An age and growth description of Red Grouper (*Epinephelus morio*) from the northeastern Gulf of Mexico: 1978-2013 for SEDAR42

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Version 2

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Changes (version 2)

- Identification of 385 red grouper caught during recreational fishing with an exempted fishing permit (Table 2, 3)
- Re-calculation of growth model with newly identified recreational fish caught without a minimum size limit (Table 11, 12; Figures 8, 9)

Abstract

Red grouper were sampled for age structure from both the commercial and recreational harvests of the Gulf of Mexico primarily from the west coast of Florida as well as from fishery independent surveys (n = 94,908, 1991-2013; n = 435, 1978-1989). This dataset builds on previously reported age information. Red grouper collected from the commercial long-line and hand-line fishery were sub-sampled based on the percentage of landings per NMFS Statistical Grid (2002-2013, n = 12,509). Red grouper fully recruited into the fishery by ages 5-7 yrs old (range: 0 – 29 yrs, 6.8 ± 3 yrs) and became rare at age 13 yrs old (<1% of samples). Annual age frequencies displayed eight dominant age classes (1989, 1990, 1991, 1996, 1999, 2002, 2006, and 2007). A size-modified von Bertalanffy growth model that takes into account non-random sampling due to minimum size restrictions using a constant coefficient of variation at age variance structure predicted the following growth parameters: L_∞ = 829 FL mm, k = 0.13, t_o = -1.20.

Introduction

Because age and growth information is critical to stock assessment, the goal of this report is to characterize red grouper (*Epinephelus morio*) age-length structure using 35 years of data collected from the northeastern Gulf of Mexico: 1978-2013. Red grouper otoliths have been sampled and aged at the National Marine Fisheries Service- Southeastern Fisheries Science Center in Panama City, Florida, since 1978 (Johnson and Collins 1994). Although there have been periods of low sampling effort, there is a continuous 23 year dataset: 1991 – 2013. This report includes a summary of data that has been provided for previous assessments in 2002, 2006 (2002 stock assessment, Lombardi-Carlson et al. 2002; SEDAR12, Lombardi-Carlson et al. 2006) and the update assessment of red grouper in 2009 (Lombardi-Carlson et al. 2009). The

following are discussed: meristic regressions, annual age and length data, annual age and length frequencies, and size-modified von Bertalanffy growth model.

Methods

Data Collection

Otoliths were collected by numerous federal and state sources representing both the commercial and recreational fisheries (Trip Interview Program – TIP, Beaufort Head Boat Survey – HB, Marine Fisheries Recreational Statistical Survey – MRFSS, Recreational Fisheries Information Network – RECFIN). Red grouper otoliths were also collected from federally funded fishery independent surveys (NMFS Panama City, FL – PCLAB, and NMFS Pascagoula, MS – MSLAB) and state funded fishery independent surveys (Florida Fish and Wildlife Research Institute -Fishery Independent Monitoring, St. Petersburg, FL – FWRI). The Cooperative Research Program (CRP) and Expanded Annual Stock Assessment Survey, NMFS Pascagoula, MS (EASA) also provided otoliths and gonads and site specific detailed capture locations. At-sea collection of otoliths and gonads from the commercial industry were made possible through two observer programs (NMFS Panama City Shark Bottom Long-line Observer Program – SBLOP and NMFS Galveston Reef fish Observer Program – GOP). Measurements of fish lengths (total and/or fork), weights (whole or gutted), and removal of otoliths and/or gonads were completed in the field.

Data Quality Control

Each of the data collection sources has separate but similar sampling procedures, data protocols, and reporting methodologies. Our facility uses data quality control guidelines in the interpretation of source-specific datasheets as described by the Procedure Manual for Age, Growth, and Reproduction (AGR) Lab (NMFS 2008). First, each species-specific collection is assigned an annual collection (or tracking) number and all collection-specific data (i.e. source, source number, state, sector, and gear) are proofed and entered in our AGR Access Databases from the original datasheets. If such data are not provided, then the collector (port agent and/or survey leader) is contacted to track down the missing data. Our AGR Access Databases were constructed with field-specific lists of suitable values (e.g. source, state, sector, and gear),

validation rules, and user-specific security for data accessibility to enhance our data quality control procedures. Additionally, the source number (or interview number) is a source-specific number (or combination of intercept specific numbers) that permits the cross-referencing of data between databases (original source and Annual AGR Database). Next, after all the individual fish data are entered, data are proofed against the original datasheets and any corrections are made to the Annual AGR Database. Prior to 1998, no manual existed to implement these procedures. Therefore, to insure these standards of quality control, all 1991-1997 data were proofed using the TIP original datasheets (archived in Panama City, FL) and any missing TIP data were resolved by accessing the TIP database (TIP-ONLINE, DELPHI, SEFHOST). Beginning in 2011, all TIP data is reported electronically via the TIP-ONLINE program and our facility ages are entered directly into a joint NMFS database (NMFS Biological Sampling Database); therefore, our facility no longer proofs these records. In more recent years, many of our data sources only provide data electronically, so our facility is conducting less proofing of external data sources.

Sub-Sampling

Due to an increase in otolith sampling that has occurred in the commercial hand-line and long-line sectors, records (minimum n = 500) from each year and gear were randomly sub-sampled based on the percentage of commercial landings by National Marine Fisheries Service (NMFS) Shrimp Grids. Landings were obtained from NMFS logbook 2002 - 2009 (S. Turner, SEFSC Miami). Red grouper otoliths collected in 1991-2013 from recreational, scientific surveys, and Cooperative Research Projects were not sub-sampled; age was estimated for all samples. This is the same sub-sampling process as used in 2006 SEDAR 12 and the update assessment in 2009.

Age Determination

The sagittal otolith was used as the primary ageing structure (Moe 1969). Red grouper ages were successfully interpreted from both whole and sectioned otoliths (Johnson and Collins 1994, Lombardi-Carlson et al. 2002, 2006, 2009). Multiple readers and ageing facilities read red grouper otoliths, indices of precision (Average Percent Error, Percent Agreement, CV, D), and ageing error matrices were calculated, see Palmer et al. 2014 for further discussion. Annual ages

were used for further analysis and fractional ages were also calculated to obtain decimal age to use in the growth model.

Annual ages, based on a calendar year, were calculated using the reader's annulus count, edge type and capture date (Jearld 1983). Annulus counts were advanced a year if the fish was captured between January 1 to June 30 and the edge type was determined to be fully translucent (edge type 6). Typically, marine fish in the southeastern U.S. complete annulus formation, an opaque zone, by late spring to early summer. Therefore, an otolith with two completed annuli and a large translucent zone would be classified as age 3 if the fish was caught during spring in expectation that a third (opaque zone) annulus would have formed soon. Any fish caught before June 30 with an opaque edge (type 2), the annual age was equal to the annulus count. After June 30, when opaque zone formation is underway or complete for red grouper in the Gulf of Mexico (Moe 1969), all fish were assigned an annual age equal to the annulus count by convention. There were a few instances when an opaque edge was detected from fish caught late in the year (November and December). It was assumed these fish were depositing the next year's band early and one year was subtracted from the annulus count to calculate an annual age.

In addition to annual or cohort age, fractional age was calculated and used in the growth model. A fractional period of a year was determined as the difference from peak spawning date (May 15; Moe 1969, Collins et al. 2002) 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.

Regressions

Meristic relationships were calculated for lengths and body weights for all red grouper caught from 1978 to 2013. A majority of red grouper are reported in fork length (94%); therefore, only 6% of lengths needed to be converted from natural total length, maximum total length, or standard length to fork length. Conversions from natural total length (mm), maximum total length (mm), and standard length (mm) to fork length were calculated through a linear regression (R, lm function). Conversions from natural and maximum total length (mm) to whole weight (kg) and gutted weight (kg) and from fork length (mm) to whole weight (kg) and gutted weight (kg) and standard length (mm) to whole weight (kg) were calculated by a non-linear

regression (R, nls function). Conversions among lengths and weights were compared to those conversions used in previous assessments.

Age & Growth Data

Age and length frequencies were produced for each year with all sectors and gears combined to examine annual trends in age structure during 1991-2013. Length and age data were also compared among years. Box plots were used to visually compare annual patterns of length and age.

Pre-Regulatory Dataset (as presented in 2006SEDAR12)

Red grouper otoliths and length data collected in 1978-1989 (prior to regulations) were recovered from NMFS Panama City otolith archive. All otoliths recovered were re-aged according to the methods described above. Temporal changes in size-at-age were investigated between pre-regulatory (1978-1989) and post-regulatory (1991-1994) datasets for fishery dependent data (commercial hand-line and recreational).

Description of 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 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. Multiple model compilations were examined using three difference variance structures in the size-at-age data. The model also uses a restrictive maximum likelihood estimation procedure with minimum size (1990-2013 REC 20 TL in, 488 FL mm; 1990-2008 CM 20 TL in, 488 FL mm; 2009-2013 CM 18 TL in, 440 FL mm) as the left truncation limit for fisheries dependent observations. Fishery independent data and age and length data collected from discarded red grouper from the commercial fishery (2009) were used

to aid the model to predict growth at smaller sizes not collected in routine fishery dependent sampling (given the minimum size limit).

The size-modified growth model used in this assessment has structural similarities with the model used in the previous assessments (Lombardi-Carlson et al. 2006, Lombardi-Carlson et al. 2009), but now the size-modified growth model is compiled in ADMB with alternative variance structures. 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_∞ = 900, 800; k = 0.14, 0.10; t_0 =0.00), standard deviations (sigma = 10), 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 and Discussion

Data Collection

The majority of samples proportionally remained consistent by state, source, and by sector with previous assessments. Red grouper were primarily harvested from Florida waters (red grouper, 99.8%; Table 1) and by Trip Interview Program (TIP) port agents (red grouper, 81.9%; Table 2). Red grouper were intercepted more frequently from commercial long-line vessels (45.8%; Table 3) than from other sectors. A cooperative research project collected red grouper from discarded fish from the commercial fishery (2009, n = 1529; Table 3 categorized as 'other'). During 2009-2011, several special projects conducted by the state of FL, FWRI collected undersized red grouper from the recreational fishery (through the use of Exempted Fishing Permits); however, these fish were not individual identified prior to the data workshop and warranted the revision of this report and some analysis. Of the red grouper otoliths read, 99% were aged (Table 4).

Sub-sampling

Red grouper otoliths collected from the commercial hand-line and long-line were sub-sampled for 12 years (2002-2013; Table 4) and from the commercial vertical long-line in 2010. Average percentages of commercial landings by gear (long-line, hand-line, vertical-line) and by NMFS grid for specific time periods (2001-2004, 2003-2007, 2005-2009) were calculated to determine the number of red grouper sub-sampled per grid (Table 5, 6, 7). The specific time periods were chosen to identify any changes in landings per grid; although, landings per grid have not fluctuated by much in the entire time period (2002-2013). For example, Grid 5 (Latitude 27^{o}N, Longitude 82-84^{o}W; time period 2001-2004) accounted for 45% of red grouper commercial long-line landings; therefore about 45% of the otoliths available each year were randomly sub-sampled per year from Grid 5. If minimum number of otoliths was not available from a particular grid to be exactly representative (e.g. Grid 5 in 2002), than more otoliths were sub-sampled from adjacent grids. A total of 12,509 otoliths were randomly sub-sampled from reported commercial samples collected in 2002-2013 (Table 5, 6, 7).

Regressions

Meristic relationships were calculated for lengths and body weights for all red grouper combined 1978- 2013 (Table 8). The linear regression for converting to fork length was based on 5818 (maximum total lengths), 3901 (natural total lengths), and 985 (standard lengths) individual length measurements (r2 = 0.9963, r2 =0.9909, r2 = 9938; respectively, Figure 1). The non-linear regressions predicting gutted weight (kg) from maximum total length had the highest correlation (RSE = 0.7421, n = 633).

The previous assessment did not provide linear regressions for predicting fork length, the primary length designated for this assessment. There were minor differences among the non-linear regressions (Figure 2). These dissimilarities may be due to the regressions in SEDAR12 were calculated using Microsoft Excel, graphic trend line function.

Age & Growth Data

An additional 18,670 red grouper otoliths (2008: additional months of September – December, 2009-2013) were aged and incorporated into the existing red grouper dataset (n = 20,143; 1991-2008 (2008 only months January – August)). The fork length distribution of all red grouper aged continues to peak between 500 - 600 mm (Figure 3) with an overall mean fork

length of 540 ± 114 mm (std. dev). Mean fork lengths shifted to smaller lengths in the more recent years (2009-2013) reflecting the decrease in minimum size limit in the commercial fishery (Figure 4a).

