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EXECUTIVE SUMMARY

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This report documents the procedure for the direct estimation of the year-class frequencies of hoki in the non-spawning fisheries of the Chatham Rise and the Sub-Antarctic. The report also describes the procedure for generating bootstrap samples that enables estimation of the coefficients of variation of the year-class frequencies. These statistics are required for hoki stock assessments.

Because the non-spawning fisheries cover the whole fishing year, age-length key methods are not entirely suitable for estimating year-class frequencies. Instead, the direct estimation method uses otoliths sampled by observers on vessels from the hoki caught in tows. The otoliths are aged in the laboratory and estimates are obtained by scaling-up the proportions of year-classes in the otolith data weighted by the estimated numbers of fish of each sex in each tow. The procedure includes a method for identifying otolith readings that are inconsistent, and it also post-stratifies the fishery to avoid possible bias arising from unrepresentative observer coverage of the commercial hoki catch.

The bootstrap procedure for estimating coefficients of variation is designed to incorporate most of the sources of variation.

Tables are given of the estimated year-class frequencies for the Chatham Rise in the fishing years 1998–99 to 2002–03 and for the Sub-Antarctic for the fishing years 2000–01 to 2002–03. Bootstrap estimates of the coefficients of variation are included in the tables.

1. INTRODUCTION

The hoki stock assessment methods require the proportions of the commercial catch of hoki by sex and year-class. The year-class of a fish is determined from the age of the fish, the date that the fish was caught, and the "notional birthday" for the species (1 August for hoki). If the otolith of a hoki caught in the year before 1 August 2002 is of age 3 then the year-class of the hoki is 1998 since its notional birthday is 1 August 1998. The proportion of fish in a particular year-class of a particular sex caught in the fishery is referred to as the year-class frequency (sic) of the fishery for that year-class and sex and the mnemonic YCF is used.

Some years ago the decision was made to use direct ageing of otoliths collected by the Observer Programme to estimate the YCFs for the hoki fisheries on the Chatham Rise and in the Sub-Antarctic. These fisheries are non-spawning and extend over the whole of the fishing year, which makes age-length key methods unsuitable for estimation.

The purpose of this report is to document the direct estimation method of year-class frequencies that has been developed for the non-spawning hoki fisheries. The report also describes the procedure for generating the bootstrap samples that are used to estimate the coefficients of variation of the year-class frequencies estimates.

Estimates of the YCFs, together with estimates of their coefficients of variation, for the non-spawning hoki fisheries for the years where data were available are obtained using the methods.

2. ESTIMATION OF YEAR CLASS FREQUENCIES

In this section the method used to estimate the catch-at-age proportions is described. The method closely follows that of Francis (2002), but with some important changes, and includes the consistency scoring procedure of Francis (2001b) for eliminating inconsistent otolith readings.

The steps of the year class frequency direct estimation method are:

1. collection and preparation of the data, including the ageing of otoliths collected by observers
2. elimination of inconsistent otolith readings using consistency scoring
3. post-stratification of the fishery based on mean lengths by tow as a proxy for the mean age
4. calculation of the year class frequencies.

2.1 Data

Data sources required for the estimation of year class frequencies in a fishery are:

1. the age data taken from the NIWA age database comprising details of individual otoliths that have been collected by observers from hoki caught in tows in the fishery and aged in the laboratory. These data are referred to as the otolith data
2. the observer length frequency data obtained from the database *obs_lf* comprising the sex, and length frequencies of samples of hoki caught and the position, time and date, net depth, catch weight of hoki, and other descriptive data relating to the start of the observed tows where the hoki were caught. These data are referred to as the LF data
3. trawl Catch Effort (TCEPR) data extracted from the Ministry of Fisheries TCEPR database which comprise position, time and date, net depth, catch weight of hoki, and other descriptive data relating to the start of all commercial tows, referred to as the TCEPR data.

Four tow-related variables are used for post-stratification of the data. They are:

lat latitude of the start of the tow in decimal degrees

long	longitude of the start of the tow in decimal degrees
depth	depth of net at the start of the tow
fdayn	day of the fishing year at the start of the tow counting from 1 October.

The two non-spawning fisheries that are used for the hoki stock assessment are defined by their position coordinates as follows:

Chatham Rise	East of the South Island, extending to the edge of the Exclusive Economic Zone (EEZ) with latitudes between 42° S and 46° S
Sub-Antarctic	South of latitude 46° S, bounded in the south and east by the EEZ and bounded in the west by the South Island and the Solander Trough.

Tows with coordinates outside these fisheries were excluded from all calculations; specifically tows in the Puysegur fishery and on the Macquarie Ridge (west of the Solander Trough) were excluded.

The data analysed cover the Chatham Rise fishery for the fishing years 1998–99 to 2002–03, and the Sub-Antarctic fishery for the fishing years 2000–01 to 2002–03; see Table 1 for the details of the numbers of tows where hoki was caught and the total weights of the hoki catches.

2.2 Consistency of otolith readings

The hoki otoliths were aged using the validated method developed by Horn & Sullivan (1996). Some otoliths are difficult to read and are read a second time if the reader has doubts about the validity of the first reading. The reading method, in addition to ageing the otolith, measures the radii of the outer edge of (up to) the first three age zones. Francis (2001a) developed a consistency score that uses a distance measurement based on these radii, and determines statistically how far away the measured radii are from the centre of the distribution of the radii measurements in a calibration set of otoliths from hoki known to be of age 3. The score is a percentage representing the proportion of the calibration otoliths that have a distance greater than that of the otolith being read. A small score means that the age read for the otolith is inconsistent with the size radii of the age zones. The rule, advocated in Francis (2001a), of rejecting age readings with consistency scores below 5% is used.

For otoliths that are difficult to age, two readings of age are often made. In some cases the scoring was able to eliminate one of the readings. If both readings had scores above 5% then both were retained and a weight of 0.5 assigned to each reading for the purposes of the year-class frequency calculation, as advocated by Francis (2001a).

Details of the numbers of otoliths in the otolith data set before and after the consistency score method was applied are given in Table 2. The table shows that the proportion of inconsistent readings varies considerable over the years, between 10.6% in 1999–2000 and 0.9% in 2002–03.

2.3 Post-stratification

Post-stratification of the data is required to avoid bias because the observer coverage of the TCEPR trawls is patchy in space, time, and net depth (Bradford 2000). Post-stratification is carried out using regression tree-based methods described by Breiman et al. (1984) and in an ecological context by De'Ath & Fabricius (2000). The tree construction method is similar to that used in Francis (2002) and Hicks et al. (2002), but the rule for determining when to stop splitting is different and, in addition, weights determined by the size of the LF sample for each tow are used.

Consideration was given to using the ages in the otolith data for the response variable in the regression tree for post-stratification but only about three otoliths were aged for each of the tows in the otolith data, and furthermore not all tows with length frequency samples had otoliths taken. The small sample sizes and reduced coverage by the otolith data mean that they are not suitable for use in post-stratification as the overall variability is too great to be able to detect stratification effects reliably. Instead the mean length of the hoki for each tow in the LF data is used as a proxy response variable for age.

In contrast with the method used by Francis (2002), it was decided to weight the mean lengths by the inverse of their variances rather than giving equal weights to all tows, irrespective of the sample size. The variance calculation takes account of the correlation between the lengths of fish within each tow, by assuming a simple variance components model for the lengths of fish. The two variance components are: a between-tow random effects component with variance σ_T^2 and the usual individual random error component with variance σ^2. Thus a single measurement of the length of a fish will have variance $\sigma_T^2 + \sigma^2$. The variance of the mean of the lengths of fish measured in a sample from a single tow, is then

$$\sigma_T^2 + \frac{\sigma^2}{n} = \sigma^2\left(v + \frac{1}{n}\right)$$

where

$$v = \frac{\sigma_T^2}{\sigma^2} \qquad (1)$$

denotes ratio of the between-tow variance to the error variance and n is the sample size. The appropriate weight to assign to each tow is proportional to the reciprocal of the variance and given by

$$w \propto \frac{1}{\sigma^2\left(v + 1/n\right)}$$

The proportionality constant is arbitrarily set to make the weight 1 when the sample size is 1 and consequently the weight assigned to the mean length for a tow is

$$w = \frac{v+1}{v + 1/n} \qquad (2)$$

The regression tree method for obtaining the stratification is iterative and at each stage subdivides one of the existing strata by "splitting" on one of the four stratification variables, lat, long, depth, and fdayn. The choice of variable together with the splitting value is made so that the reduction in the weighted sum of squares is the greatest possible at each stage.

The total sum of squares, when there is no stratification, is

$$Q = \sum_i w_i \left(y_i - \tilde{y}\right)^2$$

where y_i is mean length for the i^{th} tow in the LF data and

$$\tilde{y} = \frac{\sum_i w_i y_i}{\sum_i w_i}$$

is the weighted mean length for the whole data set with the weights for each tow given by Equation (2). At each stage of the regression tree process the relative error for the stratification is then given by

$$R = \frac{\sum_j \sum_i w_{ij} \left(y_{ij} - \tilde{y}_j\right)^2}{Q}$$

j denotes the stratum number, i ranges over the tows in stratum j, and the weighted mean length for stratum j is

$$\bar{y}_j = \frac{\sum_i w_{ij} y_i}{\sum_i w_{ij}}$$

Starting at 1, when there is no stratification, the relative error, R, decreases as the iterations progress and more strata are added.

Because some tows catch very few hoki, it was decided to limit the data set used for the specific purpose of obtaining the stratification. Only those tows in the LF data where 150 kg or more of hoki were caught are used. This is the value which Dunn & Livingston (2004) argue is a good cut-off point for determining whether a tow is treated as a zero catch tow for the purposes of calculating hoki catch per unit effort statistics. A constraint is also placed on the minimum number of tows that a stratum must have in order to be a candidate for subdivision at the next stage of the iteration process. This was set at 75 for the Chatham Rise and 60 for the Sub-Antarctic. The recursive partitioning program rpart, available in the statistical package R (Ihaka & Gentleman 1996), was used for the analysis.

