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EXECUTIVE SUMMARY

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The purpose of this investigation is to determine whether spatial heterogeneity in East Northland longline landings considerably affects the precision of catch-at-length and catch-at-age estimates. This may influence the choice of sampling design, taking into consideration the desired level of precision and the resources required to implement a design.

The sampling design used until 2000–01 has been unstratified with respect to area, and therefore has pooled the length and age data from all spatial strata of East Northland. Typically the design collects length frequency samples from 40–50 landings, and random subsamples for age of about 25 otoliths per landing. This design generally satisfies the desired precision of a target mean weighted coefficient of variation (MWCV) equal to 0.2, but samples collected from the East Northland longline fishery have characteristically higher variance estimates compared to other stocks in SNA 1. A review of this design was suggested by the Ministry of Fisheries, to consider potential for the improvement of precision by taking account of heterogeneity in catch-at-age between strata within East Northland. Consequently a variation was made to the project SNA2000/02 to include an objective titled: East Northland substratum analyses.

To address the objective, the East Northland longline fishery was stratified on the finest possible spatial scale (fisheries statistical areas 002 and 003), and historical length and age data were used for two separate analyses. First, to estimate stratum catch-at-length, catch-at-age, and variance from 1995–96 to 1999–2000; and second, simulations of alternative sampling designs using the most recent length and age data. These analyses were done for both the length frequency plus age-length key (LF+ALK) and random age frequency (RAF) sampling strategies, using the stratified and unstratified designs.

Few differences in the age composition of landings between strata were evident, with variations in the abundance of particular year classes for some years between 1995–96 and 1999–2000, suggesting some heterogeneity in catch-at-age within East Northland. However, the age distributions and between-landing variability in catch-at-age were broadly similar between strata. This was reflected in the simulation results showing almost negligible effect on catch-at-age precision by stratifying either the LF+ALK or RAF sampling designs, suggesting no considerable heterogeneity in catch-at-age in the East Northland strata. The most likely explanation for the characteristically high catch-at-age MWCV for East Northland relative to other SNA 1 stocks is the broader age composition with few dominant age classes in catches.

The relative benefit gained in catch-at-age precision obtained by using the stratified RAF sampling design compared to an unstratified design was almost negligible (less than 1% absolute reduction in MWCV). For most of the logistically feasible sample size options investigated for the LF+ALK sampling strategy, stratification produces marginally worse catch-at-age precision than the unstratified design. This was due to the allocation of small age-length key sample sizes to each stratum under the stratified design creating low precision in stratum catch-at-age estimates, hence offsetting benefits gained from deriving weighted mean variance across strata. However, irrespective of sampling design (stratified or unstratified), the LF+ALK sampling strategy produces higher precision in catch-at-age compared to the RAF strategy. Despite this benefit, the additional resources required for implementing the LF+ALK sampling strategy, and for applying the stratified sampling design, and the almost negligible improvement gained by stratifying the RAF sampling

design, leads us to recommend the unstratified RAF sampling design be used for estimating catch-at-age in the East Northland longline fishery. The random selection of landings from the entire fishery, and all processing sectors, is likely to ensure sampling is proportional between strata relative to landings from the fishery, and assures the sample is representative.

1. INTRODUCTION

Landings of snapper from the SNA 1 and SNA 8 fisheries have been sampled for length and age annually since 1989 to create a time series for input to snapper stock assessments (Walsh et al. 2003). Under the sampling design used, landings are stratified hierarchically by stock, fishing method, and season, e.g., Bay of Plenty – longline – spring. The stocks correspond to the four areas: west coast North Island, Bay of Plenty, Hauraki Gulf, and East Northland (Figure 1). Fishing methods sampled were longline (BLL) for the SNA 1 stocks, and single trawl (BT) and pair trawl (BPT) for the SNA 8 stock. Consequently, the East Northland longline fishery has been sampled annually during the spring and summer seasons.

Spatial heterogeneity in landings of fish sampled for length and age may considerably affect the precision of derived catch-at-length and catch-at-age estimates. If such spatial heterogeneity exists, then efforts should be made to ensure the sampling covers each spatial entity correctly, and is in proportion to the spatial distribution of catches across the entire stock. The pre-stratification of the sampling effort into geographical areas or other aspects of the catching process is recommended, and should help to avoid bias and improve precision (Bull & Gilbert 2001).

Samples collected from the East Northland longline fishery have characteristically higher variance estimates than other stocks in SNA 1. Consequently, the Ministry of Fisheries requested an investigation of the existence of spatial heterogeneity in East Northland longline catches. A variation was made to the snapper research project SNA2000/02 to add an objective for this investigation:

1. *To determine whether stratification of the East Northland longline snapper catch-at-length and catch-at-age data by statistical area improves estimated precision.*

We examine historical data from the East Northland longline fishery for evidence of spatial heterogeneity in catch-at-age and catch-at-length compositions, and for the effects on precision of applying a sampling design that is stratified by statistical area. Recommendations for an optimum design for estimating catch-at-age are made.

2. METHODS

Historical data from the East Northland longline fishery were stratified on the finest spatial scale possible using commercial catch records and the time series of catch-at-length and catch-at-age samples. The strata corresponded to the commercial fishing statistical reporting area used for the collection of Catch Effort Landing Returns (CELR) by the Ministry of Fisheries. Two statistical areas, 002 and 003, constitute the East Northland region and defined the spatial strata (Figure 1). Historical length and age data from the commercial longline fishery operating in the two strata were used for two separate analyses. First, to derive stratum catch-at-age and variance estimates for 1995–96 to 1999–2000; and second, to investigate alternative sampling strategies within and between the strata using simulations.

2.1 Catch-at-age estimates 1995–96 to 1999–2000

A full description of the collection and analysis of snapper catch-at-length and catch-at-age samples from East Northland was given in a series of reports by Walsh et al. (1997, 1998, 1999, 2000, 2001). A brief overview follows to provide a background for the treatment of these data in this study.

Snapper length and age samples collected during spring and summer from 1995–96 to 1999–2000 were analysed for each stratum to calculate proportion of catch-at-age and to estimate variance expressed as mean weighted coefficient of variation (MWCV). Data from the spring and summer seasons in each year were combined for this investigation. Length and age data and the corresponding CELR records stored on the Ministry of Fisheries databases were extracted for each stratum. Data for a landing where fish were caught from both strata were excluded from the analysis, but such instances were few. Catch information for longline landings over the entire fishery (weight and number of landings) was summarised by stratum.

Two methods for sampling catch-at-length and catch-at-age were used from 1995–96 to 1999–2000. The first was the length frequency and age-length key strategy (LF+ALK) that was used in 1995–96, 1996–97, and 1999–2000. This involved the annual collection of about 40–50 length frequency samples, with a total of about 600–1000 otolith samples collected as a subsample from the length frequency samples. The otoliths were collected by proportional allocation according to the length frequency distribution as estimated for the previous year. Estimates of stratum proportion caught at length and age, and analytical variances (expressed as *coefficients of variation, c.v.) followed those of Davies & Walsh (1995). Bootstrap mean* and c.v. estimates were not determined because the difference between bootstrap and analytical estimates has been found to be negligible (Davies et al. in prep.). Estimates were calculated for the recruited age classes with the maximum age being a 20 years plus group.

The second method, the random age frequency (RAF) strategy (Davies et al. 2003, Blackwell et al. 1999), was used from 1996–97 to 1999–2000. RAF samples were collected from an individual landing by taking random otolith samples from each grade of fish making up the landing. No length frequency sample was required. A random sample of bins from each landing was taken with the systematic selection of every n^{th} fish counted in a continuous sequence from the sampled bins. The optimum selection interval, n, was determined from simulations using data from historical length and age samples that achieved a desired level of precision. This range took account of the expected mean number of fish in a bin and the total number of bins in landings. Sample sizes typically ranged from 15 fish collected from landings of 10 bins to 45 fish from landings of above 100 bins. A total sample size of 1000 otoliths was targeted for collection from each fishery. Estimates of proportion caught at age and c.v.s (analytical and bootstrap) for the two East Northland strata were calculated from the RAF samples. Bootstrap mean estimates are not presented because the difference between analytical and bootstrap means in proportion at age estimates has been found to be negligible (Davies et al. 2003).

In 1996–97 and 1999–2000 the RAF method was used for otolith collection, and length frequency samples were also collected. The age-length data from the otolith samples was used to formulate an age-length key and, therefore, LF+ALK estimates of catch-at-age were calculated in addition to the RAF estimates using the same otolith data. The numbers of landings sampled for length frequency differed slightly from the number sampled for RAF in 1996–97.

