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Age estimation and catch-at-age of southern bluefin tuna (*Thunnus maccoyii*) in the New Zealand surface longline fishery, 2022–2024

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PLAIN LANGUAGE SUMMARY

This report describes research conducted in 2022, 2023, and 2024 to determine the age of southern bluefin tuna (*Thunnus maccoyii*; STN) caught in New Zealand's surface longline (SLL) fishery. Ages were assessed using counts of opaque and translucent zones in STN otoliths ('ear bones'). Otoliths used this this study were collected from fish heads supplied by Licensed Fish Receivers (LFRs), collected by observers onboard SLL vessels, or from sampling of the recreational fishery in a related Fisheries New Zealand project. A total of 150, 156, and 163 STN were aged in 2022, 2023, 2024, respectively. Assigned ages ranged from 2–26 years old, with most aged fish around 4–12 years old. An age-length key was constructed applied to the lengths of STN provided by LFRs to estimate the age structure of the SLL catch in each year. The information generated by this study will be used for assessments and fisheries management advice.

EXECUTIVE SUMMARY

Moore, B.R.[1]; Hamill, J.; Ó Maolagáin, C. (2025). Age estimation and catch-at-age of southern bluefin tuna (*Thunnus maccoyii*) in the New Zealand surface longline fishery, 2022–2024.

***New Zealand Fisheries Assessment Report 2025/30.* 40 p.**

This report describes age estimation and catch-at-age analyses for southern bluefin tuna (*Thunnus maccoyii*; STN) in the New Zealand surface longline (SLL) fishery in 2022, 2023, and 2024. It adds to a time series of age data collected from the fishery since 2001. Southern bluefin tuna is managed as a single stock globally by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), and forms a valuable fishery in New Zealand waters, with most commercial landings made by SLL vessels. The species is also a popular target for recreational fishers.

Typically, age estimation and catch-at-age of STN in New Zealand's SLL fishery is conducted using samples and length data collected by fishery observers onboard SLL vessels. However, observer coverage in the SLL fleet has been limited in recent years, with only a few STN otoliths collected by observers in 2022, and none collected in 2023 or 2024. Accordingly, otoliths were sampled from heads provided by Licensed Fish Receivers (LFRs). Fish lengths, required along with age estimates to construct annual age-length keys (ALK), were collected from CCSBT Catch Documentation Scheme (CDS) data. These samples were supplemented by those collected by observers where available (2022 only), and by samples collected from the recreational fishery under Fisheries New Zealand project STN2021-02. For the LFR-sourced individuals, all length data were initially recorded as anal length (AL) by the LFRs, which were then converted by Fisheries New Zealand to fork length (FL).

Samples collected and selected for ageing in 2022 (n = 150), 2023 (n = 156), and 2024 (n = 163) were aged using CCSBT protocols. Derived ages for samples collected between 2022 and 2024 ranged from 2 to 26 years, with most samples ranging from 4 to 12 years old. Fish sampled by fishery observers or from the recreational catch were generally older than those sampled from LFRs.

Proportional catch-at-age of the commercial SLL fishery in each year was estimated by applying the ALK to the lengths recorded in the CCSBT CDS. Modal ages of the landed catch were 6, 5, and 4 years in 2022, 2023, and 2024, respectively. As with the aged subsample, most fish landed were estimated to be between 4 and 12 years old. There was little evidence of strong year-class progression in any year.

Four areas for future research to improve New Zealand data provided to CCSBT for assessment and management of STN are suggested:

1. Assess the appropriateness of the AL-FL conversion used, both across the spatial distribution of the catch and with STN ontogeny. Fork lengths for fish provided by LFRs during this study were estimated using the Fisheries New Zealand conversion equation. However, it was found to underestimate FL when compared against a data set collected from the recreational catch under Fisheries New Zealand project STN2021-02 and against FL-AL conversion factors derived for Atlantic bluefin tuna (*Thunnus thynnus*).
2. Assess the degree of variation in the way LFRs are measuring STN lengths and, should variation exist, ensure that measurements are being collected in a standardised way as best as possible.
3. Investigate approaches to allow the inclusion of length data that lack a corresponding record in the ALK to be included in the catch-at-age analyses.
4. Continue to investigate the timing of opaque zone deposition in STN otoliths in New Zealand.

[1] All authors affiliation to National Institute of Water and Atmospheric Research Ltd (NIWA).

1. INTRODUCTION

Southern bluefin tuna (*Thunnus maccoyii*; STN) are a large tuna species capable of reaching up to 2.5 m in length and up to 260 kg in weight. They are found in eastern Atlantic, Indian, and south-west Pacific Ocean waters between 30°S and 50°S. Across this range, STN comprise a single stock, with mature fish returning to a single spawning ground located in the north-east Indian Ocean between Australia and Indonesia (Hobday et al. 2016). They occupy a broad thermal niche, occurring in waters from ~6°C to 30°C, and in surface waters to depths greater than 600 m (although typically show a preference for surface waters to around 250 m in depth) (Patterson et al. 2008).

Fisheries for STN are managed under the auspices of the Commission for the Conservation of Southern Bluefin Tuna (CCSBT). The species forms a valuable fishery in New Zealand waters, with annual commercial catches of approximately 800–1100 tonnes since 2014 (Fisheries New Zealand 2024). The majority of landings are made by surface longline (SLL) vessels, and smaller amounts by troll vessels (Moore & Finucci 2024). The species supports a growing recreational fishery, with recreational and charter vessel catches estimated to be approximately 70 tonnes (t) in 2023 and 2024 (Holdsworth 2024).

Southern bluefin tuna in New Zealand are monitored through trends in catch, effort and catch-per-unit-effort (CPUE), as well as through annual age and catch-at-age estimates. The latter has been conducted since 2001, under New Zealand Ministry for Primary Industries projects IFA2004/03, (Krusic-Golub 2005), STN2006/01, STN2007/01, STN2009/01 (Krusic-Golub 2012), STN2011/01, SEA2015–19 (Krusic-Golub 2017), STN2016-01 (Sutrovic & Krusic-Golub (2021) and STN2018-01 (Krusic-Golub et al. 2023).

1.1 Objectives

The overall objective of Fisheries New Zealand research project STN2021-01 was to determine the age composition of the commercial surface longline catch of southern bluefin tuna in New Zealand fisheries waters. The specific objectives were to:

1. Age 150 otoliths for southern bluefin tuna in each of the 2021–22, 2022–23, and 2023–24 fishing years (2022, 2023 and 2024 calendar years).
2. Use the resulting age estimates to develop an ALK for each year.
3. Apply the ALK for each year to length frequency information from the CCSBT Catch Documentation Scheme (CDS) to calculate catch-at-age estimates for the New Zealand surface longline southern bluefin tuna fishery.

2. METHODS

2.1 Description of the fishery

To contextualise the sampling design and patterns in catch-at-age, a brief visualisation analysis of the fishery was undertaken (See Appendix A). An extract from the *Enterprise Data Warehouse (EDW)* was obtained from Fisheries New Zealand (replog 16279), comprising all landing records for STN and all effort records for the primary method (SLL), for the period 1989–90 to 2023–24. The fishing year for the SLL fishery extends from 1 October to 30 September the following year. References to single fishing years correspond with the latter year in the time-period.

2.2 Sample collection

The targeted number of age estimates to be derived each year under project STN2021-01 was 150. Historically, otolith samples used for deriving ages and estimating catch-at-age of STN in New Zealand waters have been subsampled from those collected by observers onboard commercial fishing vessels. In recent years, however, there has been limited observer coverage on the New Zealand SLL fleet (Fisheries

New Zealand 2024). As such, there has been limited sampling of STN otoliths, with no otoliths collected by observers in 2023 or 2024, and only 32 collected in 2022 (See Results). Otoliths were therefore obtained from STN heads sampled from fish provided by Licenced Fish Receivers (LFRs). In 2022, specimens were provided by Bay Packers LP in Tauranga, who primarily process STN caught in CCSBT Management Area 5 (Figure 1, see also Appendix A). In 2023 and 2024, sampling from this LFR was not possible, so specimens were provided by Solander Seafood Limited in Nelson, who processes STN caught in CCSBT Management Area 6 (Figure 1, Appendix A). The LFRs measured the anal length (AL) of the fish and shipped the heads with their assigned CDS number (2-letter country code and 8-digit numerical code e.g. NZ2200 0001) to NIWA Auckland (2022) and NIWA Nelson (2023 and 2024). Otoliths were extracted by removing the top of the head to expose the brain cavity (i.e. lifting-the-lid technique). Extracted otoliths were cleaned of adhering tissue, dried, and stored in plastic vials inside labelled paper envelopes for processing.

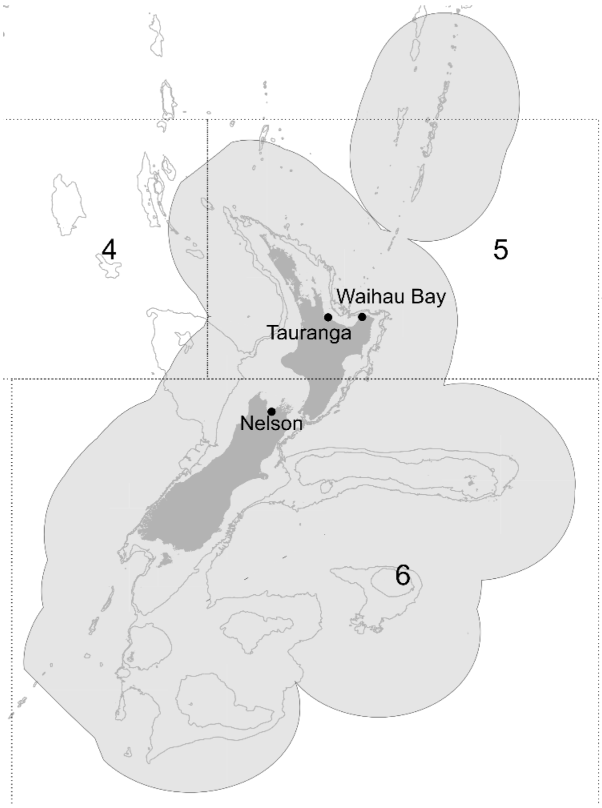

Figure 1: Locations (Licenced Fish Receivers or boat ramps) where most southern bluefin tuna samples were collected from in this study. Also shown are the 500 and 1000 m depth contours and the areas where the boundaries of CCSBT Management Areas 4, 5, and 6 (dotted lines) intersect with the New Zealand Exclusive Economic Zone (grey shading).

In addition, otoliths were subsampled from those collected by Blue Water Marine Research (BWMR) Ltd staff from recreationally caught STN landed at Waihau Bay in the eastern Bay of Plenty under project STN2021-02 (Figure 1, see Holdsworth 2025). Subsampling of the recreationally sourced otoliths aimed to ensure that length classes not adequately covered by LFR-sourced otoliths were included. These samples were sent to NIWA Wellington, accompanied by a data file containing the date and approximate area of capture, FL (in cm), and weight (in g).

To facilitate examination of growth and construction of ALKs, each aged fish was linked back to its length and collection data. For observer- and recreational-fisher sourced fish, lengths were supplied as fork length (FL), measured as a straight horizontal line (i.e. not curved over the body) from the tip of the lower jaw to the ‘v’ in the tail. For LFR-sourced fish, lengths were provided via an extract of annual CDS data from Fisheries New Zealand and comprised estimated FLs, which were converted from ALs measured by the LFRs using the Fisheries New Zealand conversion factor, specifically:

FL = 1.482×AL.

2.3 Otolith selection

Under project STN2021-01, a total of 150 age estimates are required to be provided annually. In each year, the total number of samples available exceeded this value. Accordingly, a selection process was undertaken to select samples for ageing. The method of selecting otoliths for ageing varied between years in accordance with the different sample numbers provided by each source (i.e. LFRs, fishery observers, and recreational fishers). In 2023 and 2024, samples collected from LFR-supplied fish were grouped into 5 cm FL classes and then otoliths in each FL class were selected randomly in numbers approximately proportional to the occurrence of the length class in the length frequency from the CDS data, with the constraint that the number of otoliths in each length class (where available) was at least one. In addition, otoliths from fish over 180 cm FL were over-sampled where possible because of low numbers of available otoliths and a higher potential number of age classes per length class, while fish less than 75 cm FL were under-sampled, due to the low number of potential ages classes per length class. Recreationally caught samples were then used to supplement these samples. In 2023, otoliths were selected from recreationally caught fish for any length classes poorly represented in the LFR samples using the selection approach described above. In 2024, only 15 otoliths from recreationally caught fish were available, and so all were processed for ageing. Due to operational reasons, in 2022, fewer than 150 samples were available from the commercial fishery, although larger numbers of recreational otoliths were available (see Results). Accordingly, all commercially caught samples were prioritised for ageing in 2022, and these were supplemented by recreationally caught samples using the length-stratified sampling approach described above.

2.4 Sample preparation and ageing

Otoliths collected in 2022, 2023, and 2024 that were selected for ageing 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 (Anon 2002; hereafter referred to as the CCSBT Ageing Protocol). Prior to sectioning, one otolith from each pair was weighed to the nearest 0.001 g on a precision balance. Only undamaged otoliths were considered for weighing. Two thin sections (~300 µm) were then taken from a single otolith of each specimen selected for ageing, with care taken to ensure that at least one section contained the otolith core. Otolith sections were then mounted onto glass microscope slides with a coverslip using resin.

All otolith reads under this contract were conducted according to the CCSBT Ageing Protocol (Anon 2002). Opaque zones were primarily counted along a transect starting at the primordium and running out through the ventral arm to the otolith edge (Figure 2). Where opaque zones along this axis were not clear, opaque zones were counted along a transect starting at the primordium and running out through the dorsal arm to the otolith edge. Opaque zones were only counted if complete, and the count of opaque zones was considered as the age. For each otolith section aged, a single image was taken. Where possible, the marginal increment and the width of the previous completed annuli were measured, and the otolith edge was classified as wide translucent (WT; translucent material past the last opaque zone is greater than 1/3 of previously completed translucent zone), narrow translucent (NT; translucent material past the last opaque zone is less than 1/3 of previously completed translucent zone), or opaque (O; opaque material visible on the marginal edge of the otolith). The section was also assigned a readability score from 0–5, whereby 0 = No pattern obvious/not aged; 1 = Pattern present – no meaning; 2 = Pattern present – unsure with age estimate; 3 = Good pattern present – slightly unsure in some areas; 4 = Good pattern – confident with age estimate; 5 = No doubt, as defined for sectioned otoliths in the CCSBT Ageing Protocol (Anon 2002).

Figure 2: Sectioned southern bluefin tuna otolith. The white circles indicate counted opaque zones for determining age. Scale bar = 1 mm.

Before reading any new otoliths collected, three activities were conducted to ensure consistency with previous STN age estimates and catch-at-age analyses. First, an online mini workshop was held in October 2022 between NIWA project staff and the previous service provider (Fish Ageing Services). Participants discussed preparation methods, marginal increment / edge classifications, and growth band determination, in accordance with the approaches outlined in the CCSBT Ageing Protocol.

Second, in each year, NIWA STN otolith readers (hereafter the primary and secondary readers) read otoliths from 30 individuals processed under previous STN ageing contracts STN2016-01 and STN2018-01 with knowledge of the length of the fish and the previous age estimate as a recalibration exercise.

Third, following this recalibration read, the primary and secondary readers independently read a minimum of 100 randomly selected otoliths prepared and read under projects STN2016-01 and STN2018-01. These reads were conducted without knowledge of the fish's length or the previous age estimate. To evaluate the performance of these comparative reads, differences between the agreed age of these samples and the age determined by the NIWA primary reader were assessed visually through age-bias plots (Campana et al. 1995), frequency plots of the difference in age estimates, as well as through evaluation of the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE; Beamish & Fournier 1981). Following the recommendations in the CCSBT Ageing Protocol, a CV of 10% or less was required for readers to proceed with reading newly collected otoliths.

Once close agreement was achieved between the primary reader's age estimates and previously agreed ages, each otolith collected in 2022, 2023, and 2024 that was processed for ageing was read twice by the primary reader without knowledge of the length, collection source, or collection location of the fish. If the age estimate from the two readings by the primary reader agreed, the age was accepted as the final age. If the two readings differed, a third reading was made, and a final agreed age was assigned. This third reading was completed with knowledge of the first two ages. To provide a measure of intra-reader variability, a minimum of 20% of otoliths in each year were re-read by the secondary reader. Intra-reader precision (i.e., primary vs. secondary reads of the primary reader, and inter-reader precision (i.e. agreed ages of the primary reader vs. the secondary reader) was evaluated via age-bias plots, frequency plots of the difference in age estimates, as well as through evaluation of the CV and IAPE.

2.5 Data analysis

Marginal increment measurements

For those otoliths in which it was possible to measure the both the marginal increment and width of the previously completed annulus, the percentage completion of the marginal increment formation was examined by calculating the mean index of completion (C), whereby:

$C = W_n/W_{n-1}$

where W_n is the width of the marginal increment (distance from the start of the last opaque zone to the marginal edge) and W_{n-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).

