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Description of age data and estimated growth of Gray Snapper from the northern Gulf of Mexico: 1982-1983 and 1990-2015

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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 Gray Snapper from off the southeast U.S. using scales (Croker 1962, Starck and Schroeder 1970, Rutherford et al. 1983) and otoliths (Manooch and Matheson 1981, Johnson et al. 1994, Burton 2001, Fischer et al. 2005, Allman and Goetz 2009). Otolith based ages have been validated in Gray Snapper using bomb radiocarbon analysis (Fischer et al. 2005) and the timing of opaque zone formation has been reported using otolith margin analysis (Burton 2001, Fischer et al. 2005, Allman and Goetz 2009). The goal of this report is to characterize the age and length distributions and growth of Gulf of Mexico (GOM) Gray Snapper collected during 1982-1983 and 1990-2015. Gray Snapper age data were supplied by National Marine Fisheries Service, Panama City Laboratory (PCLAB), National Marine Fisheries Service Beaufort laboratory (Beaufort), the Florida Fish and Wildlife Research Institute (FWRI) and the Gulf States Marine Fisheries Commission (GSMFC).

Methods

Data collection

Gray Snapper were sampled from the commercial and recreational fisheries and from fishery independent surveys by state and federal sampling programs. Fish were measured to the nearest mm fork length (FL), or converted to FL from total length (TL) (FL = 0.9341*Maximum TL + 3.5801, r^2 = 0.99, n = 3050; FL = 0.9610*Natural TL + 2.4603, r^2 = 0.99, n = 8722). A whole or gutted weight was sometimes recorded (g) and sex was determined macroscopically if the fish was landed whole. One or both sagittal otoliths were removed, cleaned with water, dried and weighed to the nearest 0.0001 g.

Age determination

Otoliths were prepared for age determination by making two transverse cuts through the otolith core to a thickness of approximately 0.5 mm on either a low-speed or high speed saw, depending on ageing laboratory. Ages were assigned based on the count of annuli (opaque zones on the dorsal side of the sulcus acousticus in the transverse plane with reflected light at 40-70x), including any partially completed opaque zones on the otolith margin and subsequent degree of marginal edge completion. Age was advanced by one year if a large translucent zone was observed 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 2009). 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 July 1 for Gray Snapper) and capture date (difference in days divided by 365). This fraction is added to annual age if capture date is after July 1 and subtracted if capture date is before July 1 (Vanderkooy 2009).

A set of annotated Gray Snapper otolith section images (n= 100) was developed by FWRI as a training tool for new readers and otolith reader exercises were conducted during annual GSMFC otolith processer's meetings to resolve any large ageing discrepancies among laboratories/agers. To estimate reader precision a reference set of 100 Gray Snapper otolith sections was assembled by FWRI from previously aged sections. Otolith sections were selected based on time of year collected and across observed age classes. A reference age for each section was determined by reader consensus by experienced FWRI otolith readers. The reference set was read by 6 laboratories (PCLAB, Beaufort, FWRI, Mississippi Department of Marine Resources (MSDMR), Louisiana Division of Wildlife and Fisheries (LADWF) and Texas Department of Parks and Wildlife (TXDPW)). Average percent error (APE), coefficient of variation (CV) and index of precision (D) were calculated (Beamish and Fournier 1981; Campana 2001) across all laboratories' final age and between each laboratories' final ages and the reference ages.

Description of Growth Models

A growth curve, based on biological (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 (federal commercial and recreational fishery same size limits: 1990-2016, 12 inch Maximum Total Length or 288 mm Fork Length) as the left truncation limit for fisheries dependent observations. A large majority of Gray Snapper were intercepted from recreational sources fishing within the state of Florida waters, where the recreational size limit is smaller than the federal size limit (state of Florida recreational size limit: 1990-2016, 10 inch Maximum TL, 241 mm FL); therefore, various size limit scenarios were applied (size limit scenarios A: all fishery dependent records, federal size limit; B: state of Florida recreational size limit for recreational fish caught in state of Florida jurisdictional waters, all other fishery dependent records federal size limit; C: state of Florida recreational size limit for recreational fish landed in Florida, all other fishery dependent records federal size limit). The size limit scenarios B and C used both the federal and state of Florida recreational size limits. 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 Gray Snapper; however this model has been applied to multiple species assessed in the southeastern United States (e.g., Red Snapper, Vermilion Snapper, King Mackerel, Red Grouper, Gag Grouper, Grey Triggerfish, Greater Amberjack). 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 negative log-likelihood) and the ability to predict similar growth parameters and coefficients of variation, providing alternative initial growth parameters (L_∞ =

500, 550, 600; k = 0.20, 0.15, 0.10; t0 =0.00), standard deviations (sigma = 50, 70, 80), and coefficients of variation (CV = 10%, 15%, 20%). Model diagnostic plots such as predicted growth compared to observed data and the normalcy of residuals were examined.

Results and discussion

Collection

A total of 33,836 Gray Snapper otoliths were aged. The gear type recorded most often was recreational hand-line comprising 47% of fish aged, followed by commercial hand-line at 30% (Table 1). Commercial long-line samples accounted for about 10% of ages. Other gears including seine, spear, trawl, trap, and vertical long-line were reported and together accounted for 11% of fish aged. Almost half (47%) of Gray Snapper were sampled through the Trip Interview Program (TIP) (Table 2). Recreational samples accounted for 48% of otoliths collected followed by commercial (44%) and fishery independent survey (8%). From 2002 to 2015, the recreational fishery was mainly sampled by the Gulf States Marine Fisheries Commission, Recreational Fisheries Information Network (RECFIN). Otoliths collected from FL and LA made up the majority of collection (80% and 17%, respectively), while AL, MS, and TX collectively contributed approximately 3% (Table 3).

Size Structure

Size frequency distributions can provide some indication of the underlying age structure and differences were noted in sizes of Gray Snapper by fishing mode. The commercial long-line fishery was composed of the largest individuals, with dominant size classes from 400-500 mm FL and mean size of 458 mm FL (Fig. 1). The commercial hand-line size distribution had a mode of 300-350 mm FL and a mean size of 406 mm FL. The recreational hand-line fish were notably smaller with a mode at the 250-300 mm FL size class and a mean size of 394 mm FL. This difference may be partially attributed to differences in the size limit for Florida state waters (10 inches) versus federal waters (12 inches). The smallest individuals were collected by fishery independent seine and fishery independent trawl with modes in the 200-250 mm FL size class and mean sizes of 228 mm FL and 263 mm FL respectively. Fishery independent hand-line had a mode in the 400-450 mm FL size range and mean size of 405 mm FL.

Ageing

Overall APE for all 6 laboratories was 7.98%, CV was 10.71 and D was 1.80. There was large variation among laboratory in estimates of precision for final age compared to the reference age (Table 4). This was probably related to the number of Gray Snapper otoliths aged annually by each laboratory. The Florida and Louisiana laboratories historically have aged more Gray Snapper than other GOM laboratories. This was also the first exchange of a reference set for this species and reader agreement will likely improve as readers gain more experience.

Gray Snapper morphology is similar to that of the largest lutjanid the Cubera Snapper, *Lutjanus cyanopterus*. The only readily distinguishing characteristic is the vomerine tooth patch, until the Cubera Snapper reaches a size greater than that of Gray Snapper (>1 meter FL; Allen, 1985). There was evidence that some small Cubera Snapper misidentified as Gray Snapper were sampled for otoliths. Differences in otolith morphology (whole and cross-section) between these two species were observed. In addition, otolith weight plotted on age indicated heavier otoliths at age for suspected Cubera Snapper relative to Gray Snapper. These suspected Cubera Snapper otoliths (n=6) were removed from the dataset. It is possible that other Cubera Snapper were misidentified and aged as Gray Snapper, but due to the relative rarity of this species, especially in the northern GOM, these samples are expected to be few.

Gray Snapper ranged in age from 1 to 32 years. Our maximum reported age of 32 is consistent with the maximum estimated age of 28 years reported by Fischer et al. (2005), who validated with bomb radiocarbon (C-14) to ~20 years. Currently, a bomb radiocarbon (C-14) validation study is being conducted by personnel from the Panama City laboratory and the Pacific Islands Fisheries Science Center that has validated a minimum age of ~28 years.

A comparison of age distributions indicated differences by fishing mode and by sampling year. The recreational hand-line fishery selected younger fish than the commercial fishery with over half of ages 3 to 6 years. Fish fully recruited to the fishery by age 4 with a mean age of 6.6 years and only 6% of fish aged 15 or older. Fish were recruited to the commercial hand-line fishery by age 4 with a mean age of 8.4 years and 12% of fish 15 years or greater. The commercial long-line gear selected the oldest individuals with fish first fully recruited to the fishery by age 11, a mean age of 11.9 years and 26% of individuals 15 years or older (Fig. 2). Gray Snapper fully recruited to the trawl gear at age 3 with a mean age of 3.6 and 78% of fish estimated less than age 5. Recruitment to the fishery independent seine gear occurred at age 2 with a mean age of 1.7 years and 90% estimated as 1 or 2 years old. However, fishery independent hand-line fish did not recruit to the gear until age 8 and had a mean age of 9.7 years. Most of these otoliths were collected through the FWRI fishery independent monitoring (FIM) program. Fishery-dependent age frequency distributions by sampling year revealed changes in the age at recruitment, as well as a possible influence of strong year classes. The annual recruitment pattern of Gray Snapper from the commercial and recreational hand-line fishery indicates recruitment occurred by ages 3 to 6 for most years (Fig. 3). There was evidence of potentially strong year classes in 1988, 1991, 1997, 2005 and possibly 2011. Generally, the influence of strong year classes can be followed for 2 to 3 consecutive years.

