Understanding the Virginia Cobia Stock Through Analysis of Trophy Fish

Principal Investigators: Kevin Weng, Susanna Musick, John Hoenig
Student participants: Daniel Crear and Eric Alpert

SEDAR58-RD43

April 3 2019

Final Report to VMRC-Recreational Fishing Advisory Board

Project Title: Understanding the Virginia Cobia Stock Through Analysis of Trophy Fish

Report Number: Final

Contract # RF 17-13

Principal Investigators: Kevin Weng, Susanna Musick, John Hoenig

Student participants: Daniel Crear and Eric Alpert

Period of Performance: 25 January 2017 to 1 March 2019

Funding Total: $63,249

This report serves as the final report for the grant.

1 Introduction

1.1 The cobia fishery

Cobia (*Rachycentron canadum*) is an important recreational and aquaculture fish throughout the world, and a major recreational resource in Virginia. Cobia has become a popular sport fish along the mid and south Atlantic, as well as in the Gulf of Mexico (GOM) (Brown-Peterson et al., 2000). Cobia range from North and South Carolina to Florida and the GOM; however in the warmer months cobia can extend up into New England (SEDAR, 2013). Cobia are thought to be split into two genetically separate populations with the south Atlantic population ranging from parts of Florida (north of Cape Canaveral) to New York and the GOM population spanning the GOM and southern parts of Florida (south of Cape Canaveral) (SEDAR, 2013). In the south Atlantic, cobia migrate northward in the spring and early summer to spawn in bays and estuaries in North and South Carolina and within Chesapeake Bay, Virginia (Darden et al., 2014), while in the GOM, cobia migrate from southern Florida to their spawning and feeding grounds in the northern GOM (Meyer and Franks, 1996). Currently cobia are managed jointly by the South SAFMC and GMFMC as two genetically distinct populations, with the south Atlantic population ranging from Cape Canaveral, FL to NY and the GOM population spanning south of Cape Canaveral, FL to the GOM (SEDAR, 2013).

1.2 Recent developments in the Cobia fishery in Virginia

The 2012 SEDAR stock assessment concluded that the south Atlantic spawning stock biomass of cobia in recent years (2007 & 2009) has been approaching overfishing. SEDAR also stated that it appears regional fishing pressure has increased as well. South Carolina's Department of Natural Resources is concerned that we may be observing hyperstability (Erisman et al., 2011) in the cobia fishery where spawning aggregations are fished so fishing appears to be good until the catch drops drastically (Pers. Comm. M. Denson).

A large increase in recreational catch in recent years (Figure 1) caused the Federal Government to close the recreational cobia fishery in federal waters starting 20 June 2016. This action resulted in a great deal of controversy, and interest in learning more about the cobia stock that is fished in Virginia.

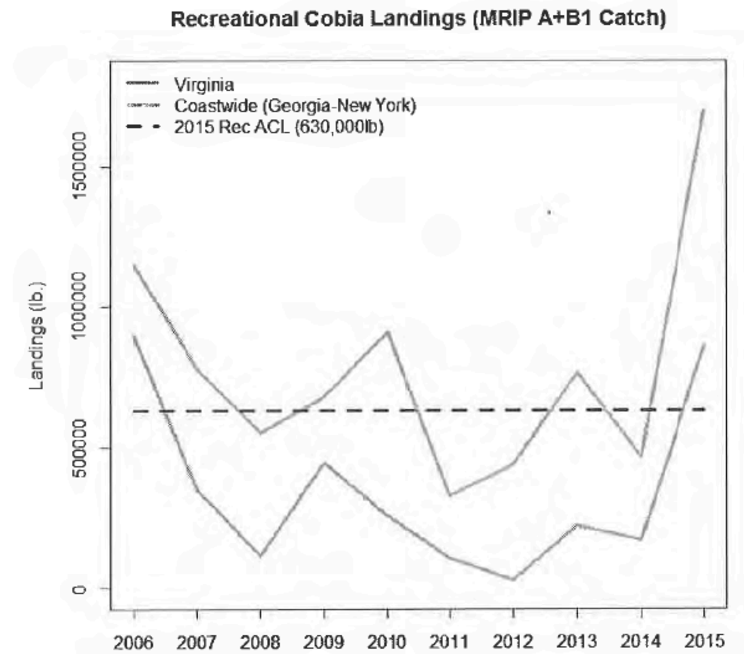

Figure 1. A graph of cobia landings distributed by VMRC as part of the Fisheries Management Division Evaluation, 05/24/2016 (Figure 1 of Attachment 6, March 17 FMAC Meeting)

1.3 Assessment approaches for data-limited fisheries

Advanced model-based stock assessment typically requires three types of data: catch, effort and composition of size or age for the fished population. Such approaches are typically used in large fisheries that have major research programs supporting them. When not all three data types are available, model-based approaches often perform poorly, and when only one type is available, the fishery is considered to be data-poor (Berkson and Thorson, 2015). In data-poor fisheries, management may be more likely to achieve sustainability by using model-free approaches (Berkson and Thorson, 2015), which employ a single data type, such as length-frequency, to create an indicator time series that is used in a prescribed management procedure (Butterworth et al., 1997) such as harvest control rules (Pazhayamadom et al., 2015).

These simple indicators may be more sensitive to changes in stock status than CPUE and advanced model-based indicators, rapidly detecting responses to management actions (Erisman et al., 2014). In fact, a comprehensive analysis revealed that both the data-intensive CPUE approach, and the data-limited body-length approach, are effective in the estimation of fishing mortality (Ault et al., 2014). The authors also noted that both CPUE and size-composition are related to stock productivity in population dynamics theory.

Two important indicators used in model-free management procedures are length of individual fish, and differences (in abundance or size structure) between fished and unfished areas (Berkson and Thorson, 2015). Mean length can be used as an indicator, but is perhaps too simplified, because a strong recruitment pulse will reduce mean length, giving a false impression of an overfished state (Gedamke, 2007; Quang Huynh et al., 2015). A study of reef fishes in Florida indicated that using mean length introduced limited bias (Ault et al., 2005), so the effect may not necessarily be strong.

Another key indicator of stock status that can be used for data-limited fisheries is the percentage of mature fish in the catch (Edwards et al., 2012; Froese, 2004). Many species show increased duration and frequency of spawning in larger, older individuals (Lowerre-Barbieri et al., 2011). The percentage of 'megaspawners' in the catch has been proposed as a simple, model-free indicator of stock status (Froese, 2004), but such individuals may be missing from the catch in fished populations. For fisheries that have strong size selectivity, percent megaspawners in catch may not equal percent megaspawners in the population. Some fisheries are sustainable, but lack megaspawners due to a combination of size limits and high fishing mortality (fish are captured after maturity, but not allowed to grow old) (Erisman et al., 2014). This indicates that spawning output could be much higher if some individuals escaped the fishery. Management strategies that can preserve natural age structure in a population therefore have benefits across the board, from production, to stability, to evolution.

1.4 Sensitivity of stock indicators to changes in stock status

While indicators such as average length may allow for model-free management, there are situations in which indicators may be insensitive to changing stock status, i.e., hyperstability (Erisman et al., 2011; MacCall, 1976). Size-selective fisheries may compensate for changing size structure in the population in order to maintain the desired body size in the catch. In the case of trophy fisheries, only the largest individuals may be reported, such that even in the face of a stock decline, a small number of trophy fish are still captured each year and thus maintain an apparently stable size time series.

1.5 Objective

We used existing recreational catch records for Virginia waters to evaluate change in maximum size of cobia over time. Cobia maximum size data were used to develop several size-based stock indices using published methods. It should be noted that we do not propose to replace or compete with SEDAR in the assessment of this or any fish stock, but instead we aim to provide data and approaches to VMRC and other management bodies for consideration.

2 Methods

2.1 Data sources

The cobia fishery in Virginia operates largely as a trophy fishery, in which participants aim to capture the largest individuals. As such, there is likely to be bias in the targeting strategies of anglers while on the water (biased to large fish), as well as bias in which individuals are recorded in records. Thus the catch records are unlikely to provide size frequency data for the population as a whole. The degree of bias may vary between sources. For instance, trophy citations recorded by VMRC have a minimum cutoff and therefore the data are truncated by definition; while the fish tagged and released by the Virginia Gamefish Tagging Program are likely to be smaller individuals that anglers elected not to retain. Creel survey records should in theory reflect the size distribution of retained fish, and thus represent more size classes and have less bias towards large fish than citation records. Fishing club records are likely to be similar in bias to citation records. Privately held records may include lengths of all individuals caught. We used the following data sources.

2.1.1 Creel survey records

We downloaded data from the Marine Recreational Information Program (MRIP) and the Marine Recreational Fisheries Statistics Survey (MRFSS). In these creel surveys, many records are based on visual estimates of size, rather than measurements. MRIP/MRFSS data was collected from the website https://www.st.nmfs.noaa.gov/recreational-fisheries/data-and-documentation/downloads. MRFSS data recorded information from 1981-2003. In 2004 the MRIP system replaced MRFSS but kept the same basic format for the data. Each year contains six datasets encompassing two months each. All of these sets were combined into one sheet for a single year and the data was filtered to list only records of cobia. From this set we extracted date, location, and size measurements. Then the data were filtered to retain only records from Virginia.

2.1.2 Charter captain records

Personal logbooks were acquired from local fishermen and charter captains. Fishermen recorded information with details concerning date, time, location, species, and size of catch. Not every record contained all the aforementioned information. When the date and size information referenced a cobia, the record was collected as an observation. Some fishermen listed the size of catch but did not record the species, or it was unclear if the size measurements concerned a cobia or another fish species that had been caught in the same day. These records were not collected.

