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Analyses and Applications of Cobia Length-age Data Collected by Virginia Marine Resources Commission between 1999 and 2018

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INTRODUCTION

Atlantic Cobia (*Rachycentron canadum*) are an economically important species that have become increasingly popular amongst recreational anglers in Virginia. Since 1999, Virginia Marine Resources Commission (VMRC) has collected biological data from the recreational Cobia fishery in order to provide length-age information for future stock assessments. The precision of length-age estimates depend on the sample size (Quinn and Deriso 1999), however, the conventional collection method provides few Cobia. In order to increase the sample size of Cobia length-age data, VMRC has been collecting Cobia carcass donations (including the carcasses from Cobia tournaments) from recreational anglers through the marine sportfish collection program since 2007. Because the carcass donation program is not designed to sample randomly and fishermen donate the carcasses more or less opportunistically, the Cobia Data workshop has raised concerns on whether or not Virginia length data from carcass donations may represent the catch and be used in the future stock assessment. Therefore, it is important that the concern should be addressed properly before the data can be used. The primary goal of this study is to find out if the carcass donations have introduced biases into the length distributions toward either smaller or larger fish compared to those fish collected randomly. The specific objectives are: 1) Compare Virginia length frequency distributions collected by VMRC from the recreational and commercial fisheries to those collected by MRIP; 2) compare the mean lengths between the cobia collected randomly by VMRC and donated by Virginia recreational fishermen; 3) compare year effect on the mean lengths of cobia collected VMRC from 1999 to 2018; 4) examine cohort progressions in the landing age distributions developed using Virginia ALKs and Virginia harvest estimated by MRIP; and 5) compare length distributions between Virginia and other Atlantic states.

METHODS

Data collection

Three sets of data were used in this study, including the data collected by Virginia, other Atlantic states, and MRIP, respectively. Fish fork lengths were either measured to 1 mm, converted from total length, or from weight. The total-fork length and weight-fork length conversion equations are provided by NOAA Fisheries. 1-cm Length interval was used in the analysis as standardized by the Cobia Data Workshop.

Virginia data

VMRC collected Cobia from 1999 through 2018 using a conventional 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 fisherman. The marine sportfish collection program started in 2007 and uses freezer donation centers to collect length-age data from recreational fisherman. The donations were encouraged but not randomly designed. All Virginia data were aged by Old Dominion University using otoliths. We also compared length distributions between the recreational and commercial fisheries.

Other Atlantic state data

In this study, other Atlantic states include Georgia, North Carolina, and South Carolina. The length data were collected by state agencies from 1999 to 2018, and provided by the NOAA Beaufort Laboratory. Due to the small sample size of each state, we pooled all three states' data together and referred to those states as "Others" hereafter.

MRIP data

We used Virginia fish length interval, harvest in each 1-cm length interval, total annual harvest, and annual mean length from MRIP survey data. Fish length interval (Column "l_cm_bin") and harvest at each length interval (Column "wp_size") are in MRIP size files (such as "size_19991.csv", meaning the length data collected from Wave 1 of 1999) stored at the MRIP raw data website. The summary of total annual harvest (A+B1) and annual mean length can be downloaded at the MRIP query website. However, there is no age information provided in MRIP data.

We also retrieved Georgia, North Carolina, and South Carolina length data from MRIP size files from 1999 to 2018, and pooled these data with the data collected by state agencies under the category of "Others" (Please see Section *Other Atlantic state data*) in order to increase sample sizes.

Data analysis

Virginia Length distributions

We used histogram analysis to examine Virginia length distributions of cobia samples collected by VMRC from commercial, recreational (non-tournament), and tournament, respectively, from 1999 to 2018. This comparisons intended to examine whether the fish collected from the different fisheries could be pooled to increase the sample sizes of length data. If yes, the length data were pooled from the different fisheries. If not, the length data only from recreational fishery were used in the further analysis. Then, we compared the length distributions (Either the fishery-pooled or the recreational-only) collected by VMRC to those by MRIP from 1999 to 2018. Hereafter, if the fishery-pooled data was chosen, it will be referred to as "Virginia data"; if the recreational-only data was chosen, it will be referred to as "Recreational".

Virginia length distributions between random and non-random samples

We divided Virginia recreational time-series length data into two periods, 1999-2006 vs. 2007-2018. The cobia specimen were randomly collected by VMRC from Virginia recreational fishermen during the first period whereas opportunistically donated by Virginia recreational fishermen during the second period. We used histogram analysis and one-way ANOVA to examine length distributions and mean lengths between two periods.

Variations in Virginia length distribution through years

We used a linear model to examine the year-effect on Virginia length distributions from 1999 to 2018. The specific steps of the linear model analysis are as follows:

1. Fit a linear model Fork $\sim$ Year to Virginia length-year data;
2. Examine assumptions of linear model on linear relationship, normality, homoscedasticity, and influential points. Because the length-year data is a time-series data, we also examined autocorrelation of residuals using Durbin-Watson test;
3. Based on the examinations of assumptions, if necessary, transform the length data and/or adjust the model;
4. Fit adjusted model to the transformed length data if needed.
5. Apply Tukey test to the results from the adjusted linear model in order to identify different groups of mean fork lengths through years.

Virginia landing length distributions

We estimated Virginia annual landing length distribution from 1999 to 2018 using Virginia total annual landings (number of fish) estimated by MRIP (Table 1) multiplied by Virginia annual length distributions developed by VMRC.

Virginia landing age distribution (Catch-at-age)

We developed ALKs using Virgina length-age data collected by VMRC from 1999 through 2018, and then applied the ALKs to Virginia landing length distributions estimated in Section *Virginia landing length distributions*. Finally, we used a histogram analysis to identify strong cohort progressions in Virginia landing age distributions from 1999 to 2018.

Length distributions of Virginia and other Atlantic states ("Others")

We used a histogram analysis to examine the length distributions between Virginia and "Others". We fitted a linear model Fork $\sim$ Year + State + Year:State (full model) to the data, and used "backward" model selection to decide if any reduced model is a better fit. Then, we used ANOVA on the selected model. We also tested the assumptions of a linear model as described previously.

However, the ANOVA results from the full model didn't display the difference in mean length between VA and "Others" within each year, therefore, we used one-way ANOVA to examine the differences for two reasons: 1) It will be invalid to examine the mean length difference by visualizing overlaps of standard error and/or confidence interval bars when the sample sizes of VA and "Others" are unequal; 2) a Tukey test could be misleading when the effect of the interaction between year and state exists in the full model. However, such one-way ANOVA doesn't consider the year-effect on the mean length and should not be used to compare the mean lengths between years.

RESULTS

Virginia length distributions

In general, Virginia commercial fisheries catch smaller cobia than the recreational (Figure 1 and 2), therefore, their length samples should not be used for the recreational length distribution to increase sample sizes, and were removed from the further analysis. Within the recreational collections, the tournament fish were collected from 6 of 20 years (2000-2002, 2007, and 2008 in Figure 1, and 2017 in Figure 2). Among the six years, the mean lengths of tournament fish are larger than the non-tournament fish in three years (2000, 2002, and 2017) and smaller in other three years (2001, 2007, and 2008), but in general, the lengths of the tournament fish are within the range of the recreational fish. As a result, we combined the length data collected from both non- and tournament fish referred to as "Recreational" in the further analysis.

The recreational sample sizes during the first 10 years are significantly smaller than those during the second 10 years. More specifically, the sample sizes range from the minimum of 7 fish in 2003 and 2004 to the maximum of 126 fish in 1999 between 1999 and 2008 (Figure 1) whereas the minimum and maximum sample size are 77 and 350 fish in 2012 and 2015, respectively, between 2009 and 2018 (Figure 2), indicating that VMRC donation program has helped to increase the recreational sample sizes significantly. For comparison, we listed the annual mean lengths of VA recreational data (R and T, respectively) and of VA MRIP data in Figure 1 and 2.

The dome-shaped length distribution should be more representative of the length distribution in catch (more fish caught in middle sizes and less fish caught in small and large sizes), such as in 2013-2018 (Figure 2)

Virginia sample size of lengths collected by MRIP are very small for all the years, ranging from the minimum of 3 fish in 2004 and 2012 to the maximum of 39 fish in 2015 (Figure 3 and 4). Small sample sizes may misrepresent the length distribution of catch each year, and further misrepresent the annual landing length distribution. For many years, few fish were scattered along the length range, resulting in the lack of fish in many length intervals. In addition, the sample mean length for each year estimated using MRIP length data is different from that directly downloaded from the MRIP website. Someone who knows how MRIP estimates the annual mean length may explain the reason. Or I could simply download the wrong length data from MRIP website.

Even though MRIP length sample sizes are very small in general, the length ranges between VMRC and MRIP do not show any trends, supporting that neither data set intended to collect more larger or smaller fish for each year. In other words, MRIP length range may indirectly support that VMRC length data are within the range of the catch length distribution for each year.

Because this study focuses on examining Virginia data collected by VMRC and also because the sample sizes of Virginia data collected by MRIP were very small, we removed MRIP data from the further analysis. However, if necessary, the two data sets could be pooled to increase Virginia sample sizes in the stock assessment.

Virginia recreational length distributions

The histogram analysis and one-way ANOVA indicate that the length distributions and mean lengths are significantly different between two periods (Figure 5). The first period collected more large fish whereas the second period collected more small fish, implying that the donations might be possibly biased toward smaller fish compared to the random collections.

In the linear model analysis on year-effect, we found that there was a first lag (lag-1) autocorrelation of residuals in the time-series data (Durbin-Watson test: $p < 0.0001$ in the top panel in Figure 6). Therefore, we used the residuals as an extra independent variable with one lag in the adjusted model to remove the lag-1 autocorrelation. The adjusted model effectively removed the lag-1 autocorrelation (Durbin-Watson test: $p = 1.0000$ in the bottom panel in Figure 6), that is, the bar of lag-1 falls between two blue horizontal dash lines (Significant range). In addition, other lags of autocorrelations also decrease close to the significant range in the adjusted model. As a result, the adjusted linear model with both year and lag-1 residuals as independent variables was used in the further analysis.

The linear model diagnoses do not show any significant violations on assumptions of a linear relationship (Top-left plot in Figure 7), normality (Top-right plot in Figure 7), and homoscedasticity (Bottom-left plot in Figure 7) even though they are not perfect (The perfect means the red line should be completely flat and the data points should lay right along the top of dotted line in Q-Q plot). The diagnose doesn't identify any influential points (Bottom-right plot in Figure 7).

