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Length and age composition of commercial snapper landings in SNA 8, 2018–19

New Zealand Fisheries Assessment Report 2019/73

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A length frequency and age-length key sampling approach was employed during spring and summer 2018–19 to estimate catch-at-age for snapper caught by bottom trawl (i.e., the main fishing method) in SNA 8. Length frequency samples were collected from the fishery, and age data were collected randomly in the form of a semi-fixed allocation age-length key. Fifteen landings were sampled for length frequency from the bottom trawl fishery with a total of 6495 fish measured. The age-length key was based on 580 otolith pairs.

Relative year class strengths inferred from the SNA 8 bottom trawl landings in 2018–19 were generally consistent with trends observed in recent years. The age composition was dominated by the three most recently recruited year classes (2016 to 2014), occupying the 3 to 5 year age range, collectively contributing to one in every two fish landed (54%) over spring-summer. The 2014 year class (5-year-olds) was the most dominant in the fishery in 2018–19, accounting for one in every four fish landed. The newly recruited 2016 year class (3-year-olds) accounted for 14% of the catch in 2018–19, the third (equal) highest estimate of 3-year-olds in 24 years of sampling SNA 8 since 1989–90. This year class was not yet fully recruited to the fishery.

The age composition in 2018–19 has remained almost as broad as that in 2015–16, mainly due to the progression of previously strong year classes (2010, 2009, 2006 that now occupy the 9-, 10- and 13-year-old age classes, respectively). Mean age of snapper landed by bottom trawl in 2018–19 was 6.6 years, the second highest recorded estimate in 30 years, and suggests that improvement in the status of the fishery in 2015–16 has largely been maintained in 2018–19, despite a paucity of old fish (i.e., 15 years and older) in SNA 8.

Mean weight-at-age (with weight inferred from a length-weight relationship) for young snapper 3 to 8 years in 2018–19 has remained relatively stable and similar to estimates from 2012–13 and 2015–16, while mean weight-at-age for fish 9 years and older has continued to decline, now the lowest recorded in three decades. Although mean age in 2018–19 was high (6.6 years) relative to previous estimates, mean length (35.6 cm) has declined by 1 cm from 2015–16 and from the long-term mean, indicating that overall, growth rates have continued to slow. The fishery is likely to land more snapper now than it did 10–30 years ago to achieve the same unit weight.

Fishery characterisations reveal that the sample design adequately reflected the temporal and spatial spread of the bottom trawl catches from SNA 8 in 2018–19, and that length and age estimates presented here provide representative descriptions. Mean weighted coefficients of variation for both the unstratified and stratified age compositions were equivalent at 17%, both within the target of 20%.

1. INTRODUCTION

Snapper (*Chrysophrys auratus*) is New Zealand's most important commercial inshore fish species. Over 20% of the national Total Allowable Commercial Catch (TACC) of 6357 t is allocated to SNA 8 (1300 t), which spans the west coast of the North Island (Figure 1). In most recent years the greatest proportion of the SNA 8 catch has been taken by bottom trawl from the northern half of the Quota Management Area (QMA), predominantly as a bycatch when targeting trevally (*Pseudocaranx dentex)*. The annual SNA 8 catch over the past decade has, on average, been close to the TACC of 1300 t (Figure 2, Fisheries New Zealand 2018).

SNA 8 has been one of the most researched inshore finfish fisheries in New Zealand. Staff of the National Institute of Water and Atmospheric Research (NIWA) and, formerly MAF Fisheries, have sampled the length and age compositions of snapper from commercial landings in port (market sampling) intermittently since 1963 (Davies et al. 1993). The first sampling to determine the age composition of the fishery took place during the mid-1970s. In the 1988–89 fishing year, a structured sampling programme was designed to establish a time series of length and age composition data for the dominant fishing methods in SNA 1 and SNA 8. The time series of length and age information from the SNA 8 fishery continued uninterrupted for a period of 22 years up until 2009–10 and has been summarised in a number of reports. Triennial sampling was adopted after 2009–10 based on research investigating the optimum frequency for market sampling (Bian et al. 2009), with two further sampling programmes undertaken in 2012–13 and 2015–16 (Walsh et al. 2014c, 2017). The age composition of the commercial catch is a critical data input to SNA 8 stock assessments.

This report presents the results of market sampling from the SNA 8 stock between October 2018 and February 2019, the third triennial sampling event since the cessation of annual sampling in 2009–10. Funding for this project, SNA2018/01, was provided by Fisheries New Zealand.

The specific objectives of this project for 2018–19 were:

1. To characterise the SNA 8 fishery by analysing existing commercial catch and effort data to the end of 2016/17 fishing year.

2. To carry out sampling and estimate the relative proportion at age and length of recruited snapper sampled from the commercial catch in SNA 8 in spring/summer of 2018/19. The target coefficient of variation (CV) for the catch-at-age will be 20% (mean weighted CV across all age classes).

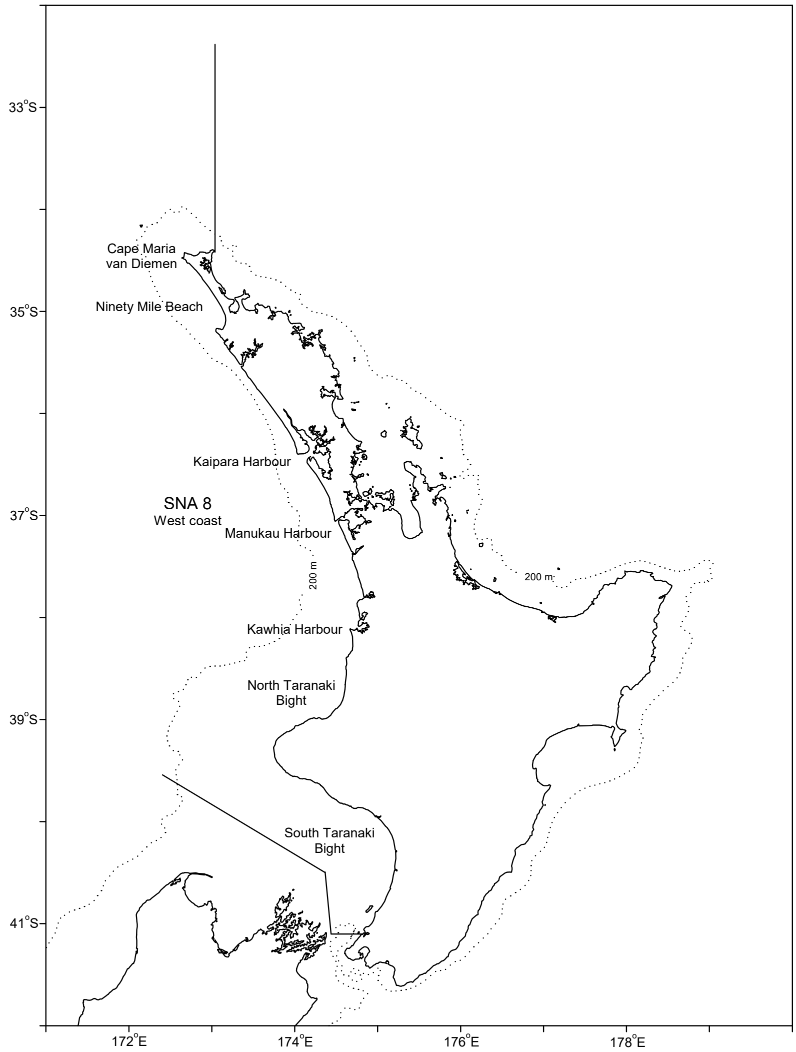

Figure 1: Quota Management Area for the west coast North Island snapper stock (SNA 8).

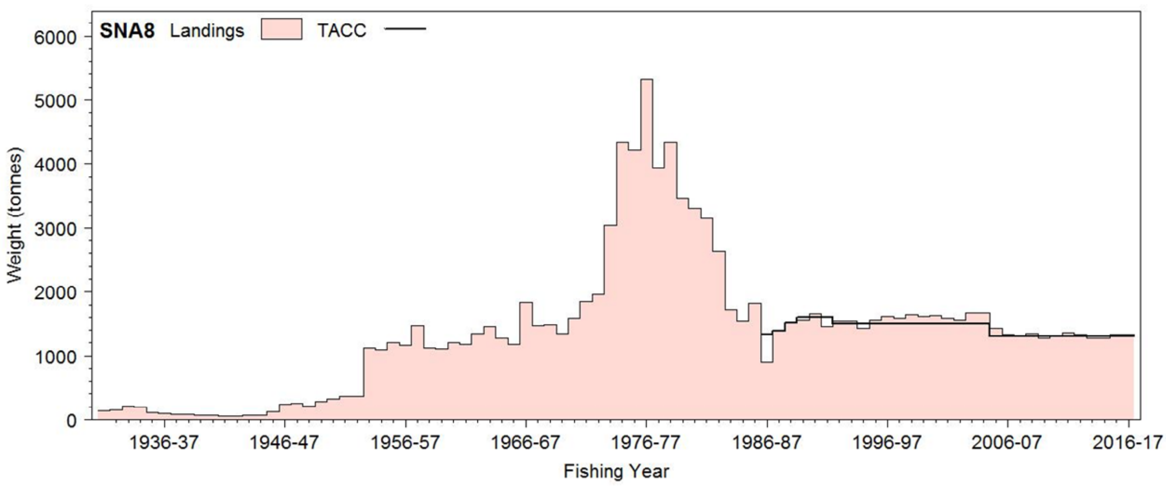

Figure 2: Reported landings of snapper in SNA 8 and TACCs to 2016–17 (Reproduced from Fisheries New Zealand 2018).

2. METHODS

2.1 Characterisation of recent fishery profile data for SNA 8, 2014–15 to 2016–17

A characterisation of the spatial, temporal and operational patterns in the SNA 8 fishery over the period October 2014 through to September 2017 (spanning three fishing years) was undertaken using data extracted from the Fisheries New Zealand commercial catch reporting system, to inform the design of a catch sampling programme in 2018–19. A "predicted 2018–19 fishing year catch" was also included in the design based on the 2016–17 year catch along with information that a new fishing method, Modular Harvest System (MHS), was expected to replace conventional bottom trawl (BT) to some extent in SNA 8.

All effort details and associated catch weights (all species including snapper) from all trips landing SNA 8 were requested. Data obtained from Fisheries New Zealand were groomed and checked for typical reporting errors. The data used to inform the characterisation were compiled in two tables:

1. Landed catch weight: A file containing the verified green (unprocessed) landed weight of all SNA 8 trips.
2. Trip specific data: A file containing demographic information (location, method, target species, estimated catch etc).

Although the trip effort data table provided information on catch, these weights were based on fisher estimates rather than measured weights. The process followed was to prorate the actual trip landed weight totals across the effort information (location, method, target species) on the basis of the estimated catch ratios. The link between the two data tables was the common trip number field (trip_key).

Operational aspects such as fishery timing, gear type, target species, statistical area, fine scale spatial distribution, port of landing, and annual number of vessels and landings were summarised.

A Northern Inshore Finfish Working Group (NINSWG) meeting in September 2018 (NINSWG-2018-23b) accepted the sample design, deciding to sample only conventional bottom trawl catches in 2018–19 for the following reasons: 1) the key aim of the programme was maintaining the catch-at-age series from the conventional bottom trawl fishery, diverting samples to allow selectivity of the MHS gear to be estimated risked compromising sampling of the conventional bottom trawl fishery; and 2) selectivity of the part of the fishery that uses MHS gear is likely to be changing as a result of expansion of the area where this gear is permitted for use. Permit conditions did not allow the use of MHS gear within the West Coast North Island Marine Mammal Sanctuary during 2017/18 (out to 12 nautical miles between Maunganui Bluff in the north and Pariokariwa Point in the South) whereas standard bottom trawl gear is permitted within 2 or 4 nautical miles of the coast in this area, so most landings made by vessels using MHS gear consisted of fish taken by both methods. The spatial limits for MSH gear were removed in 2019.

2.2 Design of SNA 8 sampling in 2018–19

The SNA 8 stock encompasses almost all of the west coast of New Zealand's North Island and for sampling purposes is considered one continuous spatial stratum (Figure 1). To be consistent with previous sampling of the SNA 8 fishery (as outlined in the section above), only bottom trawl landings greater than 5 tonnes were to be sampled in 2018–19, which in recent years accounted for the majority of the commercial catch. Sampling usually occurs during spring (October–November) and summer (December–February) when most of the SNA 8 stock becomes vulnerable to fishing. The month of September, usually clustered with spring, was not included in the seasonal stratification as it lies outside the bounds of the fishing year (October to September) that the sampling relates to. Limited fishing generally occurs in September (the last month of the fishing year) and its absence from the spring sampling stratum was deemed to have minimal effect on the final results.

Details of the sampling design used in previous years are described in Davies & Walsh (1995) with sample collections undertaken in proportion to the catch of the main commercial fishing companies. Although a more structured approach to sampling amongst the bottom trawl fleet (based on perceived differences in vessel selectivity patterns for length and age in TRE 7; Langley et al. 2015) had been undertaken for SNA 8 in 2015–16, this was not implemented in the in 2018–19. Results had shown that there was no strong basis for stratification by vessel. Instead, between-vessel differences were more likely to be a factor of the spatiotemporal heterogeneity of the stock length composition, that is, where a vessel fished i.e., proportionally more large snapper are caught off the Kaipara and Manukau Harbours during spring when spawning occurs (Walsh et al. 2017).

2.3 Sampling SNA 8 bottom trawl landings for length and age data

Optimisation of sample sizes had previously been investigated using simulation with the aim of achieving a target level of catch-at-age precision with a mean weighted coefficient of variation (MWCV) over all age classes, of less than or equal to 0.20. Historical length frequency and otolith data from the SNA 8 bottom trawl fishery were used in optimisations to calculate the MWCV associated with different combinations of landing and otolith sample sizes using the length frequency and age-length key sampling method. The optimisation results indicated that the MWCV was more sensitive to changes in the otolith sample size than the number of landings sampled from the fishery and proposed that a sample size of 15 landings and 300–500 otoliths would adequately achieve a MWCV of about 0.15. As a result, a total of 15 bottom trawl landings sampled for length frequency in combination with a 500 otolith pair age-length key have been used for SNA 8 for more than two decades to estimate catch-at-age, which has consistently achieved MWCVs below 0.20. This same approach was chosen for sampling the SNA 8 fishery in 2018–19 (Table 1), with 6 landings targeted during spring and 9 during summer.