Growth

Following Sutrovic & Krusic-Golub (2021), a von Bertalanffy Growth Function (VBGF) curve was fitted to the length-at-age data for each year to identify outliers in the FL-age data. VBGF curves were fitted using the non-linear least squares method and took the form:

$$L_t = L_\infty[1 - e^{-k(t-t_0)}]$$

where L_t is the length-at-age t, L_∞ is the hypothetical asymptotic maximum FL, k is the growth coefficient, and t_0 is the hypothetical age at which fish would have zero length.

As the LFR-supplied fish examined in this study had FLs that were estimated from ALs, we undertook a sensitivity analysis to test for the effect of using different AL-FL conversion ratios on resulting growth curve parameters. Here, a data set of 44 paired AL and FL measurements taken as both straight line and curved measurements collected by BWMR at Waihau Bay in 2024 under Fisheries New Zealand Project STN2021-02 (reported in Holdsworth 2025) were used to generate alternative AL-FL conversion factors using a linear model (Figure 3). For the straight-line measurements (i.e., as STN should be measured), the resulting relationship between FL and AL took the form:

$FL = 1.644 \times AL + 2.160$

This conversion was then used to predict the FL of fish that had FLs estimated from AL (i.e., the LFR samples), and the resulting estimated FLs were used to derive VBGF curves and parameters as above.

Catch-at-age

For each year, summaries were produced for the number of fish at each age and 5-cm FL class, and number of fish at each FL for each age (i.e., an age-length key; ALK). To ensure that results were comparable to those of previous analyses, following Krusic-Golub (2017) and Sutrovic & Krusic-Golub (2021), the age composition of the SLL catch in each calendar year (1 January to 30 September) was estimated by applying the ALK to the length-frequency data provided by the LFRs under the CCSBT Catch Documentation Scheme for each year as follows:

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

where A_t = the estimated number of fish of age t in the CDS length data, L_x = the number of fish of length x in the CDS length data, and P_{tx} = the proportion of aged fish of length x which were age t. Note that under this approach, only length classes that are represented in the ALK are included in the catch-at-age.

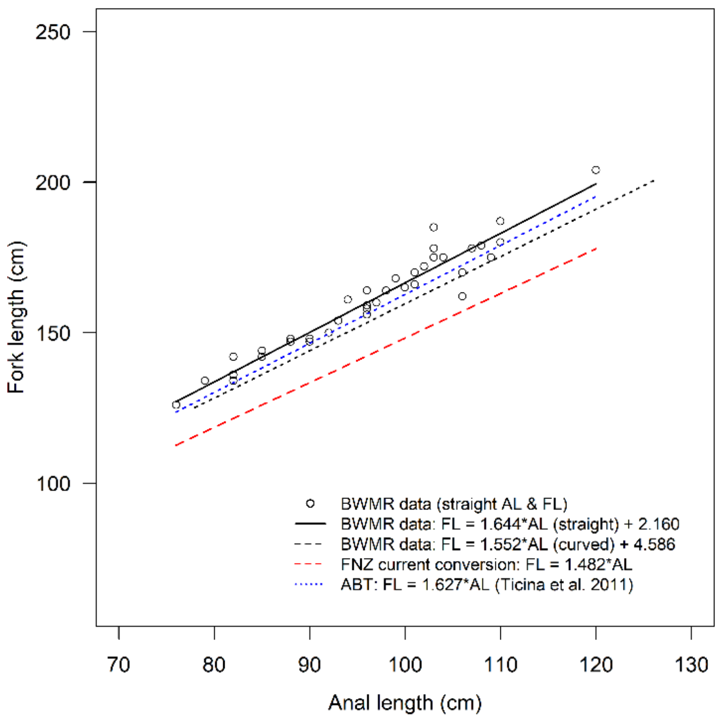

Figure 3: Paired anal length and fork length straight-line measurement (black open circles) collected under Fisheries New Zealand project STN2021-02 by Blue Water Marine Research (BWMR) and the resulting AL-FL conversion equation (black solid line). Also shown is the relationship between curved AL-FL line measurements (black dotted line), the AL-FL conversion for Atlantic bluefin tuna (*Thunnus thynnus*; ABT) of Tičina et al. (2011) (blue dotted line) and the AL-FL conversion using the equation of Fisheries New Zealand (i.e. FL = 1.482×AL) applied to the BWMR paired straight-line AL-FL data (red dashed line).

3. RESULTS

3.1 Sample collection

A total of 616 samples of paired STN length data and otoliths were sampled from the commercial catch (i.e. through LFRs or fishery observers) for this project, with these supplemented by 153 samples from the recreational fishery under Fisheries New Zealand project STN2021-02. A total of 212, 346, and 211 paired otolith-length samples were available in 2022, 2023, and 2024, respectively. The length distributions of the catch from the CDS, the subsample for which paired length data and otoliths were available, and the subsample of fish for which age estimates were derived in each year are presented in Appendix B. Sampling covered most lengths of fish processed by LFRs, although there was a general lack of sampling of the smallest (< 80 cm FL) and largest (> 180 cm FL) length classes (Appendix B, Figures B1–B3). In 2024 there was a noticeable absence of fish in the 125 cm FL class (= 140 cm FL using the AL-FL conversion equation based on the data of Holdsworth 2025) in the samples provided for otolith sampling (Appendix B, Figure B3).

Of the total of 769 STN for which both otoliths and length data were available, a total of 469 otoliths were aged across the three years, with 150, 156, and 163 individuals aged in 2022, 2023, and 2024, respectively (Table 1). Typically, less than 5% of otoliths prepared in each year were considered unreadable and thus were not aged.

Table 1: Numbers of southern bluefin tuna otoliths collected, prepared, and aged in 2022, 2023, and 2024 by collection source.

Year	Source	Sampled	Prepared	Aged[d]
2022	Fishery observers	32	26	26
	Licenced Fish Receiver	91	84	81
	Recreational[a]	89	45	43
	Annual total	**212**	**155**	**150**
2023	Fishery observers	0	0	0
	Licenced Fish Receiver	297[b]	150	142
	Recreational[a]	49	14	14
	Annual total	**346**	**164**	**156**
2024	Fishery observers	0	0	0
	Licenced Fish Receiver	196[c]	156	149
	Recreational[a]	15	15	14
	Annual total	**211**	**171**	**163**
Total		**769**	**490**	**469**

[a] Sampling of the recreational fishery was conducted under Fisheries New Zealand project STN2021-02.
[b] A total of 334 individuals were sampled from the LFR in 2023, however 16 of these had no corresponding length data supplied and otoliths from a further 21 of these were too broken to prepare, most likely due to the pithing approach used for euthanising the fish upon capture.
[c] 231 individuals provided by the Licenced Fish Receiver were sampled for otoliths in 2024, however accompanying length data could not be retrieved for 35 of these.
[d] Age estimates generated following the exclusion of outliers.

3.2 Ageing precision

Comparisons of age estimates from the NIWA primary reader and the agreed age estimate for material prepared under previous STN ageing projects are presented in Appendix C. Overall, there was close agreement between age estimates from the NIWA primary reader and the previously agreed age, with CVs of 4.3%, 6.1%, and 3.9%, and IAPEs of 3.0%, 4.3%, and 2.8%, for re-reads conducted in 2022, 2023, and 2024, respectively (Appendix C, Figures C1–C3). The overall CV and IAPE (i.e., when combining samples from all years) was 4.8% and 3.4%, respectively (Appendix C, Figure C4).

There was also close agreement between the first and second reads by the primary reader. CVs between the first and second reads in 2022, 2023, and 2024 were 7.0%, 8.0%, and 5.2%, respectively, while IAPEs were 5.0%, 5.7%, and 3.7% (Appendix C, Figures C5–C7). The overall CV and IAPE (i.e., when combining samples from all years) was 6.7% and 4.8%, respectively (Appendix C, Figure C8).

Finally, there was also general agreement between the age estimates of the subsets read by the primary and secondary readers in each year, with CVs of 8.6%, 7.2%, and 5.1%, and IAPEs of 6.1%, 5.1%, and 4.6%, for reads conducted in 2022, 2023, and 2024, respectively (Appendix C, Figures C9–C11). The overall CV and IAPE (i.e., when combining samples from all years) was 7.1% and 5.0%, respectively (Appendix C, Figure C12).

3.3 Growth

The VBGF parameters for STN sampled in New Zaland waters are presented in Table 2 and resulting curves are presented in Figure 4. Growth in 2023 and 2024 appeared much slower than in previous STN ageing projects, with individuals reaching a smaller FL-at-age than previously estimated.

However, most of the individuals used to derive the VBGF parameters in these years had FLs estimated from ALs using the Fisheries New Zealand conversion equation. When re-analysed using the revised FL-AL equation derived from the paired FL-AL data of Holdsworth (2025), growth curves were similar in all instances (Figure 4).

Considerable differences were also observed in raw AL-at-age of LFR-supplied fish between years included in this project. Samples collected in 2022 (from Bay Packers in the North Island) were larger than those collected in 2023–2024 (from Solander in the South Island), and these differences appeared to increase as fish got older (Figure 5). However, no such pattern was evident in otolith weight-at-age data, with otoliths sampled in 2022 being generally comparable to, or lighter than, those from 2023–2024 for all ages examined (Figure 6).

Table 2: von Bertalanffy growth function parameter estimates for southern bluefin tuna (STN) from the current study (STN2021-01) and from previous STN catch-at-age analyses.

Project	L_∞	k	t_0
IFA2003/04	183.50	0.16	-2.52
STN2006/01	187.96	0.12	-5.65
STN2007/01	179.27	0.24	-0.34
STN2009/01	185.26	0.17	-2.48
STN2011/01	178.19	0.20	-1.30
SEA2015-19	180.35	0.18	-2.00
STN2016-01	182.64	0.16	-2.32
STN2018-01	180.64	0.20	-1.91
STN2021-01: 2022	177.50	0.17	-2.01
STN2021-01: 2023 – FNZ AL-FL conversion	175.40	0.13	-3.93
STN2021-01: 2023 – BWMR AL-FL conversion	186.43	0.14	-3.88
STN2021-01: 2024 – FNZ AL-FL conversion	167.78	0.15	-2.48
STN2021-01: 2024 – BWMR AL-FL conversion	188.28	0.15	-2.56

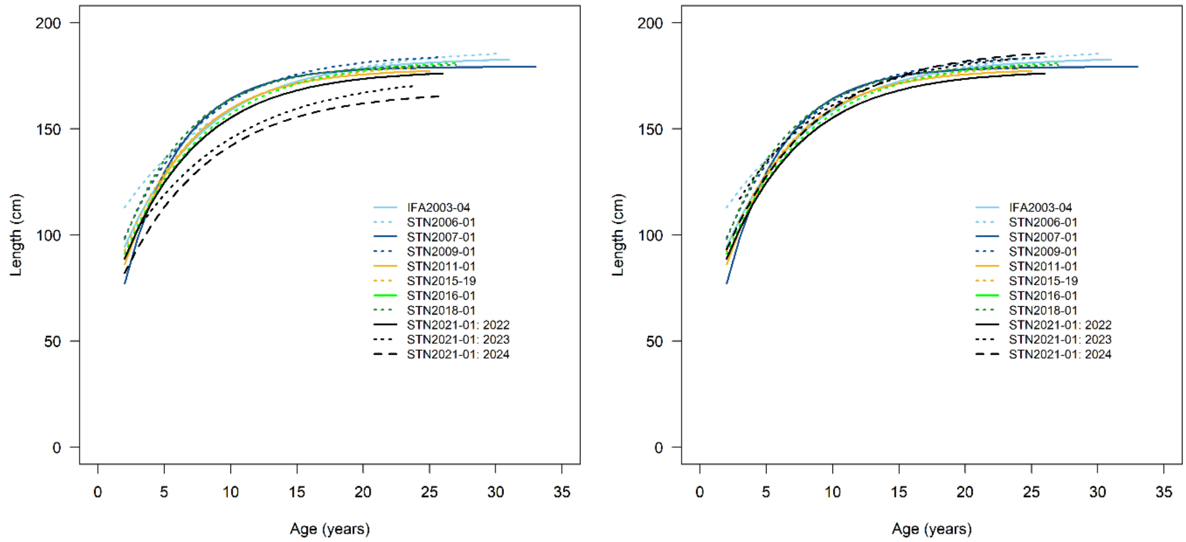

Figure 4: Comparison of von Bertalanffy growth function curves for southern bluefin tuna from the current and previous catch-at-age analyses. Left: growth curves generated from fork lengths provided by Fisheries New Zealand. Right: growth curves for 2023 and 2024 generated from fork lengths derived from anal lengths using the straight-line equation in Figure 3 (i.e. LF = 1.644×AL + 2.160).

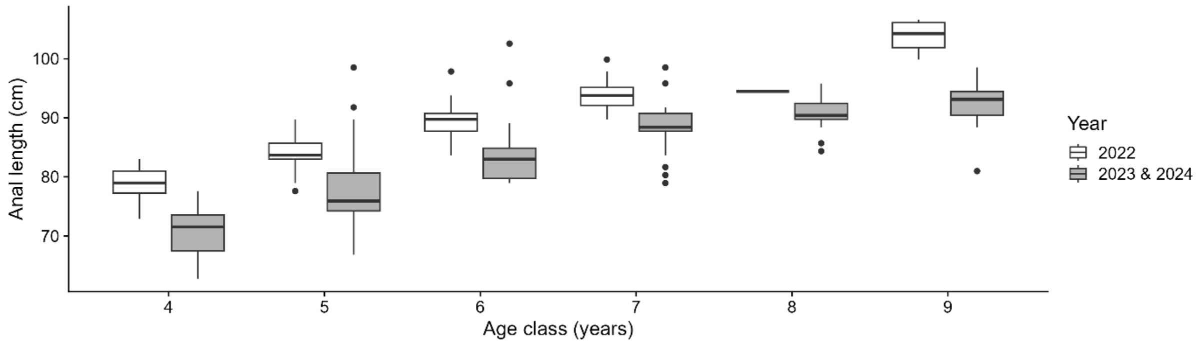

Figure 5: Anal length-at-age (cm) for STN aged in 2022 and 2023–2024. Only age classes 4–9 are displayed due to small numbers of fish in the 2–3 and 10+ age classes.

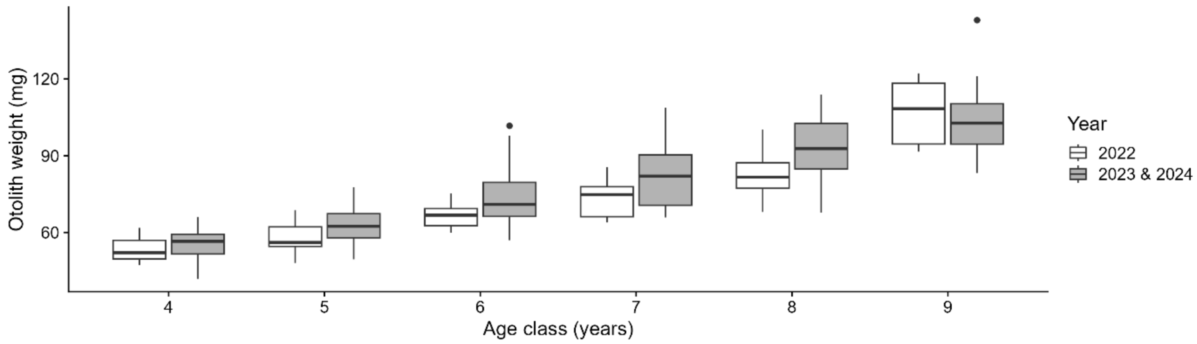

Figure 6: Otolith weight-at-age (cm) for STN aged in 2022, and 2023-2024. Only age classes 4–9 are displayed due to small numbers of fish in the 2–3 and 10+ age classes.

3.4 Otolith marginal state and increment width

Results from the edge type classification and marginal increment measurements are presented in Figure 7. Otoliths with wide translucent edges dominated samples collected in March-July, comprising between 60–75% of all samples in these months. There was a slight increase in the proportion of samples with narrow translucent otolith margins across the March-August sampling period. In March, 30% of samples (3 of 10) had opaque zones forming on their otolith edges. By August, 50% of samples examined had narrow translucent edge types. Marginal increment distances were greatest between April and July.