The value for the ratio of the variance components, ν, (Equation (1)) is required for the weights given by Equation (2) and $\nu = 0.5$ was used throughout for both the Chatham Rise and the Sub-Antarctic fisheries. ν in the range 0.3 to 1 was not critical in determining the stratification. Only when ν was changed to a value close to zero (corresponding to weighting by n, the sample size) or to a value much greater than 1 (corresponding to no weighting by sample size) were there substantial changes in the stratification. The value of 0.5 was obtained using the Chatham Rise and Sub-Antarctic fisheries data for the 2000–01 fishing year. It was calculated iteratively by first fitting a linear mixed model to the individual fish lengths to get the components of variance estimates. Next the data were stratified using the value for ν calculated from the variance components. The linear mixed effects model with fixed mean effect for each stratum was then fitted providing new estimates of the components of variance. ν was recalculated and a new stratification obtained using weights calculated with the new value of ν. Although the first value of ν was larger for both fisheries, the same stratification was obtained. Therefore only two iterations were needed to obtain the values for the variance components ratio. For the Chatham Rise, $\hat{\sigma}_T = 5.21$ cm and $\hat{\sigma} = 7.34$ cm giving $\nu = 0.50$, and for the Sub-Antarctic $\hat{\sigma}_T = 4.37$ cm and $\hat{\sigma} = 6.34$ cm giving $\nu = 0.48$.

The decision to stop further subdivision of the strata is made on the basis of cross-validation of the reduction in the relative error after each iteration. Each subdivision always results in a reduction but there is danger of over-fitting the recursive partition model and producing too many strata that only account for random variation. Cross-validation checks the predictive power of a particular size of tree and therefore avoids over-fitting.

Cross-validation is carried out by first splitting the data randomly into 10 data subsets. Trees of the particular size are fitted to the combined data of 9 of the subsets and the reduction in the relative error is calculated for the tenth subset. The process is repeated for each of the 10 subsets and the predicted reduction calculated. The average reduction is then an "honest" estimate of the reduction in relative error for each tree size. Estimates of the standard error in the relative error, are also available from the 10-fold cross validation. Breiman et al. (1984) advocated growing a large tree and then pruning the tree back to the smallest size tree that is within 1 standard error of the minimum cross-validated relative error, and this is the approach that we have used. To get a better estimate of the optimal size of the tree (number of strata) it was sometimes necessary to reduce the minimum size for splitting an existing stratum in order to grow a larger tree. However, the final stratifications all conformed to the specified minimum splitting size.

Plots of the cross-validated relative error against tree size for the fitting process, for both fisheries, and dendrograms of the resultant trees appear in Figures 1 to 8. Detailed descriptions of the stratifications are given in Table 3.

To illustrate how the iterative stratification procedure works, I will describe how the stratification of the Chatham Rise 1998–99 data was carried out using Figure 1. The upper panel plots the relative error as the tree size increases. The solid line plots the mean relative error (from the 10 cross-validations) against the size of the tree, which is the axis at the top of the plot. The minimum relative error occurs for a tree of size 11 (corresponding to 11 strata) and the vertical bar through the point gives plus and minus one standard deviation bounds. The horizontal dotted line runs through the top of this bound and gives the minimum relative error plus one standard deviation. The smallest tree size for which the mean relative error is below the dotted line is a tree of size 6. The tree of size 6 that is fitted to all the FL tow data, for which the hoki catch is at least 150 kg, is the tree that is used to determine the stratification for the Chatham Rise in the 1998–99 fishing year. The dendrogram for this tree is given in the lower panel of Figure 1. The split criterion at a branch point gives the condition for the left branch. For example, at the first branching, tows that are at a depth of 502 m or shallower belong to the left branch and ultimately belong in one of the strata 1 to 3.

A random partition of the data into 10 subsets is used for the cross-validation. It is useful to do several plots for the same fishery and year, each of which will use a different random partition of the data set, to get an appreciation for the correct tree size, because one random partition may be atypical.

There is considerable variation between years in the relative error threshold, given by the horizontal dotted line, apparent in the plots in Figures 1 to 8. For the Chatham Rise fishery it varies between 0.39 in 1999–2000 and 0.92 in 2002–03. The width of this range is of concern, but as can be seen from Table 3 the differences from year to year between the stratifications for the Chatham Rise (and for the Sub-Antarctic) are not so great. Because of the way the procedure of Breiman et al. (1989) uses the complexity parameter to establish an order for the trees with increasing numbers of leaves, a tree of a particular size may be missing from the cross-validation plot. This is the case in Figure 1, for the Chatham Rise in 1998–99, where the tree of size 4 does not appear in the cross-validation plot.

2.4 Year-class frequency estimates

The method used to estimate year-class frequencies follows Francis (2002) and is described below.

It is assumed that there is a stratification of the fishery, using the method described in Section 2.3, and that a set of otoliths have been aged with the estimates refined by the consistency method of Francis (2001a) as described in Section 2.2. For a specific fishery the following data are available.

- m_{isy} sex year-class counts of sex s and year-class y for tow i of the LF data (where there are hoki that have been aged).
- n_{isk} sex length frequency of sex s and length k for tow i of the LF data.
- w_i total weight of hoki catch for tow i from which LF data were taken.
- W_i total weight of hoki catch for tow i of the TCEPR data.

The stratification allocates tows from the various data sets to the strata. A_j, L_j, and C_j, respectively, denote the sets of tows in the LF data with aged fish, the set of tows in all the LF data and the set of tows in the TCEPR data that are allocated to stratum j by the stratification.

The first step in the estimation process is to estimate the total number of hoki of each sex caught for tow i of the LF data. The estimated number of hoki of sex s in the total catch for tow i is obtained by scaling up the number of sex s in the measured hoki and is given by

$$\hat{t}_{is} = n_{is}\frac{w_i}{\hat{w}_i^L}$$

where $\hat{w}_i^L$ is the estimated weight of hoki with measured lengths using the hoki length-weight relationship from Francis (2001b) and also given by Annala et al. (2002); and n_{is} is the total number of measured hoki of sex s for tow i. Since the length weight coefficients, a and b, are the same for both sexes

$$\hat{w}_i^L = a\sum_k k^b\left(\sum_s n_{isk}\right)$$

In the second step the estimated total number of hoki caught in each stratum in the TCEPR data is calculated by dividing the total TCEPR catch weight for the stratum by the estimated average weight of measured LF hoki in the stratum. The estimated total number of hoki caught in stratum j for the TCEPR data is given by

$$\hat{T}_j = W_j\frac{n_j}{\hat{w}_j^L}$$

where

$$n_j = \sum_{i\in L_j}\sum_s n_{is}$$

is the total number of hoki measured in stratum j in the LF data,

$$\hat{w}_j^L = \sum_{i\in L_j}\hat{w}_i^L$$

is the estimated weight of the hoki measured in stratum j, and

$$W_j = \sum_{i\in C_j} W_i$$

is the total weight of hoki caught in stratum j for the TCEPR data.

Thirdly, the proportions of hoki by sex and year-class in each stratum are estimated. To do this proportions of hoki by year-class for each sex are estimated for each tow in the age data, and then scaled up by the number of hoki of each sex in the tow and added over the tows in the stratum. The proportion in each year-class y for hoki of sex s is

$$p_{iy}^s = \begin{cases}\dfrac{m_{isy}}{\sum_y m_{isy}}, & \text{if } \sum_y m_{isy} > 0,\\ 0, & \text{otherwise,}\end{cases}$$

where the proviso in the above equation accounts for the possibility that all aged hoki in a tow are of the same sex. The estimated proportion of hoki in stratum j that are of year-class y for each sex s is then given by

$$\frac{1}{\sum_{i\in A_j}\hat{t}_{is}}\sum_{i\in A_j}\hat{t}_{is}p_{iy}^s$$

which is in turn multiplied by the proportion of hoki by sex in the LF data to get the estimated YCF for stratum j $\hat{P}_{jsy}$. This is given by

$$\hat{P}_{jsy} = \frac{\hat{t}_{js}}{\hat{t}_j}\frac{1}{\sum_{i\in A_j}\hat{t}_{is}}\sum_{i\in A_j}\hat{t}_{is}p_{iy}^s$$

where

$$\hat{t}_{js} = \sum_{i \in L_j} \hat{t}_{is}$$

is the estimated total number of hoki of sex s caught in stratum j for the LF data and

$$\hat{t}_j = \sum_s \hat{t}_{js}$$

so that $\frac{\hat{t}_{js}}{\hat{t}_j}$ is the estimated proportion of hoki of sex s in stratum j.

Finally the YCF for the whole of the TECPR data is estimated by adding the YCFs for each stratum weighted by the proportion of hoki caught commercially in the stratum to get

$$\hat{P}_{sy} = \frac{1}{\sum_j \hat{T}_j} \sum_j \hat{T}_j \hat{P}_{jsy}$$

which is the estimated YCF for the fishery.

The year class frequencies for the Chatham and Sub-Antarctic fisheries are given in Tables 4 and 5 respectively. The tables are arranged so that the proportions for each year-class and sex are in the same line enabling the cohort strength to be compared across the fishing years. The coefficients of variation are expressed as percentages in parentheses beside each year-class sex proportion. Estimates of the YCFs for the 2000–01 fishing year differ slightly from those given by Ballara et al. (2003) because of subtle changes in the stratification that arose from restricting the tows used for the stratification to those where at least 150 kg of hoki were caught. The restriction was not applied in the earlier estimates.

