Age and ageing error of Scamp from the northern Gulf of Mexico

Steven B. Garner, Laura A. Thornton, Robert J. Allman

SEDAR68OA-WP-04

1 July 2022
Updated: 8 July 2022

Please cite this document as:

Garner, Steven B., Laura A. Thornton, Robert J. Allman. 2022. Age and ageing error of Scamp from the northern Gulf of Mexico. SEDAR68OA-WP-04. SEDAR, North Charleston, SC. 29 pp.

Age and ageing error of Scamp from the northern Gulf of Mexico

Steven B. Garner, Laura A. Thornton , Robert J. Allman

NOAA Fisheries, Southeast Fisheries Science Center, 3500 Delwood Beach Road, Panama City, FL, 32408

INTRODUCTION

Scamp, *Mycteroperca phenax*, is an ecologically and economically important Serranid reef fish found along the South Atlantic (SA) continental shelf of the United States and throughout the northern Gulf of Mexico (nGOM) (Hoese and Moore 1998; Kells and Carpenter 2011). Scamp are smaller and more abundant than other more desirable, high-profile congeners, which tends to support higher dockside prices for commercial fishers (FMRI 1999). Declines in gag, *Mycteroperca microlepis*, and red grouper, *Epinephelus morio*, stocks combined with high market value have increased fishing pressure on scamp in recent years with 2017 having the highest total landings concomitant with lowest stock biomass to date (SEDAR 68 2021). Commercial harvest is the predominant source of landings in the GOM (>80%) with infrequent but considerable landings by the recreational fleet (Lombardi-Carlson 2012; SEDAR 68 2021). The majority of landings occur in Florida (>75%) but a significant portion have been landed in Louisiana in recent years (SEDAR 68 2021). Scamp typically occupy and are targeted by fishers at natural reef structures including shelf edge banks and relic limestone shorelines in shallow and mesophotic depths (Smith, 1976; Garner et al. 2019; Reed et al. 2019). The nGOM scamp stock was formally assessed only once since the fishery management plan was enacted in 1984 (GMFMC 1981), but stock status could not be determined (SEDAR 68 2021).

As with most species assessed in the nGOM, scamp age is estimated from sectioned sagittal otoliths, but have low reader agreement and precision compared to many other reef fishes. Given the high volume of otoliths to process for SEDAR 68 (2021), a new high-speed method was used to process otoliths collected from 2003-2012. Upon detailed examination of these sections, processing errors reduced confidence in age estimates beyond a reasonable level, and the sections were excluded from any subsequent analyses. Consequently, the relationship between otolith weight (g) and age (yr) was estimated with linear regression to provide predicted ages as placeholder data for the affected years. The operational assessment for GOM scamp (SEDAR 68 2023) will utilize all previous years of data used in SEDAR 68 (2021), reprocessed age estimates for fish collected from 2003-2012, and age estimates for new age data collected since SEDAR 68 (2021). Age estimates for the years 2003-2012 were taken from age samples that were not processed (i.e., not subsampled) during the previous SEDAR 68 research track assessment or samples that were processed, but have a second otolith available. This report details age data and ageing precision for all scamp collected in the nGOM since 1972, including the reprocessed age data for years 2003-2012, and new age data from 2018-2020.

METHODS

Sample collection and processing

Scamp were sampled from the Gulf of Mexico (GOM) from Texas to the west coast of Florida during most years between 1972 and 1982 and annually from 1986-2020. Throughout the time series, fish were measured to the nearest mm fork length and/or total length and weighed to the nearest g, and sex was determined macroscopically if landed whole. Sagittal otoliths were removed, cleaned with distilled water, dried and a subset weighed to the nearest 0.0001 g prior to sectioning. All otoliths were processed and aged with the exception of those from the commercial handline and longline fleets, which were sub-sampled due to large sample sizes. Subsample numbers were proportional to landings by NMFS fishing grid. During SEDAR 68 (2021), age samples processed for the years 2003-2012 were deemed unreliable due to the processing method. Therefore, otolith weight was used to estimate fish age. To correct this issue, age samples collected from 2003 to 2012 (n = 500 per year) that had a second otolith available or were not processed previously were processed using standard methodology for SEDAR 68 (2023) to provide direct age data for the years 2003-2012.

Otoliths were processed with a Hillquist high-speed thin sectioning machine utilizing the methods of Cowan et al. (1995) or on an Isomet low-speed saw. Two transverse cuts were made through the otolith core to a thickness of 0.5 mm. Ages were assigned based on the count of annuli (opaque zones observed on the dorsal side of the sulcus acousticus in the transverse plane with reflected and/or transmitted light at 40x magnification, including any partially completed opaque zones on the otolith margin). The degree of marginal edge completion was estimated but not included in any analsyes. Biological (i.e., fractional) ages were estimated for fitting growth curves. Biological age accounts for the difference in time between peak spawning and capture date (difference in days divided by 365.25). However, it was extremely difficult to assign accurate marginal edge codes for scamp, thus, the capture date was divided by 365.25 instead of the date of peak spawning, April 1st (Lombardi-Carlson 2012). This fraction was added to the annual age estimate (Vanderkooy et al., 2020).

Reader precision and ageing error

Multiple primary readers (n = 3) were utilized due to the sheer volume of samples (n ≈ 9,000 otoliths) selected for processing given typical sectioning and ageing schedules. Primary readers were trained by an expert reader using a training set of otoliths (n = 110) collected from the Gulf of Mexico and South Atlantic that had age estimates agreed upon by multiple expert readers. A true reference set was previously constructed, but the same processing issues mentioned above affected the readability of this initial reference set. Therefore, the training set was utilized to train primary readers as well as haphazardly selected otoliths from the production set. Multiple training sessions were conducted during which the expert reader differentiated the first annulus, subsequent true annuli from false annuli (e.g., bifurcations, faint annuli, cracks, etc.), and banding patterns for this species. Training sessions occurred prior to the start of production ageing and were conducted intermittently throughout production ageing to avoid reader drift.

Ageing error was estimated by comparing age estimates from primary readers to those of the expert reader. The expert reader aged a subset (20%) of all age samples processed since the previous SEDAR was completed (i.e., samples from years 2003-2012; 2018-2020). Average percent error (APE; Beamish and Fournier, 1981) was used to estimate precision between each primary reader and the expert reader. An APE threshold of ≤5% is typical for a relatively long-lived species with moderately difficult to read otoliths (Morison et al. 1998; Campana, 2001). However, a target APE of ≤10% was set for Scamp due to the difficulty in ageing this species. Scamp are moderately long-lived and inhabit both shallow and mesophotic depths (>40 m; Smith 1976; Garner et al. 2019; Reed et al. 2019). Ontogenetic movement to deeper waters cause fish to interact with permanent thermoclines, which may affect the deposition rate and banding pattern of their otoliths making them more difficult to age. Regardless, the APE estimate in this case is simply an indicator of the accuracy and bias of the primary agers relative to the expert reader, who can be assumed to age with or without bias. Bias in the "true" ages is not known because there is no reference set of validated ages for this species, thus, ages provided by the expert may be assumed to be with or without error.

Ageing error was estimated with several different scenarios to model bias and precision for the primary reader using the package "nwfscAgeingError" (Thorson et al. 2012) in R (R core team 2021) based on the methods described in Punt et al. (2008). The Punt et al. (2008) model calculates the likelihood of model parameters given an age dataset for at least two readers. The model approximates the expected age of each sample and the standard deviation (SD) of a normally distributed reading error (Thorson et al. 2012). Ageing error and bias were modeled under two assumptions: expert reader ages 1) do contain and 2) do not contain error. The estimate of precision was modeled under four scenarios: 1) no error, 2) as a constant of the coefficient of variation (CV), 3) as a curvilinear function of the standard deviation (SD), or 4) as a curvilinear function of the CV. Akaike's corrected information criterion (AICc) along with diagnostic plots of expected values, expected CIs, and SDs were evaluated to select the best fit model to describe ageing error and select the appropriate ageing error vector for input in the assessment.

RESULTS

Sample collection

A total of 21,693 ages were assigned to scamp collected from the GOM between 1972 and 2020, the majority of which were collected from the commercial fishery (Table 1; Figure 1); between 8.7 and 18.0% of age samples were taken from the recreational fleet in the later years of the time series (2013-2019). Ages were assigned from samples collected only from unknown sources during 1972 and 1973 (n = 13). No samples from the commercial fishery were aged during 1986-1990. No samples were aged from fishery independent sources until 1993, after which relatively few samples were aged annually (~38 yr^{-1}). Specifically, there were only three years during which >100 age samples were aged from fishery independent sources. The overwhelming majority of age samples were collected in Florida (85.5%) but several hundred samples per year have been collected in LA since 2012 (Table 2; Figure 2). Most scamp age samples were taken by commercial fishing modes (84.5%; Table 3) using either handline or bottom longline (Table 4).

Age data were distributed approximately evenly with similar median values since about 2000 with numerous fish older than age 20 (Figure 3). Age distributions were relatively similar among states with LA samples having the oldest ages and highest median value (Figure 4). Commercial samples had the oldest individuals with recreational and fishery independent samples having several individuals older than 20 and fishery independent samples predominantly more small individuals (Figure 5). Samples taken with commercial gears were significantly older than those taken with other gears except for tournament samples, which had a high proportion of older individuals; all other gears had similar age distributions (Figure 6). Size distributions were generally similar among gear types except for tournament fish, which were comprised of more large individuals (Figure 7). Specifically, most age samples were taken with hand line or bottom longline gears, the latter taking slightly more older individuals; age distributions were different among the other gear types (Figure 8). Fork lengths were similar between handline, bottom longline, and vertical line gears and different among the other gear types (Figure 9). Age frequency distributions were right skewed from 1991 to 1999 with modal ages ranging from 2 to 6, but were approximately normally distributed around age 9 or 10 throughout the rest of the time period (Figure 10). Size-at-age scatterplots by year were linear in many of the early years (pre-2001) due to low sample sizes with a gradual inflection point between 600 and 700 during later years when sample sizes were large (Figure 11). Few fish younger than age-1 (n = 43) have been collected throughout the entire time period.