Description of Growth

Gray Snapper data (observed fork lengths and fractional ages) from the entire time series (1991-2015; n = 37,482) were fit to a size-modified von Bertalanffy growth model to obtain population growth parameters (Table 5). A sub-set of records (n = 4,155) were not used in the model fits (landed along the east coast of Florida, north of Monroe County, n = 281; collected before 1991, n = 453; reported without length, n = 22; otolith unreadable, n=3,106; outlier in meristic data, n = 86; non-random bias, n = 207). Since this model takes in the effect of the minimum size limit, those fishery dependent records with fork lengths less than the corresponding minimum size limits (federal, 288 mm FL; FL state, 241 mm FL) were not used in model fitting (size limit scenarios, number of records not used: A, n = 3,234; B, n = 2,466; C, n = 703). This model also takes into consideration the variance structure of the observed size-at-age data. Gray Snapper showed an increase variation in length among all ages (Fig. 4a), which corresponded to a linear pattern of coefficient of variation size-at-age (Fig. 4b).

In attempts to better model growth for Gray Snapper, the size-modified von Bertalanffy growth model was fit using four different variance structures and fit to data corresponding to three size limit scenarios. Among the three size limit scenarios, the predicted growth model parameters resulted in: asymptotic lengths (range: 532-547 mm FL) growth coefficients (range: 0.1547 – 0.1740) and sizes-at-time zero (range: -0.7816 – -1.4557), the differences in the predicted values are most likely is due to the number of smaller size-at-age records utilized in each model given the size limits applied to the data (Table 6). Each of the size-modified von

Bertalanffy growth model and size limit scenarios predicted smaller sizes-at-age compared to observed lengths for most ages less than 7 years but predicted sizes-at-age were well within one standard deviation beginning at age 3 (size limit scenario C, Fig. 5). In all size limit scenarios, three of the four variance structures predicted similar growth curves, and the standard deviation at age variance structure predicted the smallest size-at-time zero (size limit scenario C, Fig. 5). All size limit scenarios growth models resulted in the smallest delta AICc values using the increase in coefficient variation (CV) with age variance structure (Table 6). Therefore, if the preferred model fit is based on the delta AICc values this would corresponded to the coefficient variation (CV) with age variance structure from the size limit scenario C, and resulted in the following growth parameters: $L\infty$ = 547 mm FL, k = 0.1547, to = -1.4557 (Fig. 5, Table 6). Model diagnostic plots showed similar residual patterns for each variance structure for each size limit scenario: normally distributed residuals, reasonable distribution of residuals by age, and probability plots showed divergence (Fig. 6, Fig. 7, Fig. 8). Visually, there are little differences in the residuals among the multiple variance structures and size limit scenarios model fits.

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Table 1. Numbers of Gray Snapper otoliths collected by mode (COM-commercial, REC-recreational (includes charter boat, headboat and private vessels), FI-fishery independent) by gear (CN-cast net, HL-handline, GN – gill net, LL-longline, SN – seine net, SP-spear, TN – trammel net, TR-trap, TRW-trawl, UA – unassigned, UNK-unknown, VLL-vertical longline), and by state landed (1982-2015 data combined) and by US Gulf of Mexico state (AL – Alabama, FL – Florida including Monroe to Escambia counties, LA – Louisiana, MS – Mississippi, TX – Texas). Not all otolith numbers are represented in the table due to incomplete state, mode and/or gear data.

Mode & Gear	AL	FL	LA	MS	TX	Grand Total	Percent
COM - CN		15				15	0.04
COM - HL	13	9395	1475	59	216	11158	30.41
COM - LL		3537	2		1	3540	9.65
COM - SN		4				4	0.01
COM - SP		758	60			818	2.23
COM - TR		69				69	0.19
COM - TRW			20			20	0.05
COM - UA		13				13	0.04
COM - UNK		62	158			220	0.60
COM - VLL		73				73	0.20
FI - GN		1				1	0.00
FI - HL		350				350	0.95
FI - LL		29		20		49	0.13
FI - SN		957				957	2.61
FI - SP		20				20	0.05
FI - TN		18				18	0.05
FI - TR		45				45	0.12
FI - TRW		1474		2	1	1477	4.03
FI - VLL		2				2	0.01
REC - CN		1				1	0.00
REC - HL	167	12037	4521	20	563	17308	47.17
REC - SP		372	46		10	428	1.17
REC - UNK		97	10			107	0.29
Grand Total	180	29329	6292	101	791	36693	

Table 2. Number of Gray Snapper otoliths by year and by sampling source (fishery dependent: TIP- Trip interview program, RECFIN-Gulf States Marine Fisheries Commission, Recreational 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). Not all otolith numbers are represented in the table due to incomplete year or source data.

Year	TIP	RECFIN	HB	MRFSS	PCLAB	FWRI	MSLAB	Other	Total
1980			33						33
1981			25						25
1982			105					196	301
1983			5					85	90
1990			4						4
1991	111		60						171
1992	126		161						287
1993	258		105						363
1994	521		145			1			667
1995	276		98						374
1996	321		82		8				411
1997	495		60		2				557
1998	251		7						258
1999	203		7	10	10				230
2000	95		29	8	7				139
2001	252		13	37	21		2		325
2002	273	206	44	10	48	13		64	658
2003	385	308	96	13	2	2	1	24	831
2004	424	135	54	9	9	1	2	26	660
2005	373	415	160	4	3			250	1205
2006	600	247	197	6	1	11		5	1067
2007	667	559	181	19	26	66	22	53	1593
2008	1015	1047	170	169	1	112		1	2515
2009	1558	1277	280	36	7	773	7	9	3947
2010	979	695	249	17	1	731	24	1	2697
2011	1112	811	399	18	2	309		26	2677
2012	1852	835	816	2	7	406	25	82	4025
2013	1999	724	608		5	534	1	25	3896
2014	1951	719	690	9	12	456		33	3870
2015	1389	418	859		19	460	2	37	3184
2016		110							110
Total	17486	8506	5742	367	191	3875	86	917	37170
Percent	47.04	22.88	15.45	0.99	0.51	10.43	0.23	2.47	

Table 3. Number of Gray Snapper otoliths by year and US Gulf of Mexico state landed (AL – Alabama, FL – Florida including Monroe to Escambia counties, LA – Louisiana, MS – Mississippi, TX – Texas. Not all otolith numbers are represented in the table due to incomplete year or location data.

Year	AL	FL	LA	MS	TX	Total
1980		33				33
1981		25				25
1982		301				301
1983		90				90
1990		4				4
1991	1	80	69		4	154
1992	1	189	87		7	284
1993		261	97		5	363
1994		602	62		3	667
1995		327	43		4	374
1996		354	3		2	359
1997		587				587
1998		253				253
1999		229			1	230
2000		137	2			139
2001		309	16			325
2002	18	588	52			658
2003	7	740	83	1		831
2004	3	618	37		2	660
2005	4	880	315	3	3	1205
2006	6	845	200	4	12	1067
2007	7	998	493	28	67	1593
2008	6	1767	634	7	101	2515
2009	39	3019	725	4	160	3947
2010	6	2438	166		87	2697
2011	12	1904	685	15	61	2677
2012	22	2897	952	6	148	4025
2013	18	3078	670	15	115	3896
2014	15	3394	456		4	3869
2015	20	2798	339	18	9	3184
2016			110			110
Total	185	29745	6296	101	795	37122
Percent	0.50	80.13	16.96	0.27	2.14	

Table 4. Estimates of precision for a Gray Snapper reference set by ageing laboratories. National Marine Fisheries Service, Beaufort, NC (Beaufort); Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, St. Petersburg, FL (FWRI); National Marine Fisheries Service, Panama City, FL (PCLAB); Mississippi Department of Marine Resources, Ocean Springs, MS (MSDMR); Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA (LADWF); Texas Department of Park and Wildlife (TXDPW).

Laboratory	n	APE	CV	D
Beaufort	99	1.87	2.65	1.32
FWRI	100	1.6	2.26	1.13
PCLAB	99	2.56	2.2	1.1
MSDMR	99	6.36	7.57	3.78
LADWF	100	1.64	2.32	1.16
TXDPW	100	11.08	15.67	7.83

Table 5. 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 Gray Snapper from the northern Gulf of Mexico for fractional ages and observed fork lengths at capture (1991-2015).

Size limit scenario A: federal size limit for all fishery dependent records.

Model	n	L_∞	k	t_0	Sigma	CV
Constant std dev	30093	538 ± 1.81	0.1720 ± 2.5 x 10^{-3}	-1.0225 ± 5.2 x 10^{-2}	67.75 ± 0.33	
Constant CV	30093	532 ± 1.76	0.1740 ± 2.1 x 10^{-3}	-1.3524 ± 3.5 x 10^{-2}		0.1649 ± 9.0 x 10^{-4}
Increase CV w/Age	30093	534 ± 1.89	0.1712 ± 2.2 x 10^{-3}	-1.3668 ± 3.6 x 10^{-2}		0.1713 ± 1.9 x 10^{-3} 0.1568 ± 2.2 x 10^{-3}
Increase CV w/ Size-at-Age	30093	532 ± 1.76	0.1740 ± 2.1 x 10^{-3}	-1.3524 ± 3.5 x 10^{-2}		0.1500 ± 1.8 x 10^{+2} 0.1649 ± 9.0 x 10^{-4}

Size limit scenario B: state of Florida recreational size limit for recreational fish caught in state of Florida jurisdictional waters, all other fishery dependent records federal size limit.

