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Snapper catch-at-length and catch-at-age heterogeneity between spatial strata in SNA 2 bottom trawl landings, 2007–08 and 2008–09

New Zealand Fisheries Assessment Report 2012/40

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ISSN 1175-1584 (print)
ISSN 1179-5352 (online)
ISBN 978-0-478-40087-8 (print)
ISBN 978-0-478-40088-5 (online)
September 2012

New Zealand Government

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EXECUTIVE SUMMARY

Walsh, C.; McKenzie, J.; Bian, R.; Armiger, H.; Buckthought, D.; Smith, M.; Ferguson, H.; Miller, A. (2012). Snapper catch-at-length and catch-at-age heterogeneity between spatial strata in SNA 2 bottom trawl landings, 2007–08 and 2008–09.

***New Zealand Fisheries Assessment Report 2012/ 40*. 44 p.**

This report presents the results of Objective 1 of the Ministry of Fisheries project "Review SNA 2 catch-at-age data for the most recent years (2007–08, 2008–09) and present separate age distribution comparisons for the north and south subareas" (SNA2010/04). The general objective was to develop an optimised catch sampling design for future SNA 2 catch sampling projects, that adequately accounts for the underlying spatial and temporal patterns in age composition, if they exist.

The aim of previous SNA 2 catch sampling programmes was to sample the age composition of the bottom trawl fishery throughout the fishing year in order to produce catch-at-age distributions for use in quantitative stock assessment models. However, inconsistencies evident in the catch-at-age time series from the SNA 2 bottom trawl fishery were determined at a Ministry of Fisheries Northern Inshore Working Group meeting in 2009 and two main reasons were advocated: landings from Napier consistently contained larger, and thus, older fish, than those from Gisborne; and, ageing error was apparent in early collections. It is possible that these are key reasons why previous assessments of the SNA 2 fishery have proved to be inconclusive, producing implausible results.

The random age frequency sampling design was previously used to sample the fishery with stratification based on season, but unstratified for area, with length and age data collections from Napier and Gisborne pooled for analysis. To investigate whether snapper landed to these two ports had different size and age structure, samples collected during 2007–08 and 2008–09 were analysed according to two spatial strata: north and south of the Mahia Peninsula.

Out of a total of 53 and 58 bottom trawl landings sampled from SNA 2 during the 2007–08 and 2008–09 fishing years, 44 and 57 landings respectively were useful for spatial catch-at-age comparisons, having come from only one of the two spatial strata. The remaining landings sampled were of mixed area origin. Overall, 70% of identified subarea specific landings were sampled from the northern subarea, where two-thirds of the total SNA 2 catch was taken. Sampling allocation in general was proportional to the monthly landed catch, statistical areas fished, and target species, and considered representative of the commercial fishery.

Of the total 6890 otoliths collected from SNA 2 over the two consecutive fishing years, 2310 were randomly subsampled and aged, with 96% agreement and high precision (IAPE less than 1%). The number of otoliths selected per landing for ageing was roughly proportional to the landed weight with a minimum number set at ten.

Length and age compositions were estimated for the SNA 2 fishery and subarea strata for 2007–08 and 2008–09 and indicate that consistent spatially heterogeneous patterns exist. Although bottom trawl landings from both subareas comprised mainly young snapper, over 90% less than 10 years of age, the southern subarea, principally Hawke Bay, had a greater proportion of large and appreciably more old fish by number than catches made north of Mahia Peninsula, some over 50 years of age. The relative proportion by weight that these large fish contribute to the southern subarea, and SNA 2, in terms of biomass and long-term sustainability, is likely to be considerable.

There was poor correlation between strong and weak year classes in bottom trawl catches from the northern and southern subareas of SNA 2. Northern subarea year class strength was significantly correlated only with estimates from the adjacent Bay of Plenty bottom longline fishery of SNA 1.

Investigations further revealed that snapper from the southern subarea demonstrate substantially higher growth rate than those from the northern subarea, possibly the fastest in New Zealand, and similar to that of SNA 7. Mean length-at-age and mean weight-at-age estimates for fully recruited age classes differed considerably between subareas, with southern subarea snapper weighing on average 60 to 70% more at a given age (averaged across all age classes). The overall mean weight of snapper landed in the northern subarea for the consecutive fishing years was around 0.9 kg compared to 1.4 kg for the southern subarea. Northern subarea snapper grow considerably faster than Bay of Plenty snapper, which have the fastest growth rates in SNA 1. A trend of increasing growth appears to exist down a latitudinal cline for five distinct snapper stock or substock fisheries on the east coast of New Zealand's North Island.

Spatial differences in snapper length and age structure, year class strength, growth, and genetics (not this study) suggest that fish north and south of Mahia Peninsula, represent separate biological stocks. Past tagging studies show that a minor level of fish migration occurs from SNA 1 into SNA 2. Movement between the subareas of SNA 2 has not been studied. Previous research found sufficient numbers of juvenile snapper (less than 25 cm) at East Cape and on the Wairoa Hard in Hawke Bay to suggest that nursery areas for snapper exist within the SNA 2 fishery, and that successful spawning had occurred.

Mean weighted coefficients of variation for catch-at-age estimates ranged between 0.20 and 0.32 for the SNA 2 subareas for 2007–08 and 2008–09, the highest estimate associated with the lowest sample size from the southern subarea in 2007–08. Recommendations are made for sampling designs for future SNA 2 catch-at-age programmes, based on the division of SNA 2 into two spatial strata.

1. INTRODUCTION

Bottom trawl landings of snapper from the SNA 2 commercial fishery were first sampled for catch-at-age data in 1991–92 (Ryan 1993). The fishery was subsequently sampled intermittently in the following fishing years: 1997–98 (Blackwell et al. 1999), 1998–99 (Blackwell et al. 2000), 1999–2000 (Blackwell & Gilbert 2001), 2002–03 (Blackwell & Gilbert 2005), 2004–05 (Blackwell & Gilbert 2006), 2007–08 (Blackwell 2009).

In April 2009, the results for the most recent SNA 2 catch-at-age sampling project (SNA2007/03) were presented to the Ministry of Fisheries Northern Inshore Working Group (NINSWG). Although the overall sampling, ageing, proportion-at-age and precision estimates were adequate in 2007–08, inconsistencies were evident in the proportions of the catch-at-age time series samples from the SNA 2 fishery with two main reasons advocated: anecdotal evidence suggested that landings from Napier consistently contained larger (and thus older) fish than those from Gisborne (Appendix 1); and, otoliths collected in the 1997–98 and 1998–99 were aged by different personnel. It was postulated that if disproportionate sampling of Napier and Gisborne landings occurred, and different interpretations of growth zones by agers were made in some years, then these could profoundly influence and therefore bias the overall SNA 2 catch-at-age time series estimates. Pre-stratification of sampling effort into strata (i,e., geographical regions) is recommended to avoid such bias and improve precision in catch sampling data (Bull & Gilbert 2001).

In the following year, 2010, a SNA 2 stock assessment (SNA2009/01) was undertaken by Langley (2010) and the results presented to the NINSWG. The assessment incorporated all recent catch sampling data and a trawl based catch per unit effort (CPUE) analysis, but proved to be inconclusive, producing implausible results, similar to a previous assessment by Gilbert & Philips (2003). Given the conflict between catch-at-age data and the abundance index, the NINSWG requested that additional analysis was required to investigate the existence of spatial patterns in length and age frequencies in catches from SNA 2, proposing a review of data collected and analysed from 2007–08 (SNA2007/03). It was also suggested that catch-at-age samples from the following year (2008–09), should be aged and analysed to explore the temporal consistency of the spatial patterns in the sample collections.

This report presents an investigation into the differences in the size and age of snapper caught from two spatial subareas of SNA 2 – i.e., north and south of Mahia Peninsula (39.264°S) – in the 2007–08 and 2008–09 fishing years. Recommendations for an optimum sampling design for estimating catch-at-age and precision in future SNA 2 catch sampling programmes are also made. Funding for this project, SNA2010/04, was provided by the Ministry of Fisheries.

The specific objective of this project for 2010–11 was:

1. *Review SNA 2 catch-at-age data for the most recent years (2007–08, 2008–09) and present separate age distribution comparisons for the North and South subareas*

2. METHODS

Spatial stratification of the SNA 2 fishery

Commercial catch records (Ministry of Fisheries) and catch-at-age sample data from the SNA 2 bottom trawl fishery in 2007–08 and 2008–09 were stratified into two spatial subareas, north and south of the southern-most tip of Mahia Peninsula (39.264S 177.866E), a prominent landmark division of the southeast coast of the North Island of New Zealand (Figure 1). The spatial strata were selected *a priori* based on previous knowledge that the majority of the bottom trawl vessels operating out of the two main ports on the coast, Gisborne and Napier, mainly fished in the northern or southern subareas, respectively, during each trip.

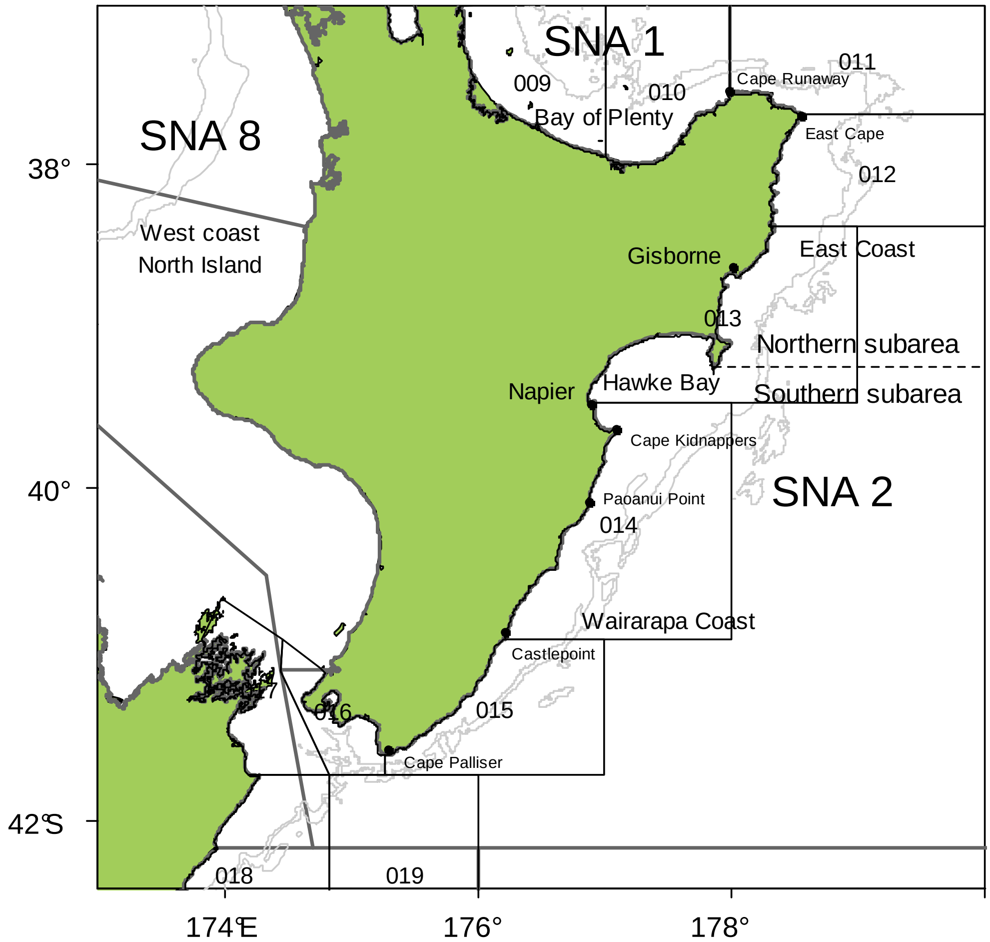

Figure 1: The SNA 2 quota management area, associated statistical areas, and locations referred to in the text. The dashed line indicates the spatial division of the SNA 2 stock into two subarea strata, north and south of the southern-most tip of Mahia Peninsula.

The most recent SNA 2 catch-at-age data were collected during the 2007–08 and 2008–09 fishing years. These data, where fishers report the exact latitude and longitude of the tow positions of their catches, were more suitable to investigate spatial differences in catch-at-age than data collected prior to October 2007, which were based solely on the statistical area fished. This was particularly important as statistical area 013 straddles both major ports, as well as the proposed subarea stratification boundary for SNA 2 in this study (Figure 1).

The original design for catch sampling in SNA 2 during 2007–08 and 2008–09 recognised four temporal "seasons", but had no formal spatial stratification (Blackwell 2009). However, as fewer landings were available and sampled from the southern subarea compared to the northern (Table 1), it was anticipated that sub-optimal numbers of landings in temporal (season) stratification may increase observation error and create possible bias in the sample estimates, similar to that found in the East Northland snapper longline fishery (Walsh et al. 2006a). As a result, no within-year temporal stratification was imposed on the current study, thus treating each subarea fishing year catch-at-age collection as a single stratum. It was envisaged that seasonal stratification of the subarea fisheries could be investigated for temporal patterns in future catch-at-age sampling of SNA 2.

Table 1: Summary of the sample collections (number of landings, and number of fish sampled for otoliths, and number aged) from bottom trawl landings in SNA 2 subarea strata in 2007–08 and 2008–09.

Fishing year	Method	Area	Landings sampled	Otoliths collected	Otoliths aged
2007–08	Bottom trawl	Northern	37	2 494	710
		Southern	7	350	350
		Mixed/UNK	9	534	0
		SNA 2 total	53	3 378	1 060
2008–09	Bottom trawl	Northern	41	2 664	600
		Southern	16	798	650
		Mixed/UNK	1	50	0
		SNA 2 total	58	3 512	1 250

Sampling SNA 2 bottom trawl landings

Random age frequency (RAF) samples were collected from the SNA 2 bottom trawl fishery using a two-stage sampling procedure similar to that described for length sampling (West 1978). The random selection of landings and a random sample of bins within landings represent the first and second stages respectively. Approximately 50 bottom trawl landings were targeted for sampling in each fishing year from a representative cross section of the fishery and included both target and bycatch (Blackwell et al. 1999); the only stipulation being that the landed weight of snapper in a given landing was at least 80 kg. The RAF sampling method for collecting otoliths generally followed those methodologies outlined by Davies et al. (2003), with every fifth fish systematically sampled for age. Sample sizes typically ranged between 40–60 fish from each landing, usually in proportion to the quantity of snapper landed. Total annual sample sizes from the SNA 2 bottom trawl fishery were around 3000 otolith pairs. Although the length measurement of each fish in the random sample for age from each landing was recorded, no direct length frequency sampling of the landing was undertaken.

Ageing snapper

As the total number of otoliths collected from the SNA 2 fishery in the 2007–08 and 2008–09 fishing years exceeded the nominal target of 800–1000 otoliths required for adequately describing catch-at-age, random subsamples were selected from each sampled landing, the number roughly proportional to the landed weight (Blackwell & Gilbert 2001), with a minimum number of otoliths set at ten. In addition, as a portion of otolith samples from the 2007–08 collection had already been selected and aged under project SNA2007/03 (Blackwell 2009), only samples selected from southern subarea landings required ageing. As no ageing had previously been undertaken on the 2008–09 otolith collection, all random subsamples selected from the northern and southern subareas were aged (Table 1).

A standardised procedure for preparing and reading otoliths was followed (Davies & Walsh 1995). Two readers read the entire randomly selected subsample of otoliths independently to determine an unbiased reading estimate. Where agreement was reached, it was deemed to be the final agreed reading. If no agreement was attained, then the otolith was reviewed again by both readers to reach agreement, or discarded from the set as unreadable (if it was of an age less than 20 years, as samples over 19 years were combined into an aggregate age group for the analysis). A forced margin was implemented to anticipate *a priori* the otolith margin type (wide, line, or narrow) in the month in which the fish was sampled to provide guidance in determining age. The forced margin method was found to be essential for ageing snapper sampled throughout the year, as some otolith readers had difficulty correctly interpreting otolith margins in year-round collections (Walsh et al. 2011a). The nominal birth date of snapper is taken as 1 January.

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

Snapper age data were stored in the Ministry of Fisheries *age* database, and landing details in the *market* database, administered by NIWA.

Catch-at-age analysis

Proportion-at-age and variance (bootstrap) estimates for the SNA 2 subarea trawl fisheries were calculated from the RAF samples collected from each landing. Proportions at age across all landings were estimated from sample proportions, weighted by the estimated number of fish in each landing, using NIWA's C++ software tool CALA (catch-at-length and -age, Francis & Bian 2011). The weighted mean proportion-at-age and variance across spatial strata to describe the SNA 2 fishery was calculated following Blackwell et al. (1999).

Calculation of mean weight-at-age was based on the length-weight relationship given in Paul (1976), in accordance with methods described in Davies et al. (2003).

Proportions-at-age, mean weight-at-age, and mean length-at-age were calculated for the range of fishing year age classes (herein referred to as "age classes" encompassing October to September) recruited, with the maximum age being an aggregate of all age classes over 19 years. Estimates of mean age determined from annual catch-at-age estimates in each stock and subarea strata were calculated such that all fish comprising the aggregate (over 19 years) age group were assigned an age of 20.

Catch sampling optimisations

Snapper RAF data collected from the SNA 2 subarea fisheries in 2007–08 and 2008–09 were used to derive mean weighted coefficients of variation (MWCVs) for a range of annual sampling designs, with variations on the number of landings sampled and the number of otoliths collected from each of the respective subareas. A series of bootstrap optimisations were run for the RAF sampling approach. The bootstrap methodology employed is described in Davies & Walsh (2003).

3. RESULTS

3.1 Relative SNA 2 catch by method and area in 2007–08 and 2008–09

Bottom trawl was by far the most dominant method in the SNA 2 fishery, estimated to take approximately 99% of the current 345 t Total Allowable Commercial Catch (TACC) in the 2007–08 and 2008–09 fishing years (Figure 2). On average, 95% of the landed catch in SNA 2 was taken from the northern half of the stock, statistical areas 011 to 013, with more than half from statistical area 013 alone.