Table 1: Level of sampling proposed to describe the SNA 8 bottom trawl fishery in 2018–19 based on historical sampling for catch-at-age data that derived MWCVs below 0.20.

Stock	Sampling method	Number of landings	Number of otoliths
SNA 8	Length frequency–age-length key	15 (6 spring, 9 summer)	500

In keeping with the general design of previous SNA 8 catch sampling programmes, a two-stage sampling procedure was used to obtain length frequencies (West 1978), whereby the random selection of landings and a random sample of bins within landings represent the first and second stages, respectively. The sampling procedure was modified to account for the grading of fish according to length and quality by taking a stratified random sample of bins within a landing (Davies et al. 1993). All fish in bins making up the sample were measured to the nearest centimetre below the fork length. It was expected that a sample size of about 400 fish from landings greater than 5 t would adequately describe the length distribution of each landing. As snapper show no differential growth between sexes (Paul 1976), sex was not determined.

The age-length key method was used for collecting otoliths, as described by Davies & Walsh (1995). In previous years the sample allocation for each length class interval for the age-length key was made according to the broadest proportion at length distribution of either the bottom trawl or bottom pair trawl collection from the year before. However, as large snapper (i.e., those over 65 cm) were often poorly represented or absent in proportion at length distributions from SNA 8 collections in recent years, it was felt that a proportional allocation age-length key design may under-represent fish in the large length class intervals and over-represent those in the mid-range. To determine whether a broadening of the age-length key collection had any real effect on the resulting catch-at-age estimates, the sample collection in 2007–08 was altered to a semi-fixed allocation design, and this same design has been implemented for sampling ever since, including 2018–19 (see Appendix 1).

A semi-fixed allocation design for the age-length key should ensure that the right hand tail of the distribution, comprising the large and old snapper, is adequately sampled. For 2018–19, a step-wise sample size of about seven fish for length intervals greater than 46 cm, six fish over 48 cm, five fish over 52 cm, four fish over 56 cm, three fish over 61 cm, two fish over 68 cm, and one fish over 74 cm was specified for collection. It was thought that a broad, but slightly less dominant, mode (capped at 25 samples for the most common length intervals) based on the length distribution of the bottom trawl sample from 2015–16 (the most recent sampling event) that covered the mid-length class intervals of the age-length key collection would suitably describe the mid-range of cohorts currently present in the fishery. To attain the age-length key target, 30 to 40 otoliths from a range of fish sizes would be subsampled from each landing sampled for length, spread throughout the five month sampling period until the target sample sizes for each length class (in the age-length key) were achieved (see Appendix 1).

2.4 Quality assurance of sampling processes

To ensure that standards were maintained throughout the project all new NIWA staff received specific training for sampling and worked alongside experienced samplers on each occasion. All sampling events were conducted by two samplers, one measuring and the other recording. Furthermore, a sampler with three decades experience in sampling SNA 8 conducted six of the fifteen sampling events, working with other staff to ensure that sampling practice was consistent. As a length frequency and age-length key sampling design requires the selection of a fixed number of fish to be collected for otolith sampling across a specific size range, there is no requirement to select anything other than a fish of the correct size (i.e. the fish selected for otolith sampling from a particular landing are not meant to be representative of the size distribution of that landing). Furthermore, the routine checks for sampling bias that are undertaken for a random age frequency (RAF) sampling design (i.e., comparison of the length frequency measurement distribution with the length frequency distribution of fish subsampled for otolith collection) are not relevant for a length frequency and age-length key design. An incorrect length measurement in the age-length key sample, should it occur, would be obvious as an outlier in the age-at-length scatterplot and removed from the dataset.

2.5 Snapper age determination

All snapper otoliths were prepared using the break and burn technique (Chugunova 1963) and a standardised procedure for reading otoliths was followed, outlined in the age determination protocol for snapper (Walsh et al. 2014a). Two readers were used in ageing SNA 8 otolith samples in 2018–19, with each reader having no prior knowledge of the other’s zone count obtained, or of the fish length. For otoliths where both readers agreed on the zone count, the age was determined from this count. When readers disagreed, the otolith was re-examined together to determine the likely source of disagreement and a final count agreed upon. The forced margin method was implemented to anticipate the otolith margin type (wide, line, narrow) *a priori* based on the month in which the fish was sampled to provide guidance in determining age. To determine the “fishing year age class” of fish using the forced margin, ‘wide’ readings are increased by 1 year (e.g., 3W is aged as a 4 year old) while ‘line’ and ‘narrow’ readings remain the same as the zone count (e.g., 4L or 4N are aged as a 4 year old), meaning that regardless of whether the fish was caught before or after the nominal birth date of 1 January, age remains the same throughout, unlike that which would be used for age groups/age classes or in growth rate estimation (see Walsh et al. 2014a).

Otolith reading precision was quantified by carrying out within and between-reader comparison tests after Campana et al. (1995), including those between each reader and the final agreed age. The Index of Average Percentage Error, IAPE (Beamish & Fournier 1981), and mean coefficient of variation (CV) (Chang 1982), were calculated for each test.

The age-length key derived from the age data was assumed to be representative of the spring-summer period. The main assumption to be satisfied for an age-length key is that the sample was taken randomly with respect to age from within each length interval (Southward 1976).

2.6 Snapper catch-at-age analysis

NIWA's catch-at-length and -age analysis software tool CALA (catch-at-length and -age, Francis & Bian (2011)) was used in the calculation of proportions at length and age, and variances (bootstrap) from length frequency samples and the age-length key. For samples collected from the SNA 8 bottom trawl fishery in 2018–19, estimates of proportion at length and age were calculated according to two possible designs: unstratified and stratified. In the unstratified design, length and age data were pooled across temporal strata (spring and summer), thus treating the fishery as a single stratum. In the stratified design, estimates of proportion at age and length (and coefficient of variation) were calculated for each stratum separately, and then combined, weighted by the catch in each stratum. CALA scales up the numbers of fish in the samples to the numbers of fish in landings and finally the numbers of fish in each seasonal stratum, based on the weights of both samples and landings. Bootstrap variances were determined for both stratified and unstratified combined spring and summer proportion at length and proportion at age estimates.

The calculation of inferred mean weight-at-age and variances followed Quinn II et al. (1983), with a length-weight relationship: w (g) = 0.04467 $l^{2.793}$ (cm) (Paul 1976). Proportions at age, mean length-at-age and derived mean weight-at-age (with estimates of coefficient of variation, CV) were calculated for the range of fishing year age classes (herein referred to as "age classes" encompassing October 2018 to February 2019) recruited, with the maximum age being an aggregate of all age classes over 29 years. Estimates of mean age determined from spring-summer catch-at-age estimates were calculated such that all fish comprising the aggregate (over 29 years) age group were assigned an age of 30.

Snapper length and age data are stored on the Fisheries New Zealand *market* and *age* databases respectively, administered by NIWA.

3. RESULTS

3.1 Updated fishery characterisation 2014–15 to 2018–19

An updated characterisation of the SNA 8 fishery spanning four and a half fishing years (2014–15 to 2018–19) was conducted to provide a comparison of the recent four year catch with that of the catch sampling programme, October 2018 to February 2019 (Figures 3a–c).

The SNA 8 fishery has landed in excess of 1250 t of snapper annually since 2015–16. Despite a slight temporal decline, catches were dominated by bottom trawl accounting for about 75% of the total catch in recent years (Figure 3a). The new trawl method, Modular Harvest System, that became operational in SNA 8 in 2015–16, consistently accounted for the second largest catch of snapper, about 14% of the total.

Although operating across all eight statistical areas and varying over time, the highest bottom trawl catches of snapper in recent years have occurred in the northern reaches of SNA 8 from either Statistical Area 045 (outside the Kaipara Harbour) or 047 (Ninety Mile Beach) (Figure 3b). Consistent moderate-sized catches have also occurred in Statistical Areas 041, 042 and 046, while catches to the south (Statistical Areas 037–040) were low.

The monthly pattern of bottom trawl catches in SNA 8 was generally consistent over the four and a half year period, with the majority occurring in October through to March/April (Figure 3c). An annual average of 57% of the bottom trawl catch occurred over the period nominated for sampling, October through to February.

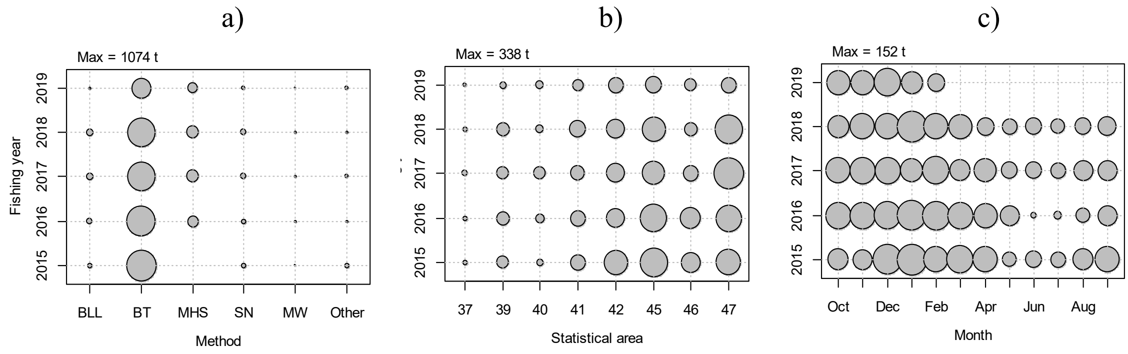

Figure 3: a) Catch of snapper in SNA 8 by gear type; b) by statistical area for bottom trawl only, and c) by month for bottom trawl only, from fishing years 2014–15 to 2018–19 (2018–19 includes data up to February only). (BLL, Bottom longline; BT, Bottom trawl; MHS, Modular Harvest System; SN, Set net; MW, Midwater trawl).

3.2 Sampling of the SNA 8 bottom trawl fishery in 2018–19

Sample collections

Summaries of the length frequency sample sizes for bottom trawl-season-strata are given in Table 2. A total of 15 bottom trawl landings were successfully sampled for length information (number of fish measured = 6495) from the SNA 8 fishery in 2018–19, meeting the required overall target. However, due to contract negotiation, no samples were collected during October 2018. This resulted in the number of landings sampled over spring and summer (four and eleven landings, respectively) not meeting the target of six and nine landings (see Table 1). Samples were selected from two fishing vessels that collectively contributed to over three-quarters (78%) of the total bottom trawl catch from SNA 8 during the sampling programme. Other vessels contributing to the catch in the northern part of SNA 8 often used mixed gears (i.e. bottom trawl and MHS) within a trip, so were not sampled. The number and weight of landings is summarised in Table 2.

Table 2: Summary of the catch (total number and weight of landings) and samples (number of landings and weight sampled, and number of fish measured) in method–season strata for the SNA 8 snapper bottom trawl fishery from spring and summer 2018–19.

		Number of landings			No. of fish	Weight of landings (t)		
Method	Season	Total	Sampled	% of total	measured	Total	Sampled	% of total
Bottom trawl	Spring	67	4	5.9	1 673	196	43	21.9
	Summer	84	11	13.1	4 822	262	119	45.4
	Combined	151	15	9.9	6 495	458	162	35.4

A total of 580 snapper otolith pairs were collected from landings sampled for length frequency (Table 3) exceeding the overall target of 500 (see Table 1).

Table 3: Details of snapper otolith samples collected in 2018–19 from SNA 8.

Method	Sampling period	Sampling method	Length range	No. aged
Bottom trawl	Spring, summer	Stratified random	23–76	580

Sample representativeness

Despite the initial delay where no samples were collected during October, sample representativeness over the remaining four months was generally consistent and evenly distributed throughout by weight and number of landings sampled (Figure 4). The highest number of landings of snapper occurred in November and the largest landed catch weight (over 120 t) was in December, the catch declining significantly to less than half in February. The average size of sampled landings (from the two vessels) over both seasons was the same, at 10.8 t, and ranged between 9.6 and 13.3 t. The sampled component accounted for 35.4% by weight and 9.9% by number of landings of the total bottom trawl catch of SNA 8 over the sampling period (Figure 4, Table 2).

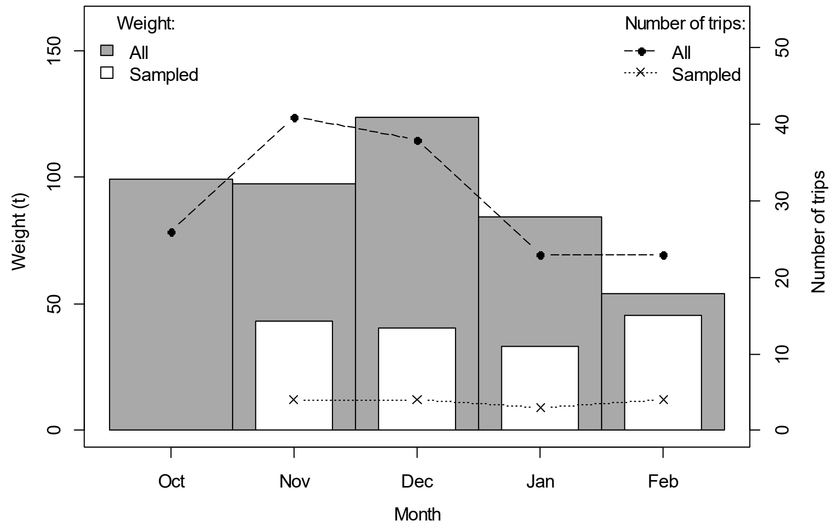

Figure 4: Comparison of the monthly distribution of landed weight (grey bars) and numbers of landings (dashed line) of snapper in the SNA 8 bottom trawl fishery for all landings where snapper was caught for the period October to February 2018–19. Included are corresponding estimates for all sampled landings (white bars and dotted line) to show the representativeness of sampling.

The sampling performance relative to the cumulative proportion of the total number and catch weight of landings throughout the sampling period only appears disproportionate to the operation of the fishery due to absence of sampling in October (Figures 5 and 6). The sampling performance comparison by depth was more aligned with the fishery operation, although a slightly higher proportion of the sampled catch came from depths in the 50–80 m and 130–150 m ranges, compared to that of the fishery (Figure 7).

