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Catch-at-age data for southern bluefin tuna in the New Zealand longline fishery, 2019–2021

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EXECUTIVE SUMMARY

Krusic-Golub, K.[1]**; Sutrovic, A.; Barrow, J. (2023). Catch-at-age data for southern bluefin tuna in the New Zealand longline fishery, 2019–2021.**

***New Zealand Fisheries Assessment Report 2023/23.* 28 p.**

This report describes the collection of age data that adds to the long-term ageing data of southern bluefin tuna (*Thunnus maccoyii*) caught in the New Zealand longline fishery. Southern bluefin tuna (STN) are managed by the Commission for the Conservation for Southern Bluefin Tuna (CCSBT) and form a valuable fishery in New Zealand waters, taken by domestic and chartered longline vessels as well as recreational fishers. Previously, cohort strength has been determined using cohort slicing to convert catch-at-length to catch-at-age. However, the CCSBT has recognised that it is preferable to use direct age estimation from otoliths. Sub-samples of otoliths collected during each fishing season since 2000/01 have been aged under various Ministry for Primary Industries projects and used to determine catch-at-age for each fishing year.

As with the previous project (STN2016-01), throughout the duration of this project there have been logistical issues that have limited the number of STN otoliths that have been collected for ageing, particularly from routine collection of otoliths by observers aboard New Zealand domestic and foreign charter vessels. A higher proportion of otoliths collected from the recreational fishing sector have somewhat made up for the shortfall in commercial samples. Over the duration of this project, 243 STN otoliths were collected between 12/6/2019 and 23/07/2021. Ageing protocols developed at the "Direct Age Estimation Workshop of the CCSBT" held 11–14 June 2002, in Queenscliff, Australia were followed to provide estimates of age. There were 79 otoliths that were aged from a total of 80 otoliths collected with a 2019 (2018/19) date-of-capture, 115 otoliths from a total of 117 collected with a 2020 (2019/20) date-of-capture, and 44 otoliths from a total of 46 collected with a 2021 (2020/21) date-of-capture. Ageing data from the duration of the STN2018-01 project have been provided to the Ministry for Primary Industries (now Fisheries New Zealand). Age estimates ranged from 3 to 24 years across all years. Repeat readings were performed and results were within the predetermined acceptable precision limits, indicating a low level of error within the readings.

Age composition for each year was estimated and results of this project showed that the age composition for the 2019 (2018/19) season was dominated by age classes 6 to 11, the age composition for the 2020 (2019/20) season by age classes 6 to 12, and the age composition for the 2021 (2020/21) by age classes 6 to 13. There were very few individuals less than 4 years of age and greater than 16 years of age that were aged throughout this project. The length frequency data from the onboard sampling indicated that there may have been a recent recruitment event; however this could not be supported by the ageing data due to the limited sample size.

[1] All authors: Fish Ageing Services, Victoria, Australia.

1. INTRODUCTION

Southern bluefin tuna (STN, *Thunnus maccoyyi*) are managed by the Commission for the Conservation for Southern Bluefin Tuna (CCSBT) and form a valuable fishery in New Zealand waters targeted by domestic and chartered longliners, and recreational vessels.

The assessments and indicators presented at the 2004 CCSBT Stock Assessment Group (SAG) agreed that there was at least one year of markedly low recruitment amongst the 1999–2001 year classes, supporting the concerns around ongoing recruitment outlined in the 2003 SAG report. Moreover, the lack of small fish in the longline fisheries and other indicators raised concern that there may have been several years of markedly lower recruitment among those year classes. Concerns were also raised regarding possible reductions in spawning stock size. Therefore, accurately estimating the cohort strength from year to year is critical for assessing the status of the stocks and future abundance levels.

Given the low current biomass levels of the stock, information on recent year class strength is particularly important. Previously, cohort strength has been determined using cohort slicing to convert catch-at-length to catch-at-age, but it has been increasingly realised that it is more reliable to use direct age estimation.

The sample size for age estimation for each fishing year is based on estimates described by Morton & Bravington (2003). They concluded that 100–200 otolith age readings per year would be sufficient for the Australian surface longline fishery, 200 for the Japanese longline fishery, and 500 for the Indonesian fishery. At the beginning of this work (project IFA2004/03), 200 fish per year were aged and, although the patterns in the data were generally consistent across years, it was apparent that an increased number of otoliths would likely reduce the uncertainty in the proportions of younger ages taken in the catch. Based on this conclusion, the target number of otoliths collected per year has been set at a minimum of 250 otoliths per year.

Sub-samples of otoliths collected during 2000/01 to 2017/18 have been aged under projects IFA2004-03, STN2006-01, STN2007-01, STN 2009-01, STN2011-01, and STN2016-01. The results of this work were found to be useful within both a local and stock context in terms of providing an indication of recruitment strength. This project will add to the time series for the recent history of the New Zealand fishery.

Since foreign chartered fishing vessels were excluded from fishing in New Zealand waters from May 2015, the number of otoliths collected by fishery observers has decreased substantially. The number collected from the remaining domestic vessels has decreased to slightly more than 100 otoliths per year. Consequently, for this project the otolith collection targets were reduced, and the specific ageing objectives were changed to include the ageing of a maximum 150 otoliths for each of the fishing seasons covered by this project (2019–2021). The report of the "Direct Age Estimation Workshop of the CCSBT" held 11–14 June 2002, in Queenscliff, Australia forms the basis for the protocols employed in this project. These protocols include double blind readings of each otolith and the determination of an agreed final age.

The main output from this project was to estimate the catch-at-age of STN sampled from vessels fishing in New Zealand waters from 2019 to 2021 and generate individual age data for the CCSBT age database. As stipulated by the CCSBT, it is a requirement that each otolith be assigned an individual identification number that can be linked to biological data including year and month of capture, latitude and longitude of capture, fish length, otolith age estimate, and any other relevant comments.
This report describes the collection and analysis of age data provided from the entirety of the project STN2018-01 (fishing seasons 2019–2021) and is a continuation of work started under IFA2004/03 to monitor the ages of STN taken in the New Zealand fishery.

1.1 Objectives

- Age up to 150 STN otoliths collected by scientific observers aboard commercial vessels fishing in New Zealand waters and otoliths sampled from the recreational sector during the 2019 (2018/19), 2020 (2019/20), and 2021 (2020/21) fishing seasons.
- Provide marginal increment measurements and an image of each otolith section.
- Prepare annual reports and a final report describing collection and analysis of age data from project STN2018-01.

2. METHODS

Appendix 1 provides a full description of the methods used in this project. Full methods with detailed diagrams have also been presented previously in document CCSBT-ESC/0509/12, "Catch at age of Southern Bluefin Tuna in the New Zealand longline fishery, 2001–2004", prepared for the CCSBT SAG/SC meetings in Taipei, Taiwan 28 August to 8 September 2005.

2.1 Otolith collection

The otoliths sampled for this project were collected during the 2018/19, 2019/20, and 2020/21 fishing seasons, herein referred to as the 2019, 2020 and 2021 seasons. Otoliths were collected from fish caught by the recreational sector (REC) and observers working aboard New Zealand domestic vessels and foreign charter vessels as part of the Scientific Observer programme (SOP). Onboard observers also carried out random sampling of length estimates from the STN commercial catch. Otoliths were stored within marked envelopes by NIWA. Data detailing the trip number, fish number, fish length, date of capture, area of capture, and sex for each sample were obtained from NIWA. These data were supplied in electronic form, with reference to trip and fish number as the unique identifiers. Fish Ageing Services (FAS) has an internal numbering system which groups samples into batches based usually on the location, date, or area of capture. For the STN sample registration, separate batches were assigned to SOP and REC and split further by the year of capture (fishing year). Table 1 details the FAS batch numbers, the corresponding trip numbers, the number of otolith available from that trip, and the various capture details relevant to this project.

Table 1: Batch detail of otoliths registered over the duration of this project, separated by trip id, total number of samples, fishing year, origin, and fisheries management area (FMA): Bay of Plenty (BPLE), Challenger (CHA), Central East (CEE), Auckland East (AKE).

Batch	Trip	N	Fishing year	Origin	FMA
123	58402–58418	80	2018/19	REC	BPLE
124	59002–59019	92	2019/20	REC	BPLE
125	5994, 6013	25	2019/20	SOP	CHA/CEE/AKE
129	60606–60614	46	2020/21	REC	BPLE

SOP = Scientific Observer Programme – Catch Sampling
REC = Recreational

2.2 Sample selection

The targeted number for otolith processing each year is 150. In previous projects the number of otoliths collected each year has often exceeded the number required for processing. For those years, it was necessary to select a random sub-sample from the total otolith sample available. For each year of this project the sample collection did not exceed the target numbers, therefore no sub-sampling was necessary, and all available otoliths were selected for preparation.

One otolith from each pair was weighed to the nearest milligram on an electric balance. Only undamaged otoliths were considered for weighing. Otolith weight is a useful diagnostic tool in assessing potential errors in age estimates and for examining patterns of otolith growth. Morison et al. (1998) found that otolith weight has a strong relationship with fish size and age and in medium to long-lived species, the relationship of otolith weight against estimated age may show an increased slope if the ages have been underestimated. Large variation about the relationship may indicate a lack of precision in the estimates. Also, any outlying data points in the otolith weight/age and the fish length/otolith weight relationship may indicate an incorrect assignment of age or an issue with the length measurements.

2.3 Preparation and ageing

Otoliths were prepared and aged following protocols outlined in the report of the "Direct Age Estimation Workshop of the CCSBT" held 11–14 June 2002, in Queenscliff, Australia. Opaque zones were counted along a transect starting at the primordium and running out through the ventral arm to the otolith edge where possible; otherwise, opaque zones were counted along a transect starting at the primordium and running out through the dorsal arm to the otolith edge (Figure 1). For each otolith section aged, a single image was taken, the marginal increment was measured, and the otolith edge was classified as wide translucent (WT), narrow translucent (NT), or opaque (O). See Section 2.4 below for a detailed description of the assigned edge types.