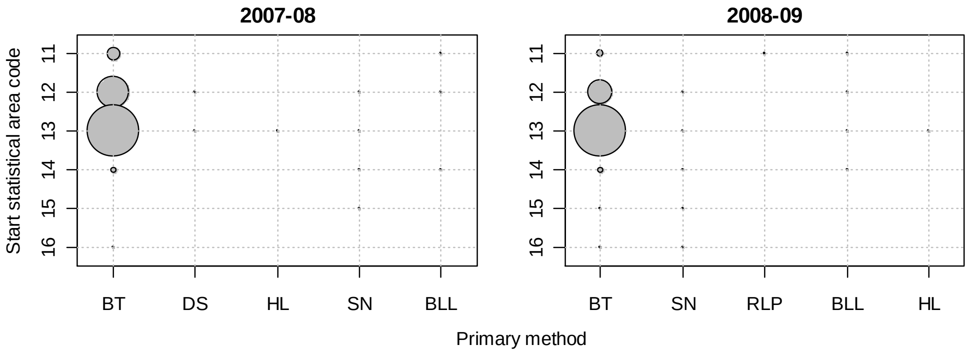

Figure 2: Relative catch by method and statistical area in SNA 2 in 2007–08 and 2008–09 (BT, bottom trawl; DS, Danish seine; HL, Handline; SN, Set net; BLL, Bottom longline, RLP, Rock lobster pot).

3.2 Sampling of the SNA 2 bottom trawl fishery in 2007–08 and 2008–09

Sample collections

Summaries of the number of bottom trawl landings sampled and otoliths collected and aged for the spatial strata of SNA 2 in 2007–08 and 2008–09 are given in Table 1. A total of 53 and 58 landings were sampled from the SNA 2 bottom trawl fishery in 2007–08 and 2008–09, with 44 and 57 landings respectively deemed useful for spatial subarea comparisons of catch-at-age. From these, 1060 and 1250 otoliths were randomly subsampled for ageing from the respective fishing year collections. Only a small number of otoliths and landings (350 otoliths sampled from 7 landings) were available for analysis from the southern subarea in 2007–08 (Table 1).

Sampling representativeness

Bottom trawl landings from the SNA 2 fishery (for catch weight and numbers of landings) were reasonably well spread over the entire year, with the highest proportion of annual catch most often taken over the spring and summer months (Figure 3). In addition, the sampling performance relative to the cumulative catch of the fishery throughout each sampling year is illustrated in Figure 4. A disproportionately low number of landings were sampled in the first half of the 2007–08 fishing year relative to the fishery operation, while sampling in 2008–09 was distributed in reasonable proportion to, and representative of the fishery (Figures 3 and 4).

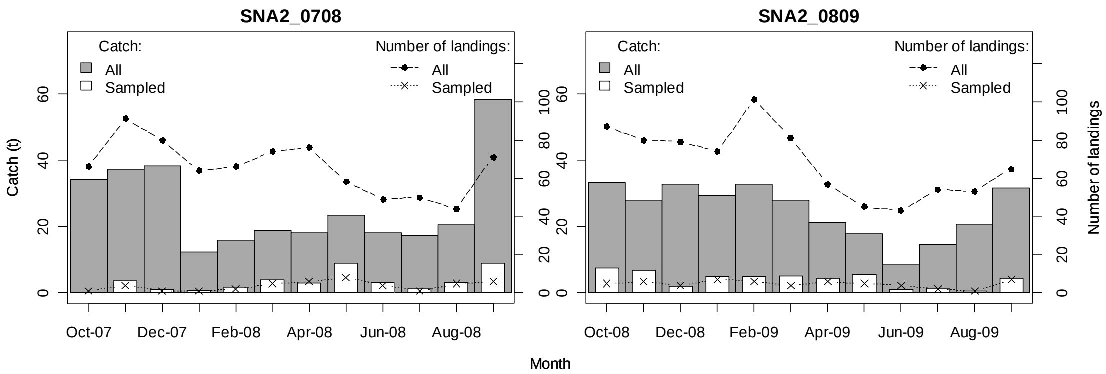

Figure 3: Comparison of the monthly distribution of landed weight (grey bars) and numbers of landings (dashed line) of snapper in the SNA 2 bottom trawl fishery for all landings where snapper was caught in 2007–08 and 2008–09. Included are corresponding estimates for all sampled landings (white bars and dotted line) to show representativeness of collections.

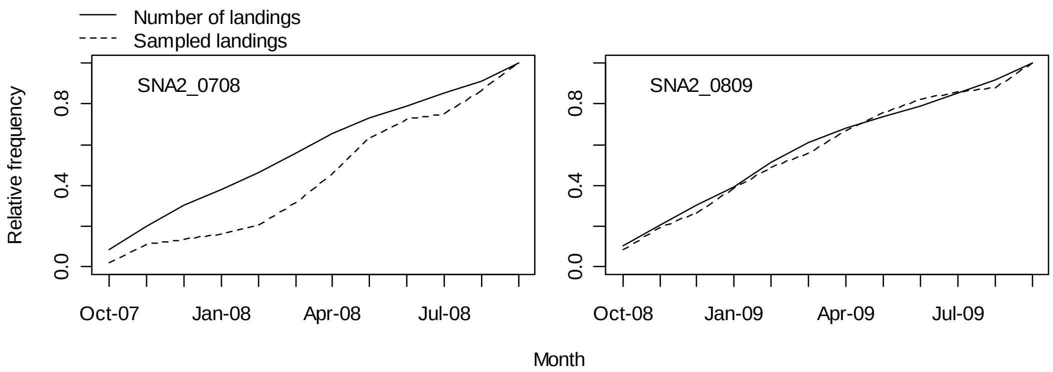

Figure 4: The cumulative proportion of the number of landings and samples taken from the SNA 2 bottom trawl fishery in 2007–08 and 2008–09.

A temporal comparison of the seasonal distribution of landings in the fishery (for catch weight and numbers of landings) to those sampled from the respective subarea strata of SNA 2 (north and south) for 2007–08 and 2008–09 demonstrates the representativeness of the sample collections (Figure 5). Approximately two-thirds of the landed catch was taken from the northern subarea in both years, and was spread reasonably well over the entire fishing year with the exception of September in 2007–08. The highest catches of snapper from the southern subarea were taken mainly in spring or summer. The sampled subarea catch accounted for 6–16% by weight and 2–8% by number of landings in the total bottom trawl subarea catch of SNA 2 (Figure 5).The average weight of landings sampled over the 2007–08 to 2008–09 fishing years ranged between 0.8–0.9 t for the northern subarea and 0.9–1.0 t for the southern subarea.

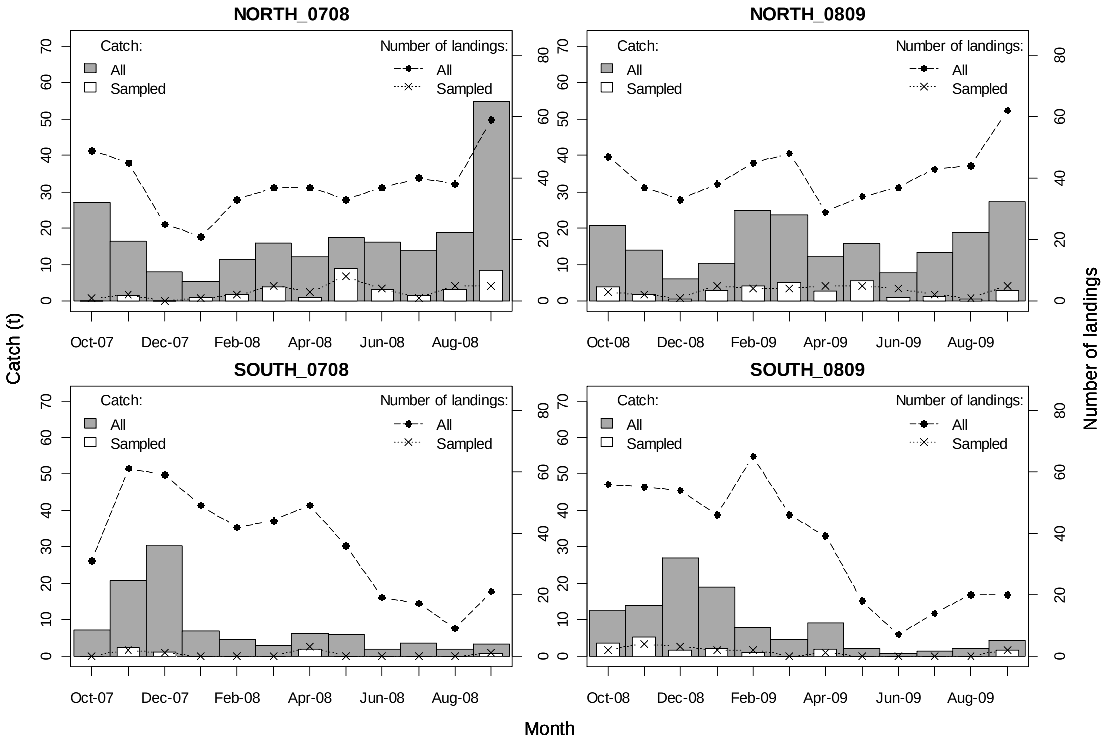

Figure 5: Comparison of the monthly distribution of landed weight (grey bars) and numbers of landings (dashed line) of snapper in the SNA 2 bottom trawl subarea fisheries for all landings where snapper was caught in 2007–08 and 2008–09. Included are corresponding estimates for all sampled landings (white bars and dotted line) to show representativeness of collections.

Fine scale spatial comparisons (0.1 degree blocks) of the proportional distribution of the estimated bottom trawl fishery catch and sampled catch for 2007–08 and 2008–09 are presented in Figures 6 and 7. Figure 8 presents the distribution of catch and sampled catch over the same fishing years, but by statistical area. Over 90% of the entire SNA 2 bottom trawl catch is taken between Cape Runaway in the north and Napier in the south, with the greatest proportion (approximately 50%) from statistical area 013 alone, which contains both of the major ports, Gisborne and Napier.

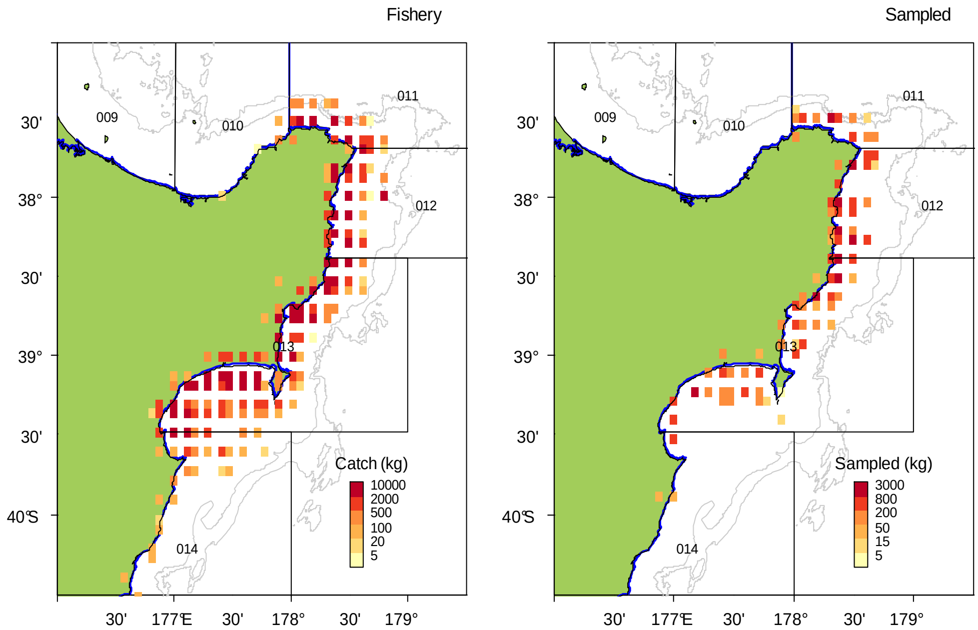

Figure 6: Comparison of the spatial distribution of the bottom trawl catch and the sampled component for the SNA 2 stock in 2007–08.

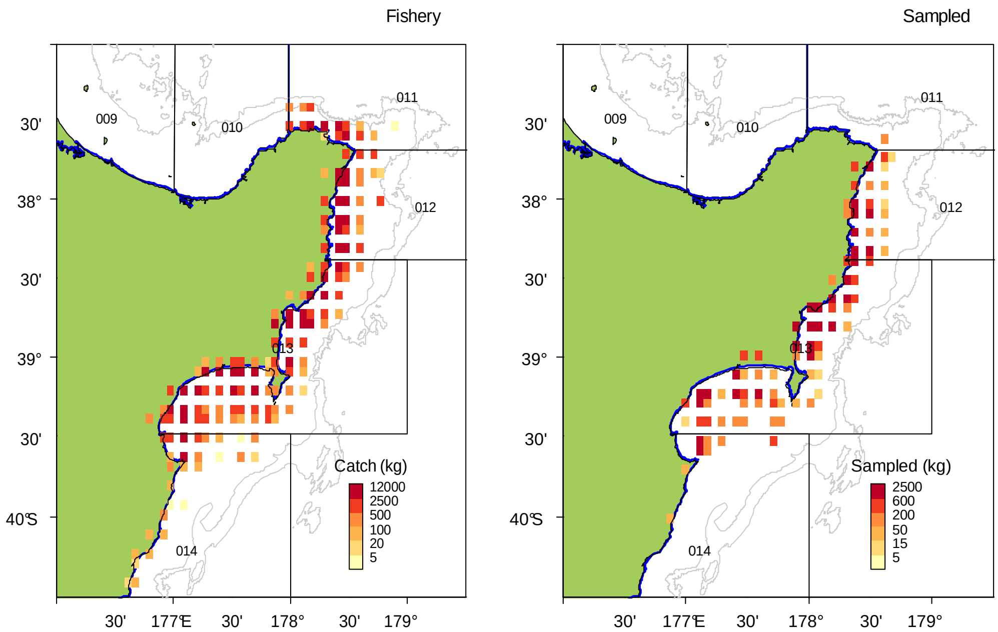

Figure 7: Comparison of the spatial distribution of the bottom trawl catch and the sampled component for the SNA 2 stock in 2008–09.

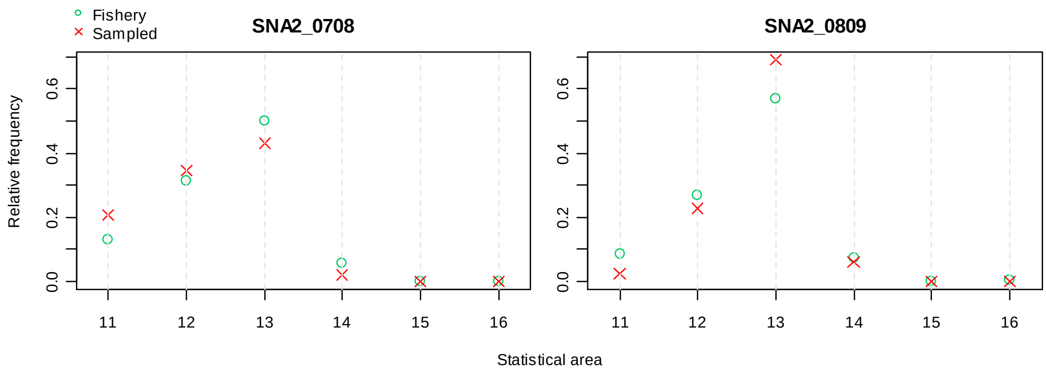

Figure 8: Comparison of the proportional distribution of the estimated bottom trawl catch and the sampled component by statistical area over the sampling period for the SNA 2 stock in 2007–08 and 2008–09.

A similar comparison for the same time periods depicting the bottom trawl catch by target species is given in Figure 9 and shows that approximately 80% of the annual landed catch of snapper is caught when either red gurnard (*Chelidonichthys kumu*) or tarakihi (*Nemadactylus macropterus*) are the target species, although some directed snapper targeting (approximately 17%) does occur in SNA 2. The proportionality of the sampled component to that of the fishery suggests that the sampled landings, by and large, are representative of the operation of the SNA 2 bottom trawl fleet as a whole.

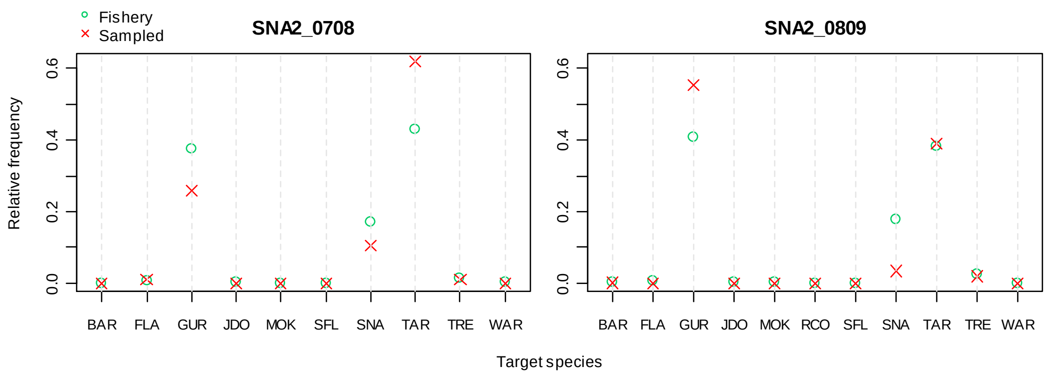

Figure 9: Comparison of the proportional distribution of the estimated bottom trawl catch and the sampled component by target species over the sampling period for the SNA 2 stock in 2007–08 and 2008–09.

