Comparisons in Growth between Cobia Males and Females and among Years Using Virginia Length-age Data Collected by Virginia Marine Resources Commission between 1999 and 2018

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Comparisons in Growth between Cobia Males and Females and among Years Using Virginia Length-age Data Collected by Virginia Marine Resources Commission between 1999 and 2018

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INTRODUCTION

VA working paper (DW01) (Liao et al. 2018) examined the mean fork lengths of Cobia samples collected by VMRC from 1999 to 2018 and found that the VA Sportfish Collection Program (hereafter referred to as "Donation program") didn't result in the observed decreases of the mean lengths during the period of 2007 to 2018 when VMRC collected donated carcasses for the length-age data. This study is to verify the results of DW01 and to identify possible factors causing changes in the mean length and growth. The specific objectives are: 1) Compare growth rates between Cobia males and females; 2) identify factors driving annual variations in Cobia growth; 3) compare Cobia growth rates between different periods from 1999 to 2018; 4) discuss the influence of the donation program on estimates of Cobia growth; and 5) discuss factors which could affect the application of the VA length-age data in the Cobia stock assessment.

METHODS

Data collection

VMRC collected Cobia from 1999 to 2018 using a conventional harvest sampling method and the marine sportfish collection program. The conventional method started in 1999 and consisted of VMRC personnel randomly collecting length-age data through the purchase of individual cobia from recreational fishermen. The donation program started in 2007 and uses freezer donation centers to collect length-age data from recreational fishermen. The fishermen were encouraged to donate their Cobia carcasses whenever they could, therefore, the donations were not randomly designed.

The fish purchased through the conventional method were measured for fork length to mm, weighed to 0.01 pound, and sex was identified by VMRC personnel. The fish carcasses donated by the recreational fishermen were measured for fork length to mm and sex was identified by the personnel at the Ageing and Growth Lab at ODU (ODU Lab). The sex of a carcass without any gonads was assigned as "Unknown". The ODU Lab processed and aged all Cobia otoliths from both programs. Details on processing and ageing Cobia otoliths can be found from the VMRC Finfish Ageing Annual Reports posted at the ODU Lab website.

Data analysis

Year-pooled sex-specific growth

We pooled all years of length-age data from 1999 to 2018 to examine the difference in growth between males and females. First, we fitted von Berlanffy growth model to the mean length-at-age data of males and females, respectively. Then, we used the Kimura likelihood ratio test to examine the difference (Kimura 1980). The model fitting and the Kimura test were conducted by using growthlrt() function in R Package "fishmethods" developed by Dr. Gary Nelson at Massachusetts Division of Marine Fisheries.

There are four hypothesis tests in the the Kimura test: H0 vs. H1, H0 vs. H2, H0 vs. H3, and H0 vs. H4. If more than one hypothesis was not rejected ($p > 0.05$), the models for the female and male associated with the hypothesis with the smallest AIC were selected. The details on the four tests can be found in Kimura (1980).

Effects of sex-ratio in a sample

When the growth rates between the males and females were significantly different, we examined the relationships between the sex-ratio and observed mean fork length in a sample. We also examined the relationship between the sex-ratio and an annual growth estimated using the sample. Sex-ratio in a sample is calculated as follows:

$$S = \frac{M}{F}, \tag{1}$$

where S is a year-specific sex-ratio, and M and F are number of males and females observed in the year, respectively.

Sex-pooled and sex-specific annual growth

We fit von Bertalanffy growth models to sex-pooled and sex-specific length-age data to estimate the sex-pooled and sex-specific annual growth. We examined the relationship between the sex-pooled annual growth and sex-ratio observed each year. Because there were annual variations in the sex-ratios and different growth rates between sexes, we examined the annual growth from 1999 to 2018 using the sex-specific growth. We didn't fit the growth model to any length-data with less than three ages.

Comparisons in growth between periods

Finally, we used the Kimura test (Kimura 1980) to examine the growth rates between two periods within the time series in four different comparisons. The four comparisons were set up based on the year (2007) when the donation program started and the analysis of the length distribution reported in our previous working paper (Liao et al. 2018). The four comparisons were:

A. The donation program started in 2007. Assuming that VMRC conducted random sampling before 2007, we divided the time series into "Random" (1999-2006) and "Donation" (2007-2018) period;

B. Liao et al. (2018) found that the mean fork length decreased significantly since 2013, therefore, the "Donation" period was further divided into "FirstDonation" (2007-2012) and "SecondDonation" (2013-2018) period;

C. Liao et al. (2018) reported that the mean fork length didn't decrease significantly from the "Random" period after the donation program started in 2007. Therefore, we examined the growth rates between "Random" and "FirstDonation" period;

D. If there was no significantly different growth between "Random" and "FirstDonation" period, we combined the two periods into "RandomFirstDonation" period (1999-2012) and tested it against "SecondDonation" period.

The model selection for two periods from the Kimura test is the same as described in Section *Year-pooled sex-specific growth*. The examinations on the growth rates between two periods within each of the four comparisons could help fisheries scientists to better understand the quality of length-age data collected through VA donation program and to further decide if such data can be used in the Cobia stock assessment.

RESULTS

Year-pooled sex-specific growth

The Kimura test didn't reject the hypothesis of H0 vs. H2, that is, the L_∞s (Asymptotic length in Quinn and Deriso (1999)) and t_0s were significantly different between the males and females whereas the Ks (Brody growth parameter in Quinn and Deriso (1999)) were not significantly different (Figure 1). The female Cobia grew much faster and larger than the male Cobia in Virginia waters during the period of 1999 to 2018.

Effect of sex-ratio on estimated mean length and growth

Because the growth rates are significantly different between Cobia males and females, the sex-ratio in a particular sample could significantly affect the sex-pooled mean length and growth rate estimated from the sample. Figure 2 shows that there is a negative correlation between the sex-ratio and the mean length through the time series, and the 72% variation (R^2=0.7237) in the mean length are explained by the sex-ratio. In general, the sex-ratios increased through years, indicating that more and more males were collected during the past several years.

Figure 3 shows that the sex-ratio could influence the estimate of an sex-pooled annual growth of Cobia population. In the 2006 sample the sex-ratio is 0.04 while the estimate of the growth rate for 2006 is the highest (The dash-brown line). In contrast, in the 2015 sample the sex-ratio is 1.01 while the estimate of the growth rate for 2015 is the second lowest (The short dash-red line). It is obvious that a higher sex-ratio results in a lower growth rate and vice versa. Therefore, a comparison in growth between years using a sex-pooled data could be misleading due to different growth rates between males and females and different sex-ratios observed between years.

Sex-specific annual growth

The examination of sex-specific annual growth could provide a clearer picture on the growth rates between years by removing the effect of sex-ratio (Figure 4). However, a sample size by sex sometimes could be so small that a growth model either doesn't converge or is misleading. In this study, the small sample sizes of males accounted about non-convergence in many early years (Bottom-panel in Figure 4). Therefore, we will focus our analysis on the female growth through years (Top-panel in Figure 4). In general, the female cobia growth rates varied through years. However, there seems to be a period of low growth for females from 2013 through 2018 (All red lines and the dash-dot pink line), indicating that the cobia (at least the females) could grow more slowly during the recent years (Year-effect).

