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INTRODUCTION

Accurate age and growth information is crucial to stock assessment and previous studies have examined the age and growth of vermilion snapper from the Northern Gulf of Mexico using scales (Nelson 1988) and otoliths (Hood and Johnson 1999; Allman 2007; Johnson et al. 2010). The goal of this report is to characterize the age and length structure and growth of Gulf of Mexico vermilion snapper over the last 21 years (1994-2014) for the SEDAR 45 standard stock assessment. Vermilion snapper age data was supplied by National Marine Fisheries Service, Panama City laboratory (PCLAB), the Florida Fish and Wildlife Research Institute (FWRI) and the Gulf State Marine Fisheries Commission (GSMFC).

METHODS

Vermilion snapper were sampled from the northern Gulf of Mexico from 1994 to 2014. Samples were collected from recreational and commercial fisheries and from fishery independent surveys by state and federal programs. Fish were measured to the nearest mm fork length (FL), or converted to FL from total length (TL) with the equations: FL = Maximum TL * 0.8876 + 1.980 (r^2=0.9982; N=11,700); FL = Natural TL * 0.8828 + 8.6645 (r^2=0.9813; N=10,036) . A weight was recorded (g) and sex was determined macroscopically if the fish was landed whole. One or both sagittal otoliths were removed, cleaned with distilled water, dried and weighed to the nearest 0.0001 g. For later years, commercial handline collections were sub-sampled by selecting 500 otoliths each from the eastern (FL, AL, MS) and western (LA & TX) gulf. Samples were selected by shrimp grid in proportion to commercial handline landings for each grid.

Otoliths were prepared for age determination by making two transverse cuts through the otolith core to a thickness of 0.5 mm on either a low-speed or high speed saw depending on the ageing laboratory. Ages were assigned based on the count of annuli (opaque zones observed on the dorsal side of the sulcus acusticus in the transverse plane with reflected light at 40x, (including any partially completed opaque zones on the otolith margin) and the degree of marginal edge completion. Age was advanced by one year if a large translucent zone was visible on the margin and capture date was from 1 January to 30 June; after 30 June age was equal to opaque zone count (Jerald 1983; Vanderkooy and Guindon-Tisdel, 2003). Biological (fractional) ages were also estimated for use in fitting growth curves. Biological age accounts for the difference in time between peak spawning (defined as 1 July for vermilion snapper) and capture date (difference in days divided by 365). This fraction is added to annual age if capture date is after 1 July and subtracted if capture date is before 1 July (Vanderkooy and Guindon-Tisdel, 2003). For a description of estimates of reader precision see Thornton et al. (2015).

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 can predict growth using a choice of the variance structures in the size-at-age data: constant standard deviation with age, constant coefficient of variation with age, variance proportion to the mean, coefficient of variation increase linearly with age, coefficient of variation increase linearly with size-at-age. Multiple model compilations were examined using four difference variance structures in the size-at-age data. The model also uses a restrictive maximum likelihood estimation procedure with minimum size (commercial and recreational fishery same size limits:1990-1997, 8 inch TL, 182 mm FL; 1998-June 2005, 10 inch, 227 mm FL; July 2005-June 2007, 11 inch TL, 250 mm FL; July 2007-2014, 10 inch TL, 227 mm FL) as the left truncation limit for fisheries dependent observations. Fishery independent age and length data were used to aid the model to predict growth at smaller sizes not collected in routine fishery dependent sampling (given the minimum size limit).

This is the first time that the size-modified growth model has been applied to vermilion snapper; however this model has been applied to multiple species assessed in the southeastern United States (e.g., red snapper, king mackerel, red grouper, gag grouper, grey triggerfish). Since not all species have the same variance structure of variation of sizes-at-age, it is valuable to model growth with the variance structure most representative of the species. 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 ($L\infty$ = 500, 400, 300; k = 0.30, 0.20, 0.10; t0 =0.00), standard deviations (sigma = 50, 70), and coefficients of variation (CV = 10%, 20%, 30%). Model diagnostic plots such as predicted growth compared to observed data and the normalcy of residuals were examined.

RESULTS

Collection

A total of 47,343 vermilion snapper were aged. The gear type recorded most often was commercial handline followed by recreational handline (Table 1). Commercial longline samples accounted for about 2% of ages. A small number of spear, vertical longline, trap, cast net, kali pole and gear unknown were also recorded. The majority of vermilion snapper were sampled through the Trip Interview Program (TIP) and this was reflected in the large number of commercial samples collected annually (Table 2). Commercial samples annually accounted for 56% of otoliths aged followed by recreational (26%) and fishery-independent samples (18%). To date, the recreational fishery remains largely sampled by the Southeast Recreational Fisheries Information Network (RECFIN) through the Gulf States Marine Fisheries Commission (GSMFC). Otoliths collected from FL, TX and LA made up the majority of collections (61%, 17% and 15%, respectively), while AL and MS together contributed about 7% (Table 3).

<u>Size structure</u>

Size frequency distributions can provide some indication of the underlying age structure and differences were noted in the sizes of vermilion snapper by fishing mode. The commercial longline fishery was composed of the largest individuals, with a dominant size class in the 301-400 mm FL size range and mean size of 339 mm FL (Fig. 1). The commercial handline and recreational handline size distributions had modes in 251-300 mm FL size range and mean sizes of 322 and 302 mm FL respectively. The smallest individuals were collected by fishery independent trawl with a mode in the 151-200 size range and mean size of 172 mm FL. Fishery independent trap and handline had modes in the 201-250 mm FL size range and mean sizes of 246 and 269 mm FL respectively.

<u>Age Structure</u>

A comparison of age distributions by fishing mode indicated differences by fishing mode and by sampling year. Vermilion snapper ranged in age from young-of -the-year (<1 year) to 26 years. The commercial longline selected the oldest individuals with fish first fully recruited to the fishery by age 7 with a mean age of 7.9 years and 26% of individuals 10 years or older (Fig. 2). The recreational fishery selected younger fish with fish first entering the fishery at 3 years with 64% of individuals ages 3 to 5 (mean 4.6 years) and only 2% of fish 10 years or older. The commercial handline recruited to the fishery by age 4 with a mean age of 5.3 years and 7.3% of fish 10 years or greater. Vermilion snapper recruited to the fishery independent trawl gear by age 1 with a mean age of 2.5 years and most fish (59%) 1 or 2 years old. Fishery independent trap and handline age distributions were similar, with fish recruiting to both gears by age 3 and mean ages of 5.2 and 5 respectively.

Age frequency distributions by sampling year revealed changes in the age at recruitment, as well as the potential influence of strong year classes. The annual recruitment pattern of vermilion snapper from the commercial and recreational handline fishery indicated recruitment occurred by ages 3-5 for most years (Fig. 3). There was evidence of potentially strong year classes in 1996, 1999 and 2006. Generally, the influence of these strong year classes can be followed for 2 to 3 consecutive years.

Growth

Vermilion snapper data (observed fork lengths and fractional ages) from the entire time series (1994-2014; n = 47,197) were fit to a size-modified von Bertalanffy growth model to obtain population growth parameters (Table 4). A small sub-set of records were not used in the model fits due to unknown fishing mode or no known fork length (n=146). Since this model takes in the affect of the minimum size limit, those fishery dependent records less than the corresponding minimum size limit (n = 649) were not used in model fitting. This model also takes into consideration the variance structure of the observed size-at-age data. Vermilion snapper showed a unique variation in length among all ages (Figure 4a), which did not correspond to a standard pattern of coefficient of variation size-at-age (Figure 4b).

Multiple variance structures were modeled with the size-modified von Bertalanffy growth model, in attempt to match the observed variance in size-at-age data. The predicted growth parameters for the four variance structures were very similar, as well as with the models' objective functions and Akaike Information Critierias (AIC) (Table 5). The preferred model fit was based on the smallest AICc and delta AICc values that corresponded to the constant coefficient variation at age variance structure and resulted in the following growth parameters: L_{∞} = 334 mm, k = 0.3254, to = -0.7953 (Figure 5, Tables 4, 5). The size-modified von Bertalanffy growth model predicted smaller similar sizes compared to observed lengths for most ages (Figure 5a, 5b). This model corrects for the biased observations due to the minimum size limits and sample truncation at the younger ages. Model diagnostic plots showed similar residual patterns for each variance structure: normally distributed residuals, reasonable distribution of residuals by age, and probability plots showed divergence (Figure 6, 7, 8).

Region specific vermilion snapper data (observed fork lengths and fractional ages) from the entire time series (1994-2014; n = 47,197) were fit to a size-modified von Bertalanffy growth model with a constant coefficient of variation to obtain region specific growth parameters (Table 6). Region was assigned based on either the NMFS Statistical Shrimp Grid (East, 1-12; West, 13-21) or state landed (East- FL, AL, MS; West- LA, TX). Region specific data showed similar patterns of variation in size-at-age data, especially at ages 0 – 2 yrs, but less variation, more constant variation in size-at-age data for vermilion snapper west of the Mississippi River for ages 3-17 yrs (Figure 9b). Vermilion snapper in the west were predicted to grow faster (East, 0.33; West, 0.38) and obtain a larger asymptotic length (East, 333 mm FL; West, 359 mm FL) (Figure 10, Table 6). Region specific size-modified von Bertalanffy growth models, fit the observed data fairly better than the model fit with all the data (Figure 10, Table 7). Model diagnostic plots showed similar residual patterns for each region: normally distributed residuals, reasonable distribution of residuals by age, and probability plots showed less divergence for data from the east (Figure 11, 12, 13).

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Table 1. Number of vermilion snapper otoliths collected by mode (CM-commercial, REC-recreational (includes charter boat, headboat and private vessels), FI-fishery independent) and by gear (CN-cast net, HL-handline, LL-longline, SP-spear, VLL-vertical longline, KP-kali pole, TR-trap, TRW-trawl, UNK-unknown), and by state landed (1994-2014).