3.3 Otolith readings

All SNA 2 otolith subsamples selected for ageing from the 2007–08 and 2008–09 collections were successfully aged. Between-reader tests with graphical comparisons of these are given in Figures 10 and 11. Negligible differences in interpretation between readers was indicated by: symmetry of the histograms in Figures 10 and 11(a); the even distribution of plotted points about the zero line in Figures 10 and 11(b); and overlap of the error bars on the age-bias plot for almost all age classes on the one-to-one line in Figures 10 and 11 (c). The overall percent agreement between readers was 96%. The between reader c.v. and IAPE were less than 1% (Figures 10 and 11(c)) and the profiles show that precision was high across almost all age classes (Figures 10 and 11(d)). Comparisons of the age-bias plots for reader 1 and 2 with the agreed age show that overall agreement was excellent and precision high with c.v. and IAPE estimates less than 1% (Figures 10 and 11(e) and (f)).

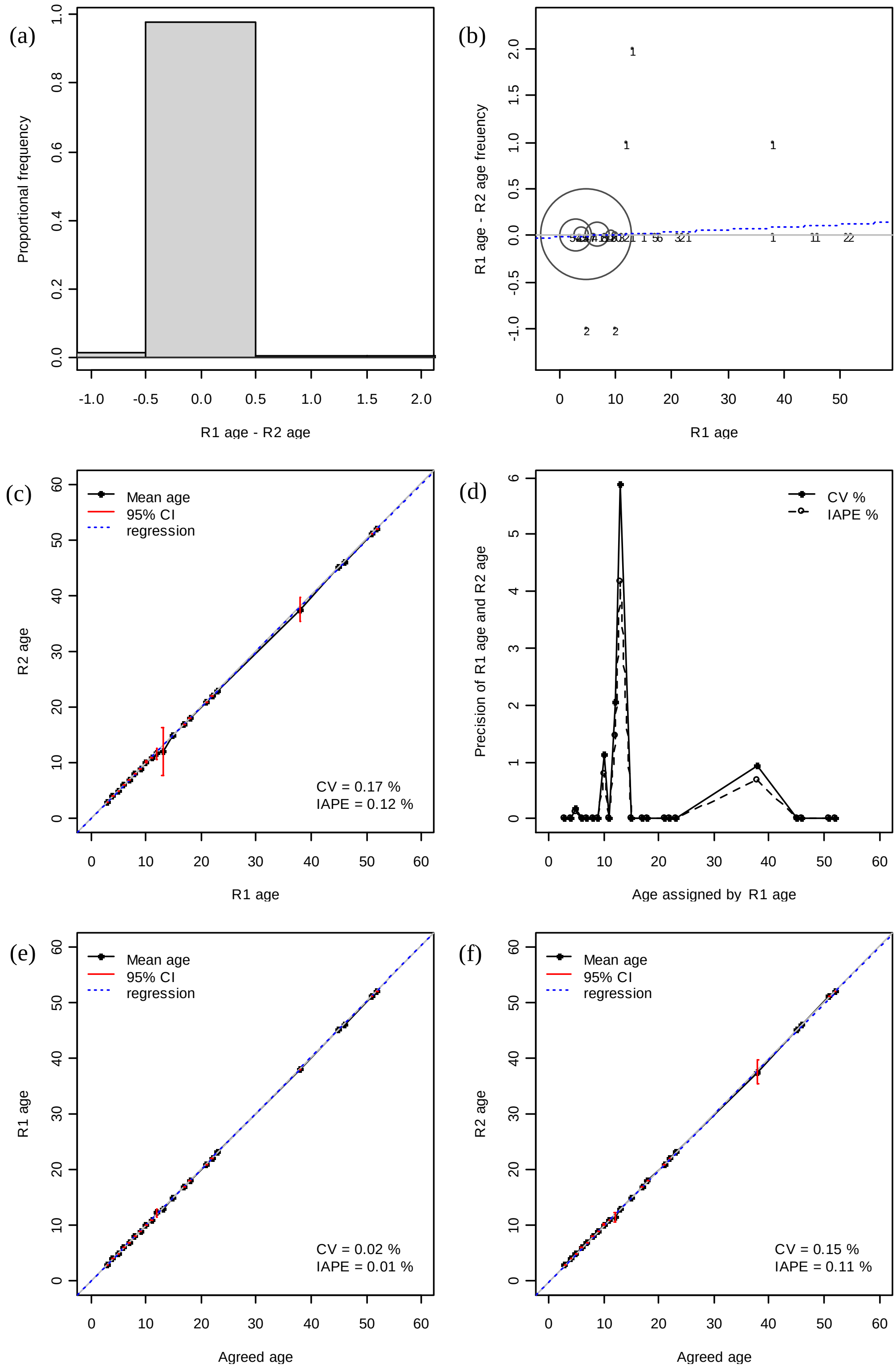

Figure 10: Results of between-reader comparison test (reader 1 and 2) for SNA 2 otoliths collected in 2007–08 (*n* = 350): (a) histogram of differences between readings for the same otolith; (b) bias plot between readers; (c) differences between readers for a given age assigned by reader 1 (d) c.v. and 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).

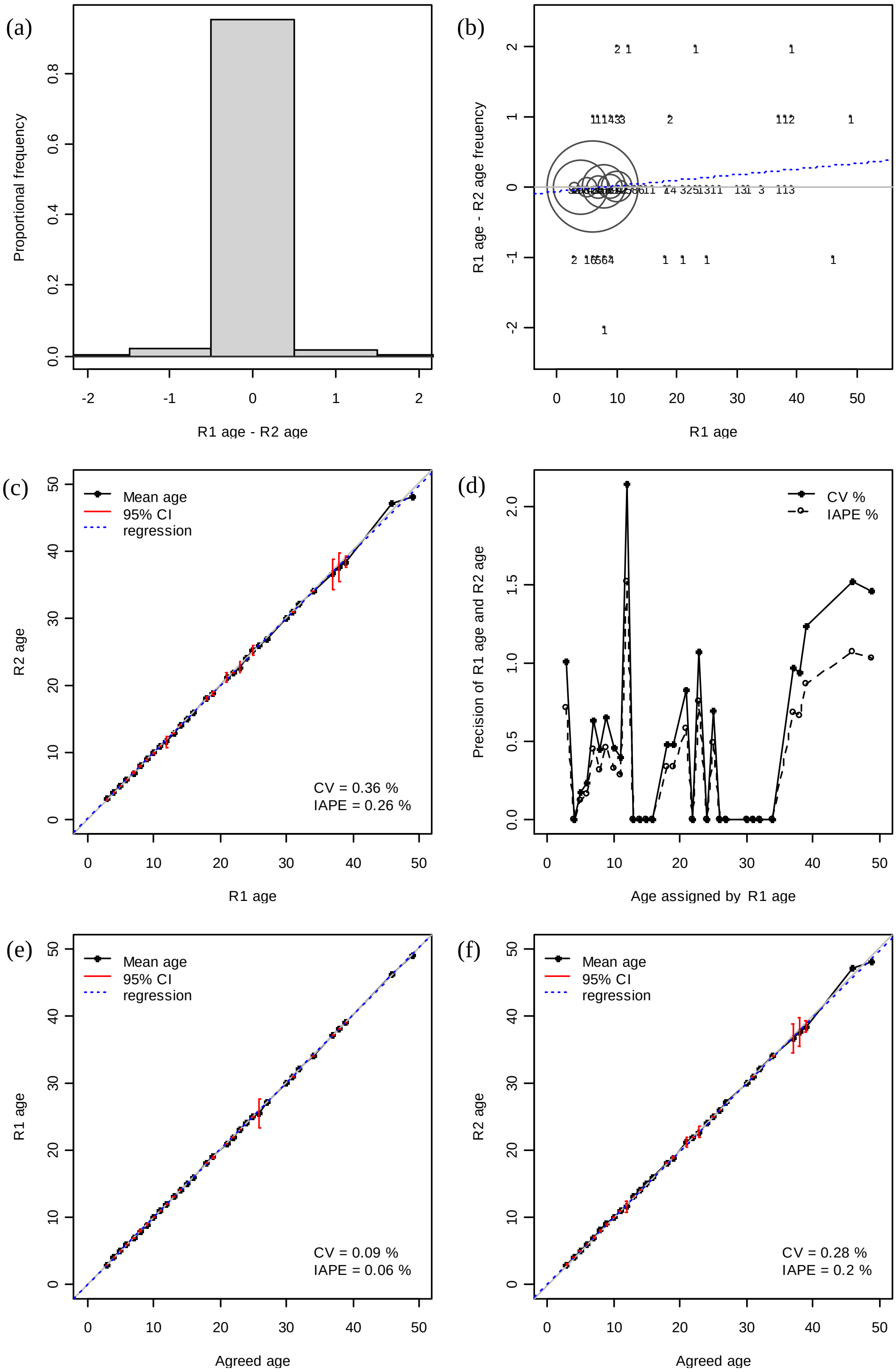

Figure 11: Results of between-reader comparison test (reader 1 and 2) for SNA 2 otoliths collected in 2008–09 (*n* = 1250): (a) histogram of differences between readings for the same otolith; (b) bias plot between readers; (c) differences between readers for a given age assigned by reader 1 (d) c.v. 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).

The oldest snapper aged from the northern and southern subarea samples of SNA 2 in 2007–08 were 25 and 52 years respectively, and for 2008–09, 39 and 49 years.

3.4 SNA 2 bottom trawl catch-at-age estimates

Catch-at-age compositions (using the RAF sampling approach) with bootstrap variance estimates were derived for the SNA 2 bottom trawl fishery and subarea strata for the 2007–08 and 2008–09 fishing years and are used to compare spatial differences in age structure and to identify relative year class strengths (Figures 12 to 14, Appendices 2a and b). The subarea proportion-at-age estimates determined from sampling over consecutive fishing years indicate consistent spatial heterogeneity in age structure within the SNA 2 fishery, with relative year class strengths persisting across years within each subarea (Figures 12 to 14). Catches from the northern subarea were largely comprised of young snapper, over 90% of landed catch by number aged 10 years or younger, and closely resembled the combined subarea estimates determined for the SNA 2 stock. The 2003 year class was the most dominant in the northern subarea accounting for one in every four fish landed, about twice that of most other common age classes. For the southern subarea, proportion at age varied significantly between years, indicative of high inter-annual recruitment variability.

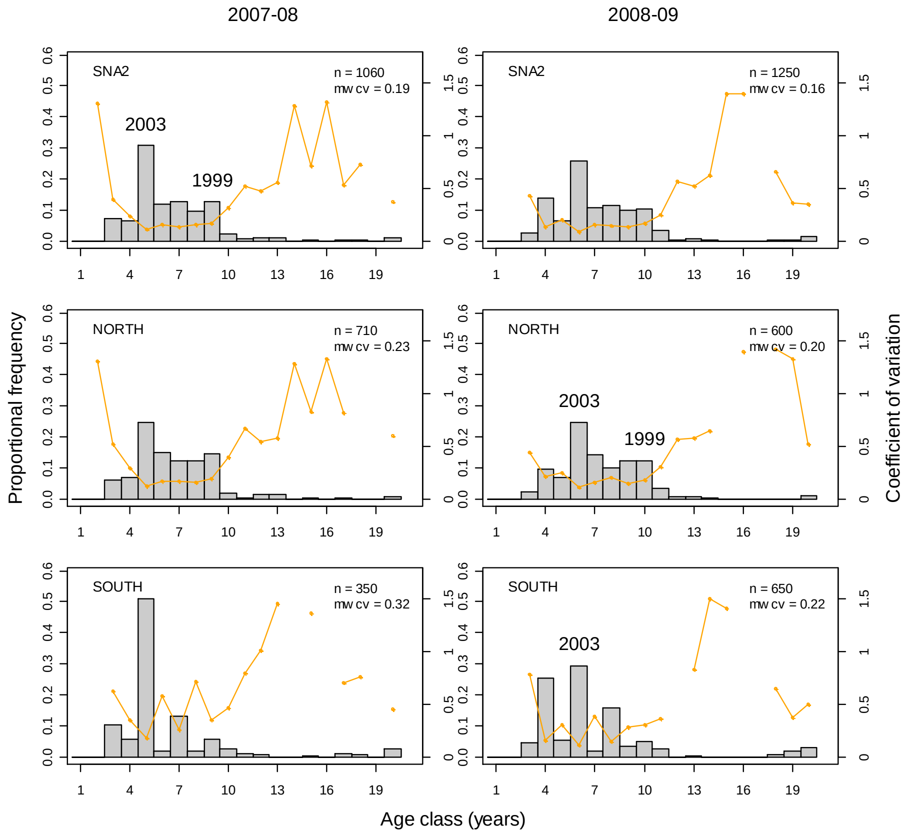

Figure 12: Proportion at age distributions (histogram) and c.v.s (line) determined from snapper landings sampled from SNA 2 and the northern and southern subarea bottom trawl fisheries in 2007–08 and 2008–09.

Although mainly comprised of young snapper, southern subarea landings also contained a small but appreciable number (approximately 5%) of fish greater than 20 years of age. The 2003 year class was even more dominant in the southern subarea, making up between one in every two or three snapper landed in the 2007–08 and 2008–09 fishing years.

Proportional and cumulative plot comparisons of catch-at-age for the northern and southern subarea strata by fish number and fish weight are given in Figures 13 and 14. Although proportionality at age differences were apparent between the subarea age compositions for the 2007–08 and 2008–09 fishing years, the overall cumulative differences by number were not as marked as those presented for weight, especially in relation to the older age classes (Figures 13 and 14).

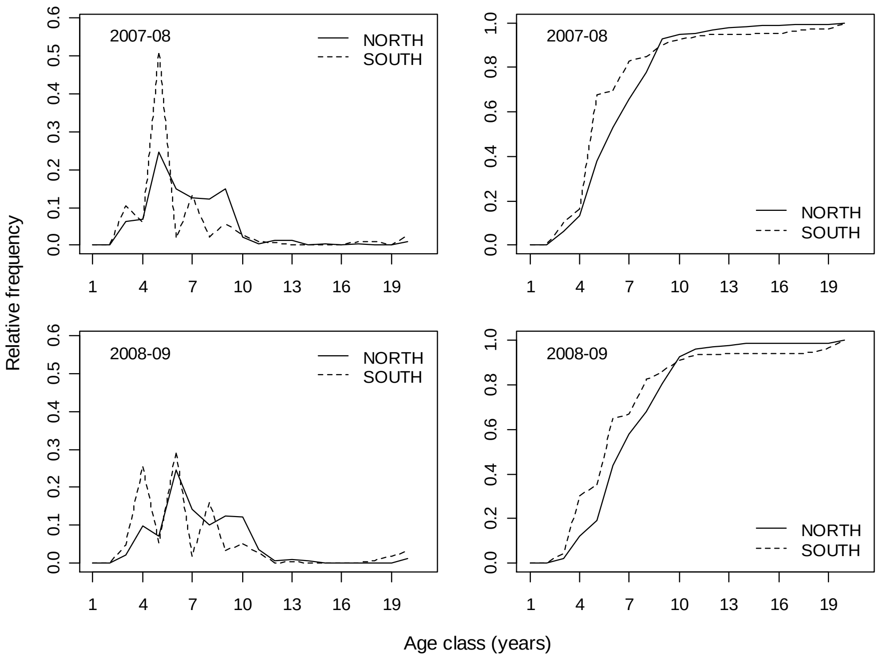

Figure 13: Comparison of the proportion (by numbers of fish) and cumulative proportion at age distributions determined from snapper landings sampled from the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09.

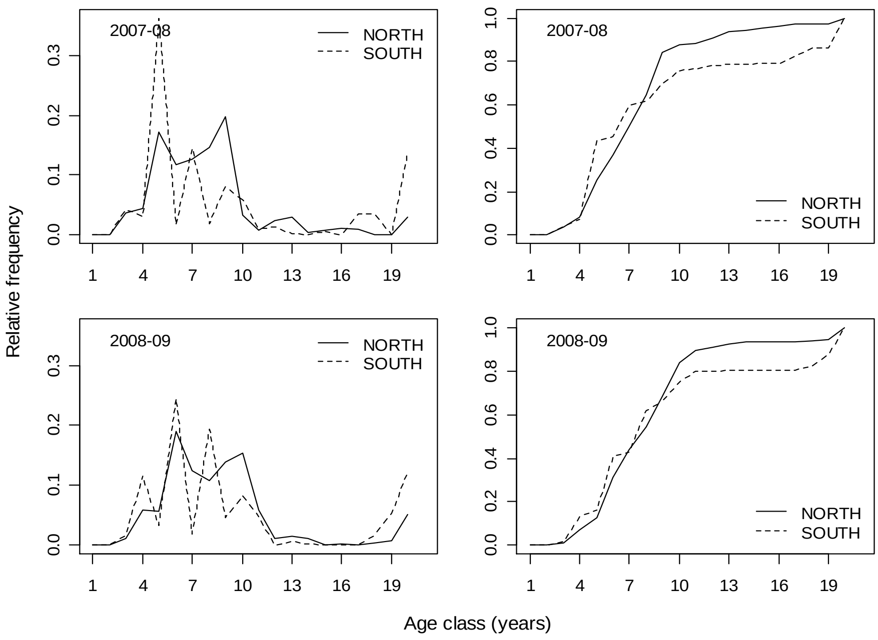

Figure 14: Comparison of the proportion (by weight of fish) and cumulative proportion at age distributions determined from snapper landings sampled from the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09.

Mean age for the northern subarea catch-at-age estimates in 2007–08 and 2008–09 ranged between 6.8 and 7.4 years and for the southern subarea, 6.3 and 6.8 years. Precision on estimates was generally high with MWCVs generally close to 0.20. The lowest precision (MWCV = 0.32) was calculated for the southern subarea in 2007–08 as sample size was low (n = 350) (Figure 12).

