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Length-at-age of southeast US Atlantic red snapper (*Lutjanus campechanus*)

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Abstract

In this working paper, we describe approaches taken to represent somatic growth (length-at-age) of US Atlantic red snapper. We estimated growth for the population at large using the three-parameter von Bertalanffy model. We additionally characterized length-at-age for fishery landings using an empirical approach, after demonstrating that von Bertalanffy models are inappropriate for these data.

Introduction

Length-at-age information has multiple uses in integrated stock assessment models. When describing growth of the population at large, length-at-age information can contribute toward computation of spawning biomass and age- or length-based natural mortality (Lorenzen et al. 2022). When characterizing landings, length-at-age information can contribute toward computation of landings in weight and predictions of fishery dependent length compositions. Length-at-age of landings may differ from that of the population if fishers are selective about sizes of fish that they retain. This may occur if a size limit is in effect, if high-grading occurs, or simply as a result of angler preference.

The most common somatic growth model for fishes is the von Bertalanffy equation (von Bertalanffy 1938). Here we fit the von Bertalanffy growth model to Atlantic red snapper length-at-age data, both to develop a population growth curve and to evaluate adequacy of such fits for describing fishery dependent data. We additionally examined empirical estimates for fishery dependent data. In all cases, length measures maximum total length (MTL) in millimeters.

Data and Treatment

Samples comprise paired observations of age and MTL, and were received from multiple agencies, including South Carolina Department of Natural Resources (SCDNR; n=18,775), Georgia Department of Natural Resources (GADNR; n=2,784), Florida Fish and Wildlife Research Institute (FWRI; n=44,059) and NOAA Fisheries-SEFSC/Beaufort Lab (NOAA; n=17,147). Of all these samples (total n=82,438), the majority were from fishery dependent sources (recreational n=33,063; commercial n=18,251), but with a substantial number also from fishery independent sources (n=31,124).

Ages were based on otolith reads. Prior to ageing with a stereo microscope, otoliths were processed using low speed saws and taking a thin section of the otolith core. Ages ranged from 0 to 54 years, MTL ranged from 36 to 1116 mm, and years sampled encompassed 1977-2024.

Models and Estimation

We fit the standard von Bertalanffy growth model to the various data sets. This three-parameter model predicts length (L_a, here Maximum Total Length) as a function of age (a),

$$L_a = L_\infty\left(1 - \exp\left(-k(a - t_0)\right)\right)$$

where L_∞ is the average asymptotic length in mm, k is the growth coefficient, and t_0 is the theoretical age at which length is zero. Each model was fitted using maximum likelihood, assuming that error followed a normal distribution, which adds a fourth estimated parameter to characterize the variance of length-at-age. For fishery dependent data collected under the influence of a size limit, we applied a truncated normal distribution, bounded below by the relevant minimum legal size (McGarvey & Fowler 2002). Other SEDAR stock assessments have referred to this methodology as the "Diaz correction." This correction was applied when developing the population growth curve, but not when evaluating fishery dependent curves for which the goal is to describe length-at-age of the retained catch whether or not it is influenced by a size limit.

The data set for estimating the population growth curve contained all paired observations of fractional ages and lengths from all years. Given the large sample size and spread of lengths across ages, all observations were given equal weight in the likelihood for estimating the population growth curve. For fishery dependent curves, where observations of younger and older fish may be lacking, observations were weighted inversely by sample size at age (based on calendar year ages). Time periods considered for fishery dependent curves were 1983-1991, 1992-2009, 2010-2024. The earlier period had a 12-inch (305 mm) federal size limit, the middle period had a 20-inch (508 mm) federal size limit, and the latter period had no federal size limit. However, in the latter period, if a red snapper was landed outside of the mini-season, it was assumed to have come from state waters (coast-side of the Exclusive Economic Zone) where a 20-inch limit applied in the following way. Georgia and Florida had size limits for all years after 2010, South Carolina enacted a size limit starting in 2022, and North Carolina did not have a state size limit.

For each data set, we fit von Bertalanffy growth models assuming either a constant standard deviation (SD) of length-at-age or a constant coefficient of variation (CV) of length-at-age. In all cases, the model with constant SD provided the better fit, based on maximum likelihood, suggesting that the variance of length-at-age does not increase with age. Thus, we report only results from those models with constant SD. All models were fitted using AD Model Builder (Fournier et al. 2012).

An alternative to fitting a growth model is to use empirical estimates of mean length-at-age and standard deviation of length-at-age. Empirical estimates may be most useful for describing fishery dependent data, where the goal is simply to represent mean and variance of length-at-age, and a mechanistic underpinning of growth is unnecessary.

Results and Discussion

Population growth curve

The population growth curve is shown in Figure 1. Parameter estimates, their standard errors (SEs), and correlations are shown in Table 1.

Fishery dependent length-at-age – Pre1983

Because there was no size limit in place prior to 1983, the population growth curve should be adequate to describe length-at-age of landings in this early period.

Fishery dependent length-at-age – 1983-1991

A growth curve was fitted to fishery dependent data from the period 1983-1991 (Figure 2). However, with relatively small sample size (n=2306) and with 97% of all observations spanning only a small number of ages (<= age 5), it is impossible to evaluate whether this curve is adequate for describing length-at-age for the full set of ages. In addition, for those ages with largest sample sizes (ages <=5), the distributions of residuals did not appear to conform to normality centered on zero (Figure 3). Thus, this growth curve is not recommended for use in the assessment.

Empirical estimates of mean and standard deviation of length-at-age were computed for all ages with observations (Table 2), although at least two observations were necessary for computing the standard deviation. Not surprisingly, the empirical estimates have more flexibility to describe the data and demonstrate less of a pattern in the residuals (Figure 4). However, empirical estimates can be unreliable under small sample size, and clearly sample sizes diminish for ages older than 5. Thus, for those ages with sample size fewer than $n = 25$, i.e., ages 6+, we propose using the means and standard deviations from the population growth curve (Table 2). Using the population growth curve to fill in missing or inadequately estimated values can be justified under two considerations. First, given the distributions of length at age implied by the population-growth-curve estimates, few fish in the population would have been smaller than the 12-inch size (305 mm), especially for fish age 2+ (Figure 1). Second, empirical estimates are not statistically different from population-growth-curve estimates (Figure 5).

Fishery dependent length-at-age – 1992-2009

A 20-inch (508 mm) size limit was in place during the period 1992-2009. Thus, during that time, it is expected that average length-at-age of retained catch would be larger than that of the population at large. Using these data, parameter estimates of the von Bertalanffy model were $L_\infty = 902.93$, $k = 0.22$, $t_0 = -1.23$, and $SD = 45.15$ (Figure 6). Residual patterns were generally well centered on zero, but with some deviation particularly for younger ages (Figure 7).