Mode & Gear	AL	FL	LA	MS	TX	Total	Percent
CM-CN		1				1	0.00
CM-HL	1484	13646	6209	325	3549	25213	53.26
CM-LL		588	26		302	916	1.93
CM-SP		55				55	0.12
CM-TR		2				2	0.00
CM-VLL		17				17	0.04
CM-UNK		1	305			306	0.65
REC-HL	1647	6599	283	35	3552	12116	25.59
REC-SP							0.00
FI-TR	4	1955	45	1	52	2057	4.34
FI-TRW	23	2640	137	7	421	3228	6.82
FI-HL	27	2973	114	3	86	3203	6.77
FI-LL		36	1			37	0.08
FI-SP		2				2	0.00
FI-VLL	6	129	3			138	0.29
FI-KP		2				2	0.00
Other	1	33	16			50	0.11
Total	3192	28679	7139	371	7962	47343	

Table 2. Number of vermilion snapper otoliths by sampling source (TIP- Trip interview program, RECFIN-Gulf States Marine Fisheries Commission, Fisheries Information Network, HB-Southeast Regional Headboat Survey, MRFSS- Marine Recreational Fisheries Statistical Survey; fishery independent: PCLAB-NMFS Panama City, FL, MSLAB-NMFS Pascagoula, MS, FWRI-Florida Fish and Wildlife Research Institute; Other: Cooperative Research Program, Expanded Stock Assessment, Gulf Headboat Cooperative IFQ, Galveston Observer Program, Shark Bottom Longline Observer Program, US Geological Survey and University of Texas, Marine Science Institute).

Year	TIP	RECFIN	HB	MRFSS	PCLAB	FWRI	MSLAB	Other	Total
1994	49								49
1995	90								90
1996	137		128					2	267
1997	2		40					4	46
1998	138		12	2	1				153
1999	42		5	199	26		5	1	278
2000	258		114		558		5		935
2001	1353		35	9	441		22	273	2133
2002	1320	7	8	14	241	10	45	147	1792
2003	2712		35	41	63			3	2854
2004	1144	67	15	12	12			75	1325
2005	1524	84	59	24	426	10	143	36	2306
2006	1674	117	43		208	52	59	238	2391
2007	1817	592	68	2	95	43	128	1	2746
2008	2051	1112	110	2	79	235	158		3747
2009	2110	1235	196	10	112	660	205	38	4566
2010	1795	949	224		190	584	62	37	3841
2011	3728	1109	356	6	104	532	58	513	6406
2012	1266	1152	848		111	562	290	152	4381
2013	1041	934	828		37	814	93	12	3759
2014	1040	446	676		343	683	82	8	3278
Total	25291	7804	3800	321	3047	4185	1355	1540	47343
Percent	53.42	16.48	8.03	0.68	6.44	8.84	2.86	3.25	

Table 3. Number of vermilion snapper otoliths by year and state landed

Year	AL	FL	LA	MS	TX	Total
1994		34	15			49
1995		22	68			90
1996		196	61		10	267
1997		46				46
1998		19		134		153
1999	155	93		30		278
2000	12	815	81	4	23	935
2001	41	1886	115	67	24	2133
2002	4	1663	72	53		1792
2003	19	2233	441	41	120	2854
2004		776	388		161	1325
2005	116	1271	461	2	456	2306
2006	217	1301	551	18	304	2391
2007	176	922	715	5	928	2746
2008	328	1508	892		1019	3747
2009	529	2500	846		691	4566
2010	146	2326	685		684	3841
2011	329	4639	751		687	6406
2012	390	2304	332	4	1351	4381
2013	322	2115	346	9	967	3759
2014	408	2010	319	4	537	3278
Total	3192	28679	7139	371	7962	47343
Percent	6.74	60.58	15.08	0.78	16.82	

Table 4. Growth curve parameters ± standard deviation (L_∞ - asymptotic length, k – growth coefficient, t_0 – size at time zero, sigma – standard deviation for models, CV – coefficient of variation) for vermilion snapper from the northern Gulf of Mexico for fractional ages and observed fork lengths at capture (1994-2014) and previous von Bertalanffy growth parameters. *Recommended growth model to use.

Model	n	L_∞	k	t_0	Sigma	CV
Constant CV*	46548	344 ± 1.28 (FL)	$0.3254 \pm 4.4 \times 10^{-3}$	$-0.7953 \pm 2.1 \times 10^{-2}$		$0.2535 \pm 1.4 \times 10^{-3}$
Constant std dev	46548	369 ± 1.77 (FL)	$0.2802 \pm 5.7 \times 10^{-3}$	$-0.6799 \pm 4.6 \times 10^{-2}$	68.32 ± 0.30	
Increase CV w/Age	46548	360 ± 2.03 (FL)	$0.2817 \pm 5.4 \times 10^{-3}$	$-0.9102 \pm 2.8 \times 10^{-2}$		$0.2798 \pm 2.9 \times 10^{-3}$ $0.1720 \pm 6.6 \times 10^{-3}$
Increase CV w/ Size-at-Age	46548	360 ± 1.62 (FL)	$0.2922 \pm 4.3 \times 10^{-3}$	$-0.8025 \pm 2.2 \times 10^{-2}$		$0.3350 \pm 4.9 \times 10^{-3}$ $0.2158 \pm 2.3 \times 10^{-3}$
Standard VB	47197	351 ± 7.5 (FL)	$0.4100 \pm 5.4 \times 10^{-3}$	$-0.6721 \pm 2.9 \times 10^{-2}$		
SEDAR9 & update	7980	426 (TL), 380 ([1]FL)	0.20	-3.9		

[1] Fork length predicted from total length, using FL = 1.98 + TL * 0.8876

Table 5. The resulting model objective functions (negative log likelihood), the change in the objective function, and resulting Akaike Information Criteria for each phase of the model for the size-modified von Bertalanffy growth model using four types of variance structures (std dev – standard deviation, CV – coefficient of variation) and a standard von Bertalanffy growth model with no effect of size limit included. *Recommended growth model to use.

Variance Structure	Phase	# parameters	Objective Function (nLL)	Change Obj. function	AIC	AICc	Delta AICc
Constant CV*	1	3	$2.47 \times 10^{+05}$		$4.95 \times 10^{+05}$	$4.95 \times 10^{+05}$	
	2	3	$2.47 \times 10^{+05}$		$4.95 \times 10^{+05}$	$4.95 \times 10^{+05}$	-3.49×10^{-10}
	3	4	$2.47 \times 10^{+05}$	$-3.69 \times 10^{+02}$	$4.94 \times 10^{+05}$	$4.94 \times 10^{+05}$	$-7.36 \times 10^{+02}$
Constant std dev	1	3	$2.50 \times 10^{+06}$		$5.01 \times 10^{+05}$	$5.01 \times 10^{+05}$	
	2	3	$2.50 \times 10^{+06}$		$5.01 \times 10^{+05}$	$5.01 \times 10^{+05}$	-4.07×10^{-10}
	3	4	$2.47 \times 10^{+05}$	$-3.29 \times 10^{+03}$	$4.94 \times 10^{+05}$	$4.94 \times 10^{+05}$	$-6.58 \times 10^{+03}$
Increase CV w/ Age	1	3	$2.85 \times 10^{+05}$		$5.70 \times 10^{+05}$	$5.70 \times 10^{+05}$	
	2	4	$2.47 \times 10^{+05}$	$-3.80 \times 10^{+04}$	$4.94 \times 10^{+05}$	$4.94 \times 10^{+05}$	-7.59×10^{-04}
	3	5	$2.47 \times 10^{+05}$	$-8.35 \times 10^{+01}$	$4.94 \times 10^{+05}$	$4.94 \times 10^{+05}$	$-1.65 \times 10^{+02}$
Increase CV w/ Size-at-Age	1	3	$2.48 \times 10^{+05}$		$4.97 \times 10^{+05}$	$4.97 \times 10^{+05}$	
	2	4	$2.47 \times 10^{+05}$	$-9.91 \times 10^{+02}$	$4.94 \times 10^{+05}$	$4.94 \times 10^{+05}$	-1.98×10^{-03}
	3	5	$2.47 \times 10^{+05}$	$-5.07 \times 10^{+02}$	$4.94 \times 10^{+05}$	$4.94 \times 10^{+05}$	$-1.01 \times 10^{+03}$
Standard VB	1	3	$2.60 \times 10^{+05}$		$5.19 \times 10^{+05}$	$5.19 \times 10^{+05}$	

Table 6. Region specific growth curve parameters ± standard deviations (L_∞ - asymptotic length, k – growth coefficient, t_0 – size at time zero, CV – coefficient of variation) for vermilion snapper from the northern Gulf of Mexico for fractional ages and observed fork lengths at capture (1994-2014). Size-modified growth model was completed using a constant coefficient of variation at age. Region was assigned to the data based either on the NMFS Statistical Shrimp Grid (East, 1-12; West, 13-21) or State landed (East-FL, AL, MS; West-LA, TX).

Region	n	L_∞	k	t_0	CV
East	31468	333 ± 1.67 (FL)	$0.3275 \pm 6.0 \times 10^{-3}$	$-0.8320 \pm 3.0 \times 10^{-2}$	$0.2618 \pm 1.7 \times 10^{-3}$
West	15080	359 ± 1.53 (FL)	$0.3809 \pm 6.7 \times 10^{-3}$	$-0.6184 \pm 2.3 \times 10^{-2}$	$0.2097 \pm 2.1 \times 10^{-3}$

Table 7. The resulting region specific model objective functions (negative log likelihood), the change in the objective function, and resulting Akaike Information Criteria for each phase of the model for the size-modified von Bertalanffy growth model using constant coefficient of variation at age.