Under both sampling strategies, the estimates of proportion caught at age and length for the East Northland fishery were calculated according to two possible design options; unstratified, or stratified. In the unstratified design, length and age data were pooled across both spatial strata, thus treating the fishery as a single stratum. In the stratified design, estimates of proportion caught at age and length were calculated for each stratum, and combined to calculate weighted mean estimates. The stratum estimates were combined across strata and weighted according to the estimated number of fish landed in each stratum following Blackwell et al. (1999):

$$\hat{p}_i = \frac{\sum_{j=1}^{n} \frac{\hat{p}_{ij} T_j}{\hat{w}_j}}{\sum_{j=1}^{n} \frac{T_j}{\hat{w}_j}}$$

where $\hat{p}_i$ is the weighted mean proportion at age i across all strata j from 1 to n strata, $\hat{p}_{ij}$ is the estimated proportion at age in stratum j, T_j is the reported total weight of fish landed in stratum j, and $\hat{w}_j$ is the mean fish weight in the stratum estimated from the sample length composition. Hence, the variance of $\hat{p}_i$ was estimated by

$$\hat{\text{var}}(\hat{p}_i) = \frac{\sum_{j=1}^{n} \frac{\hat{v}_{ij} T_j^2}{\hat{w}_j^2}}{\left(\sum_{j=1}^{n} \frac{T_j}{\hat{w}_j}\right)^2}$$

where $\hat{v}_{ij}$ is the estimate of variance of $\hat{p}_{ij}$ that was calculated following Davies & Walsh (1995). Bootstrap estimates of $\hat{\text{var}}(\hat{p}_i)$ were also calculated for the RAF samples using 1000 replicates of $\hat{p}_i$ derived from the bootstrap estimates of $\hat{p}_{ij}$. In each bootstrap, landings and fish within landings were sampled with replacement from the original samples taken in each stratum up to the original total sample size for each stratum and landing respectively. The pseudo-replicate samples were then used to calculate the bootstrap estimate of $\hat{p}_{ij}$ and $\hat{w}_j$, and consequently $\hat{p}_i$.

The estimated MWCVs of age and length compositions of commercial catches derived from both sampling strategies were compared with those derived using the stratified sampling design with the unstratified design.

2.2 Alternative sampling design options

For the LF+ALK and RAF sampling strategies, and for both the stratified and unstratified designs, a range of alternative sample size options was investigated by simulation. An approach similar to that described by Bentley et al. (2002) was followed, where samples taken from the fishery were resampled under a range of sample size options to determine optimum levels of precision. Catch-at-age MWCV was estimated for alternative sample sizes under the stratified and unstratified designs, using data collected by both the LF+ALK and RAF sampling strategies.

Data from 1999–2000 were used to include current observed variability in length and age compositions between landings and recent patterns in relative year class strengths. Both these factors will determine catch-at-age precision derived from particular sample size options, and will differ from year to year. The number of landings sampled in that year was 32 and 15, and the otolith sample sizes were 651 and 321 for strata 002 and 003 respectively. These comprise data from both the LF+ALK and RAF sampling strategies carried out in that year.

Length frequency and otolith data were used to calculate the MWCV associated with different combinations of landing and otolith sample sizes using the LF+ALK strategy. The landing sample size is the total number of landings selected at random from the fishery, and the otolith sample size is the total number of otoliths making up the age-length key. Sample size options were investigated within the ranges of 10 to 60 landings, and 200 to 1200 otoliths collected. For each option investigated, 1000 bootstraps were carried out. In each bootstrap, both landings and bins within landings were randomly resampled with replacement to derive a landing length frequency. Similarly, otoliths within each length class interval of the age-length key were randomly resampled with replacement to produce an age-length key for the specified total sample size. The variance and MWCV of the 1000 bootstrap catch-at-age estimates were calculated.

Simulations of the RAF sampling strategy were undertaken for sample size options within a range of 10 to 60 landings, with 10 to 60 otoliths being sampled from each landing. An option was therefore a specific combination of the number of landings sampled, and an otolith sample size taken from each landing, e.g., 40 landings with 20 fish randomly sampled from each landing. For each option, 1000 bootstraps were carried out to estimate the catch-at-age MWCV. In each bootstrap, both landings and individual fish in the sample taken from a landing were randomly resampled with replacement to derive pseudo-replicate RAF samples.

For both the LF+ALK and RAF strategies, the MWCVs were compared for simulations using the stratified sampling design with those using an unstratified design. The comparison was made in terms of the absolute percentage difference in MWCV obtained from the stratified compared to the unstratified design for every sampling strategy investigated, i.e.,

$$\partial\% = (MWCV_{strat} - MWCV_{unstrat}) \times 100$$

where $MWCV_{strat}$ and $MWCV_{unstrat}$ is the mean weighted coefficient of variation for the mean proportion caught at age over 1000 bootstraps under the stratified and unstratified designs respectively.

3. RESULTS

3.1 Catch-at-age estimates, 1995–96 to 1999–2000

3.1.1 Sample collections

Summaries of the number of landings and otoliths sampled under each sampling strategy and the total number of landings in the fishery are given by stratum for the combined spring and summer seasons from 1995–96 to 1999–2000 in Table 1. The ratio of the proportion of landings in the fishery from stratum 002 compared to 003 ranged from 0.56:0.44 in 1997–98 and 1999–2000, to 0.61:0.39 in 1995–96. The ratio of the proportion of landings sampled in stratum 002 compared to 003 ranged from 0.39:0.61 in 1997–98, to 0.68:0.32 in 1999–2000. In some years the number of landings sampled from each stratum was not proportional to the total number of landings in the fishery in each stratum.

The number of otoliths collected by the LF+ALK strategy in 1995–96 was roughly equally distributed at about 300 otoliths for strata 002 and 003 respectively. The stratum otolith sample sizes collected by the RAF method (1996–97 to 1999–2000) were roughly proportional to the number of landings collected in each stratum. For example, in 1999–2000, the ratio of sampled landings from strata 002 and 003 was 0.68:0.32 and the subsampled otolith collection was 651:321.

The total longline snapper catch and the number of landings in strata 002 and 003 from 1995–96 to 1999–2000 for the combined spring and summer seasons are presented in Figure 2. The total catch ranged between 365 and 565 tonnes. The relative proportions of the catch weight in each stratum were similar in most years except 1997–98, when the catch from stratum 003 exceeded that of 002. The total number of landings from respective strata was similar between years, with the number from stratum 002 always exceeding that from 003.

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

The time series of catch-at-length and catch-at-age estimates for the East Northland longline fishery from 1995–96 to 1999–2000 derived from the unstratified sampling design is presented in Figure 3. Catch-at-age analytical MWCV estimates for all years ranged from 0.11 to 0.18. In some years the sample sizes exceed the sum of the samples collected from each stratum listed in Table 1. This is because the data from any landing in which fish were caught from both strata were excluded from the data summarised in Table 1, but were included in deriving the unstratified estimates presented in Figure 3.

LF+ALK sample estimates of catch-at-length and catch-at-age, number of landings sampled, length frequency and otolith sample sizes, mean length, mean age, and MWCV for strata 002 and 003 are presented in Figures 4 and 5 for length and age respectively. Although the length distributions were similar in 1995–96, more small fish were caught in stratum 003 than in 002 in the other years. This was reflected in the catch-at-age, with stratum 003 having higher abundances of young fish in 1996–97 and 1999–2000. The catch-at-age MWCV over all years ranged from 0.14 to 0.23, depending upon the number of landings sampled and otolith sample size (Figure 5). For between 20 and 30 landings and an otolith sample of about 500, the MWCV was about 0.15 for both strata. Where samples of landings were less than 20 in stratum 003, and where otolith samples were below 300 in both strata, the MWCV increased to about 0.2 or higher. This indicates a similar level of observed variability in catch-at-age in both strata.

The length and age distributions derived from the LF+ALK samples (Figure 6) show differences between strata for some years. Length estimates were similar in 1995–96, but consistently different in 1996–97 and 1999–2000 where stratum 002 contained larger fish. Age estimates were generally similar, although some minor differences occur for particular age classes, and the mean age in stratum 003 appears on average to be 1.2 years lower than for stratum 002 (*see* Figure 5).

RAF sample estimates of catch-at-age, number of landings sampled, otolith sample sizes, mean age, and MWCV from strata 002 and 003 are presented in Figure 7. There are some differences in the RAF age distribution for 1999–2000 compared to the LF+ALK estimates shown in Figure 5. Although both estimates are derived from the same otolith sample, this difference reflects the effect of the length frequency sample on the LF+ALK estimates, resulting in slightly higher proportions of younger fish compared to the RAF estimates. Catch-at-age analytical MWCV estimates for both strata and over all years ranged from 0.18 to 0.27. A similar pattern in MWCV relative to sample size is evident for both strata. For samples of less than 20 landings and 400 otoliths, analytical and bootstrap MWCV are about 0.24 and 0.33 respectively. This reduces to about 0.19 and 0.25 respectively for samples of about 25 landings and 450 to 600 otoliths. This is evident in both strata, indicating similar between landing variability in observed catch-at-age.

The age distributions derived from RAF samples (Figure 8) show differences between strata for some year classes. For example, the 1989 and 1991 year classes (visible as 9 and 7 year olds respectively in 1997–98) appear to have consistently higher relative strength in stratum 003 than in stratum 002. Mean age was similar between strata and ranges from 9.4 to 10.7 years (*see* Figure 7).

The variability in catch-at-age MWCV relative to otolith sample size for the LF+ALK and RAF samples from the East Northland longline fishery (strata 002 and 003 combined) from

1995–96 to 1999–2000 is given in Figure 9. For an otolith sample size of about 1000, lower MWCV estimates were obtained using the LF+ALK compared to the RAF method.

