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EXECUTIVE SUMMARY

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Annual catch sampling of trevally for length and age from commercial fisheries was conducted in TRE 1 and TRE 7 between 1997–98 and 2002–03. This report presents a review of the data, funded by the Ministry of Fisheries under projects TRE2004/01 and TRE2004/02. The specific objectives are to review and summarise the historical biological data (including length frequency, sex ratio, otoliths, and reproductive condition data) for trevally collected from the shed sampling programme and other sources and the use of these data as inputs into a stock assessment.

Summaries of the TRE 1 and TRE 7 commercial catch by the main fishing method, area, and month were determined for 1996–97 to 2003–04. Trevally research length and age data sampled between 1997–98 and 2002–03 from the TRE 1 (6 years) and TRE 7 (4 years) stocks were investigated, and, where possible, spatial and temporal summaries made for method and sub-area sample collections. Other aspects, such as growth, sampling strategies, and ageing of trevally were reviewed to determine the likely sources of error and reasons for uncertainty in trevally age estimates.

Catch-at-length compositions for the purse seine and single trawl methods in TRE 1 and single trawl and pair trawl methods in TRE 7 show that, although considerable variability exists between fishing methods, they are thought to be representative in describing the fishing mortality by length class for that fishing year.

In the TRE 1 fishery it is difficult to determine any consistent trend in the progression of year classes in the age compositions from one year to the next. Year class strength progression in TRE 7 appears more apparent for some year classes, especially for groups of year classes with relatively similar strengths. All TRE 1 and TRE 7 catch-at-age compositions comprise a broad range of age classes and a consistently high proportion (5–10%) of fish 20 years and older.

Similarities in relative strengths of adjacent age classes may be a result of a “smoothing” in the catch-at-age compositions, where adjacent age classes most often appear to be of a similar relative strength to each other, and strong and weak year classes become less apparent. Misinterpretation of growth zones (in difficult otolith sections) and inaccurate determination of the margin and/or its relativity to the collection and birth dates are likely to be the main contributing factors leading to ageing error. Trevally is a difficult species from which to attain high levels of age agreement. It may not be possible to get accurate and consistent patterns of year class strengths in catch-at-age data.

The sampling of landings for length and age, although at times representative of the fishery extraction in that year, can vary considerably between years because of the sub-area of collection. It was not possible to conclude from the data whether heterogeneity in age structure exists within the TRE 1 and TRE 7 stocks. Heterogeneity appears to exist in the length structure of trevally from TRE 7, with fish from the Far North observed to grow to a larger size than those from most other areas. Future sampling may be improved if the spatial variation in the fishery is well accounted for.

Otolith samples from purse seine landings appear especially prone to sampling bias, whereby otolith subsamples are often collected in an inconsistent manner, with either too large a sample taken from a single landing or samples taken predominantly from one sub-area, and this may cause variability in catch-at-age estimates.

Past catch sampling designs have proved to be largely inadequate to achieve the specified mean weighted coefficient of variation target of 0.20. Catch sampling optimisations indicate significantly more otoliths need to be collected in order to achieve the specified MWCV target. It is largely

unknown to what degree precision is reduced by ageing error, and whether precision is affected more by an age-length key or the random age sampling approach.

TRE 1 single trawl appears to capture a wider representative range of sizes and ages of trevally than purse seine and therefore is likely to have better stock monitoring utility.

Estimates of catch-at-age should be improved to some extent if a more rigorous ageing and sampling standard is adopted. Otoliths could be collected over a relatively narrow time span, and with appropriate recognition of the collection date and birth date for trevally, this may improve the accuracy of readers interpreting margin estimates. To monitor quality control in ageing consistency the inclusion of an agreed-age reference collection may be useful.

1 INTRODUCTION

The purpose of this document is to review the results of the catch sampling conducted in the TRE 1 and TRE 7 fisheries between 1997–98 and 2002–03.

The specific objectives of this work were as follows:

1. To analyse age, length frequency, sex ratio, and reproductive condition data for trevally collected by the shed sampling programmes and from other sources up to the 2003/04 fishing year for input into a stock assessment model.
2. To review and summarise the historical biological data (including length frequency, sex ratio, otoliths, and reproductive condition data) for trevally collected from the shed sampling programme and other sources and the use of these data as inputs into a stock assessment.

1.1 Background

A structured catch sampling programme for the main fishing methods in the TRE 1 and TRE 7 stocks was first developed in the 1997–98 fishing year (Walsh et al. 1999). Annual sampling continued in the TRE 1 fisheries until 2003–04, and in TRE 7 until 2000–01, and the data are summarised in a series of subsequent reports (Walsh et al. 2000, Langley 2001, 2002, 2003, 2004).

The main methods that catch trevally in the TRE 1 stock are single trawl and purse seine and in TRE 7 are single trawl and pair trawl. In the early years of the programme, sampling was undertaken from the two main methods operating in each stock, but was reduced to one method in more recent years; purse seine in TRE 1 and single trawl in TRE 7 (Tables 1 & 2).

An unpublished review of the catch sampling from these fisheries was conducted in September 2000 (A. Langley) summarising data for the first three years (1997–98 to 1999–2000), enabling consideration of the following points:

- the reliability of the current estimates of length and age composition of the catch
- the utility of these data in the assessment (and management) of TRE 1 and TRE 7
- the requirement for ongoing sampling of the catch from these fisheries
- the frequency of future sampling

The purpose of this current review is to include and expand on the summaries presented by Langley, taking specific consideration of the spatial aspect of the length and age collections, and the difficulties involved in the ageing of trevally otoliths. In summary, we propose to summarise details of the sampling programme in TRE 1 and TRE 7 for the entire period 1997–98 to 2002–03, with an aim to investigate the following questions.

- How well do the current estimates of length and age data collected from the fisheries describe the fishing mortality?
- How do the problems of age interpretation arise for a relatively difficult species to age?
- Does the current ageing method provide useful estimates of year class strength for use in an assessment model?
- Does heterogeneity in length and age occur within a stock, and if so, is it possible to adequately sample the fishery for stock assessment purposes?
- What is the most appropriate method of sampling the TRE 1 and TRE 7 stocks: length frequency and age-length key, or a random age sampling approach; from which methods, and at what frequency?

2 HISTORICAL LENGTH AND AGE SAMPLING

The TRE 1 fishery management area occupies the northeast coast of the North Island from North Cape to Cape Runaway and the TRE 7 fishery occupies most of the west coast of New Zealand, with fishing mainly occurring along the North Island's west coast only (Figure 1). Each stock has been further subdivided into a number of sub-areas largely based on the geographic spread of fishing effort for trevally in the respective stocks. These sub-areas were determined by James (1984) in a comprehensive summary of trevally focusing on age determination, population biology, and the commercial fishery. Summaries of the trevally fisheries sampled in the recent catch sampling programme have incorporated the same spatial patterns when and where applicable, and these have been used to investigate heterogeneity in length and age within stocks.

Historical collections of trevally length and age data from TRE 1 in the 1970s summarised by James (1984) are not readily available electronically as only limited catch sampling data from this era are stored on the current Ministry of Fisheries *market* and *age* databases. All the readily accessible data from this era have been summarised for use in the TRE 1 and TRE 7 stock assessments (McKenzie 2007, 2008) and are not presented in this report. Much of the raw early trawl survey data are not readily available and may exist on old magnetic tape archives or stored as hard copy forms. Although collation and analysis of these data were seen to be outside the scope of this report, a brief overview describing the James (1984) collections and findings are given. Samples of trevally length, age, sex ratio, and weight, collected for population analysis (i.e., length and age composition data, length-weight relationship, growth, mortality, and yield estimates), were taken from bottom trawls by research vessels and from commercial purse seine catches during the 1970s and are outlined as follows.

Area	Population type	Method	Year	Sample collections
Western Bay of Plenty	Demersal	Research trawl	1971–74, 1976	Length, age, sex ratio
East Coast North Island	Pelagic	Purse seine	1972–78	Length, age, sex ratio
West Coast New Zealand	Demersal	Research trawl	1971–72, 1974 and 1970, 1973, 1979	Length, age, sex ratio

Although minor differences in sex ratios may have been encountered (size, season, and depth), overall, James (1984) found the numbers of male and female trevally at most lengths and ages were similar, as were growth rates between the sexes and combined them all for growth analysis. There are no recent data updating reproductive condition, sexual maturity, and sex related growth in trevally other than those reviewed by James (1984). Similarly, as trevally show no noticeable sex ratio or growth differences, recent catch sample collections and analyses have been made without reference to sex.

Summaries of trevally length and age sample collections by fishing year and method in the TRE 1 and TRE 7 fisheries between 1997–98 and 2002–03 are given in Tables 1 and 2 and outline the area, season, and sample sizes of the collections. No further analyses of length and age data were undertaken on these collections other than reproducing what was available from the current publications (Walsh et al. 1999, 2000, Langley 2001, 2002, 2003, 2004) and summarising data as best could be done in a spatial and temporal sense.

The main methods that catch trevally in TRE 1 are single trawl and purse seine, each landing on average about 40% and 35% of the annual catch respectively over the last 8 years (Figure 2). The purse seine catch from TRE 1 has increased in recent years and now lands slightly more than that of single trawl. The main methods that catch trevally in TRE 7 are single trawl and pair trawl, each landing on average about 75% and 15% of the annual catch respectively over the last 8 years (Figure 3). Single trawl continues to be the main method to catch trevally in TRE 7, although the pair trawl catch has increased in recent years.

2.1.1 Catch by area and season

The distribution of the TRE 1 catch by statistical area for the single trawl and purse seine fisheries indicates that both methods catch trevally in two spatially discrete locations; East Northland and the Bay of Plenty (Figures 1 & 4). Most of the single trawl catch is from the Far North (Statistical Area 002), and central (009) and eastern (010) Bay of Plenty regions, while purse seine catches are almost entirely from the Far North (002), and western (008) and central (009) Bay of Plenty regions (see Figures 1 & 4). Single trawl landings of trevally are broadly distributed throughout the year with the greatest proportion generally landed between October and April, while purse seine landings are almost exclusively caught from September to January (Figure 5).

The distribution of the TRE 7 catch by statistical area for the single trawl and pair trawl fisheries indicates that most of the catch is landed by single trawl in the northern bounds of the stock from South Taranaki Bight to Ninety Mile Beach (Statistical Areas 040 to 047; Figures 1 & 6). Pair trawl catch by area is relatively small and based mainly on catches around the Kaipara and Manukau Harbours (045) and more recently off Ninety Mile Beach (047) (Figures 1 & 6). Although trevally can be caught all year round in TRE 7, most of the catch is taken between October and April (Figure 7). In most years trevally is targeted during the summer months when fish aggregate before spawning, after the snapper (*Pagrus auratus*) target fishery in spring. However, a greater proportion of target trevally fishing now occurs in the spring to autumn period (Andrew Bond, Sanford Ltd, pers. comm.).

2.1.2 Sampling of landings

Recent catch sampling of the TRE 1 fishery concentrated on landings from both the single trawl and purse seine methods in the first 3 years, then on purse seine landings for the following 3 years (see Table 1, Figure 8).

Although only 12 landings were sampled from the single trawl fishery in 1997–98, they were evenly spread across all sub-areas of TRE 1, while those collected in 1999–2000 numbered over 20 and were only from vessels fishing the Bay of Plenty. The number of landings sampled for length frequency from the purse seine fishery generally reflected the commercial operations in each fishing year. Collections were based on 7–9 large landings of trevally, usually between 20–80 tonnes, caught by one vessel, fishing either in the East Northland and Bay of Plenty sub-areas in varying proportions annually. Samples from these landings are thought to be an adequate representation of the purse seine extraction. There is a voluntary agreement by the fishing industry that purse seine vessels will not operate within the Hauraki Gulf (Dave Allen (MFish), pers comm.), resulting in landings being unobtainable from there. The sampling regime required the sampling of all trevally purse seine landings exceeding 10 t (Langley 2003).

TRE 1 otolith collections were most often sub-sampled from of a portion of those landings sampled for length, and almost entirely from the single trawl fishery in the first 3 years of the of the sampling programme and only from the purse seine fishery in the latter 3 years (see Table 1).

Sampling of TRE 7 landings from 1997–98 to 2000–01 mainly concentrated on the single trawl peak (spring–autumn) season, although some samples were also collected from the pair trawl fishery (1997–98, 1998–99, 2000–01) to determine variability in catch by method (Table 2, Figure 8). The number of single trawl landings sampled for length frequency per year was generally high (26–55), while those from the pair trawl fishery were less frequently sampled (7–14). Landings sampled from both fisheries largely reflected the commercial operation in each fishing year. Most were from a wide range of sub-areas in the northern part of TRE 7 with an occasional catch from South Taranaki Bight and none further south (Figure 8). A high proportion of samples comprised more than one sub-area, reflecting the movement of commercial vessels up and down the coast on a single trip. In the 1997–98 fishing year, single trawl landings were sampled during the off-peak (winter) season to determine whether there was a temporal variability component to the fishery (see Table 2), and these contained a higher proportion of small fish compared to catches in the peak season (Walsh et al. 1999).

TRE 7 otolith samples were mostly collected from the single trawl fishery over the main peak period in which the fishery operates, usually summer to autumn (see Table 2).

2.1.3 TRE 1 single trawl and purse seine length compositions

Final combined annual estimates of the length compositions for the single trawl and purse seine fisheries in TRE 1 are presented in Figure 9, and a summary of the spatial breakdown of the length compositions by sub-area (i.e. Bay of Plenty, East Northland, Hauraki Gulf) is given in Figure 10.

The length compositions for single trawl method were generally broad and contained a higher proportion of small, and at times, larger fish compared to that of purse seine (Figure 9). The length compositions of the single trawl fishery in TRE 1 varied between years and probably reflect the high level of variability in this fishery where trevally is often caught as a bycatch to other species. This is best illustrated with about 50% of the sampled landings in each year being of 1 t or less, although landings over 2 t were not uncommon. Mean weighted coefficient of variation (MWCV) estimates for single trawl length compositions ranged from 0.20 to 0.24.

The final combined annual purse seine length compositions for TRE 1 from 1997–98 to 2002–03 appear relatively similar between years, and mostly comprised a single mode centred between 40–45 cm, with relatively low numbers of small and large fish (Figure 9). Although some variation in the final combined length compositions for purse seine landings exists, generally the inter-annual variation appears low and the landings relatively homogeneous. It is possible that differences in length compositions between years may be influenced by the dominant spatial area of collection (i.e., East Northland or Bay of Plenty). Years where most samples were collected from landings in the Bay of Plenty were 1997–98, 2000–01, 2001–02, whereas in 2002–03 most landings were from East Northland (see Table 1, Figure 10). In 1997–98, purse seine samples collected from East Northland fishery comprised larger fish on average (the mode centred around 45 cm) than those from the Bay of Plenty (the mode centred around 40 cm). By 2002–03, sample collections almost reversed, with Bay of Plenty samples containing a higher proportion of larger fish than those from East Northland. Only in 1999–2000 did the length compositions from the two sub-areas appear relatively similar. Individual landing length frequency summaries were presented by Langley (2002, 2003, 2004) and show that there is variability between landings within a sub-area , where each landing most often reflects a single shot on a large school of fish. This may be the main reason for the variation in the length compositions between years, and therefore not solely related to the sub-area of collection. James (1984) found the most striking feature of purse seine landings was the preponderance of large fish in samples, quite different from the trawl samples where there was a wide range of sizes of fish. He found that purse seine catches from different schools clearly showed similar size compositions and little variation, which supports the pattern seen in landings sampled between 1997–98 and 2002–03. The MWCV estimates for the purse seine length compositions in this recent series ranged from 0.14 to 0.27.

Length samples collected from single trawl landings in 1997–98 from the three sub-areas of TRE 1 comprised fish with considerably different length structures, although the sample sizes are small and may not allow useful comparisons (Figure 10). Those samples collected in 1998–99 (a larger sample size than the previous year) comprised fish from East Northland and Bay of Plenty single trawl landings, and where combined sub-area length compositions were found to be relatively similar. The sample in 1999–2000 appeared broader than the previous year and was caught entirely in the Bay of Plenty. These results indicate that the size composition of the single trawl trevally fishery from the sub-areas of TRE 1 can be highly variable between years and sometimes within years. Unless a comprehensive and rigorous sampling strategy concentrating on trevally target landings from all areas of TRE 1 is employed, the possibility of making good use of this data in its current state seems unlikely.

2.1.4 TRE 1 single trawl and purse seine age compositions

The final combined annual estimates of catch-at-age for single trawl and purse seine landings from TRE 1 are given in Figure 11. The age compositions for both methods are similar, although single trawl landings most often contain a higher proportion of younger fish. That the distributions are relatively similar is reflective of both method summaries using the same underlying age data in the form of an age-length key. The distributions at age over all years for both methods are broad and contain fish in all recruited age classes, with a relatively high proportion (6–14%) of fish 20 years and over. MWCV estimates for single trawl and purse seine age compositions ranged from 0.20 to 0.24 and 0.22 to 0.29 respectively.

In most years there appears to be only moderate variation in year class strength between most age classes both within a year and between years, especially in the mid to older age range, and a noticeable smoothing of the distributions where strong and weak year classes appear less apparent (Walsh et al. 1999). Smoothing in catch-at-age distributions is generally indicative of a species with constant recruitment and little variation in year class strength, or, of ageing error, where incorrect age estimates frequently spill over into adjacent age classes, as is likely the case here, reducing the accuracy of age estimation. In TRE 1, it is difficult to determine any consistent progression of cohorts in the TRE 1 fisheries over the period that the samples have been collected. However, the recruiting 1995 and 1994 year classes (4 and 5 year olds) in 1998–99 appear to progress into the following year (1999–2000) as the dominant year classes but are not clearly discernable to subsequent annual samples. A current assessment of the TRE 1 stock shows the model does not fit well to the catch-at-age data (McKenzie 2007). Trevally is a relatively difficult species to age (see Section 3) and the high level of inter-annual variability in proportions at age may be a result of ageing error, spatial variability and method of collection, or a combination of these factors.

A summary of the otolith collections by age class and sub-area for the TRE 1 fishery is given in Figure 12. Samples collected in 1997–98 contain fish from the range of sub-areas of TRE 1 over most age classes. Those samples from 1998–99, 1999–2000, and 2000–01 were predominantly from the Bay of Plenty with a smaller proportion from mixed or other sub-areas, by and large spread relatively evenly across most age classes. Collections in 2002–03 were largely influenced by samples from East Northland, while those in 2001–02 had disproportionate numbers at age from either East Northland (more younger fish) or the Bay of Plenty (more older fish), and reflect the fishing effort of purse vessels in only those sub-areas. Again, if spatial heterogeneity in age stock composition is an underlying feature of TRE 1, the lack of spatial consistency in age collection may have been a substantial cause of the annual variability seen in the catch-at-age estimates. It was not possible to test for spatial differences in age composition across TRE 1 as otolith collections were either too variable in their sub-area of collection, and in respective age classes, or the sample sizes were too small to allow meaningful comparisons to be made. A purposefully designed programme integrating spatial sampling for age would be required to investigate spatial pattern in the TRE 1 age compositions.

The number and sub-area of collection for otolith samples from the TRE 1 fishery for each year by month between 1997–98 and 2002–03 are given in Figure 13. Over the period of the catch sampling programme, otolith samples from TRE 1 have been collected in an inconsistent manner (by method and season) over the years and at times were not always reflective of the spatial catch in TRE 1. There are also examples in every year where the number of otoliths sampled from a single catch has been from well over 100 fish, exceeding the recommended sample size collected from a single landing, given the otolith collection for the respective stocks generally numbers only 300–500 otoliths in total. In particular, sampling undertaken in 2000–01 and 2001–02 reflects the irregularity with which otolith samples were collected where half of the total otolith sample size, numbering 745 and 360 for these collections respectively, was taken in the last month of the fishing year, reflecting a ‘catch up’ sampling scenario (Figure 13). In addition to this, the entire otolith collection for 2001–02 was made from samples from only two landings, further reflecting a poor sampling strategy. In some years the proposed otolith collections for particular size class intervals were not always met, especially for the very small and very large fish. This was mainly when samples were collected from the purse seine fishery as this method is generally poor at selecting for fish in these size classes. In some instances there was an over-sampling in some of the more common size classes, but this was unlikely to have influenced the results other than to better describe the variability in age about length in the age-length key. Variability in age compositions caused by temporal and spatial differences is likely to be exacerbated if age sampling is not carried out in a consistent manner in each year, and may be further influenced by changes in annual fishing patterns.

2.1.5 TRE 7 single trawl and pair trawl length compositions

Final combined annual length compositions for the single trawl and pair trawl fisheries in TRE 7 are presented in Figure 14. A spatial summary of the length compositions where landings could be readily assigned to sub-area (i.e., Ninety Mile Beach, Kaipara-Manukau, North Taranaki Bight, South Taranaki Bight) is given in Figure 15.

The length compositions for the single trawl fishery were very similar between years showing the same modal peaks and are largely dominated by fish in the 30–45 cm size range (Figure 14). The sample from 1999–2000 appears the least similar of all the years and may be influenced by the strong recruitment of a younger age class (i.e., 4 year olds, see Figure 16). The collections were comprehensive with 13 000–23 000 fish measured annually. The length compositions of the pair trawl fishery were relatively consistent between years, and slightly different to single trawl, having proportionally more fish in the mid to late 30 cm size range (see Figure 14). There also appears to be a slightly higher proportion of large fish (over 50 cm) taken by the pair trawl method. The differences may indicate that the selectivity characteristics are different or that the catch was taken from distinct sub-areas containing different sized trevally to other areas. There was no spatial information available for the pair trawl length compositions to test this theory. MWCVs for single trawl and pair trawl length compositions ranged from 0.08 to 0.14 and 0.13 to 0.27 respectively.

A comparison of the length compositions from the sub-areas of TRE 7 for the single trawl method show that a high level of heterogeneity exists within the stock (see Figure 15). Those collections made in 1997–98 indicate landings from Ninety Mile Beach were generally made up of fish of a broad range of sizes and contain the highest proportion of large fish. Those catches from the Kaipara-Manukau or North Taranaki Bight areas were very similar and comprised mainly small-moderate sized fish, and few large fish over 50 cm. In 1998–99, the same general pattern could be observed although landings from Ninety Mile Beach and North Taranaki Bight had proportionally more small fish than in the previous year. In 1999–2000 and 2000–01, landings from Ninety Mile Beach, Kaipara-Manukau, and North Taranaki Bight did not appear to differ considerably from one another, and were largely made up of a relatively high proportion of small fish in the 30–45 cm size range. Although only one and two landings were collected from the South Taranaki Bight area in 1997–98 and 1999–2000 respectively, they were considerably different from all other areas of TRE 7 with a single dominant mode centred around 40–45 cm. Spatial differences in the length compositions in snapper landings from the west coast (SNA 8) fishery have also recently been determined (Walsh et al. 2006).

The potential for differences in the length composition between sub-areas highlights the importance of ensuring the sampling coverage is representative of the areal distribution of the entire fishery to ensure the collection of an unbiased sample of the length composition of the catch (Langley 2002).

2.1.6 TRE 7 single trawl and pair trawl age compositions

As expected, the single trawl and pair trawl age compositions are relatively similar as both use the same age-length key. Pair trawl appears to have a slightly higher proportion of younger fish than single trawl (Figure 16). The age structure of the TRE 7 fisheries appears broad and comprises various strong and weak year classes, with a relatively high abundance (4–10%) of fish 20 years of age and greater. MWCVs for single trawl and pair trawl age compositions ranged from 0.18 to 0.22 and 0.18 to 0.23 respectively.

There appears to be some general pattern among the age groups of strong and weak year classes progressing through the fishery. The weak 1992 and 1991 year classes (6 and 7 year olds in 1997–98) appear to progress from year to year as do a range of moderate aged fish of average cohort strength and older fish of relatively low strength. However, there is a general inconsistency in the pattern of progressing individual year classes from year to year that may be related to either ageing error or spatial heterogeneity in age within the stock (see ageing section). Despite these misgivings, a recent assessment of the TRE 7 stock achieved a reasonable fit to the catch-at-age data (McKenzie 2008).