Region	Phase	# parameters	Objective Function (nLL)	Change Obj. function	AIC	AICc	Delta AICc
East	1	3	$1.67 \times 10^{+05}$		$3.34 \times 10^{+05}$	$3.34 \times 10^{+05}$	
	2	3	$1.67 \times 10^{+05}$		$3.34 \times 10^{+05}$	$3.34 \times 10^{+05}$	0.00
	3	4	$1.66 \times 10^{+05}$	$-1.08 \times 10^{+02}$	$3.32 \times 10^{+05}$	$3.32 \times 10^{+05}$	$-2.15 \times 10^{+03}$
West	1	3	$8.08 \times 10^{+04}$		$1.62 \times 10^{+05}$	$1.62 \times 10^{+05}$	
	2	3	$8.08 \times 10^{+04}$		$1.62 \times 10^{+05}$	$1.62 \times 10^{+05}$	-8.44×10^{-10}
	3	4	$8.04 \times 10^{+04}$	$-4.29 \times 10^{+02}$	$1.61 \times 10^{+05}$	$1.61 \times 10^{+05}$	$-8.55 \times 10^{+02}$

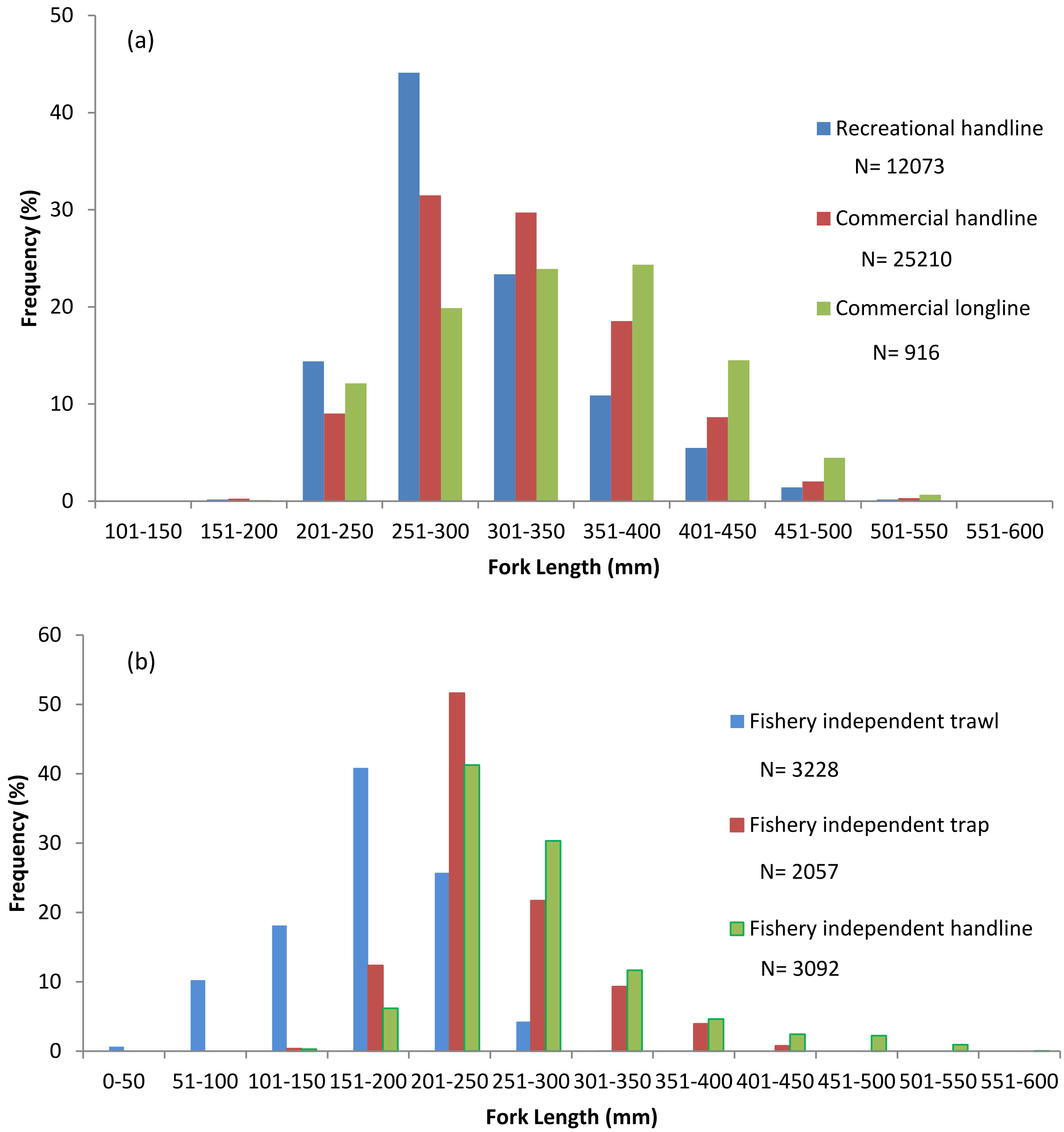


Figure 1. Gulf of Mexico vermilion snapper length frequency distributions for (a) fishery dependent and (b) fishery independent fish for all years combined (1994-2014).

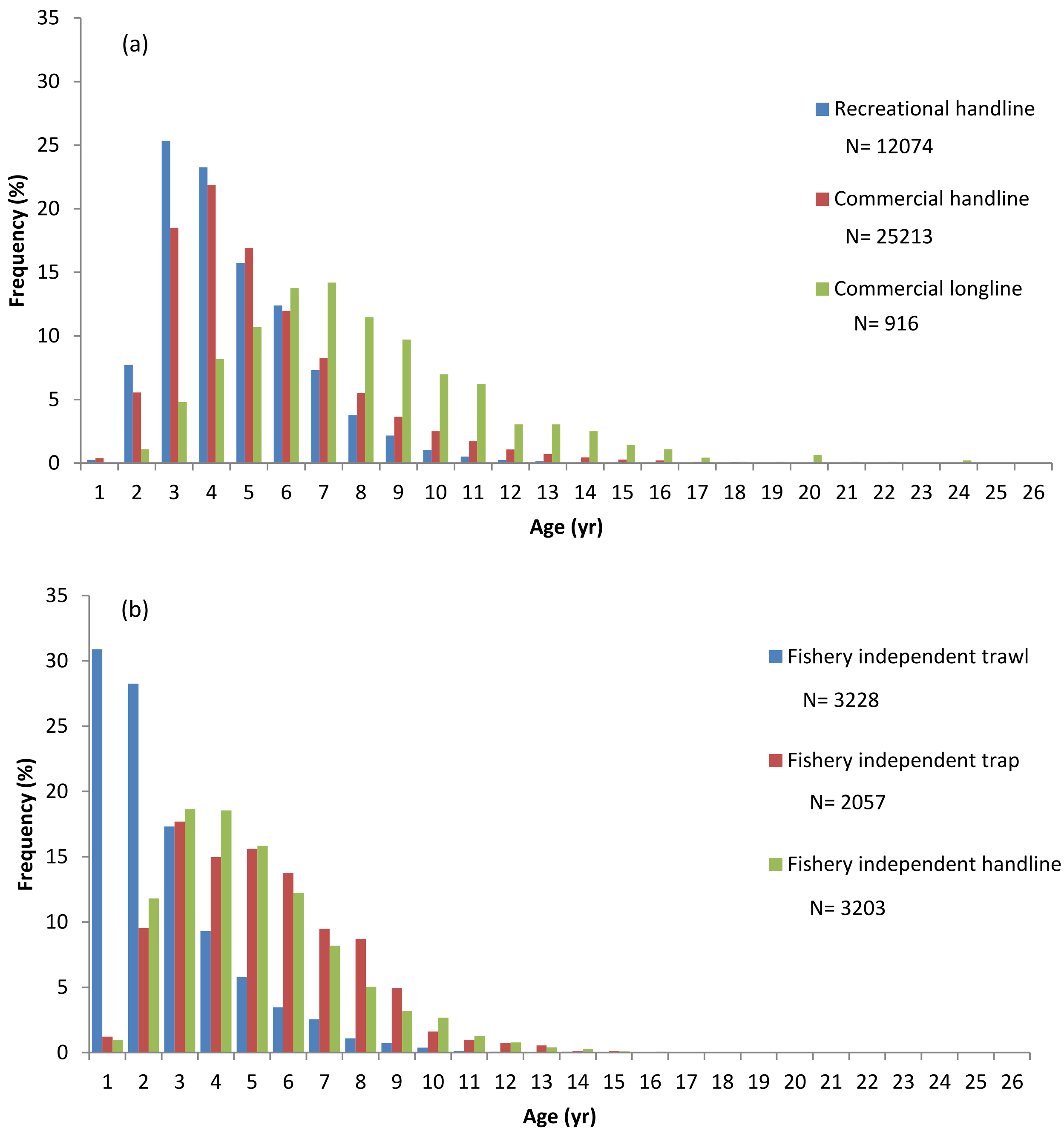


Figure 2. Gulf of Mexico vermilion snapper age frequency distributions for (a) fishery dependent and (b) fishery independent fish for all years combined (1994-2014).