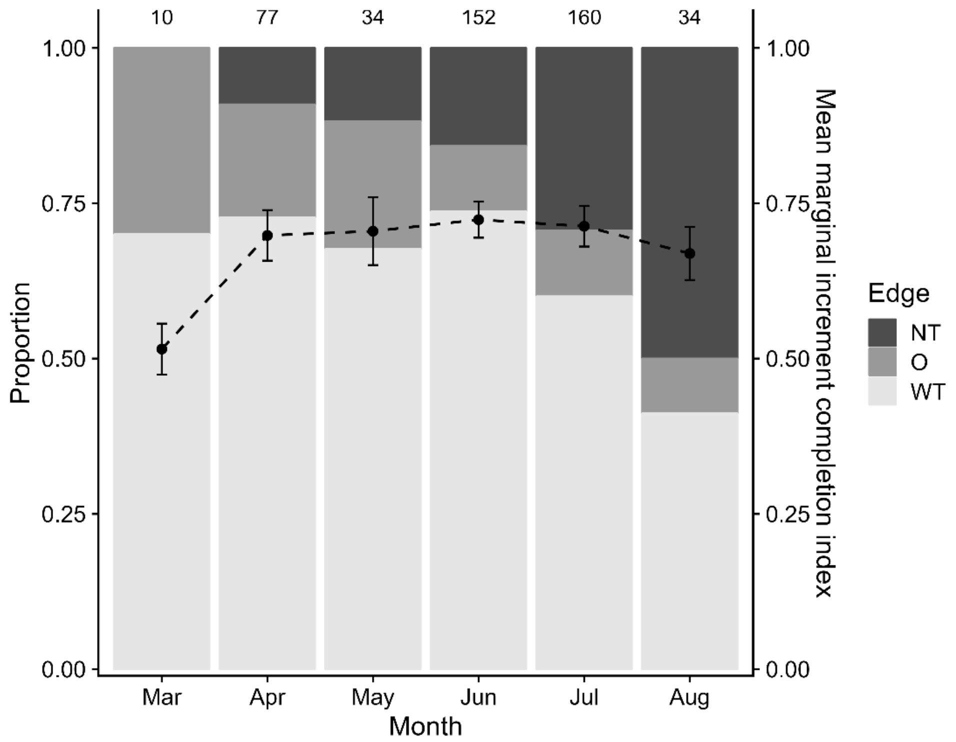

Figure 7: Proportion of samples collected by month with narrow translucent (NT), opaque (O), and wide translucent (WT) marginal edge types (bars and left axis) and trends in the monthly marginal increment completion index (line and right axis). Samples sizes for each month used in the edge type analysis are also shown.

3.5 Catch-at-age

The ALKs derived from the direct age estimates and FLs for 2022–2024 are given in Table 3, 4, and 5, and the proportions-at-age from direct ageing for 2022–2024 are given in Table 6. The proportions-at-age for all years between 2009–2024 (inclusive) are illustrated in Figure 8. The proportions-at-age were similar among years in that the aged component of the fishery was dominated by fish aged 4–6 years, with few samples estimated to be younger than 4 or older than 12 years (Figure 8). Fish sampled by fishery observers or from the recreational catch were generally older than those sampled from LFRs (Figure 9).

The length-scaled catch-at-age of the SLL fishery for 2015–2017 and 2022–2024 are presented in Figure 10, and the length scaled catch-at-age for 2009 to 2024 are provided in Appendix D. The estimated proportion of each observed age class in the catch-at-age for 2022–2024 is presented in Table 7. Modal ages of the landed catch were 6, 5, and 4 years in 2022, 2023, and 2024, respectively. Compared to 2015–2017, there were a relatively large proportion of young (6 years old or less) fish observed in recent years. Only small numbers of 7-year-old fish were estimated in 2024, most likely arising from the small number of individuals in the corresponding 140 cm FL length class (when converted from AL using the data of Holdsworth 2025) in the fish made available for otolith sampling. There was also little evidence of strong year-class progression in any year.

Table 3: Age-length-key for direct age estimates of southern bluefin tuna based on samples collected in 2022.

	Age																					
FL (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+	Total
75																						
80																						
85			1																			1
90				1																		1
95				1																		1
100																						
105				1	1																	2
110					4																	4
115					8	4																12
120					6	14	1															21
125						9	5															14
130						4	14	2														20
135							5	5														10
140								3	2													5
145							1	5	7	2	1											16
150								1	1	4	2	2	3									13
155										6			2									8
160										1	1	1		1		3					1	8
165														3	1	1	1					6
170															1			1		1		3
175																		1	1		1	3
180																			1			1
185																						
190																					1	1
Total	0	0	1	3	19	31	26	16	10	13	4	3	5	4	2	4	1	2	2	1	3	150

Table 4: Age-length-key for direct age estimates of southern bluefin tuna based on samples collected in 2023. Note fork length has been estimated from the anal length for most records in this table.

	Age																					
FL (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+	Total
75																						
80																						
85																						
90																						
95																						
100				5																		5
105				1	6	1																8
110					1	8																9
115					1	4	3	1														9
120						7	5	2		1												15
125						2	4		1													7
130						1	4	6	6	4	4		1									26
135						1		2	6	4	2											15
140							1	1	1	3	2	2										10
145						1		2		2	3	1	1	2		1	1		1			15
150							1				1	3	1	2	1	1						10
155										1	2	1	2	1			1				1	9
160										2	1	1	3		1				1		1	10
165														1		2						3
170																						
175																					2	2
180																		1				1
185													1									1
190																				1		1
Total				6	8	25	18	14	14	17	15	8	9	6	2	4	2	1	2	1	4	156

Table 5: Age-length-key for direct age estimates of southern bluefin tuna based on samples collected in 2024. Note fork length has been estimated from the anal length for most records in this table.

	Age																				
FL (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+	Total
75			1																			1
80				1																		1
85				2																		2
90				2	1																	3
95				3	4	1																8
100					12	1																13
105					9	9																18
110					3	10																13
115						3	7	1														11
120						1	8															9
125									1													1
130							1	4	3	5	3	3		1	1							21
135									3	2	3	3	1			1						13
140										2	4	5	1	1								13
145											3	3	1	1	2		1		2		1	14
150														2			1			1		4
155												1		1					1	1		4
160													1				1				1	3
165												1		1	1			1			1	5
170															2	1						3
175																					2	2
180																					1	1
185																						
190																						
Total			1	8	29	25	16	5	7	9	13	16	4	7	6	2	3	1	3	2	6	163

Table 6: Raw proportions at age for southern bluefin tuna in New Zealand aged under the current STN ageing project.

	Age																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
2022		0.0067	0.0200	0.1270	0.2070	0.1730	0.1070	0.0667	0.0867	0.0267	0.0200	0.0333	0.0267	0.0133	0.0267	0.0067	0.0133	0.0133	0.0067	0.0200
2023			0.0385	0.0513	0.1600	0.1150	0.0897	0.0897	0.1090	0.0962	0.0513	0.0577	0.0385	0.0128	0.0256	0.0128	0.0064	0.0128	0.0064	0.0256
2024		0.0061	0.0491	0.1780	0.1530	0.0982	0.0307	0.0429	0.0552	0.0798	0.0982	0.0245	0.0429	0.0368	0.0123	0.0184	0.0061	0.0184	0.0123	0.0368

Table 7: Length-scaled proportional catch-at-age of southern bluefin tuna in the New Zealand surface longline fishery, 2022–2024

	Age																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
2022		0.0047	0.0617	0.1320	0.1500	0.1900	0.1790	0.1020	0.0739	0.0216	0.0135	0.0255	0.0091	0.0044	0.0146	0.0016	0.0038	0.0027	0.0028	0.0065
2023			0.0338	0.0518	0.1700	0.1250	0.0957	0.0959	0.1130	0.0980	0.0510	0.0468	0.0375	0.0111	0.0246	0.0121	0.0030	0.0124	0.0022	0.0168
2024		0.0002	0.0248	0.1680	0.1380	0.1220	0.0293	0.1100	0.0531	0.0721	0.0866	0.0258	0.0471	0.0260	0.0089	0.0256	0.0026	0.0168	0.0172	0.0252

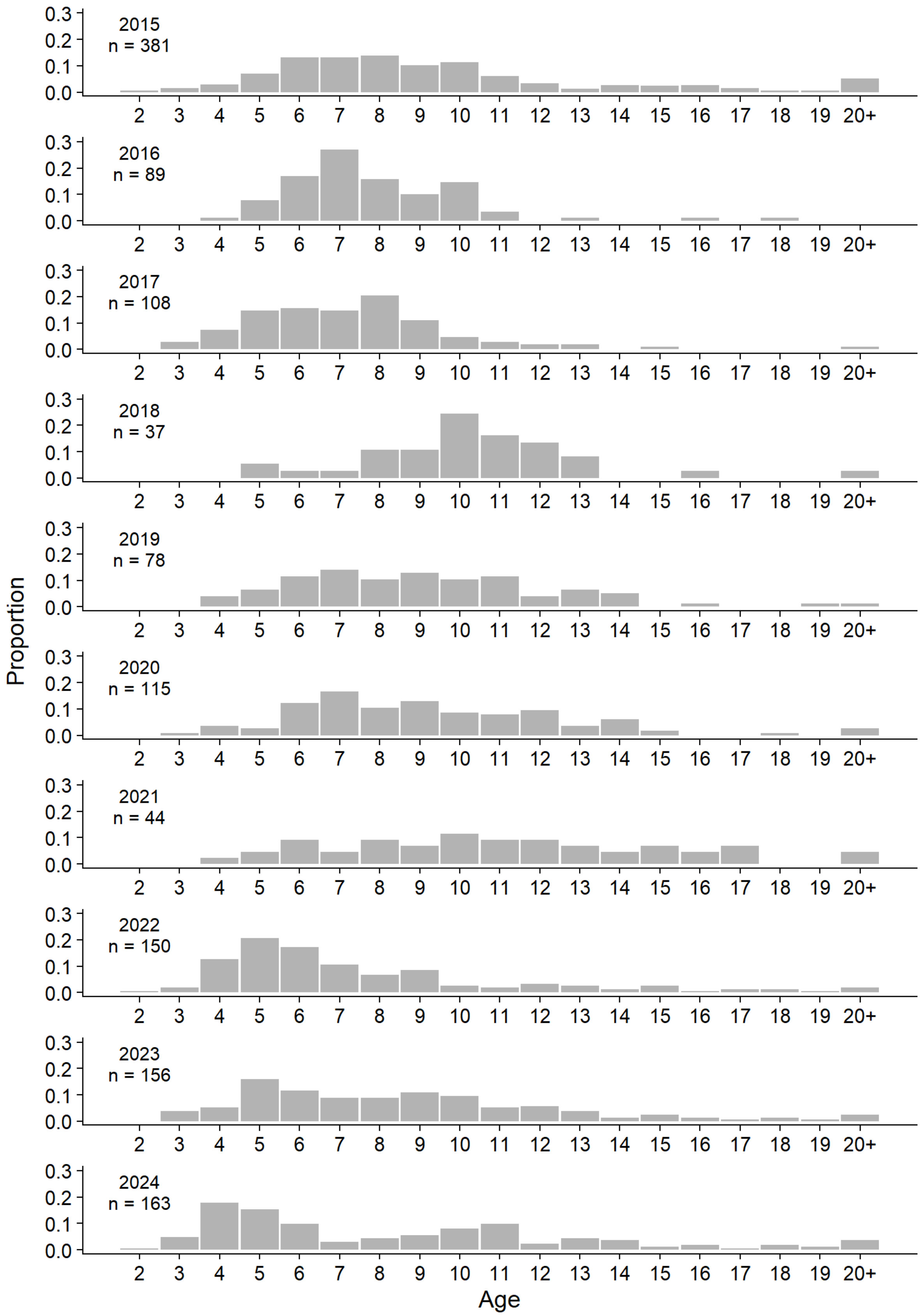

Figure 8: Proportions-at-age of southern bluefin tuna aged in the 2015 to 2024 calendar years from direct ageing. Data for 2015–2021 are from Fisheries New Zealand's *age* database. Data for 2022, 2023, and 2024 data are from the current project (STN2021-01). Note ageing in 2018–2021 was based on recreationally-sourced samples only and thus caution should be applied when comparing age frequencies in these years to other years.

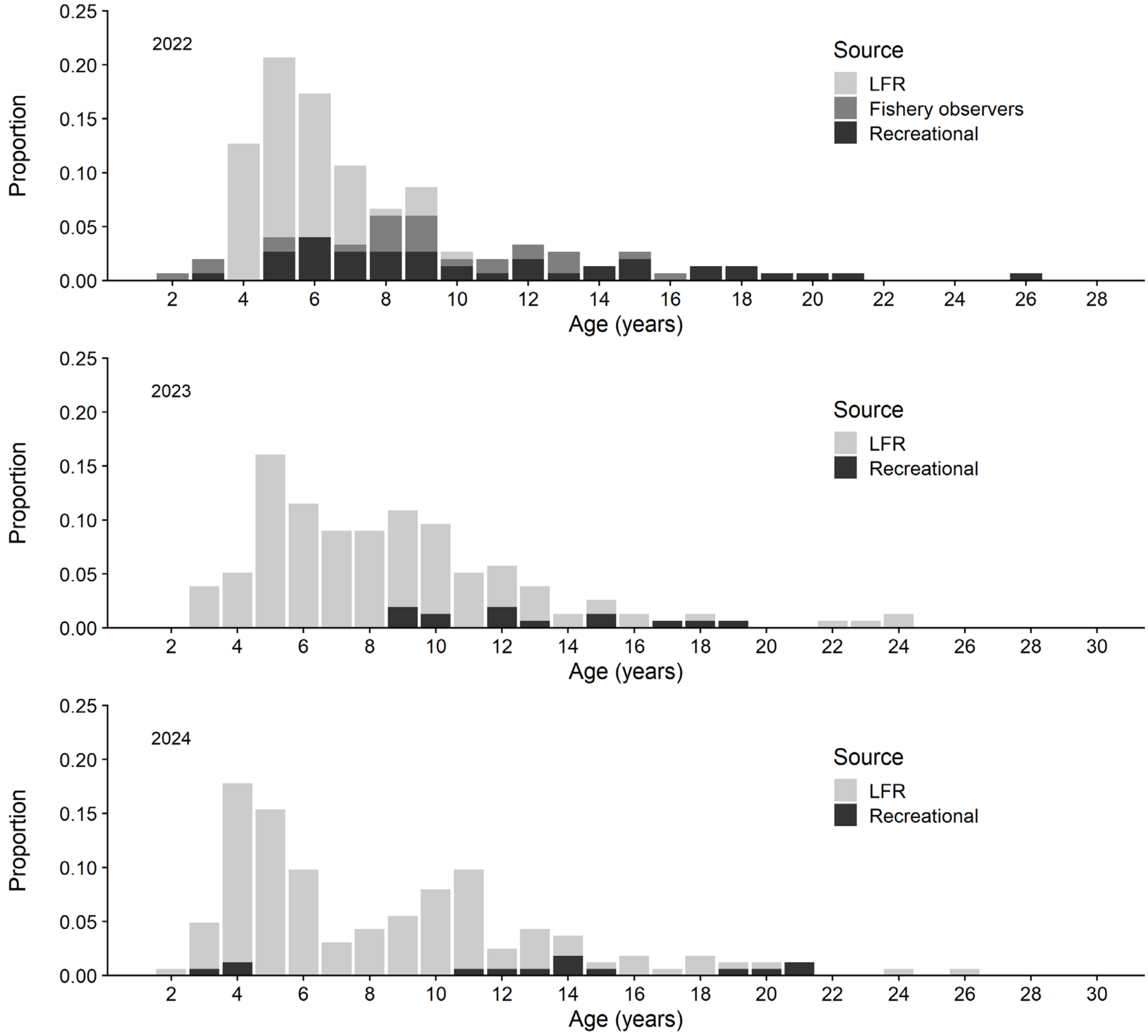

Figure 9: Proportions-at-age of southern bluefin tuna aged in the 2022, 2023, and 2024 calendar years by collection source. LFR = Licenced Fish Receiver.