Ageing error

A total of 2,057 scamp were read by the expert reader and at least one of the primary readers (referred to as overlap ages) with 2,002 samples (97.3%) deemed readable (Figure 12). The number of overlap ages estimated by each primary reader was approximately equal with readers ageing 2,148, 2,135, or 1,832 otoliths, not all of which were unique as some otoliths were aged by all readers as well as the expert to compare precision periodically during the production ageing process. For otoliths aged by a single primary reader, the final age estimate corresponded to the age estimate from the primary reader. For otoliths aged by multiple primary readers, a hierarchy was constructed based on reader precision such that the final age assigned to a sample was the age estimated by the reader with the highest precision (i.e., lowest average percent error) compared to the expert reader. Percent agreement between final ages and expert ages was relatively low (24.3%) with an average coefficient of variation (ACV) of 11.6 and an average percent error (APE) of 8.2%. Our APE was higher than the APE reported in the literature for GOM scamp (APE = 7.7%) based on n = 1,426 otolith ages (Lombardi-Carlson 2012) and that the APE value (5.1%) reported in SEDAR 68 (2019). However, reader agreement reported in Lombardi-Carlson (2012) was similarly low (30%) and our APE estimate was below the 10% target threshold set *a priori*. Absolute differences between final ages and expert ages ranged from 0 to 18 yrs but ages >3 yrs comprised 13.3% and ages >5 yrs comprised <5% of the age estimates.

Pairwise t-tests for each age-specific expert reader age indicated significant differences between each age-specific expert age and final ages (mean difference in years from expert age) for ages 4 (+0.8), 7 (+0.7), 11 (-0.5), 15 (-0.9), 16 (-1.8), 17 (-1.7), and 24 (-4) (Table 5). There was a slight positive bias (i.e. overageing bias) in primary age estimates through age-8 and slightly negative bias (i.e., underageing bias) in primary age estimates after age-15, but most age groups were not significantly different from the expert or were, on average, within one year of the expert's age estimate. Similar bias but higher precision was observed in previous scamp age estimates compared between a primary and expert reader (Lombardi-Carlson 2012; SEDAR 68 2021). For models under the assumption of expert ages with error, overageing bias increased at older mode predicted ages (Figure 13) while the standard deviation increased slightly and towards an asymptote. Fit statistics indicated that models with linear bias and either constant CV, curvilinear CV, or curvilinear SD fit the data similarly well (<5 unit difference in ΔAICc among candidate models) with the constant CV model having the lowest AICc value (Table 6). For models under the assumption that expert ages were without error, the standard deviation increased as a very gradual exponential function through age-25 where it began to increase past the range of the observed data. The slight positive and negative biases at younger and older ages, respectively, are apparent when plotted against a 1:1 prediction line (Figure 14). Fit statistics (ΔAICc values) indicated that the best-fit model to the ageing error data had curvilinear bias and curvilinear standard deviation (Table 7). No other model had a relatively good fit to the data (all other ΔAICc >90 units).

DISCUSSION

Scamp are a difficult to age species due to inconsistent banding patterns, stacking or compaction of annuli, false annuli, faint annuli, disproportionately large "apparent" edge margins, and the predominance of older ages in the data. Although percent agreement between expert and primary readers was low (<25%), the majority of ages were within 5 years of the "true" age estimated by the expert and similar precision and agreement was observed in the literature for this species (Lombardi-Carlson 2012). The overall APE was higher at 8.2% than the 5.14% observed in SEDAR 68 (2021), but still below the target threshold of 10%. Bias relative to the expert's ages was minimal for most ages but increased at older ages (>20 yrs). The mean age-specific age by the primary readers was not significantly different from the expert for most ages or was relatively small (<1 yr) in most cases when significantly different.

A reference set would be extremely useful in quantifying bias and precision in the age estimates as well as minimizing and maximizing each of these two sources of error, respectively. However, no reference set exists for GOM scamp due to processing differences that affected readability discovered during SEDAR 68 for samples from the years 2003 to 2012, samples from which were used to develop the initial reference set. A training set exists of sectioned otoliths from the Gulf of Mexico and the South Atlantic that has been read by multiple expert readers and is used to tune expert agers and new agers to maximize accuracy and remove bias. However, scamp otoliths sampled from the South Atlantic tend to be less difficult to age, presumably due to more intensely contrasting seasonal water temperatures. The difference in otolith readability likely means that SA otoliths may not reasonably reflect the precision of age estimates for GOM scamp and therefore should not be included in a GOM reference set used to estimate precision. The development of a true reference set ($n \geq 200$ samples) with at least a subset of validated ages, such as through bomb radiocarbon ($\Delta^{14}C$), should prove extremely beneficial to tuning new readers, recalibrating expert readers and reduce model uncertainty due to ageing error.

Multiple primary readers were used to age data from 2003-2012 and new data from 2018-2020 collected since SEDAR 68 (2021). Although reader error followed a generally similar pattern to that observed in SEDAR 68 (2021), precision was reduced due to all three primary readers being new to ageing scamp. The expert reader for SEDAR 68 (2023) was previously the single primary reader for SEDAR 68 (2021) and was trained by the previous expert reader, both of whom have aged thousands of scamp otoliths to date. Multiple primary readers is atypical of standard ageing methods, which predominantly use only a single expert ager, or a single expert ager and primary ager, depending on the difficulty of ageing a given species and availability of experienced readers. However, the need to reprocess samples from 10 years in addition to the 4 years of new data necessitated the use of multiple readers. Ageing error was thoroughly modeled under different scenarios for bias, variance, and two different assumptions for expert ageing error, but it is unclear how much improvement (via a reduction in model uncertainty) would be gained by reducing the error in the age estimates and what degree of improvement is possible. The increase in precision could be substantial if a single primary reader is tuned via a true reference set of sufficient sample size.

REFERENCES

Beamish, R.J. and D.A. Fournier. 1981. A method for comparing the precision of a set of age determinations. Canadian Journal of Fisheries and Aquatic Science 38:982-983.

Burnham, K.P. and D.R. Anderson. 2004. Multimodel inference: understanding AIC and BIC in model selection. Sociological Methods & Research. 33:261-304.

Campana, S.E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. Journal of Fish Biology 59:197-242.

Cowan, J.H. Jr., R.L. Shipp, H.K. Bailey IV, and D.W. Haywick 1995. Procedure for rapid processing of largeotoliths. Transactions of the American Fisheries Society 124:280-282.

Garner, S.B., K.M. Boswell, J.P. Lewis, J.H. Tarnecki, and W.F. Patterson III. 2019. Effect of reef morphology and depth on fish community structure and trophic structure in the northcentral Gulf of Mexico. Estuarine, Coastal, and Shelf Science. 230:106423.

GMFMC (Gulf of Mexico Fishery Management Council). 1981. Fishery management plan for the reef fish fishery of the Gulf of Mexico. GMFMC, Tampa, Florida.

Hoese, H.D. and R.H. Moore. 1998. Fishes of the Gulf of Mexico, Texas, Louisiana, and adjacent waters. Texas A&M University Press, College Station.

Kells, V. and K. Carpenter. 2011. A field guide to coastal fishes from Maine to Texas. The Johns Hopkins University Press, Baltimore.

Lombardi-Carlson, L.A., M. Cook, H. Lyon, B. Barnett, and L. Bullock. 2012. A description of Age, Growth, and Reproductive Life History Traits of Scamps from the Northern Gulf of Mexico. Marine and Coastal Fisheries. 4:129-144.

Morison, A.K., P.C. Coutin and S.G. Robertson. 1998. Age determination of black bream, *Acanthopagrus butcheri* (Sparidae), from the Gippsland Lakes of south-eastern Australia indicates slow growth and episodic recruitment. Marine and Freshwater Research 49:491-498.

Punt, A.E., Smith, D.C., KrusicGolub, K., and Robertson, S. 2008. Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Canadian Journal of Fisheries and Aquatic Sciences 65: 1991-2005.

R Core Team. 2021. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna Austria. https://www.R-project.org/.

Reed, J.K., S. Farrington, A. David, S. Harter, S.A. Pomponi, M. Cristina Diaz, J.D. Voss, K.D. Spring, A.C. Hine, V.H. Kourafalou, and R.H. Smith. 2019. Pulley ridge, Gulf of Mexico, USA. In *Mesophotic coral ecosystems* (pp. 57-69). Springer, Cham.

SEDAR (Southeast Data Assessment and Review) 68. 2021. Gulf of Mexico Scamp Grouper. SEDAR Stock Assessment Report. September 2021. North Charleston, SC 29405. 601 pp.

Smith, G.B. 1976. Ecology and distribution of eastern Gulf of Mexico reef fishes. Florida Department of Natural Resources Marine Research Laboratory 19.

Thorson, J.T., I.J. Stewart and A.E. Punt. 2012. nwfscAgeingError: a user interface in R for the Punt et al. (2008) method for calculating ageing error and imprecision. Available from: http://github.com/nmfsc-assess/nwfscAgeingError.

Vanderkooy, S., J. Carroll, S. Elzey, J. Gilmore and J. Kipp, editors. 2020. A practical handbook for determining the ages of Gulf of Mexico fishes. Gulf States Marine Fisheries Commission, Publication No. 300.

TABLES AND FIGURES

Table 1. Number of scamp age samples by fishery (commercial, fishery independent, recreational, or unknown) and year (1972-2020).

Year	Com	FI	Rec	Unk
1972	0	0	0	6
1973	0	0	0	7
1977	20	0	0	16
1978	15	0	0	8
1979	149	0	11	43
1980	96	0	26	17
1981	102	0	12	0
1986	0	0	38	5
1987	0	0	7	1
1988	0	0	12	1
1989	0	0	19	0
1990	0	0	4	0
1991	224	0	26	3
1992	108	0	62	0
1993	304	2	40	0
1994	125	5	114	0
1995	113	5	83	0
1996	85	0	156	0
1997	37	15	49	0
1998	65	2	53	0
1999	96	28	52	0
2000	172	28	11	0
2001	1100	25	8	0
2002	1577	42	83	1
2003	464	0	13	0
2004	478	5	5	0
2005	470	13	3	0
2006	513	8	7	0
2007	471	21	5	0
2008	465	17	7	0
2009	460	109	26	0
2010	503	200	16	0
2011	761	63	33	0
2012	914	67	4	0
2013	1146	143	177	1
2014	1118	29	181	0
2015	1108	63	235	0
2016	1150	58	265	0
2017	1189	50	131	0
2018	1012	63	102	0
2019	801	4	166	0
2020	822	0	33	0

Table 2. Number of scamp age samples by state landed (Alabama, AL; Florida, FL; Louisiana, LA; Mississippi, MS; or Texas, TX) and year (1972-2020).

