2018 Final Report
Virginia ~ Chesapeake Bay
Finfish Ageing
and
Population Analysis

Hongsheng Liao, Cynthia M. Jones,
& Jessica L. Gilmore

November 4, 2019

VMRC ~ ODU Age and Growth Laboratory
Center for Quantitative Fisheries Ecology
Old Dominion University
Norfolk, Virginia 23508

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Contents

EXECUTIVE SUMMARY

In this report we present the ageing results of 14 finfish species collected from commercial and recreational catches made in the Chesapeake Bay and Virginia waters of the Atlantic Ocean, U.S.A. in 2018. All fish were collected by the Virginia Marine Resources Commission's (VMRC) Stock Assessment Program and the Center for Quantitative Fisheries Ecology (CQFE) at Old Dominion University in 2018 and aged in 2019 at the Age and Growth Laboratory of CQFE. This report is broken into chapters, one for each of the 14 species. We present measures of ageing precision, graphs of year-class distributions, and age-length keys for each species.

Three calcified structures (hard-parts) are used in age determination. Specifically, two calcified structures were used for determining fish ages of the following three species: Striped Bass, *Morone saxatilis*, (n = 826); Summer Flounder, *Paralichthys dentatus*, (n = 857); and Tautog, *Tautoga onitis*, (n = 28). Scales and otoliths were used to age Striped Bass and Summer Flounder, opercula and otoliths were used to age Tautog. Comparing alternative hard-parts allowed us to assess their usefulness in determining fish age as well as the relative precision of each structure. Ages were determined from otoliths only for the following species: Atlantic Croaker, *Micropogonias undulatus*, (n = 274); Black Drum, *Pogonias cromis*, (n = 274); Bluefish, *Pomatomus saltatrix*, (n = 390); Cobia, *Rachycentron canadum*, (n = 324); Red Drum, *Sciaenops ocellatus*, (n = 17); Sheepshead, *Archosargus probatocephalus*, (n = 69); Atlantic Spadefish, *Chaetodipterus faber*, (n = 353); Spanish Mackerel, *Scomberomorous maculates*, (n = 201); Spot, *Leiostomus xanthurus*, (n = 214); Spotted Seatrout, *Cynoscion nebulosus*, (n = 309); and Weakfish, *Cynoscion regalis*, (n = 289). In total, we made 9,938 age readings from scales, otoliths and opercula collected during 2018. A summary of the age ranges for all species aged is presented in Table 1.

In this report, we also present sample sizes and coefficient of variation (CV) for estimates of age composition for the following species: Atlantic Croaker, Bluefish, Spadefish, Spanish Mackerel, Spot, Spotted Seatrout, Striped Bass, Summer Flounder, Tautog, and Weakfish. The sample sizes and the CVs enabled us to determine how many fish we needed to age in each length interval and to measure the precision for estimates of major age classes in each species, respectively, enhancing our efficiency and effectiveness on ageing those species.

To support environmental and wildlife agencies, and charities, we donated more than 1,523 pounds of dissected fish to the Salvation Army to feed the homeless, and the Wildlife Response, Inc., a local wildlife rescue agency which is responsible for saving injured animals found by the public.

In 2018, we continued to upgrade our Age and Growth Laboratory website, which can be accessed at http://odu.edu/sci/research/cqfe/research/ageing-lab. The website includes an electronic version of this document and our previous VMRC final reports from 2001 to 2017. The site also provides more detailed explanations of the methods and structures we use in age determination.

Table 1: The minimum and maximum ages, number of fish and their hard-parts collected, number of fish aged, and age readings for the 14 finfish species in 2018. The hard-parts and age readings include both scales and otoliths for Striped Bass and Summer Flounder, and both opercula and otoliths for Tautog.

Species	Number of fish collected	Number of hard-parts	Numnber of fish aged	Number of readings	Minimun age	Maximum age
Atlantic Croaker	360	360	274	548	0	9
Black Drum	275	274	274	548	1	55
Bluefish	590	588	390	780	0	10
Cobia	325	324	324	648	2	13
Red Drum	17	17	17	34	0	2
Sheepshead	69	69	69	138	2	31
Spadefish	422	422	353	706	1	9
Spanish Mackerel	295	295	201	402	1	7
Spot	296	296	214	428	0	3
Spotted Seatrout	379	379	309	618	0	5
Striped Bass	1,135	1,403	826	2,194	3	22
Summer Flounder	1,067	1,311	857	2,204	0	14
Tautog	28	55	28	112	1	11
Weakfish	306	305	289	578	0	5
Totals	5,564	6,098	4,425	9,938		

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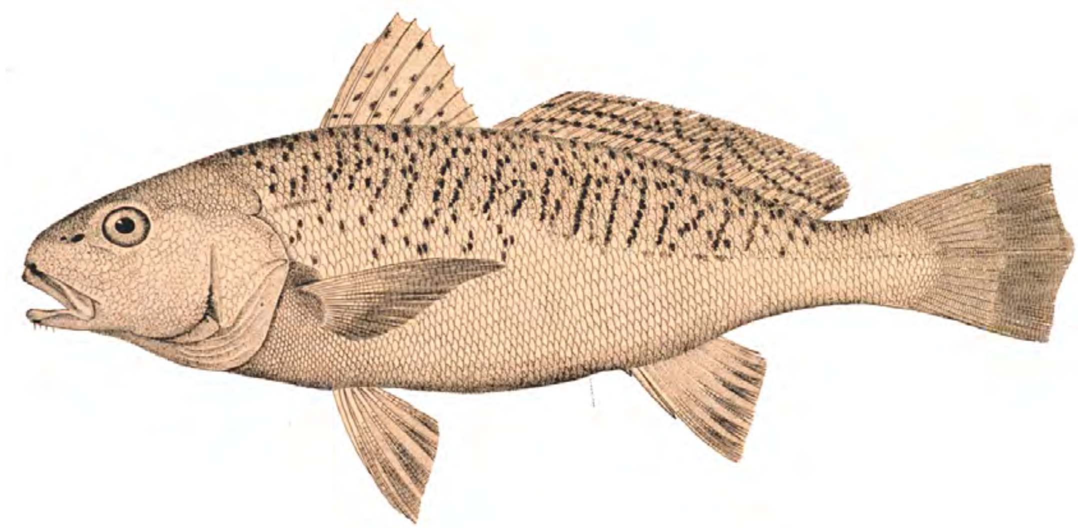
ACKNOWLEDGEMENTS

We thank Emily Davis and Alex Gikakis for their technical expertise in preparing otoliths, scales, and opercula for age determination. They all put in long hours processing "tons" of fish in our lab. A special note of appreciation is extended to Joe Cimino, Adam Kenyon, and their technicians at the VMRC, including Richard Hancock, Myra Thompson, and Chris Williams for their many efforts in this cooperative project. We would like also to thank our graduate student Kathleen Kirch for her help in processing fish whenever we were short of hands.

Chapter 1

ATLANTIC CROAKER
Micropogonias undulatus



1.1 INTRODUCTION

We aged a total of 274 Atlantic Croaker, *Micropogonias undulatus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Croaker ages ranged from 0 to 9 years old with an average age of 4.5, a standard deviation of 2, and a standard error of 0.12. Ten age classes (0 to 9) were represented, comprising fish of the 2009 to 2018 year-classes. The sample was dominated by fish from the year-class of 2012 with 32.1%.

1.2 METHODS

1.2.1 Sample size for ageing

We estimated sample size for ageing Croaker in 2018 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \tag{1.1}$$

where A is the sample size for ageing Croaker in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Croaker used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Croaker collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018.

1.2.2 Handling of collections

Otoliths were received by the Age and Growth Laboratory in labeled coin envelopes, were sorted by date of capture. Their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

1.2.3 Preparation

Sagittal otoliths, hereafter, referred to as "otoliths", were processed for age determination following the methods described in Barbieri et al. (1993) with a few modifications. The left or right otolith was randomly selected and attached, distal side down, to a glass slide with clear Crystalbond™ 509 adhesive or imbedded in epoxy. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core was marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton diamond grinding wheels (hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). Thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-sections.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Atlantic Croaker.

1.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Atlantic Croaker otolith annulus formation occurs between April and May (Barbieri et al. 1993, 1994). A Croaker captured between January 1 and May 31, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification. Each reader aged all of the otolith samples.

Due to discrepancy on identification of the first annulus of Atlantic Croaker among Atlantic states, Atlantic States Marine Fisheries Commission (ASMFC) has decided not to count the smallest annulus at the center of the thin-section as the first annulus. Following ASMFC's instruction, we didn't count the smallest annulus at the center as the first annulus in 2018 (Figure 1.1) .

All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the

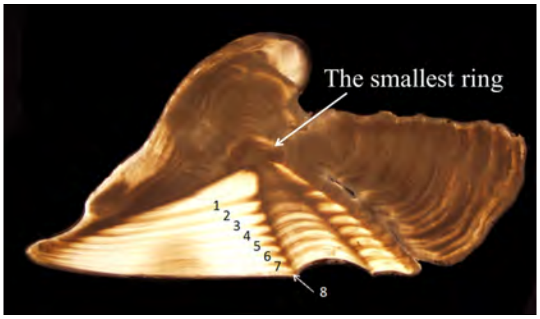


Figure 1.1: Otolith thin-sections of a 8 year-old Croaker without counting the smallest ring and with the last annulus on the edge of the thin-section

fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Click here to obtain the protocol at the CQFE website on how to age Atlantic Croaker using their otolith thin-sections.

1.2.5 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

1.3 RESULTS

1.3.1 Sample size

We estimated a sample size of 432 Atlantic Croaker in 2018, ranging in length interval from 4 to 19 inches (Table 1.1). This sample size provided a range in (CV) for age composition approximately from the smallest (CV) of 7% for Age 4 to the largest (CV) of 24% for Age 1. In 2018, we aged 274 of 360 Croaker (The rest of fish were either without otoliths or over-collected for certain length interval(s)) collected by VMRC. We fell short in our overall collections for this optimal length-class sampling estimate by 176 fish. We were short many fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would definitely be influenced significantly. Therefore, precaution should be used when developing ALK using these age data.

1.3.2 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 96% and a CV of 0.53% (test of symmetry: $\chi^2 = 2$, $df = 2$, $P = 0.3679$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 94% and a CV of 0.6% (test of symmetry: $\chi^2 = 3$, $df = 2$, $P = 0.2231$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 91.24% and a CV of 1.5% (test of symmetry: $\chi^2 = 15$, $df = 9$, $P = 0.0909$) (Figure 1.2).

There was no time-series bias for either reader. Reader 1 had an agreement of 98% with ages of fish aged in 2003 with a CV of

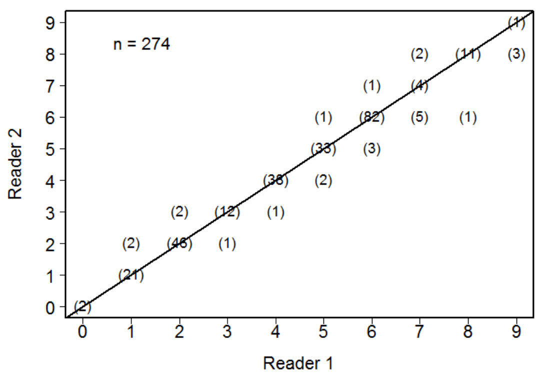


Figure 1.2: Between-reader comparison of otolith age estimates for Atlantic Croaker collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

0.13% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$). Reader 2 also had an agreement of 100% .

1.3.3 Year class

Of the 274 fish aged with otoliths, 10 age classes (0 to 9) were represented (Table 1.2). The average age was 4.5 years, and the standard deviation and standard error were 2 and 0.12, respectively. Year-class data show that the fishery was comprised of 10 year-classes: fish from the 2009 to 2018 year-classes, with fish primarily from the year class of 2012 with 32.1%. The ratio of males to females was 1:1.98 in the sample collected (Figure 1.3).

1.3.4 Age-length key (ALK)

We developed an age-length-key (Table 1.3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

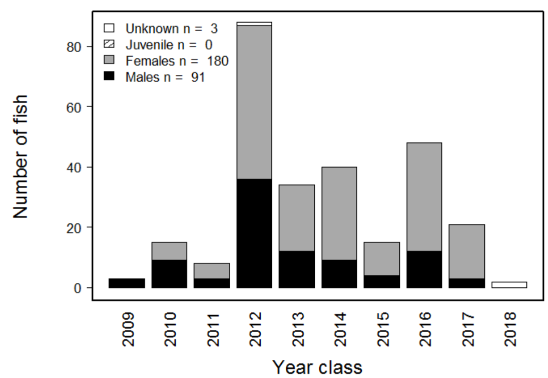


Figure 1.3: Year-class frequency distribution for Atlantic Croaker collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' is for gonads that were not available for examination or were not examined for sex during sampling.

Table 1.1: Number of Atlantic Croaker collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
4 - 4.99	5	1	1	4
5 - 5.99	5	1	1	4
6 - 6.99	5	2	2	3
7 - 7.99	8	15	15	0
8 - 8.99	8	36	8	0
9 - 9.99	21	67	22	0
10 - 10.99	37	51	38	0
11 - 11.99	64	73	73	0
12 - 12.99	103	90	90	13
13 - 13.99	75	22	22	53
14 - 14.99	47	1	1	46
15 - 15.99	25	1	1	24
16 - 16.99	13	0	0	13
17 - 17.99	6	0	0	6
18 - 18.99	5	0	0	5
19 - 19.99	5	0	0	5
Totals	432	360	274	176

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Table 1.2: The number of Atlantic Croaker assigned to each total length-at-age category for 274 fish sampled for otolith age determination in Virginia during 2018.

	Age										
Interval	0	1	2	3	4	5	6	7	8	9	Totals
4 - 4.99	1	0	0	0	0	0	0	0	0	0	1
5 - 5.99	1	0	0	0	0	0	0	0	0	0	1
6 - 6.99	0	2	0	0	0	0	0	0	0	0	2
7 - 7.99	0	3	8	2	2	0	0	0	0	0	15
8 - 8.99	0	0	2	2	3	0	1	0	0	0	8
9 - 9.99	0	0	6	3	2	3	7	0	1	0	22
10 - 10.99	0	2	3	3	6	4	16	0	2	2	38
11 - 11.99	0	4	6	1	13	9	27	5	8	0	73
12 - 12.99	0	7	15	3	10	16	31	3	4	1	90
13 - 13.99	0	3	7	1	4	1	6	0	0	0	22
14 - 14.99	0	0	1	0	0	0	0	0	0	0	1
15 - 15.99	0	0	0	0	0	1	0	0	0	0	1
Totals	2	21	48	15	40	34	88	8	15	3	274

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Table 1.3: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Atlantic Croaker sampled for age determination in Virginia during 2018.

	Age									
Interval	0	1	2	3	4	5	6	7	8	9
4 - 4.99	1	0	0	0	0	0	0	0	0	0
5 - 5.99	1	0	0	0	0	0	0	0	0	0
6 - 6.99	0	1	0	0	0	0	0	0	0	0
7 - 7.99	0	0.2	0.53	0.13	0.13	0	0	0	0	0
8 - 8.99	0	0	0.25	0.25	0.38	0	0.12	0	0	0
9 - 9.99	0	0	0.27	0.14	0.09	0.14	0.32	0	0.05	0
10 - 10.99	0	0.05	0.08	0.08	0.16	0.11	0.42	0	0.05	0.05
11 - 11.99	0	0.05	0.08	0.01	0.18	0.12	0.37	0.07	0.11	0
12 - 12.99	0	0.08	0.17	0.03	0.11	0.18	0.34	0.03	0.04	0.01
13 - 13.99	0	0.14	0.32	0.05	0.18	0.05	0.27	0	0	0
14 - 14.99	0	0	1	0	0	0	0	0	0	0
15 - 15.99	0	0	0	0	0	1	0	0	0	0

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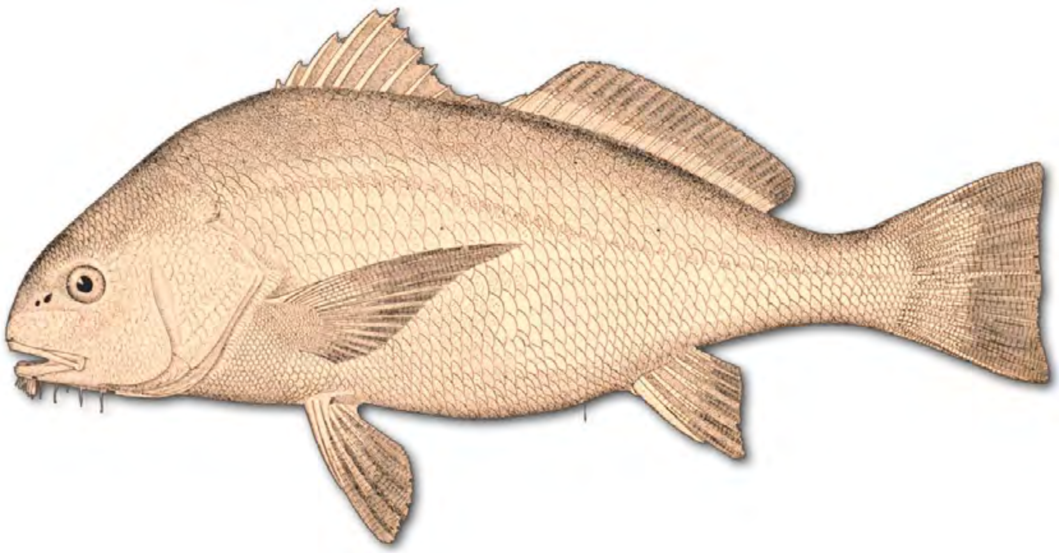
Chapter 2

BLACK DRUM *Pogonias cromis*



2.1 INTRODUCTION

We aged a total of 274 Black Drum, *Pogonias cromis*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Black drum ages ranged from 1 to 55 years old with an average age of 14.1, a standard deviation of 10.1, and a standard error of 0.61. Thirty-six age classes (1 to 7, 9 to 23, 25 to 29, 32 to 33, 38, 44, 47 to 50, and 55) were represented, comprising fish of the 1963, 1968 to 1971, 1974, 1980, 1985 to 1986, 1989 to 1993, 1995 to 2009, and 2011 to 2017 year-classes. The sample was dominated by fish from the year-classes of 2001 and 2015 with 15.7% and 13.5%, respectively.

2.2 METHODS

2.2.1 Handling of collections

Sagittal otoliths, hereafter, referred to as "otoliths", were received by the Age and Growth Laboratory in labeled coin envelopes. In the lab they were sorted by date of capture, their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

2.2.2 Preparation

Otoliths were processed for age determination following the methods described in Bobko (1991) and Jones and Wells (1998). The left or right sagittal otolith was randomly selected and attached, distal side down, to a glass slide with Crystalbond™ 509 adhesive or embedded in epoxy. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, three inch diameter, Norton Diamond Grinding Wheels, separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The position of the marked core fell within the 0.5 mm space between the blades, such that the core was included in the removed thin-section. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Black Drum.

2.2.3 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Black Drum otolith annulus formation occurs between May and June (Beckman et al. 1990; Bobko 1991; Jones and Wells 1998). A Black Drum captured between January 1 and June 30, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 2.1). Each reader aged all of the otolith samples.

All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the

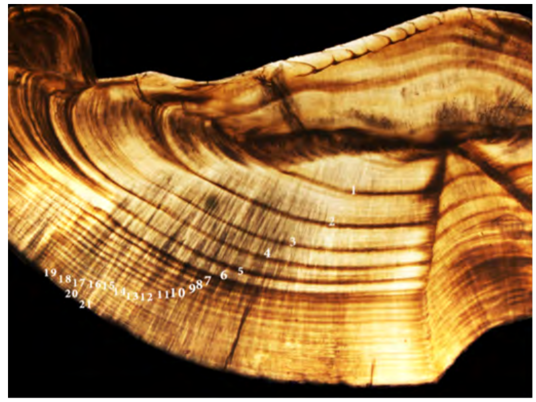


Figure 2.1: Otolith thin-section of a 21 year-old Black Drum

fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Click here to obtain the protocol at the CQFE website on how to age Black Drum using their otolith thin-sections.

2.2.4 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core

Team 2019).

2.3 RESULTS

2.3.1 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 92% and a *CV* of 0.27% (test of symmetry: $\chi^2 = 4$, $df = 4$, $P = 0.406$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 100% . There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 98.18% and a *CV* of 0.06% (test of symmetry: $\chi^2 = 5$, $df = 5$, $P = 0.4159$) (Figure 2.2).

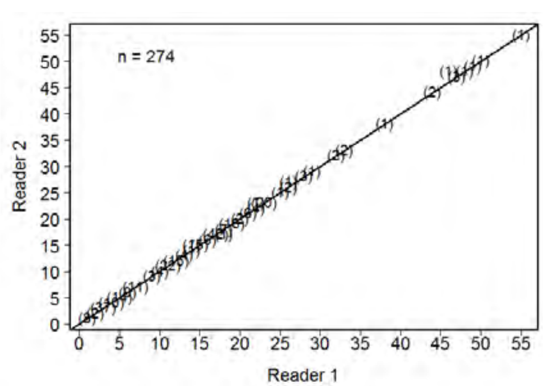


Figure 2.2: Between-reader comparison of otolith age estimates for Black Drum collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 76% with ages of fish aged in 2000 with a *CV* of 0.86% (test of symmetry: $\chi^2 = 12$, $df = 10$, $P = 0.2851$). Reader 2 had an agreement of 84%with a *CV* of 0.44% (test of symmetry: $\chi^2 = 8$, $df = 7$, $P = 0.3326$).

2.3.2 Year class

Of the 274 fish aged with otoliths, 36 age classes (1 to 7, 9 to 23, 25 to 29, 32 to 33, 38, 44, 47 to 50, and 55) were represented (Table 2.1). The average age was 14.1 years, and the standard deviation and standard error were 10.1 and 0.61, respectively. Year-class data show that the fishery was comprised of 36 year-classes: fish from the 1963, 1968 to 1971, 1974, 1980, 1985 to 1986, 1989 to 1993, 1995 to 2009, and 2011 to 2017 year-classes, with fish primarily from the year classes of 2001 and 2015 with 15.7% and 13.5%, respectively. The ratio of males to females was 1:1.1 in the sample collected (Figure 2.3).

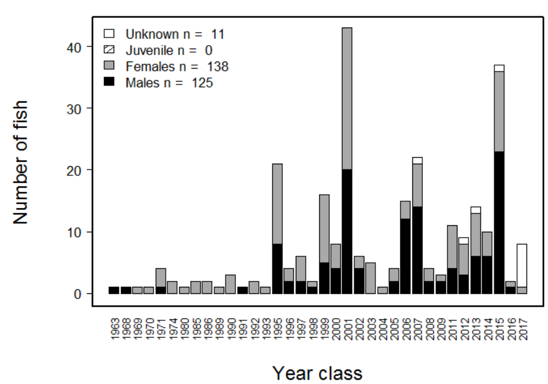


Figure 2.3: Year-class frequency distribution for Black Drum collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

2.3.3 Age-length key (ALK)

We developed an age-length-key (Table 2.2) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

Table 2.1: The number of Black Drum assigned to each total length (inch)-at-age category for 274 fish sampled for otolith age determination in Virginia during 2018.

	Age																																			
Interval	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	25	26	27	28	29	32	33	38	44	47	48	49	50	55	Totals
7 - 7.99	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
9 - 9.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
10 - 10.99	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
11 - 11.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
12 - 12.99	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
19 - 19.99	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
20 - 20.99	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
21 - 21.99	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
22 - 22.99	0	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
23 - 23.99	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
24 - 24.99	0	0	10	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
25 - 25.99	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
26 - 26.99	0	0	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
27 - 27.99	0	0	1	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
28 - 28.99	0	0	1	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
29 - 29.99	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
30 - 30.99	0	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
31 - 31.99	0	0	1	0	0	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
32 - 32.99	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
33 - 33.99	0	0	0	0	0	0	2	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
34 - 34.99	0	0	0	0	0	0	1	1	1	5	3	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
35 - 35.99	0	0	0	0	0	0	0	1	3	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
36 - 36.99	0	0	0	0	0	0	0	0	0	4	5	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
37 - 37.99	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	6	0	1	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	11
38 - 38.99	0	0	0	0	0	0	0	0	0	2	4	1	0	0	2	8	2	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
39 - 39.99	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	5	3	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
40 - 40.99	0	0	0	0	0	0	0	0	0	2	0	0	0	2	2	4	2	2	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
41 - 41.99	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	8	1	5	1	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
42 - 42.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	1	0	2	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	14
43 - 43.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	2	1	2	0	1	0	2	0	0	0	1	0	0	0	0	0	0	12
44 - 44.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2	0	1	0	0	0	1	1	0	0	0	0	0	0	0	7
45 - 45.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	1	0	0	1	1	0	0	0	0	0	0	0	6
46 - 46.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	2	0	1	0	0	6
48 - 48.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Totals	8	2	37	10	14	9	11	3	4	22	15	4	1	5	6	43	8	16	2	6	4	21	1	2	1	3	1	2	2	1	2	4	1	1	1	1	274

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Table 2.2: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Black Drum sampled for age determination in Virginia during 2018.

	Age																																			
Interval	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	25	26	27	28	29	32	33	38	44	47	48	49	50	55
7 - 7.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9 - 9.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 - 10.99	0.5	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 - 11.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 - 12.99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 - 19.99	0	0.4	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 - 20.99	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 - 21.99	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 - 22.99	0	0	0.86	0	0	0	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 - 23.99	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24 - 24.99	0	0	0.83	0.08	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25 - 25.99	0	0	0.6	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 - 26.99	0	0	0.4	0.4	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27 - 27.99	0	0	0.14	0.43	0.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28 - 28.99	0	0	0.12	0.25	0.38	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 - 29.99	0	0	0	0	0.75	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 - 30.99	0	0	0	0	0.2	0.4	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 - 31.99	0	0	0.17	0	0	0.33	0.33	0	0	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 - 32.99	0	0	0	0	0.29	0.29	0.29	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 - 33.99	0	0	0	0	0	0	0.4	0	0	0.4	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 - 34.99	0	0	0	0	0	0	0.08	0.08	0.08	0.38	0.23	0	0	0.08	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 - 35.99	0	0	0	0	0	0	0	0.09	0.27	0.45	0.09	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 - 36.99	0	0	0	0	0	0	0	0	0	0.27	0.33	0	0	0	0.07	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 - 37.99	0	0	0	0	0	0	0	0	0	0.09	0	0	0	0	0	0.55	0	0.09	0	0	0	0.18	0	0	0	0.09	0	0	0	0	0	0	0	0	0	0
38 - 38.99	0	0	0	0	0	0	0	0	0	0.09	0.17	0.04	0	0	0.09	0.35	0.09	0.13	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39 - 39.99	0	0	0	0	0	0	0	0	0	0	0.06	0.06	0.06	0.06	0	0.31	0.19	0.12	0.06	0	0	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40 - 40.99	0	0	0	0	0	0	0	0	0	0.12	0	0	0	0.12	0.12	0.24	0.12	0.12	0	0	0.06	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 - 41.99	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0.05	0	0.38	0.05	0.24	0.05	0.05	0	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42 - 42.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.36	0	0.07	0	0.14	0	0.36	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0
43 - 43.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0.08	0	0.08	0	0.17	0.08	0.17	0	0.08	0	0.17	0	0	0	0.08	0	0	0	0	0	0
44 - 44.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0	0	0.14	0.29	0	0.14	0	0	0	0.14	0.14	0	0	0	0	0	0	0
45 - 45.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0	0	0	0	0	0.33	0	0	0.17	0	0	0.17	0.17	0	0	0	0	0	0	0
46 - 46.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0	0	0	0	0.17	0	0	0	0.17	0.33	0	0.17	0	0
48 - 48.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

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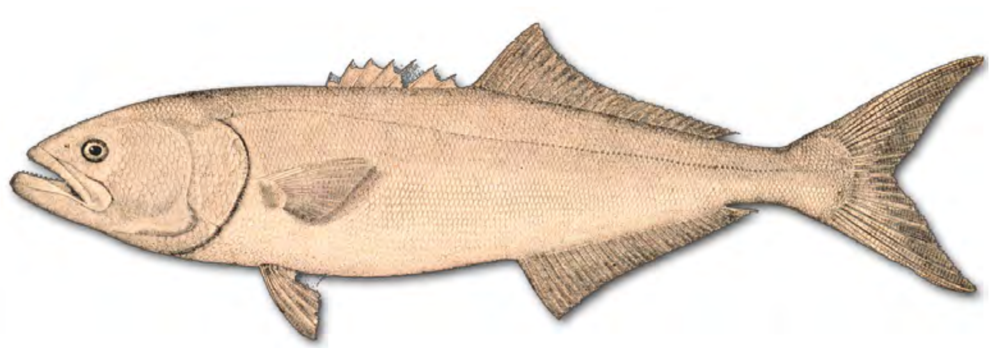
Chapter 3

BLUEFISH *Pomatomus saltatrix*



3.1 INTRODUCTION

We aged a total of 390 Bluefish, *Pomatomus saltatrix*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Bluefish ages ranged from 0 to 10 years old with an average age of 2.9, a standard deviation of 2.4, and a standard error of 0.12. Eleven age classes (0 to 10) were represented, comprising fish of the 2008 to 2018 year-classes. The sample was dominated by fish from the year-classes of 2016 and 2017 with 22.1% and 30%, respectively.