3.2 Sampling design comparisons

The MWCVs of proportions caught at age and length derived from LF+ALK and RAF sampling strategies from 1995–96 to 1999–2000 using either a stratified or unstratified design are compared in Table 2. Overall, there was little difference in the MWCV derived from the stratified or unstratified designs. In 6 out of the 14 comparisons there was no difference in MWCV, and the maximum absolute difference was 2%. In two out of the three years using the LF+ALK sampling strategy, the absolute difference in MWCV of catch-at-length was 1% lower following stratification. Similarly, the absolute difference in MWCV of LF+ALK catch-at-age estimates was both 1% lower, and 1% higher, due to stratification in two out of the three years. This indicates stratification of the LF+ALK design may not always improve precision of catch-at-age estimates, and, as in 1999–2000, may marginally reduce precision. MWCV of catch-at-age estimates derived from RAF sampling was generally the same or slightly lower as a result of stratification (Table 2). Stratifying the RAF sampling design resulted in a 2% absolute reduction in analytical and bootstrap MWCV estimates in 1997–98 and a 1% reduction in the bootstrap estimate for 1998–99.

MWCV estimates derived from bootstrap simulations of alternative LF+ALK and RAF sample size options using data from 1999–2000 are presented in Figure 10. LF+ALK MWCV estimates were lower than those from RAF samples. For the LF+ALK sampling strategy, precision is largely determined by the total otolith sample size. For the RAF sampling options, MWCV was less sensitive to the number of otoliths collected per landing than it was to the number landings sampled. A higher number of landings resulted in a higher otolith sample size overall, and consequently lower MWCV (Figure 10).

Stratification of the design options applied under the LF+ALK and RAF sampling strategies resulted in only slight increases (1.5%) or decreases (-2.75%) in precision in catch-at-age estimated from bootstraps (Figure 11). For only a narrow range of the LF+ALK sample size options (20 to 40 landings and high otolith sample size) was precision improved by stratifying the sampling design. For all other LF+ALK sample size options, stratification reduced catch-at-age precision, with an absolute increase in MWCV of 1.5% occurring for low otolith sample sizes. Over the range of sample size options examined, stratification improved precision in RAF catch-at-age estimates by reducing MWCV by on average 0.25%. However, improvements occurred mostly for sample size options having low numbers of landings with few otoliths collected per landing. The relative effect for other and most practical sampling options did not consistently improve precision, and was generally negligible (Figure 11).

4. DISCUSSION

The sampling of commercial landings for estimating catch-at-age has two requirements. First, samples must be representative of commercial catches in the fishery during the season surveyed, and second, samples must provide a sufficient number of observations to achieve the desired level of precision. The first requirement relates to the accuracy of the sample estimate, and depends on the allocation of sample effort over landings from the fishery. The second requirement relates to a predetermined target of precision, and depends on the choice of strategy, stratification, and sample size option.

This investigation relates particularly to the second requirement in that heterogeneity in strata affects precision and may be addressed by appropriate sample designs that optimise the allocation of sampling effort between strata. However, the effects that the sample design may have on the first requirement must be considered, because the allocation of sampling effort between strata may influence how representative it is of all strata.

4.1 Stratum catch-at-age

Some differences between strata are evident in the inferred relative strength of particular year classes, suggesting some heterogeneity in the length and age composition of snapper in East Northland landings. Several year classes were more abundant in stratum 003 than in 002, and in the earlier years, slightly more old fish occurred in stratum 002 than in stratum 003. Despite these differences, the age distributions are broadly similar, especially in recent years, with a wide range of classes represented, including the dominant 20 years plus group. This is typical of landings from the East Northland substock compared to the other substocks of SNA 1.

Catch-at-age estimates from stratum 003 resembled estimates derived for the adjacent Hauraki Gulf fishery in some years. Many samples collected from 003 are from catches taken in the southern part of the statistical area, i.e., Bream Bay, Hen and Chickens, and Tutukaka coastline. Similarly, almost all samples collected from stratum 002 are from the northern half of the statistical area, Whangaroa, Mangonui, and Houhora. Very few vessels fish the area between, and the two fishing grounds can, therefore, be regarded as being discrete.

The age at first recruitment also appears to vary between the 002 and 003 strata in some years. For example, in the RAF samples, 3 year-old fish are present in the 002 stratum for the 1996–97, 1997–98, and 1998–99 fishing years, but are absent in the 003 stratum samples in all years. Similarly, the average proportion of 4 year-old fish in stratum 002 is higher than in stratum 003. Although no growth rate analysis has been undertaken in this investigation, the age at which fish first recruit is indicative of small but significant growth differences between strata. The growth differences exhibited by snapper from the East Northland and Hauraki Gulf stocks have been known for some years, and provide some basis for separating the SNA 1 stock into smaller units for stock assessment. Small young fish have been known to grow faster in the Far North and recruit sooner than those from the Hauraki Gulf (Davies et al. 2003).

Some differences between strata in the precision of the catch-at-age time series were attributable to the sample sizes taken from respective strata. In years when sampling effort was disproportionately allocated between strata, differences in precision were apparent, whereas in years when sampling effort was evenly distributed across strata (e.g., 1996–97), similar precision in catch-at-age was obtained. The results show that for comparable sample sizes, the time series of catch-at-age precision is generally similar between strata, which suggests that variability in catch-at-age between landings is similar across strata.

4.2 Sampling designs

The results of simulations of the LF+ALK and RAF sampling strategies by bootstrap resampling from the 1999–2000 data enabled a comparison of the relative precision in catch-at-age obtained by either stratifying the East Northland longline fishery into two areas, or regarding it as one stratum by pooling the data. This revealed generally little benefit in stratifying the fishery, and the maximum benefit found was an absolute reduction in MWCV of 2.75% for the RAF sampling strategy using low sample sizes. For most other RAF sampling size options, the effect of stratifying was almost negligible (less than 1%). For the LF+ALK strategy, stratifying the sampling design produced marginally lower precision, and only for the sample size options having large numbers of otoliths was precision improved, and then only by less than 0.5% (absolute).

The simulation results suggest that stratification of the East Northland fishery does not improve precision in catch-at-age appreciably. For the stratified LF+ALK design, slightly worse precision was indicated. This is most likely due to the stratification of the otolith sample size into two age-length keys. Consequently, the stratum age-length key sample size is half of the total, resulting in low precision in catch-at-age estimates for each stratum. This reduction in precision appears to offset any benefits gained by deriving weighted mean catch-at-age across strata for most of the sampling size options. This was true for all the options that are logistically practical. Only for options with over 1000 otoliths, hence about 500 per stratum, was any improvement in precision possible.

Marginal improvement in catch-at-age precision was gained by stratifying the RAF sampling strategy, as indicated by the results of the sampling design simulations and analyses of historical samples using the stratified sampling design. For two of the four years using the RAF strategy, MWCV was reduced by up to 2% as a result of stratifying the sampling design. However, this improvement is slight and indicates that heterogeneity in catch-at-age between strata is likely to be low. This is reflected in the comparisons of stratum catch-at-age compositions from 1995–96 to 1999–2000 that revealed consistent differences for only few age classes, and similar mean age.

Between-landing variability in catch-at-age appears to be similar between strata. This was indicated by the similarity in catch-at-age precision between strata over comparable sample sizes for both the LF+ALK and RAF sampling stategies from 1995–96 to 1999–2000. The combination of this, and low heterogeneity in catch-at-age between strata produces little difference in the precision of catch-at-age estimates derived using either a stratified or unstratified sampling design. The characteristically high MWCV obtained for catch-at-age estimates in East Northland is therefore probably due to a combination of the broad age distribution and between-landing variability instead of being a reflection of within-stock heterogeneity.

4.3 Practical considerations

The estimates of catch-at-age precision suggest that a sampling design providing acceptable precision for the fishery (MWCV of 0.2) is one that allocates samples between strata in proportion to the number of landings, and, hence, the numbers of fish landed in each strata. Therefore, the sampling design must address the requirement that samples are representative such that the allocation of samples between strata must be proportional to landings from the fishery. This raises some important practical considerations.

It is not possible at the outset of sampling a fishery to determine where fishers will distribute their fishing effort between strata during the survey period. One can only predict the likely proportion of vessels fishing in a stratum in any given year. For example, in the 1997–98 fishing year, the proportion of the catch from stratum 002 and 003 was roughly equal, which was substantially different from most other years (see Figure 2). This difference was mainly because of unseasonably cold water temperatures in the Hauraki Gulf that resulted in low catch rates, and subsequently fishers moved to southern parts of the East Northland region to improve their catch rates (see Walsh et al. 1999).

A number of factors apparent from sampling of snapper landings in the past make it difficult and cumbersome to determine the exact catch locations for a landing. First, some of the current commercial longline fishers are relatively new to fishing and not familiar with the statistical areas and therefore often misreport their catch locations. Second, the port of landing is only a broad indication of catch location and only close communication with the fisher at the time of landing determines the catch location. Fishermen do not always land into one port and therefore do not always fish at the same fishing grounds. This is usually dependent on changes in catch rates or market demands for particular sized fish or bycatch. Furthermore, all landings are sampled from Licensed Fish Receivers (LFR) the day following the landing of the catch, and information of the port of landing is often not available. One may therefore rely on the CELR information of catch location by statistical area that becomes available some months after sampling. Consequently, exact information on fishing localities is often unavailable before sampling the catch, and the sampler must choose the sample on the basis of some confidence in it originating from the East Northland region.