Therefore, we fitted the adjusted model to the data and reported the results (Table 2). Then, we applied a Tukey test on the adjusted model results to identify groups of mean length through years. The Tukey test identified 10 groups of least square mean lengths (a to g, a is for the shortest fork length whereas g is for the longest fork length) from the adjusted model (Figure 8). The fork lengths varied through years, however, the grouping results are more complicated. In general, one length group could cross multiple years, and one year could belong to multiple groups. Three important patterns were identified from this analysis:

1. Group g includes 1999, 2000, and 2002-2006 (in the first period), implying that the donations could result in a significant reduction of fork length as the analysis on the fork length between two periods identified;
2. However, Group d, e, and f cross both period, ranging from 1999 to 2012, which could indicate that the donation may not account for a significant reduction of fork length as the analysis on the fork length between two periods identified;
3. The cobia fork lengths gradually decreased significantly in Virginia recreational catches since 2013 (Group a, b, and c).

In conclusion, the mean folk lengths gradually decreased through years, and the donation program may not be the factor or the only factor causing the mean length decrease within the second period.

Virginia recreational landing length distribution

The landing distributions in 1999 and 2000 also look dome-shaped even though the VMRC donation program didn't exist by then (Figure 9). Virginia Cobia landing length distributions appear more and more dome-shaped with the increases of sample sizes during the second 10 years (Figure 10). These two observations indicate:

1. A sample size of length data is very crucial for estimating landing length distribution;
2. Virginia donation program has made significant contributions to the increase of sample sizes of length data.

Virginia recreational landing age distribution (Catch-at-age)

The landing age distributions follow cohort progressions well. The histogram analysis indicates that there have been a few strong year-classes present throughout the time-series. In the mid to late 90's, we see a strong year-class of 1995 (Light-blue bar in Figure 11) and 1998 (Red bar in Figure 11), which is consistent with what the previous stock assessment (SEDAR 28) reported. SEDAR 28 also reported that 2005 was the most current strong year-class, and our analysis indicates that 2005 is a strong year-class. However, our analysis has identified three more strong year-classes after 2005, Year-class 2007 (Yellow bar in Figure 12), 2010 (Light-green bar in Figure 12), and 2012 (Pink bar in Figure 12). In addition, Year-class 2015 could be the most current strong year-class (Black bar in Figure 12) and make significant contributions to VA Cobia fisheries in coming years.

Research recommendations from the assessment workshop were to implement a systematic age-sampling program for the recreational sector because age samples were important in the assessment for identifying strong year-classes. However, sample sizes were relatively small in practice. Therefore, we believe that Virginia's data, especially collected from the donation program, can be used to supplement the findings of strong year-classes present in the fishery.

Length distributions of Virginia and Others

The histogram analysis indicates that the length distributions between VA and other states are similar in some years but different in other years (Figure 13 and 14). The full model (Fork $\sim$ Year + State + Year:State) was selected as the best fit, meaning that the mean length varied through years, between VA and "Others", and VA length larger than "Others" in some years but smaller in other years. The assumptions of linear model are not violated (Figure 15). The ANOVA indicates that the effects of year, state, and interaction of year and state are statistically significant (Table 3).

Table 4 and Figure 16 show the one-way ANOVA results on the mean lengths between VA and "Others" within each year. There are no significant differences in the mean length between VA and "Others" in 2007, 2008, 2010, 2011, and 2013, indirectly supporting that the donations didn't result in the significant decrease of length during the second period identified by the ANOVA on the two-period analysis. However, it is unknown why other states continued to catch larger cobia after 2013 than VA. It worths to mention that the one-way ANOVA within each year could be misleading because it ignores the year-effect as found in the linear full model.

DISCUSSION

Five findings from this study are worth attention. First, the fish collected from tournaments may not be necessarily larger than those collected from other recreational fishermen, as a result, the tournament fish can be used in the length-age data. However, the commercial fish were smaller than the recreational fish, therefore, can't be used to increase the sample size of recreational fish. Second, the analysis on the length distributions between two periods could be misleading due to its lack of year-effect on the length distribution. In contrast, the linear model analysis indicates that the donations could not, at least directly and/or immediately, cause the decreases of lengths in the second period, instead, the systematic length decreases in the past several years did. The comparison in length between VA and other states indirectly verifies that VA donation program may not cause the length decreases. Third, the sample size of length has to be large enough to represent the length distribution of catch. VMRC sample sizes in the recent years do have an advantage compared to MRIP sample sizes. Fourth, Quinn and Deriso (1999) introduces the two-stage sampling method, taking a length sample from catch, and then taking a subsample from the length sample for ageing. Because VMRC aged all the fish from its length data (few fish were not aged due to broken otoliths), and also because VMRC length distributions appear in dome-shaped, especially in the recent years, VMRC length-age data may be used to convert Virginia catch to CAA for the recent years. Finally, the small sample sizes of Cobia length-age data are a common problem along Atlantic coast, which could influence the quality of Cobia stock assessment. Virginia recreational donation program has set an example on how to increase the sample size without increasing the cost significantly and introducing any bias in length distribution.

As this study was completed, we didn't find any evidence that Virginia recreational fishermen intentionally or unintentionally donated their smaller carcasses. However, we did periodically receive unofficial reports from Virginia recreational fishermen that they have encountered a higher abundance of smaller cobia in the past several years. Therefore, it may worth for VMRC to conduct two surveys in the future: 1) Investigate if fishermen intentionally donate their smaller cobia carcasses; 2) investigate if fishermen are encountering more smaller cobia in Virginia waters. The first survey may justify and help state agencies (including VMRC) to either modify or adopt the carcass donation program so that Atlantic Cobia sample size of length-age data can be increased and its stock assessment can be improved. The second survey may help VMRC to better understand the length-age data collected from different fisheries in Virginia.

ACKNOWLEDGMENTS

We thank all the previous and current personnel in the biological sampling program of VMRC and Age and Growth Lab of ODU for their hard work on collecting the biological data, processing, and ageing the otoliths. We specifically thank Kelly Fitzpatrick at the NOAA Beaufort Laboratory for providing the length data collected by Georgia, North Carolina, and South Carolina. We thank Jessica Gilmore for editing the draft.

REFERENCE

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

Table 1: Annual harvests (A+B1) from 1999 to 2018 estimated by MRIP. The table was downloaded from MRIP query website on Feb. 26, 2019.

Estimate Status	Year	Common Name	Total Harvest (A+B1)	PSE
FINAL	1999	COBIA	5,504	52.30
FINAL	2000	COBIA	10,752	55.90
FINAL	2001	COBIA	6,954	63.20
FINAL	2002	COBIA	7,833	64.20
FINAL	2003	COBIA	4,872	63.00
FINAL	2004	COBIA	2,399	68.50
FINAL	2005	COBIA	38,530	59.20
FINAL	2006	COBIA	39,231	49.60
FINAL	2007	COBIA	13,127	40.00
FINAL	2008	COBIA	8,522	58.50
FINAL	2009	COBIA	33,504	31.80
FINAL	2010	COBIA	16,580	39.50
FINAL	2011	COBIA	12,663	55.70
FINAL	2012	COBIA	1,429	100.90
FINAL	2013	COBIA	24,145	52.50
FINAL	2014	COBIA	21,585	42.50
FINAL	2015	COBIA	38,672	49.30
FINAL	2016	COBIA	43,780	18.90
FINAL	2017	COBIA	14,613	42.30
PRELIMINARY	2018	COBIA	73,380	36.20

Table 2: Results from the linear model without lag-1 autocorrelation, in which both year and lag-1 residual as independent variables. The significant level $\alpha \leq 0.05$.

X	Estimate	SE	t_value	p_vlaue
(Intercept)	115.70	0.80	144.46	<0.0001
YEAR2000	4.00	1.13	3.57	0.0004
YEAR2001	-6.80	1.29	-5.28	<0.0001
YEAR2002	0.10	1.90	0.08	0.9402
YEAR2003	5.80	3.48	1.66	0.0979
YEAR2004	1.90	3.48	0.55	0.585
YEAR2005	6.10	2.94	2.07	0.0383
YEAR2006	8.50	1.96	4.33	<0.0001
YEAR2007	-6.20	1.41	-4.41	<0.0001
YEAR2008	-6.90	1.54	-4.49	<0.0001
YEAR2009	-7.00	1.16	-6.02	<0.0001
YEAR2010	-8.50	1.16	-7.34	<0.0001
YEAR2011	-9.00	1.24	-7.26	<0.0001
YEAR2012	-14.30	1.30	-11.01	<0.0001
YEAR2013	-16.90	1.02	-16.57	<0.0001
YEAR2014	-17.60	0.95	-18.43	<0.0001
YEAR2015	-19.50	0.93	-20.86	<0.0001
YEAR2016	-15.00	0.98	-15.40	<0.0001
YEAR2017	-15.70	0.99	-15.95	<0.0001
YEAR2018	-19.00	0.94	-20.21	<0.0001
lag1	0.70	0.01	51.21	<0.0001

Table 3: ANOVA test on the full model (Fork $\sim$ Year+State+Year:State). The significant level $\alpha \leq 0.05$.

Source	df	Sum_Sq	Mean_Sq	F_value	p_value
STATE	1	4495	4495	21.42	<0.0001
YEAR	1	65135	65135	310.43	<0.0001
STATE:YEAR	1	46675	46675	222.45	<0.0001
Residuals	3658	767521	210		

Table 4: One-way ANOVA test on the mean fork lengths between VA and other states (pooled) from 1999 to 2018. The significant level $\alpha \leq 0.05$.