The most recent age distribution indicates two strong year classes (2006 and 2007) progressions (as defined as, exceeding 30% of the total age structure during at least one year and dominating the age structure for two or more years within the time period, Lombardi-Carlson et al. 2006; Figure 5, Table 9). Mean ages differed among years and varied given the dominating age of the strong year class (Figure 4b). Annual age composition of red grouper continues to represent an extensive range (1 – 29 yrs; Figure 5), but more recent years (2006-2013) fewer (<10) fish older than 20 years are reported (Table 10).

Pre-Regulatory Dataset (as presented in 2006SEDAR12)

A total of 1,378 red grouper records collected in 1978-1989 were recovered from NMFS Panama City Laboratory otolith archive and data from several sampling programs. Only 435 records had otoliths, of which 421 were aged. The otoliths were collected from all sectors: 53% commercial, 28% recreational and 19% scientific survey. Commercial hand-line samples (n = 230, 1980-1981) were collected from three main regions of Florida: northwest, central, and south (categories as reported on datasheets). Recreational samples were obtained from dock-side sampling of recreational ports located in Panama City (n = 83, 1979-1980; Saloman and Fable 1981) and from Beaufort Head Boat Survey sampling from Naples and throughout the panhandle of Florida (n = 42, 1985-1989). In 1981, a scientific survey (R/V Oregon II) collected red grouper from the Florida Middle Grounds mainly with traps (n = 81; Russell 1982).

In 1990, the first federal regulatory amendments were enacted on the shallow-water grouper fishery by the Gulf of Mexico Fishery Management Council. These amendments established a minimal size limit (20 in), a recreational bag limit (5 grouper), a commercial quota (9.2 million LB for shallow-water groupers), and a commercial long line vessel fishing boundary (east of Cape San Blas, outside 20 fm). Pre-regulatory fishery dependent length and age data (1978-1989) were compared to post-regulatory data (1991-1994; Figure 6a-b). Post-regulatory red grouper were larger in size-at-age for 9 of the 12 age classes for sample sizes ≥ 5 (Figure 6c), but standard deviation error bars overlapped for all ages. The fishery independent survey caught red grouper that were majority (94%) smaller than 450 mm FL and almost all (95%) were

younger than age 6 yr (mean ± sd; FL 324 ± 85 mm, range 210- 697 mm,; age 2.5 ± 2 yr, range 1-13 yr).

Description of Growth

Red grouper data (observed fork lengths and fractional ages) from the entire time series (1991-2013; n = 38,813) were fit to a size-modified von Bertalanffy growth model to obtain population growth parameters (Table 11). Since this model takes in the affect of the minimum size limit, those fishery dependent records less than the corresponding minimum size limit (n = 2030) were not used in model fitting. This model also takes into consideration the variance structure of the observed size-at-age data. Red grouper showed a variable standard deviations in length among all ages (Figure 7a), which corresponded to a constant coefficient of variation at age variance structure for the most prominent ages (ages 3 – 13, 95% age structure; Figure 7b).

The preferred model fit used the variance structure matching the observed data, a constant coefficient variation at age and resulted in the following growth parameters: L_∞ = 829 mm, k = 0.1251, to = -1.2022 (Figure 8, Table 11). These parameters are similar to those calculated for two other variance structures and for previous assessments (Table 11 and 12). The size-modified von Bertalanffy growth model predicted similar sizes compared to observed lengths, even at younger ages (Figure 8a, 8b). 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 9a, 9b, 9c).

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Table 1. Summary of the number of red grouper otoliths collected by state landed (FL – west coast Florida, AL – Alabama, MS – Mississippi, LA – Louisiana).

Year	FL	AL	MS	LA	TX	Total
1978				1		1
1979	75					75
1980	8					8
1981	309					309
1985	1					1
1986	9					9
1987	11					11
1988	10					10
1989	11					11
1991	134					134
1992	285		5			290
1993	497					497
1994	526					526
1995	569		12			581
1996	470					470
1997	176					176
1998	306					306
1999	905					905
2000	809					809
2001	2,069					2,069
2002	2,872	7	5			2,884
2003	3,351	14	2	7		3,374
2004	4,060	28	1			4,089
2005	4,388	6		2		4,396
2006	4,540	7		6		4,553
2007	4,168	4		1		4,173
2008	3,309	5		4		3,318
2009	9,728	5		2		9,735
2010	7,457	13		7		7,477
2011	13,477	25		5	1	13,508
2012	16,189	22		14	1	16,226
2013	14,393	13		5	1	14,412
Total	**95,112**	**149**	**25**	**54**	**3**	**95,343**
Percent	**99.8**	**0.2**	**0**	**0**	**0**	

Table 2. Summary of the number of red grouper otoliths collected by source (TIP - Trip Interview Program, FWRI - Florida Fish and Wildlife Research Institute, HB - Beaufort Head Boat Survey, MRFSS - Marine Recreational Fisheries Statistical Survey, RECFIN - Recreational Fisheries Information Network, MSLAB -NMFS Pascagoula MS; PCLAB - NMFS Panama City, FL; CRP - Cooperative Research Proposals, EASA – Expanded Annual Stock Assessment Survey, NMFS Pascagoula, MS; Obs – NMFS Reef Fish Observer Program, Galveston, TX; NMFS Shark Bottom Long-line Observer Program, Panama City, FL; Other - ALLIANCE – expanded vertical line survey from MSLAB, DISL – Dauphin Island Sea Lab, Fishery Independent Survey; FIN – Gulf States Marine Fisheries Commission, Fisheries Information Network, samples from Alabama only; SEAMAP – Fishery Independent Survey, state of Alabama; US Geological Survey, Unknown). Shaded fields identify those fish caught with an Exempted Fishing Permit through FWRI special projects and were identified after the first draft of this report.

Year	TIP	FWRI	HB	MRFSS	RECFIN	MSLAB	PCLAB	CRP	EASA	Obs	Other	Total
1978						1						1
1979							75					75
1980			5								3	8
1981			14			80					215	309
1985			1									1
1986			9									9
1987			11									11
1988			10									10
1989			11									11
1991	102		32									134
1992	252		31			5					2	290
1993	479		18									497
1994	490		23			6	7					526
1995	522		34			25						581
1996	436		34									470
1997	165		10			1						176
1998	283	13				7	3					306
1999	850		2	33		11	9					905
2000	697		11	12		1	88					809
2001	1,852			31		83	100	2			1	2,069
2002	2,190	18	1	69	44	30	216	310			6	2,884
2003	3,026	28	29	121		62	48	54			6	3,374
2004	2,982	63	41	68	87	170	186	478			14	4,089
2005	3,623	21	29	18	67	50	127	458			3	4,396
2006	4,282	122	21		33	58	32				5	4,553
2007	3,625	305	22	7	32	51	24			105	2	4,173
2008	2,853	182	9	18	113	42	92			9		3,318
2009	6,047	1,007	9	8	190	96	132	2,235		10	1	9,735
2010	5,583	1,021	18	35	353	197	100			145	25	7,477
2011	10,679	968	35	68	439	147	139		1,014		19	13,508
2012	14,460	644	34	18	199	140	95	162		463	11	16,226
2013	12,595	833	16		274	56	23			613	2	14,412
Total	**78,073**	**5,225**	**520**	**506**	**1,831**	**1,319**	**1,496**	**3,699**	**1,014**	**1,345**	**315**	**95,343**
Percent	**81.9**	**5.5**	**0.5**	**0.5**	**1.9**	**1.4**	**1.6**	**3.9**	**1.1**	**1.4**	**0.3**	

Table 3. Summary of the number of red grouper otoliths collected by sector (CM - Commercial, CP - Charter Party, HB – Headboat, PR - Private, SS - Scientific Survey, Other Modes – Tournament, Unknown) and gear (LL - Long-Line, HL - Hand-Line, VLL – Vertical Long-line, TR - Trap, TRW – Trawl, Other – kali pole, seine net, spear, unknown and undersized fish from CRP in 2009 and recreational vessels in 2009-2011). The recreational (REC) sector composed of otoliths intercepted from charter boats (CP), head boats (HB), and private vessels (PR) from HL in 1979-1980 and spears in other years. Shaded fields identify those fish caught with an Exempted Fishing Permit through FWRI special projects and were identified after the first draft of this report.

Year	CM LL	CM HL	CM VLL	CM TR	CM Other	CP HL	HB HL	PR HL	REC Other	SS HL	SS LL	SS TR	SS TRW	SS VLL	SS Other	Other	Total
1978										1							1
1979									75								75
1980		1					5		2								8
1981		215					14			11	4	64			1		309
1985							1										1
1986							9										9
1987							11										11
1988							10										10
1989							11										11
1991	48	46		2		1	37										134
1992	156	44		16		25	33	1		5						10	290
1993	201	94		84		61	21	2				5				29	497
1994	88	242		29		75	29			7		6				50	526
1995	151	202		41		99	61			21		4				2	581
1996	103	152		9	6	151	44			5							470
1997	8	41		17	1	69	30	9		1							176
1998	124	42		33		74	21	4		8							306
1999	662	77		31		104	9	2		20							905
2000	412	213		38	6	59	12			68		1					809
2001	1,238	583		40	3	48	1	2		71	80	3					2,069
2002	1,809	573		89	1	287	50	7	6	9	16	18				19	2,884
2003	2,422	567		65	4	101	30	64	4	25	62	14	9			7	3,374
2004	2,340	1,070		38	1	144	43	39	2	139	168	52	52		1		4,089
2005	3,442	630			4	64	52	1		72	32	88	5		1	5	4,396
2006	3,465	633		174		38	33	6		5	98	55	28		14	4	4,553
2007	2,553	1,139			2	46	29	10	6	74	80	59	107		60	8	4,173
2008	2,065	755			11	64	44	25	17	33	30	154	97		2	21	3,318
2009	2,704	3,840	180		17	89	104	16	14	400	64	490	261			1,556	9,735
2010	2,481	1,776	1,341		149	263	86	31	18	705	93	341	98	80		15	7,477
2011	4,613	5,892	115		24	391	114	15	1	198	1,090	534	76	15		431	13,508
2012	5,898	8,943	188		40	225	40	12	2	181	116	435	116	6		24	16,226
2013	5,607	7,479	32		80	216	45	17	8	295	111	359	65	71	1	26	14,412
Total	**42,590**	**35,249**	**1,856**	**706**	**349**	**2,694**	**1,029**	**263**	**155**	**2,354**	**2,044**	**2,682**	**914**	**172**	**80**	**2,207**	**95,343**
Percent	**44.7**	**37.0**	**1.9**	**0.7**	**0.4**	**2.8**	**1.1**	**0.3**	**0.2**	**2.5**	**2.1**	**2.8**	**1.0**	**0.2**	**0.1**	**2.3**	

Table 4. Summary of the number of red grouper otoliths collected, read, and determined unreadable (1978-2001) or sub-sampled to be aged (2002-2013). *These totals also include those otoliths and ages provided by other ageing facilities. The only fish sub-sampled were those collected by Trip Interview Program port agents from the commercial industry (see Table 5 and text for further information on sub-sampling).

Year	Otoliths collected	Otoliths sub-sampled*	Otoliths read	Otoliths not readable	Otoliths not readable (%)
1978	1		1	1	100
1979	75		75	4	5
1980	8		8	0	0
1981	309		309	8	3
1985	1		1	0	0
1986	9		9	1	11
1987	11		11	0	0
1988	10		10	0	0
1989	11		11	0	0
1991	134		134	15	11
1992	290		290	18	6
1993	497		497	3	1
1994	526		526	7	1
1995	581		581	53	9
1996	470		470	39	8
1997	176		176	17	10
1998	306		306	7	2
1999	905		905	20	2
2000	809		809	15	2
2001	2,069		2,069	41	2
2002	2,884	2,150	2,150	9	0
2003	3,374	2,036	2,036	14	1
2004	4,089	2,910	2,910	20	1
2005	4,396	2,424	2,424	20	1
2006	4,553	1,624	1,624	13	1
2007	4,173	1,577	1,577	19	1
2008	3,318	1,499	1,499	6	0
2009	9,735	4,901	4,901	44	1
2010	7,477	3,447	3,447	45	1
2011	13,508	3,989	3,989	38	1
2012	16,226	3,109	3,109	60	2
2013	14,412	2,993	2,993	54	2
Total	**95,343**	**32,659**	**39,857**	**591**	**1**

Table 5. Summary of the red grouper (2002-2005) commercial long-line otoliths randomly sub-sampled for age determination based on the percentage of red grouper commercial long-line landings within corresponding NMFS grid in 2001-2004 (S.Turner, SEFSC Miami). The NMFS grid associated with otolith samples was reported to port agents during intercepts.