The resources required for the LF+ALK and RAF sampling strategies are different. Whereas for the RAF strategy only an otolith sample is collected, the LF+ALK strategy requires the collection of an additional large length frequency sample of up to 8000 fish from 40 landings (Walsh et al. 2003). Thus the RAF strategy is more cost effective for estimating catch-at-age, and if there is no requirement for precise catch-at-length estimates. The stratified design under both sampling strategies requires more resources than the unstratified design. This is because of the need to address the practical considerations mentioned above in accurately determining the catch location relative to the strata, and collating additional information for data analysis.

4.4 Proposed future sampling strategies

Although the LF+ALK sampling strategy, whether stratified or unstratified, produces higher precision in catch-at-age estimates than the RAF strategy, it is more expensive. Unless, there is a specific requirement for estimating catch-at-length, the RAF strategy is preferable. Given the data used in this investigation, and for the design options most likely to yield desired precision, the stratified RAF design is more likely to produce marginally higher precision in catch-at-age compared to an unstratified design. However, this improvement is almost negligible, and probably does not warrant the additional resources required to implement the design. Given the difficulties mentioned above in implementing the stratified design, and the almost negligible improvement gained in precision, the unstratified RAF sampling strategy for estimating catch-at-age in the East Northland longline fishery is recommended.

To achieve the aim of a obtaining a representative sample, the recommended sampling strategy must be flexible to capture shifting trends in fishing effort between strata within a season. The application of random selection of landings from both strata combined will assure that the sample represents each stratum in proportion to the total landings from each stratum. This approach may suffice when sampling effort is applied to all sectors of the fishery, and to all LFRs processing landings from both strata.

5. CONCLUSIONS

- Although some differences in the age composition of landings between strata were evident for particular year classes, the time series of catch-at-age estimates and the simulation results indicate no considerable heterogeneity in catch-at-age, or between-landing variability in the East Northland strata.
- Catch-at-age precision in East Northland is low relative to other SNA 1 stocks because the age distribution is broader, with currently few age classes constituting more than 15% of catches.
- The relative benefit gained in catch-at-age precision obtained by using the stratified RAF sampling design compared to an unstratified design, was almost negligible (less than 1% absolute reduction in MWCV).

- The stratified design for the LF+ALK sampling strategy produces marginally worse catch-at-age precision compared to the unstratified design for most logistically feasible sample size options.
- Irrespective of sampling design (stratified or unstratified), the LF+ALK sampling strategy produces higher precision in catch-at-age than the RAF strategy.
- The random selection of landings from the entire fishery, and all processing sectors, is likely to ensure sampling is proportional between strata relative to landings from the fishery, and assures the sample is representative.
- Given the additional resources required for implementing the LF+ALK sampling strategy, and for applying the stratified sampling design, and the almost negligible improvement gained by stratifying the RAF sampling design, we recommend that the unstratified RAF sampling design be used for estimating catch-at-age in the East Northland longline fishery.

6. ACKNOWLEDGMENTS

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Table 1: Number of samples taken using alternative sampling strategies* and total number of landings by statistical area from the East Northland longline fishery from 1995–96 to 1999–2000.

Year	Sampling strategy*	Stat area	Landings sampled		Otoliths	Landings in fishery	
				Proportion	collected		Proportion
1995–96	LF+ALK	002	24	0.62	295	896	0.61
		003	15	0.38	284	583	0.39
1996–97	LF+ALK	002	23	0.44	464	958	0.59
		003	29	0.56	522	668	0.41
	RAF	002	23	0.47	464	958	0.59
		003	26	0.53	522	668	0.41
1997–98	RAF	002	16	0.39	337	827	0.56
		003	25	0.61	615	656	0.44
1998–99	RAF	002	27	0.63	628	780	0.59
		003	16	0.37	393	549	0.41
1999–2000	LF+ALK; RAF	002	32	0.68	651	916	0.56
		003	15	0.32	321	710	0.44

* LF+ALK = Length frequency and age-length key strategy; RAF = Random age frequency strategy.

Table 2: Analytical and bootstrap MWCV estimates of proportions caught at age from the LF+ALK and RAF sampling approaches with either stratification or pooling of length and age data from the 002 and 003 statistical areas of the East Northland longline fishery from 1995–96 to 1999–2000.

Year	Sampling design	LF+ALK		RAF	
		Catch at length	Catch at Age	Catch at age	
		Analytic	Analytic	Analytic	Bootstrap
1995–96	Stratified	0.13	0.16	-	-
	Unstratified	0.13	0.17	-	-
1996–97	Stratified	0.12	0.11	0.14	0.18
	Unstratified	0.13	0.11	0.14	0.18
1997–98	Stratified	-	-	0.16	0.22
	Unstratified	-	-	0.18	0.24
1998–99	Stratified	-	-	0.15	0.19
	Unstratified	-	-	0.15	0.20
1999–2000	Stratified	0.10	0.12	0.16	0.23
	Unstratified	0.11	0.11	0.16	0.23

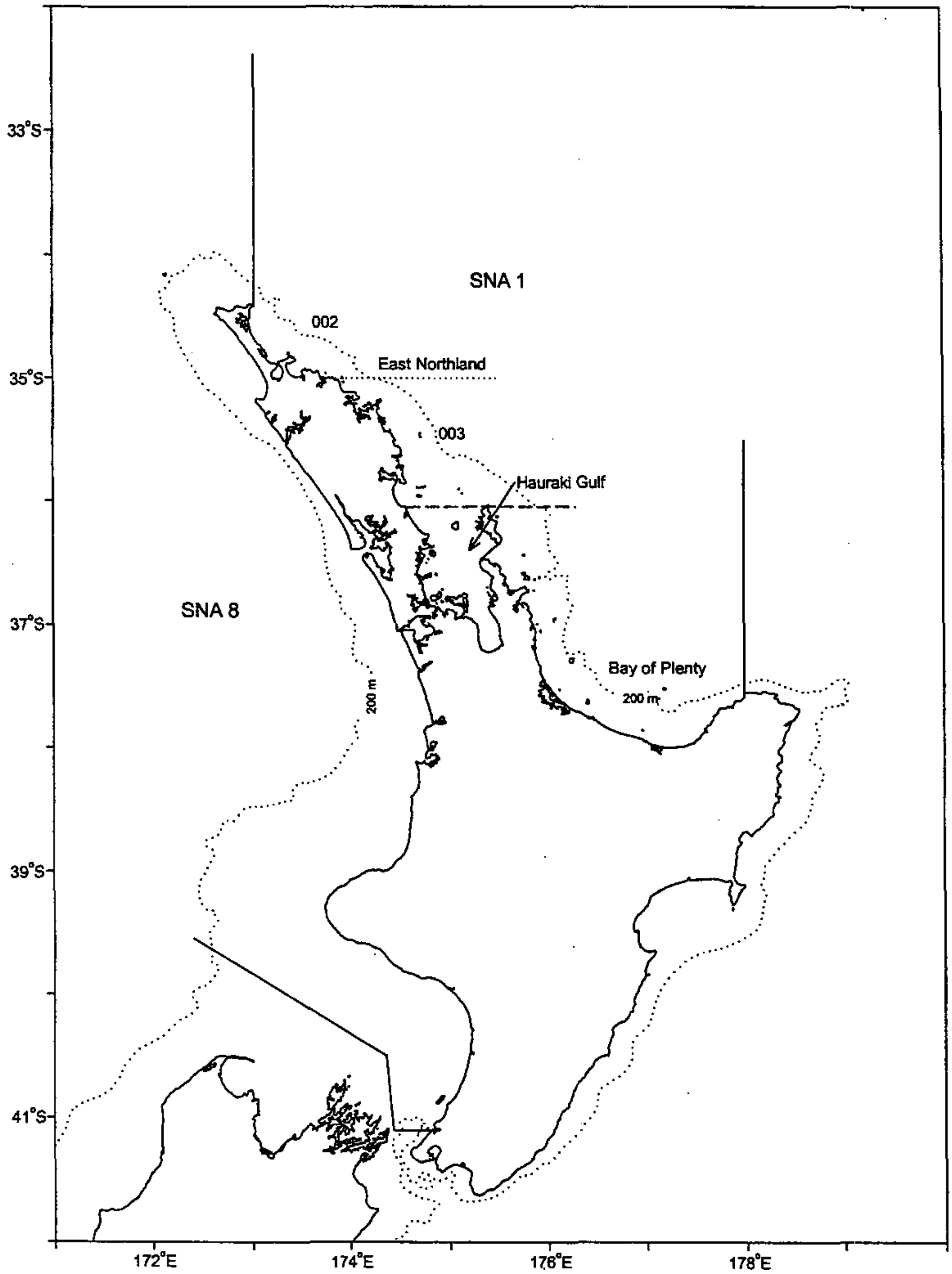


Figure 1: Quota management areas for the east and west coast North Island snapper stocks (SNA 1 and SNA 8 respectively) and the range of the three SNA 1 substocks; East Northland, Hauraki Gulf, and Bay of Plenty, and the two fisheries statistical areas making up East Northland (002 and 003).