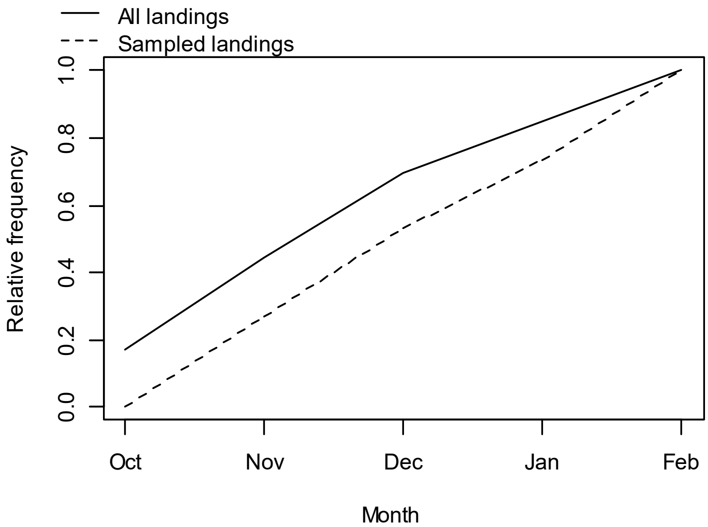

Figure 5: Comparison of the cumulative proportion of the number of landings with samples taken from the SNA 8 bottom trawl fishery in 2018–19.

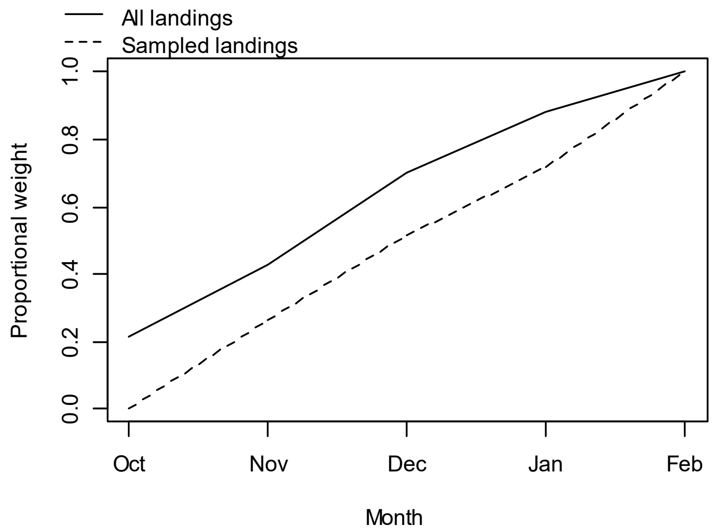

Figure 6: Comparison of the cumulative proportion of the catch weight of landings with samples taken from the SNA 8 bottom trawl fishery in 2018–19.

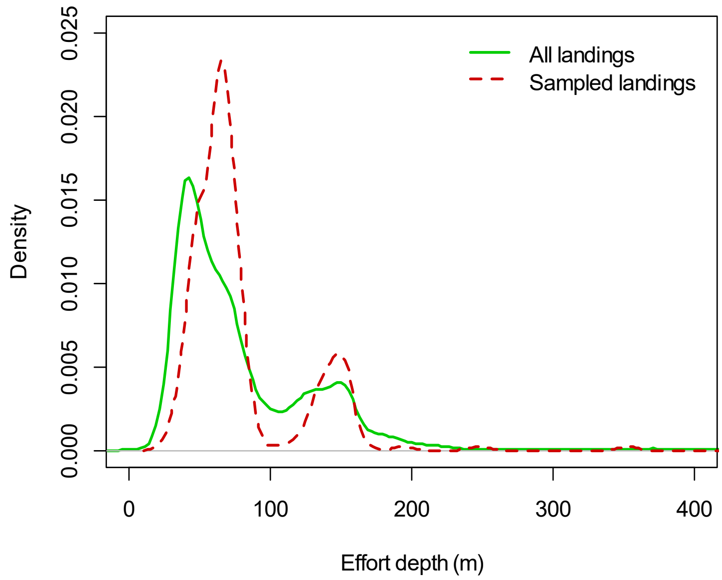

Figure 7: Comparison of the proportion of the number of tows by depth (m) for all landings with samples taken from the SNA 8 bottom trawl fishery in 2018–19.

The number of otoliths subsampled from landings in each month is given in Figure 8 and suggests that in the absence of sampling October, a reasonable level of temporal consistency was achieved in the otolith collection across the remaining four months, although proportionally fewer otoliths (about one quarter) were collected over spring (n = 156) compared to summer (n = 424). A comparison of the length distribution of snapper subsampled for the otolith collection to that targeted from the SNA 8 fishery in 2018–19 illustrates the size range of samples achieved for the age-length key (Appendix 1). The collection was relatively broad with length intervals from 25 to 67 cm being well represented, meeting or exceeding the required targets. Only four snapper longer than 69 cm were sampled for age (one each at 72, 73, 75 and 76 cm), with all remaining size classes (70, 71, 74 cm and over 76 cm) absent from catch samples. Note: there were no observed length classes not represented by at least one otolith.

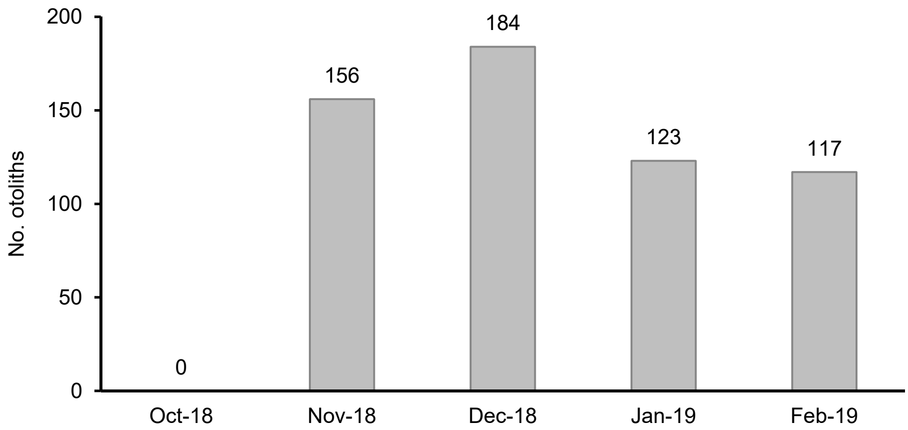

Figure 8: Numbers of otolith pairs collected by month from the SNA 8 bottom trawl fishery from October 2018 to February 2019.

Fine scale spatial comparisons (0.1 degree blocks) of the distribution of the SNA 8 bottom trawl fishery estimated catch and sampled catch for 2018–19 showed that although sporadic catches of snapper were made in the southern coastal regions of SNA 8, the majority of the catch (78%), as well as of the sampled component (84%), was taken from coastal regions between Cape Maria van Diemen and Kawhia Harbour (Figures 9 and 10). With the exception of South Taranaki Bight Statistical Areas 037 and 039, the sampled component was generally spread throughout areas where the commercial bottom trawl fishery operated in 2018–19, suggesting that sampled landings, by and large, are likely to be spatially representative of the SNA 8 fishery.

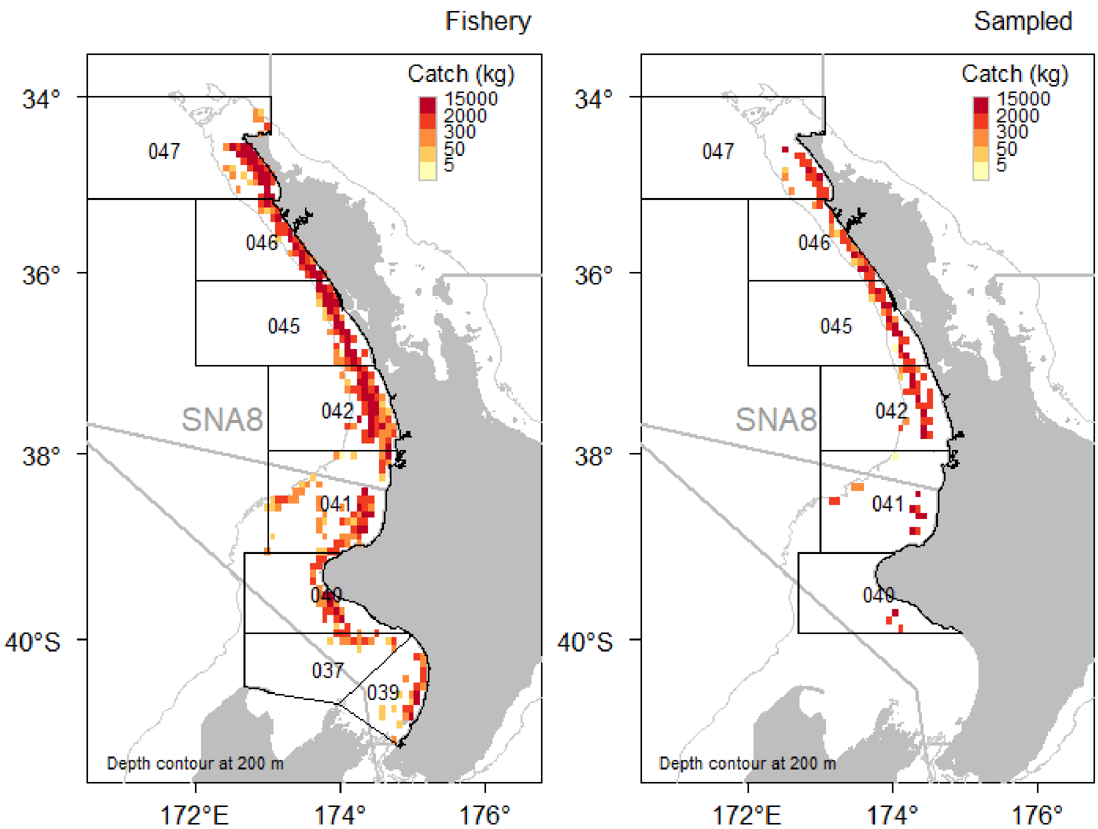

Figure 9: Comparison of the spatial distribution of the bottom trawl catch and the sampled component for the SNA 8 stock in 2018–19.

A comparison of the distribution of the bottom trawl estimated catch of snapper with that of sampled catch in 2018–19 in the Statistical Areas that make up SNA 8 is given in Figure 10. Similar proportions of snapper caught by bottom trawl came from vessels fishing in Statistical Areas 042, 045 (coastal Manukau and Kaipara Harbour regions) and 047 (Ninety Mile Beach), with smaller but significant catches also taken from adjacent statistical areas to the north (046) and south (041) (see Figures 9 and 10). Overall, sampling was largely representative of the SNA 8 Statistical Area catch (Figure 10).

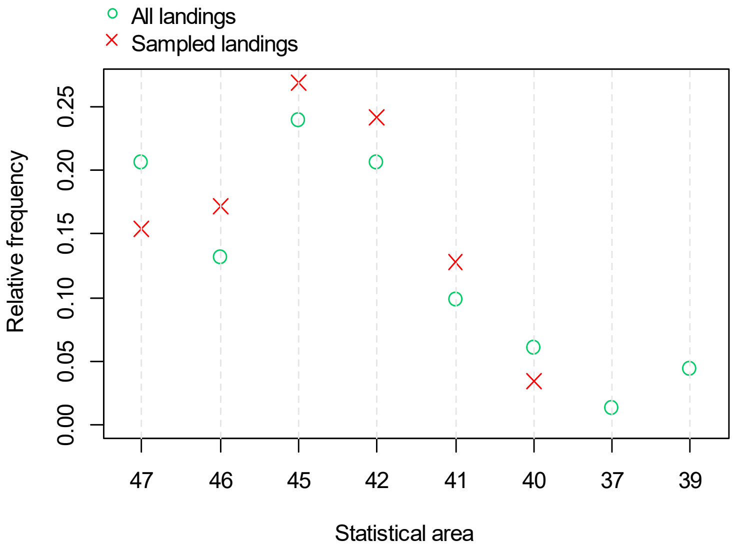

Figure 10: Comparison of the proportional distribution of estimated bottom trawl catch and the sampled component by statistical area for the SNA 8 stock over the sampling period in 2018–19.

Eighty percent of the total snapper catch in spring and summer 2018–19 was taken when trevally (*Pseudocaranx dentex*) was the target species, with red gurnard (*Chelidonichthys kumu*) (11%) and snapper (7%) targeted less frequently (Figure 11). The proportionality of the sampled component to that of the fishery suggested that the sampled landings, by and large, were representative of the operation of the SNA 8 bottom trawl fleet as a whole.

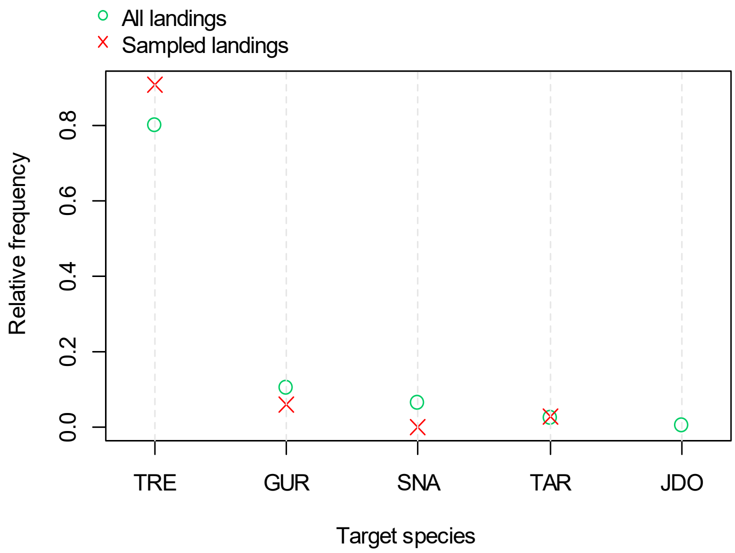

Figure 11: Comparison of the proportional distribution of the estimated bottom trawl catch and the sampled component by target species over the sampling period for the SNA 8 stock in 2018–19.

3.3 Snapper otolith readings: reader comparison tests for reference readings

To assess reader competency in ageing snapper otoliths in 2018–19, a newly trained reader (Reader 2) aged a subsample of 50 reference otolith preparations with the aim of achieving a score for Index of Average Percentage Error, IAPE (Beamish & Fournier 1981), and mean coefficient of variation (CV) (Chang 1982), of below 1.50 % and 2.12 %, respectively (Walsh et al. 2014a). Reader 2 achieved CV and IAPE scores below the targets (Table 4).