NMFS Shrimp Grid	Percent Landed	Theoretical Sample Size	2002 # otoliths	2002 sub-sampled	2003 # otoliths	2003 sub-sampled	2004 # otoliths	2004 sub-sampled	2005 # otoliths	2005 sub-sampled	Total	Total sub-sampled
1	0.00	2									0	0
2	0.04	42	56	56	97	95	113	43	97	82	363	276
3	0.07	68	33	27	70	68	95	87	93	95	291	277
4	0.22	221	163	145	621	218	619	235	475	221	1,878	819
5	0.45	448	215	210	551	450	583	456	822	445	2,171	1,561
6	0.16	156	1,158	544	842	160	586	150	1,274	157	3,860	1,011
7	0.03	31		1							0	1
8	0.02	20	120	51	154	50	192	51	201	113	667	265
9	0.01	5	18	18	24	24					42	42
10	0.00	4									0	0
11	0.00	0									0	0
13	0.00	1									0	0
unknown	0.00	1	46	24	44	1	16	3	125	2	231	30
Total	1.00	1,000	1,809	1,076	2,403	1,066	2,204	1,025	3,087	1,115	9,503	4,282

Table 6a. Summary of the red grouper (2006-2008) commercial long-line otoliths randomly sub-sampled for age determination based on the percentage of red grouper commercial long-line landings within corresponding NMFS grid, averaged across years 2003-2007 (S. Turner, SEFSC Miami). The NMFS grid associated with otolith samples was reported to port agents during intercepts.

NMFS Shrimp Grid	Percent Landed	Theoretical Sample Size	2006 # otoliths	2006 sub-sampled	2007 # otoliths	2007 sub-sampled	2008 # otoliths	2008 sub-sampled	Total otoliths	Total sub-sampled
1	0.00	1	0			0	0	0	0	0
2	0.05	26	134	26	120	26	31	31	285	83
3	0.08	38	232	38	126	38	16	16	374	92
4	0.21	103	493	103	563	104	166	103	1,222	310
5	0.41	207	1,146	209	975	210	664	207	2,785	626
6	0.18	91	1,172	93	429	91	493	143	2,094	327
7	0.04	18	30	18	18	18	0	0	48	36
8	0.03	13	102	13	19	13	0	0	121	26
9	0.00	2	0	0		0		0	0	0
10	0.00	1	0	0		0		0	0	0
Unknown	0.00	0	117	0	303	0	270	0	690	
Total	1.00	500	3,426	500	2,553	500	1,640	500	7,619	1,500

Table 6b. Summary of the red grouper (2006-2008) commercial hand-line otoliths randomly sub-sampled for age determination based on the percentage of red grouper commercial hand-line landings within corresponding NMFS grid, averaged across 2003-2007 (S. Turner, SEFSC Miami). The NMFS grid associated with otolith samples was reported to port agents during intercepts.

NMFS Shrimp Grid	Percent Landed	Theoretical Sample Size	2007 # otoliths	2007 sub-sampled	2008 # otoliths	2008 sub-sampled	Total otoliths	Total sub-sampled
1	0.01	3	0	0	0	0	0	0
2	0.02	8	9	26	8	31	17	57
3	0.04	20	0	38	5	16	5	54
4	0.09	45	10	104	51	103	61	207
5	0.14	69	54	210	62	207	116	417
6	0.35	177	843	91	454	143	1297	234
7	0.26	131	29	18	0	0	29	18
8	0.07	33	164	13	74	0	238	13
9	0.02	10	10	0	0	0	10	0
10	0.01	3	6	0	0	0	6	0
Unknown	0.00	0	14	0	62	0	76	0
Total	1.00	500	1,139	500	716	500	1,855	1,000

Table 7. Summary of the red grouper (2009-2013) commercial (a) long-line, (b) hand-line and (c) vertical long-line otoliths randomly sub-sampled for age determination based on the percentage of red grouper commercial long-line landings within corresponding NMFS grid, averaged across years 2005-2009 (S. Turner, SEFSC Miami). The NMFS grid associated with otolith samples was reported to port agents during intercepts.

Table 7a. Commercial long-line

NMFS Shrimp Grid	Percent Landed	Theoretical Sample Size	2009 # otoliths	2009 sub-sampled	2010 # otoliths	2010 sub-sampled	2011 # otoliths	2011 sub-sampled	2012 # otoliths	2012 sub-sampled	2013 # otoliths	2013 sub-sampled	Total otoliths	Total sub-sampled
1	0.00	0		0		0							0	0
2	0.04	22	9	9	82	20	110	20	57	20	81	25	339	94
3	0.06	31	48	10	86	30	126	40	445	40	177	35	882	155
4	0.18	92	536	100	874	75	948	100	1,187	100	895	100	4,440	475
5	0.46	231	1,090	325	843	300	2,027	240	2,030	230	2,504	240	8,494	1,335
6	0.15	74	268	45	358	80	876	100	1,218	100	583	75	3,303	400
7	0.06	28		0	2	2	477	2	423	30	407	30	1,309	64
8	0.04	18	4	4		0			141	20	333	20	478	44
9	0.00	2	10	10		0			48	20			58	30
10	0.00	1		0		0					5	5	5	5
10+	0.00	0		0		0							0	0
Unknown	0.00	0	241	0	92	0							333	0
Total	1.00	500	2,206	503	2,337	507	4,564	502	5,549	560	4,985	530	19,641	2,602

Table 7b. Commercial hand-line

NMFS Shrimp Grid	Percent landed	Theoretical Sample Size	2009 # otoliths	2009 sub-sampled	2010 # otoliths	2010 sub-sampled	2011 # otoliths	2011 sub-sampled	2012 # otoliths	2012 sub-sampled	2013 # otoliths	2013 sub-sampled	Total otoliths	Total sub-sampled
1	0.00	1		0	1	1			2	2	17	5	20	8
2	0.01	4	24	10		0	44	5	68	10	190	4	326	29
3	0.02	8	28	10	35	35	47	10	80	10	118	8	308	73
4	0.11	56	617	50	197	60	366	60	439	60	655	60	2,274	290
5	0.12	59	475	50	566	60	845	60	1,401	60	1,221	60	4,508	290
6	0.34	170	2,017	230	745	300	1,844	170	3,058	170	2,787	170	10,451	1,040
7	0.33	164	104	104		0	1,837	160	2,210	170	1,487	170	5,638	604
8	0.06	30	163	30	123	30	813	30	948	30	838	30	2,885	150
9	0.01	3	7	7		0	59	5	311	10	30	5	407	27
10	0.00	2	9	9	5	5	3	3	35	10	54	5	106	32
10+	0.01	3	2	2	7	7	15	15	27	27	20	20	71	71
Unknown	0.00	0		0	71	0	14				1		86	0
Total	1.00	500	3,446	502	1,750	498	5,887	518	8,579	559	7,418	537	27,080	2,614

Table 7c. Commercial vertical long-line.

NMFS Shrimp Grid	Percent Landed	Theoretical Sample Size	2010 # otoliths	2010 sub-sampled
1	0.00	1		
2	0.01	4		
3	0.02	8	89	30
4	0.11	56	346	150
5	0.12	59	763	200
6	0.34	170	131	131
7	0.33	164		0
8	0.06	30		0
9	0.01	3		0
10	0.00	2		0
10+	0.01	3		0
Unknown	0.00	0	12	0
Total	1.00	500	1,341	511

Table 8. Meristic regressions for red grouper (1978-2013) from the Gulf of Mexico. Data combined from all data sources, both fishery independent and dependent. Length Type: Max TL – Maximum Total Length, FL – Fork Length, Nat TL – Natural Total Length, SL – Standard Length. Weight Type: G Wt – Gutted Weight, W Wt – Whole Weight. Units: length (mm) and weight (kg). Linear and non-linear regressions calculated using R (lm and nls functions, respectively).

Regression	Equation	statistic	N	Data Range
Max TL to FL	FL = 5.35 + max_TL *0.95	r^2=0.9963	5818	Max TL: 120 – 954; FL: 116 – 910
Nat TL to FL	FL = 5.71 + nat_TL * 0.95	r^2=0.9909	3901	Nat TL: 151 – 957; FL: 149 – 910
SL to FL	FL = 15.90 + SL * 1.14	r^2=0.9938	985	SL: 130 – 686; FL: 159 – 830
SL to Max TL	Max_TL = 9.19 + SL * 1.21	r^2=0.9944	3399	SL: 130 – 720; Max TL: 161 – 876
SL to Nat TL	Nat_TL= -51.18 + SL * 1.32	r^2=0.9791	7	SL: 404 – 670; Nat TL: 484 – 860
Max TL to G Wt	G WT = $4.33 \times 10^{-8} * (max\_TL^{2.83})$	RSE = 0.7421	633	Max TL: 458 – 980; G WT: 0.82 – 15.05
Max TL to W Wt	WWT = $5.21 \times 10^{-09} * (max\_TL^{3.16})$	RSE = 0.5152	3725	Max TL: 127 – 954; W WT: 0.03 – 16.96
Nat TL to G Wt	GWT = $5.70 \times 10^{-08} * (nat\_TL^{2.78})$	RSE = 0.6398	34	Nat TL: 490 – 802; G WT: 1.28 – 7.17
Nat TL to W Wt	WWT = $7.58 \times 10^{-09} * (nat\_TL^{3.10})$	RSE = 0.3482	3912	Nat TL: 120 – 957; W WT: 0.02 – 14.00
FL to G Wt	GWT= $3.37\ 10^{-09} * (FL^{3.25})$	RSE = 0.3499	37414	FL: 230 – 935; G WT: 0.26 – 16.96
FL to W Wt	WWT = $5.46 \times 10^{-09} * (FL^{3.18})$	RSE = 0.4667	7361	FL: 123 – 965; W WT: 0.05 – 16.96
SL to W Wt	WWT = $2.32 \times 10^{-08} * (SL^{3.03})$	RSE = 0.1825	483	SL: 147 – 670; W WT: 0.10 – 9.00

Table 9. Annual observed proportions at age for red grouper sampled from the northeastern Gulf of Mexico for 1991-2013. Data combined from fishery dependent (commercial and recreational) and independent sources. Strong year classes (as defined as, exceeding 30% of the total age structure during at least one year and dominating the age structure for two or more years within the time period) in bold and corresponding color (1989 – red, 1990 – orange, 1991 – green, 1996 – blue, 1999- purple, 2006 – maroon, 2007 – teal). The 2002 year class is presented in bold and shaded, not as strong of a year class but dominated age structure.

Age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	6%	0%	0%	0%	0%	0%	1%
2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	1%	1%	**9%**	6%	1%	1%	2%	1%	2%
3	2%	0%	1%	2%	0%	0%	1%	1%	0%	1%	0%	1%	1%	0%	2%	1%	1%	0%	**26%**	**12%**	2%	2%	1%	5%
4	6%	2%	**9%**	**15%**	3%	2%	6%	7%	1%	**18%**	4%	3%	**10%**	4%	1%	4%	1%	3%	5%	**31%**	**25%**	3%	2%	9%
5	17%	18%	11%	**24%**	**18%**	**20%**	12%	16%	10%	8%	**37%**	9%	7%	**30%**	10%	3%	**18%**	6%	8%	4%	**43%**	**23%**	7%	16%
6	15%	20%	23%	14%	**30%**	**32%**	**26%**	20%	12%	18%	12%	**30%**	13%	8%	**44%**	15%	10%	**24%**	8%	7%	5%	**44%**	**34%**	19%
7	12%	23%	24%	17%	19%	**23%**	**32%**	**24%**	15%	12%	17%	14%	**22%**	13%	7%	**40%**	16%	10%	**22%**	11%	6%	6%	**35%**	16%
8	8%	16%	17%	11%	12%	7%	**13%**	**14%**	**24%**	11%	8%	12%	11%	**14%**	10%	15%	**26%**	15%	8%	**16%**	4%	5%	6%	11%
9	14%	7%	7%	7%	8%	10%	2%	**8%**	**19%**	**11%**	4%	8%	10%	8%	**10%**	6%	8%	**16%**	8%	7%	7%	3%	4%	8%
10	13%	6%	3%	4%	4%	4%	1%	3%	**9%**	**7%**	7%	5%	6%	6%	6%	5%	4%	4%	6%	6%	2%	5%	3%	5%
11	3%	3%	2%	2%	2%	1%	2%	3%	5%	**7%**	5%	5%	4%	4%	3%	3%	4%	3%	2%	2%	2%	3%	4%	3%
12	4%	3%	1%	1%	2%	0%	1%	2%	3%	3%	2%	4%	4%	2%	2%	2%	2%	2%	0%	0%	1%	2%	1%	2%
13	3%	1%	1%	1%	1%	0%	2%	0%	1%	2%	2%	3%	3%	2%	1%	1%	1%	1%	0%	1%	0%	2%	1%	1%
14	0%	0%	0%	1%	1%	0%	1%	1%	1%	1%	1%	2%	2%	2%	1%	1%	1%	0%	0%	0%	0%	0%	1%	1%
15	1%	0%	0%	0%	0%	0%	1%	1%	0%	1%	1%	1%	2%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	1%
16	2%	0%	0%	0%	0%	0%	1%	0%	0%	0%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
17	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
18	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
19	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
20	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 10. Annual observed numbers at age for red grouper sampled from the northeastern Gulf of Mexico for 1991-2013. Data combined from fishery dependent (commercial and recreational) and independent sources.