3.2 METHODS

3.2.1 Sample size for ageing

We estimated sample size for ageing Bluefish in 2018 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \qquad (3.1)$$

where A is the sample size for ageing Bluefish in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Bluefish used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Bluefish collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018. Based on VMRC's request in 2010, we used 1-cm length interval for Bluefish, which differed from other species (1-inch).

3.2.2 Handling of collections

Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes, and were sorted by date of capture. Their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

3.2.3 Preparation

We used our thin-section and bake technique to process Bluefish sagittal otoliths (hereafter, referred to as "otoliths") for age determination (Robillard et al. 2009). Otolith preparation began by randomly selecting either the right or left otolith. Each whole otolith was placed in a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400 °C. Baking time was dependent on the otolith's size and gauged by color, with a light caramel color desired. Once a suitable color was achieved the baked otolith was embedded in epoxy resin with its distal surface orientated downwards. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core. Then, the position of the core was marked using a permanent marker across the epoxy resin surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton diamond grinding wheels (hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The otolith was positioned so the blades straddled each side of the otolith focus. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in broad and distorted winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-section.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Bluefish.

3.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Bluefish otolith deposition occurs between March and June (Robillard et al. 2009). A Bluefish captured between January 1 and May 31, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 3.1). Each reader aged all of the otolith samples.

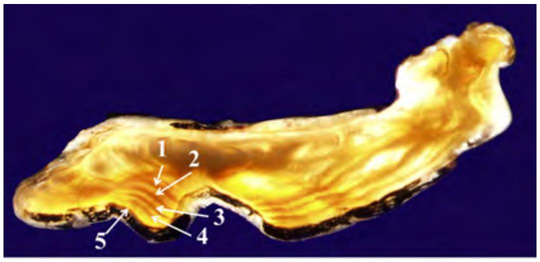


Figure 3.1: Otolith thin-section of a 5 year-old Bluefish with the last annulus on the edge of the thin-section

If an otolith was properly sectioned, the sulcal groove came to a sharp point within the middle of the focus. Typically the first year's annulus was found by locating the focus of the otolith, which was characterized as a visually distinct dark, oblong region found in the center of the otolith. The first year's annulus had the highest visibility proximal to the focus along the edge of the sulcal groove. Once located, the first year's annulus was followed outward from the sulcal groove towards the dorsal perimeter of the otolith. Often, but not always, the first year was associated with a very distinct crenellation on the dorsal surface and a prominent protrusion on the ventral surface. Both of these landmarks had a tendency to become less prominent in older fish.

Even with the bake and thin-section technique, interpretation of the growth zones from the otoliths of young Bluefish was difficult. Rapid growth within the first year of life prevents a sharp delineation between opaque and translucent zones. When the exact location of the first year was not clearly evident, and the otolith had been sectioned accurately, a combination of surface landscape (1st year crenellation) and the position of the second annuli were used to help determine the position of the first annulus.

What appeared to be "double annuli" were occasionally observed in Bluefish 4-7 years of age and older. This double-annulus formation was typically characterized by distinct and separate annuli in extremely close proximity to each other. We do not know if the formation of these double annuli were two separate annuli, or in fact only one, but they seemed to occur during times of reduced growth after maturation. "Double annuli" were considered to be one annulus when both marks joined to form a central origin (the origin being the sulcal groove and the outer peripheral edge of the otolith). If these annuli did not meet to form a central origin they were considered two distinct annuli, and were counted as such.

All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Click here to obtain the protocol at the CQFE website on how to age Bluefish using their otolith thin-sections.

3.2.5 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

3.3 RESULTS

3.3.1 Sample size

We estimated a sample size of 577 Bluefish in 2018, ranging in length interval from 14 to 122 centimeters (Table 3.1). This sample size provided a range in (CV) for age composition approximately from the smallest (CV) of 6% for Age 1 and 2 to the largest (CV) of 20% for Age 8. In 2018, we randomly selected and aged 390 fish from 588 Bluefish collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 233 fish. We were not short any fish from the major length intervals (The interval requires more than 5 fish), as a result, the precision for the estimates of major age groups would not be influenced significantly.

3.3.2 Reading precision

Reader 1 had moderate self-precision and Read 2 had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 88% and a CV of 7.41% (test of symmetry: $\chi^2 = 6$, $df = 5$, $P = 0.3062$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 90% and a CV of 4.37% (test of symmetry: $\chi^2 = 5$, $df = 4$, $P = 0.2873$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 89.23% and a CV of 4.87% (test of symmetry: $\chi^2 = 8.64$, $df = 12$, $P = 0.7331$) (Figure 3.2).

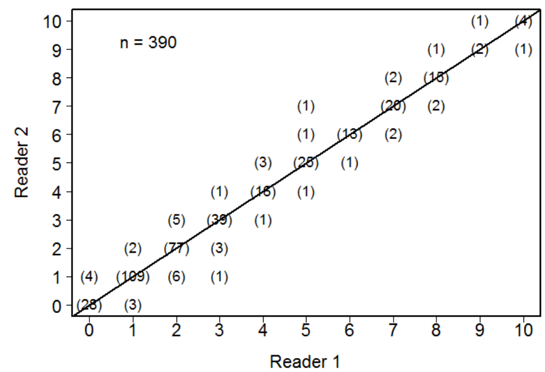


Figure 3.2: Between-reader comparison of otolith age estimates for Bluefish collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 84% with ages of fish aged in 2000 with a CV of 13.79% (test of symmetry: $\chi^2 = 8$, $df = 4$, $P = 0.0916$). Reader 2 had an agreement of 96% with a CV of 3.77% (test of symmetry: $\chi^2 = 2$, $df = 2$, $P = 0.3679$).

3.3.3 Year class

Of the 390 fish aged with otoliths, 11 age classes (0 to 10) were represented (Table 3.2). The average age was 2.9 years, and the standard deviation and standard error were 2.4 and 0.12, respectively. Year-class data show that the fishery was comprised of 11 year-classes: fish from the 2008 to 2018 year-classes, with fish primarily from the year classes of 2016 and 2017 with 22.1% and 30%, respectively. The ratio of males to females was 1:2.04 in the sample collected (Figure 3.3).

3.3.4 Age-length key (ALK)

We developed an age-length-key (Table 3.3) that can be used in the conversion of numbers-at-length in the estimated catch

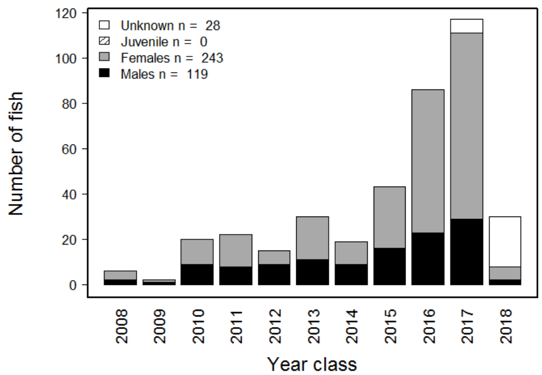


Figure 3.3: Year-class frequency distribution for Bluefish collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length cm intervals.

Table 3.1: Number of Bluefish collected and aged in each 1-cm length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

(Go back to text)

Interval	Target	Collected	Aged	Need
14 - 14.99	5	0	0	5
15 - 15.99	5	0	0	5
16 - 16.99	5	0	0	5
17 - 17.99	5	0	0	5
18 - 18.99	5	4	4	1
19 - 19.99	5	6	6	0
20 - 20.99	5	6	6	0
21 - 21.99	5	11	7	0
22 - 22.99	5	14	6	0
23 - 23.99	5	8	6	0
24 - 24.99	5	7	4	1
25 - 25.99	5	11	6	0
26 - 26.99	5	14	6	0
27 - 27.99	5	19	6	0
28 - 28.99	5	22	6	0
29 - 29.99	5	19	6	0
30 - 30.99	5	22	6	0
31 - 31.99	5	15	6	0
32 - 32.99	6	19	6	0
33 - 33.99	5	16	6	0
34 - 34.99	6	15	6	0
35 - 35.99	6	7	6	0
36 - 36.99	7	14	8	0
37 - 37.99	8	16	8	0
38 - 38.99	7	10	8	0
39 - 39.99	8	14	8	0
40 - 40.99	8	14	8	0
41 - 41.99	7	10	8	0
42 - 42.99	8	8	8	0
43 - 43.99	8	16	8	0
44 - 44.99	5	12	6	0
45 - 45.99	9	12	10	0
46 - 46.99	6	13	6	0
47 - 47.99	7	12	8	0
48 - 48.99	6	7	6	0
49 - 49.99	5	13	6	0
50 - 50.99	5	7	6	0
51 - 51.99	5	10	8	0
52 - 52.99	5	6	6	0
53 - 53.99	5	5	5	0

(To continue)

Table 3.1 (Continued)

Interval	Target	Collected	Aged	Need
54 - 54.99	5	5	5	0
55 - 55.99	5	6	6	0
56 - 56.99	5	3	3	2
57 - 57.99	5	6	6	0
58 - 58.99	5	4	4	1
59 - 59.99	5	2	2	3
60 - 60.99	5	5	5	0
61 - 61.99	5	3	3	2
62 - 62.99	5	3	3	2
63 - 63.99	5	1	1	4
64 - 64.99	5	3	3	2
65 - 65.99	5	0	0	5
66 - 66.99	5	1	1	4
67 - 67.99	5	0	0	5
68 - 68.99	5	0	0	5
69 - 69.99	5	0	0	5
70 - 70.99	5	3	3	2
71 - 71.99	5	4	4	1
72 - 72.99	5	1	1	4
73 - 73.99	5	4	4	1
74 - 74.99	5	1	1	4
75 - 75.99	5	3	3	2
76 - 76.99	5	6	6	0
77 - 77.99	5	4	4	1
78 - 78.99	5	2	2	3
79 - 79.99	5	3	3	2
80 - 80.99	5	6	6	0
81 - 81.99	5	2	2	3
82 - 82.99	5	6	6	0
83 - 83.99	5	5	5	0
84 - 84.99	5	5	5	0
85 - 85.99	5	8	8	0
86 - 86.99	5	4	4	1
87 - 87.99	5	9	9	0
88 - 88.99	5	3	3	2
89 - 89.99	5	5	5	0
90 - 90.99	5	12	12	0
91 - 91.99	5	5	5	0
92 - 92.99	5	6	6	0
93 - 93.99	5	0	0	5
94 - 94.99	5	1	1	4
95 - 95.99	5	2	2	3
96 - 96.99	5	1	1	4
97 - 97.99	5	0	0	5
98 - 98.99	5	0	0	5

(To continue)

Table 3.1 (Continued)

Interval	Target	Collected	Aged	Need
99 - 99.99	5	0	0	5
100 - 100.99	5	0	0	5
101 - 101.99	5	0	0	5
102 - 102.99	5	0	0	5
103 - 103.99	5	0	0	5
104 - 104.99	5	0	0	5
105 - 105.99	5	0	0	5
106 - 106.99	5	0	0	5
107 - 107.99	5	0	0	5
108 - 108.99	5	0	0	5
109 - 109.99	5	0	0	5
110 - 110.99	5	0	0	5
111 - 111.99	5	0	0	5
112 - 112.99	5	0	0	5
113 - 113.99	5	0	0	5
114 - 114.99	5	0	0	5
115 - 115.99	5	0	0	5
116 - 116.99	5	0	0	5
117 - 117.99	5	0	0	5
118 - 118.99	5	0	0	5
119 - 119.99	5	0	0	5
120 - 120.99	5	0	0	5
121 - 121.99	5	1	1	4
122 - 122.99	5	0	0	5
Totals	577	588	390	233

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Table 3.2: The number of Bluefish assigned to each total length (cm)-at-age category for 390 fish sampled for otolith age determination in Virginia during 2018.

	Age											
Interval	0	1	2	3	4	5	6	7	8	9	10	Totals
18 - 18.99	4	0	0	0	0	0	0	0	0	0	0	4
19 - 19.99	6	0	0	0	0	0	0	0	0	0	0	6
20 - 20.99	5	1	0	0	0	0	0	0	0	0	0	6
21 - 21.99	4	3	0	0	0	0	0	0	0	0	0	7
22 - 22.99	3	3	0	0	0	0	0	0	0	0	0	6
23 - 23.99	3	3	0	0	0	0	0	0	0	0	0	6
24 - 24.99	1	3	0	0	0	0	0	0	0	0	0	4
25 - 25.99	1	5	0	0	0	0	0	0	0	0	0	6
26 - 26.99	1	5	0	0	0	0	0	0	0	0	0	6
27 - 27.99	1	5	0	0	0	0	0	0	0	0	0	6
28 - 28.99	1	5	0	0	0	0	0	0	0	0	0	6
29 - 29.99	0	6	0	0	0	0	0	0	0	0	0	6
30 - 30.99	0	6	0	0	0	0	0	0	0	0	0	6
31 - 31.99	0	6	0	0	0	0	0	0	0	0	0	6
32 - 32.99	0	6	0	0	0	0	0	0	0	0	0	6
33 - 33.99	0	5	1	0	0	0	0	0	0	0	0	6
34 - 34.99	0	6	0	0	0	0	0	0	0	0	0	6
35 - 35.99	0	5	1	0	0	0	0	0	0	0	0	6
36 - 36.99	0	4	4	0	0	0	0	0	0	0	0	8
37 - 37.99	0	4	4	0	0	0	0	0	0	0	0	8
38 - 38.99	0	3	5	0	0	0	0	0	0	0	0	8
39 - 39.99	0	4	4	0	0	0	0	0	0	0	0	8
40 - 40.99	0	3	3	2	0	0	0	0	0	0	0	8
41 - 41.99	0	4	4	0	0	0	0	0	0	0	0	8
42 - 42.99	0	2	4	2	0	0	0	0	0	0	0	8
43 - 43.99	0	2	4	2	0	0	0	0	0	0	0	8
44 - 44.99	0	3	1	2	0	0	0	0	0	0	0	6
45 - 45.99	0	1	9	0	0	0	0	0	0	0	0	10
46 - 46.99	0	1	3	2	0	0	0	0	0	0	0	6
47 - 47.99	0	1	5	2	0	0	0	0	0	0	0	8
48 - 48.99	0	3	1	2	0	0	0	0	0	0	0	6
49 - 49.99	0	2	3	1	0	0	0	0	0	0	0	6
50 - 50.99	0	2	4	0	0	0	0	0	0	0	0	6
51 - 51.99	0	2	4	2	0	0	0	0	0	0	0	8
52 - 52.99	0	0	3	3	0	0	0	0	0	0	0	6
53 - 53.99	0	1	2	2	0	0	0	0	0	0	0	5
54 - 54.99	0	0	2	3	0	0	0	0	0	0	0	5
55 - 55.99	0	1	2	3	0	0	0	0	0	0	0	6
56 - 56.99	0	0	3	0	0	0	0	0	0	0	0	3
57 - 57.99	0	1	3	2	0	0	0	0	0	0	0	6
58 - 58.99	0	0	2	2	0	0	0	0	0	0	0	4

(To continue)

Table 3.2 (Continued)

	Age											
Interval	0	1	2	3	4	5	6	7	8	9	10	Totals
59 - 59.99	0	0	0	2	0	0	0	0	0	0	0	2
60 - 60.99	0	0	2	3	0	0	0	0	0	0	0	5
61 - 61.99	0	0	1	1	1	0	0	0	0	0	0	3
62 - 62.99	0	0	2	0	1	0	0	0	0	0	0	3
63 - 63.99	0	0	0	1	0	0	0	0	0	0	0	1
64 - 64.99	0	0	0	3	0	0	0	0	0	0	0	3
66 - 66.99	0	0	0	1	0	0	0	0	0	0	0	1
70 - 70.99	0	0	0	0	3	0	0	0	0	0	0	3
71 - 71.99	0	0	0	0	3	1	0	0	0	0	0	4
72 - 72.99	0	0	0	0	0	1	0	0	0	0	0	1
73 - 73.99	0	0	0	0	4	0	0	0	0	0	0	4
74 - 74.99	0	0	0	0	1	0	0	0	0	0	0	1
75 - 75.99	0	0	0	0	3	0	0	0	0	0	0	3
76 - 76.99	0	0	0	0	2	2	2	0	0	0	0	6
77 - 77.99	0	0	0	0	1	3	0	0	0	0	0	4
78 - 78.99	0	0	0	0	0	2	0	0	0	0	0	2
79 - 79.99	0	0	0	0	0	3	0	0	0	0	0	3
80 - 80.99	0	0	0	0	0	4	2	0	0	0	0	6
81 - 81.99	0	0	0	0	0	0	2	0	0	0	0	2
82 - 82.99	0	0	0	0	0	2	3	0	1	0	0	6
83 - 83.99	0	0	0	0	0	5	0	0	0	0	0	5
84 - 84.99	0	0	0	0	0	2	2	0	1	0	0	5
85 - 85.99	0	0	0	0	0	2	1	2	3	0	0	8
86 - 86.99	0	0	0	0	0	1	0	2	1	0	0	4
87 - 87.99	0	0	0	0	0	0	1	2	3	1	2	9
88 - 88.99	0	0	0	0	0	0	0	2	1	0	0	3
89 - 89.99	0	0	0	0	0	1	0	3	1	0	0	5
90 - 90.99	0	0	0	0	0	0	2	5	4	1	0	12
91 - 91.99	0	0	0	0	0	0	0	2	3	0	0	5
92 - 92.99	0	0	0	0	0	0	0	4	0	0	2	6
94 - 94.99	0	0	0	0	0	0	0	0	0	0	1	1
95 - 95.99	0	0	0	0	0	0	0	0	1	0	1	2
96 - 96.99	0	0	0	0	0	0	0	0	1	0	0	1
121 - 121.99	0	0	0	0	0	1	0	0	0	0	0	1
Totals	30	117	86	43	19	30	15	22	20	2	6	390

(Go back to text)

Table 3.3: Age-Length key, as proportion-at-age in each 1-cm length interval, based on otolith ages for Bluefish sampled for age determination in Virginia during 2018.

	Age										
Interval	0	1	2	3	4	5	6	7	8	9	10
18 - 18.99	1	0	0	0	0	0	0	0	0	0	0
19 - 19.99	1	0	0	0	0	0	0	0	0	0	0
20 - 20.99	0.83	0.17	0	0	0	0	0	0	0	0	0
21 - 21.99	0.57	0.43	0	0	0	0	0	0	0	0	0
22 - 22.99	0.5	0.5	0	0	0	0	0	0	0	0	0
23 - 23.99	0.5	0.5	0	0	0	0	0	0	0	0	0
24 - 24.99	0.25	0.75	0	0	0	0	0	0	0	0	0
25 - 25.99	0.17	0.83	0	0	0	0	0	0	0	0	0
26 - 26.99	0.17	0.83	0	0	0	0	0	0	0	0	0
27 - 27.99	0.17	0.83	0	0	0	0	0	0	0	0	0
28 - 28.99	0.17	0.83	0	0	0	0	0	0	0	0	0
29 - 29.99	0	1	0	0	0	0	0	0	0	0	0
30 - 30.99	0	1	0	0	0	0	0	0	0	0	0
31 - 31.99	0	1	0	0	0	0	0	0	0	0	0
32 - 32.99	0	1	0	0	0	0	0	0	0	0	0
33 - 33.99	0	0.83	0.17	0	0	0	0	0	0	0	0
34 - 34.99	0	1	0	0	0	0	0	0	0	0	0
35 - 35.99	0	0.83	0.17	0	0	0	0	0	0	0	0
36 - 36.99	0	0.5	0.5	0	0	0	0	0	0	0	0
37 - 37.99	0	0.5	0.5	0	0	0	0	0	0	0	0
38 - 38.99	0	0.38	0.62	0	0	0	0	0	0	0	0
39 - 39.99	0	0.5	0.5	0	0	0	0	0	0	0	0
40 - 40.99	0	0.38	0.38	0.25	0	0	0	0	0	0	0
41 - 41.99	0	0.5	0.5	0	0	0	0	0	0	0	0
42 - 42.99	0	0.25	0.5	0.25	0	0	0	0	0	0	0
43 - 43.99	0	0.25	0.5	0.25	0	0	0	0	0	0	0
44 - 44.99	0	0.5	0.17	0.33	0	0	0	0	0	0	0
45 - 45.99	0	0.1	0.9	0	0	0	0	0	0	0	0
46 - 46.99	0	0.17	0.5	0.33	0	0	0	0	0	0	0
47 - 47.99	0	0.12	0.62	0.25	0	0	0	0	0	0	0
48 - 48.99	0	0.5	0.17	0.33	0	0	0	0	0	0	0
49 - 49.99	0	0.33	0.5	0.17	0	0	0	0	0	0	0
50 - 50.99	0	0.33	0.67	0	0	0	0	0	0	0	0
51 - 51.99	0	0.25	0.5	0.25	0	0	0	0	0	0	0
52 - 52.99	0	0	0.5	0.5	0	0	0	0	0	0	0
53 - 53.99	0	0.2	0.4	0.4	0	0	0	0	0	0	0
54 - 54.99	0	0	0.4	0.6	0	0	0	0	0	0	0
55 - 55.99	0	0.17	0.33	0.5	0	0	0	0	0	0	0
56 - 56.99	0	0	1	0	0	0	0	0	0	0	0
57 - 57.99	0	0.17	0.5	0.33	0	0	0	0	0	0	0
58 - 58.99	0	0	0.5	0.5	0	0	0	0	0	0	0

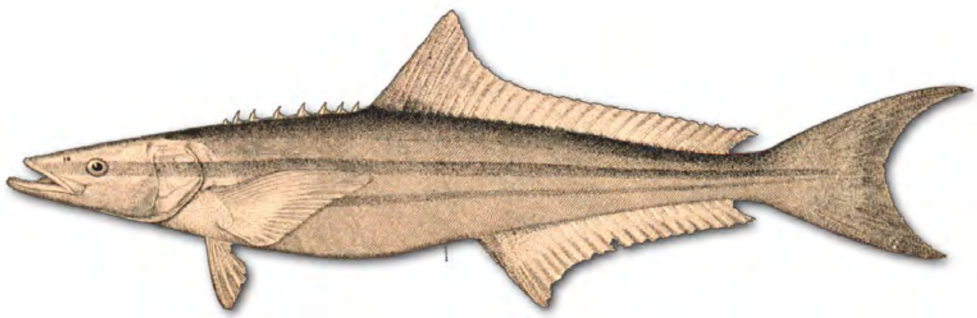
(To continue)

Table 3.3 (Continued)

	Age										
Interval	0	1	2	3	4	5	6	7	8	9	10
59 - 59.99	0	0	0	1	0	0	0	0	0	0	0
60 - 60.99	0	0	0.4	0.6	0	0	0	0	0	0	0
61 - 61.99	0	0	0.33	0.33	0.33	0	0	0	0	0	0
62 - 62.99	0	0	0.67	0	0.33	0	0	0	0	0	0
63 - 63.99	0	0	0	1	0	0	0	0	0	0	0
64 - 64.99	0	0	0	1	0	0	0	0	0	0	0
66 - 66.99	0	0	0	1	0	0	0	0	0	0	0
70 - 70.99	0	0	0	0	1	0	0	0	0	0	0
71 - 71.99	0	0	0	0	0.75	0.25	0	0	0	0	0
72 - 72.99	0	0	0	0	0	1	0	0	0	0	0
73 - 73.99	0	0	0	0	1	0	0	0	0	0	0
74 - 74.99	0	0	0	0	1	0	0	0	0	0	0
75 - 75.99	0	0	0	0	1	0	0	0	0	0	0
76 - 76.99	0	0	0	0	0.33	0.33	0.33	0	0	0	0
77 - 77.99	0	0	0	0	0.25	0.75	0	0	0	0	0
78 - 78.99	0	0	0	0	0	1	0	0	0	0	0
79 - 79.99	0	0	0	0	0	1	0	0	0	0	0
80 - 80.99	0	0	0	0	0	0.67	0.33	0	0	0	0
81 - 81.99	0	0	0	0	0	0	1	0	0	0	0
82 - 82.99	0	0	0	0	0	0.33	0.5	0	0.17	0	0
83 - 83.99	0	0	0	0	0	1	0	0	0	0	0
84 - 84.99	0	0	0	0	0	0.4	0.4	0	0.2	0	0
85 - 85.99	0	0	0	0	0	0.25	0.12	0.25	0.38	0	0
86 - 86.99	0	0	0	0	0	0.25	0	0.5	0.25	0	0
87 - 87.99	0	0	0	0	0	0	0.11	0.22	0.33	0.11	0.22
88 - 88.99	0	0	0	0	0	0	0	0.67	0.33	0	0
89 - 89.99	0	0	0	0	0	0.2	0	0.6	0.2	0	0
90 - 90.99	0	0	0	0	0	0	0.17	0.42	0.33	0.08	0
91 - 91.99	0	0	0	0	0	0	0	0.4	0.6	0	0
92 - 92.99	0	0	0	0	0	0	0	0.67	0	0	0.33
94 - 94.99	0	0	0	0	0	0	0	0	0	0	1
95 - 95.99	0	0	0	0	0	0	0	0	0.5	0	0.5
96 - 96.99	0	0	0	0	0	0	0	0	1	0	0
121 - 121.99	0	0	0	0	0	1	0	0	0	0	0

Chapter 4

COBIA *Rachycentron canadum*



4.1 INTRODUCTION

We aged a total of 324 Cobia, *Rachycentron canadum*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Cobia ages ranged from 2 to 13 years old with an average age of 4.5, a standard deviation of 1.7, and a standard error of 0.09. Ten age classes (2 to 9, 11, and 13) were represented, comprising fish of the 2005, 2007, and 2009 to 2016 year-classes. The sample was dominated by fish from the year-classes of 2012, 2014, and 2015 with 26.2%, 19.1%, and 42%, respectively.

4.2 METHODS

4.2.1 Handling of collections

Sagittal otoliths, hereafter, referred to as "otoliths", were received by the Age and Growth Laboratory in labeled coin envelopes and were sorted by date of capture, their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored inside of protective Axygen 2 ml micro-tubes within their original labeled coin envelopes.

4.2.2 Preparation

Otoliths were processed for age determination. The left or right otolith was randomly selected and embedded, distal side down, in epoxy resin and allowed to harden overnight. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a permanent marker across the epoxy resin surface. At least one transverse cross-section (hereafter "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet^{TM} low-speed saw equipped with two, three inch diameter, Norton Diamond Grinding Wheels, separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The position of the marked core fell within the 0.5 mm space between the blades, such that the core was included in the removed thin section. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the section.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Cobia.