2.1.3 Fishing club records

We obtained records from a club that reported the three largest cobia caught during a given year.

2.1.4 VIMS cobia research

A cobia research program lead by John Olney collected information on cobia length, and was provided by Brian Watkins.

2.1.5 VMRC Citation records

VA Citation data were collected from the website: http://mrc.virginia.gov/vswft/index.shtm. Each data set recorded an entire year. Once the data were filtered to only contain cobia we extracted date, location, and size measurements. Citation records have a knife-edge bias to larger fish resulting from length threshold required to receive a citation.

2.1.6 Virginia Game Fish Tagging Program records

The Virginia Game Fish Tagging Program data[1] were provided by Susanna Musick. Each data set recorded an entire year. Once the data were filtered to only contain cobia we extracted date, location, and size measurements. These records are likely to be biased towards smaller fish since large individuals are generally kept for consumption, citations, etc.

2.2 Length weight conversion

In some cases, fish may be weight but not length measured. We converted weight to length as follows:

$W = aFL^b$ where a=2.00E-09 and b=3.28, W=weight, FL=total length (SEDAR28 table 2.16)

Such conversions are subject to error since major changes in girth occur pre- and post-spawn for females.

2.3 Analysis

We proposed a menu of analytical approaches, with some requiring data that is unbiased by size and other approaches being more flexible. The data sources that we obtained all had considerable bias in the sizes of fish that were represented, and thus not all of the approaches on our initial menu were possible. We added additional analytical approaches that were suitable for the data.

We did not pool across data sources because there was evidence that each data source had its own sampling bias, and different sources represented different time periods. Therefore, pooling data could create spurious trends. Since most of the data sources contained a small total number of records, some analyses suffered from having too few data points to obtain reliable parameter estimates.

2.3.1 Temporal change in maximum length

The simplest indicator of fishing effects is a temporal decline in reported maximum length. Because maximum observed length is highly dependent on sample size, upper quartiles are more robust, so we plotted L95%, the mean of the largest 5% of reports for the year (Shin et al., 2005).

The L95% approach is susceptible to showing a decrease in response to strong recruitment, since a large influx of small fish will cause the mean of the population to decrease, even though the event is good for the status of the stock. In other words, L95% may give you bad news when in fact something good is happening (lots of small fish recruiting to population is good, but it causes a decrease in average size). Therefore, we employed a similar approach that is robust to recruitment pulses, the mean of the largest five individuals. Since this approach takes a fixed number of records from the top, it does not get 'diluted' by a large number of small individuals in a recruitment event. For datasets with few observations the difference between L95% and largest five can be counterintuitive, which is discussed below.

2.3.2 Large Fish Indicator

We were not able to apply the Large Fish Indicator (Greenstreet et al., 2011) because it requires length frequency data for the entire fishery, i.e. not only for large individuals. (LFI=proportion of individuals over X cm FL).

2.3.3 Samples to yield large individual (NZ50)

We were not able to apply the NZ50 index because it requires length frequency data for the entire fishery. This index measures the rarity of large individuals in the catch. NZ50 is the least number of observations required of a random sample to include one or more individuals equal to or greater than a specified size in

[1] https://www.vims.edu/research/units/centerspartners/map/recfish/index.php

50% of such samples (i.e., the smallest number of observations to include fish at least that big half the time) (Goodyear, 2015).

2.3.4 Length converted catch curve

The length converted catch curve (LCCC) is a length-based method for estimating total mortality (*Z*) in exploited fishes (Pauly, 1983) and is used when age data area not available for more complex assessment approaches (Huynh et al., 2018). The LCCC uses the natural logarithm of catch (Cj) in the jth length interval of a length-frequency distribution regressed on the relative age (t_j) at the midpoint of the length-bin (λ_j). The relative age at the jth length-bin is given by

$$t'_j = -\log_e\left(1 - \frac{\lambda_j}{L_\infty}\right)$$

where λ is the midpoint of the length bin and L_∞ is the Von Bertalanffy asymptotic length.

The length-frequency distribution is obtained by counting the number of fish within each length bin, and the $\log_e$ of these counts are then plotted against their corresponding relative ages (for the midpoint length, λ_j) (Figure 2). The slope of the descending limb ($\hat{b}$) and the von Bertalanffy growth coefficient (K) are used to calculate the relative index of mortality ($\hat{Z}$), given by

$$\hat{Z} = K(1 - \hat{b})$$

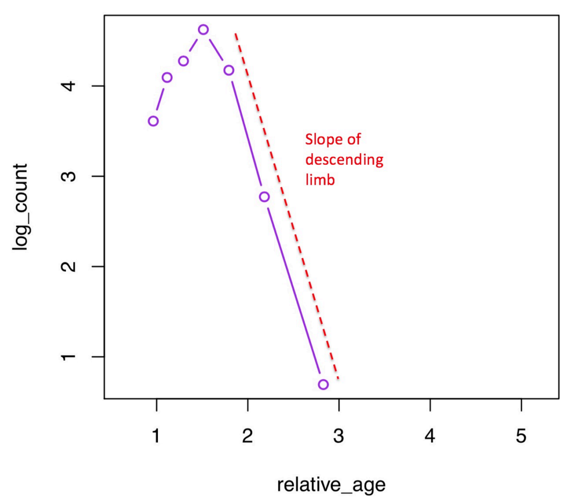

Figure 2. Example of an LCCC plot used to estimate a relative index of mortality. The log of the count of individuals within a relative age bin shows abundance. On the left side of the curve the size classes have not fully entered the targeted sizes for the fishery so the curve descends to the youngest ages. On the right side of the curve the age bands represent sizes that are targeted, and the decrease shows how much rarer the larger sizes (older ages) are. The slope of this portion of the curve represents mortality.

Relative mortality was estimated for each year of the data source in order to create a time series of relative mortality, which could then be evaluated for trend. For data sources with fewer numbers of observations we counted abundance across more than one year so that we would have more observations available to create a curve.

In order to count the abundance of fish in a certain age (size) range we created length bins of 10 cm width (Table 1). The value for von Bertalanffy's K (0.27) was obtained from the stock assessment[2]. We were unable to use the stock assessment's value for von Bertanlanffy's L_∞ of 139 cm TL because the relative age equation divides the observed lengths by L_∞ and most of our observed lengths were larger than L_∞ meaning we would take the log of a negative number, which does not have a solution. We therefore used the maximum observed size in any of the sources as our L_∞ value (referred to as L_{max}), rounded up to the nearest cm (which was 186 cm TL). Given the use of L_{max} instead of L_∞ our mortality estimate should be considered a *relative* index of mortality. It can be used to assess trend through time, but not as an indication of actual mortality levels.

Table 1. Length bins used in Length-Converted Catch Curve Analysis, Total Lengths of Cobia. Bins were 10 cm wide, "floor" refers to the lower bound, so a bin with a floor of 120 cm has a ceiling of 130 cm and a midpoint of 125 cm TL

Floor (cm)	Midpoint (cm)	Midpoint (inch)
180	185	73
170	175	69
160	165	65
150	155	61
140	145	57
130	135	53
120	125	49
110	115	45
100	105	41
90	95	37
80	85	33

[2] http://sedarweb.org/sedar-28-stock-assessment-report-south-atlantic-cobia

3 Results

The number of records for each data source used in the study is provided in Table 2.

Table 2. Data sources used in the analysis

Source	Year(max)	Year(min)	Records
Source_1 (private)	2016	2014	183
Source_2 (private)	2015	2010	54
Source_3 (club)	2016	1997	59
Olney/Watkins	2013	1996	504
VMRC Citation	2017	2000	3839
VGTP	2017	1995	3942
MRFSS	2003	1981	95
MRIP	2017	2004	211

3.1 Data exploration and visualization

The size frequency for each data source provides an indication of the likely sampling bias for each source (Figure 3 and Figure 4).