Table 4: **Reader comparison scores determined from ageing 50 randomly selected snapper reference otolith samples ranging in age from 4 to 46 years.**

	IAPE	CV	Agreed age	Pass/Fail
Target	1.50%	2.12%	–	–
Reader 2	1.23%	1.74%	70%	Pass (1st attempt)

3.4 Reader comparison tests for SNA 8 readings

Of the 580 SNA 8 otolith samples collected in 2018–19, all were successfully aged. Between-reader tests with graphical comparisons in Figure 12 indicate a low level of consistency between readers with substantial systematic differences (bias) evident in their first counts. The negative weighting of the histogram in Figure 12(a), the relative clustering of plotted points about the zero line in Figure 12(b), and the deviation from the one-to-one line on the age-bias plot for almost all age classes (Figure 12(c)) indicate that the second reader consistently over-counted zones relative to the first reader. The overall percentage agreement between readers was low at 54.5%, the vast majority of disagreements (256 out of 264 readings (97.0%)) were ±1 year. The between reader CV and IAPE were greater than 4% (Figure 12(c)) and the profiles show that precision was low, particularly across young to moderate age classes (Figure 12(d)). Comparisons of the age-bias plots for reader 1 and 2 with the agreed age resulted in agreement of 99.3% for reader 1 and 55.1% for reader 2 (Figures 12(e) and (f)), the latter with CVs and IAPEs almost identical to the between-reader estimates (Figure 12(c)).

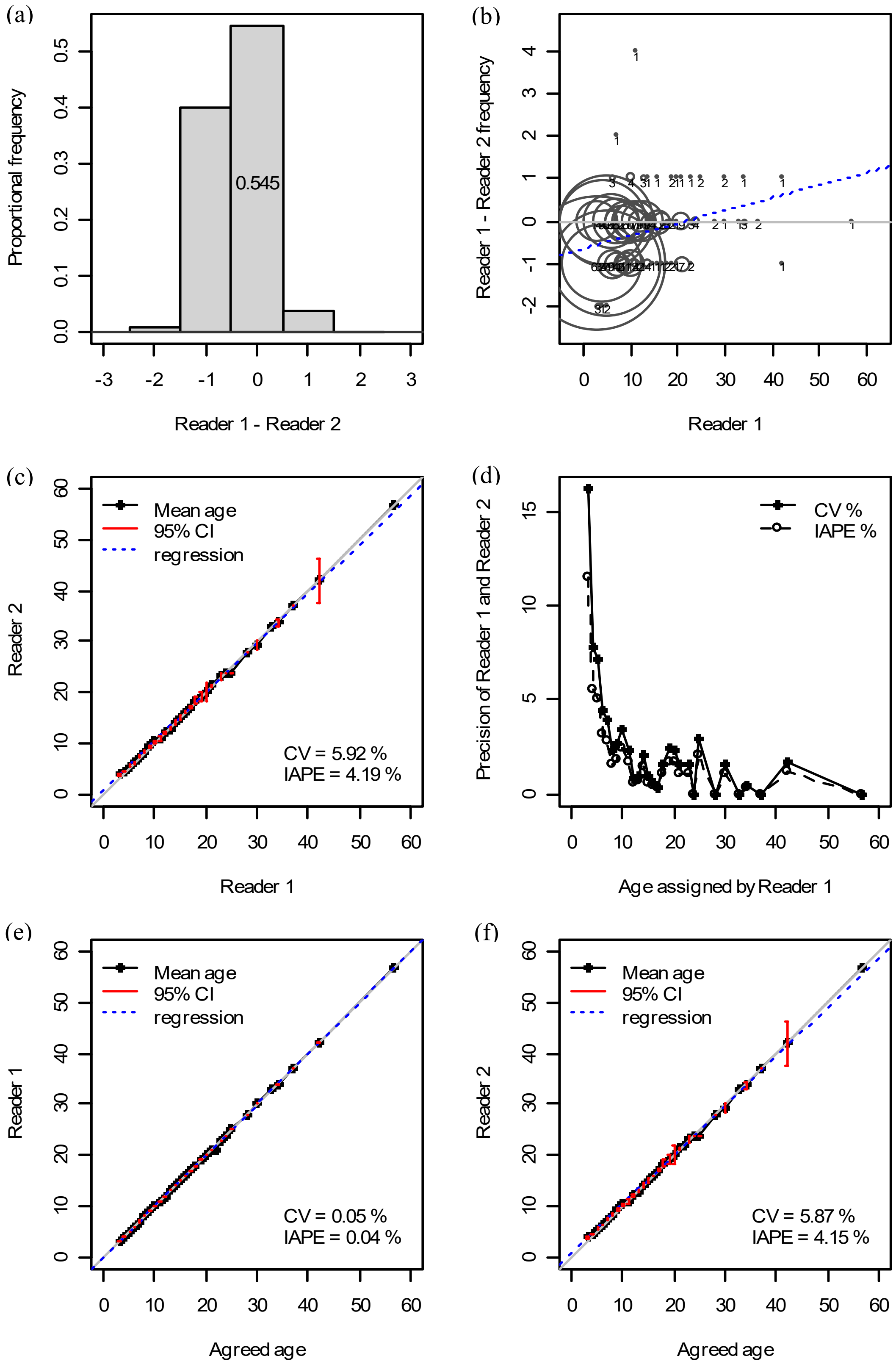

Figure 12: Results of between-reader comparison test (reader 1 and 2) for SNA 8 otoliths collected in 2018–19 (*n* = 580): (a) histogram of differences between readings for the same otolith; (b) differences between readers for a given age assigned by reader 1; (c) bias plot between readers; (d) CV and IAPE profiles (precision) relative to the age assigned by reader 1; (e) bias plot between reader 1 ((f) reader 2) and agreed age. The expected one-to-one (solid line) and actual relationship (dashed line) between readers are overlaid on (b) and (c), and between reader 1 and 2 and the agreed age on (e) and (f).

3.5 Length and age distributions

The catch-at-age compositions (using the length frequency and age-length key approach) were derived from the combined spring and summer length distributions, and used to identify year class strengths. Although otolith samples were collected from each sampled landing, they were not collected consistently across the entire spring or summer period. In combining the seasonal data, it is assumed that an age-length key collected from spring and/or summer can be applied to the combined spring and summer length data. Because the growth of snapper over 25 cm long is not great between spring and summer, this assumption is reasonable. This assumption has been accepted for other species with growth rates comparable to those of snapper (Westrheim & Ricker 1978).

The age-length key is presented in Appendix 2 and an age-at-length scatterplot (using decimalised ages and not fishing year ages) is given in Appendix 3.

3.6 Catch-at-length and catch-at-age estimates

Stratifying the length data by season made little difference, as the unstratified and stratified distributions were essentially identical (due to similar proportionality of weighting over spring and summer) characterised by one main mode centred around 33–34 cm and a tail extending to over 55 cm (Figure 13, Appendix 4). As a result, mean lengths of snapper sampled from the fishery were almost the same at 35.6 and 35.4 cm, with proportion at length MWCVs differing slightly at 0.17 and 0.16 respectively.

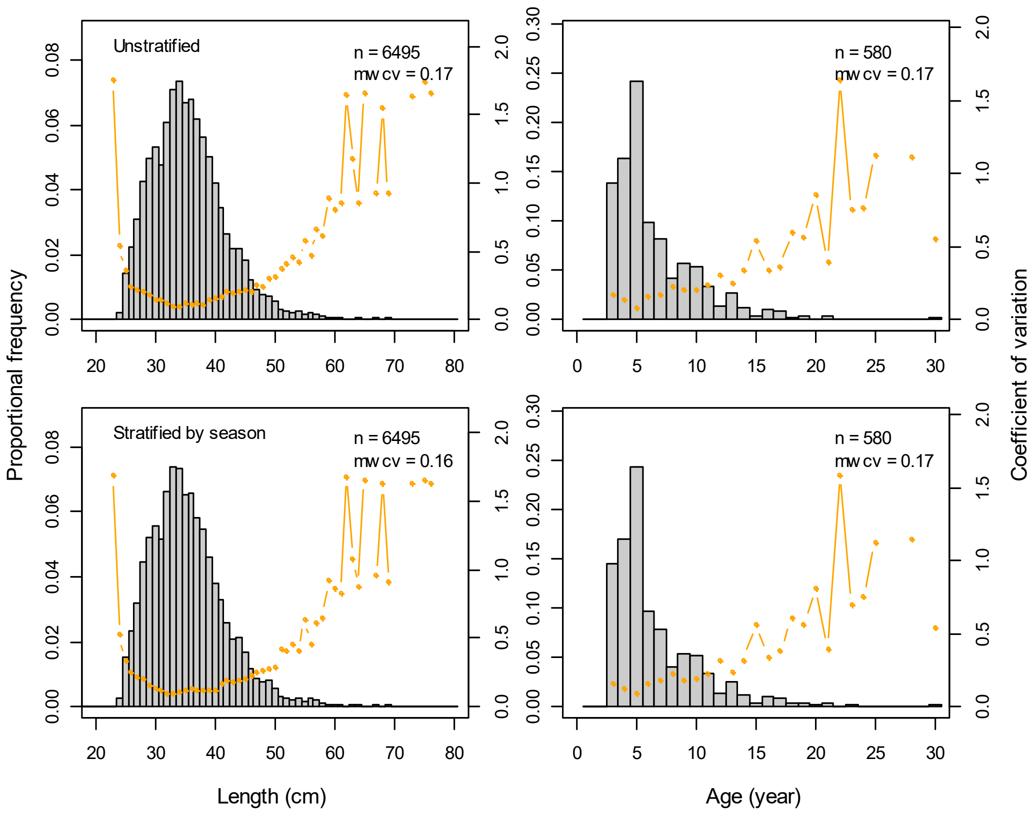

Figure 13: Unstratified (top) and seasonally stratified (bottom) proportions at length and age distributions (histograms) and bootstrap CVs (lines) determined from snapper landings sampled from the SNA 8 bottom trawl fishery in 2018–19 using the length frequency and age-length key approach (*n*, sample size; MWCV, mean weighted CV).

The corresponding unstratified and stratified age distributions were also essentially identical, dominated mainly by young snapper 3 to 7 years, but also comprising a reasonable number of moderate aged fish, 8 to 11 years, collectively making up over 90% of the total number landed by bottom trawl in SNA 8 (Figure 13, Appendix 5). The 2014 year class (5-year-olds), singularly the most dominant in the fishery in 2018–19, accounted for almost one in every four fish landed in SNA 8, followed closely by the second and third most dominant, 2015 and 2016 year classes (4- and 3-year-olds). Year classes that were obvious in the mid-age range of the distribution were 2010, 2009 and 2006 (9-, 10- and 13-year-olds), but few stood out in the right-limb, those snapper 20 years or older making up about 1% of the overall catch, much lower than the age-length key sample (8%) (Appendix 6). The oldest fish sampled from the SNA 8 fishery over spring and summer 2018–19 was 57 years (Appendix 3).

The 2014 year class (5-year-olds) appears fully recruited as it contains no fish under 29 cm, unlike the 2016 and 2015 year classes (3- and 4-year-olds) (see Appendix 2). Based on relative proportions in the 2018–19 catch-at-age distribution, the 2016 year class appears to be of above average strength making up about 14% of the catch. The mean ages of snapper from the spring-summer bottom trawl fishery were almost identical at 6.6 and 6.5 years for the unstratified and stratified approaches, respectively, and the catch-at-age MWCVs were the same at 0.17 (Figure 13).

Slight temporal differences were evident in seasonal length and age distributions with spring samples overall comprising a higher proportion of small young fish (and marginally more large and old fish) compared to summer samples, which contained marginally more fish of intermediate length and age (Figures 14 and 15, Appendices 4 and 5). The mean length and age of snapper landed over the spring period was 34.7 cm and 6.2 years, and during summer, 36.0 cm and 6.7 years. Seasonal catch-at-length and -age MWCVs ranged between 0.19 and 0.26.

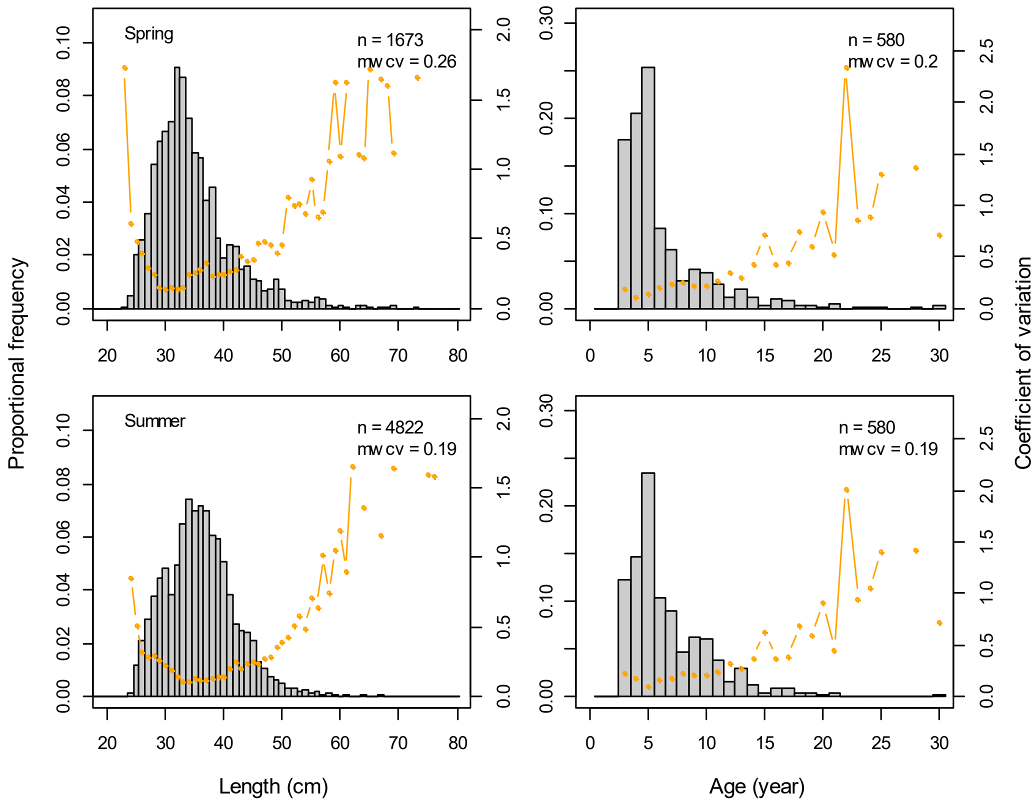

Figure 14: Seasonal proportions at length and age distributions (histograms) and bootstrap CVs (lines) determined from snapper landings sampled from the SNA 8 bottom trawl fishery in spring (top) and summer (bottom) 2018–19 using the length frequency and age-length key approach (*n*, sample size; MWCV, mean weighted CV).

