Inputs for a stock assessment of smooth oreo, Pukaki Rise (part of OEO 6)

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EXECUTIVE SUMMARY

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A standardised CPUE analysis of Pukaki Rise (part of OEO 6) smooth oreo was developed using regression based methods similar to those of previous oreo CPUE analyses. Data were divided into pre- and post-GPS series as in other recent oreo standardised CPUE analyses, but there were insufficient pre-GPS data to form an index. The post-GPS index declined markedly.

The data quality, quantity, and experimental design (vessel by year) are suitable for this type of standardised analysis. However, data were dominated by a single vessel and the analysis was therefore not as robust as those used for other oreo standardised CPUE analyses. This motivated the investigation of a nested bootstrap re-sampling approach to estimating the variance of the index. We recommend the index and associated bootstrap c.v. as a putative index of abundance for stock assessment analysis.

Fish length data collected by fishery observers from 1996–97 to 2004–05 were analysed first to determine any important covariates. This identified that mean length increases with depth. Consequently the length data were post stratified by depth and catch-weighted composite length frequencies were calculated. Variance by length class was estimated by bootstrap resampling. These length frequencies are assumed to represent the fishery size structure in the stock assessment model.

A catch history for the stock assessment was derived from declared catch against quota and tow by tow records of estimated species catch.

The median depth at which catch is taken by year, i.e., the 50% point of the cumulative catch with respect to depth distribution, and the inter-quartile range of the same distribution were calculated as additional information for the stock assessment.

1. INTRODUCTION

1.1 Objective

This work addresses the following objectives in the MFish project "Oreo stock assessment" (OEO2005/02).

Overall objective

1. To carry out a stock assessment of black oreo (*Allocyttus niger*) and smooth oreo (*Pseudocyttus maculatus*), including estimating biomass and sustainable yields.

Specific objective

3. To carry out a stock assessment of smooth oreo in Pukaki (part of OEO 6), including estimating biomass and sustainable yields.

1.2 Overview

The Pukaki Rise smooth oreo fishery has not been assessed previously. The purpose of this study was to provide a standardised CPUE analysis, an analysis of observer length data, a catch history, and other inputs for Pukaki Rise smooth oreo to enable a new CASAL stock assessment to be carried out. The CASAL stock assessment is presented in a separate document.

Recent oreo stock assessments used separate time series of standardised CPUE based upon the timing of the adoption of Global Positioning System (GPS) navigation, i.e., a series before the arrival of GPS (pre-GPS, up to and including 1988–89) and a series after the arrival of 24 hour GPS coverage (post-GPS, from and including 1992–93 onwards). Previous oreo stock assessments, e.g., OEO 4 smooth oreo (Doonan et al. 2003), Southland smooth oreo (Coburn et al. 2003), also used a CASAL population model employing Bayesian statistical techniques (Bull et al. 2003).

1.3 General

Coburn et al. (2005) described catch and effort for Pukaki Rise smooth oreo as well as for the other New Zealand oreo fisheries. Other smooth oreo standardised CPUE studies include those in OEO 3A (Coburn et al. 2006) and Southland (Coburn et al. 2003).

Smooth oreo and black oreo are managed together despite the two species having different population size and life histories. They have extensively overlapping depth and geographic distributions and fishers' preference for one over the other has not been constant. Target species is commonly recorded as the generic OEO (unspecified oreo) and it is not generally possible to fish one species without substantial bycatch of the other. At various times one or other species is believed to have been discarded in volume (particularly small fish). Catches have typically been recorded by species, but the generic OEO code was used extensively in some early years and also to some extent more recently. These factors make a successful oreo CPUE study a more difficult task than for a typical single species target fishery.

Standardisation is designed to take out the effects of changes in the fishery, e.g., it may be that catch rates are better in deeper water. If there was a trend over time toward a greater or lesser proportion of fishing in deeper water, then an unstandardised measure of CPUE may not be an index of abundance. The linear models employed are able to identify these sorts of effects and to take account of them quantitatively, thereby providing an index that better reflects underlying fish abundance. However, the models are unable to explain major changes in the fishery, e.g., adoption of GPS and the changes in fishing technique it enabled. Separate series of CPUE may be required through the history of the fishery.

Observers have collected catch effort and biological data (including lengths) from fishing vessels in New Zealand since 1986. Until the late 1990s the data were collected by Ministry of Fisheries observers. Since then various industry bodies have also collected similar information. This study examines length data collected from both sources. In some earlier work (Coburn et al. 2003) there appeared to be differences in data between the two sources, and industry data were dropped in some cases.

2. CATCH HISTORY

A catch history was derived using declared catches of OEO from OEO 6 (see Table 2, p. 460, Ministry of Fisheries 2006) and tow-by-tow records of catch from the assessment area (see Figure 1). The tow-by-tow data (see Section 3.1.2) were used to estimate the species ratio (SSO/BOE) and therefore the SSO taken. It was assumed that the declared catches provided the best information on total catch quantity and that the tow-by-tow data provided the best information on the species and area breakdown of catch. There may be unreported catch, although this is thought to be small. Before the 1983–84 fishing year the species catch data were combined over years to get an average ratio that was then applied in each of those early years. For the years from 1983–84 onwards, each year's calculation was made independently. The catch history used in the population model is given in Table 1.

3. CATCH PER UNIT OF EFFORT

3.1 Methods

3.1.1 Definitions and abbreviations

All data are grouped by fishing year, 1 October to 30 September. Abbreviations used are: SSO, smooth oreo; BOE, black oreo; OEO, unspecified oreo; ORH, orange roughy; FSU, Fisheries Statistics Unit; TAC, total allowable catch; CPUE, catch per unit effort; c.v., coefficient of variation; GPS, global positioning system; GLM, generalised linear model.

