Growth models for king mackerel from the south Atlantic and Gulf of Mexico

Linda Lomdardi

SEDAR38-AW-01

7 March 2014
Addendum Added: 9 May 2014

Please cite this document as:

Lombardi. L. 2014. Growth models for king mackerel from the south Atlantic and Gulf of Mexico. SEDAR38-AW-01. SEDAR, North Charleston, SC. 62 pp.

Growth models for king mackerel from the south Atlantic and Gulf of Mexico

Linda Lombardi

March 2014

National Marine Fisheries Service
Southeast Fisheries Science Center
3500 Delwood Beach Road
Panama City, FL 32408

Panama City Laboratory Contribution 14-01

Abstract

A total of 68100 king mackerel otoliths were collected from the south Atlantic and Gulf of Mexico by numerous data sources sampling both the commercial and recreational fishery, with additional sampling from fishery independent sources. Those king mackerel allocated as the winter mixing (n = 1990) or unknown (n = 154) stock where not used in the analysis of growth and fish with unknown sex older than age 3 were also not used (Atlantic, n = 40; Gulf of Mexico, n = 319). Fishery independent sources, in particularly SEAMAP annual trawl surveys, provided a majority (80%) of the age zero fish. The oldest king mackerel (age ≥ 15 years) were collected from fishing tournaments in North Carolina. Growth parameters predicted by size-modified von Bertalanffy growth model resulted in similar growth patterns by sex between stocks; females had slower growth coefficients but larger asymptotic lengths compared to males.

Introduction

King mackerel distribution encompasses the entire U.S. Atlantic coast, as well as, the entire Gulf of Mexico, Caribbean and south to Brazil (Hoese and Moore 1977). For the purposes of this report, king mackerel have been allocated to three stocks: south Atlantic (fish collected from Virginia to Dade County, Florida), Gulf of Mexico (fish collected from Texas, Louisiana, Mississippi, Alabama, to Collier County, Florida), and winter mixing (Monroe County, FL during winter months). King mackerel are schooling fish and some schools migrate, particularly, in the winter months (December, November, January, February, and March) in search of prey and/or optimal water temperatures. During these winter months, stocks from the south Atlantic and

Gulf of Mexico may mix and therefore are allocated as 'winter mixing' king mackerel. Those king mackerel caught in the winter months from Monroe County, FL are not used to predict growth, since it is impossible to designate the origin of these fish.

Predicting growth from fishery dependent data is not ideal, given that most fishery dependent data is influenced by some minimum size limit or other fishery regulations, size-selective nature of fishing (catching faster growing fish), and other associated biases with fishing gear (e.g., hook size, mesh size). A careful approach should be taking into consideration when predicting growth from fishery dependent data (Haddon 2001). In this report, additional fishery independent data has been incorporated in the growth models in attempt to model growth better at the smaller sizes and younger age classes. In addition, a size modified von Bertalanffy growth model has been applied to help account for the non-random sampling due to the fishery size limits (Diaz et al. 2004).

This report has four objectives:

1) Summarize all the king mackerel age and length data provided for SEDAR38,

2) Calculate the predicted growth parameters and coefficients of variation,

3) Statistically compare growth curves by sex and stock for king mackerel from the U.S. South Atlantic and Gulf of Mexico, and

4) Discuss differences in growth models calculated in this report to those models calculated for SEDAR16 in 2008.

Methods

Data Collection

Multiple ageing facilities provided annual ages (n = 68100) for the king mackerel SEDAR38 growth curves (Table 1).

The ageing facilities were:

1) National Marine Fisheries Service (Panama City, FL; data collected 1986-2013; Palmer et al. 2014),
2) Gulf States Marine Fisheries Commission (ages were provided by the states of Alabama, Mississippi, Louisiana, and Texas; data collected 2002-2012; Donaldson and Bray 2008),
3) University of West Florida (data collected 2006-2008, Shepard et al. 2010), and
4) South Carolina Department of Natural Resources (data collected 2011-2012; Smart and Boylan 2014).

For specific information regarding the data collection methodology or other specific information, please see the respective citations per ageing facility.

A majority of these ages were completed at the National Marine Fisheries Service, Panama City Laboratory (n = 60668, 89%). This ageing facility has historically provided ages for king mackerel and is the primary ageing lab for king mackerel from both the south Atlantic and Gulf of Mexico stocks. The last assessment included otoliths collected 1986 - 2006 and a few fish collected in 2007 (n = 45,276; Ortiz and Palmer 2008) and this assessment includes an additional 22,824 records (1986-2012, partial 2013 records; Table 1). King mackerel were collected by numerous state and federal agencies, along with fishery independent sampling (Table 2). A majority of king mackerel were collected from intercepts from the commercial industry by federal port agents. King mackerel were evenly collected between the south Atlantic (n = 32710) and Gulf of Mexico (n = 32887).

Data Discarded

There were several reasons why a data record was discarded and not used in the analysis of growth. These reasons were:

1) no age (n = 94),
2) no length (n = 6),
3) no date (n = 4), and
4) If the record was a duplicate. Duplicate records (n = 789) were discovered between the NMFS Panama City and University of West Florida data sets. In these instances, the University of West Florida data records were removed from further analysis and the final age from the NMFS Panama City Laboratory were applied.
5) If the record indicated being caught in the winter months (January, February, March, November, and December) and in the mixing zone (State: SF, County: Monroe) (n = 2140). For the complete explanation of why the winter mixing zone was changed and for a complete description for allocating records to the winter mixing zone, see SEDAR38-Data Workshop Report.
6) If the record indicated an 'unknown' sex and the fish had an annual age > 3 (south Atlantic, n = 40; Gulf of Mexico, n = 319). Those records with 'unknown' sex and ≤ age 3 were used in each growth curve (combined, female and male), since determining the sex of a young fish can be difficult (especially in the field) but these fish provide important size information for the younger age classes, and help fit the growth models (Ortiz and Palmer 2008; Haddon 2001).

Calculating Fractional Age

In addition to annual or cohort age, fractional age was calculated and used in the growth models. A fractional period of a year was determined as the difference from peak spawning date (July 1, Fitzhugh et al. 2008) and capture date. If capture date was after the peak spawning date, the fractional period was added to annual age. If capture date was before the peak spawning date, the fractional period was subtracted from annual age to yield an estimate of fractional age. For those fish age 0 and caught before July 1, a fractional age of 0.25 was assumed (as decided by M. Ortiz 2008, Ortiz and Palmer 2008).

Modeling Growth

A growth curve, based on fractional ages and observed fork lengths at capture, was modeled using the von Bertalanffy growth model and was executed in ADMB (Auto Differentiate Model Builder). Since the majority of the data were derived from commercial and recreational samples, a size-modified von Bertalanffy model was used to predict growth parameters that take into account the non-random sampling due to minimum size restrictions (Diaz et al. 2004). This model uses either a constant standard deviations or constant coefficient of variation. A constant coefficient of variation was chosen to better model the linear increase in variation with size-at-age (decision agreed by Data Workshop Panel during Post-Data Workshop Webinar, January 14, 2014).

The size-modified von Bertalanffy growth model accounts for the non-random sampling associated with fishery dependent data by using a restrictive maximum likelihood estimation procedure with minimum size as the left truncation limit for fisheries dependent observations. The south Atlantic and Gulf of Mexico commercial and recreational fisheries have had the same minimum size limits: 1986-1989, no minimum size; 1990-1991, 30.48 cm, 12 inches; 1992-1998, 50.8 cm, 20 inches; 1999-2013, 60.96 cm, 24 inches. Fishery independent data (n = 759) were used to aid the model to predict growth at smaller sizes (below the size limits) and ages not collected in fishery dependent sampling. This is the same method as was used in the previous assessment (Ortiz and Palmer 2008). Model convergence was based on value of the model objective function (minimal log-likelihood) and the ability to predict similar growth parameters and coefficients of variation, providing alternative initial growth parameters (L_∞ = 90%* L_∞, 95% *L_∞; k = 0.20, 0.25; t_0 =0.00, -0.25, -1.00) and coefficients of variation (CV = 10%, 30%, 50%). Model diagnostic plots such as predicted growth model compared to observed data and the normalcy of residuals were examined.

Regional size-modified growth curves by gender were compared using a likelihood ratio test (LRT) for coincident curves (Kimura 1980; Haddon 2001). The LRT uses the resulting residual sum of squares for fitting curves separately and from fitting curves together (e.g., south Atlantic males and females vs. south Atlantic combined sex data). In this report, the resulting log-likelihoods (the statistic minimized in ADMB) were also used in the LRT.

Results and Discussion

Due to the extensive sampling of king mackerel by both fishery dependent and fishery independent sampling, a large size range (8 – 170 cm FL) of fish were used in the growth analysis (Figure 1). King mackerel were determined to be between age 0 to 26 years (Table 3 and 4, Figure 2), with the majority of the fish between ages 2 – 6 years (70%). The smallest (8 – 60 cm FL) and youngest (age 0-1) fish were collected in trawls during the National Marine Fisheries Service, Pascagoula, MS and South Carolina Department of National Resources annual SEAMAP surveys (Pollack 2014, n = 280; Smart and Boylan 2014, n = 165). Less than 2% of the age data were ages 15 – 26, and these fish were mainly (60%) collected from tournaments along the south Atlantic coast (Table 5a). A majority of these older, tournament fish were collected in North Carolina with 63% of these fish caught prior to 2000 (Table 5b).

Growth models for king mackerel resulted in similar growth parameters by sex for each stock (Table 6). In each of the stocks, females grew slower than males but females obtained a larger asymptotic length (Figure 3). Similar trends in sex-specific growth and calculated growth parameters were also concluded by Ortiz and Palmer 2008 and Shepard et al. 2010. Sex-specific growth curves were determined to be non-coinciding within stocks and between stocks (Table 7); however, there were very little biological differences in sex-specific growth curves between stocks (Figure 4).

Several model diagnostics plots were created to visually inspect the ability to predict growth for king mackerel by stock and by sex using the size-modified von Bertalanffy growth model. By plotting the observed fractional ages and observed fork lengths with the predicted growth curves; it is concluded that the resulting growth curves fit the data rather well, with the predicted growth curves (± 2 standard deviations) incorporating most observed data with the predicted curve in the middle of the data (Figure 5). The size-modified growth model had difficulties predicting similar sizes-at-ages for the youngest (age 0) and oldest ages (age ≥ 15) (Figure 6). In addition, the stock and sex specific models' residuals showed normal distributions, respectively (Figure 7 and 8). Residuals by age (by stock and by sex) also showed a reasonable distribution of residuals for the most common ages (age 2-7, Figure 9); there are some residuals that are not normally distributed by age but these anomalies can be explained by small sample sizes by age (age 0, age ≥ 15) for a particular stock and sex (Table 4).

The growth coefficients calculated for males were greater than those calculated in previous assessments (Table 8, Ortiz and Palmer 2008). In attempt to predict similar growth coefficients, higher initial values (k = 0.30, 0.35) of growth coefficient (k) were explored in additional growth model analysis. These models resulted in slower growth coefficients, similar asymptotic lengths, larger negative sizes at time zero, and higher coefficients of variation and overall model objective functions (Table 9). These models diagnostic plots showed an inaccuracy in predicting growth and skewed (non-randomly distributed) residuals (Figure 10).

Predicted growth parameters (asymptotic lengths, growth coefficients, and sizes at time zero) were compared between this report and the previous assessment in 2008 (Ortiz and Palmer 2008). Stock specific growth parameters for all data combined and for females were fairly similar, even with the additional 22,824 records (Table 8, Figure 11 and 12). However, stock-specific male growth models for this assessment predicted smaller asymptotic lengths, faster growth rates, and smaller sizes at time zero. The differences in the predicted growth parameters for males between assessments could be due to the majority of the additional 13,735 male king mackerel in the new dataset were ≤ age 5 (South Atlantic, 81.4%; Gulf of Mexico, 58.5%).

Literature Cited

Diaz, G.A., C.E. Porch, and M. Ortiz. 2004. Growth models for red snapper in U.S. Gulf of Mexico waters estimated from landings with minimum size limit restrictions. NMFS/SEFSC/SFD 2004-038, 13 p.

Donaldson, D., and G. Bray. 2008. Biological data collection and ageing procedures under the Fisheries Information Network (FIN). Southeast Data, Assessment, and Review, Charleston, SC. SEDAR16-DW-02.

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. Southeast Data, Assessment, and Review, Charleston, SC. SEDAR16-DW. NMFS SEFSC Panama City Laboratory Contribution 08-01.

Haddon, M., 2001. Modelling and Quantitative Methods in Fisheries. Chapman and Hall/CRC Press, Boca Raton, FL.

Hoese, H. D., and R. H. Moore. 1977. Fishes of the Gulf of Mexico, Texas, Louisiana,
499 and Adjacent Waters. Texas A and M University Press. College Station, Texas.

Kimura, D.K., 1980. Likelihood methods for the von Bertalanffy growth curve. Fishery Bulletin 77: 765–776.

Ortiz, M., and C. Palmer. 2008. Review and estimates of von Bertalanffy growth curves for the king mackerel Atlantic and Gulf of Mexico stock units. Southeast Data, Assessment, and Review, Charleston, SC. SEDAR16-DW-12. p. 20.

Palmer, C., D. DeVries, C. Fioramonti, and H. Lang. 2014. A review of Gulf of Mexico and Atlantic king mackerel (*Scomberomorus cavalla*) age data, 1986 – 2013, from the Panama City Laboratory, Southeast Fisheries Science Center, NOAA Fisheries Service. Southeast Data, Assessment, and Review, Charleston, SC. SEDAR38-DW-15.

Pollack, A. 2014. King Mackerel Abundance Indices from SEAMAP Groundfish Surveys in the Northern Gulf of Mexico. Southeast Data, Assessment, and Review, Charleston, SC. SEDAR38-DW-02.

Shepard, K., W.Patterson III, D. DeVries, and M. Ortiz. 2010. Contemporary versus historical estimates of king mackerel (Scomberomorus cavalla) age and growth in the U.S. Atlantic Ocean and Gulf of Mexico. Bulletin of Marine Science. 86: 515-532. SEDAR38-RD-04.

Smart, T. and J. Boylan. 2014. King mackerel index of abundance in coastal US South Atlantic waters based on a fishery-independent trawl survey. Southeast Data, Assessment, and Review, Charleston, SC. SEDAR38-DW-11.

Table 1. Number of king mackerel otoliths collected by year provided by four ageing facilities (NMFS: National Marine Fisheries Service, Panama City, FL; GSMFC: Gulf States Marine Fisheries Commission; UWF: University of West Florida; SCDNR: South Carolina Department of Natural Resources).

Year	NMFS	GSMFC	UWF	SCDNR	Total
1986	874				874
1987	1439				1439
1988	1256				1256
1989	1889				1889
1990	1910				1910
1991	2596				2596
1992	2810				2810
1993	2310				2310
1994	2018				2018
1995	1684				1684
1996	2729				2729
1997	1742				1742
1998	1451				1451
1999	1472				1472
2000	1552				1552
2001	2581				2581
2002	2964	291			3255
2003	4094	382			4476
2004	2866	328			3194
2005	1332	457			1789
2006	1558	409	669		2636
2007	1912	496	1680		4088
2008	2875	260	815		3950
2009	2970	572			3542
2010	3201	284			3485
2011	2865	583		74	3522
2012	2991	47		85	3123
2013	727				727
Total	60668	4109	3164	159	68100

Table 2. Number of king mackerel ages by source, fishing mode, and stock. Otoliths from king mackerel were provided by multiple state and federal agencies and fishery independent sampling (see Appendix A for definitions of abbreviations). Each of these sources sampled both commercial and recreational fishing modes (see Appendix A for definitions of abbreviations). Theses totals reflect those records used in final growth analysis.

south Atlantic	CM	CP	HB	ID	PR	REC	SS	TRN	Unknown	Total
CO-OP							33			33
FIN		88			20					108
FWRI								57		57
HB		1	337							338
MRFSS	3	762	18		99			483		1365
NCDMF	1344	330			191	4	196	8853	537	11455
PCLAB		3						72		75
RECFIN	8	479	138		1030			145		1800
SCDNR	75	24	7		29		159	329	139	762
TIP	12813	1108			37		9	506	16	14489
Unknown	32	177	188		83			255	256	991
USAL	409									409
UWF	567			244						811
VADMR					17					17
south Atlantic Total	15251	2972	688	244	1506	4	397	10700	948	32710

Gulf of Mexico	CM	CP	HB	ID	PR	REC	SS	TRN	Unknown	Total
CO-OP		76					9	44		129
EASA							1			1
FIN	1175	1368	13		1128	32				3716
FLDEP									115	115
FWRI							2	61		63
HB		2	146							148
LADWF		4								4
MRFSS		261			176			268		705
MSLAB							281			281
PCLAB	64	2903	72		145		67	348	46	3645
RECFIN	4	922	26		217			300		1469
TIP	12037	2938	685		81		2	2514	3	18260
Unknown	123	247	394		41			560	1303	2668
USAL	399							124		523
UWF	362			151		176		471		1160
Gulf of Mexico Total	14164	8721	1336	151	1788	208	362	4690	1467	32887

Table 3. Number of king mackerel otoliths aged by four ageing facilities (NMFS: National Marine Fisheries Service, Panama City, FL; GSMFC: Gulf States Marine Fisheries Commission; UWF: University of West Florida; SCDNR: South Carolina Department of Natural Resources). Theses totals reflect those records used in final growth analysis.

Age	NMFS	GSMFC	UWF	SCDNR	Total
0	160		180	150	490
1	4404	164	81	9	4658
2	11800	649	708		13157
3	9811	705	619		11135
4	8446	606	416		9468
5	6524	407	188		7119
6	4687	348	120		5155
7	3245	303	88		3636
8	2494	243	124		2861
9	1800	159	87		2046
10	1338	83	56		1477
11	1045	44	69		1158
12	815	49	39		903
13	594	30	27		651
14	440	15	27		482
15	368	7	13		388
16	244	7	12		263
17	165	4	8		177
18	147	1	6		154
19	85				85
20	49				49
21	40		1		41
22	29				29
23	5				5
24	7				7
25	2				2
26	1				1
Total	58745	3824	2869	159	65597

Table 4. Number of king mackerel ages by stock, sex and age. Only those unknown sex fish ≤ 3 were used in final growth analysis. King mackerel allocated as winter mixing or unknown stocks were not used in final growth analysis.

	south Atlantic				Gulf of Mexico				Winter Mixing				Unknown				Grand
Age	Female	Male	Unknown	Total	Female	Male	Unknown	Total	Female	Male	Unknown	Total	Female	Male	Unknown	Total	Total
0	13	118	78	209	46	17	218	281	1	2		3	2			2	495
1	1057	674	152	1883	1949	675	151	2775	44	28		72	1	14	2	17	4747
2	4271	2571	32	6874	4334	1780	169	6283	333	186	1	520	16	7	5	28	13705
3	3631	2177	13	5821	3508	1759	47	5314	229	163	1	393	8	10		18	11546
4	2879	1703	12	4594	3241	1645	42	4928	204	107	1	312	19	8		27	9861
5	2107	1317	9	3433	2296	1399	32	3727	153	53		206	7	11	2	20	7386
6	1554	907	7	2468	1539	1155	42	2736	92	33	1	126	14	7		21	5351
7	1084	531	5	1620	1087	934	40	2061	80	24		104	7	1		8	3793
8	833	474	2	1309	827	727	30	1584	71	13		84	1	3		4	2981
9	660	336	1	997	572	478	30	1080	56	8		64	3	2		5	2146
10	503	286		789	412	276	30	718	34	3		37	4			4	1548
11	395	241	1	637	313	209	22	544	24	1		25					1206
12	320	188		508	221	174	16	411	15	2		17					936
13	237	154		391	145	115	12	272	13	2		15					678
14	192	121	2	315	114	55	14	183	9			9					507
15	172	99		271	74	43	3	120	2	1		3					394
16	115	78	1	194	46	24	1	71									265
17	87	54		141	26	10	2	38									179
18	70	41		111	35	8	1	44									155
19	50	19		69	11	5	1	17									86
20	30	12		42	5	2	1	8									50
21	21	13		34	6	1		7									41
22	17	10		27		2		2									29
23	2	2		4		1		1									5
24	3	3		6	1			1									7
25	2			2													2
26	1			1													1
Total	20306	12129	315	32750	20808	11494	904	33206	1360	626	4	1990	82	63	9	154	68100

Table 5. Detailed collection information for older (age ≥ 15 years) king mackerel (a) by fishing mode and (b) tournament only caught fish by year (years grouped reflecting changes in size limit). See Appendix A for definitions of abbreviations.