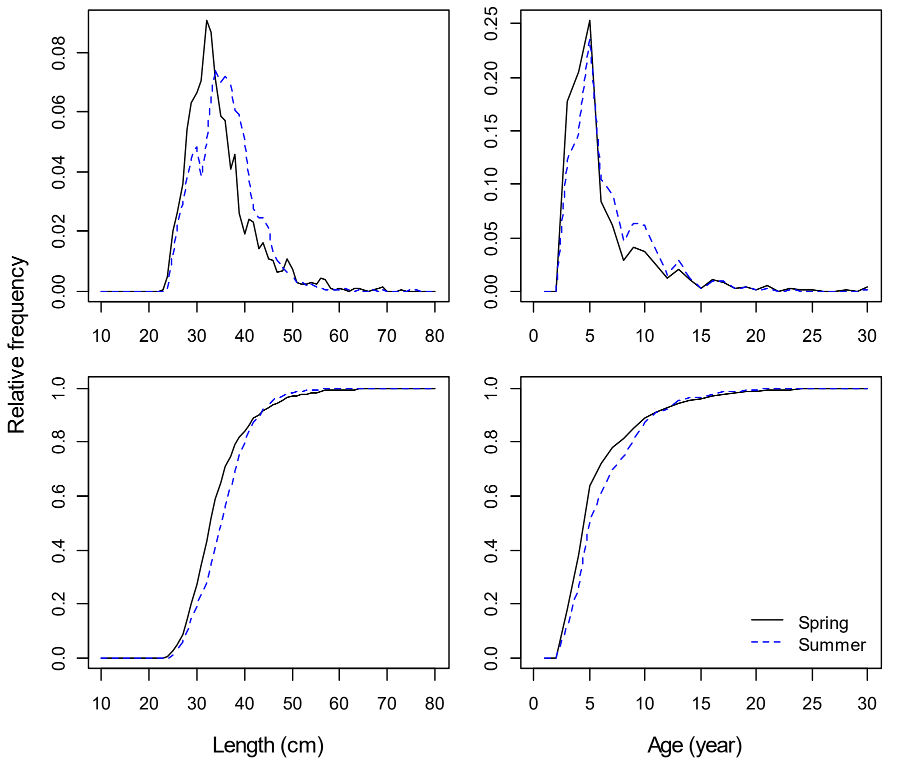

Figure 15: Comparison of the proportion and cumulative proportion at length and age distributions determined from snapper landings sampled over the spring and summer seasons from the SNA 8 bottom trawl fishery in 2018–19.

3.7 Mean length-at-age and mean weight-at-age

A trend of increasing mean length-at-age and inferred mean weight-at-age over successive age classes up to 12 years was generally evident in data collected from the SNA 8 bottom trawl fishery in 2018–19 (Figure 16, Appendices 7 and 8) while for older age classes they tended to fluctuate. For 3–4 year old snapper, estimates of mean length-at-age and mean weight-at-age may have been positively biased because of the minimum legal size (MLS) restriction of 25 cm in commercial catches, and also because fish of this age range may not yet be fully recruited to the fishery. Similarly, older fish may be under-represented in the catch because bottom trawl gear has dome-shaped selectivity.

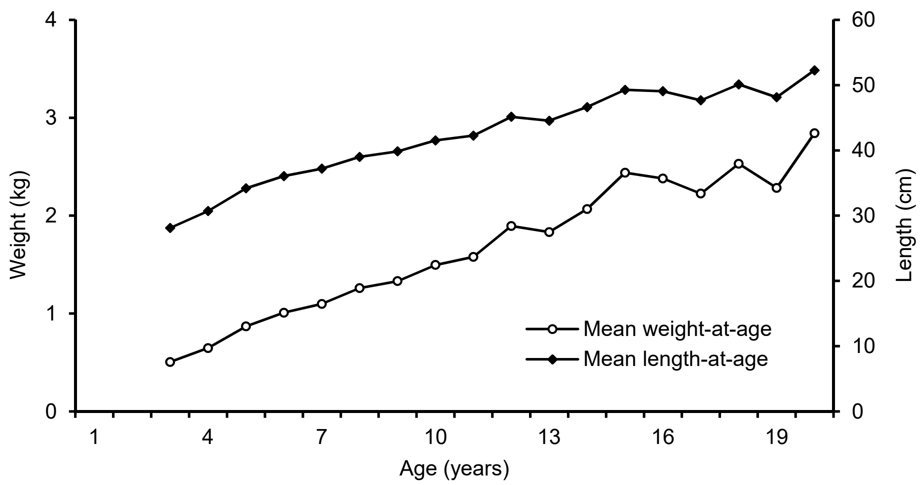

Figure 16: Observed mean weight-at-age and mean length-at-age estimates from snapper landings sampled from the SNA 8 bottom trawl fishery in 2018–19. Note: data presented for ages 3–20 years only.

Mean length and mean age

Estimates of mean length and mean age for snapper sampled from the SNA 8 bottom trawl fishery between 1974–75 and 2018–19 are given in Figure 17 with estimates for the bottom pair trawl method collected over slightly more contracted periods included for comparison. The bottom trawl mean length for snapper in 2018–19 was 35.6 cm, the sixth smallest in the 30 year time series (since 1989–90), while mean age (6.6 years) was the second highest recorded estimate determined over the same period (Figure 17).

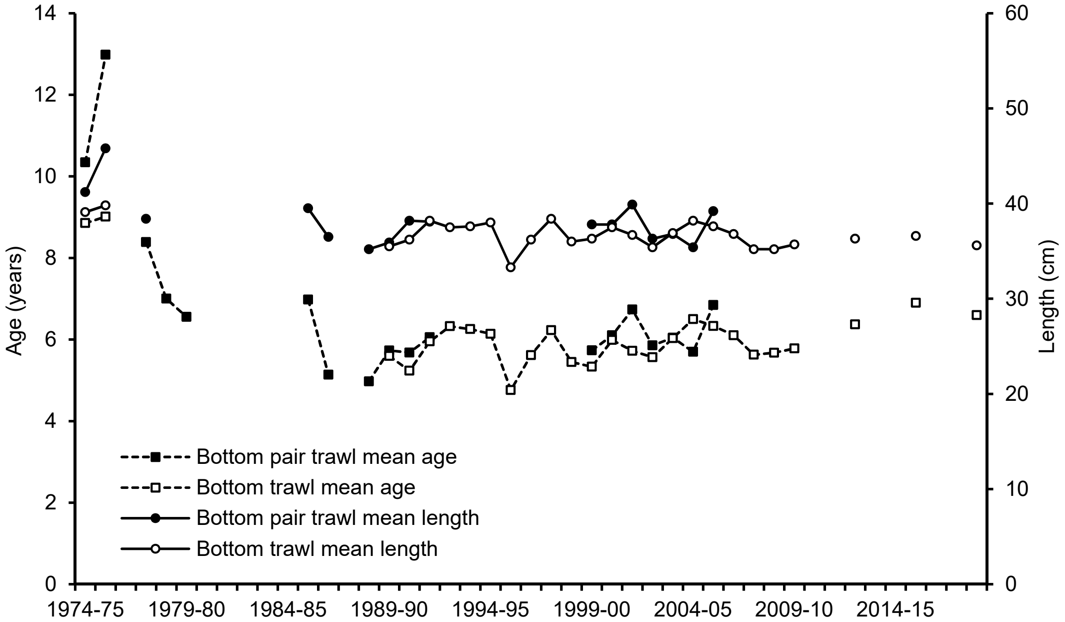

Figure 17: Time series of mean length and mean age estimates from the SNA 8 bottom trawl fishery (1974–75 to 2018–19). The 2012–13, 2015–16 and 2018–19 length and age estimates lie to the right hand side of the figure detached from the time series. Note: Mean estimates from the bottom pair trawl method (1974–75 to 2005–06) have been included for comparison.

Mean weight-at-age time series

A time series comparison of inferred mean weight-at-age estimates derived from sampling the SNA 8 bottom trawl fishery between 1990–91 and 2018–19 shows that although inter-annual variations may exist for snapper for the common age classes (i.e., 6–13 years old), the most recent estimates from 2012–13, 2015–16 and 2018–19 are some of the lowest recorded and indicative of a decline in growth rate since sampling began in 1990s (Figures 18 and 19). Annual mean weight-at-age estimates for many of the older age classes (i.e., over 13 years of age) are highly variable from year to year and unlikely to provide realistic estimates due to the low number of individuals present (Figure 18).

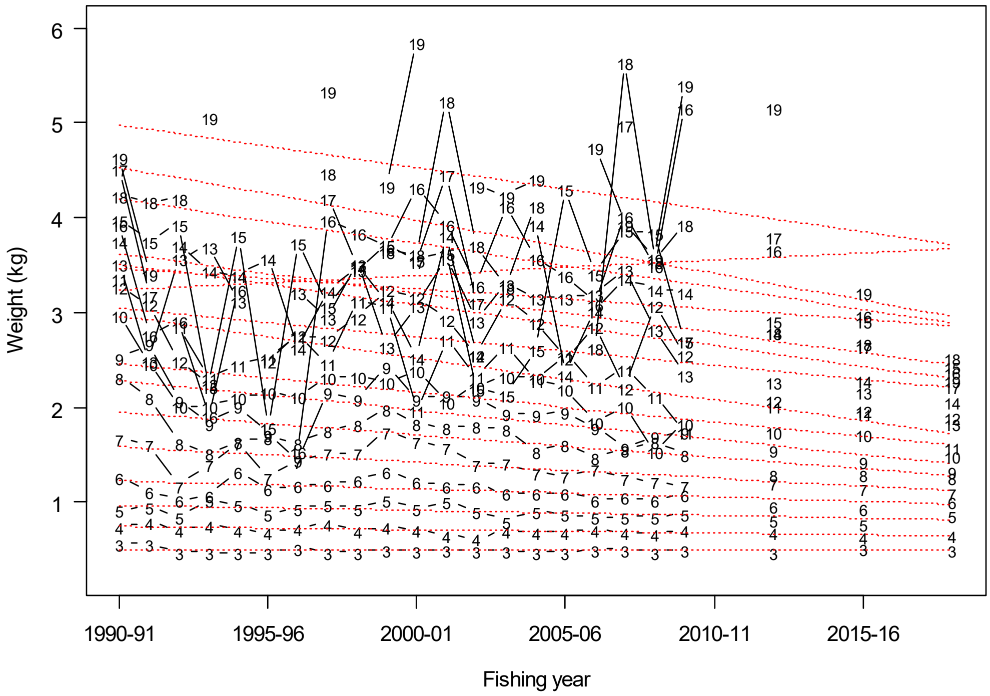

Figure 18: Mean weight-at-age estimates for 3 to 19 year old snapper sampled from the SNA 8 bottom trawl fishery between 1990–91 and 2018–19 with fitted trend lines (dotted red) for each age class depicting long-term changes in growth rates over the 29 year period.

Comparisons of mean weight-at-age estimates for snapper from the three most recent sampling years (2012–13, 2015–16, 2018–19) to a time series comprising the average of two decadal collections (1990s and 2000s) indicates that mean weight-at-age has remained much lower than earlier decades (Figure 19). Over the past decade, mean weight-at-age for young snapper, 3 to 8 years, has remained relatively stable, while estimates for fish 9 years and older have noticeably declined, those in 2018–19 being the lowest ever recorded (Figure 19). The difference in mean weight-at-age between the first decade (1990s) and 2018–19 indicates the overall net weight loss/gain to the fishery, estimated at around -10% to -30% for most of the common age classes in SNA 8 (Figure 19).

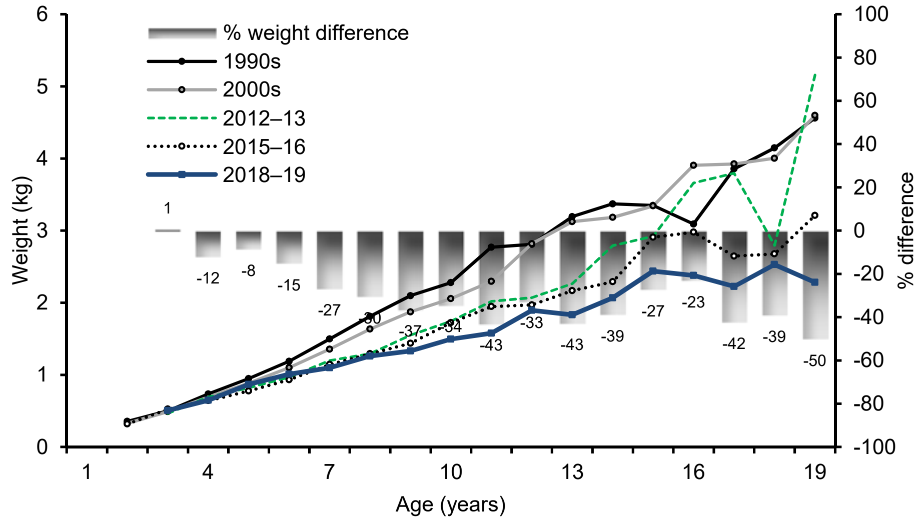

Figure 19: Mean weight-at-age estimates for snapper sampled from the SNA 8 bottom trawl fishery from two decadal time periods (1990s and 2000s) and from the most recent sampling years 2012–13, 2015–16 and 2018–19, and where each period reflects the average mean weight-at-age for those years. The percentage weight difference for each age class (positive or negative) is the difference between the first decade (1990s) and 2018–19, and indicative of a net weight gain or loss in mean weight-at-age through time.

4. DISCUSSION

A length frequency and age-length key sampling approach was employed during spring and summer 2018–19 to estimate catch-at-age for snapper caught by conventional bottom trawl in SNA 8 and followed a similar design as that first implemented in 1989–90. Fifteen landings were sampled for length frequency with a total of 6495 fish measured and 580 otoliths selected for age information from two vessels that collectively contributed over 75% of the bottom trawl catch. Catch samples from 2018–19 provide the third opportunity to view the age composition of the SNA 8 fishery since 2009–10, when triennial sampling was first adopted.

