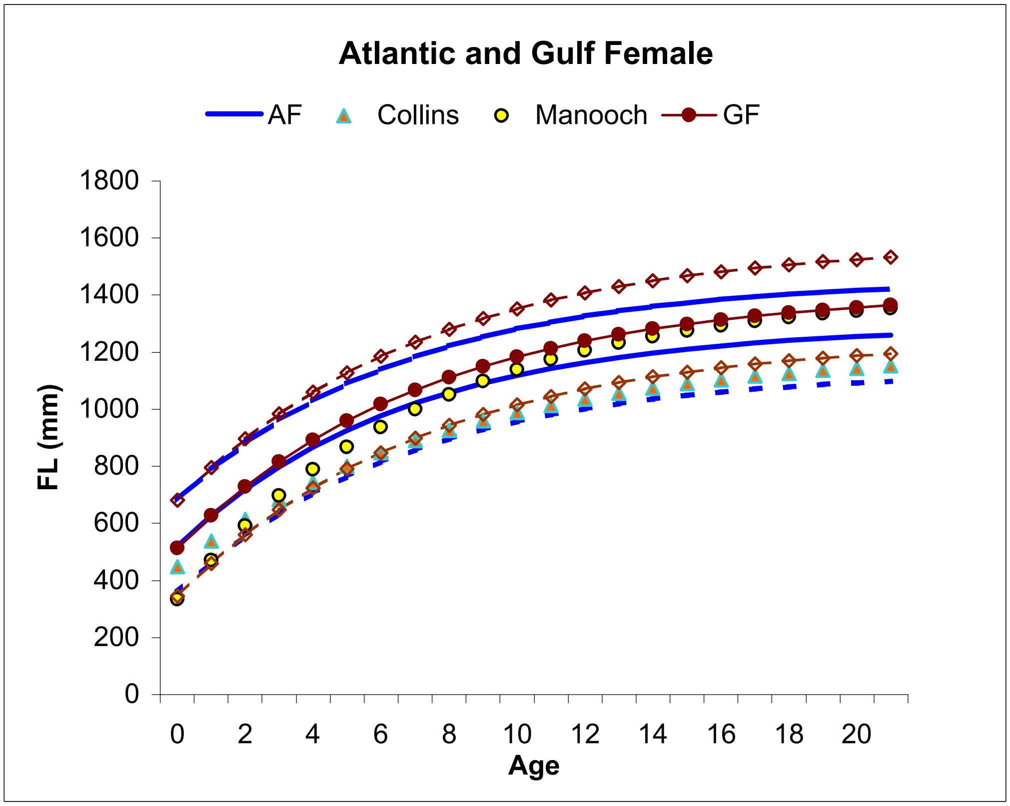


Figure 8. Age distribution of otolith samples from this study versus Manooch et al. (1987).



