Review and estimates of von Bertalanffy growth curves for the king mackerel Atlantic and Gulf of Mexico stock units.

Mauricio Ortiz[1] and Chris Palmer[2]

SUMMARY

Age and size data derived from otolith samples of king mackerel were reviewed and updated by the Panama City laboratory and used to estimate von Bertalanffy growth models. Analyses were done by sex and stock unit with and without age-size samples from the mixing zone included in the data. Model fits accounted for sampling truncation due to minimum size restrictions and the large number of fishery dependent samples. Results indicated that there were statistically different growth patterns between males and females by stock unit, but not differences regardless of whether samples from the mixing zone are included or not.

Sustainable Fisheries Division Contribution SFD-2008-006

[1] NOAA/NMFS SEFSC Miami Lab Sustainable Fisheries Div. 75 Virginia Beach Drive, Miami FL 33149
Mauricio.ortiz@noaa.gov
[2] NOAA/NMFS Panama City Laboratory. 3500 Delwood Beach Road, Panama City Beach, FL 32408.
Chris.palmer@noaa.gov.

Size and age king mackerel

Stock assessments of king mackerel in the southeastern United States and Gulf of Mexico have been conducted since 1985 using age-based assessment methodology. Ageing of landed catch are based on the combination of published growth models and readings of otolith samples collected since the 1980's (Ortiz et al 2003). Otolith collection and methodology for ageing otoliths have been described previously (DeVries and Grimes, 1997, Cummings and DeVries 2003). This report updates the available size at age information since the last assessment (2003) and compares the estimated growth functions for the Atlantic and Gulf of Mexico king mackerel stocks.

King stocks tend to migrate southwards during the winter time and their distribution overlaps mainly in the so-called "Mixing zone", the Florida East coast and Florida Keys areas. Mixing proportions are not well known and likely are not constant through the years (Patterson et al 2004). Because of this mixing, biological samples collected in the mixing zone have the potential to be assigned to the wrong stock unit. To measure the impact in parameter estimates, the present study estimated growth models excluding samples collected in the mixing zone and compared those estimates with models that included those samples.

Methods

King mackerel otoliths were aged at the Panama City Laboratory and by Fisheries Information Network (FIN) staff. Altogether, 45,276 otolith size-age were available, of which 17,808 corresponded to the Atlantic stock unit (current stock definition), and 24,468 corresponded to the Gulf of Mexico stock (Table 1). However, 14,598 of these samples were collected within the mixing zone (Fig 1). Table 2 shows the number of size-age samples by year, stock unit and region. In the Gulf of Mexico, 17,786 of the otoliths were from females, 9,097 from males, and 585 of undetermined sex fish; in the Atlantic, 11,012 were from females, 6,538 from males, and 258 of unknown sex fish (Table 3, Fig 3).

The age information provided by the otolith readings estimated a whole year age. Fig 3 and 4 shows the proportions of samples by month and year for the Atlantic and Gulf stock units. For the Atlantic stock, samples were more uniformly collected by month in the earlier years; recently, most sampling was restricted to fewer months, mainly during the summer. Similarly, for the Gulf stock sampling proportions by month has changed through the years (Fig 4). Thus, it was decided to estimate a fractional age for each sample based on the date of collection and assuming that the date of birth for king mackerel were July 1^{st}. Spawning season extends from late spring to early fall, and peak spawning season is in the summer months for both stocks (Fitzhugh et al 2008). If a sample was collected after July 1^{st}, then the fraction of the year was added to the whole age; otherwise a corresponding fraction was subtracted from the integer age. If a sample was age 0 and collected before July 1st. it was assumed to be age 0.25.

Fig 5 shows the number of age-size samples by the source or program/institution that provided the otoliths. About 50% of samples were from the TIP program, followed by North Carolina Division of Marine Fisheries (NCDMF), Panama City Lab, and MRFSS and other co-operative and institutions. The majority of age-size samples came from fishery-dependent collections. Table 4 shows the distribution of age-size samples by source and by the fishing mode of collection for each stock unit (Fig 5). Few otoliths (322) were collected under a scientific survey (SS) program. Therefore, it is likely that the minimum size management regulations limited the size sampling of age-size king mackerel. For all fishing modes except the scientific survey, it was assumed that the minimum size regulations truncated the sampling in years when these were present. Table 5 summarizes the size regulations (Fork length) and the year-periods that applied for the age-size samples of king mackerel. Estimated growth models assumed that minimum size restrictions censored the age-size sampling of king mackerel below the given sizes for all but the scientific surveys.

One objective of this study was to compare the growth parameters of samples collected in the mixing zones. Thus, von Bertalanffy growth curves were estimated for each stock (Atlantic and Gulf), with or without the samples from the mixing zone. Additionally, growth fit curves were estimated for males, females, and both sexes combined. The growth fitting used maximum likelihood estimation with a modified von Bertalanffy model that takes into account the sampling truncation due to the minimum size restrictions (Ortiz et al in preparation). Fig 6 shows the size-at-age distributions of Atlantic king from samples collected outside of the mixing zone. The oldest aged fish was a 26 year-old female. Ages ranged from 1 to 26 years for females, and 1 to 24 years for males. There were 202 samples that had no sex identification that were predominantly age 0 and age 1 fish. Fig 8 shows the scatter plots of size at age for the Atlantic data. The data clearly show a difference in the size at age by sex, with females attaining a larger size at age than males. Fig 7 shows the size at age distributions of Gulf king from samples collected outside of the mixing zone. The oldest fish in the Gulf was a female age 24 years. Ages range from 0 to 24 years for females and 0 to 23 years for males. There were 569 samples that had no sex identification that were mainly composed of age 0 and age 1 fish (Table 6). Gulf females show a larger size at age than males (Fig 8).

Determining the sex of age 1 or 0 fish can be difficult (in the field) but they do provide important size information for these age classes, and help in the fitting of growth models (Haddon 2001). Thus, it was decided that unknown sex samples of ages 0 and 1 should be included with each sex group for the fitting by sex analyses. This provided better information to estimate the growth parameters, particularly t0. Scatter plots of mean size at age versus standard deviation of size at age (Fig 9) indicated an increase of variance at size with age, at least from ages 3 to 20 years. In the past, growth models had assumed a constant variance of size at age, contrary to what is indicated by the scatter plots of the observed data. Therefore, two error structures were considered for the fitting of von Bertalanffy growth models: a) a constant deviance of size at age (cte SD), and b) a linear increase of deviance of size at age (or constant CV).

Results

Parameter estimates for von Bertalanffy growth parameters are given in Table 7 for Atlantic and Gulf stock units. Estimates are provided by sex and for the two error distributions evaluated. There were minor differences if the size-age observations from the mixing zone were included in the dataset. In most cases, the corresponding estimated parameters between excluding mixing and including mixing observations where within their estimated ± two standard deviations (Fig 10). Main differences were between sex groups, for both Atlantic and Gulf stocks (Fig 11). Overall, females always attained larger asymptotic sizes than males, while males always had greater estimated growth rates (K parameter) (Fig 11). Growth curves were tested for statically significant differences between the sex-separated versus the combined sex for each stock unit using data outside of the mixing zone. Tables 7 and 8 present the results of two non-linear comparisons of growth curves: a) Analysis of the residual sum of squares (ARSS) (Chen et al 1992), and b) Likelihood ratio test (LRT) (Kimura 1980, Haddon 2001). Both tests indicated significant differences of growth curves by sex. For the Atlantic no-mix stock, the ARSS F was 2443.1 and the LRT chi-square was 5762, respectively, with a probability of accepting the Ho (similar growth curves) less than 0.001. The LRT also compared individual parameters; the results indicated that the Linf, K, and t0 were statistically different, while CV was not (Table 8). For the Gulf of Mexico no-mix stock, the ARSS F was 3430.2 and the LRT chi-square was 8117.9, respectively. The LRT test indicated that t0 and CV parameters were not significantly different between the sexes for the Gulf stock (Table 9).