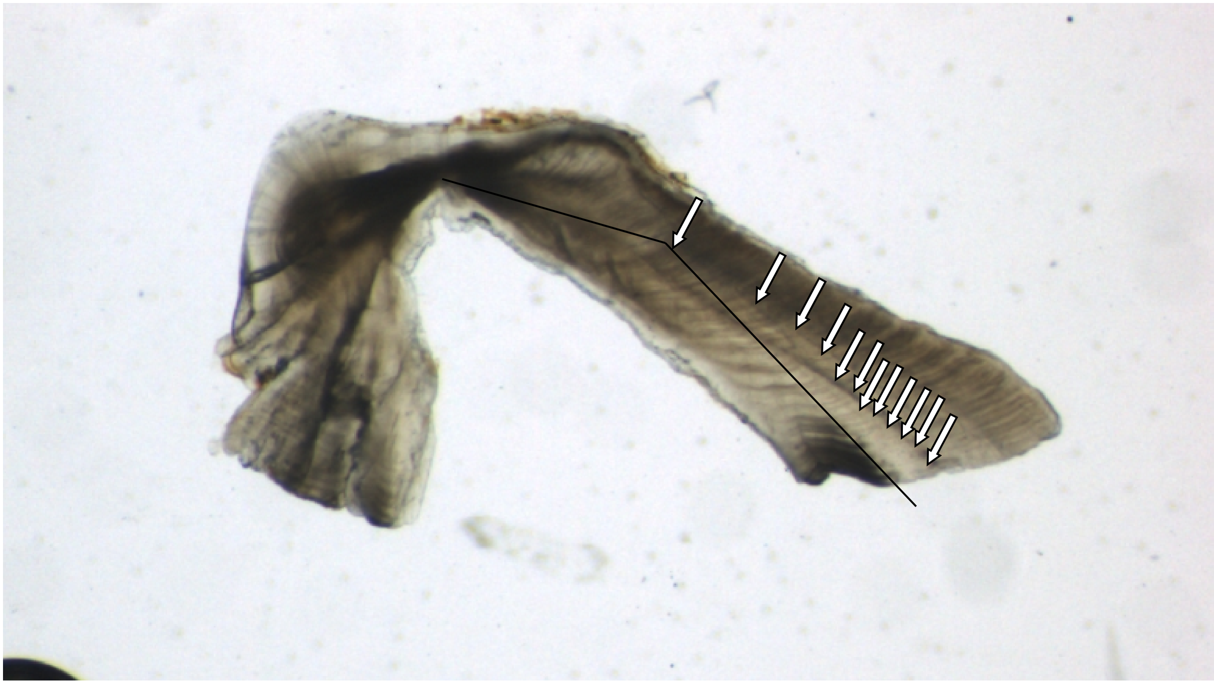


Figure 1: Southern bluefin tuna otolith section indicating the count path (black line) and the opaque zones counted (white arrows) for determining age.

2.4 Birthdate

Assigning age to STN from zone counts is problematic due to the theoretical birthdate being 1 January because opaque zones are thought to be formed during winter (April to August). The sampling of the New Zealand fishing seasons occurs through the middle of the year (May to August), and otoliths sampled from this period may exhibit both opaque and translucent margins. Using the number of opaque zones as an estimate of age can be misleading. For example, STN that are biologically the same age can differ by 1 year if the opaque increment has or hasn't formed on the otolith edge. To adjust for this, zone counts can be converted to age estimates by a theoretical birthdate adjustment. This can, however, lead to difficulties when comparing age estimates and biological parameters from samples caught in the middle of the year with those caught at the end of the year.

To be consistent with previous approaches (Krusic-Golub 2005, Krusic-Golub 2012) the last opaque zone formed prior to the edge of the otolith was only counted when considered completed, i.e., translucent otolith material was observed between the last opaque zone and the edge. The edge type was then recorded as narrow translucent (NT) if the last incomplete increment was less than 1/3 complete, relative to the thickness of the previously completed increment or wide translucent (WT) if greater than 1/3 complete. Otoliths with an incomplete opaque zone observed on the edge were recorded as opaque (O). If all otoliths are aged consistently to this protocol, then zone counts can be post-adjusted according to requirements of the data users. In addition, the marginal increment of each otolith was measured to allow for the marginal increment completeness to be estimated. This will facilitate potential future analysis or comparisons.

2.5 Marginal increment measurement

The percentage completion of the marginal increment formation was examined by calculating the mean index of completion (C). Indices of completion were calculated using the equation:

$$C = Wn/Wn\text{-}1$$

where Wn is the width of the marginal increment (distance from the start of the last opaque zone to the marginal edge) and $Wn\text{-}1$ is the width of the previously completed annulus (the distance from the start of the second most outer opaque zone to the last opaque zone).

2.6 Data analysis

The relationship between biological attributes can be used to determine whether any inconsistencies or outliers are present within the data. Age estimates were combined with fish length and otolith mass data and checked for outliers.

Length and age frequency distributions for otoliths collected during each fishing year were produced separately for the REC and the SOP samples. The age and length data from all years were combined and a von Bertalanffy growth curve was fitted to the combined length-at-age data using the non-linear least squares method. The growth equation was determined using the equation:

$$L(t) = L_\infty\,(1\text{-}e^{-k(t-to)})$$

where L_∞ indicates the mean asymptotic fork length (FL, cm), k represents the growth constant, and t_o is the theoretical age at length zero.

Summaries were produced for the number of fish at each age and length and number of fish at each length for each age (age-length key) were derived from Excel spreadsheets and presented separately by year and sector. Previous projects have estimated the age composition of the sampled catch using the age-length key (ALK), and then applied to the length frequency data for each corresponding fishing year as follows:

$$A_t=\sum_x(L_x p_{tx})$$

where A_t = the estimated number of fish of age t in the length frequency sample, L_x = the number of fish of length x in the length frequency sample, and P_{tx} = the proportion of aged fish of length x which were age t. This method should only be used if the otoliths samples are randomly sampled from the catch (i.e., the number of specimens aged from each length category is proportional to the number in each length category) or fixed (i.e., a constant number of specimens aged from each length category) (Kimura 1977). Considering the nature of the sampling (majority of samples sourced from the recreational sector and the small number of samples available each year from the commercial sector), using the age key method to estimate proportions-at-age for the catch within the entire STN fishery was not possible. Instead, age compositions for each year were simply derived from the raw ageing data.

2.7 Precision estimates

All otoliths were read twice without reference to anything other than the otolith ID. If the two initial readings differed, the otolith sample was re-read a third time and a final age assigned. The final age reading was completed with the knowledge of the two previous readings and date of capture.

Re-reading of otoliths by the same reader provides a measure of precision within the readings. The readings were compared, and the index of average percentage error (IAPE) was calculated using the Fish Stock Analysis package in the statistical program R (R core team 2022). The distribution of the differences between repeat readings was also inspected as another indicator of ageing errors, and of any potential bias between readings. To provide a measure of inter-reader variability, for each fishing season all otolith sections were read by a secondary reader experienced in reading STN otoliths. The purpose of the re-reading is to provide an indication of error between readers and to investigate potential bias, not an agreed age.

3. RESULTS

3.1 Length frequency data

The length frequency distributions of the fish sampled for otoliths each fishing season are presented in Figure 2 and the length frequency distributions of the sampled catch are presented in Figure 3.

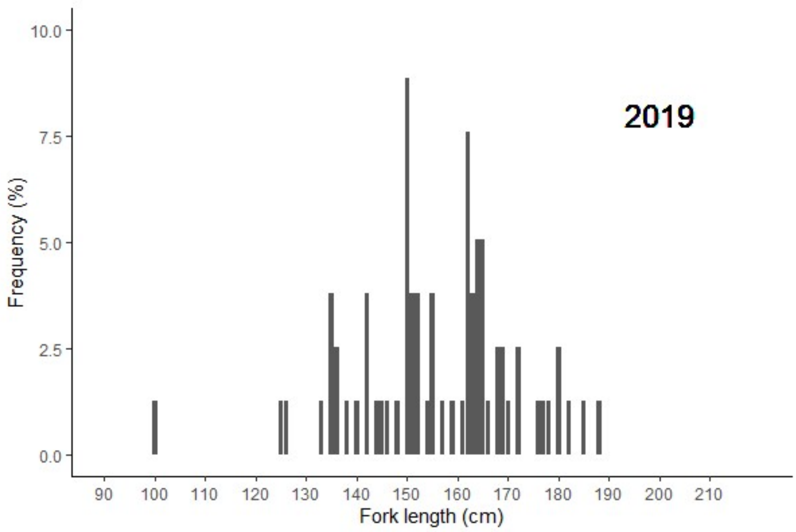


Figure 2: Length frequency distribution of individuals sampled for otoliths during the 2019 (18/19), 2020 (19/20), and 2021 (2020/21) fishing seasons. (Continued on next page)