Year	AL	FL	LA	MS	TX
1972	0	6	0	0	0
1973	0	7	0	0	0
1977	0	36	0	0	0
1978	0	23	0	0	0
1979	0	203	0	0	0
1980	0	139	0	0	0
1981	0	114	0	0	0
1986	0	18	0	0	25
1987	0	2	0	0	6
1988	0	8	0	0	5
1989	0	19	0	0	0
1990	0	3	0	0	1
1991	0	159	91	0	3
1992	0	69	92	0	9
1993	0	180	150	0	16
1994	0	184	42	0	18
1995	0	198	1	0	2
1996	0	240	1	0	0
1997	0	100	1	0	0
1998	0	120	0	0	0
1999	4	172	0	0	0
2000	7	199	1	2	2
2001	0	1069	49	14	1
2002	21	1631	35	14	2
2003	0	477	0	0	0
2004	2	484	2	0	0
2005	0	472	14	0	0
2006	2	525	0	0	1
2007	1	486	8	0	2
2008	1	485	1	0	2
2009	5	578	8	0	4
2010	4	700	12	0	3
2011	20	797	40	0	0
2012	9	672	166	0	138
2013	21	1195	106	0	145
2014	69	1062	168	0	29
2015	20	1180	186	1	26
2016	49	1078	329	0	17
2017	27	1030	305	0	11
2018	5	969	201	3	0
2019	7	856	104	0	4
2020	1	606	242	0	6

Table 3. Number of scamp age samples by fishing mode (charter boat, CB; private, PR; commercial, CM; headboat, HB; scientific survey, SS; tournament, Trn; or unknown, Unk) and year (1972-2020).

Year	CB	PR	CM	HB	SS	Trn	Unk
1972	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0
1977	0	0	20	0	0	0	0
1978	0	0	15	0	0	0	0
1979	0	0	149	11	0	0	0
1980	9	0	96	17	0	0	0
1981	12	0	102	0	0	0	0
1986	0	0	0	38	0	0	0
1987	0	0	0	7	0	0	0
1988	0	0	0	12	0	0	0
1989	0	0	0	19	0	0	0
1990	0	0	0	4	0	0	0
1991	5	0	224	18	0	3	0
1992	10	1	108	51	0	0	0
1993	10	0	304	30	2	0	0
1994	59	0	125	53	5	2	0
1995	51	0	113	32	5	0	0
1996	113	5	85	38	0	0	0
1997	27	1	37	21	15	0	0
1998	47	0	65	6	2	0	0
1999	45	2	96	5	28	0	0
2000	4	0	172	7	28	0	0
2001	6	0	1100	2	25	0	0
2002	52	7	1577	24	42	0	0
2003	6	0	464	7	0	0	0
2004	2	1	478	2	5	0	0
2005	3	0	470	0	13	0	0
2006	3	1	513	1	8	2	0
2007	1	1	471	3	21	0	0
2008	1	0	465	6	17	0	0
2009	6	1	460	18	109	1	0
2010	5	2	503	9	200	0	0
2011	25	3	761	4	62	2	0
2012	2	0	914	2	67	0	0
2013	111	0	1146	64	143	2	0
2014	121	14	1118	46	29	0	0
2015	148	17	1108	70	63	0	7
2016	174	26	1150	65	58	0	0
2017	71	5	1189	52	50	3	3
2018	57	4	1012	37	63	4	1
2019	80	2	801	84	4	0	0
2020	24	5	822	4	0	0	0

Table 4. Number of scamp age samples by gear (handline, HL; bottom longline, BLL; Kali pole, KP; trawl, TRW; trap, TR; vertical longline, VLL; spear, SP; troll line; TRL; or unassigned, UA) and year (1972-2020).

Year	HL	BLL	KP	TRW	TR	VLL	SP	UA
1972	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0
1977	20	0	0	0	0	0	0	0
1978	15	0	0	0	0	0	0	0
1979	160	0	0	0	0	0	0	0
1980	122	0	0	0	0	0	0	0
1981	114	0	0	0	0	0	0	0
1986	38	0	0	0	0	0	0	0
1987	7	0	0	0	0	0	0	0
1988	12	0	0	0	0	0	0	0
1989	19	0	0	0	0	0	0	0
1990	4	0	0	0	0	0	0	0
1991	225	24	0	0	0	0	0	0
1992	120	50	0	0	0	0	0	0
1993	305	39	0	0	2	0	0	0
1994	235	8	0	0	0	0	1	0
1995	196	3	0	0	1	0	0	0
1996	220	21	0	0	0	0	0	0
1997	72	27	0	0	1	0	1	0
1998	86	34	0	0	0	0	0	0
1999	99	71	0	0	6	0	0	0
2000	72	122	0	0	17	0	0	0
2001	446	681	0	0	6	0	0	0
2002	415	1265	0	0	10	0	12	0
2003	14	463	0	0	0	0	0	0
2004	8	479	0	0	1	0	0	0
2005	18	461	0	0	7	0	0	0
2006	6	513	1	1	5	0	2	0
2007	13	469	0	5	7	0	3	0
2008	10	457	0	5	10	0	1	0
2009	191	333	0	9	46	0	2	0
2010	344	330	0	6	8	9	0	0
2011	379	447	0	1	28	1	1	0
2012	705	241	0	2	37	0	0	0
2013	747	656	0	6	23	23	11	0
2014	706	537	0	5	14	2	64	0
2015	786	498	0	6	39	0	84	0
2016	926	524	0	9	1	4	8	1
2017	813	544	0	2	8	3	3	0
2018	634	521	0	2	6	7	8	0
2019	514	455	0	0	0	1	0	0
2020	665	177	0	0	0	0	7	6

Table 5. Sample size, minimum, maximum, mean age, standard error, critical value (t), significance value, and lower and upper confidence interval (95%) of primary reader age estimates for samples also aged by the expert reader.

Expert age	n	Min	Max	Mean	SE	t-value	p-value	LCI	UCI
1	4	1	2	1.8	0.25	3.00	0.692	0.95	2.55
2	21	2	3	2.1	0.08	1.83	0.829	1.98	2.31
3	60	2	14	3.3	0.21	1.48	0.907	2.89	3.75
4	86	2	12	4.8	0.18	4.21	**0.002**	4.40	5.11
5	76	3	16	5.6	0.24	2.59	0.186	5.14	6.09
6	91	2	15	6.3	0.20	1.68	0.862	5.94	6.72
7	112	3	15	7.7	0.19	3.58	**0.012**	7.30	8.04
8	176	4	15	8.4	0.14	2.79	0.106	8.12	8.69
9	172	1	16	9.2	0.16	1.21	1.000	8.88	9.52
10	198	4	18	9.9	0.14	-0.71	1.000	9.62	10.18
11	167	5	16	10.5	0.15	-3.35	**0.022**	10.18	10.79
12	165	6	17	11.5	0.17	-2.82	0.103	11.19	11.86
13	128	5	22	12.6	0.22	-2.04	0.566	12.12	12.99
14	110	7	20	13.8	0.26	-0.67	1.000	13.32	14.34
15	110	7	22	14.1	0.26	-3.68	**0.009**	13.53	14.56
16	62	8	20	14.2	0.35	-5.06	**0.000**	13.50	14.92
17	68	10	22	15.3	0.31	-5.44	**0.000**	14.69	15.93
18	60	9	22	16.9	0.37	-2.86	0.106	16.19	17.68
19	29	10	25	17.6	0.61	-2.24	0.461	16.36	18.88
20	36	11	30	18.7	0.69	-1.93	0.692	17.26	20.07
21	15	15	26	19.7	0.75	-1.77	0.862	18.05	21.28
22	8	16	23	19.0	0.94	-3.18	0.234	16.77	21.23
23	8	15	26	21.5	1.34	-1.12	1.000	18.34	24.66
24	12	16	24	20.0	0.71	-5.66	**0.004**	18.44	21.56
25	9	17	25	21.1	0.90	-4.30	0.055	19.03	23.20
26	2	26	28	27.0	NA	NA	NA	NA	NA
27	1	22	22	22.0	NA	NA	NA	NA	NA
28	3	19	29	24.7	2.96	-1.13	1.000	11.92	37.41
29	3	20	22	21.0	0.58	-13.86	0.103	18.52	23.48
30	2	14	27	20.5	NA	NA	NA	NA	NA
31	2	27	27	27.0	NA	NA	NA	NA	NA
33	3	15	27	23.0	4.00	-2.50	0.907	5.79	40.21
34	1	27	27	27.0	NA	NA	NA	NA	NA
35	1	29	29	29.0	NA	NA	NA	NA	NA
43	1	30	30	30.0	NA	NA	NA	NA	NA

Table 6. Model fit statistics for Akaike's information criterion (AIC; corrected AICc) or Bayesian information criterion (BIC) and the change in fit (Δ) among models compared to the best-fit model for scenarios with no bias, linear bias, or curvilinear bias and no error, constant coefficient of variation (CV), curvilinear standard deviation (SD), or curvilinear CV. Expert reader ages are assumed to be with error.

Bias model	SD model	AIC	AICc	BIC	ΔAIC	ΔAICc	ΔBIC
None	None	700481.3	700483.0	700571.7	679871.3	679870.2	679854.7
None	Constant CV	20643.1	20645.0	20737.8	33.2	32.2	20.8
None	Curvilinear SD	20640.3	20642.6	20743.6	30.4	29.8	26.6
None	Curvilinear CV	20641.4	20643.7	20744.8	31.5	30.9	27.8
Linear	None	700483.3	700485.2	700578.0	679873.3	679872.4	679861.0
Linear	Constant CV	20618.0	20620.1	20717.0	8.0	7.2	0.0
Linear	Curvilinear SD	20612.6	20615.1	20720.2	2.7	2.2	3.2
Linear	Curvilinear CV	20613.6	20616.1	20721.3	3.7	3.3	4.3
Curvilinear	None	788718.0	788720.3	788821.4	768108.1	768107.5	768104.4
Curvilinear	Constant CV	20616.2	20618.7	20723.8	6.3	5.8	6.8
Curvilinear	Curvilinear SD	20609.9	20612.8	20726.2	0.0	0.0	9.2
Curvilinear	Curvilinear CV	20619.0	20621.9	20735.2	9.0	9.0	18.2

Table 7. Model fit statistics for Akaike's information criterion (AIC; corrected AICc) or Bayesian information criterion (BIC) and the change in fit (Δ) among models compared to the best-fit model for scenarios with no bias, linear bias, or curvilinear bias and no error, constant coefficient of variation (CV), curvilinear standard deviation (SD), or curvilinear CV. Expert reader ages are assumed to be without error.