Von Bertalanffy fits provided similar estimates whether assuming a constant deviance at size (cte SD) or a linear increasing deviance at size with age (cte CV) (Table 6). However, diagnostic residual plots indicated that the linear increase deviance at size (cte CV) fit the observed variability at size data better (Fig 12).

Literature Cited

Brooks, E.N. and M. Ortiz. 2004. Estimated von Bertalanffy growth curves for King mackerel stocks in the Atlantic and Gulf of Mexico. NOAA/NMFS SEFSC Sustainable Fisheries Div 2004. SEDAR5-AW-01.

Chen, Y., Jackson D.A. and H. H. Harvey. 1992. A comparison of von Bertalanffy and polynomial functions in modeling fish growth data. Can. J. Fish. Aqua Sci. 49: 1228-1235.

Cummings, N.J. and D.A. DeVries. 2003. Updated information on the otolith ageing data used in the 2003 king and Spanish mackerel stock assessment analyses. NOAA/NMFS SEFSC Sustainable Fisheries Div 2003-11.

DeVries, D.A. and C.B. Grimes. 1997. Spatial and temporal variation in age composition and growth of king mackerel, Scomberomorus cavalla, 1997-1992. Fish. Bull. 95:694-708.

Fitzhugh, G.R., C.F. Levins, W.T. Walling, M. Gamby, H. Lyon, and D.A. DeVries. 2008. Batch fecundity and an attempt to estimate spawning frequency of king mackerel (Scomberomorus cavalla) in U.S. waters. SEDAR16-DW. NMFS SEFSC Panama City Laboratory Contribution 08-01.

Haddon, M. 2001. Modelling and quantitative methods in fisheries. Chapman & Hall/CRC Press.

Kimura, D. K. 1980. Likelihood methods for the von Bertalanffy growth curve. Fish. Bull. 77: 765-776.

Ortiz, M, C. Porch and G. Diaz. In preparation. Estimation of growth parameters from data truncated by minimum size restrictions.

Patterson, W.G., R.L. Shipp, T.R. Clardy and Z. Chen. 2004. Discrimination among US South Atlantic and Gulf of Mexico king mackerel stocks with otolith shape analyses and otolith microchemistry. MARFIN Final Report Grant N. NA17FF2013 33 pages.

Table 1. Distribution of otolith based size-age samples available for king mackerel by stock unit and region.

N samples	Region			
MigGrp	**ATLnoMix**	**GLFnoMix**	**MixZone**	**Grand Total**
ATL	12374		5434	17808
GLF		18304	9164	27468
Grand Total	**12374**	**18304**	**14598**	**45276**

Table 2. Number of size-age samples by year and region king mackerel stocks.

N samples	MigGrp	Region			
	ATL		GLF		Grand Total
Year	ATLnoMix	MixZone	GLFnoMix	MixZone	
1986	382	139	357		878
1987	405	96	858	49	1408
1988	332	136	775	45	1288
1989	832	3	981	74	1890
1990	960	9	846	95	1910
1991	757	27	1556	256	2596
1992	1057	230	1359	169	2815
1993	683	222	1307	93	2305
1994	527	352	1093	46	2018
1995	307	351	805	221	1684
1996	575	341	1095	718	2729
1997	385	139	554	664	1742
1998	516	228	289	418	1451
1999	491	398	345	238	1472
2000	596	65	251	640	1552
2001	656	222	502	1201	2581
2002	564	328	1256	1241	3389
2003	849	979	1561	1205	4594
2004	1080	616	755	772	3223
2005	186	164	744	460	1554
2006	234	383	847	278	1742
2007		6	168	281	455
Grand Total	12374	5434	18304	9164	45276

Table 3. Distribution of size-age samples by stock, region and sex.

N samples		Region			
MigGrp	**Sex**	**ATLnoMix**	**GLFnoMix**	**MixZone**	**Grand Total**
ATL	Fem	8439		2573	11012
	Mal	3733		2805	6538
	Unk	202		56	258
GLF	Fem		11866	5920	17786
	Mal		5869	3228	9097
	Unk		569	16	585
Grand Total		**12374**	**18304**	**14598**	**45276**

Table 4. Distribution of otolith samples by fishing mode and program collection source.

N samples		Mode									
Stock	**Source**	**CM**	**CP**	**HB**	**PDV**	**PR**	**PR**	**SS**	**TRN**	**Unknown**	**Grand Total**
ATL	NCDNR	656	318		187	38	131	194	7040	351	8915
	TIP	2993	842	2			36	5	480	17	4375
	RECFIN		376	9			923		96		1404
	MRFSS		600	1			97		483		1181
	Unknown	1	175	108		69	14		255	273	895
	SCDNR	75	24	7		29			329	141	605
	HB			137							137
	FIN		96			21					117
	PCLAB								72		72
	FMRI								57		57
	CO-OP							33			33
	VADMR					17					17
GLF	TIP	10585	3565	697			100	10	2699	6	17662
	Unknown	171	314	522		24	18		561	1351	2961
	PCLAB	26	1718	58		137	5	67	348	46	2405
	FIN	969	331	20		249					1569
	USAL	808	95				54		124		1081
	MRFSS	13	351				175		268		807
	RECFIN	4	223	6			144		161		538
	HB		3	152							155
	FLDEP									115	115
	CO-OP		53					9	44		106
	FWRI								61		61
	LADWF		4								4
	MSLAB							4			4
Grand Total		**16301**	**9088**	**1719**	**187**	**584**	**1697**	**322**	**13078**	**2300**	**45276**

Table 5. Historic trends of the minimum size regulations that were in effect for king mackerel stocks and considered in the estimation of growth functions.

Minimum Size regulations for King mackerel			
Date effective	FL_minsz_cm, in		Notes
1/1/1982	0	0	Coastal Migratory Fisheries Management Plan
8/1/1990	30.48	12	Amendment 5 CM FMP
11/1/1992	50.8	20	Amendment 6 CM FMP
4/1/2000	60.96	24	Amendment 9 CM FMP

Table 6. Number of age-size samples from the non-mixing zones by stock and sex, and age class.

N samples		Sex						Sex			
Region	Age	F	M	U	Total		Age	F	M	U	Total
ATLnoMix	0			24	24	GLFnoMix	0	25	10	12	47
	1	251	171	146	568		1	1553	582	119	2254
	2	947	354	16	1317		2	2688	1168	154	4010
	3	1061	451	5	1517		3	1845	951	46	2842
	4	993	393	2	1388		4	1464	717	32	2213
	5	950	353	3	1306		5	1077	538	20	1635
	6	828	354	1	1183		6	779	480	27	1286
	7	700	246	3	949		7	569	389	25	983

8	570	243	1	814	8	459	283	24	766
9	449	188		637	9	390	217	23	630
10	396	208		604	10	290	139	26	455
11	280	174		454	11	223	117	18	358
12	235	149		384	12	153	112	14	279
13	182	118		300	13	100	67	10	177
14	141	90		231	14	84	30	11	125
15	139	82		221	15	57	29	3	89
16	86	51	1	138	16	34	14	1	49
17	68	36		104	17	23	9	1	33
18	56	28		84	18	30	6	1	37
19	42	12		54	19	11	5	1	17
20	24	12		36	20	5	2	1	8
21	18	9		27	21	6	1		7
22	15	7		22	22		2		2
23	2	1		3	23		1		1
24	3	3		6	24	1			1
25	2			2					
26	1			1					
Total	8439	3733	202	12374	Total	11866	5869	569	18304

Table 7. Estimate parameters von Bertalanffy growth model king mackerel stocks by sex. Results from two error distribution assumption models (see text for further detail).