SNA 8 catch-at-age 2018–19

Catch samples from SNA 8 bottom trawl landings in 2018–19 were dominated by the three most recently recruited year classes, 2016 to 2014, occupying the 3 to 5 year age range, and collectively contributing one in every two fish landed (54%) over spring-summer. However, the fishery still retains a good proportion of fish up to 13 years of age, the distribution being almost as broad as that last described in 2015–16 (Walsh et al. 2017). The progression of strong year classes (i.e., 2010, 2009, 2006) from 2015–16 remain evident in the 2018–19 age distribution occupying 9-, 10- and 13-year-old age classes, respectively (see Appendices 9 and 10). As a result, the mean age of snapper landed by bottom trawl in 2018–19 was the second highest recorded estimate (6.6 years) for SNA 8 since 1989–90, a period spanning 30 years (see Figure 17, Appendix 9). This suggests that improvement in the status of the fishery seen three years prior in 2015–16, where mean age (6.9 years) was the highest estimate recorded in three decades, has largely been maintained in 2018–19, and that a slight decline in the broadness of the distribution is most likely due to the recent strong recruitment of the 2016–2014 year classes (3- to 5-year-olds). Nevertheless, the combined total of old fish in SNA 8 (i.e., those 15 years and older) has continued to remain low (currently about 4%) over the same period and is unlikely to improve until dominant year classes of above average strength grow older and broaden the right hand limb of the age distribution (see Appendices 9 and 10). Previous catch sampling data from SNA 8 (Sullivan & Gilbert 1978) and SNA 2 (Walsh et al. 2012) clearly indicate that bottom trawling is capable of capturing a significant proportion of large old snapper should they be present in the fishery.

The 2014 year class (5-year-olds), singularly the most dominant in the SNA 8 fishery, accounted for almost 25% of all snapper in bottom trawl landings in 2018–19. With an average size of 34 cm (about 0.870 kg) the 2014 year class should now be fully recruited as it contains no fish below 29 cm (see Appendix 3), and is likely to be significant to the fishery for many years to come, not just by number, but by its contribution by weight, should the catch from, and recruitment to, the fishery, remain relatively constant.

The newly recruited 2016 year class accounted for 14% of the catch in 2018–19, the third (equal) highest estimate for 3-year-old snapper in 24 years of sampling SNA 8 since 1989–90. Those year classes that have appeared in the SNA 8 commercial catch at 3 years with more than a 10% contribution by number (i.e., 1991, 1993, 1995, 1996, 1998, 2005, 2006) have gone on to be of above average strength and important to the short term sustainability of the fishery (Davies & Walsh 1995, Walsh et al. 1997, 2000, 2002, 2009, Walsh & Buckthought 2010). It is highly likely that the 2016 year class will significantly contribute to the continued rebuild of SNA 8 over the coming decade. A comparison of a fully recruited 2016 year class (as 6-year-olds) relative to other year classes in 2021–22, the next triennial SNA 8 sampling event, will further confirm its importance. By way of an indication as to the possible magnitude of the 2016 year class in SNA 8, the relationship between sea surface temperature and snapper recruitment in the Hauraki Gulf stock of SNA 1 (Francis 1993) predicts that the 2016 year class may be one of the strongest year classes (if not the strongest) ever recorded in five decades.

SNA 8 catch-at-age time series

In the two decades following the introduction of the Quota Management System (QMS) in 1986, the age structure of SNA 8 was seen to be consistent with that of a heavily exploited fishery, comprising a handful of young age classes, with often one or two dominating and a distinct lack of accumulation of older fish (Walsh et al. 2011b), suggesting that only moderate change has occurred in the fishery. Two absolute abundance estimates from tagging programmes in 1990 and 2002 (see Davies et al. 1999, Gilbert et al. 2005) and two stock assessments, in 2003–04 and 2004–05 (Davies et al. 2006, 2013), indicated that the stock was between 8% and 12% of the unfished equilibrium biomass, B_0. In October 2005, the SNA 8 TACC was reduced from 1500 t to 1300 t to ensure a faster rebuild of the stock (Fisheries New Zealand 2018). Eight years later in 2012–13, Walsh et al. (2014c) reported that catch sampling results indicated that a slow but consistent rebuild may be underway in SNA 8, most likely as a result of the TACC reduction (e.g., broadening age composition, increasing mean age, and slowing growth rate). The same effects were again evident in 2015–16 (Walsh et al. 2017) and the current study, 2018–19. Furthermore, the 2015–16 age composition data was found to be consistent with a strong increase in CPUE indices for bottom trawl from 2007–08 to 2015–16 (Langley 2017) suggesting that the level of rebuild of the SNA 8 stock over the past decade may have been significant.

Trends in snapper growth rates

Using the time series of catch sampling data available from SNA 8, Walsh et al. (2014c) documented temporal trends in the growth rates of snapper by comparing changes in mean weight-at-age for the common age classes over time. They found growth rates for snapper sampled during the 1990s to be some of the fastest in New Zealand, declining slightly during the mid-2000s. However, it was catch sampling data from 2012–13 that indicated that the most obvious decline in growth rate in SNA 8 had occurred, further supported by sample collections in 2015–16 that demonstrated a similar, but less pronounced trend (Walsh et al. 2014c, 2017). They attributed the temporal change in growth rates to compensatory density dependence (Rose et al. 2001) as the SNA 8 stock biomass increased, rather than temperature related effects or bias associated with sampling design or fishing method selectivity. Further support for the declining growth rates was evident in the incremental deposition of a number of the SNA 8 otoliths aged in 2012–13 that exhibited a noticeable narrowing of zones close to the margin (becoming more common in 2015–16), than had generally been observed in the ageing over the previous two decades, meaning that somatic growth in some fish had slowed considerably and this slowing appeared to be becoming more common (Walsh et al. 2014c, 2017).

In 2015–16, Walsh et al. (2017) suggested that a slower rate of recruitment of younger age classes into the fishery because of slow growth, coupled with a lower exploitation rate compared to past years as the biomass increased, may have enabled west coast snapper to attain a greater average age, albeit at a relatively constant size. From the current study in 2018–19, catch samples revealed mean weight-at-age for young snapper, 3 to 8 years to have remained relatively stable and similar to estimates from 2012–13 and 2015–16 (Walsh et al. 2014c, 2017), while mean weight-at-age for snapper 9 years and older have continued to decline (see Figure 19) and are now the lowest recorded in three decades. Although the mean age of snapper landed in SNA 8 has remained relatively stable, currently at 6.6 years, mean length (35.6 cm, about 0.96 kg) has declined by 1 cm from 2015–16 and from the long-term mean, indicating that overall, growth rates have continued to slow.

Walsh et al. (2014c, 2017) suggested that the decline in growth rates in SNA 8 and the net weight loss to the fishery in terms of yield per recruit compared to that of the 1990s would be likely to result in a decrease in productivity in the stock, correlating with a gradual increase in stock size. This would mean that the fishery was likely to land more snapper now than it did 10–30 years ago to achieve the same catch weight, an effect unlikely to improve, given that growth rates in 2018–19 appear the slowest documented for SNA 8 in three decades, either equal to, or even less than those from 2012–13 and 2015–16. Similar density dependent growth trends in relation to changes in biomass have been recently documented for the Hauraki Gulf and Bay of Plenty stocks of SNA 1 (Walsh et al. 2011a, 2011c, 2014b, 2019).

It is important to note that the assessment of mean weight-at-age, as described above, was conducted using a length-weight relationship that was established in the 1970s (Paul 1976), and was re-verified in the 1990s (NINSWG-2019-13). Whether the use of the same length-weight relationship remains appropriate (as biomass has increased) has been raised by the NINSWG, but presently there is no recent information to determine whether the length-weight relationship has changed.

Changes in fishing behaviour

Length and age collections from the SNA 8 bottom trawl fishery were made over the spring and summer seasons, when most of the annual catch of snapper has historically been caught, and when fish aggregate for spawning (Davies et al. 2013). However, in 2018–19 only about half (49%) of the TACC was taken over the spring and summer seasons, which is likely to be the lowest bottom trawl snapper catch during this period in three decades. The continued decline in SNA 8 landings over spring-summer in recent years has been attributed to the broadening of the fishing season, the limited availability of ACE (Annual Catch Entitlement) and high relative lease prices compared with other species, a downsizing and rationalisation of the number of vessels and other economic and market related factors (Walsh et al. 2009). Furthermore, since the TACC reduction in October 2005, considerable changes to the SNA 8 bottom trawl operation have occurred, including changes in the seasonality of catches, areas and depths fished, modification of trawl gear and the target species sought and other forms of avoidance behaviour to limit the catch of snapper (Langley 2017). The trend of commercial fishers targeting trevally over the past decade in the SNA 8 fishery and taking snapper mainly as a bycatch has continued in 2018–19, with trevally the principal target in 80% of all SNA 8 fishing events and in all 15 sampled landings. The proportion of snapper taken as a target species is now likely to be the lowest recorded since the introduction of the Quota Management System in 1986. However, bottom trawl remains the dominant fishing method in SNA 8, as it has been for over a decade, and the fact that over three-quarters of the total landed catch is taken by bottom trawl from the northern half of the QMA, suggests that a good proportion of the stock biomass continues to reside there. This area was the most heavily fished in the past (Reid 1969) and is still considered the main area to catch snapper commercially today, although information from the commercial and recreational sectors suggested considerable improvement throughout the entire SNA 8 fishery in recent years, with greater spatial dispersion of the stock due to increased abundance, particularly over the lower half of the QMA (Walsh et al. 2014c). A national panel survey of marine recreational fishers in 2017–18 estimated the SNA 8 catch to be 892 t (Wynne-Jones et al. 2019), equivalent to two-thirds of the current annual commercial catch allowance of 1300 t.

Precision in catch-at-age

It is expected that samples used here to derive proportional length and age distributions from these landings are adequate and representative descriptions of the SNA 8 bottom trawl fishery over spring-summer 2018–19, and are therefore comparable to those collections from past years, despite significant shifts during the mid to late 2000's in target species and spatiotemporal fishing effort. The MWCV (bootstrap estimates) for the combined spring-summer length and age distributions sampled from the SNA 8 bottom trawl fishery in 2018–19 ranged between 0.16 and 0.17. The level of precision in the catch-at-age estimates has been similar in recent years and reflects the rigorous sampling methodology and precise ageing.

Vessel selectivity

The catch sampling design for SNA 8 landings in 2015–16 involved sub-stratification of sampled vessels because of perceived differences in selectivity patterns for TRE 7 length and age (Langley et al. 2015) in which it had been observed that one vessel (Vessel X) dominated the annual catch and caught larger (and older) fish than other core vessels in the fleet. However, sampling implementation in 2015–16 showed that between-vessel differences for snapper were more likely to be a factor of the spatiotemporal heterogeneity of the stock length composition than selectivity issues, that is, where a vessel fished, and similar to past research findings (Walsh et al. 2017). In a review of SNA 8 length composition data (7 vessels, 33 landings) from 2015–16 and 2017–18, to provide design considerations for sampling SNA 8 in 2018–19 (NINSWG-2018-16), it was concluded that there was no longer any strong basis for stratification of samples from Vessel X as length compositions were not appreciably different to the remainder of the conventional bottom trawl fleet. A comparison of the combined length frequencies for each of the two sampled bottom trawl vessels (Vessel X and Vessel Y) from SNA 8 in 2018–19 showed no obvious difference either, resulting in identical estimates of median length (Appendix 11). Retrospectively, it would therefore seem reasonable to treat future SNA 8 catch sampling as a single stratum without stratification by vessel, the same as sampling was prior to 2015–16, and that conventional bottom trawl (excluding Modular Harvest System) remains the primary sampling method series of catch-at-age for stock assessments. As we did not sample any other vessels fishing in SNA 8 in 2018–19 (which contributed a quarter of the overall catch, some of which used mixed gears), it is not known whether the combined length frequency distribution of the two vessels we did sample would differ greatly from that of the total commercial catch. What we do know is that other factors (outlined above in the section on "Changes in fishing behaviour") relating to changes in the operation of the SNA 8 trawl fishery since the mid-late 2000s (Langley 2017) may be more influential in the size and number of snapper caught than they were beforehand.

5. ACKNOWLEDGMENTS

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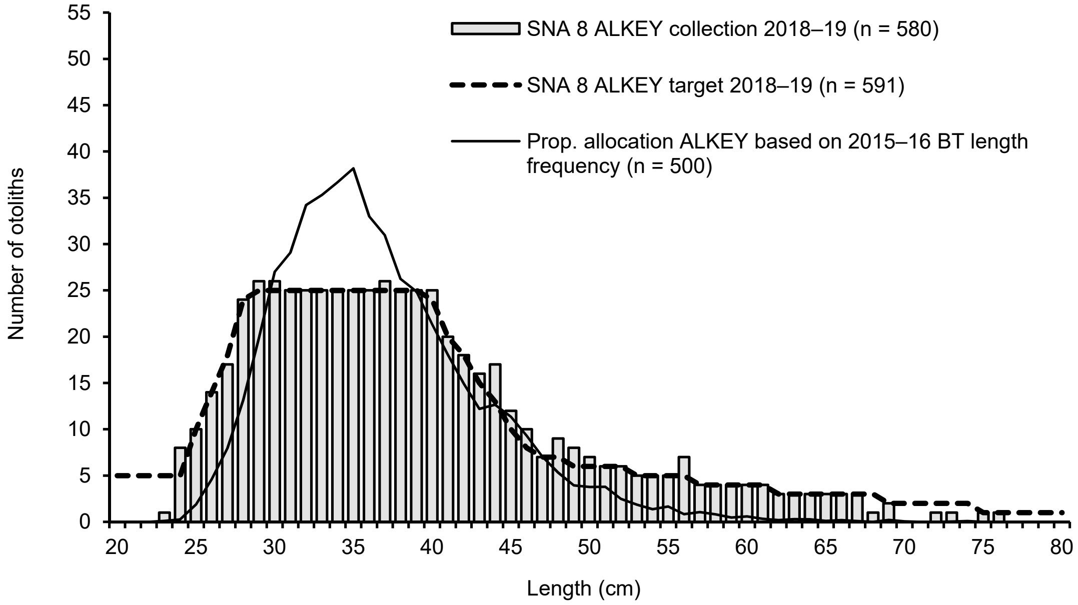
7. APPENDICES

Appendix 1: Length distributions of the target semi-fixed allocation otolith sample (dashed line) and the achieved otolith collection (histogram) sampled from the SNA 8 fishery in 2018–19. For comparison, the proportional allocation otolith sample of 500 fish based on the bottom trawl length distribution from 2015–16, the previous fishing year in which catch sampling was undertaken in SNA 8, is also given (solid line).