Bias model	SD model	AIC	AICc	BIC	ΔAIC	ΔAICc	ΔBIC
None	None	700481.3	700483.0	700571.7	679654.0	679652.8	679628.1
None	Constant CV	35519.0	35520.9	35613.7	14691.7	14690.7	14670.1
None	Curvilinear SD	20950.4	20952.7	21053.8	123.1	122.5	110.2
None	Curvilinear CV	35523.0	35525.2	35626.3	14695.7	14695.1	14682.8
Linear	None	700483.3	700485.2	700578.0	679656.0	679655.0	679634.5
Linear	Constant CV	35521.0	35523.1	35620.0	14693.7	14692.9	14676.5
Linear	Curvilinear SD	20918.3	20920.8	21026.0	91.0	90.6	82.4
Linear	Curvilinear CV	35525.0	35527.4	35632.6	14697.7	14697.3	14689.1
Curvilinear	None	788718.0	788720.3	788821.4	767890.8	767890.1	767877.8
Curvilinear	Constant CV	34920.4	34922.9	35028.1	14093.2	14092.7	14084.5
Curvilinear	Curvilinear SD	20827.3	20830.2	20943.5	0.0	0.0	0.0
Curvilinear	Curvilinear CV	34924.4	34927.3	35040.7	14097.2	14097.2	14097.2

Figure 1. Proportion of age samples by fishery (commercial, Com; recreational, Rec; fishery independent, FI; or unknown, Unk) and year (1972-2020).

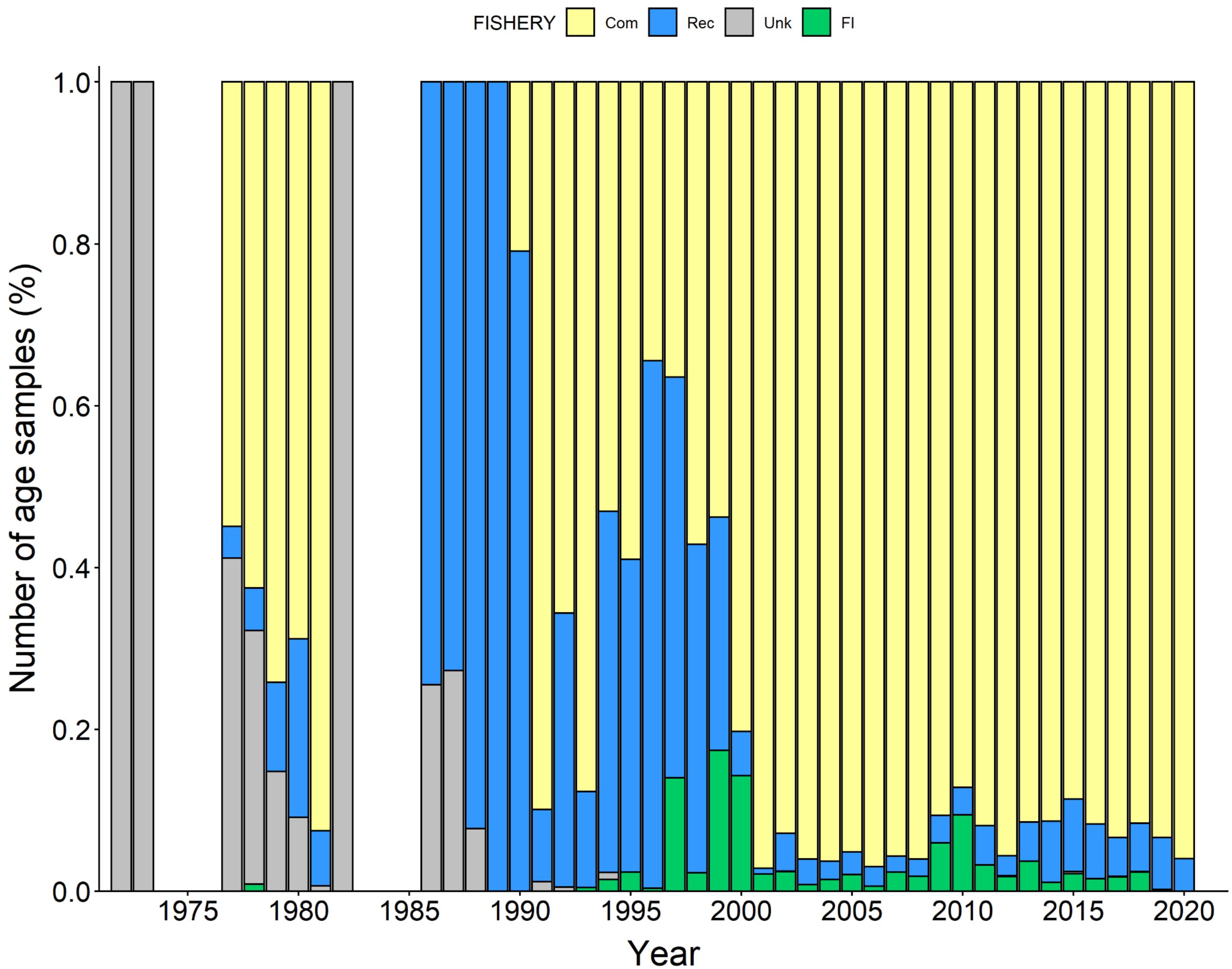

Figure 2. Proportion of age samples by state landed (Alabama, AL; Florida, FL; Louisiana, LA; Mississippi, MS; or Texas, TX) and year (1972-2020).

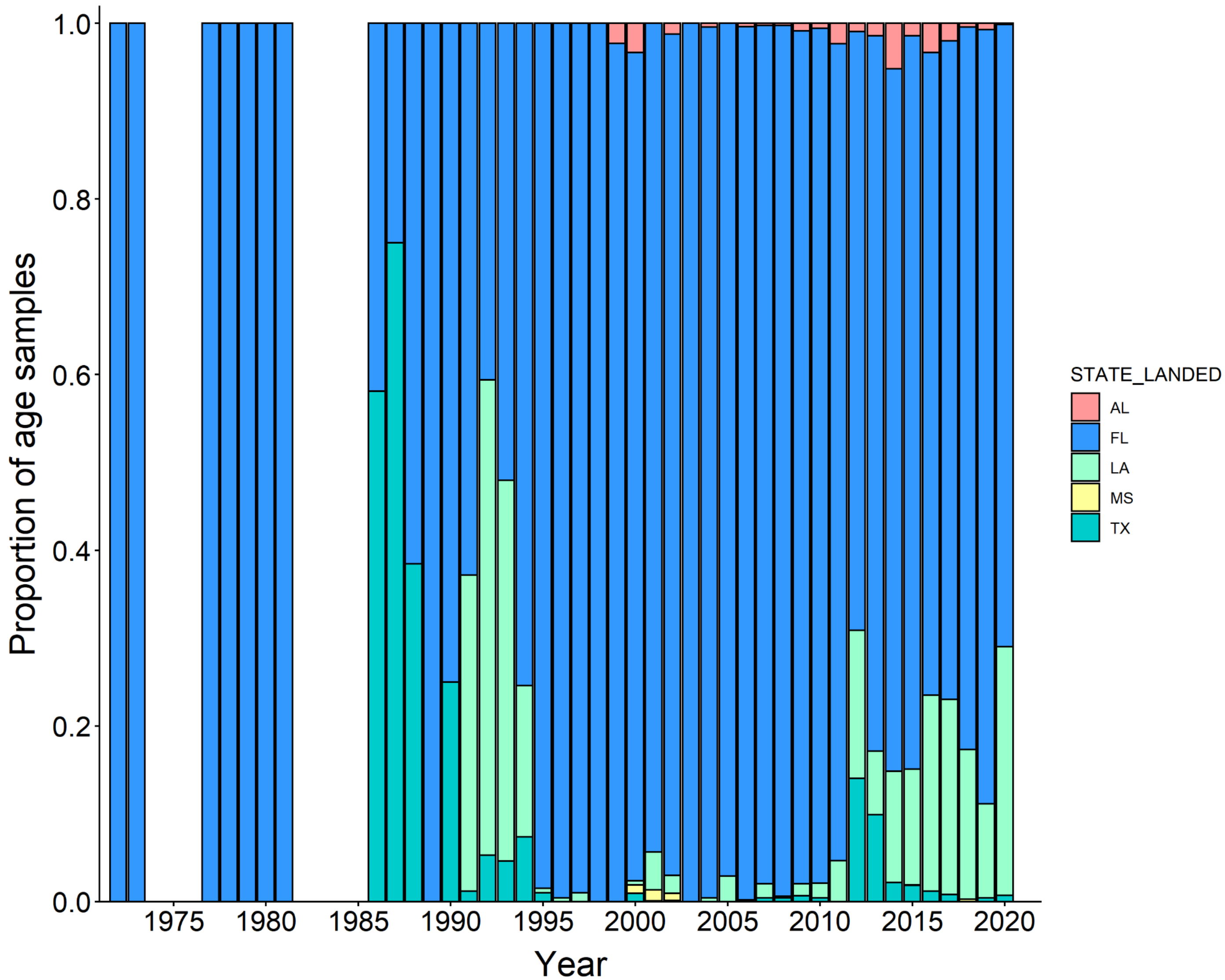

Figure 3. Boxplots of calendar age (yr) by year (1972-2020) for scamp collected from the Gulf of Mexico.