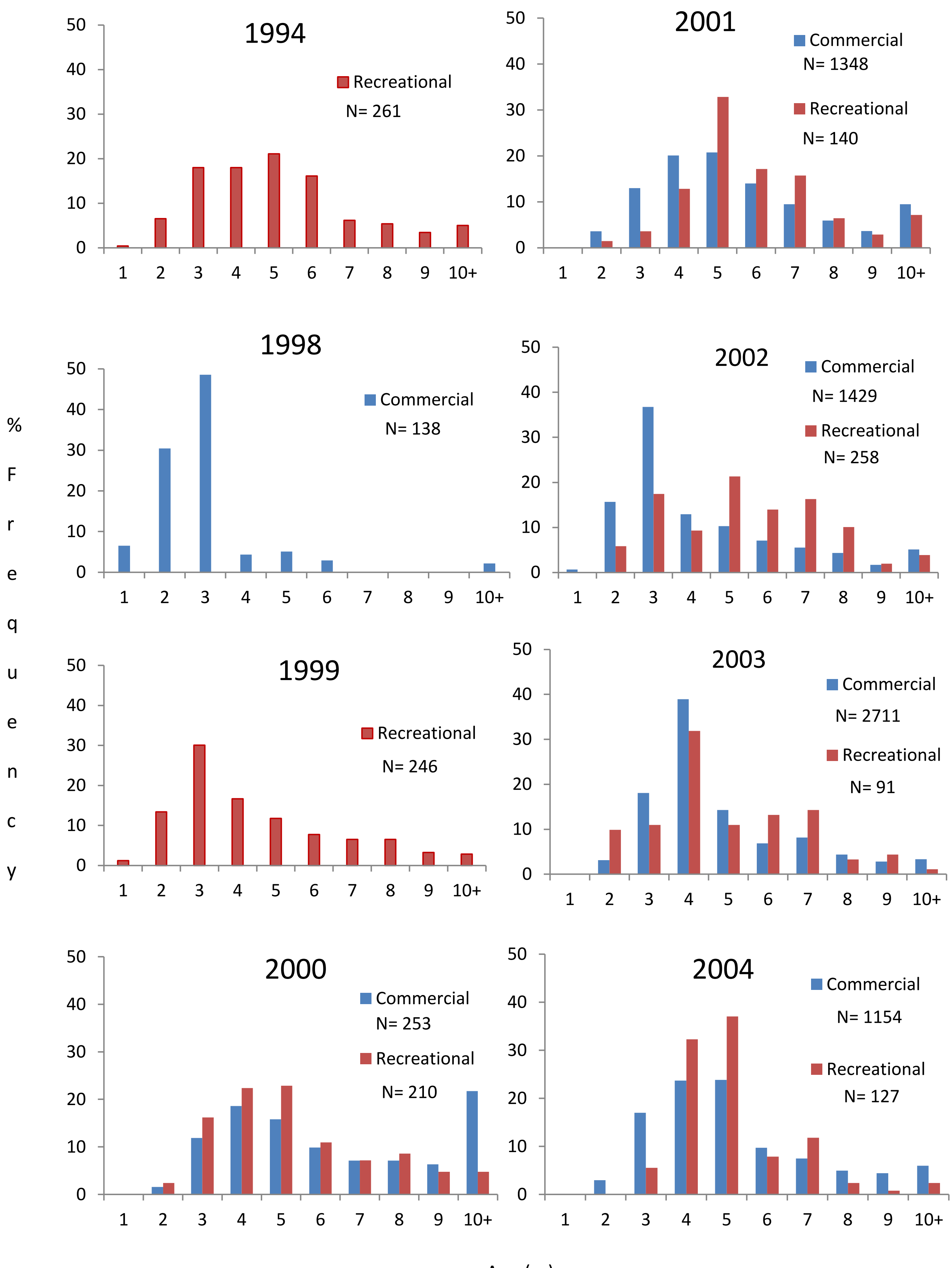


Figure 3. Gulf of Mexico vermilion snapper age frequency distributions by year. Only years with at least 50 observations were included.

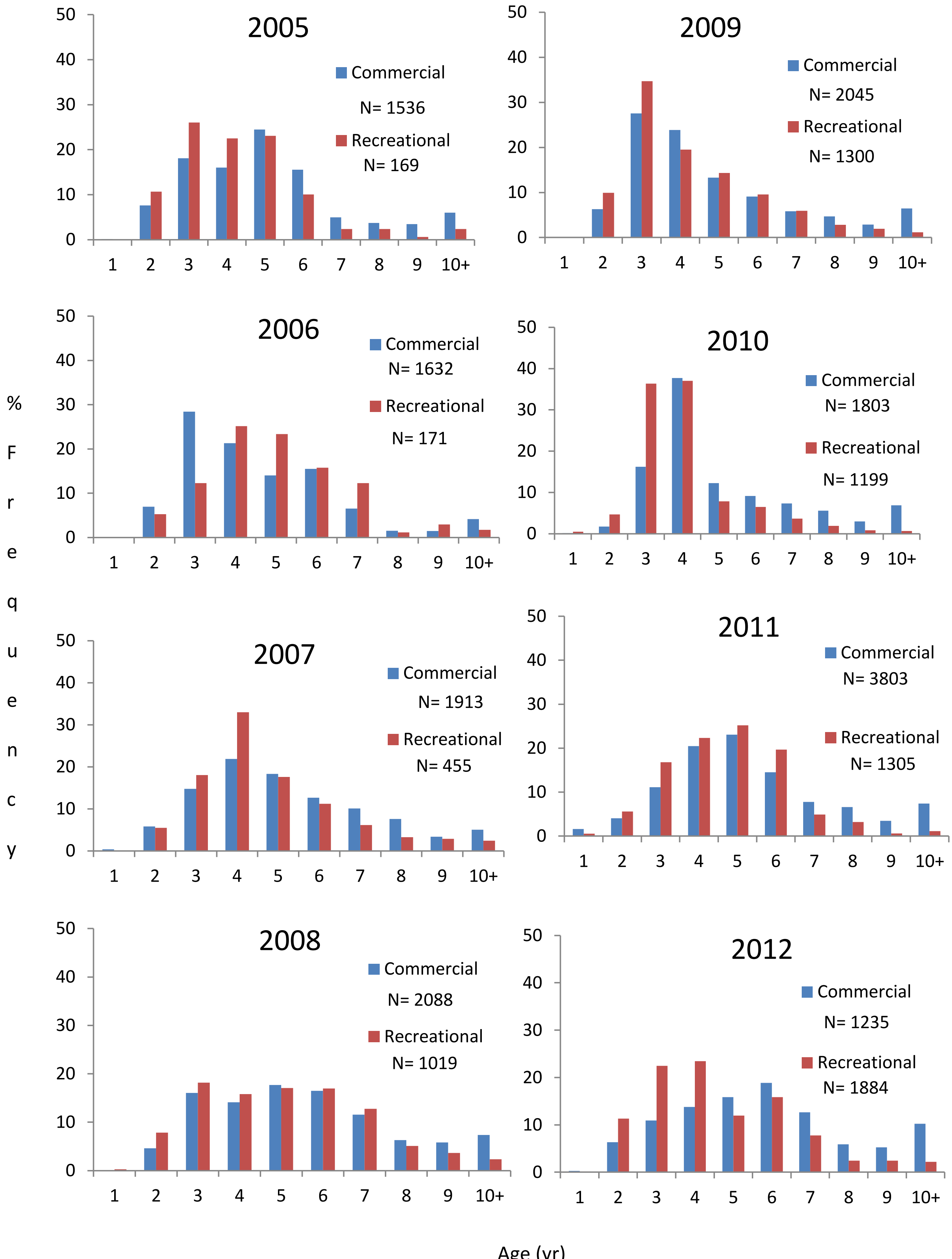
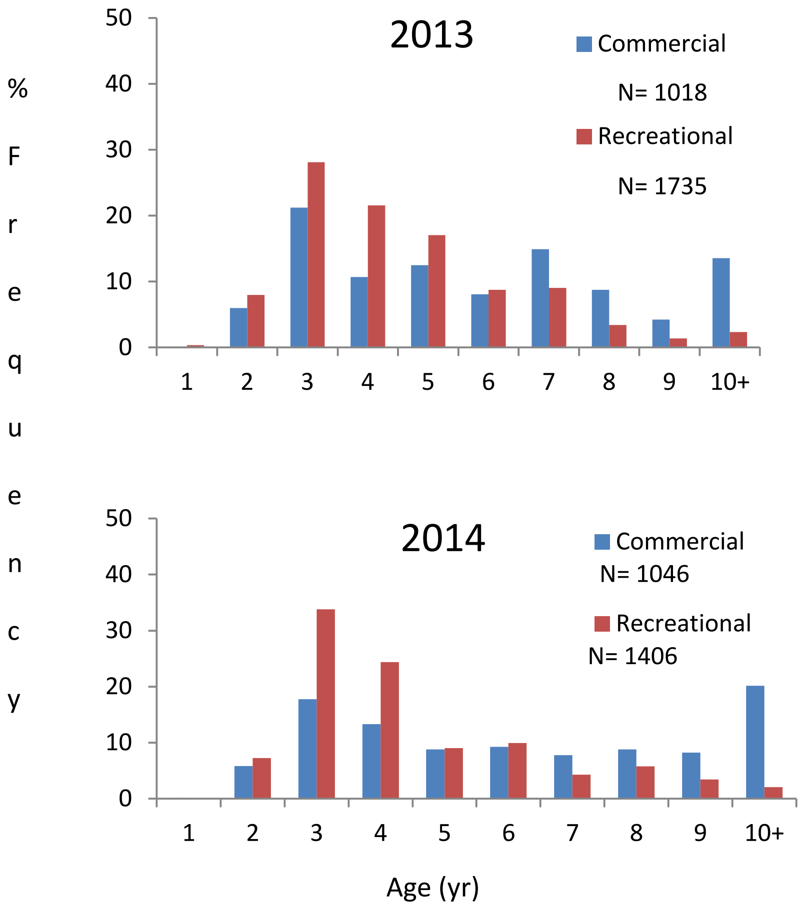