Model	n	L_∞	k	t_0	Sigma	CV
Constant std dev	30861	538 ± 1.78	0.1733 ± 2.5 x 10^{-3}	-0.9817 ± 5.0 x 10^{-2}	67.55 ± 0.33	
Constant CV	30861	532 ± 1.78	0.1723 ± 2.1 x 10^{-3}	-1.3870 ± 3.5 x 10^{-2}		0.1652 ± 9.0 x 10^{-4}
Increase CV w/Age	30861	535 ± 1.90	0.1695 ± 2.2 x 10^{-3}	-1.3994 ± 3.6 x 10^{-2}		0.1721 ± 1.9 x 10^{-3} 0.1564 ± 2.2 x 10^{-3}
Increase CV w/ Size-at-Age	30861	533 ± 1.86	0.1718 ± 2.1 x 10^{-3}	-1.3830 ± 3.5 x 10^{-2}		0.1694 ± 3.4 x 10^{-3} 0.1636 ± 1.5 x 10^{-3}

Size limit scenario C: state of Florida recreational size limit for recreational fish landed in Florida, all other fishery dependent records federal size limit

Model	n	L_∞	k	t_0	Sigma	CV
Constant std dev	32624	542 ± 1.83	0.1698 ± 2.3 x 10^{-3}	-0.7816 ± 5.0 x 10^{-2}	68.70 ± 0.33	
Constant CV	32624	541 ± 2.01	0.1597 ± 2.0 x 10^{-3}	-1.4531 ± 3.5 x 10^{-2}		0.1729 ± 9.5 x 10^{-4}
Increase CV w/Age	32624	547 ± 2.09	0.1547 ± 2.0 x 10^{-3}	-1.4557 ± 3.6 x 10^{-2}		0.1891 ± 2.0 x 10^{-3} 0.1514 ± 2.2 x 10^{-3}
Increase CV w/ Size-at-Age	32624	544 ± 2.1	0.1580 ± 2.0 x 10^{-3}	-1.4163 ± 3.6 x 10^{-2}		0.1922 ± 3.5 x 10^{-3} 0.1643 ± 1.7 x 10^{-3}

Table 6. The resulting model objective functions (negative log-likelihood, nLL), the change in the objective function, and resulting Akaike Information Criteria (AIC) 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) for Gray Snapper from the northern Gulf of Mexico.

Size limit scenario A: federal size limit for all fishery dependent records.

Variance Structure	Phase	# parameters	Objective Function (nLL)	Change Obj. function	AIC	AICc	Delta AICc
Constant std dev	1	3	$1.630 \times 10^{+05}$		$3.261 \times 10^{+05}$	$3.261 \times 10^{+05}$	
	2	3	$1.630 \times 10^{+05}$		$3.261 \times 10^{+05}$	$3.261 \times 10^{+05}$	0.00
	3	4	$1.630 \times 10^{+05}$	-21.43	$3.260 \times 10^{+05}$	$3.260 \times 10^{+05}$	-40.86
Constant CV	1	3	$1.622 \times 10^{+05}$		$3.244 \times 10^{+05}$	$3.244 \times 10^{+05}$	
	2	3	$1.622 \times 10^{+05}$		$3.244 \times 10^{+05}$	$3.244 \times 10^{+05}$	-6.98×10^{-10}
	3	4	$1.620 \times 10^{+05}$	-165.70	$3.240 \times 10^{+05}$	$3.240 \times 10^{+05}$	-327.40
Increase CV w/ Age	1	3	$1.691 \times 10^{+05}$		$3.381 \times 10^{+05}$	$3.381 \times 10^{+05}$	
	2	3	$1.691 \times 10^{+05}$		$3.381 \times 10^{+05}$	$3.381 \times 10^{+05}$	0.00
	3	5	$1.620 \times 10^{+05}$	-3528.41	$3.240 \times 10^{+05}$	$3.240 \times 10^{+05}$	-14109.60
Increase CV w/ Size-at-Age	1	3	$1.691 \times 10^{+05}$		$3.381 \times 10^{+05}$	$3.381 \times 10^{+05}$	
	2	3	$1.691 \times 10^{+05}$		$3.381 \times 10^{+05}$	$3.381 \times 10^{+05}$	0.00
	3	5	$1.620 \times 10^{+05}$	-3524.65	$3.240 \times 10^{+05}$	$3.240 \times 10^{+05}$	-14094.60

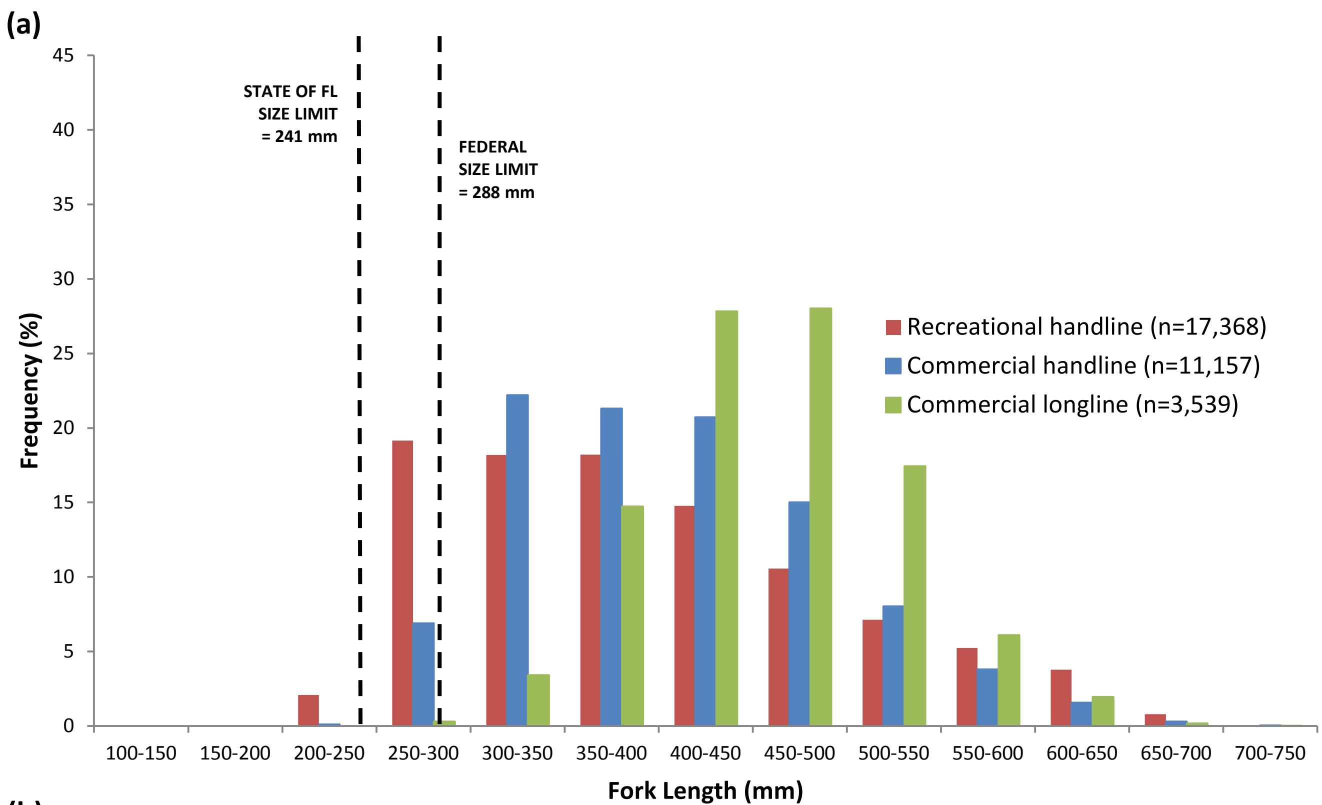
Size limit scenario B: state of Florida recreational size limit for recreational fish caught in state of Florida jurisdictional waters, all other fishery dependent records federal size limit.

Variance Structure	Phase	# parameters	Objective Function (nLL)	Change Obj. function	AIC	AICc	Delta AICc
Constant std dev	1	3	$1.696 \times 10^{+05}$		$3.392 \times 10^{+05}$	$3.392 \times 10^{+05}$	
	2	3	$1.696 \times 10^{+05}$		$3.392 \times 10^{+05}$	$3.392 \times 10^{+05}$	-5.82×10^{-11}
	3	4	$1.671 \times 10^{+05}$	-2490.49	$3.342 \times 10^{+05}$	$3.342 \times 10^{+05}$	-4978.97
Constant CV	1	3	$1.662 \times 10^{+05}$		$3.325 \times 10^{+05}$	$3.325 \times 10^{+05}$	
	2	3	$1.662 \times 10^{+05}$		$3.325 \times 10^{+05}$	$3.325 \times 10^{+05}$	-2.91×10^{-10}
	3	4	$1.661 \times 10^{+05}$	-176.63	$3.321 \times 10^{+05}$	$3.321 \times 10^{+05}$	-351.25
Increase CV w/ Age	1	3	$1.734 \times 10^{+05}$		$3.467 \times 10^{+05}$	$3.467 \times 10^{+05}$	
	2	3	$1.734 \times 10^{+05}$		$3.467 \times 10^{+05}$	$3.467 \times 10^{+05}$	0.00
	3	5	$1.661 \times 10^{+05}$	-3652.52	$3.321 \times 10^{+05}$	$3.321 \times 10^{+05}$	-14606.10
Increase CV w/ Size-at-Age	1	3	$1.661 \times 10^{+05}$		$3.322 \times 10^{+05}$	$3.322 \times 10^{+05}$	
	2	3	$1.661 \times 10^{+05}$		$3.322 \times 10^{+05}$	$3.322 \times 10^{+05}$	-2.91×10^{-10}
	3	5	$1.661 \times 10^{+05}$	-24.86	$3.221 \times 10^{+05}$	$3.221 \times 10^{+05}$	-95.44

Size limit scenario C: state of Florida recreational size limit for recreational fish landed in Florida, all other fishery dependent records federal size limit