Comparisons in growth between periods

Comparison A

The growth rates were significantly different between Period "Random" and "Donation" when using the sex-pooled (Top-panel in Figure 5) and female-only data (Middle-panel Figure 5) whereas the male model could not converge (Bottom-panel in Figure 5). However, the sex-pooled growth estimate was influenced by the mix of the sex-ratio and year effect and listed here just for a reference. In the female-only analysis, the "Donation" L_∞ is larger than the "Random" whereas the "Donation" K is smaller than the "Random". One of two possible factors or both together could cause the relationships in L_∞ and K between the "Donation" and "Random" period: 1) There is an intrinsic inverse relationship between K and L_∞ (Quinn and Deriso 1999), that is, an increase in L_∞ will cause an decrease in K; 2) the lack of fish from older ages in the "Donation" period could result in a larger L_∞. Therefore, a conclusion as to which period had a faster growth and larger female fish is unwarranted.

Comparison B

The growth rates were significantly different between Period "FirstDonation" and "SecondDonation" within females (Middle-panel in Figure 6) and males (Bottom-panel in Figure 6), respectively. However, it is unknown (unusual, too) that the sex-pooled model can't converge with such a large sample size (Top-panel in Figure 6). As mentioned above, the sex-pooled is listed here for a reference. Both male and female cobia grew larger (Significantly larger L_∞) in "FirstDonation" than in "SecondDonation" period.

Comparison C

The growth rates were not significantly different between Period "Random" and "FirstDonation" when using the sex-pooled (Top-panel in Figure 7) and female-only data (Middle-panel in Figure 7). The male model didn't converge even with reasonable sample sizes (Bottom-panel in Figure 7). Female growth was not significantly different between Period "Random" and "FirstDonation", indicating that the donation program didn't immediately cause the possible different growth rates identified in Comparison A.

Comparison D

The growth rates were significantly different between period "RandomFirstDonation" and "SecondDonation" in the sex-pooled, female-only, and male-only analysis (Figure 8). As discussed in Comparison A, due to the sex-ratio effect, the sex-pooled analysis is listed here as a reference. The females grew faster (Larger K) and males grew larger (Larger L_{∞}) in "RandomFirstDonation" than in "SecondDonation" period.

In conclusion, the significantly different sex-specific growth rates occurred between "FirstDonation" and "SecondDonation" period and between "RandomFirstDonation" and "SecondDonation" period. Such findings may indicate:

1. The donation program didn't immediately result in any change in the Cobia growth after 2007 (including 2007);
2. The year-effect may play an important role in the decreases in VA cobia growth during the recent years (2013-2018).

DISCUSSION

The comparison in Cobia growth between two periods within each comparison is challenging due to three factors: 1) The growth rates between the male and female Cobia are significantly different, in that females grow faster and larger than the males; 2) the sex-ratios of male to female varied through years; the two factors make it necessary to analyze sex-specific growth between two periods; however, 3) a small sex-specific sample size could result in neither convergence of a model nor definitive results. Among the eight pairs of sex-specific growth in the four comparisons, two pairs can not be converged so that no results can be made (The male in Comparison A and C), and one pair is converged but the Kimura tests doesn't provide any definitive result in one pair (The females in Comparison A).

Among five pairs with definitive results, the comparisons in both female and male growth allowed us to conclude that the VA Cobia population growth rates were larger in "FirstDonation" than in "SecondDonation", and in "RandomFirstDonation" than in "SecondDonation" period. However, we had to extrapolate the population growth from the female growth in the comparison between "Random" and "FirstDonation" period (No significant difference).

The inference from the sex-specific to the population growth is not ideal but probably the best available, considering the current small sample sizes of length-age data along the coast. Therefore, we recommend that not only should VA continue its donation program but also other states may start to plan their donation programs, to increase sample sizes of Cobia along the coast.

Liao et al. (2018) working paper concludes that the VA donation program may not be the factor causing the observed reductions of annual mean fork length in the VA samples, instead, the year-effect, especially after 2013 (including 2013), made the contribution to such reductions. By examining the growth of Cobia between different periods, this study has drawn similar conclusions to the working paper (Liao et al. 2018).

It is unknown what caused the decrease in VA Cobia growth during the past several years. The similar trend is observed in the growth of Atlantic croaker (*Micropogonias undulatus*). Atlantic croaker females grew faster and larger than the males (Figure 9), and the sex ratios of male to female varied randomly through years (Figure 10). However, their growth rates decreased dramatically in the recent years (Figure 11). It is obvious that the decreases in the recent years were most likely caused by year-effect instead of the sex ratio. Therefore, future research may explore the relationship between Cobia (also Atlantic Croaker) growth and their biotic and abiotic environmental conditions.

Because of the significant influence of sex-ratio on Cobia population growth estimates, and to better understand the VA length-age data, it will be imperative to find out possible reasons why the proportions of males increased in the samples during the recent years. We believe that there could be three possible reasons:

1. Since the donation program started in 2007, the fishermen gradually donated more and more males from their catches. The possible explanation: the males are smaller compared to the females, and are easily bagged, carried to, and dropped in the freezers;

2. There were more and more males in VA waters, as a result, fishermen caught more males than females during the recent years;

3. VA Cobia sample sizes gradually increased due to the success of the donation program. With the sample sizes increasing, the sex-ratios observed in the samples may be gradually approaching to the true sex-ratios in catch during the recent years. Kalinowsky et al. (2016) reported that the ratio of male to female was 1:1.1 for the Cobia collected from South Carolina recreational fishermen between 2005 and 2007.

If the first situation is true, the VA data from the donation program will be biased toward smaller fish, probably should not be used or at least be statistically/mathematically adjusted before being used in the stock assessment (Schueller et al. 2014). However, if the first situation is false and either the second or third is true, the VA data should be used in the stock assessment. Unfortunately, we don't have any evidence to verify any of three situations. Because it is statistically challenging to falsify the third situation, we suggest to survey VA fishermen to investigate the first and second situation in the future. Before that, we believe that the VA data should be used in the benchmark stock assessment this time because: 1) The first situation, so far, is a speculation and has not been verified; 2) the

VA length-age data, especially those collected after the donation program, have reasonable sample sizes; 3) the VA CAAs tracked the strong cohort of 1995 and 1998 identified by the previous stock assessment (SEDAR 28) (Liao et al. 2018). In conclusion, the VA length-age data more or less satisfies the SEDAR data criteria, that is, the most recent, best available, and scientifically sound data.

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REFERENCE

Kalinowsky, C. A., M. C. Curran, and J. W. Smith
2016. Age and growth of Rachycentron canadum (L.)(Cobia) from the nearshore waters of South Carolina. *Southeastern naturalist*, 15(4):714–728.

Kimura, D. K.
1980. Likelihood methods for the von bertalanffy growth curve. *Fishery bulletin*, 77(4):765–776.

Liao, H., A. Aspinwall, R. O'Reilly, and C. Jones
2018. Analyses and applications of cobia length-age data collected by virginia marine resources commission between 1999 and 2018. Working paper: SEDAR58-DW01.

Quinn, T. J. and R. B. Deriso
1999. *Quantitative Fish Dynamics*. Oxford University Press.

Schueller, A. M., E. H. Williams, and R. T. Cheshire
2014. A proposed, tested, and applied adjustment to account for bias in growth parameter estimates due to selectivity. *Fisheries research*, 158:26–39.