Error distribution linear increase of deviance at size with age Constant CV					**Constant deviance at size with age Constant SD**				
		Combined Sex	***Females***	***Males***			***Combined Sex***	***Females***	***Males***
ATL	Linf	114.9	122.8	97.5	**ATL**	Linf	115.6	125.3	99.3
	K	0.220	0.211	0.319		K	0.211	0.191	0.277
	t0	-2.162	-2.032	-1.584		t0	-2.259	-2.296	-1.972
	CV	10.3%	9.1%	7.9%		sigma	9.55	8.31	6.05
ATL no Mix	Linf	114.1	121.6	98.4	**ATL no Mix**	Linf	115.4	124.7	99.8
	K	0.245	0.228	0.316		K	0.225	0.199	0.281
	t0	-1.689	-1.692	-1.340		t0	-1.965	-2.085	-1.649
	CV	10.6%	9.1%	7.9%		sigma	9.99	8.47	6.26
GLF	Linf	98.4	132.4	98.7	**GLF**	Linf	122.3	134.9	100.4
	K	0.316	0.173	0.255		K	0.182	0.164	0.235
	t0	-1.340	-2.524	-2.479		t0	-2.566	-2.587	-2.670
	CV	7.9%	9.9%	8.6%		sigma	10.00	8.64	6.42
GLF no Mix	Linf	122.4	132.8	100.0	**GLF no Mix**	Linf	123.0	135.1	102.0
	K	0.177	0.170	0.235		K	0.173	0.162	0.214
	t0	-2.651	-2.464	-2.554		t0	-2.657	-2.520	-2.808
	CV	11.5%	9.8%	8.6%		sigma	10.30	8.61	6.50

Table 8. Non-linear comparison of growth curves by sex versus combined for Atlantic king mackerel. Data from the non-mixing zone.

	ARRS Test					
	Female	Male	Comb		***BySex***	***Pooled***
SSQ	622229.95	156552.28	1238831.1	SSQ	778782.22	1238831.1
df	8554	3851	12409	df	12405	12409
				F statisc	2443.0562	
				p	0.000	

Likelihood Ratio Test Results

	BaseCase	**Coincident**	**Linf**	**K**	**t0**	**CV**
Linf_fem	121.6	114.1	118.3	118.9	120.5	121.7
K_fem	0.228	0.245	0.256	0.257	0.241	0.228
t0_fem	-1.692	-1.689	-1.441	-1.388	-1.528	-1.695
CV_fem	9.1%	10.6%	9.2%	9.2%	9.1%	8.8%
Linf_mal	98.4	114.1	118.3	101.3	99.1	98.2
K_mal	0.316	0.245	0.126	0.257	0.295	0.315
t0_mal	-1.340	-1.689	-4.219	-1.864	-1.528	-1.340
CV_mal	7.9%	10.6%	9.4%	8.1%	8.0%	8.8%
SSq	778782	1238831.1	852779.4	792902	782661.5	778797.55
n	12413	12413	12413	12413	12413	12413
χ^2		5762.0	1126.7	223.0	61.7	0.2442216
df		3	1	1	1	1
p		0.000	0.000	0.000	0.000	0.621

Table 9. Non-linear comparison of growth curves by sex versus combined for Gulf of Mexico king mackerel. Data from the non-mixing zone.

	ARRS Test					
	Female	Male	Comb		***BySex***	***Pooled***
SSQ	850526.73	245309.85	1731685.1	SSQ	1095836.6	1731685.1
df	11824	5909	17737	df	17733	17737
				F statisc	3430.1871	
				p	0.000	

Likelihood Ratio Test Results

	BaseCase	**Coincident**	**Linf**	**K**	**t0**	**CV**
Linf_fem	132.8	121.8	128.5	129.7	133.1	133.0
K_fem	0.170	0.183	0.189	0.185	0.169	0.170
t0_fem	-2.464	-2.521	-2.240	-2.261	-2.488	-2.478
CV_fem	9.8%	11.5%	9.8%	9.8%	9.8%	9.4%
Linf_mal	100.0	121.8	128.5	104.9	99.7	99.9
K_mal	0.235	0.2	0.093	0.185	0.240	0.235
t0_mal	-2.554	-2.5	-5.726	-3.323	-2.488	-2.538
CV_mal	8.6%	11.5%	9.1%	8.7%	8.6%	9.4%
SSq	1095837	1731685.1	1134759.2	1102533.2	1095740.5	1096013.2
n	17741	17741	17741	17741	17741	17741
χ^2		8117.9	619.2	108.1	-1.6	2.9
df		3	1	1	1	1
p		0	0.000	0.000	*NA*	0.091

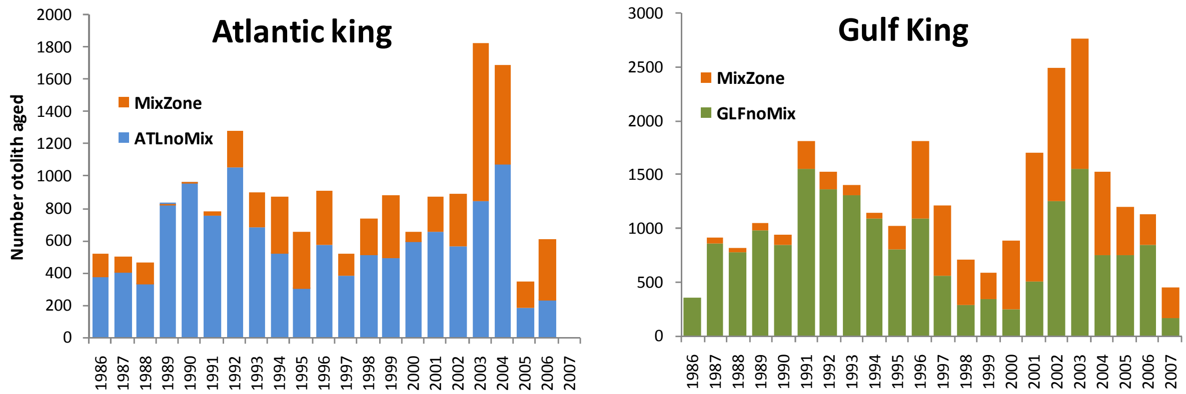


Figure 1. Number of age-size otolith samples king mackerel by stock unit, region and year.

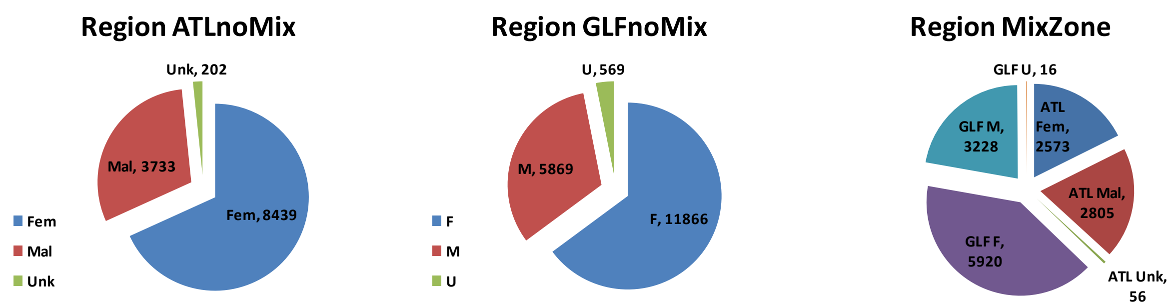


Figure 2. Distribution of age-size samples king mackerel by stock unit, region and sex.