Variance Structure	Phase	# parameters	Objective Function (nLL)	Change Obj. function	AIC	AICc	Delta AICc
Constant std dev	1	3	$1.760 \times 10^{+05}$		$3.520 \times 10^{+05}$	$3.520 \times 10^{+05}$	
	2	3	$1.760 \times 10^{+05}$		$3.520 \times 10^{+05}$	$3.520 \times 10^{+05}$	-1.80×10^{-09}
	3	4	$1.760 \times 10^{+05}$	-7.32	$3.520 \times 10^{+05}$	$3.520 \times 10^{+05}$	-12.66
Constant CV	1	3	$1.754 \times 10^{+05}$		$3.508 \times 10^{+05}$	$3.508 \times 10^{+05}$	
	2	3	$1.754 \times 10^{+05}$		$3.508 \times 10^{+05}$	$3.508 \times 10^{+05}$	-4.66×10^{-10}
	3	4	$1.750 \times 10^{+05}$	-389.13	$3.500 \times 10^{+05}$	$3.500 \times 10^{+05}$	-776.27
Increase CV w/ Age	1	3	$1.839 \times 10^{+05}$		$3.679 \times 10^{+05}$	$3.679 \times 10^{+05}$	
	2	3	$1.839 \times 10^{+05}$		$3.379 \times 10^{+05}$	$3.379 \times 10^{+05}$	0.00
	3	5	$1.750 \times 10^{+05}$	-4492.14	$3.499 \times 10^{+05}$	$3.499 \times 10^{+05}$	-17964.50
Increase CV w/ Size-at-Age	1	3	$1.754 \times 10^{+05}$		$3.508 \times 10^{+05}$	$3.508 \times 10^{+05}$	
	2	3	$1.754 \times 10^{+05}$		$3.508 \times 10^{+05}$	$3.508 \times 10^{+05}$	0.00
	3	5	$1.750 \times 10^{+05}$	-202.99	$3.500 \times 10^{+05}$	$3.500 \times 10^{+05}$	-807.95

Figure 1. Gulf of Mexico Gray Snapper length frequency distributions for (a) fishery dependent and (b) fishery independent fish for all years combined (1980-2015). Not all lengths are represented due to incomplete mode data.



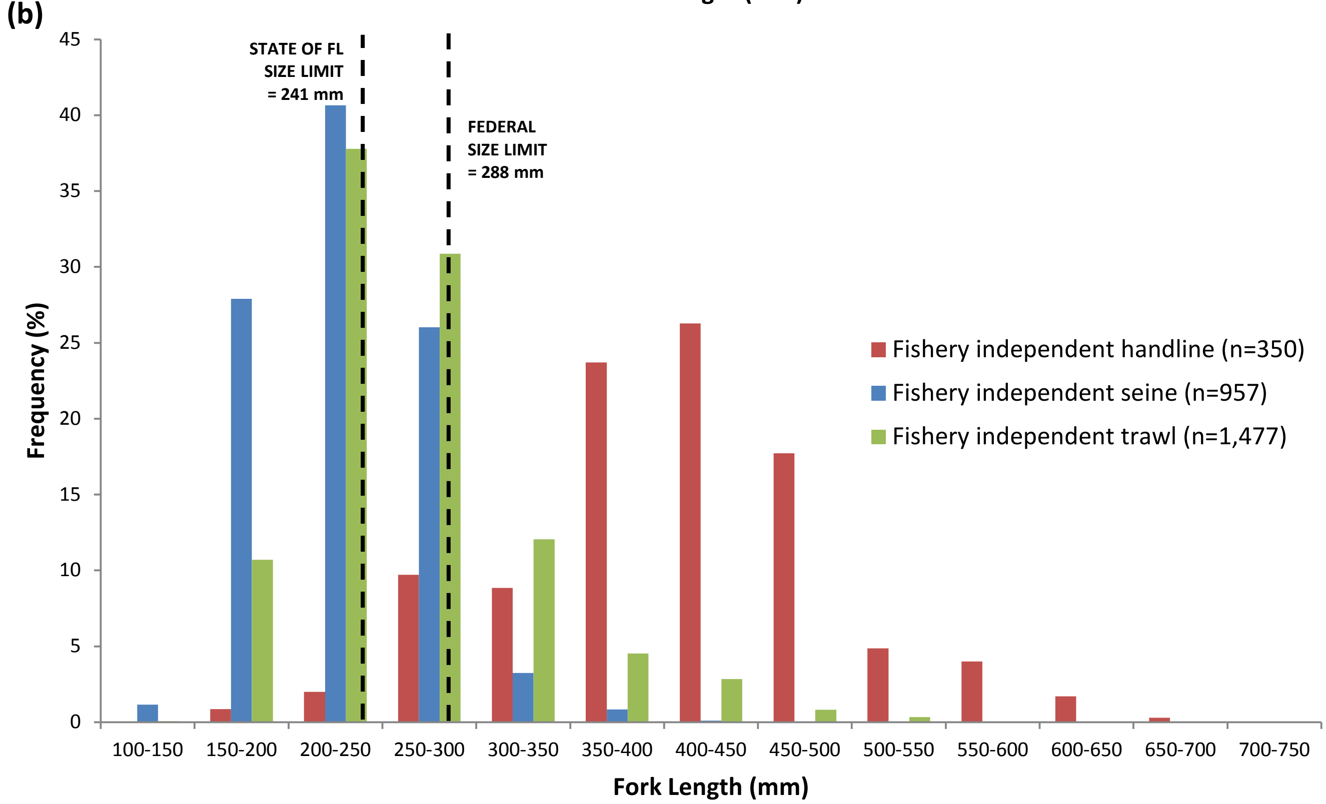


Figure 2. Gulf of Mexico Gray Snapper age frequency distributions for (a) fishery dependent and (b) fishery independent fish for all years combined (1980-2015). Not all ages are represented due to incomplete mode data. Arrows indicate maximum age.