A summary of the otolith collections by age class and sub-area for the TRE 7 fishery is given in Figure 17. Samples collected from 1997–98 to 1999–2000 largely consist of fish from the Ninety Mile Beach, North Taranaki Bight, and a combination of mixed sub-areas, while those from 2000–01 were mainly from vessels fishing only the Kaipara-Manukau area. Should spatial differences in age structure occur within TRE 7, as has been shown for west coast snapper (Walsh et al. 2006), then potential exists for variability in the results in catch-at-age estimates if the fishery operates in different areas between years. The area composition of the individual age classes within a given fishing year is relatively similar in otolith collections (Figure 17), meaning that older or younger fish were not disproportionally represented spatially in an annual sampling event.

The number and sub-area (where data were available) of collection for otolith samples from the TRE 7 fishery for each year by month between 1997–98 and 2000–01 is given in Figure 18. Otolith samples have generally been collected in a relatively consistent manner encompassing about 4 months, mainly between December and March. However, there are examples in each year (except 1998–99) where the number of otoliths sampled from a single catch has come from about 100 fish, exceeding the recommended sample size collected from a single landing. Given the large number of mixed sub-area samples in the collections, it is difficult to determine whether the fishery has or has not been adequately represented. Should age samples not be collected in the same consistent manner in each year, then the possibility of temporal and spatial variability in the collections may increase, largely influenced by annual fishing patterns.

2.1.7 Growth of trevally in TRE 1 and TRE 7

Von Bertalanffy growth curves for trevally have been generated from the TRE 1 and TRE 7 otolith collections to show any between-year variability in samples (Figures 19 & 20). It should be noted that these curves are fitted to the commercially caught trevally and do not include the full range of unrecruited age classes that are necessary to estimate population growth parameters. However, in general, the growth of recruited trevally from TRE 1 and TRE 7 appears relatively similar, although a proportion of faster growing large individuals appear more frequently in samples from TRE 7. The TRE 7 age samples produced marginally lower estimates of k and higher estimates of L_{inf} than those from TRE 1 (Tables 3 & 4).

Five of the six TRE 1 age samples presented here generate growth curves and parameter estimates not dissimilar to each other and only the collection made in 1997–98 appears to be slightly different (Table 3). Otoliths sampled from single trawl landings in 1997–98 are the only collection to include samples from the Hauraki Gulf, and have the highest proportion of large individuals (23%) for fish over 49 cm. For their size some of these fish were of a relatively young age, indicating that individual growth variation might be high (see Figure 19). These samples appear to come from a wide range of sub-areas and are not reflective of just an isolated catch or area of collection. Otolith collections from 1998–99 to 2002–03 appear to be absent of these largest trevally and targeted samples for fish in these size classes were seldom achieved, especially from purse seine landings. It appears that both purse seine and single trawl have a relatively low selectivity for the largest fish in TRE 1. Either fish in the larger size classes are rare in the population because of over-fishing, or more likely, few fish in TRE 1 fishery grow to attain a size greater than 49 cm.

Growth estimates for the TRE 7 fishery were generally more similar between years (Table 4) than estimates from TRE 1. Collections in 1997–98 and 2000–01 contained a higher number of fast growing large individuals than in the other years, and subsequently derived the highest estimates of L_{inf}. These fish were usually over 55 cm in length ranging in age from about 15 to 30 years, similar in size and age to the 1997–98 collection from TRE 1. The largest trevally seen are most often from catches in the Far North, especially off the Ninety Mile Beach to North Cape area, (James 1984; fishers pers. comm.) and may be part of a separate substock (Walsh et al. 1999) attaining a maximum size and weight of up to 10 cm longer and 2.5 kg heavier than areas to the south or from TRE 1 (Walsh et al. 2000).

Variations in growth of trevally collected from the TRE 1 and TRE 7 stocks from year to year may be related to a combination of the following factors; inconsistencies in the number of fish collected at each size class in the age-length keys, the fishing method used and the area of collection of the age data, and ageing error.

No estimates of mean length or mean weight-at-age were presented in the catch sampling reports by Walsh et al. (1999, 2000) or Langley (2001, 2002, 2003, 2004), and therefore no easy identifiable comparisons can be made in estimate variations through time. Langley (2002) examined differences in age at length estimates for the 2000–01 otolith collection from the purse seine method to that from 1999–2000 where single trawl was used. The comparison indicated that over the 35–42 cm length range the purse seine sample was generally 1–2 years older than for the single trawl sample (Langley 2002). He concluded that any strong differences in the distribution of age at length between the two methods would necessitate the collection of method specific age-length keys. Aside from growth related factors from cohort density dependence or the onset of maturity with respect to pelagic or demersal phases as suggested by Langley (2002), other potential factors contributing to growth variation are sampling error, spatial heterogeneity in estimates of mean length-at-age (or mean weight-at-age), and ageing error.

3 AGEING TREVALLY

3.1 Otolith preparations

With the introduction of a structured catch sampling programme for the TRE 1 and TRE 7 stocks in the 1997–98 fishing year, NIWA ageing staff held a trevally ageing workshop in February 1999 and set about determining the best approach to age trevally otoliths, establishing a five stage reading protocol (Walsh et al. 1999).

Initially, three methods were tested to determine the most appropriate for use in ageing trevally otoliths. These were: breaking, grinding and burning; baking, embedding, and sectioning; and embedding and thin sectioning. The latter two methods were preferred and it was decided to implement the baking, embedding, and sectioning method in 1997–98 because it was less time consuming and cheaper than thin sections. However, in 1998–99 and for all subsequent collections, it was decided that thin-sectioned otoliths were preferred as early growth bands were more clearly countable and the contrast between the later (including marginal) bands was enhanced (see Walsh et al. 1999).

Other issues such as the position of the first annual increment, development of a readability scale, margin interpretation, and the timing of ring deposition were also discussed and were outlined by Walsh et al. (1999). If there was a discrepancy between the counts by readers, the otolith was rechecked, and the higher count used (Walsh et al. 1999). At other times, when no consensus on readings was reached, the primary reader re-read the otolith and decided on a final reading and age estimate. In the current datasets, no age estimates were derived for individual readers, only ring count and margin interpretations. A trevally otolith reading protocol was developed in April 1998 and a summary of these points is given in Appendix 1.

3.2 Ageing error, time of collection, and otolith readability

James (1984) undertook a detailed investigation into ageing trevally, concentrating on otoliths as the most appropriate structure from which best to determine age, confirming that only one hyaline and opaque zone were laid down annually. For convenience, James adopted 1 January to assign as a birth date for trevally cohorts, following that chosen by Paul (1976) for snapper. The establishment of a birth date allows fish collected during spring and summer, when opaque zones are being formed, to be assigned to the correct age group. James (1984) also examined trevally otolith samples from research trawls undertaken in 1971 and 1973 off Farewell Spit, and found one very strong cohort present from a wide range of ages of fish, concluding that year class strength in trevally varies considerably. The relative year class strength indices for juvenile trevally derived from trawl surveys in the Bay of Plenty (between 1983 and 1991) also suggest high variability in annual recruitment (Langley, unpublished MFish report). If year class strength variation is high at the juvenile stage for trevally, then as with snapper, variation in the year class strength of the recruited stock is expected.

James used two preparation methods; whole otoliths for smaller (hence younger) fish, and the break, polish, and burn method described by Christensen (1964) and Williams & Bedford (1974) for fish older than about 12 years. James found determining the otolith margin in preparations to be a subjective decision particularly for fish with more than about five hyaline zones. He estimated that the errors associated with ageing trevally older than about 8–12 years increase progressively from about ± 1 year for fish up to about 25–30 years to ± 2 years for fish older than this. Although thin section preparations used in this recent study were thought to make future ageing work easier by making the rings more discernable and result in fewer reading errors, it appears that this has not happened. Trevally appears to be a difficult species to attain agreement in age readings regardless of the method of preparation used.

Uncertainty in age estimates can be attributed to three sources of error: inaccuracy, reader imprecision, and reader bias (Davies et al. 2003). Inaccuracy occurs when the interpretation of ring counts does not reflect the true age of the fish, imprecision is when reader ring counts vary for a given fish, while bias occurs when a reader exhibits a general trend of under or over ageing fish relative to other readers' age estimates. Reader imprecision and bias in age estimates most likely result from ambiguous structures in the otolith or poor otolith preparation. This creates uncertainty in a reader's interpretation of annual rings, and leads to reader error. The influence of precision and bias may be partially reduced by using more than one reader, as in this study, but with the inherent difficulty in interpreting trevally otoliths, the problem of reader error and thus ageing error may not easily be resolved. We believe the complexities of determining age estimates for each reader from ring counts and margin interpretations with respect to the time of collections and birth date lie outside the scope of this review and may be trivial given the high level of disagreements between the readers.

It should be noted that although otoliths may be perceived by the uninitiated to comprise the same material, laying down a series of bands representing changes in growth over the fish's life, they are far from identical representations. Each fish's otolith is unique, comprising irregularities in checks and zones in different regions of the otolith, in various degrees of clarity, and it is from these areas that readers must interpret what they perceive to be the correct number of rings (see Appendices 2a–2d). The percentage agreement between readers for each age class for data from the TRE 1 and TRE 7 fisheries (1997–98 to 2002–03), using the first initial reading (ring count) estimates only, are presented in Figure 21 and between reader differences are given in Tables 5 & 6. Except for 1997–98 estimates, the overall percentage agreement across all age classes for the first readings was relatively low at about 40% for all other collections from the TRE 1 and TRE 7 stocks (see Tables 5 & 6), reflecting high relative imprecision. As only the reading (ring count) is used in this summary, and not the margin and its possible influence in determining the final age, there is obviously some degree of error associated with interpreting the results in this manner. However, what it does show is that the level of reader agreement tends to correlate with fish age, whereby increasing age, as would be expected, results in lower levels of agreement and follows James's view of ageing error increasing progressively with fish age, outlined in a previous paragraph. The highest level of agreement for each age class was generally from samples collected in 1997–98, while most other collections had levels of agreement that appeared to be roughly similar, and not noticeably different between stocks (Figure 21). The pattern of the disagreements between readers (except for that from 1997–98) did not appear to show any systematic bias to under or over ageing, being generally evenly spread across the most age classes (Tables 5 & 6). However, in 1997–98, reader 1 appeared to have a consistently lower ring count than reader 2 (see Tables 5 & 6). The level of disagreement appeared to slightly increase with age and some of the larger disagreements (± 3 or more) between readers, although generally infrequent, were obviously reflective of the level of difficulty that ageing trevally poses (see Tables 5 & 6). Although the baking, embedding, and sectioning method (as opposed to thin sectioning) for preparing otolith samples was used only in the 1997–98 collection, it is unknown if this was the sole reason for the higher levels of reader agreement observed. Walsh et al. (1999) recommended the thin section technique for future ageing work as rings were thought to be more readily resolved, resulting in fewer reading errors, although this does not seem to be the case. The comparisons presented here have been made between the most experienced readers; 1 and 2 for the first two years, and 1 and 4 for the remaining years of the collections.

The age assignment of a fish is a function not only of annulus count, but of edge type (margin used here) in relation to date of collection and assigned birth date (Campana 2001). This change in the otolith margin with time of collection and in reference to the birth date of 1 January was acknowledged as an important factor in ageing trevally by James (1984). The implications of not acknowledging the time of collection (date, month, season) with reference to the otolith margin, or the inability to determine the margin correctly, because it is unclear especially in older trevally (Walsh et al. 1999; see Appendices 2b & 2d), is especially important as some age estimates may potentially be under or over-aged by one year relative to the time of collection. As outlined in the first paragraph of Section 3.2, the establishment of a birth date allows fish collected at a certain time of year to be assigned to the correct age group, and is especially important where otolith samples are collected over a lengthy time scale (e.g., over 6 months). The interpretation of the otolith margin in ageing recent collections largely followed that of James (1984) and was also described by Walsh et al. (1999), whereby each otolith is given a reading dependent upon the position of the opaque zone relative to the margin edge. Lines (l) represent a light opaque zone on the margin edge, and those with a translucent edge were graded as being either wide (w) or narrow (n) (see Walsh et al. 1999). Similar to James's findings, the ageing of older fish with their narrower marginal increments, the correct determination of the margin may be reasonably subjective. In determining the final age, line and narrow margins most often derived an age estimate equal to that of the reading, while wide margins usually resulted in age estimates one year greater than the reading. However, as previously mentioned, there is a degree of subjectivity, especially in older fish where the differences between narrow and wide margins may be indistinguishable. For collections made in 1997–98 and 1998–99, the margin reading and its resulting age estimate relative to the birth date were determined for all aged fish. For the remaining datasets, it appears that determination of the final age was not undertaken with the same approach, and most often age estimates were derived largely without recognition of a collection date. Using the 1999–2000 TRE 1 otolith collection as an example, there are instances where some samples have been collected from catches where no length frequency data has been sampled, and the date (and area) of these samples appears to be unknown. As no estimate of each reader's final age was available, with only ring counts and margin estimates given (as outlined in the above paragraphs), age bias plots and average percentage error for otolith readers could not be determined.

Over the period of the recent catch sampling programme, otolith samples from the TRE 1 fishery have not always been collected in a consistent manner, and the method from which otolith samples are collected changed from single trawl to purse seine in 2000–01 (see Figures 12 & 13). Some collections were made over a relatively short period of about two months (i.e., 1999–2000), while others have spanned the entire year (i.e., 2000–01), some with an 8 month break separating the samples within a year (i.e., 2000–01, 2001–02) and those in 2001–02 sampled from only two landings. There are also examples in almost every year of collection from both the TRE 1 and TRE 7 fisheries where the number of otoliths sampled from a single catch has exceeded the recommended sample size. The overall otolith collections are generally small for trevally, between about 300 and 500 otoliths for the respective fisheries, and the common sampling practices would suggest that no more than about 50–60 otoliths be sampled from a single landing, so that the geographic spread of the fishery, and the heterogeneity in the age composition within the stock, should it exist, would be adequately accounted for. From an otolith ageing perspective, it is preferable that the collection of otolith samples be undertaken in a reasonably narrow time period, i.e., no more than 3–4 months to reduce the difficulty in margin interpretation, and hence reduce the potential for increased reader error. However, collections from the TRE 1 fishery in the last 3 years (2000–01 to 2002–03) have been undertaken on the purse seine fishery (a method that can catch trevally at any time of the year), where 7 to 9 landings of trevally are sampled for length and age annually. These landings are sampled from two geographically discrete sub-areas, East Northland and the Bay of Plenty (see Figure 4), often in varying proportions and erratically throughout each fishing year (see Figure 13). It is therefore unlikely that otolith collections will be directly comparable should heterogeneity in age structure exist within the stock. Secondly, although final catch-at-age proportions from the purse seine fishery are broad and appear to contain as many age classes as samples from the single trawl fishery, it is largely unknown if samples collected from a selective method such as purse seine reflect the underlying recruited population age structure. Thirdly, although perhaps not as readily acknowledged by otolith readers (and perhaps some analysts/report writers) as well as it might be, margin interpretation of the otolith edge from purse seine sample collections is made much more difficult as landings often encompass the entire year. However, readers should be well aware of the date of collection when reading otoliths and therefore able to make adjustments in margin interpretation for samples collected over a broader time scale than 3–4 months.

Summaries of the initial margin reading estimates in trevally otolith samples aged from the TRE 1 and TRE 7 collections between 1997–98 and 2002–03 are given in Figures 22 and 23. Three readers were used in the first two years, and the same two readers have been involved in ageing the collections for the last 4 years, one of which has aged otoliths from all collections. Generally there appears to be a relatively high incidence of wide and narrow margin readings as opposed to line readings, especially in more recent years and an inconsistency in margin reading relating to the time of the collections. It would appear unlikely that all three margin reading estimates (lines, wides, narrows) would be present in otolith readings where samples were generally collected over a relatively short time period as in 1997–98 and 1998–99 in TRE 7 (Figure 23). Similarly, it would seem unlikely that all margin reading estimates were in similar relative proportions from the two otolith collections sampled 8 months apart (January and September) as occurred in 2001–02 (see Figure 13). The regularity of narrow and wide readings from the same landings may be an anomaly of the difficulty in determining the margin edge correctly (as previously mentioned), especially in older fish. James (1984) found zones at the otolith edges were too narrow to permit the type of edge, and thus age, to be determined precisely. However, overall there was general consistency in the relative proportions of margin interpretations from collections in 1999–2000 to 2002–03, where the same two readers have been used (see Figures 22 & 23). The incidence of "unknown" (Figures 22 & 23 "?") margin readings is also high in most sample collections and is indicative of the inherent difficulty in ageing trevally otoliths. Walsh et al. (1999) determined that thin section preparations allowed the reader to magnify marginal growth zones, significantly aiding resolution and resolving age differences, but this does not seem obvious in these results. Also, in some samples the date of the otolith collection may have been unknown, which, mentioned above, is an important factor in assigning the sample to the correct age group relative to the birth date. Should this be the case then it will undoubtedly have implications for determining an accurate final age estimate and may be a contributing factor responsible for the inconsistencies in year class strengths that are apparent in the catch-at-age time series plots.

The perceived readability of each prepared otolith section was given a ranking score between 1 and 5 based on the difficulty in determining the correct age (see Appendix 1 for ranking scores). A summary of the scores by each reader for the TRE 1 and TRE 7 collections between 1998–99 and 2002–03 (no scoring was undertaken in 1997–98) is given in Figures 24 and 25 and again outlines the relative difficulties in the readability of trevally otoliths. Most readers allocated a score of between 2 and 3 (‘very good’ and ‘ok’) in the earlier collections that reflected a reading estimate expected to be within 1 to 2 years of the true reading. This range broadened with the later collections to include some scores (approximating 20% in some years) of 4 and 5 (‘difficult’ and ‘not readable’), whereby most readings on average overall were estimated to be within 2 years of the true reading. A very low proportion of readings over all years in both TRE 1 and TRE 7 was given a score of 1, the otolith preparation being categorised as ‘excellent’ and ‘no doubt’ about the estimate. The summary of these ranking scores, although slightly variable over time, again demonstrates how difficult a species trevally is to age from otolith sections.

Finally, there may be some vagaries with respect to where the responsibility lies in determining the final agreed age, a task undertaken either by the otolith reader or the analyst/report writer. However, all age data collections for trevally between 1997–98 and 2002–03 reviewed here have associated initial age readings, margin interpretations, and otolith readability estimates for each reader, and include a final estimate of “agreed” age, all provided by the otolith readers. Casselman (1990) automated the calculation of age from annulus count, edge type (margin), and collection date, so as to remove the possibility of calculation error from the age (otolith) reader. However, if the margin is unclear, as is often the case in trevally otoliths, and the otolith reader makes no reference to the collection date (see paragraph 5 of Section 3.2), then a poor interpretation of the margin is likely to increase the potential for ageing error. It may be that a different approach for readers attaining agreement on the final age may need to be developed (i.e., forcing a margin upon readers for samples collected within a specific time period, and ensuring readers are aware of the collection date). Similarly, for monitoring quality control in ageing consistency the inclusion of an agreed-age reference collection based on samples from current and past otolith collections would be relevant and may also provide a means for determining long term drift in age interpretation.

4 CATCH SAMPLING OPTIMISATIONS

Catch sampling provides information on the exploitation characteristics of the main fishing methods. It also provides information on the size and or age composition of the stock critical for modelling mortality and recruitment variation. Because highly selective fishing methods like purse seine often provide a poor representation of the underlying stock productivity, the goals of catch sampling are not always achieved by sampling only a single fishing method. The single trawl method accounts for a similar proportion of the annual TRE 1 catch to purse seine, but is likely to be more representative capturing a wider range of sizes and ages than purse seine, therefore having better stock monitoring utility (see Figures 10 & 11).

The two common approaches used to collect catch-at-age information from New Zealand fish stocks are: the collection of a random length sample and an age-length key, or a random sample for age. The age-length key approach has been used for describing trevally catch-at-age since 1997–98.

The MWCV averaged over all sampled age classes is a measure of sampling precision. Since 1997–98 the target MWCV for TRE 1 and TRE 7 sampling programmes has been 0.20, a target seldom achieved (see Figures 11 & 16). For stock assessment, the greater the precision on the catch-at-age estimates, the higher their utility. We suggest that that a MWCV of 0.20 should be more strongly adhered to in future catch sampling programmes. For snapper, Davies & Walsh (2003) determined the most likely explanation for the characteristically high catch-at-age MWCV for East Northland relative to other SNA 1 stocks was the broader age composition with few dominant age classes in catches. This situation appears to be the same for trevally sampled from TRE 1 and TRE 7, where all catch-at-age collections between 1997–98 and 2002–03 have been broad and contained a high proportion of old fish. A lack of defined strong and weak year classes in the distributions, reflecting ageing error (N. Davies, pers. comm.) may further reduce the overall MWCV. Evidence suggests that trevally year class strength varies considerably (James 1984, Langley unpublished MFish report - see Section 3.2 first paragraph). Consequently, more definition in year class strength should be apparent in sample collections than are currently observed.

4.1 Methods

Trevally catch landing data collected by NIWA between 1997–98 and 1998–99 was used to derive MWCVs for a range of annual sampling designs. Designs varied between approaches relative to the number of landings sampled and the number of otoliths collected (Table 7). A series of bootstrap optimisations were run for the length frequency and age-length key, and the random age sampling approaches. The bootstrap methodology employed is described in Davies et al. (2003) and Davies & Walsh (2003).

4.2 Results and Discussion

Between 1997–98 and 2002–03 the number of otoliths collected annually from each stock to produce age-length keys ranged between 310 and 745 (see Tables 1 & 2). Between 7 and 9 landings were sampled for length frequency from the TRE 1 purse seine fishery, and for the TRE 1 and TRE 7 single trawl fisheries between 12 and 55 samples were taken (see Tables 1 & 2). On average, the level of sampling on TRE 1 purse seine and single trawl fisheries did not achieve the target MWCV of 0.20 (Figure 11). The optimisation results indicate that given the maximum number of purse seine samples (7–9) in the fishery, an age-length key of 900–1000 otoliths would be required to achieve MWCVs close to 0.20 (Table 8). Given an age-length key of 900–1000 otoliths is collected from TRE 1, the optimisation results also indicate that only 10 single trawl landings sampled for length would be required to achieve a MWCV of 0.20 for this fishery (Table 9). These results assume that the collection of otoliths is spread proportionally across the sampled landings so that no single landing contributes unduly high numbers of samples to the age-length key.

The level of age and length sampling from the TRE 7 pair and single trawl fishery has, by and large, produced adequate MWCVs (see Figure 16). The optimisation results indicate an age-length key based on 700–900 otoliths is adequate to describe the single trawl fishery with 20–30 landings sampled (Table 10).

A random age sampling approach applied to a 7–9 landing TRE 1 purse seine fishery would require the collection of substantially more otoliths than an age-length key approach (Table 11). Similarly, a random age sampling approach implemented in the TRE 1 and TRE 7 single trawl fisheries would require more otoliths (1500–1750) than an age-length key approach based on the same number of sampled landings (Tables 12 & 13). In addition, where multiple methods are sampled and independent random age collections are required (e.g., for the TRE 1 purse seine and single trawl fisheries), more than double the number of otoliths of the age-length key approach would need to be collected and is likely to be uneconomic.

It is important to note that MWCVs given in the previous trevally catch sampling reports (Walsh et al. 1999, 2000, Langley 2001, 2002, 2003, 2004) do not take into account ageing error, neither do the optimisation results given in Tables 8–13. Davies et al. (2003) found that slightly higher precision in proportion at age estimates for snapper was obtained using the length frequency and age-length key approach than the random age sampling approach. If ageing error is large, it could be speculated that catch-at-age estimates derived from the random age sampling approach may have higher MWCVs because of high between landing variability in the age frequencies. The comparable effect of this relative to the precision of catch-at-age estimates derived from the age-length key sampling approach cannot be determined at this time (N. Davies, pers. comm.).

5 CONCLUSIONS AND RECOMMENDATIONS

1. Current catch-at-length compositions for the purse seine and single trawl methods in TRE 1 and single trawl and pair trawl methods in TRE 7 show that although considerable variability exists between fishing methods, they are thought to be representative in describing the fishing mortality by length class for that fishing year. Usually catch-at-length compositions were consistent with the areal and seasonal distribution of the commercial catch.