Age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
0																3	10		1	1		1		16
1													4	4		6	91	94	19	4	7	15	11	255
2			1								7		3	53	4	22	11	132	280	27	31	53	28	652
3	2	1	3	8		1	1	2	3	8	6	24	21	13	51	17	17	3	1257	408	97	48	35	2026
4	7	5	46	79	16	8	9	20	10	142	71	70	208	129	22	69	16	48	242	1044	1002	92	54	3409
5	19	48	52	125	92	86	19	48	86	67	740	198	131	877	231	52	279	87	364	140	1682	701	195	6319
6	17	54	114	71	159	138	42	61	104	139	236	640	268	221	1048	245	153	361	366	251	187	1336	993	7204
7	14	63	120	89	97	97	51	73	130	95	339	307	439	382	178	643	248	148	1081	360	222	183	1022	6381
8	9	43	86	58	65	32	21	42	211	90	164	261	221	408	250	237	411	227	403	550	168	147	164	4268
9	16	20	35	36	40	42	3	25	165	84	81	169	199	218	248	102	124	233	397	248	266	102	111	2964
10	15	16	15	23	23	18	2	10	79	59	134	97	121	180	135	77	60	59	294	211	94	155	92	1969
11	3	7	9	9	11	3	3	8	46	52	92	101	88	103	72	46	55	38	74	82	95	79	105	1181
12	5	8	3	6	8	2	1	5	23	21	50	87	88	70	49	30	26	23	19	14	53	60	31	682
13	3	3	3	7	6	1	3	1	13	13	31	61	68	56	29	20	15	12	17	21	13	46	41	483
14			1	3	4		1	2	6	7	24	33	40	57	24	12	18	7	11	14	8	9	38	319
15	1		1	1		1	1	2	3	6	16	26	37	36	14	9	7	4	9	8	8	14	6	210
16	2		1		2		2		2	3	13	18	21	18	14	8	5	4	5	7	6	1	5	137
17		2				1			1	1	9	10	23	17	7	5	4	4	4	4	1	2	1	96
18		1	2						1	1	3	12	14	18	6	2	3	4	3	3	1		3	77
19	2									2	3	5	10	10	4	1	3	3	2	4	5	3	1	58
20									1	2	4	2	5	9	5	4	2		2		2	2	1	41
21	1			1	2					1	2	7	2	3	7			1	2		1		1	31
22					1								2	2	1	1		1	2		1	1	1	13
23	1				1					1		1	1	2	2					1				10
24	2		1	1		1					2	4	5	1					1		1			19
25			1	1	1							3	3	1	3				1					14
26												2							1					3
27				1							1	2		2										6
28									1			1												2
29		1																						1
Total	119	272	494	519	528	431	159	299	885	794	2028	2141	2022	2890	2404	1611	1558	1493	4857	3402	3951	3050	2939	38846

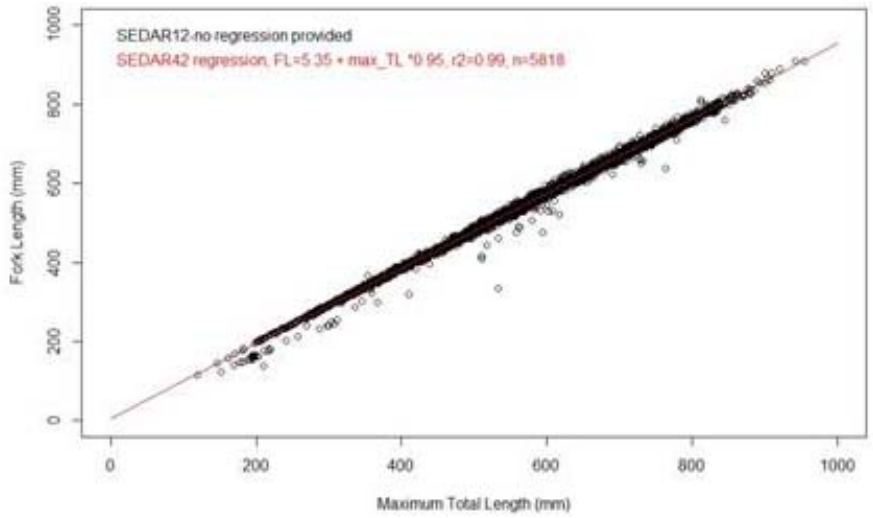
Table 11. Growth curve parameters ± standard deviation (L_∞ - asymptotic length, k – growth coefficient, t0 – size at time zero, sigma – standard deviation for models, CV – coefficient of variation) for red grouper from the northeastern Gulf of Mexico for fractional ages and observed fork lengths at capture provided for the current (1991-2013) and previous size-modified growth curves (SEDAR12, years:1991-2005, Lombardi-Carlson et al. 2006; update, years:1991-2008, Lombardi-Carlson et al. 2009). *Suggested growth model to use.

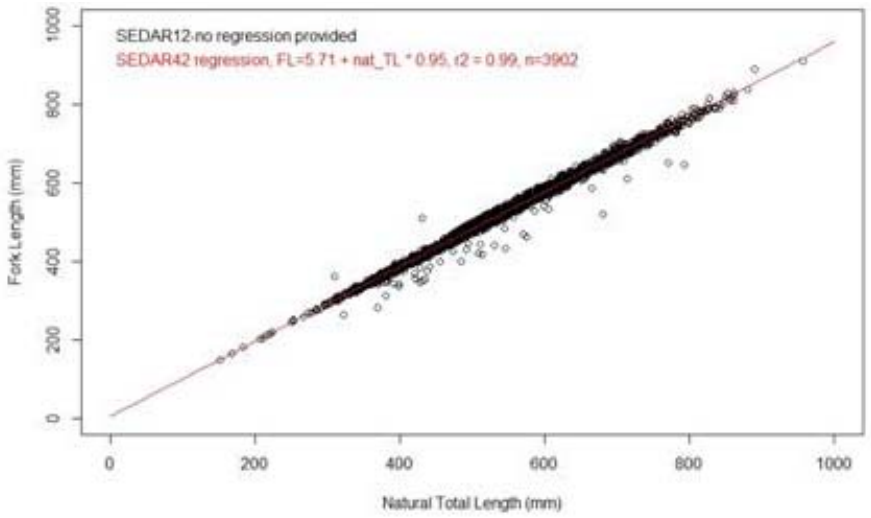
Model	n	L_∞	k	t_0	Sigma	CV
Constant CV*	38813	829 ± 5.50 (FL)	$0.1251 \pm 2.0 \times 10^{-3}$	$-1.2022 \pm 3.4 \times 10^{-2}$		$0.1548 \pm 7.7 \times 10^{-4}$
Constant std dev	38813	841 ± 5.37 (FL)	$0.1248 \pm 2.2 \times 10^{-3}$	$-1.0590 \pm 5.3 \times 10^{-2}$	79.59 ± 0.46	
CV increase with age	38813	830 ± 5.83 (FL)	$0.1249 \pm 2.0 \times 10^{-3}$	$-1.2027 \pm 3.5 \times 10^{-2}$		$0.1559 \pm 2.2 \times 10^{-3}$ $0.1510 \pm 6.9 \times 10^{-3}$
update	20143	884 (TL)	0.13	-1.01	83.37	
SEDAR12	15953	854 (TL)	0.16	-0.19	82.83	

Table 12. 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 minimum-size corrected von Bertalanffy growth model using three types of the variance structure (std dev – standard deviation, CV – coefficient of variation). *Suggested growth model to use.

Variance Structure	Phase	# parameters	Objective Function (nLL)	Change Obj. function	AIC	AICc	Delta AICc
Constant CV*	1	3	$2.07 \times 10^{+05}$		$4.13 \times 10^{+05}$	$4.13 \times 10^{+05}$	
	2	3	$2.07 \times 10^{+05}$		$4.13 \times 10^{+05}$	$4.13 \times 10^{+05}$	-1.92×10^{-09}
	3	4	$2.01 \times 10^{+05}$	$-5.72 \times 10^{+03}$	$4.02 \times 10^{+05}$	$4.02 \times 10^{+05}$	$-1.14 \times 10^{+04}$
Constant std dev	1	3	$1.08 \times 10^{+06}$		$2.15 \times 10^{+06}$	$2.15 \times 10^{+06}$	
	2	3	$1.08 \times 10^{+06}$		$2.15 \times 10^{+06}$	$2.15 \times 10^{+06}$	-2.33×10^{-09}
	3	4	$2.02 \times 10^{+05}$	$-8.73 \times 10^{+05}$	$4.05 \times 10^{+05}$	$4.05 \times 10^{+05}$	$-1.75 \times 10^{+06}$
CV increase with age	1	3	$2.06 \times 10^{+05}$		$4.12 \times 10^{+05}$	$4.12 \times 10^{+05}$	
	2	3	$2.06 \times 10^{+05}$		$4.12 \times 10^{+05}$	$4.12 \times 10^{+05}$	-3.09×10^{-09}
	3	5	$2.01 \times 10^{+05}$	$-2.53 \times 10^{+03}$	$4.02 \times 10^{+05}$	$4.02 \times 10^{+05}$	$-1.01 \times 10^{+04}$

Figure 1. Length regressions: Maximum Total Length (mm), Natural Total Length (mm), and Standard Length (mm) to Fork Length (mm).





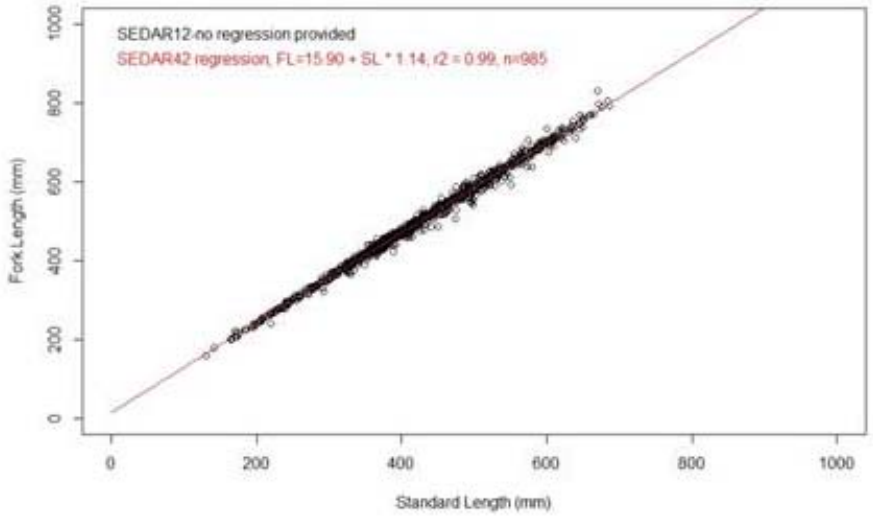


Figure 2. Weight regressions: Maximum Total Length (mm) and Natural Total (mm), to Whole Weight (kg) or Gutted Weight (kg). Regressions presented for both SEDAR12 and SEDAR42.