Length frequency summaries of RAF collections

The length distributions of snapper from the subsamples selected for ageing are very similar to those of the total RAF samples for the SNA 2 bottom trawl fishery and subarea strata in 2007–08 and 2008–09, suggesting that the aged fish are representative of the total samples (Figures 15 and 16; Appendices 3a–d). Consistent spatially heterogeneous patterns in the length structures were apparent in the SNA 2 fishery between years with the northern subarea comprising a higher proportion of small and fewer large snapper compared to the southern subarea (Figures 15–17). The significance of the proportionality differences between the subarea length compositions is most evident in the cumulative plot comparisons depicting an increase in the average size of snapper from north to south (Figure 17). Bimodality in the length distributions was more common in the southern subarea and the distributions were generally broader, especially in 2008–09 (Figures 15–17). Mean length of snapper sampled from the northern subarea in 2007–08 and 2008–09 ranged between 33.7 and 35.3 cm and was consistently lower than estimates for the southern subarea, 38.1 and 39.9 cm.

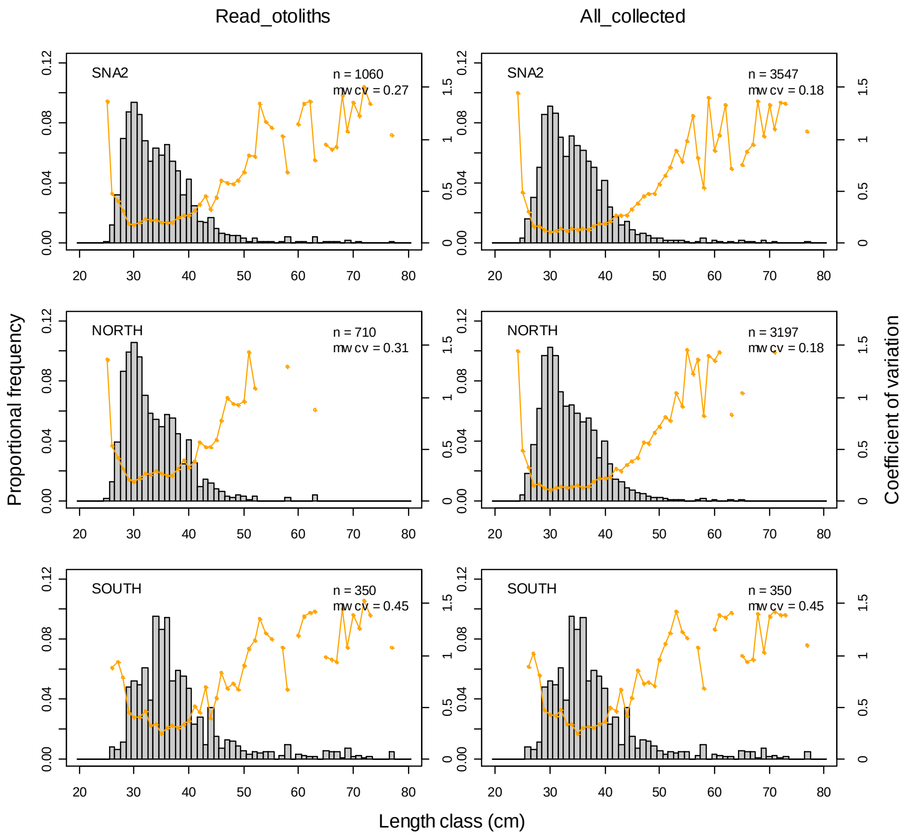

Figure 15: Proportion at length distributions (histogram) and c.v.s (line) determined from snapper landings sampled from SNA 2 and the northern and southern subarea bottom trawl fisheries in 2007–08.

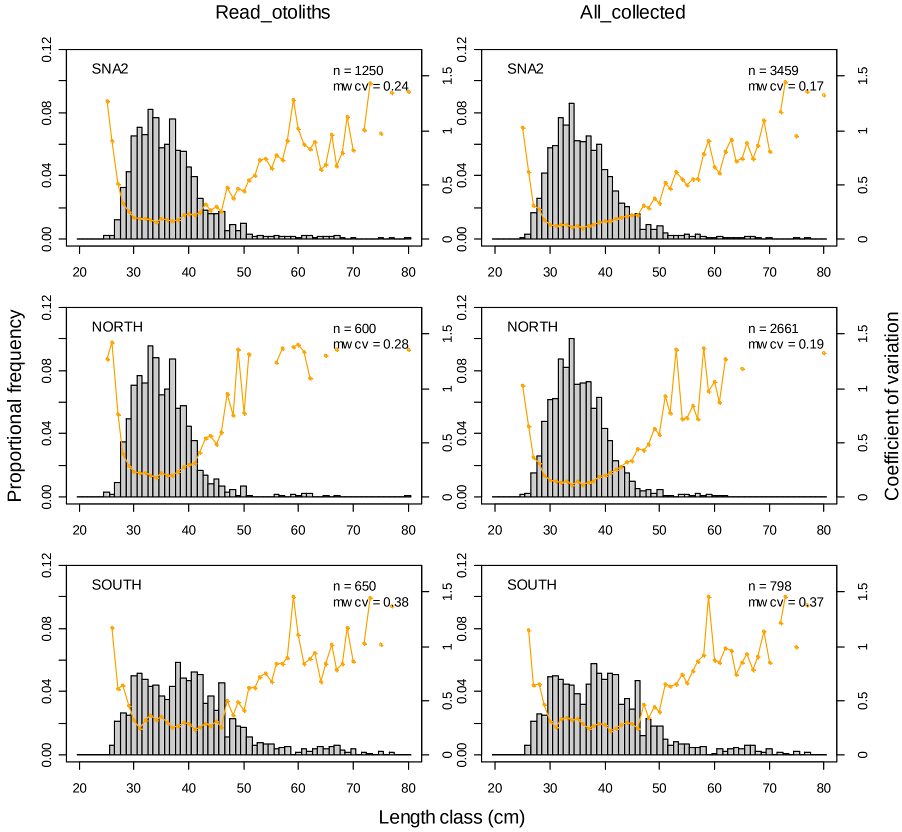

Figure 16: Proportion at length distributions (histogram) and c.v.s (line) determined from snapper landings sampled from SNA 2 and the northern and southern subarea bottom trawl fisheries in 2008–09.

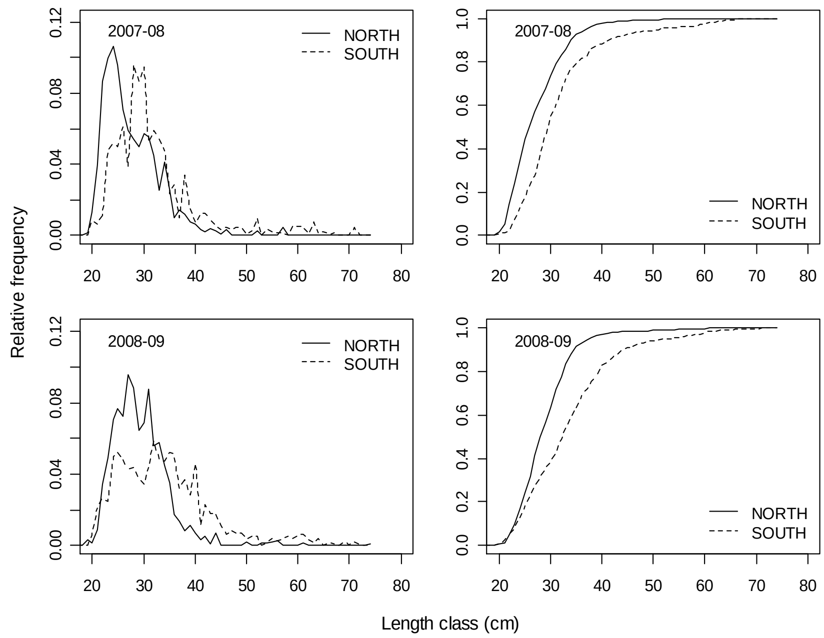

Figure 17: Comparison of the proportion (by numbers of fish) and cumulative proportion at length distributions determined from snapper landings sampled from the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09.

3.5 Spatial variation in mean weight-at age, mean length-at-age, and growth

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

Comparisons of mean weight-at-age and mean length-at-age for the SNA 2 bottom trawl fishery subarea collections from 2007–08 and 2008–09 show that substantial spatial growth differences exist within the fishery (Figure 18, Appendices 4a and b, 5a and b). Landings from the southern subarea comprise snapper of a greater average weight and size for a given age over almost all age classes than landings from the northern subarea. Spatially distinct trends in mean weight- and length-at-age were generally consistent between years, increasing with age, the exception being estimates derived from age classes comprising low sample sizes, most apparent in the southern subarea collection from 2007–08 (e.g., 8, 10, and 11 year olds) (Figure 18). Estimates of mean weight-at-age and mean length-at-age for some of the young age classes (i.e., 2 to 5 years old) did not differ considerably between subareas. These estimates may be 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.

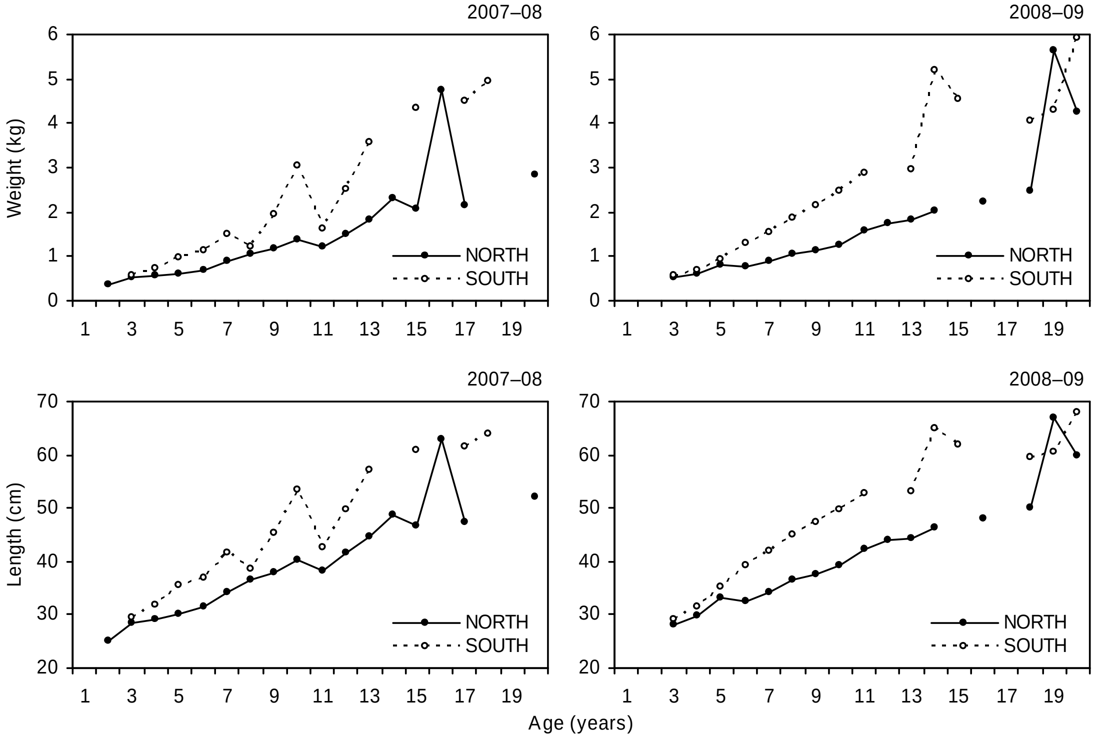

Figure 18: Observed mean weight-at-age and mean length-at-age estimates from snapper landings sampled from the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09.

The percentage weight differences in mean weight-at-age between the SNA 2 subarea fisheries in 2007–08 and 2008–09 were considerable, with snapper from the common age classes in the southern subarea weighing on average around 60% more for a given age than northern snapper (Figure 19). A comparison depicting the expected average age for three different size (and weight) categories of snapper (32, 42, and 55 cm) further illustrates the highly variable growth rate differences that exist between the subarea strata of SNA 2 (Figure 20). The direct effect of such growth variation in terms of the relative weight and number of snapper landed in SNA 2 in the respective subarea strata is presented in Figure 21. Approximately one-third of the landed SNA 2 catch in 2007–08 and 2008–09 can be apportioned to the southern subarea by weight, roughly equivalent to about one-quarter in terms of numbers of fish. The overall mean weight for a snapper landed in the northern subarea for the consecutive fishing years was around 0.9 kg compared to 1.4 kg for the southern subarea (Figure 22).

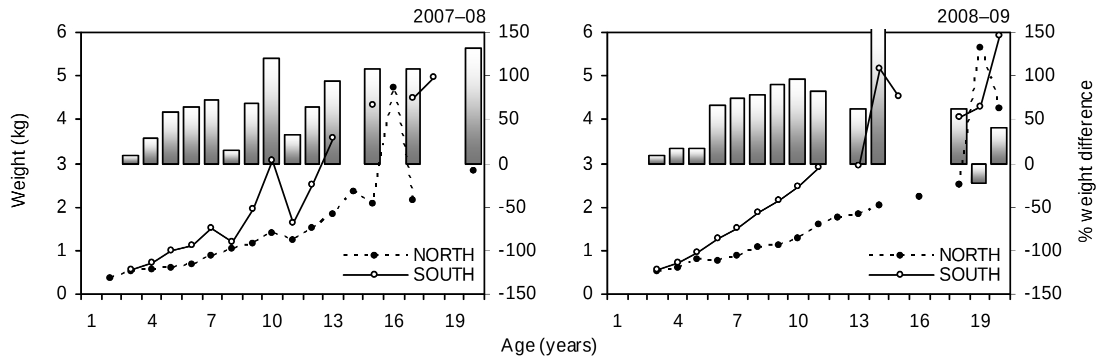

Figure 19: The percentage weight difference for each age class (positive or negative) between the SNA 2 southern and northern subarea bottom trawl mean weight-at-age estimates from 2007–08 and 2008–09.

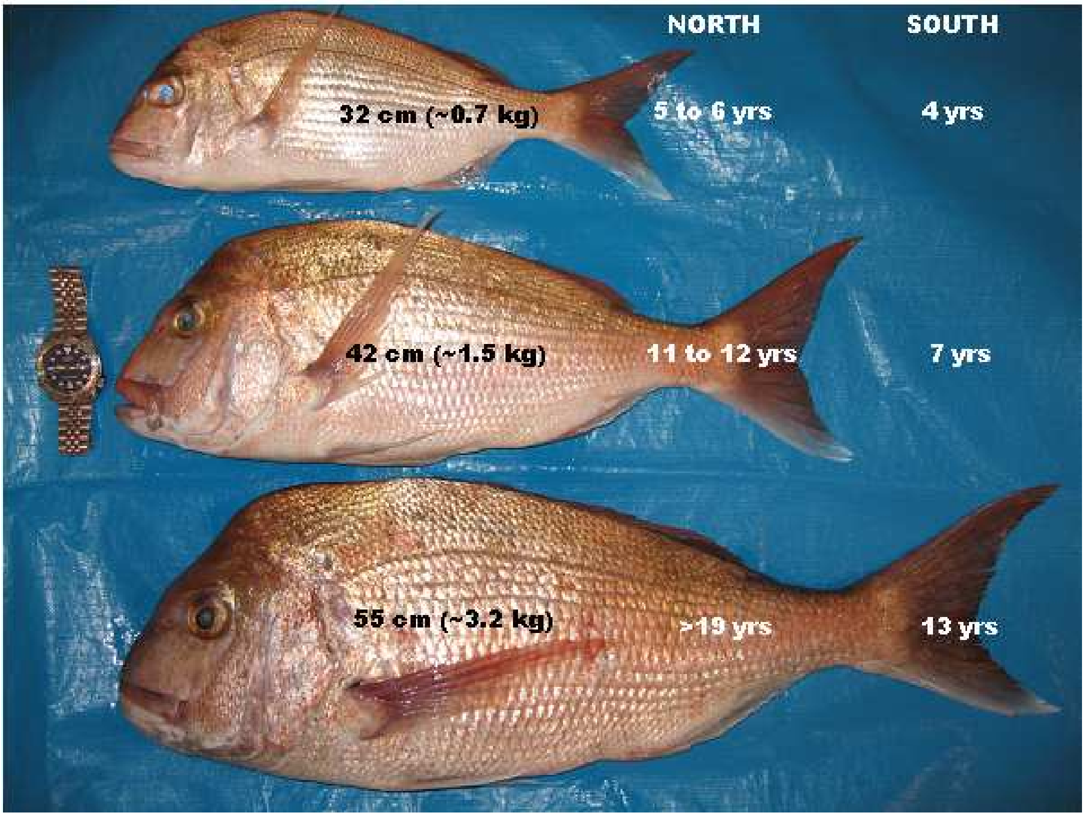

Figure 20: Age range and mean age estimates for three different size categories of snapper from the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09.

Figure 21: Comparison of the relative weight and number of snapper landed from the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09.

Figure 22: Comparison of the average size of snapper landed in the northern (top: 0.9 kg, approximately 35 cm) and southern (bottom: 1.4 kg, approximately 41 cm) subareas of SNA 2 by bottom trawl in 2007–08 and 2008–09.

A comparison of snapper mean weight-at-age estimates derived from the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09 with those from the adjacent stocks, Bay of Plenty (SNA 1) and west coast North Island (SNA 8), for the same fishing years is given in Figure 23. Mean weight-at-age information was not available from the Bay of Plenty single trawl fishery for comparison in either year, and was instead substituted with estimates from the bottom longline fishery. Southern subarea mean weight-at-age estimates were consistently high across all age classes and most often the highest for the common age classes, closely aligned to those determined for the SNA 8 bottom trawl fishery. Despite the selectivity-at-age differences between fishing methods, mean weight-at-age from northern subarea bottom trawl fishery was consistently higher than that for the Bay of Plenty bottom longline fishery, but well below estimates from the southern subarea and SNA 8.