2. Current catch-at-age compositions for the main methods collected from the TRE 1 and TRE 7 fisheries show similarities between fishing methods within a year from each stock because a single age-length key was used. For the TRE 1 fishery it is difficult to determine any consistent trend in the progression of year classes from one year to the next. Year class strength progression in TRE 7 appears more apparent for some year classes, especially for groups of year classes with relatively similar strengths, i.e., moderate aged and older aged fish. All TRE 1 and TRE 7 catch-at-age compositions contain a broad range of age classes and a consistently high proportion (5–10%) of fish 20 years and older. Although not consistent, most age compositions reveal the presence of some weak and strong age classes, which supports the view that year class strength variation in trevally does exist.

3. The similarities in relative strengths of adjacent age classes may be a result of a “smoothing” in the catch-at-age compositions, where adjacent age classes most often appear to be of a similar relative strength to each other, and strong and weak year classes become less apparent, a spill-over effect of ageing error. Misinterpretation of growth zones (in difficult otolith sections) and inaccurate determination of the margin (or inability to do so) and/or its relativity to the collection and birth dates are likely to be the main contributing factors leading to ageing error. However, if spatial heterogeneity within the stock with respect to age exists, then this will also contribute to the variability in catch-at-age estimates. As ageing trevally is inherently difficult, it may be impossible to determine whether spatial heterogeneity exists because of the level of ageing error present. The level of sampling error and its influence on results was expected to be insignificant.

4. The sampling of landings for length and age, although at times representative of the fishery extraction in that year, can vary considerably between years because of the sub-area of collection. Otolith samples from purse seine landings appear especially prone to sampling bias, whereby otolith subsamples are often collected in an inconsistent manner, with either too large a sample taken from a single landing or samples taken predominantly from one sub-area. It is recommended for future sampling that no more than 50–60 otolith samples be collected from a single landing, so that the geographic spread of the fishery, and the heterogeneity in age composition within the stock, should it exist, be adequately accounted for. Although not strictly essential for an age-length key collection, it is preferable that the otolith sample be a subsample of those landings sampled for length. Sampling of trevally for catch-at-age should initially be conducted annually until model runs determine that the data are of some use and can be undertaken on a less regular basis.

5. Purse seine landings, although containing mainly adult fish of relatively similar size structure within a catch, largely contain no very small or very large fish and are therefore not completely reflective of the underlying population length and age structure that may be observed in trawl catches.

6. We are unable to conclude from the data whether heterogeneity in age structure exists within the TRE 1 and TRE 7 stocks. Heterogeneity appears to exist in the length structure of trevally from TRE 7, with some fish from the Far North observed to grow to a larger size than in most

other areas. Future sampling may be improved if the spatial variation in the fishery is well accounted for.

7. Although largely consistent within each stock, the growth estimates for trevally were slightly different between the stocks, with a higher proportion of fish from TRE 7 growing faster and to a larger average size at age than in TRE 1. Correspondingly, there is more variability in size at age for fish from TRE 7 than for TRE 1. Many of the largest (fastest growing) individuals from both stocks are thought to come from areas of the Far North. Variations in growth from year to year may be related to a combination of the following factors; inconsistencies in the number of fish collected at each size class in the age-length keys, the fishing method and area of collection of the age data, and ageing error.

8. Past catch sampling designs have proved to be largely inadequate to achieve the specified MWCV target of 0.20. Catch sampling optimisations indicate significantly more otoliths need to be collected to achieve the specified MWCV target, and this will inevitably mean that future catch sampling programmes will be more expensive. Further, it is largely unknown to what degree precision is reduced by ageing error, and because of this an age-length key approach might be preferable to the random age sampling approach.

9. TRE 1 single trawl appears to capture a wider representative range of sizes and ages of trevally than purse seine (i.e., is more uniformly selective than purse seine) and therefore is likely to have better stock monitoring utility. It is recommended that the single trawl method be reinstated in future TRE 1 catch sampling programmes.

10. Improvement in catch-at-age estimation may be possible if a more rigorous ageing and sampling standard is adopted. Collecting otoliths over a relatively narrow time span (i.e., when the main target fisheries operate) may improve the accuracy of readers interpreting margin estimates thus resulting in better age resolution. Ageing error could also be reduced by improving reader interpretation of margins with appropriate recognition of the collection date to the birth date for trevally. It is also recommended that the development of a different approach for readers attaining agreement on the final age is undertaken. Similarly, for monitoring quality control in ageing consistency the inclusion of an agreed-age reference collection would be useful. It would be advisable to re-read age collections from previous years to see if the improved reader protocols significantly changes the ageing results. Despite all efforts it might be that trevally is simply a difficult to species to age, and accurate and consistent patterns of year class strengths in catch-at-age data are not possible to achieve.

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7 REFERENCES

Campana, S.E. (2001). Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology 59*: 197–242.

Casselman, J.M. (1990). Growth and relative size of calcified structures of fish. *Transactions of the American Fisheries Society 119*: 673–688.

Christensen, J.M. (1964). Burning of otoliths, a technique for age determination of soles and other fish. *Journal du Conseil Permanent International pour l'Exploration de la Mer 2*9: 73–81.

Davies, N.M.; Hartill, B.; Walsh, C. (2003). A review of methods used to estimate snapper catch-at-age and growth in SNA 1 and SNA 8. *New Zealand Fisheries Assessment Report 2003/10.* 63 p.

Davies, N.M.; Walsh, C. (2003). Snapper catch-at-length and catch-at-age heterogeneity between strata in East Northland longline landings. *New Zealand Fisheries Assessment Report 2003/11.* 26 p.

James, G.D. (1984). Trevally, *Caranx georgianus* Cuvier: age determination, population biology, and the fishery. *Fisheries Research Bulletin 25.* 52 p.

Langley, A.D. (2001). Length and age composition of trevally in commercial landings from TRE 1 and TRE 7, 1999–2000. *New Zealand Fisheries Assessment Report 2001/42.* 32 p.

Langley, A.D. (2002). Length and age composition of trevally in commercial landings from TRE 1 and TRE 7, 2000–01. *New Zealand Fisheries Assessment Report 2002/19.* 34 p.

Langley, A.D. (2003). Length and age composition of trevally (*Pseudocaranx georgianus*) in commercial landings from the TRE 1 purse-seine fishery, 2001–02. *New Zealand Fisheries Assessment Report 2003/48.* 18 p.

Langley, A.D. (2004). Length and age composition of trevally (*Pseudocaranx dentex*) in commercial landings from the TRE 1 purse-seine fishery, 2002–03. *New Zealand Fisheries Assessment Report 2004/39.* 17 p.

McKenzie, A. (2007). Assessment of the TRE 1 stock in the 2005-06 fishing year. Final Research Report for Ministry of Fisheries Research Project TRE2004-01 (Unpublished report held by MFish, Wellington.)

McKenzie, A. (2008). Standardised CPUE analysis and stock assessment of the west coast trevally fishery (TRE 7). *New Zealand Fisheries Assessment Report 2008/44.* 74 p.

Paul, L.J. (1976). A study on age, growth, and population structure of the snapper, *Chrysophrys auratus* (Forster), in the Hauraki Gulf, New Zealand. *Fisheries Research Bulletin No. 13.* 62 p.

Walsh, C.; McKenzie, J.; Armiger, H. (2006). Spatial and temporal patterns in snapper length and age composition and movement; west coast North Island, New Zealand. *New Zealand Fisheries Assessment Report 2006/6.* 57 p.

Walsh, C.; McKenzie, J.; Ó'Maolagáin, C.; Stevens, D.; Tracey, D. (1999). Length and age composition of trevally in commercial landings from TRE 1 and TRE 7, 1997–98. *NIWA Technical Report 66*. 39 p.

Walsh, C.; McKenzie, J.; Ó'Maolagáin, C.; Stevens, D. (2000). Length and age composition of commercial trevally landings in TRE 1 and TRE 7, 1998–99. Final Research Report for Ministry of Fisheries Research Project TRE9801 Objective 1. 24 p. (Unpublished report held by MFish, Wellington.)

Williams, T.; Bedford, B.D. (1974). The use of otoliths for age determination. *In*: Bagenal, T.B. (ed.), Ageing of fish, pp. 114–123. Unwin Brothers Limited, London.

Table 1: TRE 1 catch sampling summary from 1997–98 to 2002–03.

TRE 1

Catch sampling report	Fishing year	Fishing method	No. of landings sampled for LF	Season††	Comments*	Otolith sample size	Otolith prepn†	Season††
Walsh et al. (1999)	1997–98	Purse seine	7	Spr–Sum, Win	5 BPLE, 2 ENLD			
		Single trawl	12	Sum–Aut	3 BPLE, 4 HAGU, 4 ENLD, 1 Mixed	357	B&E	Sum–Aut
Walsh et al. (2000)	1998–99	Purse seine	9	Spr–Sum, Win	5 BPLE, 4 ENLD	30	TS	Win
		Single trawl	12	Sum–Win	8 BPLE, 3 ENLD, 1 Mixed	280	TS	Sum–Win
Langley (2001)	1999–2000	Purse seine	7	Spr–Sum	4 BPLE, 3 ENLD			
		Single trawl	22	Spr–Win	18 BPLE, 4 Mixed	572	TS	Aut–Win
Langley (2002)	2000–01	Purse seine	7	Spr–Sum, Win	5 BPLE, 2 ENLD	745	TS	Spr–Sum, Win
Langley (2003)	2001–02	Purse seine	8	Spr–Sum, Win	7 BPLE, 1 ENLD	360	TS	Sum,Win
Langley (2004)	2002–03	Purse seine	8	Spr–Sum	2 BPLE, 6 ENLD	554	TS	Spr–Sum

* BPLE = Bay of Plenty; ENLD = East Northland; HAGU = Hauraki Gulf.
† B&E = Bake and embed; TS = Thin section.
†† Spr (Oct–Nov), Sum (Dec–Feb), Aut (Mar–May), Win (Jun–Sep).

Table 2: TRE 7 catch sampling summary from 1997–98 to 2000–01.

TRE 7

Catch sampling report	Fishing year	Fishing method	No. of landings sampled for LF	Season††	Comments*	Otolith sample size	Otolith prepn†	Season††
Walsh et al. (1999)	1997–98	Single trawl	55	Spr–Aut, Win	9 NMB, 15 K-M, 10 NTB, 1 STB, 20 Mixed (47 Peak, 8 Off-peak)	375	B&E	Sum
		Pair trawl	7	Spr–Sum	Unknown			
Walsh et al. (2000)	1998–99	Single trawl	26	Spr–Aut	3 NMB, 10 K-M, 2 NTB, 11 Mixed	225	TS	Sum–Aut
		Pair trawl	14	Sum–Aut	6 NMB, 2 K-M, 2 NTB, 4 Mixed	156	TS	Sum–Aut
Langley (2001)	1999–2000	Single trawl	39	Sum–Aut	6 NMB, 7 K-M, 5 NTB, 2 STB, 19 Mixed	505	TS	Sum–Aut
Langley (2002)	2000–01	Single trawl	49	Spr–Aut	5 NMB, 16 K-M, 3 NTB, 25 Mixed	496	TS	Spr–Sum
		Pair trawl	13	Spr–Sum	2 NMB, 7 K-M, 4 Mixed			

* NMB = Ninety Mile Beach; K-M = Kaipara Manukau; NTB = North Taranaki Bight; STB = South Taranaki Bight.
† B&E = Bake and embed; TS = Thin section.
†† Spr (Oct–Nov), Sum (Dec–Feb), Aut (Mar–May), Win (Jun–Sep).

Table 3: Von Bertalanffy parameters calculated from trevally otolith data collected from TRE 1 in 1997–98 to 2002–03.

Fishing year	L_{inf}	k	t_o	n
1997–98	64.4	0.060	-8.30	387
1998–99	50.5	0.100	-7.33	310
1999–2000	49.2	0.137	-4.39	572
2000–01	50.1	0.098	-7.71	745
2001–02	50.3	0.097	-8.19	360
2002–03	51.6	0.105	-6.27	554

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

Table 4: Von Bertalanffy parameters calculated from trevally otolith data collected from TRE 7 in 1997–98 to 2000–01.

Fishing year	L_{inf}	k	t_o	n
1997–98	60.1	0.080	-5.48	375
1998–99	55.3	0.080	-6.90	381
1999–2000	53.6	0.091	-5.46	504
2000–01	60.6	0.070	-6.20	496

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

Table 5: Between-reader comparisons (using first readings only) for otolith data collected from the TRE 1 stock from 1997–98 to 2002–03*

1997–98 — Age class

Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3												1		1		1	1	1	4	9
-3										1		2	1	1					3	8
-2					1	1		1	5	7	4	6	3		2		1	1	6	38
-1		2	10	7	3	4	3	4	5	7	5	14	6	4	2	6	1		5	88
0		20	38	20	8	6	5	8	12	13	16	22	8	8	11	11	4	5	19	234
1			1	1	1		1				1	1							0	6
2																			0	0
3																			1	1
>3																			0	0
Total		22	49	28	13	11	9	13	22	28	26	46	18	14	15	18	7	7	38	384
% agreement		91	78	71	62	55	56	62	55	46	62	48	44	57	73	61	57	71	50	61

1998–99 — Age class

Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3													1			1			7	9
-3				1		1						1	1	1				1	4	10
-2		2	2	2	2	3		1	1	1	2	1		2	1				7	27
-1	1	15	17	8	6	2	2			1	3	1	1	1	2	1		1	8	70
0	1	29	28	17	6	6	2	4	6	11	2	3	1	1	1	1	1	3	4	127
1		1	6	13	6	1	2	2	1	2	1	1	1		1	2		3	1	44
2			1	1	2	4	2	1	2	1		1	1						1	17
3				1				1								1	1		1	5
>3			1											1					4	6
Total	2	47	55	43	22	17	8	9	10	16	8	8	6	6	5	6	2	8	37	315
% agreement	50	62	51	40	27	35	25	44	60	69	25	38	17	17	20	17	50	38	11	40

1999–00 — Age class

Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3										1	1			1	1		1		8	13
-3								1						1	2			1	9	14
-2			1					1	1		3	1	5	2	1	3	3	2	9	32
-1		7	12	8	9	8	5	1	5	4	8	7	5	10	6	6	2	8	21	132
0	1	32	24	36	30	10	9	3	4	13	8	5	4	10	3	3	13	7	25	240
1		9	6	8	5	9	2		5	4	1	4	2	7	6	3	7	4	17	99
2			1		2	1	1				1			3	1				13	23
3												1	1						5	7
>3																			10	10
Total	1	48	44	52	46	28	17	6	15	22	22	18	17	34	20	15	26	22	117	570
% agreement	100	67	55	69	65	36	53	50	27	59	36	28	24	29	15	20	50	32	21	42

2000–01 — Age class

Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3		1	1	2	1	2		1			1	1	1	2	1	2	4	2	4	26
-3			2		1	2				1	1	1	1	2	3	4	1	1	4	24
-2		5	2	2	4	4	5	1	3	3	6	6	7	5	4	6	10	2	18	93
-1		16	38	13	14	14	10	7	7	10	8	8	9	11	8	5	7	3	23	211
0		11	30	18	30	17	23	17	12	12	10	6	13	6	6	10	5	5	22	253
1			4	6	14	13	8	3	7	4	4	5	1	4	2	2	3	1	5	86
2					4	3	2	7	2	3	3		1	2	1		3		2	33
3		1							1			1							1	4
>3			2			1					2	1	4	1		1	1		2	15
Total		34	79	41	68	56	48	36	32	33	35	29	37	33	25	30	34	14	81	745
% agreement		32	38	44	44	30	48	47	38	36	29	21	35	18	24	33	15	36	27	34

* Note: Total otolith counts may not exactly equal the number of samples used in the text as some otoliths were deemed readable by only one party.

Table 5 continued

2001–02	Age class																			
Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3										3	1	1	2	2				2	2	13
-3										1	1		2	1	1		2		1	9
-2				1		2		1		4			1	1			1		11	22
-1		1	6	5	2	4	2	5	4	5	6	1	3	3	6	2	2	2	10	69
0		10	20	15	4	8	2	4	5	6	7	2	4	5	14	6	2	2	19	135
1		2	4	14	9	1	4	2	4	5	1	1	4	3	2	1		4	6	67
2				4	8	2	4	2	1	1	1		1			1	1		2	28
3									3									1	2	6
>3												1	1				1		2	5
Total		13	30	39	23	17	12	14	17	25	17	6	18	15	23	10	9	11	55	354
% agreement		77	67	38	17	47	17	29	29	24	41	33	22	33	61	60	22	18	35	38

2002–03	Age class																			
Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3						1						1	1	2	2	2			4	13
-3															2			1	4	7
-2					1	1	2				1	2	1	3	2	2	2	3	9	29
-1		2	7	1	2	2	2		2	3		4	4	9	4	2	1	3	17	65
0		14	34	26	6	5	14	12	14	9	8	5	7	7	10	7	10	4	23	215
1		3	15	18	22	6	6	8	11	14	7	4	12	10	6	5	9	1	14	171
2					2	2	1	1	3	4	2	2	4	1	2	2	3		7	36
3								1		1	1	3	2		3				1	12
>3					1			1	1	1				1	1					6
Total		19	56	45	34	17	25	23	31	32	19	21	31	33	32	20	25	12	79	554
% agreement		74	61	58	18	29	56	52	45	28	42	24	23	21	31	35	40	33	29	39

* Note: Total otolith counts may not exactly equal the number of samples used in the text as some otoliths were deemed readable by only one party.

Table 6: Between-reader comparisons (using first readings only) for otolith data collected from the TRE 7 stock from 1997–98 to 2002–03*

1997–98	Age class																			
Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3																			8	8
-3								1			2		1					2	4	10
-2								1	1	1	1	3	2	1	3			2	6	21
-1		4	4	2	3	2	3	7	6	3	6	3	2	1	2	2	4		10	64
0		37	30	15	2	4	16	15	7	17	14	18	3	6	6	7	8	7	54	266
1			1	1													1			3
2														1						1
3														1						1
>3																				0
Total		41	35	18	5	6	19	24	14	21	23	24	8	10	11	9	13	11	82	374
% agreement		90	86	83	40	67	84	63	50	81	61	75	38	60	55	78	62	64	66	71

1998–99	Age class																			
Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3							1			4	1	1	1	1			2	1	14	26
-3		1							2		3	1	3	1	1		1		2	15
-2		2		1	1	1	2	3		1	1	4	2						4	22
-1		15	2	13	8	4	1	9	4	3	6	3	3	2				1	1	75
0		13	26	21	12	9	3	15	3	7	9	4	5	8	1	2	3		4	145
1		4	8	7	5	1		6	3		5	4	2				2		2	49
2		2	2	3	3	1	1	1	1	2	5	3	1			1			1	27
3				1							1								0	2
>3										1	1	1	1	1		4			11	20
Total		37	38	46	29	16	8	34	13	18	32	21	18	13	2	7	8	2	39	381
% agreement		35	68	46	41	56	38	44	23	39	28	19	28	62	50	29	38	0	10	38

1999–00	Age class																			
Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3					1					1	1			1	1				7	12
-3					1					1	1								4	7
-2			1		1	2			2	3	1	2	3	2					8	25
-1	1	8	17	2	14	2		4	7	6	7	4	5	4	3	4	4	1	19	112
0	2	25	38	23	18	12	10	5	5	7	9	6	7	8	3	1	3	4	14	200
1		4	17	7	12	2	1	2	2	5	4	3	7	7	1	1	3	3	14	95
2			1		2	2	1	2	1	1	1	1	4	4		1	1		9	31
3						1				2	1	1	2	1					4	12
>3													2						3	5
Total	3	37	74	32	49	21	12	13	17	26	25	17	30	27	8	7	11	8	82	499
% agreement	67	68	51	72	37	57	83	38	29	27	36	35	23	30	38	14	27	50	17	40

2000–01	Age class																			
Difference	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	>19	Total
<-3					2					2									14	18
-3				2		1		1	1				2			1			6	14
-2		1	2	1	3	2	1	4		2	3		1	1	2	1	2		9	35
-1		11	11	9	7	4	2	4	5	6	5	4	5	2	2		3	1	14	95
0	7	26	15	15	12	6	6	3	2	12	6	2	10	10	8	2	4	2	25	173
1	1	9	4	8	7	2	1	2	1	6	3	3	6	6	5	3	3		15	85
2			1	2	4	2	3	4	2	1	1	1	3	1	5		1	1	7	39
3					2				3	2		1	2	2	1		1		4	18
>3											1		2	1	3	1	3		8	19
Total	8	47	33	37	37	17	13	18	14	31	19	11	31	23	26	8	17	4	102	496
% agreement	88	55	45	41	32	35	46	17	14	39	32	18	32	43	31	25	24	50	25	35

* Note: Total otolith counts may not exactly equal the number of samples used in the text as some otoliths were deemed readable by only one party.

Table 7: Range of sampled landings and otoliths used in bootstrap optimisations.

Length frequency and age-length key (ALK) approach

Stock	Method	No. landings	No. otoliths per ALK
TRE 1	Single trawl	5–50	200–1200
TRE 1	Purse seine	3–15	200–1200
TRE 7	Single trawl	5–50	200–1200

Random age sampling approach

Stock	Method	No. landings	No. otoliths per landing
TRE 1	Single trawl	5–50	10–100
TRE 1	Purse seine	3–15	10–100
TRE 7	Single trawl	5–50	10–100

Table 8: Bootstrapped MWCVs based on landings sampled and otoliths collected from the TRE 1 purse seine fishery 1998–99 using the length frequency and age-length key approach. The shaded area indicates the recommended number of landings to sample from the fishery and the bordered cells the target MWCV of 0.20 likely to be achieved with a particular otolith sample size.

	Number of otoliths in age-length key										
Landings	200	300	400	500	600	700	800	900	1000	1100	1200
3	0.430	0.366	0.329	0.304	0.286	0.277	0.266	0.261	0.254	0.247	0.243
4	0.413	0.350	0.315	0.287	0.268	0.259	0.247	0.242	0.235	0.229	0.223
5	0.402	0.339	0.302	0.276	0.260	0.249	0.234	0.225	0.219	0.217	0.210
6	0.395	0.331	0.293	0.271	0.251	0.239	0.227	0.221	0.209	0.207	0.201
7	0.390	0.326	0.291	0.264	0.243	0.231	0.219	0.214	0.206	0.201	0.193
8	0.383	0.322	0.284	0.258	0.243	0.226	0.215	0.207	0.200	0.192	0.189
9	0.380	0.319	0.280	0.254	0.236	0.223	0.210	0.200	0.196	0.189	0.184
10	0.376	0.314	0.279	0.251	0.233	0.219	0.208	0.200	0.192	0.186	0.178
11	0.378	0.314	0.273	0.250	0.230	0.216	0.204	0.195	0.191	0.182	0.177
12	0.376	0.312	0.272	0.249	0.229	0.215	0.202	0.194	0.187	0.181	0.174
13	0.377	0.309	0.273	0.247	0.226	0.213	0.205	0.194	0.183	0.179	0.172
14	0.375	0.308	0.270	0.244	0.222	0.214	0.196	0.192	0.180	0.179	0.169
15	0.370	0.309	0.269	0.243	0.225	0.211	0.198	0.190	0.182	0.177	0.169

Table 9: Bootstrapped MWCVs based on landings sampled and otoliths collected from the TRE 1 single trawl fishery 1998–99 using the length frequency and age-length key approach. The shaded area indicates the recommended number of landings to sample from the fishery and the bordered cells the target MWCV of 0.20 likely to be achieved with a particular otolith sample size.