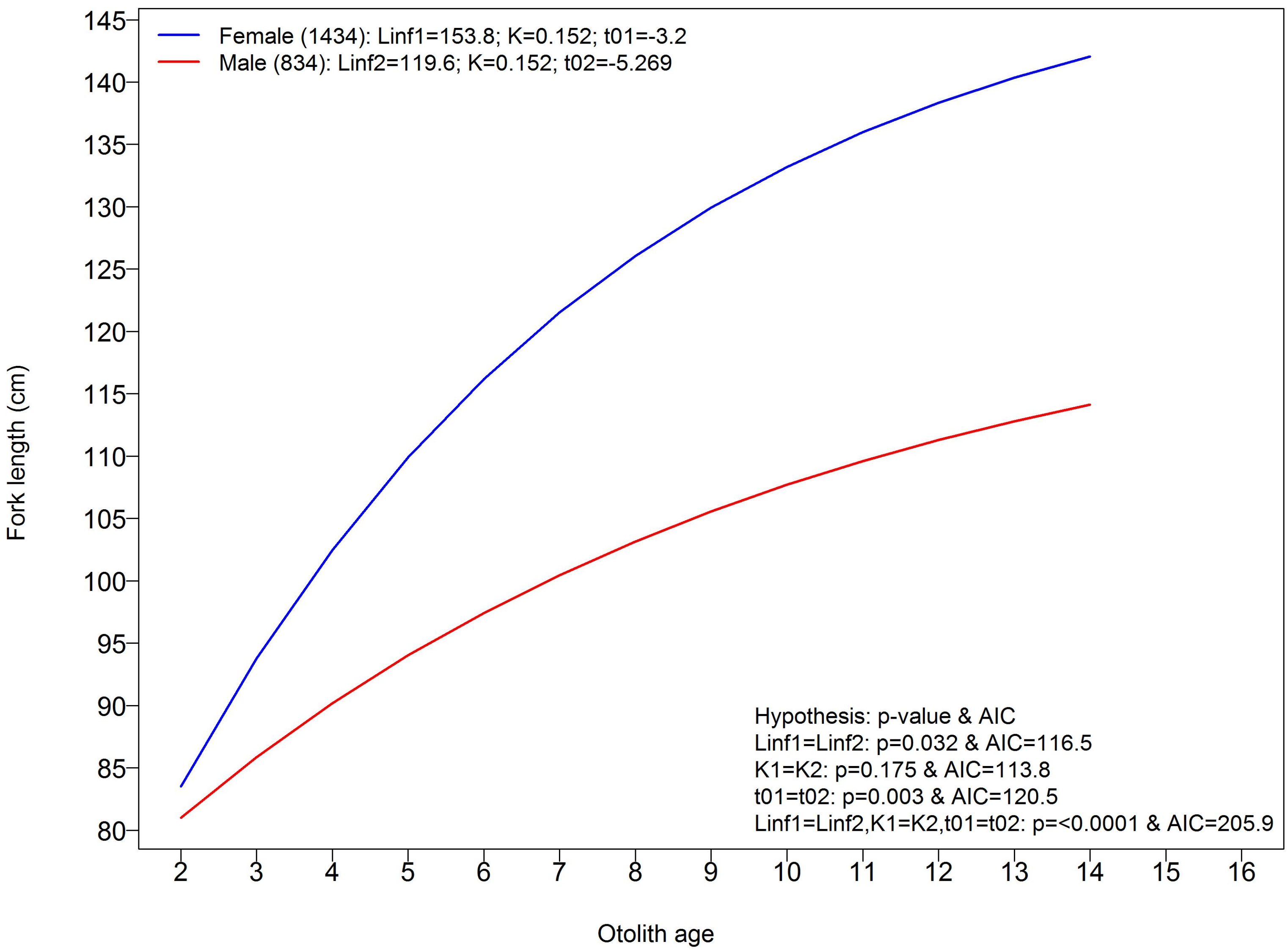

Figure 1: VA sex-specific von Bertalanffy growth using the year-pooled length-age data from 1999 to 2018. The results from the Kimura test are listed at the bottom-right and the selected growth models for the female and male Cobia are listed at the top-left. The number in parentheses is the sample size for each sex.

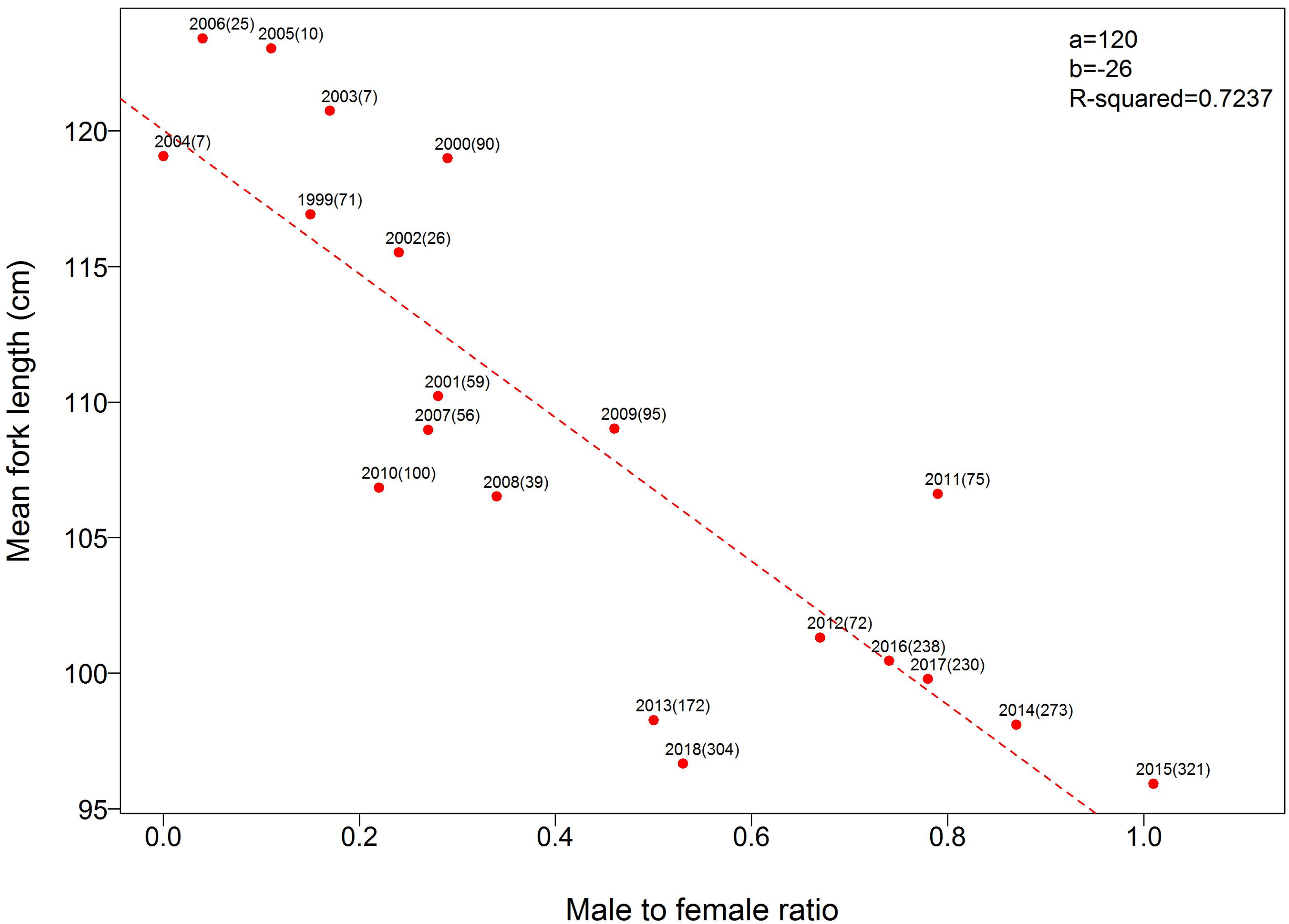

Figure 2: The linear relationship between the mean fork lengths and the ratios of male to female from 1999 to 2018. The mean length is calculated using both male and female Cobia. The red dash line is the regression line. The number in parentheses is the sample size for each year. The a, b, and R^2 stand for intercept, slope, and coefficient of determination, respectively.