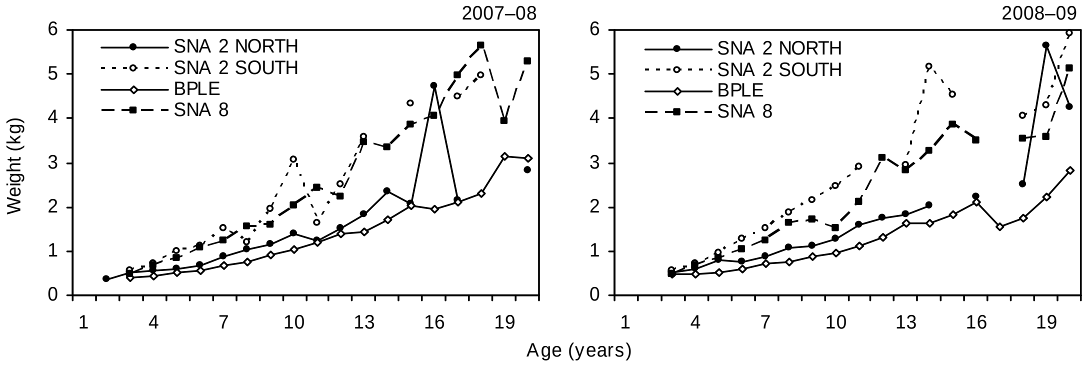

Figure 23: Comparison of mean weight-at-age estimates sampled from SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09 with estimates from the SNA 8 bottom trawl and Bay of Plenty (BPLE) bottom longline fishery in SNA 1.

Snapper growth

Scatterplots of age-length data and generated von Bertalanffy growth curves (using decimalised ages and not fishing year ages) for the combined 2007–08 and 2008–09 otolith collections from the SNA 2 fishery illustrate the marked spatial differences in growth rates present between the subarea fisheries (Figure 24). Although proportionally low numbers of old fish (20 or more years) were present in the SNA 2 subarea collections, the numbers in the southern subarea were more than twice as common than those in the north, spanned a greater age range, and where present, were often represented by more than one individual, indicative of previously strong year classes (Figure 24). There was a noticeable absence of samples occupying many of the "teenage" years, especially in the southern subarea, and across both years (Appendix 6). Brody growth coefficient (*k*) values were equivalent at 0.24 over the consecutive years for the northern subarea and ranged between 0.090 and 0.101 for the southern subarea (Table 2). Combined fishing year values of 0.027 and 0.097 were determined for the respective subareas to see if improvement could be made on the estimates. Despite an increased sample size, the paucity of older age samples in the northern subarea is unlikely to provide realistic estimates of growth (Figure 24).

Table 2: von Bertalanffy parameters calculated from RAF snapper otolith data collected from the SNA 2 subareas in 2007–08 and 2008–09.

Fishing year	SNA 2 subarea	L_{inf}	k	t_o	n
2007–08	North	106.4	0.024	-8.76	710
	South	72.9	0.090	-2.35	350
2008–09	North	103.1	0.024	-10.03	600
	South	71.0	0.101	-1.86	650
Combined years	North	98.7	0.027	-8.85	1310
	South	71.7	0.097	-2.02	1000

L_{inf} = length-at-age infinity; k = Brody's growth coefficient; t_o = hypothetical age at zero length.

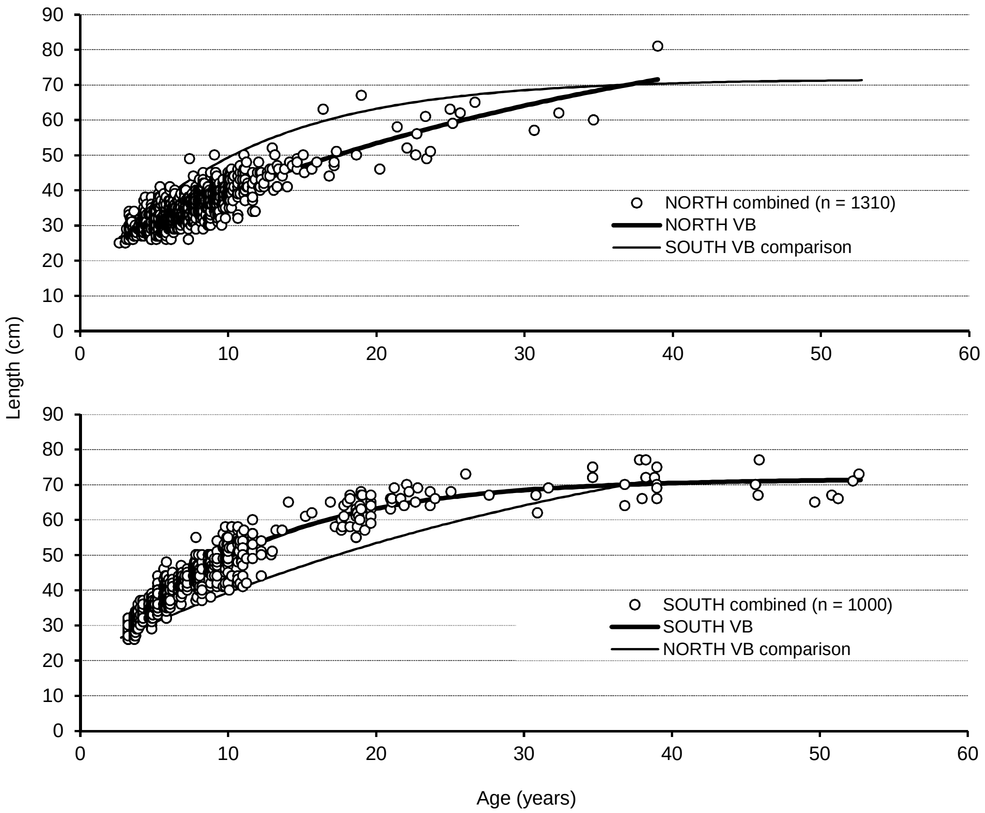

Figure 24: von Bertalanffy growth curves and scatterplots of age-length data for snapper sampled from the SNA 2 subarea bottom trawl fisheries using the combined data from 2007–08 and 2008–09 (Note: *n*, sample size). Age is decimalised as of the month of collection relative to an assumed January 1 "birthdate".

3.6 Spatial variation in year class strength

Clear differences were evident in the relative year class strength patterns between the northern and southern subareas of SNA 2 for 2007–08 and 2008–09 and Pearson correlation coefficients for catch curve residuals of year class strength were not significant at the 5% level (Figure 25, Table 3). Inter-annual year class strength variation in the northern subarea appears less than the southern subarea, especially between the 1999 and 2003 year classes, currently the most abundant in the fisheries (Figure 25).

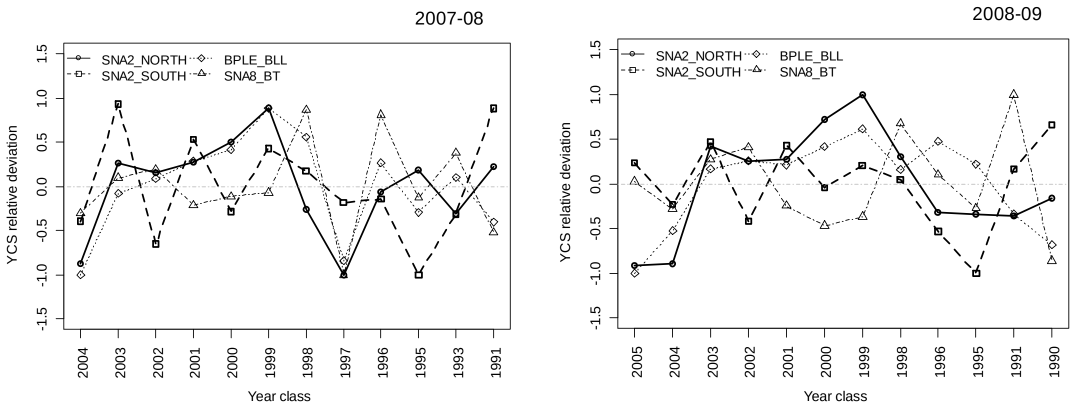

Figure 25: Relative differences in year class strengths based on deviations from a fitted log-linear regression line to catch-at-age curves for the 4–19 age classes in the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09. Note: no comparisons are presented for age classes that were absent of fish. Positive values represent year classes of above average strength.

Proportion-at-age estimates and derived relative year class strengths from adjacent Bay of Plenty bottom longline fishery in SNA 1 for the same fishing years were consistent with the northern SNA 2 subarea estimates and significantly correlated (Figures 25 and 26, Table 3). Estimates for the SNA 8 bottom trawl fishery failed to correlate to either of the SNA 2 subareas over the consecutive fishing years (Table 3).

Table 3: Pearson correlation coefficients for catch curve residuals of year class strength for the 4–19 age classes in the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09. Included for comparisons are estimates from Bay of Plenty bottom longline (BPLE_BLL) and SNA 8 (SNA8_BT) bottom trawl fisheries for the same years.

	2007–08				2008–09				
	SNA2_NTH	SNA2_STH	BPLE_BLL	SNA8_BT	SNA2_NTH	SNA2_STH	BPLE_BLL	SNA8_BT	
SNA2_NORTH	1	0.316	0.738	0.194	1	0.234	0.761	-0.084	Coeff
	0	0.317	0.006	0.547	0	0.465	0.004	0.795	p(Coeff = 0)
SNA2_SOUTH		1	0.215	-0.073		1	-0.345	-0.106	Coeff
		0	0.501	0.821		0	0.272	0.743	p(Coeff = 0)
BPLE_BLL			1	0.612			1	0.049	Coeff
			0	0.035			0	0.879	p(Coeff = 0)
SNA8_BT				1				1	Coeff
				0				0	p(Coeff = 0)

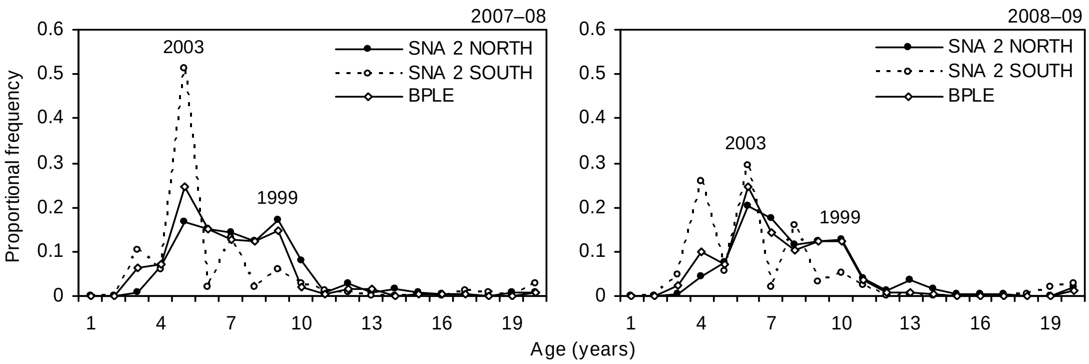

Figure 26: Proportion at age distribution comparisons for snapper landings sampled from the SNA 2 subarea bottom trawl fisheries and the Bay of Plenty substock bottom longline (BPLE) fishery in 2007–08 and 2008–09.

3.7 RAF sampling optimisations for SNA 2 subareas

The optimisation results for a RAF sampling design approach specific to each SNA 2 subarea stratum indicates that approximately 600 otoliths sampled from the northern subarea, and 300–400 otoliths from the southern subarea, would be required to achieve a target MWCV of 0.30 for each area (Table 4). The results suggest that 15–20 bottom trawl landings would need to be sampled in the northern subarea and 10 landings in the southern subarea, based on data from the 2007–08 and 2008–09 collections (under the assumption of a high level of precision in ageing snapper (see Section 3.3)).

Table 4: Bootstrapped MWCVs based on landings sampled and otoliths collected from the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09 using the random age frequency sampling approach. The shaded area indicates the recommended number of landings and otoliths per landing to sample from the fishery to achieve a target MWCV of 0.30.

2007–08 North

	Number of otoliths per landing				
Landings	20	30	40	50	60
10	0.4459	0.4235	0.4123	0.4026	0.3884
15	0.3637	0.3392	0.3303	0.3213	0.3153
20	0.3105	0.2924	0.2785	0.2763	0.2679
25	0.2752	0.2567	0.2506	0.2427	0.2396
30	0.2480	0.2338	0.2232	0.2186	0.2186
35	0.2290	0.2159	0.2068	0.2010	0.2010
40	0.2194	0.1975	0.1945	0.1911	0.1886

2007–08 South

	Number of otoliths per landing				
Landings	20	30	40	50	60
10	0.3149	0.2932	0.2793	0.2735	0.2573
15	0.2539	0.2336	0.2233	0.2121	0.2131
20	0.2200	0.2001	0.1935	0.1845	0.1813
25	0.1956	0.1762	0.1699	0.1680	0.1617
30	0.1779	0.1631	0.1570	0.1511	0.1479
35	0.1661	0.1508	0.1433	0.1403	0.1389
40	0.1537	0.1426	0.1365	0.1310	0.1297

2008–09 North

	Number of otoliths per landing				
Landings	20	30	40	50	60
10	0.3992	0.3816	0.3665	0.3501	0.3508
15	0.3309	0.3130	0.2998	0.2903	0.2817
20	0.2847	0.2642	0.2581	0.2501	0.2440
25	0.2528	0.2399	0.2244	0.2224	0.2171
30	0.2280	0.2162	0.2090	0.2029	0.1976
35	0.2142	0.2003	0.1930	0.1894	0.1864
40	0.2010	0.1868	0.1796	0.1748	0.1744

2008–09 South

	Number of otoliths per landing				
Landings	20	30	40	50	60
10	0.3527	0.3147	0.3002	0.2870	0.2771
15	0.2851	0.2592	0.2402	0.2342	0.2328
20	0.2496	0.2208	0.2155	0.2013	0.1939
25	0.2160	0.1995	0.1870	0.1855	0.1734
30	0.2035	0.1803	0.1686	0.1632	0.1639
35	0.1851	0.1687	0.1593	0.1515	0.1476
40	0.1802	0.1568	0.1478	0.1429	0.1415

4.0 DISCUSSION

A Ministry of Fisheries Northern Inshore Working Group meeting in April 2009 found that inconsistencies in catch-at-age estimates and precision were evident in the time series samples from the SNA 2 bottom trawl fishery, previously noted by Gilbert and Taylor (2001). Anecdotal evidence pointed to spatially heterogeneous patterns in length and age within the fishery being the primary cause, although inconsistencies in accurately ageing snapper in early collections were also postulated. This current study has determined that two spatially distinct substocks, if not discrete biological stocks, may exist within SNA 2, north and south of Mahia Peninsula, and that the previous single spatial stratum sampling design used in the fishery will almost certainly have biased catch-at-age estimates and affected precision. An appropriate sampling design that optimises the allocation of sampling effort within each designated spatial stratum of SNA 2, and achieves the desired level of precision in catch-at-age has been proposed.

Evidence for spatially distinct populations

Spatial differences in snapper length and age structure, relative year class strengths, and growth rates were clearly evident between the northern and southern subareas that divide SNA 2, with consistent patterns obvious over consecutive fishing years, 2007–08 and 2008–09. Such differences have been previously seen between the East Northland, Hauraki Gulf, and Bay of Plenty substocks that comprise the SNA 1 fishery (Walsh et al. 2011a), but are more apparent in SNA 2, especially in relation to growth and year class strength variability.

Growth and genetic variability

A comprehensive paper on growth rate and population structure of snapper in the East Cape region (Paul & Tarring 1980) utilising trawl survey and catch sampling data from the 1960s and early 1970s, found an increase in the average size of snapper from north to south, similar to the findings of this report. Their spatial stratification of length frequency data of what is now SNA 2, was relatively similar to ours. Their only age sample collection from the fishery in 1972 (n = 331, modified to an age-length key) from the R.V. *James Cook* did not determine any 'local variations' in growth, nor did it comprise spatially independent collections for age. Although neither complete nor fully random, these collections were reasonably well spread over the range of SNA 2. They determined that mean age increased with latitude (only for depths over 50 m), opposite to our findings, but this trend was confounded by inadequate sampling and the presence of juveniles at some shallow stations. As the time period between this and our study exceeds more than three decades, however, the exploited status of the SNA 2 fishery has changed considerably, and such comparisons may not be appropriate.

More recently, Ryan (1993) found variation in the size composition of bottom trawl samples from SNA 2 in 1991–92 that could not be explained solely by fish growth, although no stratification between Gisborne and Napier landings was undertaken, which may have been the root cause. Paul & Tarring (1980) did determine growth to be faster in the East Cape region than the Hauraki Gulf and slower than the west coast North Island stock (SNA 8), which concurs with our findings for the northern subarea of SNA 2, but not for the southern subarea. We found that snapper caught from the Hawke Bay region have one of the fastest growth rates in New Zealand, similar to SNA 7 on the north and west coast of the South Island.

With East Cape snapper 15–20% larger than fish from the Hauraki Gulf at equivalent ages, Paul & Tarring (1980) found no obvious explanation for the difference, given the southern location and cooler waters at East Cape. They postulated that population density and food availability were factors to consider in future studies, but overlooked the possibility of distinct populations. In this current study, mean weight-at-age estimates determined that snapper from the southern subarea weighed 60 to 70% more at a given age (average across all age classes) than those from the northern subarea, the greatest contrast in snapper growth observed within any New Zealand Quota Management Area (QMA). This trend mainly increased with age, and was more obvious in fully recruited age classes, despite anomalies where small sample sizes existed. A study of the genetic variation and population structure in the New Zealand snapper (Smith et al. 1978) indicated that stock mixing occurs at East Cape (i.e., between SNA 1 and SNA 2), and revealed Hawke Bay to be genetically distinct from the east coast New Zealand stock, but not significantly different to the west coast North Island (now SNA 8). Differences in growth in snapper held in captivity have been attributed to genetic variation (Tait 1996, Taniguchi et al. 1981, 1988), and may provide an explanation for the spatial variability in snapper growth seen between the subareas of SNA 2. Smith et al. (1978) emphasised that genetic anomalies for snapper appear to occur at the geographical limits of the east and west coast New Zealand stocks, possibly in response to environmental factors, such as water temperature. In addition, snapper from the southern-most range of New Zealand generally exhibit the fastest growth (Longhurst 1958, Paul & Tarring 1980), and often have low population densities (Ministry of Fisheries 2011).