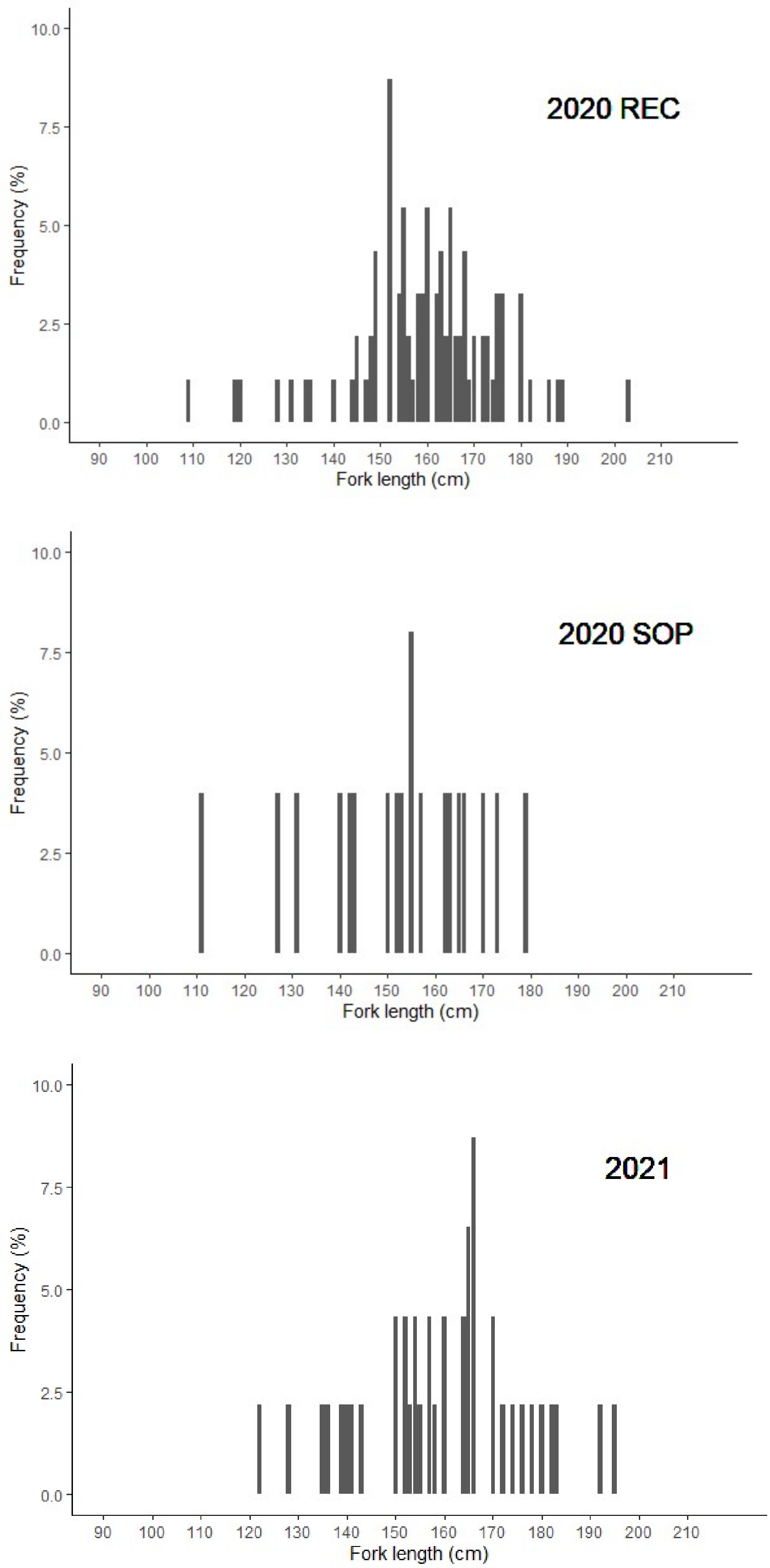


Figure 2: ***continued*****. Length frequency distribution of individuals sampled for otoliths during the 2020 (19/20) and 2021 (2020/21) fishing seasons.**

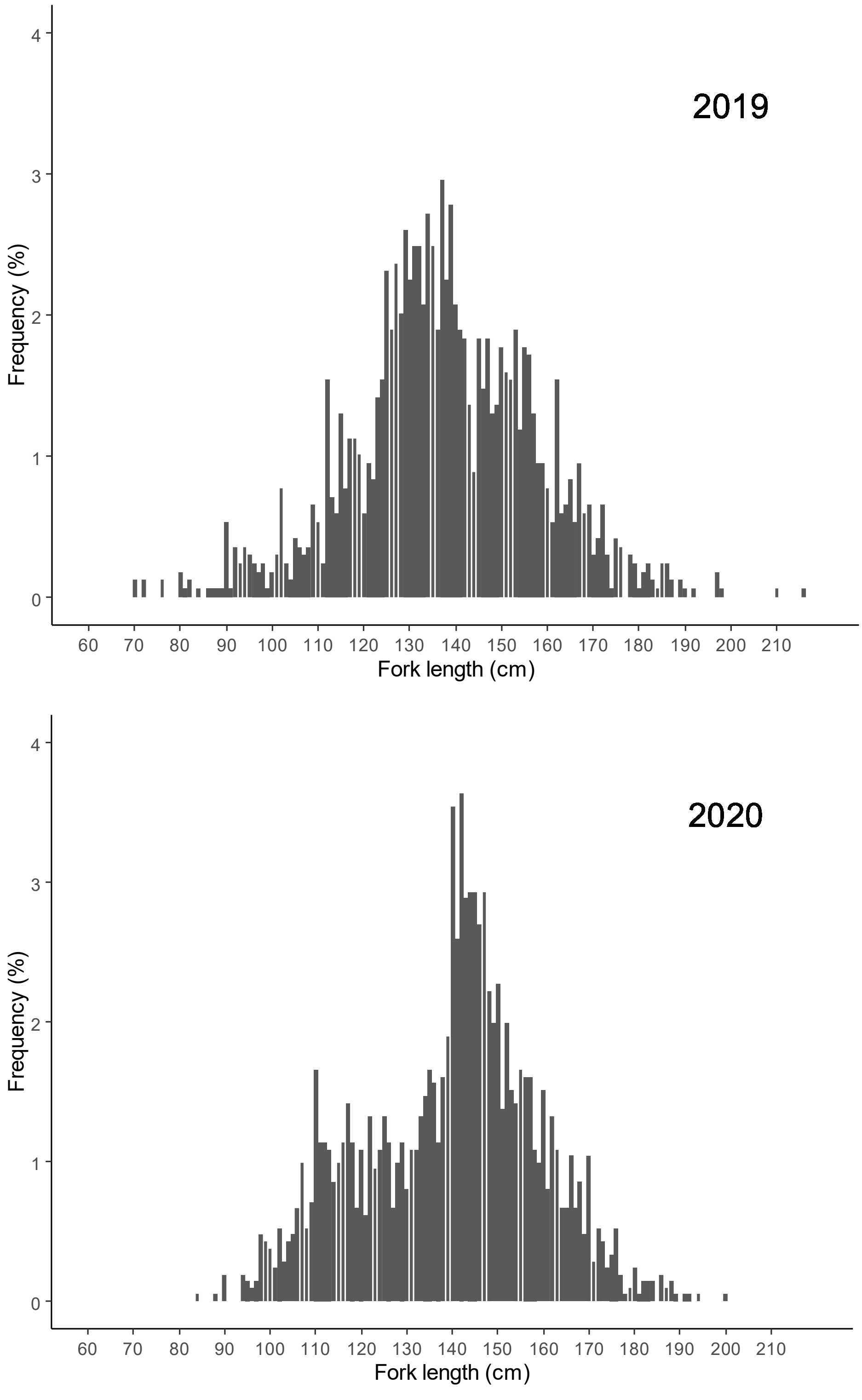


Figure 3: Length frequency distribution of the sampled onboard catch during the 2019 (18/19), 2020 (19/20), and 2021 (2020/21) fishing seasons (n = 1691, 2117, and 2120, respectively). (Continued on next page)

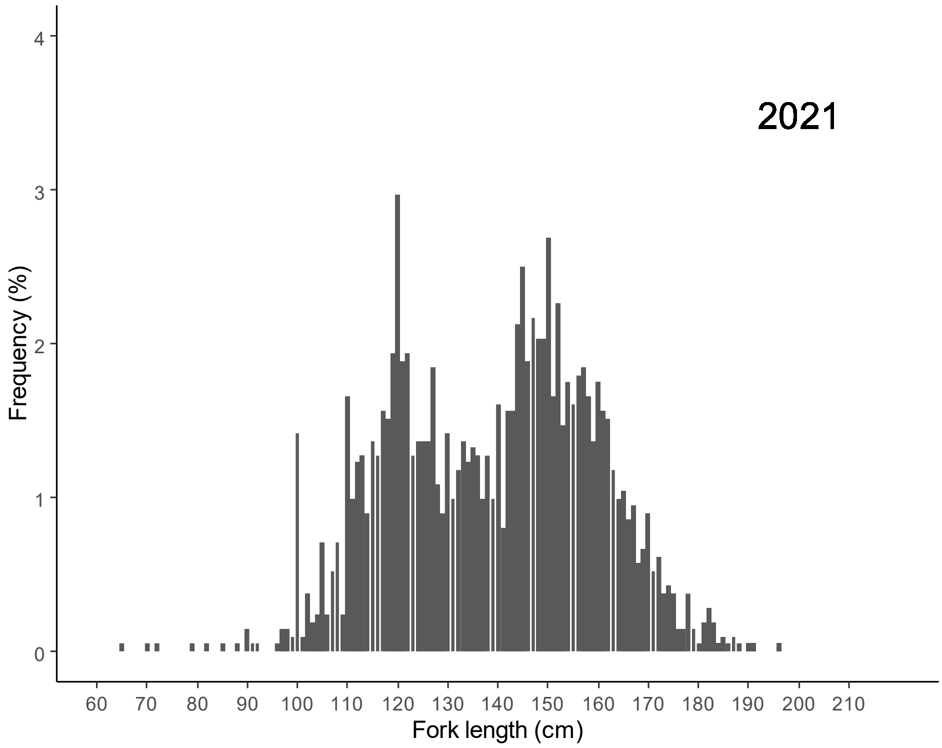


Figure 3: ***continued.*** **Length frequency distribution of the sampled onboard catch during the 2021 (2020/21) fishing seasons (n = 2120).**

3.2 Age estimation and precision

The number of otoliths per fishing year available for age estimation are shown in Table 2.