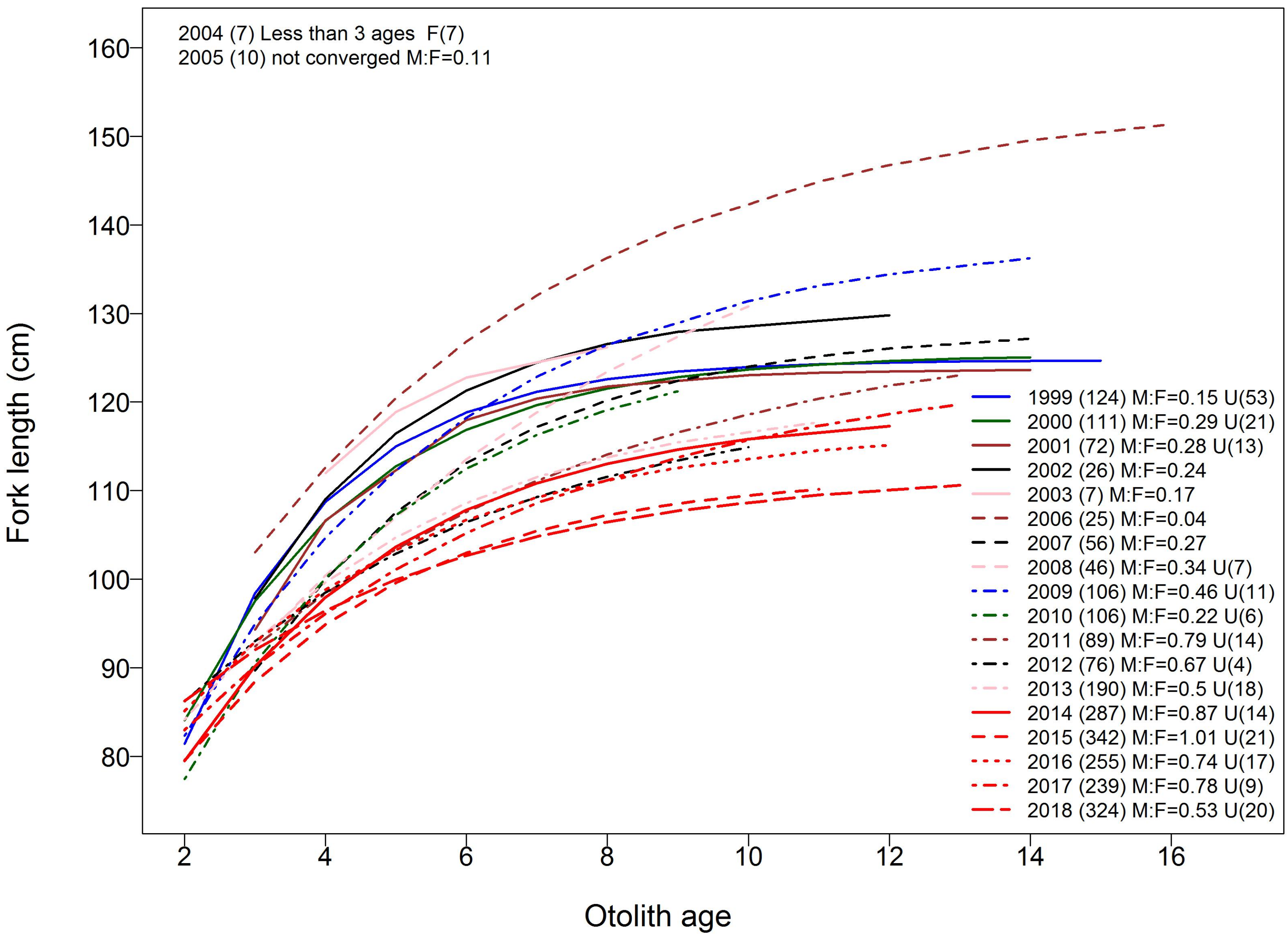

Figure 3: Annual sex-pooled von Bertalanffy growth of VA Cobia from 1999 to 2018. The number in parentheses after year, M, F, and U is the sample size of each year, male, female, and unknown-sex fish, respectively. M:F is the ratio of males to females.