3. BOOTSTRAP METHOD FOR ESTIMATING THE COEFFICIENTS OF VARIATION OF THE YEAR-CLASS FREQUENCIES

The method used to obtain bootstrap samples from the sampling distribution of the year-class frequencies allowing for sources of sampling variation is described in this section.

The hoki stock assessment requires estimates of the coefficients of variation of the estimates of the year-class sex proportions. Estimates of the c.v.s are obtained by a bootstrap procedure that accounts for most sources of variation. One source not considered is the ageing error of the otoliths. The ages of the fish read from otoliths already include ageing error and this source of variation is already accounted for in any bootstrap sample. It is proper to model ageing error in the likelihood for the population model used in the stock assessment.

The method produces a data set with rows consisting of one bootstrap sample of a set of YCFs and is the best form of output for stock assessment use. The hoki stock assessment process groups all fish over a specified age into a "plus" group of year-classes with the threshold for the plus group determined during the process. Coefficients of variation of the YCF estimates, including those for the plus class, can easily be calculated from the bootstrap sample. Typically, a minimum of 1000 bootstrap samples is necessary as the estimates of the c.v.s obtained from the bootstrap sample are not very stable.

The primary purpose of a bootstrap sample is to incorporate all sources of variation that are present in the data used to estimate the quantities of interest. Sources of variation that are likely to be present in YCF estimates are:

1. assigning of trips to be observed

2. sampling variation between tows within trips
3. sampling of hoki from the catch within a tow for length measurement
4. variation in post-stratification as a consequence of the above sources of variation
5. sampling of hoki for otolith collection and reading from within the length sample for a tow.

In addition, possible sources of correlation that may add to the variation and therefore need to be accounted for in the sampling method within the bootstrap procedure are:

6. correlation of ages of fish from different tows within a trip
7. correlation of ages of fish from within the same tow.

The TCEPR data is treated as fixed since these determine the commercial catch to which the YCFs apply.

The bootstrap sampling procedure to obtain a single bootstrap sample of a set of YCFs has been designed with the aim of incorporating all the above sources of variation. Random samples are drawn with replacement of trips, of tows within each trip in the sample of trips, of lengths of fish from among the lengths for each tow in the sample of tows, and of otoliths from within the set of otoliths for each tow (that has otolith data) in the sample of tows. Because the YCF estimates are obtained directly from the year-classes of the otolith data it is important to keep the number of otoliths in the bootstrap sample approximately the same as the number of otoliths in the otolith data. This is achieved by an acceptance/rejection process and other measures taken within the bootstrap sampling procedure.

The single bootstrap sample, obtained as above, gives rise to a bootstrapped LF data set and a bootstrapped otolith data set. A stratification is obtained from the bootstrapped LF data. The cases in the LF data, the otolith data, and the TCEPR data are each assigned a stratum by the new stratification. An estimate of the YCFs is then calculated for the single round of the bootstrap. The estimation uses the same hoki catch weights for each tow in the LF data to estimate the total numbers of hoki in the tow. The whole procedure is repeated the required number of times (usually about 1000) to get the bootstrapped samples of YCFs.

Details of the steps in the single bootstrap sample procedure are given below. In accordance with standard practice, every sample of items from a set is a random sample with replacement and of size equal to the number of items in the set.

1. Randomly sample with replacement the set of trips in the LF data. Check if the total number of otoliths included in the trips in the sample of trips is within 5% of the total number of otoliths in the otolith data. If not, a new sample of trips is drawn until the requirement is satisfied.
2. Each trip in the sample of trips will have tows with otoliths taken (this maybe none, some, or all tows) and tows where no otoliths were taken (again this may be none, some, or all tows). For each trip, a sample of tows from the set of otolith tows in the trip and a sample from the set of non-otolith tows is taken. This preserves the number of otoliths in the bootstrap approximately, since the number of otoliths taken is roughly constant across tows (usually 3).
3. For each tow in the sample of tows a sample fish is drawn from the fish with measured lengths. This gives a sample from the joint empirical distribution of length and sex for the tow.
4. For each otolith tow in the sample of tows a sample of otoliths is drawn from the otoliths in the tow.

For the stratification procedure, the bootstrap sample is used to form the new tow data with the mean length frequency calculated and restricted to tows where at least 150 kg of hoki were caught. Because of the need for automation in any bootstrap procedure, the stratification procedure used in the bootstrap has the same number of strata as in the original stratification and thus avoids determining the size of the tree by cross-validation. Nevertheless, variation in the weights used in the relative error calculation, variation in the mean lengths for the included tows, and variation in which tows are included should account for most of the variation from stratification.

The estimates of the c.v.s for both fisheries and for all years included in the analysis are given in Tables 4 and 5.

4. DISCUSSION

Francis (2002) discussed the problem of the tendency to select the otoliths of larger fish and that this can lead to bias in the estimates of the year-class frequencies. The tendency was apparent in the 1998–99 and 1999–2000 Chatham Rise data he considered and it is also present in the other years and also the Sub-Antarctic data. The quantile plots in Figure 9 clearly demonstrate the tendency. It is demonstrated by the fact that the plots of the "relative ranks" of the lengths of the otolith-aged fish lie above the straight line. Under the assumption, for each tow, that the fish sampled for otoliths is a simple random sample from the fish measured for length, the relative ranks should be uniformly distributed between 0 and 1 and therefore follow the straight line in the plot. When most or all points lie above the line there is evidence of a trend that larger fish are being selected for otolith ageing.

To test for deviation from the null hypothesis that the ranks of the lengths of the otolith sample from every tow are a simple random sample from the ranks of the lengths of the measured fish, an adaptation of the standard rank-sum statistic (or Wilcoxon statistic) was used. The rank sum of the lengths of the otolith fish, for each tow among all the lengths for the tow, is calculated and added over the tows. Where there are ties of lengths of fish in the LF data, and there usually are, an otolith fish whose length is in the tied group receives the average rank of the group. Under the null hypothesis of simple random samples, the mean of this statistic is easily calculated. The standard error calculation is also straightforward but adjustments are required for the finite population correction for each tow and for the size of the groups of tied ranks in the LF data. Standard theory suggests that the total rank sum statistic has approximately a student-t distribution but, with the number of degrees of freedom large, a normal approximation is adequate. The p-values for the two fisheries for the fishing years in the study are given in the titles of the panels in Figure 9.

The plots in Figure 9 provide evidence that all combinations of fishery and year may have the tendency towards selecting larger fish for otolith reading to a varying degree. For the Chatham Rise, the fishing years 1999–2000, 2000–01, and 2001–02 have highly significant ($p < 0.01$) evidence, whereas for the Sub-Antarctic only the fishing year 2002–03 is highly significant. All other years for both fisheries are not significant ($p > 0.05$). Such a bias will have the effect on the estimated year-class sex proportions of biasing the proportions upwards for older fish and downwards for younger fish. Correction for such bias is impossible; however the effects are likely to be less than the estimated coefficients of variation and therefore the bias is not so serious. Careful observer protocols may help reduce the tendency to select the otoliths of larger fish.

The estimates of the year-class frequencies, while having low bias under the assumptions, have large uncertainty as is demonstrated by the large c.v.s in Tables 4 and 5. Theory suggests that the c.v. of an estimated proportion is approximately inversely proportional to the square root of the proportion. One reason for the larger c.v.s associated with the very young year-classes and the older year-classes is that the proportions are small. Another possible contribution to the size of the c.v.s, is the use of the ratio estimator to obtain estimates of the proportions of catch at age for each stratum, $\hat{p}_{Jsy}$. Ratio estimates are inefficient when there is within-tow correlation between ages of fish. Schooling undoubtedly implies that this correlation exists for hoki. The use of a more efficient estimator could reduce the variability of the scaled up YCFs, but the contribution from this is likely to be small compared other sources of variation.

Code written in the R statistical language is available for estimating the YCFs and their coefficients of variation.

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6. REFERENCES

Annala, J.H; Sullivan, K.J.; O'Brien, C.J.; Smith, N.W.McL.; Varian, S.J.A. (comps) (2002). Report from the Fishery Plenary, May 2002: stock assessments and yield estimates. 640 p. (Unpublished report held in NIWA library, Wellington.)

Ballara, S.L.; O'Driscoll, R.L.; Phillips, N.L.; Livingstone, M.E.; Smith, M.H.; Kim, S.W. (2003). Catches, size, and age structure of the 2001-02 hoki fishery, and a summary of input data used for the 2003 stock assessment. . *New Zealand Fisheries Assessment Report 2003/42*. 77 p.

Bradford, E. (2000). How representative is the sampling by the Observer Programme of the commercial hoki catches on the Chatham Rise? Final Research Report for Ministry of Fisheries Project HOK1999/04 Objective 2 (in part). 20 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Breiman, L.; Friedman, J.H.; Olshen, R.A.; Stone, C.J. (1984). Classification and regression trees. Wadsworth, Belmont, California. 358 p.

De'ath, G.D.; Fabricius, K.E. (2000). Classification and regression trees: a powerful yet simple technique for ecological data anlysis. *Ecology 81*: 3178–3192.

Dunn, A.; Livingston, M.E. (2004). Updated catch-per-unit-effort indices for hoki (Macruronus novaezelandiae) on the west coast South Island, Cook Strait, Chatham Rise, and sub-Antarctic for the years 1990 to 2002. *New Zealand Fisheries Assessment Report 2004/35*. 51 p.

Francis, R.I.C.C. (2001a). Improving the consistency of hoki age estimation. *New Zealand Fisheries Assessment Report 2001/12*. 18 p.

Francis, R.I.C.C. (2001b). Hoki length weight relationships. WG-HOK-2001/67. 6 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Francis, R.I.C.C. (2002). Estimating catch at age in the Chatham Rise hoki fishery. *New Zealand Fisheries Assessment Report 2002/9*. 22 p.