Table 2: **Numbers of southern bluefin tuna otoliths collected, prepared, and aged from each fishing season for the duration of this project, between 2019 to 2021 fishing years.**

Fishing year	Samples	Prepared	Aged	Origin
2019 (2018/19)	80	80	79	REC
2020 (2019/20)	92	92	91	REC
2020 (2019/20)	25	25	24	SOP
2021 (2020/21)	46	46	44	REC

Age was estimated for 238 of the 243 STN otoliths available. Two percent (5 samples) could not be read because the otoliths were either too broken to prepare or the otolith increment structure within the sectioned otolith was too difficult to interpret. For the samples aged during this project, age ranged from 3 to 24 years. The age-otolith weight relationships for each sampling year along with the age-fish length relationship of the combined samples are shown in Appendix 2. Comparison of the first and second readings showed that 38% of the age estimates agreed across the three years of the project (Appendix 3). The intra-reader (multiple reads from primary reader) index of average percentage error (IAPE) across all years was 4.7% and the inter-reader IAPE (between the primary and secondary reader) was 3.6% (Appendix 3).

Growth parameters estimated for the three fishing seasons (2019, 2020, and 2021) are presented collectively in Table 3 as STN2018-01, along with growth estimates from previous projects. The growth curve for all years combined is presented and overlaid with the age-at-length data in Figure 4.

Table 3: Von Bertalanffy growth parameters estimated from each STN catch-at-age project (STN2018-01, STN2016-01, SEA2015/19, STN2011/01, STN2009/01, STN2007/01, STN2006/01, and IFA2003/04).

Project	$L\infty$	K	t_o
STN2018-01	180.64	0.20	-1.91
STN2016-01	182.64	0.16	-2.32
SEA2015-19	180.35	0.18	-2.00
STN2009/01	185.26	0.17	-2.48
STN2007/01	179.27	0.24	-0.34
STN2006/01	187.96	0.12	-5.65
IFA2003/04	183.50	0.16	-2.52

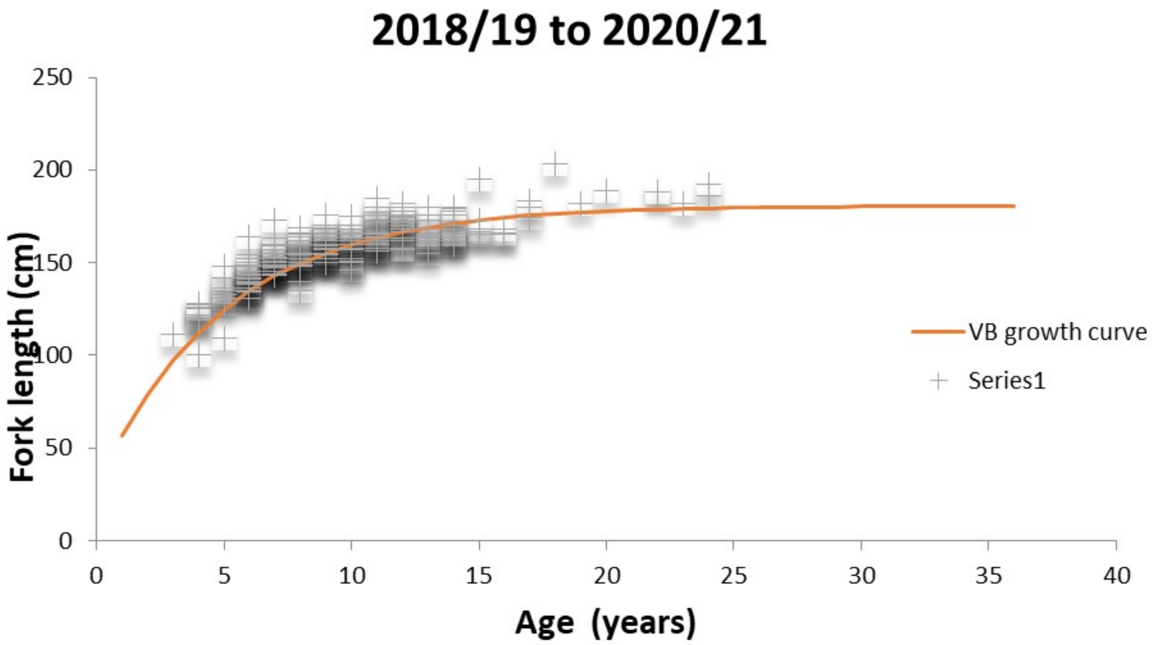


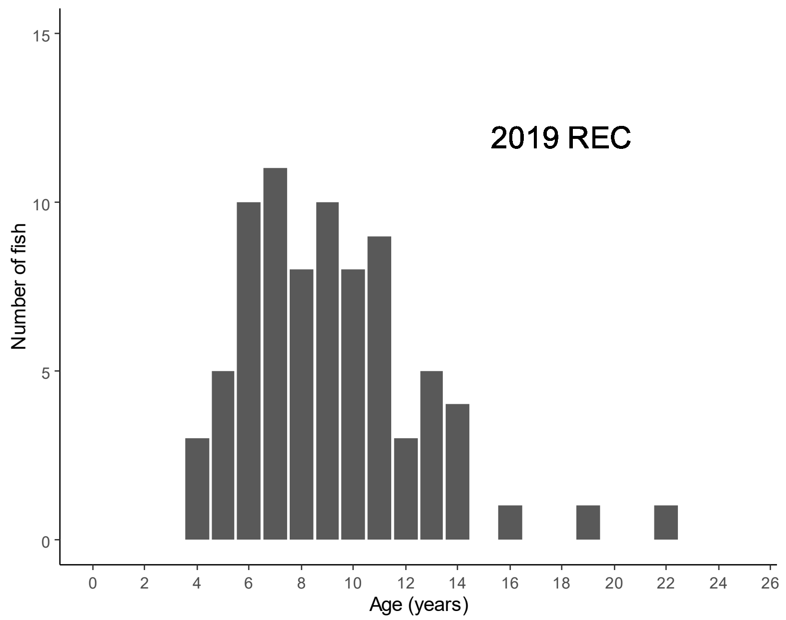
Figure 4: Von Bertalanffy growth curve estimating length-at-age for STN for project STN2018-01, for years 2019 to 2021 (n=238).

3.3 Proportions-at-age

Age compositions for 2019, 2020, and 2021 are presented in Figure 5 and the ALKs for 2019, 2020, and 2021 are presented in Table 4 to Table 7.

The results for all years are summarised as follows:

- Ages ranged from 4 to 22 years in 2019, from 3 to 15 years in 2020 (SOP), 4 to 25 years in 2020 (REC), and 4 to 24 years in 2021.
- The age composition was dominated by age classes 6 to 11 years in 2019, 6 to 12 years in 2020 (REC), and 6 to 13 years in 2021. There were not enough commercially captured samples (SOP) in 2020 to draw any inferences about the age composition of the sampled population.
- There were very few individuals captured that were less than 4 years of age, or more than 16 years of age across all years.



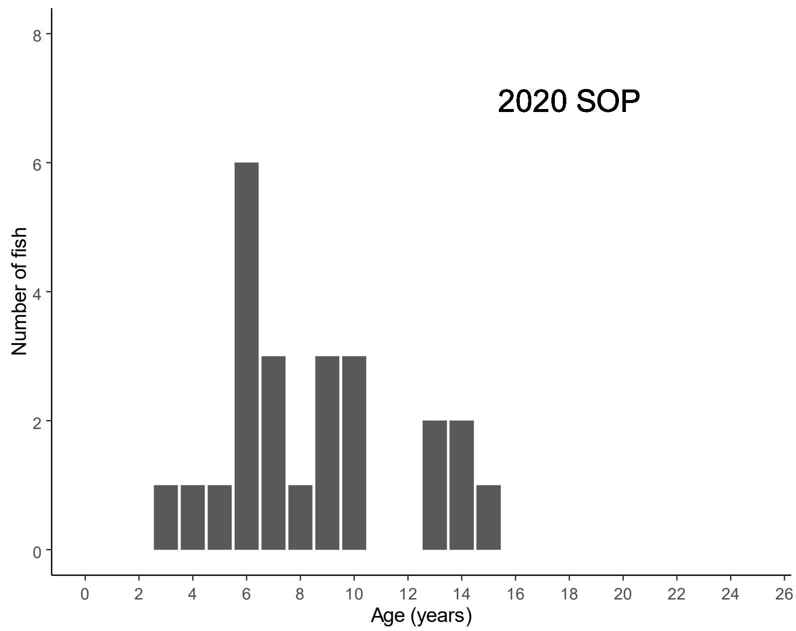
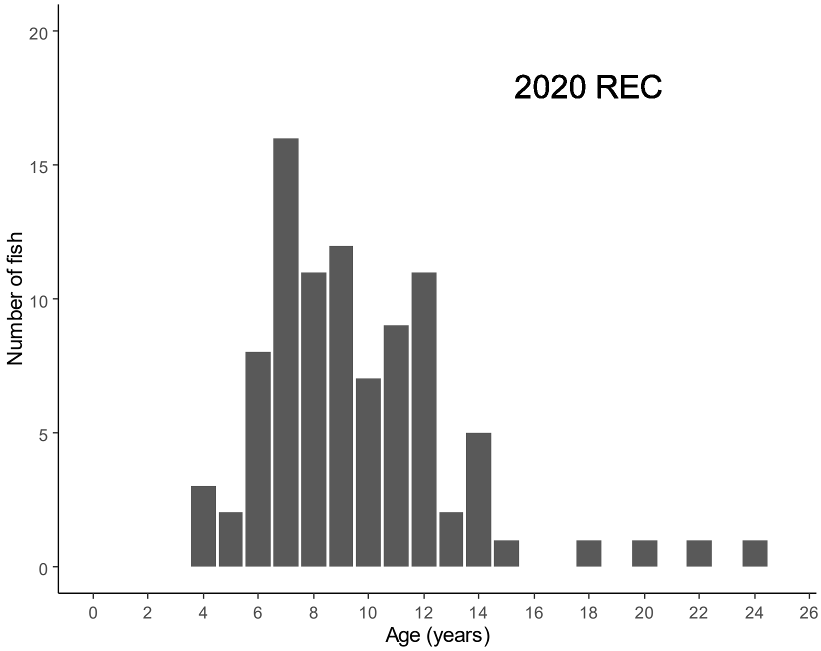