Year	Source	df	Sum_Sq	Mean_Sq	F_value	p_value
1999	STATE	1	12619	12618.80	41.7	<0.0001
	Residuals	150	45429	302.90		
2000	STATE	1	2811	2811.20	10.4	0.0016
	Residuals	137	36966	269.80		
2001	STATE	1	839	839.40	3.1	0.0803
	Residuals	101	27155	268.90		
2002	STATE	1	1248	1247.70	5	0.0294
	Residuals	58	14502	250.00		
2003	STATE	1	2883	2883.50	21.4	<0.0001
	Residuals	45	6061	134.70		
2004	STATE	1	660	659.70	3.2	0.0821
	Residuals	48	10043	209.20		
2005	STATE	1	3441	3440.60	15	0.0003
	Residuals	50	11480	229.60		
2006	STATE	1	5566	5566.20	21.6	<0.0001
	Residuals	47	12098	257.40		
2007	STATE	1	364	363.50	1.4	0.2383
	Residuals	85	21911	257.80		
2008	STATE	1	490	489.60	1.8	0.1876
	Residuals	73	20200	276.70		
2009	STATE	1	2592	2592.10	9.5	0.0025
	Residuals	134	36621	273.30		
2010	STATE	1	500	500.40	1.9	0.1691
	Residuals	223	58639	263.00		
2011	STATE	1	69	68.90	0.2	0.6841
	Residuals	134	55574	414.70		
2012	STATE	1	2192	2192.10	9.5	0.0026
	Residuals	116	26809	231.10		
2013	STATE	1	151	150.70	0.7	0.3877
	Residuals	287	57811	201.40		
2014	STATE	1	2134	2134.20	11.9	0.0006
	Residuals	396	71108	179.60		
2015	STATE	1	12199	12198.90	68.8	<0.0001
	Residuals	473	83855	177.30		
2016	STATE	1	4658	4657.50	37.7	<0.0001
	Residuals	344	42480	123.50		
2017	STATE	1	3758	3757.70	28.5	<0.0001
	Residuals	288	37965	131.80		
2018	STATE	1	5919	5918.50	57	<0.0001
	Residuals	433	44965	103.80		

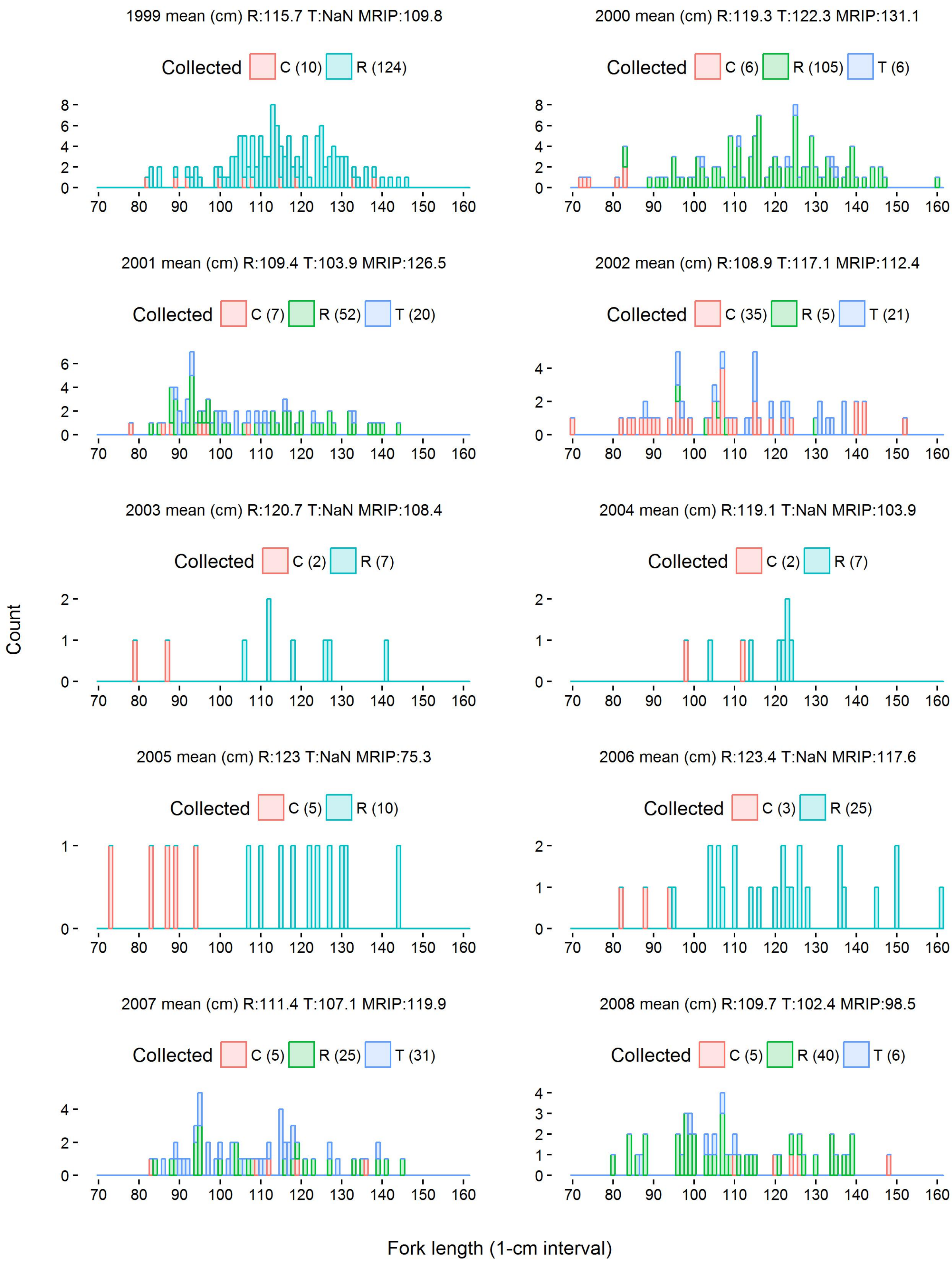

Figure 1: The length distributions of Atlantic Cobia collected by VMRC from Virginia commercial (C) and recreational (R) fisheries (T stands for tournament) between 1999 and 2008. The numbers in parentheses after C, R, and T are the sample sizes from each fishery. VA MRIP mean lengths were downloaded from MRIP website.

Figure 2: The length distributions of Atlantic Cobia collected by VMRC from Virginia commercial (C) and recreational (R) fisheries (T stands for tournament) between 2009 and 2018. The numbers in parentheses after C, R, and T are the sample sizes from each fishery. VA MRIP mean lengths were downloaded from MRIP website.

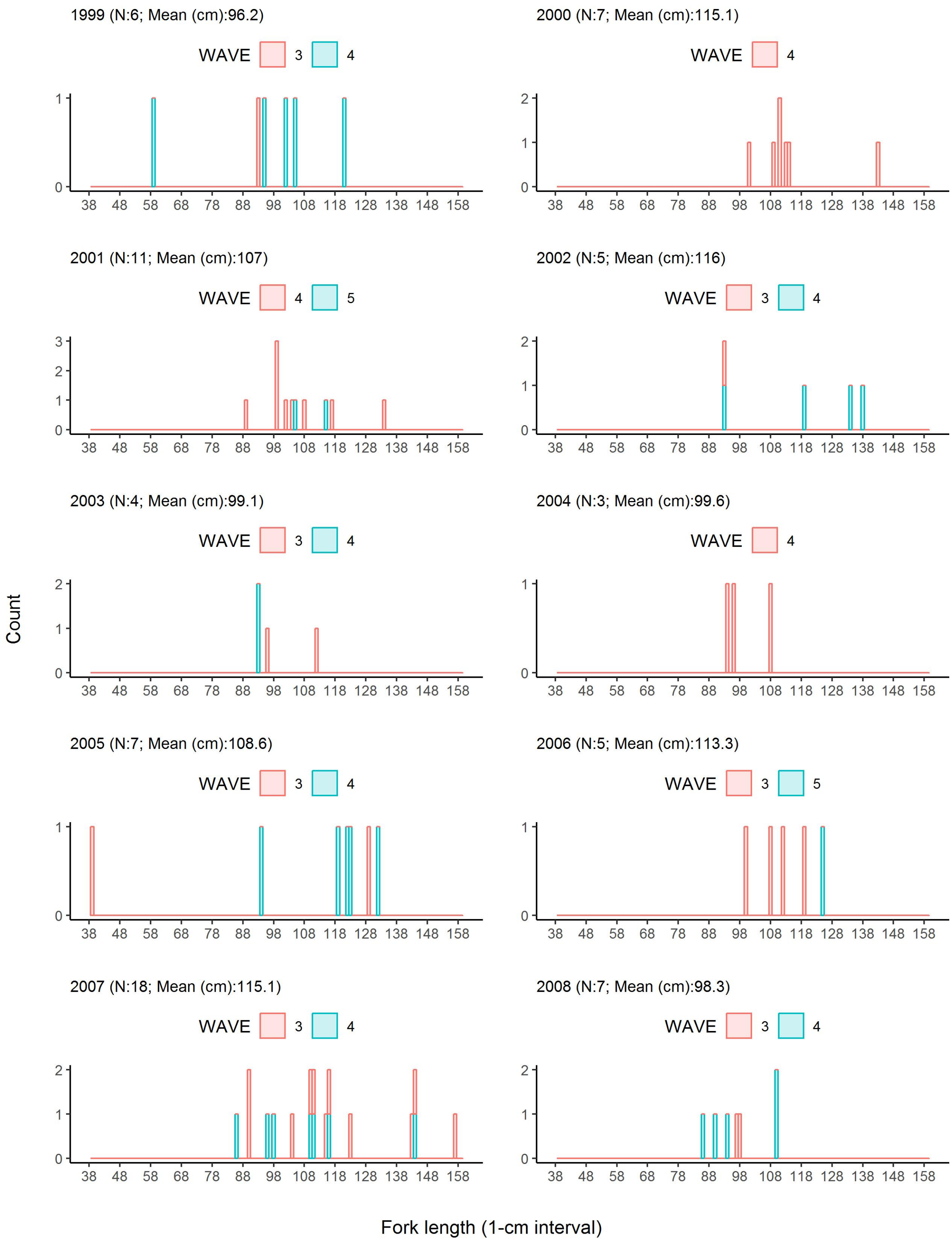

Figure 3: The length distributions of Atlantic Cobia collected by MRIP in Virginia from 1999 to 2008. The different colors indicate the different waves. N and Mean stand for the annual sample size and mean fork length (cm) of the sample, respectively.