Figure 3. Continued



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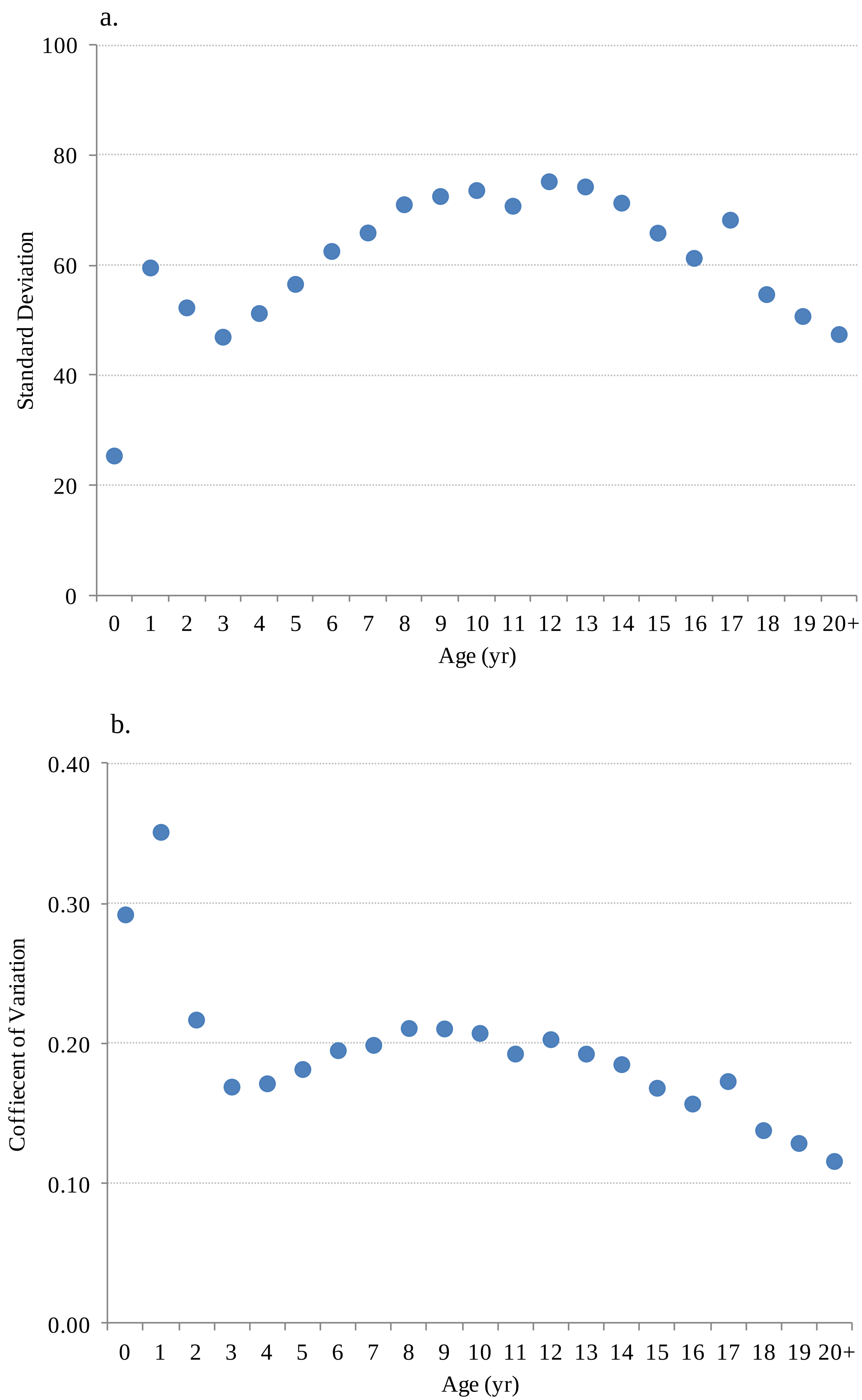

Figure 4. Variance structure for observed size-at-age data for vermilion snapper from the northern Gulf of Mexico (1994-2014) (a) standard deviation and (b) coefficient of variation at length for each age.

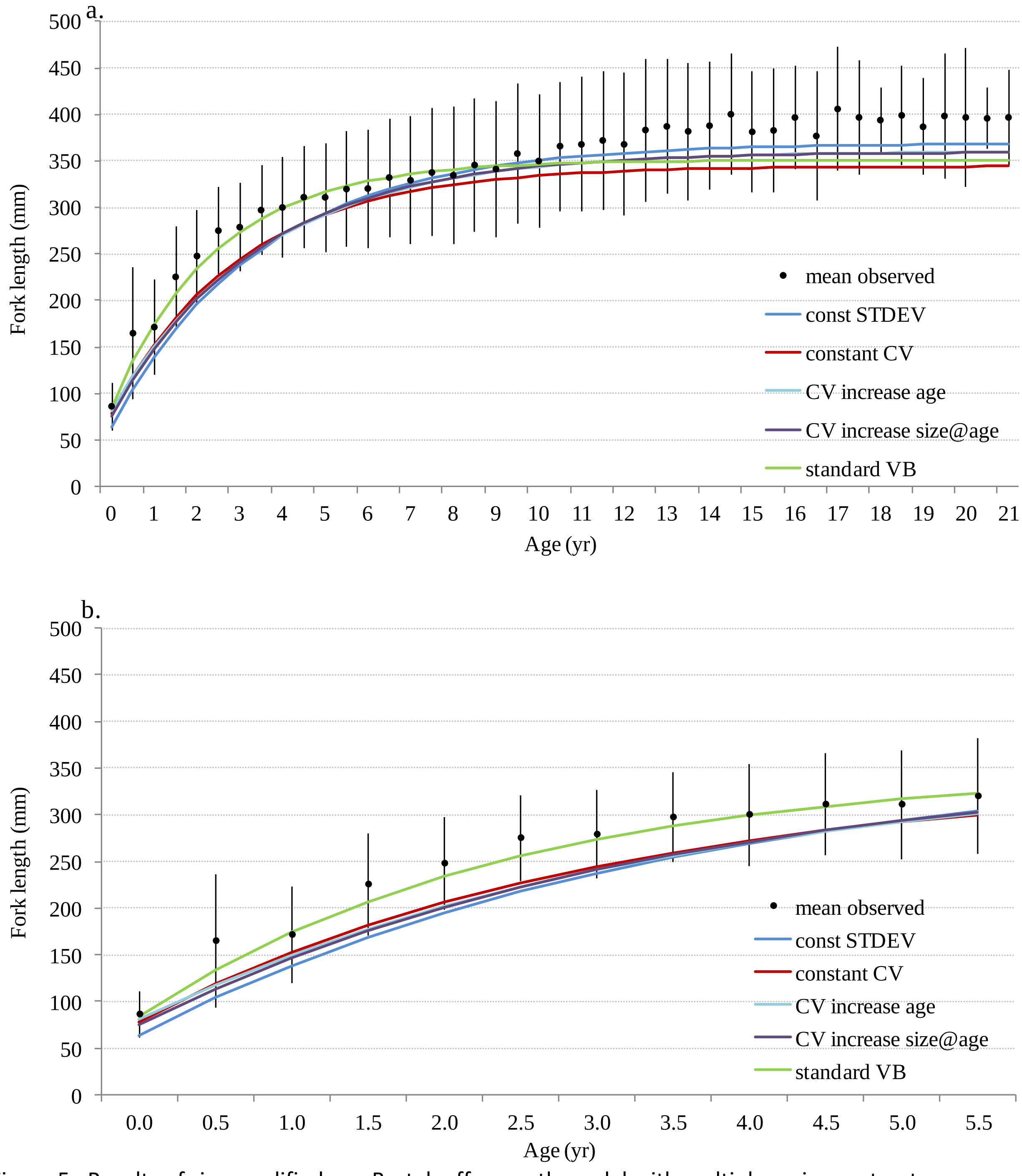

Figure 5. Results of size-modified von Bertalanffy growth model with multiple variance structures (constant standard deviation (STDEV), constant coefficient of variation (CV) with age, increase in CV with age, increase in CV with size-at-age), and a standard von Bertalanffy (VB) growth model for vermilion snapper from northern Gulf of Mexico (1994-2014) for (a) mean fractional ages 0-20 and for (b) mean fractional ages 0-5 ± std dev. Observed mean size-at-age ± standard deviations (black circles), estimated size-at-age (blue line - constant STDEV, red line - constant CV, light blue line - CV increase with age, purple - CV increase with size-at-age, green line - standard VB).