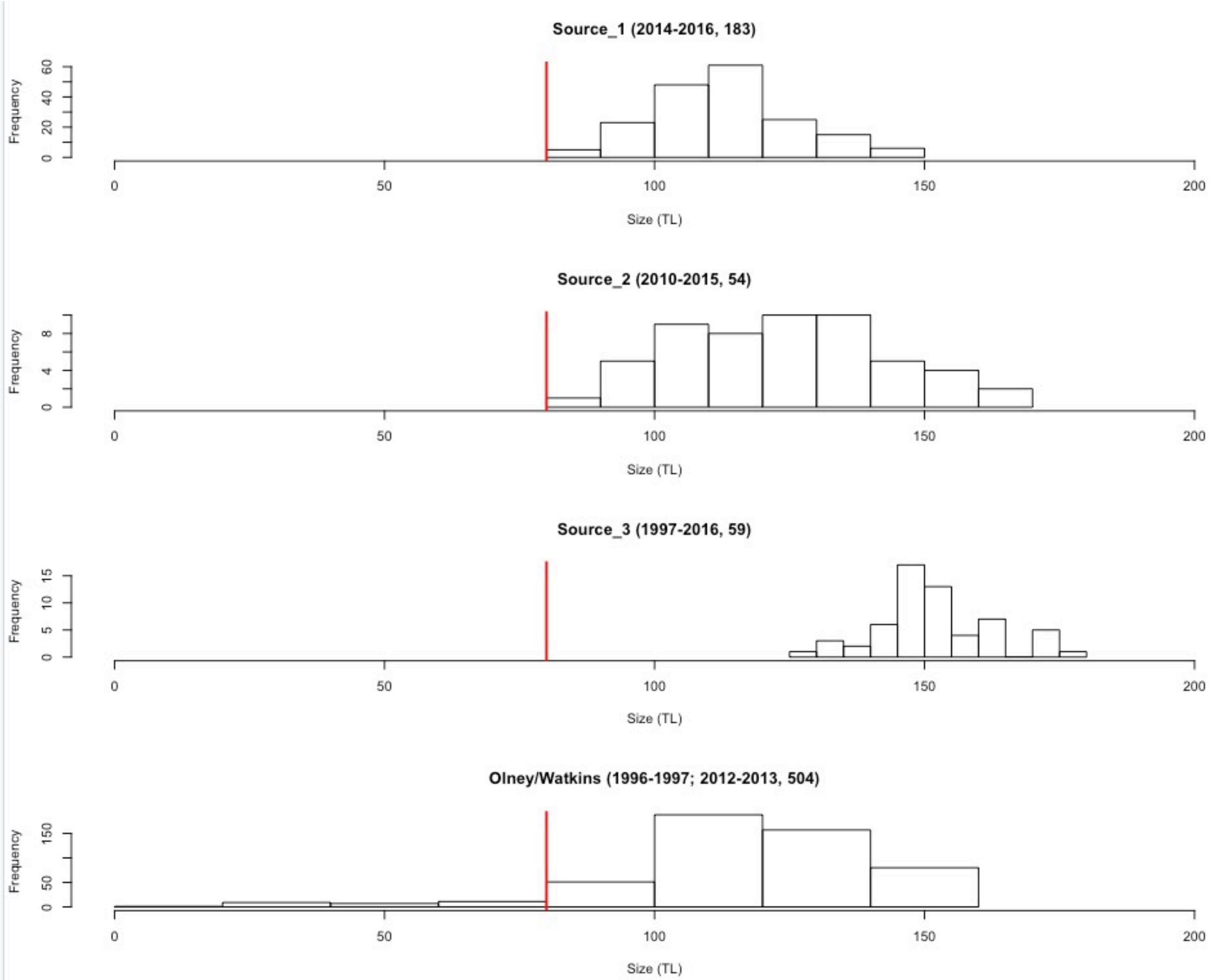

Figure 3. Size frequency distributions Size frequency distributions. Sources 1 and 2 are private records from fishermen, source 3 is a fishing club record of the largest three fish per year. The Olney/Watkins dataset is from a VIMS research program combined with person catch records from Brian Watkins. Red line shows size of female maturity (80 cm TL).

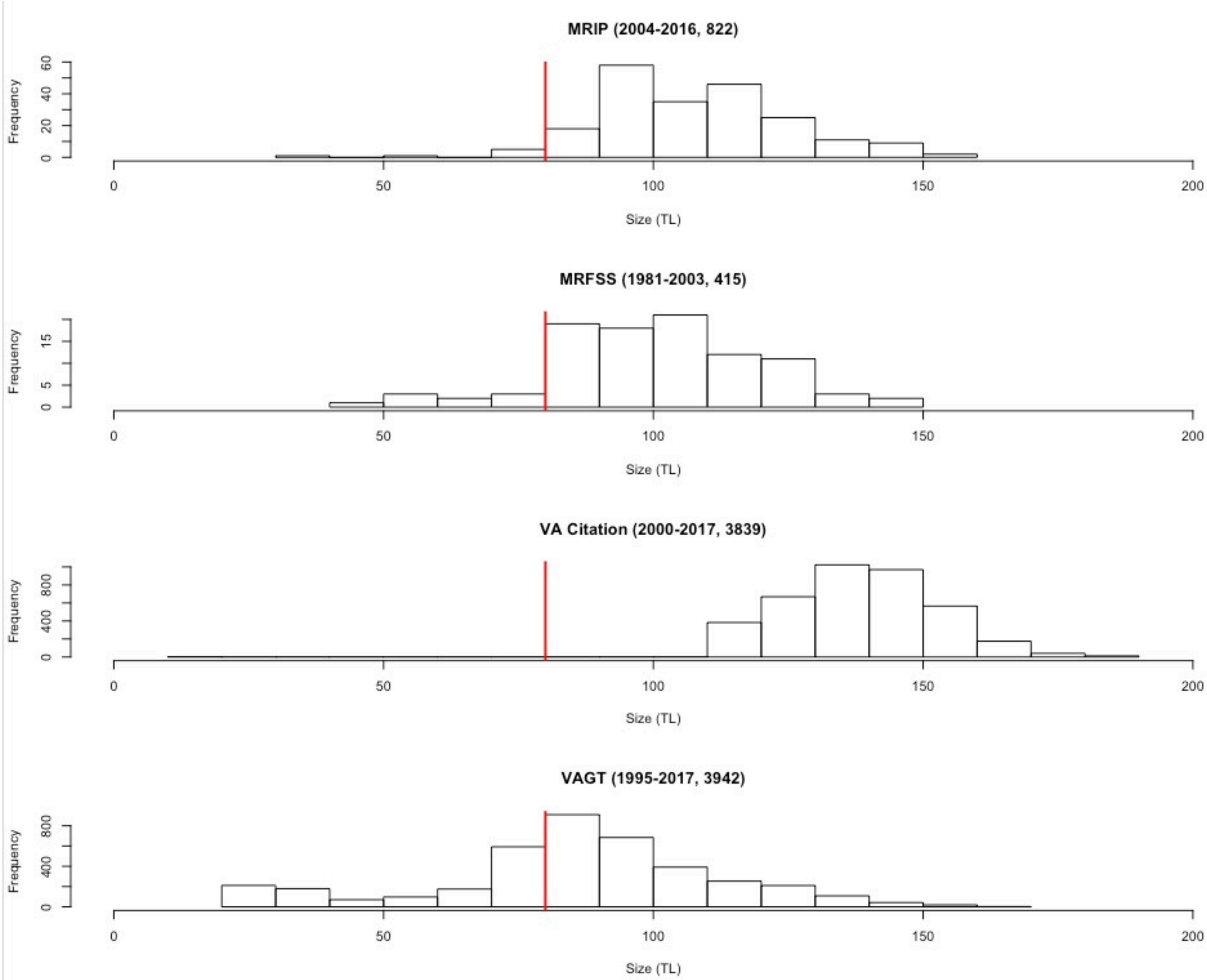

Figure 4. Size-frequency distributions. The federally collected creel survey data from MRFSS and MRIP show similar size distributions, while the VMRC Citation data shows a larger size (required in order to qualify for a citation), and the VA Game Fish Tagging Program shows a smaller size distribution, being primarily fish that were not retained for trophy or food purposes.

Pooling across sources could introduce spurious trends into the data and was not conducted. For instance, if VGTP biases small and the data occur in earlier years, and VMRC Citation biases large and occurs in later years, pooling these two data sources would generate a trend of increasing size distribution through time.

In order to get a visual sense of change in size distribution through time, within a particular data source, we can plot a timeseries of histograms by year. Because this approach requires enough data within each year to create a histogram it is not possible for most data sources. VMRC Citation and VGTP have enough data, and since the latter is known to bias to smaller fish we have carried out this analysis using VMRC Citation data (Figure 5 and Figure 6). If there were a strong change in size distribution through time, we would expect to see a shift in the distributions to the left from 2000 to the present. From a non-quantitative visual perspective there is not an obvious trend.