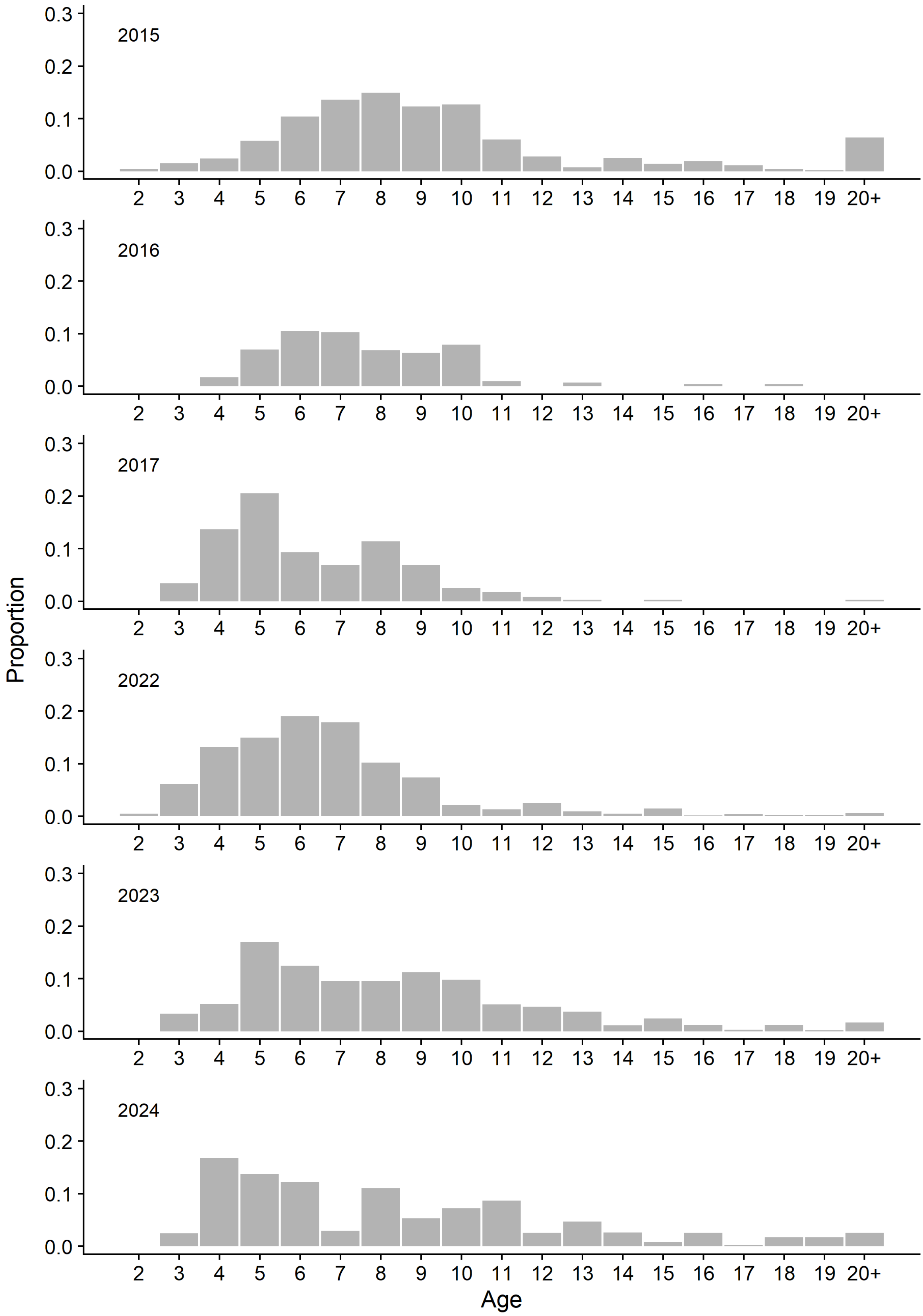

Figure 10: Proportional catch-at-age of southern bluefin tuna in the New Zealand surface longline fishery (SLL), 2015–2017 and 2022–2024. Data for 2015–2017 were derived from Sutrovic & Krusic-Golub (2021). Data for 2022–2024 are from the current study. Although ageing was conducted in 2018–2021, the majority of samples were collected from the recreational fishery and thus proportional catch-at-age estimates for these years were not compiled (see Krusic-Golub et al. 2023).

4. DISCUSSION

This report builds on a time series of age data collected for southern bluefin tuna in New Zealand's SLL fishery since 2001. A key difference in the current study compared to previous STN catch-at-age studies is that, due to low observer coverage of the SLL fleet since 2018, samples were predominantly sourced from LFRs, as opposed to being collected by observers at sea. Procedurally, this worked well, with sufficient otoliths available for ageing and the LFRs showing a keen interest in supporting the research. A key limitation of this approach, however, was that in each sampling year the larger individuals were under-represented in the samples provided for otolith sampling, and often the very largest individuals (typically those > 180 cm FL) were not supplied for sampling (although it should be noted that otoliths from large fish were rarely sampled by observers in previous years; see Krusic-Golub (2017), Sutrovic & Krusic-Golub (2021)). These large individuals are typically exported whole to international markets where they receive a premium price and thus are not able to be damaged. Accordingly, the ages of these largest individuals are likely to be under-represented in the ALKs, and thus in the resulting catch-at-age estimates. Although not an objective of the current project, model-based approaches for including these larger fish into the catch-at-age could be trialled in future iterations of this work, as recommended by the HMS WG.

Sampling from LFRs also restricted access to fish spatially and temporally. Due to budget limitations, only one LFR could be sampled in any given year, resulting (along with other factors) in fish being sampled in the North Island in 2022 and the South Island in 2023 and 2024. While the main fishing areas for STN in New Zealand occur off the west coast of the South Island and off the Bay of Plenty in the North Island, in recent years increasing numbers of fish have been caught off Otago (see Appendix A, Figure A1). These catches commence around late spring-early summer (Fisheries New Zealand unpublished data) and it is not until fishing moves around to the South Island's West Coast (Appendix A, Figure A2) that STN start to come through the South Island LFR engaged for this project and are thus able to be sampled.

Due to a change in service provider for this research, emphasis was placed on ensuring that otoliths were being interpreted consistently with previous iterations of this work, as well as between successive reads by the primary reader, and between primary and secondary readers. The estimates of precision between previous reads and re-reads of the same otoliths by the primary reader of this project, between the first and second readings from the primary reader, and readings between the primary and secondary reader were all within the acceptable maximum level suggested for multiple interpretations within the CCSBT Ageing Protocol (10% IAPE; Anon 2002), and mostly within the 5% APE limit suggested by Morison et al. (1998). The low levels of error estimated in this study suggest consistent interpretation between readings and readers.

Considerable difference was evident between AL-at-age of fish sampled from Bay Packers LP in 2022 and those sampled from Solander in 2023 and 2024. It is unlikely that these differences were driven by reader differences in age assignments. While it is acknowledged that there may be a slight amount of ageing error (as with any ageing study), considerable effort was undertaken to ensure that ageing was conducted as consistently as possible with previous years. Otolith readers involved in this study undertook extensive calibration/recalibration and testing in each year before reading new samples, and the results of these tests indicated that reading was being conducted consistently with previous STN ageing projects, between the same reader over time, and between different readers. In addition, no difference was found between otolith weight-at-age between fish from 2022 and 2023–2024, suggesting that the assigned ages were comparable for a given otolith weight in each of the reading years.

Rather, it may be that the observed differences in AL-at-age between samples in 2022 and 2023–2024 are due to differences in the way AL is recorded by LFRs. For STN, AL should be measured as a straight horizontal line (i.e. not curved over the body) from the tip of the lower jaw to the front of the anal fin. However, discussions with LFRs during this and other projects indicated that this approach may not always be followed. Accordingly, ensuring ALs are collected in a standardised way for conversion to FL is recommended as a high priority for future work.

Another potential reason for the difference in length-at-age between sampling years might be related to density dependent growth. Since reaching a low point of 10% of initial Total Reproductive Output (TRO) in 2009, the size of the STN stock has increased, with the 2023 stock assessment estimating the stock was at 23% of its initial TRO level (CCSBT 2023). Density-dependent growth effects related to such population size increases have been hypothesized as one potential factor driving the rapid decreases in length-at-age observed since approximately 2016–2017 in the Australian surface fishery that operates in the Great Australian Bight (Ann Preece, Paige Eveson, CSIRO, *pers. comm.*).

Spatial variation in growth may also drive the differences in length-at-age observed between 2022 and 2023–2024. Samples collected in 2022 were collected from catches in the north-east of New Zealand, while samples in 2023 and 2024 were collected from fish caught in the south-west. However, for such differences to manifest across all ages, examined fish would have to have been separate for much of their lives. Southern bluefin tuna comprise a single stock, with the population in New Zealand considered to move away during summer months. For the observed differences in length-at-age between areas to manifest, fish would have to remain separated with no mixing between areas. While such a hypothesis seems unlikely, little is known of the movements and residency of STN within New Zealand. Increased electronic tagging would help to elucidate patterns of these behaviours in New Zealand, including any fidelity to specific feeding grounds.

In New Zealand, most STN are landed as gilled, gutted, and trunked product (i.e., GGT), to reduce storage space onboard in SLL vessels. Accordingly, the FLs provided via the CDS for the vast majority of records are converted from ALs measured by LFRs using the equation FL = 1.482×AL. While this conversion factor has been used for many years, its origin is unknown. Notably, FLs estimated using this conversion factor were significantly smaller than when using conversion factors derived from paired AL-FL sampling of Atlantic bluefin tuna and the paired AL-FL data set of Holdsworth (2025) for STN under Fisheries New Zealand project STN2021-02. We recommend that a dedicated study be implemented to better estimate STN FLs from ALs. Ideally, this study would include collecting paired AL and FL data from individual STN across the entire size range of fish landed by the SLL fishery and across the full geographic extent of the fishery.

Should the Fisheries New Zealand conversion factor be incorrect, given most FLs provided to CCSBT are derived from conversion of ALs, there is the potential that FLs provided to CCSBT in all years that the conversion has been used are underestimated relative to the ‘true’ FLs. In addition, this will also have biased resulting catch-at-age estimates in years when ‘true’ FLs were measured by observers and used to develop the ALK, and the resulting ALK was then applied to estimated FLs obtained via the CDS. In the current project, this latter bias is expected to be negligible as the same length type was used for most samples that were used to develop the ALK and for the length records the ALK was subsequently applied to (i.e., FLs converted from ALs in the CDS data). Future iterations of this work should continue to ensure that the same length types are used in both the development and application of the ALK, to avoid introducing bias into the catch-at-age estimates.

As was the contracted requirement, the catch-at-age estimates provided for 2022–2024 herein are based on lengths of fish caught in the calendar year to the end of the New Zealand fishing year (i.e. 1 January to 30 September for any given year). This period encompasses the vast majority of landings (>99% in 2023), with only a small number of STN landed between October-December. Should STN landings in October-December increase, they should be included into the catch-at-age analyses.

Under the current CCSBT Ageing Protocol, opaque zones are only counted if deemed completed (i.e. with translucent material on their outside edge), while the age assigned to an individual is based solely on the count of opaque zones and is not adjusted for edge type or date of capture. Southern bluefin tuna are considered to deposit opaque zones in their otoliths around winter, meaning that fish caught early in the New Zealand season (i.e. before it has laid down its annual opaque zone) would be considered one year younger than a fish caught towards the end of the season (assuming the opaque zone was laid in winter). Moreover, adjustments will be required if growth from the current study is to be compared against growth estimates of fish caught during summer. Results of investigations of edge type and marginal increment analysis in this study suggest that opaque zone deposition can occur across at least March to August. Chemical tagging of STN otoliths via strontium chloride ($SrCl_2$) (e.g., Clear et al. 2000), may help to better elucidate the timing of increment formation in STN in New Zealand waters. Comparing otolith margins from New Zealand samples against those from end-of-year fisheries would also help to improve understanding of the timing of opaque zone deposition.

5. POTENTIAL RESEARCH

As outlined above, we suggest four areas of research to improve data provided to CCSBT for assessment and management of STN, specifically:

1. Assess the appropriateness of the AL-FL conversion used, both across the spatial distribution of the catch and with STN ontogeny.
2. Assess the degree of variation in the way LFRs are measuring STN and ensure that measurements are being collected in a standardised way as best as possible.
3. Investigate approaches to allow the inclusion of length data that lack a corresponding record in the ALK to be included in the catch-at-age analyses.
4. Continue to investigate increment marginal increment formation of STN in New Zealand catches.

6. ACKNOWLEDGEMENTS

The authors wish to thank staff at Bay Packers Tauranga and Solander Nelson for supplying tuna heads and associated length data. John Holdsworth (Blue Water Marine Research) kindly provided otoliths and associated data from the recreational fishery as well as the paired AL-FL data set collected from the recreational catch. Helena Armiger, Derrick Patterson, and Oliver Evans (NIWA) helped with sampling from the LFR in 2022. Kyne Krusic-Golub (Fish Ageing Services) provided expert training in STN ageing. Leyla Knittweis, Kim George, and Alexander Hann (Fisheries New Zealand) kindly provided advice and data used in the analyses. Members of the Highly Migratory Species Working Group provided useful comments on the analyses. Niki Davey and Richard O'Driscoll (NIWA) and Leyla Knittweis provided comments on an earlier draft of this report. This work was completed under Fisheries New Zealand project STN2021-01.

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APPENDIX A

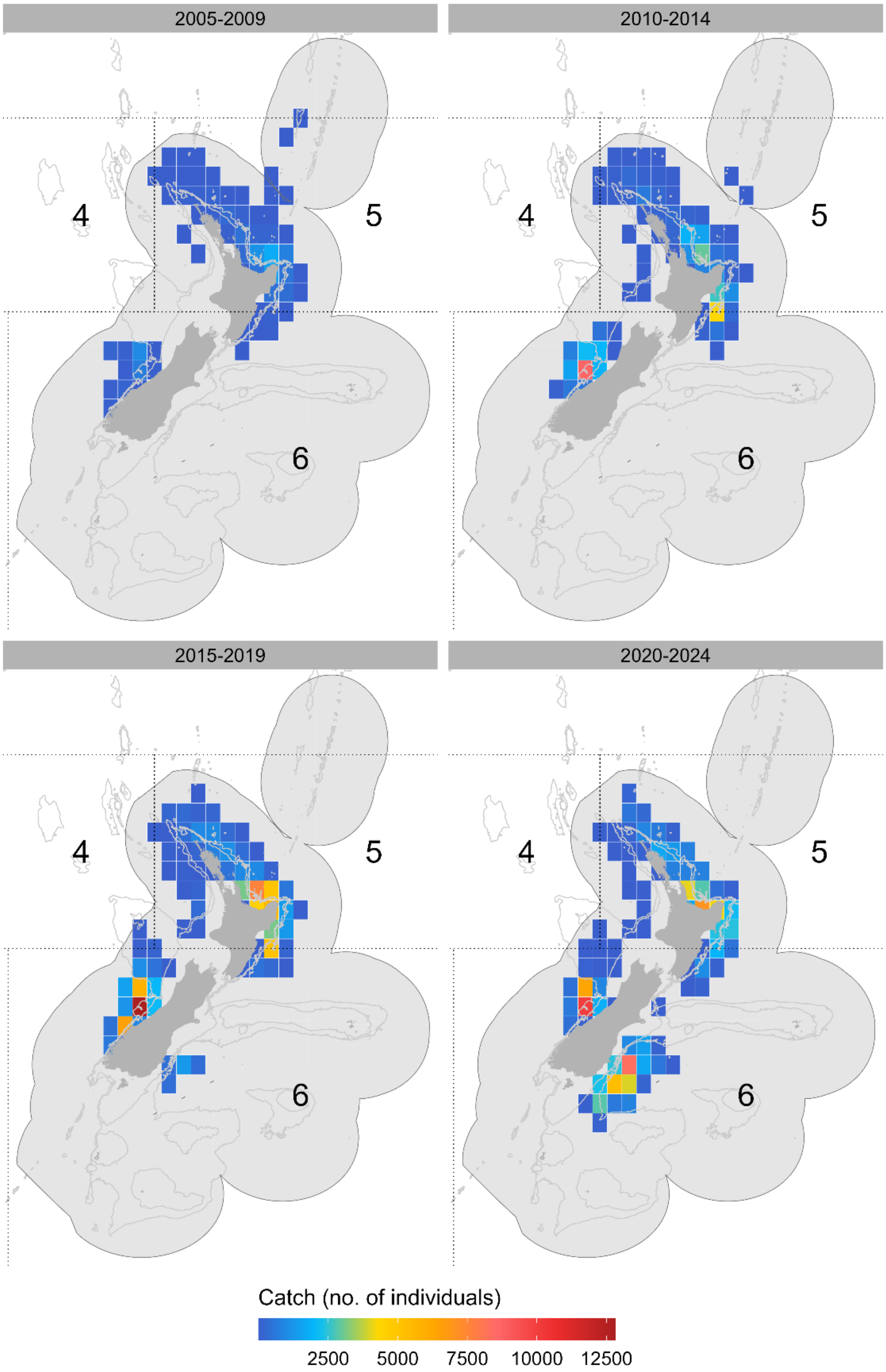

Figure A1: Southern bluefin tuna catches (in numbers of individuals) in the New Zealand Exclusive Economic Zone (EEZ; grey shaded area) aggregated in 5-year blocks and 1-degree cells, 2005 to 2024. Also shown are the 500 and 1000 m depth contours and the areas where the boundaries of CCSBT Management Areas 4, 5, and 6 (dotted lines) intersect with the New Zealand EEZ. Only those cells with catch data from at least three permit holders are displayed.