4.2.3 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Cobia otolith annulus deposition occurs between June and July (Richards 1967 and modified by CQFE). A Cobia captured between January 1 and July 31, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of July 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 4.1). Each reader aged all of the otolith samples. All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

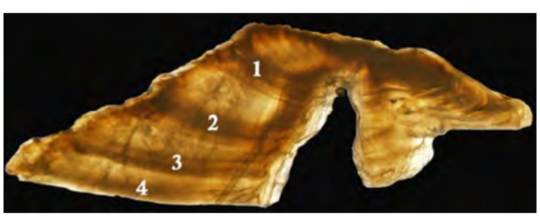


Figure 4.1: Otolith thin-section of a 4 year-old Cobia.

Click here to obtain the protocol at the CQFE website on how to age Cobia using their otolith thin-sections.

4.2.4 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

4.3 RESULTS

4.3.1 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 92% and a *CV* of 1.24% (test of symmetry: $\chi^2 = 4$, $df = 2$, $P = 0.1353$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 92% and a *CV* of 1.19% (test of symmetry: $\chi^2 = 4$, $df = 3$, $P = 0.2615$). There was an evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 96.91% and a *CV* of 0.44% (test of symmetry: $\chi^2 = 10$, $df = 3$, $P = 0.0186$) (Figure 4.2).

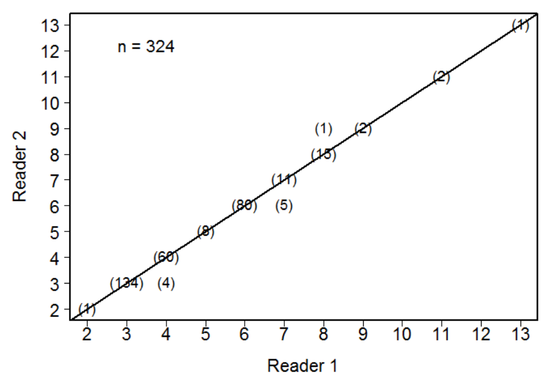


Figure 4.2: Between-reader comparison of otolith age estimates for Cobia collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 88% with ages of fish aged in 2000 with a *CV* of 1.22% (test of symmetry: $\chi^2 = 6$, $df = 6$, $P = 0.4232$). Reader 2 had an agreement of 92% with a *CV* of 0.83% (test of symmetry: $\chi^2 = 4$, $df = 4$, $P = 0.406$).

4.3.2 Year class

Of the 324 fish aged with otoliths, 10 age classes (2 to 9, 11, and 13) were represented (Table 4.1). The average age was 4.5 years, and the standard deviation and standard error were 1.7 and 0.09, respectively. Year-class data show that the fishery was comprised of 10 year-classes: fish from the 2005, 2007, and 2009 to 2016 year-classes, with fish primarily from the year classes of 2012, 2014, and 2015 with 26.2%, 19.1%, and 42%, respectively. The ratio of males to females was 1:1.9 in the sample collected (Figure 4.3).

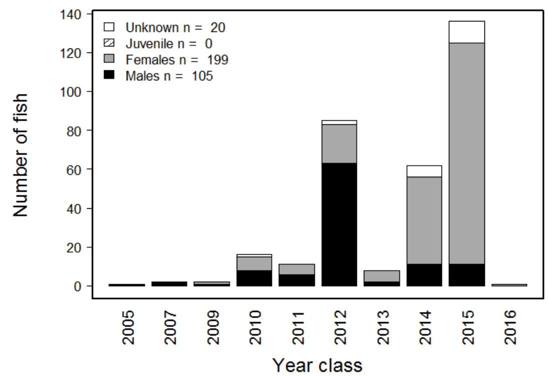


Figure 4.3: Year-class frequency distribution for Cobia collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

4.3.3 Age-length key (ALK)

We developed an age-length-key (Table 4.2) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

Table 4.1: The number of Cobia assigned to each total length (inch)-at-age category for 324 fish sampled for otolith age determination in Virginia during 2018.

	Age										
Interval	2	3	4	5	6	7	8	9	11	13	Totals
36 - 36.99	0	1	0	0	0	0	0	0	0	0	1
37 - 37.99	0	7	0	0	0	0	0	0	0	0	7
38 - 38.99	1	18	4	0	0	0	0	0	0	0	23
39 - 39.99	0	21	5	1	3	0	0	0	0	0	30
40 - 40.99	0	23	11	1	9	0	0	0	0	0	44
41 - 41.99	0	21	8	2	13	0	0	0	0	0	44
42 - 42.99	0	18	6	0	18	1	0	0	0	0	43
43 - 43.99	0	9	5	0	11	3	0	0	0	0	28
44 - 44.99	0	12	6	1	9	0	0	0	0	0	28
45 - 45.99	0	3	5	1	1	2	5	0	0	0	17
46 - 46.99	0	2	6	1	4	0	2	1	0	0	16
47 - 47.99	0	1	2	0	1	0	1	1	0	0	6
48 - 48.99	0	0	4	0	0	1	0	0	2	1	8
49 - 49.99	0	0	0	0	4	1	1	0	0	0	6
50 - 50.99	0	0	0	0	4	0	1	0	0	0	5
51 - 51.99	0	0	0	1	0	0	0	0	0	0	1
52 - 52.99	0	0	0	0	5	0	2	0	0	0	7
53 - 53.99	0	0	0	0	2	3	0	0	0	0	5
54 - 54.99	0	0	0	0	0	0	1	0	0	0	1
55 - 55.99	0	0	0	0	1	0	1	0	0	0	2
58 - 58.99	0	0	0	0	0	0	2	0	0	0	2
Totals	1	136	62	8	85	11	16	2	2	1	324

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Table 4.2: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Cobia sampled for age determination in Virginia during 2018.

	Age									
Interval	2	3	4	5	6	7	8	9	11	13
36 - 36.99	0	1	0	0	0	0	0	0	0	0
37 - 37.99	0	1	0	0	0	0	0	0	0	0
38 - 38.99	0.04	0.78	0.17	0	0	0	0	0	0	0
39 - 39.99	0	0.7	0.17	0.03	0.1	0	0	0	0	0
40 - 40.99	0	0.52	0.25	0.02	0.2	0	0	0	0	0
41 - 41.99	0	0.48	0.18	0.05	0.3	0	0	0	0	0
42 - 42.99	0	0.42	0.14	0	0.42	0.02	0	0	0	0
43 - 43.99	0	0.32	0.18	0	0.39	0.11	0	0	0	0
44 - 44.99	0	0.43	0.21	0.04	0.32	0	0	0	0	0
45 - 45.99	0	0.18	0.29	0.06	0.06	0.12	0.29	0	0	0
46 - 46.99	0	0.12	0.38	0.06	0.25	0	0.12	0.06	0	0
47 - 47.99	0	0.17	0.33	0	0.17	0	0.17	0.17	0	0
48 - 48.99	0	0	0.5	0	0	0.12	0	0	0.25	0.12
49 - 49.99	0	0	0	0	0.67	0.17	0.17	0	0	0
50 - 50.99	0	0	0	0	0.8	0	0.2	0	0	0
51 - 51.99	0	0	0	1	0	0	0	0	0	0
52 - 52.99	0	0	0	0	0.71	0	0.29	0	0	0
53 - 53.99	0	0	0	0	0.4	0.6	0	0	0	0
54 - 54.99	0	0	0	0	0	0	1	0	0	0
55 - 55.99	0	0	0	0	0.5	0	0.5	0	0	0
58 - 58.99	0	0	0	0	0	0	1	0	0	0

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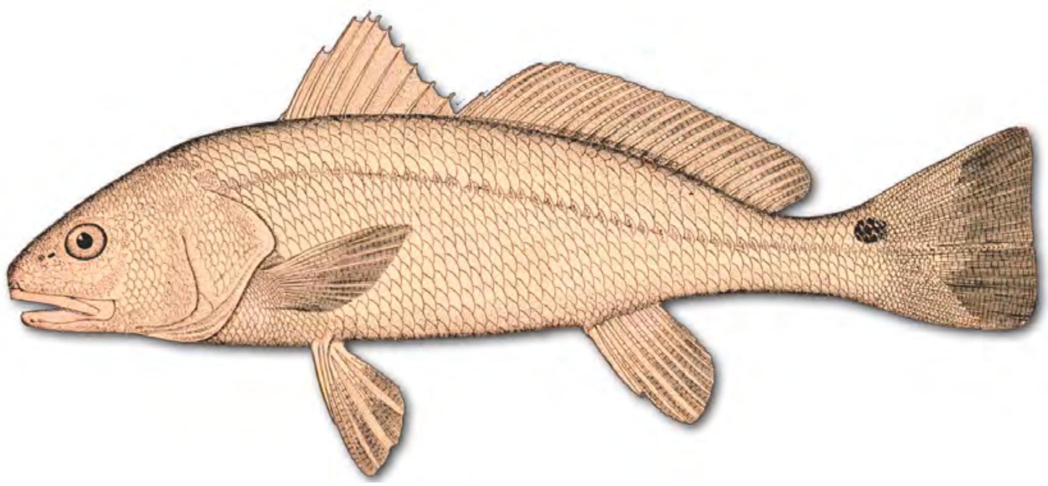
Chapter 5

RED DRUM *Sciaenops ocellatus*



5.1 INTRODUCTION

We aged a total of 17 Red Drum, *Sciaenops ocellatus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Red drum ages ranged from 0 to 2 years old with an average age of 1.1, a standard deviation of 0.8, and a standard error of 0.19. Three age classes (0 to 2) were represented, comprising fish of the 2016 to 2018 year-classes. The sample was dominated by fish from the year-classes of 2016 and 2017 with 35.3% and 41.2%, respectively.

5.2 METHODS

5.2.1 Handling of collections

Sagittal otoliths, hereafter, referred to as "otoliths", were received by the Age and Growth Laboratory in labeled coin envelopes, and were sorted by date of capture. Their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

5.2.2 Preparation

Otoliths were processed for age determination following the methods described in Ross et al. (1995) and Jones and Wells (1998) for Red Drum. The left or right sagittal otolith was randomly selected and attached, distal side down, to a glass slide with Crystalbond™ 509 adhesive. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, three inch diameter, Norton Diamond Grinding Wheels, separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The position of the marked core fell within the 0.5 mm space between the blades, such that the core was included in the removed thin-section. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Red Drum.

5.2.3 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Red Drum annulus formation occurs between March and June (Ross et al. 1995 and modified by CQFE). A Red Drum captured between January 1 and June 30, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of June 30, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 5.1). Each reader aged all of the otolith samples.

All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

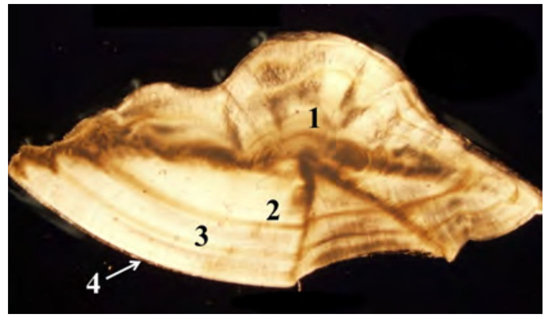


Figure 5.1: Otolith thin-section of a 4 year-old Red Drum with the last annulus on the edge of the thin-section

Click here to obtain the protocol at the CQFE website on how to age Red Drum using their otolith thin-sections.

5.2.4 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. When the sample size for the current year was smaller than 50, the entire sample was read by each reader for the second time to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

5.3 RESULTS

5.3.1 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 100% , and there was no significant difference between the first and second readings for Reader 2 with an agreement of 100%. There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 100% (Figure 5.2).

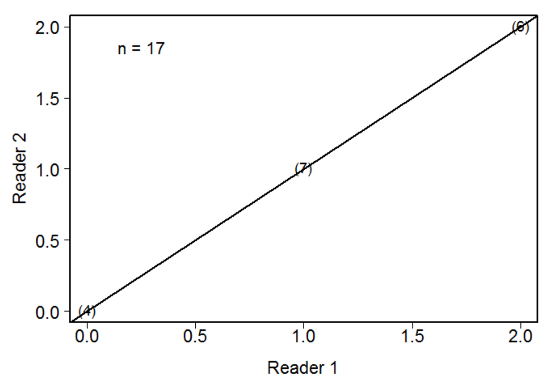


Figure 5.2: Between-reader comparison of otolith age estimates for Red Drum collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 100% with ages of fish aged in 2000. Reader 2 also had an agreement of 100% .

5.3.2 Year class

Of the 17 fish aged with otoliths, 3 age classes (0 to 2) were represented (Table 5.1). The average age was 1.1 years, and the standard deviation and standard error were 0.8 and 0.19, respectively. Year-class data show that the fishery was comprised of 3 year-classes: fish from the 2016 to 2018 year-classes, with fish primarily from the year classes of 2016 and 2017 with 35.3% and 41.2%, respectively. The ratio of males to females was 1:0.22 in the sample collected (Figure 5.3).

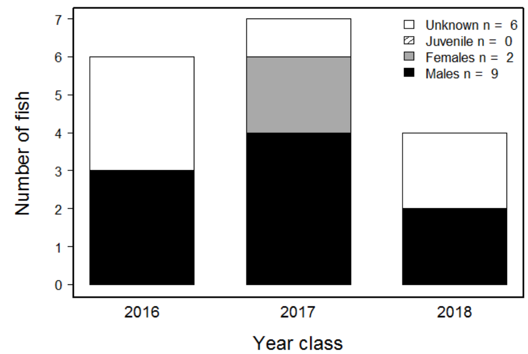


Figure 5.3: Year-class frequency distribution for Red Drum collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

5.3.3 Age-length key (ALK)

We developed an age-length-key (Table 5.2) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

Table 5.1: The number of Red Drum assigned to each total length (inch)-at-age category for 17 fish sampled for otolith age determination in Virginia during 2018.

	Age			
Interval	0	1	2	Totals
18 - 18.99	2	0	0	2
19 - 19.99	2	1	0	3
22 - 22.99	0	1	1	2
23 - 23.99	0	1	0	1
24 - 24.99	0	4	2	6
25 - 25.99	0	0	2	2
26 - 26.99	0	0	1	1
Totals	4	7	6	17

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Table 5.2: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Red Drum sampled for age determination in Virginia during 2018.

	Age		
Interval	0	1	2
18 - 18.99	1	0	0
19 - 19.99	0.67	0.33	0
22 - 22.99	0	0.5	0.5
23 - 23.99	0	1	0
24 - 24.99	0	0.67	0.33
25 - 25.99	0	0	1
26 - 26.99	0	0	1

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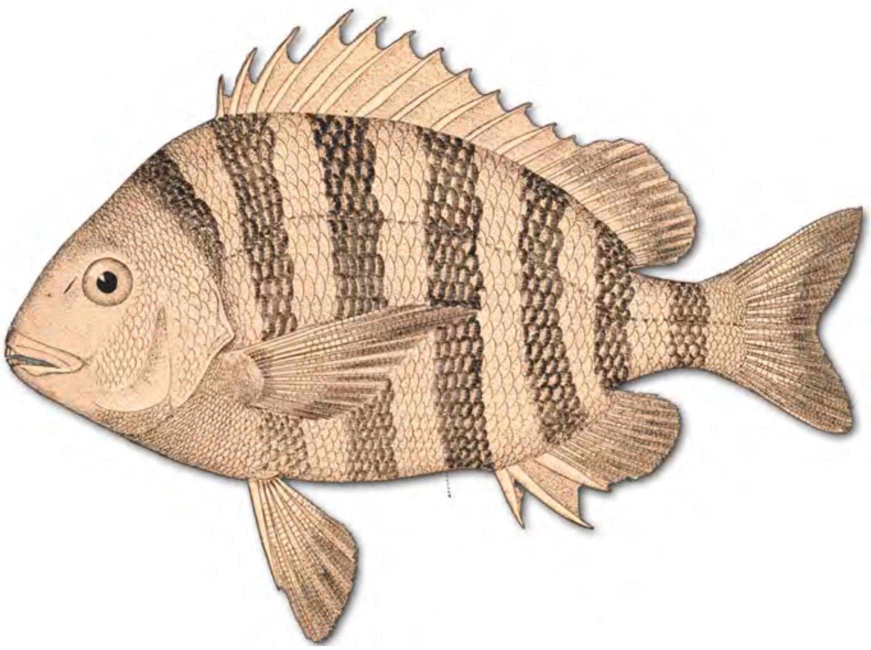
Chapter 6

SHEEPSHEAD *Archosargus probatocephalus*



6.1 INTRODUCTION

We aged a total of 69 Sheepshead, *Archosargus probatocephalus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Sheepshead ages ranged from 2 to 31 years old with an average age of 7.7, a standard deviation of 7.6, and a standard error of 0.91. Fourteen age classes (2 to 3, 5 to 7, 11 to 13, 17, 21, 27 to 29, and 31) were represented, comprising fish of the 1987, 1989 to 1991, 1997, 2001, 2005 to 2007, 2011 to 2013, and 2015 to 2016 year-classes. The sample was dominated by fish from the year-classes of 2015 and 2016 with 26.1% and 27.5%, respectively.

6.2 METHODS

6.2.1 Handling of collections

Sagittal otoliths, hereafter, referred to as "otoliths", were received by the Age and Growth Laboratory in labeled coin envelopes,and were sorted by date of capture. Their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

6.2.2 Preparation

Otoliths were processed for age determination following the methods described in Ballenger (2011). The left or right otolith was randomly selected and embedded, distal side down, in epoxy resin and allowed to harden overnight. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a permanent marker across the epoxy resin surface. At least one transverse cross-section (hereafter "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, three inch diameter, Norton Diamond Grinding Wheels, separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The position of the marked core fell within the 0.5 mm space between the blades, such that the core was included in the removed thin section. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the section.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Sheepshead.

6.2.3 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Sheepshead otolith annulus formation occurs between May and June (Ballenger 2011). A Sheepshead captured between January 1 and July 31, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 6.1). Each reader aged all of the otolith samples. All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Figure 6.1: Otolith thin-section of a 5 year-old Sheepshead

Click here to obtain the protocol at the CQFE website on how to age Sheepshead using their otolith thin-sections.

6.2.4 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

6.3 RESULTS

6.3.1 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 82% and a *CV* of 1.2% (test of symmetry: $\chi^2 = 9$, $df = 9$, $P = 0.4373$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 90% and a *CV* of 1.19% (test of symmetry: $\chi^2 = 5$, $df = 4$, $P = 0.2873$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 89.86% and a *CV* of 0.6% (test of symmetry: $\chi^2 = 7$, $df = 7$, $P = 0.4289$) (Figure 6.2).

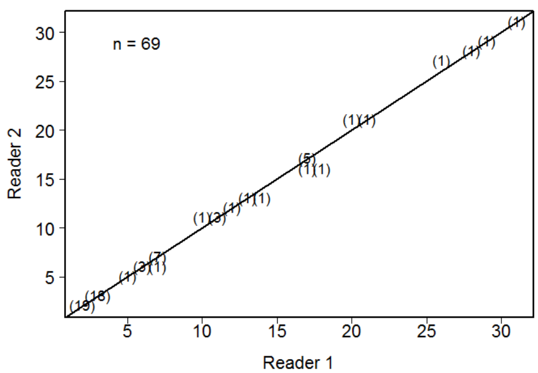


Figure 6.2: Between-reader comparison of otolith age estimates for Sheepshead collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 98% with ages of fish aged in 2008 with a *CV* of 0.08% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$). Reader 2 had an agreement of 98% with a *CV* of 0.22% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$).

6.3.2 Year class

Of the 69 fish aged with otoliths, 14 age classes (2 to 3, 5 to 7, 11 to 13, 17, 21, 27 to 29, and 31) were represented (Table 6.1). The average age was 7.7 years, and the standard deviation and standard error were 7.6 and 0.91, respectively. Year-class data show that the fishery was comprised of 14 year-classes: fish from the 1987, 1989 to 1991, 1997, 2001, 2005 to 2007, 2011 to 2013, and 2015 to 2016 year-classes, with fish primarily from the year classes of 2015 and 2016 with 26.1% and 27.5%, respectively. The ratio of males to females was 1:1.23 in the sample collected (Figure 6.3).

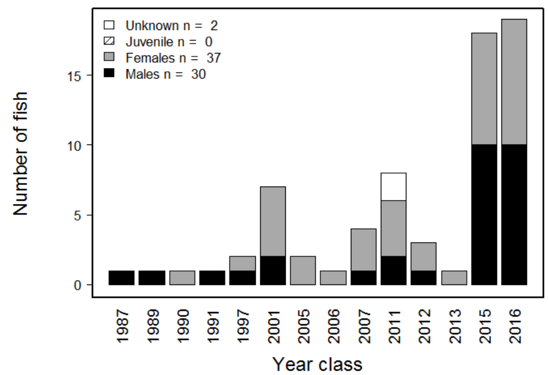


Figure 6.3: Year-class frequency distribution for Sheepshead collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

6.3.3 Age-length key (ALK)

We developed an age-length-key (Table 6.2) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

Table 6.1: The number of sheepshead assigned to each total length (inch)-at-age category for 69 fish sampled for otolith age determination in Virginia during 2018.

	Age														
Interval	2	3	5	6	7	11	12	13	17	21	27	28	29	31	Totals
11 - 11.99	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2
12 - 12.99	6	3	0	0	0	0	0	0	0	0	0	0	0	0	9
13 - 13.99	4	2	0	0	0	0	0	0	0	0	0	0	0	0	6
14 - 14.99	5	6	0	0	0	0	0	0	0	0	0	0	0	0	11
15 - 15.99	3	4	0	1	0	0	0	0	0	0	0	0	0	0	8
16 - 16.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
17 - 17.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
19 - 19.99	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2
20 - 20.99	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2
21 - 21.99	0	0	0	1	4	1	0	1	1	0	0	0	0	0	8
22 - 22.99	0	0	0	0	1	2	1	0	2	0	0	0	0	0	6
23 - 23.99	0	0	0	0	1	0	0	0	2	0	1	0	0	1	5
24 - 24.99	0	0	0	0	0	1	0	1	1	1	0	0	1	0	5
25 - 25.99	0	0	0	0	0	0	0	0	1	1	0	1	0	0	3
Totals	19	18	1	3	8	4	1	2	7	2	1	1	1	1	69

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Table 6.2: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Sheepshead sampled for age determination in Virginia during 2018.

	Age													
Interval	2	3	5	6	7	11	12	13	17	21	27	28	29	31
11 - 11.99	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0
12 - 12.99	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0	0
13 - 13.99	0.67	0.33	0	0	0	0	0	0	0	0	0	0	0	0
14 - 14.99	0.45	0.55	0	0	0	0	0	0	0	0	0	0	0	0
15 - 15.99	0.38	0.5	0	0.12	0	0	0	0	0	0	0	0	0	0
16 - 16.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0
17 - 17.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0
19 - 19.99	0	0	0	0	1	0	0	0	0	0	0	0	0	0
20 - 20.99	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0
21 - 21.99	0	0	0	0.12	0.5	0.12	0	0.12	0.12	0	0	0	0	0
22 - 22.99	0	0	0	0	0.17	0.33	0.17	0	0.33	0	0	0	0	0
23 - 23.99	0	0	0	0	0.2	0	0	0	0.4	0	0.2	0	0	0.2
24 - 24.99	0	0	0	0	0	0.2	0	0.2	0.2	0.2	0	0	0.2	0
25 - 25.99	0	0	0	0	0	0	0	0	0.33	0.33	0	0.33	0	0

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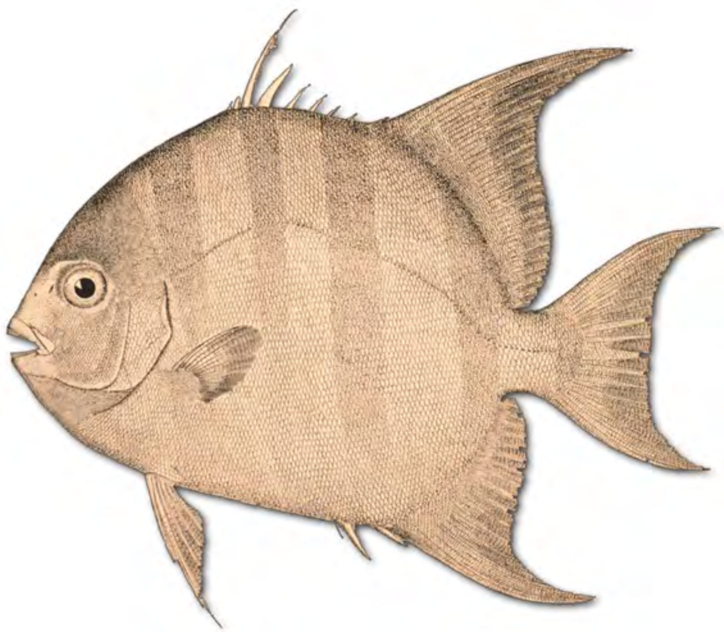
Chapter 7

ATLANTIC SPADEFISH
Chaetodipterus faber



7.1 INTRODUCTION

We aged a total of 353 Spadefish, *Chaetodipterus faber*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Spadefish ages ranged from 1 to 9 years old with an average age of 3.1, a standard deviation of 1.5, and a standard error of 0.08. Nine age classes (1 to 9) were represented, comprising fish of the 2009 to 2017 year-classes. The sample was dominated by fish from the year-classes of 2015 and 2016 with 38.2% and 38.8%, respectively.

7.2 METHODS

7.2.1 Sample size for ageing

We estimated sample size for ageing Spadefish in 2018 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \qquad (7.1)$$

where A is the sample size for ageing Spadefish in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Spadefish used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Spadefish collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018.

7.2.2 Handling of collections

Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes, and were sorted by date of capture. Their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

7.2.3 Preparation

We used our thin-section and bake technique to process Spadefish sagittal otoliths (hereafter, referred to as "otoliths") for age determination. Otolith preparation began by randomly selecting either the right or left otolith. Each whole otolith was placed in a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400 °C. Baking time was dependent on the otolith's size and gauged by color, with a light caramel color desired. Once a suitable color was achieved the baked otolith was embedded in epoxy resin with its distal surface orientated downwards and allowed to harden overnight. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core was marked using a permanent marker across the epoxy resin surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton diamond grinding wheels (hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The otolith was positioned so the blades straddled each side of the otolith focus. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in broadening and distored winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-section.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Atlantic Spadefish.

7.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Spadefish otolith annulus formation occurs between December and July (Hayse 1987 and modified by CQFE). A Spadefish captured between January 1 and July 31, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of July 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 7.1). Each reader aged all of the otolith samples. All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen

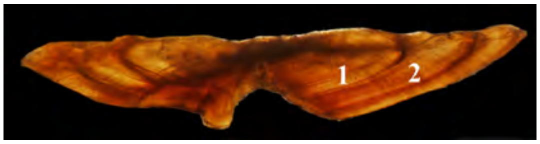


Figure 7.1: Otolith thin-section of a 2 year-old Spadefish

lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Click here to obtain the protocol at the CQFE website on how to age Atlantic Spadefish using their otolith thin-sections.

7.2.5 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

7.3 RESULTS

7.3.1 Sample size

We estimated a sample size of 364 Spadefish in 2018, ranging in length interval from 4 to 22 inches (Table 7.1). This sample size provided a range in (CV) for age composition approximately from the smallest (CV) of 6% for Age 2 to the largest (CV) of 22% for Age 6. In 2018, we randomly selected and aged 353 fish from 422 Spadefish collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 27 fish. We were short only a few fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would not be influenced significantly.

7.3.2 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 90% and a CV of 2.86% (test of symmetry: χ^2 = 5, df = 4, P = 0.2873), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 92% and a CV of 1.6% (test of symmetry: χ^2 = 4, df = 2, P = 0.1353). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 91.78% and a CV of 1.92% (test of symmetry: χ^2 = 12.57, df = 8, P = 0.1275) (Figure 7.2).

There was no time-series bias for either reader. Reader 1 had an agreement of 88% with ages of fish aged in 2003 with a CV of 2.49% (test of symmetry: χ^2 = 6, df = 4, P = 0.1991). Reader 2 had an agreement of 92% with a CV of 1.4% (test of symmetry: χ^2 = 4, df = 4, P = 0.406).