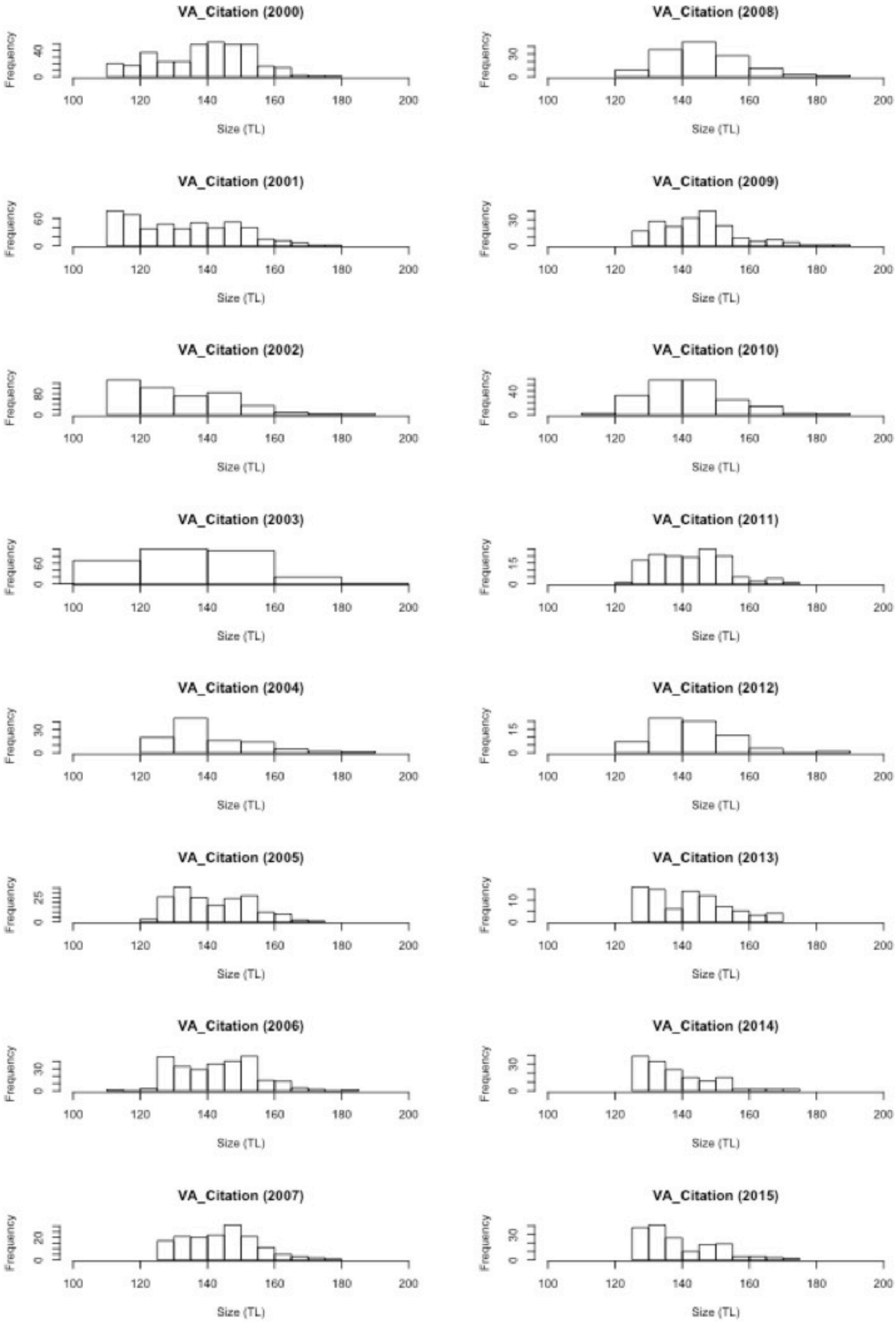

Figure 5. Length-frequency for each year of the VMRC Citation dataset

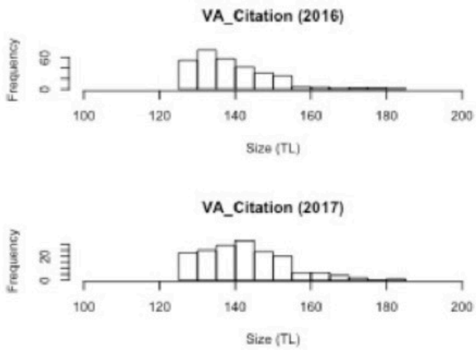

Figure 6. Length-frequency for VMRC Citation dataset, continued

3.2 Time Series Analyses of Maximum Size

The plot of L95%, the average size of the largest 5% of individuals in the catch (Figure 7 upper), did not show strong trends for any data source. The lowest variability was in the VMRC Citation and VGTP sources, which are the largest by number of observations (Table 2). Other sources showed high variability between years. It should be noted that for sources with a small number of observations in a year, the top 5% of observations might be one observation, and this would have the effect of enhancing variability between years.

The plot of the largest five individuals (Figure 7) was similar to the L95% plot. It should be noted that the effects of switching from L95% to largest five are counterintuitive for small datasets. While it would initially appear that largest five would include fewer records than top 5%, our sources other than VMRC Citation and VGTP sometimes have fewer than five records for a given year. If there are three observations, then the top 5% of records is one; whereas the largest five would select all of the available three records and report the mean. For these small datasets there is not likely to be an effect of recruitment pulses since only a small number of fish are reported, and these are likely to qualify as 'trophy' fish (they were large enough to be retained and reported). In the case of the datasets with many observations (VMRC Citation and VGTP) the effect is more intuitive, with the L95% method using more than five records to calculate the mean.

Source_3 provides records that cover the period 1997-2016, and represent the largest three cobia per year for a fishing club. Since there are three observations per year, the L95% gives the largest single fish, while the largest five plot gives the mean of the three fish. There has been a decrease in size in this data source in the past decade, but the higher levels for the 2000's decade are driven largely by only two points. The other data sources show little trend.

The methodology for both L95% and largest five allows for susceptibility to hyperstability. This is due to the fact that the methods record a small number of observations of the largest fish captured, but do not account for the rarity of such large fish. This means that in a scenario of declining stock status, where large fish are becoming more rare, it is still quite possible that in most years, several talented anglers would catch large fish. Therefore, a method that takes account of both size and frequency would be more sensitive to changes in stock status.

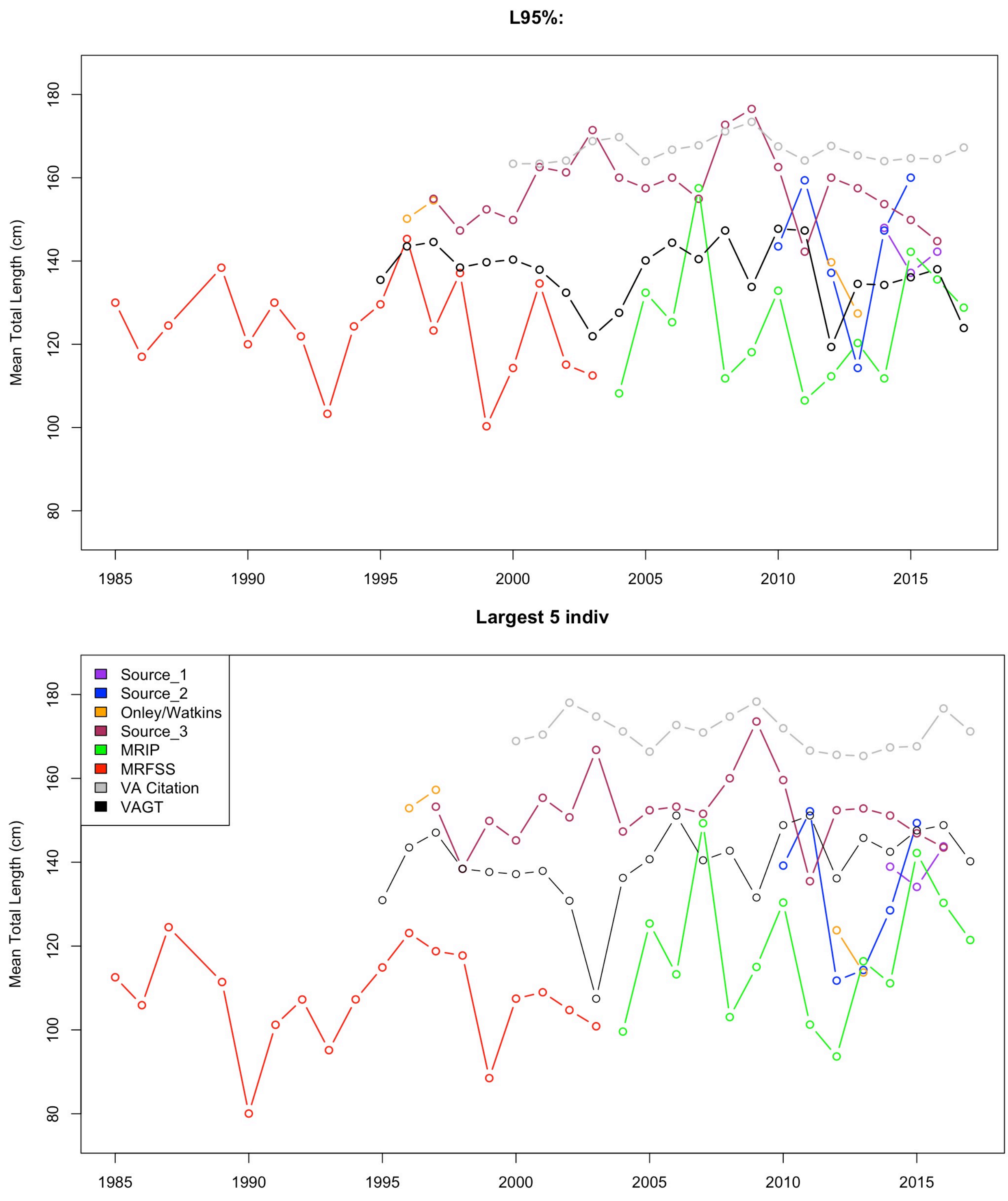

Figure 7. Upper panel: plot of L95%, the average (mean) of the largest 5% of fish reported in each year. Lower panel: mean length of the largest five individuals for each year.

3.3 Time Series Analysis of a Relative Index of Mortality (LCCC)

The length-converted catch curve analysis (LCCC) accounts for both size (age) and abundance of each size class, and uses the increasing rarity of larger (older) fish to estimate the mortality rate. By creating a time series of mortality estimates we can determine if a trend exists. Note that we are estimating a relative index of mortality, not mortality itself.

If a data source yields a dome-shaped curve of log(abundance) vs. relative age, it is likely that sufficient data were available to estimate mortality. However, if the curve is not dome-shaped, it is likely that the data are not suitable for estimation of relative mortality.

The MRFSS and MRIP sources had a relatively small number of records and so were analyzed in 5-year blocks. The data were still insufficient to yield dome-shaped curves (Figure 8), and as such the trend in the mortality index is considered unreliable (Figure 9).