The growth rate of snapper from different populations in New Zealand has been intensively studied (Cassie 1956, Longhurst 1958, Paul 1976, Vooren & Coombs 1977, Paul & Tarring 1980, Horn 1986, Francis et al. 1992, McKenzie et al. 1992, Francis 1994, Davies et al. 2003, Walsh et al. 2006b), and is known to vary between populations on a relatively small spatial and temporal scale, with spatial differences in growth between stocks usually more pronounced (Davies et al. 2003). Given the current growth differences present within the SNA 2 stock in this report, we can now determine that a trend of increasing growth rate exists for snapper from five distinct stock or substock fisheries (from north to south: East Northland, Hauraki Gulf, Bay of Plenty, northern SNA 2, southern SNA 2) down a latitudinal cline on the east coast of New Zealand's North Island. Walsh et al. (2006b) found that only minor differences in growth rates of snapper exist across the latitudinal zones of SNA 8, principally the west coast of the North Island, implying that little spatial variation occurs within this stock. Due to the paucity of old fish in the current SNA 2 collections, particularly in the northern subarea, comparisons in growth rates between areas should be treated with some caution as they are unlikely to provide realistic estimates of growth.

Environmental effects on year class strength

Although the QMA boundary at Cape Runaway geographically separates SNA 1 and SNA 2, both stocks effectively exist within the same oceanic water body. The East Auckland Current flows south-eastwards along the eastern coast of the North Island, then predominantly north at East Cape (Heath 1985), with a warm saline tongue of water flowing around East Cape (Heath 1975) extending southwards and giving rise to the East Cape Current. As year class strength variation in snapper is strongly correlated with water temperature (Francis 1993, Francis et al. 1997), it is not surprising that catch-at-age and year class strength estimates from the northern subarea bottom trawl fishery of SNA 2 for 2007–08 and 2008–09 were strongly correlated with estimates from the adjacent Bay of Plenty bottom longline fishery for the same years. Consistent patterns of inter-annual year class strength variability were evident in a 21-year time series of catch-at-age data between the substocks of SNA 1, including the Bay of Plenty (Walsh et al. 2011a). Nevertheless, considerably slower growth was obvious in Bay of Plenty snapper compared to the northern subarea of SNA 2, despite known selectivity-at-age differences between bottom longline and bottom trawl (McKenzie 2012), and these may reflect real differences in growth due to spatial (e.g., environmental and bathymetric) and temporal (e.g., climate variability) factors which have an underlying environmental and genetic basis (Kimura 1995).

Tagging studies

Since 1954, a number of large-scale snapper tag-recapture experiments have been undertaken on the east coast of New Zealand to provide information on either fish movement or to determine stock biomass (Appendix 7). During this time, a total of over 60 000 snapper have been tagged and released with external markers, almost all within SNA 1, nine of which have been recovered from SNA 2 (Appendix 7). Although the recapture rate of tagged snapper in SNA 2 was very low (0.02%), it does provide evidence of linkage between the adjacent SNA 1 and SNA 2 stocks. No recoveries were made from the 38 snapper tagged within SNA 2 between 1958 and 1960 (Paul 1967), the only snapper tagged within the stock in over 50 years of tagging studies.

Early studies trialled a range of external tags (pig ring, operculum straps, Petersen discs) with later experiments using a variety of ‘spaghetti’ type tags (lock-on, anchor, dart). The largest and most comprehensive tagging programme in New Zealand was undertaken in 1994 to estimate the recruited stock biomass of SNA 1. Internal coded wire tags were used, which were detected electronically by scanning the recapture sample (McKenzie & Davies 1996). However, as no tag detection capability was proposed for either the Gisborne or Napier ports, no movement of fish into SNA 2 could be determined.

Should the same biological stock continue past Cape Runaway, then the consistent differences in growth and the aforementioned stock mixing at East Cape would tend to indicate that the Bay of Plenty and the northern subarea of SNA 2 might be more appropriately described as adjacent substocks, with a minor level of mixing and migration occurring, similar to that seen between the substocks of SNA 1. Only a comprehensive tag-recapture programme to fully determine immigration and emigration between the SNA 1 and SNA 2 stocks, and between the subareas of SNA 2, would ultimately confirm whether or not biologically discrete stocks exist.

Spatial differences in catch-at-age

Similarities in proportion-at-age estimates between the northern and southern subareas of SNA 2 appear mostly consistent only when recruitment was well above average strength (i.e., for the 2003 year class), and indicative of warm years. Although Gilbert & Taylor (2001) determined a positive relationship between year class strength and spring–summer air temperature for SNA 2, it was found to be a less precise predictor, claiming process and sampling error for the lack of fit. It is highly likely that a combination of the following factors were the main cause. Firstly, the underlying spatial heterogeneity in catch-at-age within SNA 2 indicated by the poor correlation between strong and weak year classes in catches north and south of Mahia Peninsula, and secondly, the inconsistent sampling and ageing strategies used for early collections.

Although differing in relative proportions, catch-at-age estimates for the SNA 2 subarea bottom trawl fisheries in 2007–08 and 2008–09 were mainly comprised of fish between 3 and 10 years of age, the southern subarea having a higher proportion of larger and older fish. In comparison, the age frequency sample collected from the East Cape region in 1972 was broad, spanning a wide range of ages (1–55 years old) and comprised a number of particularly strong year classes (Paul & Tarring 1980). Some of these correlate with the few remaining old fish in the RAF samples from the southern subarea in 2007–08 and 2008–09, particularly the 1956, 1957, 1963, and 1970 year classes, now 40 or more years of age, reflecting the accurate ageing currently in place for snapper. Paul and Tarring (1980) suspected their accuracy to be plus or minus 2 years in ageing fish over 25 years, but this should not have affected the comparison here as most of the aforementioned strong year classes in the 1972 sample were less than this age.

Large snapper appear relatively common in bottom trawl landings from Napier, which was the initial reason for this investigation into perceived spatial differences in fish size within SNA 2. Large snapper have been rarely encountered in catch samples of commercial landings from SNA 1 and SNA 8 since 1989–90 (Walsh et al. 2011a, b), especially in bottom trawl landings where selectivity is generally high for small fish and low for large fish (Sullivan & Gilbert 1978; Davies et al. 2006). Consequently, the relatively high abundance of large snapper in bottom trawl landings from the southern subarea would most likely reflect the existence of a significant number of large fish within this population, relative to the stock size. The presence of large fish in the southern subarea most likely indicates that the exploitation rate of this part of SNA 2 has been historically lower than the northern subarea.

Southern geographic range for snapper

The periodic occurrences of strong year classes in the East Cape region (Paul & Tarring 1980) and the high inter-annual year class strength variability evident in the southern subarea catch-at-age collections in 2007–08 and 2008–09, almost certainly reflect the fact that the SNA 2 fishery borders the geographic range for successful recruitment, similar to SNA 7. In these two fishing years, over 99% of the SNA 2 TACC was taken north of Cape Kidnappers, the southernmost tip of Hawke Bay, geographically equivalent to the northern half of the stock. Consequently, almost all the southern subarea commercial catch can be considered as being caught entirely from Hawke Bay.

Paul & Tarring (1980) described Hawke Bay as the south-eastern limit of the commercial range of New Zealand snapper, supported by insignificant landings of snapper further south, from areas such as Castlepoint, where totals were less than 1 t per year (Proposed Central Fisheries Management Plan 1987). However, commercial trawl at-sea samples comprising large snapper were taken south of Hawke Bay (Paoanui Point to north of Cape Palliser) between 1966 and 1972 (Paul & Tarring 1980), and anecdotal information from interviews with Wairarapa fishers suggest that snapper were more common in the south during the 1950s and 1960s (Clinton Duffy pers. comm.). These were periods of high commercial fishing pressure, associated with a strong decline in the SNA 2 biomass (Gilbert & Philips 2003, Langley 2010). More recently, a series of east coast North Island trawl surveys from 1993 to 1996 found almost no snapper south of Hawke Bay (Kirk & Stevenson 1996, Stevenson & Kirk 1996, Stevenson 1996a, b), a period when the fishery was considered to be recovering, estimated to be about 15% of the virgin biomass (Langley 2010). The low number of snapper that inhabit the very southern reaches of the SNA 2 stock (Mana Island to Cape Palliser) are likely to be part of the west coast North Island stock, SNA 8, as indicated by their genetic similarities (Smith et al. 1978) and the low abundance of animals in catches between this area and Hawke Bay in recent times.

Coastal oceanography and subtidal habitats

The coastal waters of east coast North Island comprise a complex and wide range of habitats with sandy sediments common in shallow inshore waters and muddy sediments progressively increasing with depth. Although only a handful of small river estuaries are present along the coastline, inshore and offshore subtidal reefs are generally widespread. Turbid inshore waters are common, due to river discharges and suspension of sediments by wave action and inner shelf wind induced currents (Department of Conservation unpublished reports). A strong warm East Cape current flows south and a colder Southland current flows north (Barnes 1985, Chiswell & Roemmich 1998) often reaching as far as Mahia Peninsula (Ridgway & Stanton 1969). It is possible the geographic prominence of Mahia Peninsula, and the opposing water currents close to this latitude, may provide an environmental barrier to effectively divide the lower east coast North Island coastline into two distinct areas, aiding the formation of two distinct substocks within SNA 2.

Snapper spawning and nursery grounds

Although snapper are serial spawners in New Zealand with the season extending from October to January (Crossland 1977), most spawning occurs in depths of 20–70 m in November to December in northern areas, when sea bottom temperatures are around 15–17°C and sea surface temperatures 16–21°C (Cassie 1956, Crossland 1977, 1980, 1981, Scott & Pankhurst 1992). Locations and times are not well determined for SNA 2, but may be similar to those described above (Hurst et al. 2000). While spawning is unlikely to occur in very turbid or estuarine (low salinity) areas (Crossland 1981), estuaries and shallow, sheltered coastal embayments have been found to be important nursery grounds for juvenile snapper, with strong association to living biogenic habitats. These include seagrass (*Zostera mulleri*) meadows, horse mussel (*Atrina novaezealandiae*) beds and shallow coastal reefs (Kingett & Choat 1981, Francis et al. 2005, Schwarz et al. 2006, Ross et al. 2007, Morrison et al. 2009), and on occasions terrestrial debris i.e., logs and branches (Morrison et al. 2009). Research trawl survey samples in 1972 and 1973, in what is now defined as SNA 2, showed sufficient juvenile snapper (less than 25 cm; ages 0+ to 2+) were present in some inshore areas in depths less than 50 m to be defined as nursery grounds, with particularly high concentrations of juveniles at East Cape and Hawke Bay (Paul & Tarring 1980). They suggested that this demonstrates successful spawning, but not necessarily every year, and supports the high inter-annual year class variability evident in their age collection from 1972, and in the southern subarea catch-at-age collections of this present study. Despite this, the nursery areas for immediate post-settlement snapper in SNA 2 remain unknown.

Sea surface isotherms estimated from hydrological surveys in the peak of summer (February/March) from 1963–1971 (Heath 1975) and in a series of east coast North Island research trawl surveys in 1993–1996 (Stevenson & Kirk 1996, Stevenson 1996a, b) averaged around 20°C at East Cape, decreasing by about 1 degree for Hawke Bay, and a further degree for the Wairarapa coast. Despite occupying a greater latitude than the large SNA 1 population in the north, it appears that water temperatures in SNA 2 over summer are warm enough to allow for adequate larval and juvenile snapper survivorship during this period. However, as year class strength variation in SNA 1 was found to be strongly correlated with mean February–June sea surface temperatures (Francis 1993, Francis et al. 1997), the autumn temperatures in SNA 2 may not be as favourable, especially for the development of young snapper (Kilner 1983). In years of below average temperatures, juvenile snapper mortality may be considerable, particularly in the southern geographic range (i.e., Hawke Bay). Although few juvenile or immature snapper were encountered in the 1993–1996 trawl surveys, largely because an 80 mm cod end mesh size was used, many adult snapper were of a late stage gonadal development, indicating that spawning was still occurring during February and March (Kirk & Stevenson 1996, Stevenson & Kirk 1996, Stevenson 1996a, b).

Discrete biological stocks or substocks?

The proportionately high abundance of adult snapper occupying the northern subarea, the consistency in catch-at-age estimates, and the knowledge from tagging studies that the vast majority of snapper travel less than 50 n. miles from where they were released (Paul 1967, Crossland 1976, 1982, Tong 1978, Walsh et al. 2006b), support the theory of a self-sustaining northern subarea population in SNA 2, with only a minor level of immigration of fish from SNA 1. Paul & Tarring (1980) hypothesized that the East Cape stock probably comprises both locally spawned fish and an accumulation of older fish which are slowly moving south-eastward to the limits of their preferred range, but stipulated that a clearer understanding of fish movement would be essential in interpreting fluctuations in snapper abundance.

The southern subarea, principally Hawke Bay, is the largest of the coastal embayments on the coast, and has unique environmental habitats and oceanography, a diverse inshore sedimentary fauna, and few subtidal reefs (Ridgway & Stanton 1969, Bradford et al. 1980, Francis 1985). One large area in particular, colloquially known as the Wairoa Hard, extends to 11 km offshore, comprising coarse sediments, occasional patches of cobbles and rock outcrops, and extensive areas of kelp (*Ecklonia radiata*), is recognised by local fishermen to be a significant snapper nursery ground (Tai Perspectives 1996). The Wairoa Hard was closed to commercial net fishing in 1981, prompted by concerns of trawl gear impact in relation to the snapper fishery, in order to protect both juvenile snapper and their habitat. The Wairoa Hard was also identified as a primary feature of the Waihua River-Tangoio Reef "Area of Significant Conservation Value" by the Department of Conservation and Hawke's Bay Regional Council in 1995. Despite this, no scientific research has been undertaken to quantify the relative abundance of snapper from the Wairoa Hard in relation to the whole Hawke Bay area, the association of juvenile snapper to any particular biogenic habitat, and whether a nursery for snapper actually exists. Should it transpire that the Wairoa Hard is an important area for juvenile fish, then ongoing protection is essential to ensure the minimum destruction of habitat and prevent capture or disturbance of juveniles for the long term benefit of the Hawke Bay fishery. Of significance however, is that the closure of the Wairoa Hard has had a statistically significant effect on the ecological characteristics of the seafloor (Thrush et al. 1997). Nevertheless, the distribution and habitat requirement for post settlement snapper (0+) remains poorly understood within SNA 2. Research from other localities suggests that shallow estuarine habitats may be of primary importance for these early stage snapper (Morrison et al. 2009). If an ontogeny of habitat requirements does occur for juvenile snapper, protection of nursery areas that are important throughout the juvenile stages (e.g. the Wairoa Hard) may not be sufficient to ensure initial successful recruitment to the fishery. Additional research on the distribution of post settlement snapper in SNA 2 is required.

Water circulatory and hydrological patterns for Hawke Bay are complex, with inflow of oceanic water from either the East Cape or Southland currents causing two or three circulation cells, and outflows along the margin of the bay (Ridgway 1960, Ridgway & Stanton 1969, Bradford et al. 1980, Francis 1985, Heath 1985). Water salinity, modified by freshwater run-off mainly from the Wairoa and Mohaka rivers, and temperature, are lower in the bay than on the open coast (Rigdeway & Stanton 1969, Bradford et al. 1980, Heath 1985). It is conceivable that the water circulation, and unique habitats such as the Wairoa Hard, may collaboratively provide the mechanism to support a discrete biological snapper population in Hawke Bay, self-sustained by periodic recruitment from localised spawning when conditions are suitable. No information, however, of spawning aggregations or spawning conditioned snapper within Hawke Bay is currently available to help verify the hypothesis of self-sustained recruitment.

Overview and summary

SNA 2 bottom trawl landings generally comprise snapper randomly distributed throughout the catch, either binned at sea or during unloading, unlike samples from SNA 1 where clustering by fish size occurs, which may influence precision in catch-at-age estimates (Walsh et al. 2000). Aside from any potential bias due to grab sampling and gear selectivity, the results presented in this report indicate a high level of consistency in RAF sample estimates for the subarea fisheries of SNA 2 in 2007–08 and 2008–09. Comparisons of temporal and spatial fishing and sampling effort suggest a good level of representativeness in the collections, and adequate precision in the catch-at-age estimates (MWCVs 0.20–0.32) reflective of a rigorous sampling design and accurate ageing.

There is enough evidence presented in this report in relation to snapper length and age structure, year class strength, growth, and genetic variability between the northern and southern subareas of SNA 2 to demonstrate that they are distinct substocks, if not discrete biological stocks. Movement information from a tagging programme would clarify any uncertainty as to whether the arbitrary division at Mahia Peninsula forms a suitable stock boundary within SNA 2, and if significant linkage exists between SNA 1 and SNA 2 at Cape Runaway. Furthermore, if discrete stocks do exist and a change in the distribution of fishing effort occurs, localised depletion within one of the subareas may become an issue. The southern subarea may be particularly vulnerable because it is likely to have a smaller population size. Another issue arising from the potential for discrete stocks within SNA 2 is the identification and ongoing protection of nursery habitats for all ontogenetic early life stages of snapper.

Any proposed catch sampling design for the SNA 2 fishery should ensure that sampling adequately accounts for the underlying spatial patterns described above. An optimised sampling design for estimating catch-at-age and precision based on a pre-stratification of sampling effort across the two subareas, north and south of Mahia Peninsula, should be sufficient to account for spatial heterogeneity within the stock. However, as no temporal patterns were investigated in this report due to inadequate sample sizes, particularly in the southern subarea collections, this aspect may be fully addressed in future work. As the SNA 2 fishery is almost entirely trawl based, and comprised predominantly of young fish, it would be prudent to ensure that sampling is undertaken at least every three years to adequately determine relative recruitment strength on a minimum of two occasions, with consecutive year sampling a preferred option.