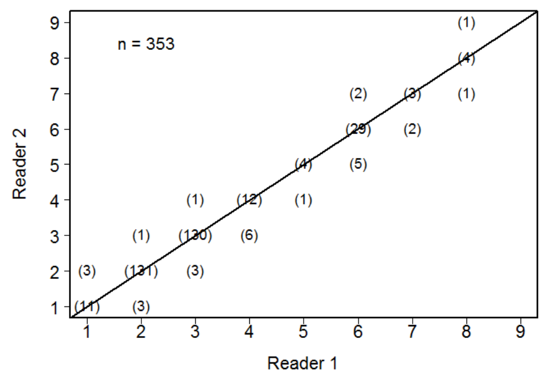


Figure 7.2: Between-reader comparison of otolith age estimates for Spadefish collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

7.3.3 Year class

Of the 353 fish aged with otoliths, 9 age classes (1 to 9) were represented (Table 7.2). The average age was 3.1 years, and the standard deviation and standard error were 1.5 and 0.08, respectively. Year-class data show that the fishery was comprised of 9 year-classes: fish from the 2009 to 2017 year-classes, with fish primarily from the year classes of 2015 and 2016 with 38.2% and 38.8%, respectively. The ratio of males to females was 1:1 in the sample collected (Figure 7.3).

7.3.4 Age-length key (ALK)

We developed an age-length-key (Table 7.3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

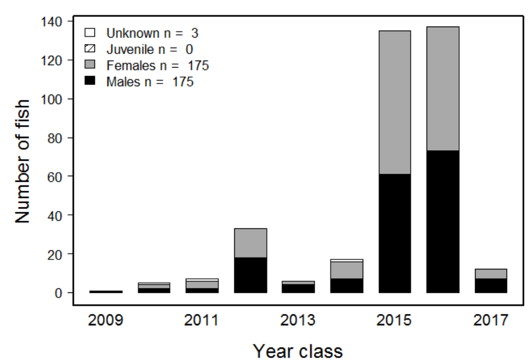


Figure 7.3: Year-class frequency distribution for Spadefish collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

Table 7.1: Number of Atlantic Spadefish collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
4 - 4.99	6	7	6	0
5 - 5.99	12	15	12	0
6 - 6.99	47	56	48	0
7 - 7.99	52	62	52	0
8 - 8.99	37	45	38	0
9 - 9.99	27	33	28	0
10 - 10.99	19	28	20	0
11 - 11.99	18	23	18	0
12 - 12.99	23	36	24	0
13 - 13.99	19	30	20	0
14 - 14.99	16	22	22	0
15 - 15.99	17	13	13	4
16 - 16.99	15	11	11	4
17 - 17.99	21	13	13	8
18 - 18.99	12	14	14	0
19 - 19.99	8	10	10	0
20 - 20.99	5	3	3	2
21 - 21.99	5	1	1	4
22 - 22.99	5	0	0	5
Totals	364	422	353	27

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Table 7.2: The number of Atlantic Spadefish assigned to each total length-at-age category for 353 fish sampled for otolith age determination in Virginia during 2018.

	Age									
Interval	1	2	3	4	5	6	7	8	9	Totals
4 - 4.99	5	1	0	0	0	0	0	0	0	6
5 - 5.99	4	8	0	0	0	0	0	0	0	12
6 - 6.99	3	42	3	0	0	0	0	0	0	48
7 - 7.99	0	45	7	0	0	0	0	0	0	52
8 - 8.99	0	24	14	0	0	0	0	0	0	38
9 - 9.99	0	12	16	0	0	0	0	0	0	28
10 - 10.99	0	3	17	0	0	0	0	0	0	20
11 - 11.99	0	0	16	2	0	0	0	0	0	18
12 - 12.99	0	1	21	2	0	0	0	0	0	24
13 - 13.99	0	0	17	1	0	2	0	0	0	20
14 - 14.99	0	1	16	4	0	1	0	0	0	22
15 - 15.99	0	0	6	3	0	3	1	0	0	13
16 - 16.99	0	0	1	1	2	4	0	2	1	11
17 - 17.99	0	0	1	3	0	8	1	0	0	13
18 - 18.99	0	0	0	1	3	8	1	1	0	14
19 - 19.99	0	0	0	0	0	5	4	1	0	10
20 - 20.99	0	0	0	0	1	1	0	1	0	3
21 - 21.99	0	0	0	0	0	1	0	0	0	1
Totals	12	137	135	17	6	33	7	5	1	353

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Table 7.3: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Atlantic Spadefish sampled for age determination in Virginia during 2018.

	Age								
Interval	1	2	3	4	5	6	7	8	9
4 - 4.99	0.83	0.17	0	0	0	0	0	0	0
5 - 5.99	0.33	0.67	0	0	0	0	0	0	0
6 - 6.99	0.06	0.88	0.06	0	0	0	0	0	0
7 - 7.99	0	0.87	0.13	0	0	0	0	0	0
8 - 8.99	0	0.63	0.37	0	0	0	0	0	0
9 - 9.99	0	0.43	0.57	0	0	0	0	0	0
10 - 10.99	0	0.15	0.85	0	0	0	0	0	0
11 - 11.99	0	0	0.89	0.11	0	0	0	0	0
12 - 12.99	0	0.04	0.88	0.08	0	0	0	0	0
13 - 13.99	0	0	0.85	0.05	0	0.1	0	0	0
14 - 14.99	0	0.05	0.73	0.18	0	0.05	0	0	0
15 - 15.99	0	0	0.46	0.23	0	0.23	0.08	0	0
16 - 16.99	0	0	0.09	0.09	0.18	0.36	0	0.18	0.09
17 - 17.99	0	0	0.08	0.23	0	0.62	0.08	0	0
18 - 18.99	0	0	0	0.07	0.21	0.57	0.07	0.07	0
19 - 19.99	0	0	0	0	0	0.5	0.4	0.1	0
20 - 20.99	0	0	0	0	0.33	0.33	0	0.33	0
21 - 21.99	0	0	0	0	0	1	0	0	0

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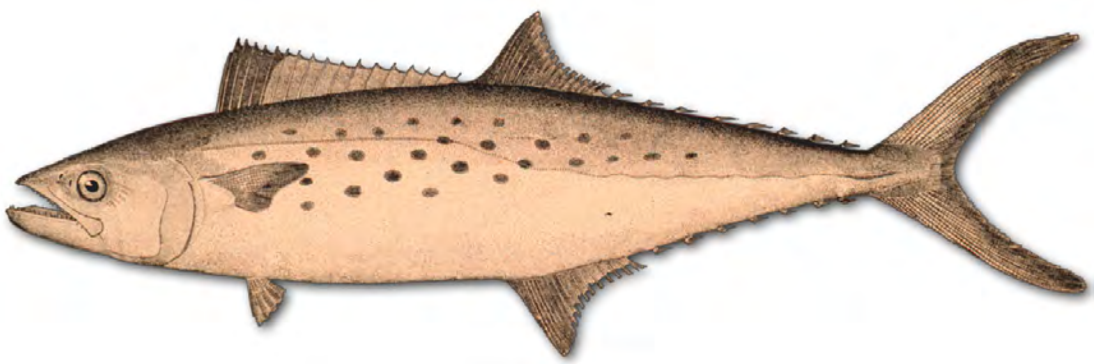
Chapter 8

SPANISH MACKEREL
Scomberomorous maculatus



8.1 INTRODUCTION

We aged a total of 201 Spanish Mackerel, *Scomberomorous maculatus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Spanish Mackerel ages ranged from 1 to 7 years old with an average age of 1.9, a standard deviation of 1.3, and a standard error of 0.09. Seven age classes (1 to 7) were represented, comprising fish of the 2011 to 2017 year-classes. The sample was dominated by fish from the year-class of 2017 with 53.2%.

8.2 METHODS

8.2.1 Sample size for ageing

We estimated sample size for ageing Spanish Mackerel in 2018 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \tag{8.1}$$

where A is the sample size for ageing Spanish Mackerel in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Spanish Mackerel used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Spanish Mackerel collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018.

8.2.2 Handling of collections

Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes, and were sorted by date of capture. Their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

8.2.3 Preparation

Sagittal otoliths, hereafter, referred to as "otolith", were processed for age determination. The left or right otolith was randomly selected and embedded, distal side down, in epoxy resin and allowed to harden overnight. The otoliths were viewed by eye, and when necessary, under a stereo microscope to identify the location of the core, and the position of the core marked using a permanent marker across the epoxy resin surface. At least one transverse cross-section (hereafter "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet^{TM} low-speed saw equipped with two, three inch diameter, Norton Diamond Grinding Wheels, separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The position of the marked core fell within the 0.5 mm space between the blades, such that the core was included in the removed thin section. Otolith thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the section.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Spanish Mackerel.

8.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Spanish Mackerel annulus formation occurs between May and June (Schmidt et al. 1993). A Spanish Mackerel captured between January 1 and June 30, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 8.1). Each reader aged all of the otolith samples. All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat

Figure 8.1: Otolith thin-section of a 3 year-old Spanish Mackerel with the last annulus on the edge of the thin-section

down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Click here to obtain the protocol at the CQFE website on how to age Spanish Mackerel using their otolith thin-sections.

8.2.5 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (*CV*) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

8.3 RESULTS

8.3.1 Sample size

We estimated a sample size of 214 Spanish Mackerel in 2018, ranging in length interval from 12 to 33 inches (Table 8.1). This sample size provided a range in (*CV*) for age composition approximately from the smallest (*CV*) of 4% for Age 1 to the largest (*CV*) of 21% for Age 3. In 2018, we randomly selected and aged 201 fish from 295 Spanish Mackerel collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 32 fish. We were not short any fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would not be influenced significantly.

8.3.2 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 92% and a *CV* of 3.02% (test of symmetry: $\chi^2 = 2$, $df = 2$, $P = 0.3679$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 98% and a *CV* of 0.4% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 94.03% and a *CV* of 1.97% (test of symmetry: $\chi^2 = 4.2$, $df = 5$, $P = 0.521$) (Figure 8.2).

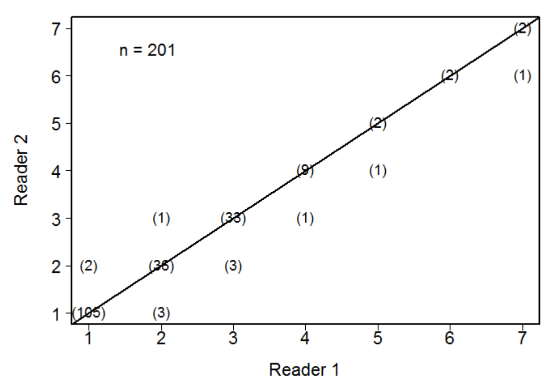


Figure 8.2: Between-reader comparison of otolith age estimates for Spanish Mackerel collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 98% with fish aged in 2003 with a *CV* of 0.94% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P =$

0.3173). Reader 2 also had an agreement of 100% .

8.3.3 Year class

Of the 201 fish aged with otoliths, 7 age classes (1 to 7) were represented (Table 8.2). The average age was 1.9 years, and the standard deviation and standard error were 1.3 and 0.09, respectively. Year-class data show that the fishery was comprised of 7 year-classes: fish from the 2011 to 2017 year-classes, with fish primarily from the year class of 2017 with 53.2%. The ratio of males to females was 1:3.33 in the sample collected (Figure 8.3).

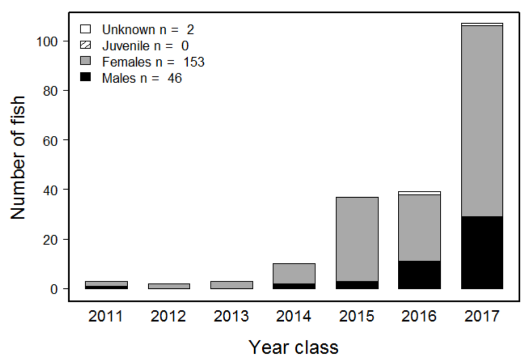


Figure 8.3: Year-class frequency distribution for Spanish Mackerel collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

8.3.4 Age-length key (ALK)

We developed an age-length-key (Table 8.3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

Table 8.1: Number of Spanish Mackerel collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
12 - 12.99	5	0	0	5
13 - 13.99	5	0	0	5
14 - 14.99	13	23	22	0
15 - 15.99	27	35	29	0
16 - 16.99	30	48	30	0
17 - 17.99	26	46	26	0
18 - 18.99	15	23	16	0
19 - 19.99	13	22	14	0
20 - 20.99	9	19	10	0
21 - 21.99	10	21	10	0
22 - 22.99	6	13	6	0
23 - 23.99	5	10	6	0
24 - 24.99	5	8	6	0
25 - 25.99	5	7	6	0
26 - 26.99	5	4	4	1
27 - 27.99	5	6	6	0
28 - 28.99	5	6	6	0
29 - 29.99	5	2	2	3
30 - 30.99	5	1	1	4
31 - 31.99	5	0	0	5
32 - 32.99	5	1	1	4
33 - 33.99	5	0	0	5
Totals	214	295	201	32

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Table 8.2: The number of Spanish Mackerel assigned to each total length-at-age category for 201 fish sampled for otolith age determination in Virginia during 2018.

	Age							
Interval	1	2	3	4	5	6	7	Totals
14 - 14.99	22	0	0	0	0	0	0	22
15 - 15.99	28	1	0	0	0	0	0	29
16 - 16.99	30	0	0	0	0	0	0	30
17 - 17.99	21	5	0	0	0	0	0	26
18 - 18.99	6	8	2	0	0	0	0	16
19 - 19.99	0	12	2	0	0	0	0	14
20 - 20.99	0	6	4	0	0	0	0	10
21 - 21.99	0	4	6	0	0	0	0	10
22 - 22.99	0	2	4	0	0	0	0	6
23 - 23.99	0	1	5	0	0	0	0	6
24 - 24.99	0	0	4	2	0	0	0	6
25 - 25.99	0	0	5	0	0	0	1	6
26 - 26.99	0	0	3	0	1	0	0	4
27 - 27.99	0	0	2	2	0	2	0	6
28 - 28.99	0	0	0	4	0	0	2	6
29 - 29.99	0	0	0	1	1	0	0	2
30 - 30.99	0	0	0	0	1	0	0	1
32 - 32.99	0	0	0	1	0	0	0	1
Totals	107	39	37	10	3	2	3	201

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Table 8.3: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Spanish Mackerel sampled for age determination in Virginia during 2018.

	Age						
Interval	1	2	3	4	5	6	7
14 - 14.99	1	0	0	0	0	0	0
15 - 15.99	0.97	0.03	0	0	0	0	0
16 - 16.99	1	0	0	0	0	0	0
17 - 17.99	0.81	0.19	0	0	0	0	0
18 - 18.99	0.38	0.5	0.12	0	0	0	0
19 - 19.99	0	0.86	0.14	0	0	0	0
20 - 20.99	0	0.6	0.4	0	0	0	0
21 - 21.99	0	0.4	0.6	0	0	0	0
22 - 22.99	0	0.33	0.67	0	0	0	0
23 - 23.99	0	0.17	0.83	0	0	0	0
24 - 24.99	0	0	0.67	0.33	0	0	0
25 - 25.99	0	0	0.83	0	0	0	0.17
26 - 26.99	0	0	0.75	0	0.25	0	0
27 - 27.99	0	0	0.33	0.33	0	0.33	0
28 - 28.99	0	0	0	0.67	0	0	0.33
29 - 29.99	0	0	0	0.5	0.5	0	0
30 - 30.99	0	0	0	0	1	0	0
32 - 32.99	0	0	0	1	0	0	0

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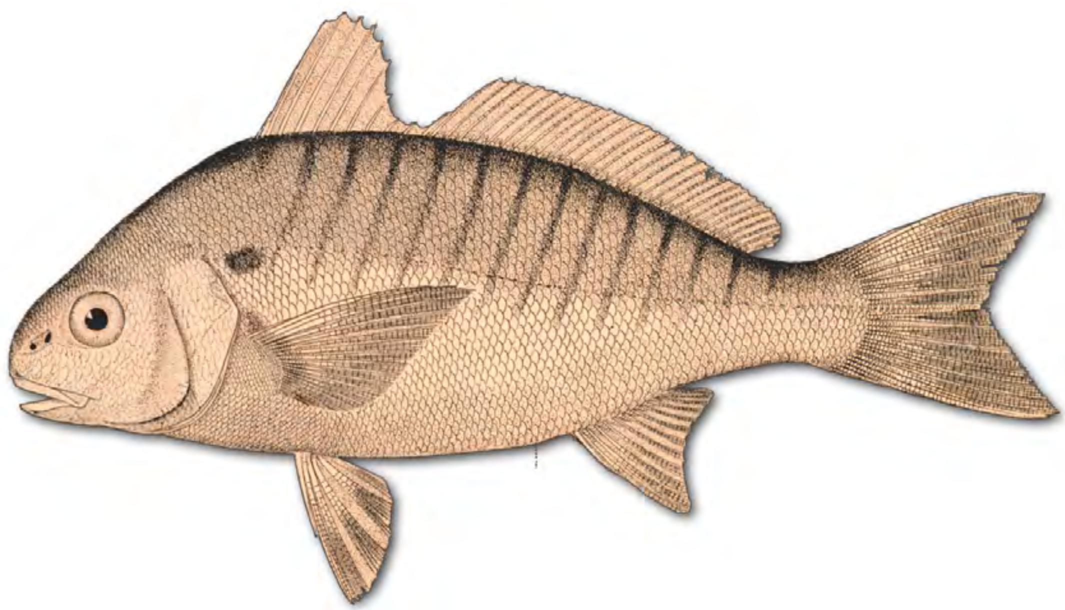
Chapter 9

SPOT *Leiostomus xanthurus*



9.1 INTRODUCTION

We aged a total of 214 Spot, *Leiostomus xanthurus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Spot ages ranged from 0 to 3 years old with an average age of 1.4, a standard deviation of 0.6, and a standard error of 0.04. Four age classes (0 to 3) were represented, comprising fish of the 2015 to 2018 year-classes. The sample was dominated by fish from the year-classes of 2016 and 2017 with 38.3% and 54.2%, respectively.

9.2 METHODS

9.2.1 Sample size for ageing

We estimated sample size for ageing Spot in 2018 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \qquad (9.1)$$

where A is the sample size for ageing Spot in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Spot used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Spot collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018.

9.2.2 Handling of collections

Otoliths were received by the Age & and Growth Laboratory in labeled coin envelopes, were sorted by date of capture. Their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

9.2.3 Preparation

Sagittal otoliths, hereafter, referred to as "otoliths", were processed for age determination following the methods described in Barbieri et al. (1994) with a few modifications. The left or right otolith was randomly selected and embedded (distal side down) in epoxy resin and allowed to harden overnight. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core was marked using a permanent marker across the epoxy resin surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet^{TM} low-speed saw equipped with two, 3-inch diameter, Norton diamond grinding wheels (hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). Thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-sections.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Spot.

9.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Spot otolith annulus formation occurs between May and July (Piner and Jones 2004). A Spot captured between January 1 and May 31, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 9.1). Each reader aged all of the otolith samples. Due to discrepancy on identification of the first annulus of Spot among Atlantic states, Atlantic States Marine Fisheries Commission (ASMFC) has decided not to count the smallest annulus at the center of the thin-section as the first annulus. Following ASMFC's instruction, we didn't count the smallest annulus at the center as the first annulus in 2018.

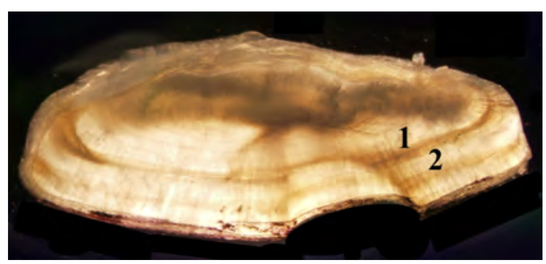


Figure 9.1: Otolith thin-section of a 2 year-old Spot

All samples were aged in chronological

order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Click here to obtain the protocol at the CQFE website on how to age Spot using their otolith thin-sections.

9.2.5 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (CV) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

9.3 RESULTS

9.3.1 Sample size

We estimated a sample size of 218 Spot in 2018, ranging in length interval from 4 to 13 inches (Table 9.1). This sample size provided a range in (CV) for age composition approximately from the smallest (CV) of 5% for Age 1 to the largest (CV) of 10% for Age 2. In 2018, we randomly selected and aged 214 fish from 296 Spot collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 14 fish. We were not short any fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would not be influenced significantly.

9.3.2 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 100% , and there was no significant difference between the first and second readings for Reader 2 with an agreement of 100% . There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 99.53% and a CV of 0.66% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$) (Figure 9.2).

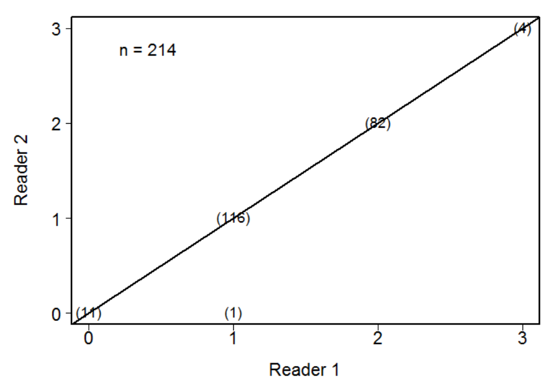


Figure 9.2: Between-reader comparison of otolith age estimates for Spot collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 96% with ages of fish aged in 2003 with a CV of 1.89% (test of symmetry: $\chi^2 = 2$, $df = 1$, $P = 0.1573$). Reader 2 also had an agreement of 100% .

9.3.3 Year class

Of the 214 fish aged with otoliths, 4 age classes (0 to 3) were represented (Table 9.2). The average age was 1.4 years, and the standard deviation and standard error were 0.6 and 0.04, respectively. Year-class data show that the fishery was comprised of 4 year-classes: fish from the 2015 to 2018 year-classes, with fish primarily from the year classes of 2016 and 2017 with 38.3% and 54.2%, respectively. The ratio of males to females was 1:5.96 in the sample collected (Figure 9.3).

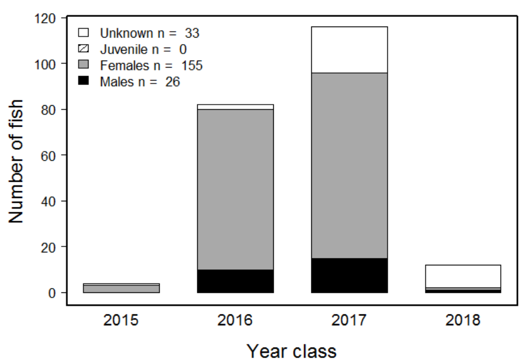


Figure 9.3: Year-class frequency distribution for Spot collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' is for gonads that were not available for examination or were not examined for sex during sampling.

9.3.4 Age-length key (ALK)

We developed an age-length-key (Table 9.3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

Table 9.1: Number of Spot collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
4 - 4.99	5	0	0	5
5 - 5.99	5	9	9	0
6 - 6.99	5	7	6	0
7 - 7.99	24	27	24	0
8 - 8.99	45	83	46	0
9 - 9.99	66	94	66	0
10 - 10.99	50	63	50	0
11 - 11.99	8	12	12	0
12 - 12.99	5	1	1	4
13 - 13.99	5	0	0	5
Totals	218	296	214	14

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Table 9.2: The number of Spot assigned to each total length-at-age category for 214 fish sampled for otolith age determination in Virginia during 2018.

	Age				
Interval	0	1	2	3	Totals
5 - 5.99	9	0	0	0	9
6 - 6.99	3	3	0	0	6
7 - 7.99	0	22	2	0	24
8 - 8.99	0	39	6	1	46
9 - 9.99	0	41	24	1	66
10 - 10.99	0	10	38	2	50
11 - 11.99	0	1	11	0	12
12 - 12.99	0	0	1	0	1
Totals	12	116	82	4	214

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Table 9.3: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Spot sampled for age determination in Virginia during 2018.

	Age			
Interval	0	1	2	3
5 - 5.99	1	0	0	0
6 - 6.99	0.5	0.5	0	0
7 - 7.99	0	0.92	0.08	0
8 - 8.99	0	0.85	0.13	0.02
9 - 9.99	0	0.62	0.36	0.02
10 - 10.99	0	0.2	0.76	0.04
11 - 11.99	0	0.08	0.92	0
12 - 12.99	0	0	1	0

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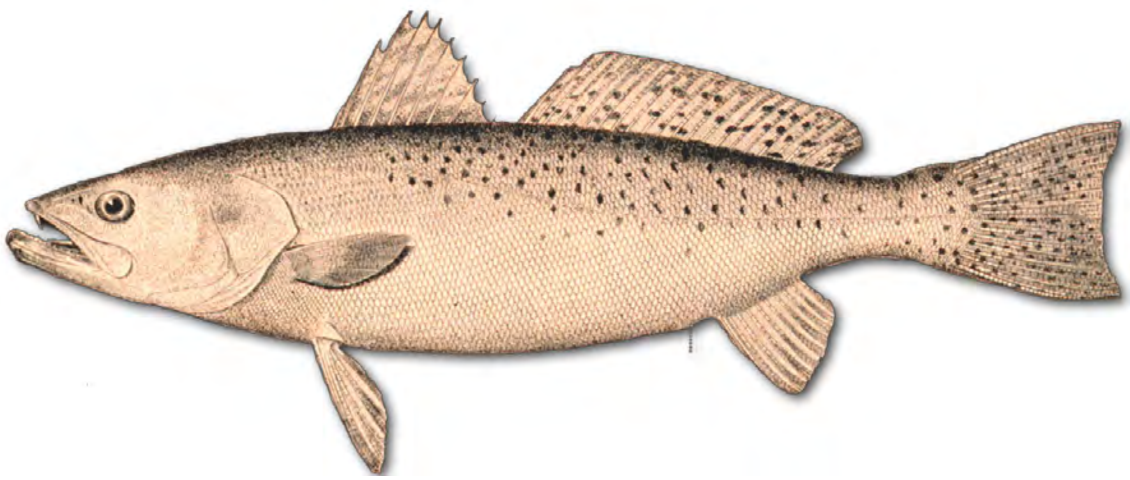
Chapter 10

SPOTTED SEATROUT *Cynoscion nebulosus*



10.1 INTRODUCTION

We aged a total of 309 Spotted Seatrout, *Cynoscion nebulosus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. Spotted seatrout ages ranged from 0 to 5 years old with an average age of 1.6, a standard deviation of 0.8, and a standard error of 0.05. Six age classes (0 to 5) were represented, comprising fish of the 2013 to 2018 year-classes. The sample was dominated by fish from the year-classes of 2016 and 2017 with 45% and 37.2%, respectively.

10.2 METHODS

10.2.1 Sample size for ageing

We estimated sample size for ageing Spotted Seatrout in 2018 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \tag{10.1}$$

where A is the sample size for ageing Spotted Seatrout in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Spotted Seatrout used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Spotted Seatrout collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018.

10.2.2 Handling of collections

Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. In the lab they were sorted by date of capture, their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

10.2.3 Preparation

Sagittal otoliths, hereafter, referred to as "otoliths", were processed for age determination. The left or right otolith was randomly selected and attached, distal side down, to a glass slide with clear Crystalbond™ 509 adhesive. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core was marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton diamond grinding wheels (hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). Thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-sections.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Spotted Seatrout.

10.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Spotted Seatrout otolith annulus formation occurs between March and May (Ihde and Chittenden 2003). A Spotted Seatrout captured between January 1 and May 31, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of May 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 10.1). Each reader aged all of the otolith samples. All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed,

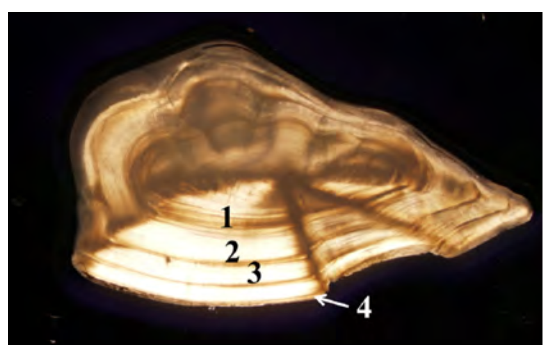


Figure 10.1: Otolith thin-section of a 4 year-old Spotted Seatrout with the last annulus on the edge of the thin-section

that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Click here to obtain the protocol at the CQFE website on how to age Spotted Seatrout using their otolith thin-sections.