	Number of otoliths in age-length key										
Landings	200	300	400	500	600	700	800	900	1000	1100	1200
5	0.383	0.329	0.295	0.274	0.259	0.250	0.243	0.239	0.229	0.226	0.221
10	0.347	0.293	0.263	0.240	0.223	0.215	0.206	0.197	0.192	0.188	0.186
15	0.338	0.280	0.248	0.226	0.210	0.200	0.189	0.181	0.178	0.171	0.165
20	0.334	0.270	0.241	0.216	0.202	0.192	0.181	0.173	0.167	0.163	0.157
25	0.323	0.269	0.234	0.212	0.197	0.185	0.174	0.169	0.161	0.156	0.151
30	0.322	0.266	0.232	0.208	0.193	0.182	0.170	0.165	0.158	0.153	0.147
35	0.321	0.263	0.230	0.206	0.190	0.179	0.167	0.161	0.155	0.148	0.144
40	0.313	0.262	0.230	0.202	0.188	0.176	0.166	0.160	0.153	0.146	0.140
45	0.317	0.259	0.225	0.204	0.184	0.176	0.163	0.156	0.150	0.145	0.140
50	0.316	0.259	0.226	0.203	0.185	0.176	0.162	0.155	0.150	0.145	0.139

Table 10: Bootstrapped MWCVs based on landings sampled and otoliths collected from the TRE 7 single trawl fishery 1997–98 using the length frequency and age-length key approach. The shaded area indicates the recommended number of landings to sample from the fishery and the bordered cells the target MWCV of 0.20 likely to be achieved with a particular otolith sample size.

	Number of otoliths in age-length key										
Landings	200	300	400	500	600	700	800	900	1000	1100	1200
5	0.448	0.390	0.370	0.351	0.340	0.329	0.329	0.310	0.320	0.313	0.314
10	0.383	0.329	0.306	0.286	0.271	0.256	0.259	0.247	0.244	0.242	0.241
15	0.360	0.303	0.274	0.256	0.242	0.234	0.227	0.222	0.217	0.208	0.203
20	0.352	0.288	0.262	0.243	0.228	0.217	0.213	0.202	0.199	0.195	0.188
25	0.343	0.281	0.255	0.235	0.219	0.209	0.199	0.194	0.187	0.183	0.179
30	0.335	0.274	0.246	0.228	0.212	0.202	0.191	0.185	0.178	0.176	0.170
35	0.330	0.272	0.244	0.225	0.205	0.196	0.185	0.181	0.172	0.169	0.163
40	0.329	0.266	0.239	0.219	0.204	0.193	0.183	0.174	0.169	0.164	0.162
45	0.327	0.264	0.236	0.214	0.200	0.190	0.181	0.171	0.165	0.162	0.155
50	0.325	0.264	0.234	0.213	0.196	0.187	0.176	0.167	0.164	0.158	0.154

Table 11: Bootstrapped MWCVs based on landings sampled and otoliths collected from the TRE 1 purse seine fishery 1998–99 using the random age sampling approach. The shaded area indicates the recommended number of landings and otoliths per landing to sample from the fishery, and the crossover point the likely MWCV achieved.

	Number of otoliths per landing									
Landings	10	20	30	40	50	60	70	80	90	100
3	0.964	0.736	0.619	0.550	0.508	0.474	0.449	0.428	0.414	0.400
4	0.776	0.620	0.535	0.475	0.441	0.409	0.390	0.376	0.357	0.351
5	0.709	0.558	0.468	0.425	0.394	0.368	0.346	0.333	0.319	0.308
6	0.664	0.507	0.432	0.388	0.352	0.333	0.313	0.300	0.296	0.278
7	0.615	0.468	0.396	0.357	0.328	0.307	0.291	0.278	0.265	0.261
8	0.588	0.439	0.372	0.332	0.311	0.284	0.269	0.259	0.247	0.238
9	0.559	0.419	0.353	0.315	0.285	0.267	0.255	0.246	0.234	0.229
10	0.529	0.393	0.331	0.296	0.273	0.258	0.238	0.232	0.221	0.218
11	0.507	0.374	0.313	0.281	0.259	0.245	0.228	0.219	0.210	0.203
12	0.487	0.359	0.304	0.270	0.250	0.231	0.218	0.210	0.202	0.196
13	0.469	0.342	0.288	0.258	0.237	0.222	0.211	0.199	0.193	0.188
14	0.459	0.334	0.282	0.248	0.230	0.215	0.204	0.194	0.184	0.180
15	0.436	0.318	0.271	0.241	0.220	0.206	0.195	0.186	0.182	0.174

Table 12: Bootstrapped MWCVs based on landings sampled and otoliths collected from the TRE 1 single trawl fishery 1998–99 using the random age sampling approach. The shaded area indicates the recommended number of landings and otoliths per landing to sample from the fishery, and the crossover point the likely MWCV achieved.

	Number of otoliths per landing									
Landings	10	20	30	40	50	60	70	80	90	100
5	0.816	0.647	0.545	0.505	0.475	0.440	0.430	0.412	0.396	0.392
10	0.586	0.462	0.403	0.365	0.336	0.322	0.304	0.306	0.289	0.278
15	0.479	0.378	0.327	0.297	0.276	0.264	0.253	0.242	0.236	0.232
20	0.418	0.323	0.277	0.257	0.239	0.230	0.218	0.212	0.205	0.200
25	0.377	0.286	0.252	0.231	0.213	0.202	0.195	0.189	0.188	0.181
30	0.344	0.262	0.232	0.209	0.197	0.185	0.179	0.178	0.170	0.168
35	0.319	0.246	0.212	0.196	0.181	0.172	0.164	0.160	0.156	0.153
40	0.293	0.229	0.199	0.184	0.171	0.163	0.155	0.149	0.145	0.143
45	0.284	0.213	0.190	0.170	0.161	0.151	0.144	0.142	0.136	0.136
50	0.266	0.205	0.178	0.162	0.151	0.146	0.144	0.134	0.131	0.129

Table 13: Bootstrapped MWCVs based on landings sampled and otoliths collected from the TRE 7 single trawl fishery 1997–98 using the random age sampling approach. The shaded area indicates the recommended number of landings and otoliths per landing to sample from the fishery, and the crossover point the likely MWCV achieved.

	Number of otoliths per landing									
Landings	10	20	30	40	50	60	70	80	90	100
5	0.771	0.650	0.598	0.554	0.538	0.515	0.508	0.505	0.490	0.486
10	0.557	0.463	0.415	0.393	0.377	0.368	0.350	0.346	0.337	0.341
15	0.447	0.367	0.332	0.310	0.301	0.291	0.280	0.277	0.274	0.271
20	0.383	0.317	0.283	0.268	0.256	0.250	0.248	0.240	0.238	0.232
25	0.345	0.278	0.257	0.239	0.224	0.217	0.222	0.215	0.208	0.207
30	0.315	0.259	0.233	0.216	0.207	0.205	0.194	0.196	0.194	0.190
35	0.289	0.234	0.217	0.200	0.193	0.189	0.185	0.186	0.180	0.177
40	0.272	0.223	0.202	0.190	0.182	0.177	0.171	0.170	0.163	0.164
45	0.257	0.206	0.187	0.177	0.172	0.165	0.163	0.158	0.157	0.156
50	0.245	0.197	0.182	0.167	0.160	0.156	0.154	0.153	0.152	0.146

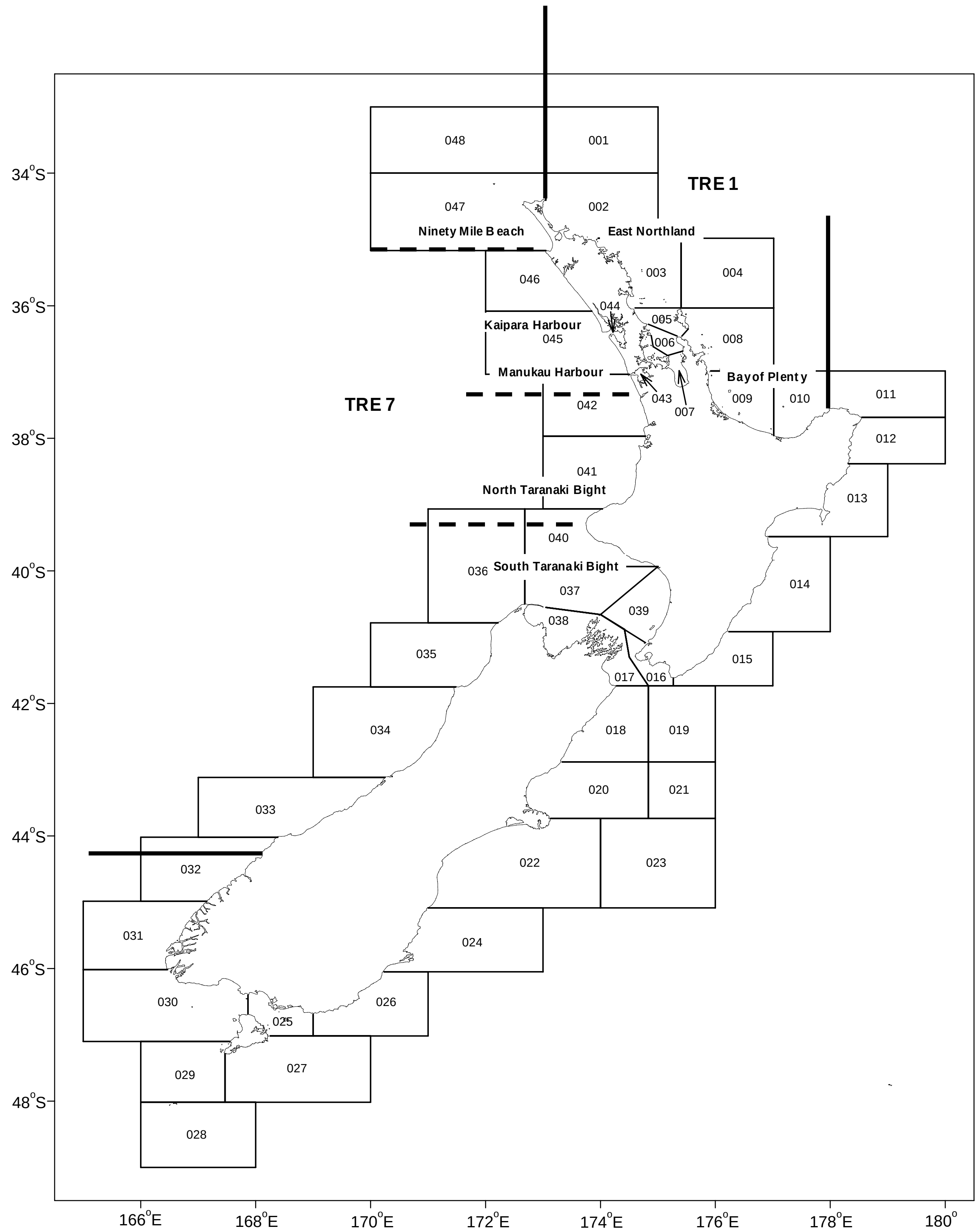


Figure 1: Trevally quota management areas, statistical areas, and locations referred to in the text.

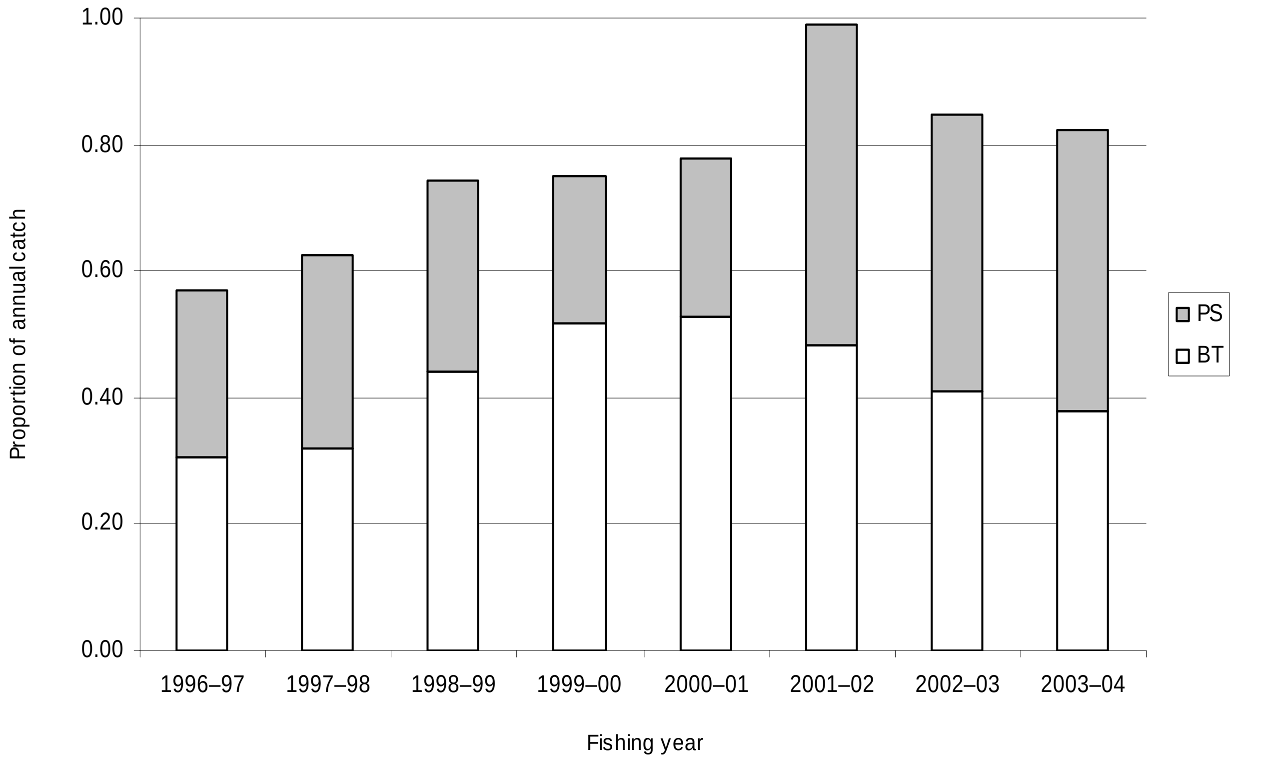


Figure 2: The proportion of the annual catch of trevally by the purse seine (PS) and single trawl (BT) methods in TRE 1 for the fishing years 1996–97 to 2003–04.

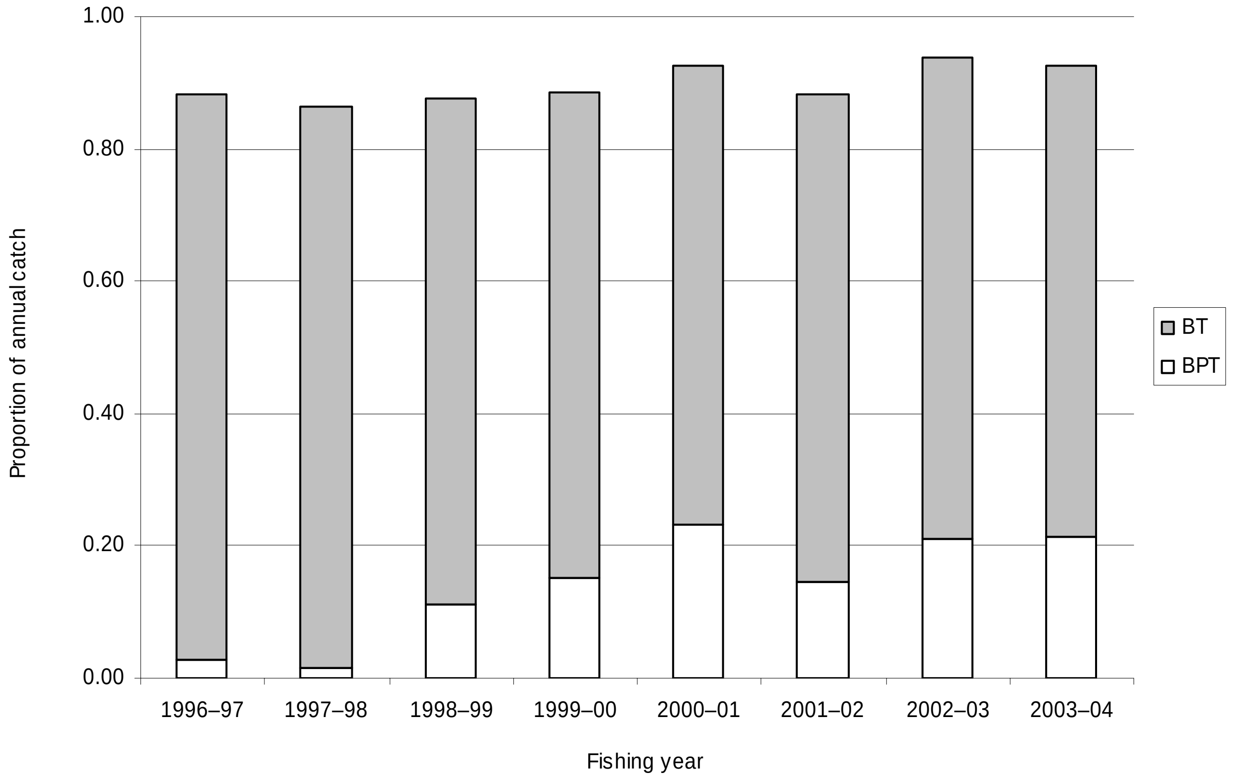
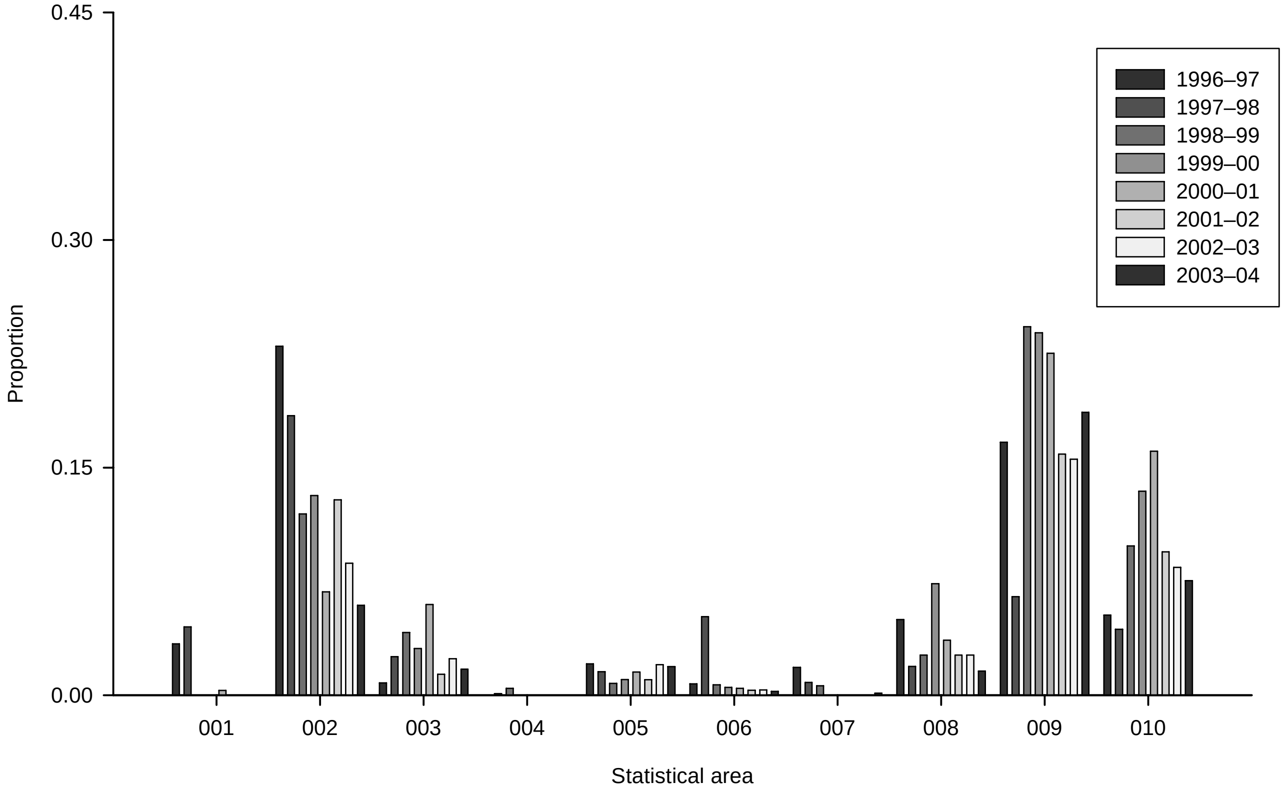


Figure 3: The proportion of the annual catch of trevally by the single trawl (BT) and pair trawl (BPT) methods in TRE 7 for the fishing years 1996–97 to 2003–04.

(a)



(b)

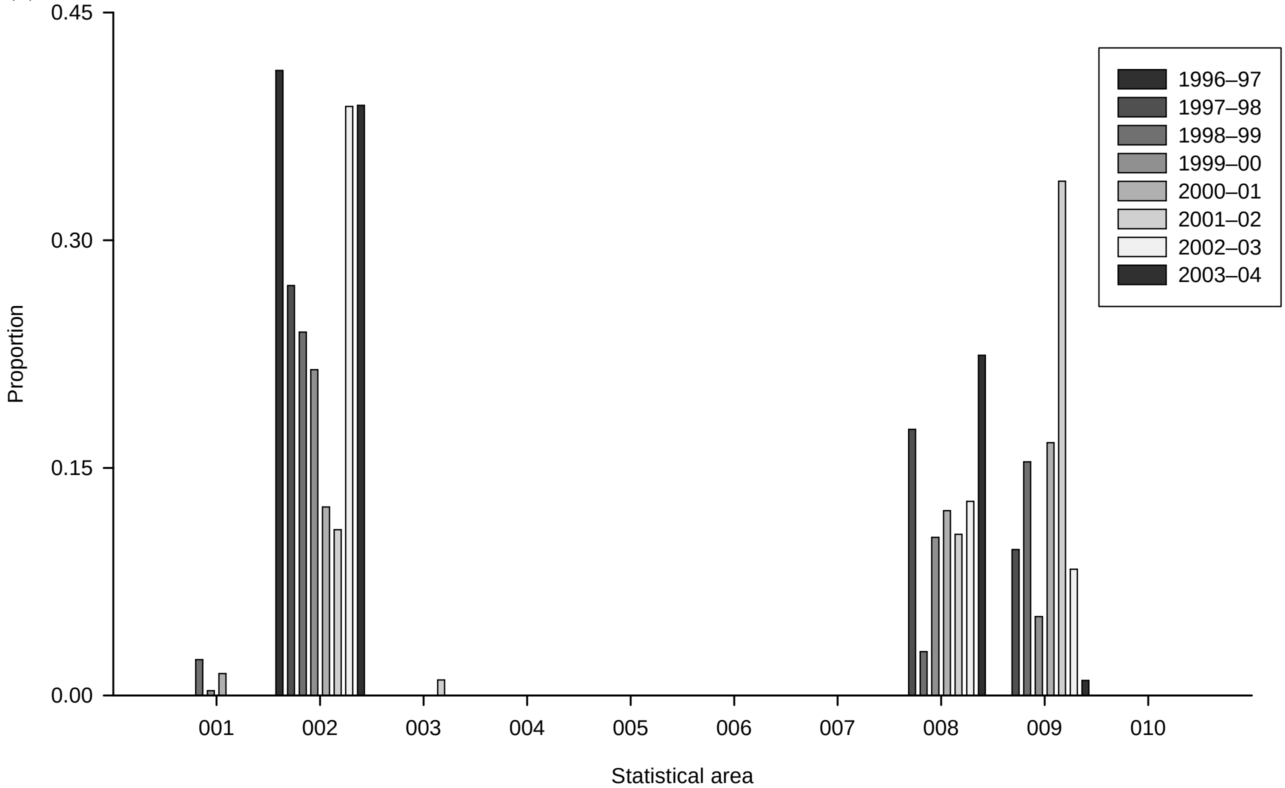
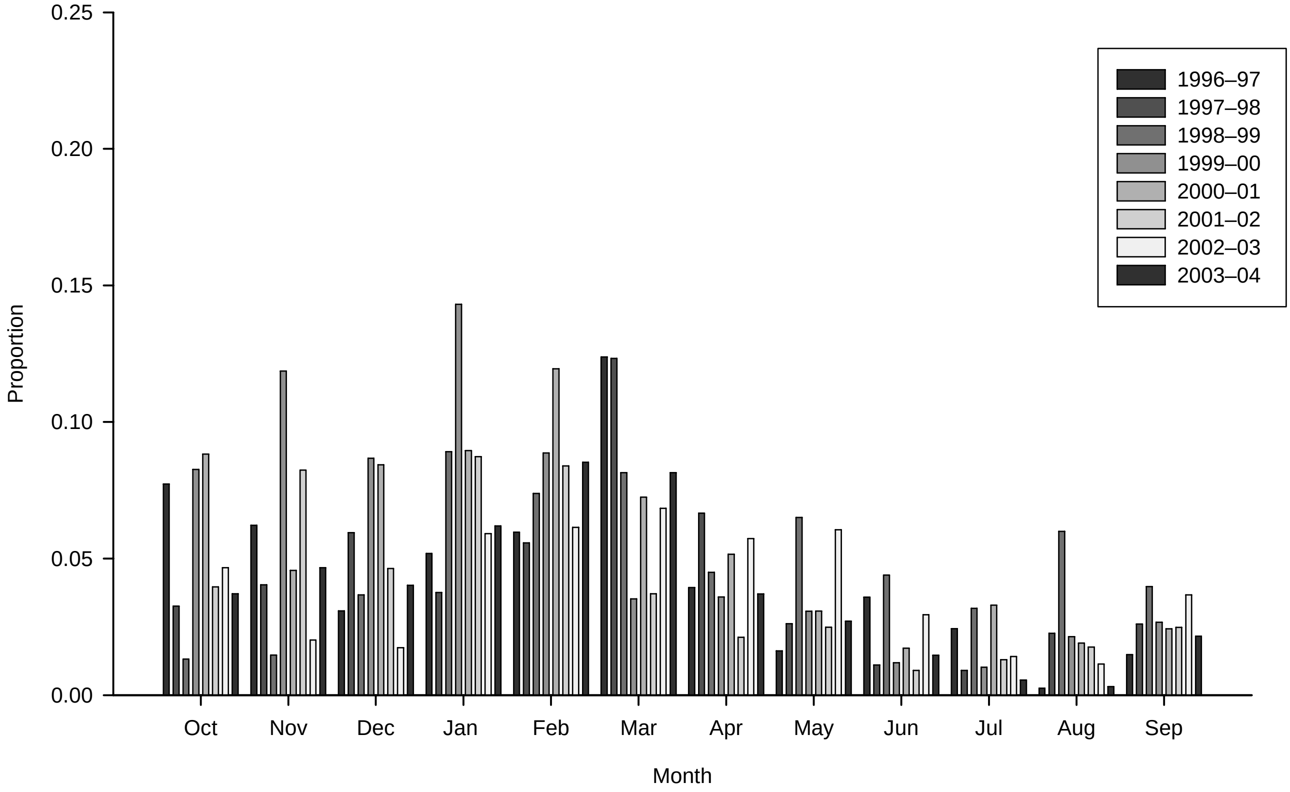


Figure 4: The distribution of the TRE 1 (a) single trawl and (b) purse seine catch by statistical area for the fishing years 1996–97 to 2003–04 (source: TCEPR and CELR estimated catch).