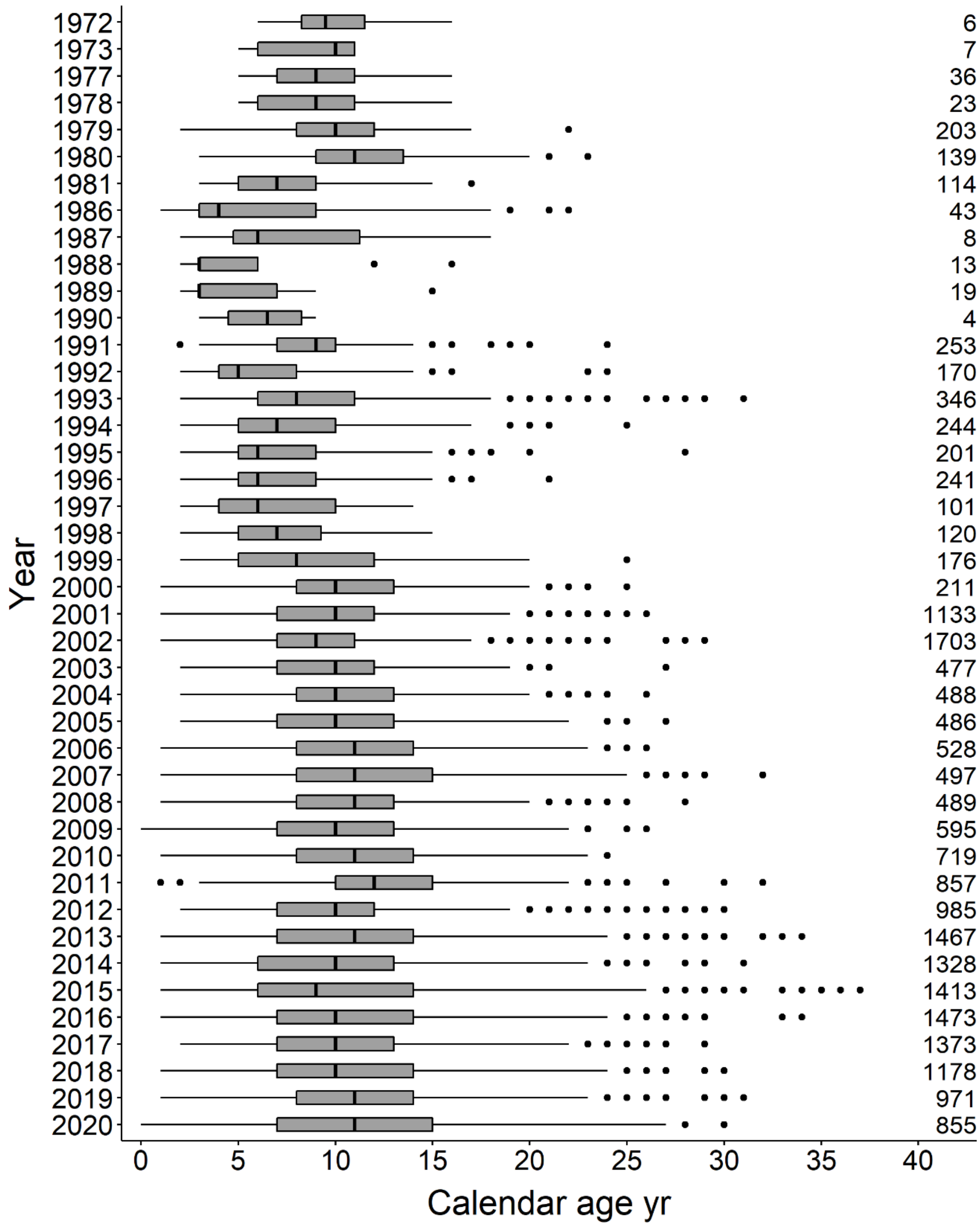

Figure 4. Boxplots of calendar age (yr) by state (Alabama, AL; Florida, FL; Louisiana, LA: Mississippi, MS: or Texas, TX) and year (1972-2020).

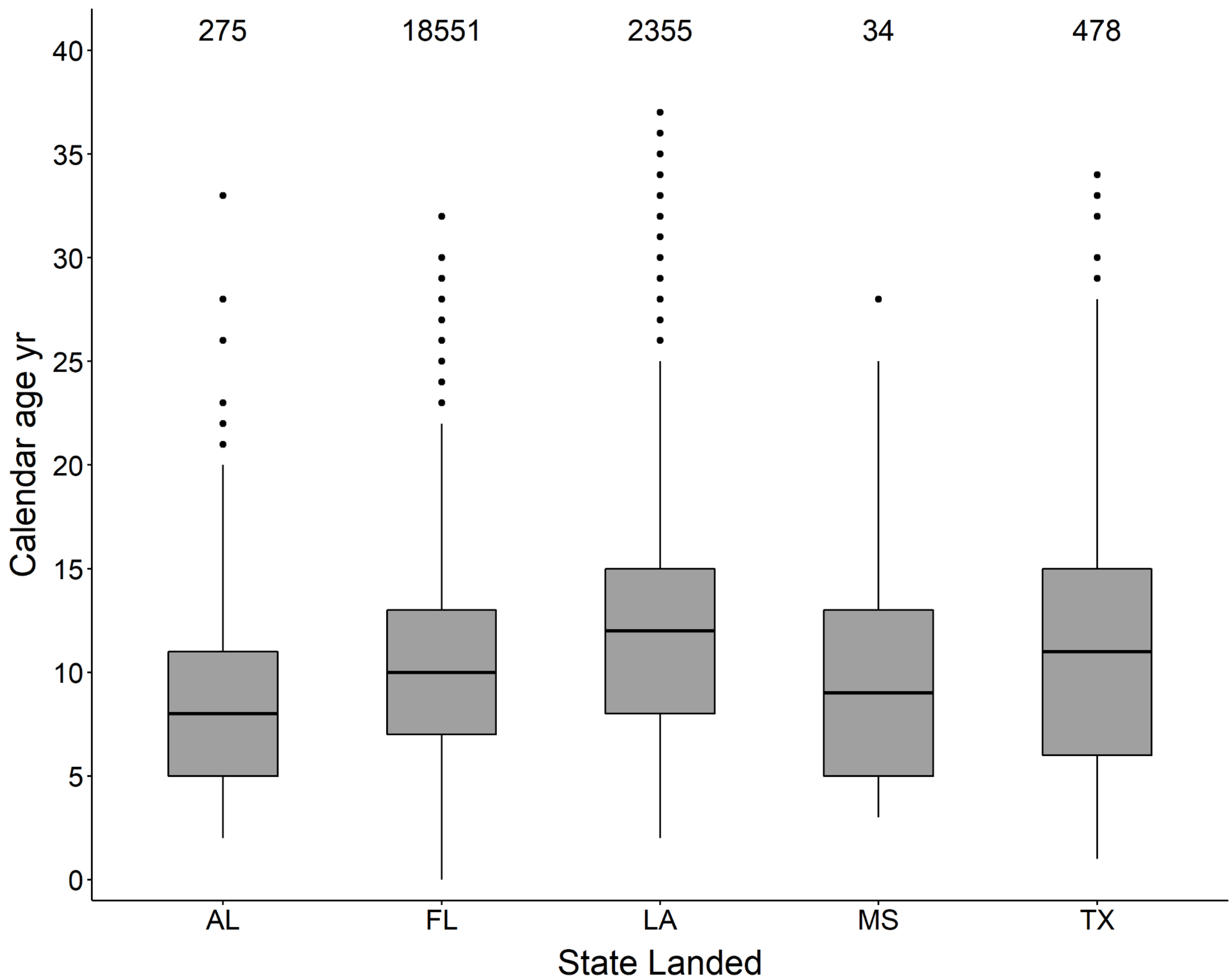

Figure 5. Boxplots of calendar age (yr) by fishery (commercial, COM; recreational, REC; Fishery Independent, FI; or unknown, Unk) and year (1972-2020) from samples collected in the Gulf of Mexico.

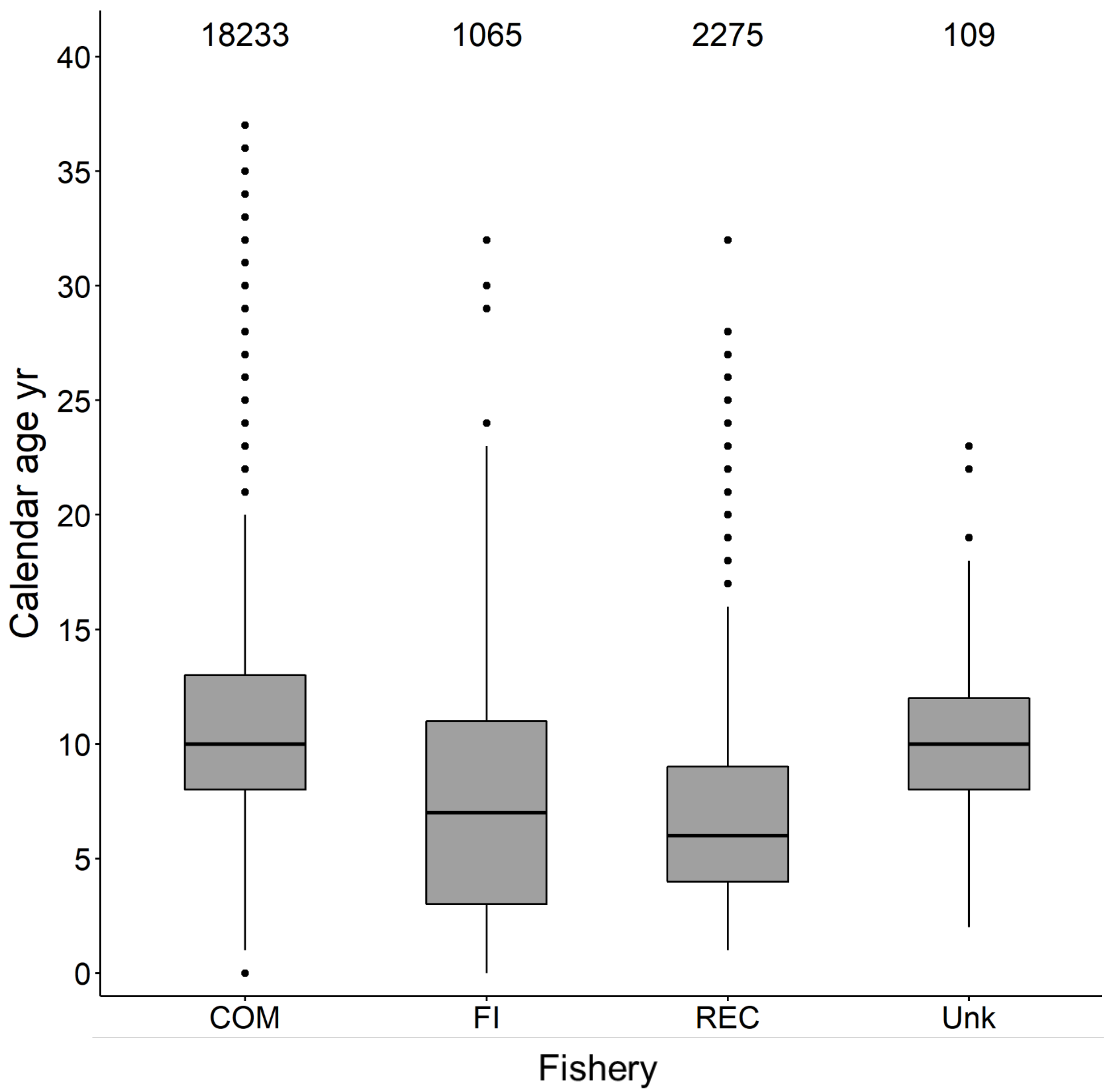

Figure 6. Boxplots of calendar age (yr) by mode (charterboat, CB; private recreational, PR; tournament, Trn; commercial, CM; headboat, HB; scientific survey, SS; or unknown, Unk) for all age samples collected from 1972-2020.