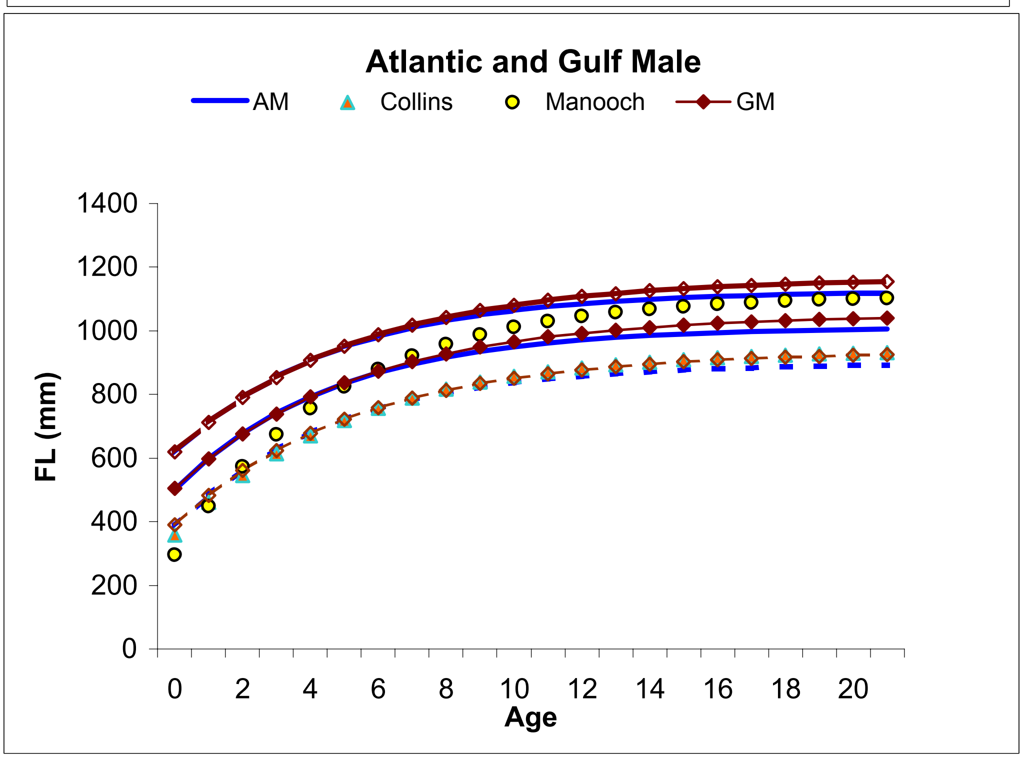


Figure 9. Estimated female growth curves for the Atlantic and Gulf of Mexico

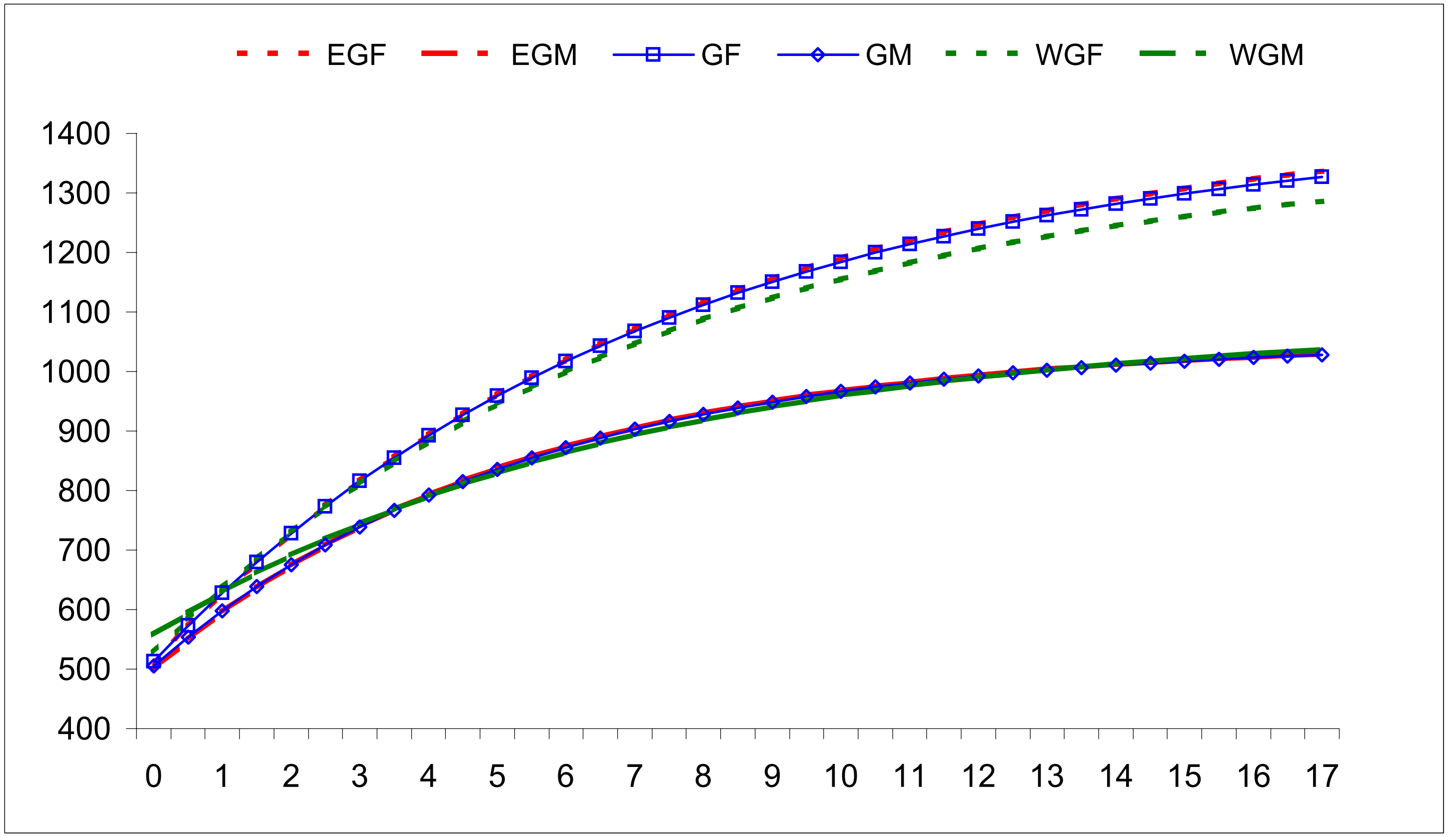


Figure 10. Comparison of Gulf-wide estimated growth curve versus separate eastern and western Gulf of Mexico growth curves.