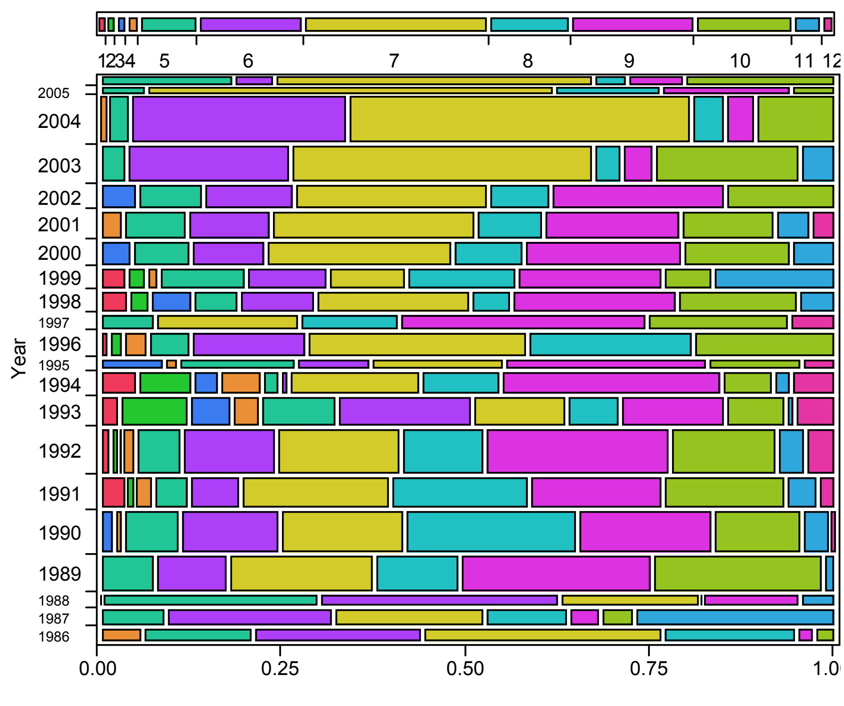


Figure 3. Proportion of age-size samples per month by year for Atlantic king mackerel.

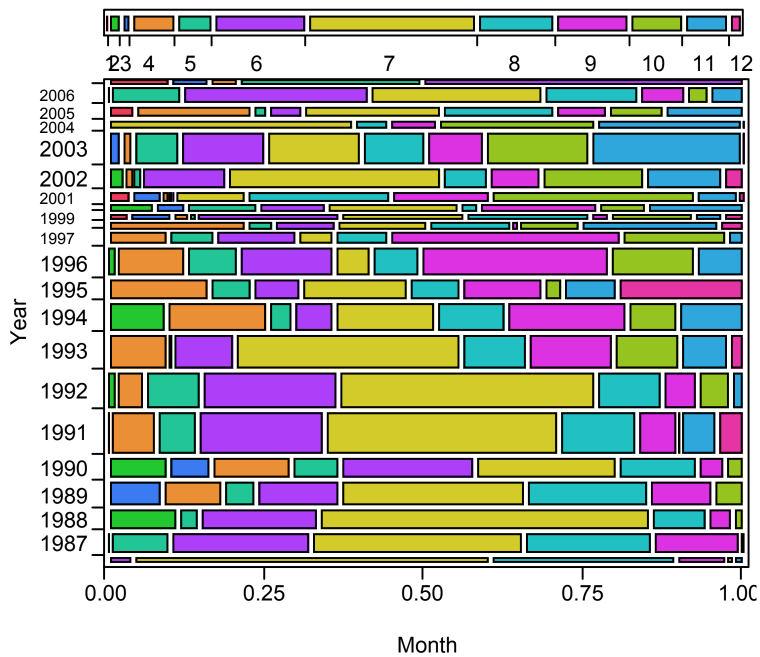


Figure 4. Proportion of age-size samples per month by year for Gulf of Mexico king mackerel.