(a)

Stock and Sex	CM	REC	SS	TRN	Unknown	Total
South Atlantic						
Female	51	47	3	456	13	570
Male	37	25		264	5	331
Atlantic Total	88	72	3	720	18	901
Gulf of Mexico						
Female	19	33		129	23	204
Male	40	19	2	31	4	96
Gulf Total	59	52	2	160	27	300

(b)

Stock and Sex	1986-1989	1990-1991	1992-1998	1999-2012	Total
South Atlantic					
Female	80	69	131	176	456
Male	52	46	79	87	264
Atlantic Total	132	115	210	263	720
Gulf of Mexico					
Female	61	17	20	31	129
Male	19	1	8	3	31
Gulf Total	80	18	28	34	160

Table 6. King mackerel von Bertalanffy growth parameters (± 1 standard deviations) from each stock, sexes combined and by sex. Observed fork lengths and fractional ages were fit to a size-modified von Bertalanffy growth model that used a constant coefficient of variation. Growth models were computed multiple times testing a range of initial growth parameters (L_∞ = 90%* L_∞, 95% *L_∞; k = 0.20, 0.25; t_0 =0.00, -0.25, -1.00) and coefficients of variation (CV = 10%, 30%, 50%) for each stock, sexes combined and by sex. Each of the models (with alternative initial values) converged with the same growth parameters, model CVs, and model objective function values (log-likelihoods).

Stock and Sex	n	L_∞	k	t_0	CV	Model objective function
All Data	65597	113.29 ± 0.3033	0.2169 ± 0.0026	-2.1947 ± 0.0351	12.6% ± 0.04%	235567
All Females	41974	122.69 ± 0.3883	0.2035 ± 0.0025	-2.1170 ± 0.0345	11.5% ± 0.05%	149516
All Males	24483	90.11 ±0.1474	0.4859 ± 0.0045	-0.6077 ± 0.0133	11.7% ± 0.06%	83151
south Atlantic						
Combined	32710	112.08 ± 0.3326	0.2470 ± 0.0037	-1.8340 ± 0.0437	11.9% ± 0.05%	116649
Female	20581	122.35 ± 0.4508	0.2039 ± 0.0033	-2.2950 ± 0.0495	10.3% ± 0.06%	72418
Male	12404	92.86 ± 0.2090	0.4646 ± 0.0051	-0.6077 ± 0.0153	11.5% ± 0.09%	41715
Gulf of Mexico						
Combined	32887	115.41 ± 0.5936	0.1879 ± 0.0038	-2.5955 ± 0.0590	13.2% ± 0.06%	118444
Female	21393	125.18 ± 0.7376	0.1887 ± 0.0039	-2.1606 ± 0.0518	12.4% ± 0.07%	76560
Male	12079	87.57 ± 0.2079	0.5111 ± 0.0083	-0.5600 ± 0.0235	11.6% ± 0.09%	41138

Table 7. Size-modified growth curves by gender within stocks and between stocks were compared using a likelihood ratio test for coincident curves using chi-square distribution with degrees of freedom equal to 1. In each comparison, the hypothesis that curves are coincident was rejected. RSS – residual sum of squares; LL – log likelihood

Comparison	Likelihood Ratio RSS	Likelihood Ratio LL	*P value*
south Atlantic			
Female vs. Male	16721	11352	0.00
Female vs. Combined	22160	15593	0.00
Male vs. Combined	48735	33636	0.00
Gulf of Mexico			
Female vs. Male	22628	13288	0.00
Female vs. Combined	20047	14351	0.00
Male vs. Combined	54832	34778	0.00
Between Stocks			
Combined Atlantic vs. All Combined	53302	46103	0.00
Combined Gulf vs. All Combined	40237	45102	0.00
Female Atlantic vs. Female Combined	35630	30429	0.00
Female Gulf vs. Female Combined	24420	28094	0.00
Male Atlantic vs. Male Combined	18401	16888	0.00
Male Gulf vs. Male Combined	17867	17229	0.00

Table 8. SEDAR-16 estimated von Bertalanffy growth parameters (± 1 standard deviations) for king mackerel by stock, sexes combined and by sex (Ortiz and Palmer 2008).

Stock and Sex	n	L_∞	k	t_0	CV	Model objective function
south Atlantic						
Combined	12394	114.02 ± 0.3362	0.2462 ± 0.0038	-1.6761 ± 0.0457	10.6% ± 0.07%	45194
Female	8619	121.59 ± 0.0490	0.2282 ± 0.0036	-1.6839 ± 0.0446	9.1% ± 0.07%	30489
Male	3913	98.37 ± 0.2761	0.3157 ± 0.0052	-1.3404 ± 0.0393	7.9% 0.09%	12700
Gulf of Mexico						
Combined	18303	122.40 ± 0.6466	0.1771 ± 0.0033	-2.6512 ± 0.0539	11.5% ± 0.07%	65130
Female	11995	132.83 ± 0.7638	0.1701 ± 0.0032	-2.4644 ± 0.0484	9.8% ± 0.07%	41337
Male	6001	100.02 ± 0.5264	0.2354 ± 0.0063	-2.5539 ± 0.8030	8.6% ± 0.08%	19283

Table 9. In attempt to predict similar growth coefficients (k) as the 2008 assessment, a higher range (k = 0.30-0.35) of initial growth coefficient values were explored (L_∞ = 95% asymptotic length, t0 =0.00, -1.00, CV = 30%). Resulting male king mackerel von Bertalanffy growth parameters (± 1 standard deviations) for each stock.

Stock and Sex	n	L_∞	k	t_0	CV	Model objective function
south Atlantic						
Male	12404	88.78 ± 0.9123	0.3450 ± 0.0168	-1.2918 ± 0.1412	20.1% ± 0.05%	43623
Gulf of Mexico						
Male	12079	91.61 ± 0.2576	0.3511 ± 0.0038	-0.8487 ± 0.0164	15.6% ± 0.25%	42152

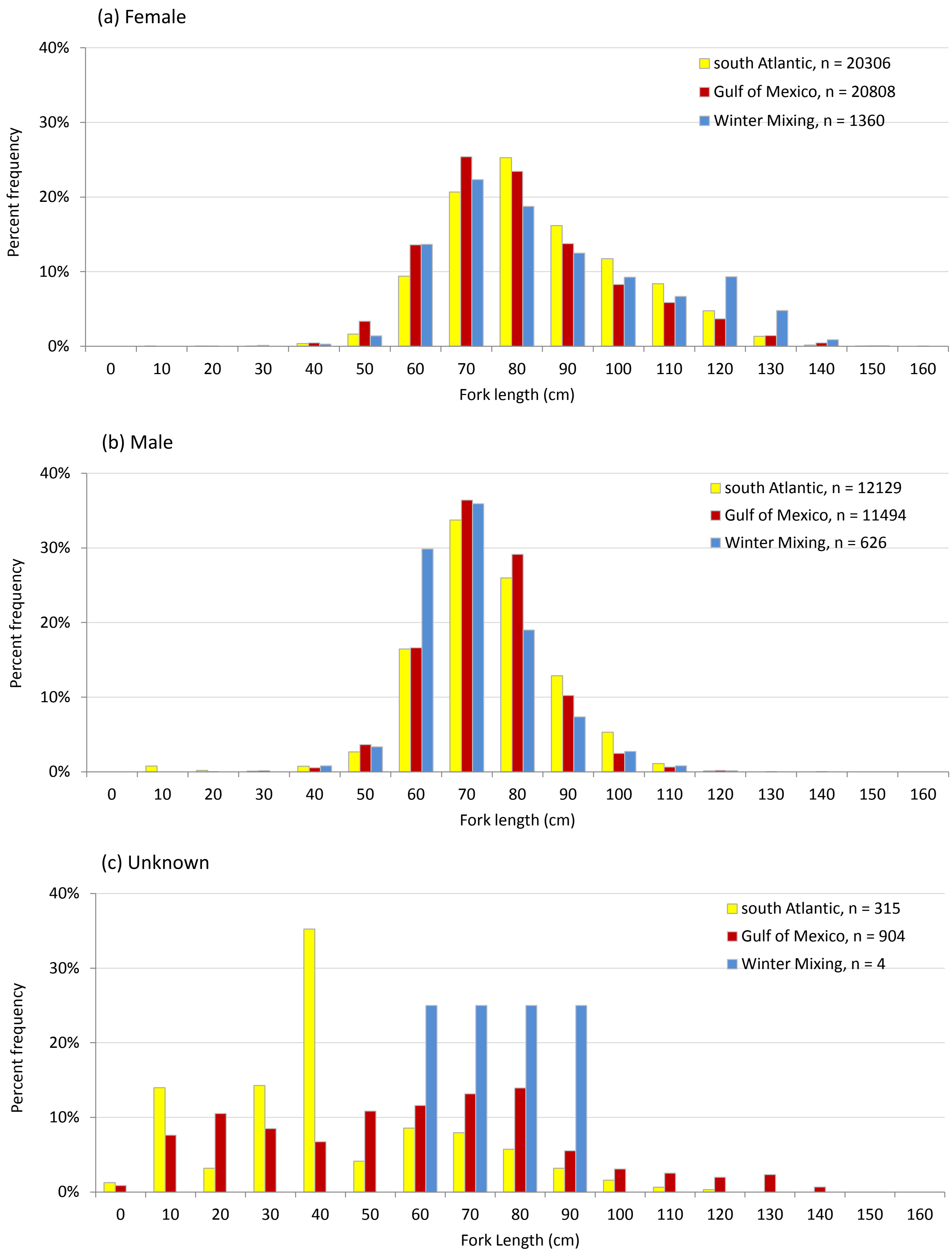


Figure 1. Length frequency by sex: (a) female, (b) male, and (c) unknown by stock for king mackerel. Theses totals reflect those records used in final growth analysis. Only those unknown sex fish ≤ 3 were used in final growth analysis. King mackerel allocated as winter mixing stock were not used in final growth analysis.

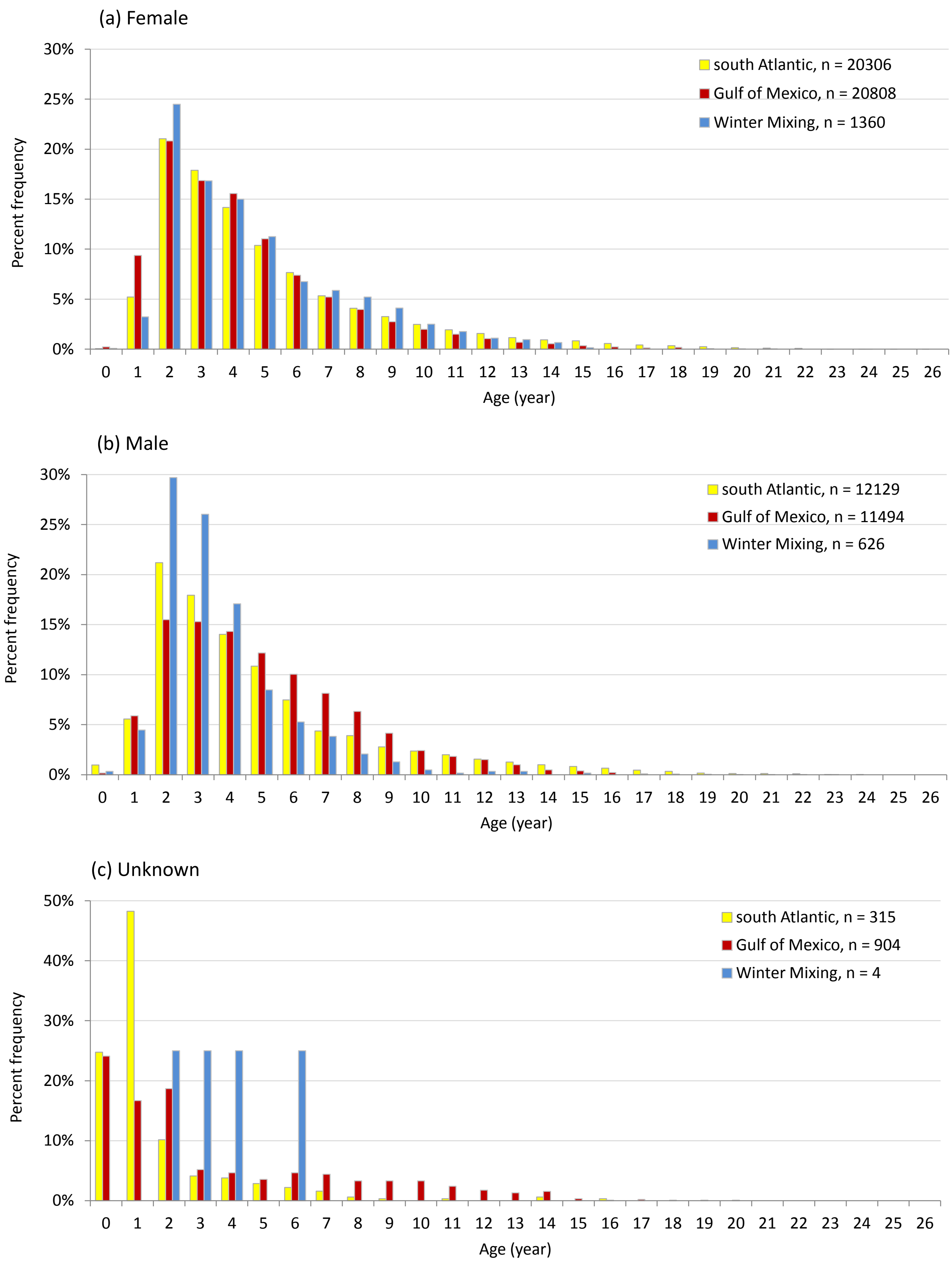


Figure 2. Age frequency by sex: (a) female, (b) male, and (c) unknown by stock for king mackerel. Theses totals reflect those records used in final growth analysis. Only those unknown sex fish ≤ 3 were used in final growth analysis. King mackerel allocated as winter mixing stock were not used in final growth analysis. Note Figure 1c y-axis scale is different.

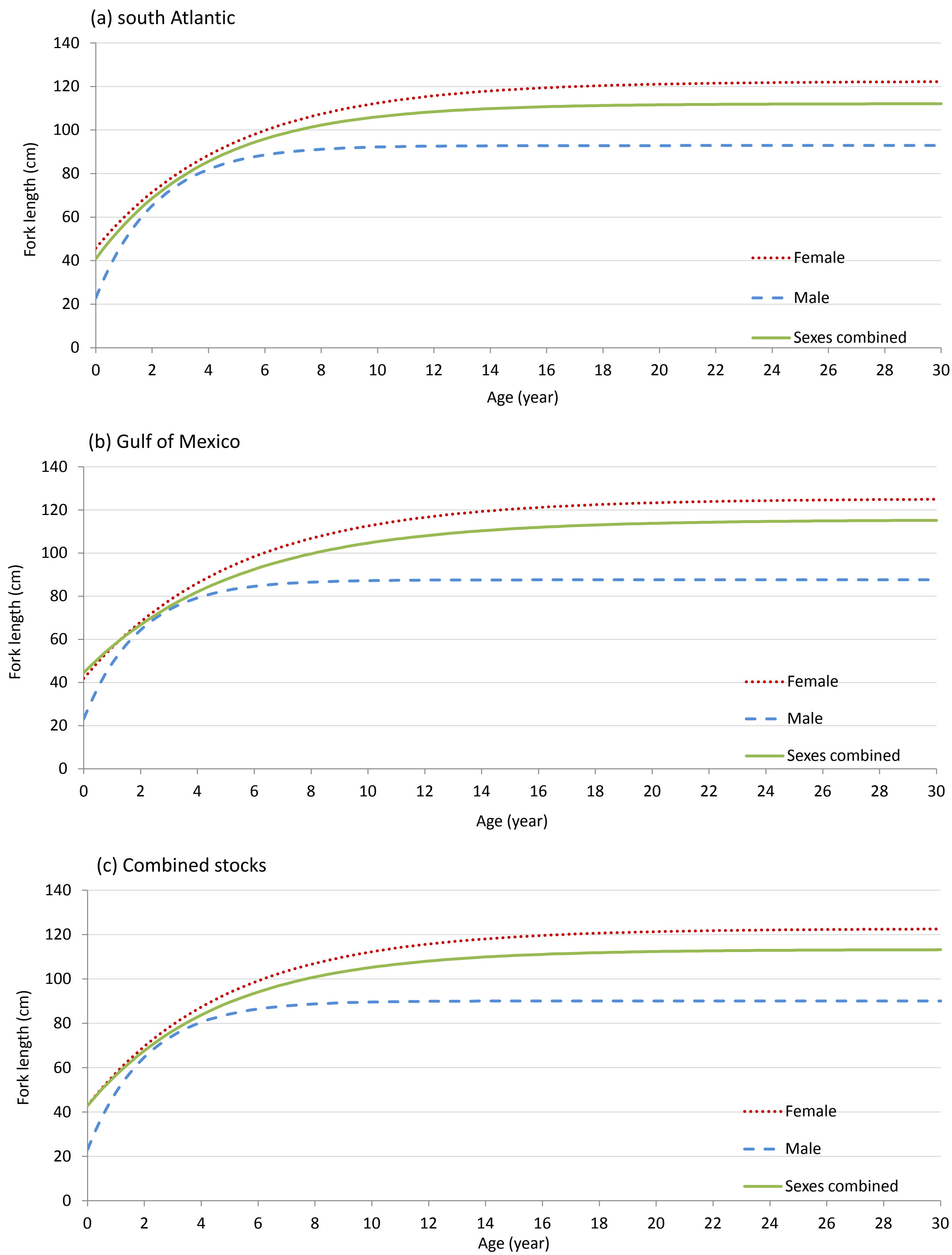


Figure 3. King mackerel sex-specific von Bertalanffy growth curves by stock (a) south Atlantic, (b) Gulf of Mexico, and (c) all data combined.