(a)



(b)

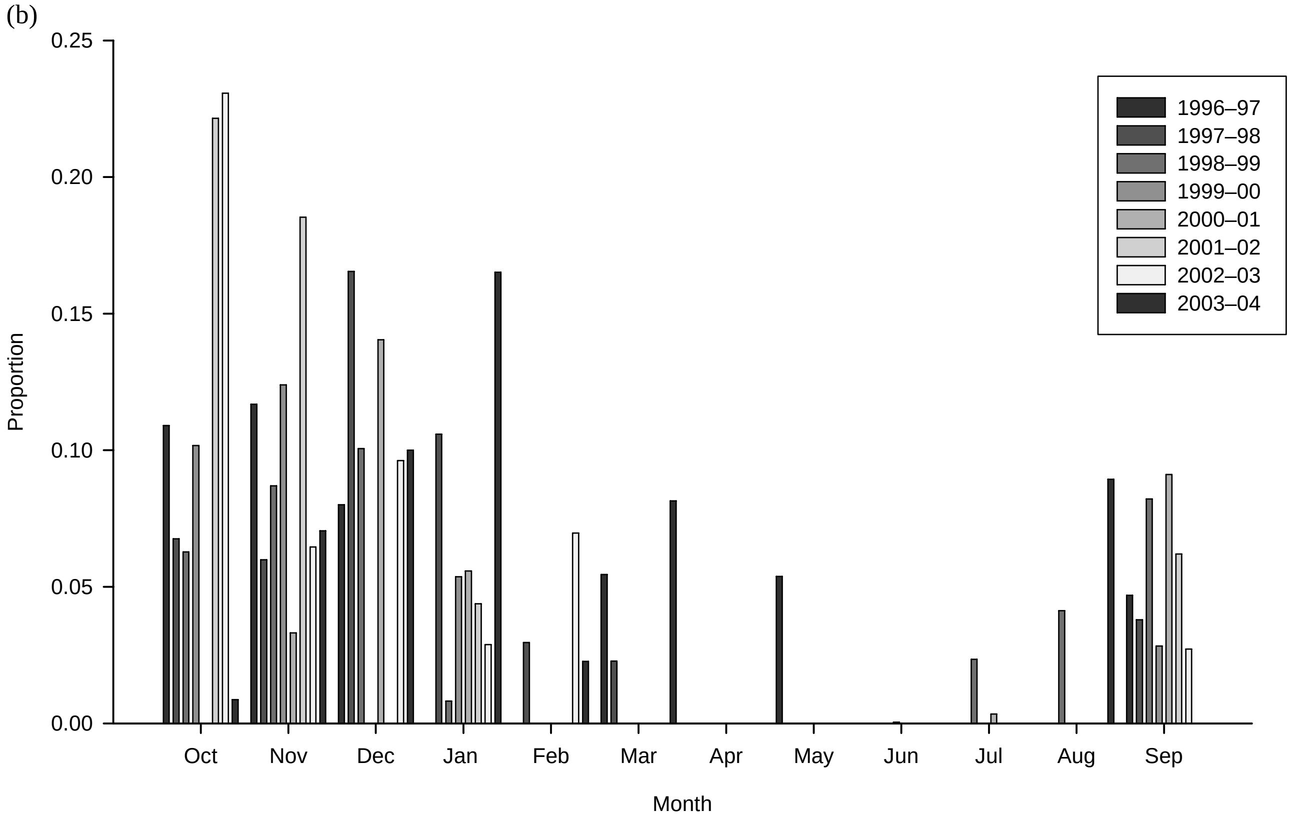
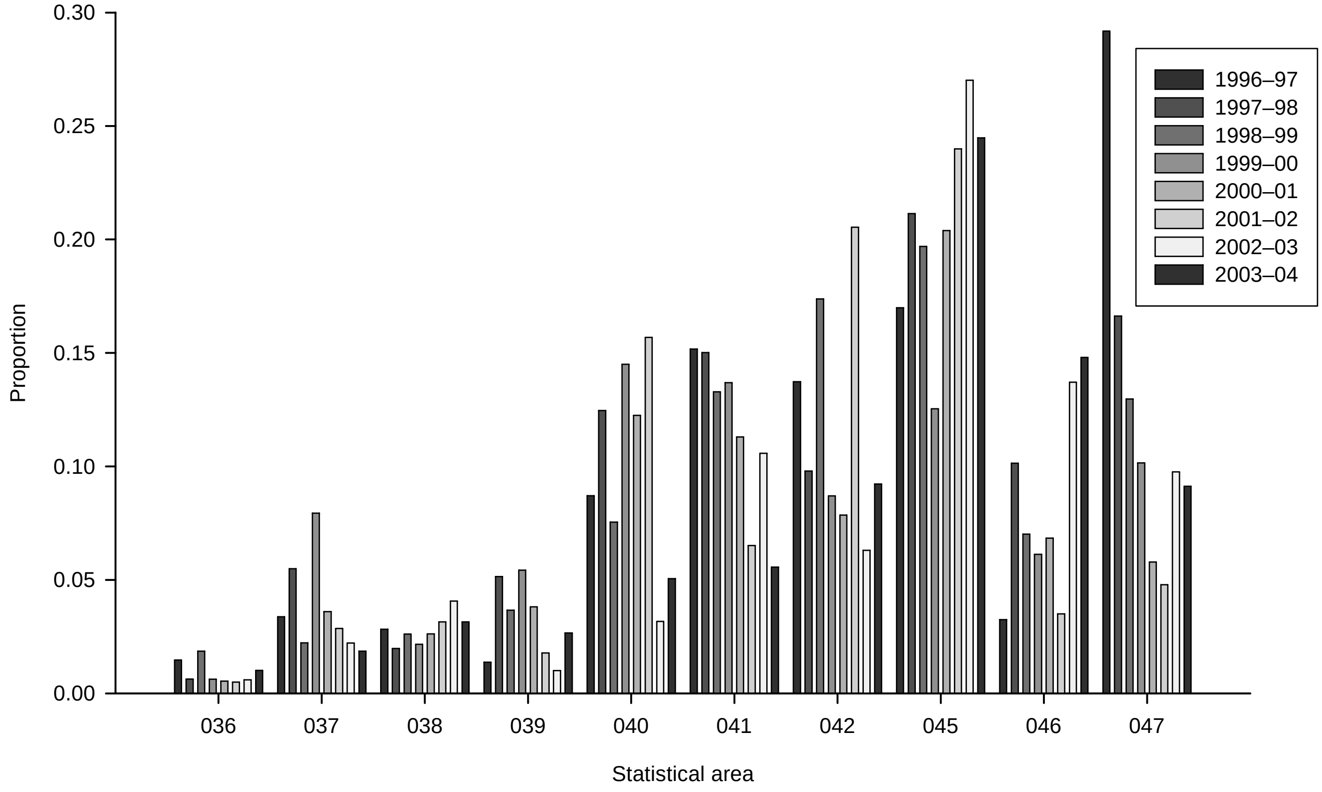


Figure 5: The distribution of the TRE 1 (a) single trawl and (b) purse seine catch by month for the fishing years 1996–97 to 2003–04 (source: TCEPR and CELR estimated catch).

(a)



(b)

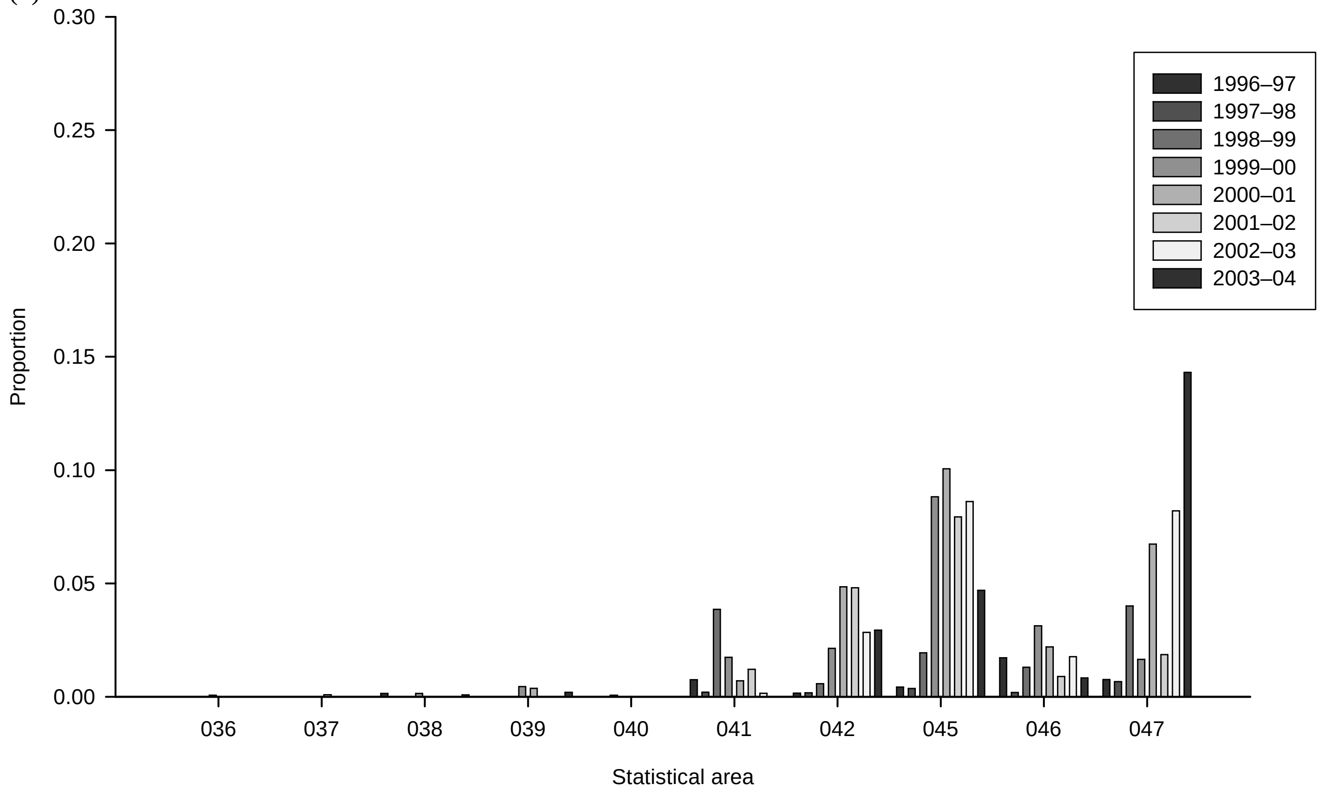
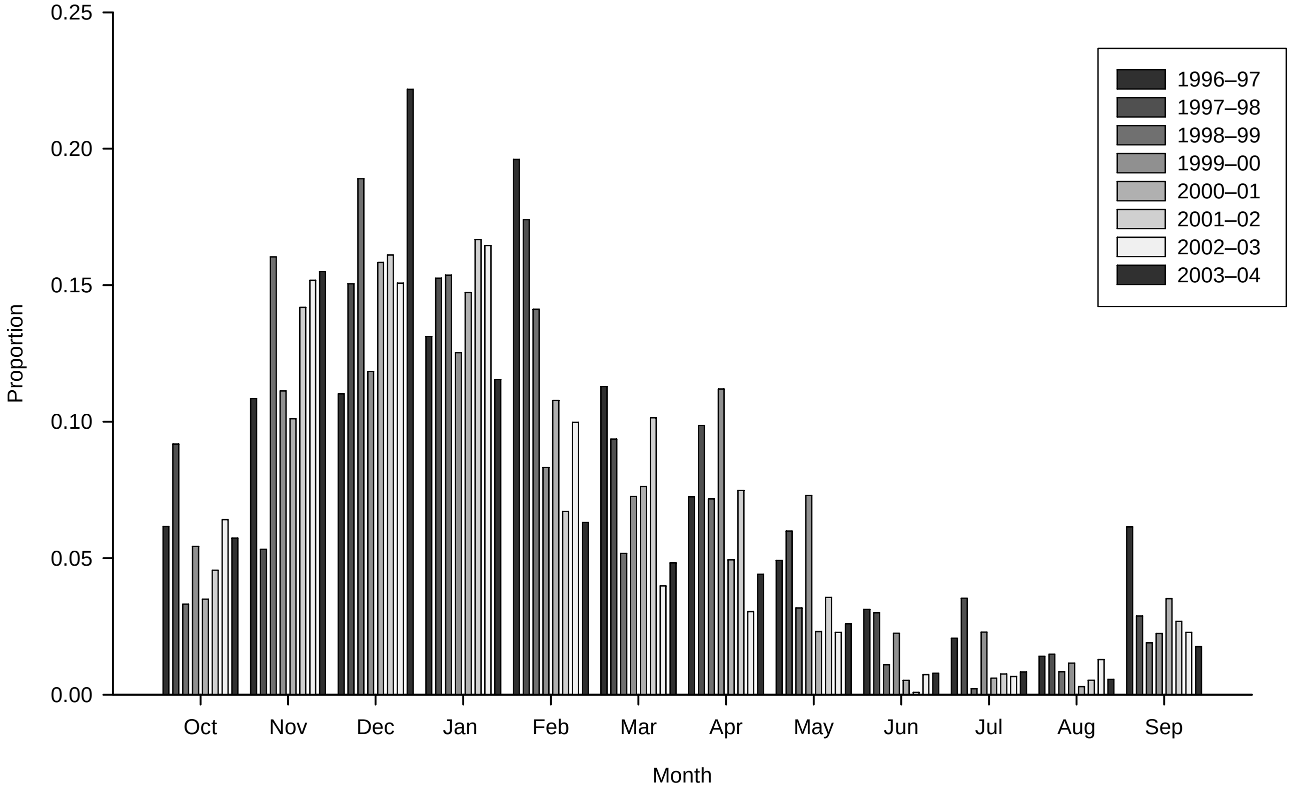


Figure 6: The distribution of the TRE 7 (a) single trawl and (b) pair trawl catch by statistical area for the fishing years 1996–97 to 2003–04 (source: TCEPR and CELR estimated catch).

(a)



(b)

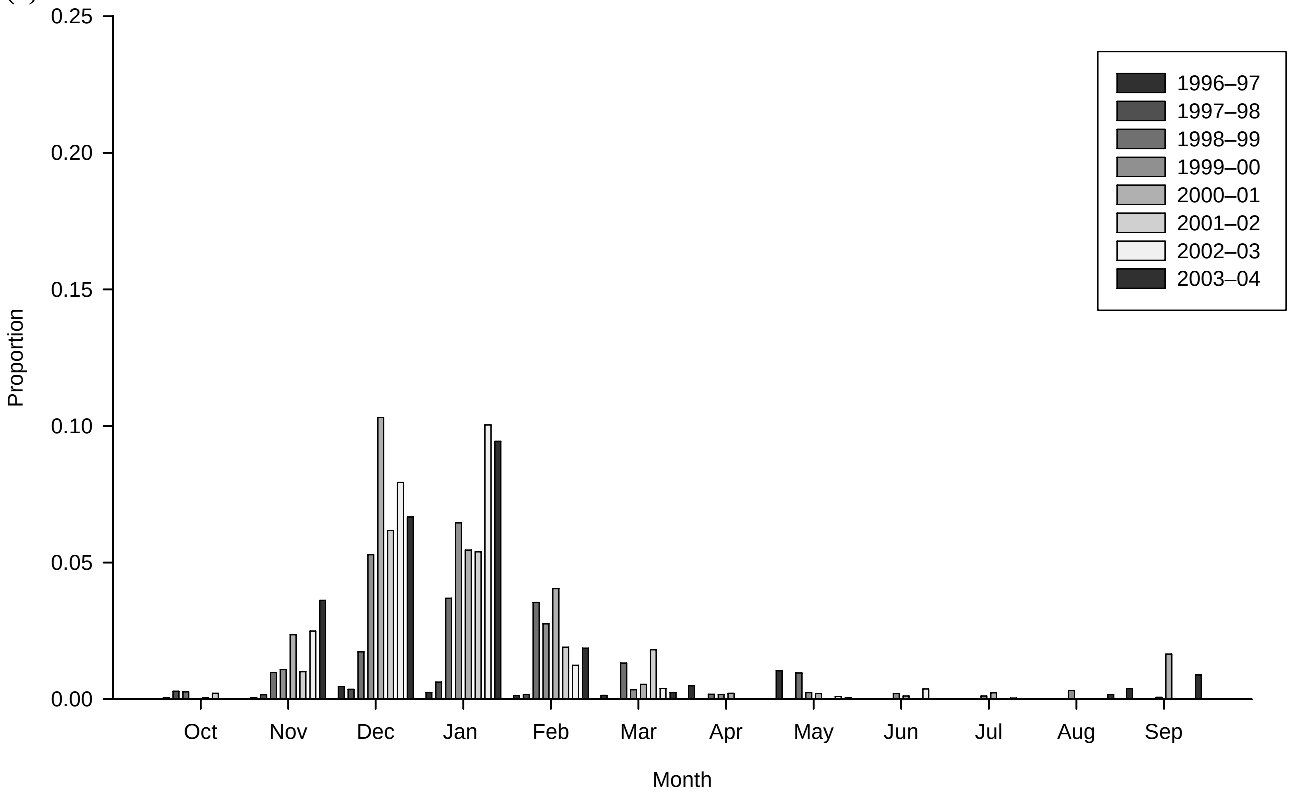


Figure 7: The distribution of the TRE 7 (a) single trawl and (b) pair trawl catch by month and the fishing years 1996–97 to 2003–04 (source: TCEPR and CELR estimated catch).

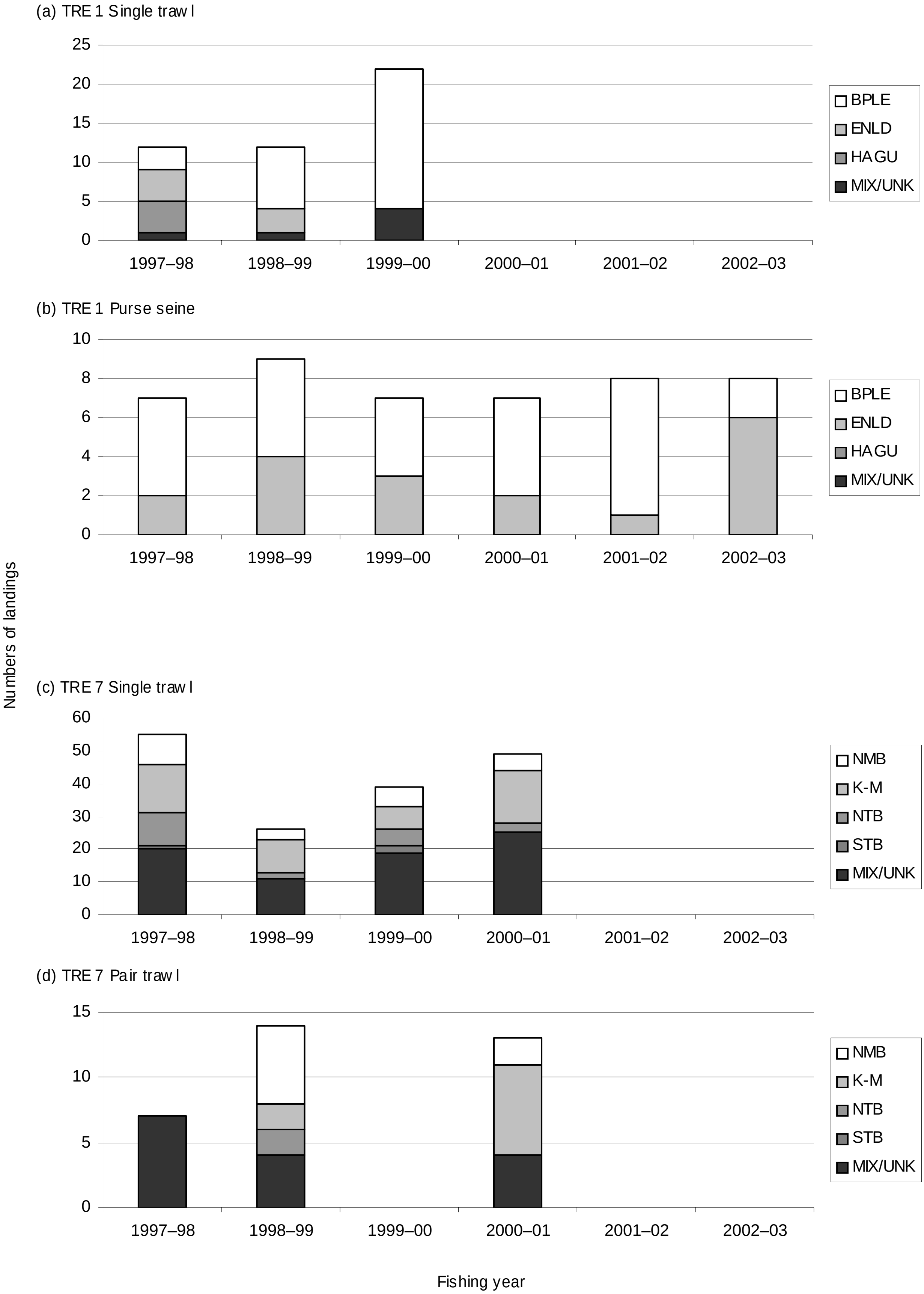


Figure 8: The number and spatial location of landings sampled for length frequency from the TRE 1 (a) single trawl and (b) purse seine fisheries and TRE 7 (c) single trawl and (d) pair trawl fisheries from 1997–98 to 2002–03. Note: Not equivalent scales used. Data missing denotes data not collected.