Hicks, A.C.; Cordue, P.L.; Bull, B. (2002). Estimating proportion at age and sex in the commercial catch of hoki using length frequency data. Hoki Working Group Document 2002/09. (Unpublished report held by Ministry of Fisheries, Wellington.)

Horn, P.L.; Sullivan, K.J. (1996). Validated aging methodology using otoliths, and growth parameters for hoki (*Macruronus novaezelandiae*) in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research 30*: 161–174.

Ihaka, R.; Gentleman, R. (1996). R: a language for data analysis and graphics, *Journal of Computational and Graphical Statistics 5*: 299-314.

O'Driscoll, R.L.; Phillips, N.L.; Livingstone, M.E.; Hicks, A.C.; Ballara, S.L. (2002). Catches, size, and age structure of the 2000–01 hoki fishery, and a summary of biologoical research for the 2002 stock assessment. *New Zealand Fisheries Assessment Report 2002/39*. 70 p.

Table 1: Numbers of tows catching hoki and weight of hoki caught in the observer LF and the commercial data by fishery and year.

		Observer LF data		TCEPR data	
Fishery	Year	Tows	Catch wt. (t)	Tows	Catch wt. (t)
Chatham Rise	1998–99	540	4 088	15323	116 684
	1999–00	379	2 168	10337	61 805
	2000–01	591	2 802	14760	72 659
	2001–02	378	2 137	10129	61 106
	2002–03	300	1 527	7731	50 733
Sub-Antarctic	2000–01	385	2 293	7689	54 960
	2001–02	348	1 793	6367	40 501
	2002–03	204	908	4985	27 816

Table 2: Numbers of otoliths aged including numbers of otoliths that were aged twice. Also included are the numbers of trips and tows where the aged otoliths were collected. Before refers to the numbers that were aged and after to the numbers remaining after the low scoring readings were deleted.

		Chatham Rise				Sub-Antarctic			
Year	Scoring	trips	tows	otoliths	aged twice	trips	tows	otoliths	aged twice
1998–99	before	14	431	1280	65				
	after	14	430	1262	59				
1999–00	before	16	338	1055	83				
	after	16	337	973	44				
2000–01	before	19	452	1395	70	25	320	1016	44
	after	19	452	1362	69	25	320	984	40
2001–02	before	21	360	1145	53	24	284	959	31
	after	20	357	1084	49	24	283	926	30
2002–03	before	21	285	927	42	20	196	674	30
	after	21	285	922	38	20	196	670	28

Table 3: Description of the stratifications of the Chatham Rise and Sub-Antarctic hoki fisheries.

Fishery	Year	Stratum	Description
Chatham Rise	1998—99	1	depth < 503 m, latitude north of 43.7° S
		2	depth < 503 m, latitude north of 43.7° S, from 12 Jan 1999
		3	depth < 503 m, latitude north of 43.7° S, before 12 Jan 1999
		4	503 m ≤ depth < 569 m, from 13 Jan 1999
		5	503 m ≤ depth < 569 m, before 13 Jan 1999
		6	503 m ≤ depth < 569 m, before 13 Jan 1999
	1999–00	1	depth < 513 m, latitude north of 43.8° S
		2	depth < 513 m, latitude south of 43.8° S
		3	513 m ≤ depth < 624 m, latitude north of 43.9° S
		4	513 m ≤ depth < 624 m, latitude south of 43.9° S
		5	depth ≥ 624 m
	2000–01	1	depth < 510 m
		2	510 m ≤ depth < 590 m, longitude west of 178.8° E, from 22 Nov 2000
		3	510 m ≤ depth < 590 m, longitude west of 178.8° E, before 22 Nov 2000
		4	510 m ≤ depth < 590 m, longitude east of 178.8° E
		5	590 m ≤ depth < 682 m
		6	depth ≥ 682 m
	2001–02	1	depth < 571 m, longitude west of 176.5° E
		2	depth < 571 m, longitude east of 176.5° E
		3	517 m ≤ depth < 637 m
		4	depth ≥ 637 m
	2002—03	1	depth < 598 m, longitude west of 177.4° E, latitude north of 43.9° S
		2	depth < 598 m, longitude west of 177.4° E, latitude south of 43.9° S
		3	depth < 598 m, longitude west of 177.4° E
		4	depth ≥ 598 m
Sub-Antarctic	2000–01	1	latitude north of 48.8° S, depth < 445 m
		2	latitude north of 48.8° S, depth ≥ 445 m
		3	latitude south of 48.8° S, longitude west of 168.3° E
		4	latitude south of 48.8° S, longitude between 168.3° E and 171.3° E
		5	latitude south of 48.8° S, longitude east of 171.3° E
	2001–02	1	longitude west of 168.3° E, latitude north of 48.8° S
		2	longitude west of 168.3° E, latitude south of 48.8° S
		3	longitude east of 168.3° E, depth < 634 m
		4	longitude east of 168.3° E, depth ≥ 634 m
	2000–01	1	latitude north of 48.8° S
		2	latitude south of 48.8° S, longitude west of 166.9° E
		3	latitude south of 48.8° S, longitude east of 166.9° E

Table 4: Estimated year-class frequencies (rounded to four decimal places) for the Chatham Rise fishery with estimated coefficients of variation (%) in parentheses. 0 indicates no fish from the year-class were caught.

		Fishing year				
	Year-class	1998–1999	1999–2000	2000–2001	2001–2002	2002–2003
Males	2001					0.0195 (81)
	2000				0.0446 (36)	0.1250 (21)
	1999			0.0098 (115)	0.0302 (55)	0.0314 (44)
	1998		0.0553 (48)	0.0429 (37)	0.0910 (24)	0.0608 (32)
	1997	0.0284 (43)	0.2194 (20)	0.1681 (16)	0.1409 (17)	0.0743 (34)
	1996	0.0788 (19)	0.0357 (37)	0.0719 (22)	0.0553 (23)	0.0351 (60)
	1995	0.1111 (16)	0.0324 (55)	0.0400 (32)	0.0138 (42)	0.0017 (91)
	1994	0.0781 (19)	0.0407 (38)	0.0231 (28)	0.0043 (55)	0.0093 (73)
	1993	0.0587 (22)	0.0106 (52)	0.0223 (34)	0.0013 (76)	0.0020 (120)
	1992	0.0349 (38)	0.0095 (49)	0.0109 (43)	0.0050 (65)	0.0017 (106)
	1991	0.0151 (49)	0.0204 (55)	0.0015 (76)	0.0005 (141)	0.0001 (585)
	1990	0.0066 (57)	0.0024 (148)	0.0018 (104)	0	0.0064 (151)
	1989	0.0022 (64)	0.0017 (122)	0.0009 (132)	0.0001 (141)	0
	1988	0.0039 (76)	0.0042 (87)	0.0015 (100)	0.0004 (148)	0.0001 (180)
	1987	0.0057 (68)	0.0003 (153)	0.0007 (99)	0	0.0010 (143)
	1986	0	0.0003 (186)	0	0	0.0010 (151)
	1985	0	0	0	0	0
	1984	0	0	0	0	0
	1983	0	0	0	0.0000 (171)	0
	1982	0	0.0005 (153)	0	0	0
	1981	0	0	0	0	0
	1980	0	0	0	0	0
	1979	0	0.0006 (169)	0	0	0
	All males	0.4234 (3.4)	0.4341 (7.0)	0.3954 (5.0)	0.3873 (5.1)	0.3694 (8.4)
Females	2001					0.0026 (80)
	2000				0.0682 (31)	0.1617 (22)
	1999			0.0070 (116)	0.0190 (72)	0.0529 (29)
	1998		0.0483 (44)	0.0480 (54)	0.0943 (23)	0.0695 (28)
	1997	0.0241 (40)	0.2114 (19)	0.1677 (13)	0.1686 (13)	0.1507 (27)
	1996	0.0849 (25)	0.0609 (21)	0.1406 (15)	0.0751 (19)	0.0639 (28)
	1995	0.1138 (17)	0.0519 (49)	0.0477 (25)	0.0437 (39)	0.0159 (49)
	1994	0.0974 (15)	0.0571 (37)	0.0565 (23)	0.0420 (29)	0.0298 (41)
	1993	0.0784 (24)	0.0326 (53)	0.0272 (27)	0.0289 (38)	0.0155 (55)
	1992	0.0536 (22)	0.0325 (32)	0.0420 (24)	0.0273 (38)	0.0197 (42)
	1991	0.0251 (32)	0.0136 (45)	0.0258 (34)	0.0110 (55)	0.0120 (72)
	1990	0.0291 (30)	0.0126 (74)	0.0058 (50)	0.0078 (55)	0.0052 (90)
	1989	0.0282 (33)	0.0078 (59)	0.0112 (41)	0.0086 (68)	0.0059 (75)
	1988	0.0162 (40)	0.0173 (44)	0.0108 (43)	0.0089 (63)	0.0028 (77)
	1987	0.0100 (44)	0.0058 (61)	0.0068 (51)	0.0070 (47)	0.0071 (94)
	1986	0.0030 (63)	0.0058 (71)	0.0038 (59)	0.0005 (150)	0.0015 (163)
	1985	0.0015 (89)	0.0062 (125)	0.0011 (111)	0.0003 (155)	0.0000 (180)
	1984	0.0050 (115)	0.0021 (86)	0.0001 (163)	0.0002 (150)	0.0012 (153)
	1983	0	0	0.0007 (186)	0	0.0126 (156)
	1982	0.0034 (112)	0	0.0014 (113)	0	0
	1981	0	0	0.0005 (143)	0.0015 (152)	0
	1980	0.0011 (163)	0	0	0	0
	1979	0	0	0	0	0
	1978	0.0017 (130)	0	0	0	0
	All females	0.5766 (2.5)	0.5659 (5.4)	0.6046 (3.3)	0.6127 (3.2)	0.6306 (4.8)

Table 5: Estimated year-class frequencies (rounded to four decimal places) for the Sub-Antarctic fishery with estimated coefficients of variation (%) in parentheses. 0 indicates no fish from the year-class were caught.