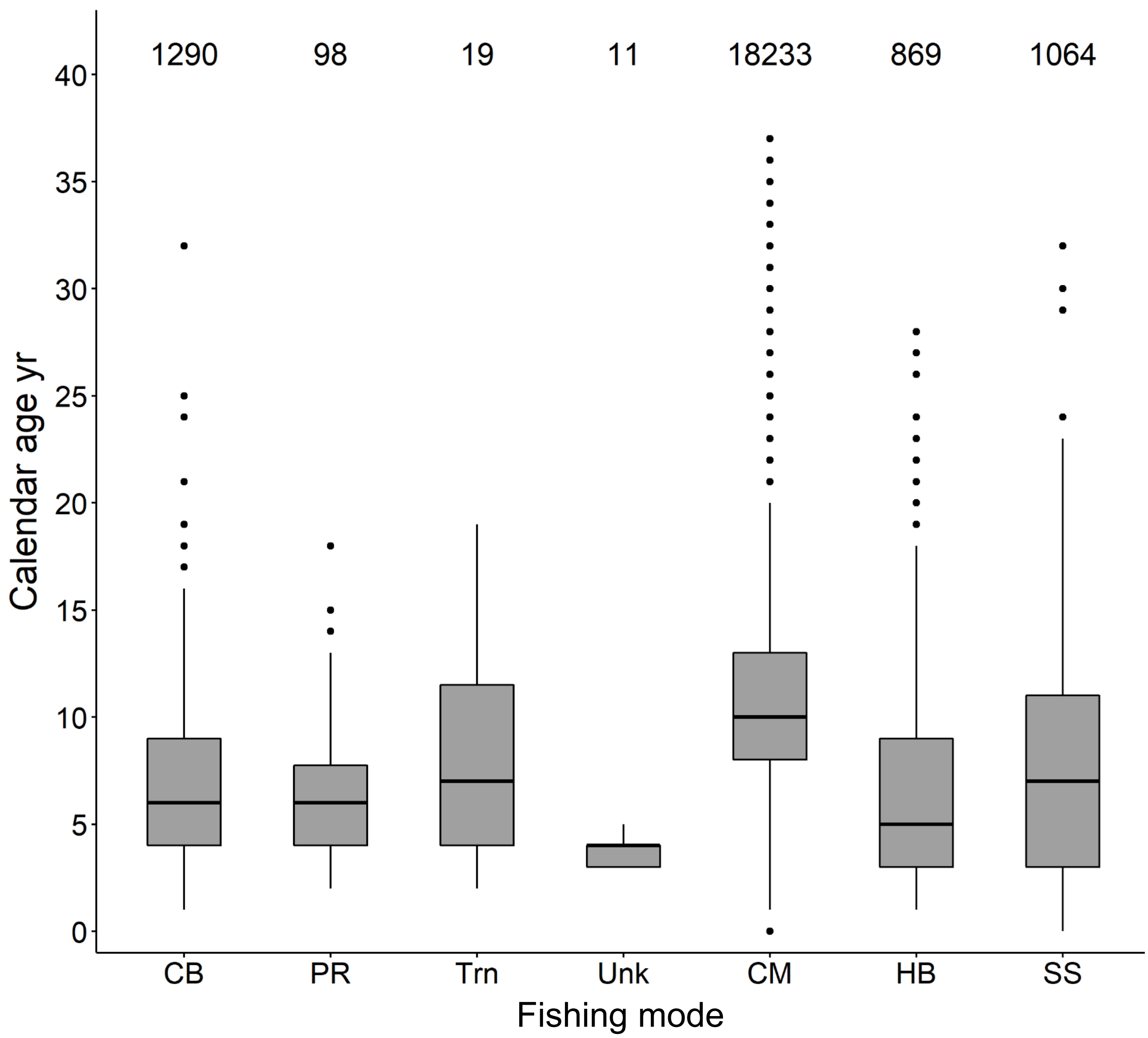

Figure 7. Boxplots of fork length (mm) by mode (charterboat, CB; private recreational, PR; tournament, Trn; commercial, CM; headboat, HB; scientific survey, SS; or unknown, Unk) for all age samples collected from 1972-2020.

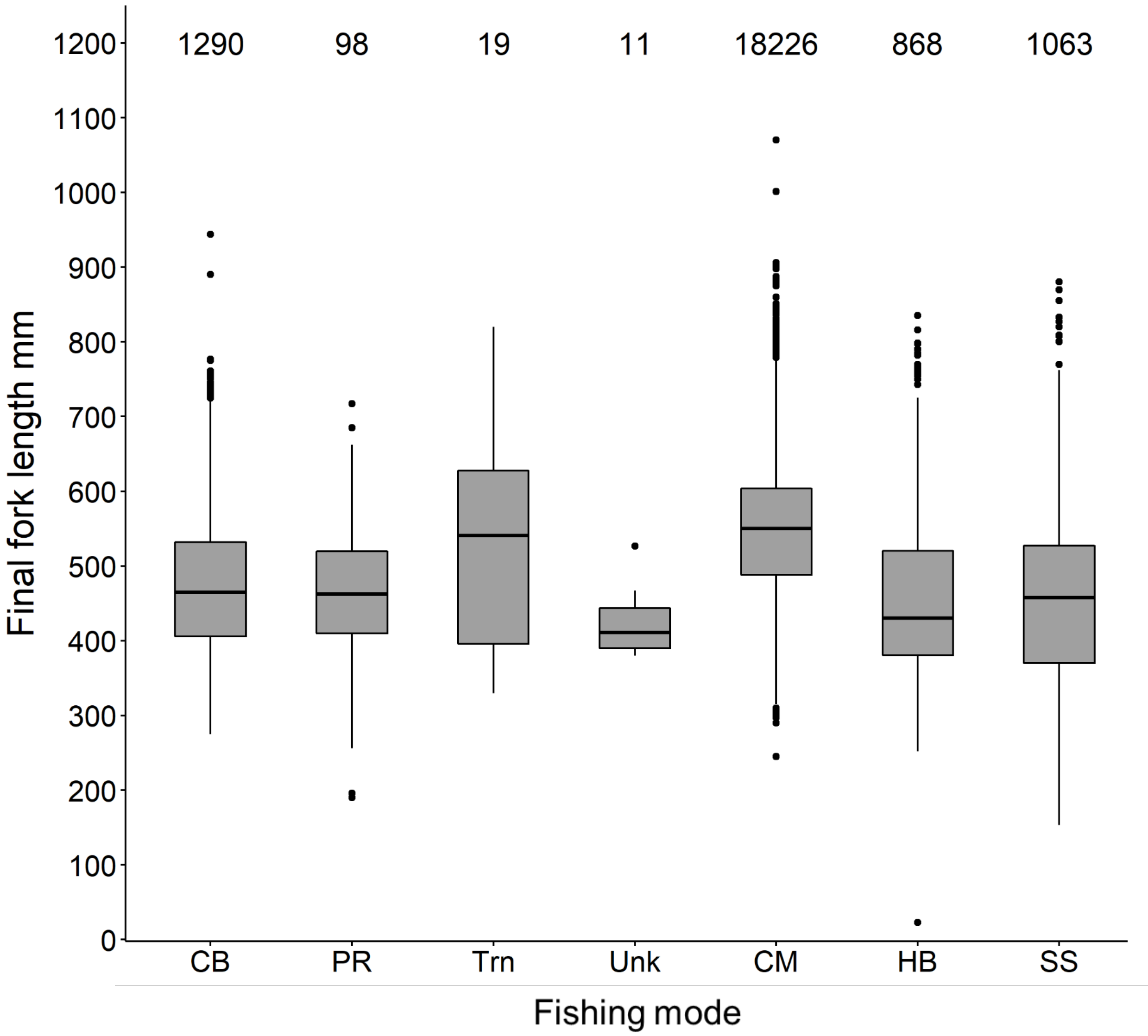

Figure 8. Boxplots of calendar age (yr) by gear (handline or hook-and-line, HL; bottom longline, BLL; Kali pole, KP; trawl, TRW; trap, TR; vertical longline, VLL; spear, SP; or unassigned, UA) for all age samples collected from 1972-2020.