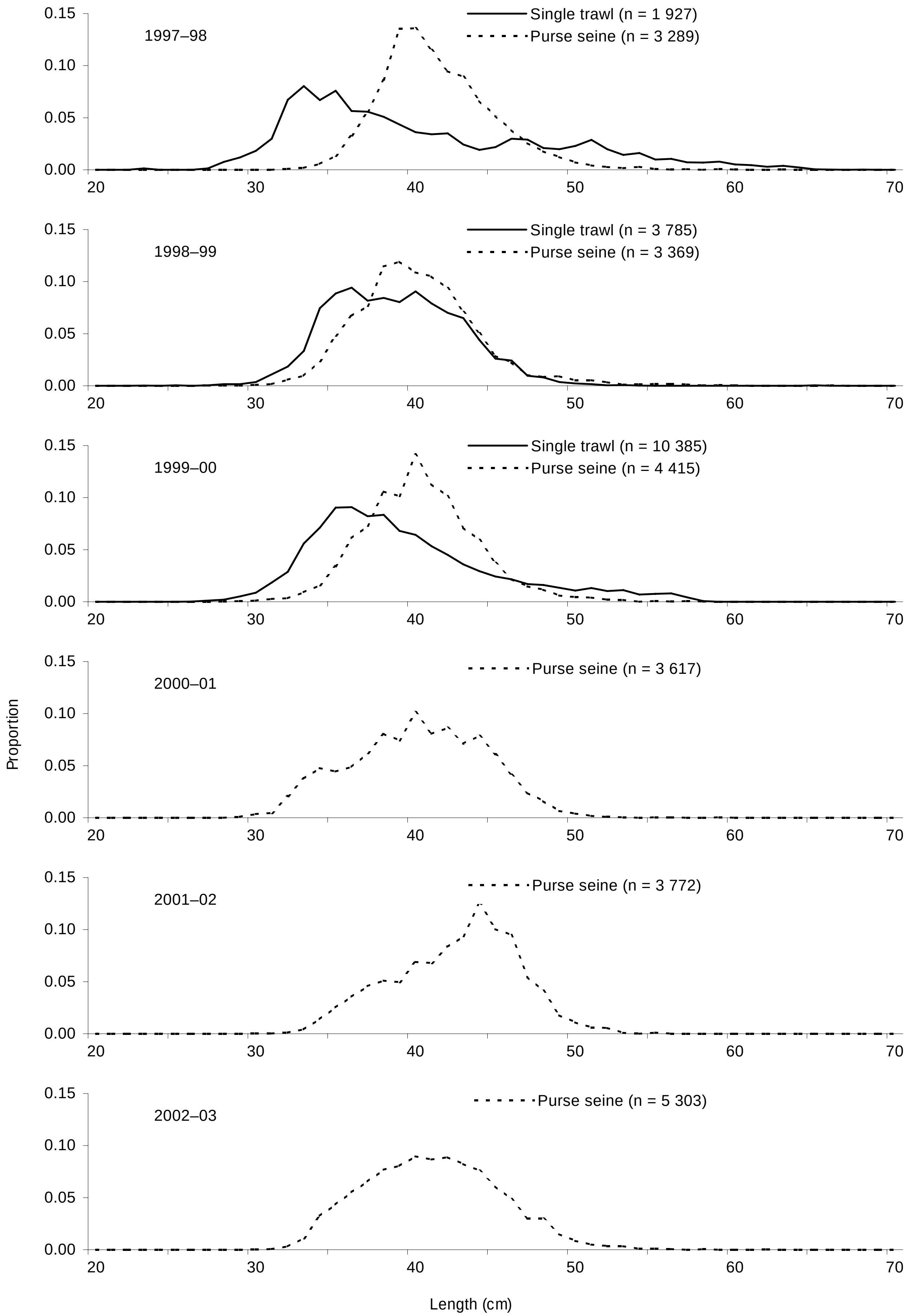


Figure 9: Length composition for the TRE 1 single trawl and purse seine fisheries from the 1997–98 to 2002–03 fishing years.

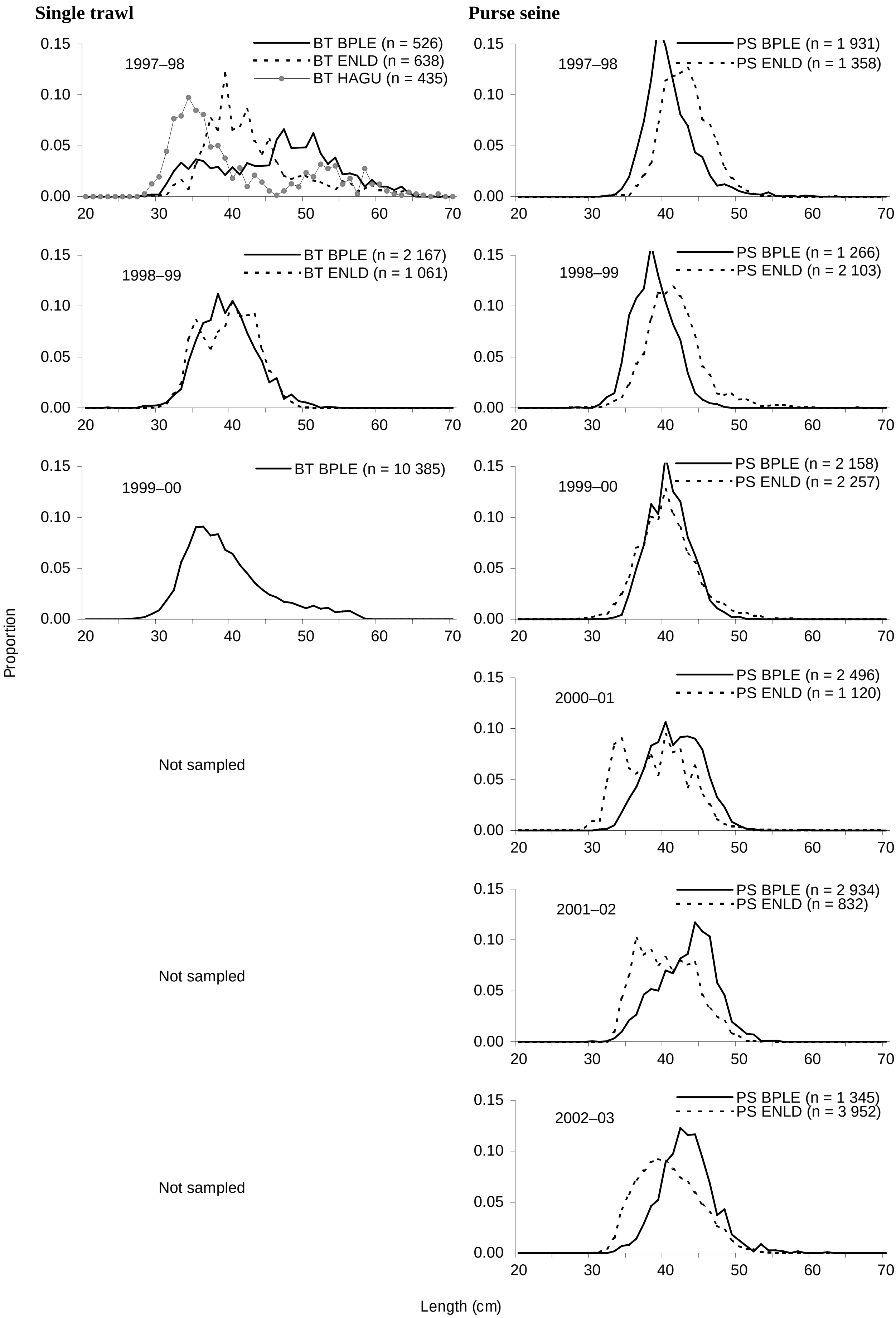


Figure 10: Comparison between length compositions of the TRE 1 single trawl and purse seine sub-area catches from the 1997–98 to 2002–03 fishing years. BPLE, Bay of Plenty; ENLD, East Northland; HAGU, Hauraki Gulf.

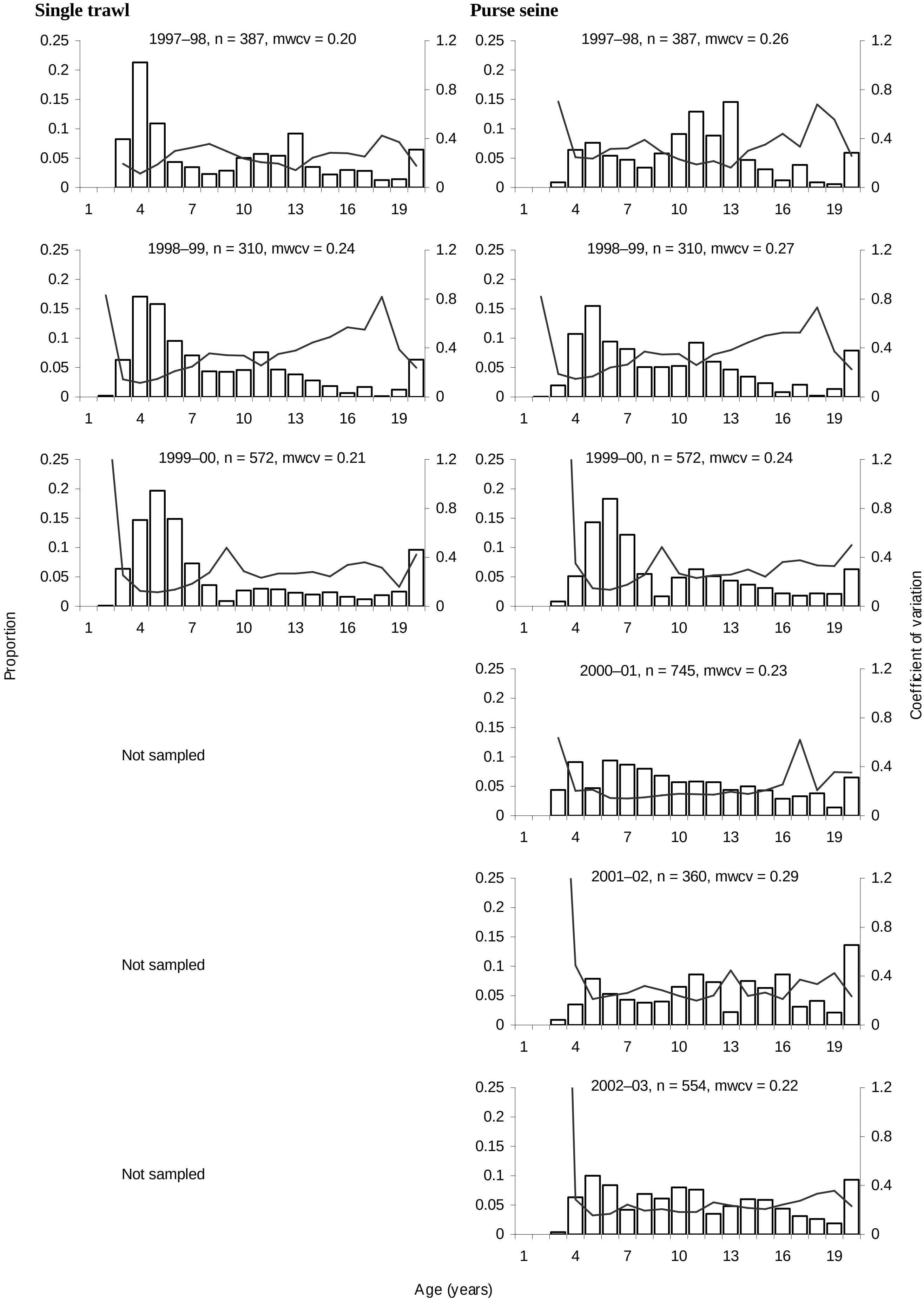


Figure 11: Age composition for the TRE 1 single trawl and purse seine fisheries from the 1997–98 to 2002–03 fishing years.

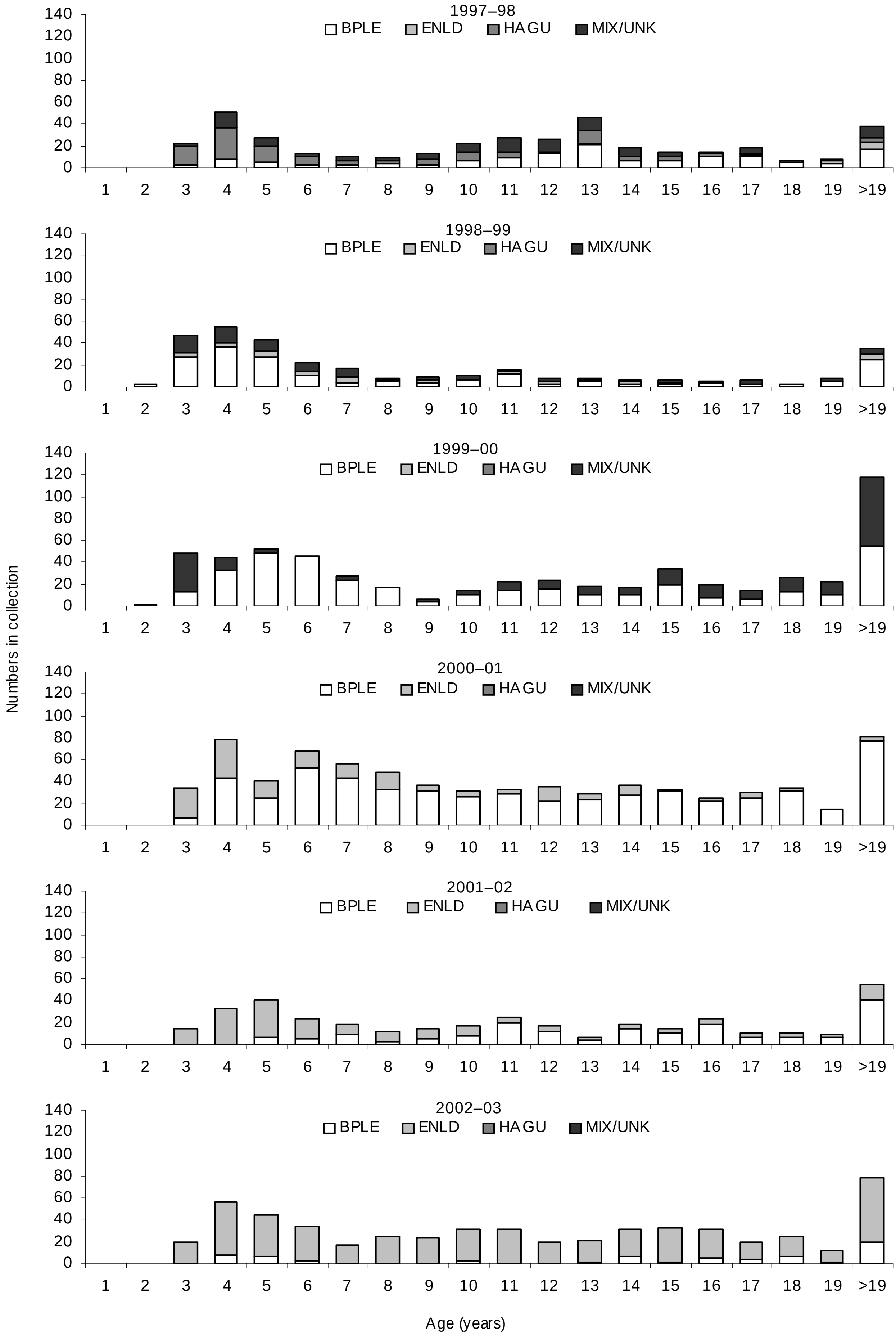


Figure 12: Comparison of the number of otoliths collected by age class and sub-area from the TRE 1 fishery, 1997–98 to 2002–03 fishing years. BPLE, Bay of Plenty; ENLD, East Northland; HAGU, Hauraki Gulf; MIX/UNK, mixed or unknown area.

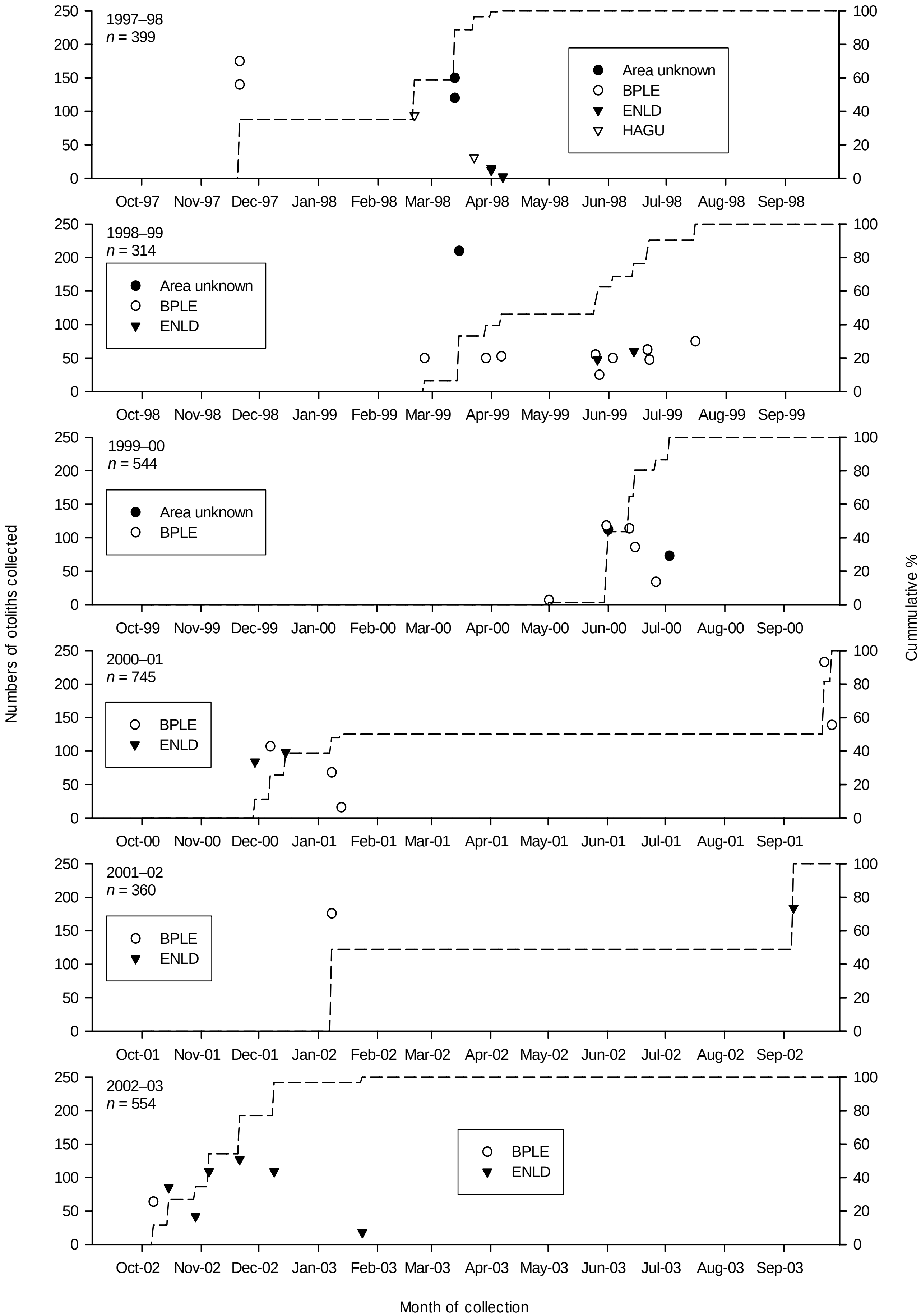


Figure 13: The number of otolith samples taken from each sub-area and the month of collection within TRE 1 for the 1997–98 to 2002–03 fishing years. Note: Another 28 otolith samples from 1999–00 are not included as the date and area of collection was unknown. BPLE, Bay of Plenty; ENLD, East Northland; HAGU, Hauraki Gulf.

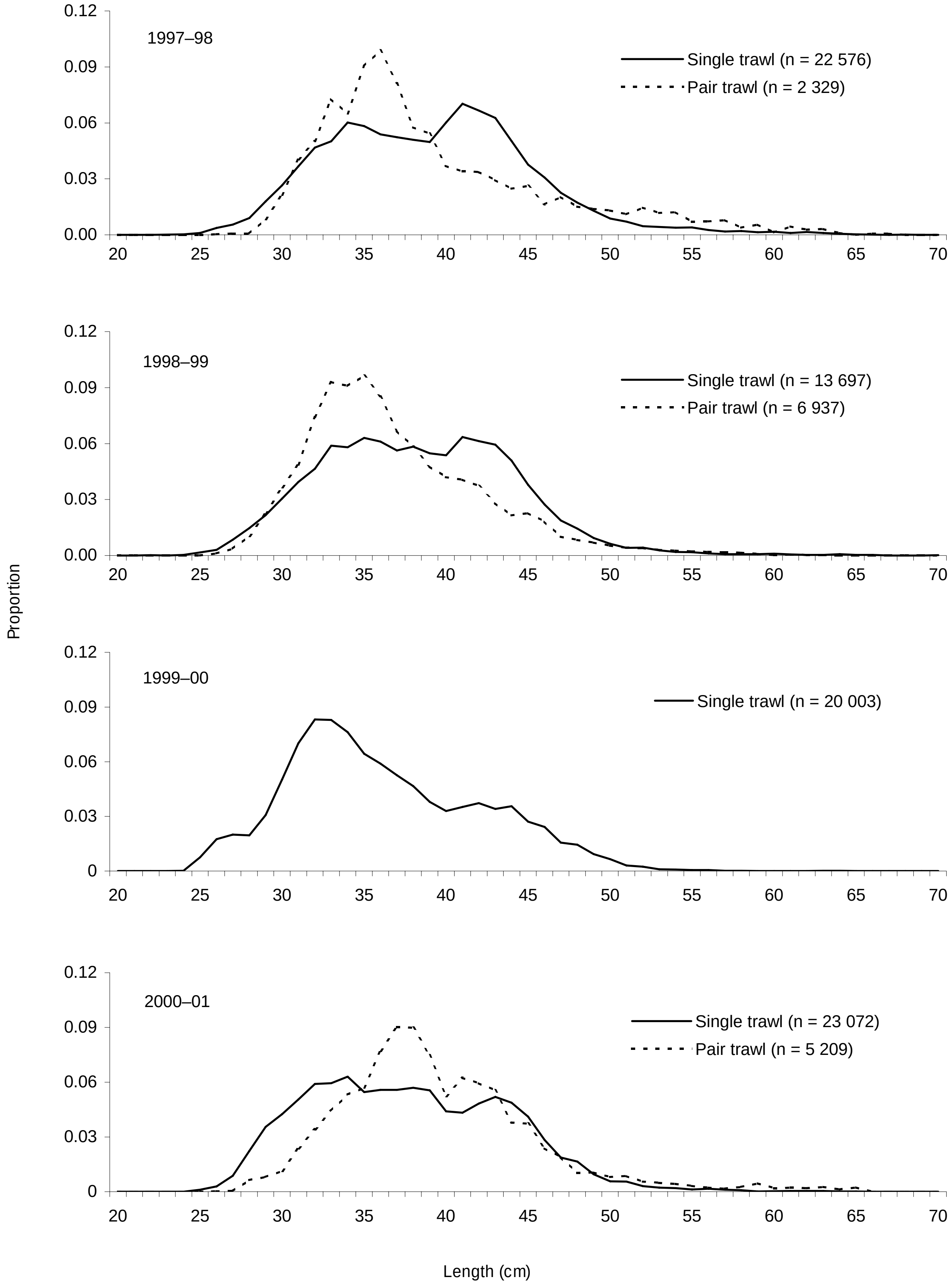


Figure 14: Length composition for the TRE 7 single trawl and pair trawl fisheries from the 1997–98 to 2000–01 fishing years.