				Fishing year
	Year-class	2000–2001	2001–2002	2002–2003
Males	2001			0
	2000		0.0799 (96)	0.0210 (73)
	1999	0	0.0026 (174)	0.0168 (91)
	1998	0.0064 (175)	0.0135 (139)	0.0610 (35)
	1997	0.0253 (85)	0.0216 (88)	0.0314 (53)
	1996	0.0561 (52)	0.0252 (85)	0.0304 (50)
	1995	0.0745 (42)	0.0070 (77)	0.0165 (67)
	1994	0.1024 (30)	0.0321 (48)	0.0474 (40)
	1993	0.0599 (41)	0.0383 (46)	0.0523 (44)
	1992	0.0713 (35)	0.0537 (42)	0.0457 (48)
	1991	0.0390 (47)	0.0288 (45)	0.0239 (54)
	1990	0.0060 (68)	0.0011 (148)	0.0031 (88)
	1989	0.0005 (140)	0.0021 (94)	0.0168 (91)
	1988	0.0013 (147)	0.0042 (164)	0.0021 (160)
	1987	0.0006 (128)	0	0
	All males	0.4434 (9.5)	0.3101 (15.5)	0.3685 (6.5)
Females	2001			0
	2000		0.0545 (83)	0.0241 (66)
	1999	0	0.0150 (105)	0.0124 (78)
	1998	0.0047 (196)	0.0066 (137)	0.0096 (70)
	1997	0.0077 (138)	0.0063 (126)	0.0391 (46)
	1996	0.0286 (60)	0.0493 (84)	0.0485 (34)
	1995	0.0511 (50)	0.0491 (58)	0.0497 (41)
	1994	0.1312 (31)	0.0924 (34)	0.1256 (22)
	1993	0.0935 (34)	0.1134 (30)	0.0683 (30)
	1992	0.1128 (27)	0.1773 (33)	0.1128 (31)
	1991	0.0656 (35)	0.0453 (37)	0.0601 (37)
	1990	0.0207 (69)	0.0239 (67)	0.0255 (60)
	1989	0.0115 (60)	0.0269 (55)	0.0146 (62)
	1988	0.0114 (88)	0.0103 (62)	0.0259 (75)
	1987	0.0095 (69)	0.0074 (63)	0.0038 (96)
	1986	0.0046 (97)	0.0045 (87)	0.0025 (178)
	1985	0.0037 (143)	0.0023 (132)	0.0004 (183)
	1984	0.0000 (346)	0.0018 (100)	0.0016 (176)
	1983	0.0000 (192)	0.0018 (136)	0.0070 (135)
	1982	0	0	0
	1981	0	0	0.0000 (184)
	All females	0.5566 (7.0)	0.6899 (7.6)	0.6315 (3.9)

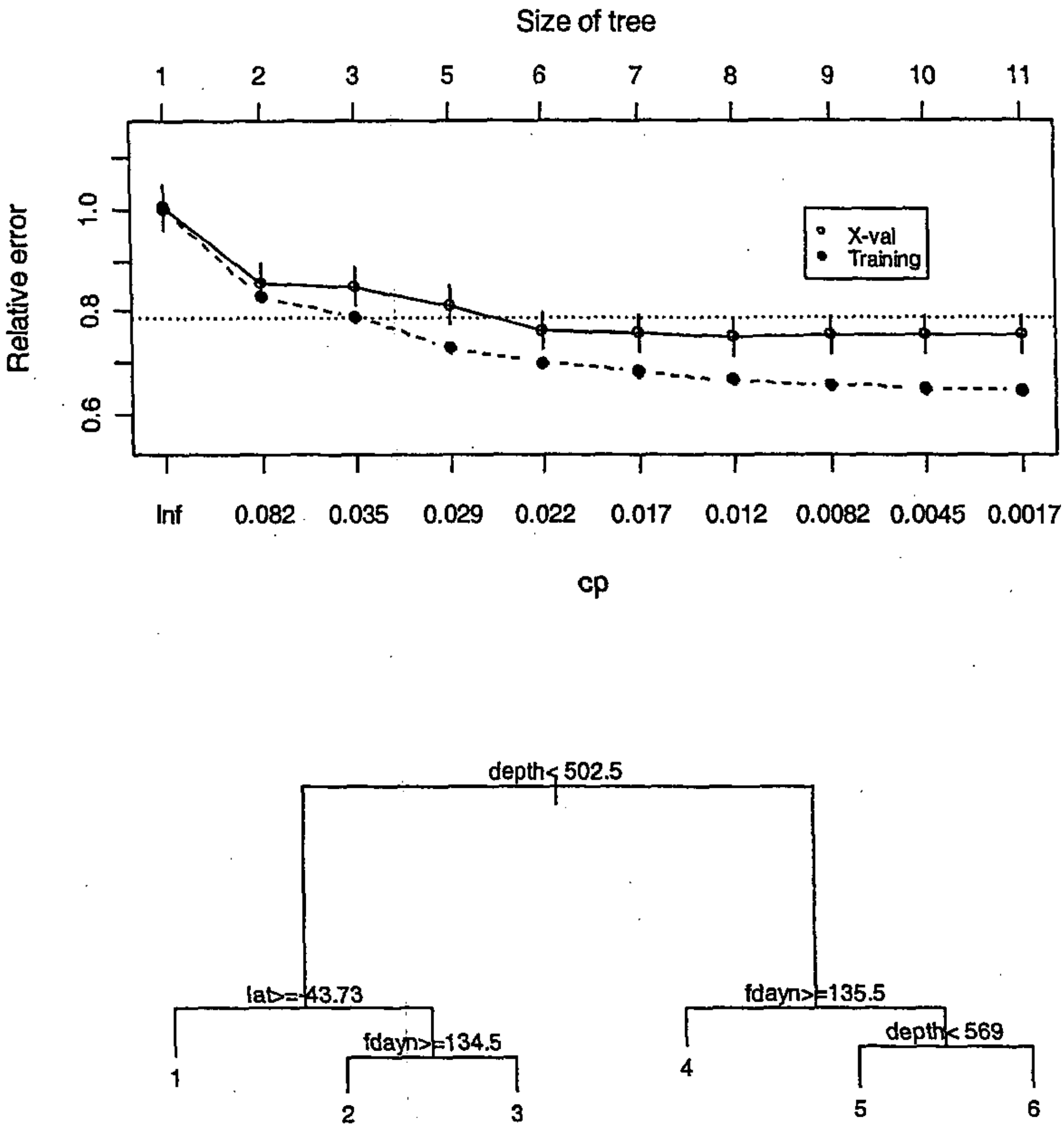


Figure 1: Stratifying the Chatham Rise fishery in the 1998–99 fishing year. The upper panel gives the plot of the relative error from the 10-fold cross-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line marked Training in the legend is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size, (see Breiman et al. (1984) for further explanation). The lower panel is the dendrogram of the tree that gives the stratification of the fishery. The split conditions are for the left branches of the tree and the numbers at the ends of the leaves are the stratum numbers.