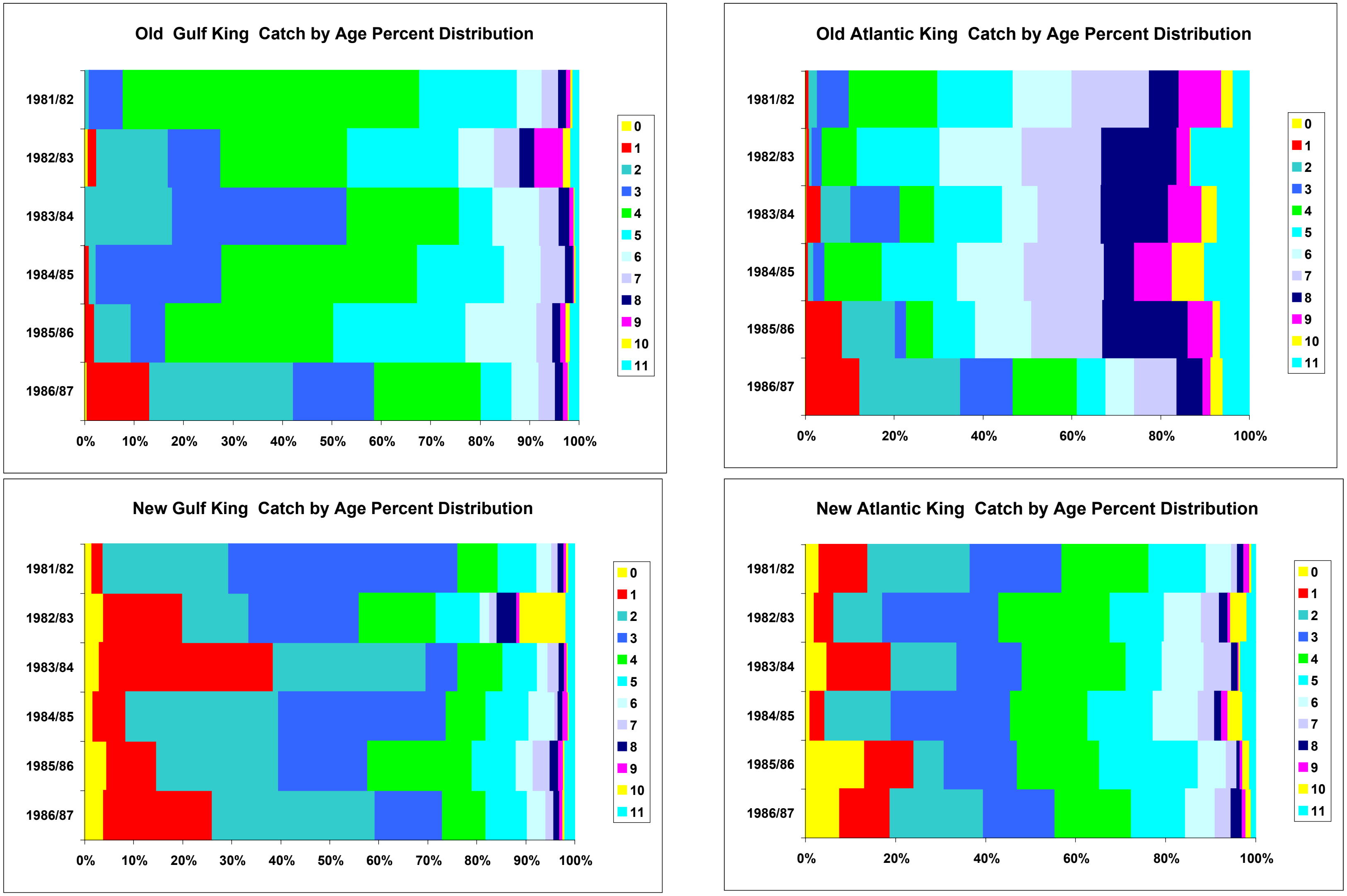


Fig. 11 Estimated catch at age using the estimated growth parameters from this study ("NEW") versus CAA estimated with the previous growth parameters ("OLD").