Empirical estimates of mean and standard deviation of length-at-age were computed for all ages with observations (Figure 8), although at least two observations were necessary for computing the standard deviation. These values were also computed with age-20 as a plus-group (Table 3). Not surprisingly, the empirical estimates have more flexibility to describe the data and demonstrate less of a pattern in the residuals (Figure 9). However, empirical estimates can be unreliable under small sample size, and clearly sample sizes diminish for older ages (Figure 8, bottom panel). Thus, for those ages with sample size fewer than $n = 25$, alternative values are proposed (Table 3). For age 1, we applied the mean and standard deviation of age-2 fish, which maintains the mean value (521 mm) above the size limit (508 mm). For ages 15-19, we linearly interpolated the mean length from age-14 to that of age-20+, and we applied the average standard deviation from ages 10-14 and age-20+, all ages with $n > 25$ and relatively little variability in standard deviation (Figure 8, Table 3).

Fishery dependent length-at-age – 2010-2024

During 2010-2024, no federal size limit was in place, but several states had a 20-inch limit for red snapper caught within state waters. Using data from this time period, parameter estimates of the von Bertalanffy model were $L_\infty = 891.4$, $k = 0.18$, $t_0 = -1.70$, and $SD =$

48.36 (Figure 10). Distributions of residuals were generally not centered on zero, indicating patterns of overpredicting (ages 1-3) or underpredicting (ages 4-9) mean length-at-age (Figure 11).

Empirical estimates of mean and standard deviation of length-at-age were computed for all ages with observations (Figure 12), although at least two observations were necessary for computing the standard deviation. These values were also computed with age-20 as a plus-group (Table 4). Empirical estimates demonstrated no concerning patterns in residuals (Figure 13).

Recommendations

We recommend that the assessment utilize the von Bertalanffy model to describe growth of the population at large (Figure 1, Table 1). In addition, the population growth curve could also be used to describe length-at-age of fishery dependent data in the time period prior to any size limits (before 1983). Starting in 1983, to describe length-at-age of fishery dependent data, the empirical estimates appear to be more reliable. For the time periods during the federal 12-inch size limit (1983-1991) and during the 20-inch size limit (1992-2009), we recommend using the empirical estimates with proposed alternative values for ages with low sample sizes (Tables 2 and 3). For the time period after the federal 20-inch size limit, we recommend using the empirical estimates from 2010-2024 (Table 4).

Literature cited

Fournier et al. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software 27:233-249.

Lorenzen, Camp, Garlock. 2022. Natural mortality and body size in fish populations. Fisheries Research 106327.

McGarvey, Fowler. 2002. Seasonal growth of King George whiting estimated from length-at-age samples of the legal-size harvest. Fishery Bulletin 100:545-558.

Von Bertalanffy. 1938. A quantitative theory of organic growth (Inquiries on growth laws II). Human Biology 10: 181-213.

Table 1. Parameter estimates, standard errors (SEs), and correlations (in italics) for the population growth curve for South Atlantic red snapper.

Parameter	Estimate	SE	Linf	k	t0	SD
Linf	890.03	1.26	*1.0*	-	-	-
k	0.23	0.001	*-0.89*	*1.0*	-	-
t0	-0.41	0.009	*-0.58*	*0.86*	*1.0*	-
SD	66.50	0.17	*0.01*	*-0.01*	*0.01*	*1.0*

Table 2. Empirical estimates of mean length-at-age (Length.mu), standard deviation of length-at-age (Length.SD), and sample size (n) for fishery dependent data from the period 1983-1991. Also shown are proposed, alternative values that are suggested for ages with low sample size (n<25). Alternative values, shown here in italics, are from the population growth curve.

		Empirical values		Alternative values	
Age	n	Length.mu	Length.SD	Length.mu	Length.SD
1	433	339.0	45.8	339.0	45.8
2	1284	391.9	48.1	391.9	48.1
3	364	450.4	79.5	450.4	79.5
4	129	511.6	105.6	511.6	105.6
5	35	640.3	107.8	640.3	107.8
6	16	723.1	93.6	*686.3*	*66.5*
7	13	740.2	90.2	*728.1*	*66.5*
8	4	856.3	32.2	*761.4*	*66.5*
9	2	806.3	28.8	*787.8*	*66.5*
10	1	820.6	NA	*808.8*	*66.5*
11	3	890.7	8.9	*825.5*	*66.5*
12	1	893.0	NA	*838.8*	*66.5*
13	1	882.8	NA	*849.3*	*66.5*
14	1	953.2	NA	*857.7*	*66.5*
15	0	NA	NA	*864.3*	*66.5*
16	1	871.6	NA	*869.6*	*66.5*
17	1	868.6	NA	*873.8*	*66.5*
18	1	892.0	NA	*877.1*	*66.5*
19	2	911.9	54.1	*879.8*	*66.5*
20+	13	917.7	31.6	*881.9*	*66.5*

Table 3. Empirical estimates of mean length-at-age (Length.mu), standard deviation of length-at-age (Length.SD), and sample size (n) for fishery dependent data from the period 1992-2009. Also shown are proposed, alternative values that are suggested for ages with low sample size (n<25). The computation of alternative values, shown here in italics, is described in the text.

	Empirical values			Alternative values	
Age	n	Length.mu	Length.SD	Length.mu	Length.SD
1	1	362.8	NA	*520.9*	*35.6*
2	546	520.9	35.6	520.9	35.6
3	3523	543.2	41.5	543.2	41.5
4	3540	609.2	61.4	609.2	61.4
5	619	668.1	76.1	668.1	76.1
6	408	727.0	68.4	727.0	68.4
7	402	763.3	58.6	763.3	58.6
8	225	790.9	50.4	790.9	50.4
9	176	805.7	45.5	805.7	45.5
10	141	832.2	41.8	832.2	41.8
11	89	841.2	40.3	841.2	40.3
12	46	859.0	43.1	859.0	43.1
13	28	857.8	43.6	857.8	43.6
14	25	868.9	39.1	868.9	39.1
15	15	845.3	78.2	*875.6*	*41.3*
16	19	879.4	57.6	*882.4*	*41.3*
17	22	877.4	44.5	*889.2*	*41.3*
18	18	865.2	88.7	*895.9*	*41.3*
19	8	874.7	33.0	*902.7*	*41.3*
20+	73	909.5	39.5	909.5	39.5

Table 4. Empirical estimates of mean length-at-age (Length.mu), standard deviation of length-at-age (Length.SD), and sample size (n) for fishery dependent data from the period 2010-2024.