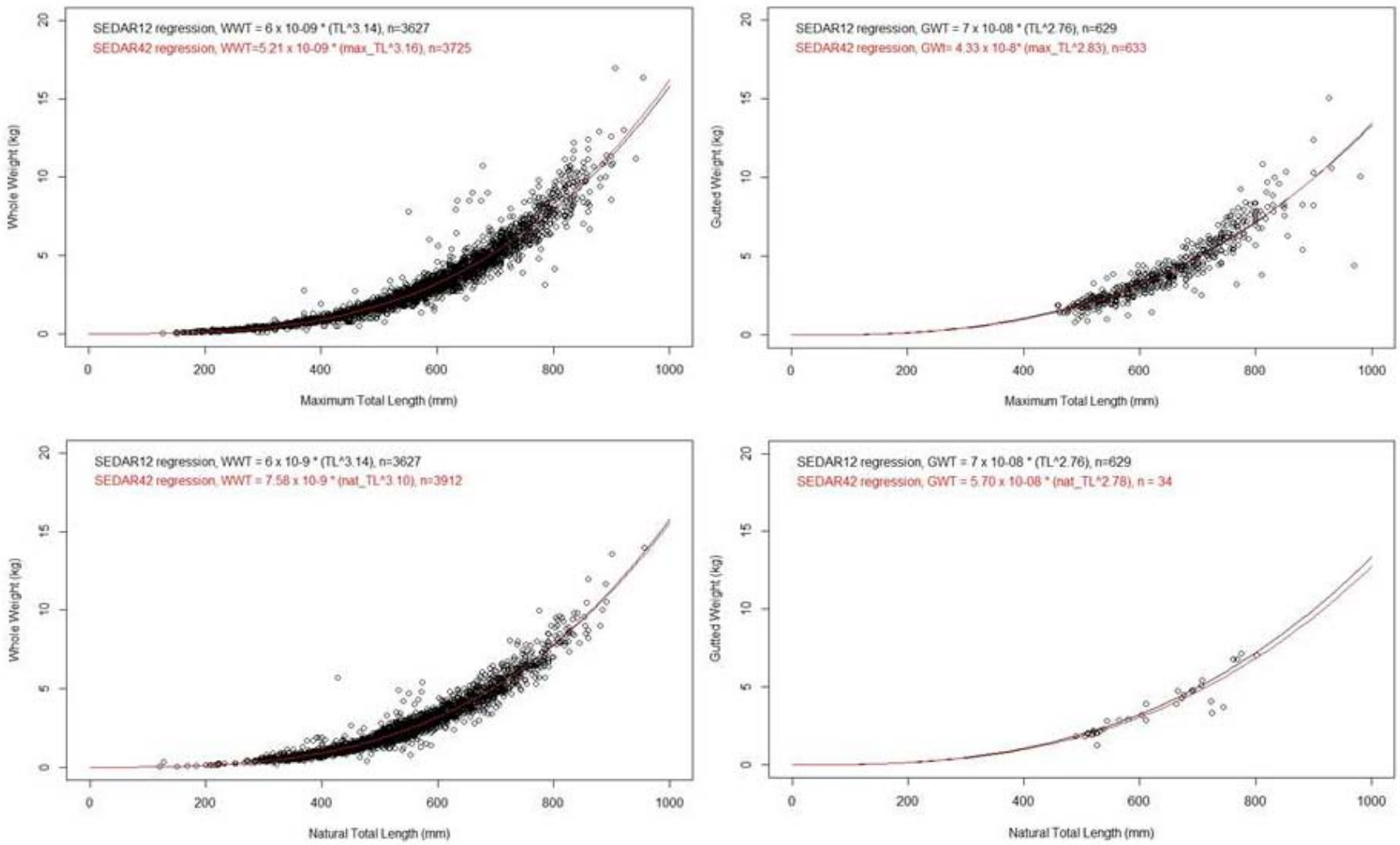


Figure 3. Observed fork length composition for red grouper aged from the northeastern Gulf of Mexico for 1991-2013. Data combined from fishery dependent (commercial and recreational) and independent sources. The trend lines indicate the normal distribution.

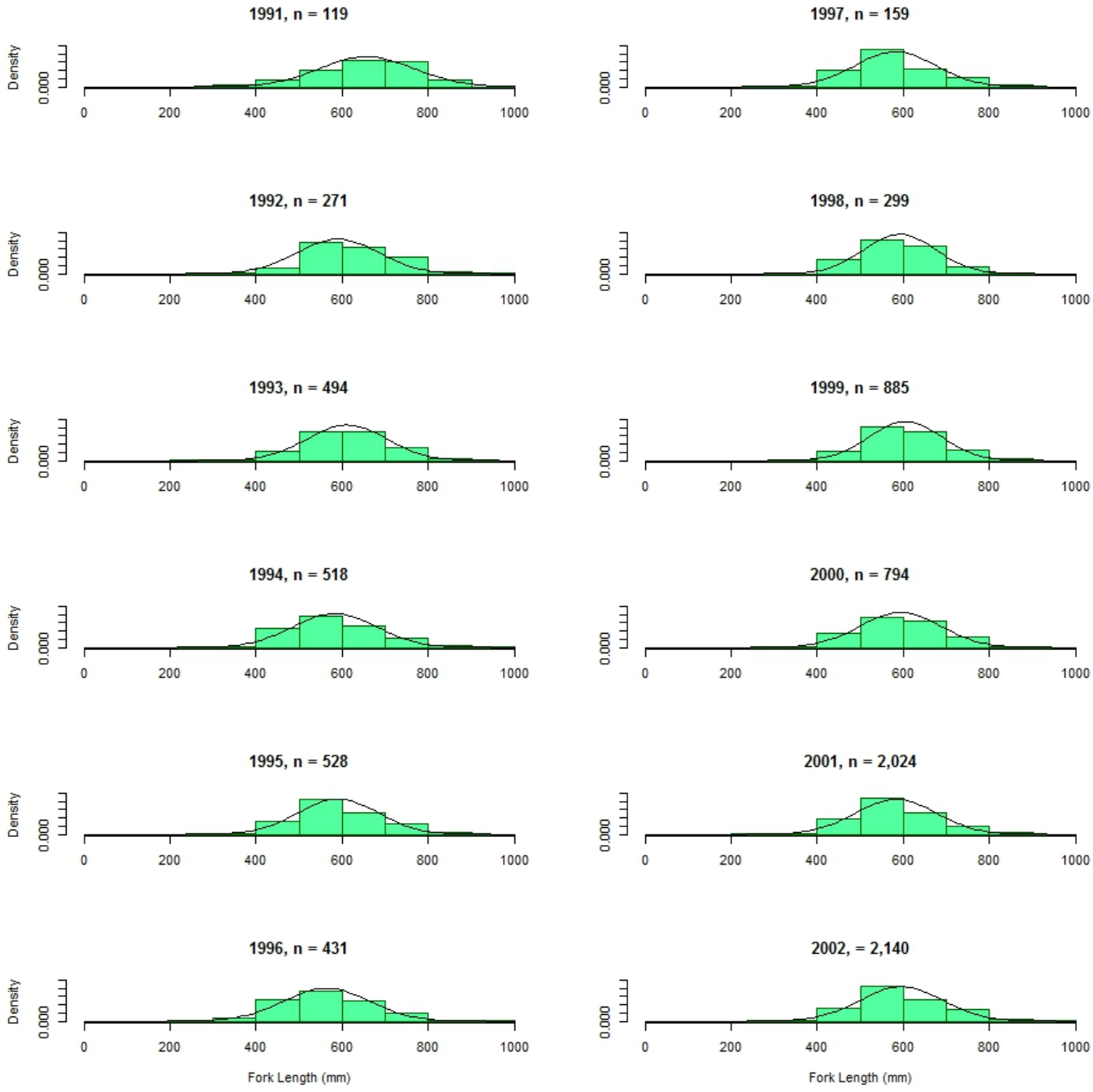


Figure 3 continued

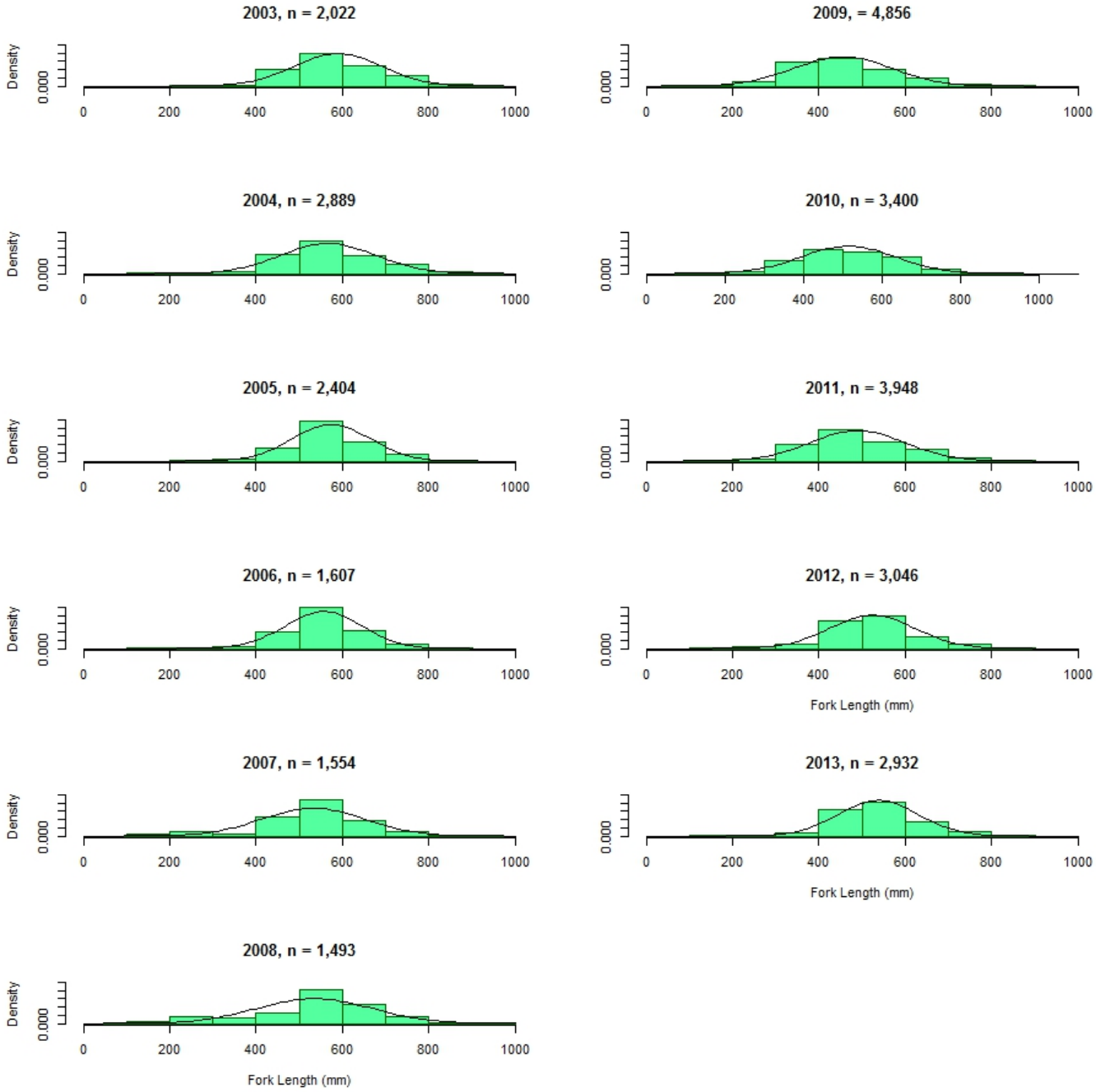


Figure 4. Box plots of Gulf of Mexico Red Grouper (1991-2013) (a) fork length and (b) age, which include the median, upper and lower quartiles (boxes: drawn in proportion to the square root of the sample size by year, upper and lower range (dashed line), and outliers (open circles). Vertical lines represent the overall mean (solid line) and upper and lower standard deviations (dashed lines).