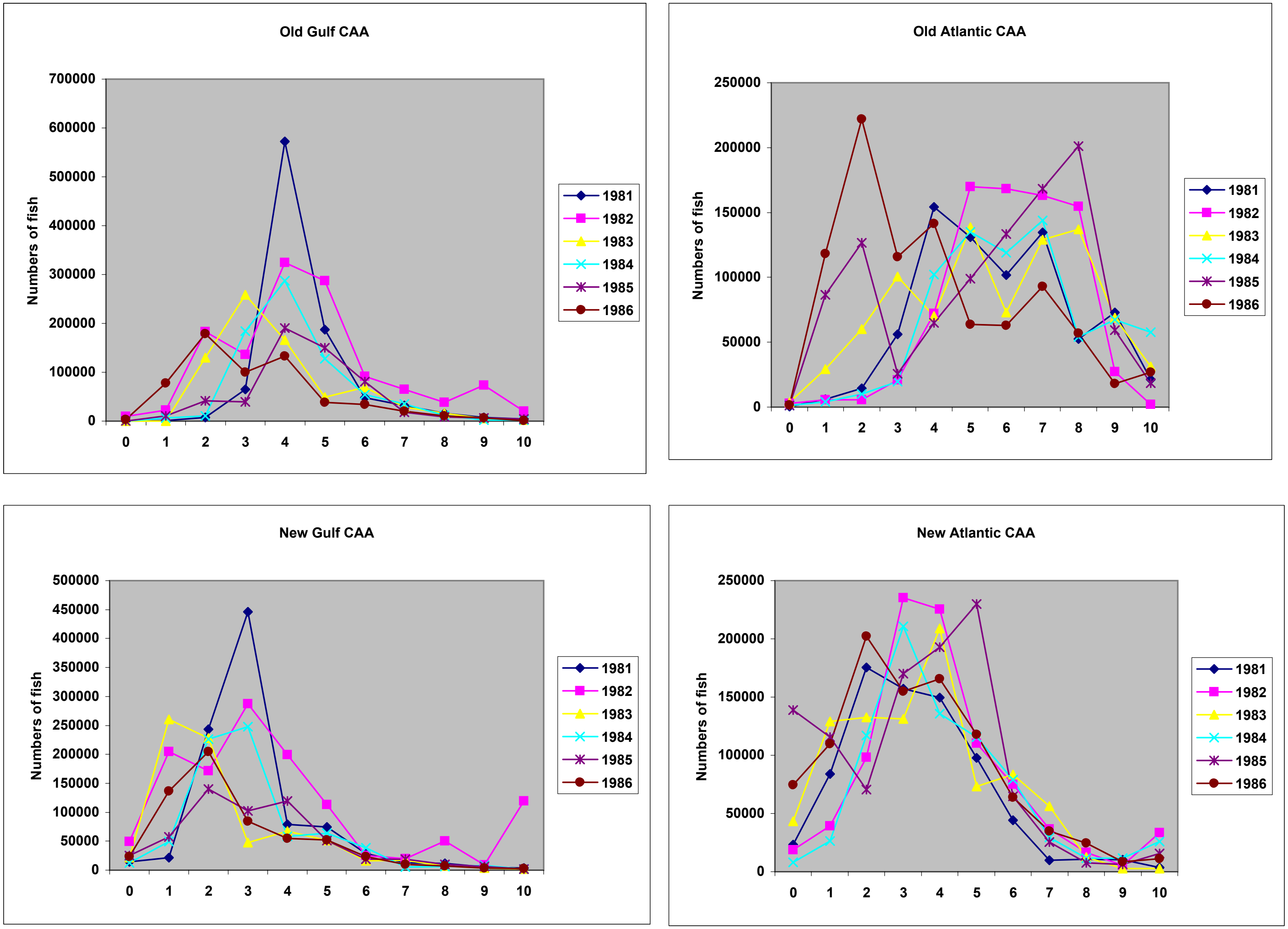
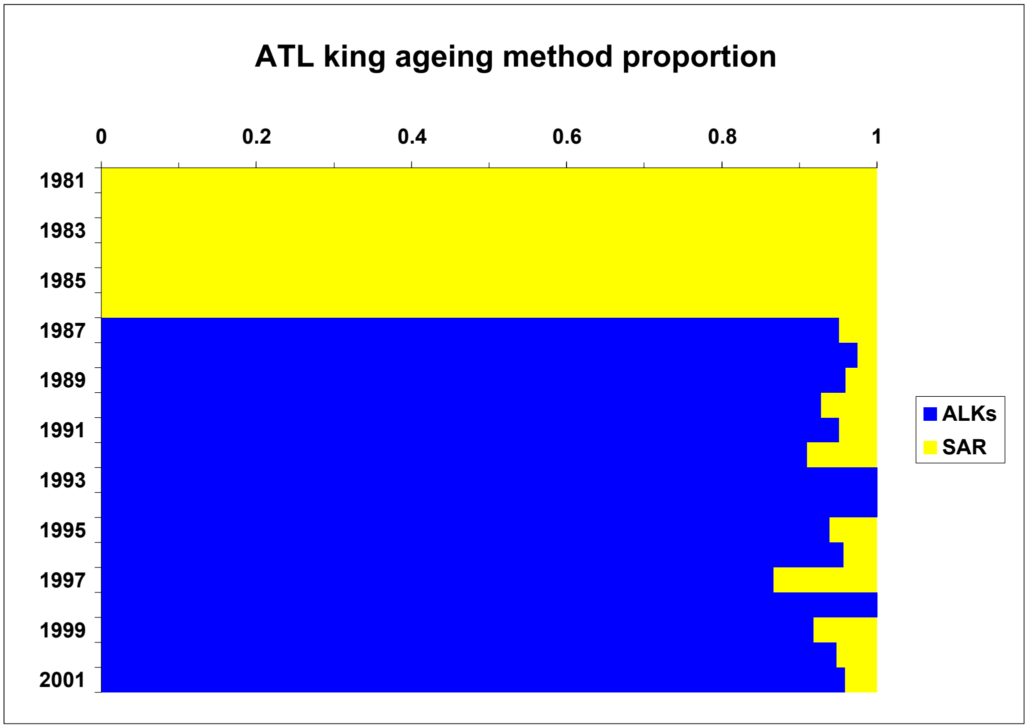