Age	n	Length.mu	Length.SD
1	570	336.3	55.8
2	5111	412.9	43.8
3	7019	498.9	59.7
4	6827	590.9	66.1
5	5854	661.5	63.2
6	3976	710.8	60.0
7	2795	752.5	48.2
8	2075	773.5	45.2
9	1166	791.9	42.9
10	392	785.6	45.0
11	359	801.9	48.8
12	475	816.1	43.5
13	438	817.5	38.4
14	393	818.6	47.9
15	286	827.5	47.2
16	166	847.0	46.7
17	115	840.6	44.2
18	83	848.3	56.8
19	55	860.7	44.8
20+	124	883.9	42.0

Figure 1. Top panel: population growth curve for South Atlantic red snapper. Bottom panel: normal distributions of length at age, conditional on midyear population growth curve estimates. Vertical lines designate 12-inch (1983-1991) and 20-inch (1992-2009) size limits. This growth curve is recommended for use in the assessment to describe the population and to describe landings prior to 1983.

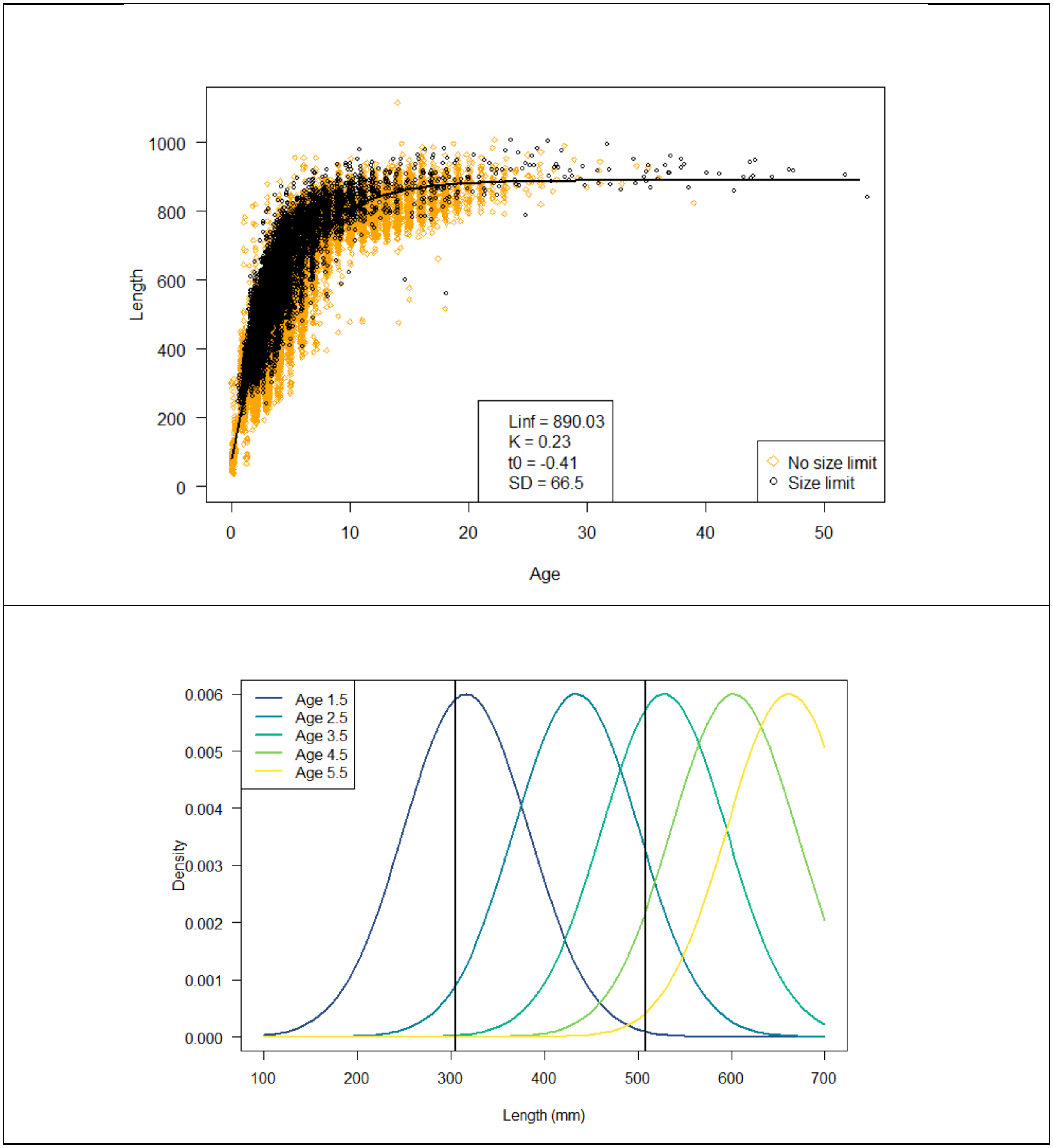

Figure 2. Growth curve for South Atlantic red snapper fitted to fishery dependent data from 1983-1991. This growth curve is not recommended for use in the assessment.

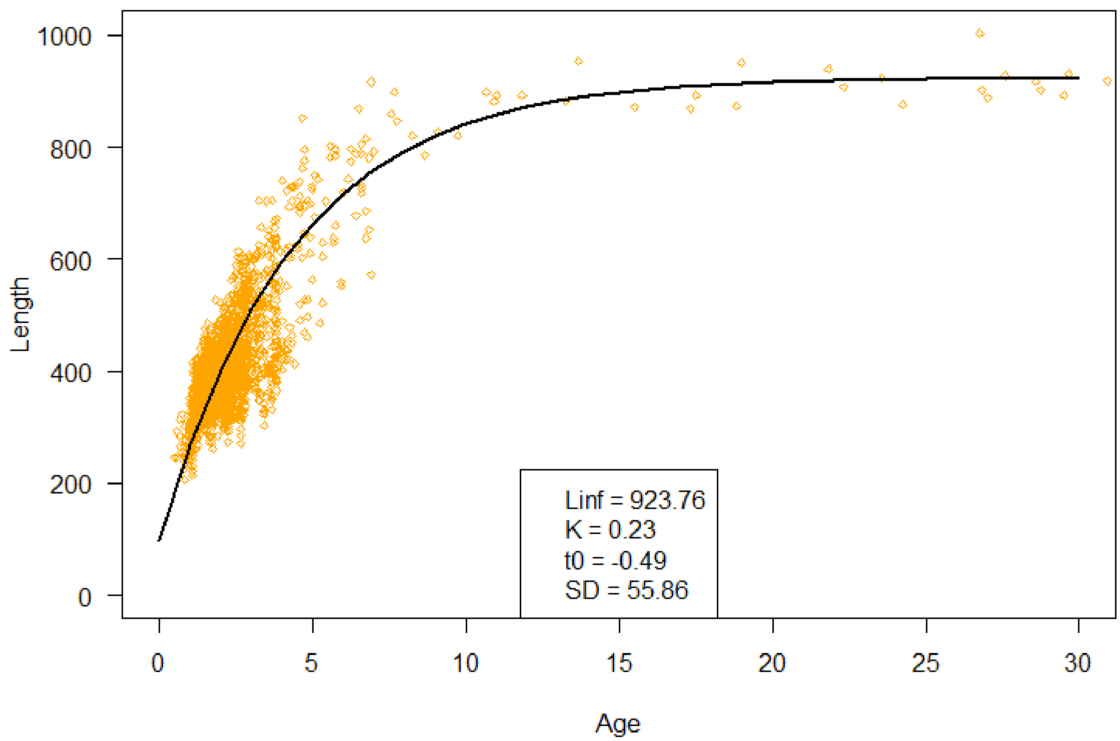

Figure 3. Residuals of the von Bertalanffy model fit to fishery dependent data from the period 1983-1991. Left panel: scatterplot of residuals. Right panel: distributions of residuals.