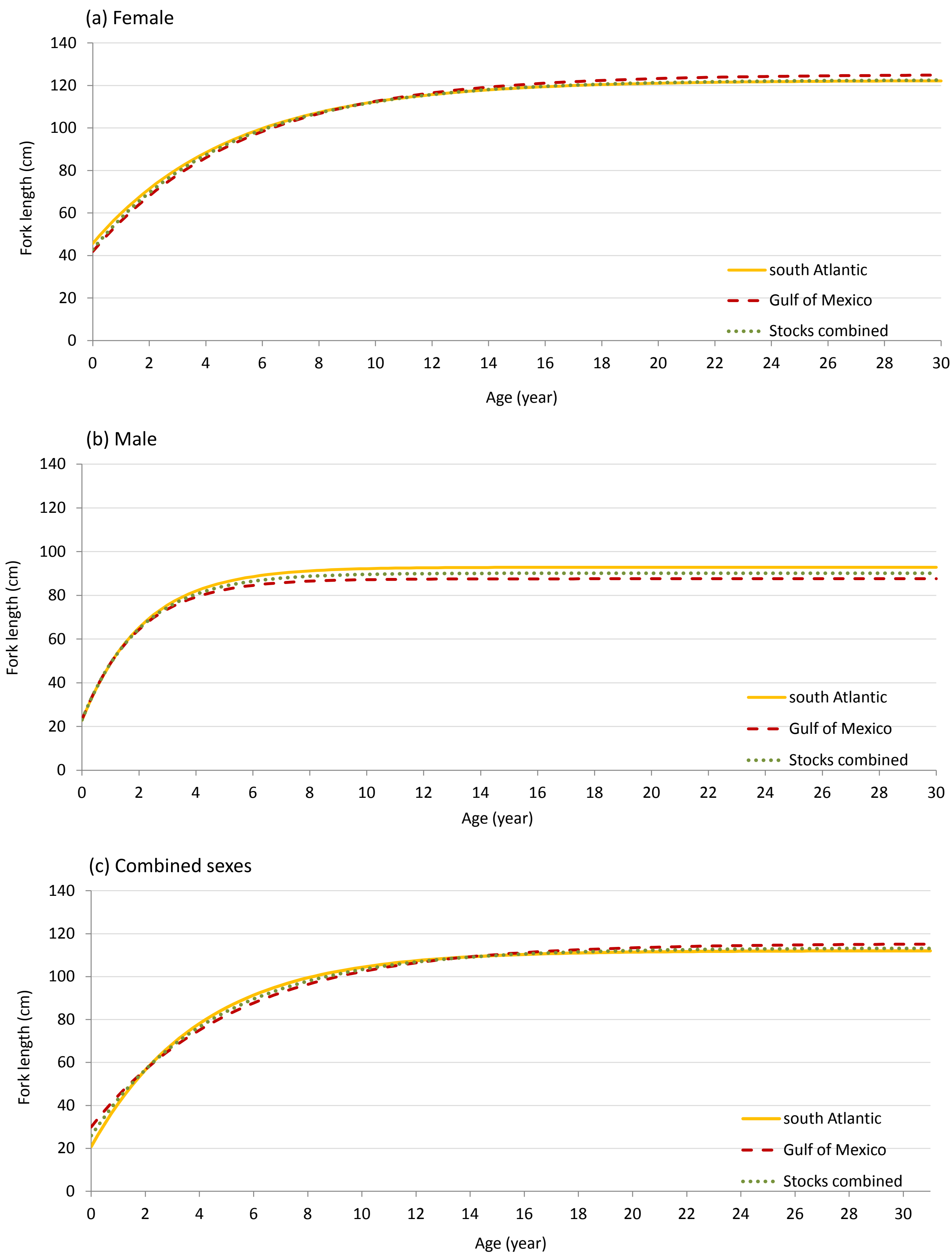


Figure 4. King mackerel stock-specific von Bertalanffy growth curves by sex (a) Female, (b) Male, and (c) all data combined.

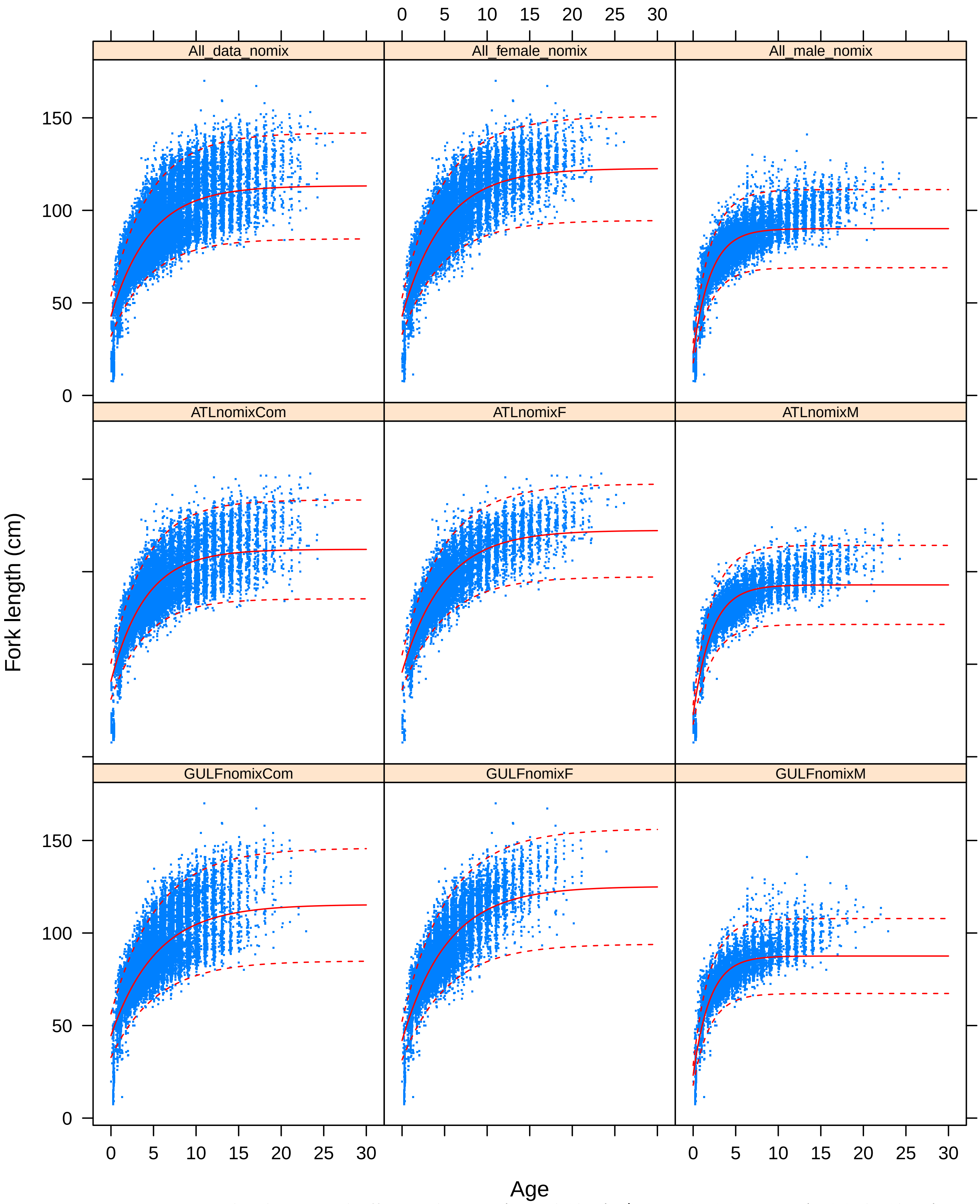


Figure 5. King mackerel von Bertalanffy growth curves (red solid line) +/- 2 standard deviations (red dashed lines), and observed fractional ages and fork lengths (blue dots) for each data combination (all data, by stock, and by sex).

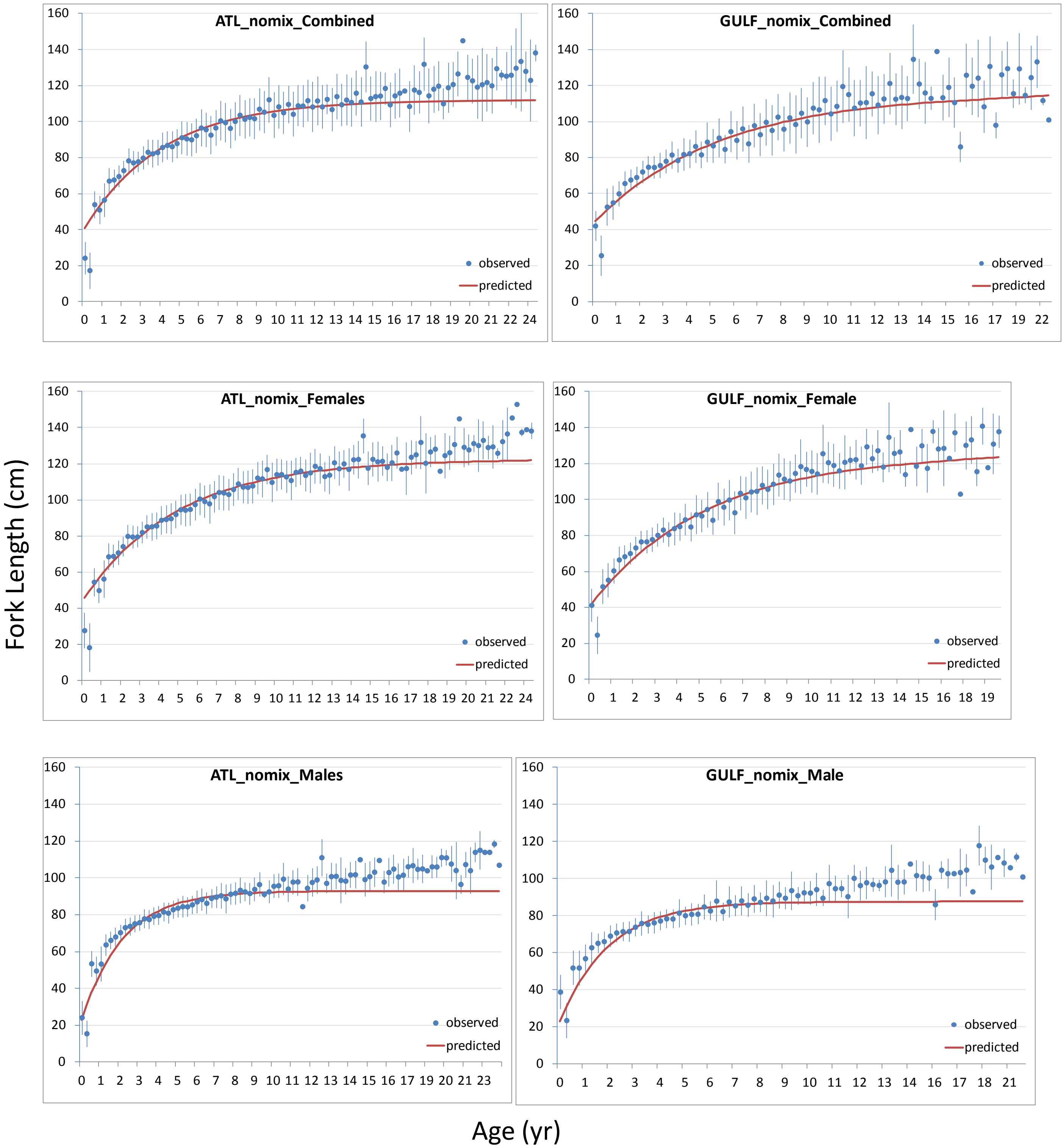


Figure 6. King mackerel von Bertalanffy growth curves (red solid line) and mean observed size- (± standard deviation) at-age for each data combination (all data, by stock, and by sex) for all ages. Note the growth curves were constructed using fractional ages, therefore, the mean size-at-age data points are the average size per decimal age per 0.25 yr.

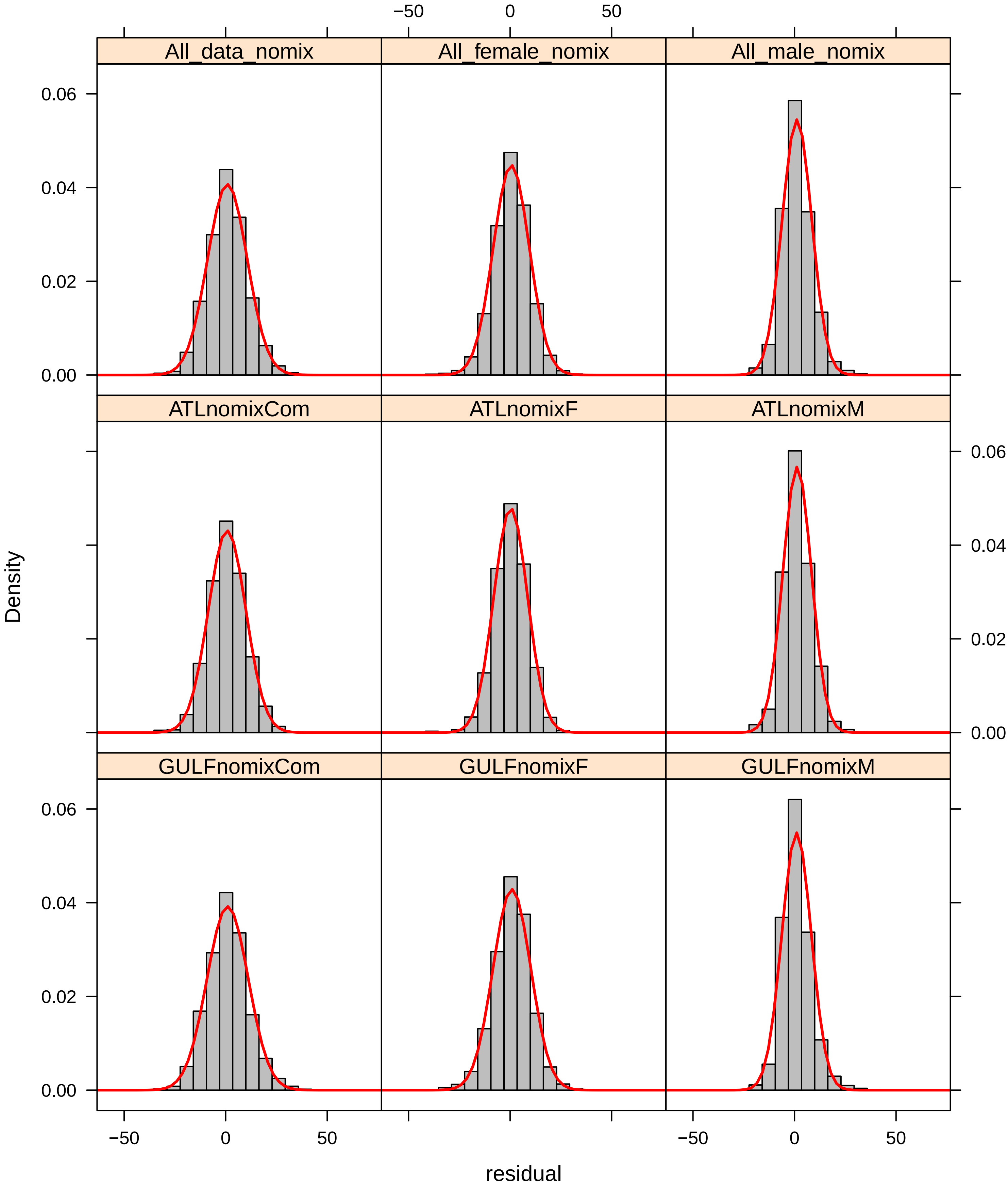


Figure 7. Distribution of residuals for each king mackerel von Bertalanffy growth model for all data combined and by stock and by sex.

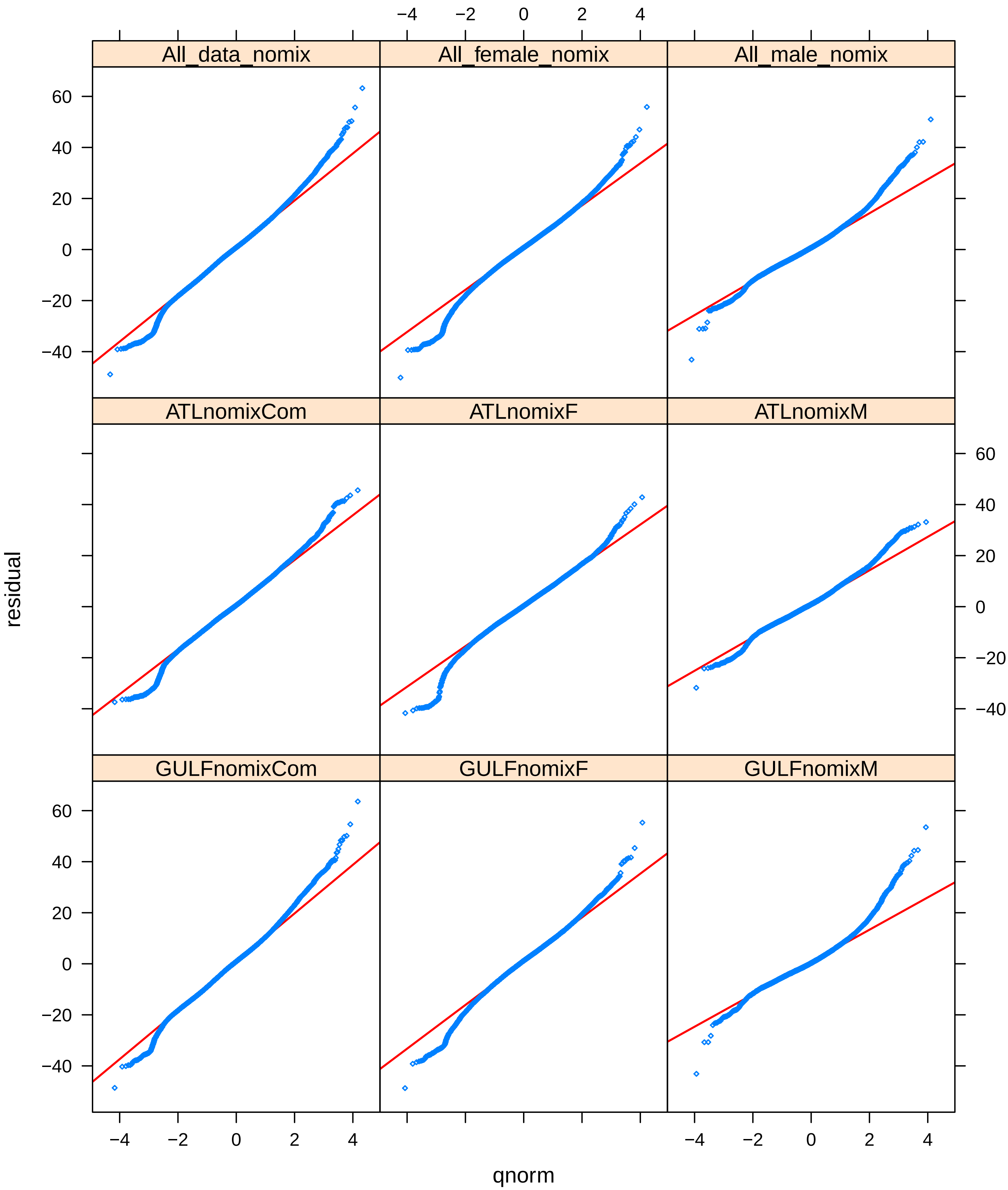


Figure 8. Normal probability plots (quantiles vs residuals) for each king mackerel von Bertalanffy growth model for all data combined and by stock and by sex.

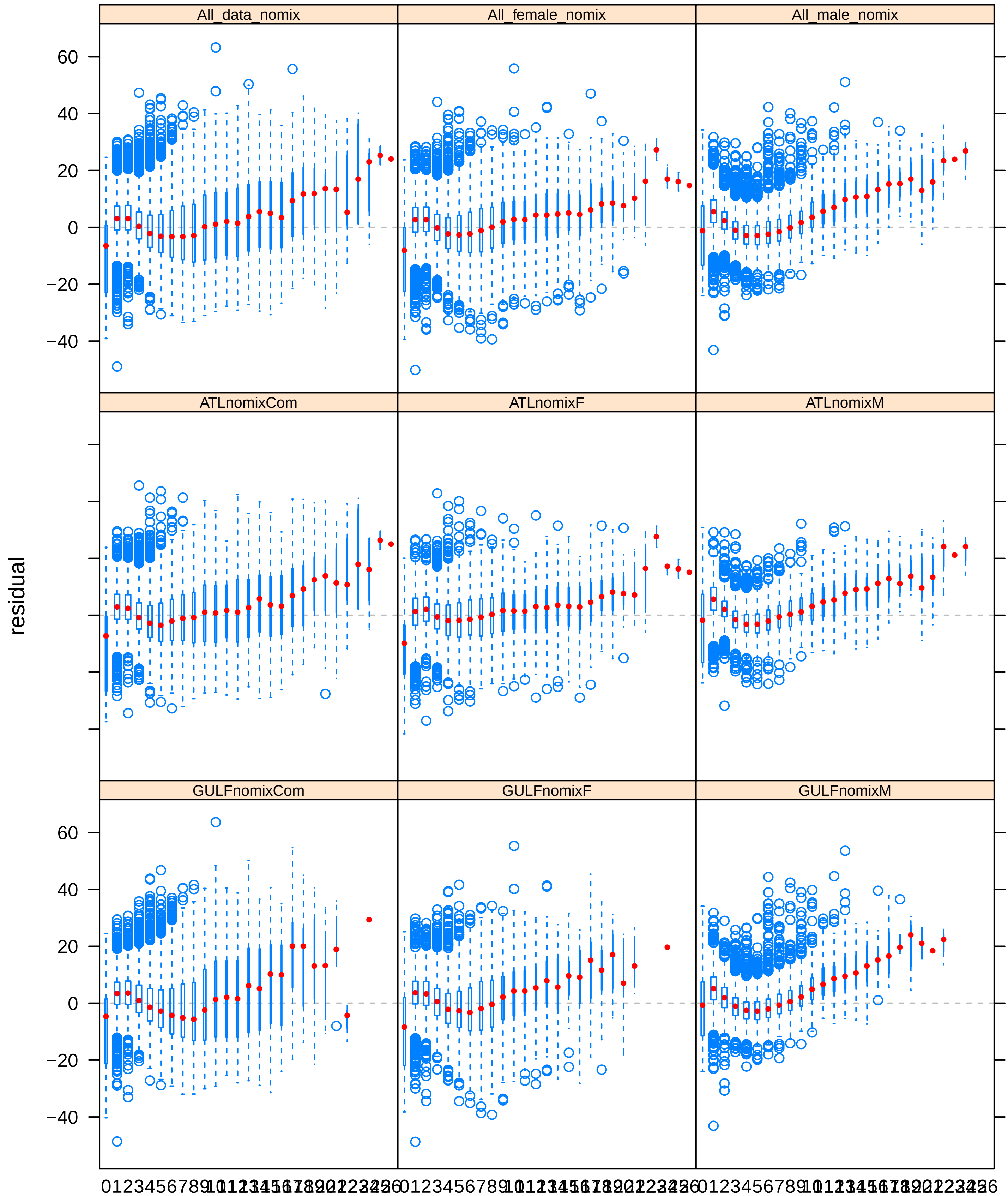


Figure 9. Residuals by age for king mackerel for all data combined, by stock, and by sex. Box plots include median (red dot), upper and lower quartiles (boxes), upper and lower range (dashed line), and outliers (open circles).