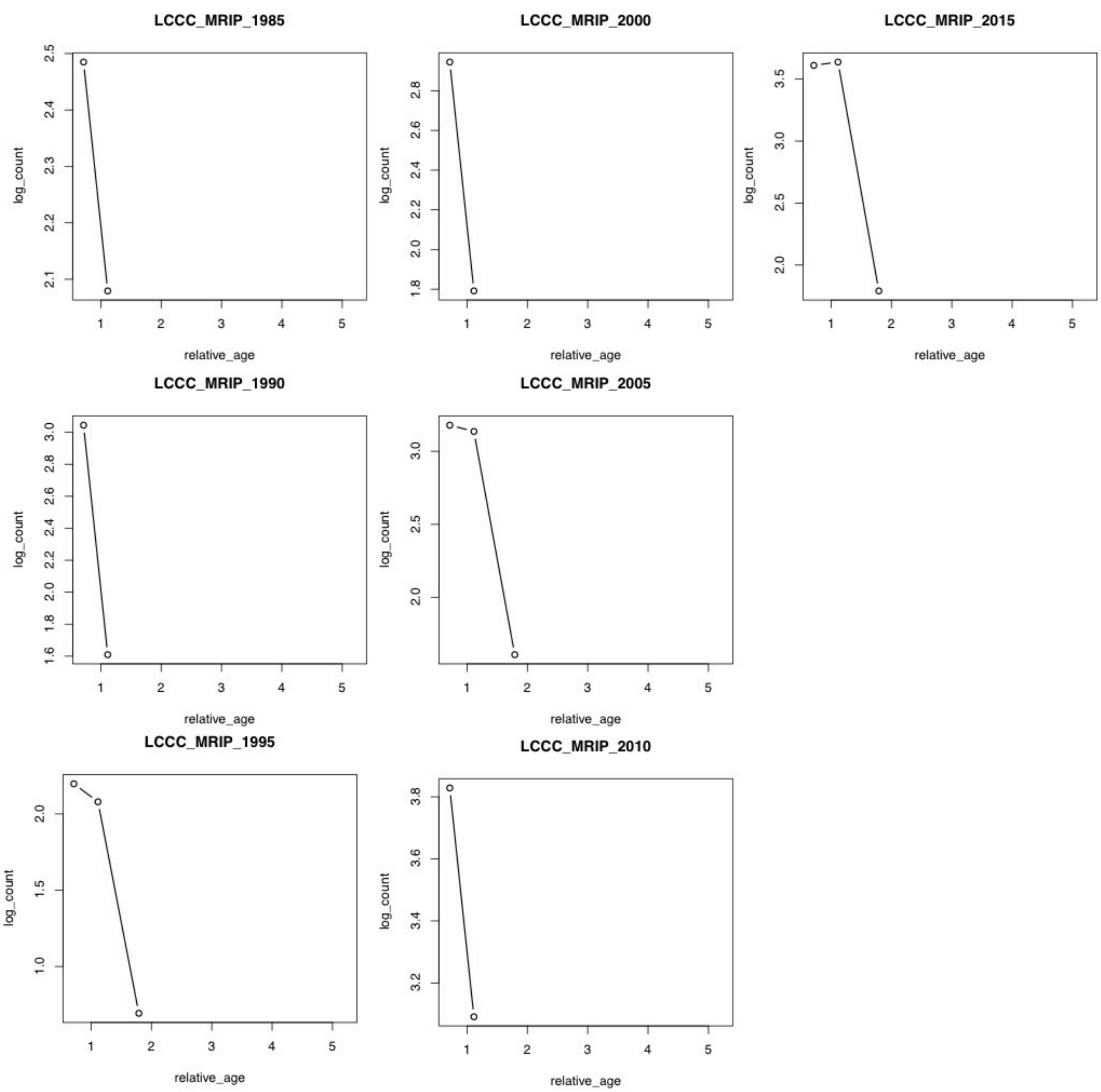

Figure 8. Length Converted Catch Curves for MRFSS and MRIP

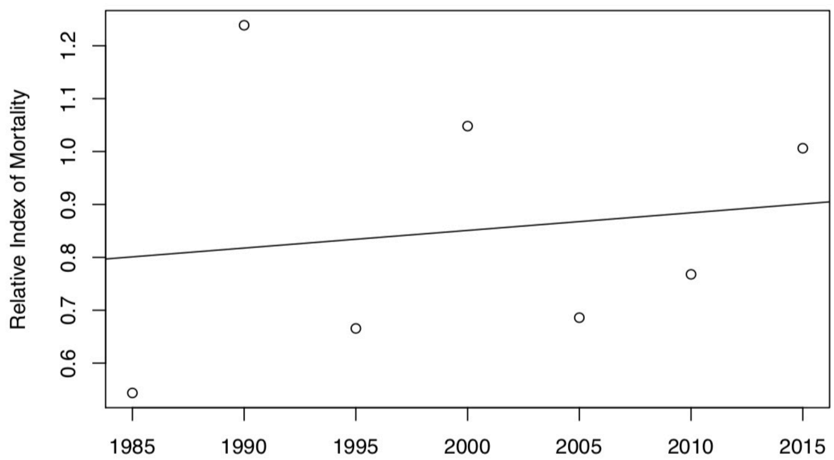

Figure 9. Time Series of Relative Index of Mortality for MRIP and MRFSS

The data from the Olney / Watkins research program had a gap of years in the middle (records occurred during 1996-1997 and 2012-2013) and thus it was difficult to produce a clear trend, and the later years did not produce clear dome shaped curves (Figure 10). Therefore the decreasing mortality trend (Figure 11) is not considered to be reliable.

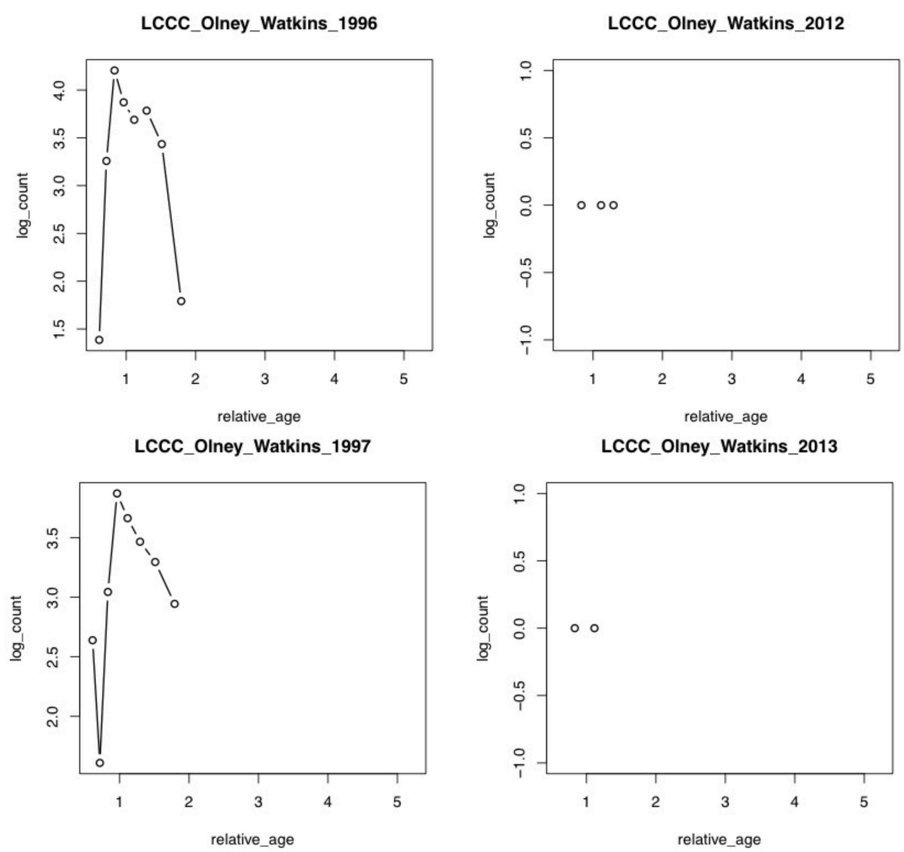

Figure 10. Length Converted Catch Curves for Olney / Watkins

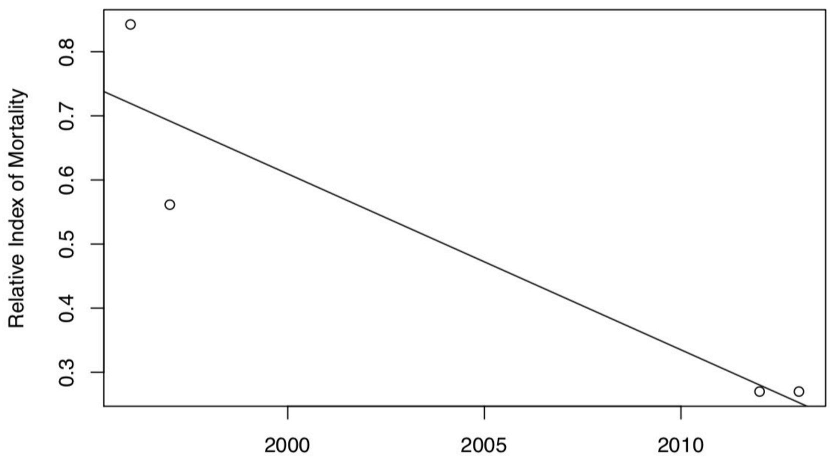

Figure 11. Time Series of Relative Index of Mortality for Olney / Watkins

Source 1 was able to yield dome shaped curves (Figure 12), and the resulting estimates of mortality showed that it is increasing through time (Figure 13), however, the records span 2014 to 2016, a relatively short period.