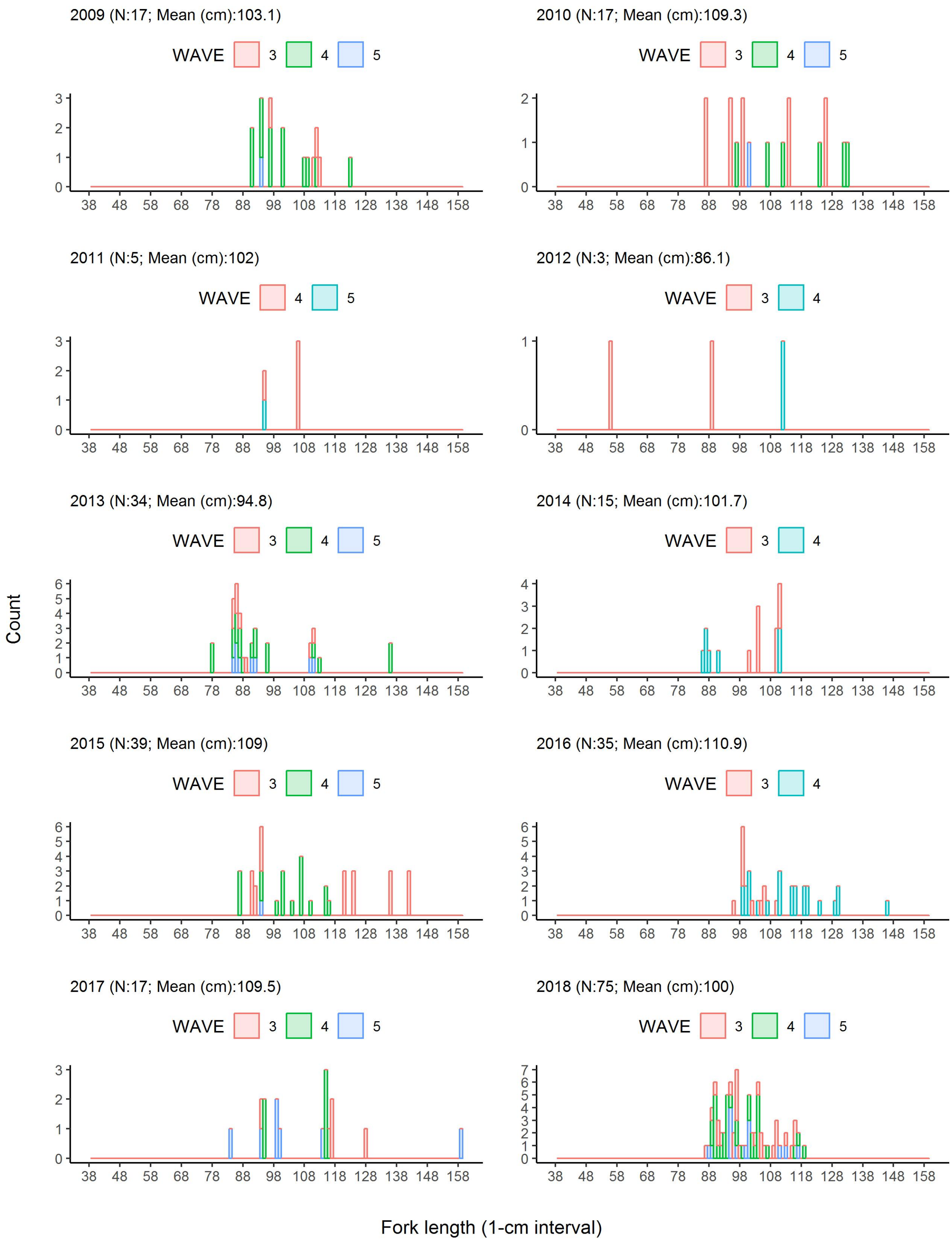

Figure 4: The length distributions of Atlantic Cobia collected by MRIP in Virginia from 2009 to 2018. The different colors indicate the different waves. N and Mean stand for the annual sample size and mean fork length (cm) of the sample, respectively.

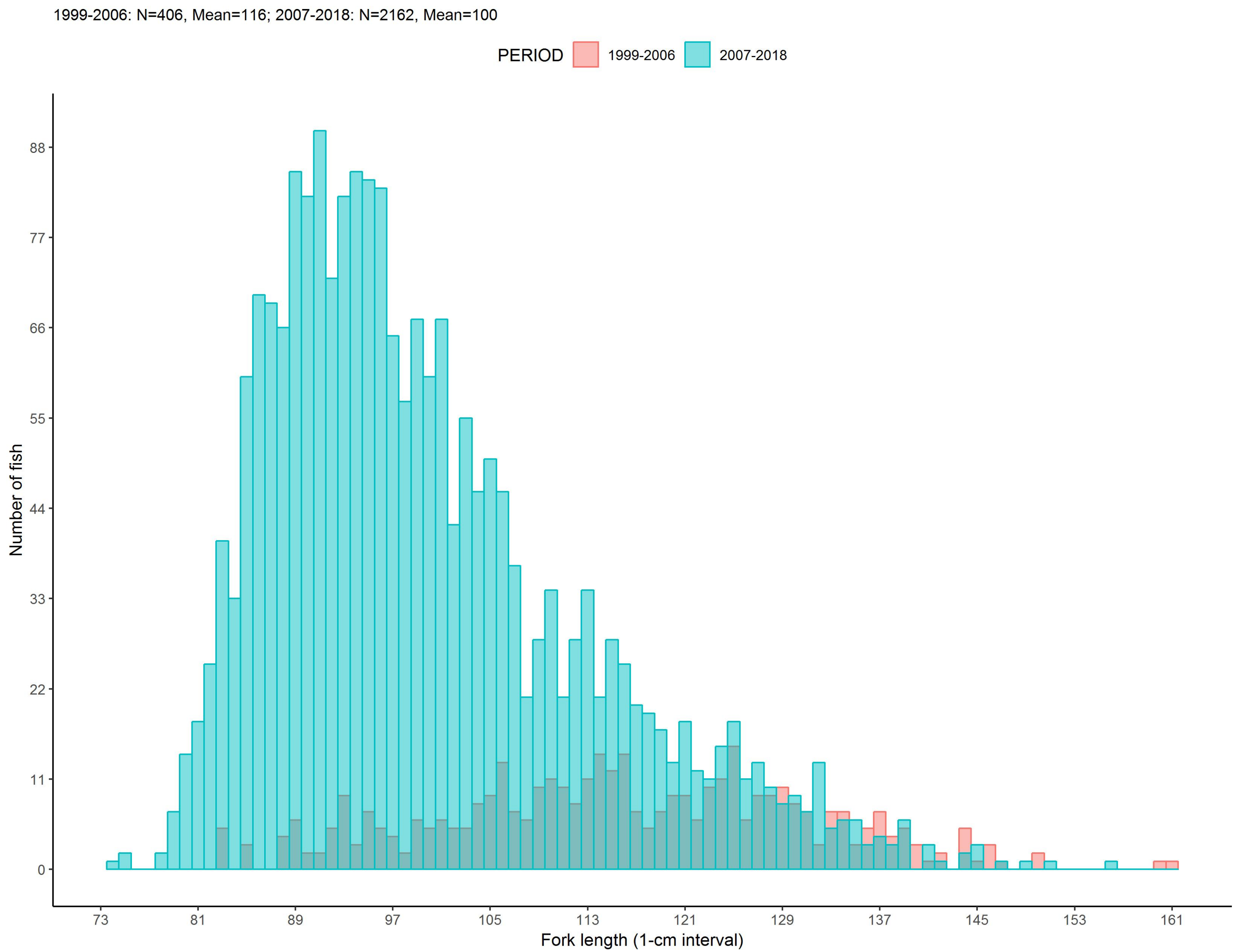

Figure 5: Virginia year-pooled length frequency distributions by period (1999-2006 vs. 2007-2018). The fish were collected randomly during the first period whereas mainly donated by Virginia recreational fishmen during the second period. "N" stands for the sample size of each period. The mean fork lengths between two periods are significantly different (ANOVA: F-value = 496.37, $p < 0.0001$, $\alpha \leq 0.05$.).

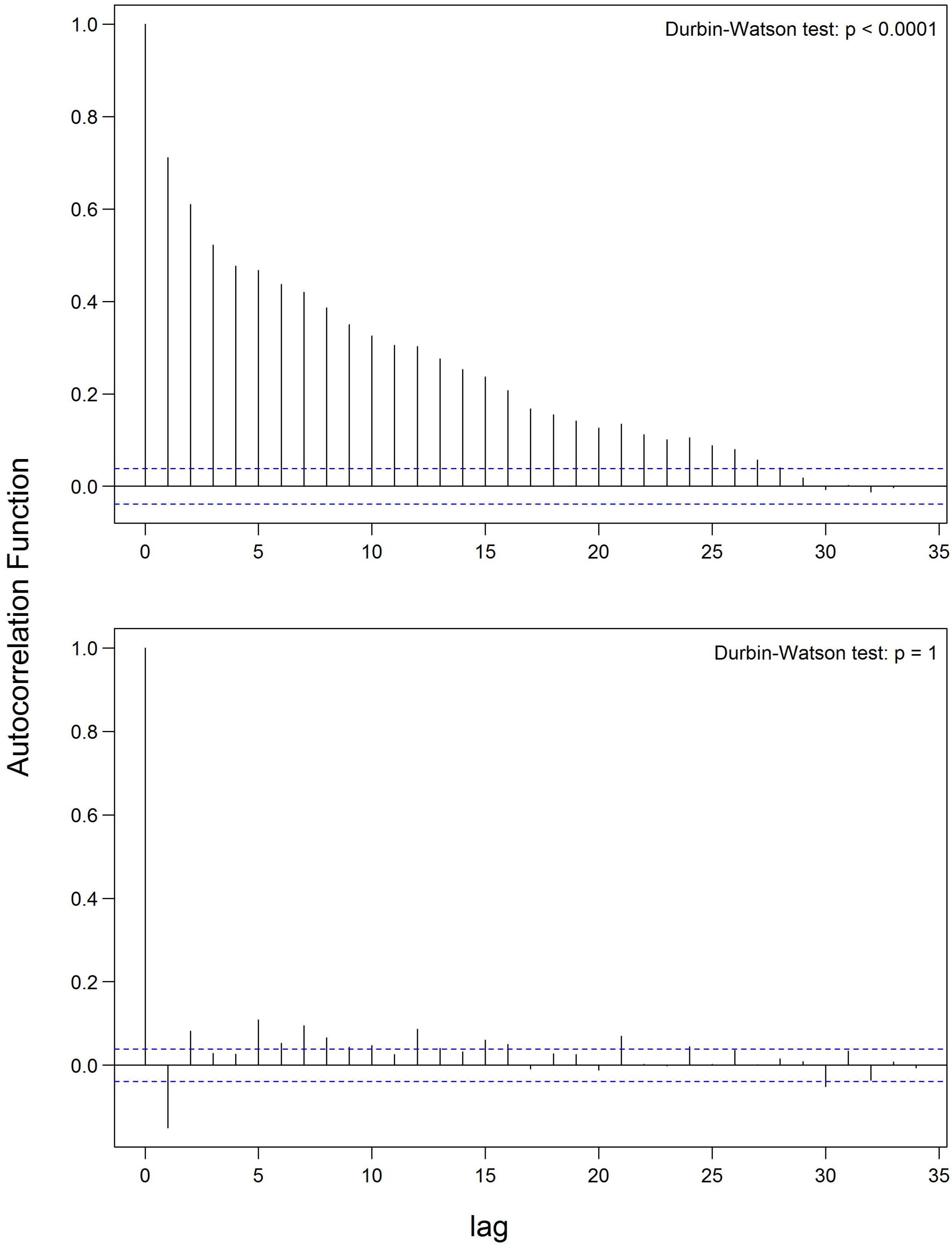

Figure 6: The examination of autocorrelation function. Top and bottom plot are for the linear model with and without the lag-1 autocorrelation, respectively. Durbin-Watson significant level $\alpha \leq 0.05$.