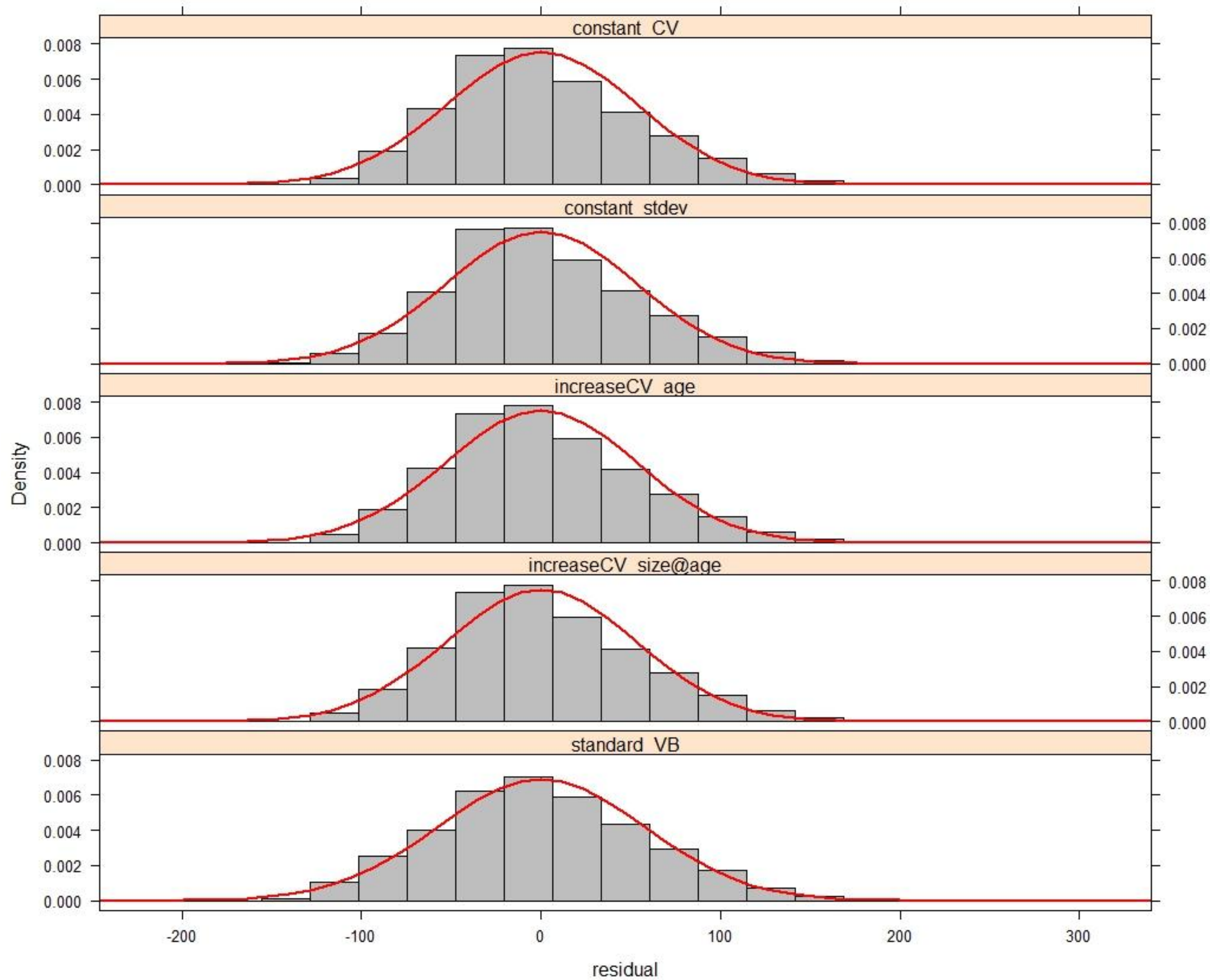

Figure 6. Distribution of residuals for each type of variance structure for vermilion snapper size-modified von Bertalanffy growth models and a standard von Bertalanffy growth model.

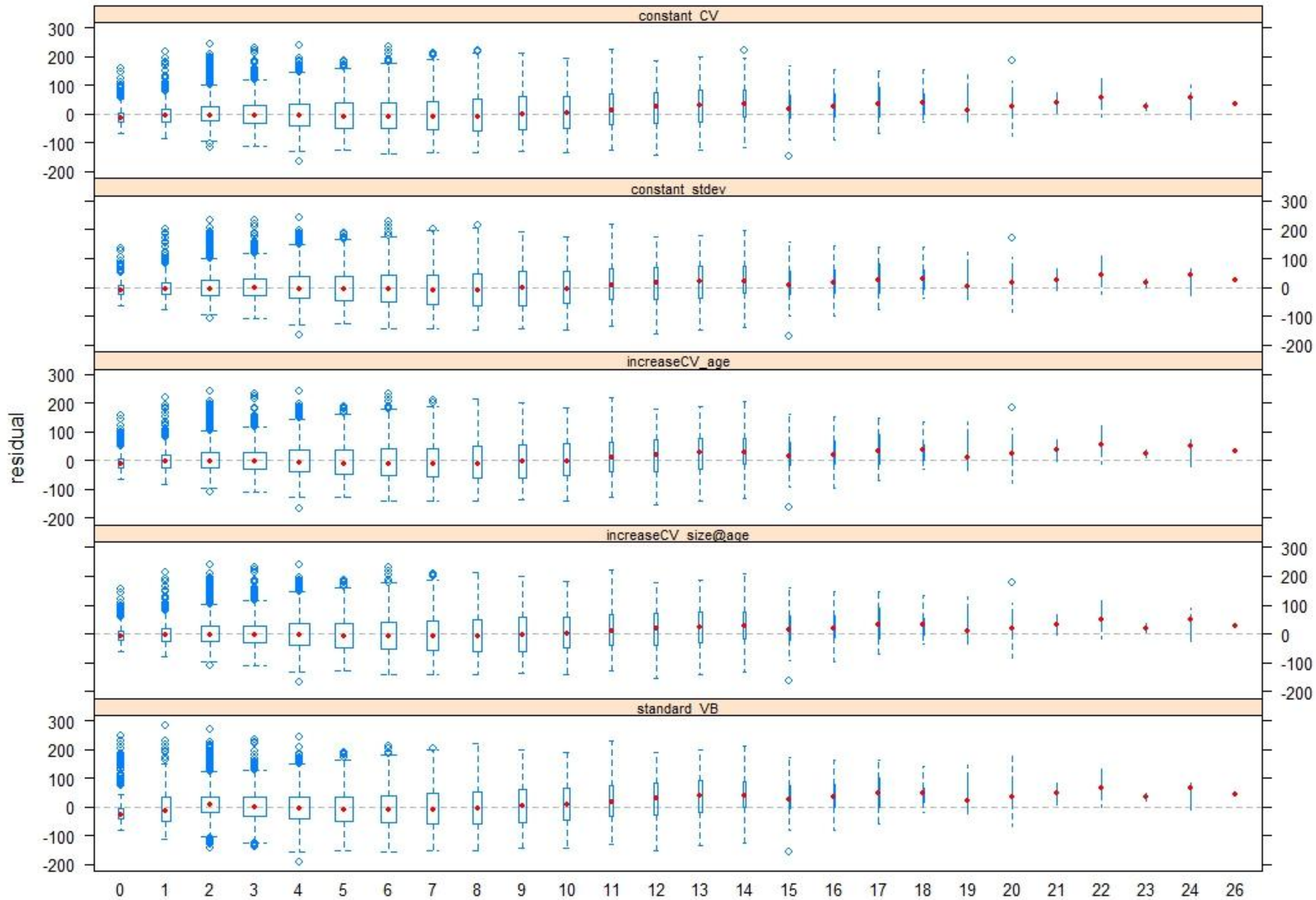

Figure 7. Residuals by age for each type of variance structure for vermilion snapper von Bertalanffy growth models and a standard von Bertalanffy growth model. Boxplots include the median, upper and lower quartiles (boxes: drawn in proportion to the square root of the sample size by age, upper and lower range (dashed line), and outliers (open circles).

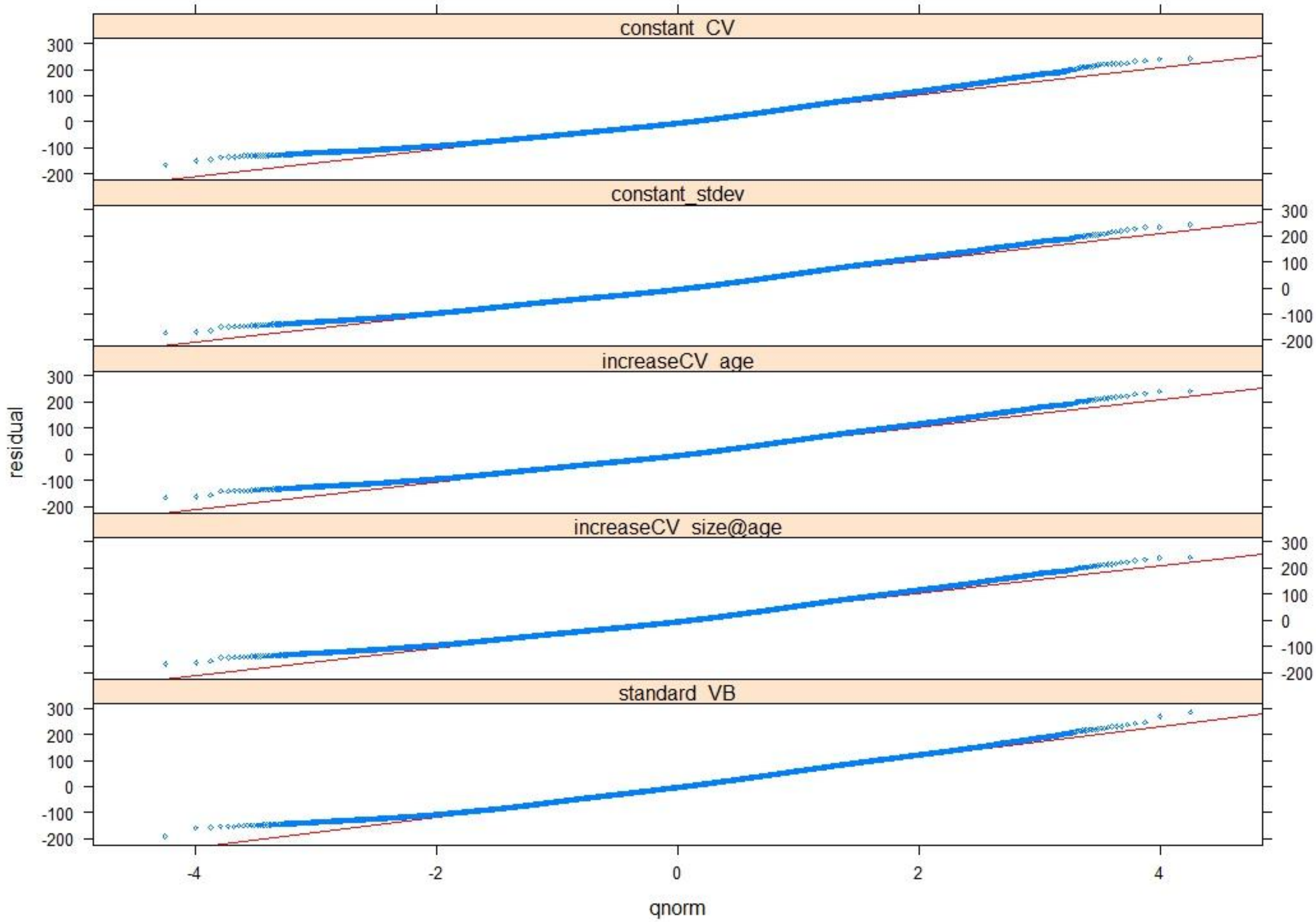

Figure 8. Normal probability plots (quantiles vs residuals) for each type variance structure for vermilion snapper von Bertalanffy growth models and a standard von Bertalanffy growth model.