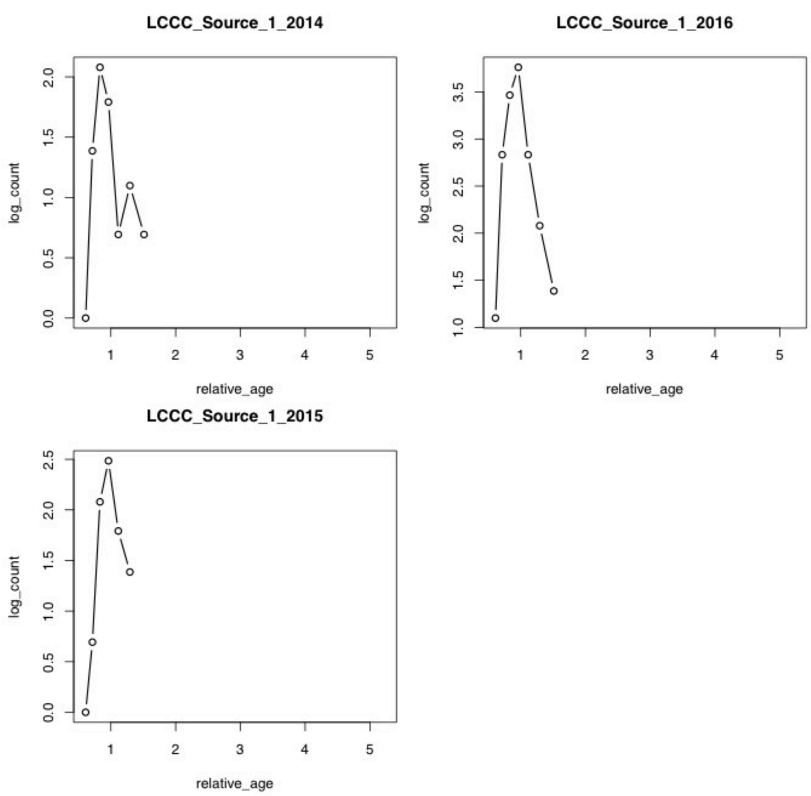

Figure 12. Length Converted Catch Curves for private records, Source 1

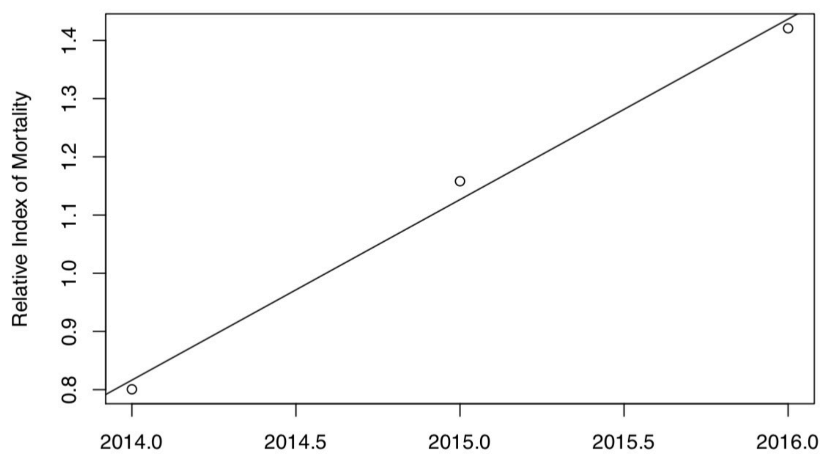

Figure 13. Time Series of Relative Index of Mortality for Source 1

Source 2 did not yield dome shaped curves (Figure 14) so the mortality estimates (Figure 15) are not considered reliable.

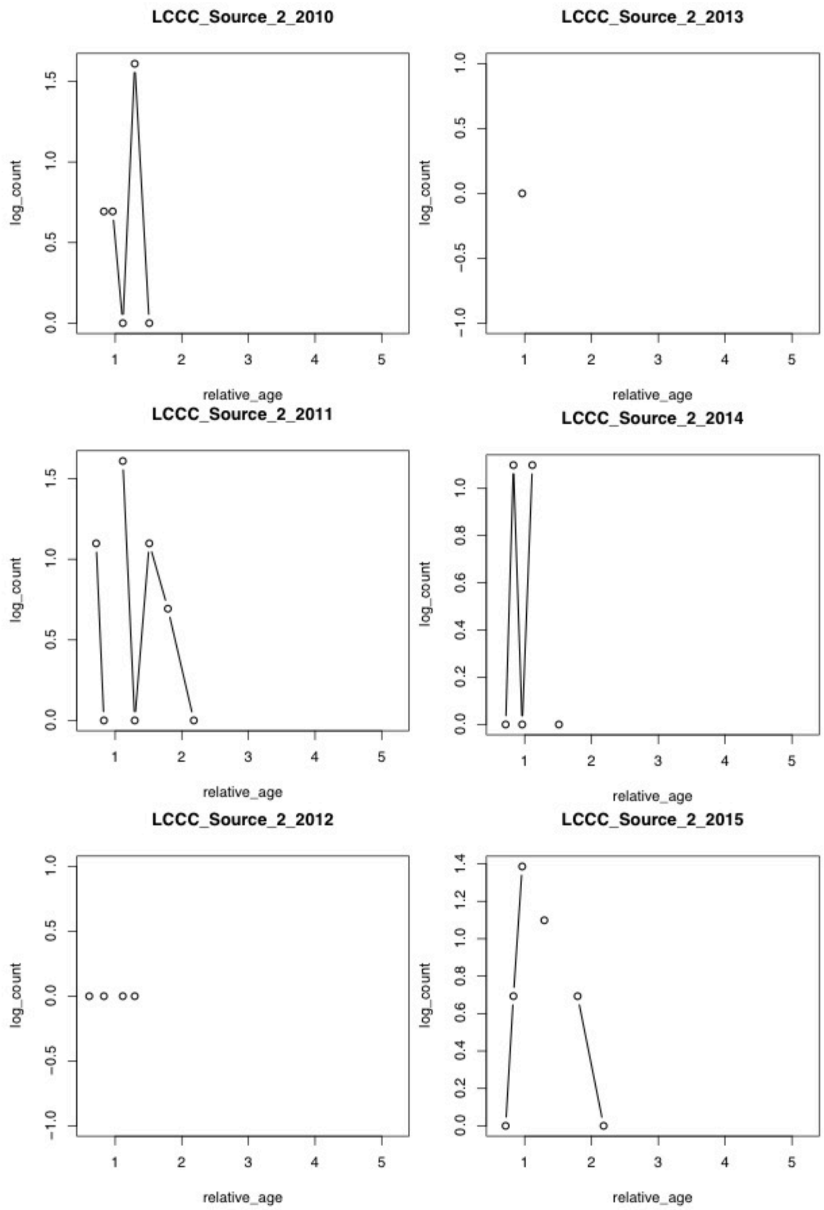

Figure 14. Length Converted Catch Curves for private records, Source 2

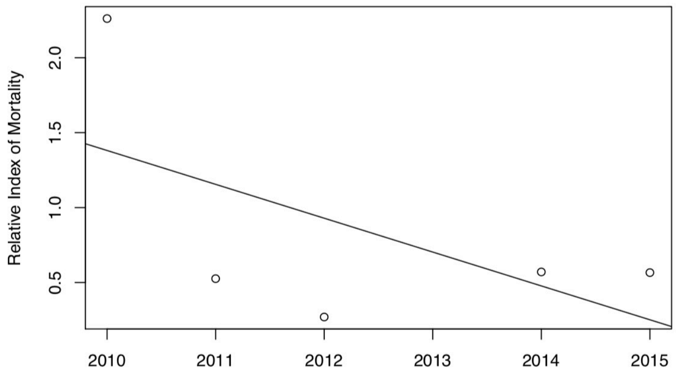

Figure 15. Time Series of Relative Index of Mortality for Source 2

The LCCC analysis could not be performed on the fishing club records, which have only three observations per year and therefore are not suitable for assessing the rarity of larger individuals.

The VMRC Citations source produced clear dome shaped curves (Figure 16) and spans a period from 2000 to 2017, thus the estimates of relative mortality (Figure 17) are considered to be reliable. The dataset indicates that there has been a very small increase in mortality rates over the course of the record, amid high variation in mortality rates.