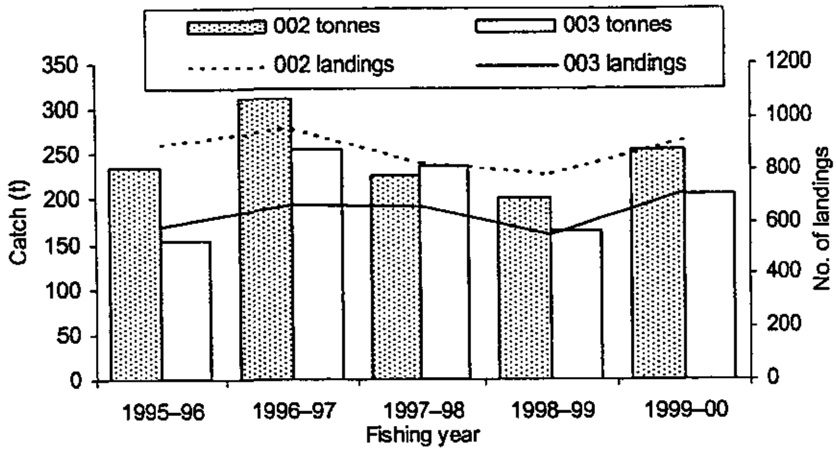


Figure 2: The total weight of snapper (tonnes) and the total number of landings by stratum (statistical area) for the East Northland longline fishery from 1995–96 to 1999–2000.

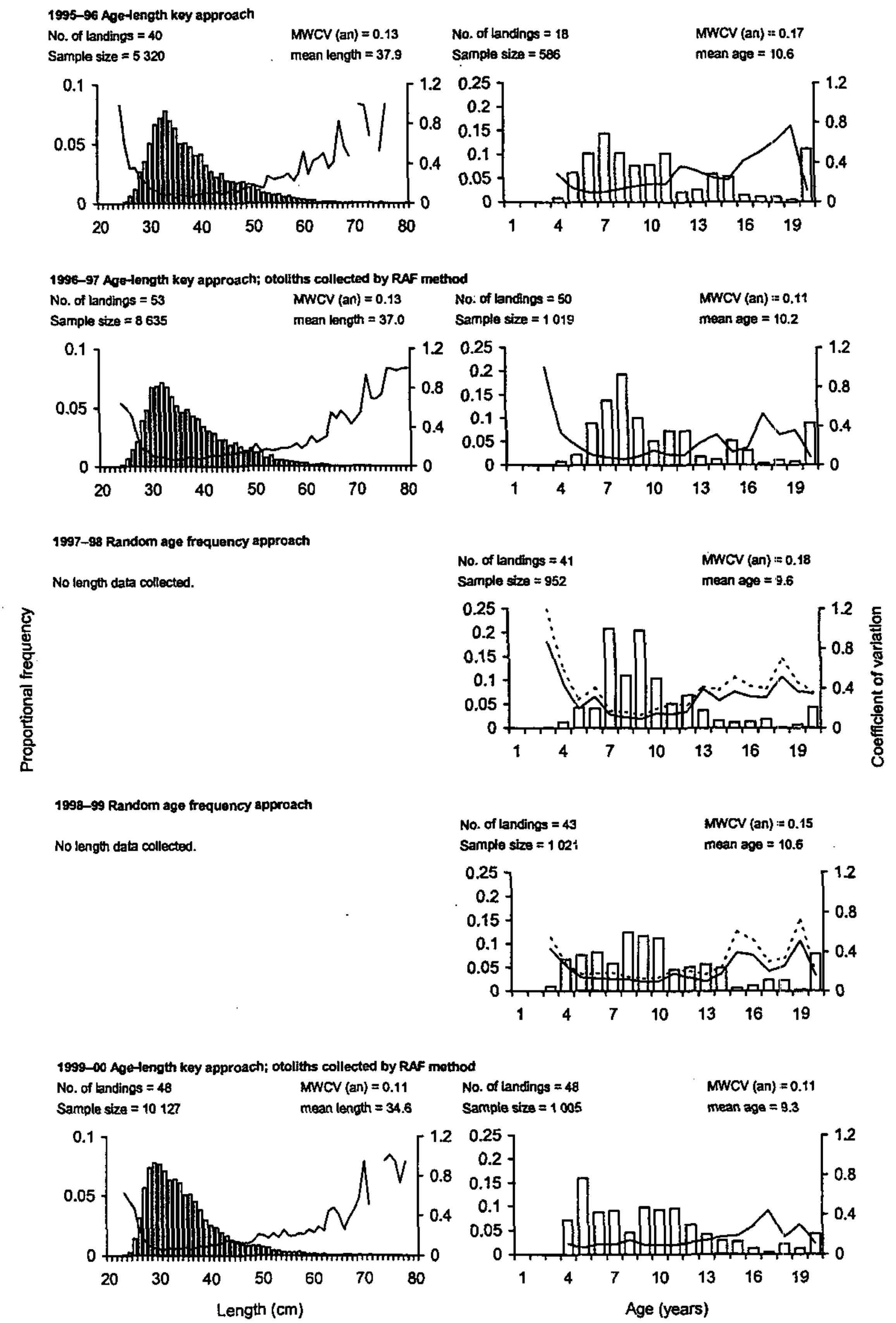


Figure 3: Length and age sample estimates for the East Northland longline fishery from 1995–96 to 1999–2000. Histograms are proportions and solid lines are coefficients of variation.

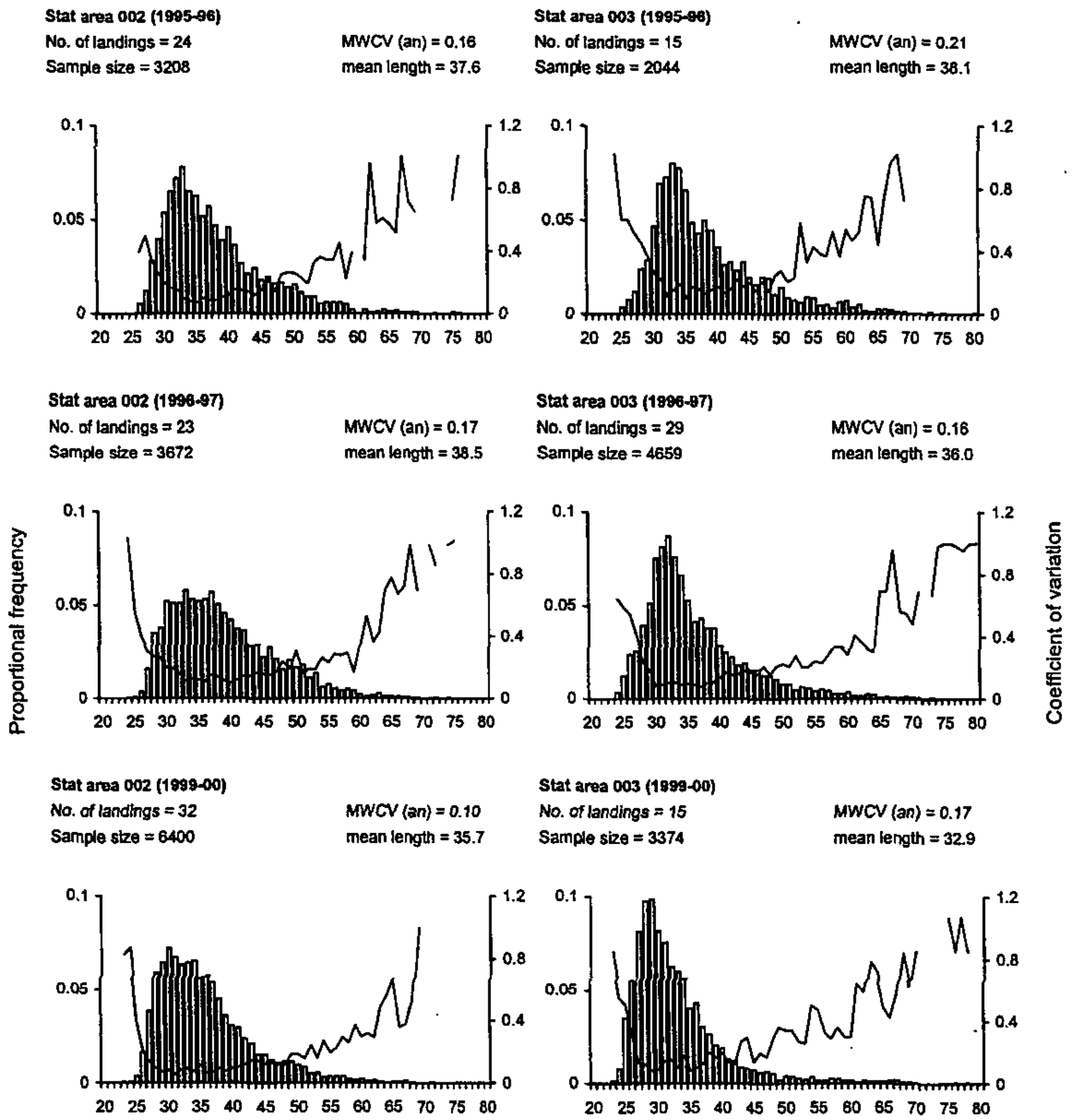


Figure 4: Proportions caught at length from LF+ALK samples taken from strata 002 and 003 of the East Northland longline fishery from 1995–96, 1996–97, and 1999–2000. Histograms are proportions and solid lines are coefficients of variation.