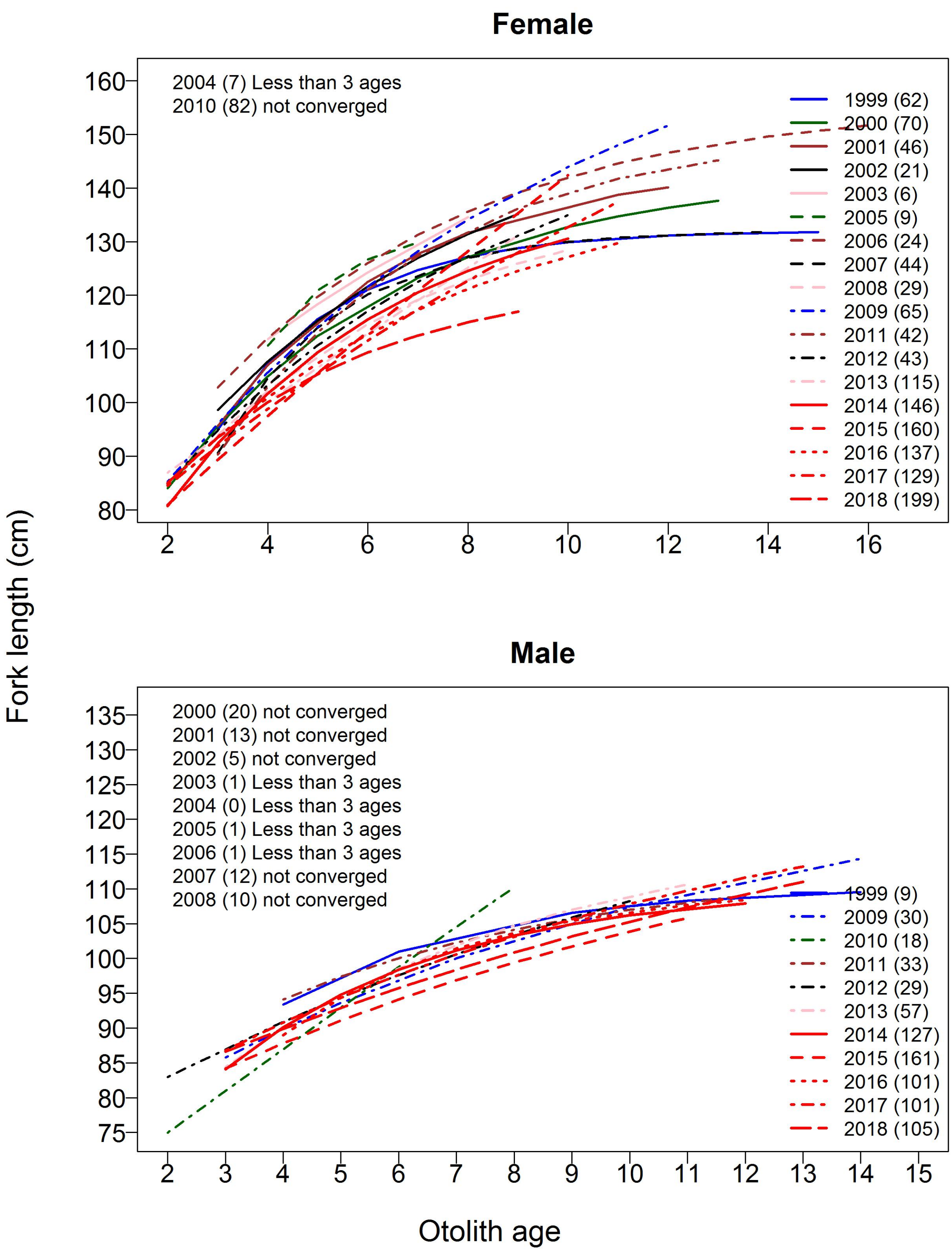

Figure 4: Annual sex-specific von Bertalanffy growth of VA Cobia from 1999 to 2018. The number in parentheses is the sample size. The unknown-sex fish are excluded from the analysis.

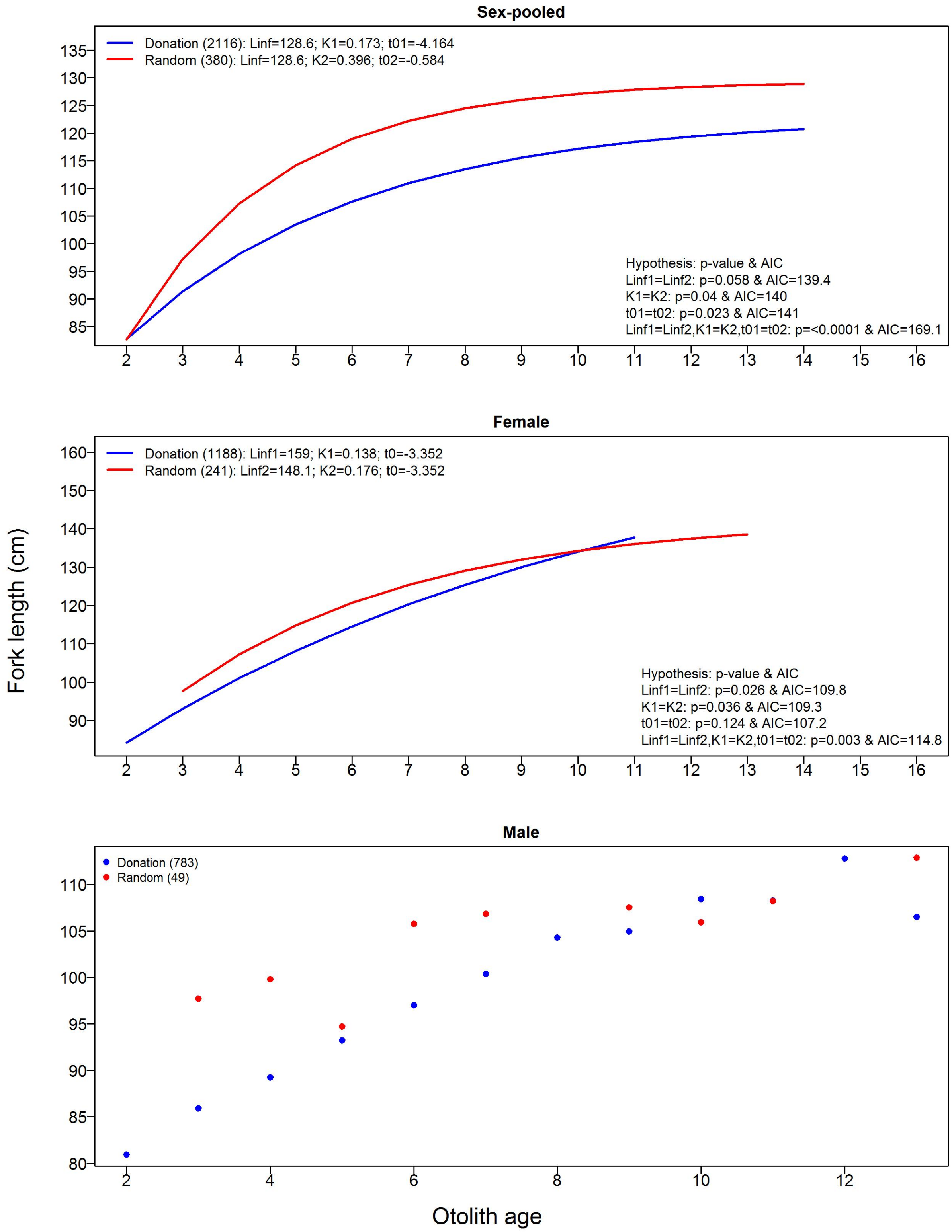

Figure 5: VA period-specific von Bertalanffy growth. Period "Random" is from 1999 to 2006 without the donation programs, and Period "Donation" is from 2007 to 2018 with the donation programs. "Sex-pooled" includes the female, male, and unknown-sex fish. The results of the Kimura test are listed at the bottom-right whereas the selected models for two periods are listed at the top-left. Solid-dot points indicate that the Kimura test can't be conducted.