Figure 5: Age composition data from the direct ageing of otoliths for fishing seasons 2019 (REC), 2020 (SOP and REC), and 2021 (REC). (Continued on next page)



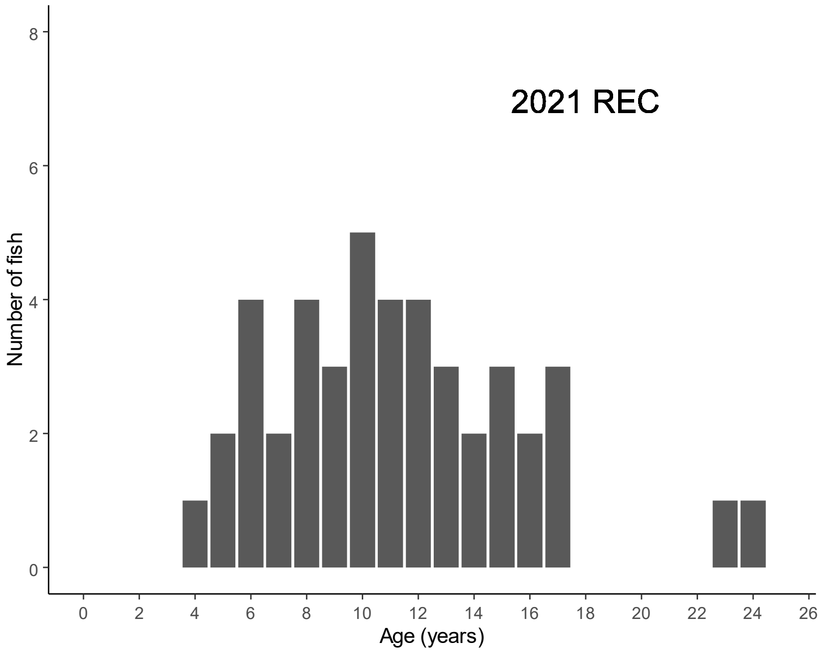


Figure 5: ***continued.*** **Age composition data from the direct ageing of otoliths for fishing 2020 (REC) and 2021 (REC).**

Table 4: Age-length key for direct age estimates – fishing season 2019 (2018/19).

Year (2019)	2018/19

	Age																					
Fork length (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+	Total
80																						0
85																						0
90																						0
95																						0
100					1																	1
105																						0
110																						0
115																						0
120																						0
125					2																	2
130						1																1
135						2	4															6
140						2	1	1	1													5
145							2				1											3
150							2	8	1	2	1											14
155								1	2	1			1									5
160								1	3	4	5	3	1	3	1							21
165									1	2	1	1		1	2		1					9
170												2	1									3
175										1		1			1							3
180												1		1						1		3
185												1									1	2
190																						0
195																						0
200																						0
205																						0
210																						0
Total	0	0	0	0	3	5	9	11	8	10	8	9	3	5	4	0	1	0	0	1	1	78

Note: One individual did not have an associated length. Thus, there is a discrepancy between the total number of ages (79) and the number of individuals in this age-length table.

Table 5: Age-length key for direct age estimates – fishing season 2020 (2019/20) from the commercial fishing sector (SOP).

Year (2020) SOP	2019/20

	Age																				
Fork length (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+	Total
80																						0
85																						0
90																						0
95																						0
100																						0
105																						0
110				1																		1
115																						0
120																						0
125					1																	1
130						1																1
135																						0
140							3															3
145							3	2	1													6
150								1			2											3
155										1	1			1								3
160										1				1								2
165															1							1
170										1						1						2
175															1							1
180																						0
185																						0
190																						0
195																						0
200																						0
205																						0
210																						0
Total	0	0	0	1	1	1	6	3	1	3	3	0	0	2	2	1	0	0	0	0	0	24

Note: One individual did not have an age estimate. Thus, there is a discrepancy between the total number of ages and the number of individuals in this age-length table.

Table 6: Age-length key for direct age estimates – fishing season 2020 (2019/20) from the recreational fishing sector (REC).

Year (2020) REC	2019/20

	Age																					
Fork length (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+	Total
80																						0
85																						0
90																						0
95																						0
100																						0
105						1																1
110																						0
115					1																	1
120					1																	1
125					1																	1
130							2															2
135									1													1
140							2															2
145						1	1	5	2													9
150							2	3	4	1	1											11
155								4	1	5		3	1									14
160							1	3	1	2	3	3	1									14
165									2	4	2	1	2		2	1						14
170								1				1	2	1	1							6
175											1		3	1	1							6
180												1	2		1							4
185																					3	3
190																						0
195																						0
200																			1			1
205																						0
210																						0
Total	0	0	0	0	3	2	8	16	11	12	7	9	11	2	5	1	0	0	1	0	3	91

Table 7: Age-length key for direct age estimates – fishing season 2021 (2020/21).

Year (2021)	2020/21

	Age																				
Fork length (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+	Total
80																						0
85																						0
90																						0
95																						0
100																						0
105																						0
110																						0
115																						0
120					1																	1
125						1																1
130																						0
135						1	2															3
140							2	1														3
145																						0
150								1	3	2												6
155									1	1	1		1									4
160												1		1	2							4
165											2	2	1	2		2	2					11
170											2		1					1				4
175												1	1									2
180																		2			1	3
185																						0
190																					1	1
195																1						1
200																						0
205																						0
210																						0
Total	0	0	0	0	1	2	4	2	4	3	5	4	4	3	2	3	2	3	0	0	2	44

4. DISCUSSION

Over the duration of project STN2018-01, 238 ages were estimated from a total of 243 otoliths collected from fish between 12/6/2019 and 23/07/2021 (2019, 2020, and 2021 fishing seasons). Ageing data displayed similar patterns to previous projects (Krusic-Golub 2005, 2012, 2015, 2017; Sutrovic & Krusic-Golub 2021). Unfortunately, there was a considerable shortage of otoliths sampled from the commercial fishery for this project that limits the scope and the inferences that can be drawn from the ageing data. Nonetheless, we discuss the results of the current project between the 2019 and 2021 fishing seasons.

The estimates of precision between first and second readings from the primary reader and readings between the primary and secondary reader were within the acceptable limits suggested by Morison et al. (1998) in all years of the current study; the authors suggest that levels of APE less than 5% are considered acceptable for age estimation studies. The low levels of error estimated in this study suggest consistent interpretation between readings and readers.

Ageing results and analysis are presented using unadjusted age (zone count = age) and no adjustment for birthdate and edge type was considered. The issue of edge adjustment and comparison with data from end of year catches (Indonesian, Japanese, and Australian surface longline fishery samples) is complex. Fifty four percent of otolith sections that were aged during the three years of this project had a marginal edge classified as wide, which is less than in previous years, but is clearly the most commonly occurring edge type. Thought needs to be given to the effect that this classification may have on comparisons between the age composition of mid-year and end-year catches if they are to be compared.

Although it was suggested that no adjustment to zone count is required when estimating proportions for catch-at-age, adjustments will be necessary if growth estimates from this study are to be compared with growth estimates from other sources (i.e., end of year samples). However, because STN do not grow at a consistent rate throughout the year, if zone counts are universally adjusted to either wide or narrow (-1 or +1), there will also be a bias. Growth in juvenile STN has been shown to peak during January to May (J. Farley, CSIRO, personal communication). Therefore, if all zone counts are adjusted for a narrow edge (as reported under project IFA2004/03), the mean length for a given age class for mid-year samples will be higher than for the end of year samples. This difference may incorrectly infer that STN from New Zealand grow more quickly than fish from other areas.

To compare growth, a method such as randomly allocating a wide or narrow edge to each sample may be necessary or perhaps thought should be given to converting the zone count into a decimal age and compare accordingly. Several methods exist to do this calculation. The most commonly applied approach is to adjust the raw count based on knowledge of the timing of otolith zone deposition, birth date, and capture date of the fish and the marginal edge type recorded. While a nominated birthdate can be applied based on knowledge of spawning for this species and may be reasonably accurate (as only one spawning ground has been identified and spawning occurs during spring and summer), limited data is available for the timing of otolith zone formation and whether zone formation occurs at the same time for the fish residing in the different fisheries throughout the Southern Ocean. An alternative and arguably preferable approach developed by Farley et al. (2020) removes the need for information on spawning and timing of band formation and instead relies on developing a relationship between daily age and the length of the ventral otolith arm for age 0+ samples and determining estimates of average increment width for each age class. This approach was not part of the scope of this project, but it could certainly be attempted in the future using previously aged samples and new samples as they become available.

The ageing data and results from this project were similar to that from previous projects and sampling years. Age ranged between 3 to 24 years, and the sampled population was dominated by a small number of age classes, generally between 6 and 12 years of age. As in previous studies, there were very few individuals that were either less than four years old or greater than 16 years old. Despite the small sample sizes in this study, we were able to observe some progressions of strong age classes through time. For example, four and five year old individuals in the 2017 fishing season were also strong age classes at six and seven years of age in 2019, seven and eight years of age in 2020, and eight years of age in 2021. Similarly, seven and nine year old fish in 2020 were strong age classes that were also strong as eight and ten years of age in 2021. However, it should be reiterated that the small sample sizes of the current and previous studies make it difficult to draw conclusive inferences about the age demographics of the population.