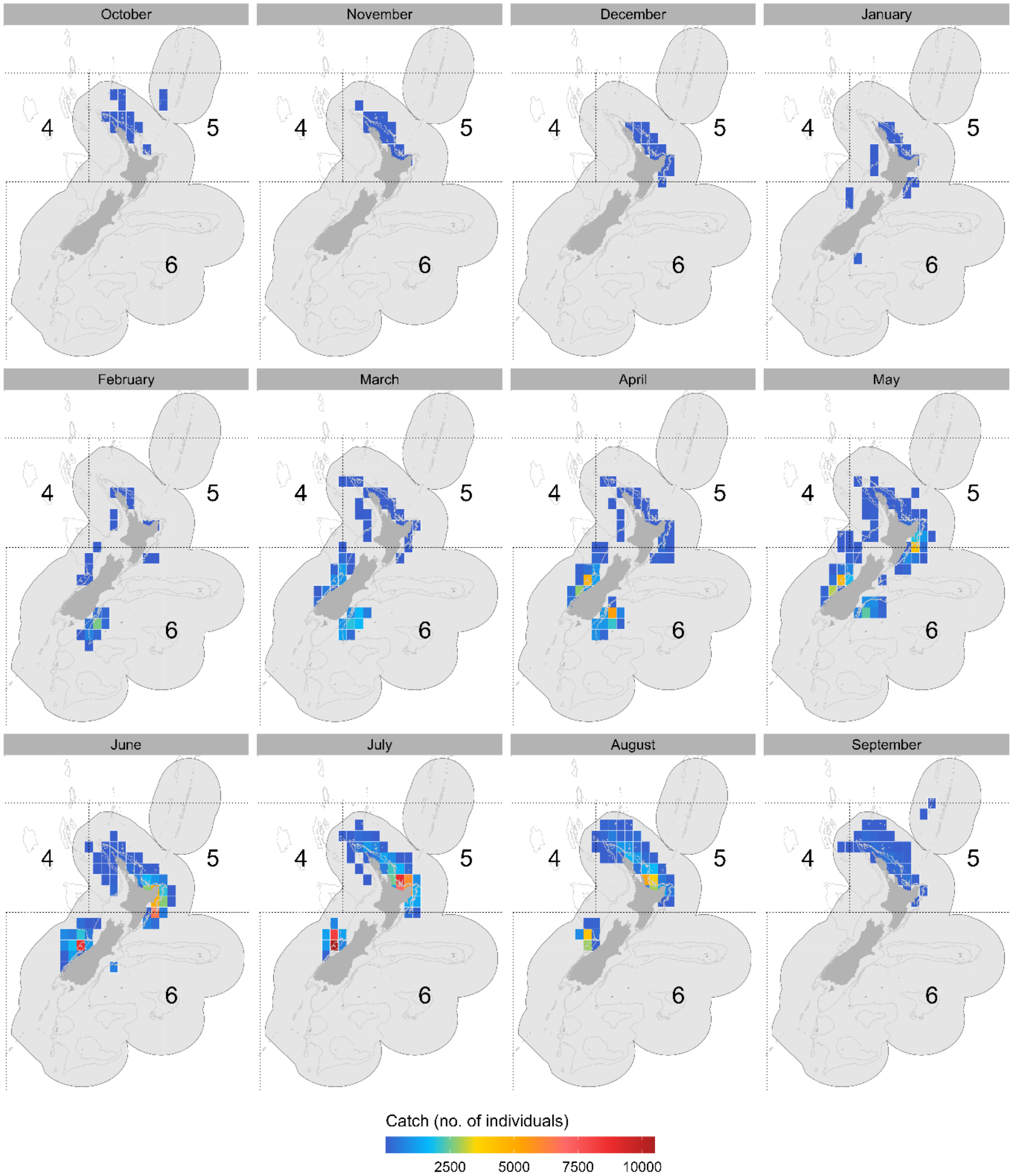

Figure A2: Southern bluefin tuna catches (in numbers of individuals) in the New Zealand Exclusive Economic Zone (EEZ; grey shaded area) for 2005–2024 aggregated in monthly and 1-degree cells. Also shown are the 500 and 1000 m depth contours and the areas where the boundaries of CCSBT Management Areas 4, 5, and 6 (dotted lines) intersect with the New Zealand EEZ. Only those cells with catch data from at least three permit holders are displayed.

APPENDIX B

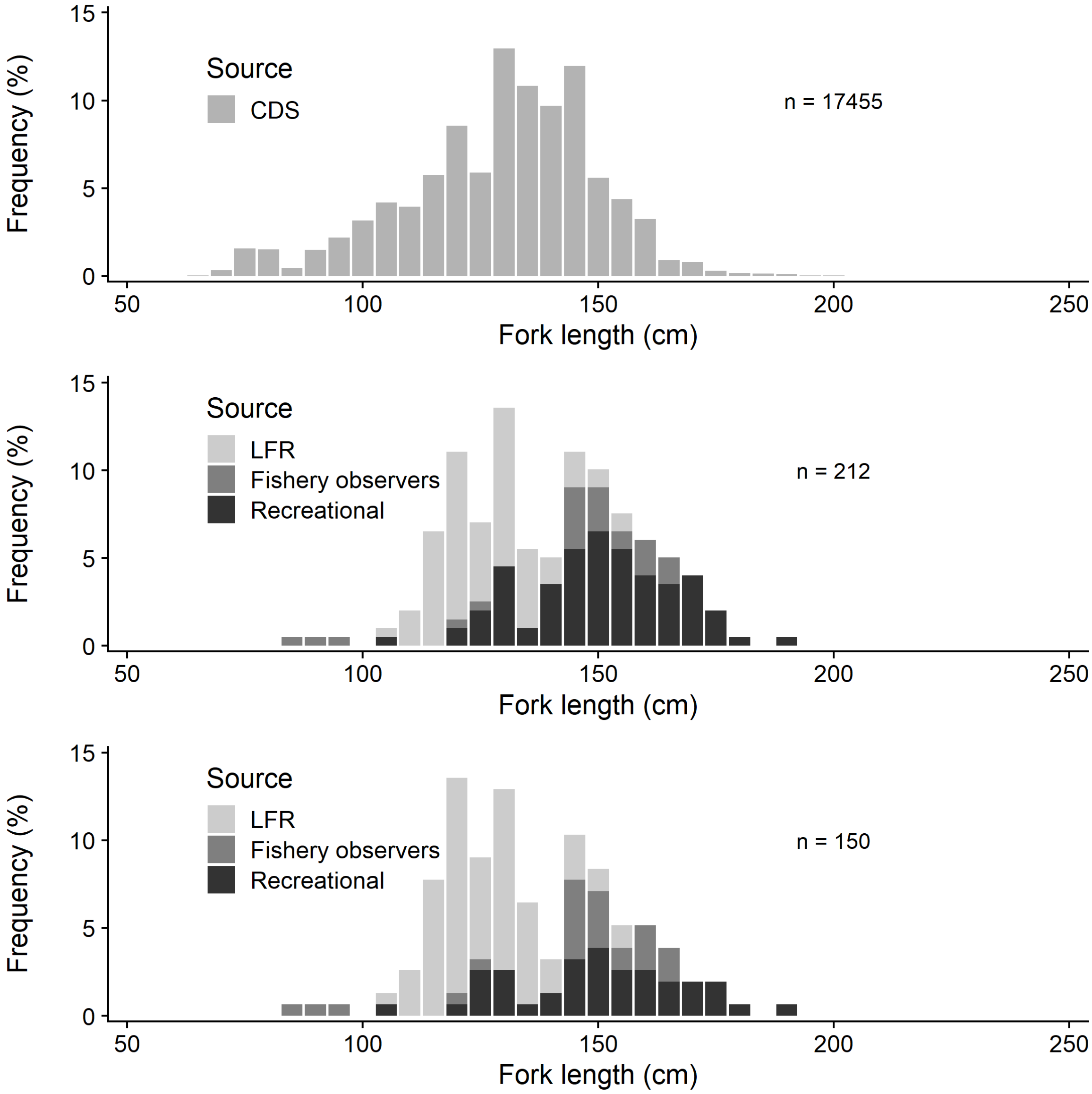

Figure B1: Length frequency (in 5-cm fork length bins) for southern bluefin tuna for 2022 (between January and September) from Licenced Fish Receiver (LFRs) through the CCSBT Catch Documentation Scheme (CDS; top row), for those fish for which paired length data and otoliths were available (middle row), and those fish for which age estimates were derived (bottom row), by collection source.

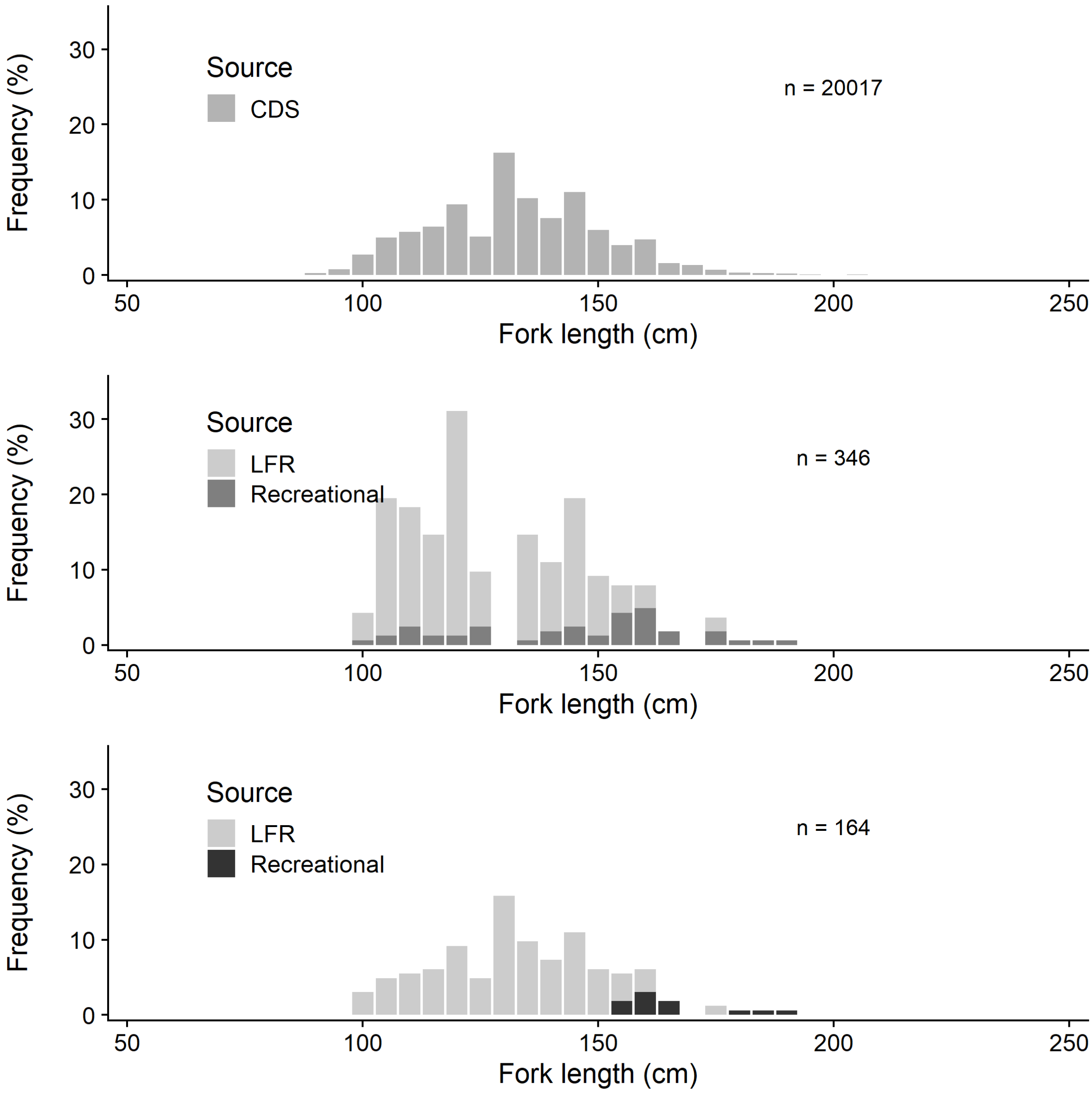

Figure B2: **Length frequency (in 5-cm fork length bins) for southern bluefin tuna for 2023 (between January and September) from Licenced Fish Receiver (LFRs) through the CCSBT Catch Documentation Scheme (CDS; top row), for those fish for which paired length data and otoliths were available (middle row), and those fish for which age estimates were derived (bottom row), by collection source.**

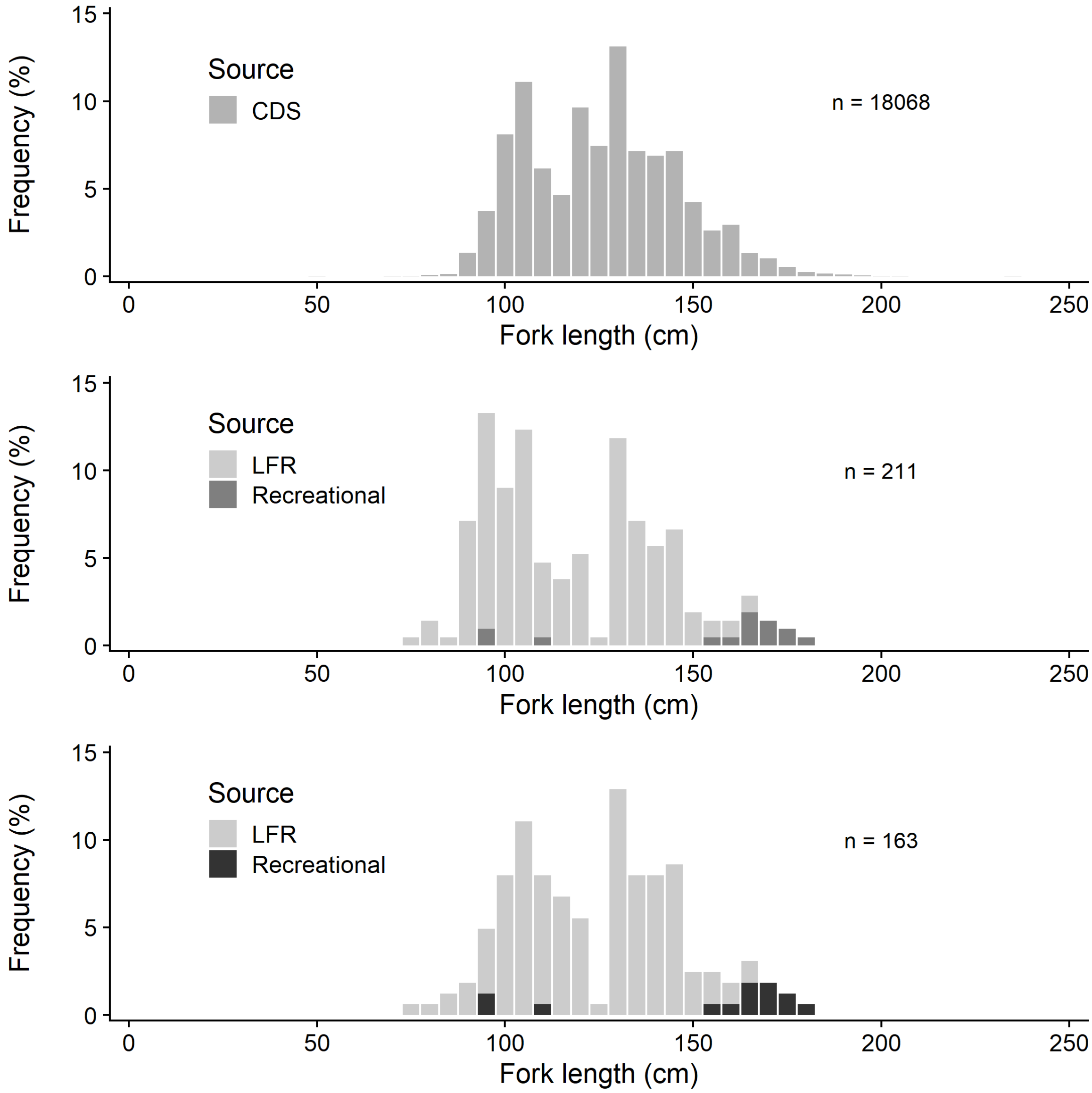

Figure B3: **Length frequency (in 5-cm fork length bins) for southern bluefin tuna for 2024 (between January and September) from Licenced Fish Receiver (LFRs) through the CCSBT Catch Documentation Scheme (CDS; top row), for those fish for which paired length data and otoliths were available (middle row), and those fish for which age estimates were derived (bottom row), by collection source.**