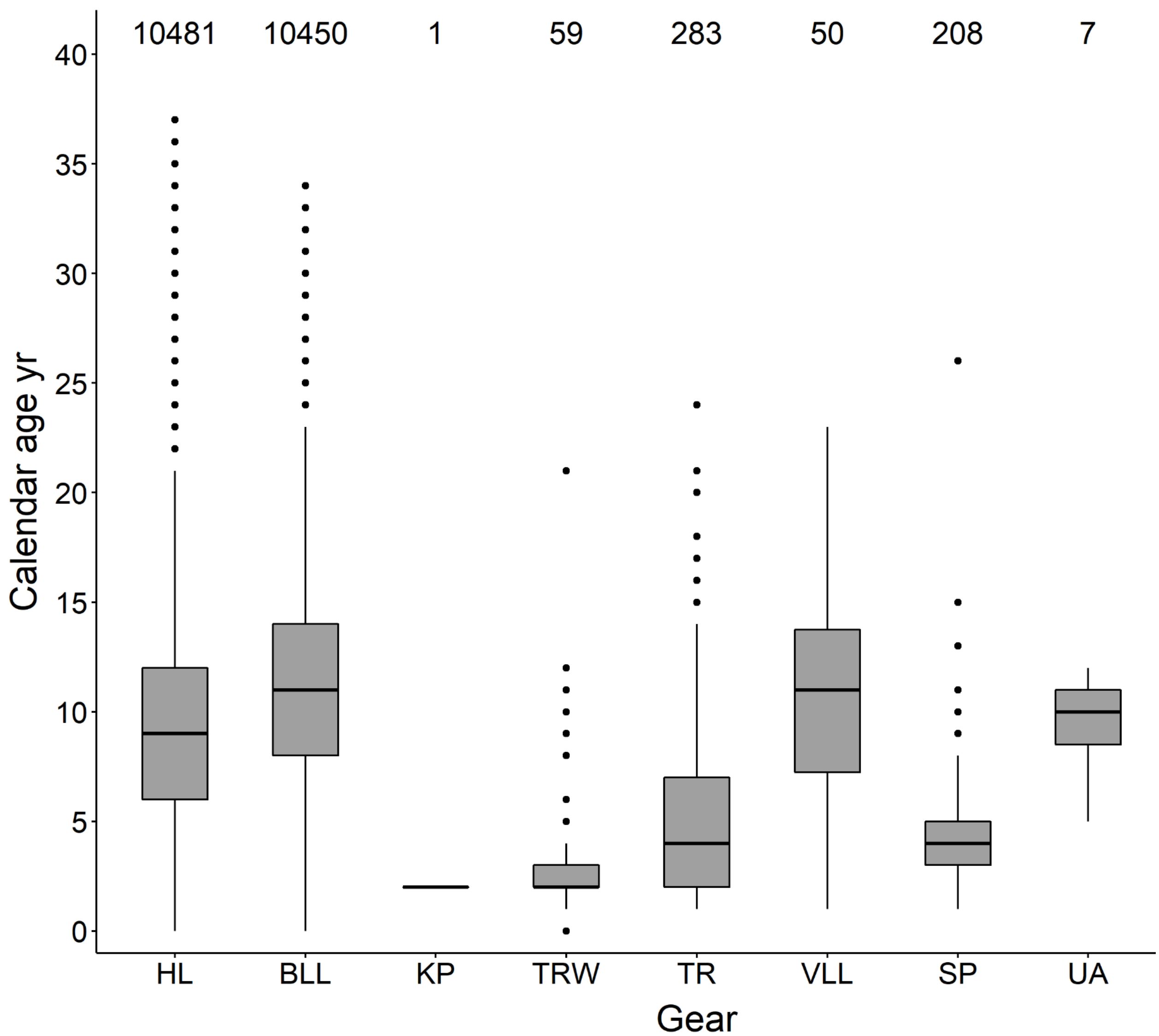

Figure 9. Boxplots of fork length (mm) by gear (handline or hook-and-line, HL; bottom longline, BLL; Kali pole, KP; trawl, TRW; trap, TR; vertical longline, VLL; spear, SP; or unassigned, UA) for all age samples collected from 1972-2020.

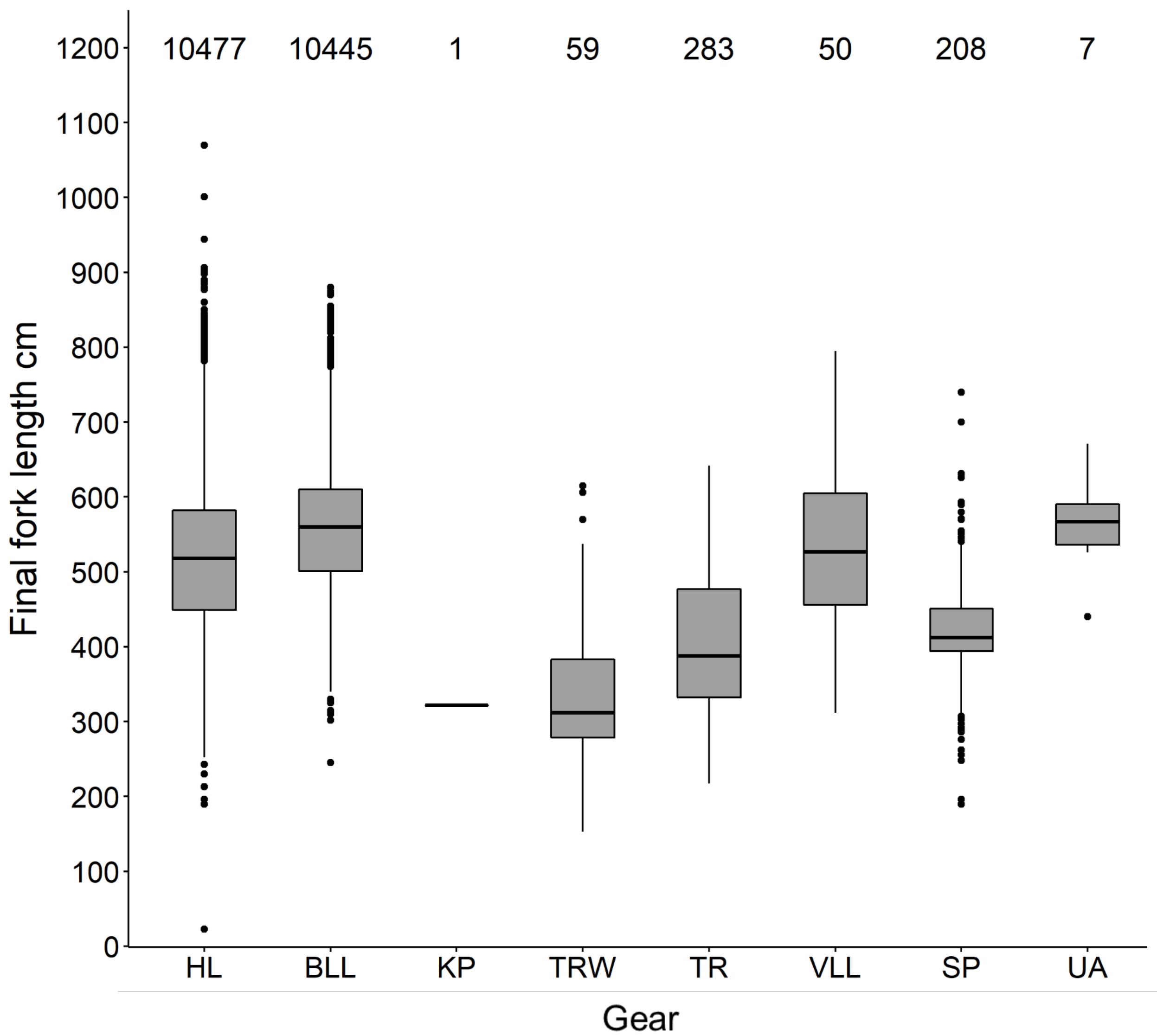

Figure 10. Percent frequency histograms of calendar age (yr) by year for scamp age samples collected from 1972-2020 from the Gulf of Mexico.

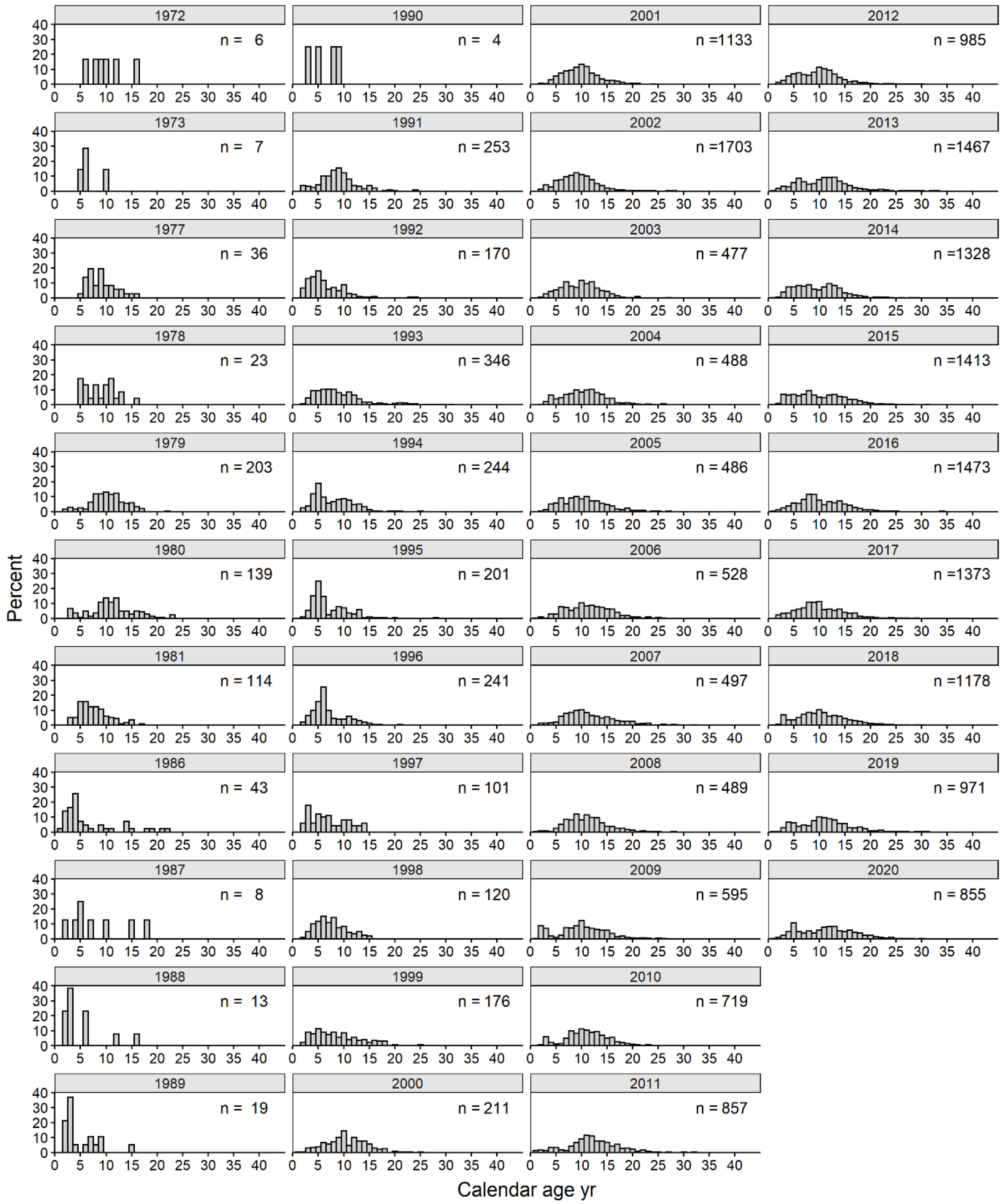

Figure 11. Scatter plots of calendar age (yr) by final fork length (mm) for scamp age samples collected from 1972-2020 from the Gulf of Mexico.