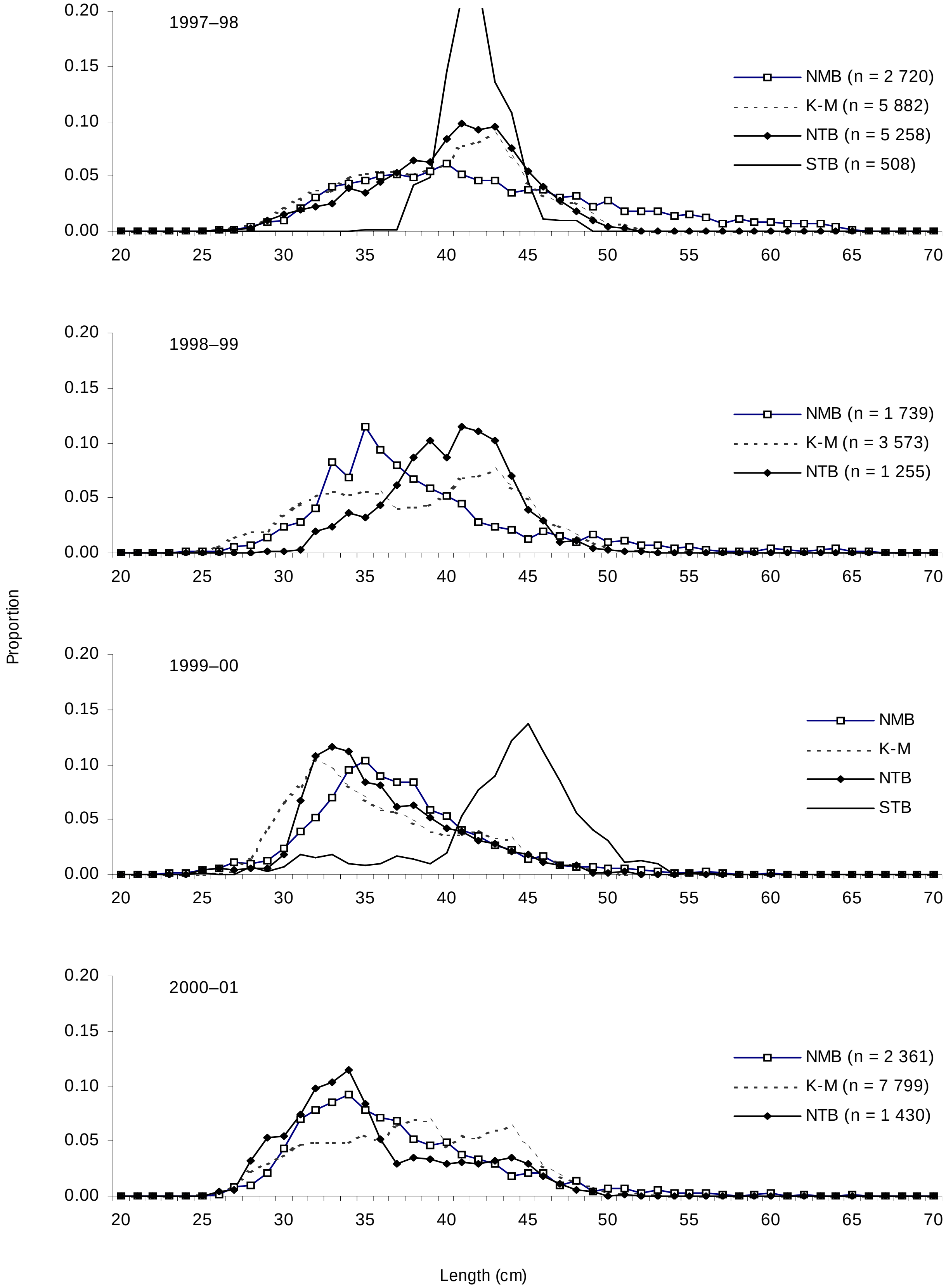


Figure 15: Comparison between length compositions of the TRE 7 single trawl sub-area catches from the 1997–98 to 2000–01 fishing years. NMB, Ninety Mile Beach; K-M, Kaipara-Manukau; NTB, North Taranaki Bight; STB, South Taranaki Bight.

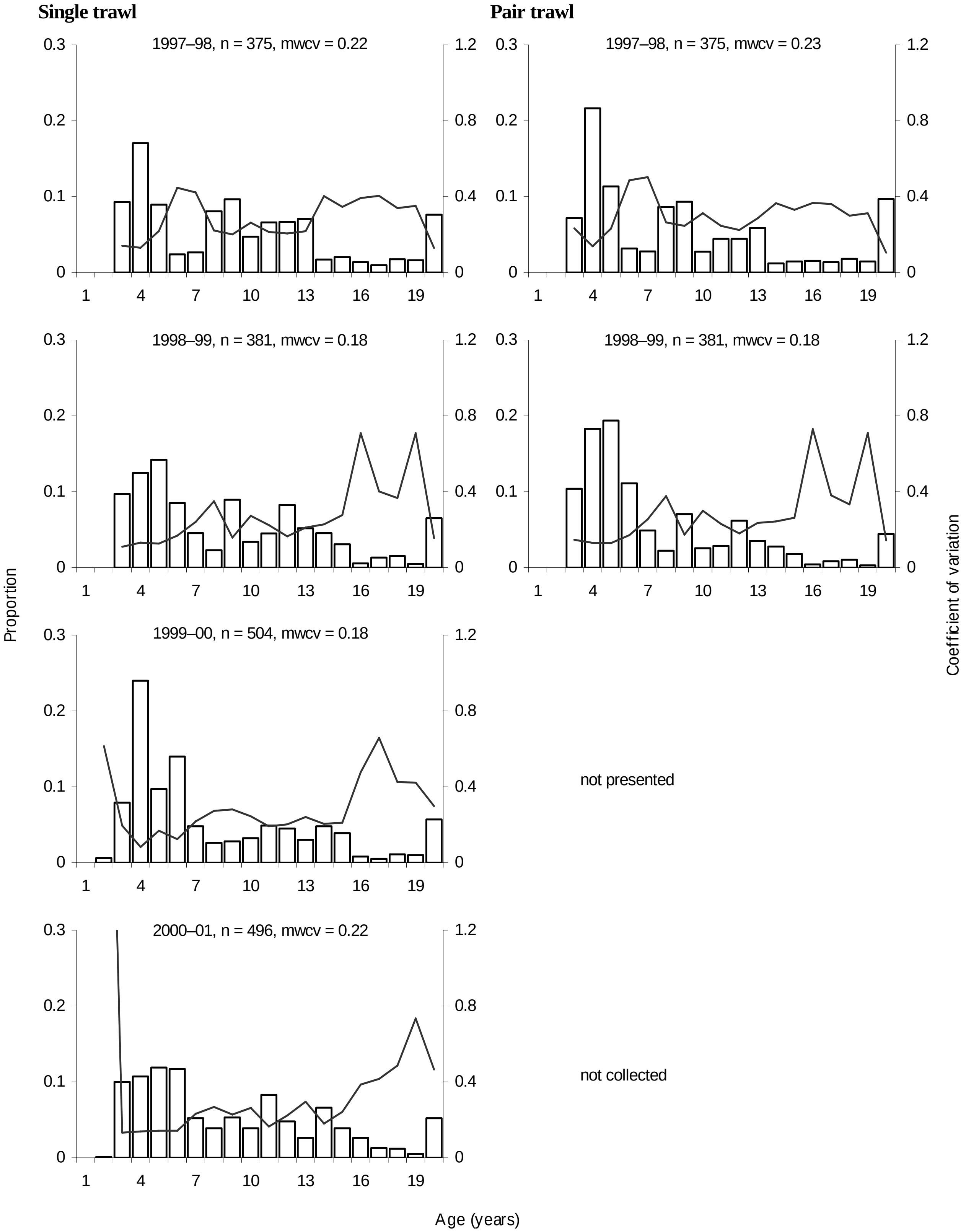


Figure 16: Age composition for the TRE 7 single trawl and pair trawl fisheries from the 1997–98 to 2000–01 fishing years.

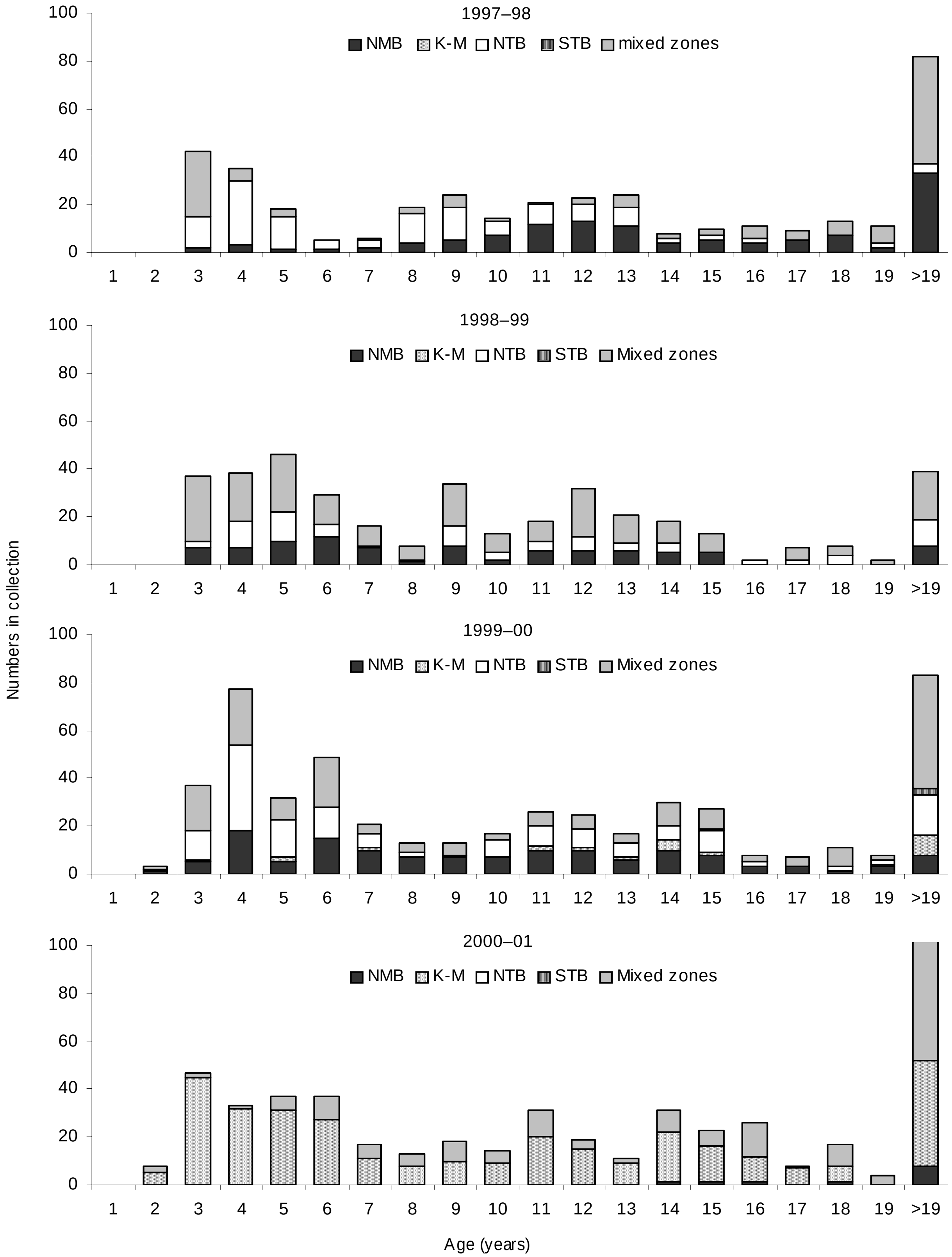


Figure 17: Comparison of the number of otoliths collected by age class and sub-area from the TRE 7 fishery, 1997–98 to 2000–01 fishing years. NMB, Ninety Mile Beach; K-M, Kaipara-Manukau; NTB, North Taranaki Bight; STB, South Taranaki Bight.

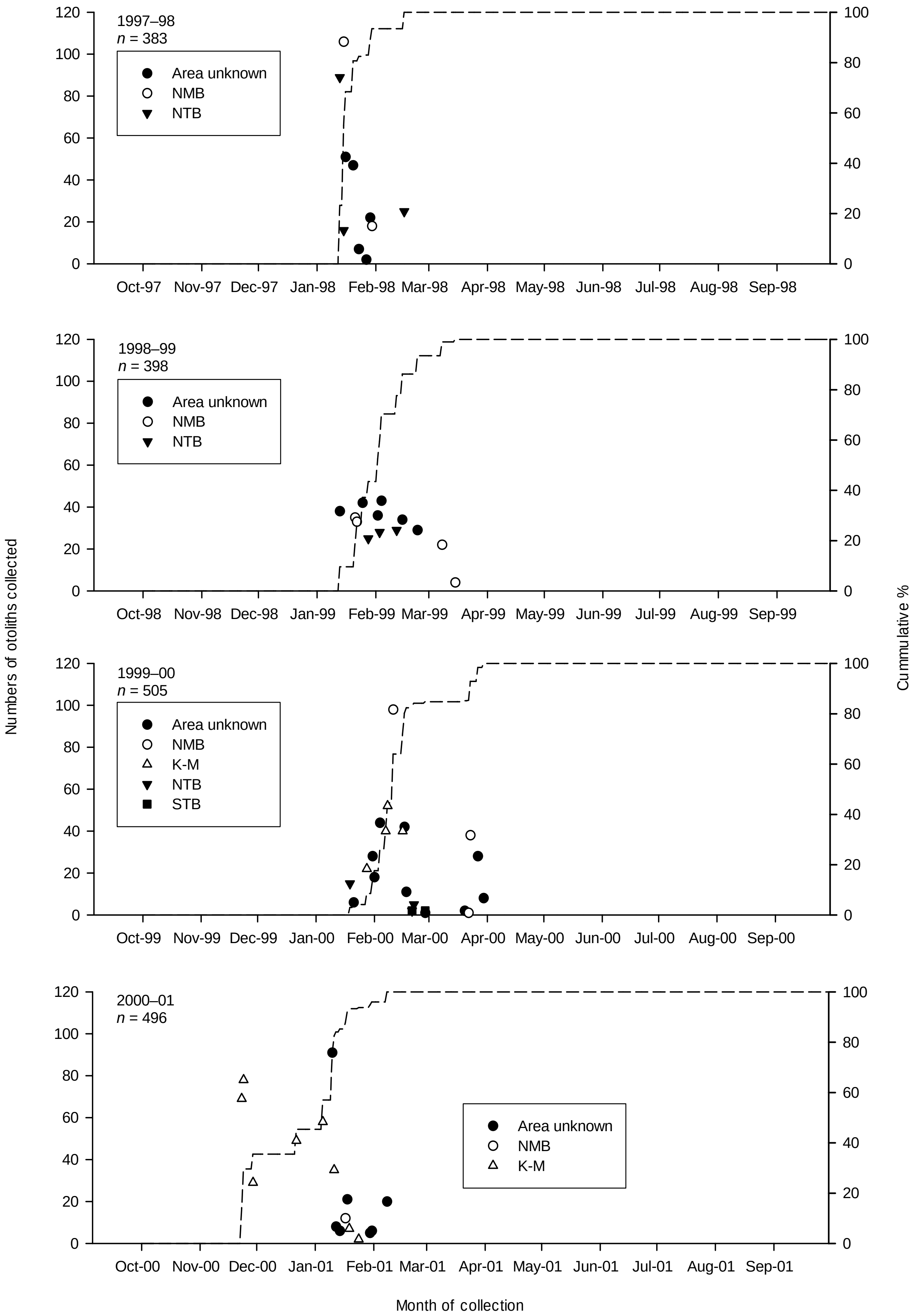


Figure 18: The number of otolith samples taken from each sub-area and the month of collection within TRE 7 for the 1997–98 to 2000–01 fishing years. NMB, Ninety Mile Beach; K-M, Kaipara-Manukau; NTB, North Taranaki Bight; STB, South Taranaki Bight.

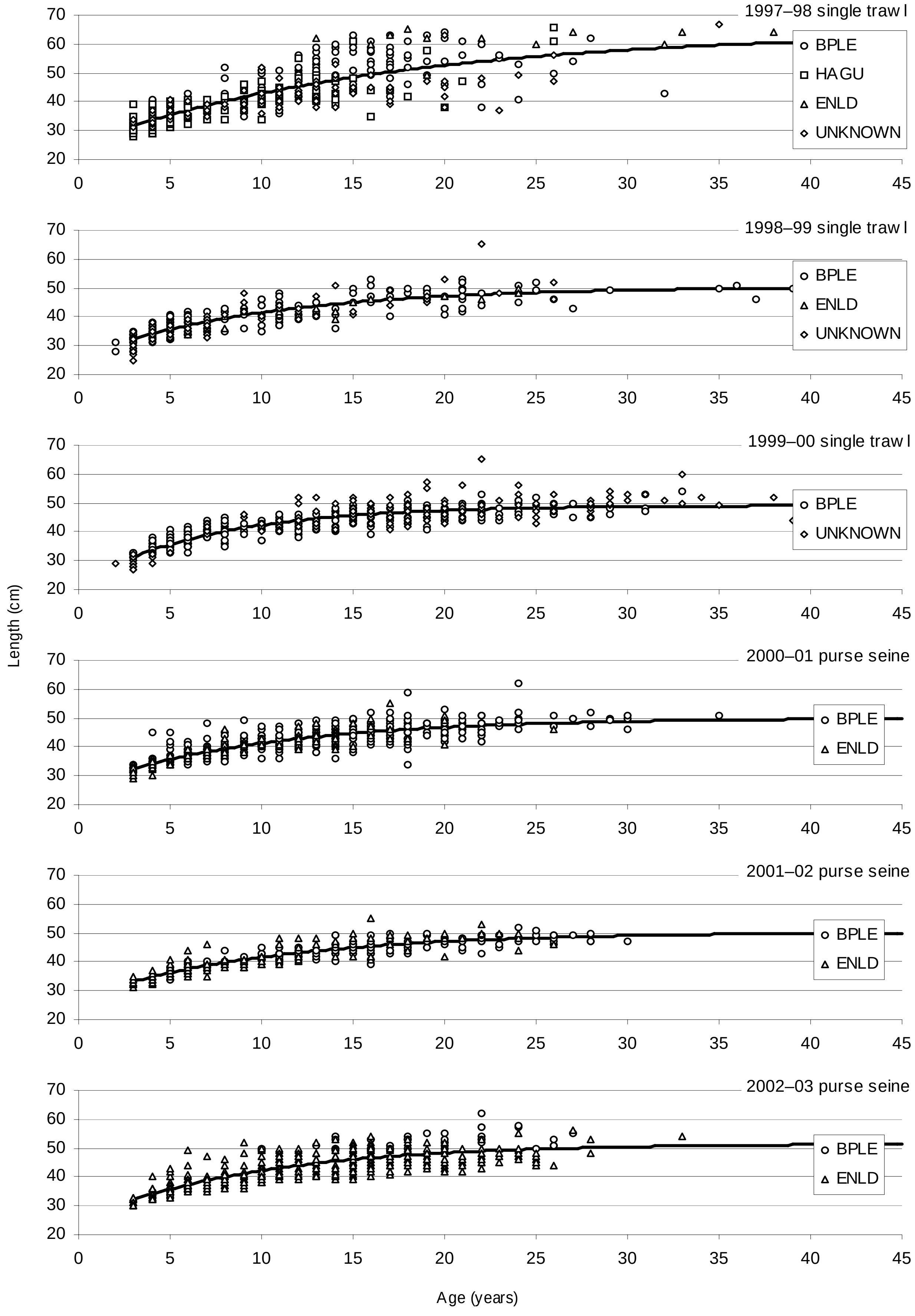


Figure 19: von Bertalanffy growth curves and scatterplots of age at length data by sub-area (and main method of capture) for trevally from TRE 1 for the 1997–98 to 2002–03 fishing years. BPLE, Bay of Plenty; ENLD, East Northland; HAGU, Hauraki Gulf.

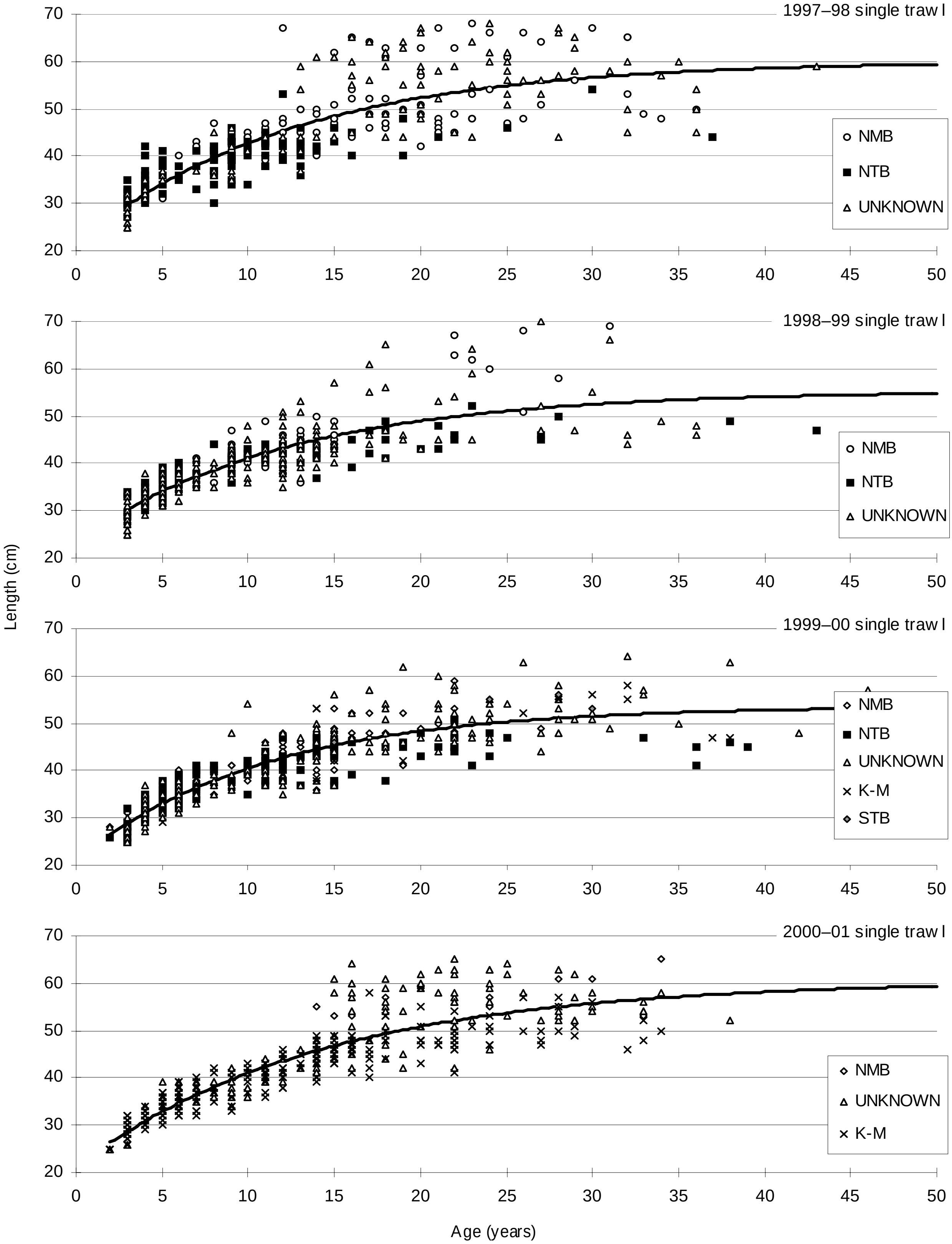


Figure 20: von Bertalanffy growth curves and scatterplots of age at length data by sub-area (and main method of capture) for trevally from TRE 7 for the 1997–98 to 2000–01 fishing years. NMB, Ninety Mile Beach; K-M, Kaipara-Manukau; NTB, North Taranaki Bight; STB, South Taranaki Bight.