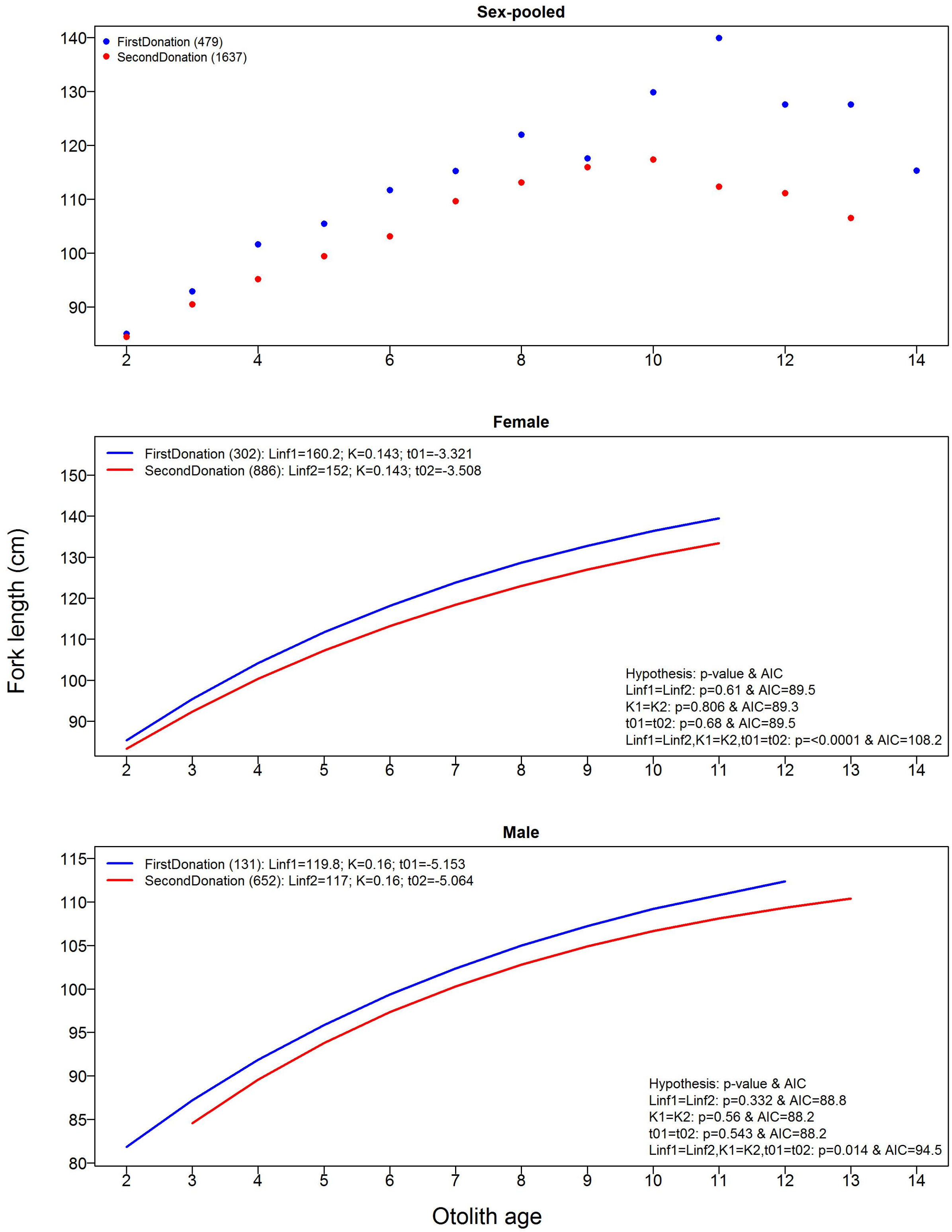

Figure 6: VA period-specific von Bertalanffy growth. Period "FirstDonation" is from 2007 to 2012, and Period "SecondDonation" is from 2013 to 2018. "Sex-pooled" includes the female, male, and unknown-sex fish. The results of the Kimura test are listed at the bottom-right whereas the selected models for two periods are listed at the top-left. Solid-dot points indicate that the Kimura test can't be conducted due to non-convergence.

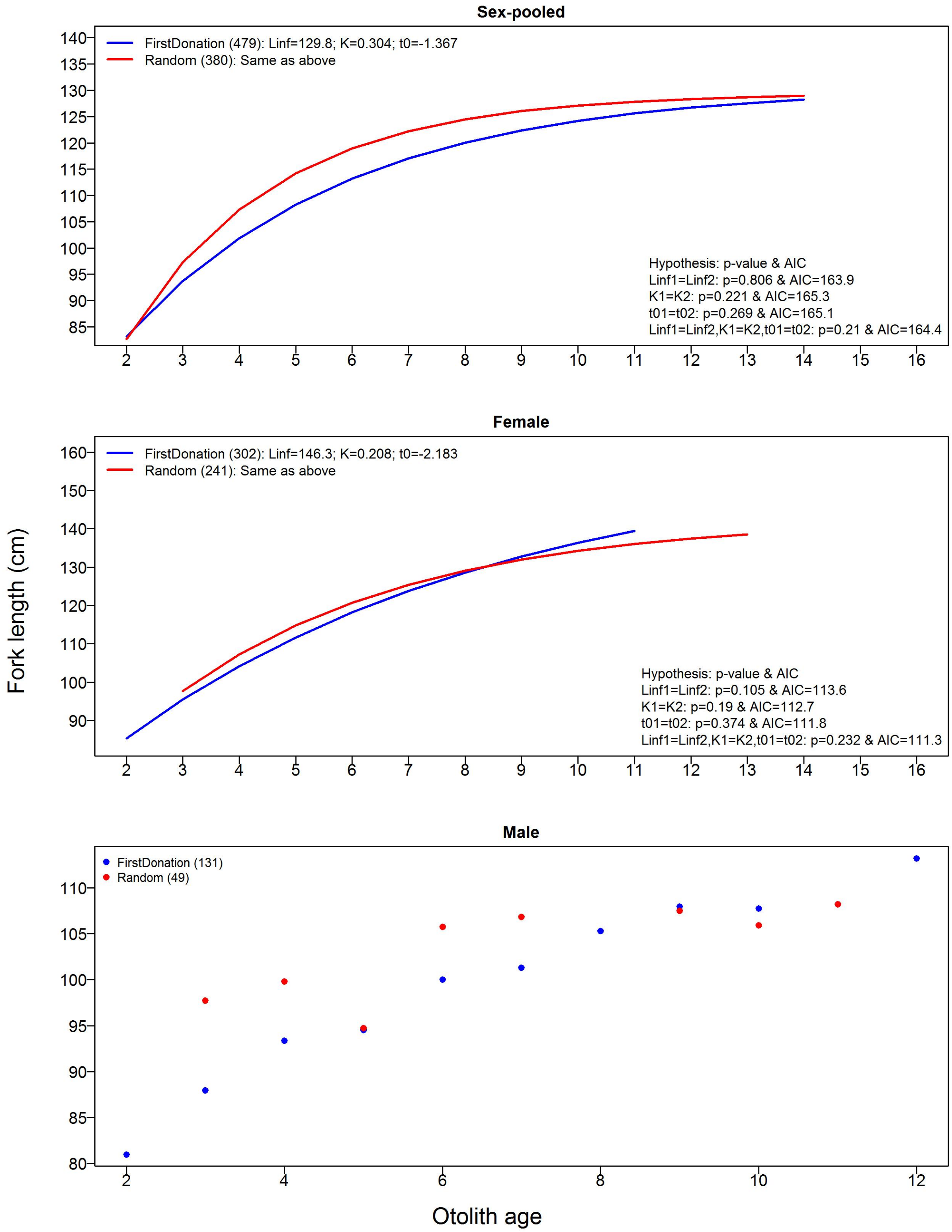

Figure 7: VA period-specific von Bertalanffy growth. Period "Random" is from 1999 to 2006 without the donation programs, and Period "FirstDonation" is from 2007 to 2012 with the donation programs. "Sex-pooled" includes the female, male, and unknown-sex fish. The results of the Kimura test are listed at the bottom-right whereas the selected models for two periods are listed at the top-left. Solid-dot points indicate that the Kimura test can't be conducted due to non-convergence.