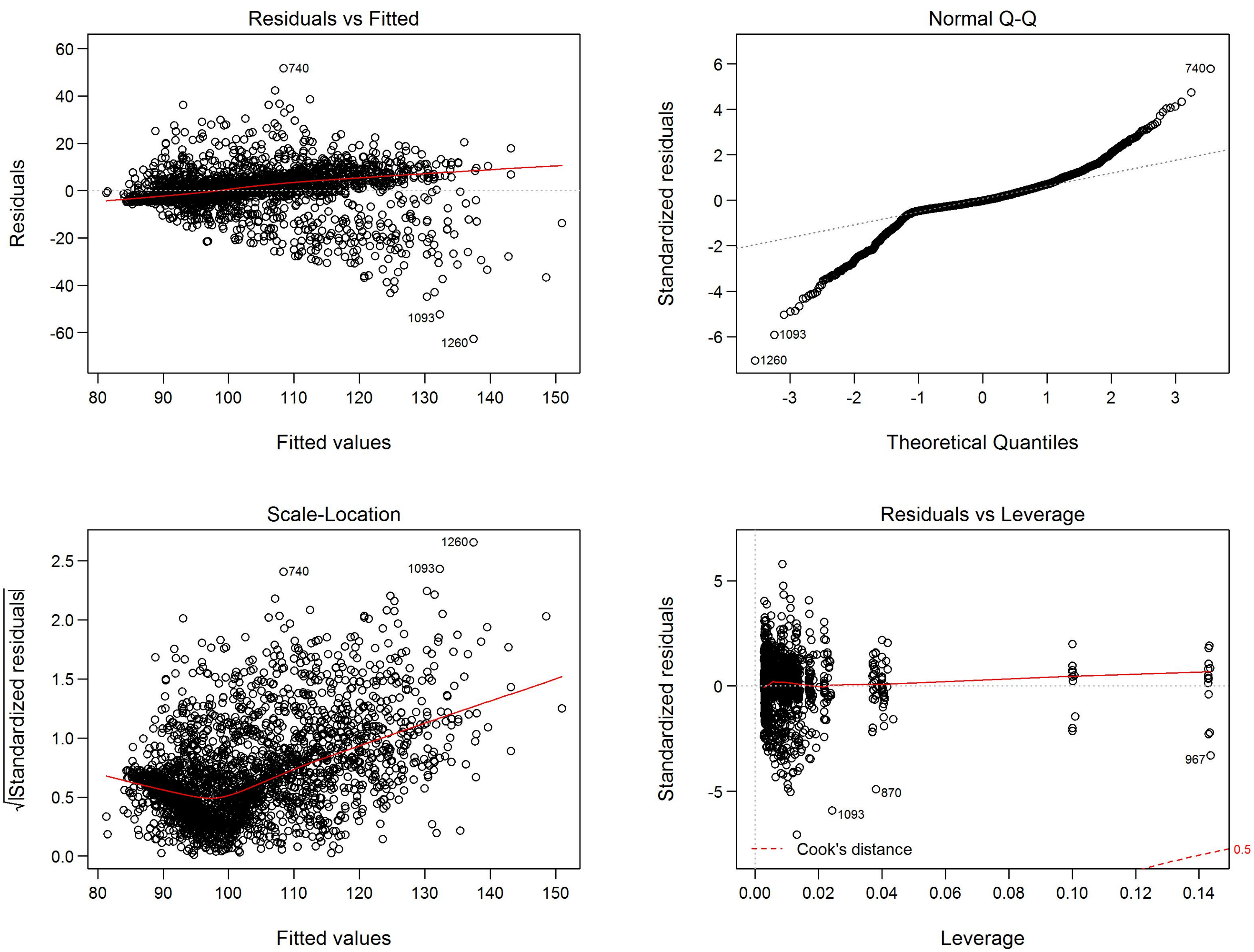

Figure 7: Linear model diagnoses on the linear model without the lag-1 autocorrelation. Top-left plot examines linear relationship between the dependent variable and independent variables. Top-right plot examines normality. Bottom-left plot examines homoscedasticity. Bottom-right plot examines influential point.

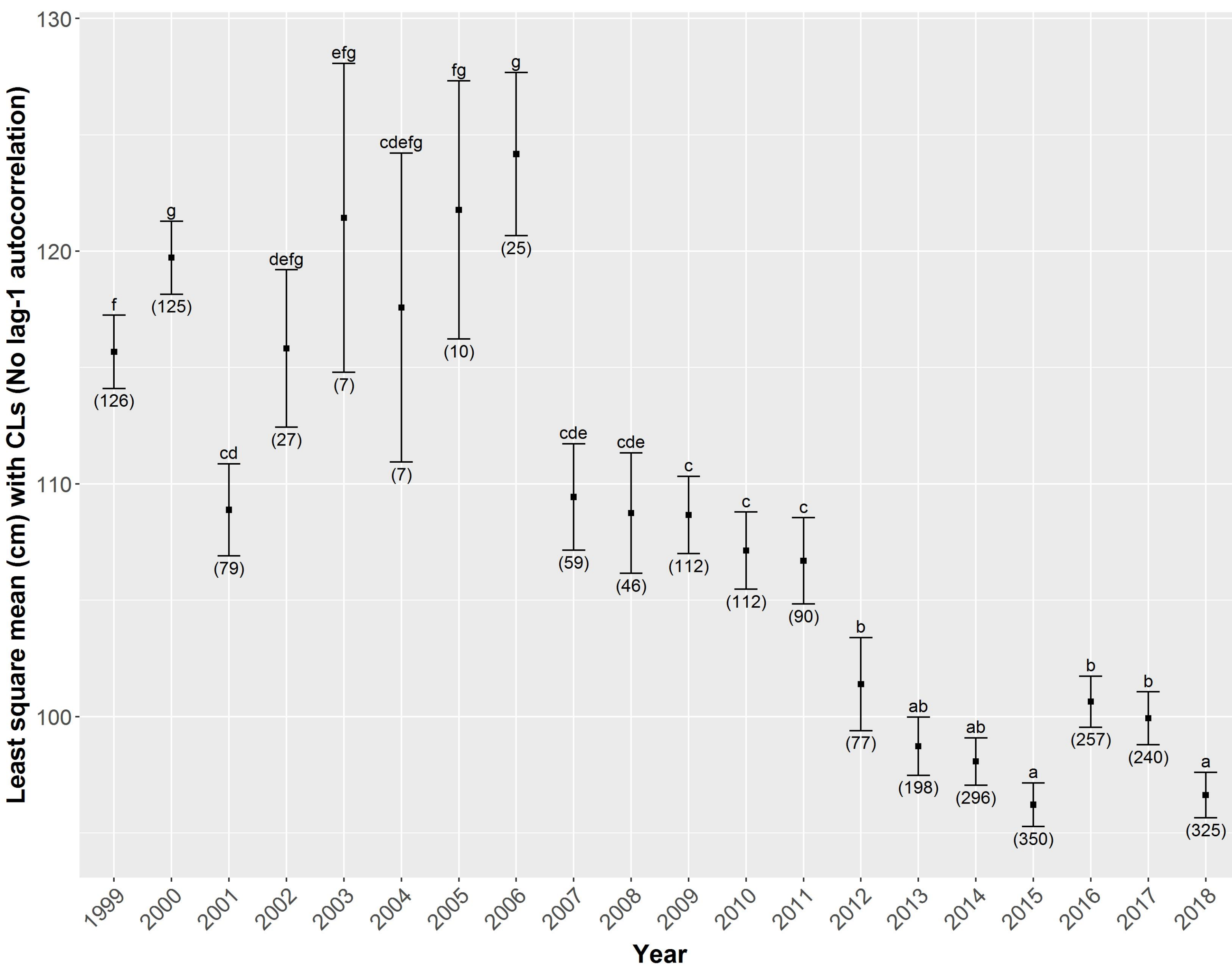

Figure 8: Tukey tests on the least square means of Virginia fork length (cm) from 1999 to 2018. "CL" stands for confidence level. The least square means share the same letter (above the upper CL bar) are not significantly different. The number in parentheses below the lower CL bar is the sample size for each year.