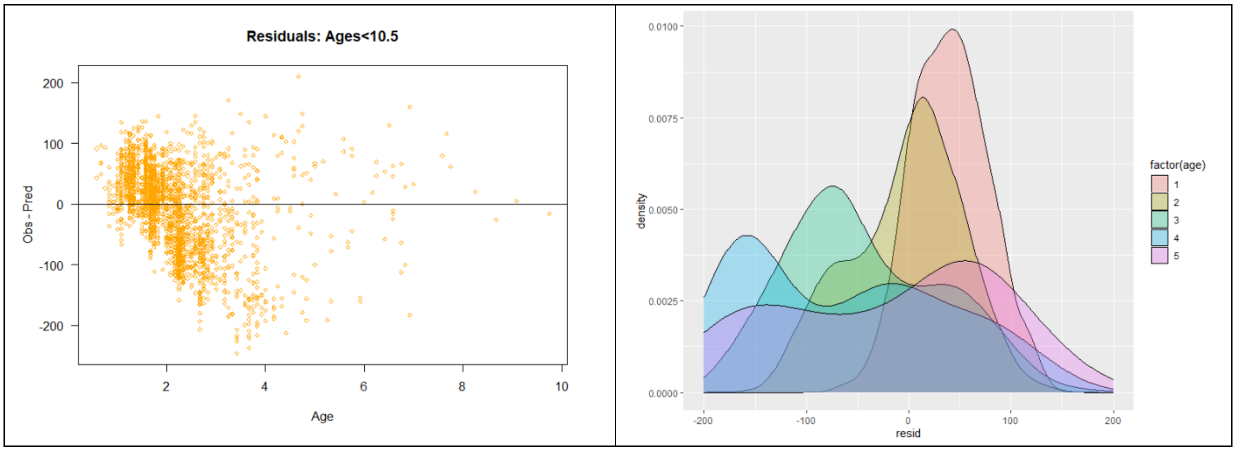

Figure 4. Residuals of the empirical fits to fishery dependent data from the period 1983-1991. Left panel: scatterplot of residuals. Right panel: distributions of residuals.

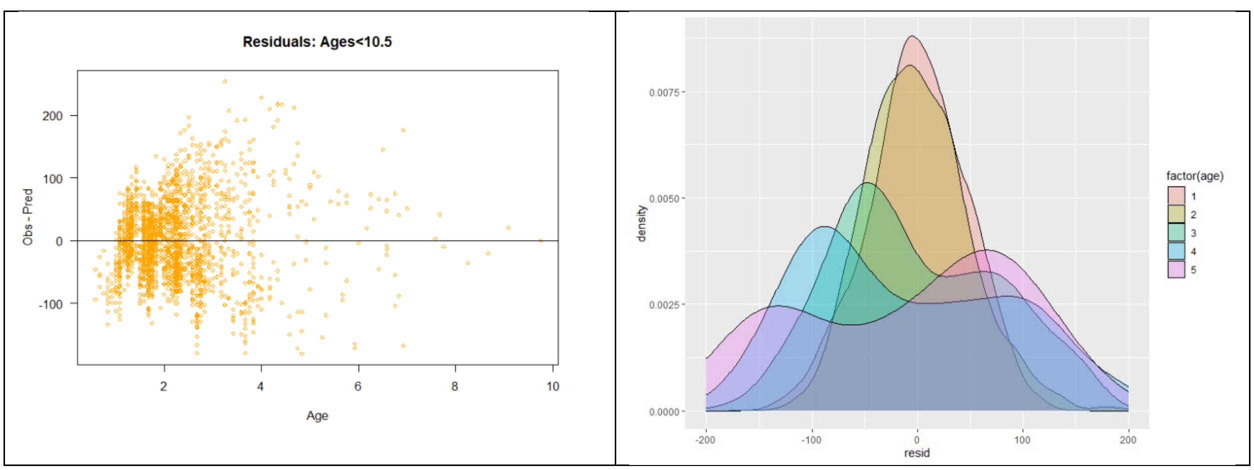

Figure 5. Comparison of the population growth curve to mean length-at-age (maximum total length in mm) from the period 1983-1991. Error bars represent plus/minus one standard deviation.