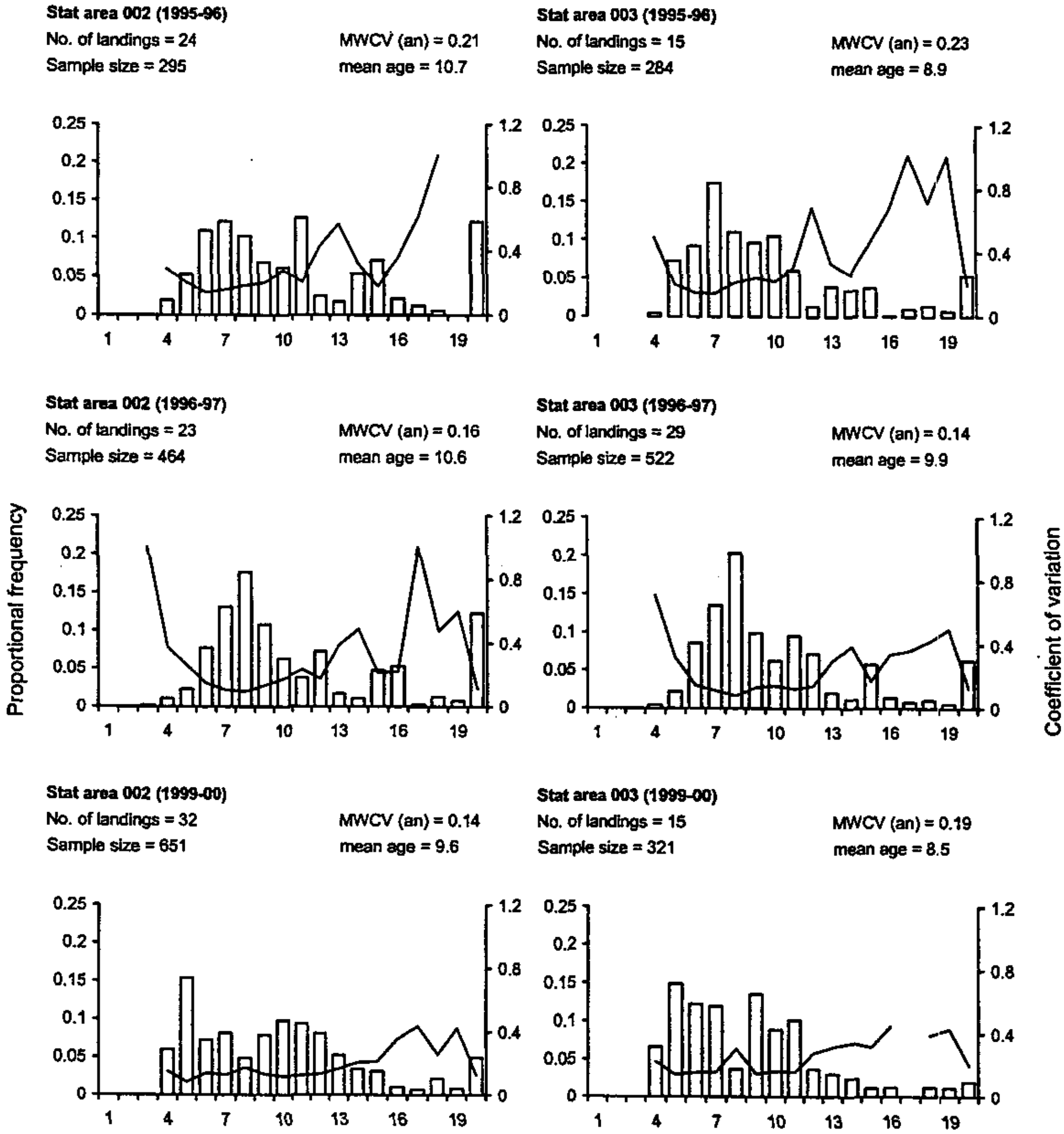


Figure 5: Proportions caught at age from LF+ALK samples taken from strata 002 and 003 of the East Northland longline fishery from 1995–96, 1996–97, and 1999–2000. Histograms are proportions and solid lines are coefficients of variation.

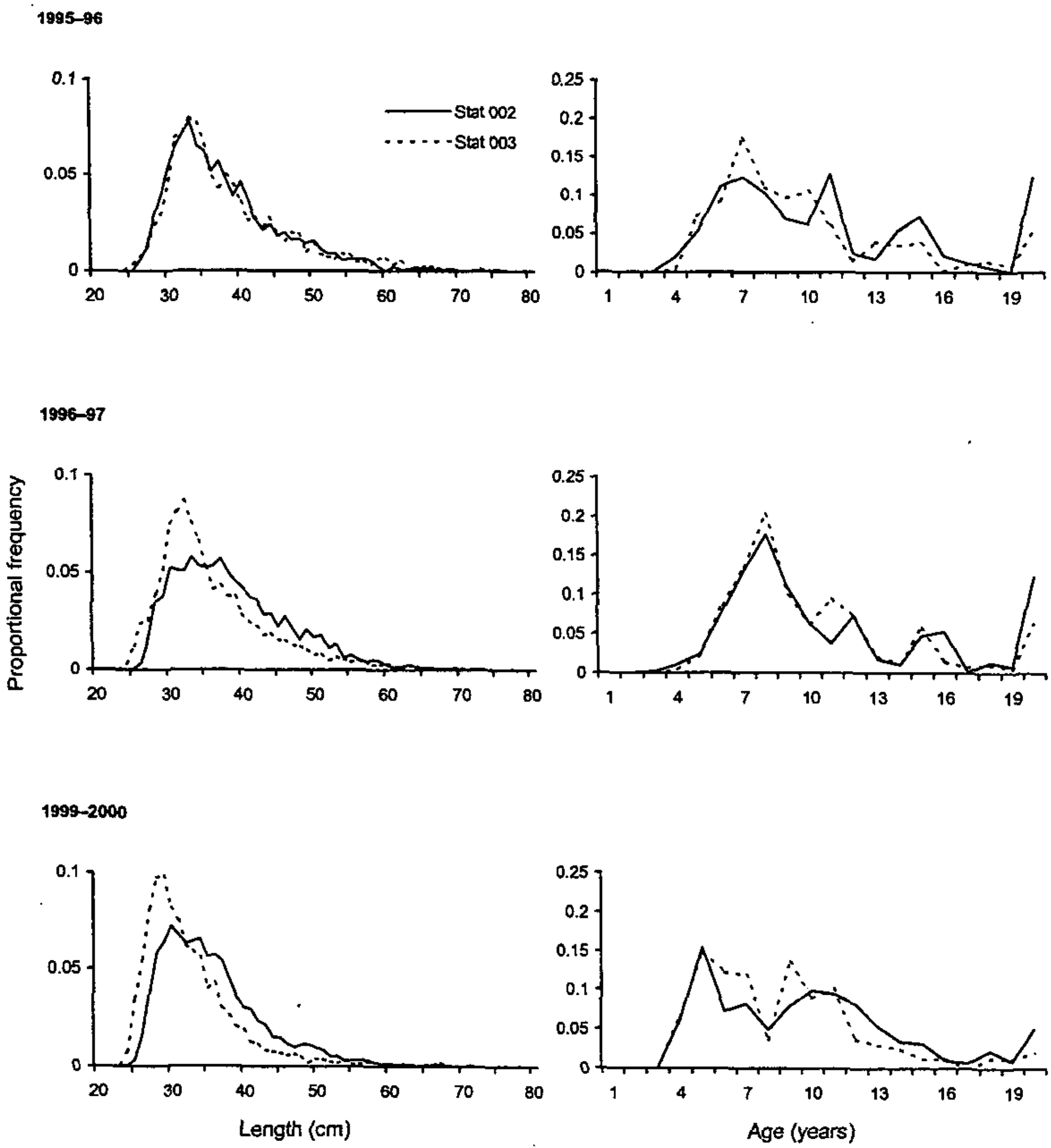


Figure 6: Comparison of the proportion caught at length and age estimates from LF+ALK samples taken from strata 002 and 003 (solid and dashed lines respectively) of the East Northland longline fishery from 1995–96, 1996–97, and 1999–2000.