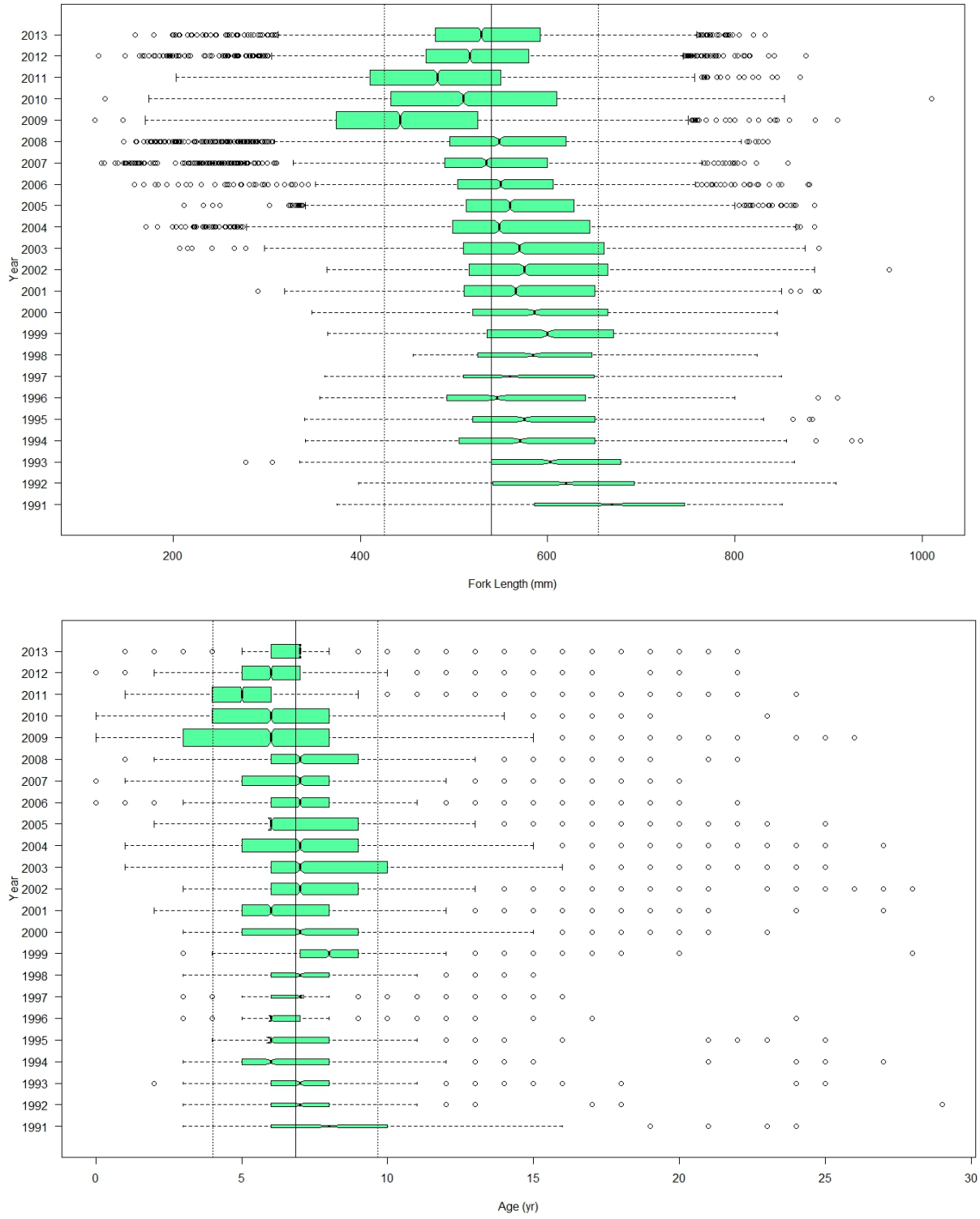


Figure 5. Observed age composition for red grouper sampled from the northeastern Gulf of Mexico for 1991-2013. Data combined from fishery dependent (commercial and recreational) and independent sources.

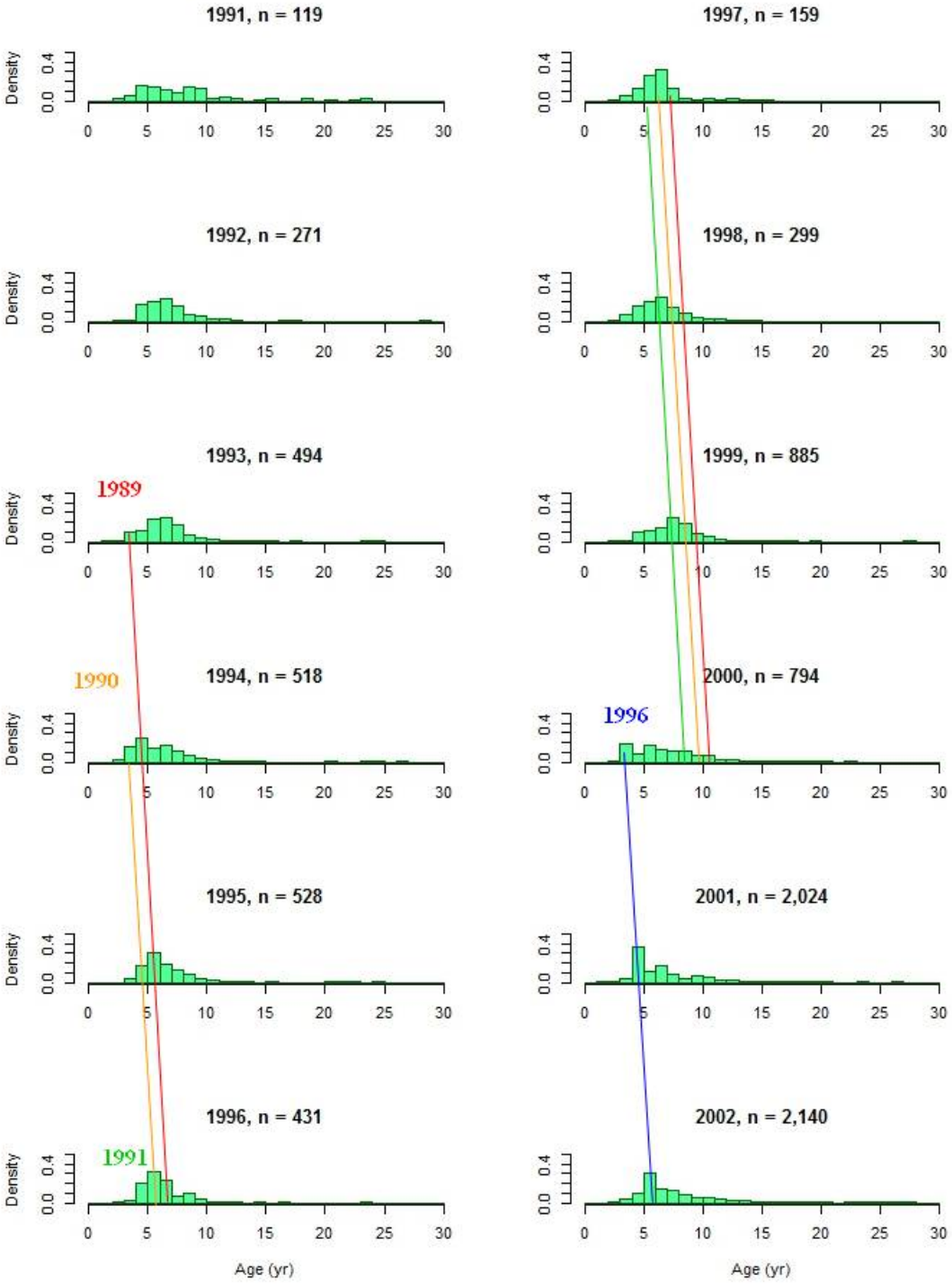


Figure 5 continued

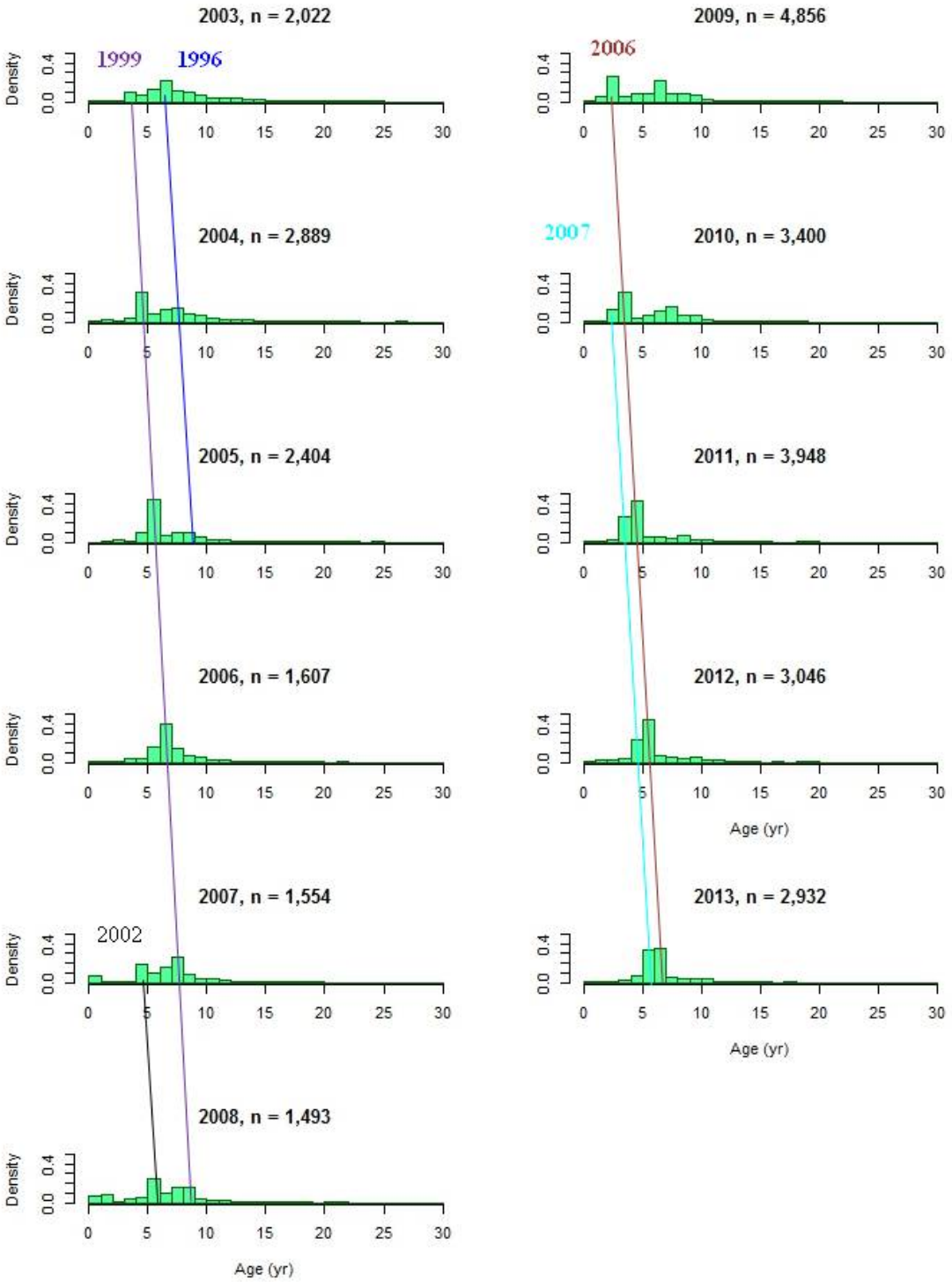


Figure 6. Comparison of red grouper (a) length distribution, (b) age distribution and (c) size-at-age (± sd) data between two time periods 1978-1989 (n = 341) and 1991-1994 (n = 696) from commercial hand-line and recreational sources. Size-at-age comparisons only for those age groups with n ≥ 5.