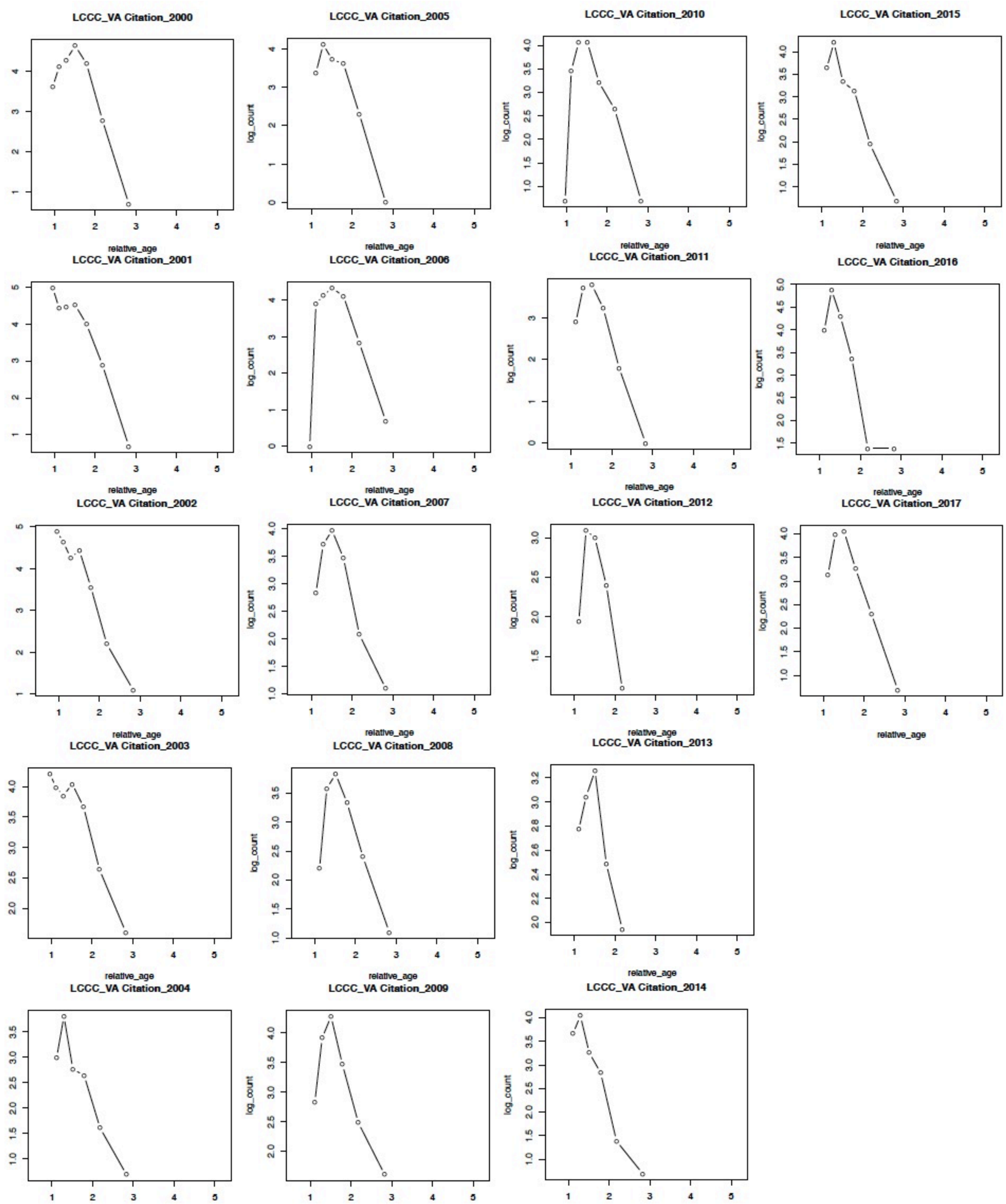

Figure 16. Length Converted Catch Curves for VMRC Citations

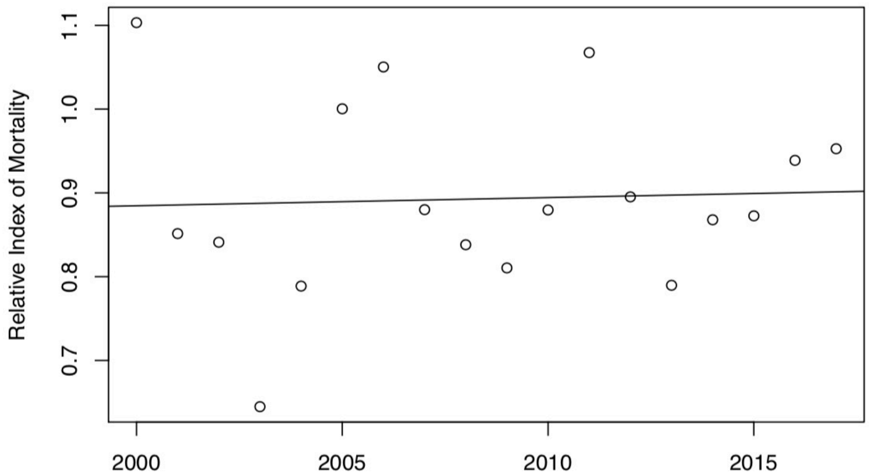

Figure 17. Time Series of Relative Index of Mortality for VMRC Citations

The VGTP did not yield clear dome shaped curves (Figure 18 and Figure 19). It is likely that this is due to the size targeting within this dataset. Since these fish are small and anglers decide not to retain them for consumption or trophy purposes, it is likely that the data set does not contain signal for the mortality rates of cobia. The larger size classes, being missing from the dataset, are likely to be the size classes with the most important mortality signal. The mortality rates among smaller size classes could be estimated if the targeting of smaller fish were such that the catch reflected abundance. However, it may be that catch of smaller fish does not represent abundance since anglers may only target smaller fish under certain circumstances, allowing catch to vary independently of abundance. Given the shape of the curves, the time series of mortality is not considered to be reliable (Figure 20).