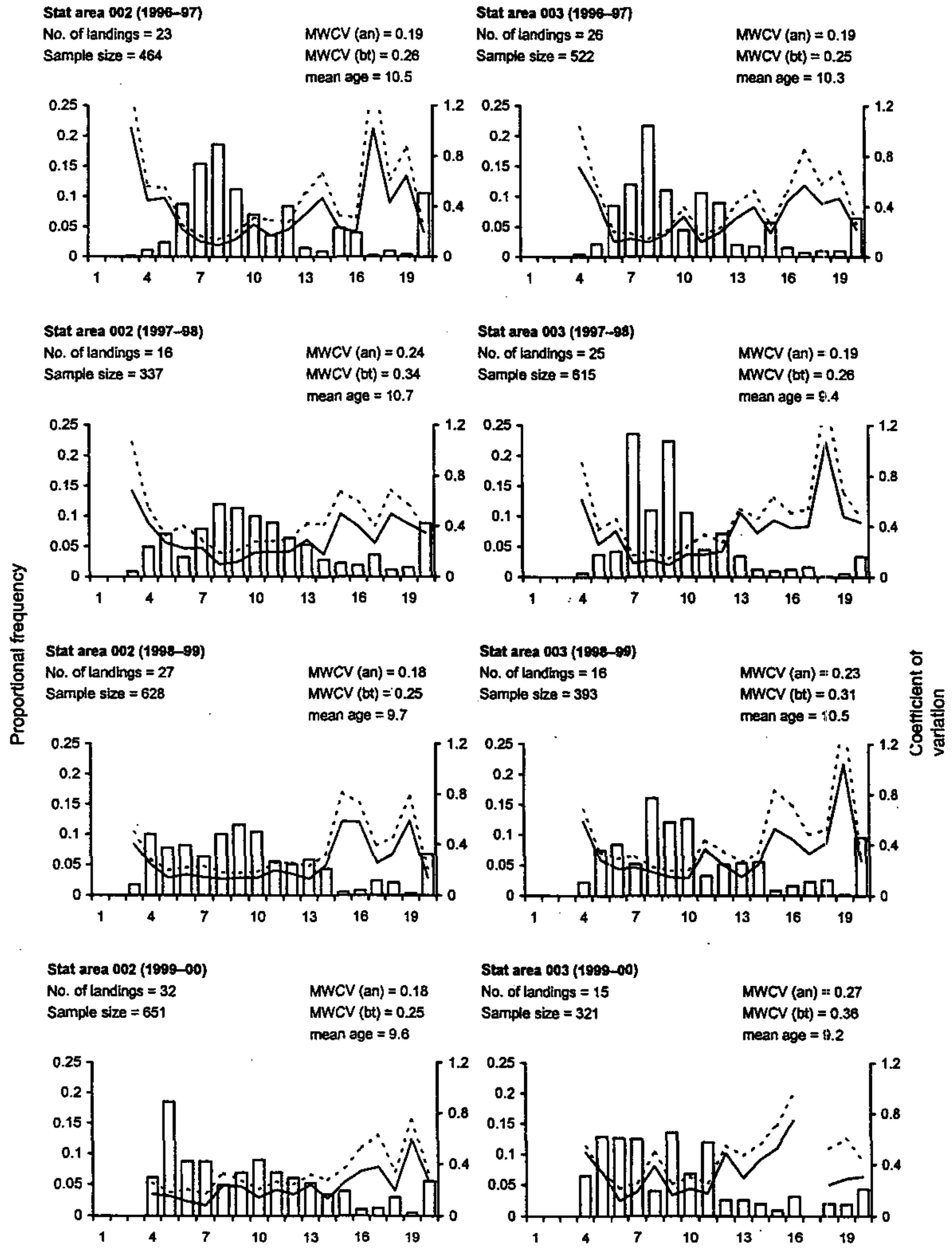


Figure 7: Proportions caught at age from RAF samples taken from strata 002 and 003 of the East Northland longline fishery from 1996–97 to 1999–2000. Histograms are proportions, and solid and dashed lines are analytical (an.) and bootstrap (bt) estimates of coefficients of variation respectively.

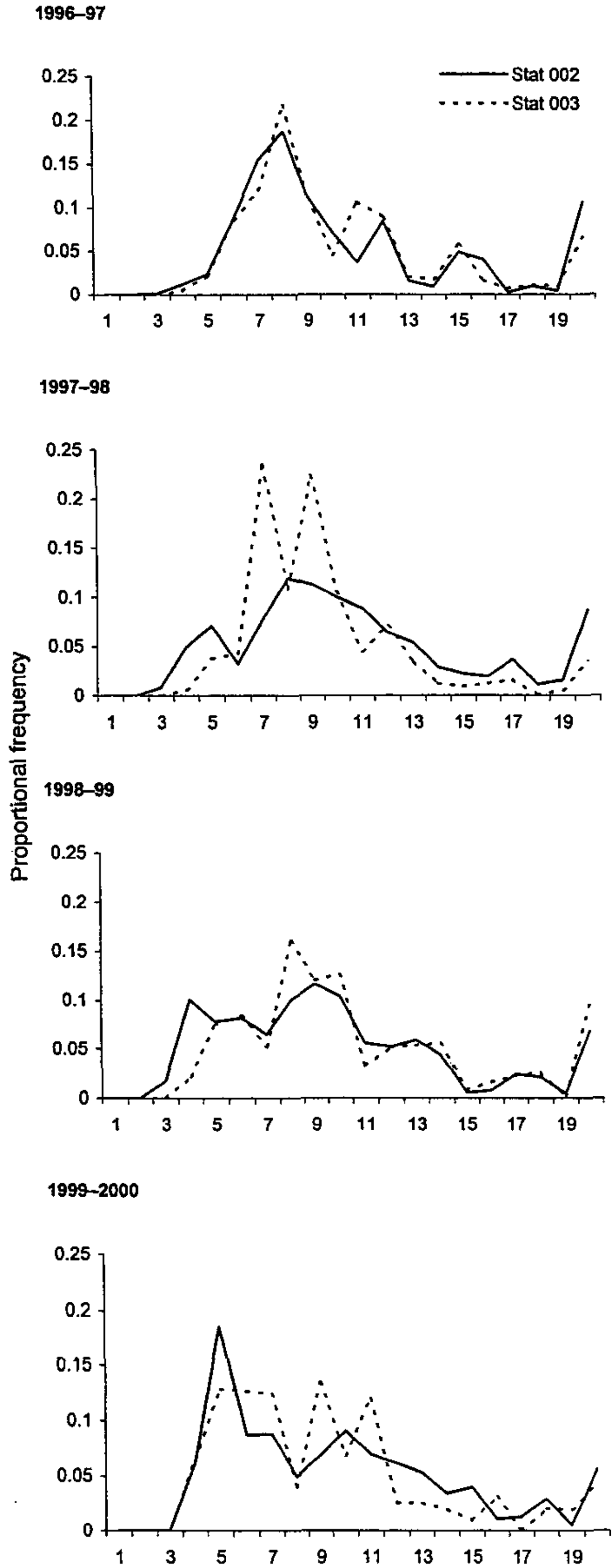


Figure 8: Comparison of the proportion caught at age estimates from RAF samples taken from strata 002 and 003 (solid and dashed lines respectively) of the East Northland longline fishery from 1996–97 to 1999–2000.

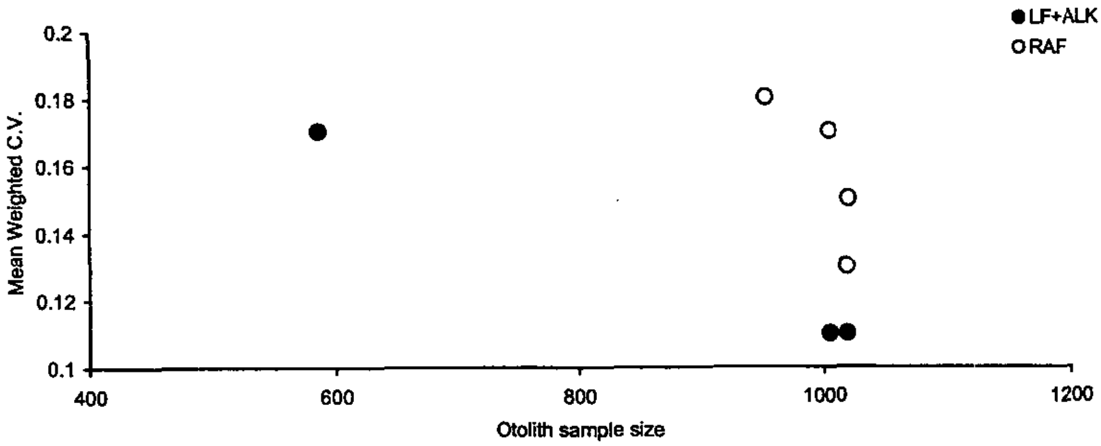
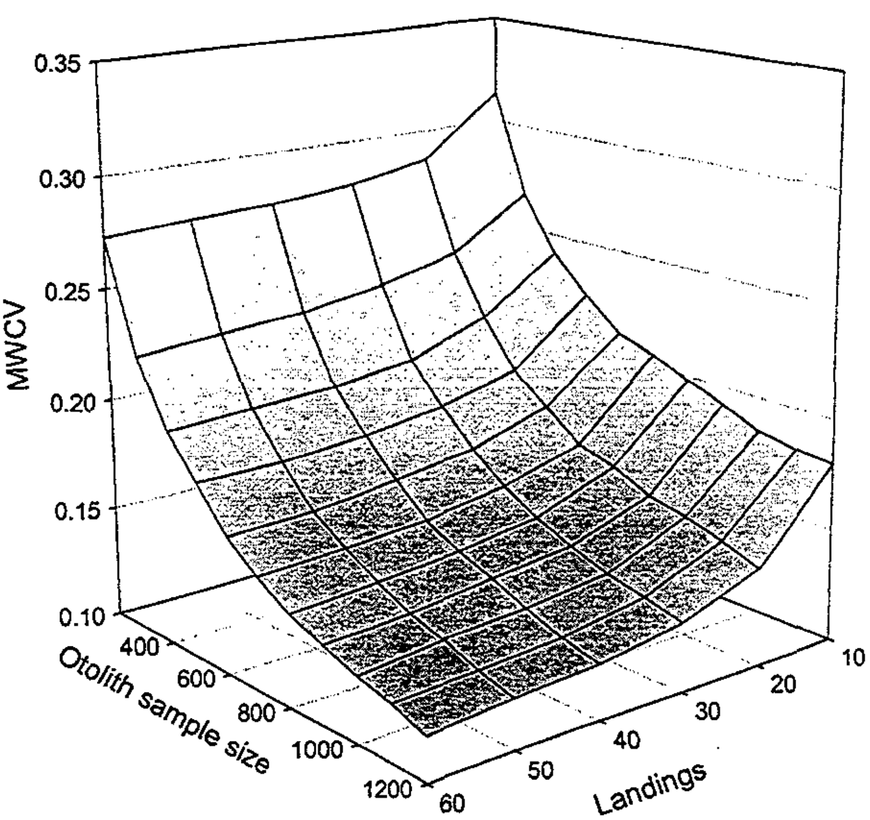