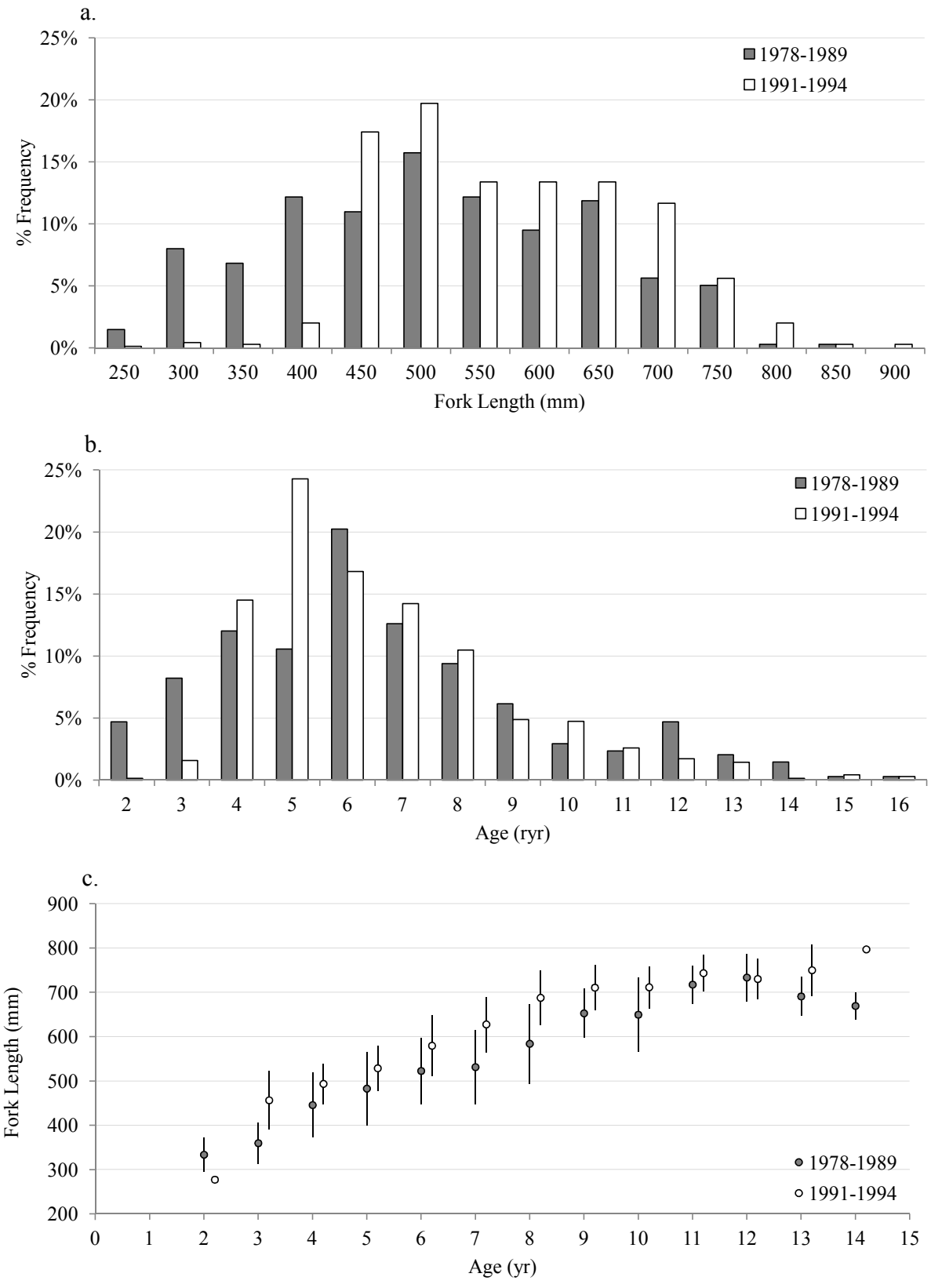
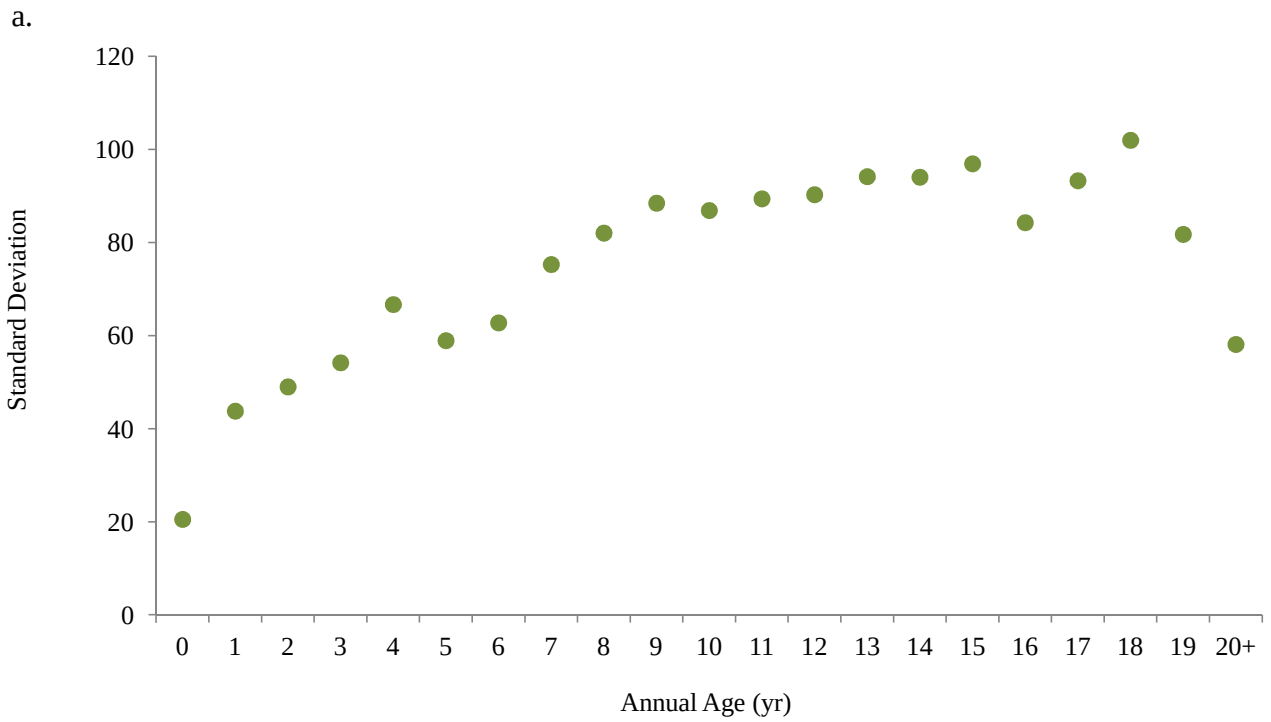


Figure 7. Variance structure for observed size-at-age data for red grouper from the northeastern Gulf of Mexico (1991-2013) (a) standard deviation and (b) coefficient of variation at length for each age group.



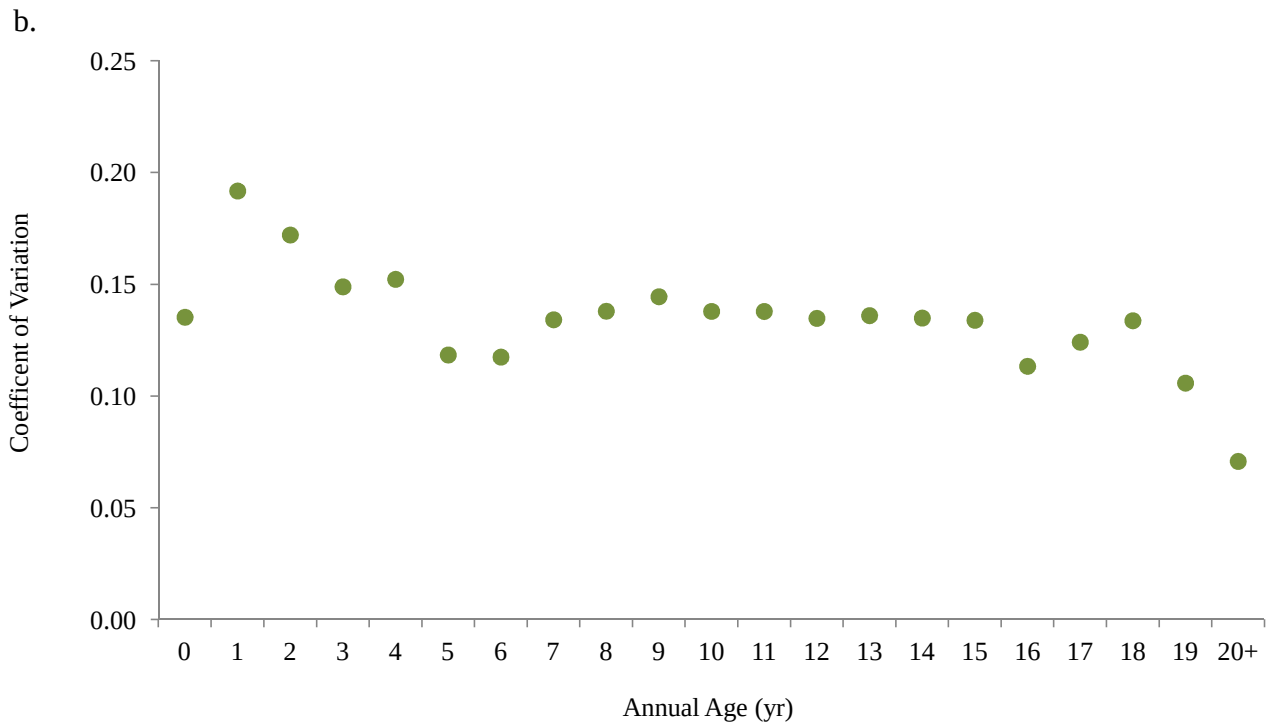
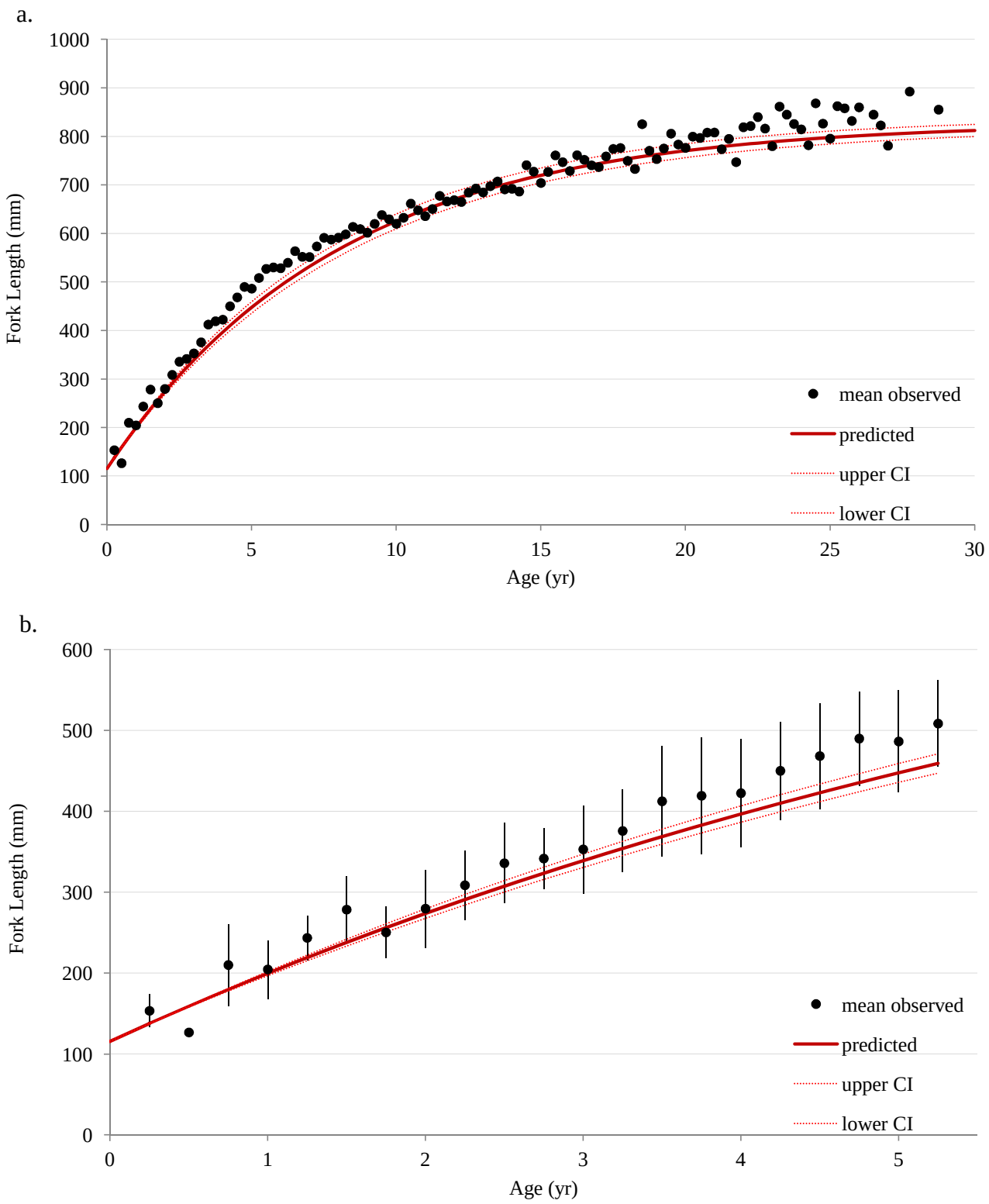


Figure 8. Results of size-modified von Bertalanffy growth model with constant variation at age variance structure for red grouper from Gulf of Mexico (1991-2013) for (a) mean fractional ages 0-30 and for (b) mean fractional ages 0-5 ± std dev. Observed mean size-at-age (black circles), estimated size-at-age (red line), and estimated 95% confidence intervals (red dashed line).