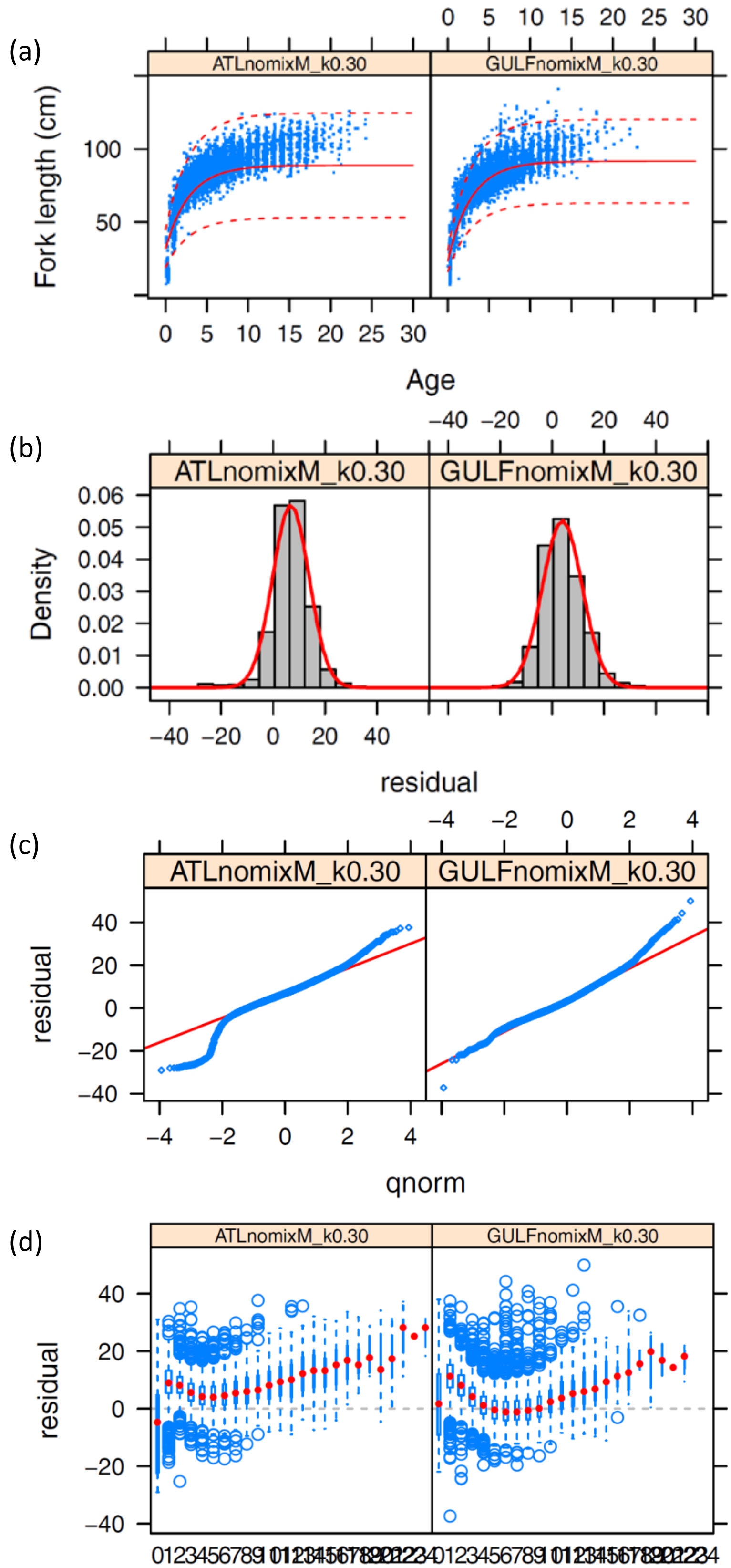
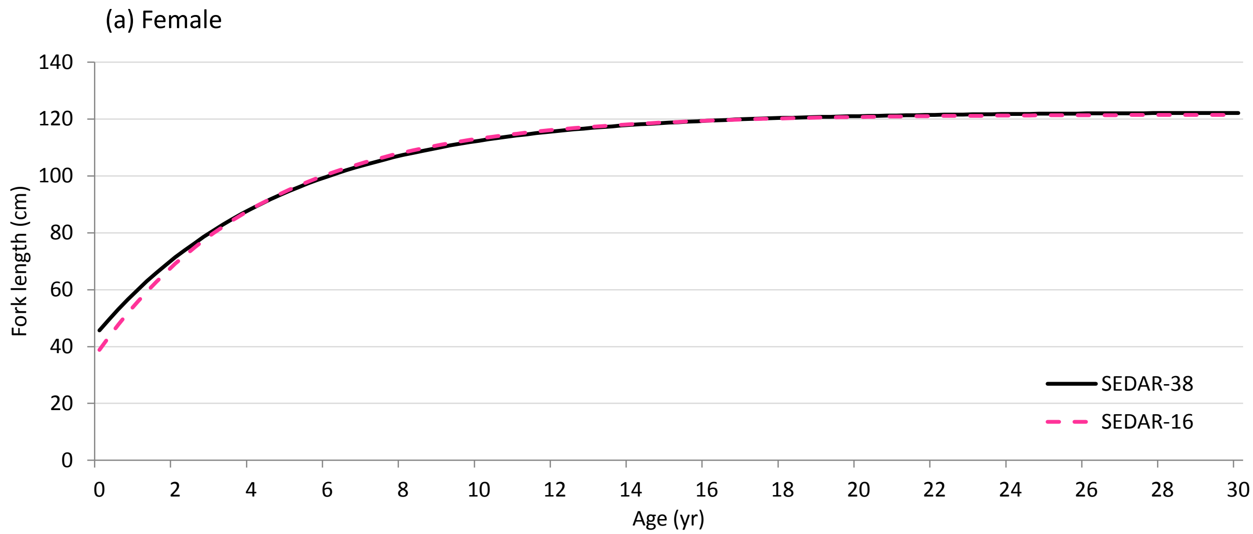
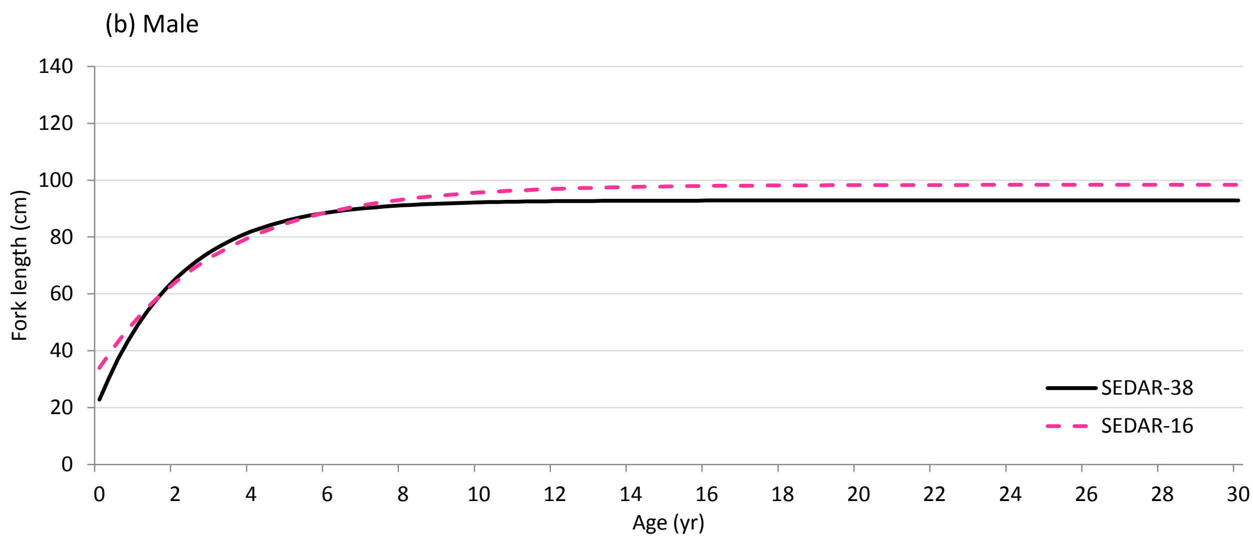


Figure 10. In attempt to predict similar growth coefficient (k) for male king mackerel as previous assessment, a higher range of k were explored (k = 0.30, 0.35); (a) von Bertalanffy growth curves (red solid lines) ± 2 standard deviations (red dashed lines) and observed fractional ages and fork lengths (blue dots), (b) distribution of residuals, (c) normal probability plots (quantiles and residuals), and (d) residuals by age (see Figure 8 for explanation of box plots).





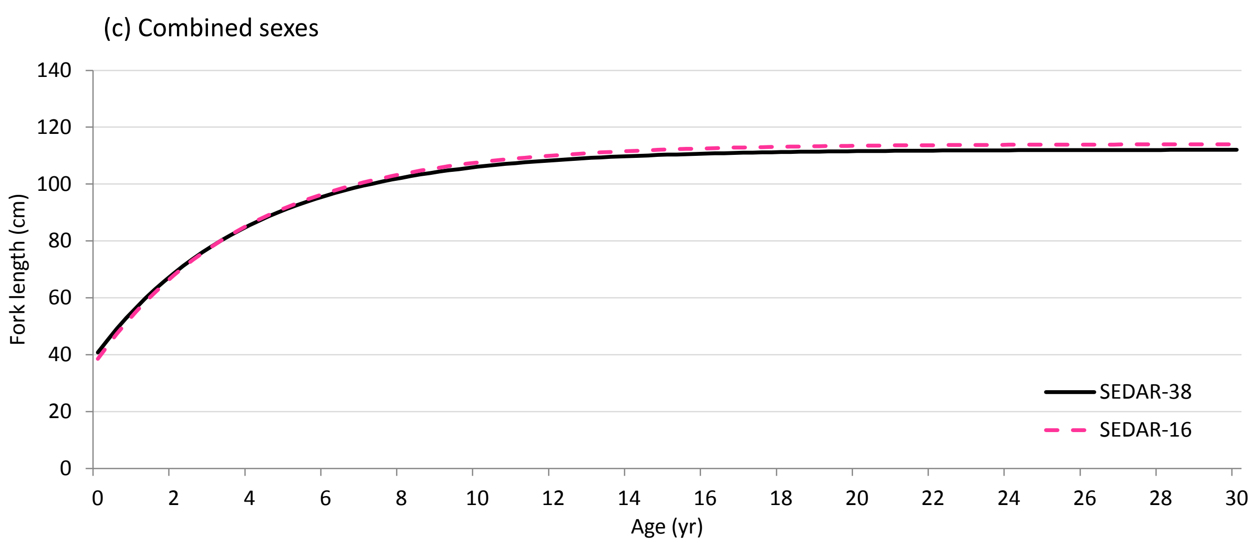


Figure 11. A comparison of king mackerel von Bertalanffy growth curves from the South Atlantic stock between the 2008 assessment (SEDAR16) and the current 2014 assessment (SEDAR38) by sex (a) Female, (b) Male, and (c) all data combined.

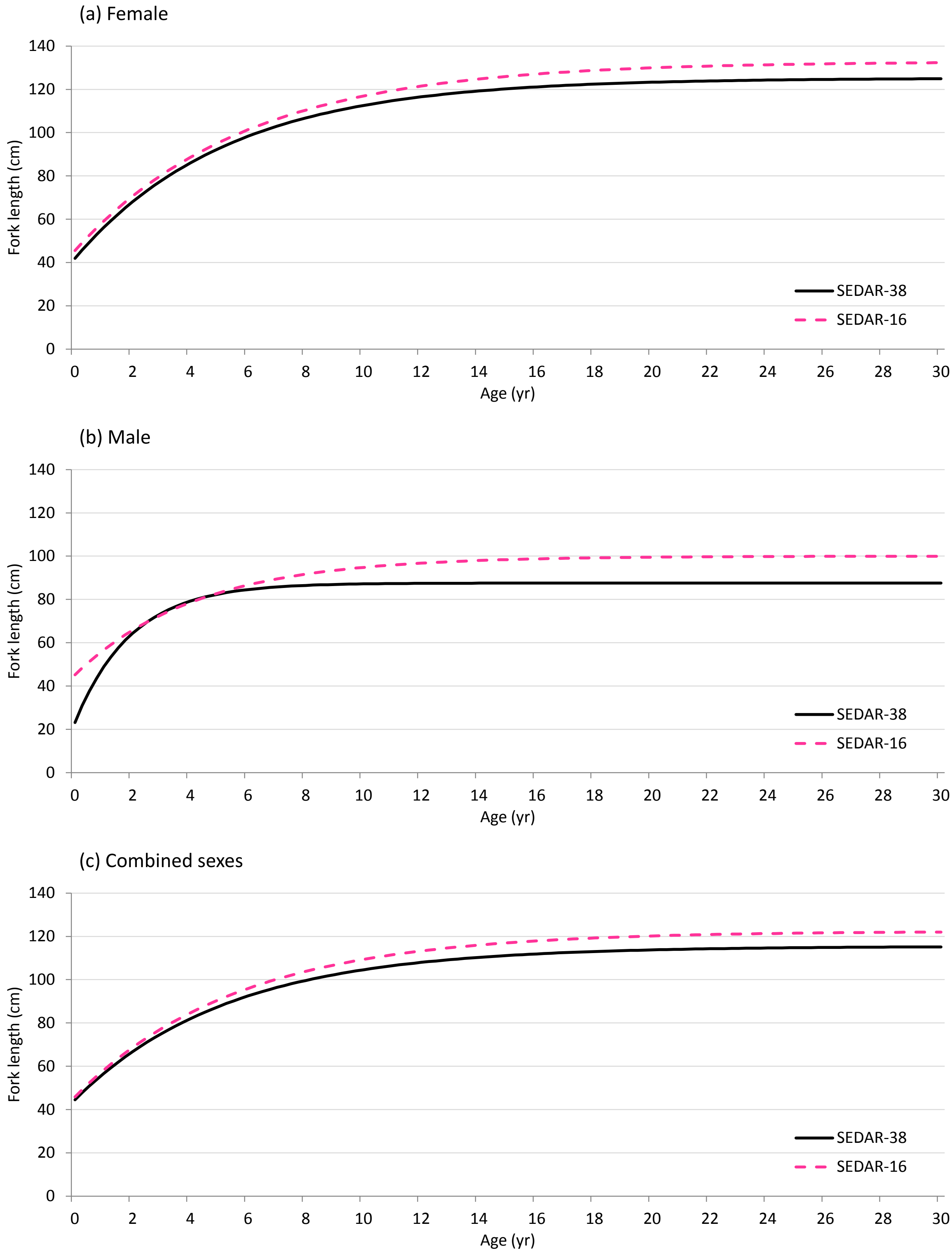


Figure 12. A comparison of king mackerel von Bertalanffy growth curves from the Gulf of Mexico stock between the 2008 assessment (SEDAR16) and the current 2014 assessment (SEDAR38) by sex (a) Female, (b) Male, and (c) all data combined.

Appendix A. List of data sources and fishing modes used for collecting king mackerel otoliths from the U.S. south Atlantic and Gulf of Mexico.

Source	Definition
CO-OP	NOAA Fisheries Cooperative Research Proposal
EASA	MSLAB, Expanded Stock Assessment Survey
FIN	GSMFC, Fisheries Information Network
FLDEP	Florida Department of Environmental Protection (only for 1996)
FWRI	Florida Wildlife Research Institute
HB	NOAA Fisheries Beaufort Head Boat Survey
LADWF	Louisiana Department of Wildlife and Fisheries
MRFSS	GSMFC, Marine Recreational Fisheries Statistical Survey
MSLAB	NMFS Pascagoula, MS
NCDMF	North Carolina Dept. of Marine Fisheries
PCLAB	NMFS Panama City, FL
RECFIN	GSMFC, Recreational Fisheries Information Network
SCDNR	South Carolina Dept. Natural Resources
TIP	NOAA Fisheries, Trip Interview Program
Unknown	
USAL	University of South Alabama
UWF	University of West Florida
VADMR	Virginia Department of Marine Resources

Mode	Definition
CM	Commercial
CP	Charter Party
HB	Headboat
ID	Independent (for UWF records)
PR	Private
REC	Recreational (for UWF records)
SS	Scientific Survey
TRN	Tournament
Unknown	

Addendum_v4

SEDAR38-AW-01

Growth models for king mackerel from the south Atlantic and Gulf of Mexico

Linda Lombardi[1], John Walter[2] and Clay Porch[2]

Revised May 2014

National Marine Fisheries Service
Southeast Fisheries Science Center
[1]Panama City Laboratory
3500 Delwood Beach Road
Panama City, FL 32408

[2]Sustainable Fisheries Division
75 Virginia Beach Drive
Miami, FL 33149

Panama City Laboratory Contribution 14-01

Summary of revised growth models

The Assessment Workshop (AW) Panel requested several revisions to the minimum-size corrected (previously referred to as size-modified) von Bertalanffy growth models for king mackerel from both the Gulf of Mexico and South Atlantic stocks. The growth model presented to the AW Panel during pre-assessment workshop webinar had difficulties in predicting growth for the younger (age 0-1 yr) and older fish (age 11+ yr). Discussions during the AW resulted in three different growth models in attempt to predict growth for all observed fish better. The first two revised growth models were applied to a reduced dataset, 1. removal of tournament caught fish and 2. systematic removal of younger aged fish (age 0, 1, 2, and 3). The third growth model was a two-phase model that used a linear model to predict growth from age 0 to age 0.5 and a non-linear model to predict growth from age 0.75 to age 20. Below are the results for each of these growth models configurations.

1. Remove tournament caught fish

Tournament caught and intercepted king mackerel may not truly be representative of the population and may provide bias to the growth models. Therefore, the AW panel requested king mackerel intercepted from tournaments (n = 15,930) to be removed from the dataset and alternative growth models were compiled. A majority (60%) of the tournament king mackerel were collected along the South Atlantic prior to 2000 (Table A1 and A2). The tournament fish dominated lengths greater than 100 cm, primarily in the South Atlantic (Table A3). The revised von Bertalanffy growth models (not including tournament intercepted king mackerel) resulted in lower asymptotic lengths, faster growth coefficients and smaller sizes at time zero compared to growth parameters calculated from all data (Figure A1 and Figure A2, Table A4, see Table 6 for growth parameters calculated with all data).

The same model diagnostic plots were created to visual inspect the revised predicted growth parameters. The revised growth curves fit the existing data points as well as the original growth models, with the predicted growth curves (± 2 standard deviations) incorporated most of the observed data (Figure A3). These revised minimum-size corrected growth model still had difficulties in predicting sizes-at-ages for the oldest ages (Figure A4). The stock and sex specific models' residuals showed normal distributions (Figure A5 and A6). Residuals by age (by stock and by sex) showed similar distribution of residuals by age compared to those calculated from growth models from all data, with the older fish having skewed residuals (Figure A7).