The length frequency distribution for each year, as determined from the sampled catch, showed little evidence of modal progression, however a higher proportion of fish between 110 to 130 cm FL within the sampled 2021 catch was observed and the length distribution was bimodal at 120 cm and 150 cm FL. This could potentially indicate some strong recruitment into the fishery as the average length at age of a four year old STN is approximately 120 cm FL.

The project was able to meet the objectives of the STN2018-01 contract, considering that access to samples for age estimation was limited. A total of 238 age estimates from 243 fish were produced from the commercial and recreational survey programmes. These samples were used to determine the age and length distributions. Even though we could not estimate proportions-at-age for the catch each year, the age compositions estimated from the raw ageing data still provide valuable information on the age and growth of individuals for the 2019, 2020, and 2021 fishing seasons. The continuous addition to the long-term ageing data provides important information for future stocks to be assessed and managed.

5. ACKNOWLEDGEMENTS

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APPENDIX 1: Detailed methods

Otolith weight

Otolith weight is a useful diagnostic tool in assessing potential errors in age estimates and for examining patterns of otolith growth. Otolith weight has a strong relationship with fish size and age. In long-lived species, the relationship of otolith weight against estimated age may show an increased slope if the ages have been underestimated. Large variation about the relationship may indicate a lack of precision in the estimates. Also, any single outlier in the relationship may indicate incorrect assignment of age and/or incorrect length and otolith weight measurements.

All undamaged otoliths were weighed to the nearest 0.001 g on an electronic balance.

Preparation of otoliths

Otoliths were prepared and aged according to standard Fish Ageing Services (FAS) procedures and protocols. The FAS procedures are modified from Morison et al. (1998).

Otoliths were embedded, in rows of five, within blocks of clear casting resin ensuring that the primordium of each otolith is inline. Four sections, approximately 300 µm thick, were cut through their centres with a modified high-speed gem-cutting saw with a 250 µm thick diamond impregnated blade. Sections from each sample were cleaned, dried, and mounted on glass microscope slides (50 x 76 mm) with resin. Sections were then covered with further resin and two glass coverslips (22 x 60 mm) were placed over the top of the resin. Prepared slides were placed in an oven at 40 °C and allowed to dry overnight.

Counts and measurements

Age estimation assumes:

- Increments counted were formed on an annual basis, and.
- One translucent zone and subsequent opaque zone represents one annual growth increment.

Sections were examined using transmitted light under a Leica M80 Zoom Stereomicroscope at 25× magnification. Higher magnification was sometimes required for the examination of the fine growth increments near the otolith edge from larger, presumably older fish. Each section of the otolith was inspected, and the section with the clearest incremental structure was chosen for ageing. This was usually, but not necessarily, the section closest to the primordium.

A customised image analysis system is used to age sectioned and whole otoliths. This system counts and measures manually marked increments and collects an image from each sample aged.

A CCD digital camera is mounted onto the stereomicroscope (Leica M80) and a live image is displayed on the monitor. Using the image analysis system, a transect is drawn on the otolith image from the primordium to the edge of the sample. The positions of the opaque zones along this transect and the otolith edge are marked with a screen cursor. Additional structures such as sub-annual zones or transition points can also be marked. The numbers of zones marked and the measurements from the primordium to each subsequent mark along the transect are exported to a Microsoft database.

In addition, the otolith image is automatically captured and exported, along with the x and y coordinates of the marked zones, into an image database. Images are captured in the Joint Photographic Experts Group (JPG) format.

To avoid the potential for biasing age estimates, all counts were initially made without knowledge of fish size, sex, location, or date of capture. Once ageing of all otoliths was completed, the ageing data were combined with biological data (fish length, date of capture) and otolith weight for subsequent analyses.

Precision of age estimates

Repeated readings of the same otoliths provide measures of intra-reader and inter-reader variability. Repeat readings do not validate the assigned ages but provide an indication of magnitude of the error to be expected with a set of age estimates, due to variation in interpretation of an otolith. Beamish & Fournier (1981) have developed an index of average percent error (IAPE), which has become a common method for quantifying this variation. The IAPE is calculated as:

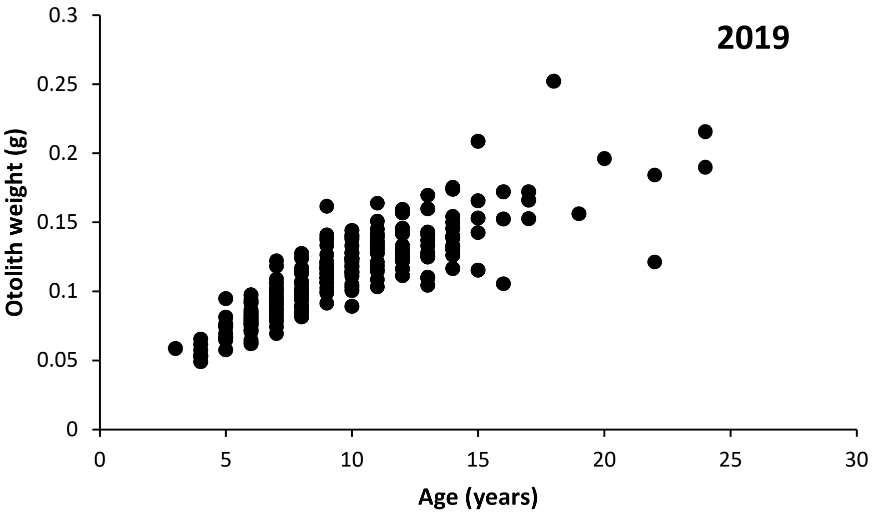
$$IAPE = \frac{100}{N} \sum_{j=1}^{N} \left[\frac{1}{R} \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j} \right]$$

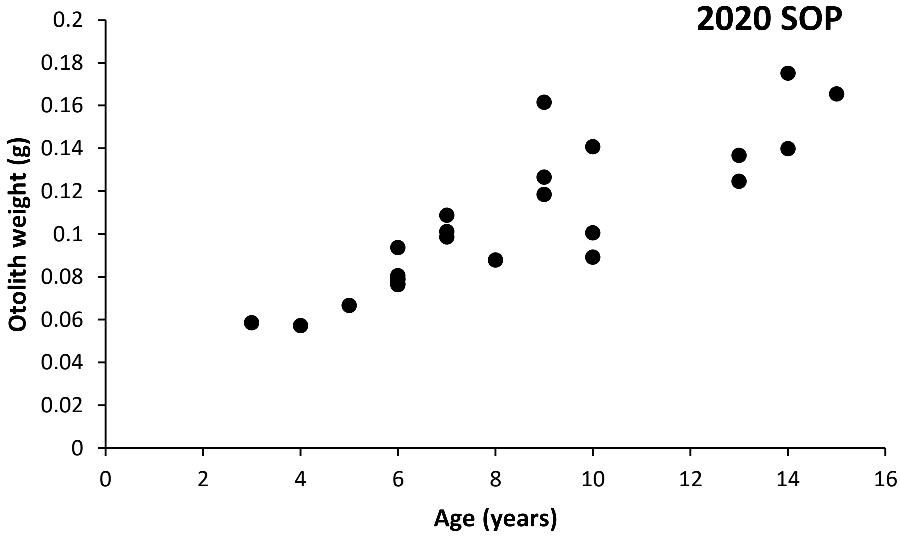
where N is the number of fish aged, R is the number of times the fish are aged, X_{ij} is the ith determination for the jth fish, and X_j is the average estimated age of the jth fish. The index has the property that differences in age estimates for younger fish will contribute more to the final value than will the same absolute error for older fish (Anderson et al. 1992).

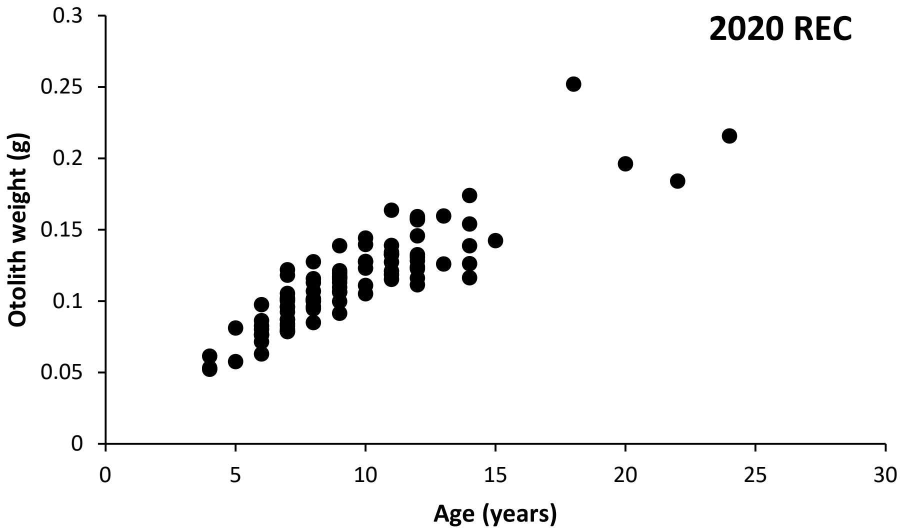
All otoliths were read twice without reference to anything other than the otolith ID and an IAPE was calculated. The distribution of the differences between repeat readings was also inspected as another indicator of ageing errors, and of any bias between readings. Re-reading of the selected otoliths by the same reader/s provides a measure of precision within the readings. The purpose of the re-reading is to provide an indication of error associated with the estimates, not an agreed age.