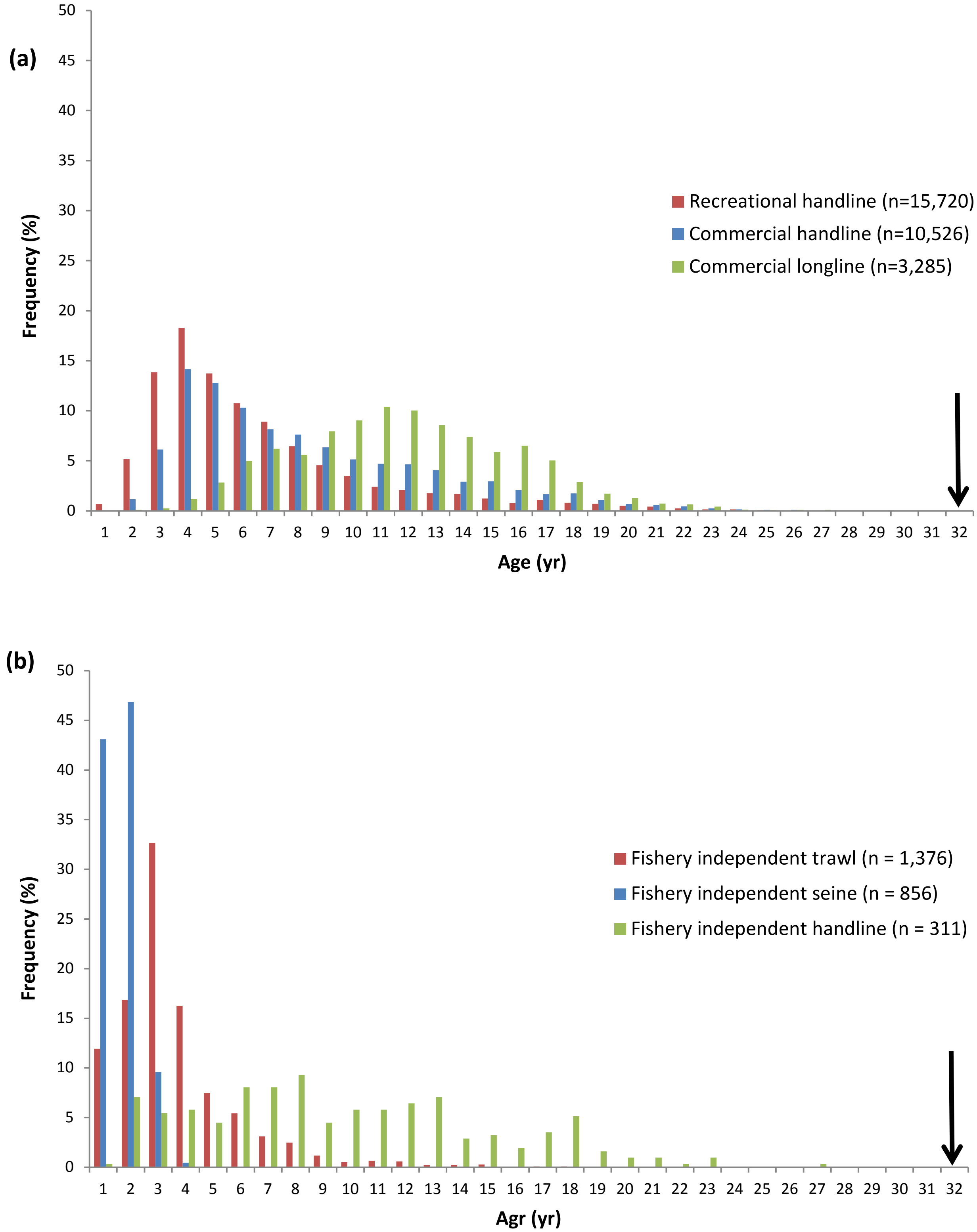
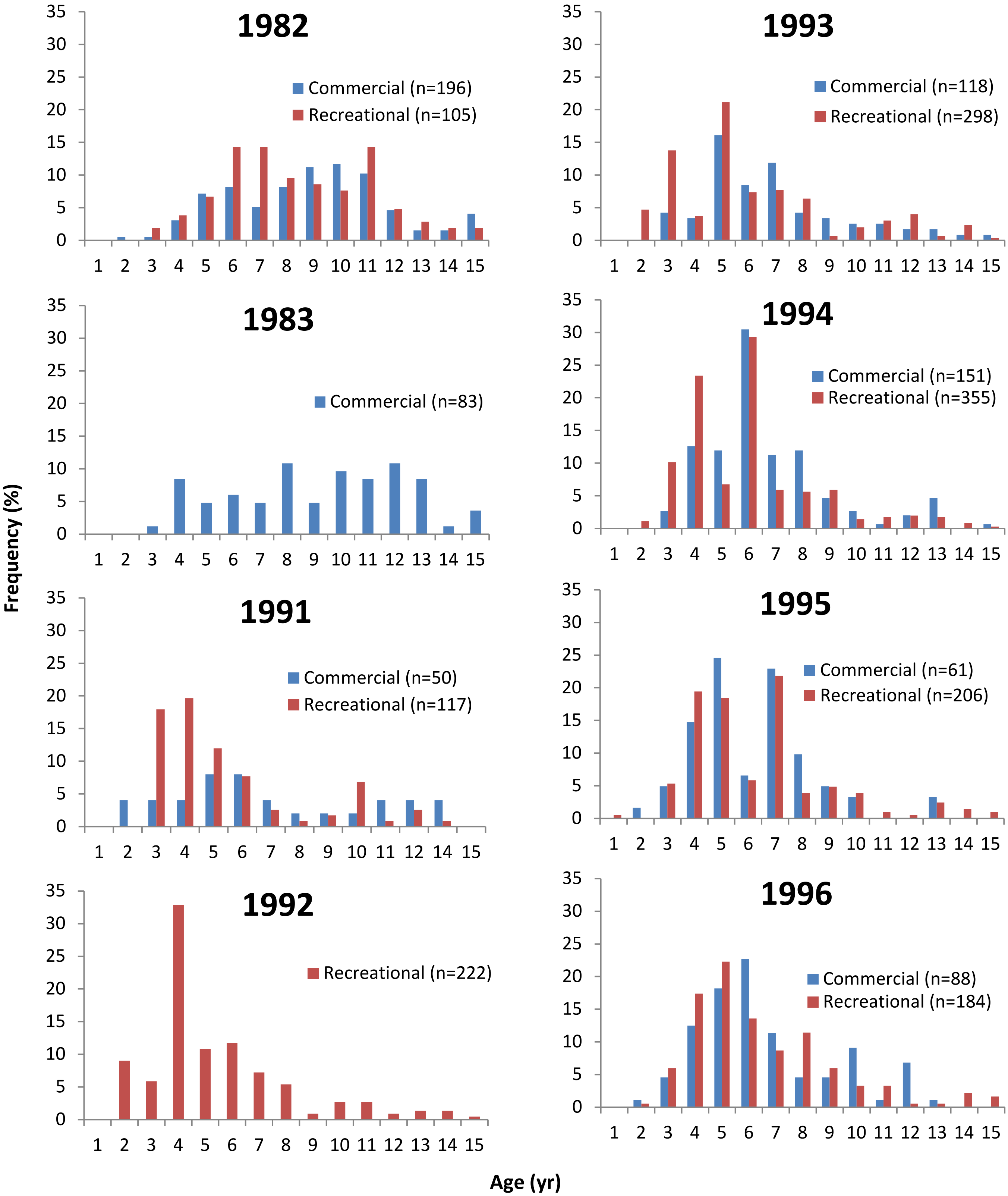
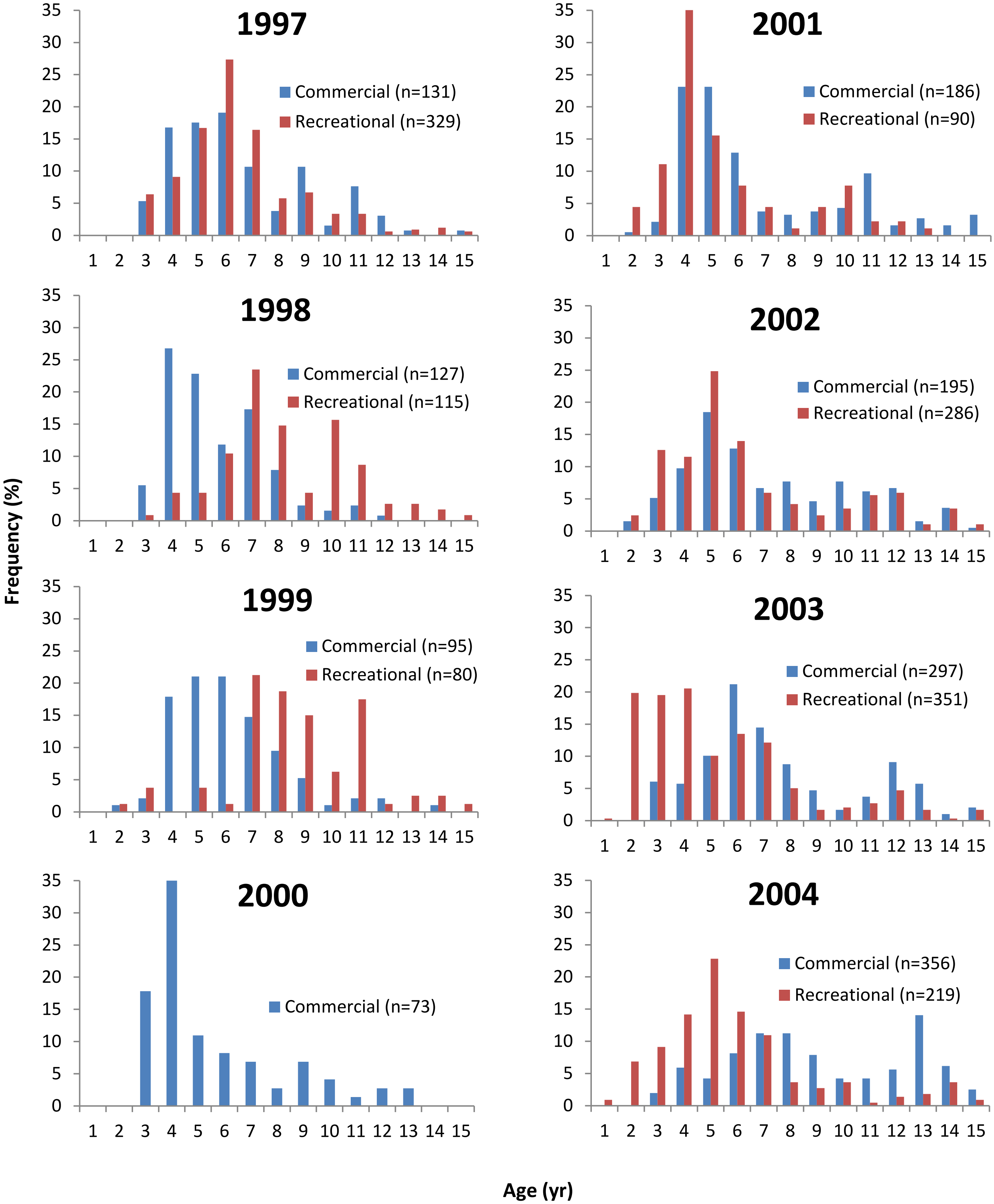
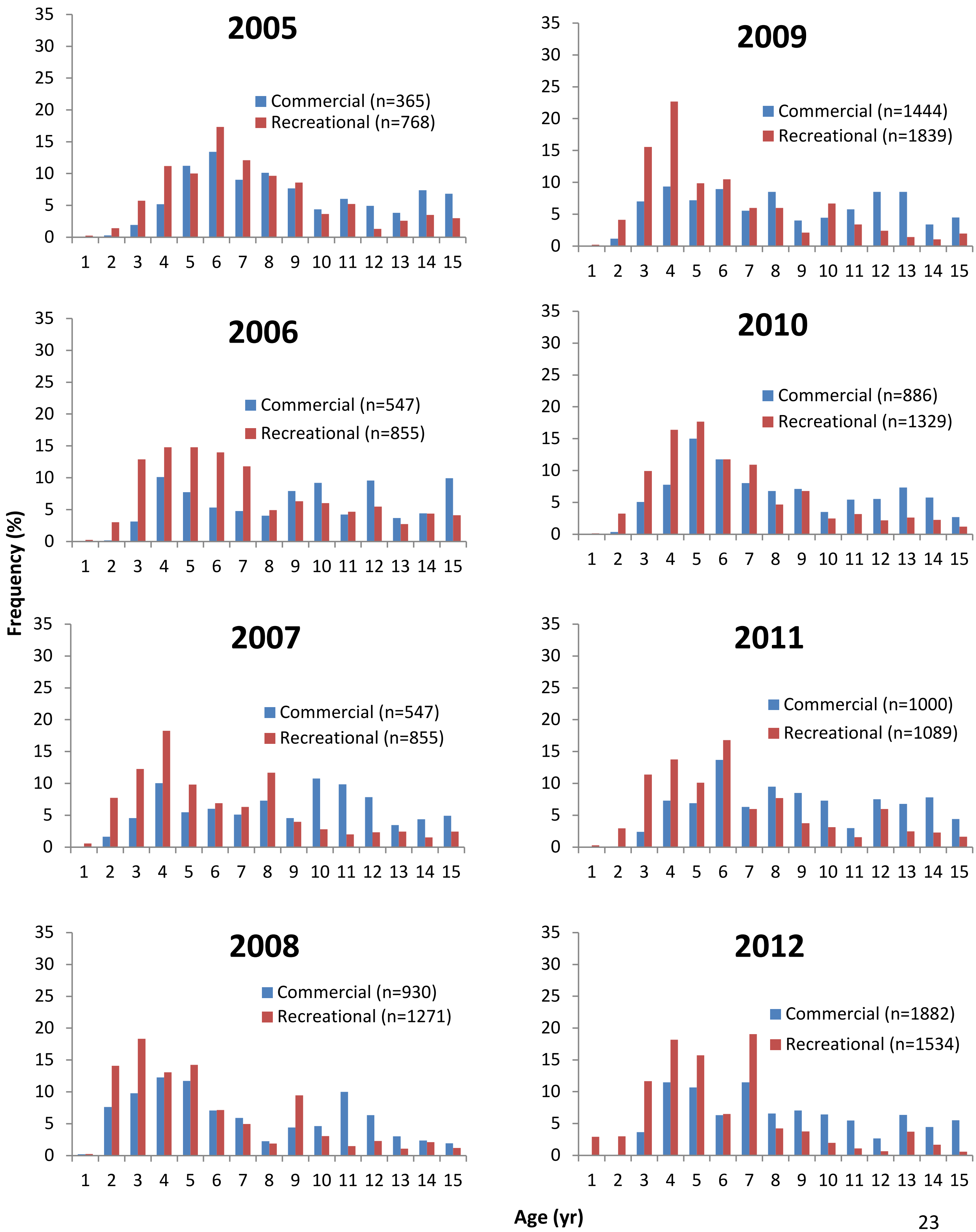