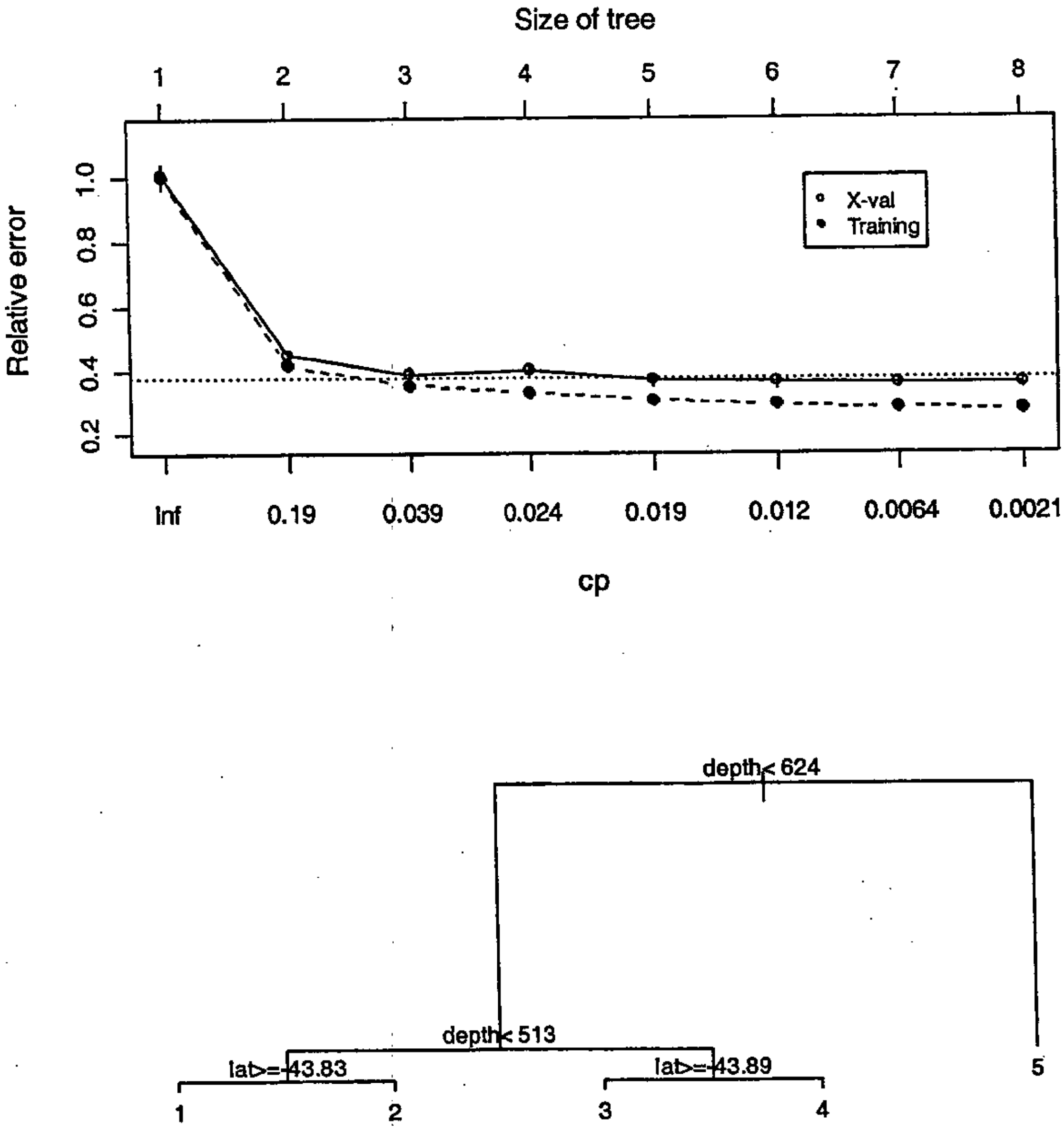
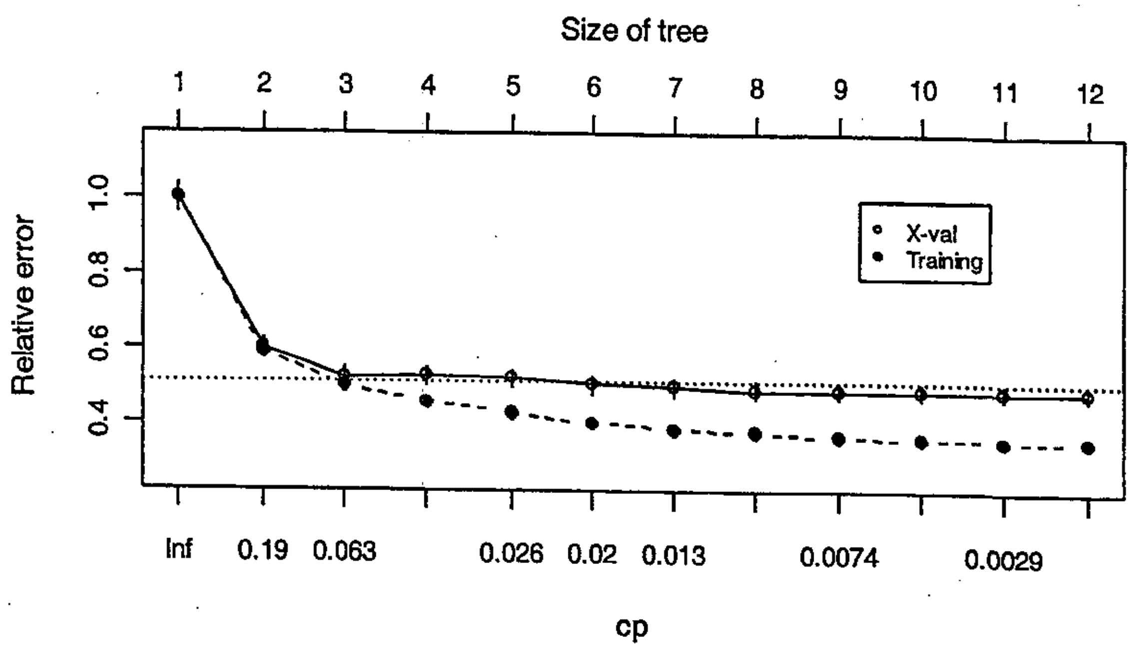


Figure 2: Stratifying the Chatham Rise fishery in the 1999–00 fishing year. See the caption to Figure 1 for a description of the plot details.



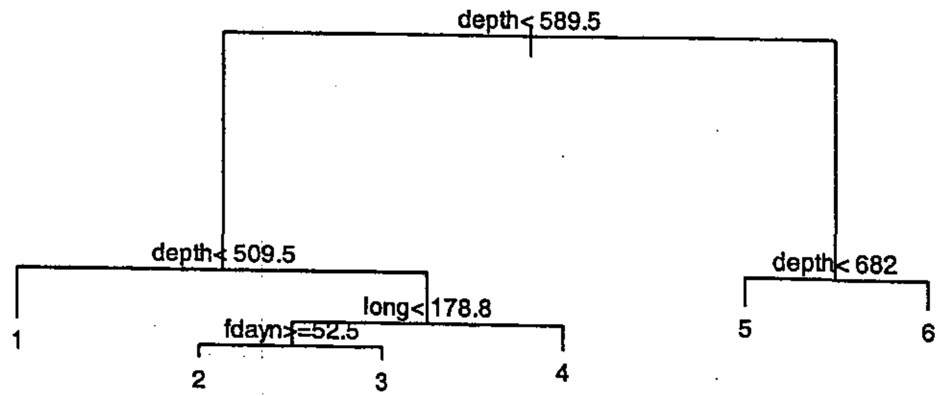


Figure 3: Stratifying the Chatham Rise fishery in the 2000–01 fishing year. See the caption to Figure 1 for a description of the plot details.

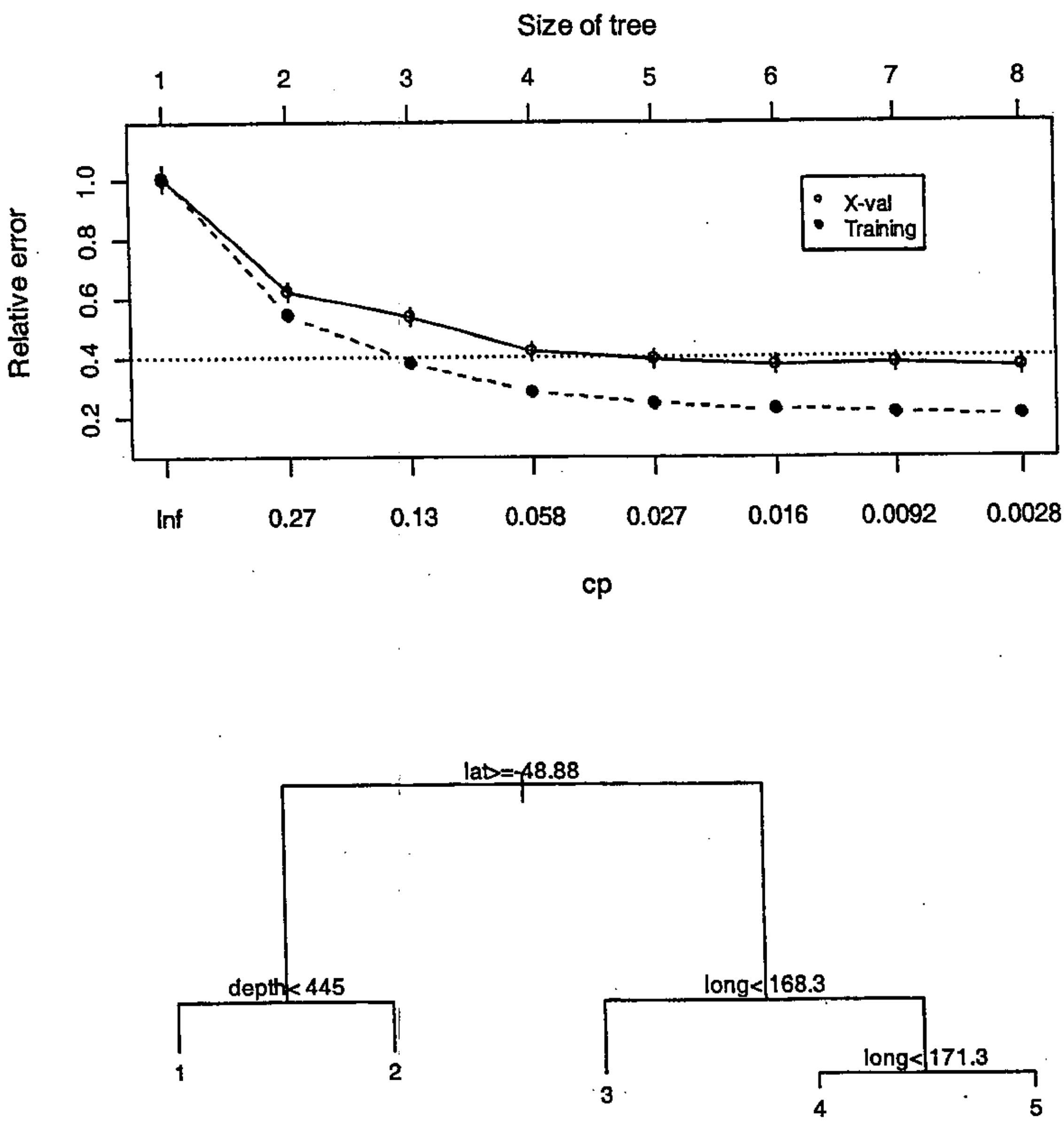


Figure 4: Stratifying the Sub-Antarctic fishery in the 2000–01 fishing year. See the caption to Figure 1 for a description of the plot details.