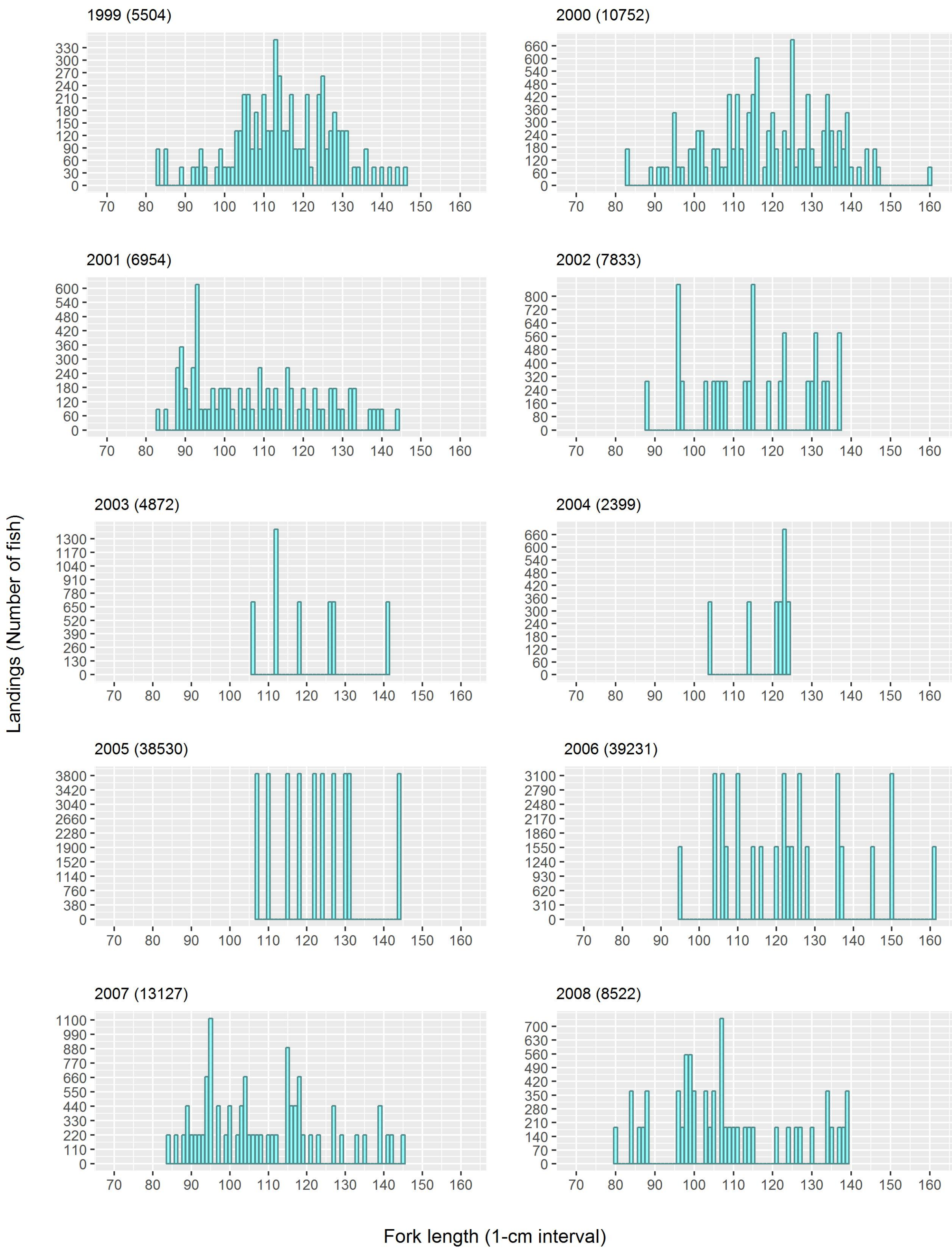

Figure 9: Atlantic Cobia landing length distributions in Virginia between 1999 and 2008, estimated using VA annual harvest (A+B1 in parentheses) reported by MRIP and recreational length distribution developed by VMRC.

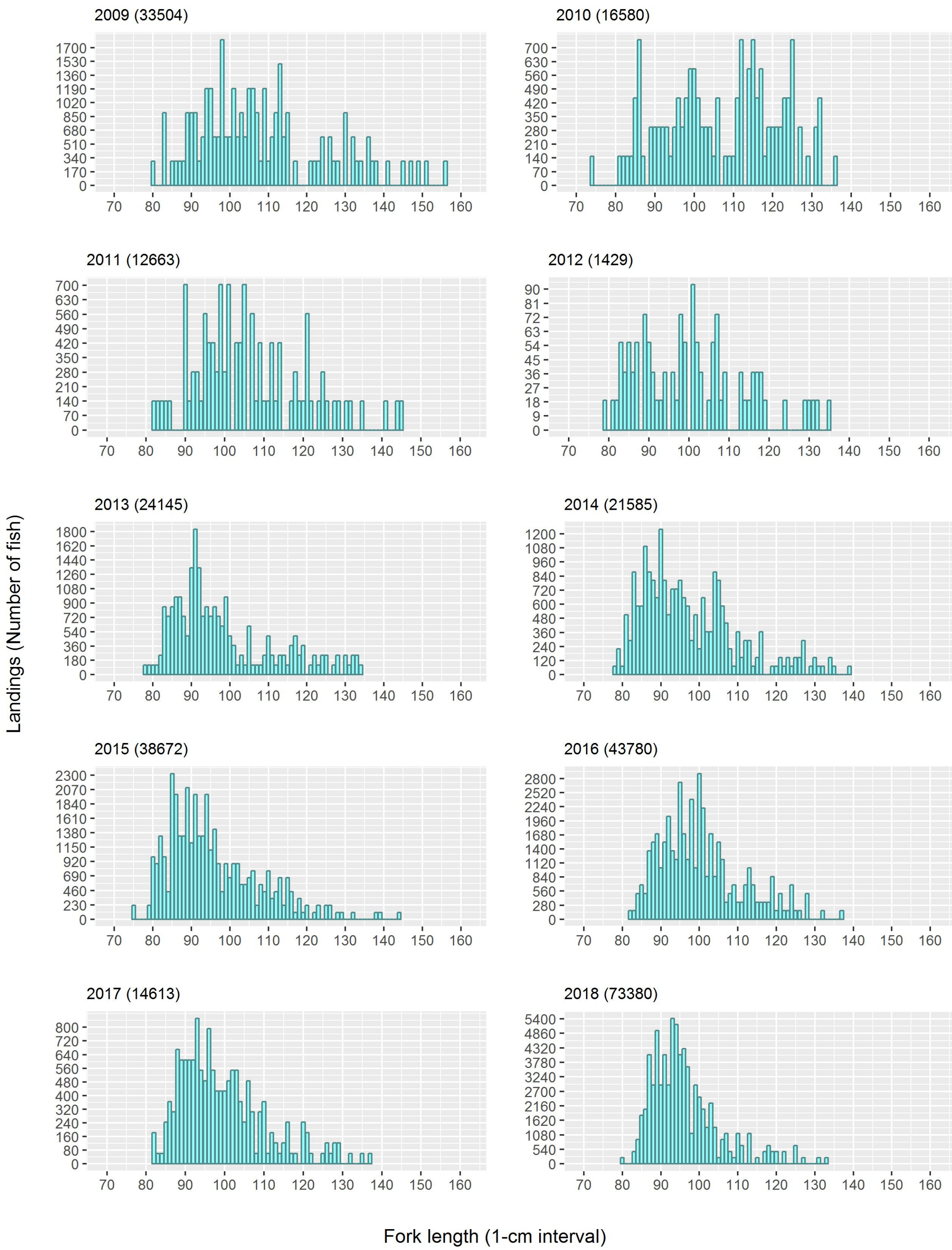

Figure 10: Atlantic Cobia landing length distributions in Virginia between 2009 and 2018, estimated using VA annual harvest (A+B1 in parentheses) reported by MRIP and recreational length distribution developed by VMRC.

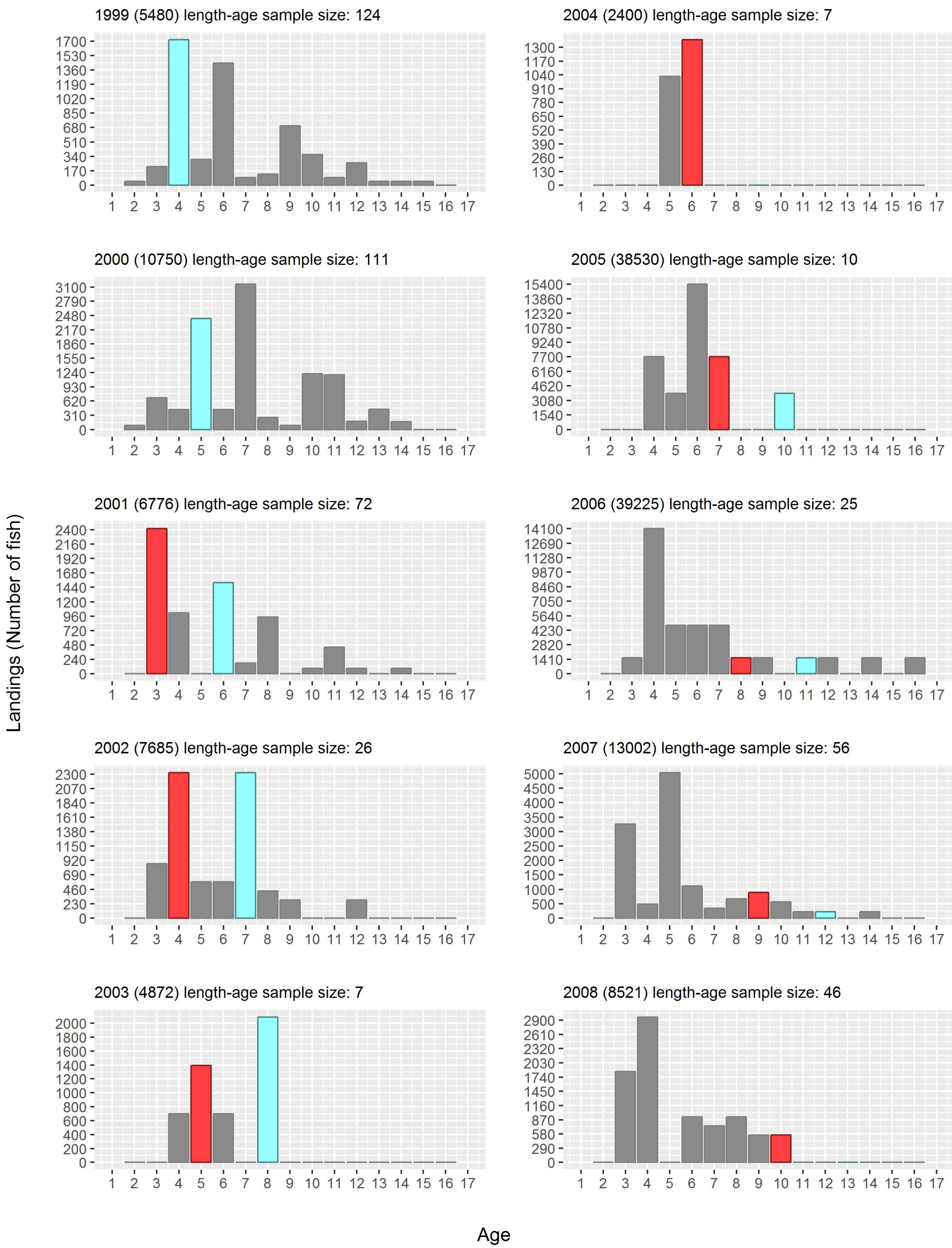

Figure 11: Atlantic Cobia landing age distributions between 1999 and 2008. The number in parentheses is the total annual harvest. Light-blue and red bars indicate the strong cohort progression of 1995 and 1998 year-class, respectively.