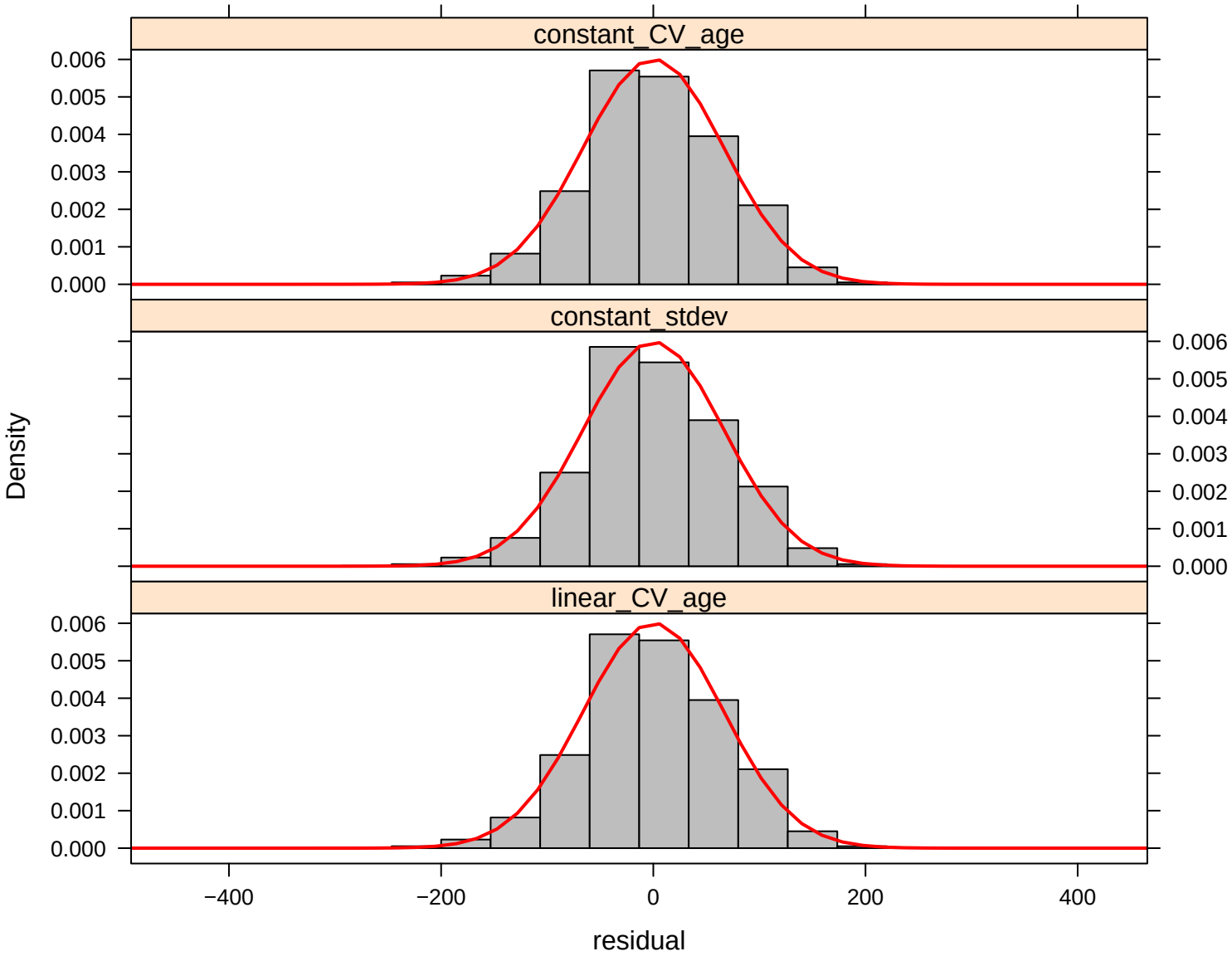


Figure 9a. Distribution of residuals for each variance structure for red grouper size-modified von Bertalanffy growth models.

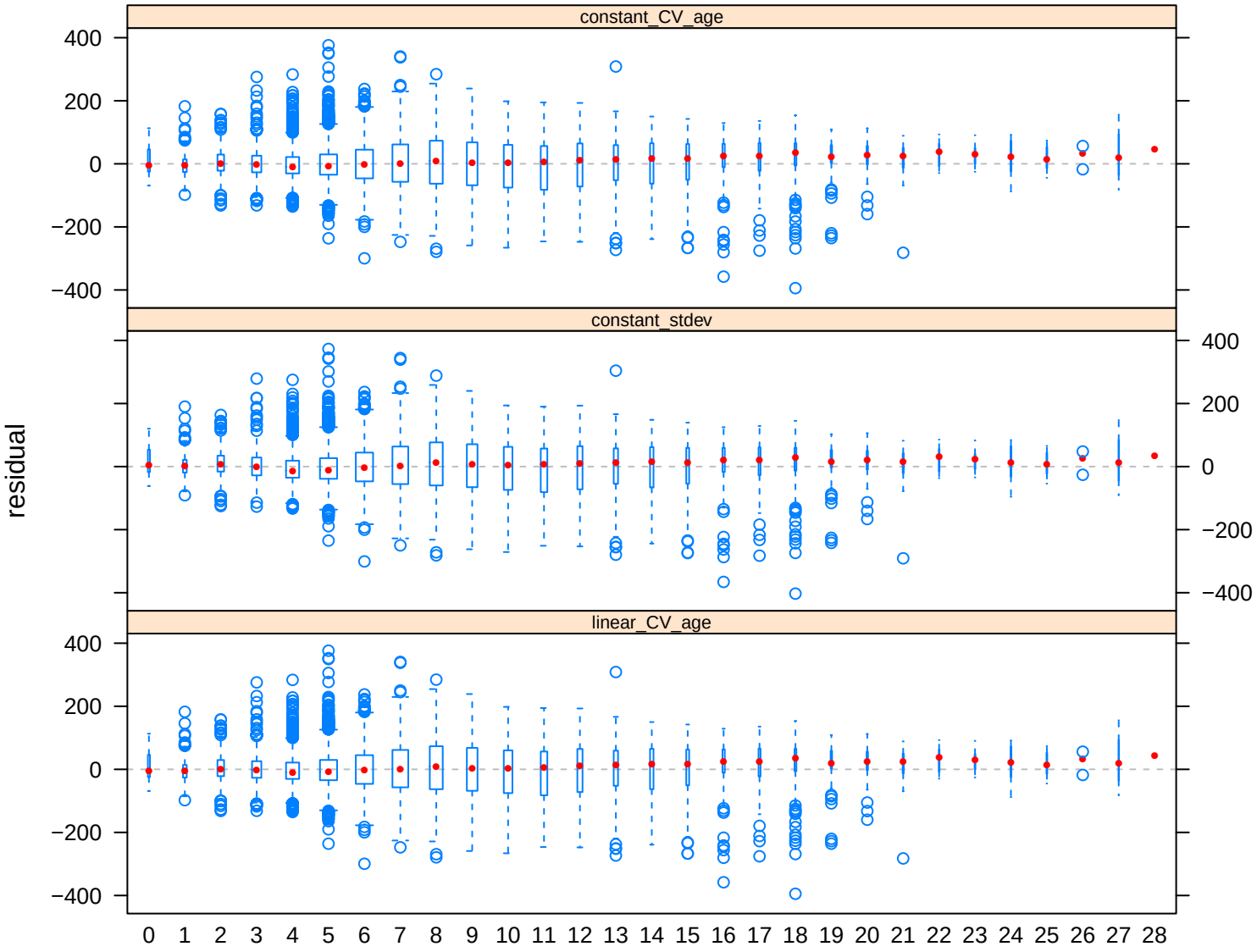


Figure 9b. Residuals by age for each variance structure red grouper von Bertalanffy growth model. See Figure 4 for description of boxplots.

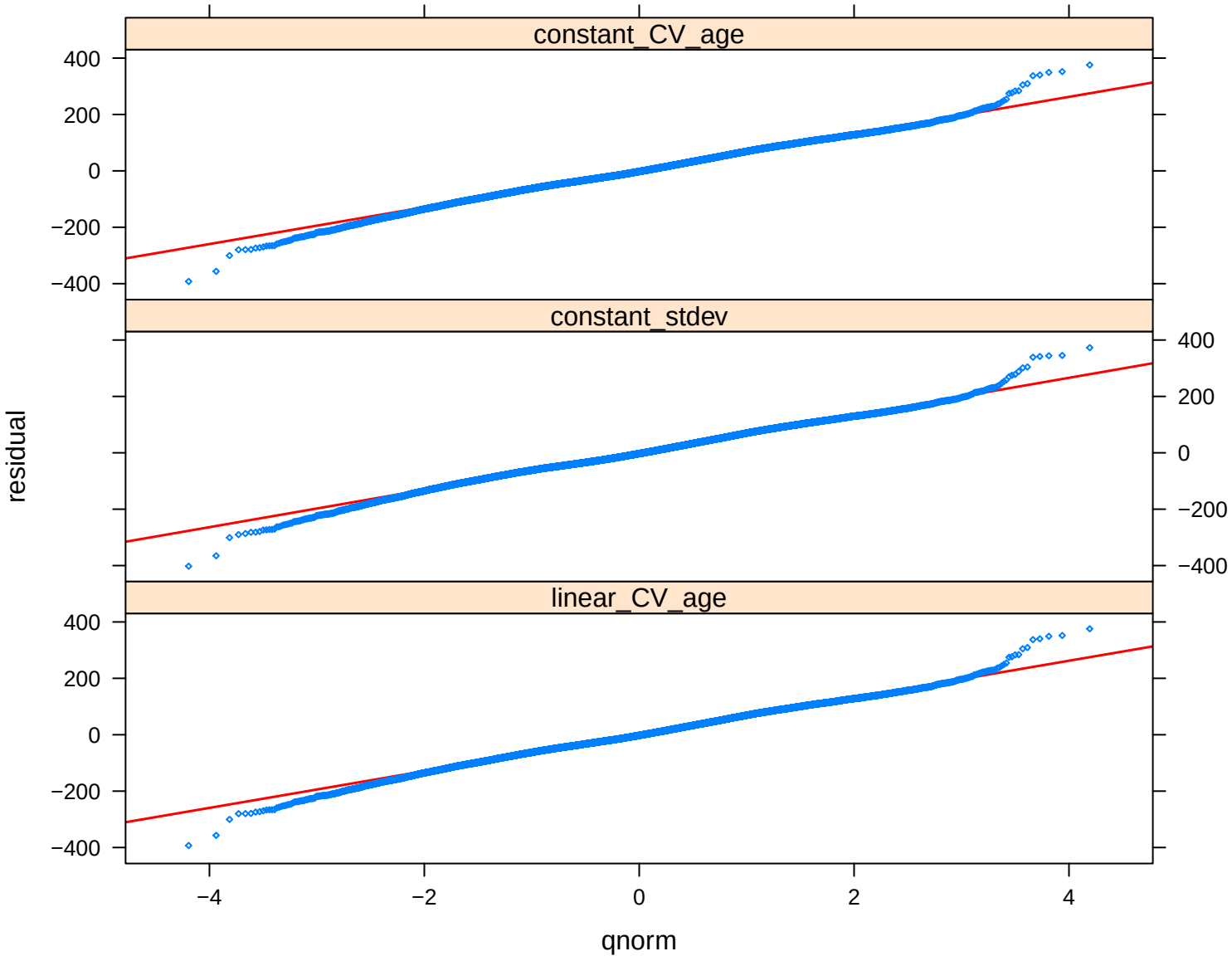


Figure 9c. Normal probability plots (quantiles vs residuals) for each variance structure red grouper von Bertalanffy growth model.