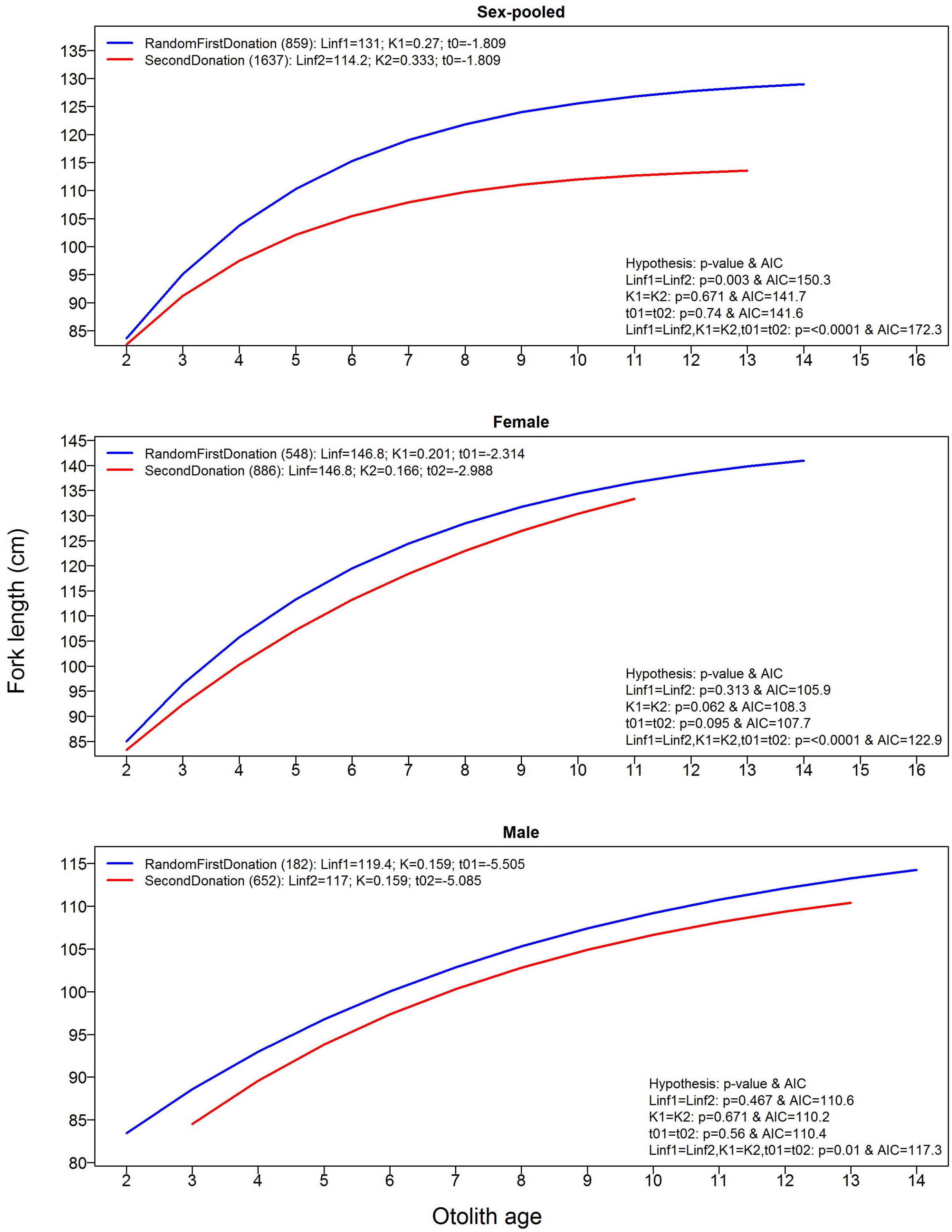

Figure 8: VA period-specific von Bertalanffy growth. Period "RandomFirstDonation" is from 1999 to 2012, including Period "Random" and the "FirstDonation" period, and Period "SecondDonation" is from 2013 to 2018. "Sex-pooled" includes the female, male, and unknown-sex fish. The results of the Kimura test are listed at the bottom-right whereas the selected models for two periods are listed at the top-left.

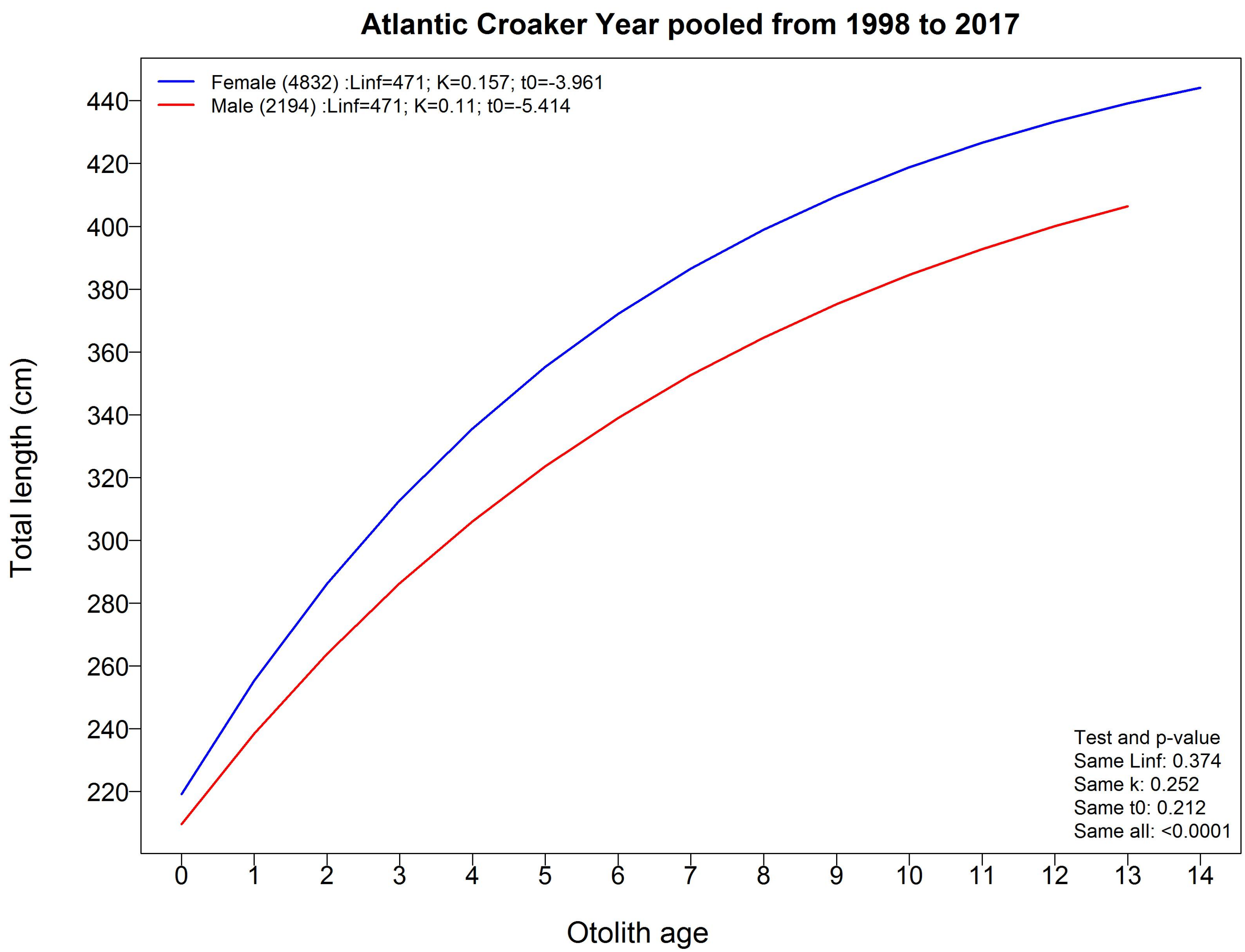

Figure 9: The growth rates of Atlantic croaker females and males randomly collected by VMRC from 1998 to 2017. The number in parentheses is number of fish.