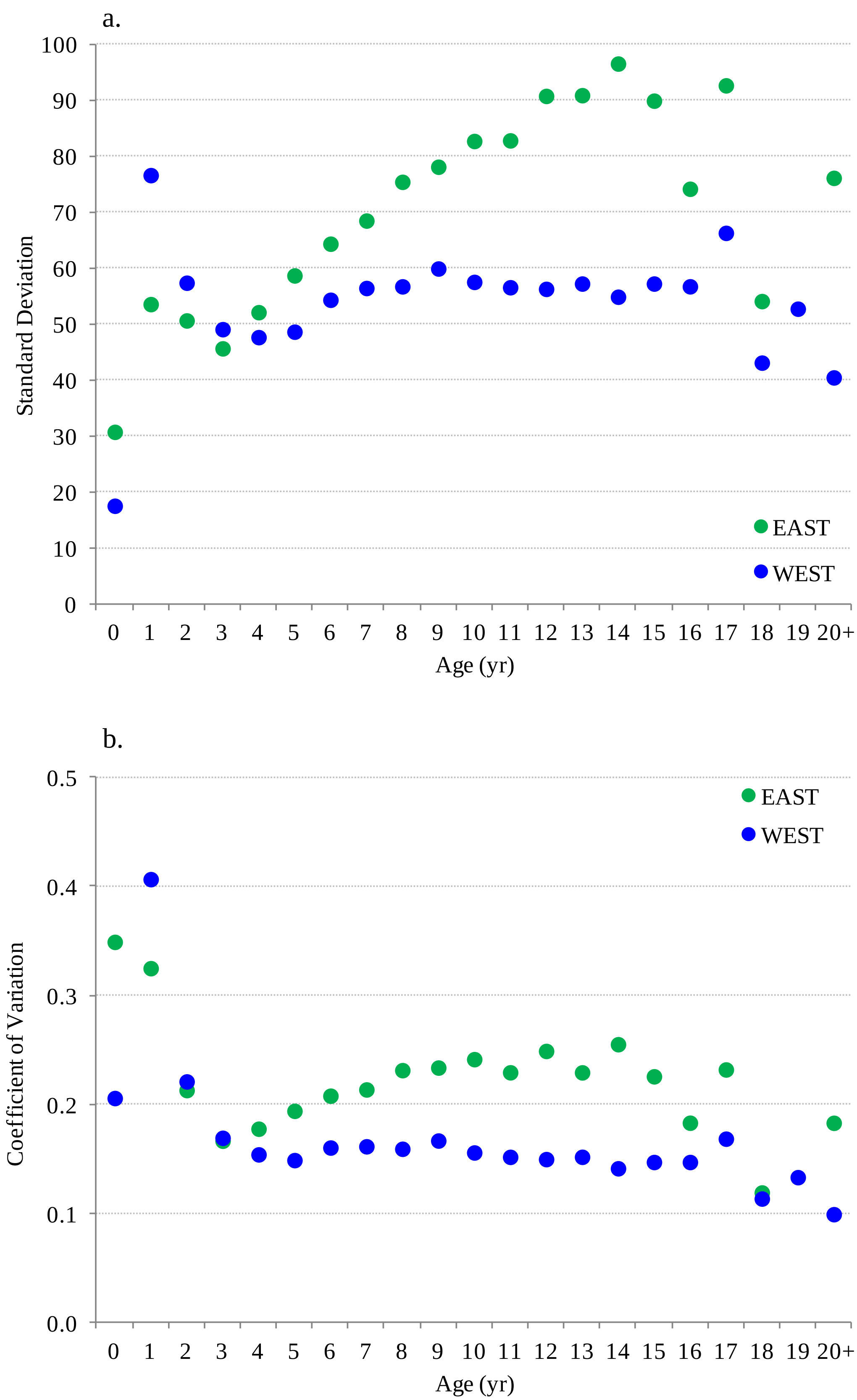

Figure 9. Variance structure for region (East or West of Mississippi River) specific observed size-at-age data for vermilion snapper from the northern Gulf of Mexico (1994-2014) (a) standard deviation and (b) coefficient of variation at length for each age.

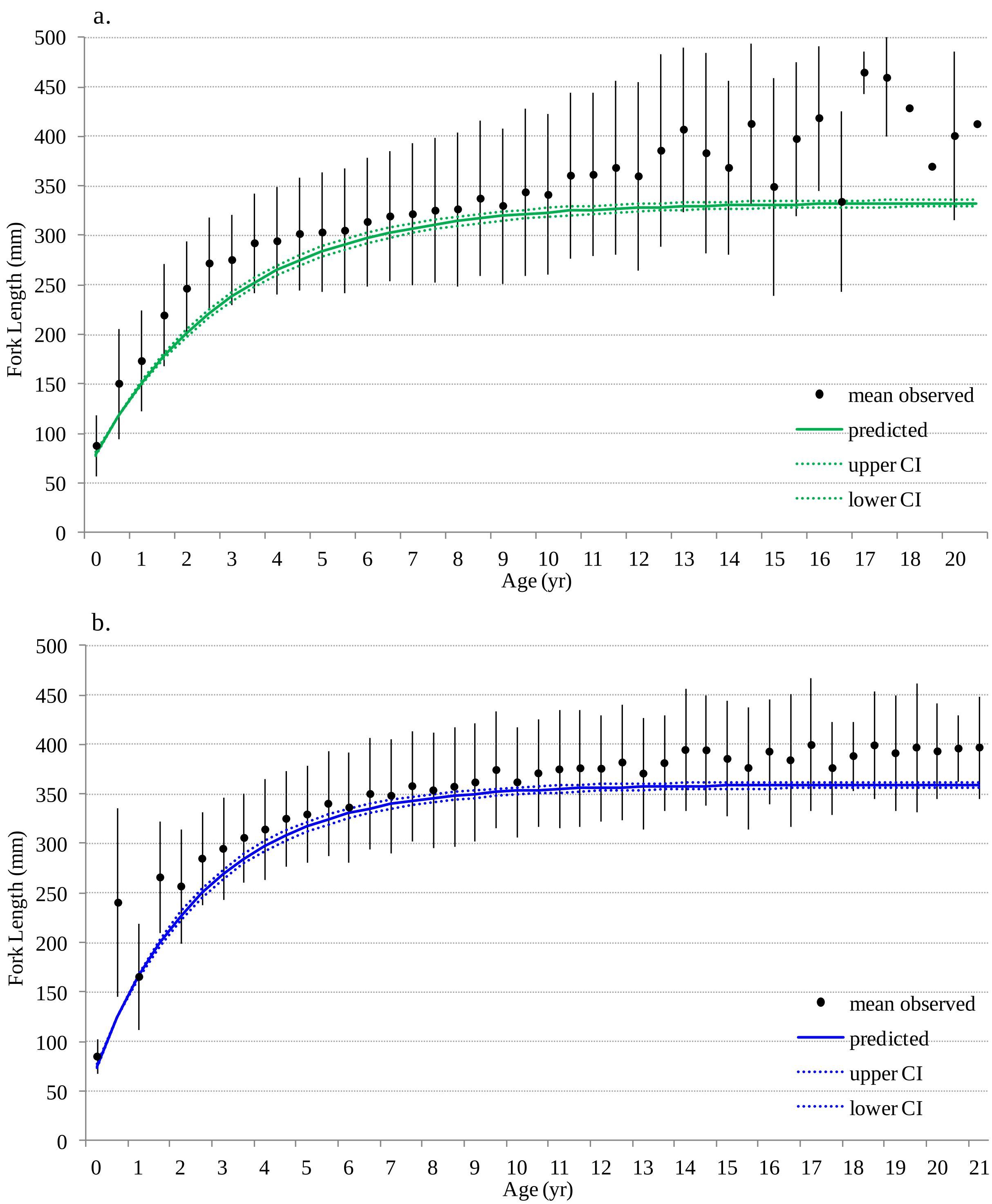

Figure 10. Results of region specific size-modified von Bertalanffy growth model with constant coefficient of variation with age variance structure for vermilion snapper from (a) East and (b) West of the Mississippi River for the northern Gulf of Mexico (1994-2014) for mean fractional ages 0-20. Observed mean size-at-age± standard deviations (black circles), estimated size-at-age (green or blue line), and estimated 95% confidence intervals (green or blue dashed line).