APPENDIX C

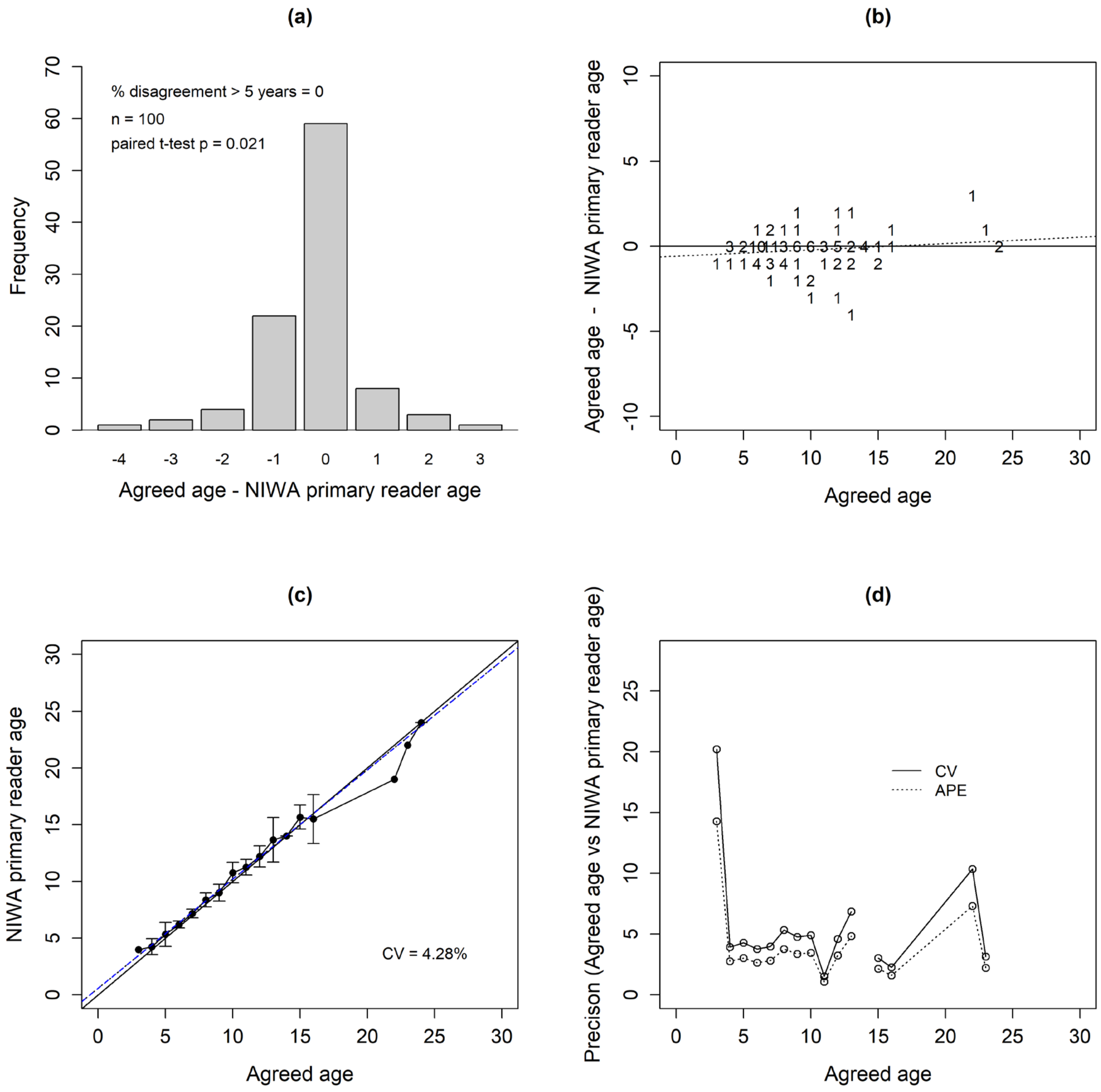

Figure C1: Comparison of agreed ages and ages assigned by the NIWA primary reader in 2022 from a subset of otoliths (n = 100) prepared under previous STN ageing contracts. (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.

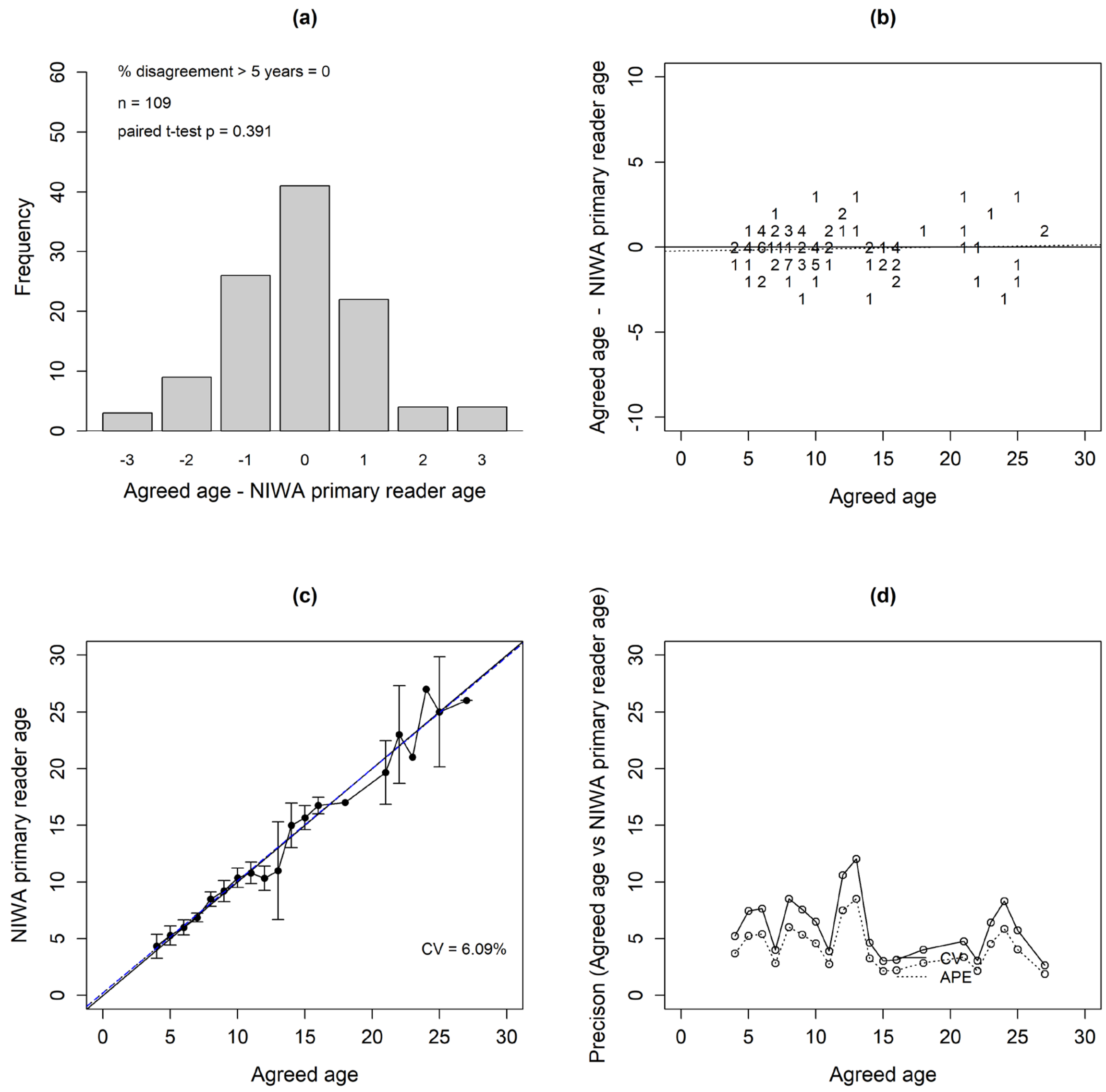

Figure C2: **Comparison of agreed ages and ages assigned by the NIWA primary reader in 2023 from a subset of otoliths (n = 109) prepared under previous STN ageing contracts. (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.**

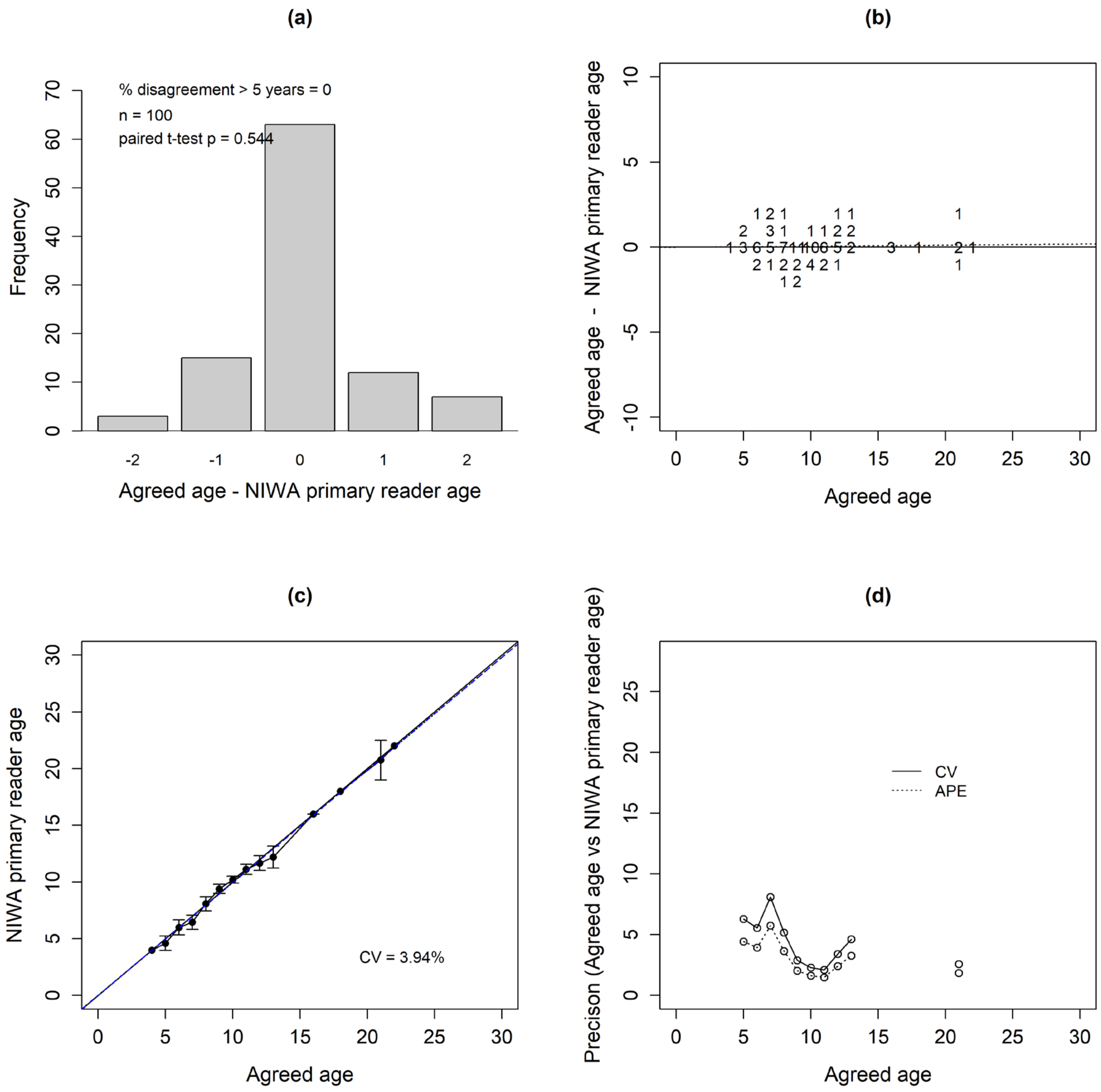

Figure C3: Comparison of agreed ages and ages assigned by the NIWA primary reader in 2024 from a subset of otoliths (n = 100) prepared under previous STN ageing contracts. (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.

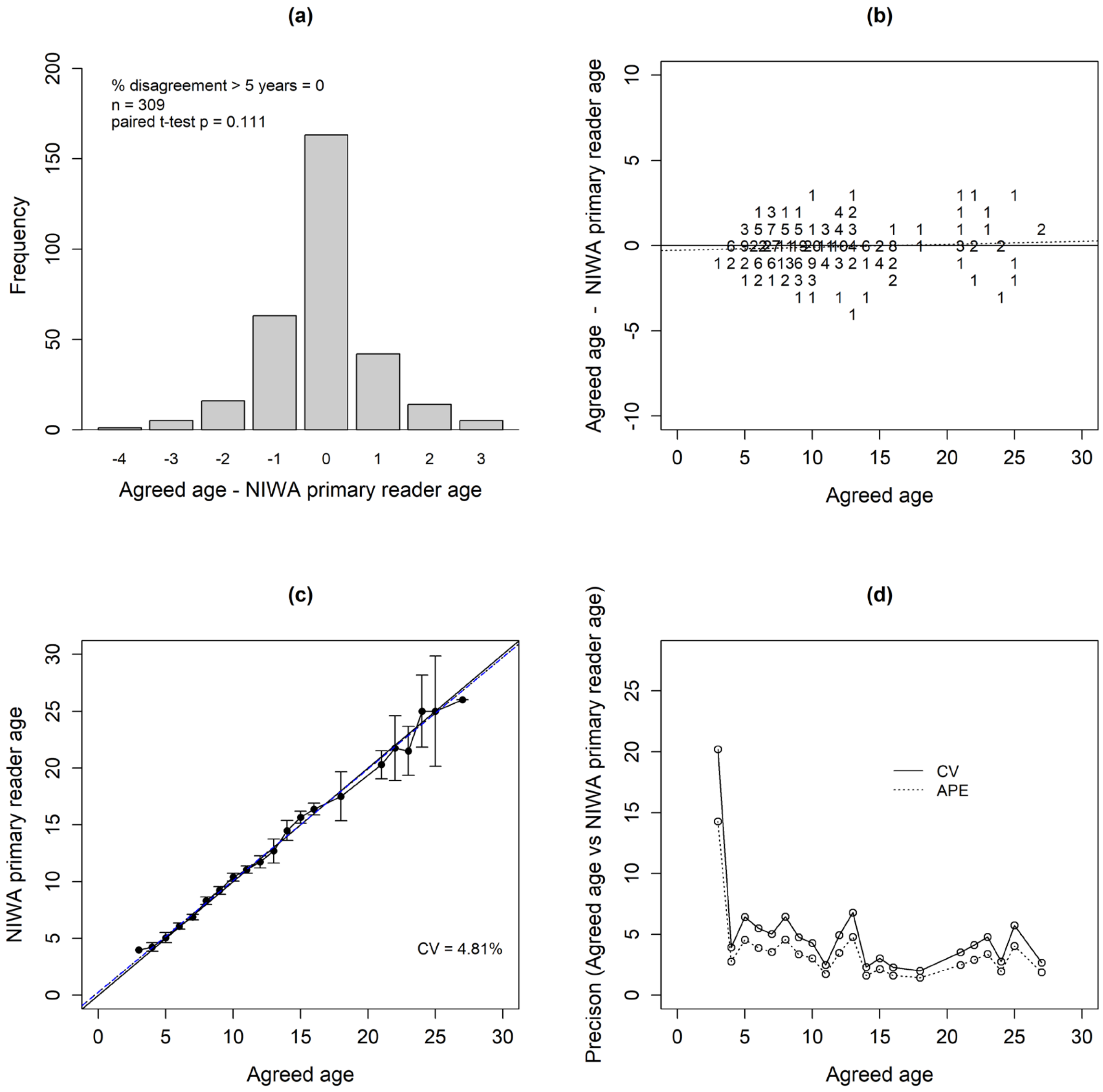

Figure C4: **Comparison of agreed ages and ages assigned by the NIWA primary reader for all repeated readings (i.e., combining samples from 2022–2024). (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.**