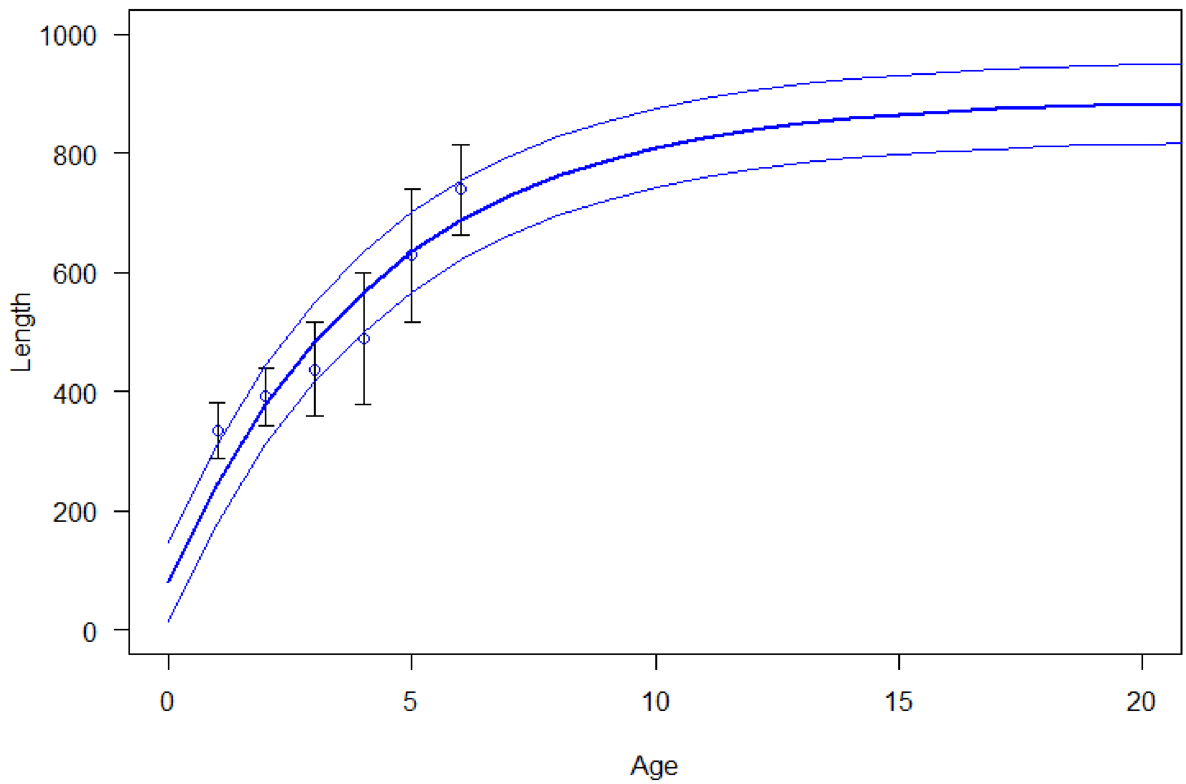

Figure 6. Von Bertalanffy growth model fit to fishery dependent data from the period 1992-2009. This growth curve is not recommended for use in the assessment.

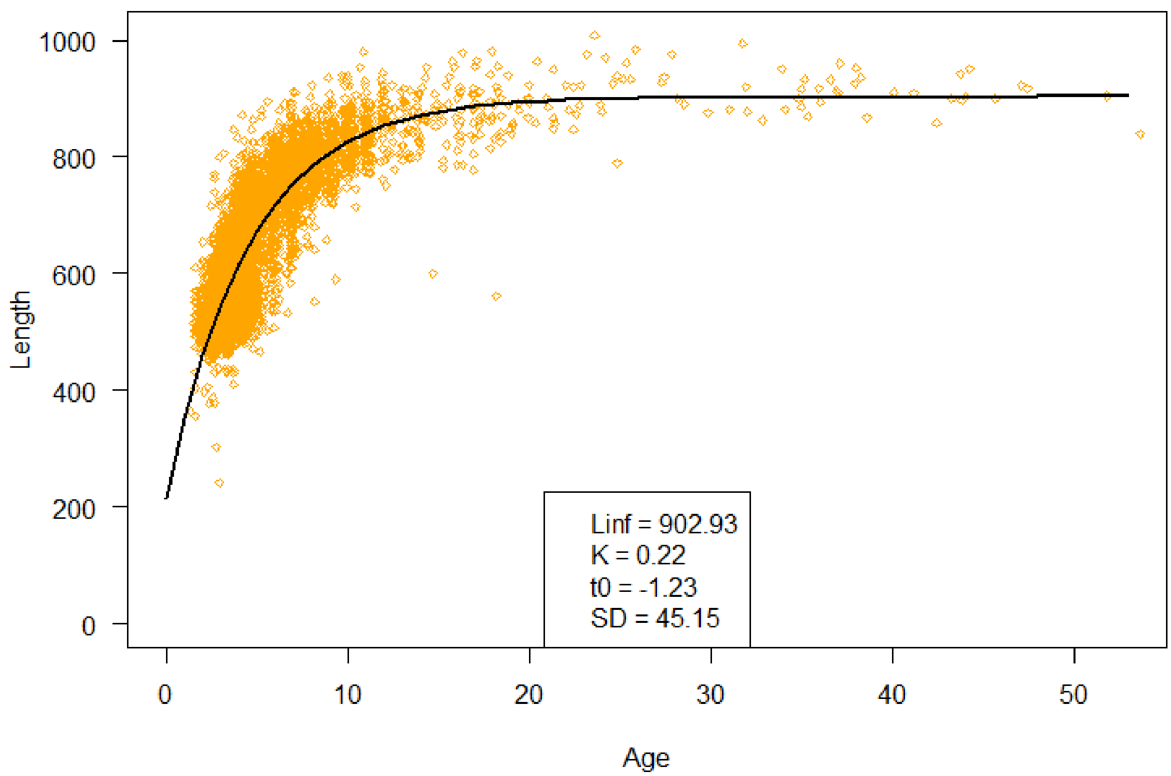

Figure 7. Residuals of the von Bertalanffy model fit to fishery dependent data from the period 1992-2009. Top panel: scatterplot of residuals. Bottom panel: distributions of residuals.