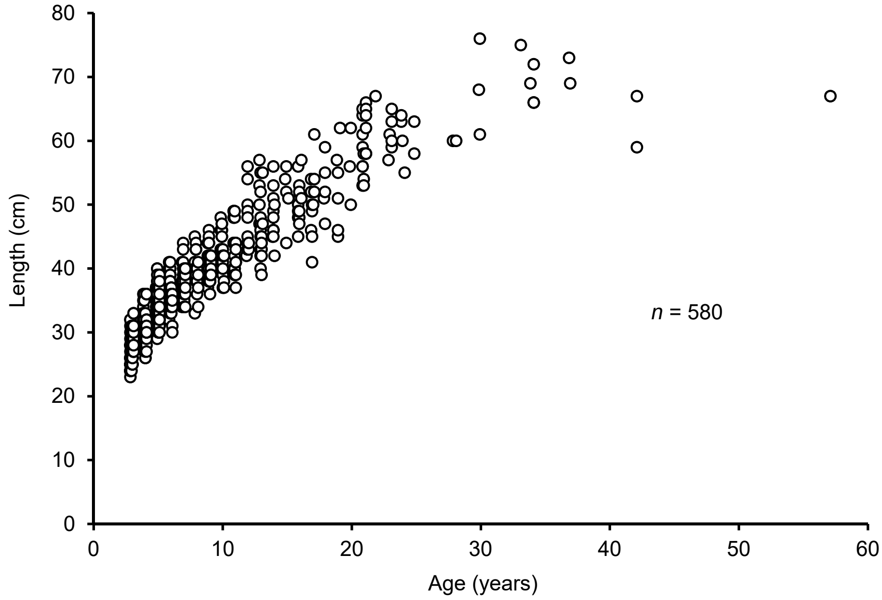


Appendix 2: Age-length key derived from snapper otolith samples collected from SNA 8 in 2018–19.

Estimates of proportion of age at length for snapper sampled from SNA 8, spring and summer 2018–19 (Note: Aged to 01/01/2019).

Length	Age (years)																				No.
(cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	aged
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
24	0	0	1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
25	0	0	1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
26	0	0	0.86	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
27	0	0	0.76	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
28	0	0	0.46	0.54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
29	0	0	0.50	0.46	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26
30	0	0	0.27	0.54	0.15	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26
31	0	0	0.20	0.52	0.24	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
32	0	0	0.08	0.28	0.60	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
33	0	0	0.08	0.20	0.60	0.08	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	25
34	0	0	0	0.04	0.56	0.20	0.16	0.04	0	0	0	0	0	0	0	0	0	0	0	0	25
35	0	0	0	0.12	0.52	0.24	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0	25
36	0	0	0	0.16	0.28	0.24	0.24	0.04	0.04	0	0	0	0	0	0	0	0	0	0	0	25
37	0	0	0	0	0.42	0.15	0.19	0.04	0.08	0.08	0.04	0	0	0	0	0	0	0	0	0	26
38	0	0	0	0	0.20	0.20	0.20	0.08	0.28	0.04	0	0	0	0	0	0	0	0	0	0	25
39	0	0	0	0	0.08	0.20	0.16	0.16	0.16	0.12	0.08	0	0.04	0	0	0	0	0	0	0	25
40	0	0	0	0	0.08	0.12	0.20	0.16	0.08	0.16	0.16	0	0.04	0	0	0	0	0	0	0	25
41	0	0	0	0	0	0.10	0.10	0.15	0.15	0.30	0.15	0	0	0	0	0	0.05	0	0	0	20
42	0	0	0	0	0	0	0	0	0.39	0.28	0.06	0.06	0.17	0.06	0	0	0	0	0	0	18
43	0	0	0	0	0	0	0.06	0.19	0	0.31	0.06	0.19	0.19	0	0	0	0	0	0	0	16
44	0	0	0	0	0	0	0.06	0.06	0.18	0	0.35	0.18	0.12	0	0.06	0	0	0	0	0	17
45	0	0	0	0	0	0	0	0.08	0.08	0.17	0	0.08	0.17	0.17	0	0.08	0.08	0	0.08	0	12
46	0	0	0	0	0	0	0	0	0.10	0.30	0	0	0.10	0.30	0	0	0.10	0	0.10	0	10
47	0	0	0	0	0	0	0	0	0	0.29	0	0	0.43	0	0	0.14	0	0.14	0	0	7
48	0	0	0	0	0	0	0	0	0	0.11	0.33	0.11	0.11	0.11	0	0.22	0	0	0	0	9
49	0	0	0	0	0	0	0	0	0	0	0.38	0.13	0	0.13	0	0.25	0.13	0	0	0	8
50	0	0	0	0	0	0	0	0	0	0	0	0.14	0.14	0.14	0	0.14	0.29	0	0	0.14	7
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0.17	0.33	0	0.17	0.17	0	6
52	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0	0.17	0.17	0.33	0.17	0	0	6
53	0	0	0	0	0	0	0	0	0	0	0	0	0.20	0.20	0	0.20	0	0	0	0.40	5
54	0	0	0	0	0	0	0	0	0	0	0	0.20	0	0	0.20	0	0.40	0	0	0.20	5
55	0	0	0	0	0	0	0	0	0	0	0	0	0.40	0	0	0	0	0.20	0.20	0.20	5
56	0	0	0	0	0	0	0	0	0	0	0	0.14	0	0.14	0.14	0.14	0	0	0	0.43	7
57	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	0.25	0	0	0.25	0.25	4
58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	4
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0.75	4
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	4
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	0.75	4
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0.67	3
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	3
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	3
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	3
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	3
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	3
68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	1
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	2
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	1
73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	1
74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	1
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	1
77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total																					580

Appendix 3: Scatterplot of age-at-length data for snapper sampled from the SNA 8 bottom trawl fishery in 2018–19 (*n*, sample size). Age is decimalised as of the month of collection relative to an assumed January 1 "birthdate".



Appendix 4: Estimates of proportion at length with CVs (bootstrap estimates) for snapper from the SNA 8 bottom trawl fishery in 2018–19.

P.i. = proportion of fish in length class. *Nt* = total number of fish caught.
CV = coefficient of variation. *n* = total number of fish sampled.

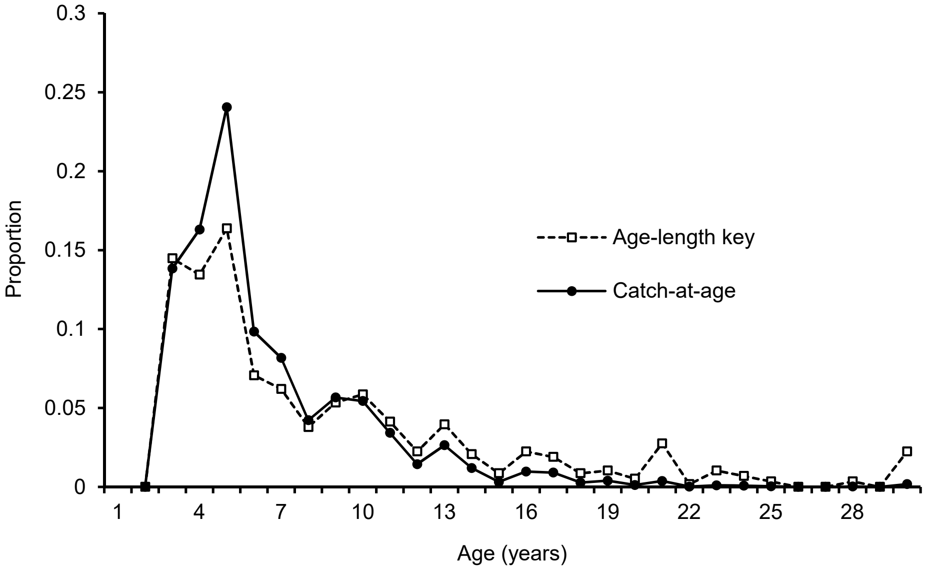
Length	Spring		Summer		Spr-sum (unstratified)		Spr-sum (stratified)	
(cm)	*P.i.*	CV	*P.i.*	CV	*P.i.*	CV	*P.i.*	CV
20	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
21	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
22	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
23	0.0006	1.73	0.0000	0.00	0.0002	1.75	0.0003	1.73
24	0.0049	0.62	0.0010	0.86	0.0021	0.54	0.0027	0.52
25	0.0202	0.48	0.0121	0.51	0.0144	0.36	0.0157	0.35
26	0.0260	0.40	0.0213	0.32	0.0226	0.25	0.0234	0.25
27	0.0358	0.30	0.0289	0.29	0.0308	0.22	0.0320	0.20
28	0.0542	0.25	0.0379	0.30	0.0424	0.21	0.0452	0.19
29	0.0629	0.15	0.0446	0.26	0.0497	0.18	0.0528	0.14
30	0.0667	0.14	0.0483	0.22	0.0534	0.15	0.0565	0.12
31	0.0707	0.15	0.0386	0.19	0.0476	0.15	0.0529	0.12
32	0.0906	0.13	0.0495	0.15	0.0610	0.13	0.0679	0.10
33	0.0869	0.15	0.0650	0.11	0.0711	0.09	0.0748	0.09
34	0.0717	0.24	0.0744	0.11	0.0737	0.10	0.0732	0.12
35	0.0588	0.26	0.0700	0.13	0.0669	0.12	0.0650	0.13
36	0.0570	0.28	0.0720	0.12	0.0678	0.11	0.0653	0.13
37	0.0407	0.33	0.0698	0.12	0.0616	0.13	0.0568	0.14
38	0.0457	0.24	0.0606	0.13	0.0564	0.11	0.0539	0.12
39	0.0263	0.24	0.0593	0.15	0.0501	0.15	0.0445	0.13
40	0.0193	0.25	0.0509	0.14	0.0421	0.16	0.0368	0.12
41	0.0241	0.27	0.0386	0.20	0.0346	0.17	0.0321	0.16
42	0.0233	0.28	0.0274	0.24	0.0263	0.20	0.0256	0.18
43	0.0145	0.37	0.0248	0.21	0.0219	0.19	0.0202	0.18
44	0.0160	0.34	0.0245	0.24	0.0221	0.21	0.0207	0.20
45	0.0110	0.35	0.0209	0.24	0.0182	0.22	0.0165	0.20
46	0.0105	0.47	0.0129	0.24	0.0122	0.21	0.0118	0.23
47	0.0064	0.48	0.0103	0.27	0.0092	0.26	0.0086	0.24
48	0.0071	0.45	0.0077	0.28	0.0075	0.24	0.0074	0.24
49	0.0108	0.40	0.0061	0.36	0.0074	0.30	0.0082	0.28
50	0.0072	0.46	0.0048	0.39	0.0055	0.31	0.0059	0.31
51	0.0027	0.80	0.0031	0.42	0.0030	0.38	0.0030	0.42
52	0.0022	0.74	0.0029	0.50	0.0027	0.41	0.0026	0.42
53	0.0022	0.75	0.0020	0.57	0.0021	0.46	0.0021	0.47
54	0.0029	0.68	0.0025	0.49	0.0026	0.43	0.0027	0.42
55	0.0023	0.93	0.0012	0.71	0.0015	0.58	0.0017	0.62
56	0.0044	0.66	0.0016	0.64	0.0024	0.47	0.0028	0.49
57	0.0038	0.70	0.0005	1.02	0.0014	0.66	0.0020	0.61
58	0.0011	1.06	0.0010	0.74	0.0011	0.61	0.0011	0.63
59	0.0007	1.62	0.0006	1.05	0.0006	0.89	0.0006	0.95
60	0.0011	1.10	0.0003	1.20	0.0006	0.81	0.0007	0.87
61	0.0005	1.62	0.0008	0.90	0.0007	0.85	0.0006	0.81
62	0.0000	0.00	0.0002	1.65	0.0002	1.64	0.0001	1.66
63	0.0011	1.11	0.0000	0.00	0.0003	1.17	0.0005	1.10
64	0.0011	1.09	0.0004	1.36	0.0006	0.86	0.0007	0.87
65	0.0006	1.72	0.0000	0.00	0.0002	1.66	0.0003	1.71
66	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
67	0.0007	1.65	0.0005	1.16	0.0005	0.93	0.0006	1.00
68	0.0007	1.60	0.0000	0.00	0.0002	1.55	0.0003	1.59
69	0.0013	1.11	0.0002	1.64	0.0005	0.93	0.0007	0.99
70	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
71	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
72	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
73	0.0007	1.66	0.0000	0.00	0.0002	1.63	0.0003	1.66
74	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
75	0.0000	0.00	0.0002	1.59	0.0001	1.74	0.0001	1.59
76	0.0000	0.00	0.0002	1.59	0.0001	1.66	0.0001	1.58
77	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
78	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
79	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
80	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
Nt	198 723		246 383		439 772			
n	1 673		4 822		6 495			

Appendix 5: Estimates of proportion at age with CVs (bootstrap estimates) for snapper from the SNA 8 bottom trawl fishery in 2018–19.