10.2.5 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (*CV*) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

10.3 RESULTS

10.3.1 Sample size

We estimated a sample size of 332 Spotted Seatrout in 2018, ranging in length interval from 7 to 34 inches (Table 10.1). This sample size provided a range in (*CV*) for age composition approximately from the smallest (*CV*) of 6% for Age 1 to the largest (*CV*) of 16% for Age 4. In 2018, we randomly selected and aged 309 fish from 379 Spotted Seatrout collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 44 fish. We were not short any fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would not be influenced significantly.

10.3.2 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 98% and a CV of 0.94% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 100%. There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 100% (Figure 10.2).

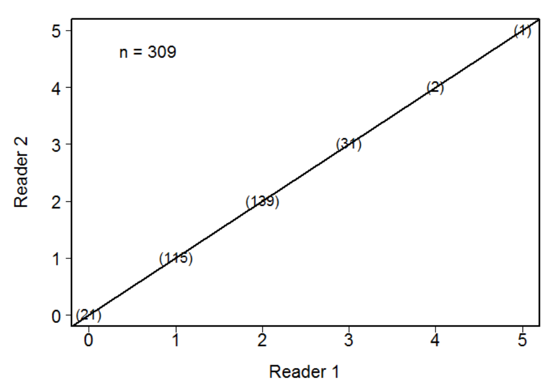


Figure 10.2: Between-reader comparison of otolith age estimates for Spotted Seatrout collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 100% with ages of fish aged in 2003. Reader 2 also had an agreement of 100%.

10.3.3 Year class

Of the 309 fish aged with otoliths, 6 age classes (0 to 5) were represented (Table 10.2). The average age was 1.6 years, and the standard deviation and standard error were 0.8 and 0.05, respectively. Year-class data show that the fishery was comprised of 6 year-classes: fish from the 2013 to 2018 year-classes, with fish primarily from the year classes of 2016 and 2017 with 45% and 37.2%, respectively. The ratio of males to females was 1:1.44 in the sample collected (Figure 10.3).

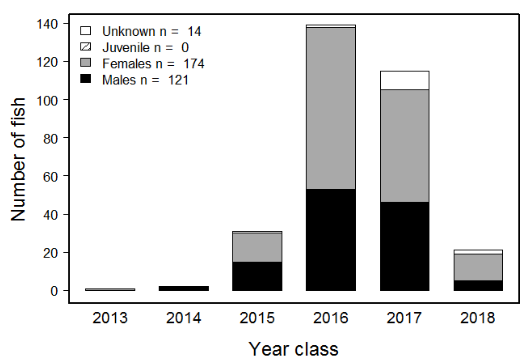


Figure 10.3: Year-class frequency distribution for Spotted Seatrout collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

10.3.4 Age-length key (ALK)

We developed an age-length-key (Table 10.3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

Table 10.1: Number of Spotted Seatrout collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
7 - 7.99	5	1	1	4
8 - 8.99	5	5	5	0
9 - 9.99	5	11	10	0
10 - 10.99	5	18	6	0
11 - 11.99	5	10	6	0
12 - 12.99	21	29	22	0
13 - 13.99	15	18	16	0
14 - 14.99	15	18	16	0
15 - 15.99	23	28	24	0
16 - 16.99	31	38	32	0
17 - 17.99	30	36	30	0
18 - 18.99	26	36	26	0
19 - 19.99	23	27	24	0
20 - 20.99	23	28	24	0
21 - 21.99	11	17	12	0
22 - 22.99	12	15	12	0
23 - 23.99	10	11	10	0
24 - 24.99	10	15	15	0
25 - 25.99	8	9	9	0
26 - 26.99	6	4	4	2
27 - 27.99	8	3	3	5
28 - 28.99	5	0	0	5
29 - 29.99	5	1	1	4
30 - 30.99	5	1	1	4
31 - 31.99	5	0	0	5
32 - 32.99	5	0	0	5
33 - 33.99	5	0	0	5
34 - 34.99	5	0	0	5
Totals	332	379	309	44

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Table 10.2: The number of Spotted Seatrout assigned to each total length-at-age category for 309 fish sampled for otolith age determination in Virginia during 2018.

	Age						
Interval	0	1	2	3	4	5	Totals
7 - 7.99	1	0	0	0	0	0	1
8 - 8.99	0	5	0	0	0	0	5
9 - 9.99	0	10	0	0	0	0	10
10 - 10.99	0	6	0	0	0	0	6
11 - 11.99	0	6	0	0	0	0	6
12 - 12.99	12	10	0	0	0	0	22
13 - 13.99	6	10	0	0	0	0	16
14 - 14.99	2	13	1	0	0	0	16
15 - 15.99	0	17	7	0	0	0	24
16 - 16.99	0	15	17	0	0	0	32
17 - 17.99	0	11	19	0	0	0	30
18 - 18.99	0	7	17	2	0	0	26
19 - 19.99	0	4	18	2	0	0	24
20 - 20.99	0	1	18	5	0	0	24
21 - 21.99	0	0	6	6	0	0	12
22 - 22.99	0	0	11	1	0	0	12
23 - 23.99	0	0	4	4	2	0	10
24 - 24.99	0	0	11	4	0	0	15
25 - 25.99	0	0	7	2	0	0	9
26 - 26.99	0	0	3	1	0	0	4
27 - 27.99	0	0	0	3	0	0	3
29 - 29.99	0	0	0	1	0	0	1
30 - 30.99	0	0	0	0	0	1	1
Totals	21	115	139	31	2	1	309

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Table 10.3: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Spotted Seatrout sampled for age determination in Virginia during 2018.

	Age					
Interval	0	1	2	3	4	5
7 - 7.99	1	0	0	0	0	0
8 - 8.99	0	1	0	0	0	0
9 - 9.99	0	1	0	0	0	0
10 - 10.99	0	1	0	0	0	0
11 - 11.99	0	1	0	0	0	0
12 - 12.99	0.55	0.45	0	0	0	0
13 - 13.99	0.38	0.62	0	0	0	0
14 - 14.99	0.12	0.81	0.06	0	0	0
15 - 15.99	0	0.71	0.29	0	0	0
16 - 16.99	0	0.47	0.53	0	0	0
17 - 17.99	0	0.37	0.63	0	0	0
18 - 18.99	0	0.27	0.65	0.08	0	0
19 - 19.99	0	0.17	0.75	0.08	0	0
20 - 20.99	0	0.04	0.75	0.21	0	0
21 - 21.99	0	0	0.5	0.5	0	0
22 - 22.99	0	0	0.92	0.08	0	0
23 - 23.99	0	0	0.4	0.4	0.2	0
24 - 24.99	0	0	0.73	0.27	0	0
25 - 25.99	0	0	0.78	0.22	0	0
26 - 26.99	0	0	0.75	0.25	0	0
27 - 27.99	0	0	0	1	0	0
29 - 29.99	0	0	0	1	0	0
30 - 30.99	0	0	0	0	0	1

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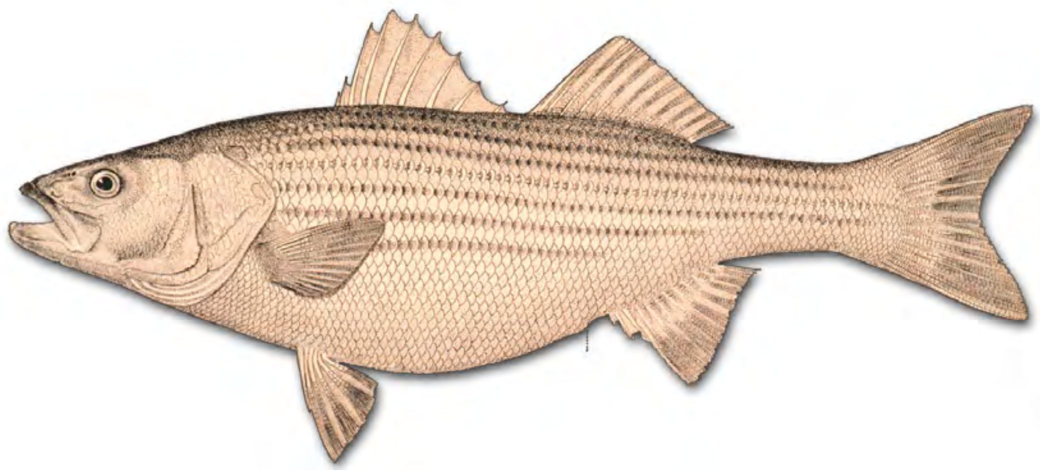
Chapter 11

STRIPED BASS *Morone saxatilis*



11.1 INTRODUCTION

We aged a total of 826 Striped Bass, *Morone saxatilis*, using their scales collected by the VMRC's Biological Sampling Program in 2018. Of 826 aged fish, 547 and 279 fish were collected in Chesapeake Bay (bay fish) and Virginia waters of the Atlantic Ocean (ocean fish), respectively. The average bay fish age was 8.6 years with a standard deviation of 4.5 and a standard error of 0.19. Twenty age classes (3 to 22) were represented in the bay fish, comprising fish from the 1996 to 2015 year classes. The bay fish sample in 2018 was dominated by the year classes of 2011, 2013, and 2014 with 22%, 14%, and 13%, respectively. The average ocean fish age was 11.9 years with a standard deviation of 3.3 and a standard error of 0.2. Sixteen age classes (7 to 22) were represented in the ocean fish, comprising fish from the 1996 to 2011 year classes. The ocean fish sample in 2018 was dominated by the year class of 2007 with 21%. We also aged a total of 271 fish using their otoliths in addition to ageing their scales. The otolith ages were compared to the scale ages to examine how close both ages were to one another (see details in Results).

11.2 METHODS

11.2.1 Sample size for ageing

We estimated sample sizes for ageing Striped Bass collected in both Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018, respectively, using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \tag{11.1}$$

where A is the sample size for ageing Striped Bass in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Striped Bass used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Striped Bass collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018.

11.2.2 Handling of collection

Sagittal otoliths (hereafter, referred to as "otoliths") and scales were received by the Age & Growth Laboratory in labeled coin envelopes, and were sorted based on date of capture. Their envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory identification number. All otoliths and scales were stored dry within their original labeled coin envelopes; otoliths were contained inside protective Axygen 2.0 ml microtubes.

11.2.3 Preparation

Scales

Striped bass scales were prepared for age and growth analysis by making acetate impressions of the scale microstructure. Due to extreme variation in the size and shape of scales from individual fish, we selected only those scales that had even margins and which were of uniform size. We selected a range of four to six preferred scales (based on overall scale size) from each fish, making sure that only non-regenerated scales were used. Scale impressions were made on extruded clear acetate sheets (25 mm x 75 mm) with a Carver Laboratory Heated Press (model "C"). The scales were pressed with the following settings:

Pressure: 15000 psi
Temperature: 77 °C (170 °F)
Time: 5 to 10 min

Striped bass scales that were the size of a quarter (coin) or larger, were pressed individually for up to twenty minutes. After pressing, the impressions were viewed with a Bell and Howell microfiche reader and checked again for regeneration and incomplete margins. Impressions that were too light, or when all scales were regenerated a new impression was made using different scales from the same fish.

Click here to obtain the protocol at the CQFE website on how to prepare scale impression for ageing Striped Bass.

Otoliths

We used our thin-section and bake technique to process Spadefish sagittal otoliths (hereafter, referred to as "otoliths") for age determination. Otolith preparation began by randomly selecting either the right or left otolith. Each whole otolith was placed in a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400 °C. Baking time was dependent on the otolith's size and gauged by color, with a light caramel color desired. Once a suitable color was achieved the baked otolith was embedded in epoxy resin with its distal surface orientated downwards and allowed to harden overnight. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core was marked using a permanent marker across the epoxy resin surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet^{TM} low-speed saw equipped with two, 3-inch diameter, Norton diamond grinding wheels (hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The otolith was positioned so the blades straddled each side of the otolith focus. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in broadening and distorted winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-section.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Striped Bass.

11.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of reading the information contained in its otolith, the date of its capture, and the species-specific period when it deposits its annulus. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called annuli. Technically, an otolith annulus is the combination of both the opaque and the translucent bands. In practice, only the opaque bands are counted as annuli. The number of these visible dark bands replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the otolith section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the dark band of the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of dark bands in the otolith. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the dark band deposition period, is interpreted as being toward the next age class.

For example, Striped Bass otolith deposition occurs between April and June (Secor et al. 1995). A Striped Bass captured between January 1 and June 30, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of June 30, the period of annulus formation, which would be noted as 4+4.

Striped bass scales are also considered to have a deposition between April and June (Secor et al. 1995), and age class assignment using these hard-parts is conducted in the same way as otoliths.

All Striped Bass samples (scale pressings and sectioned otoliths) were aged by two different readers in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish again without any knowledge of previously estimated ages or lengths, then assigned a final age to the fish. When the age readers were unable to agree on a final age, the fish was excluded from further analysis.

Scales

We determined fish age by viewing acetate impressions of scales (Figure 11.1) with a standard Bell and Howell R-735 microfiche reader equipped with 20 and 29 mm lenses. Annuli on Striped Bass scales are identi-

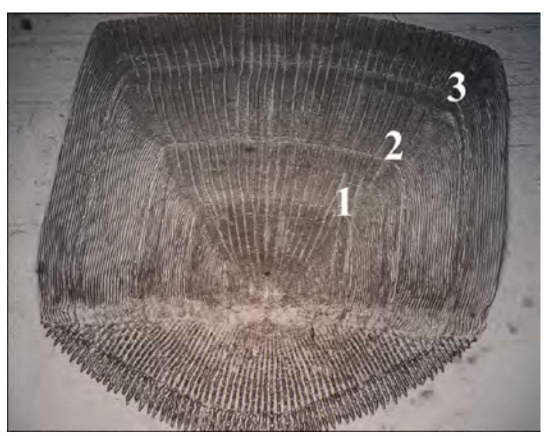


Figure 11.1: Scale impression of a 3 year-old Striped Bass.

fied based on two scale microstructure features, "crossing over" and circuli disruption. Primarily, "crossing over" in the lateral margins near the posterior/anterior interface of the scale is used to determine the origin of the annulus. Here compressed circuli (annulus) "cross-over" the previously deposited circuli of the previous year's growth. Typically annuli of the first three years can be observed transversing this interface as dark bands. These bands remain consistent throughout the posterior field and rejoin the posterior/anterior interface on the opposite side of the focus. Annuli can also be observed in the anterior lateral field of the scale. Here the annuli typically reveal a pattern of discontinuous and suddenly breaking segmented circuli. This event can also be distinguished by the presence of concentric white lines, which are typically associated with the disruption of circuli.

Annuli can also be observed bisecting the perpendicular plain of the radial striations in the anterior field of the scale. Radii emanate out from the focus of the scale towards the outer corner margins of the anterior field. These radial striations consist mainly of segmented concave circuli. The point of intersection between radii and annuli results in a "straightening out" of the concave circuli. This straightening of the circuli should be consistent throughout the entire anterior field of the scale. This event is further amplified by the presence of concave circuli neighboring both directly above and below the annulus. The first year's annulus can be difficult to locate on some scales. It is typically best identified in the lateral field of the anterior portion of the scale. The distance from the focus to the first year's annulus is typically larger with respect to the following annuli. For the annuli two through six, summer growth generally decreases proportionally. For ages greater than six, a crowding effect of the annuli near the outer margins of the scale is observed. This crowding effect creates difficulties in edge interpretation. At this point it is best to focus on the straightening of the circuli at the anterior margins of the scale.

When ageing young Striped Bass, zero through age two, extreme caution must be taken as not to over age the structure. In young fish there is no point of reference to aid in the determination of the first year; this invariably results in over examination of the scale and such events as hatching or saltwater incursion marks (checks) may be interpreted as the first year.

Otoliths

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 11.2). Each reader aged all of the otolith samples. By convention an annulus is identified as the narrow opaque zone, or winter growth. Typically the first year's annulus can be determined by first locating the focus of the otolith. The focus is generally located, depending on preparation, in the center of the otolith, and is visually well defined as a dark oblong region. The first year's annulus can be located directly below the focus, along the outer ridge of the sulcal groove on the ventral and dorsal sides of the otolith. This insertion point along the sulcal ridge resembles a check mark (not to be confused with a false annulus). Here the annulus can be followed outwards along the ventral and dorsal surfaces where it encircles the focus.

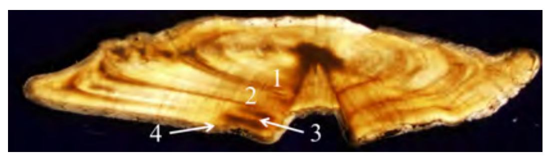


Figure 11.2: Otolith thin-section of a 4 year-old Striped Bass with the last annulus on the edge of the thin-section

Subsequent annuli also emanate from the sulcal ridge; however, they do not encircle the focus, but rather travel outwards to the distal surface of the otolith. To be considered a true annulus, each annulus must be rooted in the sulcus and travel without interruption to the distal surface of the otolith. The annuli in Striped Bass have a tendency to split as they advance towards the distal surface. As a result, it is critical that reading path proceed in a direction down the sulcal ridge and outwards to the distal surface.

Click here to obtain the protocol at the CQFE website on how to age Striped Bass using their otolith thin-sections.

11.2.5 Comparison Tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (*CV*) analysis were used to detect any systematic difference and precision on age readings, respectively, for following comparisons: 1) between the two readers in the current year; 2) within each reader in the current year; 3) time-series bias between the current and previous years within each reader; and 4) between scale and otoliths ages. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

11.3 RESULTS

11.3.1 Sample size

We estimated a sample size of 538 bay Striped Bass in 2018, ranging in length interval from 17 to 53 inches (Table 11.1). This sample size provided a range in *CV* for age composition approximately from the smallest *CV* of 10% for Age 5 to the largest *CV* of 23% for Age 13 of the bay fish. We randomly selected and aged 547 fish from 853 Striped Bass collected by VMRC in Chesapeake Bay in 2018. We fell short in our over-all collections for this optimal length-class sampling estimate by 46 fish. We were short only a few fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would not be influenced significantly.

We estimated a sample size of 458 ocean Striped Bass in 2018, ranging in length interval from 28 to 56 inches (Table 11.2). This sample size provided a range in *CV* for age composition approximately from the smallest *CV* of 10% for Age 10 to the largest *CV* of 22% for Age 8, 16, and 17 of the ocean fish. We aged all 279 Striped Bass collected by VMRC in Virginia waters of the Atlantic Ocean in 2018. We fell short in our over-all collections for this optimal length-class sampling estimate by 186 fish. We were short many fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would definitely be influenced significantly. Therefore, precaution should be used when developing ALK using these age data.

11.3.2 Scales

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 78% (1 year or less agreement of 98%) and a *CV* of

2.1% (test of symmetry: $\chi^2 = 7$, $df = 8$, $P = 0.5366$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 80% (1 year or less agreement of 100%) and a CV of 1.3% (test of symmetry: $\chi^2 = 7.33$, $df = 5$, $P = 0.197$). There was an evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 63% (1 year or less agreement of 89%) and a CV of 3.67% (test of symmetry: $\chi^2 = 97.85$, $df = 53$, $P = 0.0002$) (Figure 11.3).

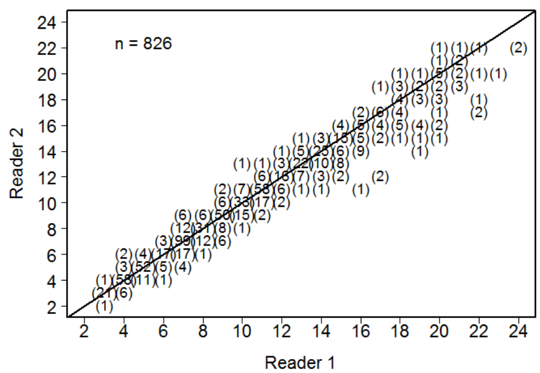


Figure 11.3: Between-reader comparison of scale age estimates for Striped Bass collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

Reader 1 had no time series bias while Read 2 did. Reader 1 had an agreement of 63% (1 year or less agreement of 92%) with ages of fish aged in 2000 with a CV of 4.58% (test of symmetry: $\chi^2 = 14.67$, $df = 15$, $P = 0.4757$). Reader 2 had an agreement of 62% (1 year or less agreement of 95%) with a CV of 4.61% (test of symmetry: $\chi^2 = 23$, $df = 13$, $P = 0.0417$).

Of the 547 bay Striped Bass aged with scales, 20 age classes (3 to 22) were represented (Table 11.3). The average age for the sample was 8.6 years. The standard deviation and standard error were 4.5 and 0.19, respectively. Year-class data (Figure 11.4) indicates that recruitment into the fishery in Chesapeake Bay begins at age 3, which corresponds to the 2015 year-class for Striped Bass caught in 2018. Striped bass in the sample in 2018 was dominated by the year classes of 2011, 2013, and 2014 with 22%, 14%, and 13%, respectively. The sex ratio of male to female was 1:2.01 for the bay fish.

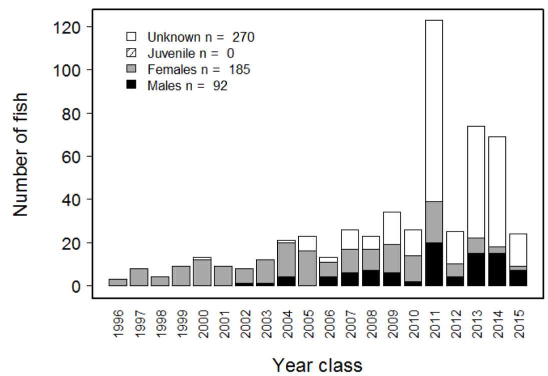


Figure 11.4: Year-class frequency distribution for Striped Bass collected in Chesapeake Bay, Virginia for ageing in 2018. Distribution is broken down by sex and estimated using scale ages. 'Unknown' represents the fish gonads that were not available for examination or were not examined for sex during sampling.

Of the 279 ocean Striped Bass aged with scales, 16 age classes (7 to 22) were represented (Table 11.4). The average age for the sample was 11.9 years. The standard deviation and standard error were 3.3 and 0.2, respectively. Year-class data (Figure 11.5) indicates that recruitment into the fishery in Virginia waters of Atlantic ocean begins at age 7, which corresponds to the 2011 year-class for Striped Bass caught in 2018. Striped bass in the sample in 2018 was dominated by the year class of 2007 with 21%. The sex ratio of male to female was 1:3.45 for the ocean fish.

11.3.3 Otoliths

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 78% and

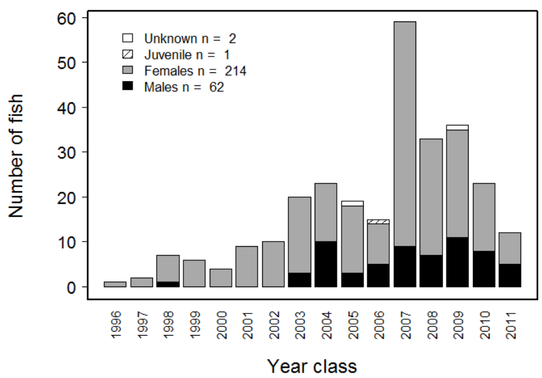


Figure 11.5: Year-class frequency distribution for Striped Bass collected in Virginia waters of the Atlantic Ocean for ageing in 2018. Distribution is broken down by sex and estimated using scale ages. 'Unknown' represents the fish gonads that were not available for examination or were not examined for sex during sampling.

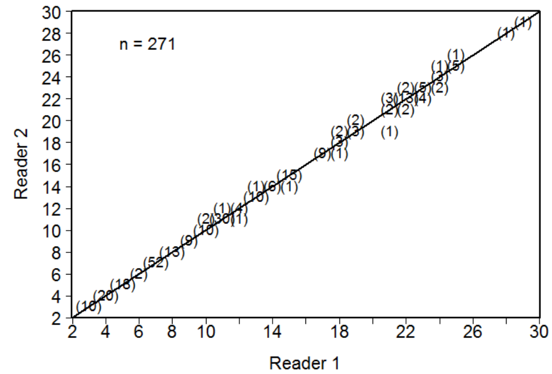


Figure 11.6: Between-reader comparison of otolith age estimates for Striped Bass collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

a *CV* of 1.05% (test of symmetry: $\chi^2 = 11$, $df = 10$, $P = 0.3575$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 88% and a *CV* of 1.02% (test of symmetry: $\chi^2 = 4$, $df = 5$, $P = 0.5494$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 90% (1 year or less agreement of 100%) and a *CV* of 0.4% (test of symmetry: $\chi^2 = 14.87$, $df = 13$, $P = 0.3158$) (Figure 11.6).

There was no time-series bias for either reader. Reader 1 had an agreement of 90% with ages of fish aged in 2003 with a *CV* of 0.96% (test of symmetry: $\chi^2 = 6$, $df = 6$, $P = 0.4232$). Reader 2 had an agreement of 82% with a *CV* of 1.4% (test of symmetry: $\chi^2 = 8.33$, $df = 7$, $P = 0.3041$).

Of the 271 Striped Bass aged with otoliths, 24 age classes (3 to 15, 17 to 25, and 28 to 29) were represented (Table 11.5). The average age for the sample was 11.7 years. The standard deviation and standard error were 6.5 and 0.39, respectively.

11.3.4 Comparison of scale and otolith ages

We aged 271 Striped Bass using scales and otoliths. There was an evidence of systematic disagreement between otolith and scale ages (test of symmetry: $\chi^2 = 100.44$, $df = 56$, $P = 0.0002$) with an average *CV* of 5.48%. There was an agreement of 52% between scale and otoliths ages whereas scales were assigned a lower and higher age than otoliths for 41% and 7% of the fish, respectively (Figure 11.7). There was also an evidence of bias between otolith and scale ages using an age bias plot (Figure 11.8), with scale generally assigned higher ages for younger fish and lower ages for older fish than otolith age estimates.

11.3.5 Age-Length-Key (ALK)

We developed an age-length-key for both bay (Table 11.6) and ocean fish (Table 11.7) using scale ages, separately. The ALK can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using scale ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

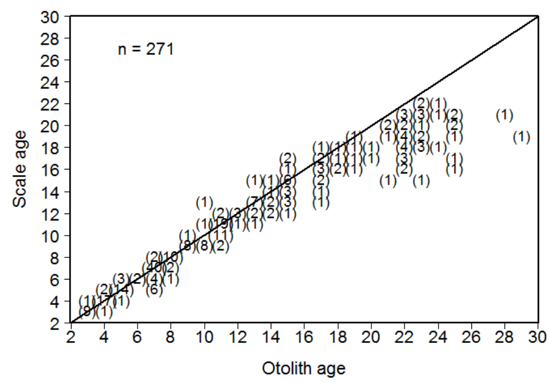


Figure 11.7: Comparison of scale and otolith age estimates for Striped Bass collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

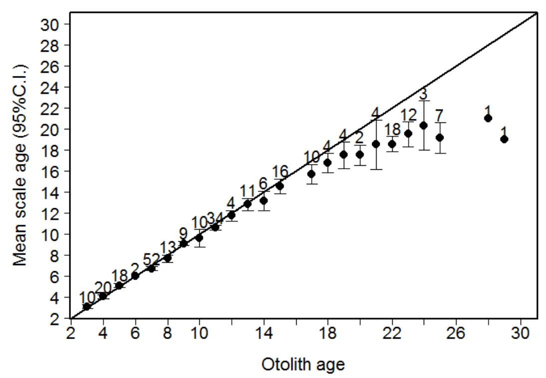


Figure 11.8: Age-bias plot for Striped Bass scale and otolith age estimates in 2018. The number above the upper CI bar is number of fish.

11.4 RECOMMENDATIONS

We recommend that VMRC and ASMFC use otoliths for ageing Striped Bass. Although preparation time is greater for otoliths compared to scales, nonetheless as the mean age of Striped Bass increases in the recovering fishery, otoliths should provide more reliable estimates of age (Secor et al. 1995; Liao et al. 2013). We will continue to compare the age estimates between otoliths and scales.