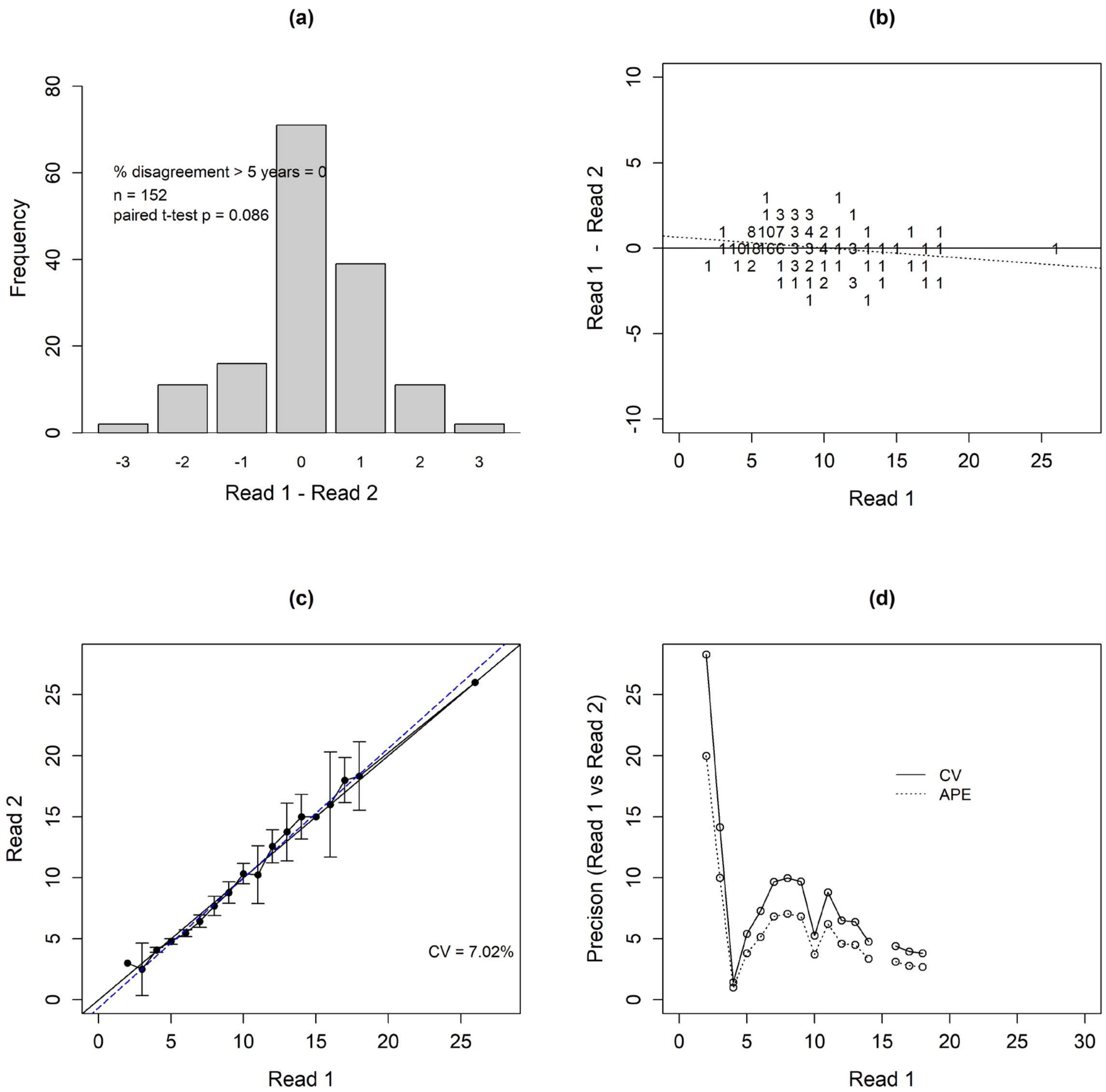

Figure C5: **Comparison of first and second reads by the NIWA primary reader for otoliths collected in 2022. (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.**

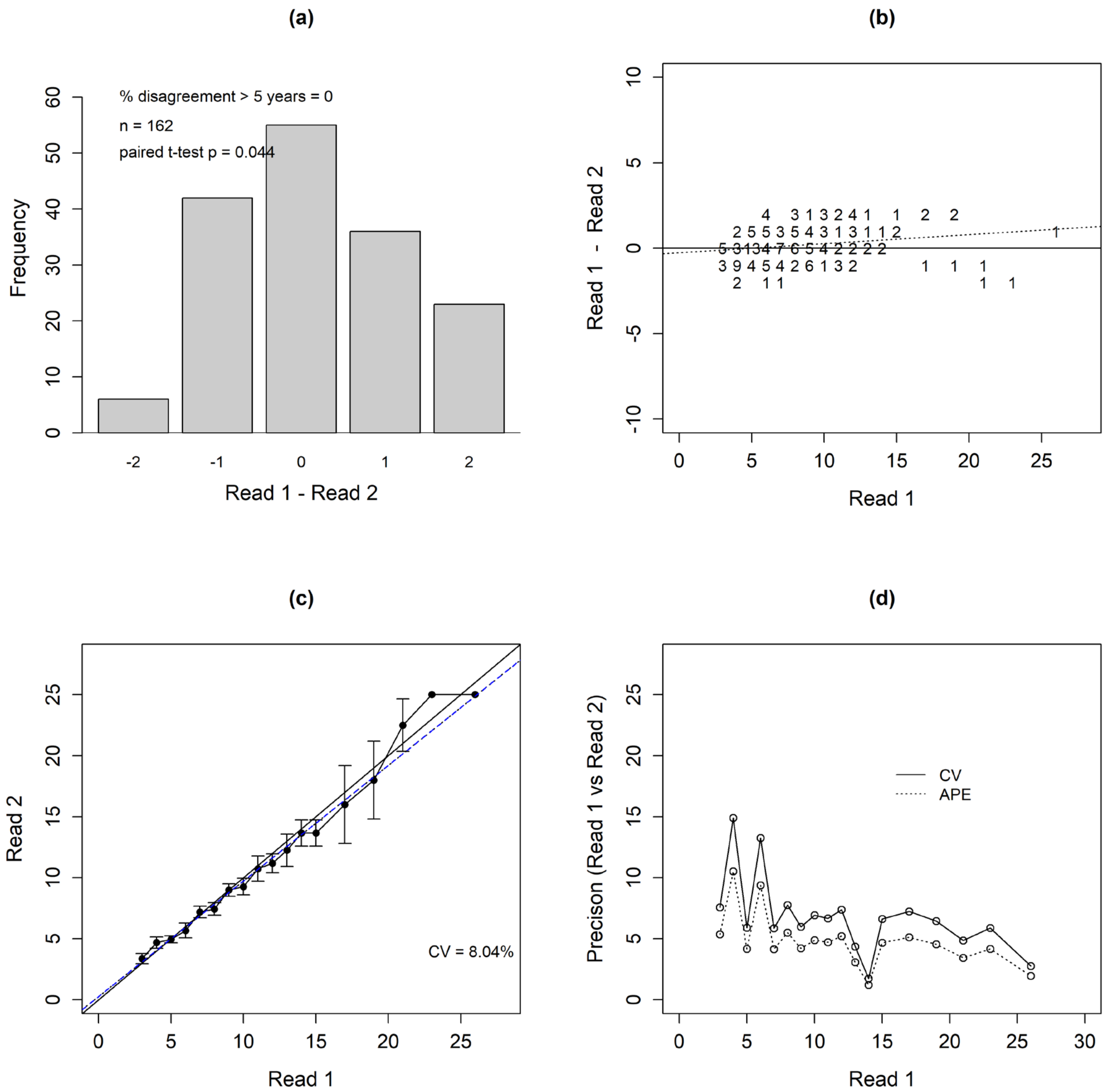

Figure C6: Comparison of first and second reads by the NIWA primary reader for otoliths collected in 2023. (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.

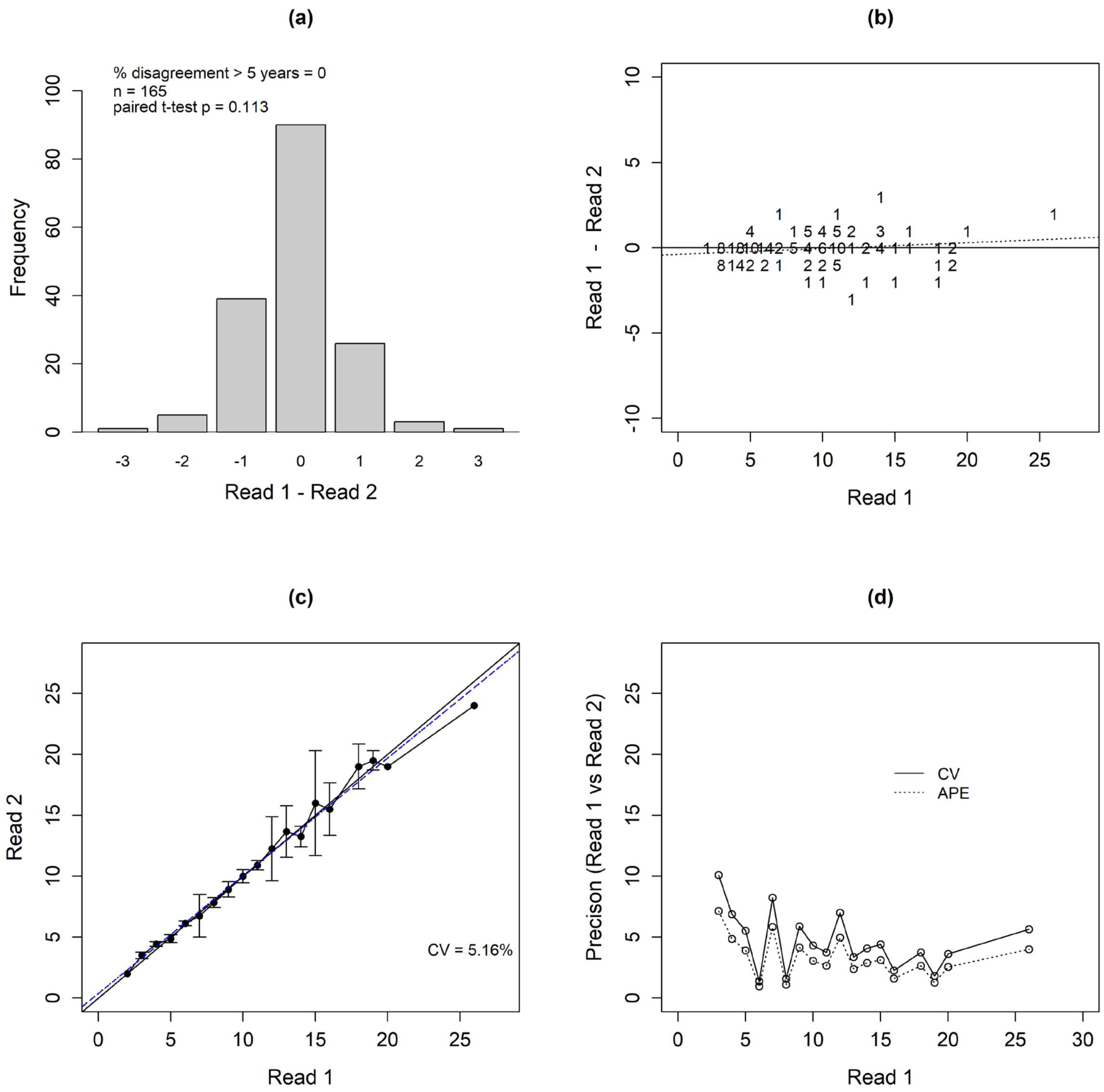

Figure C7: Comparison of first and second reads by the NIWA primary reader for otoliths collected in 2024. (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.

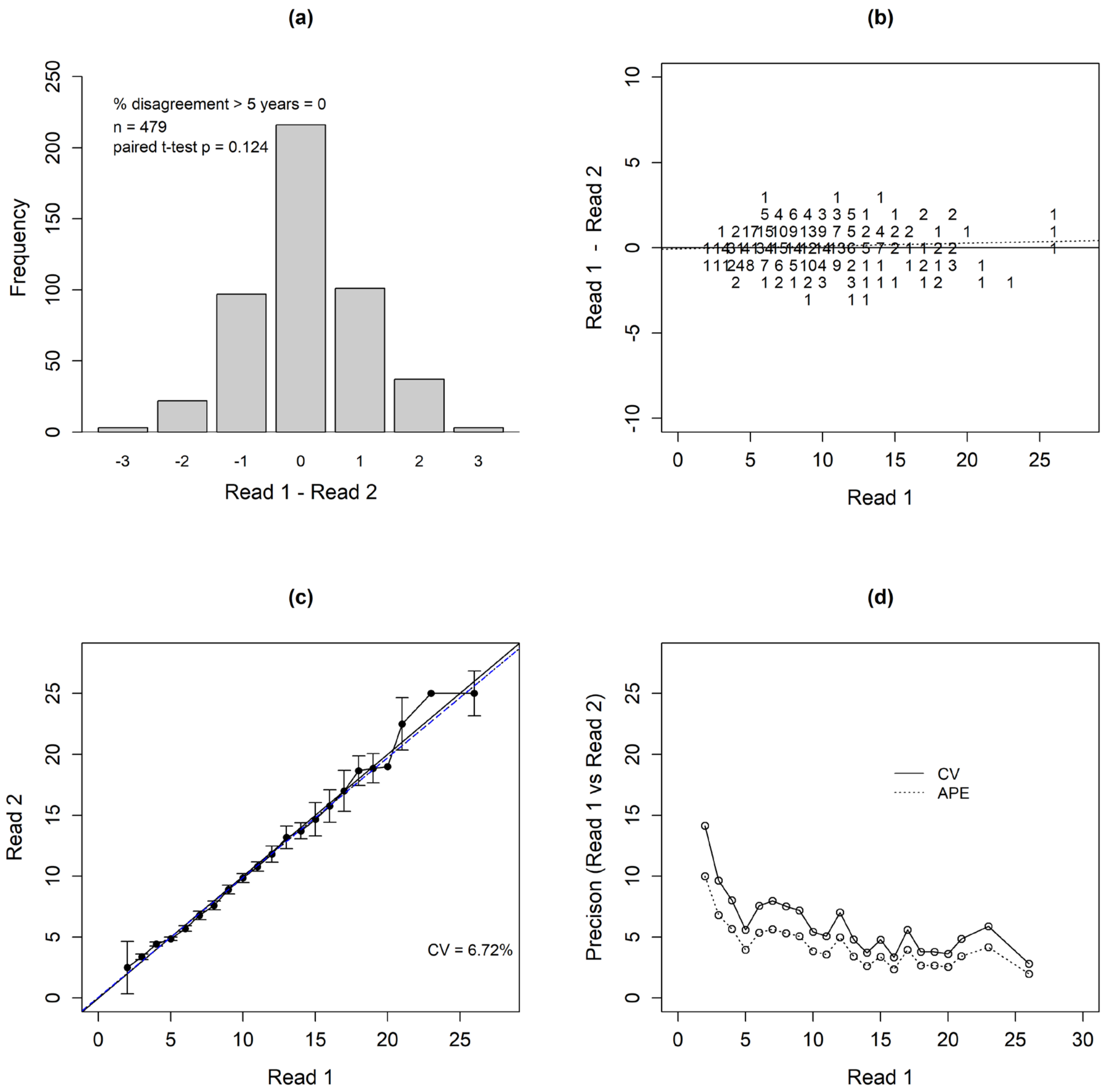

Figure C8: **Comparison of first and second reads by the NIWA primary reader for all repeated readings (i.e., combining samples from 2022–2024). (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.**

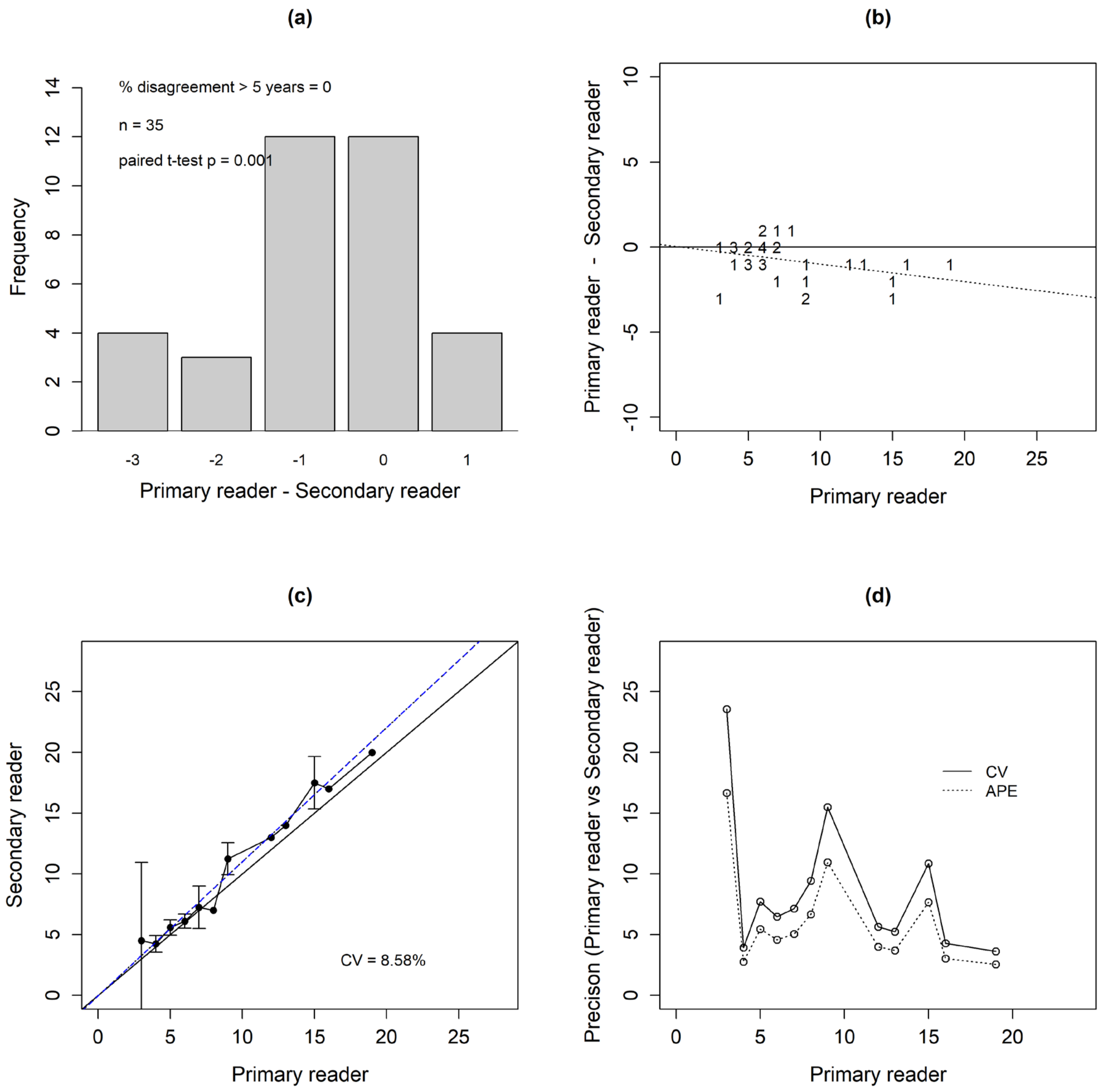

Figure C9: **Comparison of final otolith reads by the NIWA primary and secondary readers for a subset of otoliths collected in 2022. (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.**