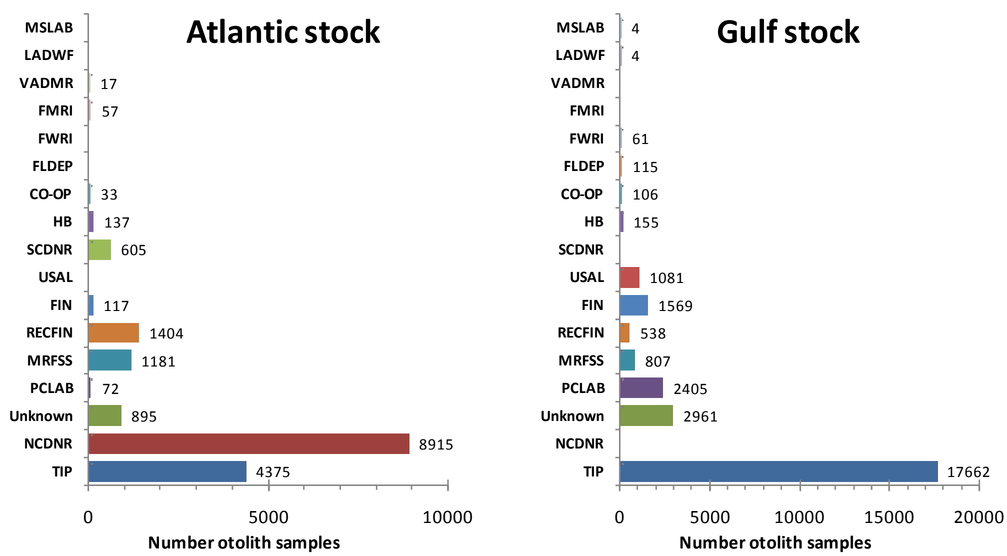


Figure 5. Number of size-age samples by source/program of collection

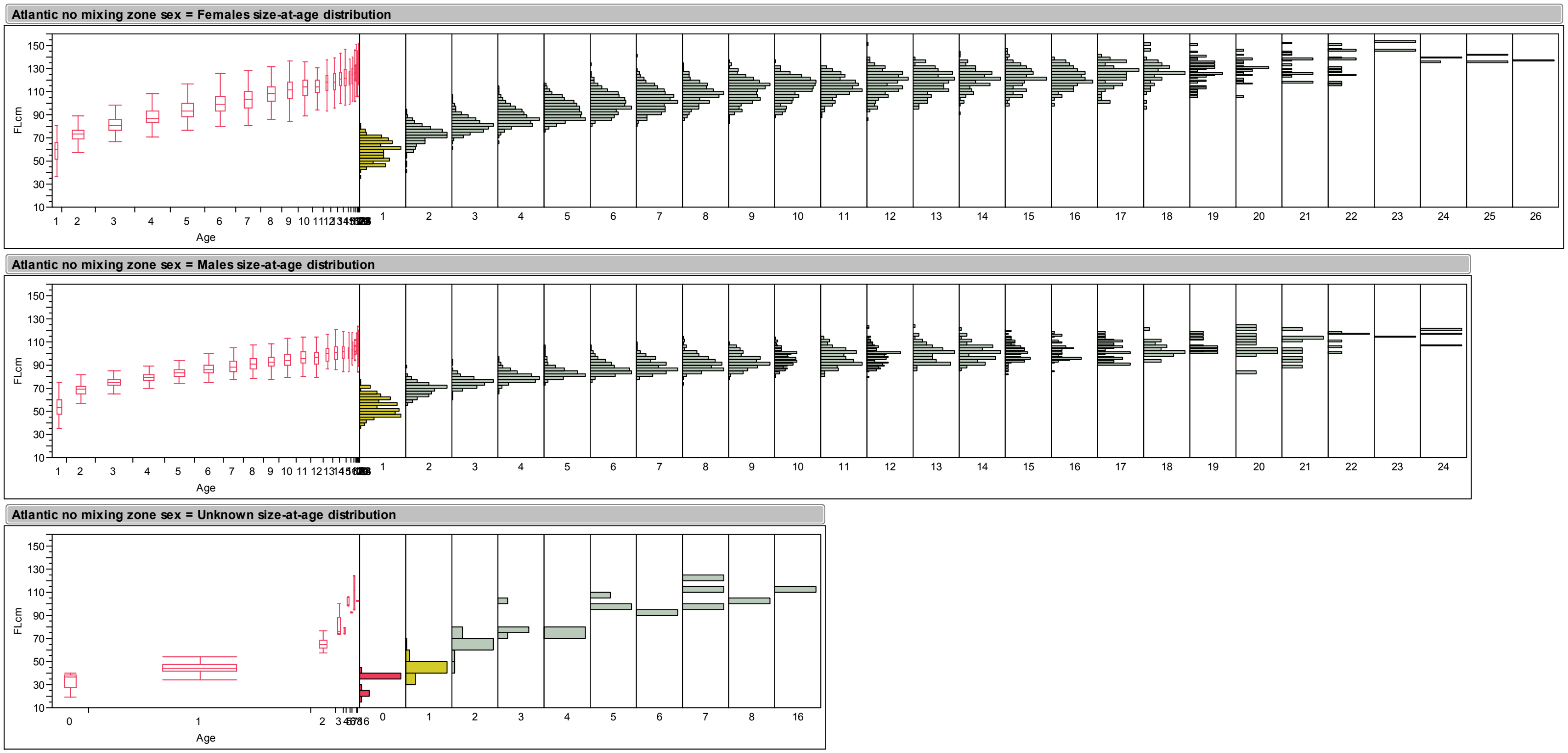


Figure 6. Size at age boxplot and histogram distribution by sex for king mackerel Atlantic no mixing zone. Note that unknown sex included age 0 fish, no present in female, male samples.

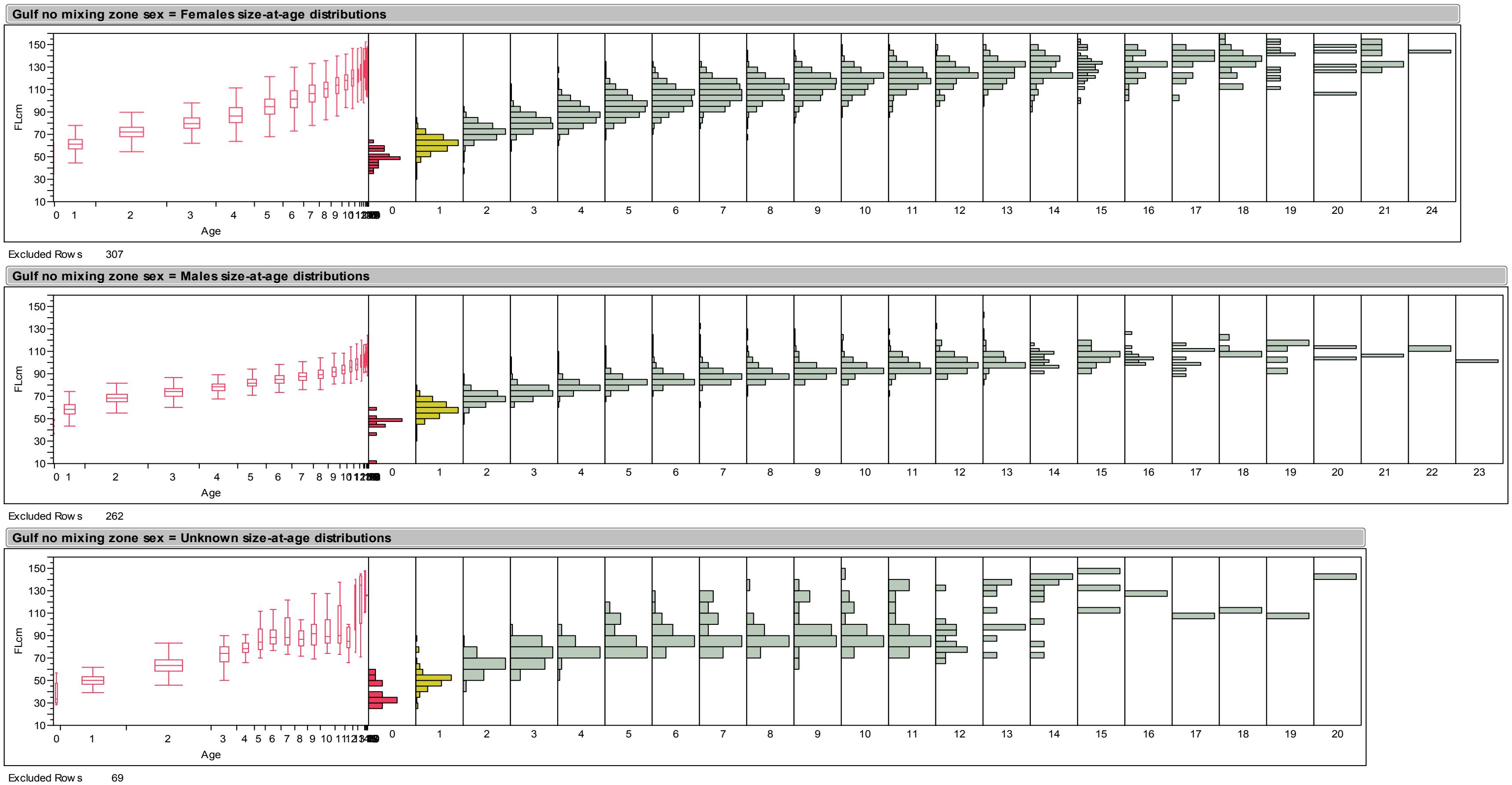


Figure 7. Size at age boxplots and histogram distributions by sex for king mackerel Gulf no mixing zone.

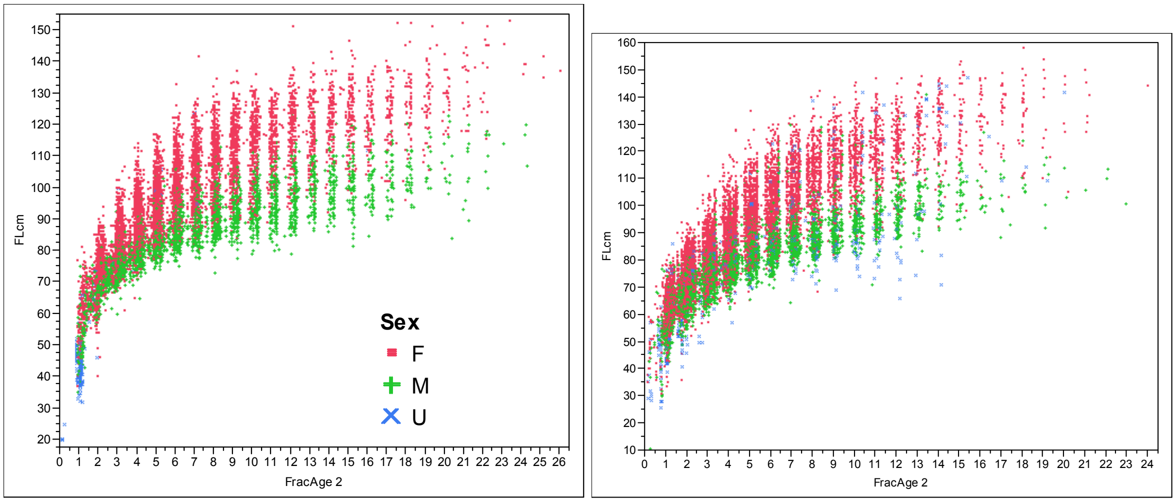


Figure 8 Observed size at age by sex for the Atlantic (top) and Gulf (bottom) stocks from data collected in the outside of the mixing zone.