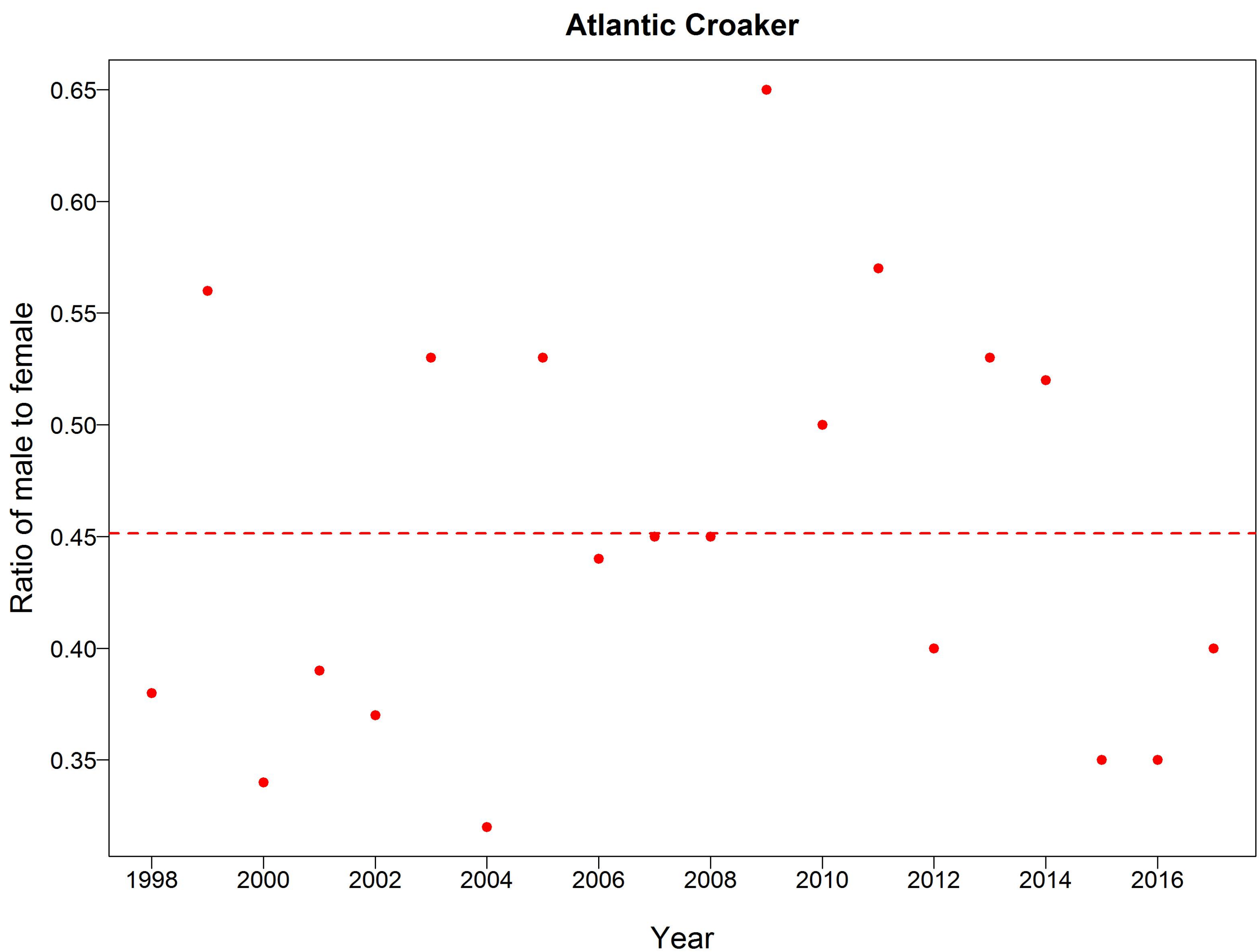

Figure 10: The sex ratios of Altantic croaker male to female from 1998 to 2017.

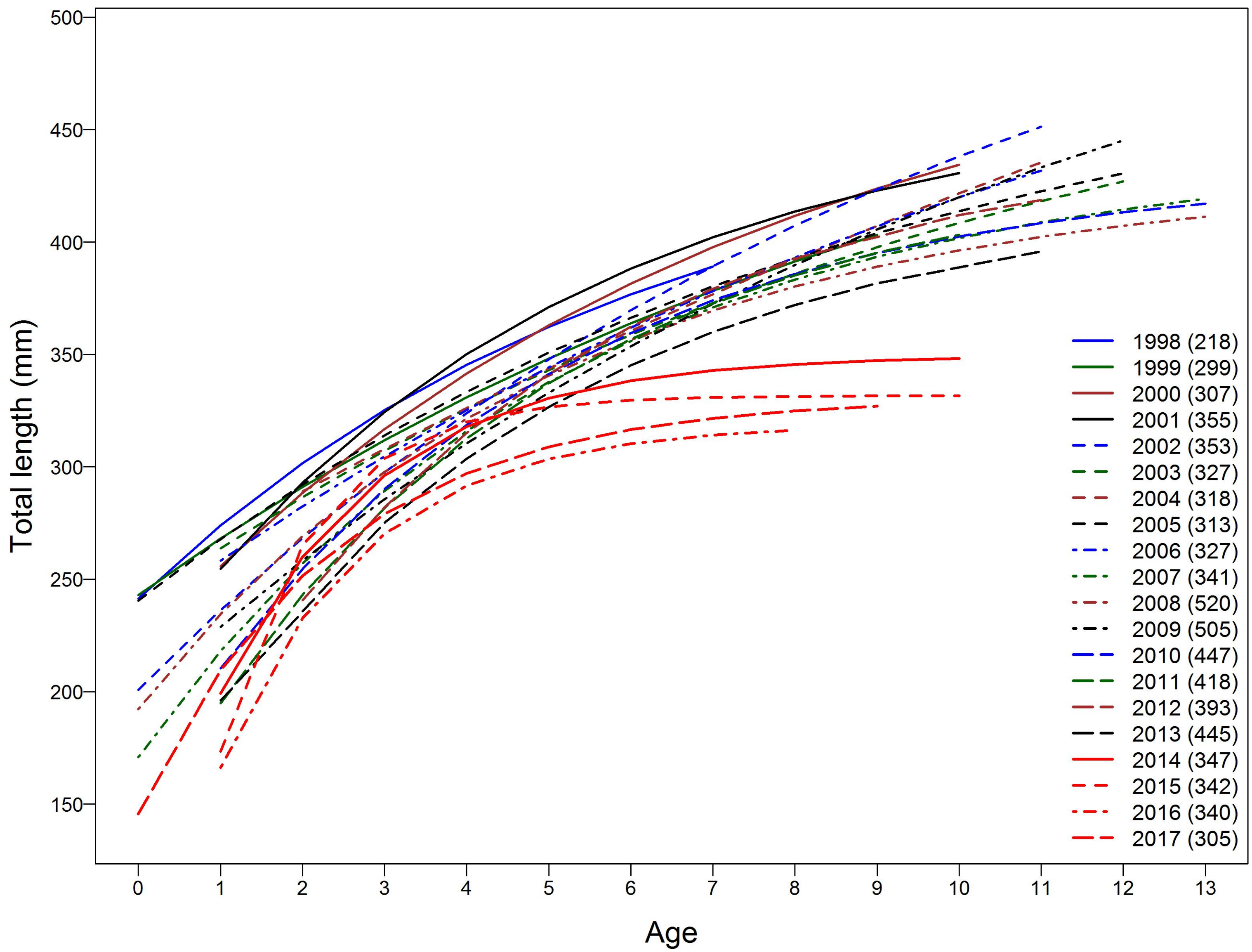

Figure 11: The annual growth rates of Atlantic croaker (sex-pooled) from 1998 to 2017. The number in parentheses is number of fish.