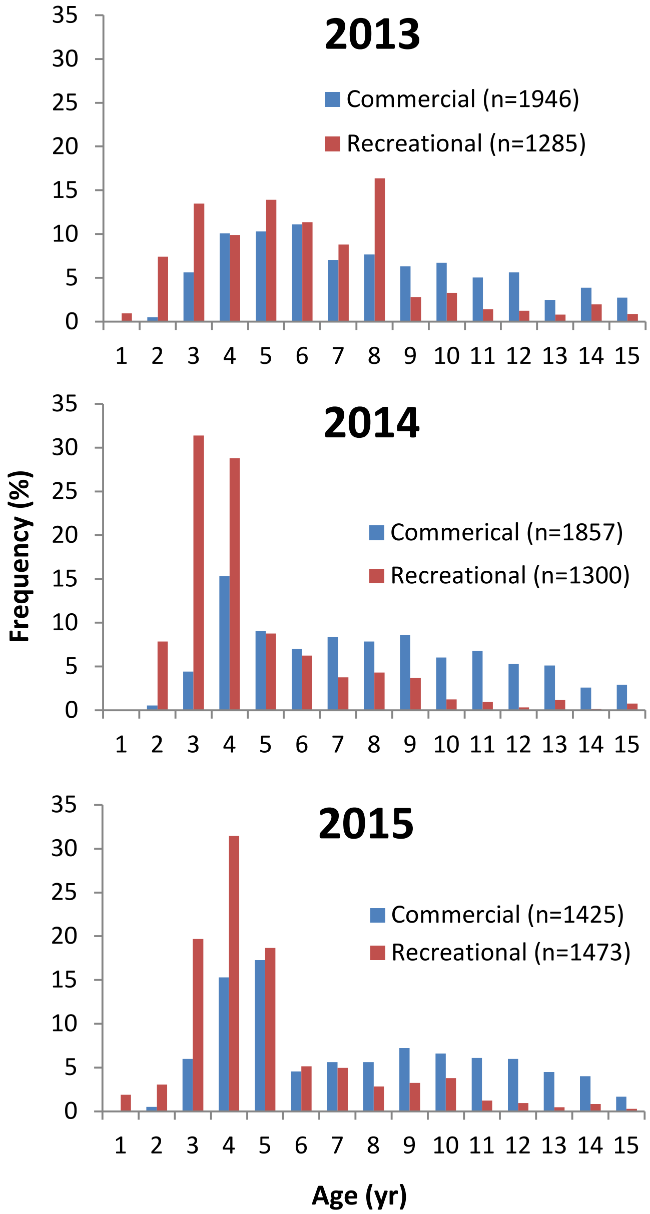
Figure 3. Gulf of Mexico Gray Snapper age frequency distributions by year. Only years with at least 50 observations were included and only ages 1-15 displayed.





1997
Commercial (n=131)
Recreational (n=329)
2001
Commercial (n=186)
Recreational (n=90)
1998
Commercial (n=127)
Recreational (n=115)
2002
Commercial (n=195)
Recreational (n=286)
1999
Commercial (n=95)
Recreational (n=80)
2003
Commercial (n=297)
Recreational (n=351)
2000
Commercial (n=73)
2004
Commercial (n=356)
Recreational (n=219)
Frequency (%)
Age (yr)


2005
Commercial (n=365)
Recreational (n=768)
2009
Commercial (n=1444)
Recreational (n=1839)
2006
Commercial (n=547)
Recreational (n=855)
2010
Commercial (n=886)
Recreational (n=1329)
2007
Commercial (n=547)
Recreational (n=855)
2011
Commercial (n=1000)
Recreational (n=1089)
2008
Commercial (n=930)
Recreational (n=1271)
2012
Commercial (n=1882)
Recreational (n=1534)
Frequency (%)
Age (yr)


2013
Commercial (n=1946)
Recreational (n=1285)
2014
Commerical (n=1857)
Recreational (n=1300)
2015
Commercial (n=1425)
Recreational (n=1473)
Frequency (%)
Age (yr)
0
5
10
15
20
25
30
35
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

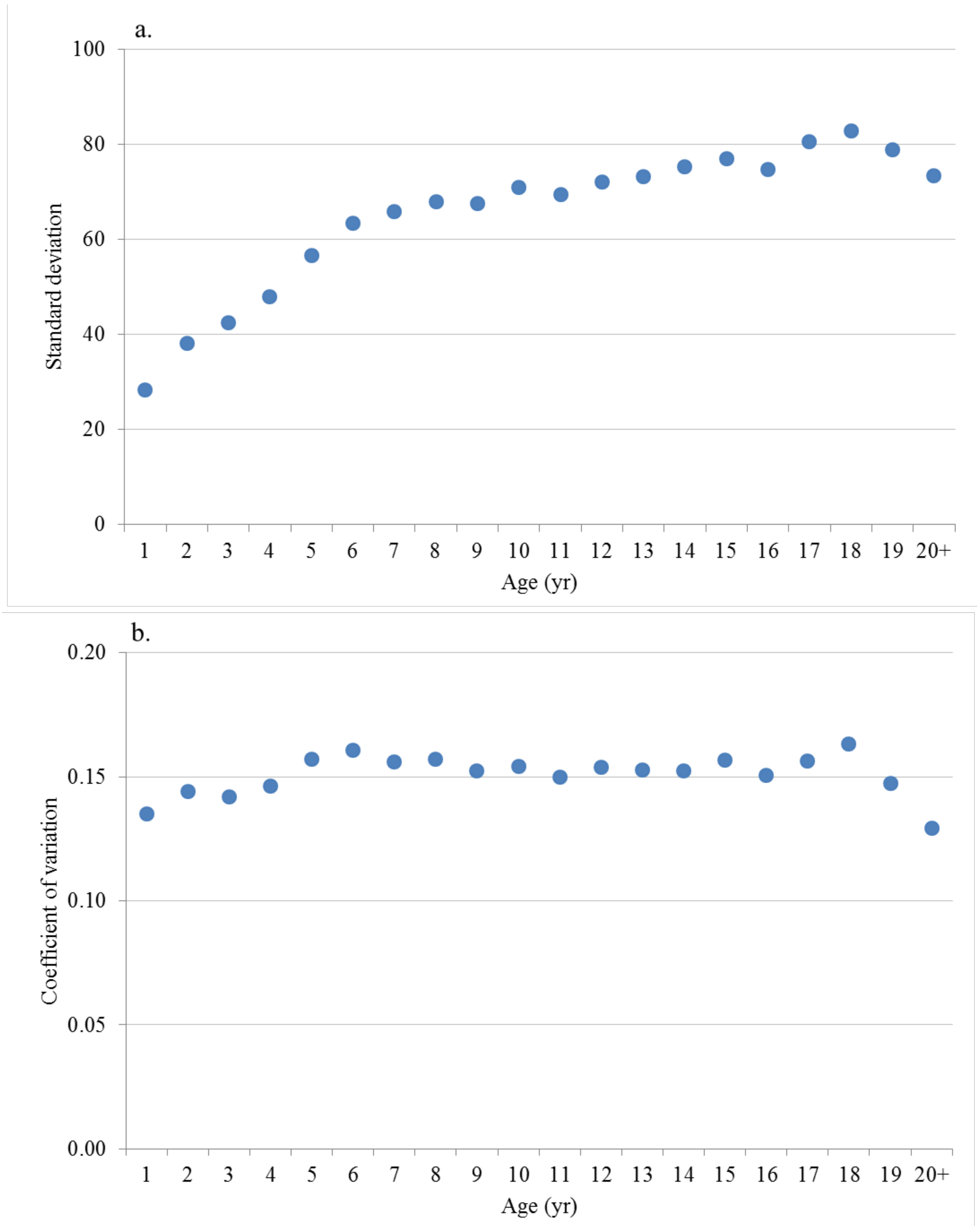


Figure 4. Variance structure for observed size-at-age data for Gray Snapper from the northern Gulf of Mexico (1991-2015) (a) standard deviation and (b) coefficient of variation at length for each age.