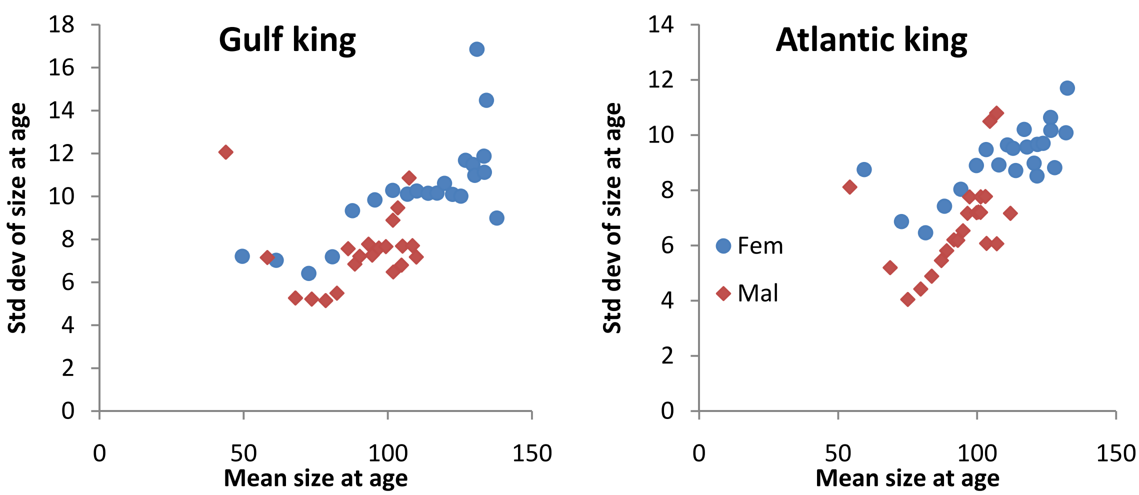


Figure 9 Mean size at age vs. standard deviation of size at age by sex for Gulf and Atlantic king mackerel from samples collected outside of the mixing zone.

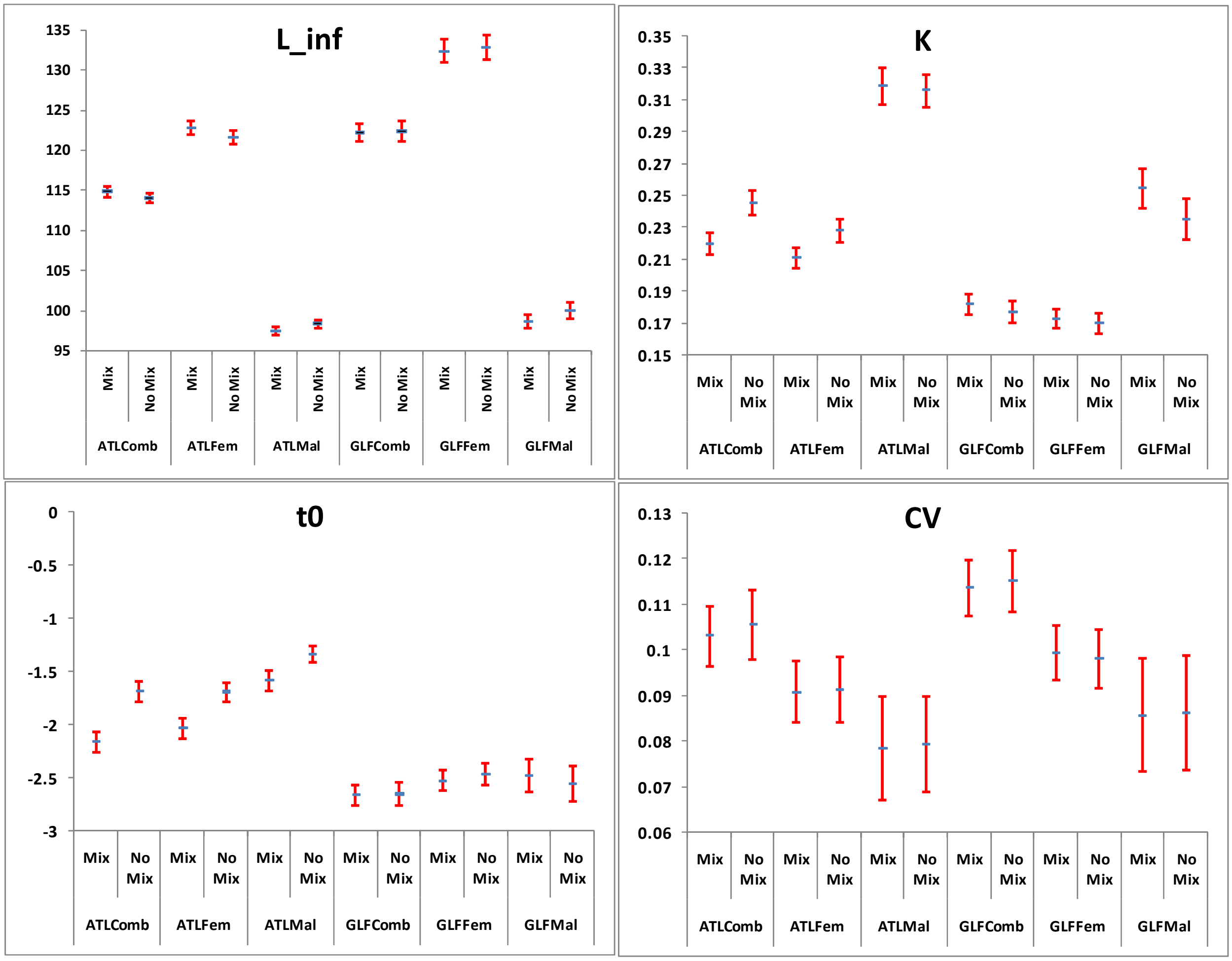


Figure 10. Comparison of von Bertalanffy parameter estimates whether including (Mix) or not (No Mix) observations from the mixing zone in each stock unit, and by sex. Vertical error bars represent + 2 standard deviation of estimates.