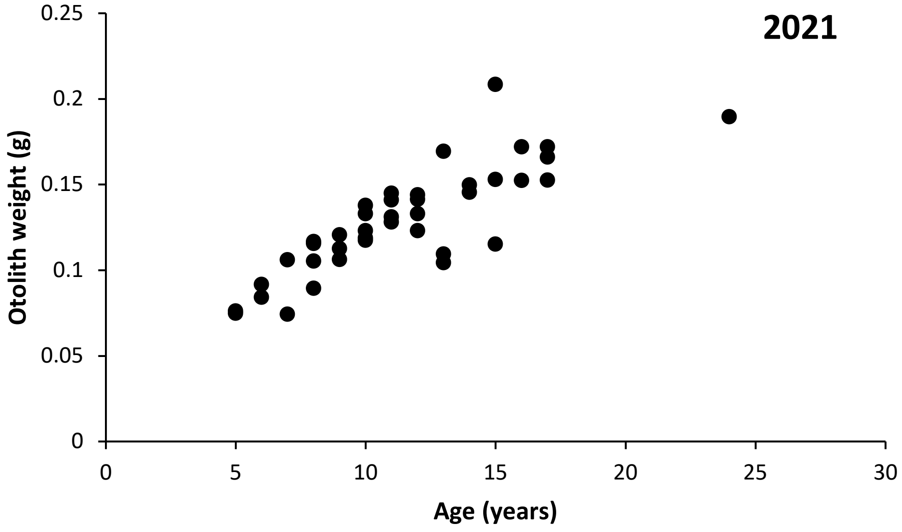
After reading each otolith twice, a final agreed age was given. If the two readings differed the otolith sample was re-read a third time and a final age assigned.

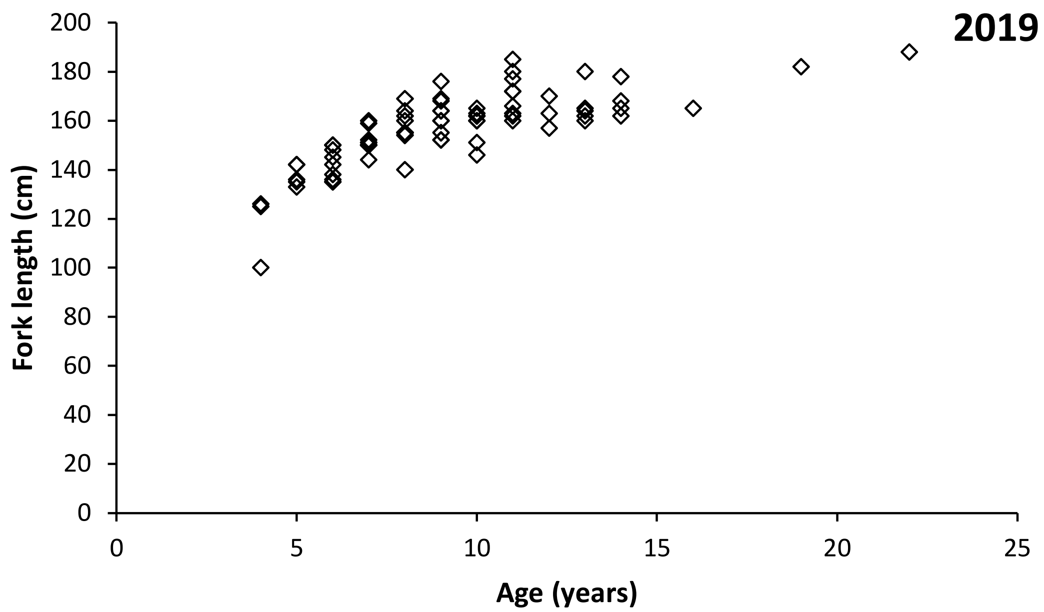
APPENDIX 2: Age-otolith weight and age-fish length relationships for each year of the current project (2019–2021). (Continued on next three pages)