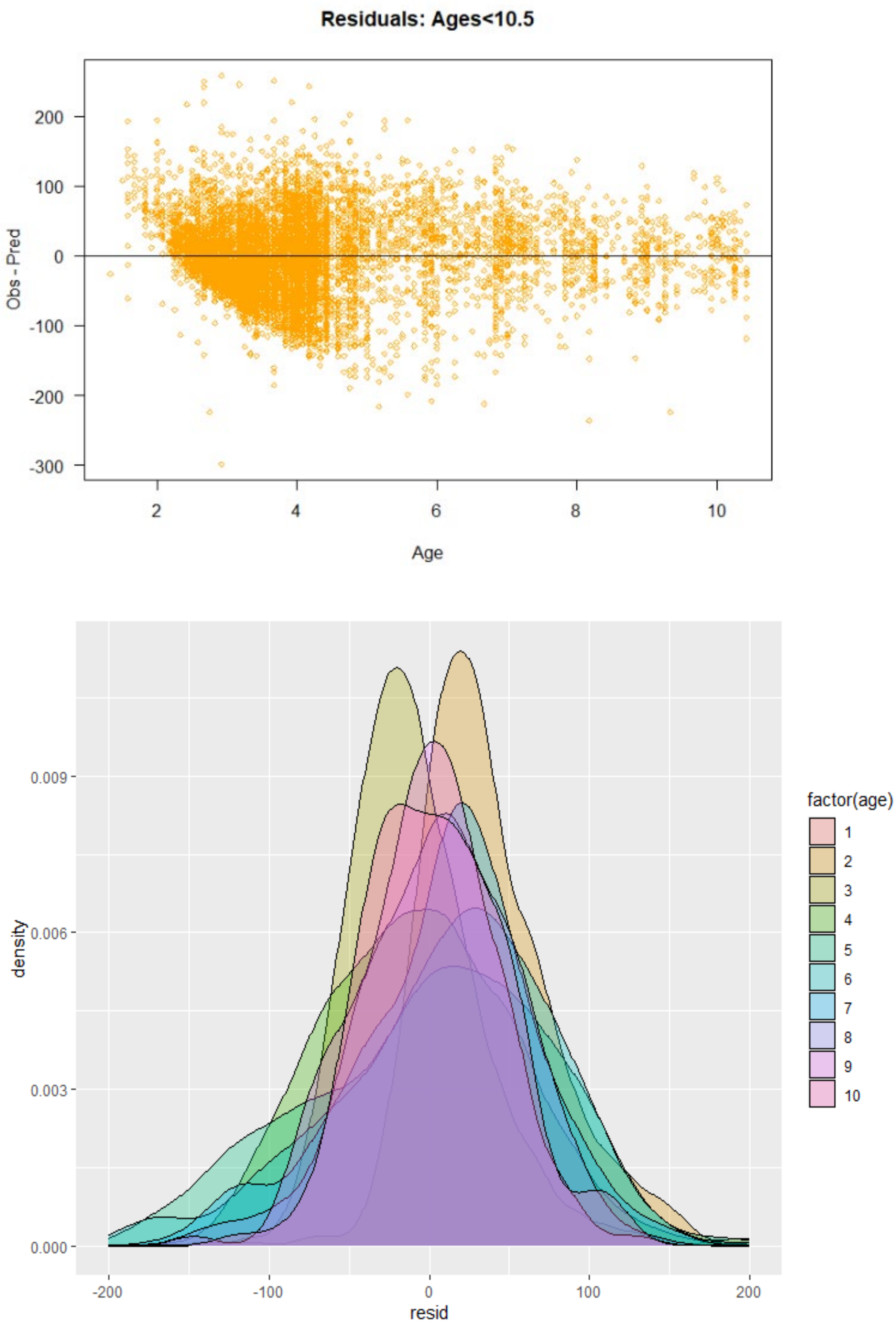

Figure 8. Empirical estimates of mean length-at-age (top) and standard deviation of length-at-age (bottom) for fishery dependent data from the period 1992-2009. Sample sizes for ages with more than one observation are shown in the bottom panel.

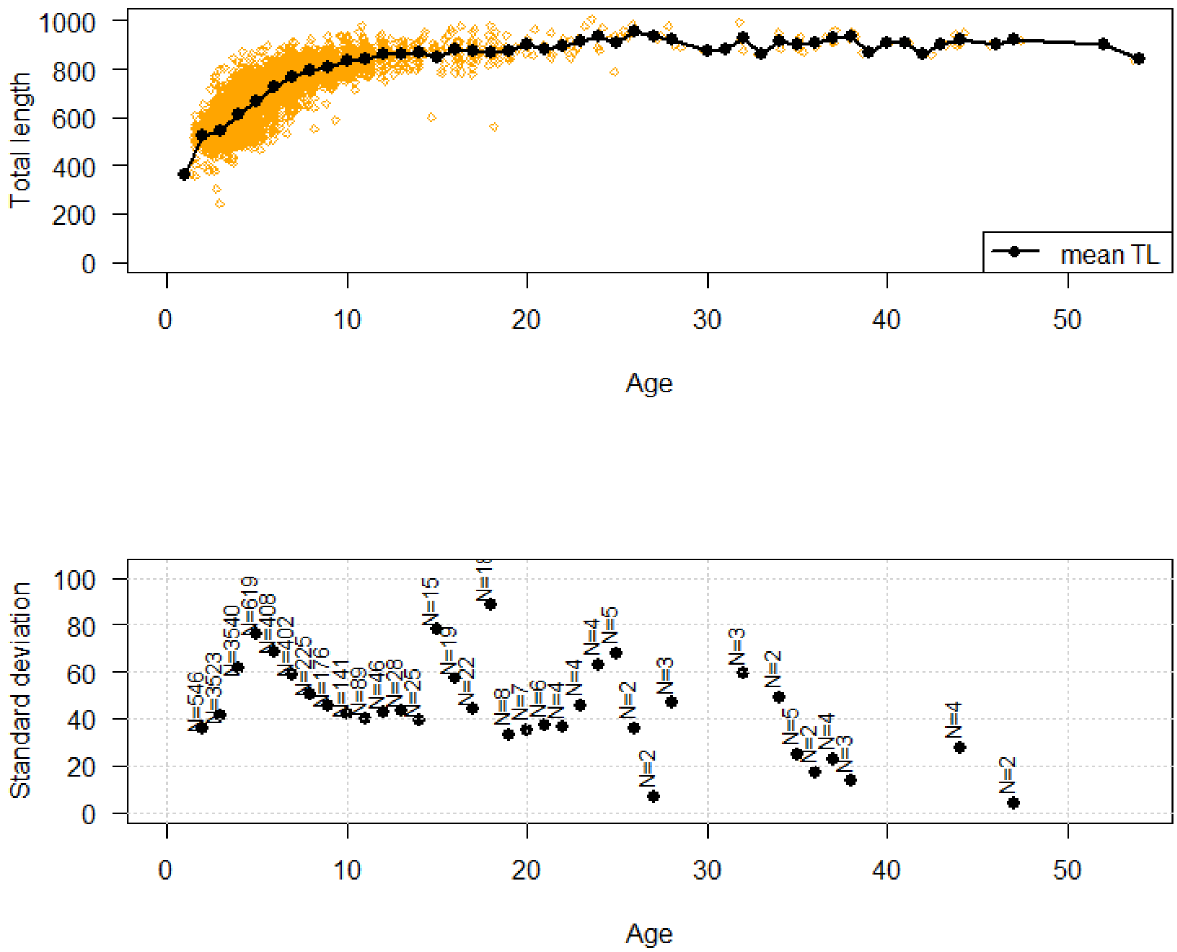

Figure 9. Residuals of the empirical fits to fishery dependent data from the period 1992-2009. Top panel: scatterplot of residuals. Bottom panel: distributions of residuals.