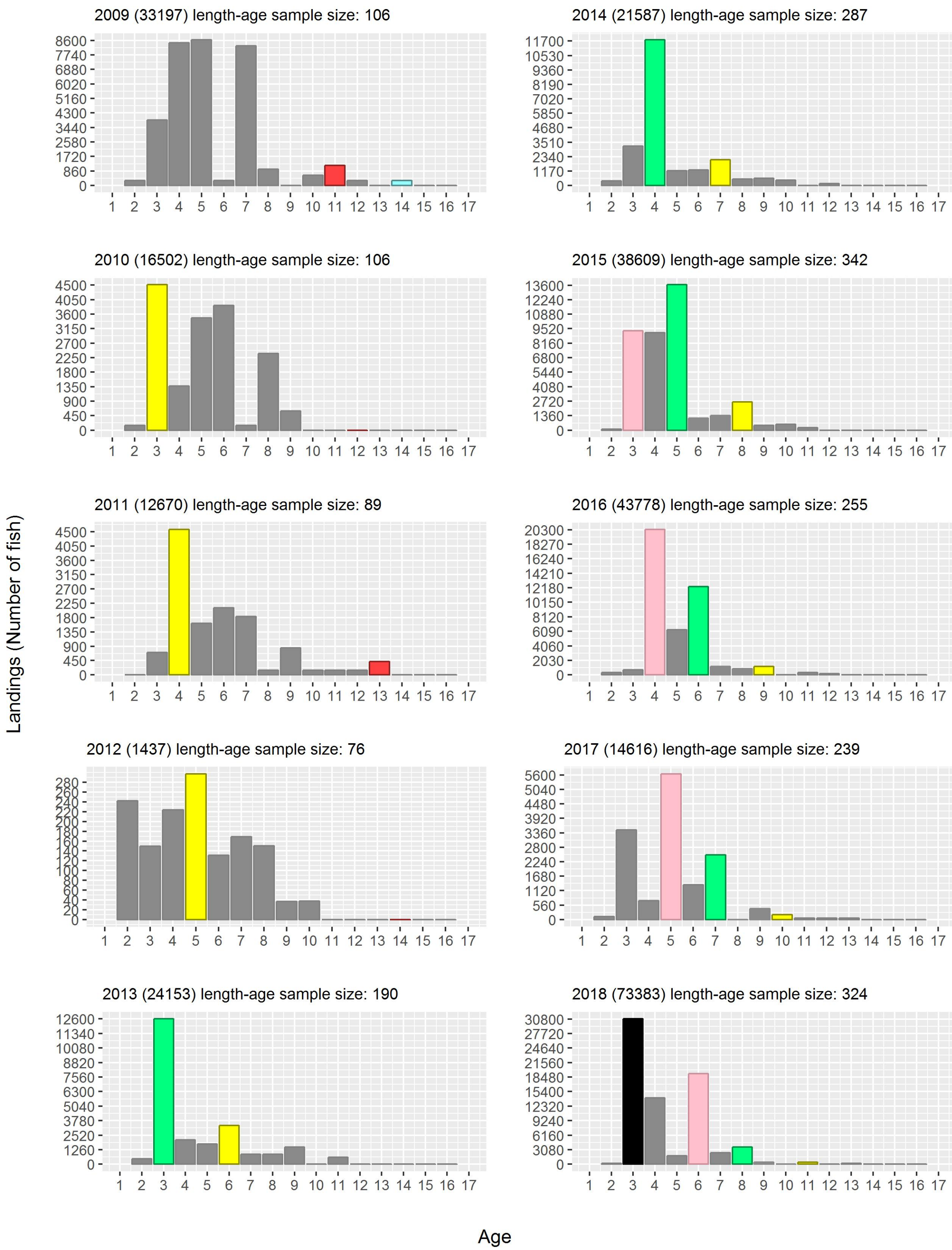

Figure 12: Atlantic Cobia landing age distributions between 2009 and 2018. The number in parentheses is the total annual harvest. Red, yellow, light-green, pink, and black bars indicate the strong cohort progression of 1998, 2007, 2010, 2012, and 2015 year-class, respectively.

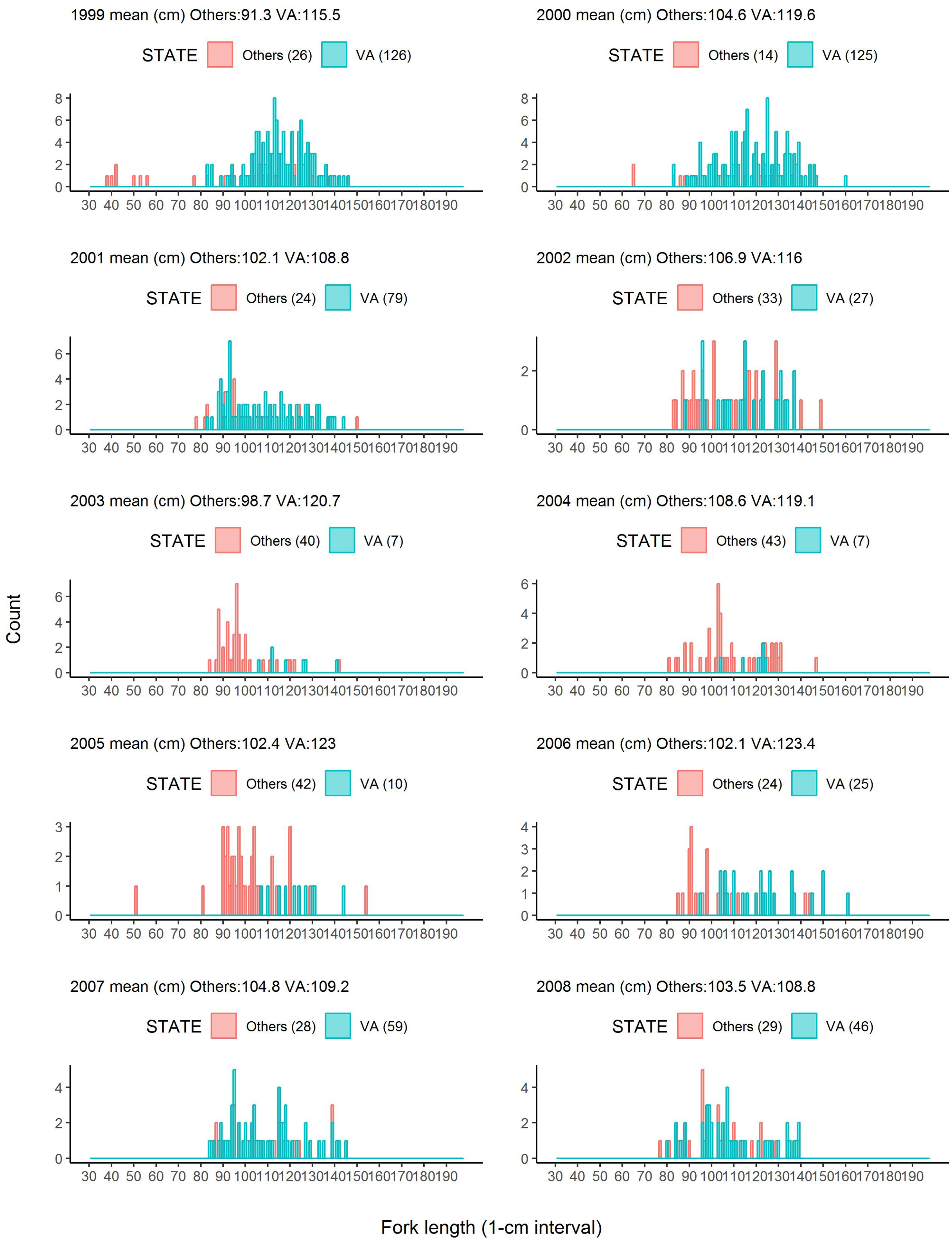

Figure 13: Comparisons in length frequency distribution between Virginia and other states (pooled) from 1999 to 2008. "Others" stands for other states pooled. The number in parentheses above standard error bar is the sample size for each year.