2. Systematically remove younger fish

Two assessment models (Stock Synthesis and a Virtual Population Analysis) are being applied to the king mackerel populations for the South Atlantic and Gulf of Mexico. Each of these assessment models require inputs of growth parameters, and for this particular assessment parameters (L_∞, k, t_0) from the von Bertalanffy growth model. Stock Synthesis (SS) uses the externally predicted growth parameters as starting guesses and internally estimates growth; however, the Virtual Population Analysis (VPA) does not internally estimate growth and requires growth parameters that accurately predict growth.

The AW panel agreed that the externally calculated growth parameters predicted growth well for the younger ages (1-10 yr) but not for the older ages (age 11+ yr). This issue is particularly important for the ‘plus’ group (age 11+) in the VPA assessment model. Therefore, the AW panel suggested modeling growth specifically for the older fish by systematically removing the younger fish (age 0, 1, 2, and 3) from the dataset (Table A5). The resulting growth parameters would only be applied in the VPA and only to the plus age group.

The same model diagnostic plots were created to visual inspect the revised predicted growth parameters. The revised growth curves did not fit the existing data points as well, especially for the younger fish (≤ 10 yr), and the predicted growth curves (± 2 standard deviations) did not incorporated the observed data at these ages (Figure A8). The revised minimum-size corrected growth model fit the older ages better (Figure A8 and A9). In the Gulf of Mexico, the additional removal of age 3 fish did not change the predicted growth parameters, compared to those parameters calculated with only removing age 0, 1 and 2 (Table A6, Figure A9). The stock, sexes combined models’ residuals showed slightly skewed, more positive, distributions (Figure A10 and A11). Residuals by age (by stock, sexes combined) showed more normally distributed residuals by age, even at the older age classes, compared to residuals calculated from previous growth models from all data (Figure A12).

3. Two-phase growth model

The AW suggested the use of a two-phase growth model similar to that employed by the stock synthesis model. Accordingly, the ADMB code was revised to provide a two-phase growth model; phase one, linear growth and phase two, non-linear growth. The age at which growth changes from linear to non-linear can be assigned in the model input file. King mackerel exhibit extremely fast growth within their first year; therefore, growth from age 0 to age 0.5 yr was modeled as linear:

$$L(t) = \begin{cases} L_\infty\left(1 - e^{-k(t-t_0)}\right) & t \geq 0.5 \\ \dfrac{t}{0.5} L_\infty\left(1 - e^{-k(t-t_0)}\right) & t < 0.5 \end{cases}$$

where $L(t)$ = the length at time t,

L_∞ = the theoretical maximum length,

t = the time,

t_0 = the theoretical size at time zero, and

k = the growth coefficient.

The two-phase model resulted in larger asymptotic lengths, faster growth coefficients and smaller sizes at time zero (Table A7, see Table 6 for growth parameters from original minimum-size corrected growth model). In addition, the decrease in the models' objective functions during the phases of the model, provides reassurance the model is optimizing with the additional variance parameters (Table A8).

Four of the five model diagnostic plots were created to visual inspect the revised predicted growth parameters. Both the fitted curve, estimated from the predicted growth parameters, and the predicted sizes-at-ages from the two-phase model resulted in similar observed size-at-age, and also fit the younger and older fish the best of all model approaches (Figure A13). The stock and sex specific models' residuals showed normal distributions (Figure A14). The probability plots revealed divergence for the male populations in both stocks (Figure

A15); however, this pattern was evident in all models. Residuals by age (by stock and by sex) also showed a reasonable distribution of residuals for a majority of the ages (age 1-15, Figure A16); there are some residuals that are not normally distributed by age but these anomalies can be explained by small sample sizes by age (age 0, age $\geq$ 20) for a particular stock and sex.

Table A1. Number of king mackerel otoliths intercepted at tournaments by and by stock.

Year	South Atlantic	Gulf of Mexico	Total
1986	55	43	98
1987	153	250	403
1988	184	291	475
1989	591	257	848
1990	795	127	922
1991	606	240	846
1992	836	437	1273
1993	408	301	709
1994	335	420	755
1995	239	370	609
1996	474	202	676
1997	319	263	582
1998	446	98	544
1999	438	20	458
2000	497	18	515
2001	537	9	546
2002	337	182	519
2003	913	311	1224
2004	364	53	417
2005	185	108	293
2006	230	194	424
2007	427	216	643
2008	246	105	351
2009	200	10	210
2010	259	10	269
2011	264	106	370
2012	362	49	411
Total	10700	4690	15390

Table A2. Number of king mackerel otoliths intercepted at tournaments and aged by stock.

Age	South Atlantic	Gulf of Mexico	Total
0		1	1
1	136	152	288
2	808	401	1209
3	1167	527	1694
4	1160	548	1708
5	1259	488	1747
6	1088	487	1575
7	913	419	1332
8	765	387	1152
9	645	334	979
10	566	251	817
11	494	180	674
12	401	160	561
13	325	106	431
14	253	89	342
15	219	51	270
16	152	41	193
17	115	23	138
18	88	28	116
19	52	8	60
20	32	3	35
21	28	4	32
22	22	1	23
23	3		3
24	6	1	7
25	2		2
26	1		1
Total	10700	4690	15390

Table A3. Length frequency of king mackerel from tournaments and non-tournament intercepts by stock.

Fork Length (cm)	Non Tournament South Atlantic	Tournament South Atlantic	Non Tournament Gulf of Mexico	Tournament Gulf of Mexico
0-10	4		8	
10-20	139		69	
20-30	33		105	
30-40	56	5	122	
40-50	267	5	208	8
50-60	621	45	1168	46
60-70	3696	235	4670	170
70-80	6932	1378	8983	545
80-90	5862	2425	7431	814
90-100	2375	2471	3215	827
100-110	1139	1889	1196	811
110-120	573	1265	588	705
120-130	224	756	291	496
130-140	76	196	105	196
140-150	8	27	31	65
150-160	5	3	5	6
160-170			1	1
Total	22010	10700	28196	4690

Table A4. Revised king mackerel von Bertalanffy growth parameters (± 1 standard deviations) from each stock, sexes combined and by sex without fish intercepted at tournaments. Observed fork lengths and fractional ages were fit to a minimum-size corrected von Bertalanffy growth model that used a constant coefficient of variation.

Stock and Sex	n	L_∞	k	t_0	CV	Model objective function
south Atlantic						
Combined	22010	100.90 ± 0.3406	0.4030 ± 0.0068	-0.8025 ± 0.0297	12.8% ± 0.08%	76630
Female	13075	113.06 ± 0.6363	0.2867 ± 0.0072	-1.4297 ± 0.0563	11.5% ± 0.08%	45587
Male	9206	88.11 ± 0.2706	0.5490 ± 0.0069	-0.4858 ± 0.0118	12.3% ± 0.12%	30332
Gulf of Mexico						
Combined	28197	101.10 ± 0.4032	0.2887 ± 0.0060	-1.7360 ± 0.0527	12.8% ± 0.07%	99021
Female	17643	110.86 ± 0.6575	0.2662 ± 0.0066	-1.5434 ± 0.0534	12.8% ± 0.08%	62075
Male	11137	85.48 ± 0.1865	0.5749 ± 0.0084	-0.4813 ± 0.0180	11.3% ± 0.09%	37463

Table A5. The number of young (age 0 – 3 yr) king mackerel for each stock, sexes combined, removed from the dataset to compile new growth models.

Age	South Atlantic	Gulf of Mexico
0	209	281
1	1883	2775
2	6874	6283
3	5821	5314

Table A6. Revised king mackerel von Bertalanffy growth parameters (± 1 standard deviations) from each stock, sexes combined with young fish (age 0-3 yr) systematically removed from dataset. Observed fork lengths and fractional ages were fit to a minimum-size corrected von Bertalanffy growth model that used a constant coefficient of variation. *For these model runs, the initial growth parameters and bounds on growth parameters in ADMB code had to be altered for the model to compile (t_0 lower bound from -5.00 to -10.00, k initial values from 0.20 to 0.10).

Stock Sexes combined Ages removed	n	L_∞	k	t_0	CV	Model objective function
south Atlantic						
0 and 1	30618	120.72 ± 0.4461	0.1604 ± 0.0025	-3.5543 ± 0.0626	9.9% ± 0.04%	106809
0, 1, and 2	23744	124.11 ± 0.6484	0.1370 ± 0.0032	-4.3606 ± 0.1191	10.0% ± 0.05%	85645
0, 1, 2, and 3	17923	122.16 ± 0.7038	0.1522 ± 0.0049	-3.6591 ± 0.1777	10.4% ± 0.06%	66424
Gulf of Mexico*						
0 and 1	29831	139.30 ± 1.6535	0.0917 ± 0.0030	-5.5980 ± 0.1342	11.4% ± 0.05%	107275
0, 1, and 2	23548	152.13 ± 3.3692	0.0699 ± 0.0040	-6.9928 ± 0.2717	11.7% ± 0.06%	87507
0, 1, 2, and 3	18234	151.39 ± 4.2386	0.0711 ± 0.0055	-6.8201 ± 0.4044	12.3% ± 0.07%	69554

Table A7. Revised king mackerel von Bertalanffy growth parameters (± 1 standard deviations) from each stock, sexes combined and by sex. Observed fork lengths and fractional ages were fit to a two-phase minimum-size corrected von Bertalanffy growth model. Filtered represents the number of records removed prior to the model run because the record's fork length was less than the size limit. Variance parameters (var. 1 and var.2). *These results differ slightly than those reported during the assessment workshop.

Stock and Sex	n	filtered	L_∞	k	t_0	var.1	var. 2
south Atlantic							
Combined	32230	480	121.11 ± 0.4525	0.1509 ± 0.0025	-3.7312 ± 0.0729	0.2200 ± 0.0017	0.0733 ± 0.0008
Female*	20349	232	125.72 ± 0.4332	0.1704 ± 0.0030	-3.0343 ± 0.0755	0.2893 ± 0.0027	0.0461 ± 0.0009
Male	12136	268	98.93 ± 0.3224	0.2603 ± 0.0061	-2.3820 ± 0.0790	0.3250 ± 0.0042	0.0510 ± 0.0011
Gulf of Mexico							
Combined	32350	537	128.88 ± 0.9917	0.1220 ± 0.0029	-4.0880 ± 0.0836	0.1533 ± 0.0012	0.1078 ± 0.0012
Female	21041	352	142.71 ± 0.9572	0.1213 ± 0.0024	-3.4103 ± 0.0643	0.1646 ± 0.0014	0.0621 ± 0.0012
Male	11890	189	97.77 ± 0.4079	0.2267 ± 0.0054	-2.6328 ± 0.0854	0.1956 ± 0.0024	0.0514 ± 0.0011

Table A8. The resulting model objective function (negative log likelihood), the change in the objective function, and resulting Akaike Information Criteria for each phase of the model for the two-phase minimum-size corrected von Bertalanffy growth model. *These results differ slightly than those reported during the assessment workshop.

Stock and Sex	Phase	# parameters	Objective Function (nLL)	Change Obj. function	AIC	AICc	Delta AICc
South Atlantic							
Combined	1	3	133484		266975	266975	
	2	4	123257	-10228	246521	246521	-20454
	3	5	122848	-408	245706	245706	-815
Female*	1	3	98539		197084	197084	
	2	4	81663	-16875	163335	163335	-33749
	3	5	80643	-1020	161296	161296	-2039
Male	1	3	61057		122119	122119	
	2	4	45839	-15218	91686	91686	-30433
	3	5	45205	-635	90419	90419	-1267
Gulf of Mexico							
Combined	1	3	422531		845068	845068	
	2	4	119169	-303362	238345	238345	-606722
	3	5	119147	-21	238305	238305	-41
Female	1	3	79004		158015	158015	
	2	4	76951	-2053	153910	153910	-4105
	3	5	76585	-366	153181	153181	-730
Male	1	3	43734		87475	87475	
	2	4	41357	-2377	82722	82722	-4753
	3	5	40587	-769	81185	81185	-1537

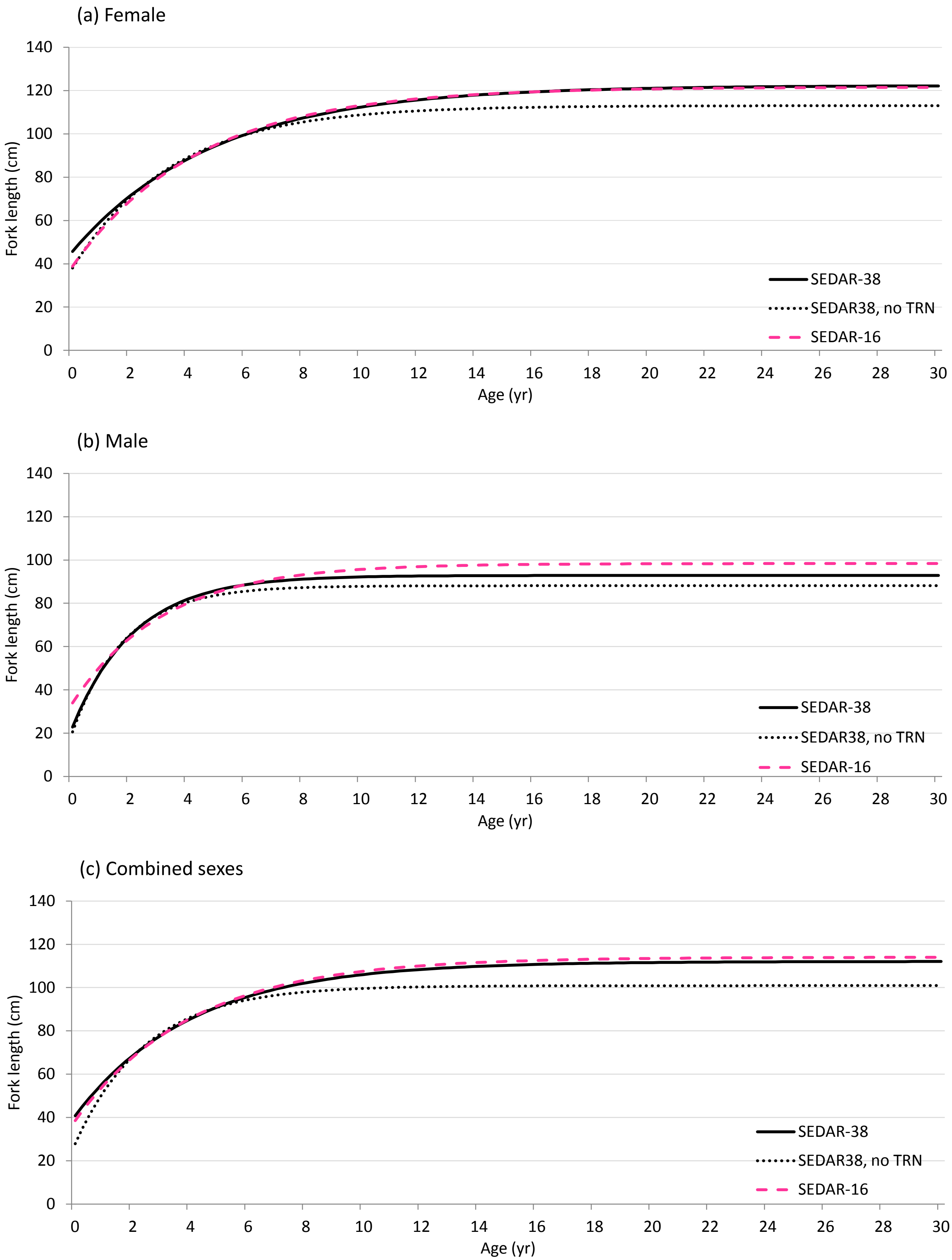


Figure A1. A comparison of king mackerel von Bertalanffy growth curves from the South Atlantic stock between the 2008 assessment (SEDAR16) ,the current 2014 assessment (SEDAR38) with and without fish intercepted at tournaments by sex (a) Female, (b) Male, and (c) all data combined.

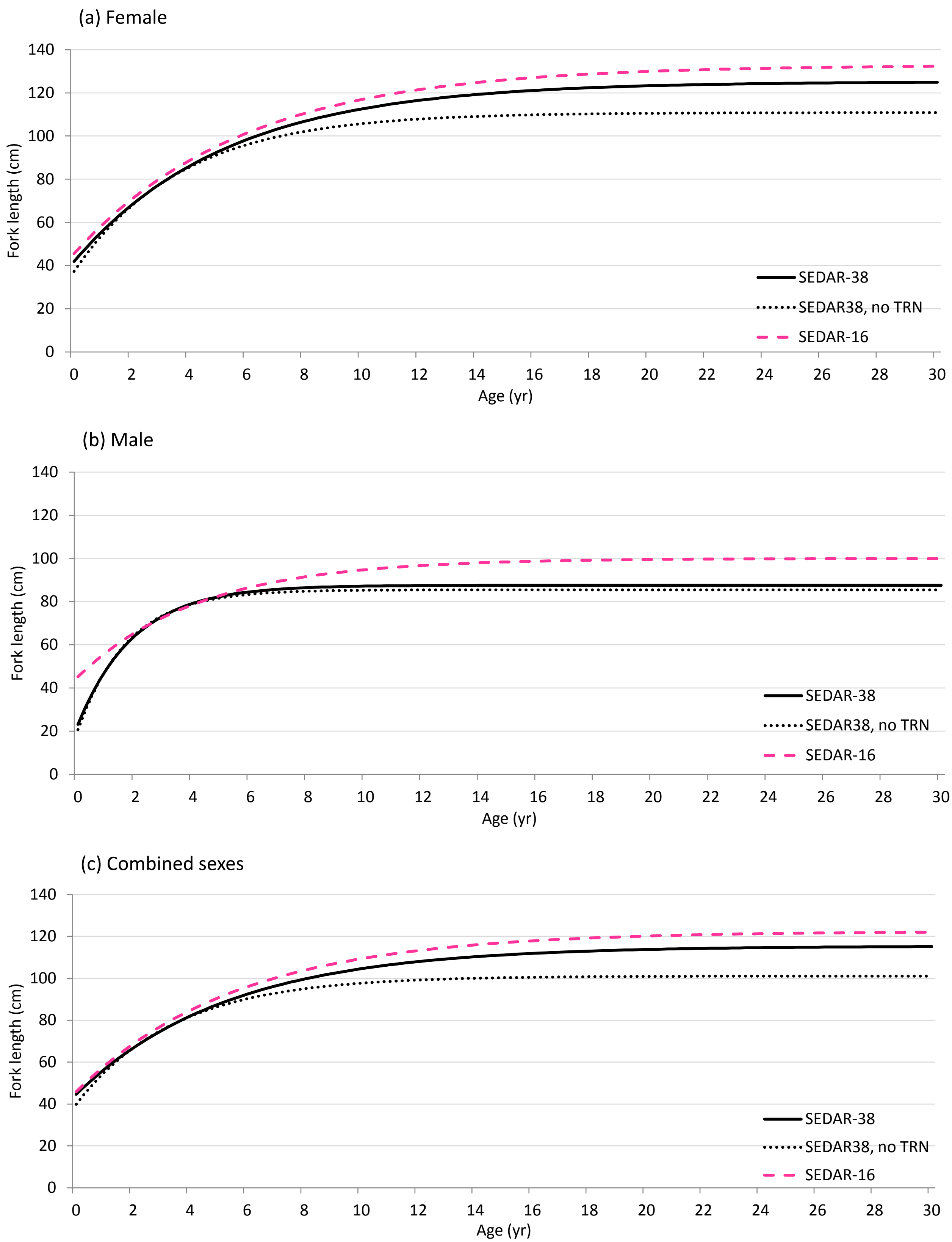


Figure A2. A comparison of king mackerel von Bertalanffy growth curves from the Gulf of Mexico stock between the 2008 assessment (SEDAR16) and the current 2014 assessment (SEDAR38) with and without fish intercepted at tournaments by sex (a) Female, (b) Male, and (c) all data combined.