Table 11.1: Number of bay Striped Bass collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
17 - 17.99	5	0	0	5
18 - 18.99	10	28	10	0
19 - 19.99	20	43	20	0
20 - 20.99	23	55	26	0
21 - 21.99	26	47	26	0
22 - 22.99	26	49	26	0
23 - 23.99	28	50	30	0
24 - 24.99	28	50	29	0
25 - 25.99	25	36	27	0
26 - 26.99	25	39	27	0
27 - 27.99	22	42	23	0
28 - 28.99	17	33	19	0
29 - 29.99	15	26	19	0
30 - 30.99	13	27	15	0
31 - 31.99	15	22	17	0
32 - 32.99	18	26	18	0
33 - 33.99	18	26	21	0
34 - 34.99	19	18	18	1
35 - 35.99	22	17	17	5
36 - 36.99	25	17	17	8
37 - 37.99	23	18	18	5
38 - 38.99	15	23	23	0
39 - 39.99	10	14	10	0
40 - 40.99	10	18	10	0
41 - 41.99	8	18	10	0
42 - 42.99	8	19	10	0
43 - 43.99	8	18	8	0
44 - 44.99	9	15	11	0
45 - 45.99	6	21	11	0
46 - 46.99	6	18	12	0
47 - 47.99	5	12	11	0
48 - 48.99	5	3	3	2
49 - 49.99	5	2	2	3
50 - 50.99	5	1	1	4
51 - 51.99	5	1	1	4
52 - 52.99	5	1	1	4
53 - 53.99	5	0	0	5
Totals	538	853	547	46

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Table 11.2: Number of ocean Striped Bass collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
28 - 28.99	5	3	3	2
29 - 29.99	5	2	2	3
30 - 30.99	7	4	4	3
31 - 31.99	7	2	2	5
32 - 32.99	11	6	6	5
33 - 33.99	23	8	8	15
34 - 34.99	25	16	16	9
35 - 35.99	44	28	28	16
36 - 36.99	58	35	35	23
37 - 37.99	64	41	41	23
38 - 38.99	44	26	26	18
39 - 39.99	30	18	18	12
40 - 40.99	23	14	14	9
41 - 41.99	19	17	17	2
42 - 42.99	15	11	11	4
43 - 43.99	12	7	7	5
44 - 44.99	13	7	7	6
45 - 45.99	10	7	7	3
46 - 46.99	6	8	8	0
47 - 47.99	7	12	12	0
48 - 48.99	5	3	3	2
49 - 49.99	5	2	2	3
50 - 50.99	5	1	1	4
51 - 51.99	5	1	1	4
52 - 52.99	5	0	0	5
56 - 56.99	5	0	0	5
Totals	458	279	279	186

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Table 11.3: The number of Striped Bass assigned to each total length-at-age category for 547 fish sampled for scale age determination in Chesapeake Bay, Virginia during 2018.

	Age																				
Interval	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Totals
18 - 18.99	8	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
19 - 19.99	5	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
20 - 20.99	4	16	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26
21 - 21.99	5	10	9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26
22 - 22.99	0	9	11	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26
23 - 23.99	0	11	13	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
24 - 24.99	1	8	6	5	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29
25 - 25.99	1	1	8	4	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27
26 - 26.99	0	1	2	2	19	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27
27 - 27.99	0	0	5	1	14	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	23
28 - 28.99	0	0	3	0	11	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	19
29 - 29.99	0	0	2	0	13	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	19
30 - 30.99	0	0	2	3	6	1	1	0	0	0	2	0	0	0	0	0	0	0	0	0	15
31 - 31.99	0	0	1	0	4	4	3	2	2	1	0	0	0	0	0	0	0	0	0	0	17
32 - 32.99	0	0	2	0	8	2	2	1	2	0	1	0	0	0	0	0	0	0	0	0	18
33 - 33.99	0	0	0	2	7	2	2	0	4	2	2	0	0	0	0	0	0	0	0	0	21
34 - 34.99	0	0	0	0	4	3	4	1	2	1	2	1	0	0	0	0	0	0	0	0	18
35 - 35.99	0	0	0	0	5	2	5	4	0	0	0	0	1	0	0	0	0	0	0	0	17
36 - 36.99	0	0	0	0	2	2	7	2	2	1	0	0	1	0	0	0	0	0	0	0	17
37 - 37.99	0	0	0	0	1	1	5	3	3	2	2	1	0	0	0	0	0	0	0	0	18
38 - 38.99	0	0	0	0	1	1	1	3	6	2	3	5	0	1	0	0	0	0	0	0	23
39 - 39.99	0	0	0	0	0	0	0	2	2	0	3	1	2	0	0	0	0	0	0	0	10
40 - 40.99	0	0	0	0	0	0	0	2	0	3	3	1	1	0	0	0	0	0	0	0	10
41 - 41.99	0	0	0	0	0	0	0	0	2	1	2	4	0	0	1	0	0	0	0	0	10
42 - 42.99	0	0	0	0	0	0	0	0	0	0	1	2	1	2	0	3	1	0	0	0	10
43 - 43.99	0	0	0	0	0	0	0	0	0	0	1	0	3	1	0	1	1	0	1	0	8
44 - 44.99	0	0	0	0	0	0	0	0	1	0	1	1	1	1	2	1	2	0	1	0	11
45 - 45.99	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	4	0	2	2	1	11
46 - 46.99	0	0	0	0	0	0	0	0	0	0	0	2	0	2	1	2	1	1	2	1	12
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	2	1	3	0	1	1	2	1	11
48 - 48.99	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	3
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Totals	24	69	74	25	123	26	34	23	26	13	23	21	12	8	9	13	9	4	8	3	547

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Table 11.4: The number of Striped Bass assigned to each total length-at-age category for 279 fish sampled for scale age determination in Virginia waters of Atlantic ocean during 2018.

	Age																
Interval	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Totals
28 - 28.99	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
29 - 29.99	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
30 - 30.99	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	4
31 - 31.99	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
32 - 32.99	3	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	6
33 - 33.99	0	4	0	1	0	0	0	2	1	0	0	0	0	0	0	0	8
34 - 34.99	1	4	5	4	0	1	0	1	0	0	0	0	0	0	0	0	16
35 - 35.99	2	3	4	4	8	2	0	5	0	0	0	0	0	0	0	0	28
36 - 36.99	1	6	12	4	6	2	1	1	2	0	0	0	0	0	0	0	35
37 - 37.99	0	3	10	9	5	3	6	4	1	0	0	0	0	0	0	0	41
38 - 38.99	0	0	1	2	10	1	3	3	4	1	0	0	0	1	0	0	26
39 - 39.99	0	0	3	2	9	1	1	1	0	0	0	0	1	0	0	0	18
40 - 40.99	0	0	0	1	11	0	0	0	2	0	0	0	0	0	0	0	14
41 - 41.99	0	0	0	2	7	2	3	2	1	0	0	0	0	0	0	0	17
42 - 42.99	0	0	0	3	1	2	1	0	2	2	0	0	0	0	0	0	11
43 - 43.99	0	0	0	0	0	0	0	2	3	1	0	1	0	0	0	0	7
44 - 44.99	0	0	0	0	0	0	1	1	1	2	1	0	0	1	0	0	7
45 - 45.99	0	0	0	0	0	0	2	1	1	1	2	0	0	0	0	0	7
46 - 46.99	0	0	0	0	0	0	0	0	1	2	1	0	2	1	1	0	8
47 - 47.99	0	0	0	0	0	0	0	0	1	1	4	3	1	1	0	1	12
48 - 48.99	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	3
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Totals	12	23	36	33	59	15	19	23	20	10	9	4	6	7	2	1	279

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Table 11.5: The number of Striped Bass assigned to each total length-at-age category for 271 fish sampled for otolith age determination in Chesapeake Bay and Virginia waters of Atlantic Ocean during 2018.

	Age																							
Interval	3	4	5	6	7	8	9	10	11	12	13	14	15	17	18	19	20	21	22	23	24	25	28	29	Totals
18 - 18.99	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
19 - 19.99	0	3	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
20 - 20.99	4	5	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
21 - 21.99	1	3	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
22 - 22.99	0	1	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
23 - 23.99	0	2	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
24 - 24.99	0	3	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
25 - 25.99	0	1	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
26 - 26.99	0	0	1	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
27 - 27.99	0	0	1	1	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
28 - 28.99	0	1	0	0	6	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
29 - 29.99	0	0	0	0	6	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
30 - 30.99	0	0	1	0	4	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	10
31 - 31.99	0	0	0	0	0	4	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	7
32 - 32.99	0	0	0	0	6	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	9
33 - 33.99	0	0	0	1	4	1	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	10
34 - 34.99	0	0	0	0	1	1	1	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
35 - 35.99	0	0	0	0	1	2	2	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	8
36 - 36.99	0	0	0	0	0	0	3	3	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	10
37 - 37.99	0	0	0	0	1	0	1	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
38 - 38.99	0	0	0	0	0	0	0	0	4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	7
39 - 39.99	0	0	0	0	0	0	0	0	4	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0	8
40 - 40.99	0	0	0	0	0	0	0	0	3	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	6
41 - 41.99	0	0	0	0	0	0	0	0	3	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	7
42 - 42.99	0	0	0	0	0	0	0	0	3	0	1	1	2	0	1	1	0	0	1	1	0	1	0	1	13
43 - 43.99	0	0	0	0	0	0	0	0	0	0	1	1	2	3	0	0	0	0	2	0	1	0	0	0	10
44 - 44.99	0	0	0	0	0	0	0	0	1	0	2	0	2	1	0	0	0	1	3	1	0	0	0	0	11
45 - 45.99	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	1	0	1	3	0	1	1	0	11
46 - 46.99	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	2	3	1	3	0	0	12
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	1	4	3	0	0	0	0	12
48 - 48.99	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	1	1	0	0	5
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	3
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	2
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Totals	10	20	18	2	52	13	9	10	34	4	11	6	16	10	4	4	2	4	18	12	3	7	1	1	271

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Table 11.6: Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for Striped Bass sampled in Chesapeake Bay, Virginia during 2018.

	Age																			
Interval	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
18 - 18.99	0.8	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 - 19.99	0.25	0.55	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 - 20.99	0.15	0.62	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 - 21.99	0.19	0.38	0.35	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 - 22.99	0	0.35	0.42	0.12	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 - 23.99	0	0.37	0.43	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24 - 24.99	0.03	0.28	0.21	0.17	0.31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25 - 25.99	0.04	0.04	0.3	0.15	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 - 26.99	0	0.04	0.07	0.07	0.7	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27 - 27.99	0	0	0.22	0.04	0.61	0.04	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0
28 - 28.99	0	0	0.16	0	0.58	0.11	0.16	0	0	0	0	0	0	0	0	0	0	0	0	0
29 - 29.99	0	0	0.11	0	0.68	0.11	0.05	0.05	0	0	0	0	0	0	0	0	0	0	0	0
30 - 30.99	0	0	0.13	0.2	0.4	0.07	0.07	0	0	0	0.13	0	0	0	0	0	0	0	0	0
31 - 31.99	0	0	0.06	0	0.24	0.24	0.18	0.12	0.12	0.06	0	0	0	0	0	0	0	0	0	0
32 - 32.99	0	0	0.11	0	0.44	0.11	0.11	0.06	0.11	0	0.06	0	0	0	0	0	0	0	0	0
33 - 33.99	0	0	0	0.1	0.33	0.1	0.1	0	0.19	0.1	0.1	0	0	0	0	0	0	0	0	0
34 - 34.99	0	0	0	0	0.22	0.17	0.22	0.06	0.11	0.06	0.11	0.06	0	0	0	0	0	0	0	0
35 - 35.99	0	0	0	0	0.29	0.12	0.29	0.24	0	0	0	0	0.06	0	0	0	0	0	0	0
36 - 36.99	0	0	0	0	0.12	0.12	0.41	0.12	0.12	0.06	0	0	0.06	0	0	0	0	0	0	0
37 - 37.99	0	0	0	0	0.06	0.06	0.28	0.17	0.17	0.11	0.11	0.06	0	0	0	0	0	0	0	0
38 - 38.99	0	0	0	0	0.04	0.04	0.04	0.13	0.26	0.09	0.13	0.22	0	0.04	0	0	0	0	0	0
39 - 39.99	0	0	0	0	0	0	0	0.2	0.2	0	0.3	0.1	0.2	0	0	0	0	0	0	0
40 - 40.99	0	0	0	0	0	0	0	0.2	0	0.3	0.3	0.1	0.1	0	0	0	0	0	0	0
41 - 41.99	0	0	0	0	0	0	0	0	0.2	0.1	0.2	0.4	0	0	0.1	0	0	0	0	0
42 - 42.99	0	0	0	0	0	0	0	0	0	0	0.1	0.2	0.1	0.2	0	0.3	0.1	0	0	0
43 - 43.99	0	0	0	0	0	0	0	0	0	0	0.12	0	0.38	0.12	0	0.12	0.12	0	0.12	0
44 - 44.99	0	0	0	0	0	0	0	0	0.09	0	0.09	0.09	0.09	0.09	0.18	0.09	0.18	0	0.09	0
45 - 45.99	0	0	0	0	0	0	0	0	0	0	0	0.18	0	0	0	0.36	0	0.18	0.18	0.09
46 - 46.99	0	0	0	0	0	0	0	0	0	0	0	0.17	0	0.17	0.08	0.17	0.08	0.08	0.17	0.08
47 - 47.99	0	0	0	0	0	0	0	0	0	0	0	0	0.18	0.09	0.27	0	0.09	0.09	0.18	0.09
48 - 48.99	0	0	0	0	0	0	0	0	0	0	0	0.33	0	0	0.33	0.33	0	0	0	0
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
52 - 52.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

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Table 11.7: Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for Striped Bass sampled in Virginia waters of the Atlantic Ocean during 2018.

	Age															
Interval	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
28 - 28.99	0.67	0	0	0	0.33	0	0	0	0	0	0	0	0	0	0	0
29 - 29.99	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 - 30.99	0.5	0	0.25	0.25	0	0	0	0	0	0	0	0	0	0	0	0
31 - 31.99	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 - 32.99	0.5	0	0	0	0.17	0.17	0.17	0	0	0	0	0	0	0	0	0
33 - 33.99	0	0.5	0	0.12	0	0	0	0.25	0.12	0	0	0	0	0	0	0
34 - 34.99	0.06	0.25	0.31	0.25	0	0.06	0	0.06	0	0	0	0	0	0	0	0
35 - 35.99	0.07	0.11	0.14	0.14	0.29	0.07	0	0.18	0	0	0	0	0	0	0	0
36 - 36.99	0.03	0.17	0.34	0.11	0.17	0.06	0.03	0.03	0.06	0	0	0	0	0	0	0
37 - 37.99	0	0.07	0.24	0.22	0.12	0.07	0.15	0.1	0.02	0	0	0	0	0	0	0
38 - 38.99	0	0	0.04	0.08	0.38	0.04	0.12	0.12	0.15	0.04	0	0	0	0.04	0	0
39 - 39.99	0	0	0.17	0.11	0.5	0.06	0.06	0.06	0	0	0	0	0.06	0	0	0
40 - 40.99	0	0	0	0.07	0.79	0	0	0	0.14	0	0	0	0	0	0	0
41 - 41.99	0	0	0	0.12	0.41	0.12	0.18	0.12	0.06	0	0	0	0	0	0	0
42 - 42.99	0	0	0	0.27	0.09	0.18	0.09	0	0.18	0.18	0	0	0	0	0	0
43 - 43.99	0	0	0	0	0	0	0	0.29	0.43	0.14	0	0.14	0	0	0	0
44 - 44.99	0	0	0	0	0	0	0.14	0.14	0.14	0.29	0.14	0	0	0.14	0	0
45 - 45.99	0	0	0	0	0	0	0.29	0.14	0.14	0.14	0.29	0	0	0	0	0
46 - 46.99	0	0	0	0	0	0	0	0	0.12	0.25	0.12	0	0.25	0.12	0.12	0
47 - 47.99	0	0	0	0	0	0	0	0	0.08	0.08	0.33	0.25	0.08	0.08	0	0.08
48 - 48.99	0	0	0	0	0	0	0	0	0	0	0.33	0	0.33	0.33	0	0
49 - 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0
50 - 50.99	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
51 - 51.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

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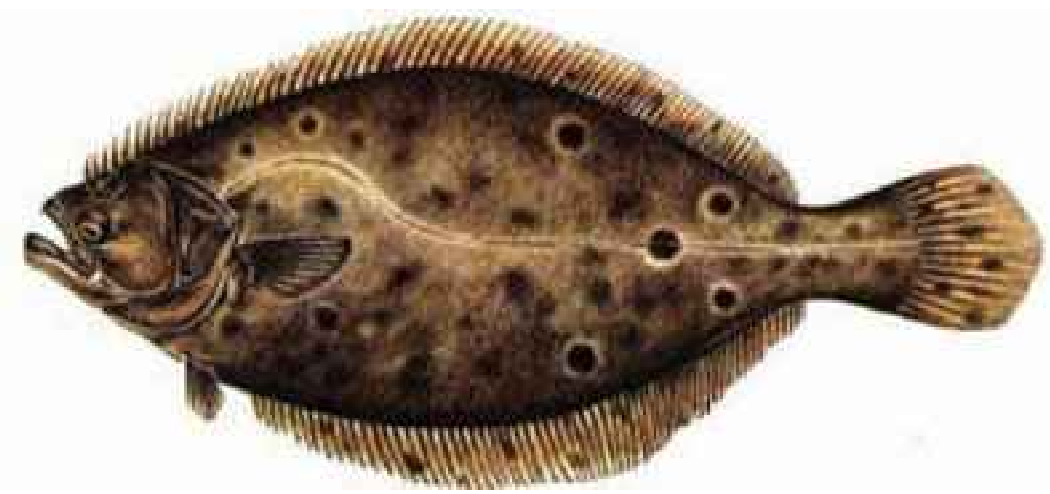
Chapter 12

SUMMER FLOUNDER *Paralichthys dentatus*



12.1 INTRODUCTION

We aged a total of 857 Summer Flounder,*Paralichthys dentatus*, using their scales collected by the VMRC's Biological Sampling Program in 2018. Of 857 aged fish, 327 and 530 fish were collected in Chesapeake Bay (bay fish) and Virginia waters of the Atlantic Ocean (ocean fish), respectively. The average bay fish age was 2.8 years with a standard deviation of 1.4 and a standard error of 0.08. Eight age classes (1 to 8) were represented in the bay fish, comprising fish from the 2010 to 2017 year classes. The bay fish sample in 2018 was dominated by the year class of 2016 with 50%. The average ocean fish age was 5.2 years with a standard deviation of 2.2 and a standard error of 0.1. Fourteen age classes (0 to 12, and 14) were represented in the ocean fish, comprising fish from the 2004, and 2006 to 2018 year classes. The ocean fish sample in 2018 was dominated by the year classes of 2013 and 2014 with 21% and 22%, respectively. We also aged a total of 245 fish using their otoliths in addition to ageing their scales. The otolith ages were compared to the scale ages to examine how close both ages were to one another (see details in Results).

12.2 METHODS

12.2.1 Sample size for ageing

We estimated sample sizes for ageing Summer Flounder collected in both Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018, respectively, using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \tag{12.1}$$

where A is the sample size for ageing Summer Flounder in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Summer Flounder used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Summer Flounder collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018.

12.2.2 Handling of collection

Sagittal otoliths (hereafter, referred to as "otoliths") and scales were received by the Age & Growth Laboratory in labeled coin envelopes, and were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory identification number. All otoliths and scales were stored dry within their original labeled coin envelopes; otoliths were contained inside protective Axygen 2.0 ml microtubes.

12.2.3 Preparation

Scales

Summer flounder scales were prepared for age and growth analysis by making acetate impressions of the scale microstructure. Due to extreme variation in the size and shape of scales from individual fish, we selected only those scales that had even margins and which were of uniform size. We selected a range of four to six preferred scales (based on overall scale size) from each fish, making sure that only non-regenerated scales were used. Scale impressions were made on extruded clear acetate sheets (25 mm x 75 mm) with a Carver Laboratory Heated Press (model "C"). The scales were pressed with the following settings:

Pressure: 15000 psi
Temperature: 77 °C (170 °F)
Time: 5 to 10 min

Summer Flounder scales that were the size of a quarter (coin) or larger, were pressed individually for up to twenty minutes. After pressing, the impressions were viewed with a Bell and Howell microfiche reader and checked again for regeneration and incomplete margins. Impressions that were too light, or when all scales were regenerated a new impression was made using different scales from the same fish.

Click here to obtain the protocol at the CQFE website on how to prepare scale impression for ageing Summer Flounder.

Otoliths

We used our thin-section and bake technique to process Spadefish sagittal otoliths (hereafter, referred to as "otoliths") for age determination. Otolith preparation began by randomly selecting either the right or left otolith. Each whole otolith was placed in a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400 °C. Baking time was dependent on the otolith's size and gauged by color, with a light caramel color desired. Once a suitable color was achieved the baked otolith was embedded in epoxy resin with its distal surface orientated downwards and allowed to harden overnight. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core was marked using a permanent marker across the epoxy resin surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton diamond grinding wheels (hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The otolith was positioned so the blades straddled each side of the otolith focus. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in broadening and distorted winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-section.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Summer Flounder.

12.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of reading the information contained in its otolith, the date of its capture, and the species-specific period when it deposits its annulus. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called annuli. Technically, an otolith annulus is the combination of both the opaque and the translucent bands. In practice, only the opaque bands are counted as annuli. The number of these visible dark bands replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the otolith section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the dark band of the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of dark bands in the otolith. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the dark band deposition period, is interpreted as being toward the next age class.

For example, Summer Flounder otolith deposition occurs between January and April (Bolz 1999). A Summer Flounder captured between January 1 and April 30, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of June 30, the period of annulus formation, which would be noted as 4+4.

Summer flounder scales are also considered to have a deposition between January and June (Bolz 1999 and modified by CQFE), and age class assignment using these hardparts is conducted in the same way as otoliths.

All Summer Flounder samples (scale pressings and sectioned otoliths) were aged by two different readers in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish again without any knowledge of previously estimated ages or lengths, then assigned a final age to the fish. When the age readers were unable to agree on a final age, the fish was excluded from further analysis.

Scales

We determined fish age by viewing acetate impressions of scales (Figure 12.1) with a standard Bell and Howell R-735 microfiche reader equipped with 20 and 29 mm lenses. Annuli on Summer Flounder scales are identified based on two scale microstructure features, "crossing over" and circuli disruption. Primarily, "crossing over" in the lateral margins near the posterior/anterior interface of the scale is used to determine the origin of the annulus. Here compressed circuli (annulus) "cross-over" the previously deposited circuli of the previous year's growth. Typically annuli of the first three years can be observed transversing this interface as dark bands. These bands

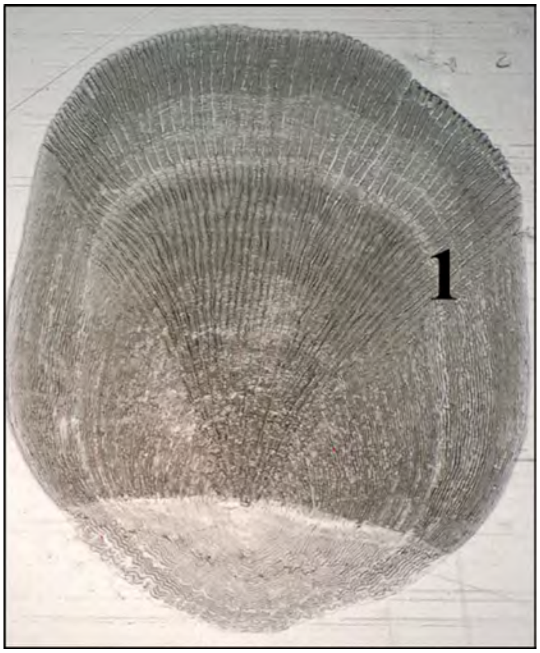


Figure 12.1: Scale impression of a 1 year-old Summer Flounder

remain consistent throughout the posterior field and rejoin the posterior/anterior interface on the opposite side of the focus. Annuli can also be observed in the anterior lateral field of the scale. Here the annuli typically reveal a pattern of discontinuous and suddenly breaking segmented circuli. This event can also be distinguished by the presence of concentric white lines, which are typically associated with the disruption of circuli.

Annuli can also be observed bisecting the perpendicular plain of the radial striations in the anterior field of the scale. Radii emanate out from the focus of the scale towards the outer corner margins of the anterior field. These radial striations consist mainly of segmented concave circuli. The point of intersection between radii and annuli results in a "straightening out" of the concave circuli. This straightening of the circuli should be consistent throughout the entire anterior field of the scale. This event is further amplified by the presence of concave circuli neighboring both directly above and below the annulus. The first year's annulus can be difficult to locate on some scales. It is typically best identified in the lateral field of the anterior portion of the scale. The distance from the focus to the first year's annulus is typically larger with respect to the following annuli. For the annuli two through six, summer growth generally decreases proportionally. For ages greater than six, a crowding effect of the annuli near the outer margins of the scale is observed. This crowding effect creates difficulties in edge interpretation. At this point it is best to focus on the straightening of the circuli at the anterior margins of the scale.

When ageing young Summer Flounder, zero through age two, extreme caution must be taken as not to over age the structure. In young fish there is no point of reference to aid in the determination of the first year; this invariably results in over examination of the scale and such events as hatching or saltwater incursion marks (checks) may be interpreted as the first year.

Otoliths

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and darkfield polarization at between 8 and 20 times magnification (Figure 12.2). Each reader aged all of the otolith samples. By convention an annulus is identified as the narrow opaque zone, or winter growth. Typically

Figure 12.2: Otolith thin-section of a 4 year-old Summer Flounder with the last annulus on the edge of the thin-section

the first year's annulus can be determined by first locating the focus of the otolith. The focus is generally located, depending on preparation, in the center of the otolith, and is visually well defined as a dark oblong region. The first year's annulus can be located directly below the focus, along the outer ridge of the sulcal groove on the ventral and dorsal sides of the otolith. This insertion point along the sulcal ridge resembles a check mark (not to be confused with a false annulus). Here the annulus can be followed outwards along the ventral and dorsal surfaces where it encircles the focus. Subsequent annuli also emanate from the sulcal ridge; however, they do not encircle the focus, but rather travel outwards to the distal surface of the otolith. To be considered a true annulus, each annulus must be rooted in the sulcus and travel without interruption to the distal surface of the otolith. The annuli in Summer Flounder have a tendency to split as they advance towards the distal surface. As a result, it is critical that reading path proceed in a direction down the sulcal ridge and outwards to the distal surface.

Click here to obtain the protocol at the CQFE website on how to age Summer Flounder using their otolith thin-sections.

12.2.5 Comparison Tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (*CV*) analysis were used to detect any systematic difference and precision on age readings, respectively, for following comparisons: 1) between the two readers in the current year; 2) within each reader in the current year; 3) time-series bias between the current and previous years within each reader; and 4) between scale and otoliths ages. The readings from the entire sample for the current year were used to examine the difference between two readers. A random sub-sample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

12.3 RESULTS

12.3.1 Sample size

We estimated a sample size of 356 bay Summer Flounder in 2018, ranging in length interval from 8 to 28 inches (Table 12.1). This sample size provided a range in *CV* for age composition approximately from the smallest *CV* of 8% for Age 2 to the largest *CV* of 19% for Age 6 of the bay fish. We randomly selected and aged 327 fish from 403 Summer Flounder collected by VMRC in Chesapeake Bay in 2018. We fell short in our over-all collections for this optimal length-class sampling estimate by 55 fish. We were short only a few fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would not be influenced significantly.

We estimated a sample size of 467 ocean Summer Flounder in 2018, ranging in length interval from 13 to 32 inches (Table 12.2). This sample size provided a range in *CV* for age composition approximately from the smallest *CV* of 9% for Age 4 to the largest *CV* of 20% for Age 8 of the ocean fish. We randomly selected and aged 530 fish from 663 Summer Flounder collected by VMRC in Virginia waters of the Atlantic Ocean in 2018. We fell short in our over-all collections for this optimal length-class sampling estimate by 13 fish. We were not short any fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would not be influenced significantly.