Figure 9: The variability in MWCV with respect to otolith sample size for the LF+ALK and RAF sampling strategies (closed and open circles respectively) of the East Northland longline fishery from 1995–96 to 1999–2000.

LF+ALK



RAF

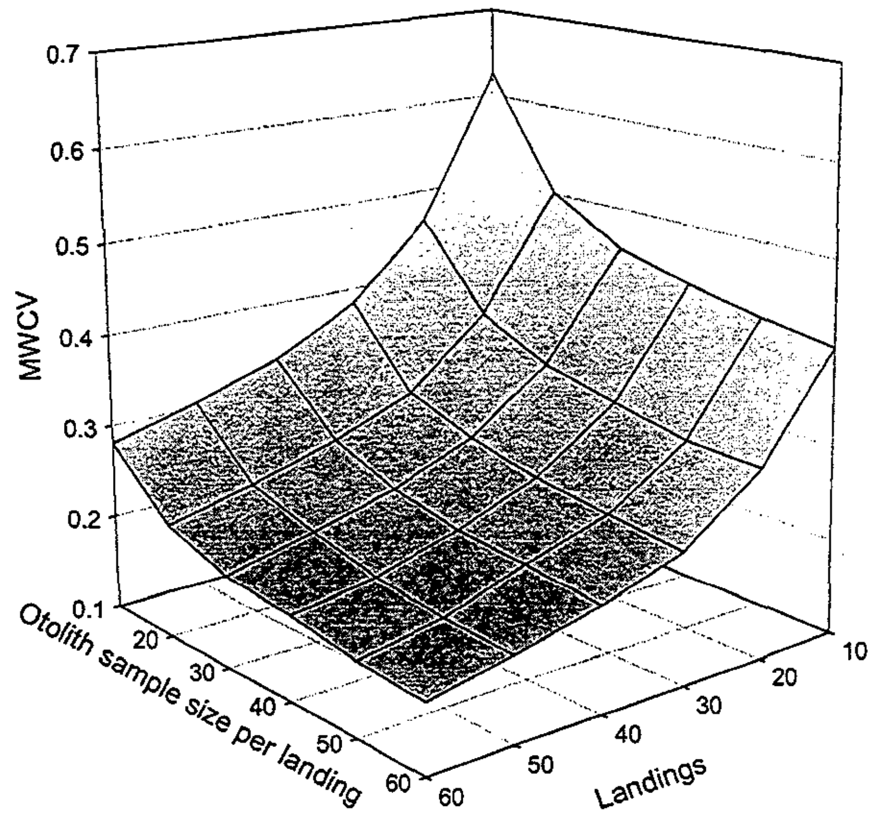
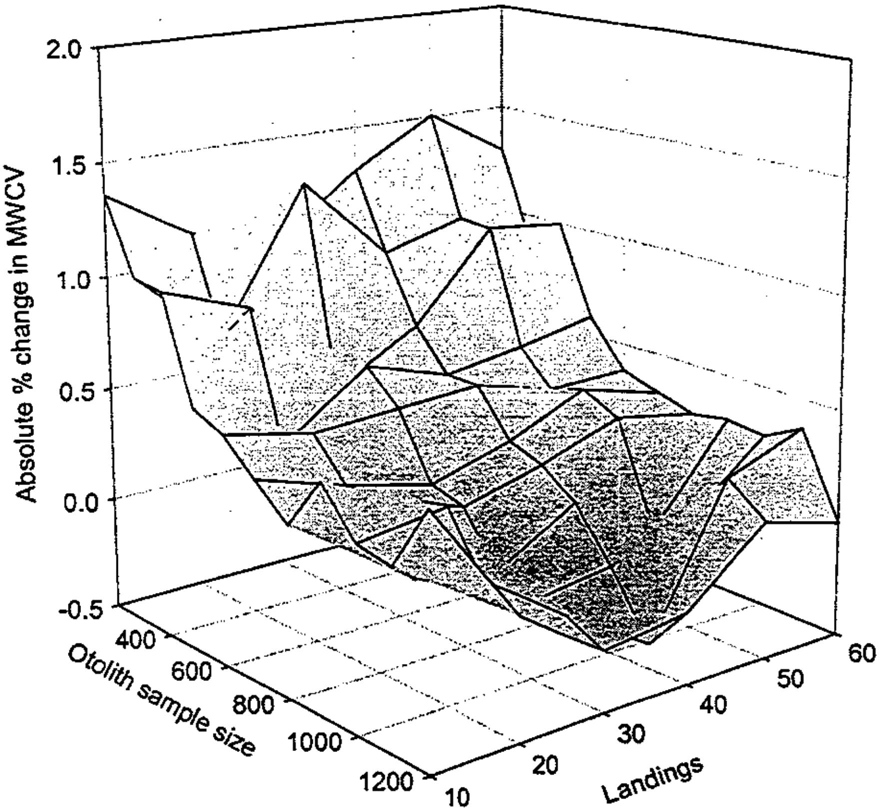


Figure 10: Bootstrap MWCV of proportions caught at age in 1999–2000 for a range of design options of the LF+ALK and RAF sampling strategies with stratification of the East Northland longline fishery by statistical areas 002 and 003.

LF+ALK



RAF

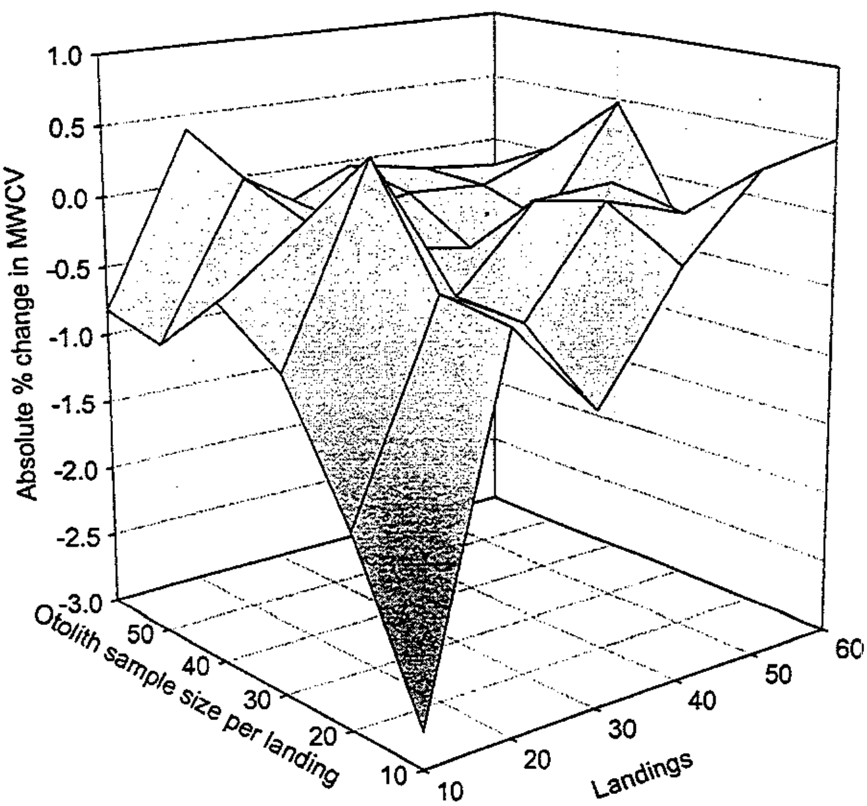


Figure 11: Absolute percentage change in the MWCV of proportions caught at age in 1999–2000 due to stratification of the LF+ALK and RAF sampling strategies (by statistical areas 002 and 003) for a range of sampling design options.