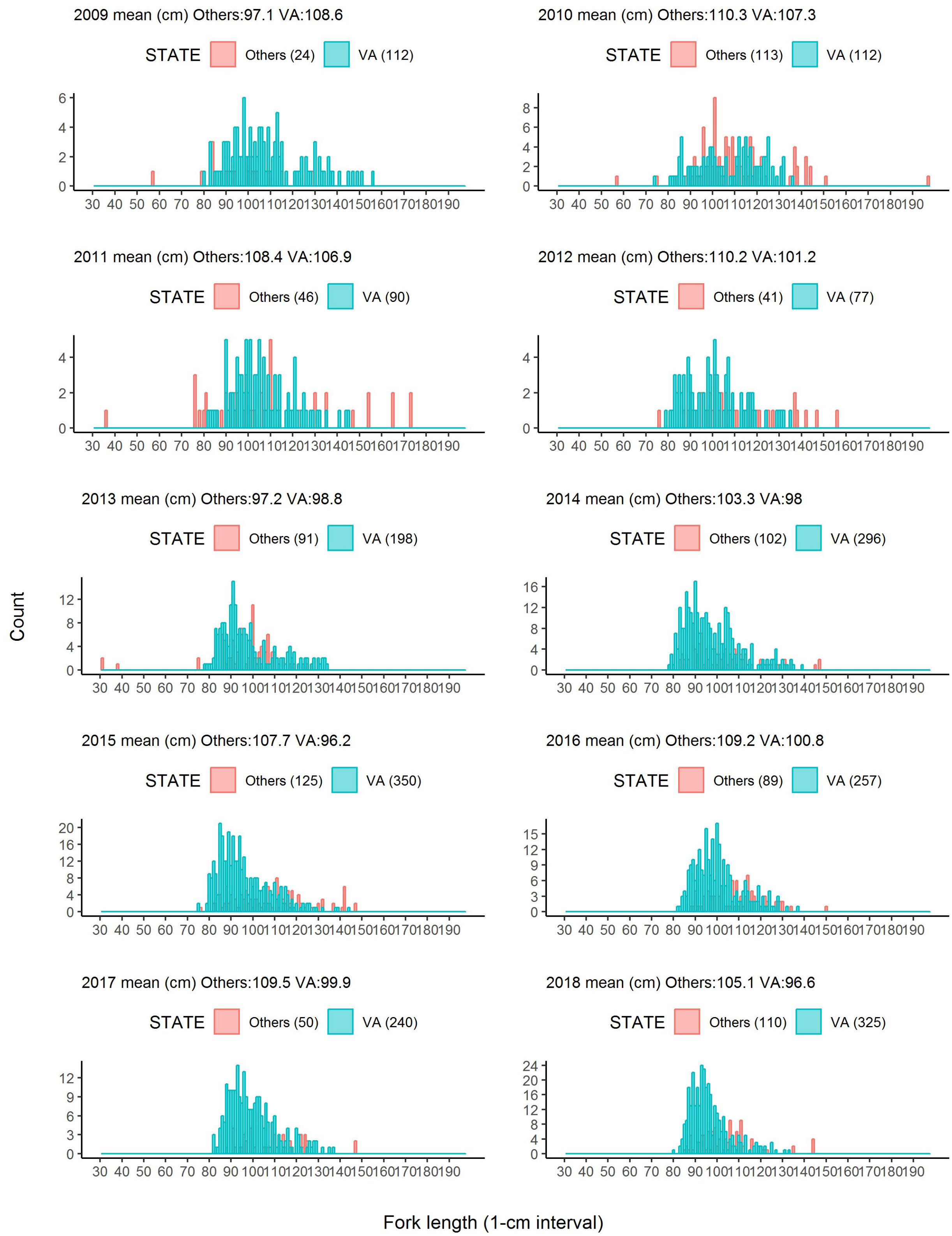

Figure 14: Comparisons in length frequency distribution between Virginia and other states (pooled) from 2009 to 2018. "Others" stands for other states pooled. The number in parentheses is the sample size.

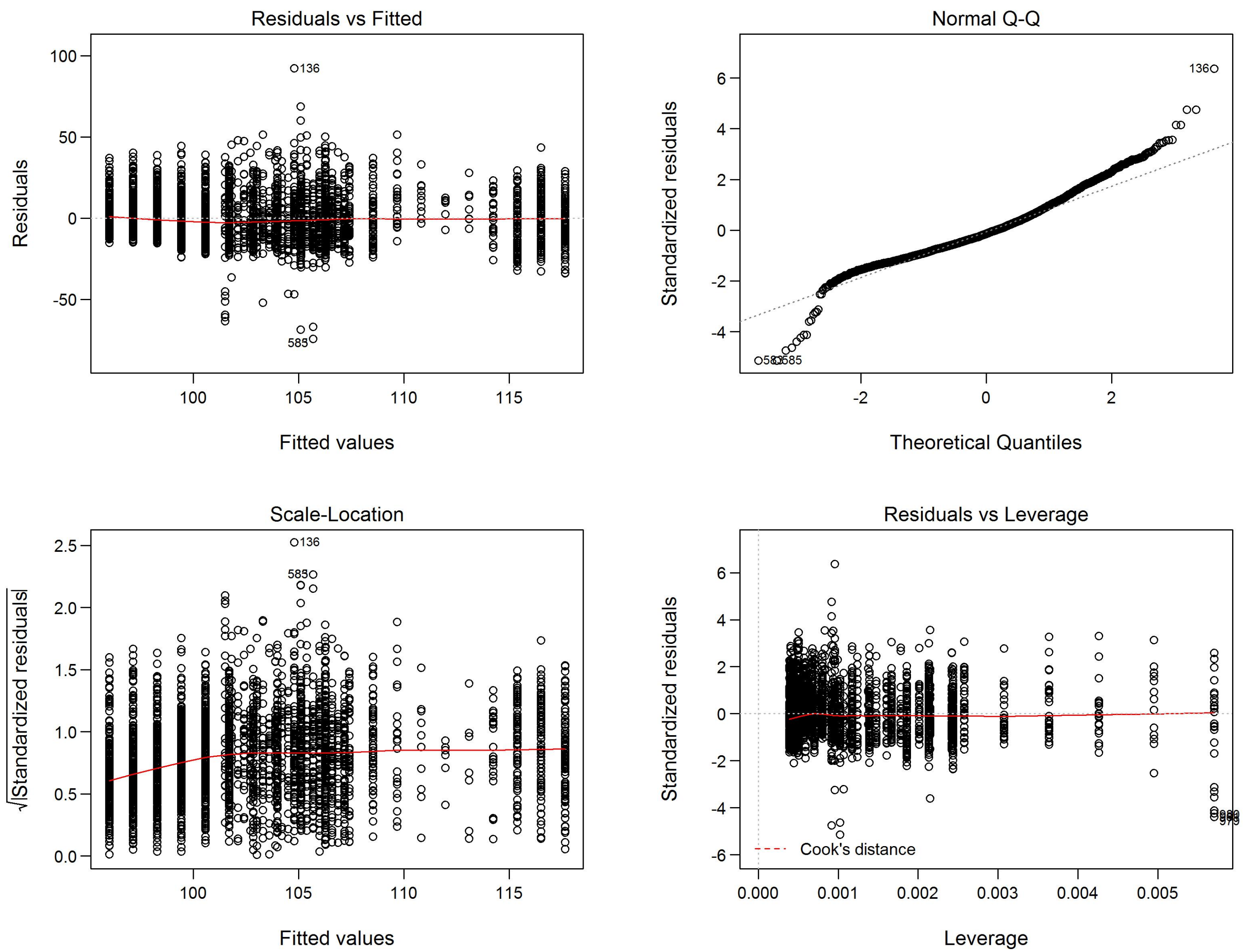

Figure 15: Linear model diagnoses on the full model (Length $\sim$ Year+State+Year:State). Top-left plot examines linear relationship between the dependent variable and independent variables. Top-right plot examines normality. Bottom-left plot examines homoscedasticity. Bottom-right plot examines influential point.

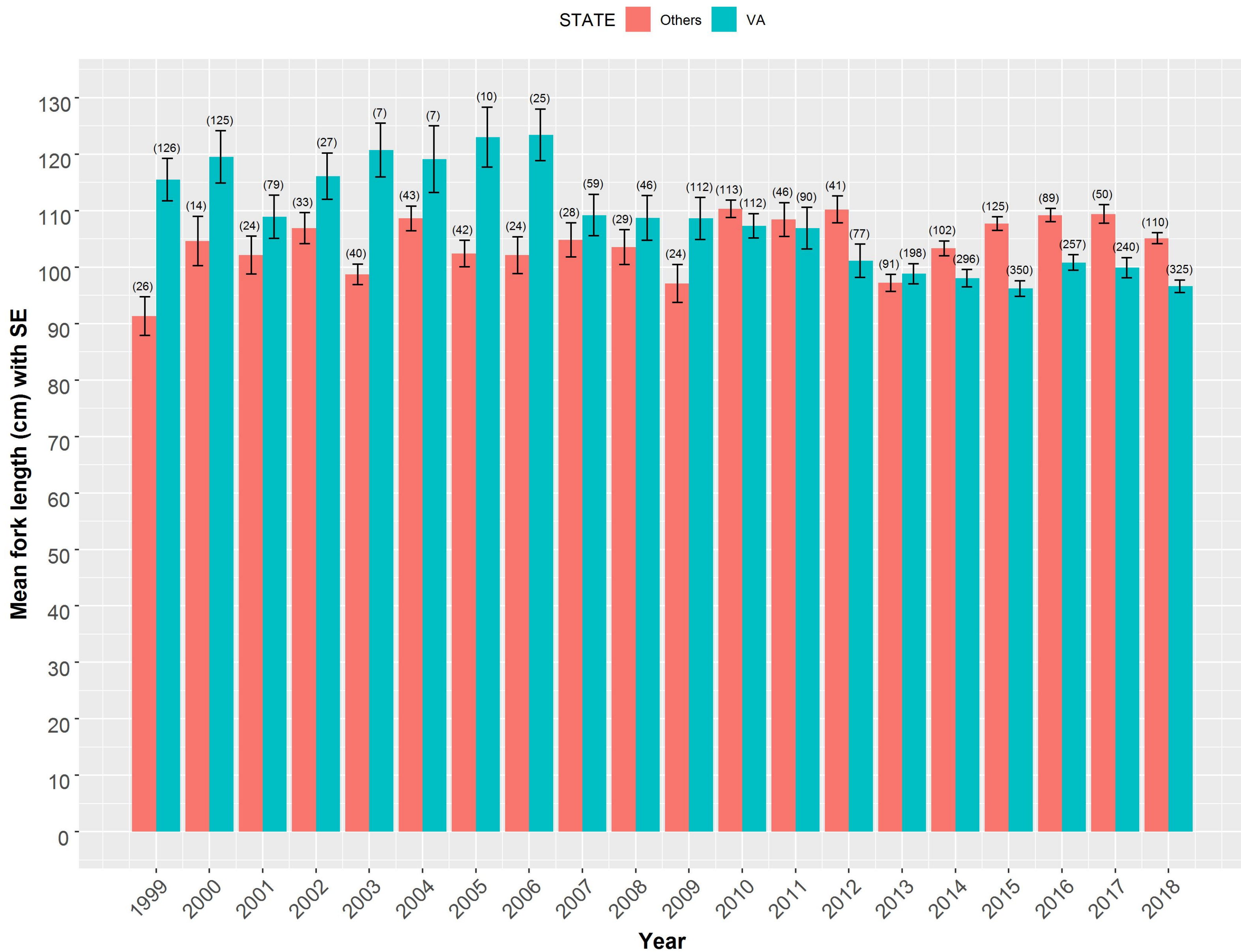

Figure 16: Comparisons in mean fork length (cm) between Virginia and "Others" from 1999 to 2018. "SE" stands for standard error. The number in parentheses above the SE bar is the sample size. Since unequal sample sizes between VA and "Others", the overlap between two SE bars could be misleading. Therefore, use one-way ANOVA results in Table 4 to examine the difference of two mean lengths within a year.