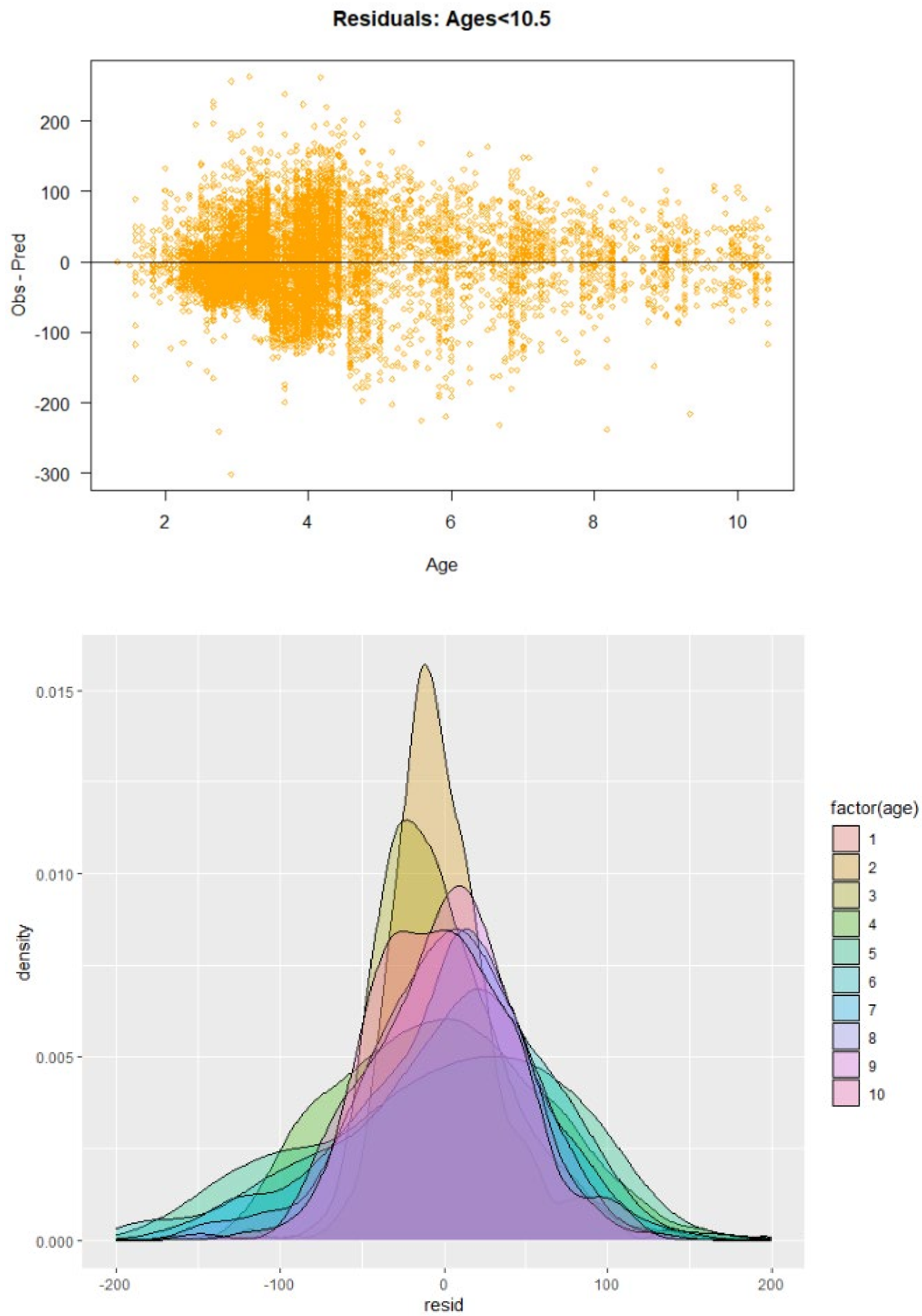

Figure 10. Von Bertalanffy growth model fit to fishery dependent data from the period 2010-2024. This growth curve is not recommended for use in the assessment.

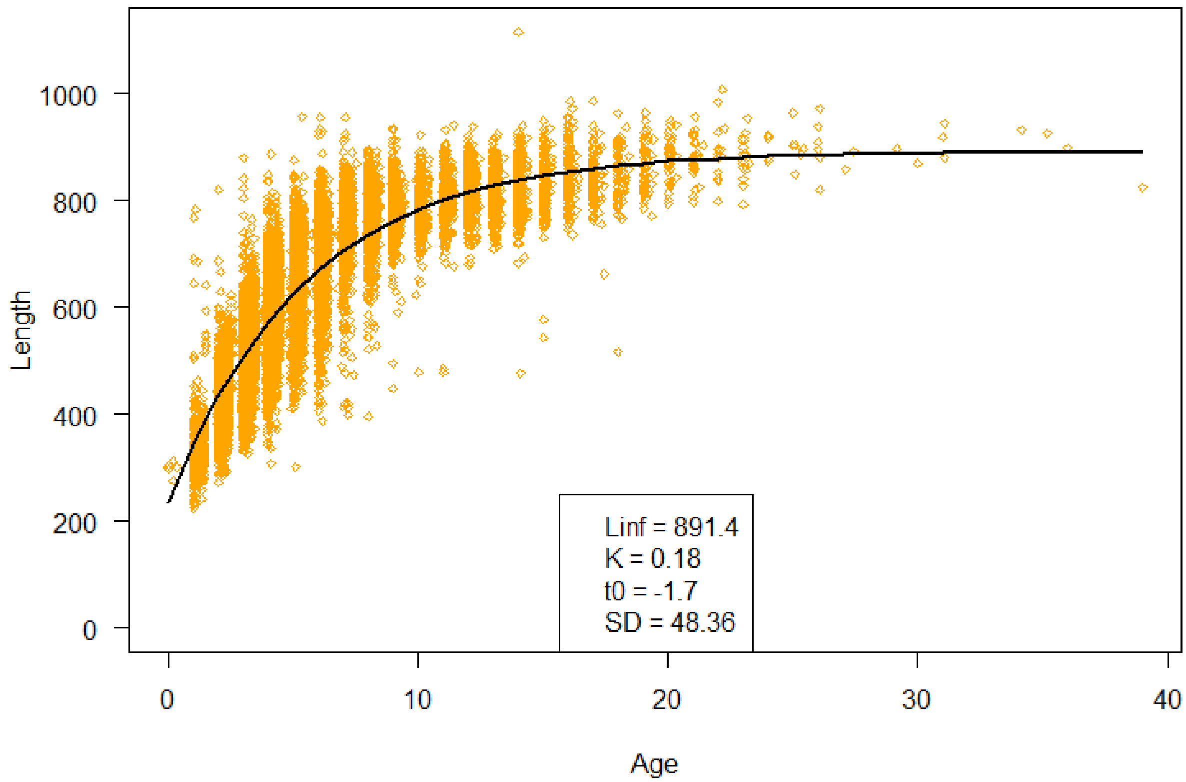

Figure 11. Residuals of the von Bertalanffy model fit to fishery dependent data from the period 2010-2024. Top panel: scatterplot of residuals. Bottom panel: distributions of residuals.