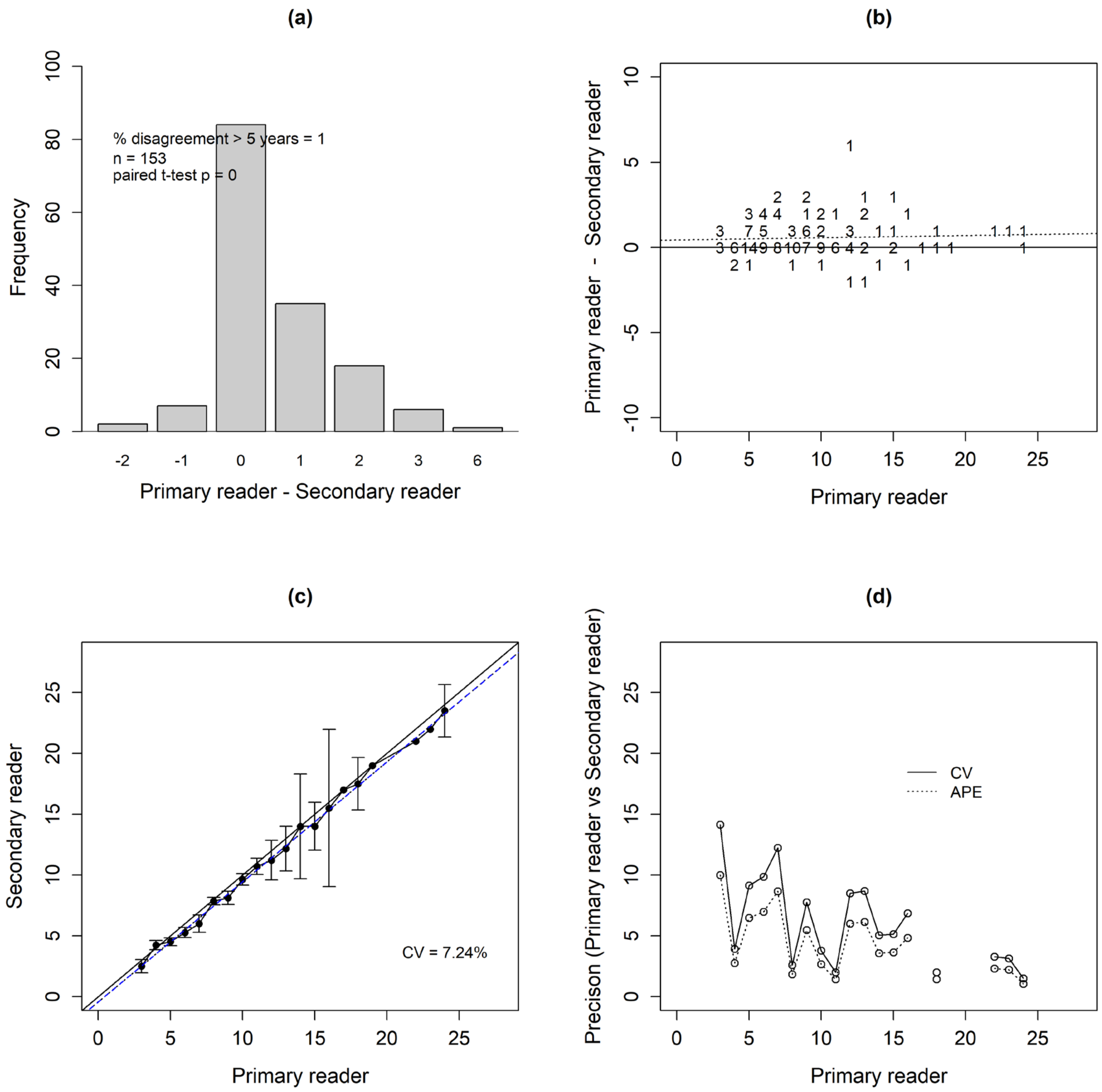

Figure C10: Comparison of final otolith reads by the NIWA primary and secondary readers for a subset of otoliths collected in 2023. (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.

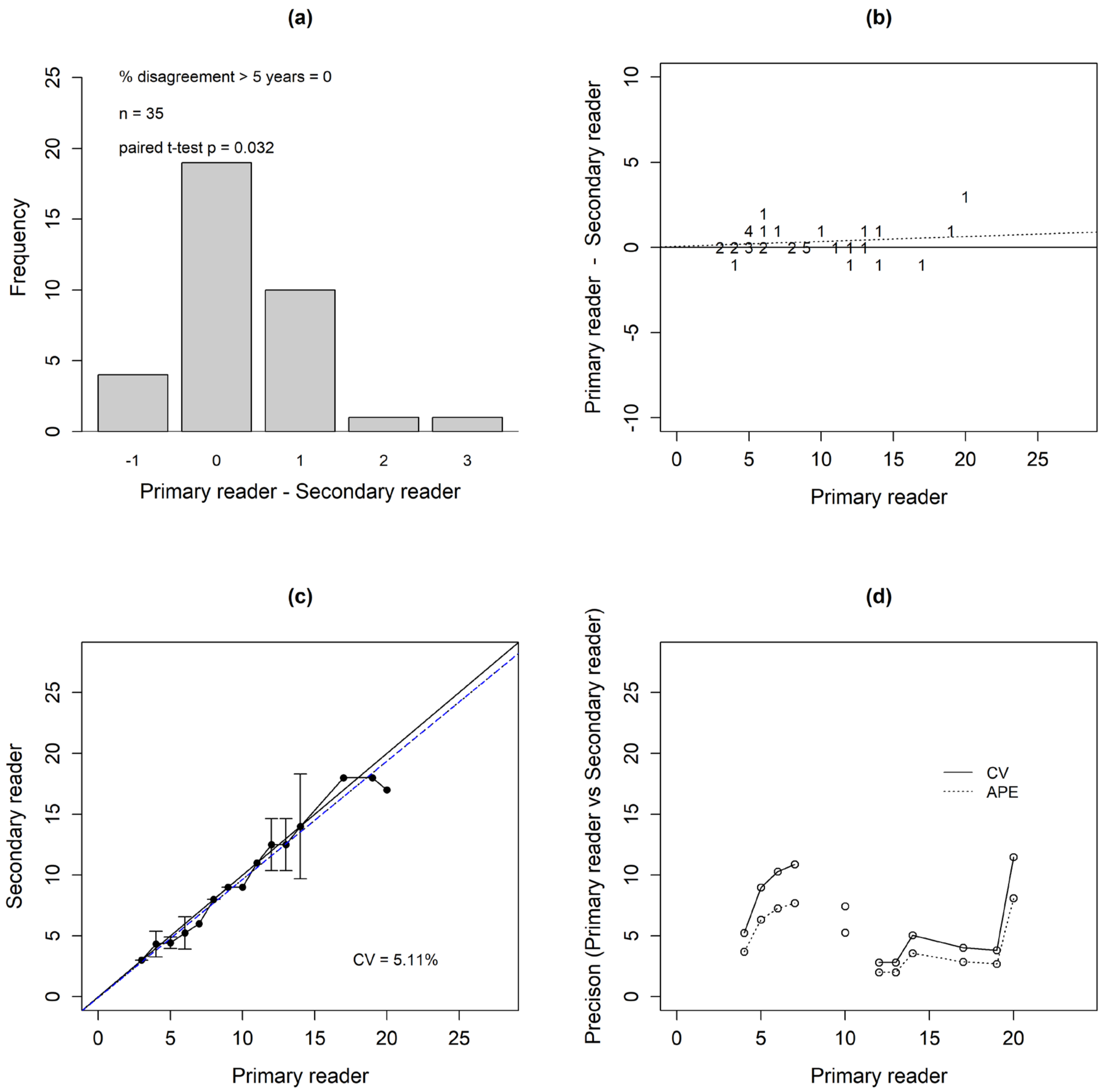

Figure C11: Comparison of final otolith reads by the NIWA primary and secondary readers for a subset of otoliths collected in 2024. (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.

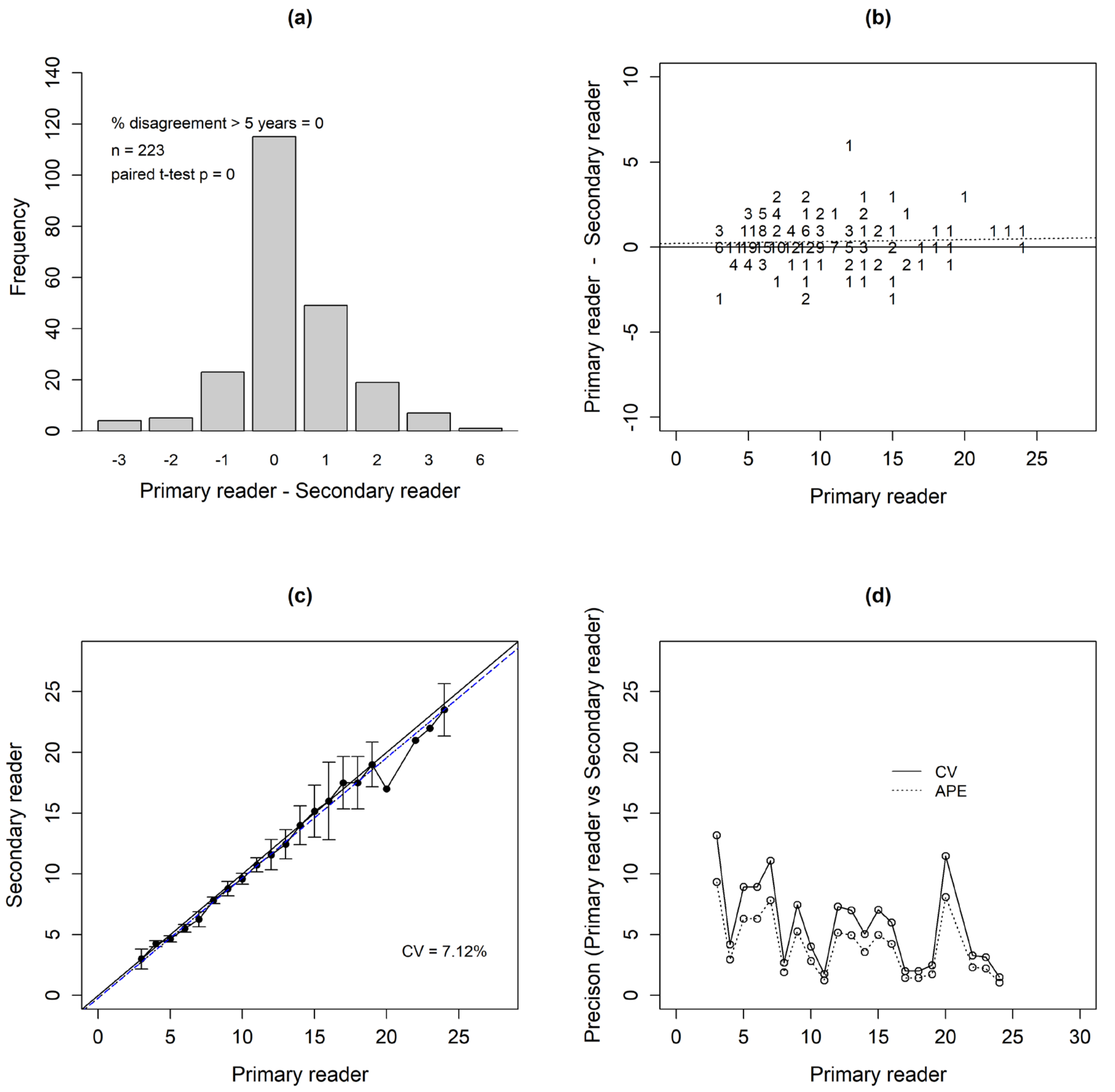

Figure C12: Comparison of final otolith reads by the NIWA primary and secondary readers for all repeated readings (i.e., combining samples from 2022–2024). (a) histogram of age differences; (b) distribution plot of age differences, (c) age bias plot, (d) trends in the Coefficient of Variation (CV) and Index of Average Percent Error (IAPE) with age.

APPENDIX D

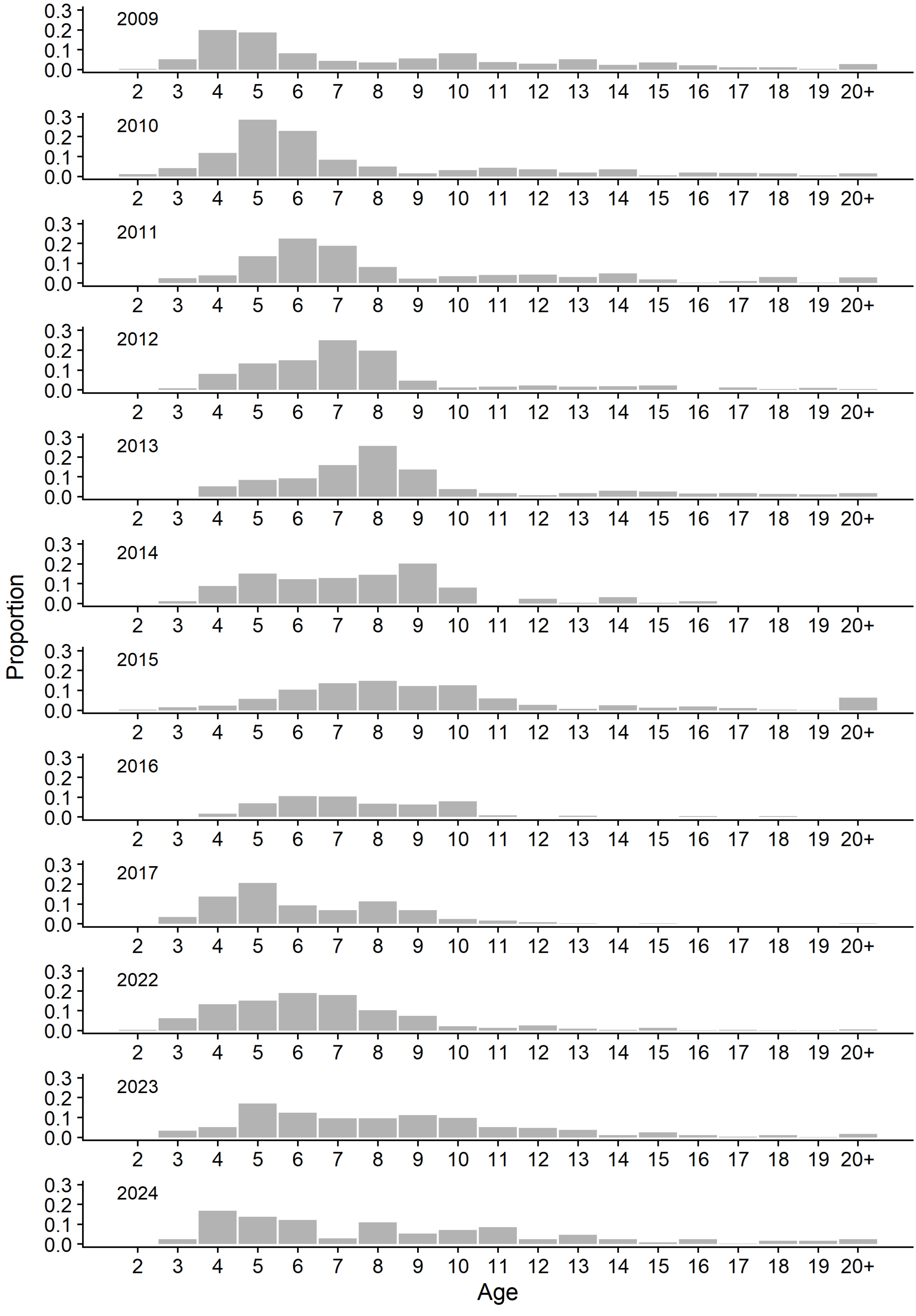

Figure D1: Proportional catch-at-age of southern bluefin tuna in the New Zealand surface longline fishery, 2009–2017 and 2022–2024. Data for 2009–2017 were derived from Sutrovic & Krusic-Golub (2021). Data for 2022–2024 are from the current study.