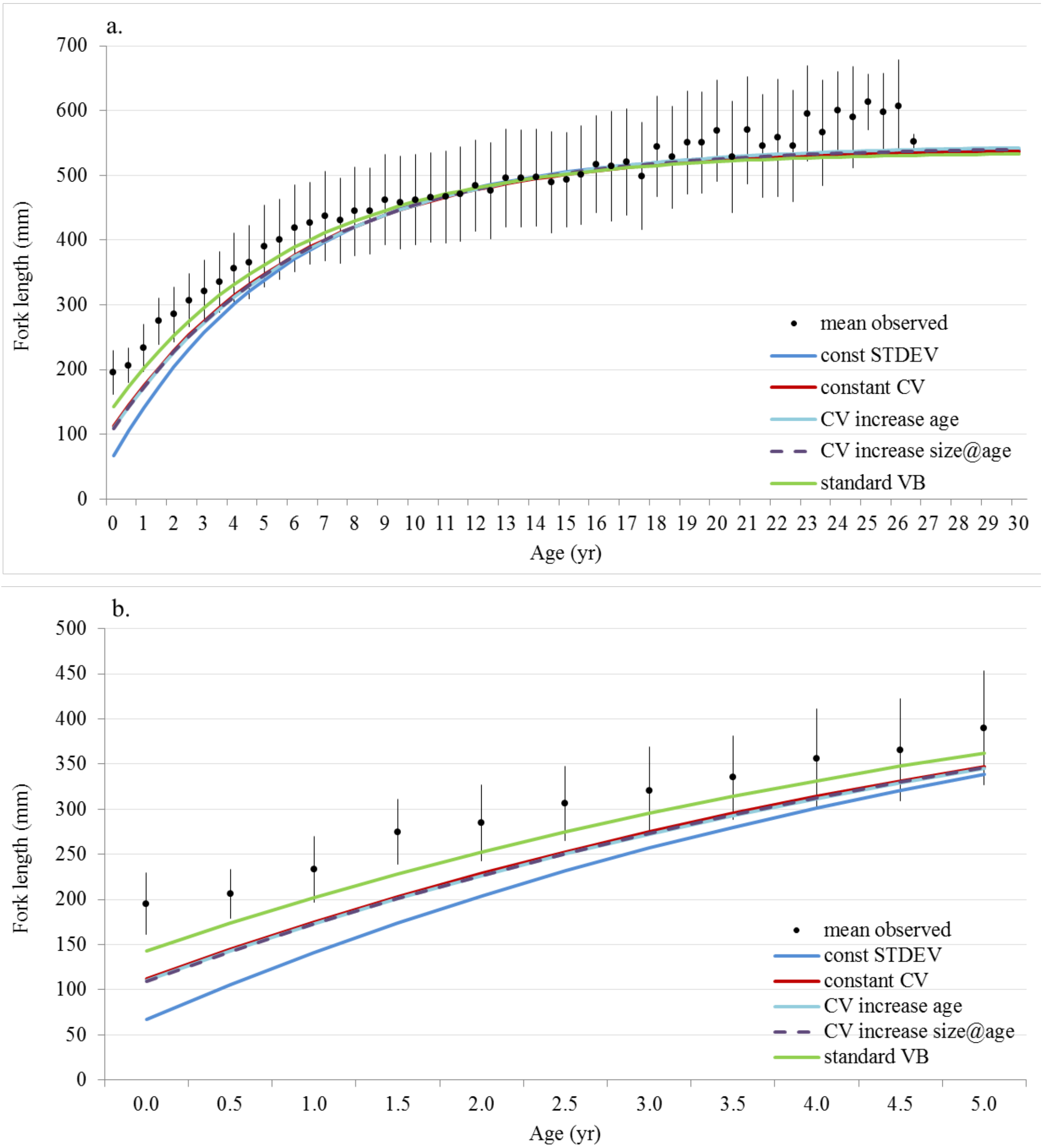
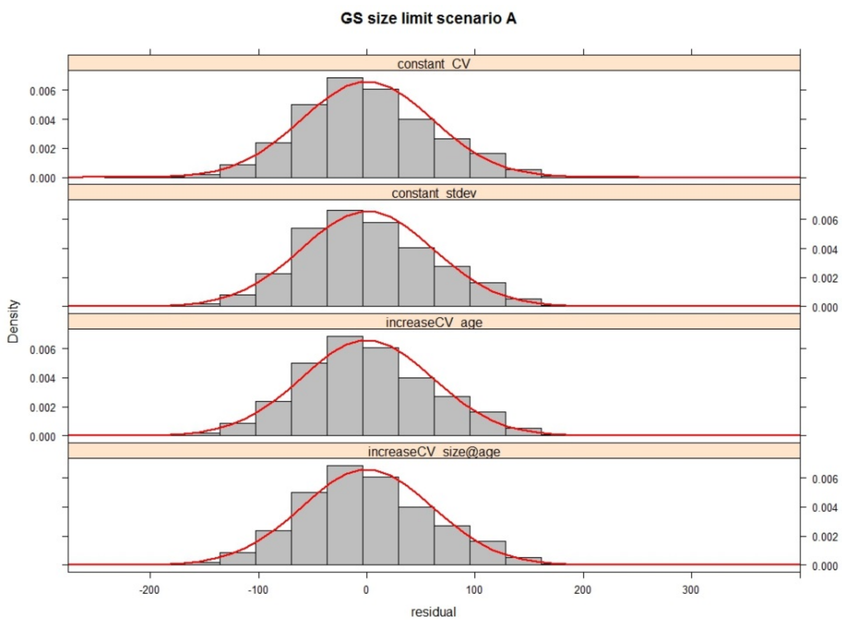
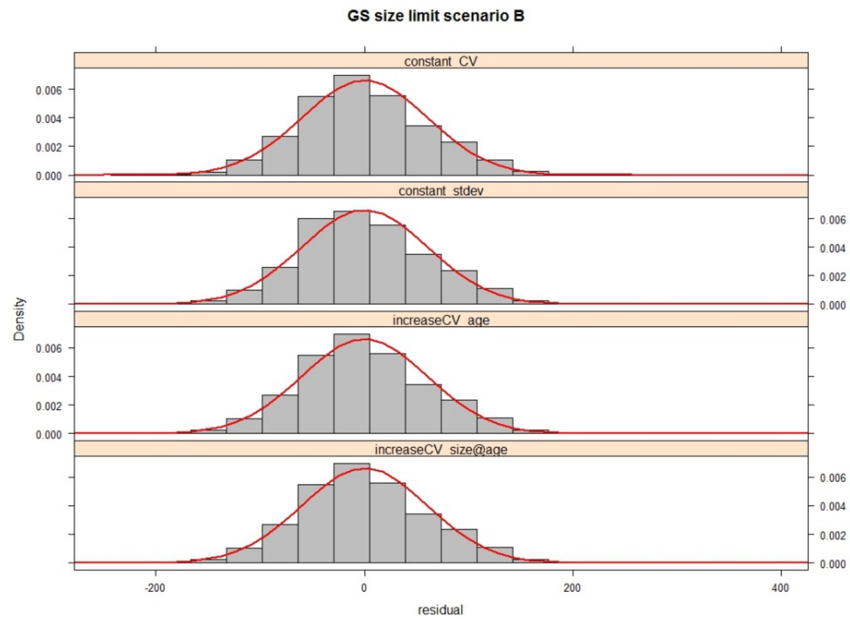


Figure 5. Results of size-modified von Bertalanffy growth model with multiple variance structures (constant standard deviation (STDEV), constant coefficient of variation (CV) with age, increase in CV with age, increase in CV with size-at-age), and a standard von Bertalanffy (VB) growth model for Gray Snapper from northern Gulf of Mexico (1991-2015) for (a) mean fractional ages 0-27 and for (b) mean fractional ages 0-5. 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, dashed purple - CV increase with size-at-age, green line - standard VB). Size limit scenario C: state of Florida recreational size limit for recreational fish landed in Florida, all other fishery dependent records federal size limit





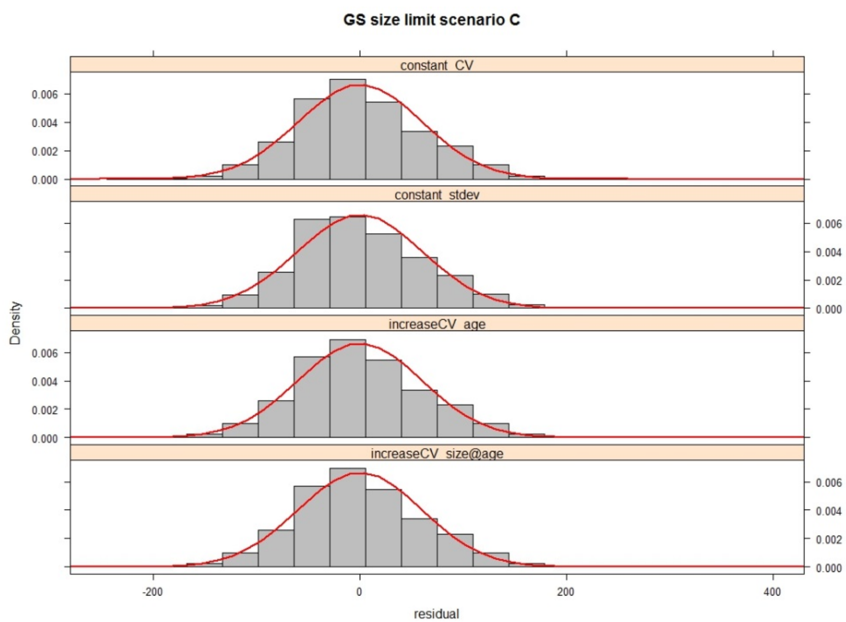
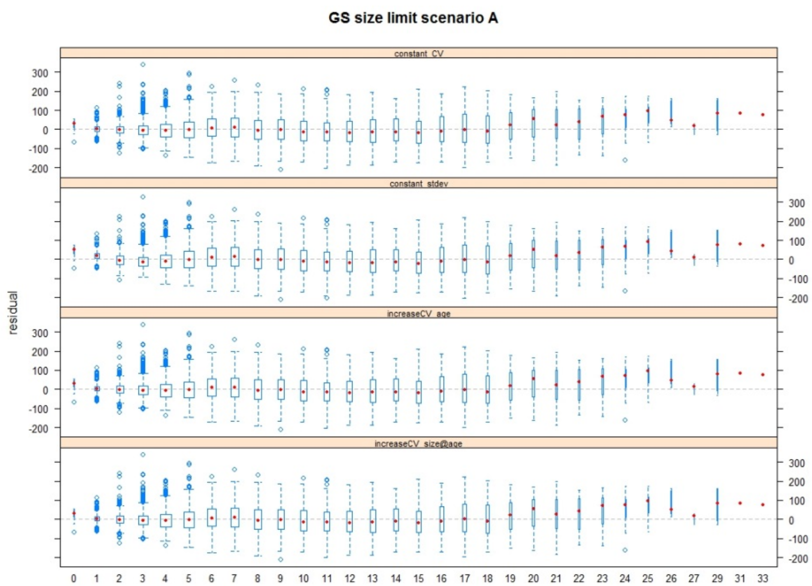
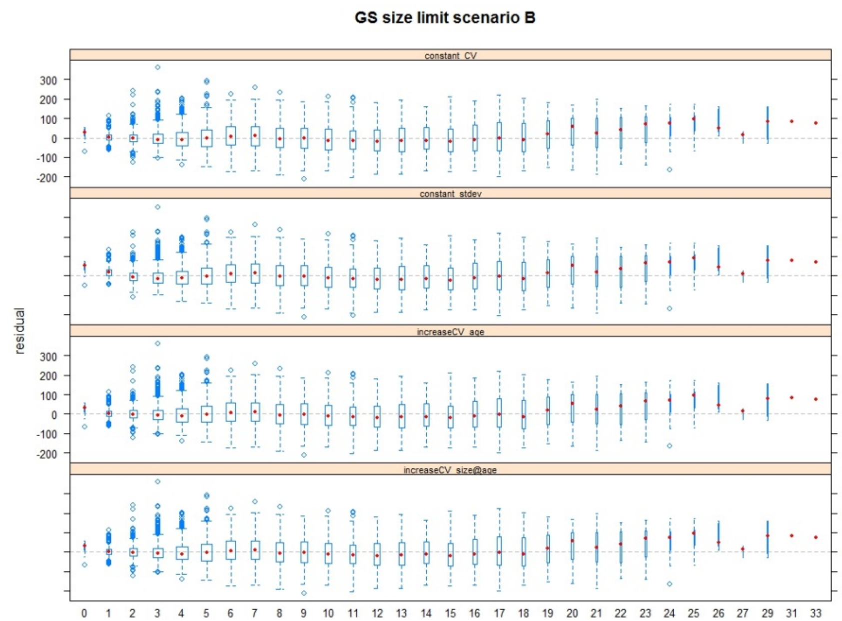