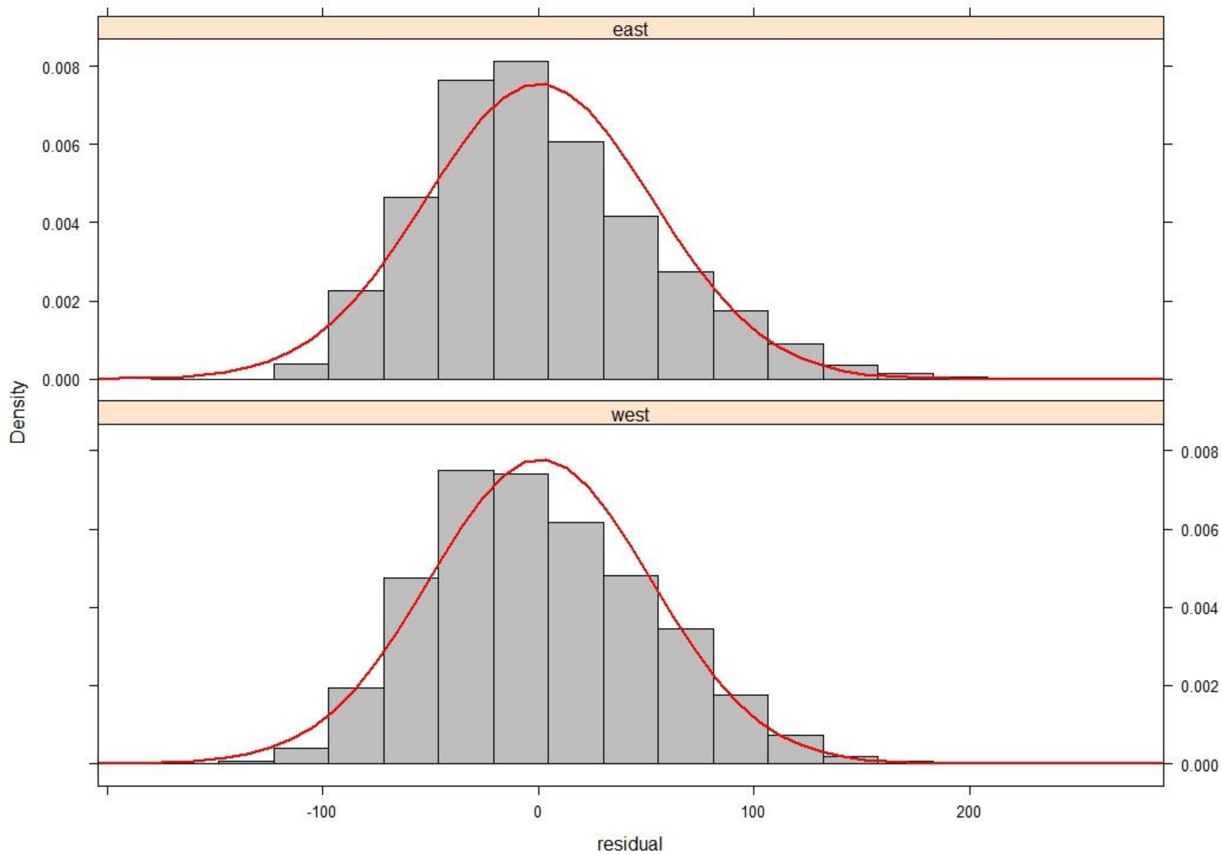

Figure 11. Distribution of region specific residuals for vermilion snapper size-modified von Bertalanffy growth models fit with a constant coefficient of variation with age variance structure.

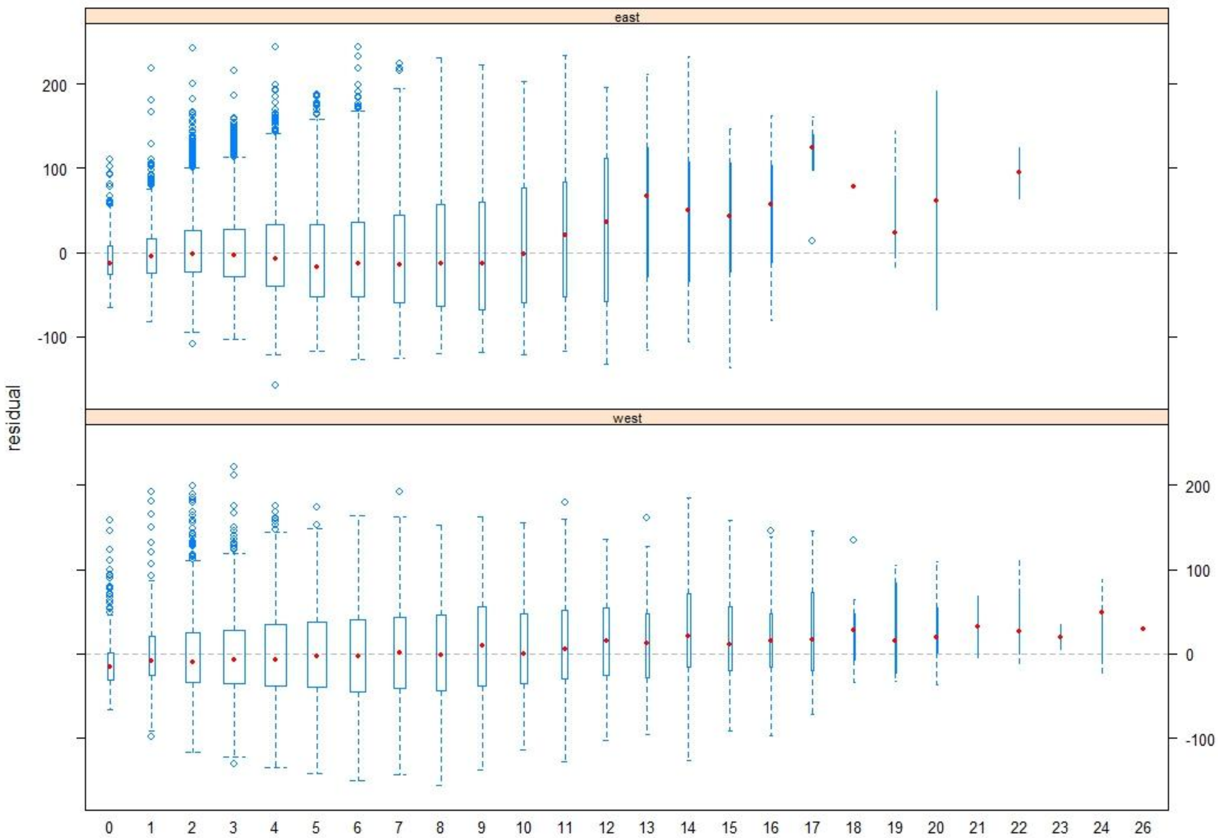

Figure 12. Residuals by age for region specific vermilion snapper size-modified von Bertalanffy growth models fit with a constant coefficient of variation with age variance structure.

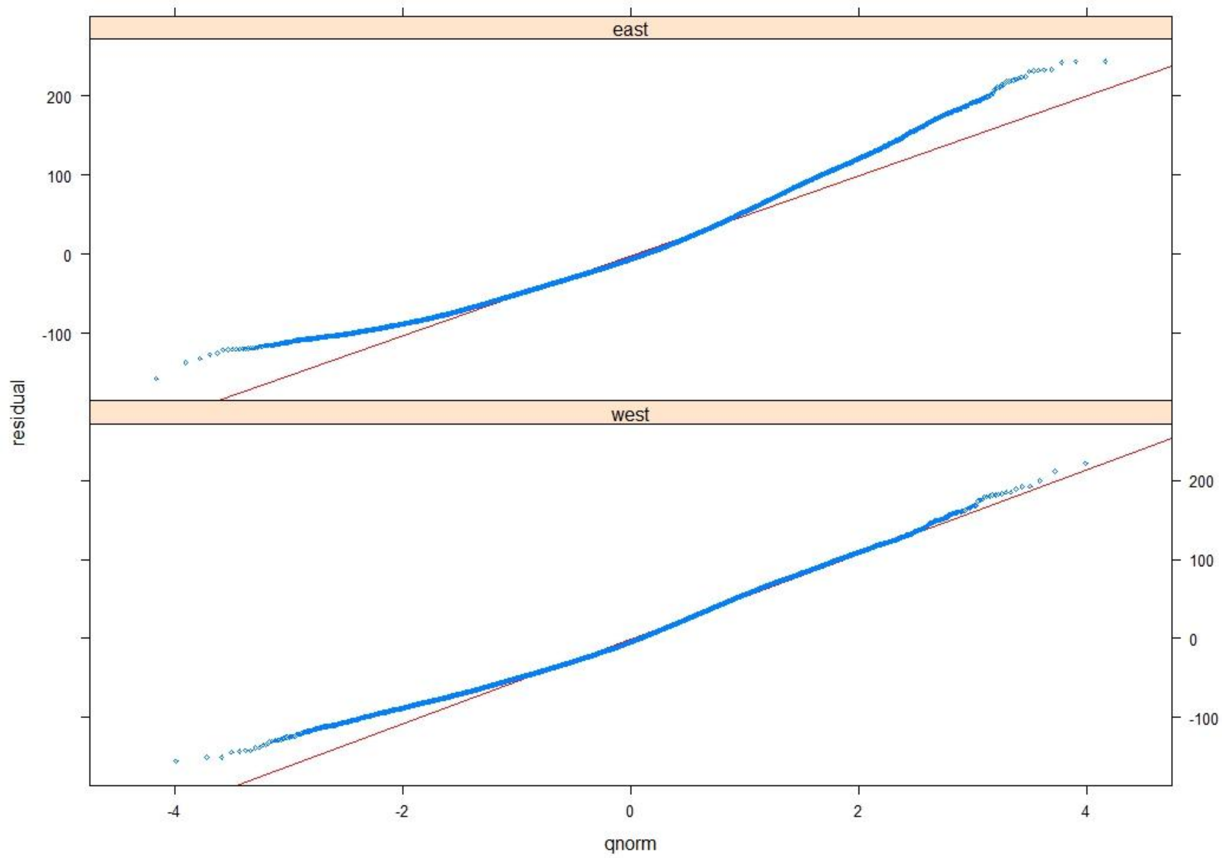

Figure 13. Normal probability plots (quantiles vs residuals) for region specific vermilion snapper size-modified von Bertalanffy growth models fit with a constant coefficient of variation with age variance structure.