Figure 12. Catch at age using the estimated growth parameters from this study ("New") versus CAA estimated with the previous growth parameters ("Old").



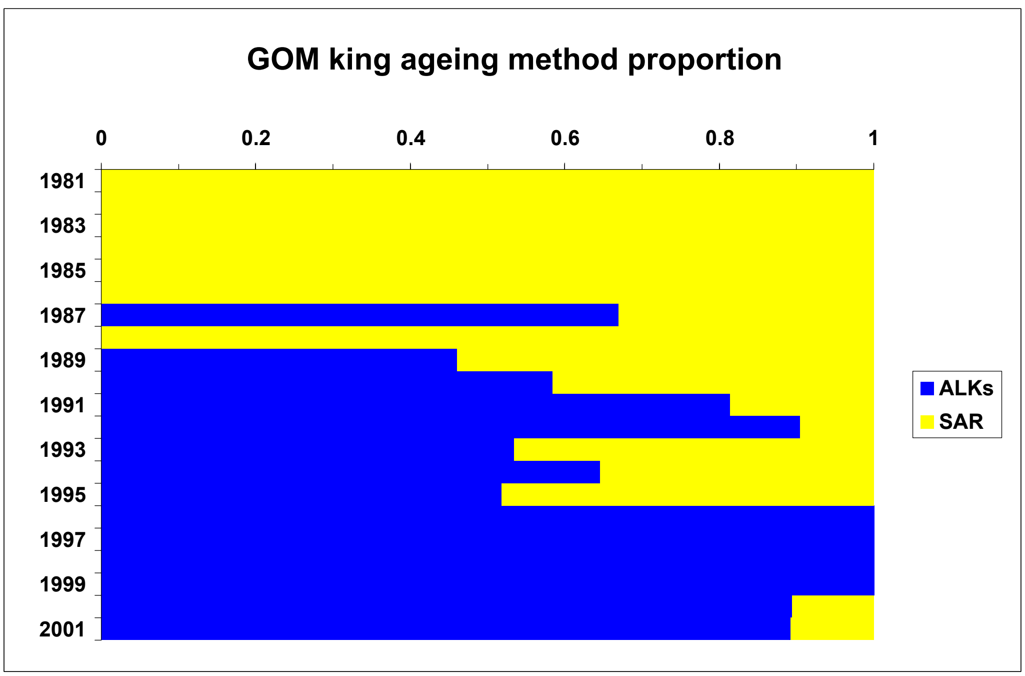


Figure 13. Ageing method by year for Atlantic and Gulf of Mexico king mackerel (ALK=Age Length Key; SAR = Stochastic Ageing Routine).