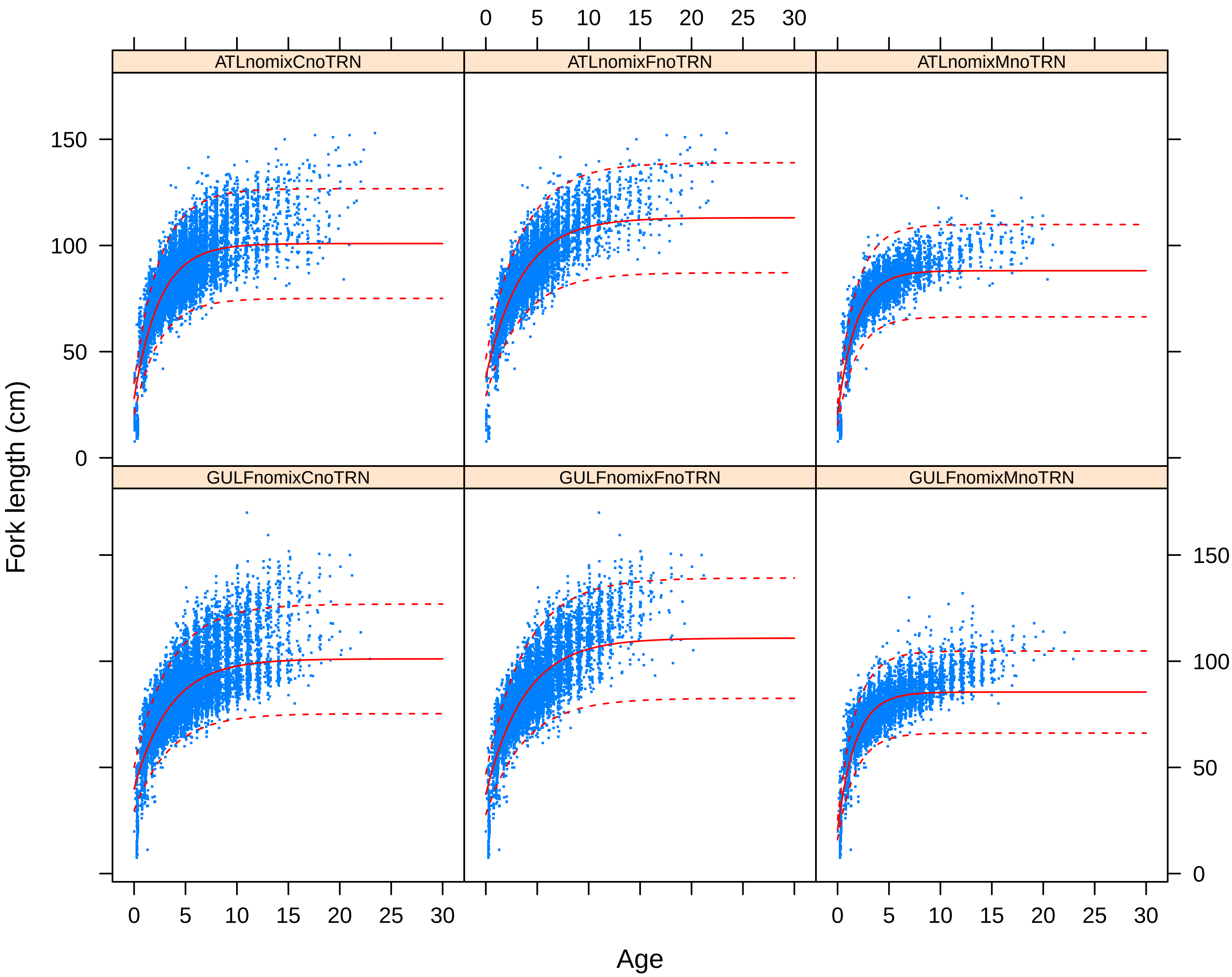


Figure A3. King mackerel von Bertalanffy growth curve (red solid line) +/- 2 standard deviations (red dashed lines), and observed fractional ages and fork lengths (blue dots) for each data combination (by stock and by sex).
All tournament intercepted fish were removed from this analysis

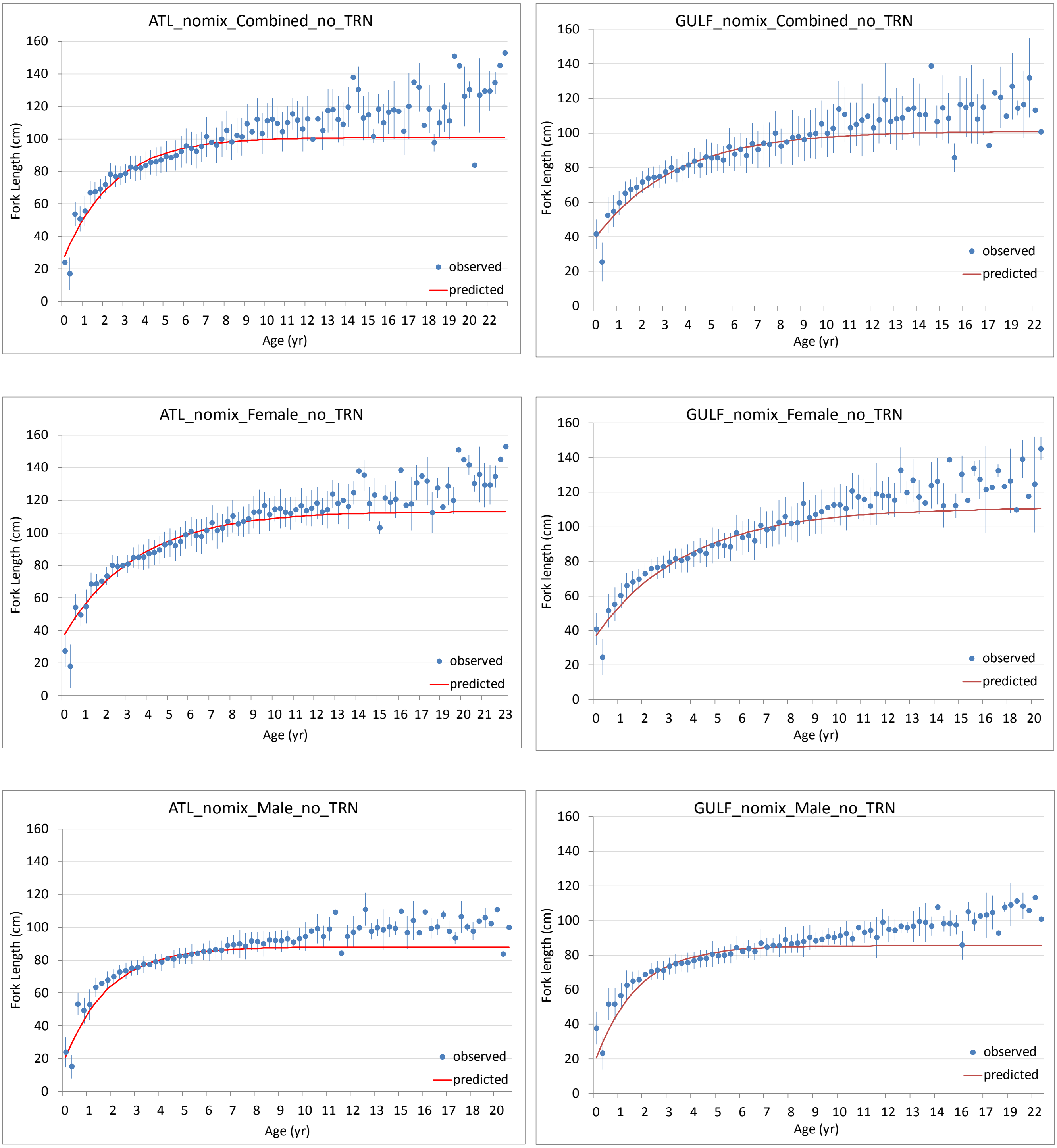


Figure A4. Revised king mackerel von Bertalanffy growth curves (red solid line) and mean observed size- (± standard deviation) at-age for each data combination (by stock, and by sex) for all ages. All tournament intercepted fish were removed from this analysis. Note the growth curves were constructed using fractional ages, therefore, the mean size-at-age data points are the average size per decimal age per 0.25 yr.

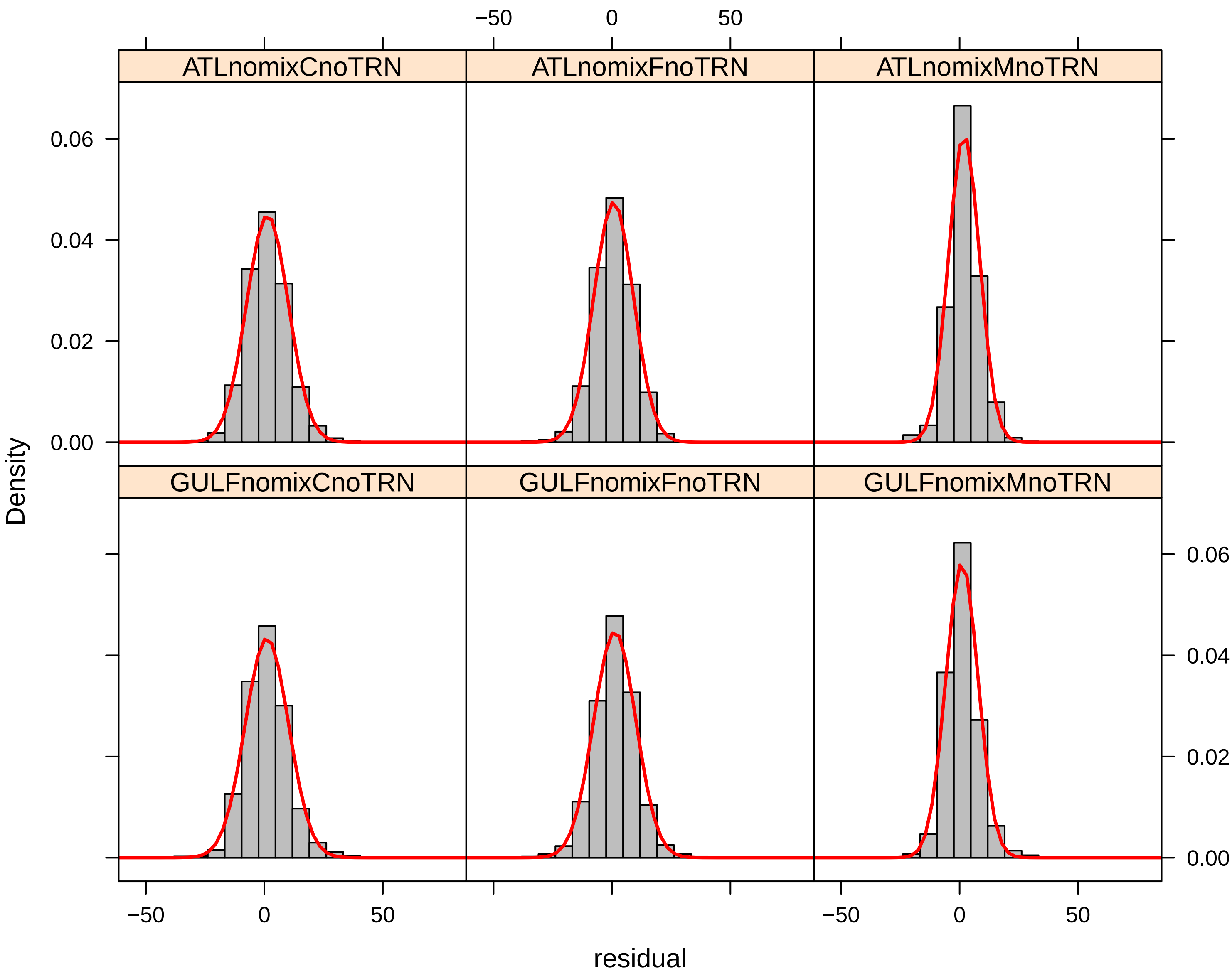


Figure A5. Distribution of residuals for each king mackerel von Bertalanffy growth model by stock and by sex. All tournament intercepted fish were removed from this analysis.

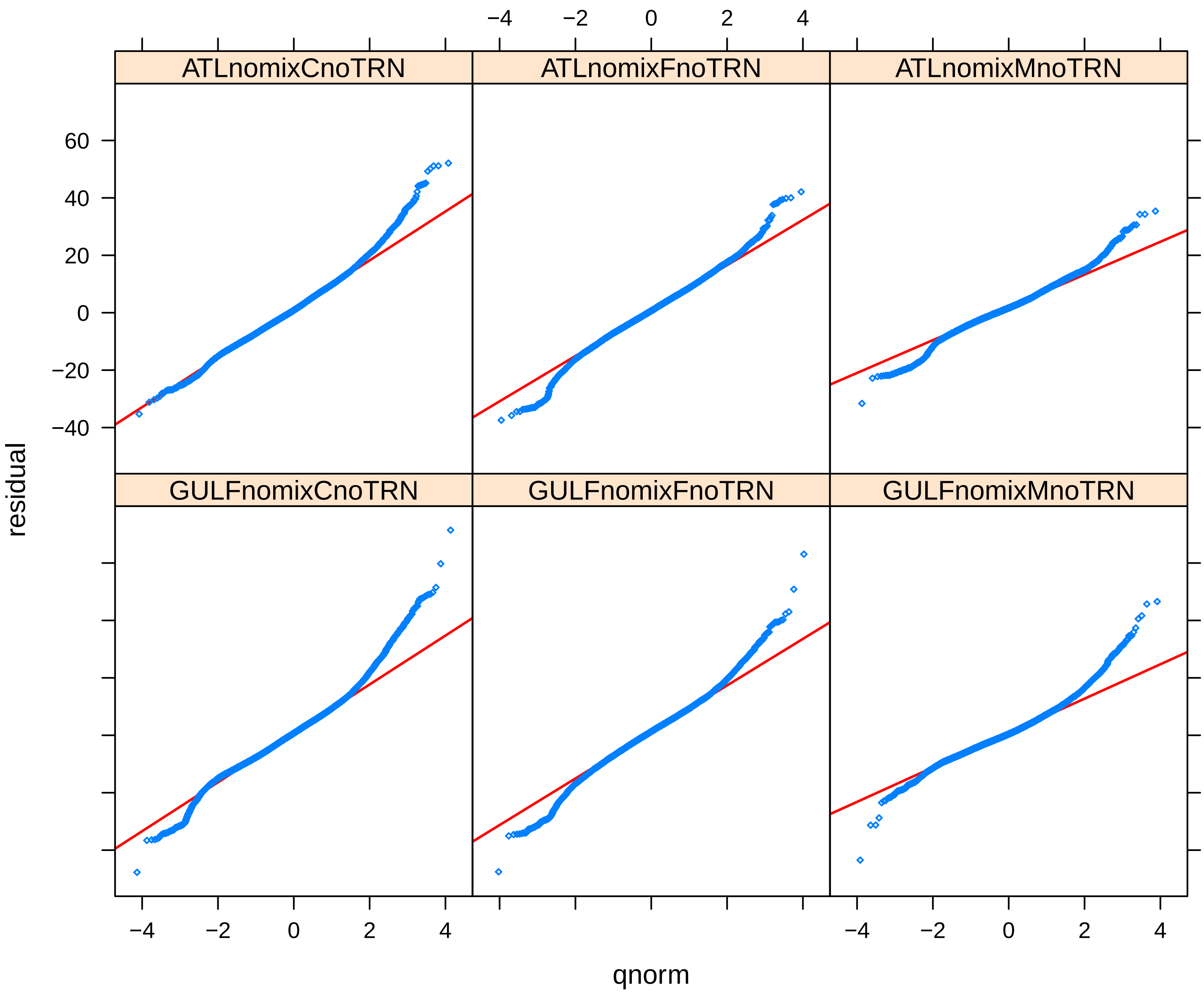


Figure A6. Normal probability plots (quantiles vs residuals) for each king mackerel von Bertalanffy growth model by stock and by sex. All tournament intercepted fish were removed from this analysis.

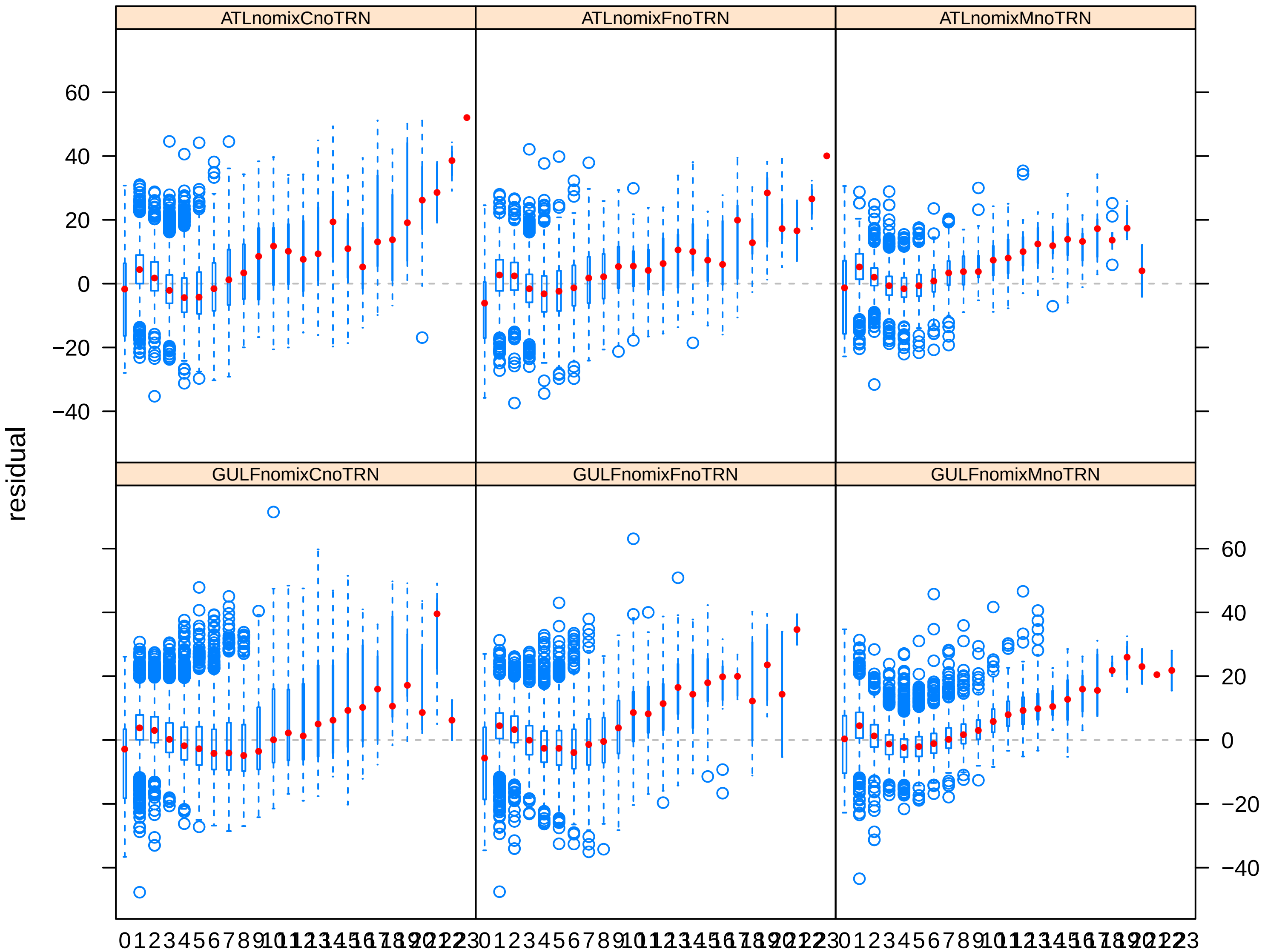


Figure A7. Residuals by age for king mackerel by stock and by sex. All tournament intercepted fish were removed from this analysis. See Figure 9 for description of boxplots.