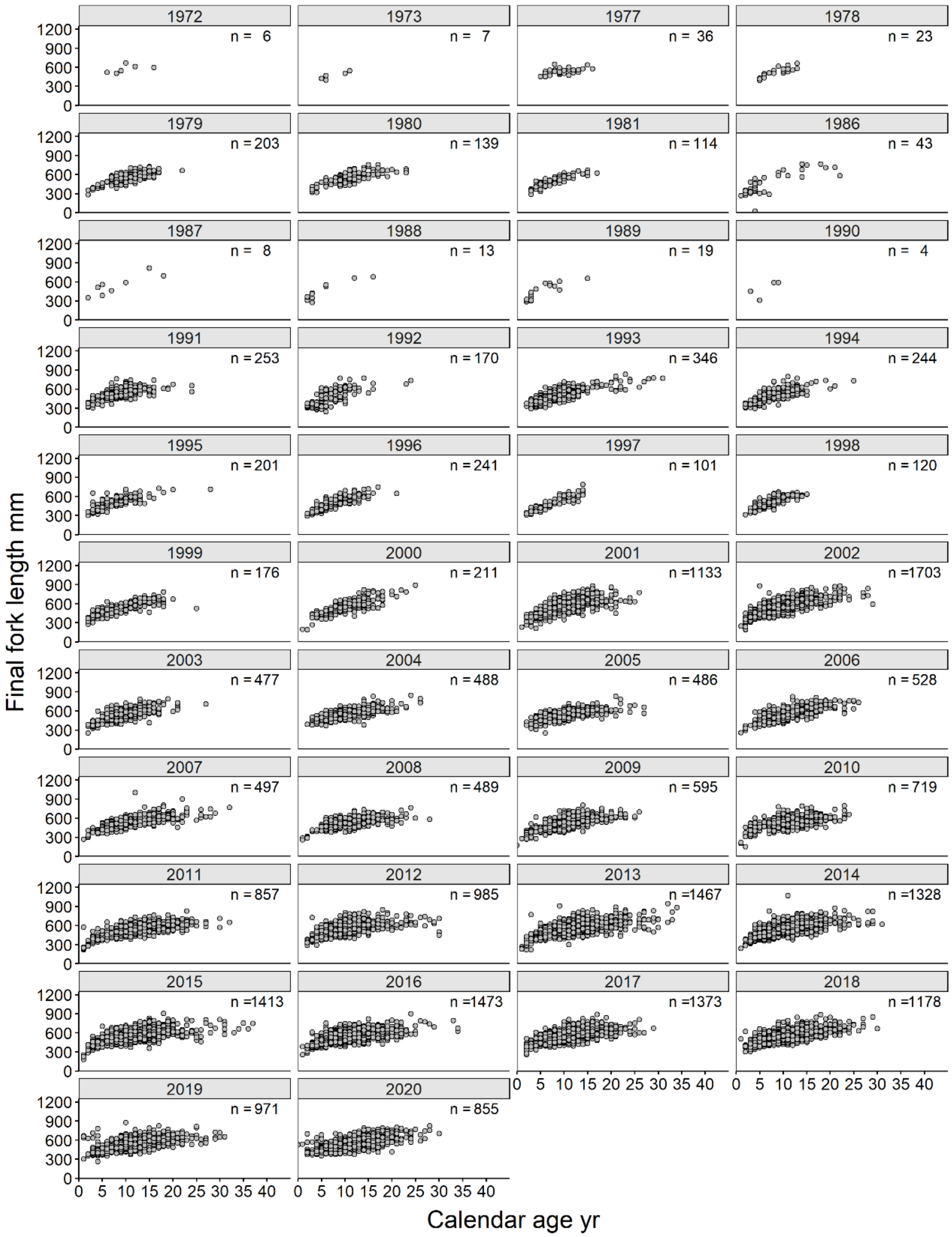

Figure 12. Bubble plot of the count (indicated by a numeric label, bubble size, and frequency histogram) of age estimates by the primary reader at each age estimated by the expert reader.

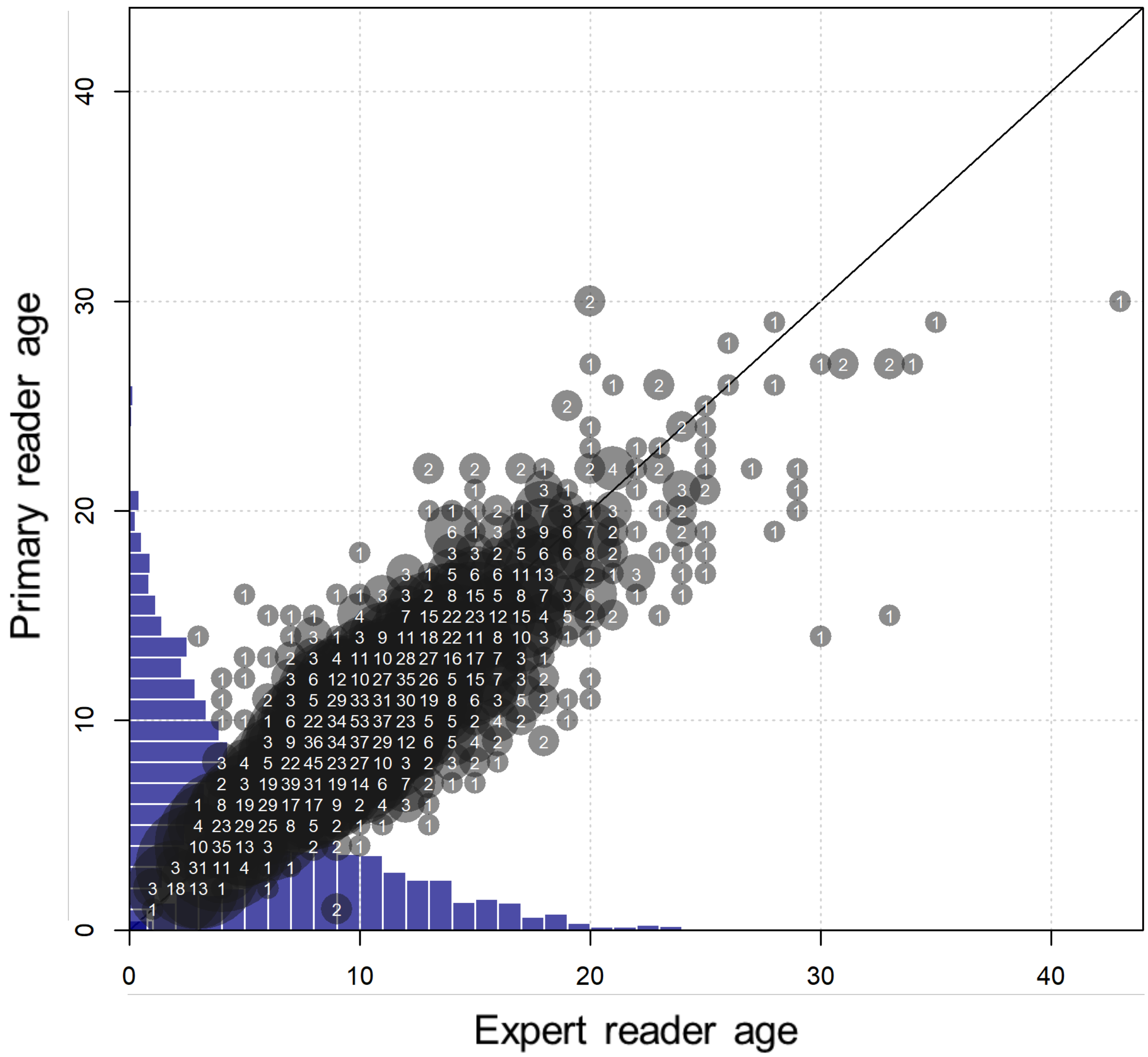

Figure 13. Scatter plots of read (gray points) versus predicted age (solid red line) with 95% CI (dashed red lines) and standard deviation of predicted ages (solid blue line) for all age samples read by at least one primary reader and the expert reader. The dashed black line indicates the line of 1:1 agreement. Expert ages are assumed to be with error.

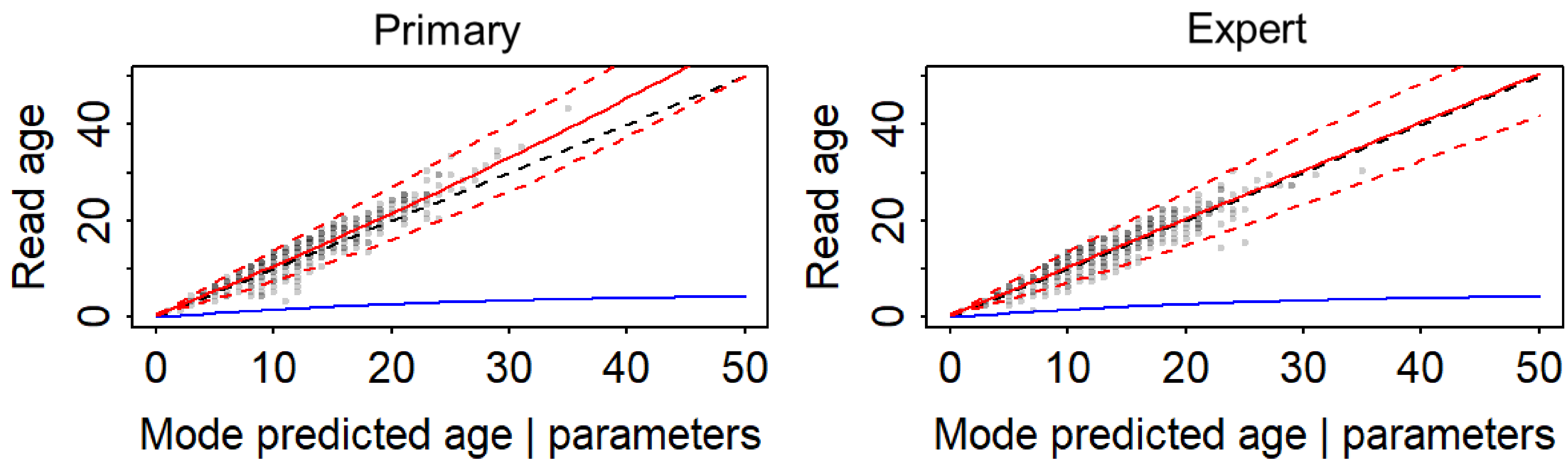

Figure 14. Scatter plots of read (gray points) versus predicted age (solid red line) with 95% CI (dashed red lines) and standard deviation of predicted ages (solid blue line) for all age samples read by at least one primary reader and the expert reader. The dashed black line indicates the line of 1:1 agreement. Expert ages are assumed to be without error.