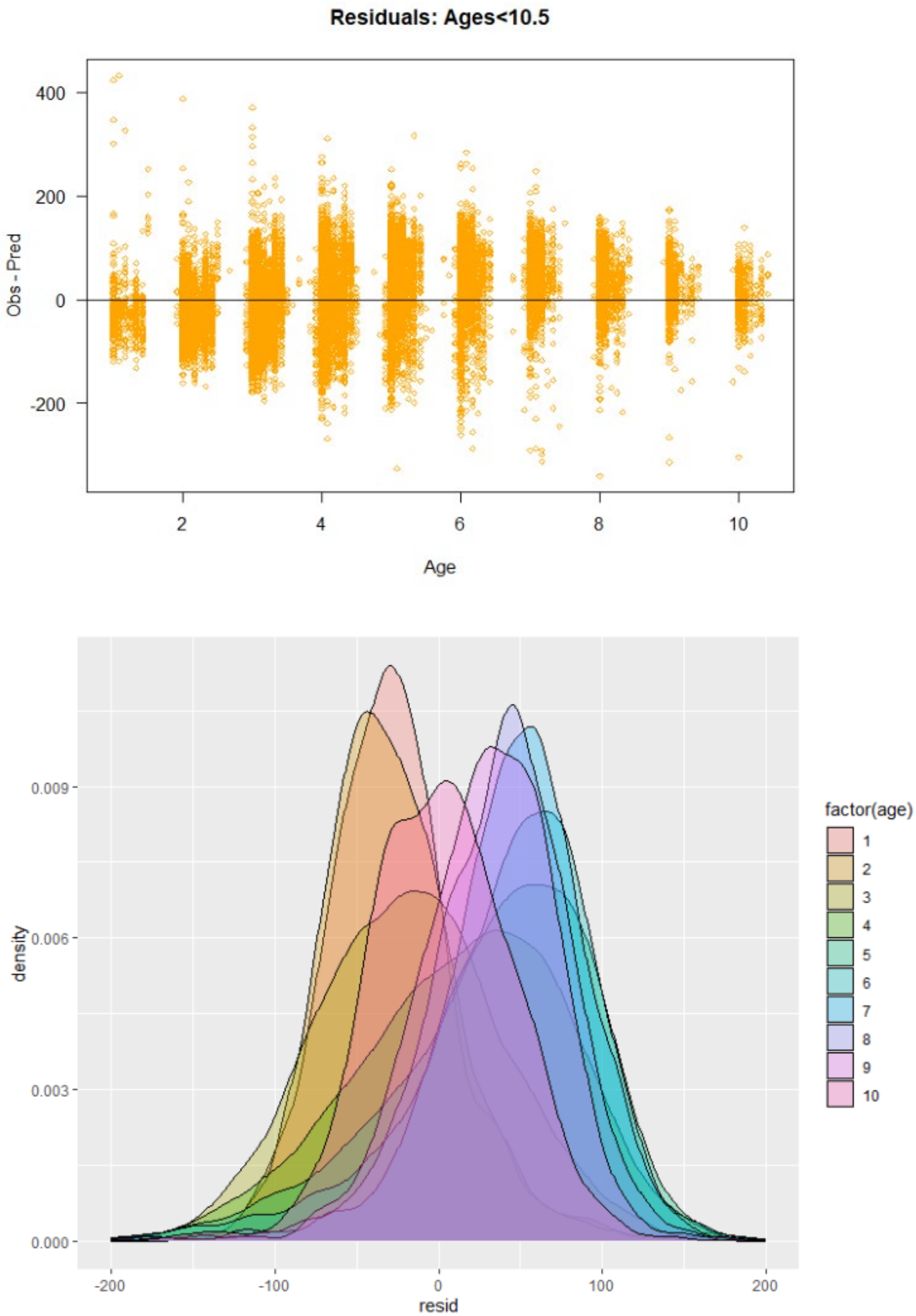

Figure 12. Empirical estimates of mean length-at-age (top) and standard deviation of length-at-age (bottom) for fishery dependent data from the period 2010-2024. Sample sizes for ages with more than one observation are shown in the bottom panel.

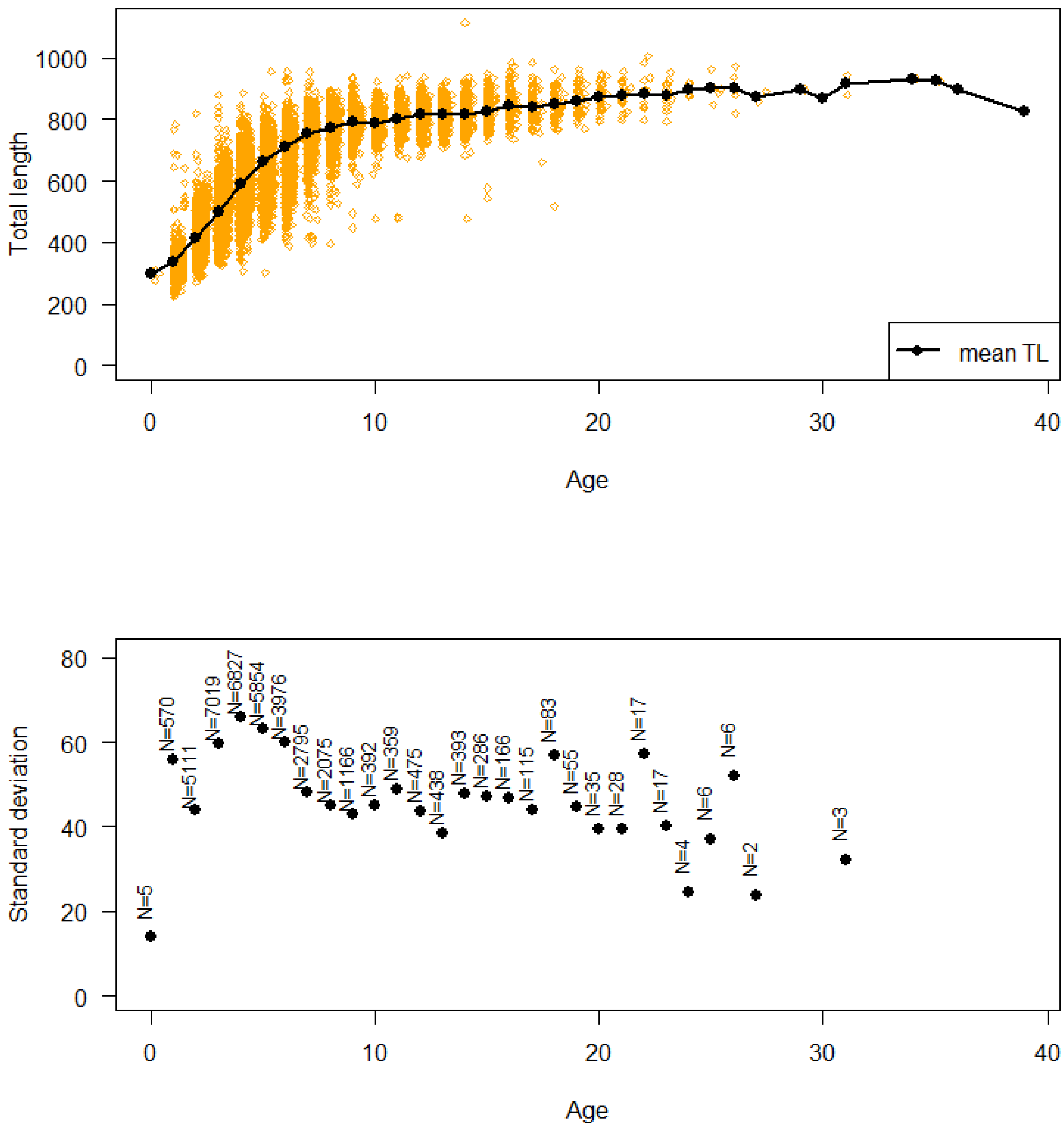

Figure 13. Residuals of the empirical fits to fishery dependent data from the period 2010-2024. Top panel: scatterplot of residuals. Bottom panel: distributions of residuals.