Recommendations for utilising historical information

Catch sampling data

To utilise historical catch-at-age collections, retrospective analysis of age data from 1997–98, 1998–99, 1999–00, 2002–03, and 2004–05 could be undertaken for each landing by investigating the following for each spatial subarea: port of landing, growth rates, and the presence/absence of large and old fish. As the smallest spatial scale in SNA 2 prior to 2007–08 was statistical area, areal-based stratification of previous SNA 2 sampling was deemed impractical by Blackwell (2009) particularly as statistical area 013 straddled both major ports, Gisborne and Napier. However, it was determined from the current study using data from 2008–09 that up to 95% of all sampled vessels fished only in the northern or southern subarea of SNA 2, and landed into the corresponding home port of that subarea. As home port appears strongly correlated to fishing activity in the adjacent subarea (despite statistical area 013 being common to both ports), it may provide a method, along with the aforementioned factors above, of stratifying historical SNA 2 catch-at-age data into spatially discrete subarea estimates. It also appears that the arbitrary subarea division of the SNA 2 stock at Mahia Peninsula in this current study, by chance, not only determined the approximate biological boundary between the substocks of SNA 2, but also reflected an obvious geographic partition that often restricted the fishing behaviour for trawlermen operating out of the respective ports.

Collections from 1991–92, 1997–98, and 1998–99 would require re-ageing as they were previously aged by different personnel using different interpretations in growth zones (i.e., no fixed margin) and age estimates residing in the *age* database are almost certainly inaccurate. Should the recommendation be considered to re-investigate historical SNA 2 age data, it is highly likely that the fit of future assessment models to the complete SNA 2 catch-at-age time series could be significantly improved.

Research trawl survey data

Length frequency data exists for snapper from the east coast North Island area from R.V. *Ikatere* (1954–66) and R.V. *James Cook* (1972–73) research trawl surveys and include otolith samples from 1972, the only age collection made from the fishery during these years. At-sea snapper length samples collected between 1966 and 1973 from commercial trawl vessels operating on the east coast North Island are archived at NIWA (L. Paul pers. comm.). Similarly, length frequency data is available from the series of east coast North Island trawl surveys from 1993 to 1996 outlined in a previous section. Otolith collections were made over all four surveys with up to four pairs collected per 1 cm size class per sex, although readings have only been undertaken on the first survey sample (n = 284), and the catch-at-age results do not appear to have been published. It is also likely that the age estimates derived from this collection may have considerable ageing error and would require re-ageing. Much of the above data are presented in Longhurst (1958), Paul & Tarring (1980), Kirk & Stevenson (1996), Stevenson & Kirk (1996) and Stevenson (1996a, b), and may be useful for future SNA 2 stock assessments.

Recreational fishing data

Recreational fishing surveys were undertaken in QMA 2 in 1993 (project CEN93) and 2000 (project NAT01), and the raw catch data exists within the *Rec* database. Although the main purpose of these surveys was to determine mean fish weight, the fish measurements can be used to generate length frequency distributions. A similar survey (project MAF2011/03) is currently underway in the 2011–12 fishing year.

6. ACKNOWLEDGMENTS

We thank Colin Sutton (NIWA) for supplying data from the *age* database, Chantal Percy (Ministry of Fisheries) for the provision of data from the catch effort return system, and those Licensed Fish Receivers for enabling NIWA staff to sample catches from the SNA 2 bottom trawl fishery in 2007–08 and 2008–09. Clinton Duffy (Department of Conservation) was generous in sharing his wide knowledge and research of the East Coast and Hawke Bay marine ecosystems and local fisheries. We also thank Darren Parsons for reviewing this report and providing useful additions.

Funding for this project, SNA2010/04, was provided by the Ministry of Fisheries.

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Appendix 1: Large old snapper (i.e., over 65 cm, approximately 5.5 kg) were not uncommon in bottom trawl landings from Hawke Bay, despite low selectivity for fish of this size for this fishing method.

Appendix 2a: Estimates of proportion at age with c. v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2007–08.

P.j., proportion of fish in age class; c.v., coefficient of variation

Age	Northern subarea		Southern subarea		Bottom trawl SNA 2	
(years)	*P.j.*	c.v.	*P.j.*	c.v.	*P.j.*	c.v.
1	0.0000	0.00	0.0000	0.00	0.0000	0.00
2	0.0015	1.31	0.0000	0.00	0.0011	1.31
3	0.0629	0.53	0.1046	0.63	0.0727	0.40
4	0.0699	0.30	0.0597	0.35	0.0675	0.24
5	0.2456	0.13	0.5104	0.18	0.3079	0.11
6	0.1488	0.17	0.0199	0.58	0.1185	0.16
7	0.1253	0.17	0.1301	0.26	0.1265	0.14
8	0.1225	0.16	0.0210	0.72	0.0986	0.16
9	0.1484	0.19	0.0574	0.36	0.1270	0.17
10	0.0212	0.41	0.0263	0.46	0.0224	0.32
11	0.0054	0.68	0.0099	0.79	0.0064	0.52
12	0.0140	0.55	0.0079	1.01	0.0126	0.48
13	0.0142	0.58	0.0012	1.46	0.0111	0.56
14	0.0019	1.29	0.0000	0.00	0.0014	1.29
15	0.0036	0.83	0.0022	1.37	0.0033	0.71
16	0.0021	1.33	0.0000	0.00	0.0016	1.33
17	0.0038	0.82	0.0110	0.70	0.0055	0.53
18	0.0000	0.00	0.0096	0.76	0.0023	0.73
19	0.0000	0.00	0.0000	0.00	0.0000	0.00
>19	0.0090	0.61	0.0288	0.46	0.0136	0.38
n	710		350		1 060	

Appendix 2b: Estimates of proportion at age with c. v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2008–09.

P.j., proportion of fish in age class; c.v., coefficient of variation

Age	Northern subarea		Southern subarea		Bottom trawl SNA 2	
(years)	*P.j.*	c.v.	*P.j.*	c.v.	*P.j.*	c.v.
1	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
3	0.0218	0.45	0.0484	0.78	0.0289	0.44
4	0.0981	0.22	0.2533	0.16	0.1395	0.14
5	0.0706	0.25	0.0535	0.31	0.0660	0.20
6	0.2469	0.12	0.2948	0.12	0.2597	0.09
7	0.1414	0.16	0.0191	0.39	0.1087	0.16
8	0.1020	0.21	0.1590	0.15	0.1172	0.15
9	0.1233	0.15	0.0333	0.28	0.0992	0.14
10	0.1224	0.19	0.0514	0.31	0.1034	0.17
11	0.0366	0.31	0.0259	0.36	0.0338	0.25
12	0.0068	0.58	0.0000	0.00	0.0050	0.57
13	0.0086	0.58	0.0031	0.83	0.0071	0.53
14	0.0059	0.65	0.0007	1.51	0.0045	0.63
15	0.0000	0.00	0.0003	1.41	0.0001	1.40
16	0.0009	1.41	0.0000	0.00	0.0007	1.40
17	0.0000	0.00	0.0000	0.00	0.0000	0.00
18	0.0014	1.43	0.0061	0.65	0.0027	0.66
19	0.0013	1.34	0.0192	0.37	0.0060	0.36
>19	0.0121	0.52	0.0320	0.50	0.0174	0.35
n	600		650		1 250	

Appendix 3a: Estimates of proportion at length (for read otoliths) with c. v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2007–08.

P.i., proportion of fish in length class; c.v., coefficient of variation

Length	Northern subarea		Southern subarea		Bottom trawl SNA 2	
(cm)	*P.i.*	c.v.	*P.i.*	c.v.	*P.i.*	c.v.
20	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
22	0.0000	0.00	0.0000	0.00	0.0000	0.00
23	0.0000	0.00	0.0000	0.00	0.0000	0.00
24	0.0000	0.00	0.0000	0.00	0.0000	0.00
25	0.0015	1.37	0.0000	0.00	0.0011	1.37
26	0.0132	0.54	0.0080	0.88	0.0120	0.47
27	0.0395	0.42	0.0064	0.94	0.0320	0.41
28	0.0868	0.31	0.0115	0.79	0.0698	0.31
29	0.0993	0.21	0.0479	0.45	0.0877	0.19
30	0.1060	0.19	0.0519	0.41	0.0938	0.18
31	0.0958	0.21	0.0500	0.40	0.0855	0.20
32	0.0708	0.26	0.0608	0.46	0.0685	0.23
33	0.0589	0.25	0.0390	0.33	0.0544	0.22
34	0.0543	0.29	0.0957	0.34	0.0636	0.22
35	0.0501	0.27	0.0866	0.25	0.0583	0.20
36	0.0575	0.24	0.0946	0.30	0.0659	0.19
37	0.0555	0.25	0.0524	0.33	0.0548	0.20
38	0.0449	0.31	0.0590	0.30	0.0481	0.24
39	0.0252	0.39	0.0550	0.34	0.0319	0.27
40	0.0413	0.33	0.0474	0.37	0.0427	0.26
41	0.0253	0.38	0.0233	0.51	0.0249	0.31
42	0.0101	0.56	0.0284	0.46	0.0142	0.37
43	0.0146	0.52	0.0100	0.70	0.0135	0.45
44	0.0119	0.52	0.0342	0.40	0.0170	0.33
45	0.0078	0.59	0.0149	0.59	0.0094	0.43
46	0.0062	0.77	0.0072	0.83	0.0064	0.60
47	0.0036	1.00	0.0126	0.69	0.0056	0.58
48	0.0022	0.93	0.0122	0.73	0.0045	0.57
49	0.0038	0.92	0.0088	0.67	0.0049	0.60
50	0.0029	0.96	0.0060	0.91	0.0036	0.68
51	0.0006	1.44	0.0033	1.06	0.0012	0.84
52	0.0032	1.09	0.0046	1.15	0.0035	0.84
53	0.0000	0.00	0.0037	1.36	0.0008	1.34
54	0.0000	0.00	0.0046	1.21	0.0010	1.16
55	0.0000	0.00	0.0046	1.16	0.0010	1.11
56	0.0000	0.00	0.0000	0.00	0.0000	0.00
57	0.0000	0.00	0.0026	1.08	0.0006	1.03
58	0.0027	1.29	0.0093	0.67	0.0042	0.68
59	0.0000	0.00	0.0000	0.00	0.0000	0.00
60	0.0000	0.00	0.0031	1.19	0.0007	1.15
61	0.0000	0.00	0.0023	1.38	0.0005	1.34
62	0.0000	0.00	0.0015	1.41	0.0003	1.37
63	0.0044	0.88	0.0015	1.43	0.0038	0.80
64	0.0000	0.00	0.0000	0.00	0.0000	0.00
65	0.0000	0.00	0.0053	0.98	0.0012	0.95
66	0.0000	0.00	0.0052	0.96	0.0012	0.91
67	0.0000	0.00	0.0049	0.94	0.0011	0.92
68	0.0000	0.00	0.0011	1.45	0.0002	1.42
69	0.0000	0.00	0.0075	1.07	0.0017	1.08
70	0.0000	0.00	0.0015	1.39	0.0003	1.35
71	0.0000	0.00	0.0023	1.26	0.0005	1.23
72	0.0000	0.00	0.0011	1.53	0.0002	1.50
73	0.0000	0.00	0.0015	1.39	0.0003	1.34
74	0.0000	0.00	0.0000	0.00	0.0000	0.00
75	0.0000	0.00	0.0000	0.00	0.0000	0.00
76	0.0000	0.00	0.0000	0.00	0.0000	0.00
77	0.0000	0.00	0.0048	1.07	0.0011	1.04
78	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
80	0.0000	0.00	0.0000	0.00	0.0000	0.00
n	710		350		1 060	

Appendix 3b: Estimates of proportion at length (for read otoliths) with c. v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2008–09.

P.i., proportion of fish in length class; c.v., coefficient of variation

					Bottom trawl	
Length	Northern subarea		Southern subarea		SNA 2	
(cm)	*P.i.*	c.v.	*P.i.*	c.v.	*P.i.*	c.v.
20	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
22	0.0000	0.00	0.0000	0.00	0.0000	0.00
23	0.0000	0.00	0.0000	0.00	0.0000	0.00
24	0.0000	0.00	0.0000	0.00	0.0000	0.00
25	0.0033	1.27	0.0000	0.00	0.0024	1.27
26	0.0015	1.43	0.0059	1.18	0.0027	0.91
27	0.0089	0.77	0.0212	0.61	0.0121	0.51
28	0.0347	0.40	0.0263	0.64	0.0325	0.33
29	0.0491	0.29	0.0249	0.45	0.0428	0.26
30	0.0705	0.24	0.0499	0.32	0.0651	0.20
31	0.0769	0.22	0.0519	0.25	0.0704	0.19
32	0.0723	0.22	0.0479	0.33	0.0659	0.19
33	0.0955	0.20	0.0430	0.37	0.0818	0.18
34	0.0883	0.18	0.0439	0.32	0.0767	0.16
35	0.0648	0.22	0.0373	0.36	0.0576	0.19
36	0.0686	0.20	0.0347	0.30	0.0598	0.18
37	0.0876	0.20	0.0436	0.26	0.0761	0.17
38	0.0559	0.23	0.0581	0.26	0.0565	0.18
39	0.0576	0.27	0.0484	0.30	0.0552	0.22
40	0.0446	0.30	0.0472	0.29	0.0453	0.23
41	0.0354	0.31	0.0525	0.23	0.0399	0.22
42	0.0171	0.41	0.0512	0.25	0.0260	0.24
43	0.0134	0.54	0.0323	0.28	0.0183	0.32
44	0.0083	0.57	0.0370	0.27	0.0158	0.27
45	0.0113	0.49	0.0281	0.31	0.0157	0.30
46	0.0071	0.60	0.0459	0.26	0.0173	0.26
47	0.0029	0.95	0.0111	0.50	0.0051	0.48
48	0.0048	0.75	0.0227	0.36	0.0095	0.38
49	0.0007	1.36	0.0179	0.48	0.0052	0.46
50	0.0067	0.77	0.0176	0.41	0.0096	0.44
51	0.0004	1.32	0.0113	0.62	0.0033	0.54
52	0.0000	0.00	0.0062	0.62	0.0016	0.59
53	0.0000	0.00	0.0079	0.72	0.0021	0.73
54	0.0000	0.00	0.0068	0.75	0.0018	0.74
55	0.0000	0.00	0.0072	0.67	0.0019	0.66
56	0.0017	1.24	0.0036	0.84	0.0022	0.78
57	0.0004	1.37	0.0049	0.84	0.0016	0.73
58	0.0000	0.00	0.0052	0.90	0.0014	0.91
59	0.0015	1.38	0.0003	1.46	0.0012	1.28
60	0.0011	1.41	0.0012	1.10	0.0011	1.02
61	0.0021	1.34	0.0037	0.85	0.0025	0.87
62	0.0026	1.10	0.0026	0.89	0.0026	0.83
63	0.0000	0.00	0.0035	0.94	0.0009	0.90
64	0.0000	0.00	0.0051	0.67	0.0013	0.64
65	0.0004	1.30	0.0038	0.84	0.0013	0.69
66	0.0000	0.00	0.0057	1.01	0.0015	0.96
67	0.0012	1.36	0.0061	0.79	0.0025	0.68
68	0.0000	0.00	0.0030	0.84	0.0008	0.80
69	0.0000	0.00	0.0016	1.17	0.0004	1.13
70	0.0000	0.00	0.0037	0.86	0.0010	0.82
71	0.0000	0.00	0.0000	0.00	0.0000	0.00
72	0.0000	0.00	0.0016	1.03	0.0004	1.00
73	0.0000	0.00	0.0006	1.45	0.0002	1.44
74	0.0000	0.00	0.0000	0.00	0.0000	0.00
75	0.0000	0.00	0.0023	1.01	0.0006	0.97
76	0.0000	0.00	0.0000	0.00	0.0000	0.00
77	0.0000	0.00	0.0018	1.37	0.0005	1.35
78	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
80	0.0007	1.36	0.0000	0.00	0.0005	1.36
n	600		650		1 250	

Appendix 3c: Estimates of proportion at length (all otoliths collected) with c. v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2007–08.