P.j., proportion of fish in age class; CV, coefficient of variation; *n*, otolith sample size

Age	Spring		Summer		Spr-sum (unstratified)		Spr-sum (stratified)		
(years)	*P.j.*	CV	*P.j.*	CV	*P.j.*	CV	*P.j.*	CV	*n*
1	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	–
2	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	–
3	0.1780	0.18	0.1229	0.23	0.1383	0.17	0.1475	0.15	84
4	0.2050	0.11	0.1467	0.17	0.1631	0.13	0.1728	0.12	78
5	0.2529	0.14	0.2358	0.09	0.2405	0.09	0.2434	0.10	95
6	0.0835	0.21	0.1042	0.16	0.0984	0.16	0.0950	0.16	41
7	0.0615	0.23	0.0896	0.17	0.0818	0.17	0.0771	0.18	36
8	0.0293	0.25	0.0472	0.23	0.0422	0.23	0.0392	0.22	22
9	0.0414	0.21	0.0626	0.21	0.0567	0.21	0.0531	0.19	31
10	0.0370	0.23	0.0611	0.21	0.0544	0.20	0.0504	0.19	34
11	0.0246	0.26	0.0379	0.25	0.0342	0.23	0.0320	0.22	24
12	0.0121	0.35	0.0153	0.33	0.0144	0.31	0.0139	0.30	13
13	0.0204	0.30	0.0287	0.28	0.0264	0.25	0.0250	0.25	23
14	0.0109	0.42	0.0123	0.36	0.0119	0.34	0.0117	0.34	12
15	0.0030	0.71	0.0032	0.62	0.0031	0.54	0.0031	0.60	5
16	0.0104	0.43	0.0094	0.36	0.0097	0.34	0.0099	0.34	13
17	0.0086	0.45	0.0092	0.38	0.0091	0.36	0.0089	0.36	11
18	0.0024	0.74	0.0028	0.68	0.0027	0.60	0.0026	0.64	5
19	0.0038	0.60	0.0040	0.59	0.0039	0.56	0.0039	0.53	6
20	0.0016	0.94	0.0010	0.91	0.0012	0.86	0.0013	0.84	3
21	0.0050	0.52	0.0032	0.45	0.0037	0.40	0.0040	0.39	16
22	0.0002	2.33	0.0002	2.01	0.0002	1.64	0.0002	1.70	1
23	0.0021	0.86	0.0005	0.94	0.0010	0.75	0.0012	0.74	6
24	0.0015	0.89	0.0005	1.06	0.0008	0.76	0.0009	0.78	4
25	0.0007	1.31	0.0003	1.40	0.0004	1.13	0.0004	1.08	2
26	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	–
27	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	–
28	0.0006	1.36	0.0002	1.42	0.0003	1.12	0.0003	1.11	2
29	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	–
>29	0.0033	0.71	0.0012	0.72	0.0018	0.55	0.0021	0.55	13

Appendix 6: Comparison of the unweighted (age-length key) and weighted (unstratified catch-at-age estimate) proportions at age sampled from the SNA 8 bottom trawl fishery in 2018–19.



Appendix 7: Estimates of mean length-at-age (cm) with CVs for snapper from the SNA 8 bottom trawl fishery in 2018–19.
CV, coefficient of variation

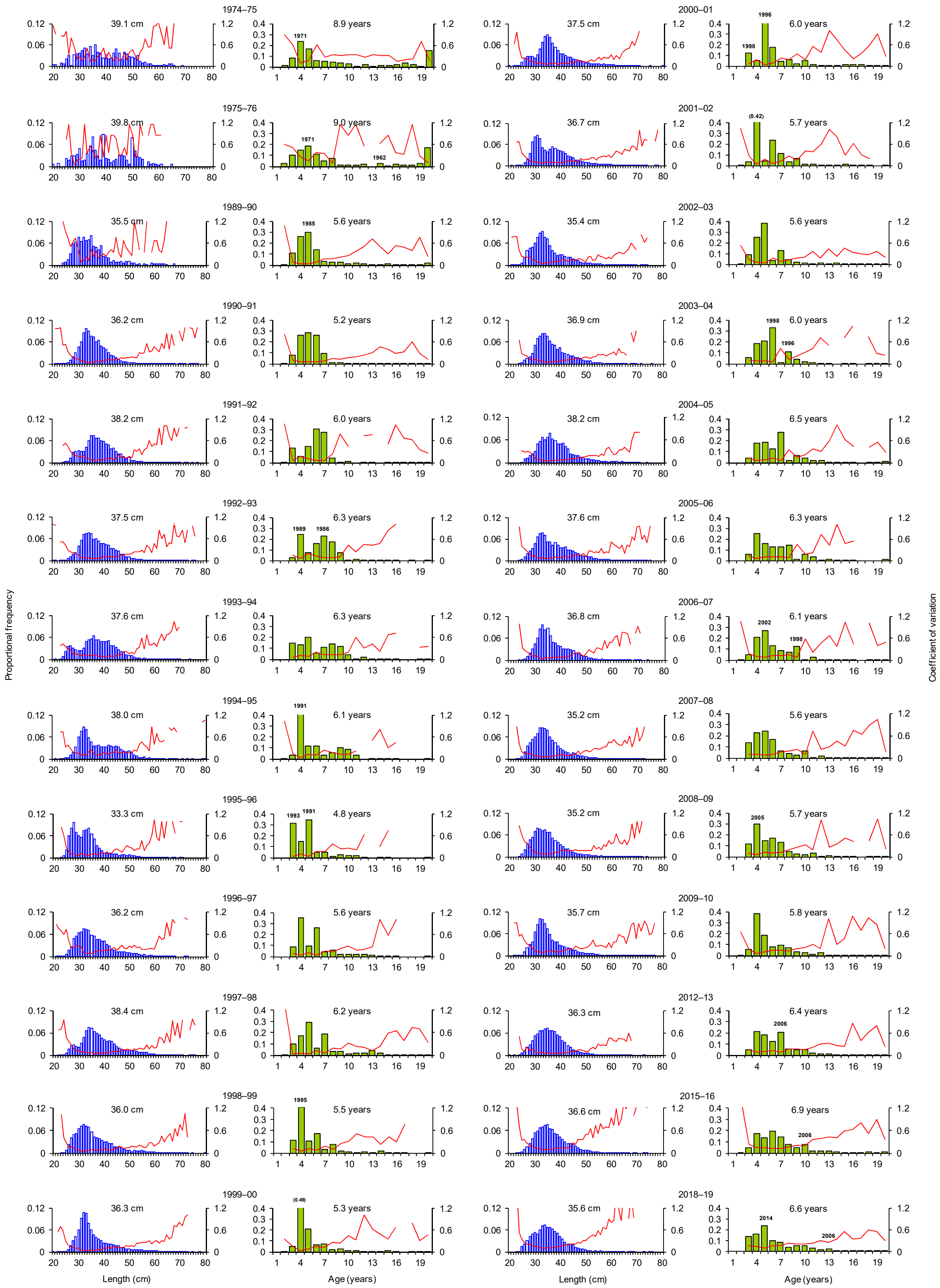
Age	Spring		Summer		Spr-sum (unstratified)		Spr-sum (stratified)	
(years)	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	28.10	0.02	28.12	0.01	28.11	0.01	28.11	0.01
4	30.55	0.01	30.79	0.01	30.70	0.01	30.66	0.01
5	33.63	0.01	34.41	0.01	34.18	0.01	34.05	0.01
6	35.45	0.01	36.24	0.01	36.05	0.01	35.93	0.01
7	36.82	0.01	37.30	0.01	37.20	0.01	37.13	0.01
8	38.41	0.03	39.14	0.02	39.00	0.02	38.90	0.02
9	39.89	0.01	39.84	0.01	39.85	0.01	39.86	0.01
10	41.75	0.01	41.47	0.01	41.52	0.01	41.56	0.01
11	43.25	0.02	42.01	0.02	42.26	0.02	42.44	0.02
12	46.06	0.03	44.86	0.02	45.14	0.02	45.33	0.02
13	45.58	0.03	44.26	0.02	44.54	0.02	44.74	0.02
14	47.31	0.02	46.40	0.02	46.63	0.02	46.78	0.02
15	50.54	0.14	48.81	0.11	49.27	0.09	49.55	0.11
16	50.02	0.02	48.66	0.02	49.07	0.02	49.30	0.02
17	48.43	0.03	47.39	0.04	47.67	0.04	47.84	0.03
18	50.95	0.19	49.83	0.11	50.10	0.10	50.28	0.11
19	50.17	0.12	47.38	0.09	48.14	0.09	48.60	0.07
20	52.26	0.40	52.26	0.34	52.26	0.33	52.26	0.32
21	57.70	0.04	56.67	0.03	57.06	0.02	57.24	0.02
22	67.00	1.55	67.00	1.25	67.00	0.97	67.00	1.01
23	59.66	0.24	59.40	0.34	59.56	0.10	59.60	0.13
24	60.18	0.32	58.60	0.44	59.48	0.21	59.74	0.21
25	60.87	0.70	58.00	0.82	59.44	0.54	59.94	0.52
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	60.00	0.79	60.00	0.88	60.00	0.56	60.00	0.52
29	–	–	–	–	–	–	–	–
>29	68.54	0.21	67.84	0.23	68.21	0.06	68.33	0.04

Appendix 8: Estimates of mean weight-at-age (kg) with CVs for snapper from the SNA 8 bottom trawl fishery in 2018–19.

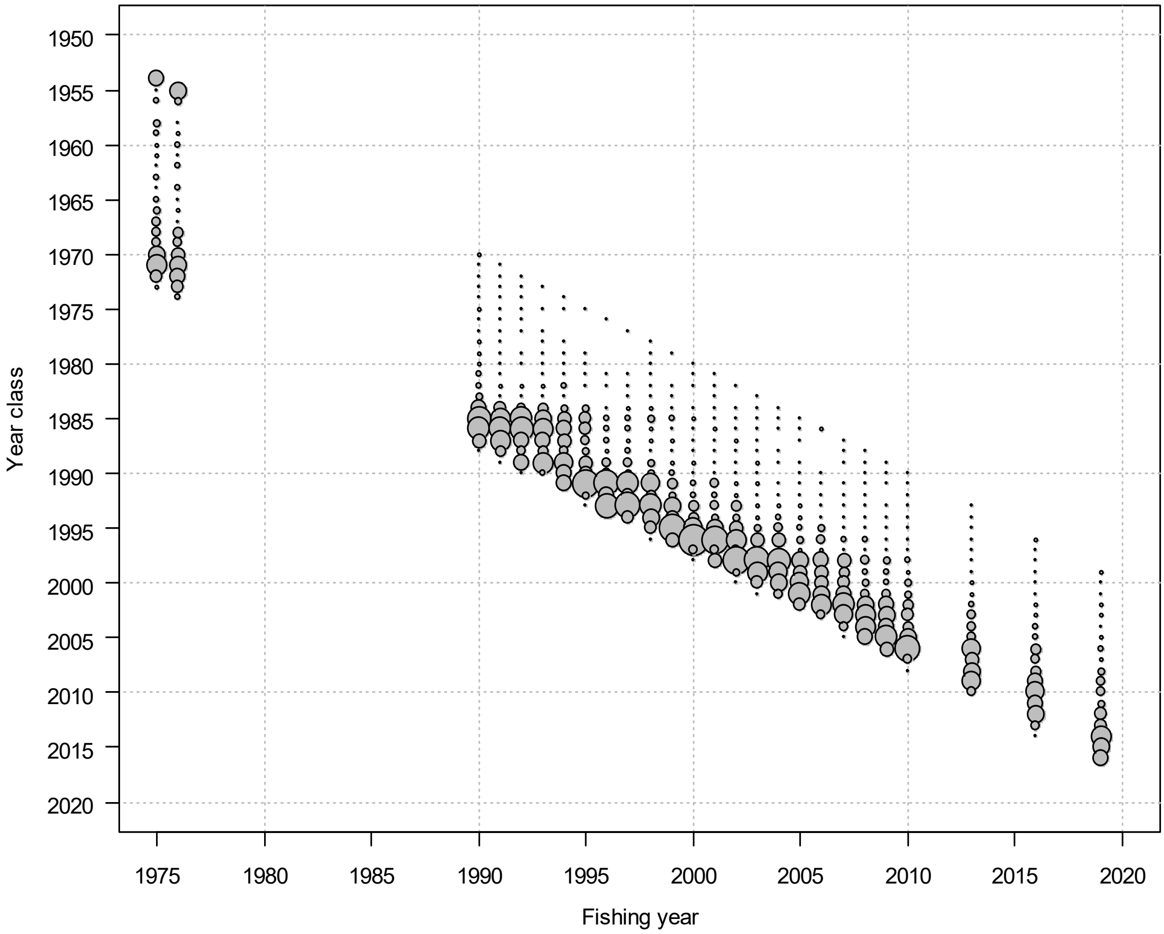
CV, coefficient of variation

Age	Spring		Summer		Spr-sum (unstratified)		Spr-sum (stratified)	
(years)	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	0.51	0.04	0.50	0.03	0.51	0.03	0.51	0.03
4	0.64	0.03	0.65	0.04	0.65	0.03	0.64	0.03
5	0.83	0.02	0.88	0.02	0.87	0.02	0.86	0.02
6	0.96	0.03	1.02	0.03	1.01	0.03	1.00	0.03
7	1.07	0.04	1.11	0.03	1.10	0.03	1.09	0.03
8	1.21	0.07	1.27	0.05	1.26	0.05	1.25	0.05
9	1.34	0.04	1.33	0.03	1.33	0.03	1.33	0.03
10	1.52	0.04	1.49	0.03	1.50	0.03	1.50	0.03
11	1.69	0.06	1.55	0.04	1.58	0.05	1.60	0.05
12	2.01	0.09	1.86	0.06	1.89	0.06	1.92	0.07
13	1.97	0.08	1.79	0.05	1.83	0.05	1.86	0.05
14	2.16	0.07	2.04	0.06	2.07	0.06	2.09	0.06
15	2.62	0.20	2.37	0.18	2.44	0.17	2.48	0.17
16	2.51	0.07	2.32	0.05	2.38	0.06	2.41	0.06
17	2.32	0.09	2.19	0.10	2.22	0.10	2.25	0.09
18	2.65	0.23	2.49	0.17	2.53	0.16	2.56	0.16
19	2.57	0.20	2.17	0.18	2.28	0.19	2.35	0.17
20	2.83	0.42	2.85	0.38	2.84	0.37	2.84	0.35
21	3.75	0.10	3.56	0.07	3.63	0.07	3.67	0.07
22	5.63	1.55	5.63	1.25	5.63	0.97	5.63	1.01
23	4.09	0.26	4.03	0.34	4.07	0.13	4.08	0.15
24	4.21	0.34	3.92	0.47	4.08	0.24	4.13	0.24
25	4.32	0.71	3.76	0.83	4.04	0.55	4.14	0.53
26	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–
28	4.13	0.79	4.13	0.88	4.13	0.56	4.13	0.52
29	–	–	–	–	–	–	–	–
>29	6.03	0.23	5.94	0.27	5.99	0.11	6.00	0.09

Appendix 9: Time series of proportion at length and age distributions and CVs for snapper from the SNA 8 bottom trawl fishery from 1974–75 to 1975–76, 1989–90 to 2009–10, 2012–13, 2015–16 and 2018–19. Data are from spring-summer and plots are annotated with estimates of mean length or age.



Appendix 10: Time series of age frequency distributions by year class and year from the SNA 8 bottom trawl spring-summer fishery from 1974–75 to 2018–19. Symbol area is proportional to the proportion at age.



Appendix 11: Comparison of the proportion at length distributions and boxplot of landing median lengths determined from snapper landings sampled over the spring and summer seasons from Vessel X and Vessel Y (bottom trawl vessels) in the SNA 8 fishery in 2018–19.