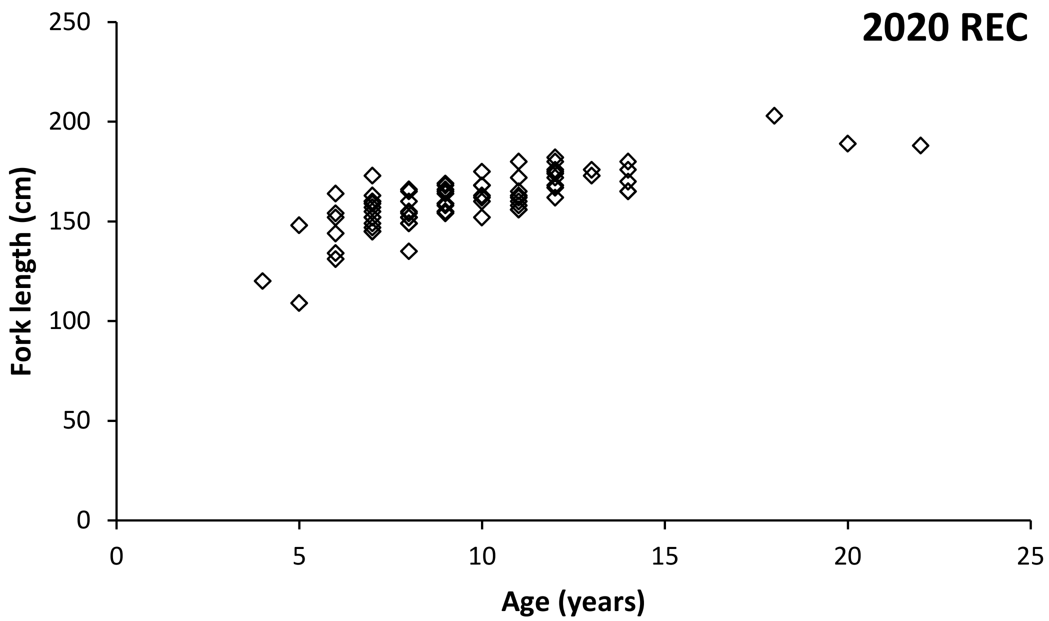


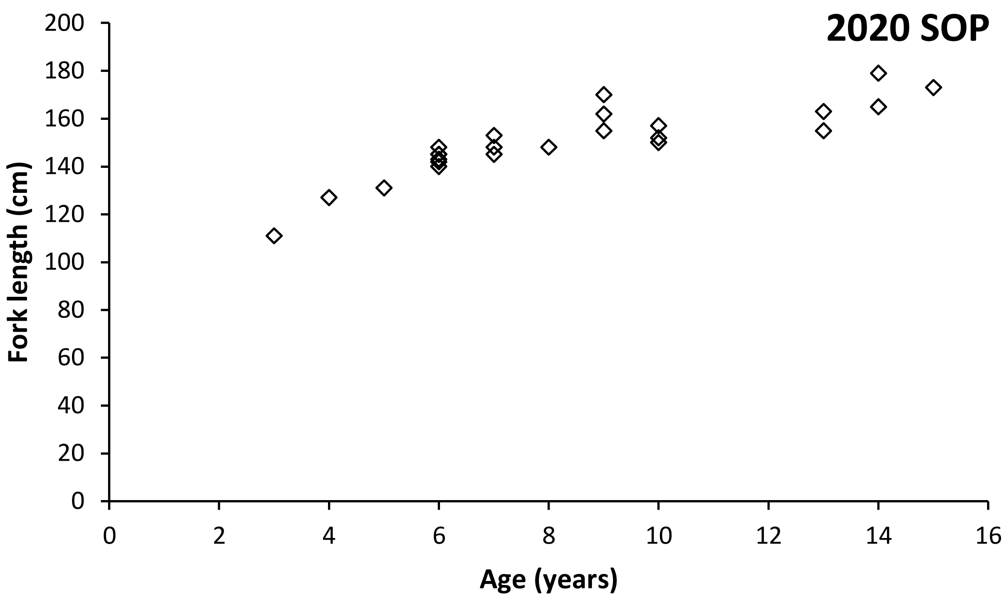


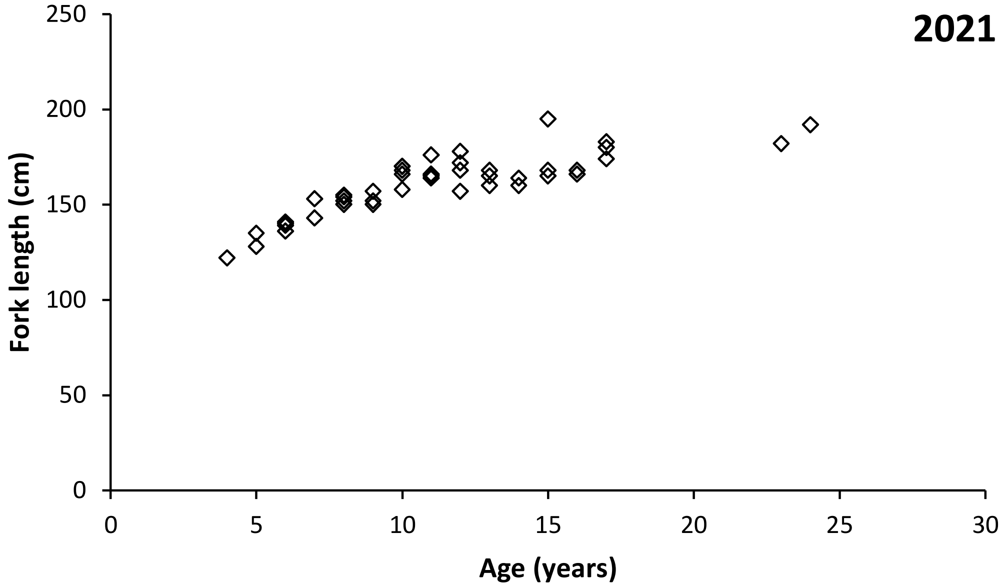



2021
Otolith weight (g)
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
Age (years)

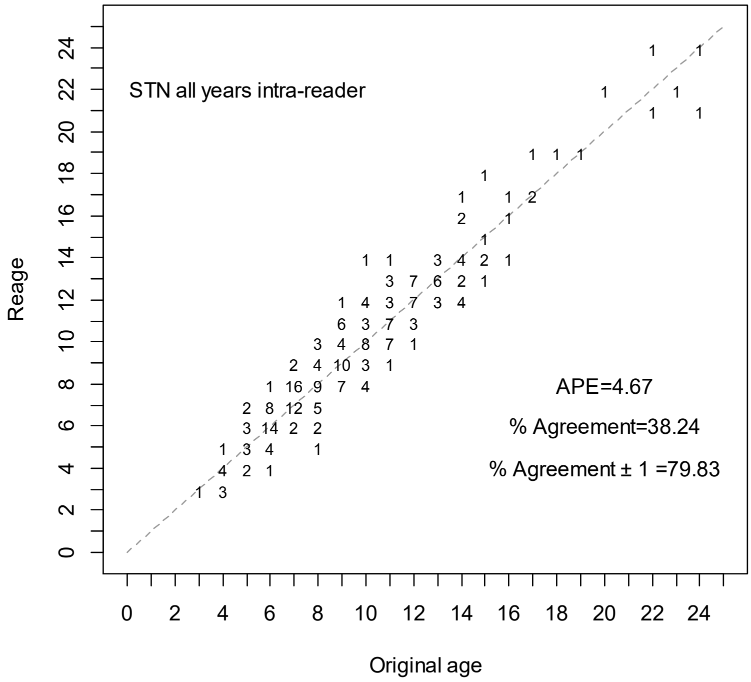

2019
Fork length (cm)
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
Age (years)

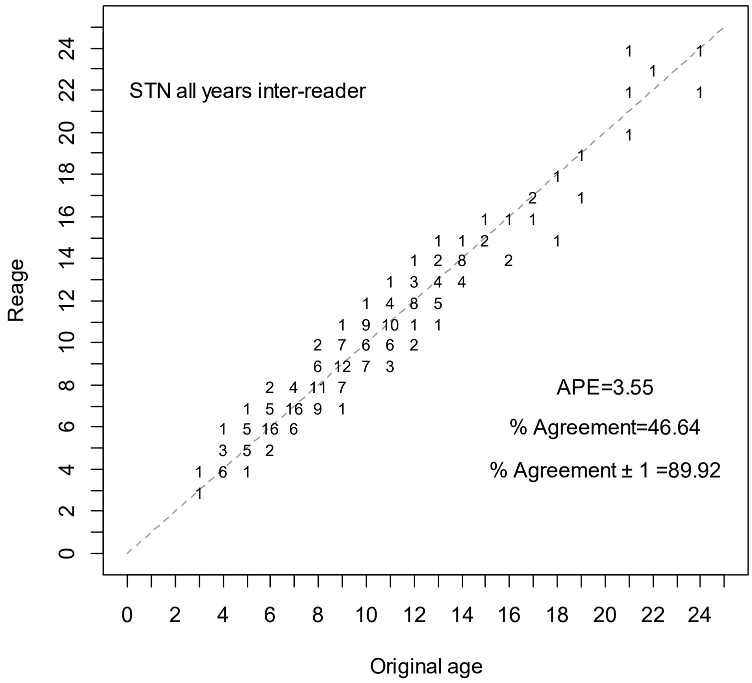

2020 REC
Fork length (cm)
Age (years)
0
50
100
150
200
250
0
5
10
15
20
25


2020 SOP
Fork length (cm)
Age (years)
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
14
16


2021
Fork length (cm)
250
200
150
100
50
0
0
5
10
15
20
25
30
Age (years)

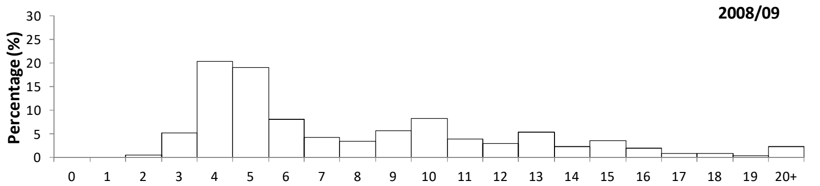
APPENDIX 3: The age difference between paired readings of the same otolith by the same reader (intra-reader) and from different readers (inter-reader) for samples from the 2018/19 to 2020/21 fishing seasons.

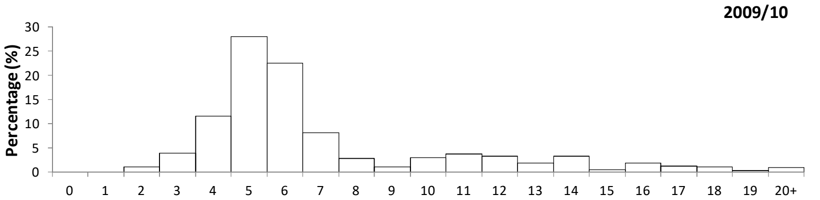


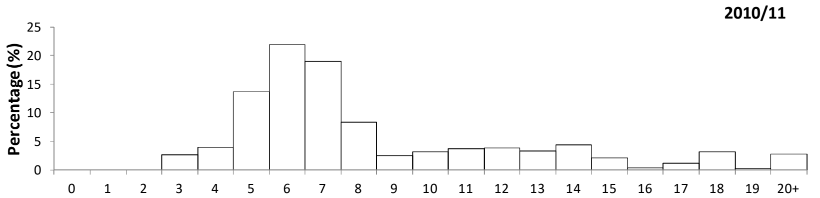


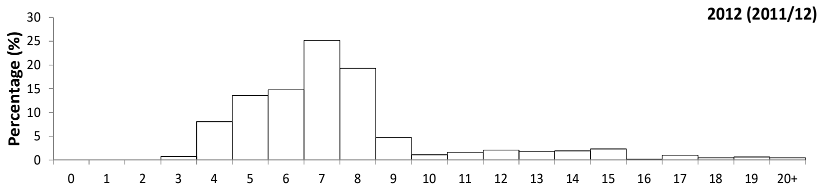
APPENDIX 4: Age composition 2009–2017 seasons

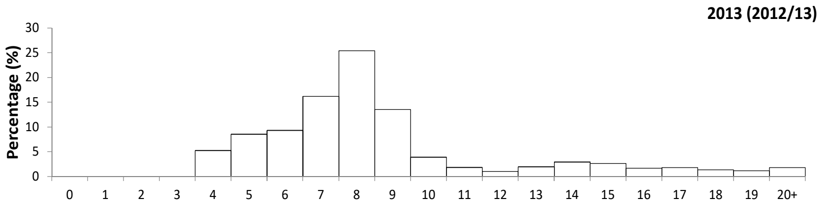
Note: 2009 to 2011 age composition sourced from Krusic-Golub (2012), 2012 to 2014 age composition from Krusic-Golub (2015), and 2015 to 2017 sourced from Sutrovic & Krusic-Golub (2021). Lack of data precluded the estimation of age compositions for 2017/18. (Continued on next page)

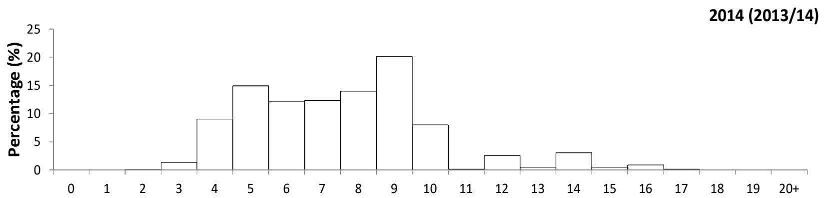


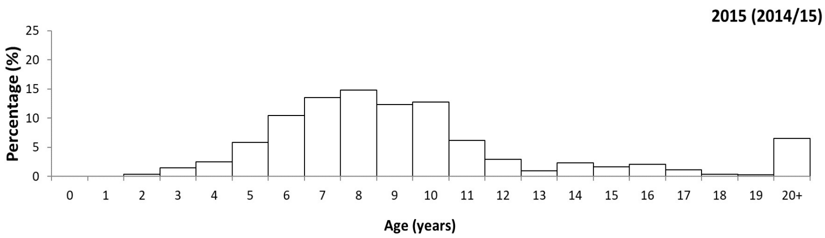


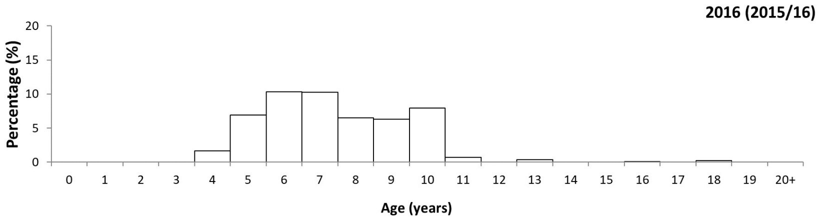


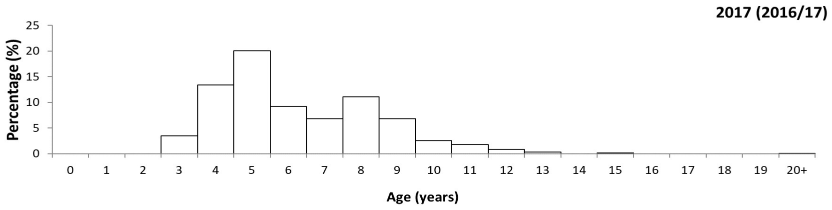









2016 (2015/16)
Percentage (%)
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20+
Age (years)


2017 (2016/17)
Percentage (%)
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20+
Age (years)