P.i., proportion of fish in length class; c.v., coefficient of variation

					Bottom trawl	
Length	Northern subarea		Southern subarea		SNA 2	
(cm)	*P.i.*	c.v.	*P.i.*	c.v.	*P.i.*	c.v.
20	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
22	0.0000	0.00	0.0000	0.00	0.0000	0.00
23	0.0000	0.00	0.0000	0.00	0.0000	0.00
24	0.0004	1.44	0.0000	0.00	0.0003	1.44
25	0.0040	0.48	0.0000	0.00	0.0031	0.49
26	0.0181	0.32	0.0080	0.89	0.0158	0.30
27	0.0376	0.16	0.0064	1.01	0.0305	0.16
28	0.0619	0.16	0.0115	0.81	0.0505	0.17
29	0.0968	0.13	0.0479	0.47	0.0857	0.13
30	0.1029	0.11	0.0519	0.43	0.0914	0.11
31	0.0971	0.13	0.0500	0.41	0.0864	0.12
32	0.0731	0.14	0.0608	0.47	0.0703	0.14
33	0.0631	0.13	0.0390	0.34	0.0577	0.12
34	0.0641	0.14	0.0957	0.34	0.0712	0.14
35	0.0589	0.15	0.0866	0.25	0.0652	0.13
36	0.0526	0.13	0.0946	0.30	0.0621	0.14
37	0.0557	0.13	0.0524	0.31	0.0549	0.12
38	0.0477	0.19	0.0590	0.30	0.0502	0.16
39	0.0292	0.22	0.0550	0.34	0.0350	0.19
40	0.0400	0.22	0.0474	0.36	0.0417	0.19
41	0.0248	0.23	0.0233	0.50	0.0244	0.21
42	0.0142	0.31	0.0284	0.46	0.0174	0.26
43	0.0131	0.30	0.0100	0.67	0.0124	0.27
44	0.0090	0.35	0.0342	0.41	0.0147	0.27
45	0.0075	0.38	0.0149	0.59	0.0092	0.33
46	0.0057	0.42	0.0072	0.85	0.0060	0.38
47	0.0046	0.57	0.0126	0.72	0.0064	0.45
48	0.0030	0.56	0.0122	0.74	0.0051	0.47
49	0.0022	0.66	0.0088	0.71	0.0037	0.48
50	0.0024	0.72	0.0060	0.96	0.0032	0.57
51	0.0013	0.81	0.0033	1.11	0.0018	0.65
52	0.0011	0.77	0.0046	1.22	0.0019	0.73
53	0.0010	1.04	0.0037	1.42	0.0016	0.89
54	0.0010	0.92	0.0046	1.23	0.0018	0.78
55	0.0003	1.46	0.0046	1.17	0.0013	0.99
56	0.0003	1.23	0.0000	0.00	0.0002	1.23
57	0.0007	1.37	0.0026	1.07	0.0011	0.83
58	0.0014	0.82	0.0093	0.68	0.0032	0.53
59	0.0001	1.40	0.0000	0.00	0.0000	1.40
60	0.0009	1.36	0.0031	1.25	0.0014	0.89
61	0.0003	1.43	0.0023	1.39	0.0007	1.04
62	0.0000	0.00	0.0015	1.37	0.0003	1.33
63	0.0012	0.83	0.0015	1.41	0.0012	0.71
64	0.0000	0.00	0.0000	0.00	0.0000	0.00
65	0.0006	1.04	0.0053	0.99	0.0016	0.76
66	0.0000	0.00	0.0052	0.94	0.0012	0.88
67	0.0000	0.00	0.0049	0.96	0.0011	0.95
68	0.0000	0.00	0.0011	1.40	0.0002	1.36
69	0.0000	0.00	0.0075	1.03	0.0017	1.03
70	0.0000	0.00	0.0015	1.37	0.0003	1.33
71	0.0003	1.43	0.0023	1.43	0.0007	1.10
72	0.0000	0.00	0.0011	1.39	0.0002	1.36
73	0.0000	0.00	0.0015	1.39	0.0003	1.35
74	0.0000	0.00	0.0000	0.00	0.0000	0.00
75	0.0000	0.00	0.0000	0.00	0.0000	0.00
76	0.0000	0.00	0.0000	0.00	0.0000	0.00
77	0.0000	0.00	0.0048	1.10	0.0011	1.07
78	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
80	0.0000	0.00	0.0000	0.00	0.0000	0.00
n	3 197		350		3 547	

Appendix 3d: Estimates of proportion at length (all otoliths collected) with c. v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2008–09.

P.i., proportion of fish in length class; c.v., coefficient of variation

Length	Northern subarea		Southern subarea		Bottom trawl SNA 2	
(cm)	*P.i.*	c.v.	*P.i.*	c.v.	*P.i.*	c.v.
20	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
22	0.0000	0.00	0.0000	0.00	0.0000	0.00
23	0.0000	0.00	0.0000	0.00	0.0000	0.00
24	0.0000	0.00	0.0000	0.00	0.0000	0.00
25	0.0016	1.03	0.0000	0.00	0.0012	1.03
26	0.0023	0.65	0.0062	1.15	0.0033	0.62
27	0.0150	0.36	0.0210	0.65	0.0166	0.31
28	0.0258	0.31	0.0261	0.66	0.0258	0.28
29	0.0481	0.19	0.0249	0.46	0.0420	0.18
30	0.0611	0.16	0.0492	0.31	0.0580	0.14
31	0.0625	0.15	0.0501	0.25	0.0593	0.13
32	0.0872	0.14	0.0478	0.34	0.0768	0.13
33	0.0819	0.15	0.0445	0.35	0.0720	0.13
34	0.1003	0.12	0.0442	0.32	0.0856	0.11
35	0.0710	0.14	0.0387	0.34	0.0625	0.13
36	0.0724	0.11	0.0321	0.29	0.0618	0.10
37	0.0728	0.13	0.0447	0.25	0.0654	0.12
38	0.0561	0.15	0.0577	0.26	0.0565	0.13
39	0.0628	0.19	0.0517	0.28	0.0599	0.16
40	0.0430	0.20	0.0477	0.28	0.0442	0.17
41	0.0354	0.22	0.0513	0.23	0.0396	0.16
42	0.0231	0.26	0.0508	0.25	0.0304	0.19
43	0.0192	0.27	0.0322	0.27	0.0226	0.20
44	0.0153	0.32	0.0354	0.29	0.0206	0.21
45	0.0102	0.33	0.0289	0.29	0.0151	0.22
46	0.0054	0.44	0.0471	0.25	0.0164	0.22
47	0.0039	0.43	0.0118	0.47	0.0060	0.31
48	0.0044	0.48	0.0224	0.34	0.0091	0.29
49	0.0020	0.63	0.0186	0.45	0.0064	0.38
50	0.0049	0.58	0.0183	0.40	0.0084	0.34
51	0.0011	0.92	0.0101	0.66	0.0035	0.52
52	0.0009	0.77	0.0060	0.63	0.0023	0.47
53	0.0002	1.36	0.0084	0.65	0.0023	0.62
54	0.0012	0.72	0.0067	0.74	0.0027	0.55
55	0.0012	0.74	0.0071	0.66	0.0028	0.50
56	0.0010	0.84	0.0044	0.77	0.0019	0.56
57	0.0020	0.72	0.0048	0.87	0.0028	0.55
58	0.0005	1.37	0.0052	0.92	0.0017	0.79
59	0.0013	0.98	0.0003	1.46	0.0011	0.91
60	0.0005	1.07	0.0011	0.88	0.0006	0.66
61	0.0011	0.88	0.0037	0.85	0.0018	0.61
62	0.0007	1.27	0.0020	0.99	0.0011	0.81
63	0.0000	0.00	0.0035	0.97	0.0009	0.92
64	0.0000	0.00	0.0043	0.74	0.0011	0.72
65	0.0002	1.19	0.0036	0.86	0.0011	0.74
66	0.0000	0.00	0.0059	0.93	0.0015	0.88
67	0.0000	0.00	0.0060	0.79	0.0016	0.75
68	0.0000	0.00	0.0026	0.91	0.0007	0.87
69	0.0000	0.00	0.0015	1.14	0.0004	1.10
70	0.0000	0.00	0.0036	0.85	0.0009	0.81
71	0.0000	0.00	0.0000	0.00	0.0000	0.00
72	0.0000	0.00	0.0012	1.22	0.0003	1.18
73	0.0000	0.00	0.0005	1.46	0.0001	1.45
74	0.0000	0.00	0.0000	0.00	0.0000	0.00
75	0.0000	0.00	0.0023	0.99	0.0006	0.96
76	0.0000	0.00	0.0000	0.00	0.0000	0.00
77	0.0000	0.00	0.0018	1.39	0.0005	1.36
78	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
80	0.0002	1.33	0.0000	0.00	0.0002	1.33
n	2 661		798		3 459	

Appendix 4a: Estimated mean weight-at-age (kg) and c.v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2007–08.

c.v., coefficient of variation

					Bottom trawl	
Age	Northern subarea		Southern subarea		SNA 2	
(years)	Mean	c.v.	Mean	c.v.	Mean	c.v.
1	–	–	–	–	–	–
2	0.36	1.02	–	–	0.36	1.02
3	0.52	0.08	0.57	0.06	0.53	0.06
4	0.55	0.05	0.71	0.10	0.59	0.04
5	0.61	0.03	0.97	0.06	0.69	0.03
6	0.68	0.03	1.12	0.30	0.78	0.10
7	0.88	0.06	1.52	0.05	1.03	0.04
8	1.05	0.04	1.21	0.31	1.08	0.09
9	1.16	0.05	1.95	0.12	1.34	0.05
10	1.38	0.08	3.05	0.10	1.76	0.07
11	1.22	0.27	1.61	0.41	1.31	0.23
12	1.51	0.13	2.49	0.46	1.73	0.16
13	1.84	0.20	3.58	1.06	2.24	0.28
14	2.33	0.64	–	–	2.33	0.64
15	2.07	0.41	4.33	1.01	2.58	0.40
16	4.74	0.99	–	–	4.74	0.99
17	2.15	0.34	4.49	0.28	2.68	0.24
18	–	–	4.96	0.27	4.96	0.29
19	–	–	–	–	–	–
>19	2.83	0.26	6.58	0.08	3.68	0.16

Appendix 4b: Estimated mean weight-at-age (kg) and c.v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2008–09.

c.v., coefficient of variation

					Bottom trawl	
Age	Northern subarea		Southern subarea		SNA 2	
(years)	Mean	c.v.	Mean	c.v.	Mean	c.v.
1	–	–	–	–	–	–
2	–	–	–	–	–	–
3	0.51	0.10	0.55	0.24	0.52	0.10
4	0.59	0.03	0.70	0.05	0.62	0.03
5	0.80	0.07	0.93	0.06	0.84	0.05
6	0.77	0.04	1.28	0.03	0.90	0.03
7	0.87	0.04	1.52	0.06	1.04	0.04
8	1.05	0.03	1.88	0.03	1.27	0.03
9	1.13	0.06	2.15	0.04	1.40	0.04
10	1.26	0.03	2.48	0.06	1.58	0.04
11	1.59	0.07	2.90	0.05	1.93	0.05
12	1.76	0.18	–	–	1.76	0.19
13	1.82	0.26	2.95	0.43	2.11	0.23
14	2.02	0.23	5.17	1.04	2.84	0.37
15	–	–	4.53	1.09	4.53	1.09
16	2.22	1.08	–	–	2.22	1.08
17	–	–	–	–	–	–
18	2.48	1.08	4.06	0.17	2.90	0.49
19	5.63	1.03	4.31	0.08	5.28	0.66
>19	4.24	0.17	5.94	0.05	4.69	0.12

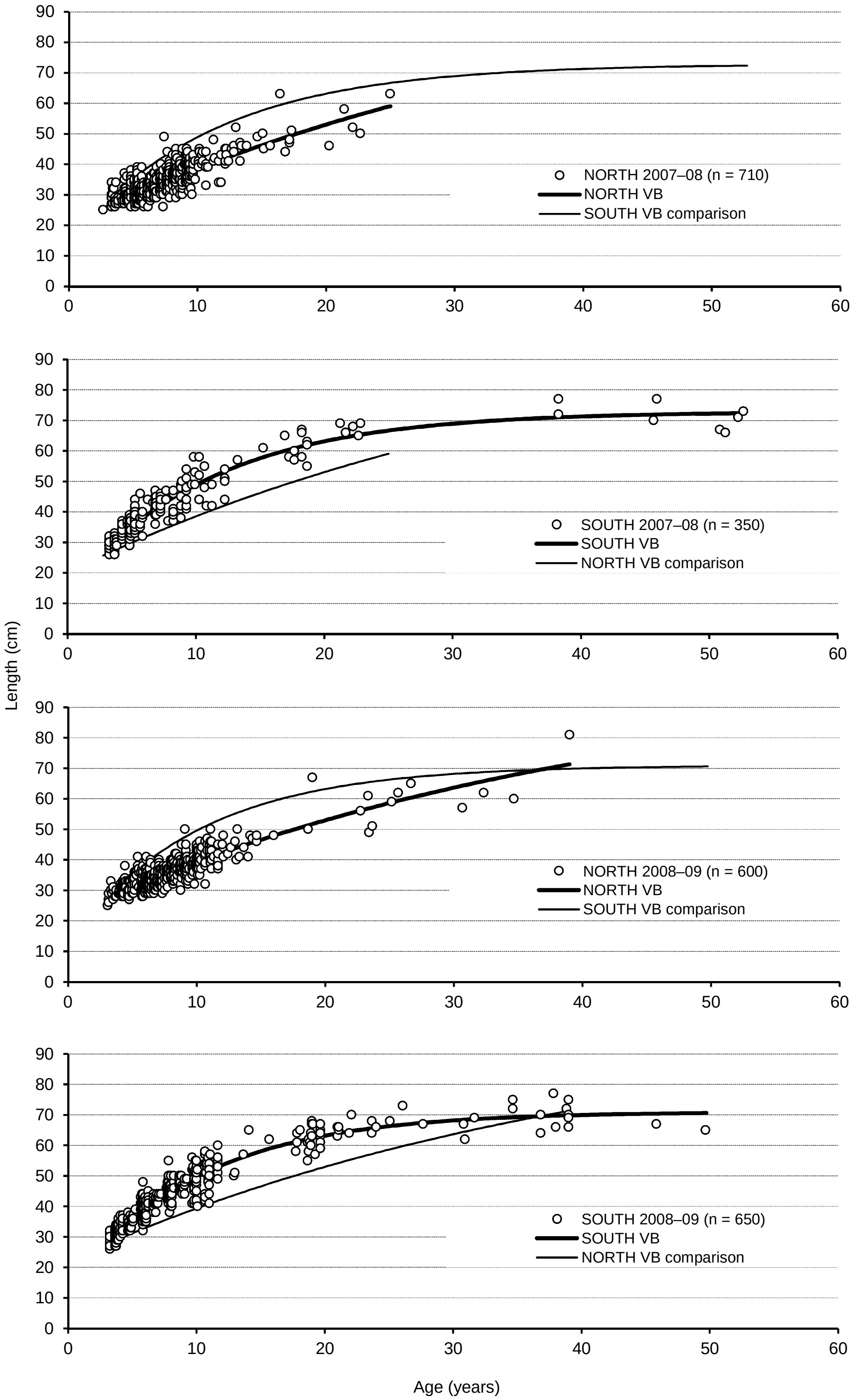
Appendix 5a: Estimated mean length-at-age (cm) and c.v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2007–08.
c.v., coefficient of variation

					Bottom trawl	
Age	Northern subarea		Southern subarea		SNA 2	
(years)	Mean	c.v.	Mean	c.v.	Mean	c.v.
1	–	–	–	–	–	–
2	25.00	1.02	–	–	25.00	1.02
3	28.42	0.03	29.44	0.05	28.65	0.06
4	29.05	0.02	31.83	0.04	29.68	0.04
5	30.09	0.01	35.56	0.02	31.32	0.03
6	31.36	0.01	36.97	0.19	32.63	0.10
7	34.17	0.02	41.74	0.02	35.88	0.04
8	36.44	0.02	38.44	0.26	36.89	0.09
9	37.85	0.02	45.48	0.04	39.57	0.05
10	40.33	0.03	53.44	0.04	43.29	0.07
11	38.27	0.17	42.73	0.37	39.28	0.23
12	41.55	0.08	49.85	0.45	43.43	0.16
13	44.74	0.16	57.00	1.06	47.51	0.28
14	48.86	0.64	–	–	48.86	0.64
15	46.75	0.40	61.00	1.01	49.97	0.40
16	63.00	0.99	–	–	63.00	0.99
17	47.30	0.31	61.65	0.26	50.54	0.24
18	–	–	63.79	0.25	63.79	0.29
19	–	–	–	–	–	–
>19	52.09	0.18	70.68	0.03	56.29	0.16

Appendix 5b: Estimated mean length-at-age (cm) and c.v.s for snapper sampled year-round from the SNA 2 and subarea strata bottom trawl fisheries in 2008–09.
c.v., coefficient of variation

					Bottom trawl	
Age	Northern subarea		Southern subarea		SNA 2	
(years)	Mean	c.v.	Mean	c.v.	Mean	c.v.
1	–	–	–	–	–	–
2	–	–	–	–	–	–
3	28.22	0.04	29.01	0.23	28.43	0.10
4	29.88	0.01	31.62	0.02	30.33	0.03
5	33.11	0.03	35.10	0.02	33.63	0.05
6	32.67	0.01	39.28	0.01	34.40	0.03
7	34.24	0.01	41.89	0.02	36.24	0.04
8	36.66	0.01	45.13	0.01	38.87	0.03
9	37.41	0.02	47.40	0.02	40.02	0.04
10	39.10	0.01	49.73	0.02	41.88	0.04
11	42.40	0.02	52.70	0.02	45.09	0.05
12	44.02	0.15	–	–	44.02	0.19
13	44.40	0.20	52.95	0.41	46.63	0.23
14	46.31	0.21	65.00	1.04	51.20	0.37
15	–	–	62.00	1.09	62.00	1.09
16	48.00	1.08	–	–	48.00	1.08
17	–	–	–	–	–	–
18	50.00	1.08	59.49	0.15	52.48	0.49
19	67.00	1.03	60.71	0.03	65.36	0.66
>19	59.96	0.06	68.09	0.02	62.08	0.12

Appendix 6: von Bertalanffy growth curves and scatterplots of age-length data for snapper sampled from the SNA 2 subarea bottom trawl fisheries in (a) 2007–08 and (b) 2008–09 (Note: *n*, sample size). Age is decimalised as of the month of collection relative to an assumed January 1 "birthdate".



Appendix 7: Summary of large-scale external tag-recapture experiments undertaken on the east coast of New Zealand indicating the number of recaptured snapper that had migrated to the SNA 2 stock.

Period of tag release programme	Principal purpose for research	Stock and (substock) localities	External tag type	Number of tagged releases	Number of recaptures in SNA 2	Statistical area released	Statistical area recovered	Research organisation	Information source
1954–1963	Movement	SNA 1 (East Northland, Hauraki Gulf, Bay of Plenty), SNA 2 (East Coast)	Pig ring, operculum strap, Petersen disc	7 366	1 (0.01%)	008	013	NZ Marine Department	Paul (1967)
1974–1977	Movement	SNA 1 (East Northland, Hauraki Gulf, Bay of Plenty)	Spaghetti (lock-on, anchor, dart)	15 215	0			NZ Ministry of Agriculture and Fisheries	Crossland (1976, 1982)
1983	Biomass	SNA 1 (Bay of Plenty)	Spaghetti (lock-on)	8 448	Unknown	Unknown	Unknown	NZ Ministry of Agriculture and Fisheries	Unpublished data
1984	Biomass	SNA 1 (East Northland, Hauraki Gulf)	Spaghetti (lock-on)	~20 000	7 (0.04%)	Unknown	2 from 011 3 from 012 2 from 013	NZ Ministry of Agriculture and Fisheries	Unpublished data
2008	Ecological	SNA 1 (Hauraki Gulf)	Spaghetti (dart)	~10 000	1 (0.01%)	007	012	National Institute of Water and Atmospheric Research	Unpublished data