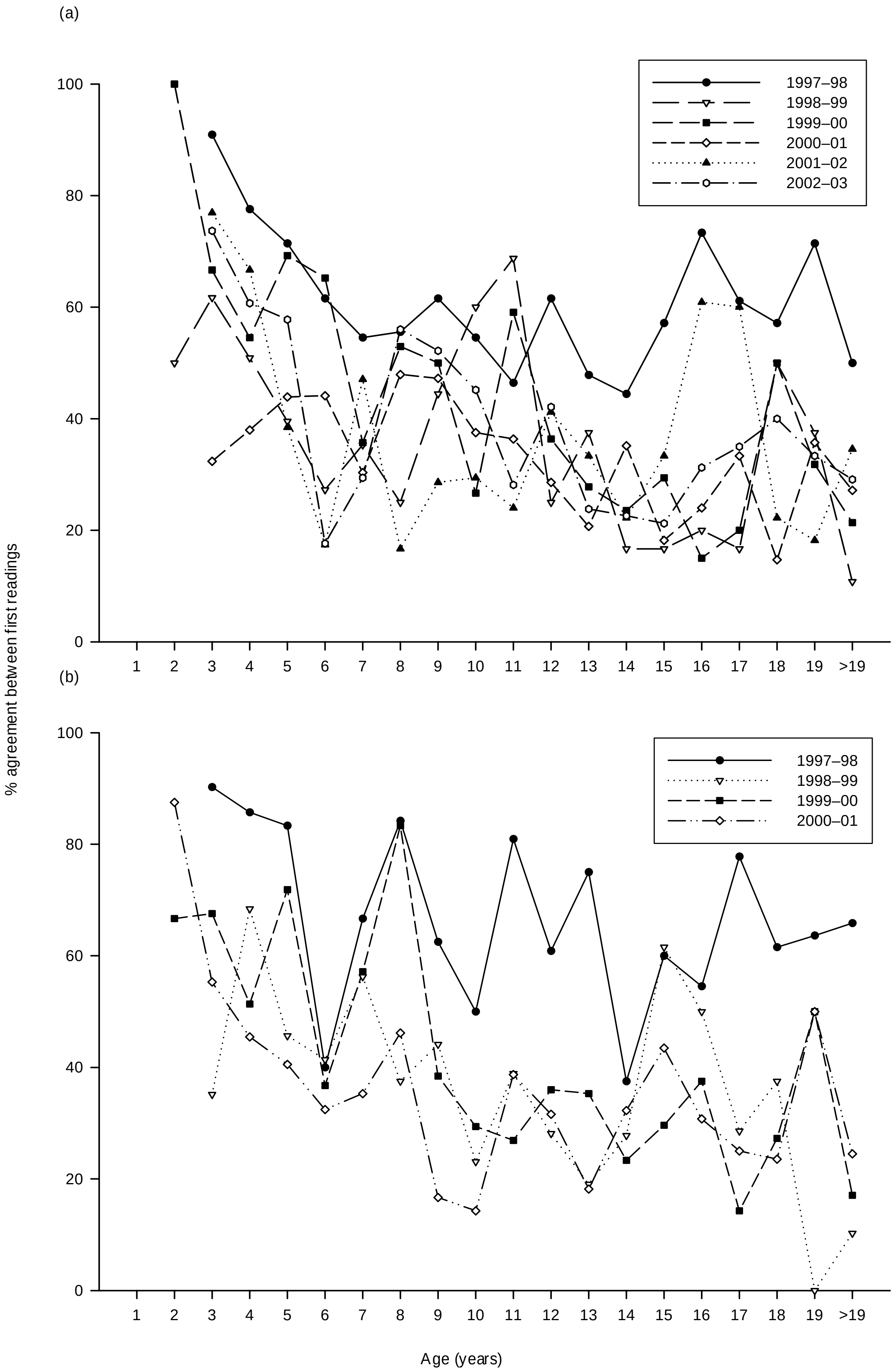


Figure 21: The percentage agreement between readers (using first reading 'ring count' only and not allowing for interpreting margin estimates) by age class using otolith data collected from the (a) TRE 1 and (b) TRE 7 stocks from 1997–98 to 2002–03. Note: Data presented for 1997–98 and 1998–99 are for readers 1 and 2, and from 1999–00 to 2002–03 readers 1 and 4 are used.

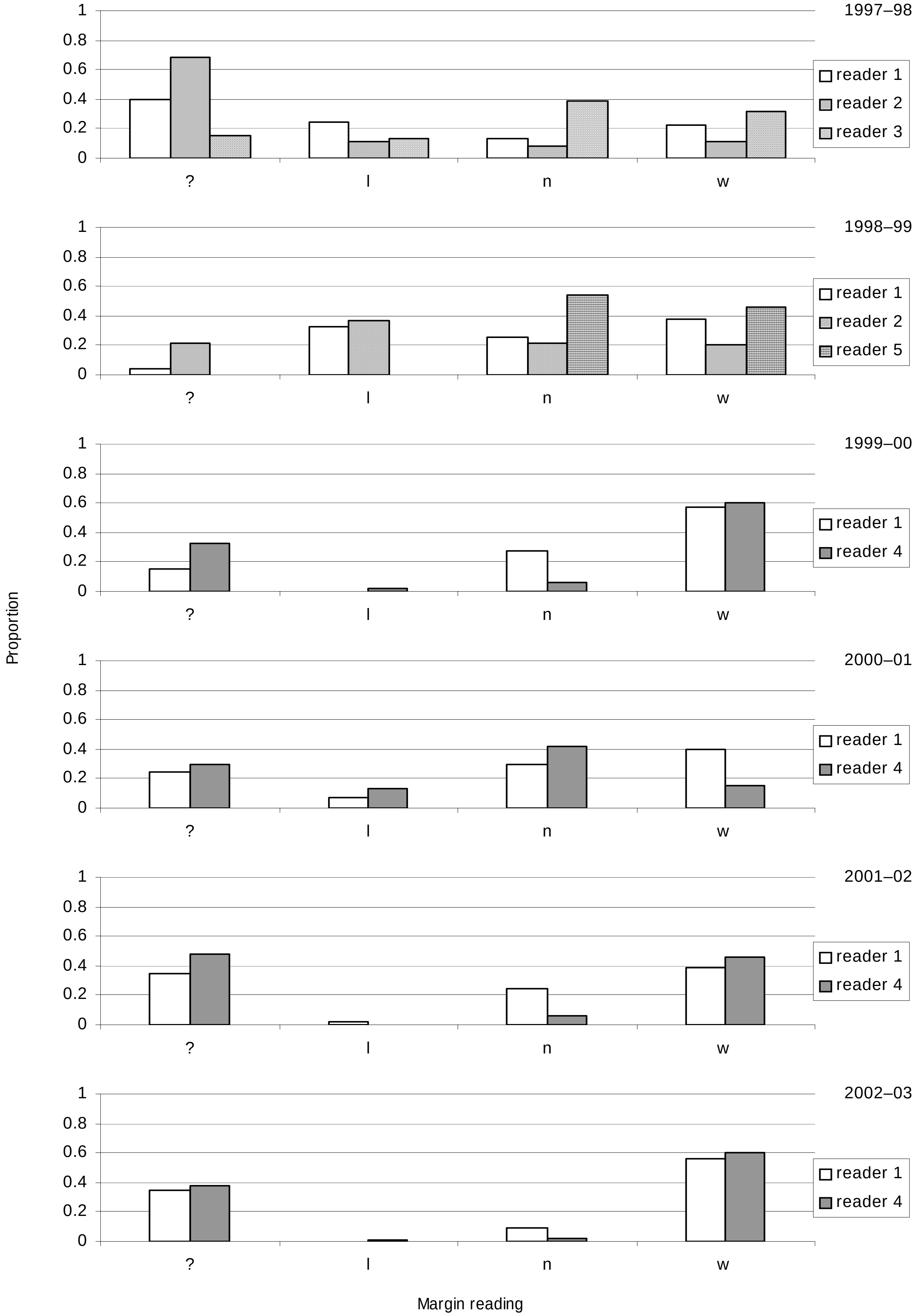


Figure 22: Proportion of margin readings (histograms) determined from readers ageing otolith collections sampled from the TRE 1 fishery from the 1997–98 to 2002–03 fishing years. Key: ?, unknown; l, line; n, narrow; w, wide.

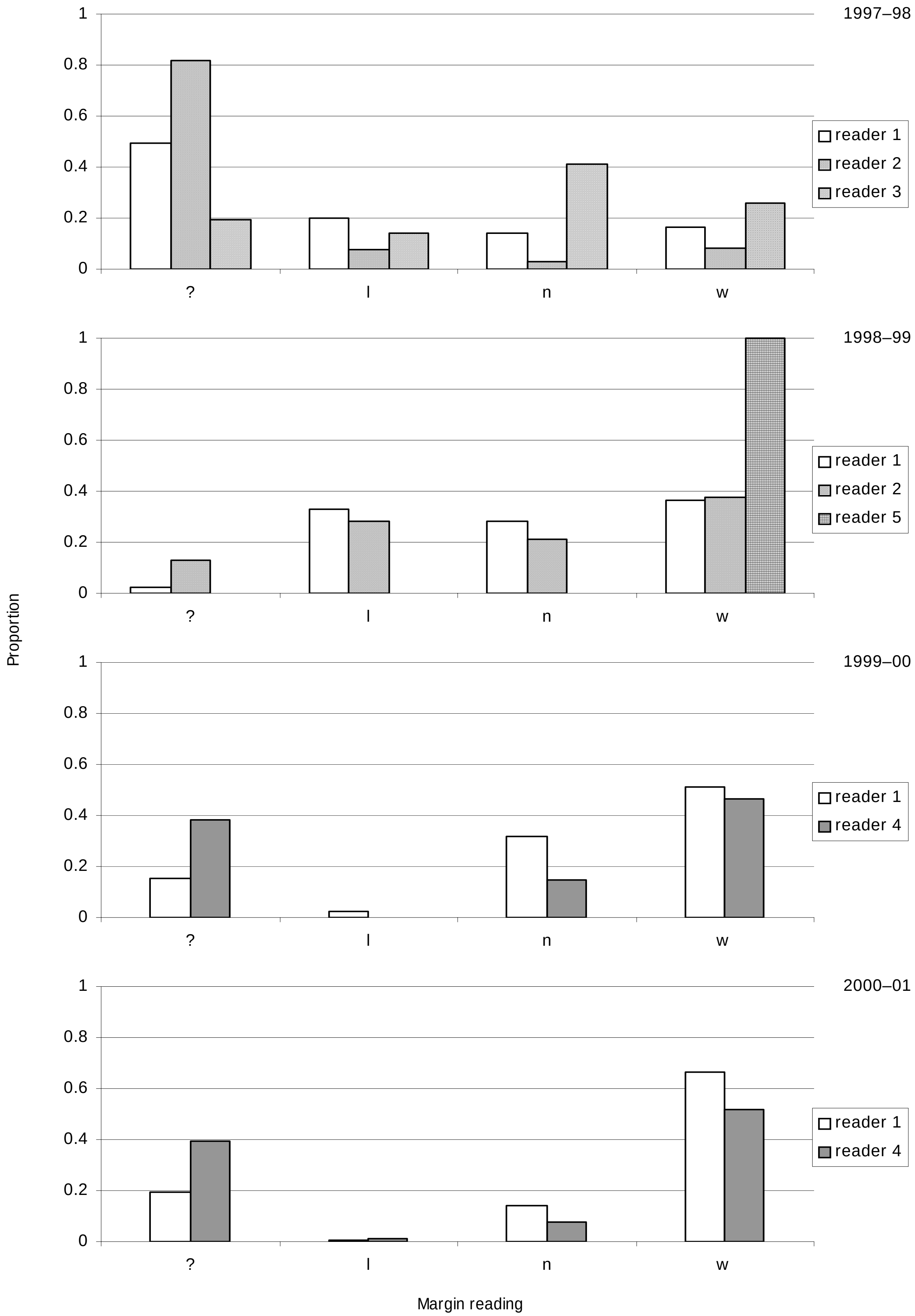


Figure 23: Proportion of margin readings (histograms) determined from readers ageing otolith collections sampled from the TRE 7 fishery from the 1997–98 to 2000–01 fishing years. Key: ?, unknown; l, line; n, narrow; w, wide.

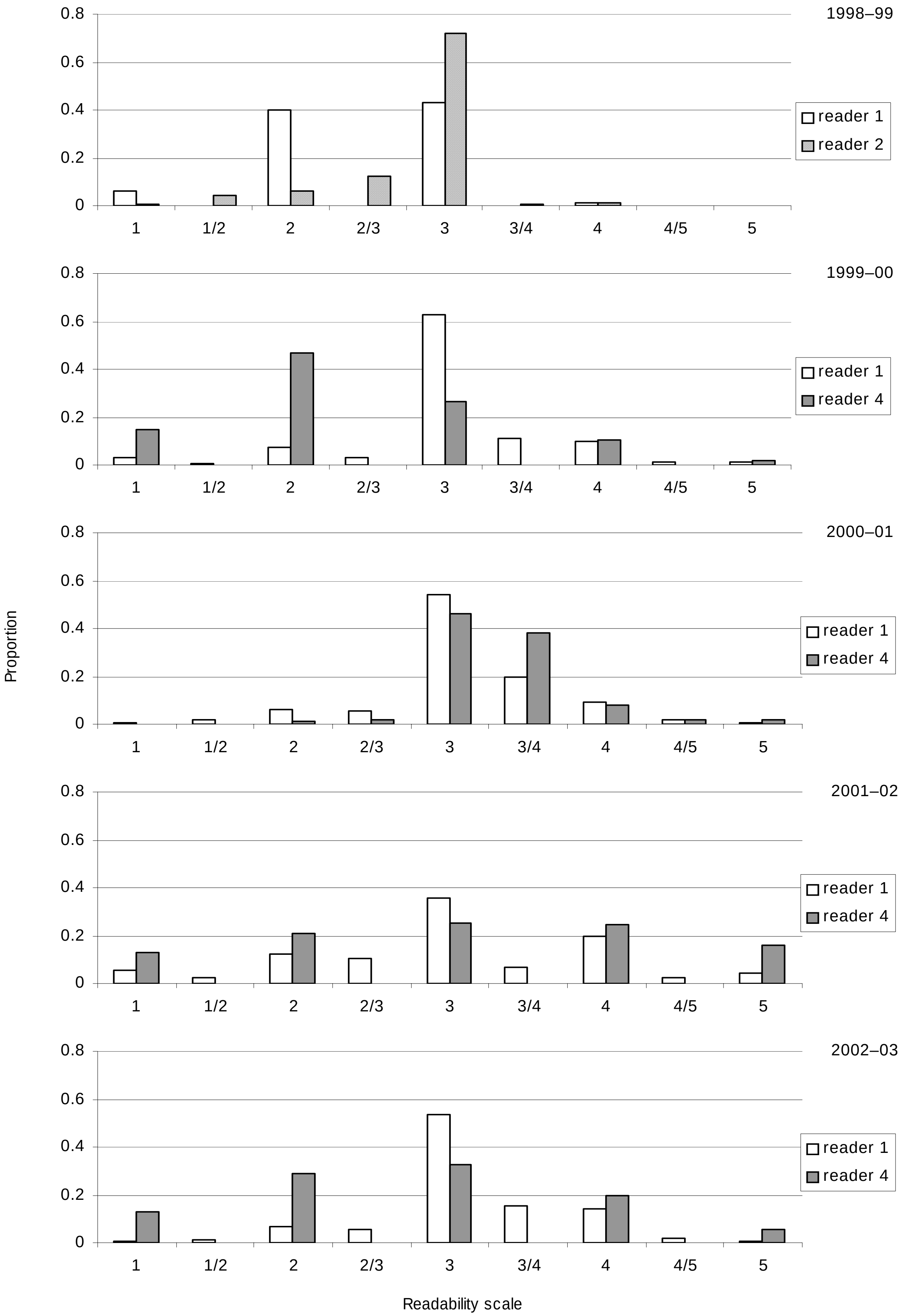


Figure 24: Proportional summary of ranking scores of otolith readability for samples collected from the TRE 1 fishery from the 1998–99 to 2002–03 fishing years. Note: Readability scale summary in Appendix 1; No ranking score was available for the 1997–98 data.

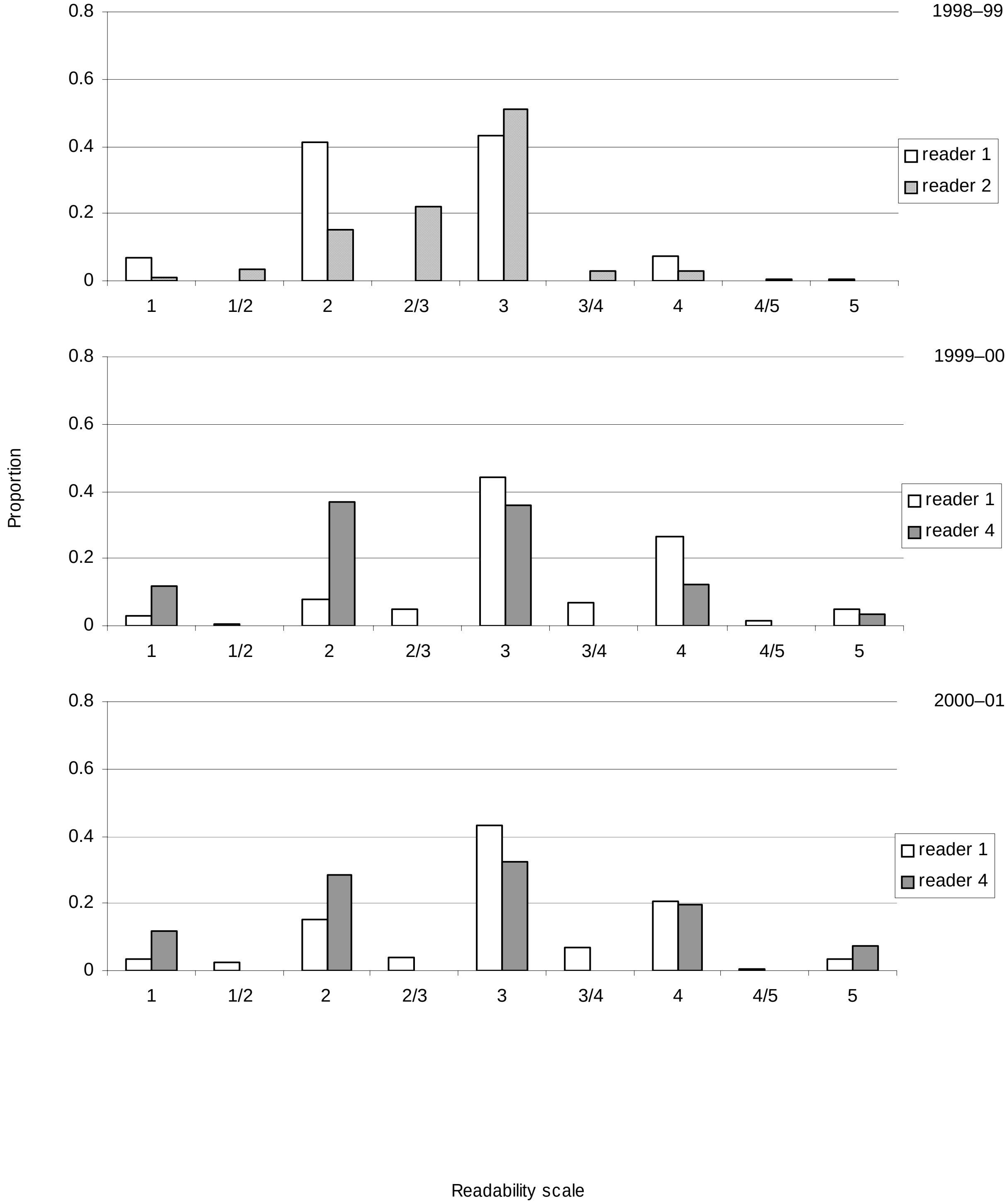


Figure 25: Proportional summary of ranking scores of otolith readability for samples collected from the TRE 7 fishery from the 1998–99 to 2000–01 fishing years. Note: Readability scale summary in Appendix 1; No ranking score was available for the 1997–98 data.

Appendix 1: Trevally otolith reading protocol

Trevally otolith reading protocol
24/4/98

Guide to the interpretation and location of the 1st zone

- Whole otoliths from small fish give an indication of the size of the nucleus and the 1st dark (opaque) zone.
- The first year zone appears as the 1st obvious zone after the wide and dark nucleus area.
- This is further clarified by a small indentation (growth feature) on the otolith edge.
- Initially when counting from the nucleus out to the edge of the otolith, clear wide zones are visible.
- Regularly these wide zones decrease proportionately in size up to the 4th zone.
- After the 4th zone evenly spaced narrow zones then occur.

Readability scale

Ranking score	*Description of readability*
1	Excellent – no doubt
2	Very good – some doubt +/- 1 year
3	Okay – +/- 2 years
4	Difficult – informed guess
5	Not readable – guess?

Marginal increment

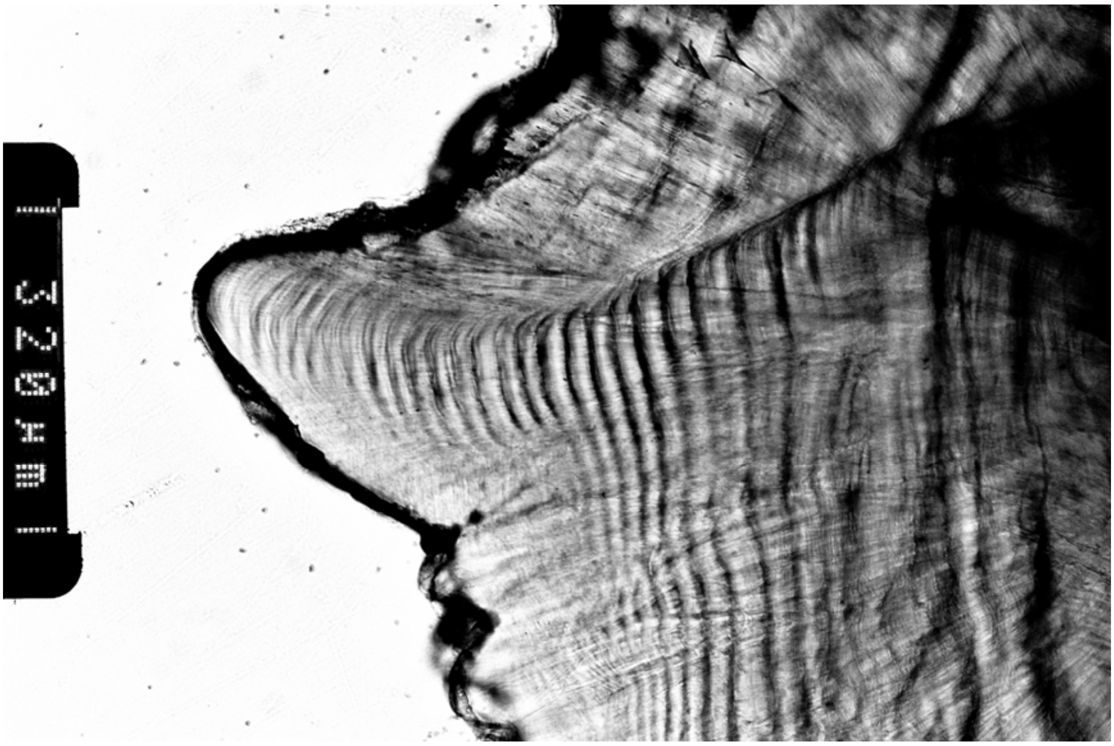
After the appearance of the dark growth zone (opaque) in young fish, the translucent (hyaline) margin is:

N – narrow band
W – wide band
L – only the zone (dark band) visible

For older fish, the margin detail after the last zone is less clear – use above criteria if possible.

Appendix 2a: Otolith of a 44 cm male trevally prepared using the thin section technique and estimated to be 29+ years. Scales are in µm.

Appendix 2b: Magnified view along the ventral sulcal growth zone of the above otolith. Scales are in µm.



Appendix 2c: Otolith of a 58 cm male trevally prepared using the thin section technique and estimated to be 32+ years. Scales are in µm.

Appendix 2d: Magnified view along the dorsal sulcal growth zone of the above otolith. Scales are in µm.