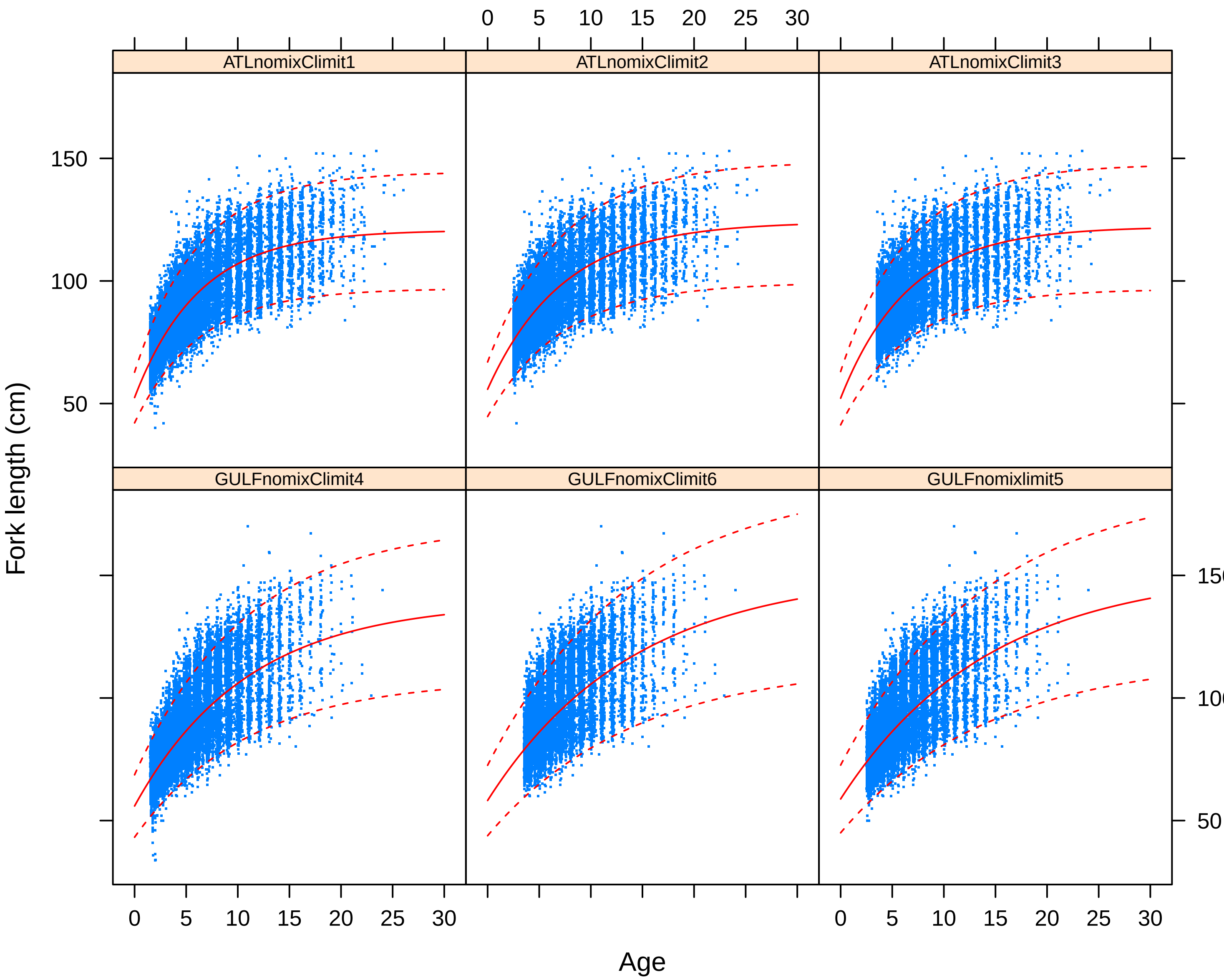
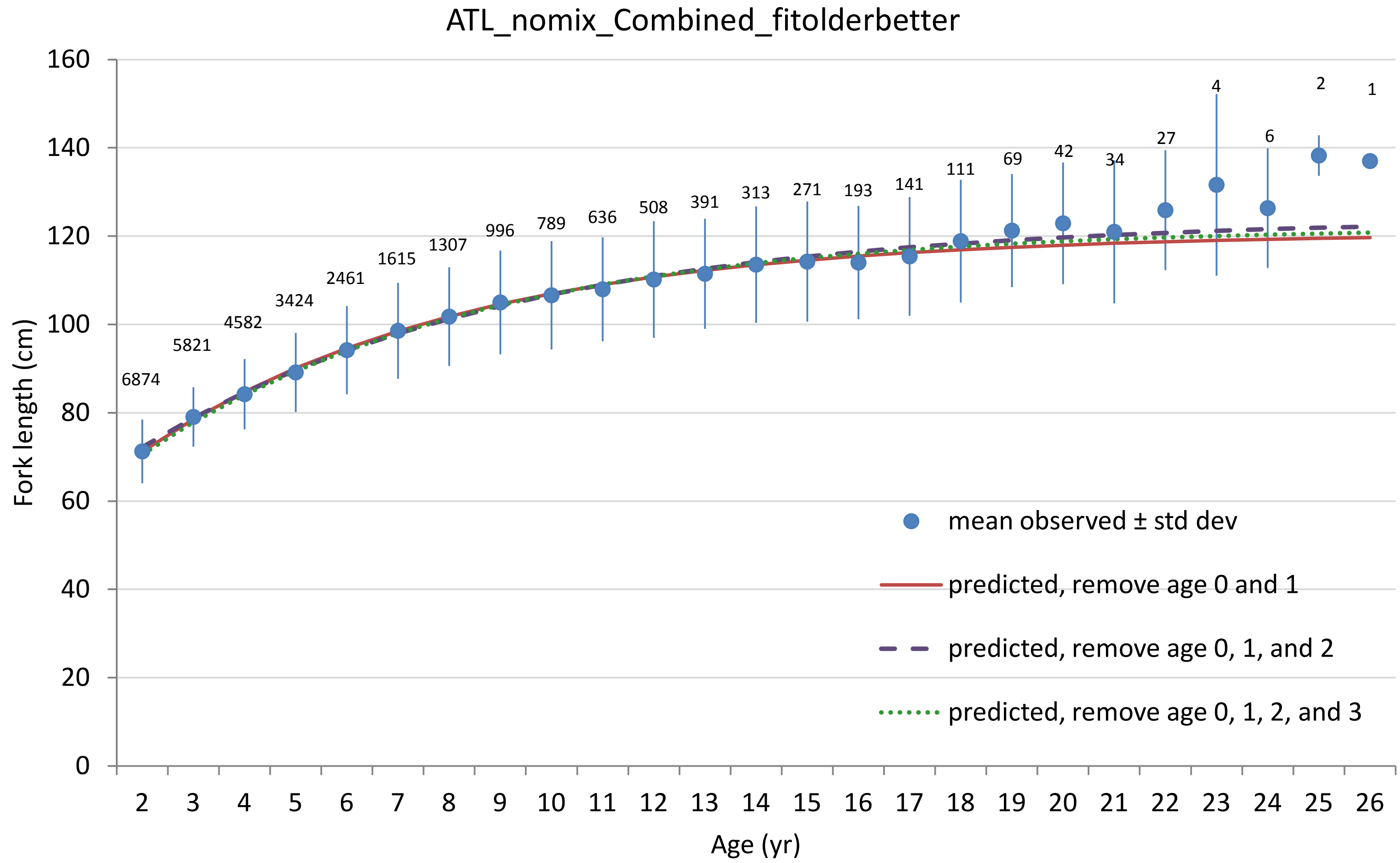


Figure A8. King mackerel von Bertalanffy growth curve (red solid line) +/- 2 standard deviations (red dashed lines), and observed fractional ages and fork lengths (blue dots) for each stock, sexes combined.
South atlantic trials 1: remove age 0 and 1; 2: removed age 0, 1, and 2; 3: removed age 0, 1, 2, and 3.
Gulf of Mexico trials 4: remove age 0 and 1; 5: removed age 0, 1, and 2; 6: removed age 0, 1, 2, and 3.



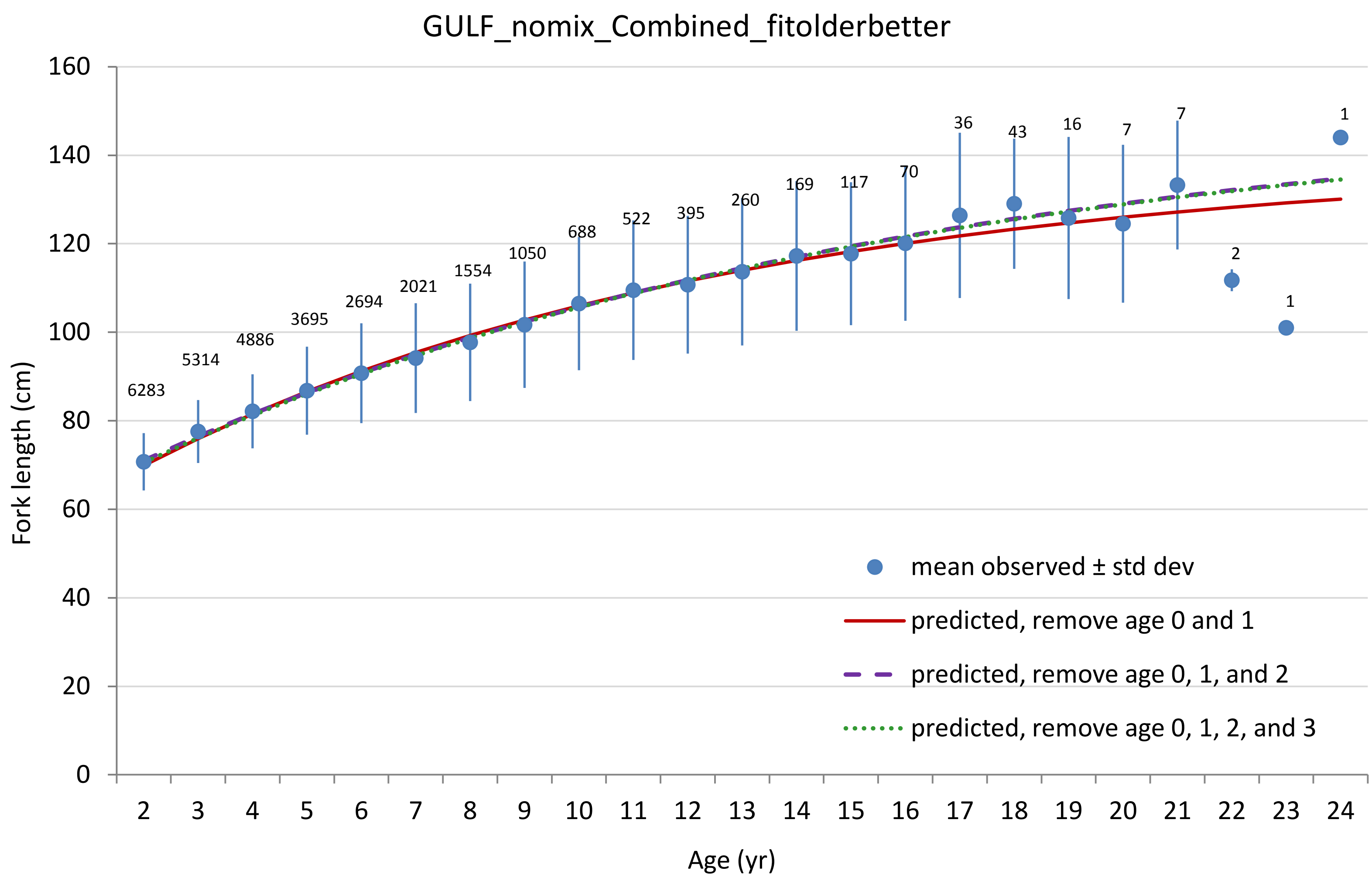


Figure A9. Revised king mackerel von Bertalanffy growth curves (red solid line - age zero and 1 removed, purple dashed line - age zero, 1, and 2 removed; green dotted line - age zero, 1, 2, and 3 removed) and mean observed size- (± standard deviation) at-age for each stock, sexes combined. Sample size per age above standard error bars.

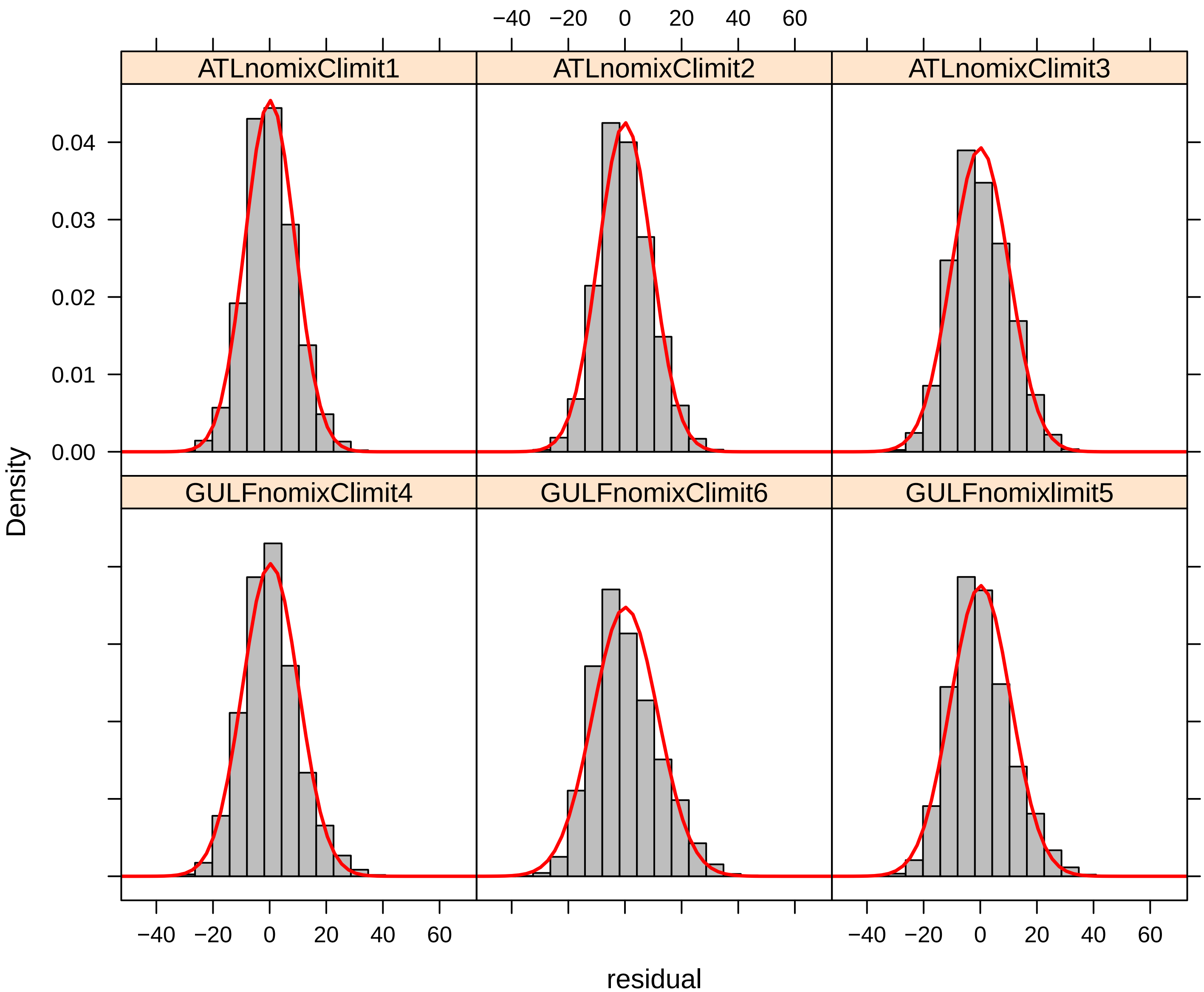


Figure A10. Distribution of residuals for each king mackerel von Bertalanffy growth model by stock, sexes combined. South Atlantic trials 1: remove age 0 and 1; 2: removed age 0, 1, and 2; 3: removed age 0, 1, 2, and 3. Gulf of Mexico trials 4: remove age 0 and 1; 5: removed age 0, 1, and 2; 6: removed age 0, 1, 2, and 3.

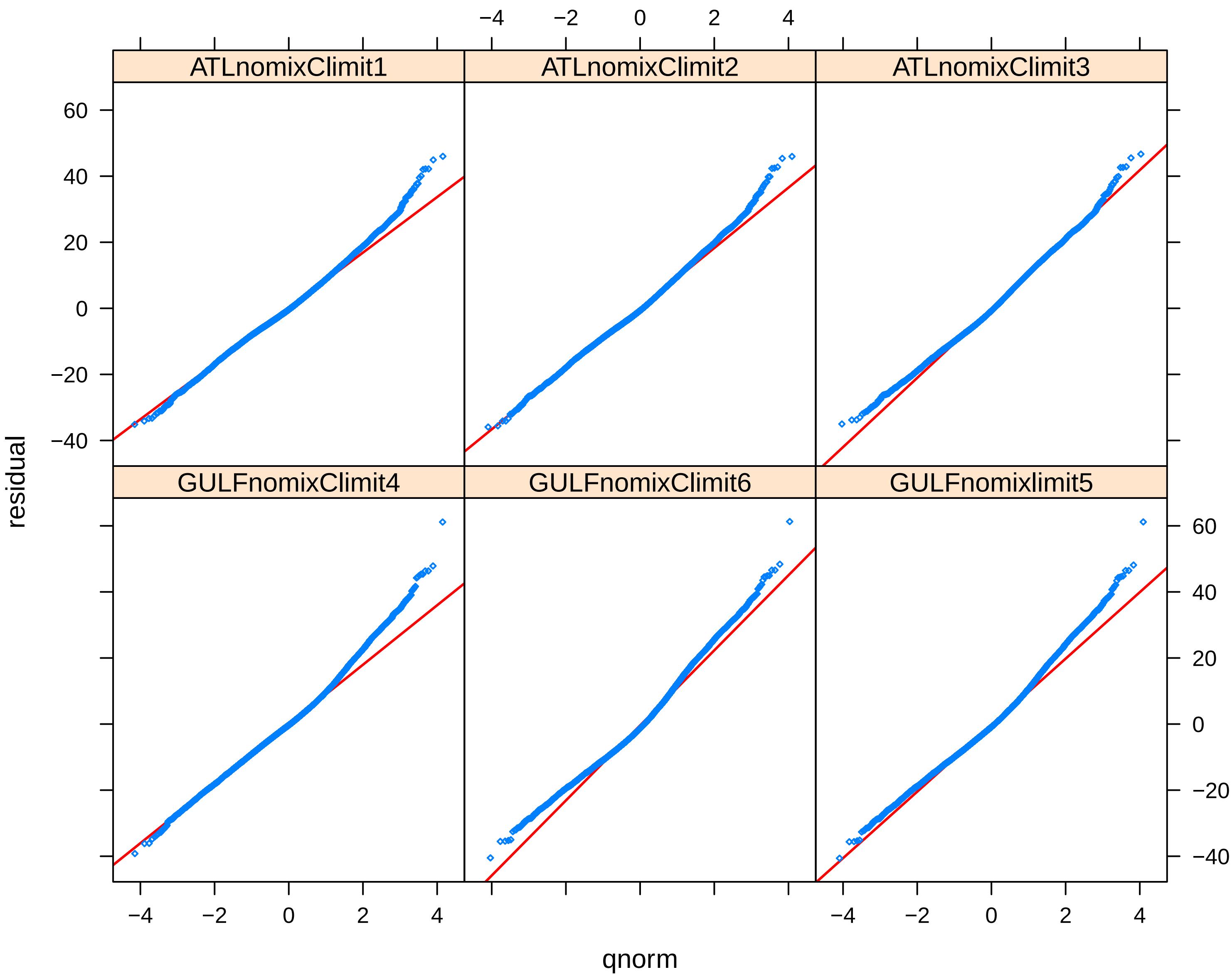


Figure A11. Normal probability plots (quantiles vs residuals) for each king mackerel von Bertalanffy growth model by stock, sexes combined.
South Atlantic trials 1: remove age 0 and 1; 2: removed age 0, 1, and 2; 3: removed age 0, 1, 2, and 3.
Gulf of Mexico trials 4: remove age 0 and 1; 5: removed age 0, 1, and 2; 6: removed age 0, 1, 2, and 3.