12.3.2 Scales

Both readers had moderate self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 60% (1 year or less agreement of 94%) and a *CV* of 7.9% (test of symmetry: $\chi^2 = 14$, $df = 10$, $P = 0.173$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 64% (1 year or less agreement of 94%) and a *CV* of 6.84% (test of symmetry: $\chi^2 = 15.33$, $df = 9$, $P = 0.0822$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 74% (1 year or less agreement of 95%) and a *CV* of 5.25% (test of symmetry: $\chi^2 = 27.93$, $df = 23$, $P = 0.2183$) (Figure 12.3).

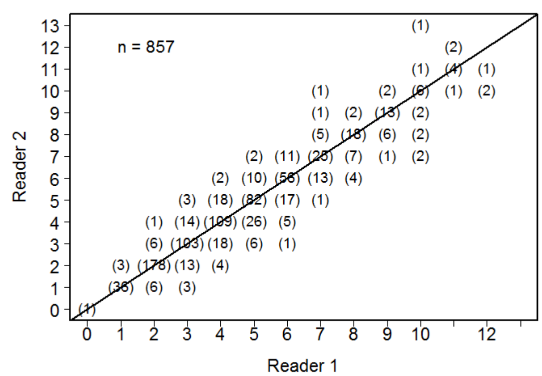


Figure 12.3: Between-reader comparison of scale age estimates for Summer Flounder collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 80% (1 year or less agreement of 100%) with ages of fish aged in 2000 with a *CV* of 3.68% (test of symmetry: $\chi^2 = 4.67$, $df = 4$, $P = 0.3232$). Reader 2 had an agreement of 78% (1 year or less agreement of 94%) with a *CV* of 5.95% (test of symmetry: $\chi^2 = 11$, $df = 5$, $P = 0.0514$).

Of the 327 bay Summer Flounder aged with scales, 8 age classes (1 to 8) were represented (Table 12.3). The average age for the sample was 2.8 years. The standard deviation and standard error were 1.4 and 0.08, respectively. Year-class data (Figure 12.4) indicates that recruitment into the fishery in Chesapeake Bay begins at age 1, which corresponds to the 2017 year-class for Summer Flounder caught in 2018. Summer flounder in the sample in 2018 was dominated by the year class of 2016 with 50%. The sex ratio of male to female was 1:74 for the bay fish.

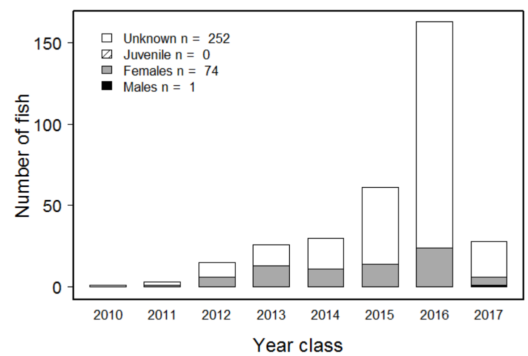


Figure 12.4: Year-class frequency distribution for Summer Flounder collected in Chesapeake Bay, Virginia for ageing in 2018. Distribution is broken down by sex and estimated using scale ages. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

Of the 530 ocean Summer Flounder aged with scales, 14 age classes (0 to 12, and 14) were represented (Table 12.4). The average age for the sample was 5.2 years. The standard deviation and standard error were 2.2 and 0.1, respectively. Year-class data (Figure 12.5) indicates that recruitment into the fishery in Virginia waters of Atlantic ocean begins at age 0, which corresponds to the 2018 year-class for Summer Flounder caught in 2018. Summer flounder in the sample in 2018 was dominated by the year classes of 2013 and 2014 with 21% and 22%, respectively. The sex ratio of male to female was 1:1.01 for the ocean fish.

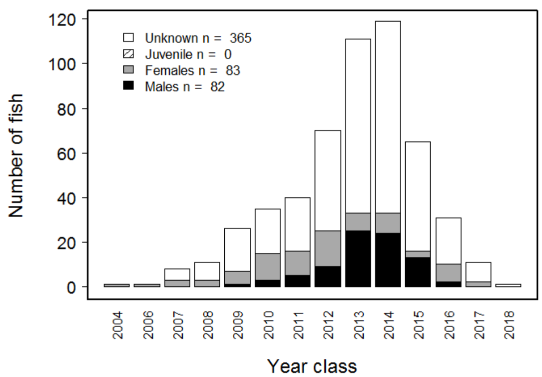


Figure 12.5: Year-class frequency distribution for Summer Flounder collected in Virginia waters of the Atlantic Ocean for ageing in 2018. Distribution is broken down by sex and estimated using scale ages. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

12.3.3 Otoliths

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 98% and a *CV* of 0.19% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 98% and a *CV* of 0.31% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 94% (1 year or less agreement of 100%) and a *CV* of 0.71% (test of symmetry: $\chi^2 = 8.67$, $df = 7$, $P = 0.2775$) (Figure 12.6).

There was no time-series bias for either reader. Reader 1 had an agreement of 94% with ages of fish aged in 2003 with a *CV* of 1.75% (test of symmetry: $\chi^2 = 3$, $df = 2$, $P = 0.2231$). Reader 2 had an agreement of 98% with a *CV* of 0.17% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$).

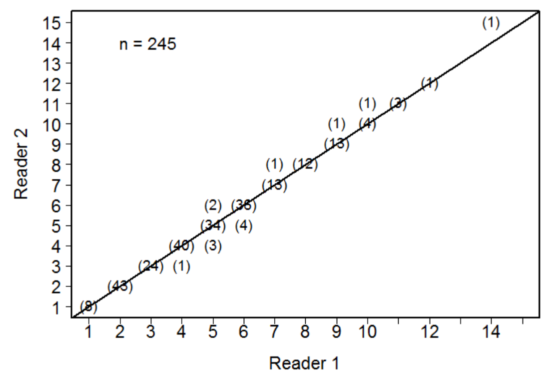


Figure 12.6: Between-reader comparison of otolith age estimates for Summer Flounder collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

Of the 245 Summer Flounder aged with otoliths, 13 age classes (1 to 12, and 15) were represented (Table 12.5). The average age for the sample was 4.9 years. The standard deviation and standard error were 2.5 and 0.16, respectively.

12.3.4 Comparison of scale and otolith ages

We aged 245 Summer Flounder using scales and otoliths. There was no evidence of systematic disagreement between otolith and scale ages (test of symmetry: $\chi^2 = 26.87$, $df = 25$, $P = 0.3627$) with an average *CV* of 9.51%. There was an agreement of 52% between scale and otoliths ages whereas scales were assigned a lower and higher age than otoliths for 28% and 20% of the fish, respectively (Figure 12.7). There was also little evidence of bias between otolith and scale ages using an age bias plot (Figure 12.8), with no trend of either over-ageing younger or under-ageing older fish.

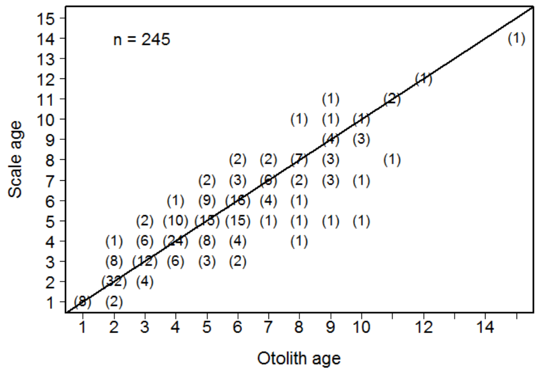


Figure 12.7: Comparison of scale and otolith age estimates for Summer Flounder collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish

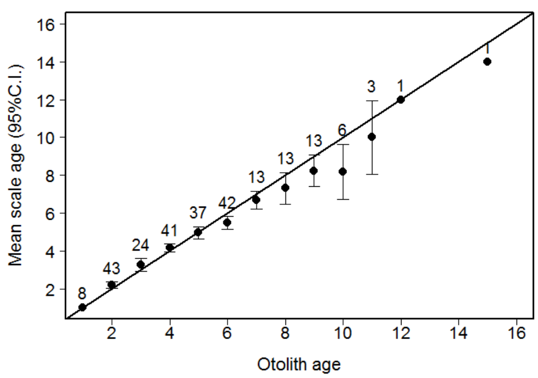


Figure 12.8: Age-bias plot for Summer Flounder scale and otolith age estimates in 2018. The number above the upper CI bar is number of fish.

12.3.5 Age-Length-Key (ALK)

We developed an age-length-key for both bay (Table 12.6) and ocean fish (Table 12.7) using scale ages, separately. The ALK can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using scale ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

12.4 RECOMMENDATIONS

Atlantic States Marine Fisheries Commission held a QAQC ageing workshop in St. Petersburg, Florida, in March of 2019 (ASMFC 2019). The workshop recommended that summer flounder should be aged using otoliths, not scales, when possible.

Table 12.1: Number of bay Summer Flounder collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
8 - 8.99	5	0	0	5
12 - 12.99	5	0	0	5
13 - 13.99	5	1	1	4
14 - 14.99	65	82	70	0
15 - 15.99	53	79	59	0
16 - 16.99	42	62	44	0
17 - 17.99	37	53	39	0
18 - 18.99	31	42	35	0
19 - 19.99	27	35	31	0
20 - 20.99	23	27	26	0
21 - 21.99	18	11	11	7
22 - 22.99	11	5	5	6
23 - 23.99	9	4	4	5
24 - 24.99	5	1	1	4
25 - 25.99	5	1	1	4
26 - 26.99	5	0	0	5
27 - 27.99	5	0	0	5
28 - 28.99	5	0	0	5
Totals	356	403	327	55

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Table 12.2: Number of ocean Summer Flounder collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
13 - 13.99	5	0	0	5
14 - 14.99	39	50	46	0
15 - 15.99	63	85	80	0
16 - 16.99	60	86	72	0
17 - 17.99	51	81	57	0
18 - 18.99	38	57	38	0
19 - 19.99	25	31	27	0
20 - 20.99	25	34	29	0
21 - 21.99	18	25	19	0
22 - 22.99	23	41	28	0
23 - 23.99	23	40	27	0
24 - 24.99	20	25	23	0
25 - 25.99	16	29	19	0
26 - 26.99	16	20	17	0
27 - 27.99	13	24	17	0
28 - 28.99	9	15	13	0
29 - 29.99	8	12	10	0
30 - 30.99	5	6	6	0
31 - 31.99	5	2	2	3
32 - 32.99	5	0	0	5
Totals	467	663	530	13

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Table 12.3: The number of Summer Flounder assigned to each total length-at-age category for 327 fish sampled for scale age determination in Chesapeake Bay, Virginia during 2018.

	Age								
Interval	1	2	3	4	5	6	7	8	Totals
13 - 13.99	0	1	0	0	0	0	0	0	1
14 - 14.99	21	44	4	0	1	0	0	0	70
15 - 15.99	5	47	5	2	0	0	0	0	59
16 - 16.99	0	33	9	2	0	0	0	0	44
17 - 17.99	0	16	16	4	3	0	0	0	39
18 - 18.99	2	14	11	4	2	2	0	0	35
19 - 19.99	0	3	8	9	8	1	1	1	31
20 - 20.99	0	3	6	4	8	4	1	0	26
21 - 21.99	0	2	1	2	2	4	0	0	11
22 - 22.99	0	0	1	2	0	2	0	0	5
23 - 23.99	0	0	0	1	1	1	1	0	4
24 - 24.99	0	0	0	0	0	1	0	0	1
25 - 25.99	0	0	0	0	1	0	0	0	1
Totals	28	163	61	30	26	15	3	1	327

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Table 12.4: The number of Summer Flounder assigned to each total length-at-age category for 530 fish sampled for scale age determination in Virginia waters of Atlantic ocean during 2018.

	Age														
Interval	0	1	2	3	4	5	6	7	8	9	10	11	12	14	Totals
14 - 14.99	1	8	10	13	9	4	1	0	0	0	0	0	0	0	46
15 - 15.99	0	1	10	18	28	13	8	1	1	0	0	0	0	0	80
16 - 16.99	0	1	5	13	23	20	6	3	1	0	0	0	0	0	72
17 - 17.99	0	1	1	10	19	15	4	2	4	1	0	0	0	0	57
18 - 18.99	0	0	4	4	11	11	4	4	0	0	0	0	0	0	38
19 - 19.99	0	0	1	3	8	8	1	4	2	0	0	0	0	0	27
20 - 20.99	0	0	0	3	5	6	6	3	3	3	0	0	0	0	29
21 - 21.99	0	0	0	0	5	8	4	1	1	0	0	0	0	0	19
22 - 22.99	0	0	0	1	3	14	8	1	1	0	0	0	0	0	28
23 - 23.99	0	0	0	0	6	2	9	3	5	1	1	0	0	0	27
24 - 24.99	0	0	0	0	2	7	5	5	2	1	1	0	0	0	23
25 - 25.99	0	0	0	0	0	1	6	8	2	1	1	0	0	0	19
26 - 26.99	0	0	0	0	0	0	6	2	1	3	4	0	0	1	17
27 - 27.99	0	0	0	0	0	2	2	1	1	5	3	3	0	0	17
28 - 28.99	0	0	0	0	0	0	0	1	8	3	0	1	0	0	13
29 - 29.99	0	0	0	0	0	0	0	0	3	4	0	2	1	0	10
30 - 30.99	0	0	0	0	0	0	0	0	0	4	1	1	0	0	6
31 - 31.99	0	0	0	0	0	0	0	1	0	0	0	1	0	0	2
Totals	1	11	31	65	119	111	70	40	35	26	11	8	1	1	530

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Table 12.5: The number of Summer Flounder assigned to each total length-at-age category for 245 fish sampled for otolith age determination in Chesapeake Bay and Virginia waters of Atlantic Ocean during 2018.

	Age													
Interval	1	2	3	4	5	6	7	8	9	10	11	12	15	Totals
14 - 14.99	7	6	2	3	0	2	0	0	0	0	0	0	0	20
15 - 15.99	1	13	3	6	3	5	2	1	1	0	1	0	0	36
16 - 16.99	0	9	1	8	7	4	0	3	1	0	0	0	0	33
17 - 17.99	0	5	4	5	5	5	2	0	0	0	0	0	0	26
18 - 18.99	0	8	3	1	3	3	0	1	0	1	0	0	0	20
19 - 19.99	0	0	5	5	3	3	0	0	0	1	0	0	0	17
20 - 20.99	0	1	2	5	2	3	1	1	2	0	0	0	0	17
21 - 21.99	0	0	2	5	3	3	0	0	0	0	0	0	0	13
22 - 22.99	0	1	2	2	6	2	0	0	0	0	0	0	0	13
23 - 23.99	0	0	0	1	2	3	1	1	0	0	0	0	0	8
24 - 24.99	0	0	0	0	2	1	3	0	1	0	0	0	0	7
25 - 25.99	0	0	0	0	1	4	3	0	0	0	0	0	0	8
26 - 26.99	0	0	0	0	0	4	0	1	0	0	0	0	1	6
27 - 27.99	0	0	0	0	0	0	1	1	2	2	1	0	0	7
28 - 28.99	0	0	0	0	0	0	0	2	4	0	0	0	0	6
29 - 29.99	0	0	0	0	0	0	0	2	0	2	1	1	0	6
30 - 30.99	0	0	0	0	0	0	0	0	2	0	0	0	0	2
Totals	8	43	24	41	37	42	13	13	13	6	3	1	1	245

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Table 12.6: Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for Summer Flounder sampled in Chesapeake Bay, Virginia during 2018.

	Age							
Interval	1	2	3	4	5	6	7	8
13 - 13.99	0	1	0	0	0	0	0	0
14 - 14.99	0.3	0.63	0.06	0	0.01	0	0	0
15 - 15.99	0.08	0.8	0.08	0.03	0	0	0	0
16 - 16.99	0	0.75	0.2	0.05	0	0	0	0
17 - 17.99	0	0.41	0.41	0.1	0.08	0	0	0
18 - 18.99	0.06	0.4	0.31	0.11	0.06	0.06	0	0
19 - 19.99	0	0.1	0.26	0.29	0.26	0.03	0.03	0.03
20 - 20.99	0	0.12	0.23	0.15	0.31	0.15	0.04	0
21 - 21.99	0	0.18	0.09	0.18	0.18	0.36	0	0
22 - 22.99	0	0	0.2	0.4	0	0.4	0	0
23 - 23.99	0	0	0	0.25	0.25	0.25	0.25	0
24 - 24.99	0	0	0	0	0	1	0	0
25 - 25.99	0	0	0	0	1	0	0	0

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Table 12.7: Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for Summer Flounder sampled in Virginia waters of the Atlantic Ocean during 2018.

	Age													
Interval	0	1	2	3	4	5	6	7	8	9	10	11	12	14
14 - 14.99	0.02	0.17	0.22	0.28	0.2	0.09	0.02	0	0	0	0	0	0	0
15 - 15.99	0	0.01	0.12	0.22	0.35	0.16	0.1	0.01	0.01	0	0	0	0	0
16 - 16.99	0	0.01	0.07	0.18	0.32	0.28	0.08	0.04	0.01	0	0	0	0	0
17 - 17.99	0	0.02	0.02	0.18	0.33	0.26	0.07	0.04	0.07	0.02	0	0	0	0
18 - 18.99	0	0	0.11	0.11	0.29	0.29	0.11	0.11	0	0	0	0	0	0
19 - 19.99	0	0	0.04	0.11	0.3	0.3	0.04	0.15	0.07	0	0	0	0	0
20 - 20.99	0	0	0	0.1	0.17	0.21	0.21	0.1	0.1	0.1	0	0	0	0
21 - 21.99	0	0	0	0	0.26	0.42	0.21	0.05	0.05	0	0	0	0	0
22 - 22.99	0	0	0	0.04	0.11	0.5	0.29	0.04	0.04	0	0	0	0	0
23 - 23.99	0	0	0	0	0.22	0.07	0.33	0.11	0.19	0.04	0.04	0	0	0
24 - 24.99	0	0	0	0	0.09	0.3	0.22	0.22	0.09	0.04	0.04	0	0	0
25 - 25.99	0	0	0	0	0	0.05	0.32	0.42	0.11	0.05	0.05	0	0	0
26 - 26.99	0	0	0	0	0	0	0.35	0.12	0.06	0.18	0.24	0	0	0.06
27 - 27.99	0	0	0	0	0	0.12	0.12	0.06	0.06	0.29	0.18	0.18	0	0
28 - 28.99	0	0	0	0	0	0	0	0.08	0.62	0.23	0	0.08	0	0
29 - 29.99	0	0	0	0	0	0	0	0	0.3	0.4	0	0.2	0.1	0
30 - 30.99	0	0	0	0	0	0	0	0	0	0.67	0.17	0.17	0	0
31 - 31.99	0	0	0	0	0	0	0	0.5	0	0	0	0.5	0	0

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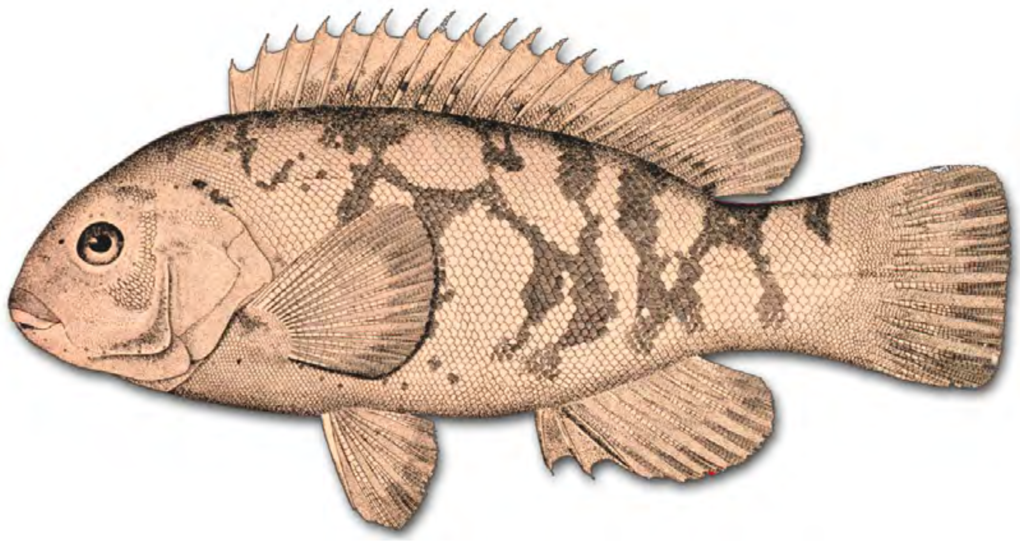
Chapter 13

TAUTOG *Tautoga onitis*



13.1 INTRODUCTION

We aged a total of 28 Tautog, *Tautoga onitis*, using their opercula collected by the VMRC's Biological Sampling Program in 2018. Of 28 aged fish, 25 and 3 fish were collected in Chesapeake Bay (bay fish) and Virginia waters of the Atlantic Ocean (ocean fish), respectively. The average age for the bay fish was 5.6 years with a standard deviation of 2.3 and a standard error of 0.46. Ten age classes (1 to 9, and 11) were represented in the bay fish, comprising fish from the 2007, and 2009 to 2017 year classes. The bay fish sample in 2018 was dominated by the year class of 2013 with 32%. The average age for the ocean fish was 9.3 years with a standard deviation of 1.2 and a standard error of 0.69. Two age classes (8, and 10) were represented in the ocean fish, comprising fish from the 2008, and 2010 year classes. The ocean fish sample in 2018 was dominated by the year class of 2008 with 67%. We also aged a total of 28 fish using their otoliths in addition to ageing their opercula. The otolith ages were compared to the operculum ages to examine how close both ages were to one another (see details in Results).

13.2 METHODS

13.2.1 Sample size for ageing

We estimated sample sizes for ageing Tautog collected in both Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018, respectively, using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \qquad (13.1)$$

where A is the sample size for ageing Tautog in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Tautog used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Tautog collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018.

13.2.2 Handling of collection

Sagittal otoliths (hereafter, referred to as "otoliths") and opercula were received by the Age & Growth Laboratory in labeled coin envelopes, and were sorted based on date of capture. Their envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory identification number. All otoliths and opercula were stored dry within their original labeled coin envelopes; otoliths were contained inside protective Axygen 2.0 ml microtubes.

13.2.3 Preparation

Opercula

Tautog opercula were boiled for several minutes to remove any attached skin and connective tissue. After boiling, opercula were inspected for damage. If there were no obvious flaws, the opercula was dried and then stored in a new, labeled envelope.

Click here to obtain the protocol at the CQFE website on how to prepare operculum for ageing Tautog.

Otoliths

We used our thin-section and bake technique to process Spadefish sagittal otoliths (hereafter, referred to as "otoliths") for age determination. Otolith preparation began by randomly selecting either the right or left otolith. Each whole otolith was placed in a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400 °C. Baking time was dependent on the otolith's size and gauged by color, with a light caramel color desired. Once a suitable color was achieved the baked otolith was embedded in epoxy resin with its distal surface orientated downwards and allowed to harden overnight. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core was marked using a permanent marker across the epoxy resin surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton diamond grinding wheels (hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). The otolith was positioned so the blades straddled each side of the otolith focus. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in broadening and distorted winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-section.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Tautog.

13.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of reading the information contained in its otolith, the date of its capture, and the species-specific period when it deposits its annulus. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called annuli. Technically, an otolith annulus is the combination of both the opaque and the translucent bands. In practice, only the opaque bands are counted as annuli. The number of these visible dark bands replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the otolith section is examined for translucent growth. If no translucent growth is visible beyond the last dark annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last dark annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the dark band of the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of dark bands in the otolith. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday", but before the dark band deposition period, is interpreted as being toward the next age class.

For example, Tautog otolith deposition occurs between May and July (Hostetter and Munroe 1993). A Tautog captured between January 1 and July 31, before the end of the species' annulus formation period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of June 30, the period of annulus formation, which would be noted as 4+4.

Tautog opercula are also considered to have a deposition period of May through July (Hostetter and Munroe 1993), and age class assignment using these hard-parts is conducted in the same way as otoliths.

All Tautog samples (opercula and sectioned otoliths) were aged by two different readers in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish again without any knowledge of previously estimated ages or lengths, then assigned a final age to the fish. When the age readers were unable to agree on a final age, the fish was excluded from further analysis.

Opercula

All prepared opercula were aged by two different readers in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. Opercula were aged on a light table with no magnification (Figure 13.1).

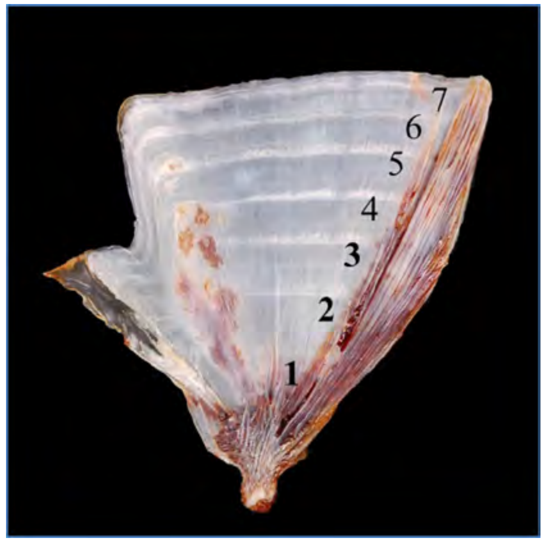


Figure 13.1: Operculum of a 7 year-old Tautog

Otoliths

All otolith thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 13.2). Each reader aged all of the otolith samples.

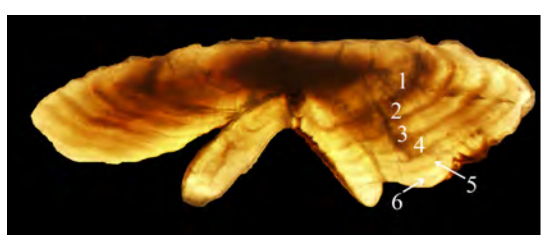


Figure 13.2: Otolith thin-section of 6 year-old Tautog

Click here to obtain the protocol at the CQFE website on how to age Tautog using their otolith thin-sections.

13.2.5 Comparison Tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (*CV*) analysis were used to detect any systematic difference and precision on age readings, respectively, for following comparisons: 1) between the two readers in the current year; 2) within each reader in the current year; 3) time-series bias between the current and previous years within each reader; and 4) between operculum and otoliths ages. The readings from the entire sample for the current year were used to examine the difference between two readers. When the sample size for the current year was smaller than 50, the entire sample was read by each reader for the second time to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2000 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

13.3 RESULTS

13.3.1 Sample size

We estimated a sample size of 404 bay Tautog in 2018, ranging in length interval from 9 to 26 inches (Table 13.1). This sample size provided a range in *CV* for age composition approximately from the smallest *CV* of 8% for Age 5 to the largest *CV* of 19% for Age 8 of the bay fish. We aged all 25 Tautog collected by VMRC in Chesapeake Bay in 2018. We fell short in our over-all collections for this optimal length-class sampling estimate by 379 fish. We were short many fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would definitely be influenced significantly. Therefore, precaution should be used when developing ALK using these age data.

We estimated a sample size of 462 ocean Tautog in 2018, ranging in length interval from 11 to 30 inches (Table 13.2). This sample size provided a range in *CV* for age composition approximately from the smallest *CV* of 9% for Age 5 to the largest *CV* of 23% for Age 15 of the ocean fish. We aged all 3 Tautog collected by VMRC in Virginia waters of the Atlantic Ocean in 2018. We fell short in our over-all collections for this optimal length-class sampling estimate by 459 fish. We were short many fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would definitely be influenced significantly. Therefore, precaution should be used when developing ALK using these age data.