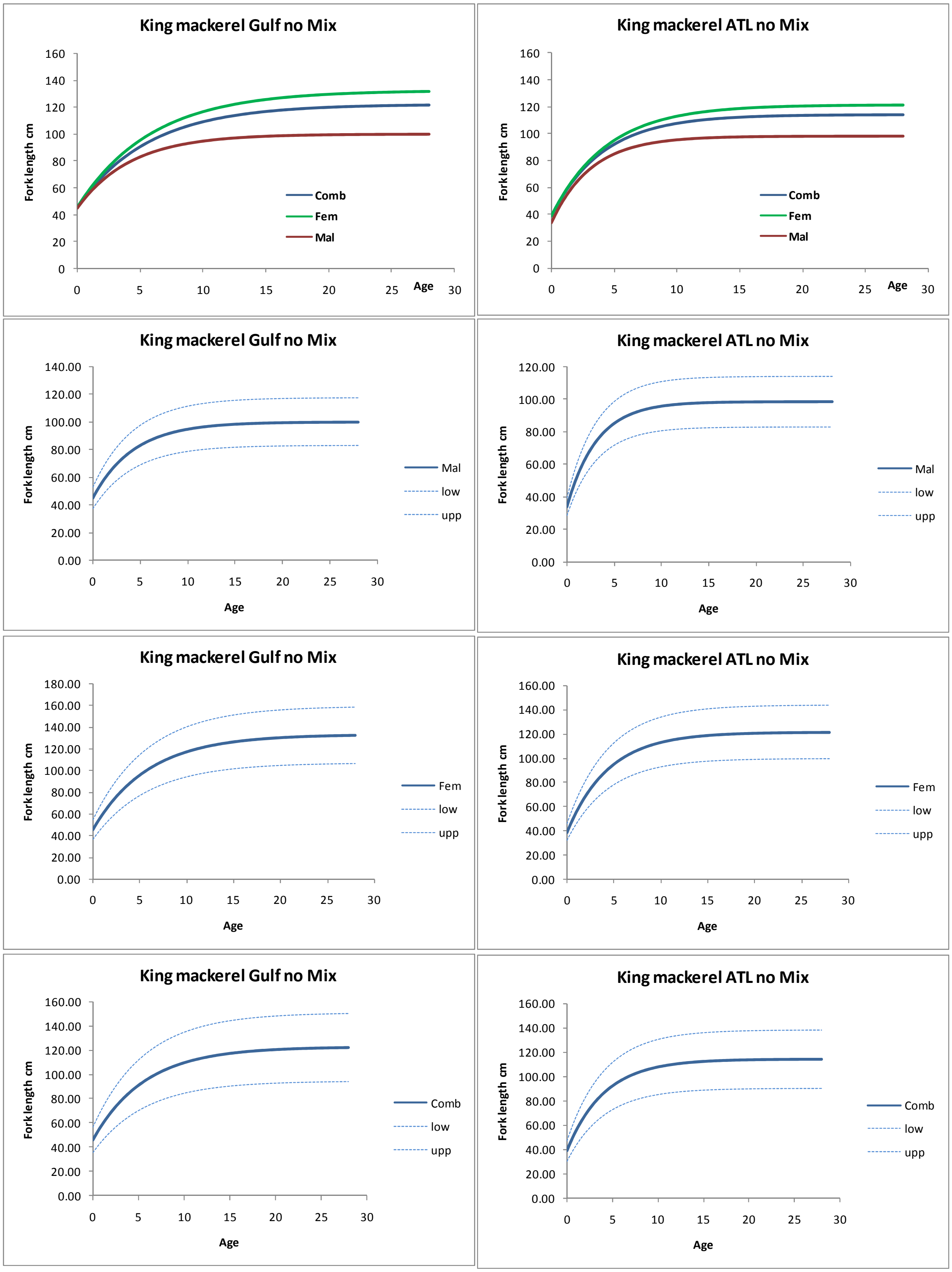
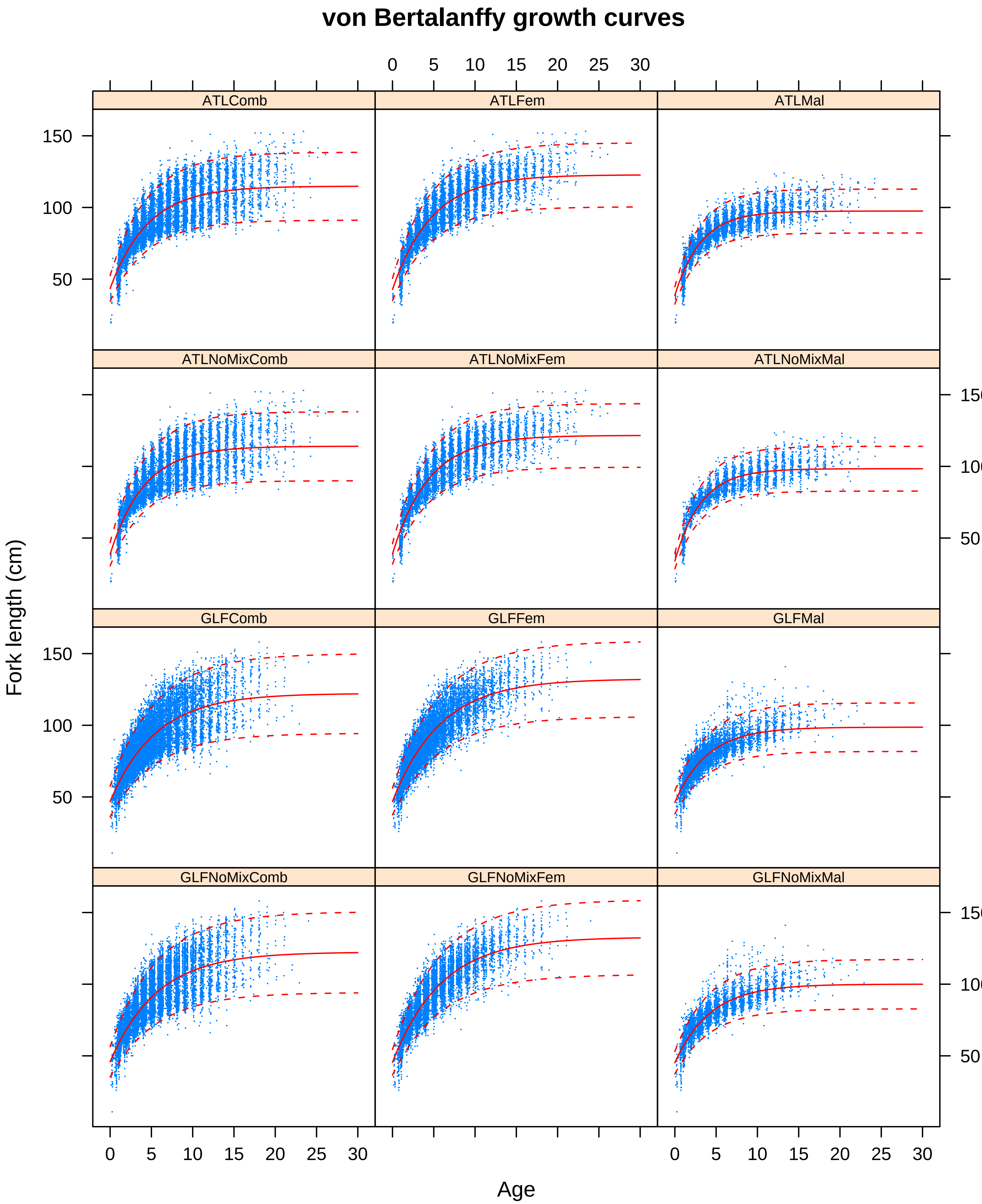
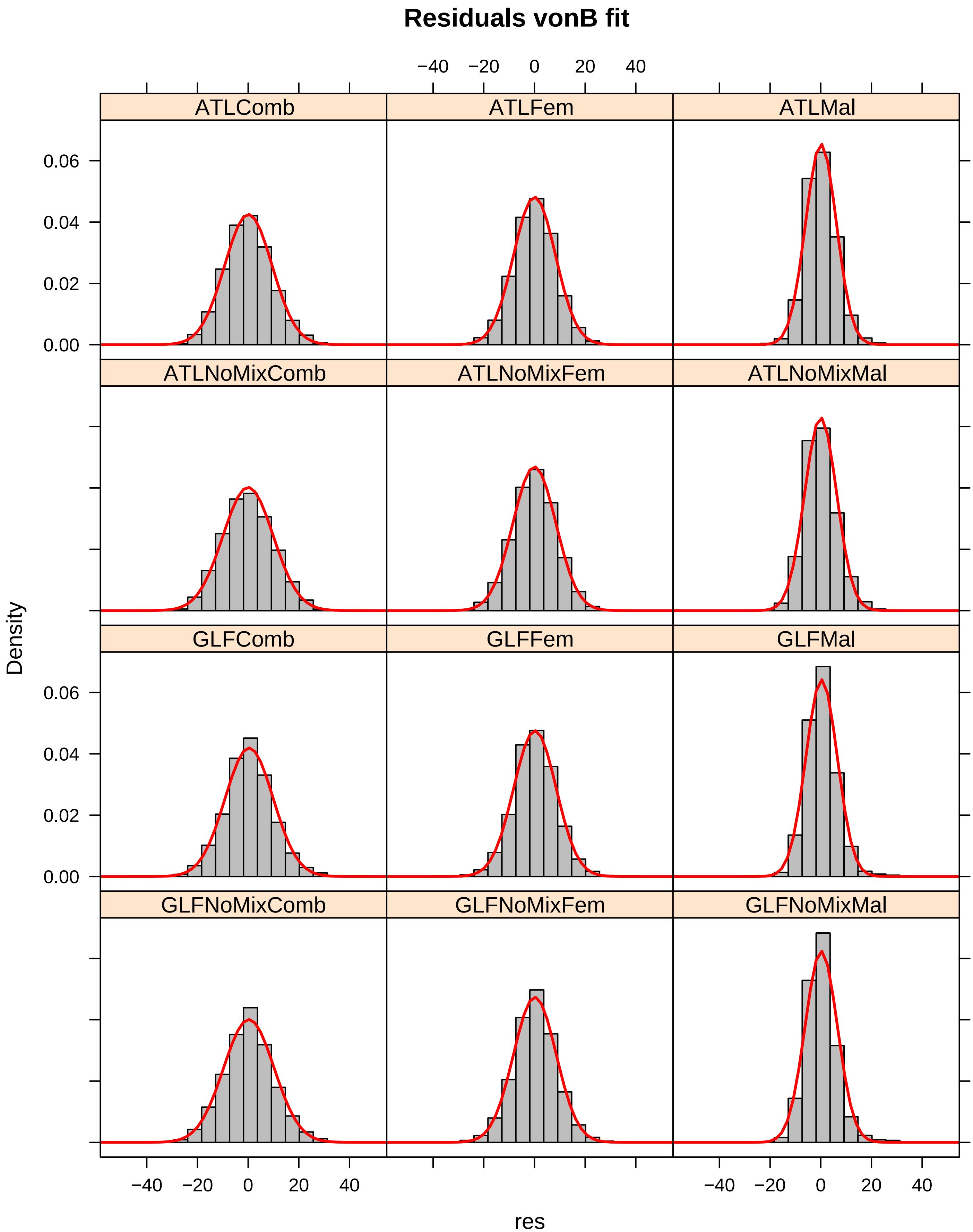
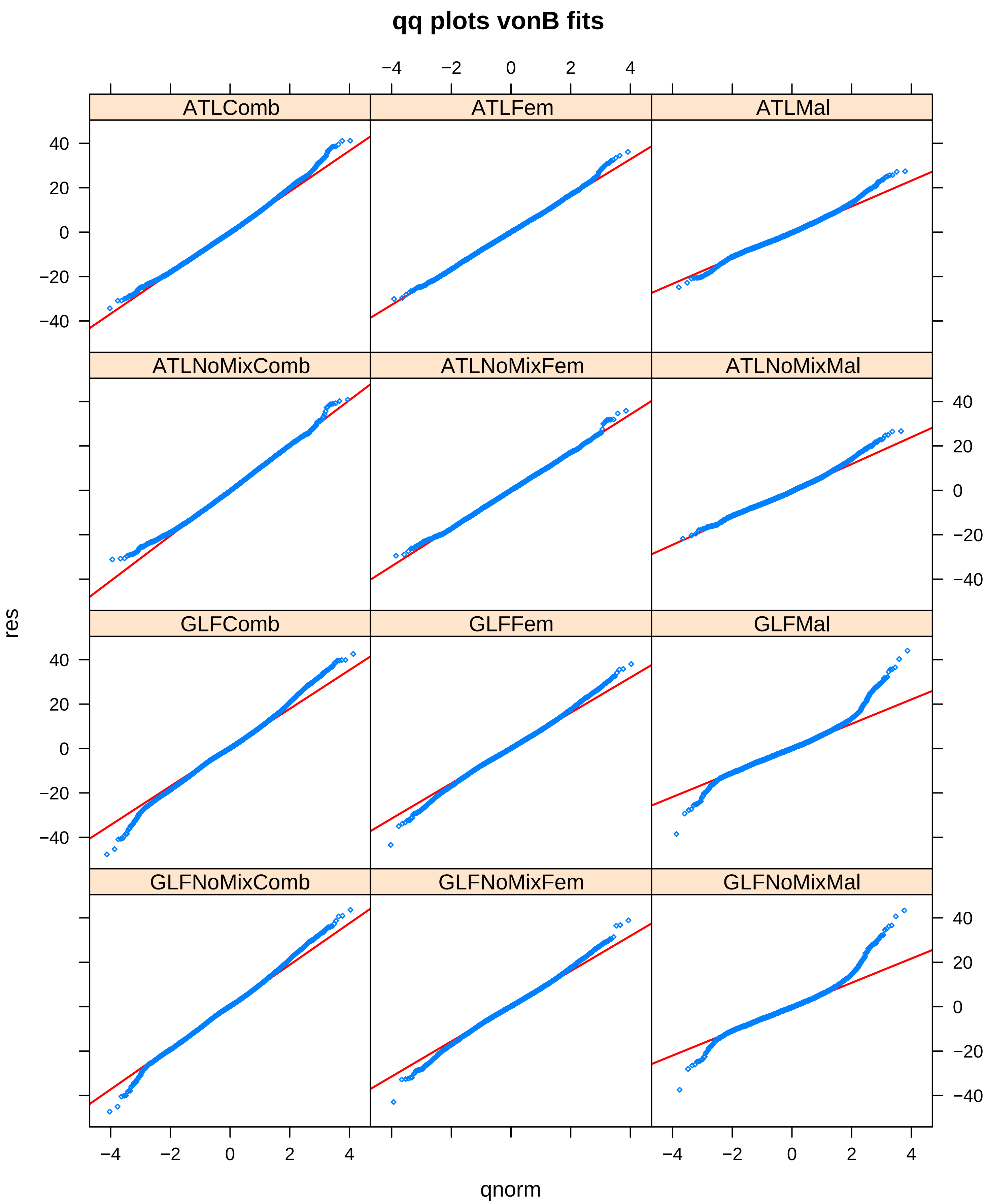


Figure 11. Fitted von Bertalanffy growth models to king mackerel Atlantic (right column) and Gulf (left column) stocks by sex. Dash lines represent ± 2 standard deviation of size at age.


von Bertalanffy growth curves
ATLComb
ATLFem
ATLMal
ATLNoMixComb
ATLNoMixFem
ATLNoMixMal
GLFComb
GLFFem
GLFMal
GLFNoMixComb
GLFNoMixFem
GLFNoMixMal
Fork length (cm)
Age
0
5
10
15
20
25
30
50
100
150



Residuals vonB fit
ATLComb
ATLFem
ATLMal
ATLNoMixComb
ATLNoMixFem
ATLNoMixMal
GLFComb
GLFFem
GLFMal
GLFNoMixComb
GLFNoMixFem
GLFNoMixMal
Density
0.00
0.02
0.04
0.06
res
−40
−20
0
20
40



qq plots vonB fits
ATLComb
ATLFem
ATLMal
ATLNoMixComb
ATLNoMixFem
ATLNoMixMal
GLFComb
GLFFem
GLFMal
GLFNoMixComb
GLFNoMixFem
GLFNoMixMal
res
qnorm
−4
−2
0
2
4
40
20
0
−20
−40

boxplot residuals by age