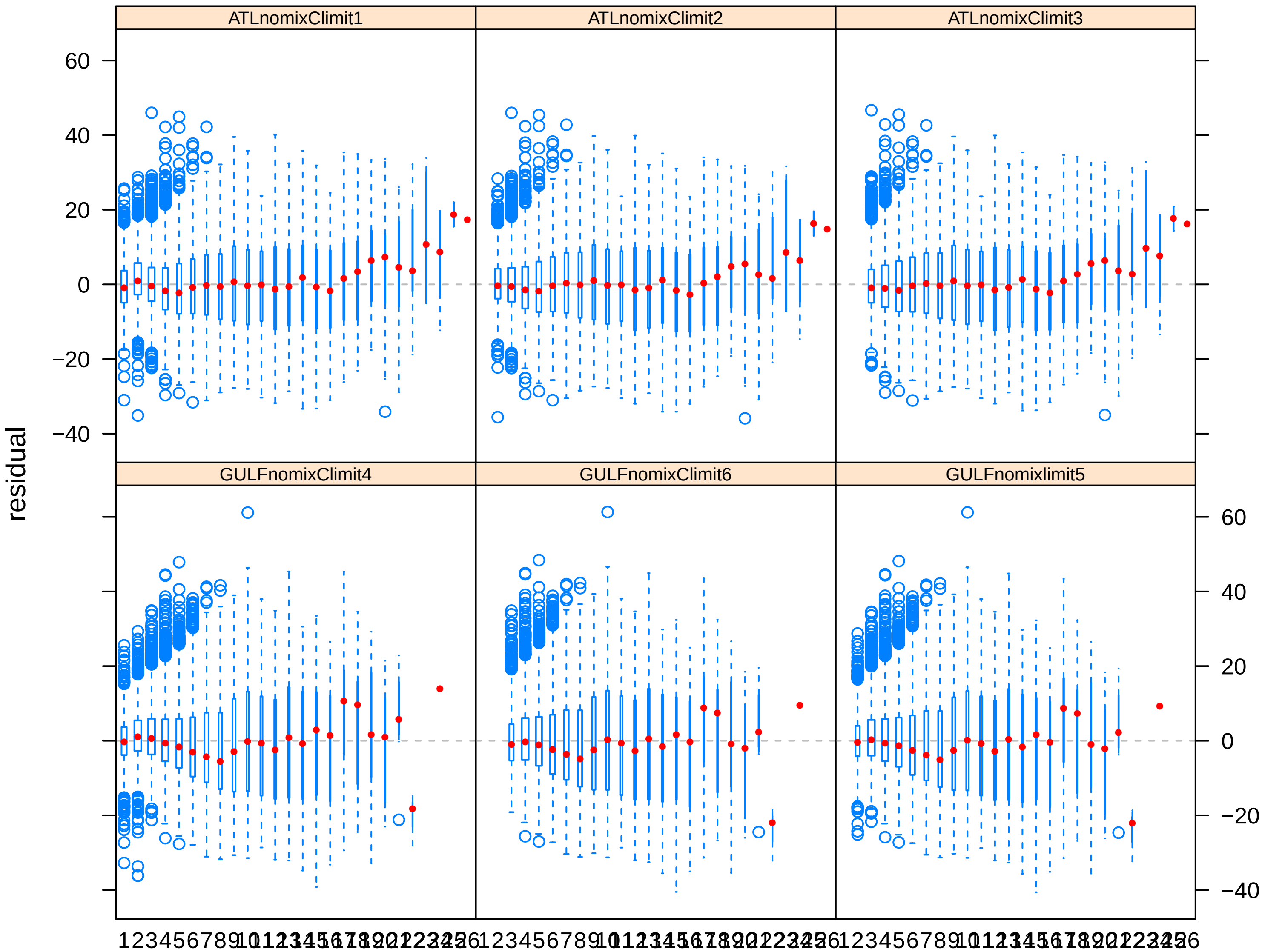


Figure A12. Residuals by age for king mackerel by stock, sex combined. See Figure 9 for description of boxplots.
South Atlantic trials 1: remove age 0 and 1; 2: removed age 0, 1, and 2; 3: removed age 0, 1, 2, and 3.
Gulf of Mexico trials 4: remove age 0 and 1; 5: removed age 0, 1, and 2; 6: removed age 0, 1, 2, and 3.

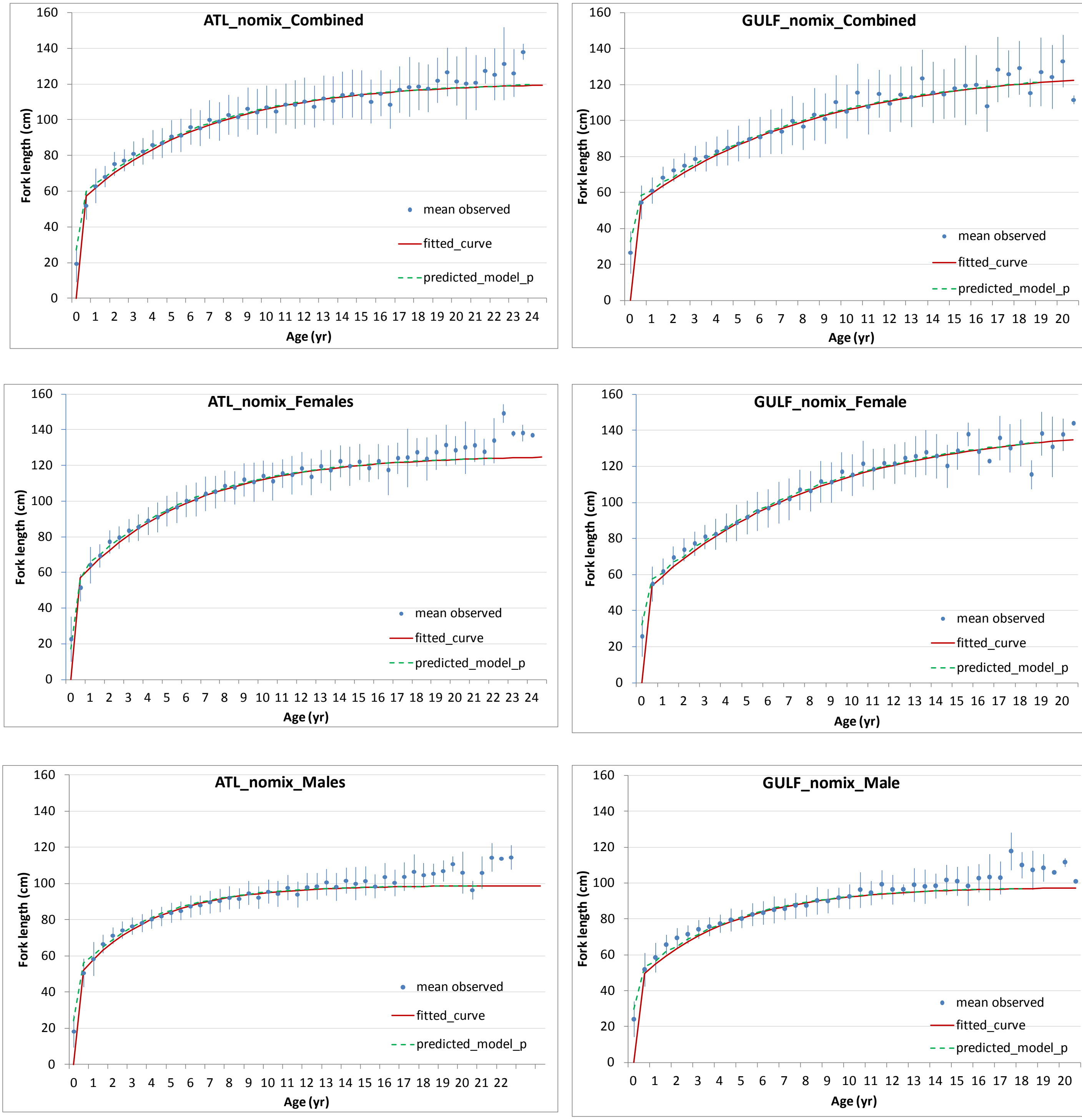


Figure A13. Revised king mackerel von Bertalanffy growth curves (red solid line – growth parameters fit to curve, green dashed line –model mean predicted value) and mean observed size-(± standard deviation) at-age for each data combination (by stock, and by sex) for all ages. The data was fit to the minimum-size corrected von Bertalanffy 2-phase growth model. Note the growth curves were constructed using fractional ages, therefore, the mean size-at-age data points are the average size per 0.5 yr.

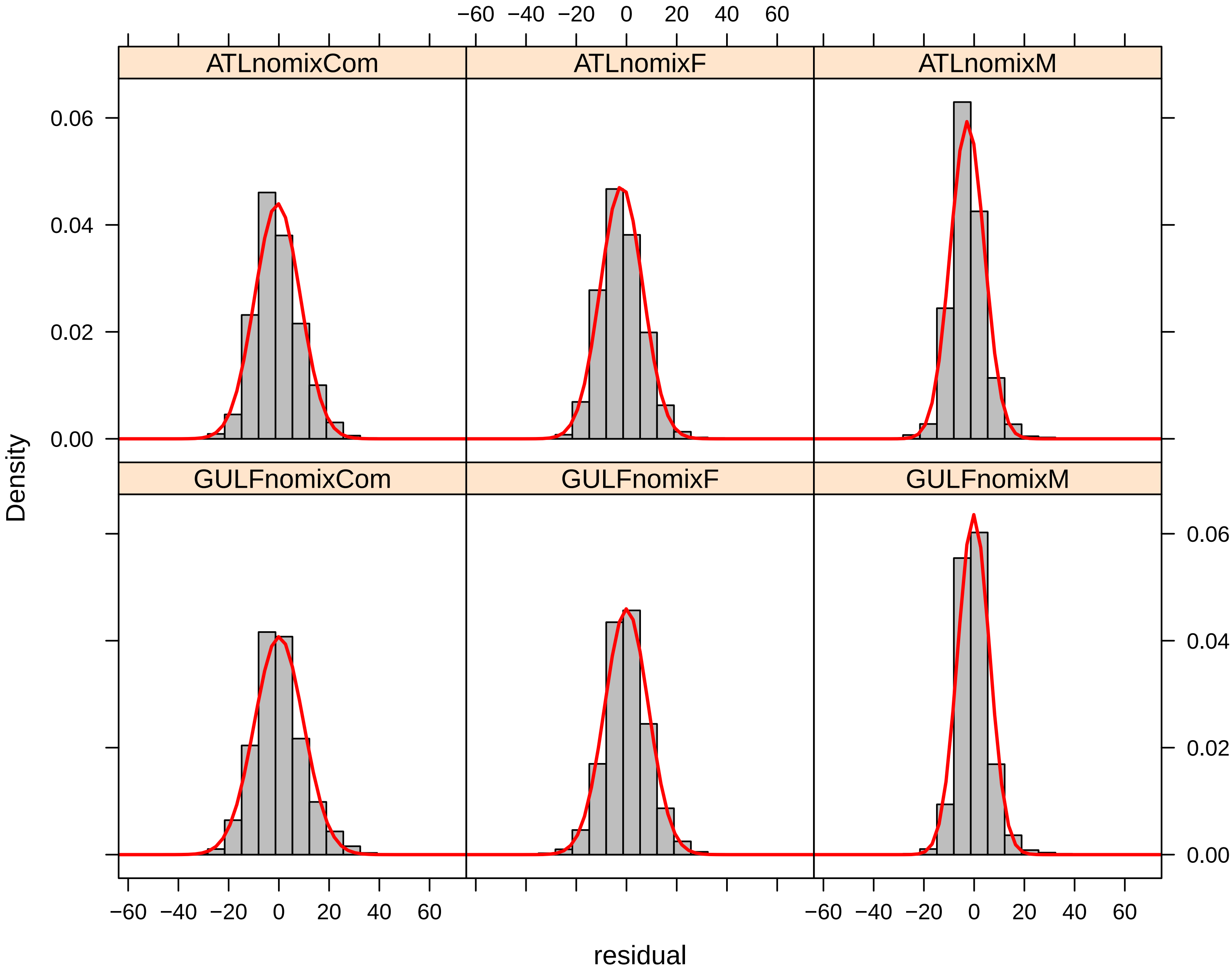


Figure A14. Distribution of residuals for each 2-phase king mackerel von Bertalanffy growth model by stock and by sex.

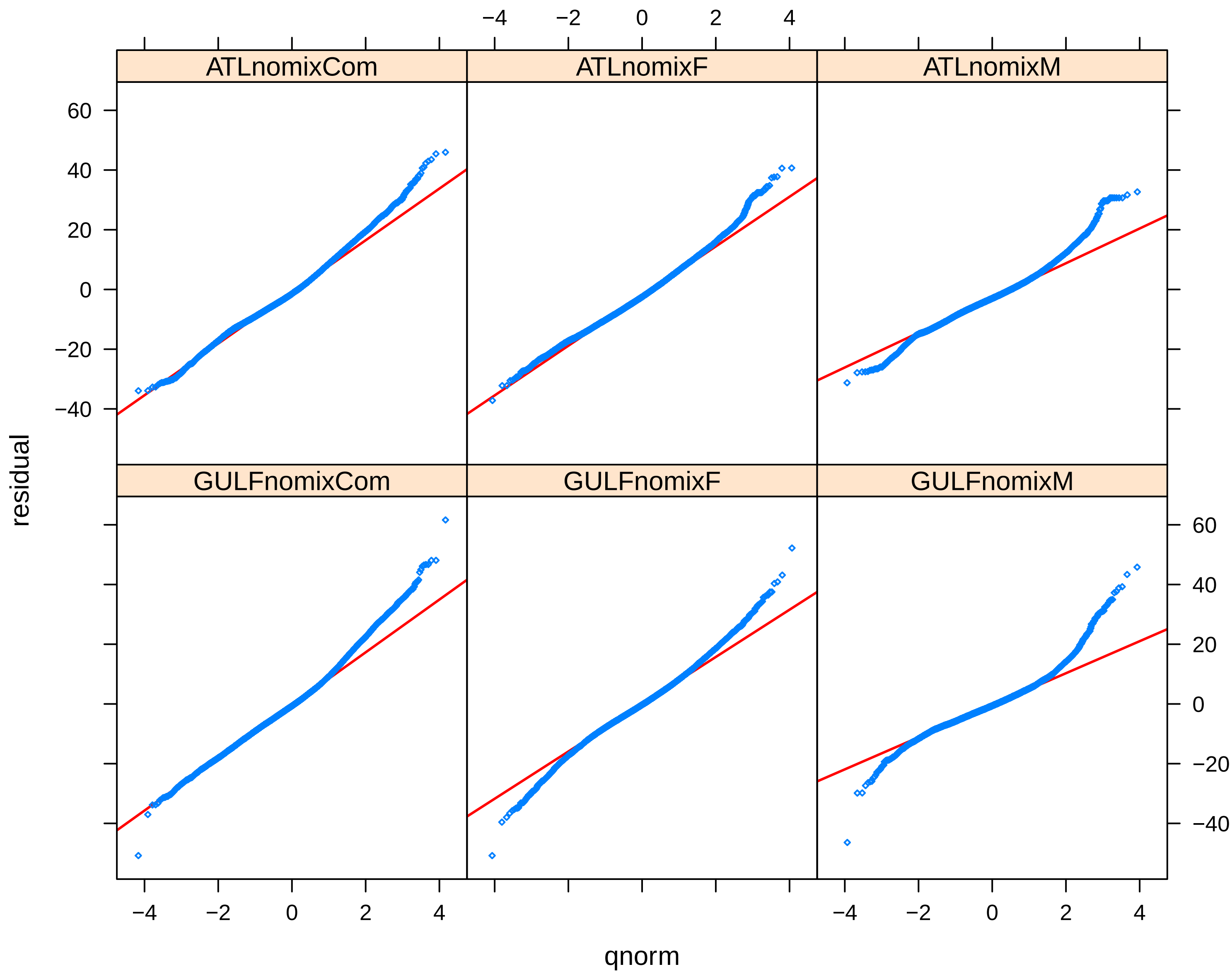


Figure A15. Normal probability plots (quantiles vs residuals) for each 2-phase king mackerel von Bertalanffy growth model by stock and by sex.

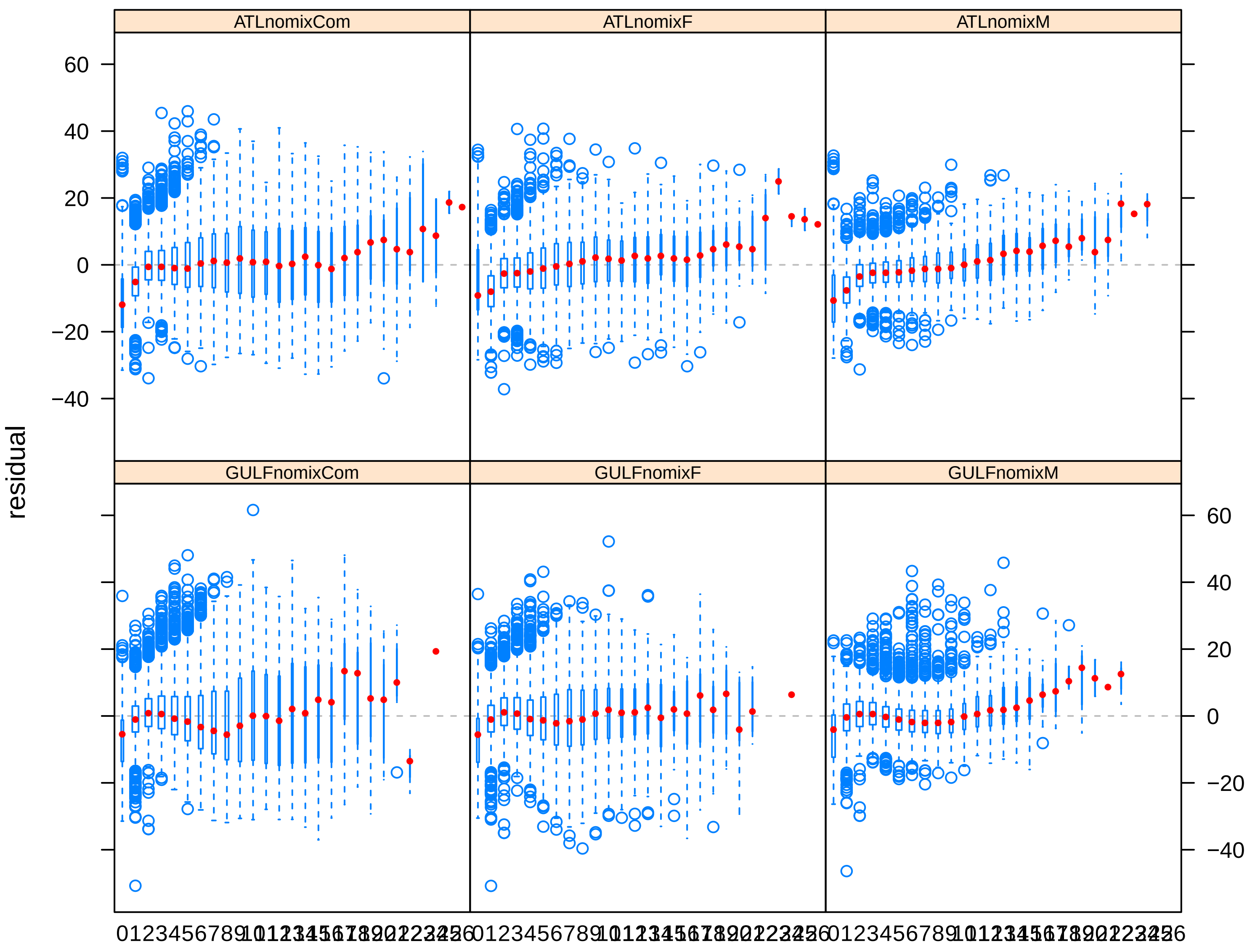


Figure A16. Residuals by age for king mackerel by stock and by sex for 2-phase von Bertalanffy growth models. See Figure 9 for description of boxplots.