13.3.2 Opercula

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 89% (1 year or less agreement of 96%) and a *CV* of 2.07% (test of symmetry: $\chi^2 = 3$, $df = 3$, $P = 0.3916$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 82% (1 year or less agreement of 100%) and a *CV* of 1.84% (test of symmetry: $\chi^2 = 5$, $df = 5$, $P = 0.4159$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 75% (1 year or less agreement of 100%) and a *CV* of 2.97% (test of symmetry: $\chi^2 = 5$, $df = 6$, $P = 0.5438$) (Figure 13.3).

There was no time-series bias for either reader. Reader 1 had an agreement of 72% (1 year or less agreement of 96%) with ages

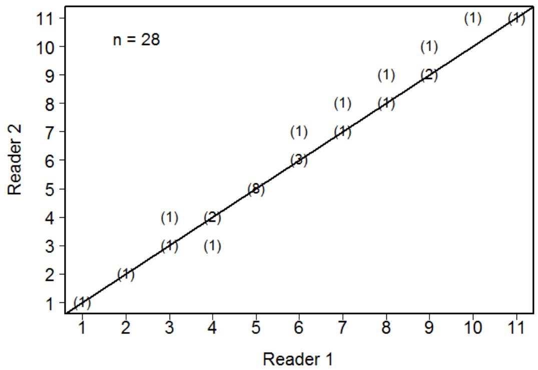


Figure 13.3: Between-reader comparison of operculum age estimates for Tautog collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

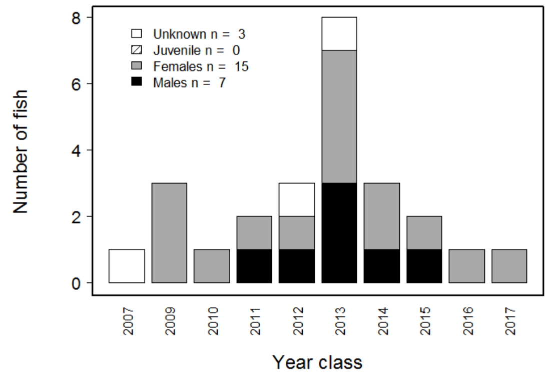


Figure 13.4: Year-class frequency distribution for Tautog collected in Chesapeake Bay, Virginia for ageing in 2018. Distribution is broken down by sex and estimated using operculum ages. 'Unknown' represents the fish gonads that were not available for examination or were not examined for sex during sampling.

of fish aged in 2000 with a CV of 4.38% (test of symmetry: χ^2 = 5.33, df = 8, P = 0.7214). Reader 2 had an agreement of 72% (1 year or less agreement of 96%) with a CV of 4.64% (test of symmetry: χ^2 = 6, df = 8, P = 0.6472).

Of the 25 bay Tautog aged with opercula, 10 age classes (1 to 9, and 11) were represented (Table 13.3). The average age for the sample was 5.6 years. The standard deviation and standard error were 2.3 and 0.46, respectively. Year-class data (Figure 13.4) indicates that recruitment into the fishery in Chesapeake Bay begins at age 1, which corresponds to the 2017 year-class for Tautog caught in 2018. Tautog in the sample in 2018 was dominated by the year class of 2013 with 32%. The sex ratio of male to female was 1:2.14 for the bay fish.

Of the 3 ocean Tautog aged with opercula, 2 age classes (8, and 10) were represented (Table 13.4). The average age for the sample was 9.3 years. The standard deviation and standard error were 1.2 and 0.69, respectively. Year-class data (Figure 13.5) indicates that recruitment into the fishery in Virginia waters of Atlantic ocean begins at age 8, which corresponds to the 2010 year-class for Tautog caught in 2018. Tautog in the sample in 2018 was dominated by the year class of 2008 with 67%. All 3 ocean Tautog were females.

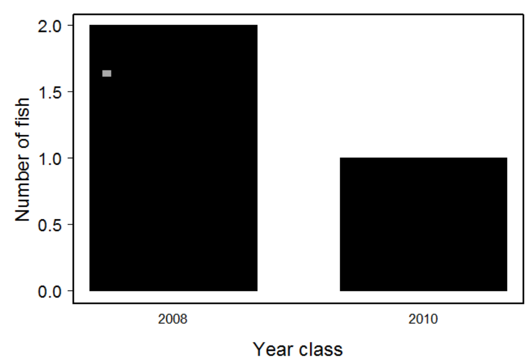


Figure 13.5: Year-class frequency distribution for Tautog collected in Virginia waters of the Atlantic Ocean for ageing in 2018. Distribution is broken down by sex and estimated using operculum ages. 'Unknown' represents the fish gonads that were not available for examination or were not examined for sex during sampling.

13.3.3 Otoliths

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 96% and a *CV* of 0.27% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 100%. There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 100% (Figure 13.6). Reader 1 had no time series

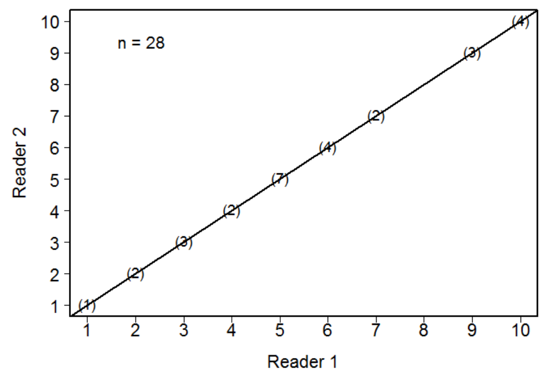


Figure 13.6: Between-reader comparison of otolith age estimates for Tautog collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

bias while Read 2 did. Reader 1 had an agreement of 90% with ages of fish aged in 2003 with a *CV* of 1.15% (test of symmetry: $\chi^2 = 5$, $df = 2$, $P = 0.0821$). Reader 2 had an agreement of 88% with a *CV* of 1.34% (test of symmetry: $\chi^2 = 6$, $df = 2$, $P = 0.0498$).

Of the 28 Tautog aged with otoliths, 9 age classes (1 to 7, and 9 to 10) were represented (Table 13.5). The average age for the sample was 5.8 years. The standard deviation and standard error were 2.7 and 0.51, respectively.

13.3.4 Comparison of operculum and otolith ages

We aged 28 Tautog using opercula and otoliths. There was no evidence of systematic disagreement between otolith and operculum ages (test of symmetry: $\chi^2 = 7$, $df = 7$, $P = 0.4289$) with an average *CV* of 5.38%. There was an agreement of 75% between operculum and otoliths ages whereas opercula were assigned a lower and higher age than otoliths for 7% and 18% of the fish, respectively (Figure 13.7). There was also little evidence of bias between otolith and operculum ages using an age bias plot(Figure 13.8), with no trend of either over-ageing younger or under-ageing older fish.

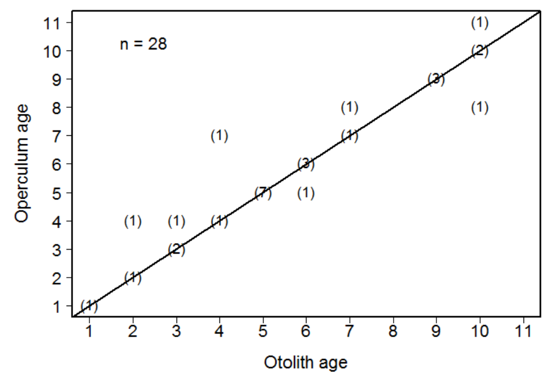


Figure 13.7: Comparison of operculum and otolith age estimates for Tautog collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

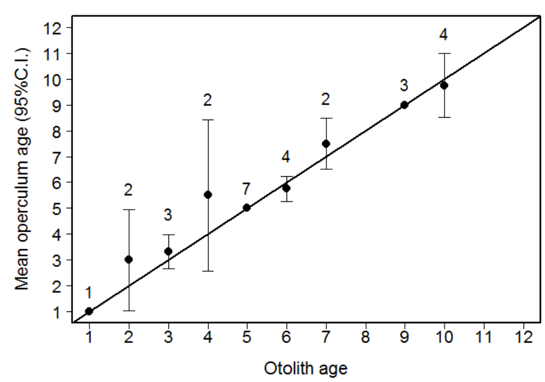


Figure 13.8: Age-bias plot for Tautog operculum and otolith age estimates in 2018. The number above the upper CI bar is number of fish.

13.3.5 Age-Length-Key (ALK)

We developed an age-length-key for both bay (Table 13.6) and ocean fish (Table 13.7) using operculum ages, separately. The ALK can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using operculum ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

Table 13.1: Number of bay Tautog collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
9 - 9.99	5	1	1	4
10 - 10.99	5	1	1	4
11 - 11.99	5	0	0	5
12 - 12.99	5	0	0	5
13 - 13.99	5	2	2	3
14 - 14.99	27	3	3	24
15 - 15.99	96	7	7	89
16 - 16.99	89	6	6	83
17 - 17.99	70	2	2	68
18 - 18.99	40	0	0	40
19 - 19.99	22	3	3	19
20 - 20.99	10	0	0	10
21 - 21.99	5	0	0	5
22 - 22.99	5	0	0	5
23 - 23.99	5	0	0	5
24 - 24.99	5	0	0	5
26 - 26.99	5	0	0	5
Totals	404	25	25	379

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Table 13.2: Number of ocean Tautog collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
11 - 11.99	5	0	0	5
14 - 14.99	8	0	0	8
15 - 15.99	56	0	0	56
16 - 16.99	75	0	0	75
17 - 17.99	46	1	1	45
18 - 18.99	38	0	0	38
19 - 19.99	36	2	2	34
20 - 20.99	33	0	0	33
21 - 21.99	31	0	0	31
22 - 22.99	21	0	0	21
23 - 23.99	26	0	0	26
24 - 24.99	20	0	0	20
25 - 25.99	18	0	0	18
26 - 26.99	11	0	0	11
27 - 27.99	18	0	0	18
28 - 28.99	8	0	0	8
29 - 29.99	7	0	0	7
30 - 30.99	5	0	0	5
Totals	462	3	3	459

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Table 13.3: The number of Tautog assigned to each total length-at-age category for 25 fish sampled for operculum age determination in Chesapeake Bay, Virginia during 2018.

	Age										
Interval	1	2	3	4	5	6	7	8	9	11	Totals
9 - 9.99	1	0	0	0	0	0	0	0	0	0	1
10 - 10.99	0	1	0	0	0	0	0	0	0	0	1
13 - 13.99	0	0	1	1	0	0	0	0	0	0	2
14 - 14.99	0	0	1	0	1	1	0	0	0	0	3
15 - 15.99	0	0	0	2	3	1	0	0	1	0	7
16 - 16.99	0	0	0	0	4	0	1	1	0	0	6
17 - 17.99	0	0	0	0	0	0	1	0	1	0	2
19 - 19.99	0	0	0	0	0	1	0	0	1	1	3
Totals	1	1	2	3	8	3	2	1	3	1	25

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Table 13.4: The number of Tautog assigned to each total length-at-age category for 3 fish sampled for operculum age determination in Virginia waters of Atlantic ocean during 2018.

	Age		
Interval	8	10	Totals
17 - 17.99	1	0	1
19 - 19.99	0	2	2
Totals	1	2	3

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Table 13.5: The number of Tautog assigned to each total length-at-age category for 28 fish sampled for otolith age determination in Chesapeake Bay and Virginia waters of Atlantic Ocean during 2018.

	Age									
Interval	1	2	3	4	5	6	7	9	10	Totals
9 - 9.99	1	0	0	0	0	0	0	0	0	1
10 - 10.99	0	1	0	0	0	0	0	0	0	1
13 - 13.99	0	1	1	0	0	0	0	0	0	2
14 - 14.99	0	0	1	0	1	1	0	0	0	3
15 - 15.99	0	0	1	1	3	1	0	1	0	7
16 - 16.99	0	0	0	1	3	1	1	0	0	6
17 - 17.99	0	0	0	0	0	0	1	1	1	3
19 - 19.99	0	0	0	0	0	1	0	1	3	5
Totals	1	2	3	2	7	4	2	3	4	28

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Table 13.6: Age-Length key, as proportion-at-age in each 1-inch length interval, based on operculum ages for Tautog sampled in Chesapeake Bay, Virginia during 2018.

	Age									
Interval	1	2	3	4	5	6	7	8	9	11
9 - 9.99	1	0	0	0	0	0	0	0	0	0
10 - 10.99	0	1	0	0	0	0	0	0	0	0
13 - 13.99	0	0	0.5	0.5	0	0	0	0	0	0
14 - 14.99	0	0	0.33	0	0.33	0.33	0	0	0	0
15 - 15.99	0	0	0	0.29	0.43	0.14	0	0	0.14	0
16 - 16.99	0	0	0	0	0.67	0	0.17	0.17	0	0
17 - 17.99	0	0	0	0	0	0	0.5	0	0.5	0
19 - 19.99	0	0	0	0	0	0.33	0	0	0.33	0.33

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Table 13.7: Age-Length key, as proportion-at-age in each 1-inch length interval, based on operculum ages for Tautog sampled in Virginia waters of the Atlantic Ocean during 2018.

	Age	
Interval	8	10
17 - 17.99	1	0
19 - 19.99	0	1

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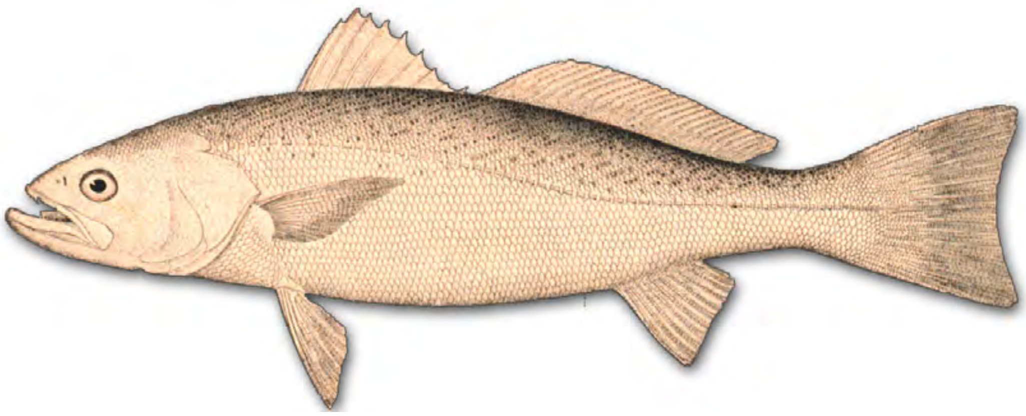
Chapter 14

WEAKFISH *Cynoscion regalis*



14.1 INTRODUCTION

We aged a total of 289 Weakfish, *Cynoscion regalis*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2018. The Weakfish ages ranged from 0 to 5 years old with an average age of 2.3, a standard deviation of 0.9, and a standard error of 0.05. Six age classes (0 to 5) were represented, comprising fish of the 2013 to 2018 year-classes. The sample was dominated by fish from the year-classes of 2015, 2016, and 2017 with 47.8%, 22.5%, and 24.9%, respectively.

14.2 METHODS

14.2.1 Sample size for ageing

We estimated sample size for ageing Weakfish in 2018 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV_a^2 + B_a/L} \tag{14.1}$$

where A is the sample size for ageing Weakfish in 2018; θ_a stands for the proportion of Age a fish in a catch; V_a, B_a, and CV_a represent the variance components within and between length intervals, and the coefficient of variation for Age a, respectively; L is the total number of Weakfish used by VMRC to estimate length distribution of the catches from 2012 to 2016. θ_a, V_a, and B_a were calculated using pooled age-length data of Weakfish collected from 2012 to 2016 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. The equation (1.1) indicates:1) The more fish that are aged, the smaller the CV_a (or higher precision) that will be obtained for Age a; 2) given a sample size A, the CV_a is different for each age due to different θ_a, V_a, and B_a among different ages. Therefore, the criterion to age A (number) of fish is that A should be a number above which there is only a 1% CV_a reduction for the most abundant age in catch by ageing an additional 100 or more fish. Finally, A_l is A multiplied by the proportion of length interval l from the length distribution of the 2012 to 2016 catch. A_l is number of fish to be aged for length interval l in 2018.

14.2.2 Handling of collections

Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes, and were sorted by date of capture. Their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original labeled coin envelopes.

14.2.3 Preparation

Sagittal otoliths, hereafter, referred to as "otoliths", were processed for age determination following the methods described in Lowerre-Barbieri et al. (1994) with a few modifications. The left or right otolith was randomly selected and attached, distal side down, to a glass slide with clear Crystalbond™ 509 adhesive. The otoliths were viewed by eye and, when necessary, under a stereo microscope to identify the location of the core, and the position of the core was marked using a pencil across the otolith surface. At least one transverse cross-section (hereafter, referred to as "thin-section") was then removed from the marked core of each otolith using a Buehler IsoMet™ low-speed saw equipped with two, 3-inch diameter, Norton diamond grinding wheels (hereafter, referred to as "blades"), separated by a stainless steel spacer of 0.5 mm (diameter 2.5"). Thin-sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only fixed the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the thin-sections.

Click here to obtain the protocol at the CQFE website on how to prepare otolith thin-section for ageing Weakfish.

14.2.4 Readings

The CQFE system assigns an age class to a fish based on a combination of number of annuli in a thin-section, the date of capture, and the species-specific period when the annulus is deposited. Each year, as the fish grows, its otoliths grow and leave behind markers of their age, called an annulus. Technically, an otolith annulus is the combination of both the opaque and the translucent band. In practice, only the opaque bands are counted as annuli. The number of annuli replaces "x" in our notation below, and is the initial "age" assignment of the fish.

Second, the thin-section is examined for translucent growth. If no translucent growth is visible beyond the last annulus, the otolith is called "even" and no modification of the assigned age is made. The initial assigned age, then, is the age class of the fish. Any growth beyond the last annulus can be interpreted as either being toward the next age class or within the same age class. If translucent growth is visible beyond the last annulus, a "+" is added to the notation.

By convention all fish in the Northern Hemisphere are assigned a birth date of January 1. In addition, each species has a specific period during which it deposits the annulus. If the fish is captured after the end of the species-specific annulus deposition period and before January 1, it is assigned an age class notation of "x+x", where "x" is the number of annuli in the thin-section. If the fish is captured between January 1 and the end of the species-specific annulus deposition period, it is assigned an age class notation of "x+(x+1)". Thus, any growth beyond the last annulus, after its "birthday" but before the end of annulus deposition period, is interpreted as being toward the next age class.

For example, Weakfish annulus formation occurs between April and July (Lowerre-Barbieri et al. 1994 and modified by CQFE). A Weakfish captured between January 1 and July 31, before the end of the species' annulus deposition period, with three visible annuli and some translucent growth after the last annulus, would be assigned an age class of "x+(x+1)" or 3+(3+1), noted as 3+4. This is the same age-class assigned to a fish with four visible annuli captured after the end of July 31, the period of annulus deposition, which would be noted as 4+4.

All thin-sections were aged by two different readers using a Nikon SMZ1000 stereo microscope under transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 14.1). Each reader aged all of the otolith samples. All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again

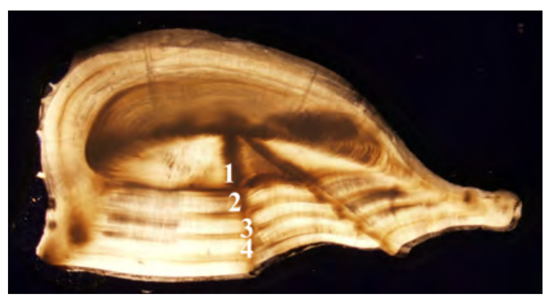


Figure 14.1: Otolith thin-section of 4 year-old Weakfish

without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Click here to obtain the protocol at the CQFE website on how to age Weakfish using their otolith thin-sections.

14.2.5 Comparison tests

A symmetry test (Hoenig et al. 1995) and coefficient of variation (*CV*) analysis were used to detect any systematic difference and precision on age readings, respectively, for the following comparisons: 1) between the two readers in the current year, 2) within each reader in the current year, and 3) time-series bias between the current and previous years within each reader. The readings from the entire sample for the current year were used to examine the difference between two readers. A random subsample of 50 fish from the current year was selected for second readings to examine the difference within a reader. Fifty otoliths randomly selected from fish aged in 2003 were used to examine the time-series bias within each reader. A figure of 1:1 equivalence was used to illustrate those differences (Campana et al. 1995). All statistics analyses were performed in R 3.5.3 (R Core Team 2019).

14.3 RESULTS

14.3.1 Sample size

We estimated a sample size of 366 for ageing Weakfish in 2018, ranging in length interval from 4 to 35 inches (Table 14.1). This sample size provided a range in (*CV*) for age composition approximately from the smallest (*CV*) of 6% for Age 2 to the largest (*CV*) of 18% for Age 4. In 2018, we aged 289 of 305 Weakfish (The rest of fish were either without otoliths or over-collected for certain length interval(s)) collected by VMRC. We fell short in our overall collections for this optimal length-class sampling estimate by 119 fish. We were short some fish from the major length intervals (The interval requires 10 or more fish), as a result, the precision for the estimates of major age groups would possibly be influenced significantly.

14.3.2 Reading precision

Both readers had high self-precision. Specifically, there was no significant difference between the first and second readings for Reader 1 with an agreement of 92% and a *CV* of 2.86% (test of symmetry: $\chi^2 = 4$, $df = 3$, $P = 0.2615$), and there was no significant difference between the first and second readings for Reader 2 with an agreement of 98% and a *CV* of 0.94% (test of symmetry: $\chi^2 = 1$, $df = 1$, $P = 0.3173$). There was no evidence of systematic disagreement between Reader 1 and Reader 2 with an agreement of 97.92% and a *CV* of 1.38% (test of symmetry: $\chi^2 = 6$, $df = 4$, $P = 0.1991$) (Figure 14.2).

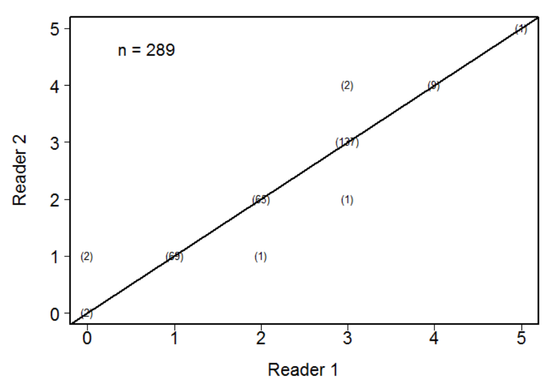


Figure 14.2: Between-reader comparison of otolith age estimates for Weakfish collected in Chesapeake Bay and Virginia waters of the Atlantic Ocean in 2018. The number in parentheses is number of fish.

There was no time-series bias for either reader. Reader 1 had an agreement of 96% with ages of fish aged in 2003 with a *CV* of 0.45% (test of symmetry: $\chi^2 = 2$, $df = 2$, P

= 0.3679). Reader 2 also had an agreement of 100%.

14.3.3 Year class

Of the 289 fish aged with otoliths, 6 age classes (0 to 5) were represented (Table 14.2). The average age was 2.3 years, and the standard deviation and standard error were 0.9 and 0.05, respectively. Year-class data show that the fishery was comprised of 6 year-classes: fish from the 2013 to 2018 year-classes, with fish primarily from the year-classes of 2015, 2016, and 2017 with 47.8%, 22.5%, and 24.9%, respectively. The ratio of males to females was 1:2.99 in the sample collected (Figure 14.3).

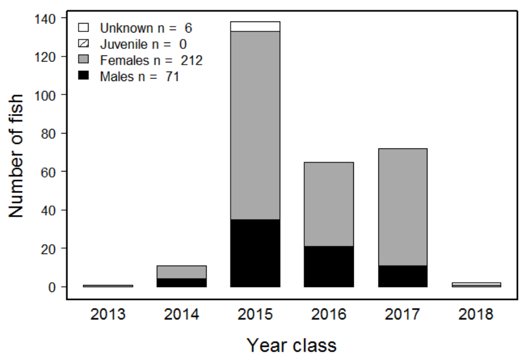


Figure 14.3: Year-class frequency distribution for Weakfish collected for ageing in 2018. Distribution is broken down by sex. 'Unknown' represents gonads that were not available for examination or were not examined for sex during sampling.

14.3.4 Age-length key (ALK)

We developed an age-length-key (Table 14.3) that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

Table 14.1: Number of Weakfish collected and aged in each 1-inch length interval in 2018. 'Target' represents the sample size for ageing estimated for 2018, and 'Need' represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
4 - 4.99	5	1	1	4
5 - 5.99	5	0	0	5
6 - 6.99	5	1	1	4
7 - 7.99	5	11	6	0
8 - 8.99	5	16	16	0
9 - 9.99	32	28	28	4
10 - 10.99	61	40	40	21
11 - 11.99	45	42	42	3
12 - 12.99	30	48	48	0
13 - 13.99	22	32	24	0
14 - 14.99	16	19	16	0
15 - 15.99	17	26	26	0
16 - 16.99	15	15	15	0
17 - 17.99	10	11	11	0
18 - 18.99	8	4	4	4
19 - 19.99	5	3	3	2
20 - 20.99	5	2	2	3
21 - 21.99	5	0	0	5
22 - 22.99	5	0	0	5
23 - 23.99	5	0	0	5
24 - 24.99	5	0	0	5
25 - 25.99	5	1	1	4
26 - 26.99	5	0	0	5
27 - 27.99	5	2	2	3
28 - 28.99	5	0	0	5
29 - 29.99	5	0	0	5
30 - 30.99	5	0	0	5
31 - 31.99	5	0	0	5
32 - 32.99	5	0	0	5
33 - 33.99	5	2	2	3
34 - 34.99	5	1	1	4
35 - 35.99	5	0	0	5
Totals	366	305	289	119

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Table 14.2: The number of Weakfish assigned to each total length-at-age category for 289 fish sampled for otolith age determination in Virginia during 2018.

	Age						
Interval	0	1	2	3	4	5	Totals
4 - 4.99	1	0	0	0	0	0	1
6 - 6.99	1	0	0	0	0	0	1
7 - 7.99	0	6	0	0	0	0	6
8 - 8.99	0	14	2	0	0	0	16
9 - 9.99	0	19	9	0	0	0	28
10 - 10.99	0	26	13	1	0	0	40
11 - 11.99	0	6	11	25	0	0	42
12 - 12.99	0	0	8	39	1	0	48
13 - 13.99	0	0	3	19	2	0	24
14 - 14.99	0	0	5	11	0	0	16
15 - 15.99	0	1	4	19	2	0	26
16 - 16.99	0	0	1	13	1	0	15
17 - 17.99	0	0	7	3	1	0	11
18 - 18.99	0	0	2	2	0	0	4
19 - 19.99	0	0	0	3	0	0	3
20 - 20.99	0	0	0	0	2	0	2
25 - 25.99	0	0	0	0	1	0	1
27 - 27.99	0	0	0	1	0	1	2
33 - 33.99	0	0	0	1	1	0	2
34 - 34.99	0	0	0	1	0	0	1
Totals	2	72	65	138	11	1	289

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Table 14.3: Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Weakfish sampled for age determination in Virginia during 2018.

	Age					
Interval	0	1	2	3	4	5
4 - 4.99	1	0	0	0	0	0
6 - 6.99	1	0	0	0	0	0
7 - 7.99	0	1	0	0	0	0
8 - 8.99	0	0.88	0.12	0	0	0
9 - 9.99	0	0.68	0.32	0	0	0
10 - 10.99	0	0.65	0.32	0.02	0	0
11 - 11.99	0	0.14	0.26	0.6	0	0
12 - 12.99	0	0	0.17	0.81	0.02	0
13 - 13.99	0	0	0.12	0.79	0.08	0
14 - 14.99	0	0	0.31	0.69	0	0
15 - 15.99	0	0.04	0.15	0.73	0.08	0
16 - 16.99	0	0	0.07	0.87	0.07	0
17 - 17.99	0	0	0.64	0.27	0.09	0
18 - 18.99	0	0	0.5	0.5	0	0
19 - 19.99	0	0	0	1	0	0
20 - 20.99	0	0	0	0	1	0
25 - 25.99	0	0	0	0	1	0
27 - 27.99	0	0	0	0.5	0	0.5
33 - 33.99	0	0	0	0.5	0.5	0
34 - 34.99	0	0	0	1	0	0

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