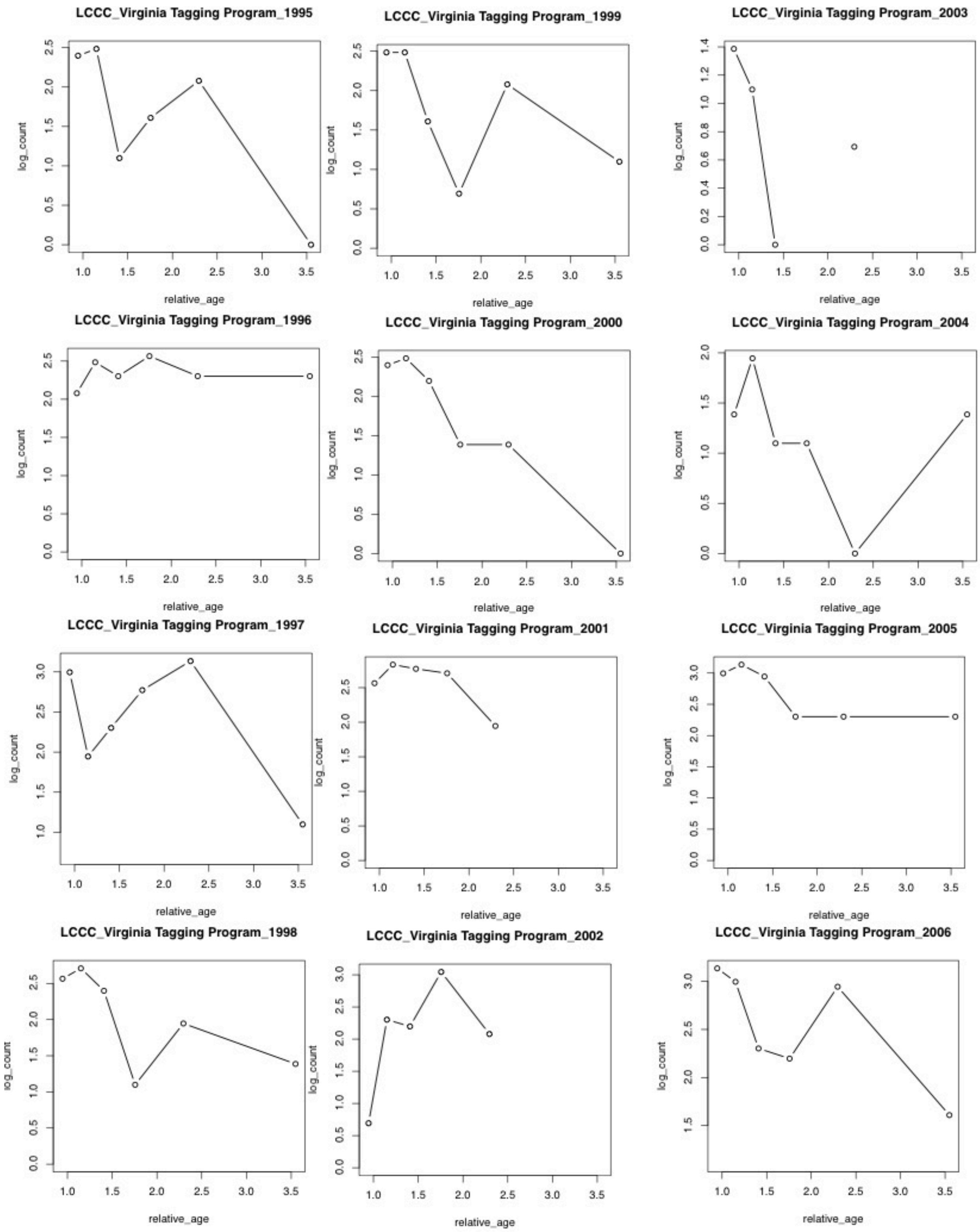

Figure 18. Length Converted Catch Curves for Virginia Game Fish Tagging Program

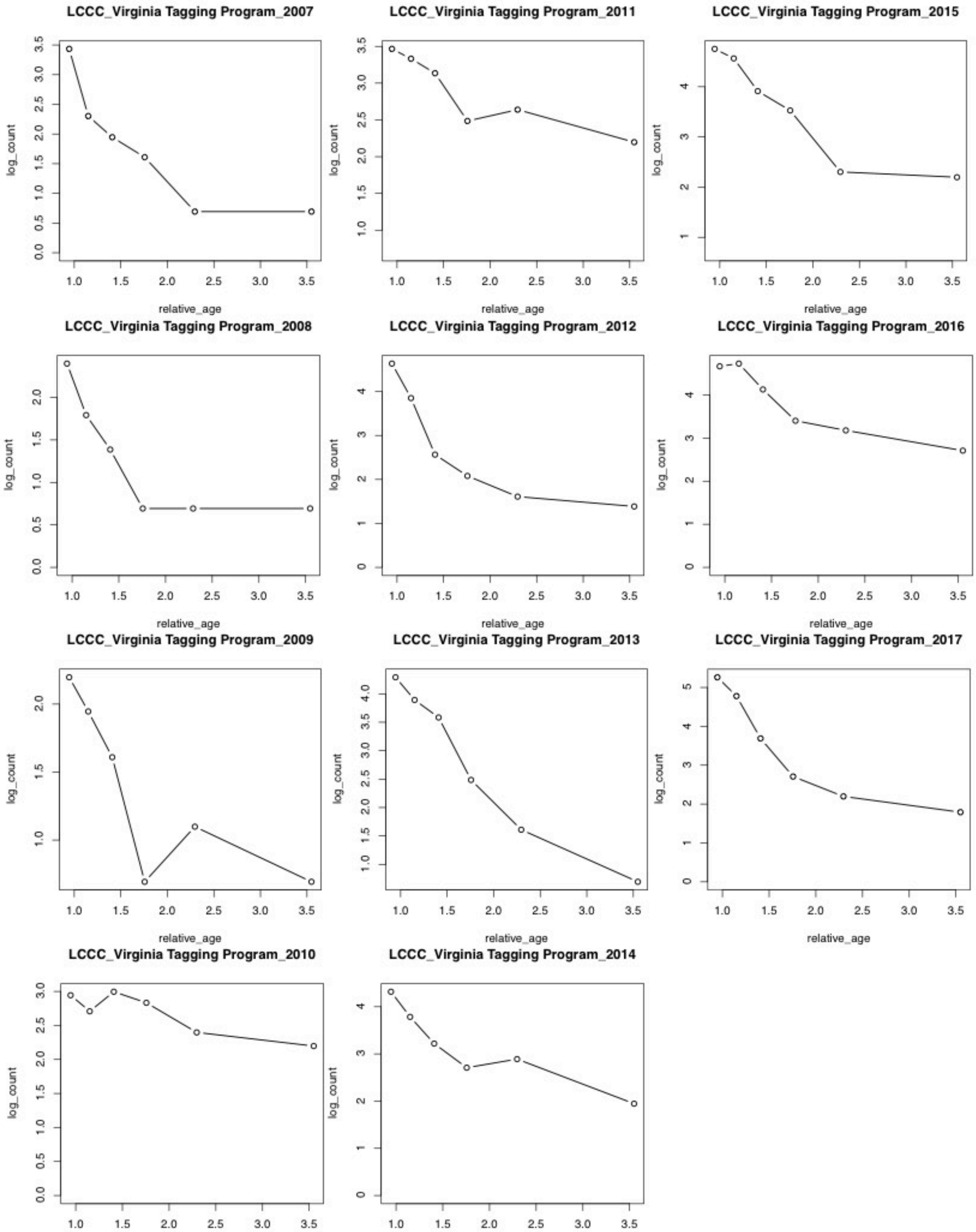

Figure 19. Length Converted Catch Curves for Virginia Game Fish Tagging Program, continued

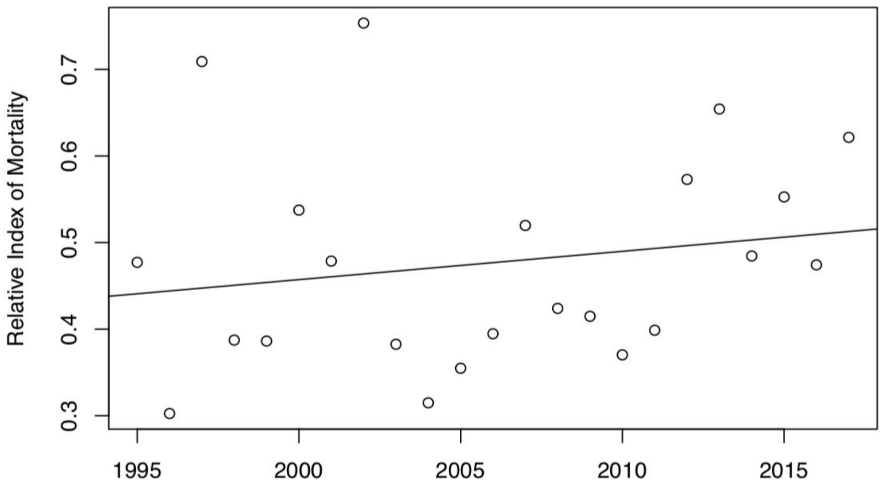

Figure 20. Time Series of Relative Index of Mortality for the VGTP

4 Conclusion

The length-frequency distributions for the various datasets in the study indicated that each source had its own sampling biases, and therefore pooling across data sources was not conducted. For the largest data source (VMRC Citations), there did not appear to be a shift in the peak of the size-frequency distribution through time. Several of the proposal analytical approaches were not possible because the data sources did not provide unbiased sampling across size classes of the population. We therefore used those proposed methods that were suitable for the datasets, and added new analytical approaches. The time series of maximum size (L95% and Largest Five Individuals) showed high variability through time without strong positive or negative trends, suggesting that maximum size has been stable through time. Since these approaches account for size, but not rarity of large fish, we then conducted an analysis using the length-converted catch curve approach. Most data sources did not have sufficient numbers of observations to produce clear curves for each year, and so the estimates of relative mortality were not considered to be reliable. Of the two largest data sources, VGTP and VMRC Citations, the VGTP samples smaller sized individuals and thus did not contain a strong signal for mortality. The VMRC Citations dataset produced clear curves for most years of the time series, so the estimates of relative mortality are considered to be reliable, and show level trend in relative mortality over the past two decades.

5 References Cited

Ault, J. S., Smith, S. G., and Bohnsack, J. A., 2005, Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community: ICES Journal of Marine Science, v. 62, no. 3, p. 417-423.

Ault, J. S., Smith, S. G., Browder, J. A., Nuttle, W., Franklin, E. C., Luo, J., DiNardoe, G. T., and Bohnsack, J. A., 2014, Indicators for assessing the ecological dynamics and sustainability of southern Florida's coral reef and coastal fisheries: Ecological Indicators, v. 44, p. 164-172.

Berkson, J., and Thorson, J. T., 2015, The determination of data-poor catch limits in the United States: is there a better way?: Ices Journal of Marine Science, v. 72, no. 1, p. 237-242.

Brown-Peterson, N. J., Overstreet, R. M., Lotz, J. M., Franks, J. S., and Burns, K. M., 2000, Reproductive biology of cobia, Rachycentron canadum, from coastal waters of the southern United States.

Butterworth, D., Cochrane, K., and De Oliveira, J., 1997, Management procedures: a better way to manage fisheries? The South African experience: Global trends: fisheries management AFS Symposium, v. 20, p. 83-90.

Darden, T. L., Walker, M. J., Brenkert, K., Yost, J. R., and Denson, M. R., 2014, Population genetics of Cobia (Rachycentron canadum): implications for fishery management along the coast of the southeastern United States: Fishery Bulletin, v. 112, no. 1, p. 24-35.

Edwards, C. T. T., Hillary, R. M., Levontin, P., Blanchard, J. L., and Lorenzen, K., 2012, Fisheries Assessment and Management: A Synthesis of Common Approaches with Special Reference to Deepwater and Data-Poor Stocks: Reviews in Fisheries Science, v. 20, no. 3, p. 136-153.

Erisman, B. E., Allen, L. G., Claisse, J. T., Pondella, D. J., Miller, E. F., Murray, J. H., and Walters, C., 2011, The illusion of plenty: hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations: Canadian Journal of Fisheries and Aquatic Sciences, v. 68, no. 10, p. 1705-1716.

Erisman, B. E., Apel, A. M., MacCall, A. D., Romon, M. J., and Fujita, R., 2014, The influence of gear selectivity and spawning behavior on a data-poor assessment of a spawning aggregation fishery: Fisheries Research, v. 159, p. 75-87.

Froese, R., 2004, Keep it simple: three indicators to deal with overfishing: Fish and Fisheries, v. 5, no. 1, p. 86-91.

Gedamke, T., 2007, Estimation of mutton snapper total mortality rate from length observations. SEDAR14-AW-05. National Marine Fisheries Service, Southeast Fisheries Science Center, Sustainable Fisheries Division Contribution No. SFD-2007-020.

Goodyear, C. P., 2015, Understanding Maximum Size in the Catch: Atlantic Blue Marlin as an Example: Transactions of the American Fisheries Society, v. 144, no. 2, p. 274-282.

Greenstreet, S. P. R., Rogers, S. I., Rice, J. C., Piet, G. J., Guirey, E. J., Fraser, H. M., and Fryer, R. J., 2011, Development of the EcoQO for the North Sea fish community: Ices Journal of Marine Science, v. 68, no. 1, p. 1-11.

Huynh, Q. C., Beckensteiner, J., Carleton, L. M., Marcek, B. J., Nepal, K. C. V., Peterson, C. D., Wood, M. A., and Hoenig, J. M., 2018, Comparative Performance of Three Length-Based Mortality Estimators: Marine and Coastal Fisheries, v. 10, no. 3, p. 298-313.

Lowerre-Barbieri, S. K., Ganias, K., Saborido-Rey, F., Murua, H., and Hunter, J. R., 2011, Reproductive Timing in Marine Fishes: Variability, Temporal Scales, and Methods: Marine and Coastal Fisheries, v. 3, no. 1, p. 71-91.

MacCall, A., 1976, Density dependence of catchability coefficient in the California Pacific sardine, Sardinops sagax caerulea, purse seine fishery: Calif. Coop. Oceanic Fish. Invest. Rep, v. 18, no. 136.148.

Meyer, G. H., and Franks, J. S., 1996, Food of cobia, Rachycentron canadum, from the northcentral Gulf of Mexico: Gulf and Caribbean Research, v. 9, no. 3, p. 161-167.

Pauly, D., 1983, Length-converted catch curves: a powerful tool for fisheries research in the tropics (part 1): Fishbyte, v. 1, no. 2, p. 9-13.

Pazhayamadom, D. G., Kelly, C. J., Rogan, E., and Codling, E. A., 2015, Decision Interval Cumulative Sum Harvest Control Rules (DI-CUSUM-HCR) for managing fisheries with limited historical information: Fisheries Research, v. 171, p. 154-169.

Quang Huynh, Todd Gedamke, Clay Porch, John Hoenig, John Walter, Meaghan Bryan, and Brodziak, J., 2015, Estimating mortality rates from mean length and CPUE: a case study of Puerto Rico mutton snapper, 2015 Lowell Wakefield Symposium.

SEDAR, 2013, SEDAR - South Atlantic Cobia Stock Assessment Report. SEDAR.

Shin, Y. J., Rochet, M. J., Jennings, S., Field, J. G., and Gislason, H., 2005, Using size-based indicators to evaluate the ecosystem effects of fishing: Ices Journal of Marine Science, v. 62, no. 3, p. 384-396.