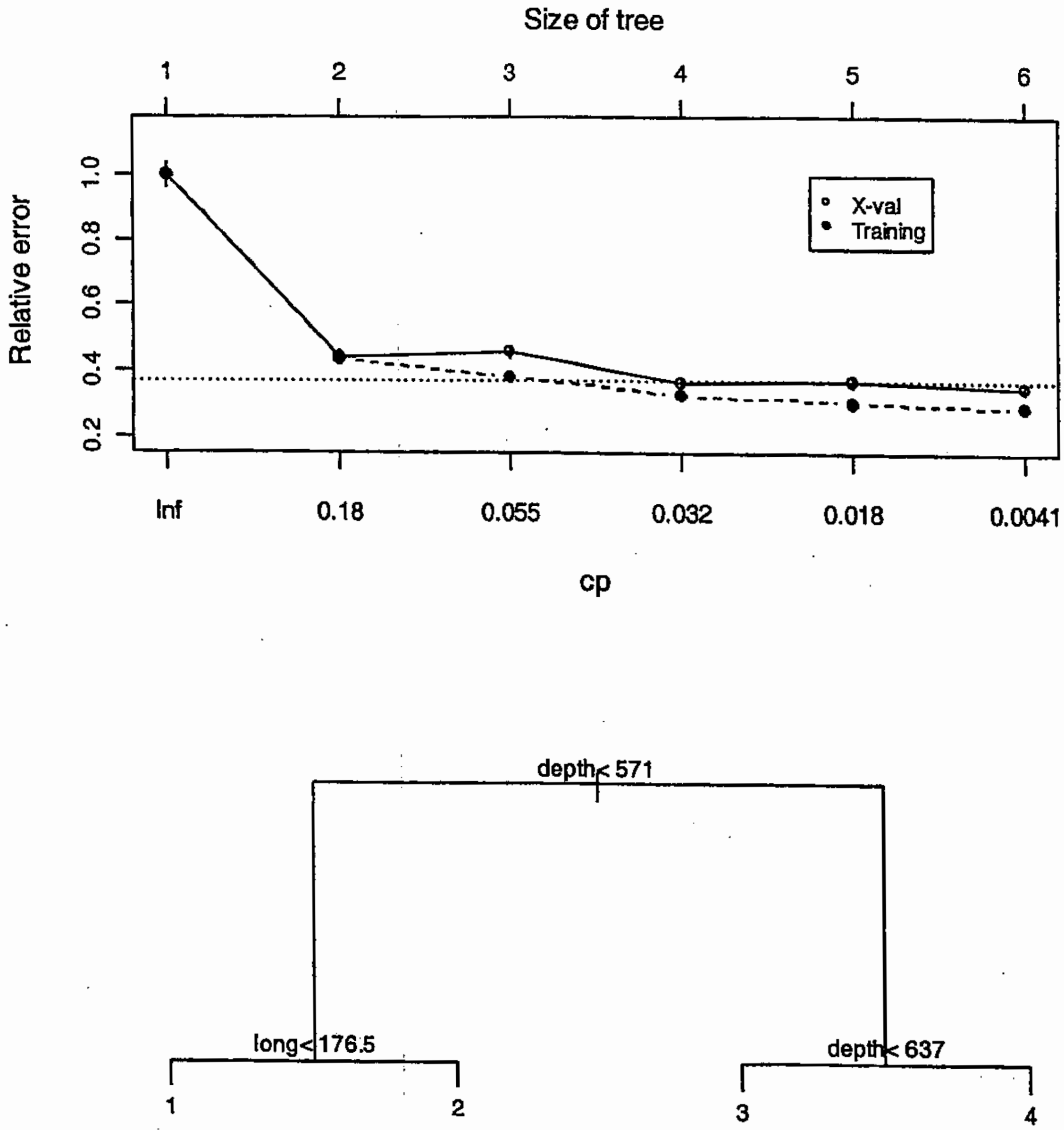


Figure 5: Stratifying the Chatham Rise fishery in the 2001–02 fishing year. See the caption to Figure 1 for a description of the plot details.

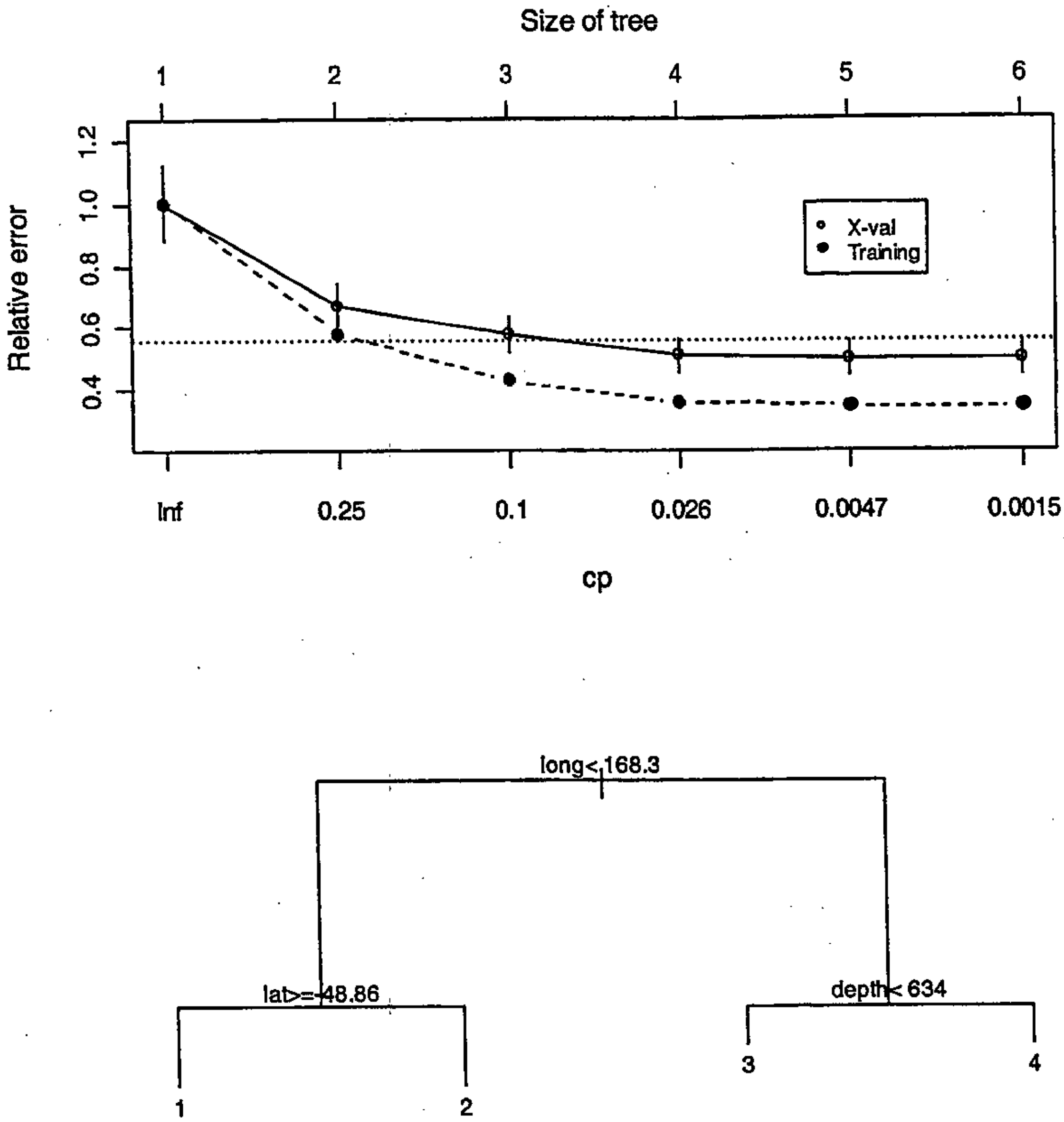
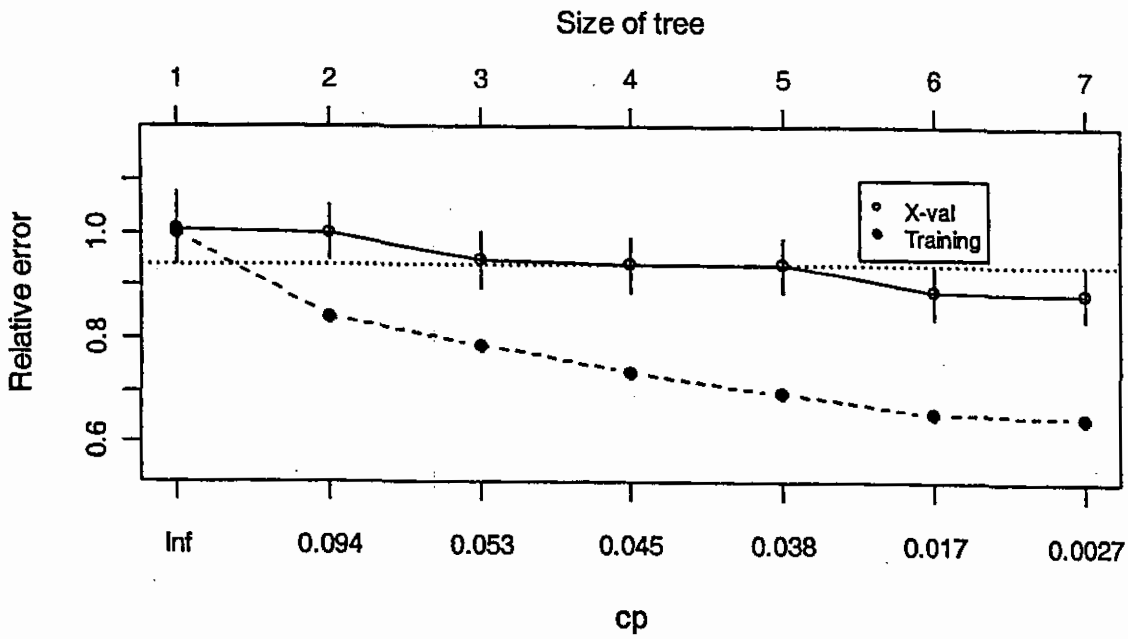


Figure 6: Stratifying the Sub-Antarctic fishery in the 2001–02 fishing year. See the caption to Figure 1 for a description of the plot details.