Figure 6. Distribution of residuals for each type of variance structure for Gray Snapper size-modified von Bertalanffy growth models for each size limit scenario A: all fishery dependent records, federal size limit, B: state of Florida recreational size limit for recreational fish caught in state of Florida jurisdictional waters, all other fishery dependent records federal size limit, C: state of Florida recreational size limit for recreational fish landed in state of Florida, all other fishery dependent records federal size limit.





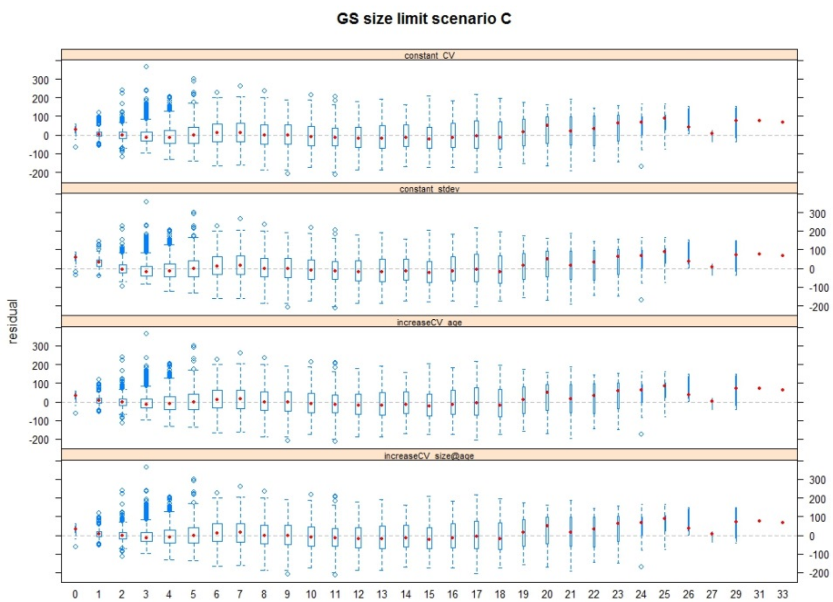
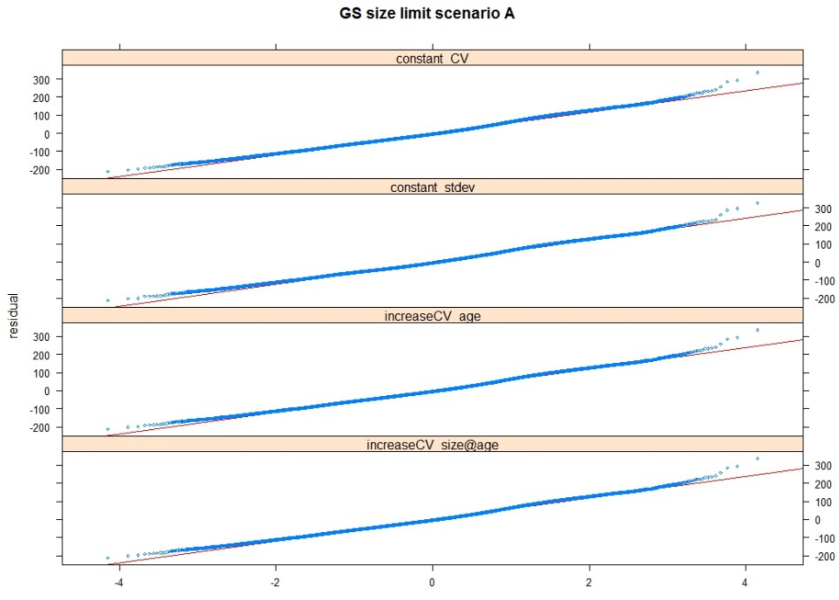
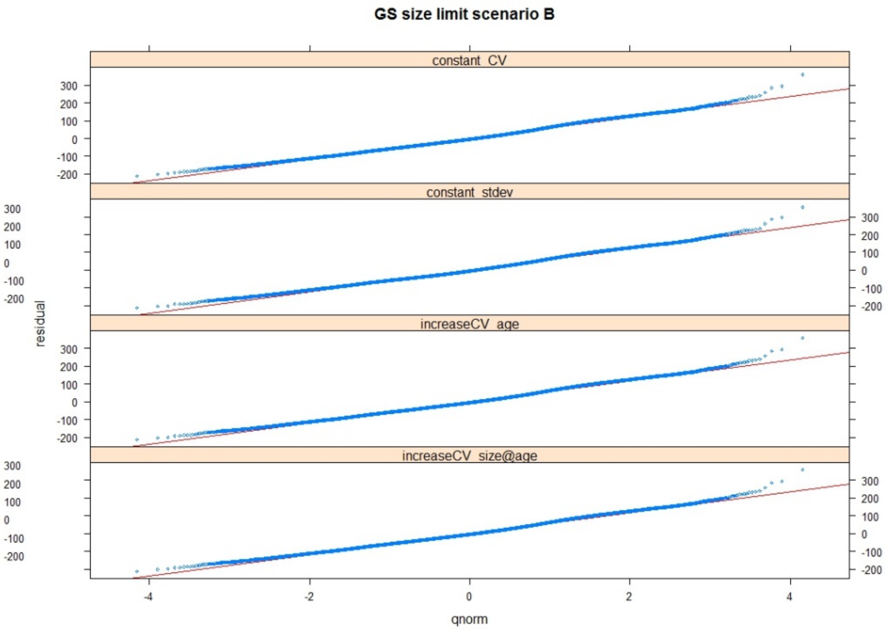


Figure 7. Residuals by age for each type of variance structure for Gray Snapper von Bertalanffy growth models for size limit scenario A: all fishery dependent records, federal size limit, B: state of Florida recreational size limit for recreational fish caught in state of Florida jurisdictional waters, all other fishery dependent records federal size limit and C: state of Florida recreational size limit for recreational fish landed in state of Florida, all other fishery dependent records federal size limit. 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).





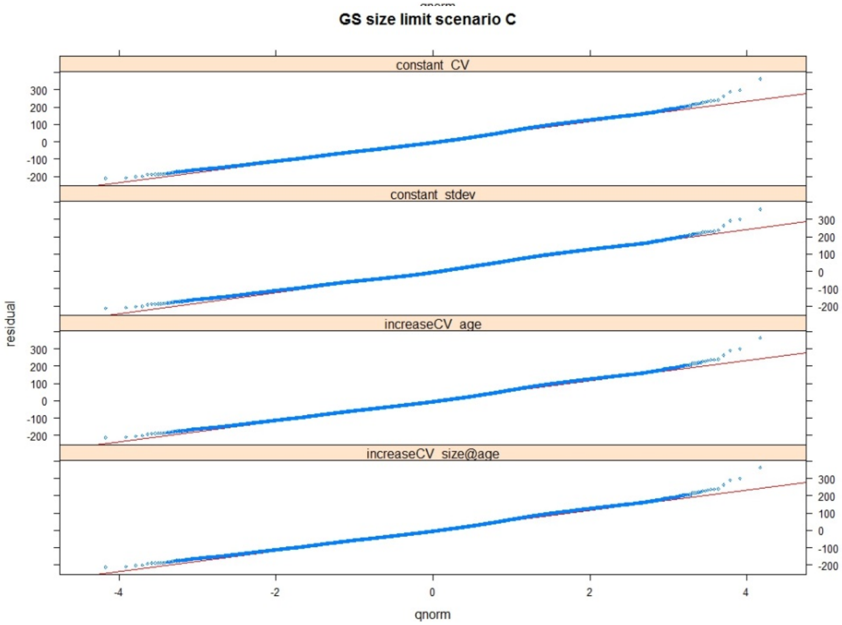


Figure 8. Normal probability plots (quantiles vs residuals) for each type variance structure for Gray Snapper von Bertalanffy growth models for size limit scenario A: all fishery dependent records, federal size limit, B: state of Florida recreational size limit for recreational fish caught in state of Florida jurisdictional waters, all other fishery dependent records federal size limit, C: state of Florida recreational size limit for recreational fish landed in state of Florida, all other fishery dependent records federal size limit.