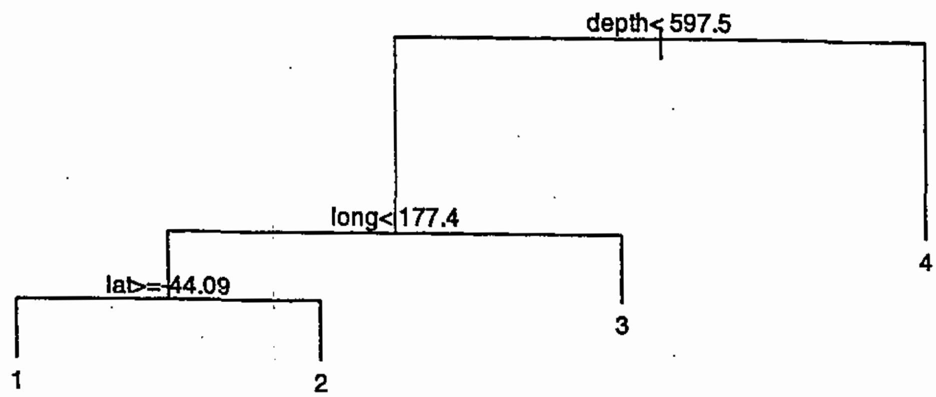
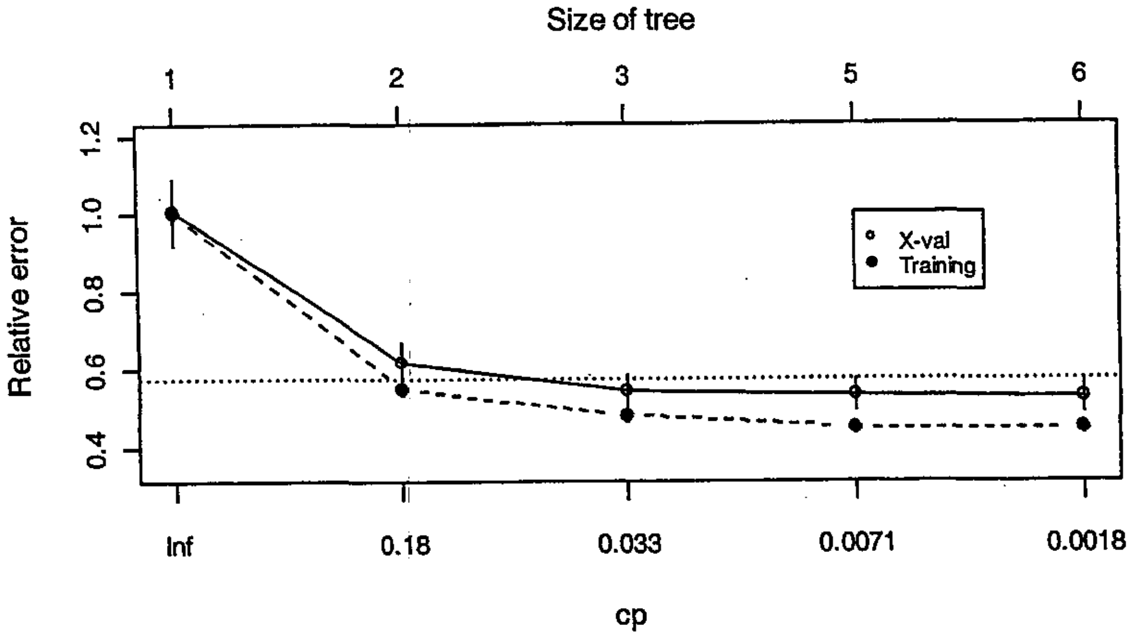


Figure 7: Stratifying the Chatham Rise fishery in the 2002–03 fishing year. See the caption to Figure 1 for a description of the plot details.



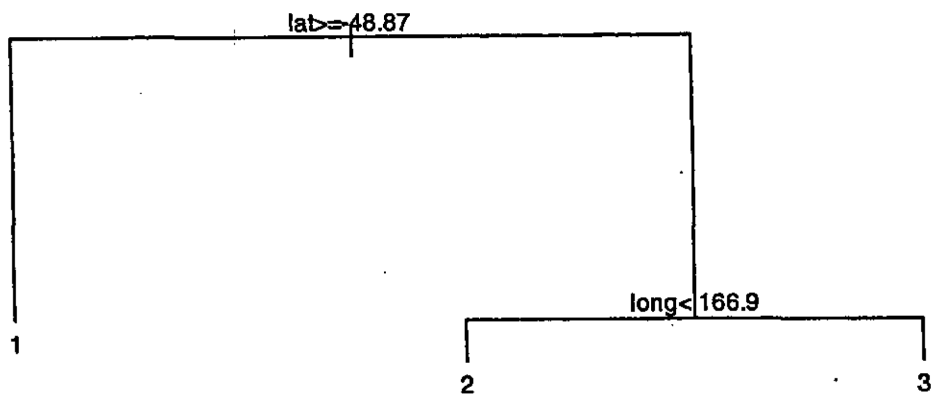


Figure 8: Stratifying the Sub-Antarctic fishery in the 2002–03 fishing year. See the caption to Figure 1 for a description of the plot details.

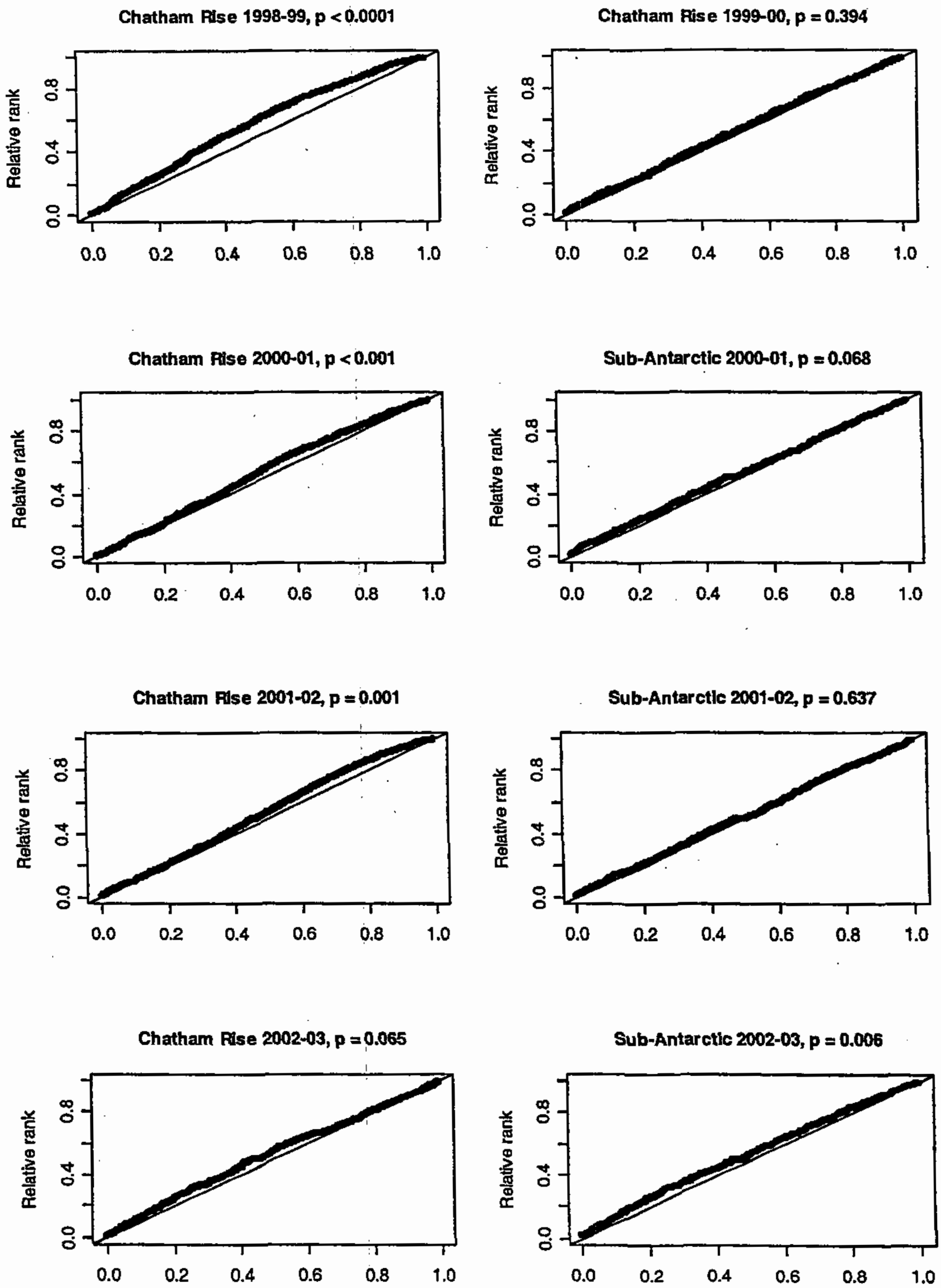


Figure 9: Quantile plots of the ranks of the lengths of fish with otoliths relative to the lengths of all fish in the LF data. The solid line is the theoretical trend the points would follow if the lengths of the otolith fish from a particular tow were a simple random sample from the fish with measured lengths. That the points lie above this line indicates that there is tendency to choose larger fish for otolith ageing. A measure of the significance of this tendency is given by the p value in the title of each plot.