3.1.2 Data

Tow-by-tow data from trawl catch effort returns were used, including those derived from the FSU from 1977–78 and from the Ministry of Fisheries Catch and Effort database from 1988 on. These data were checked for systematic errors and gross outliers and for consistency over the time series. The tow data included start position, catch by species, target species, depth, vessel, distance towed, time of day, and date. Nationality and tonnage were recorded for each vessel. This study uses tow-by-tow estimates of catch and all further reported catches or catch rates are directly from these data and not adjusted to declared catches. For the analysis of unstandardised CPUE we used tow-by-tow data where the target species was ORH or OEO or SSO or BOE, or where any of these were reported as caught. Most of the unstandardised analyses use those data from only the assessment area, but some figures include data from surrounding areas in order to provide a setting.

For the standardised analysis we used only those tow-by-tow records of fishing in a defined assessment area where smooth oreo was either reported as the target species or where smooth oreo was reported among the top five species caught, i.e., a subset of the set mentioned above. This means there may be records with a zero catch of smooth oreo, but these occurred only when the target species was smooth oreo.

3.1.3 CPUE measure

Catch-per-tow (kg-per-tow) was chosen as the index of abundance rather than catch-per-kilometre and follows the Deepwater Working Group's preference in previous smooth oreo standardised CPUE analysis (Doonan et al. 1996, 1997, 1999).

3.1.4 Assessment area

The assessment area was defined to enclose the main fishery and is shown in Figure 1 (vertices are at: 46° 26.1′ S, 174° 59.2′ E; 48° 31.8′ S, 176° 60.0′ E; 50° 59.6′ S, 176° 60.0′ E; 50° 59.6′ S, 172° 58.4′ E; 49° 0.1′ S; 168° 58.0′ E). It is not known what degree of mixing might occur between smooth oreo populations in the assessment area and those outside it.

3.1.5 Standardised CPUE

Predictor variables that were offered for selection in the regression models are listed in Table 2. Three innately categorical predictors were used: vessel had a category for each vessel having at least 50 records in the regression, and those vessels with fewer than 50 records were lumped into an aggregate category; target species had categories for SSO, BOE, OEO, and ORH, and all other target species were lumped into an aggregate category (year is also in the model as an innately categorical variable, but it is not a standardising predictor). The other predictors were innately continuous, e.g., depth. They were converted to categorical by splitting the data into eight evenly filled bins (the break points between bins were chosen so that the bins had a similar number of records). Eight bins were chosen as sufficient to model any dependencies in the data without prejudice to the shape of any dependency, while ensuring that the resulting models were not over-parameterised.

Two extra predictors were included. 'Sun' is the altitude of the sun with respect to the horizon (zero being sunrise or sunset) for each trawl and was calculated from the location, date, and start time of each trawl. It was hoped it would be a better predictor of any diurnal effect than the hour of the day. 'Moon' is the fraction of the moon surface that is visible, ranging from 1 for a full moon to near zero for a new moon. No account is given for whether the moon is above or below the horizon or of any cloud cover. This might allow detection of lunar cycle effects if moon illumination was important.

3.1.6 Pre- and post-GPS standardised CPUE

The standardised analysis was split into two time series. A pre-GPS (up to 30 September 1989) and a post-GPS (from 1 October 1992) series, because 24 h availability of GPS gradually became available to, and was adopted by, the fishing fleet between these times. Coburn et al. (2001) provided the rationale for this and included an approximate schedule of GPS availability and adoption. If information had been recorded about GPS use on a tow-by-tow basis, it might have been possible to include this in the standardising model (and hence there would be no need to split the analyses into two periods, nor would data from the adoption period need to be dropped), but this information is not available retrospectively.

3.1.7 Inclusion of years in the standardised models

Years were admitted to the standardised analysis only if (a) there were at least 50 non-zero catches of smooth oreo in the year and (b) the records for a year were not dominated by a single vessel (defined as more than 80% of the year's records). A further requirement to have at least three years admitted before considering analysis was met by only the post-GPS series, therefore no pre-GPS analysis was attempted.

3.1.8 Log linear models

Because the standardising dataset had low fractions of zero catch tows only a positive catch regression was produced. Any zero catches were ignored in the regression. The positive catch regression is a log linear model where log(CPUE) is regressed against the predictor variables. Mathematical details of the model were given by Vignaux (1994).

Year effects were extracted from the models with the method outlined by Coburn et al. (2003). The same method is used to extract the non-year effects. For example, the effect for target species X is the mean predicted value of the regression when the input data are altered so that the target predictor takes the value X in every row and the coefficients estimated in the original regression are applied. The exponential of this mean was taken to convert back to the original scale of the CPUE data.

The standardising models are built up stepwise where predictor terms are added one at a time to a base model until R^2 (expressed as a percentage) fails to increase by more than one unit. The base model has only the year term and is the minimum model required from which we can extract a year effect (termed the null model). The year indices of this model are the geometric means of the CPUE data for each year. As additional terms are added to the model, the year effect is progressively 'standardised', the index dropping in some years but rising in others.

3.1.9 Estimating c.v.

An estimate of confidence interval on the year effects was calculated using a jackknife method based on estimation of the year effect from each of n models, where there are n vessel categories in the regression. Each of the n models was fitted to those data from all vessels except one in turn (see Doonan et al. (1995) for more mathematical detail).

Bootstrap re-sampling was also investigated as a means of estimating c.v. Three re-sampling regimes were trialled. The first re-sampled randomly with replacement from the tows, i.e., each tow is treated as independent. One thousand re-sampled data sets each with the same size as the actual data set were generated and models fitted to each. The year indices were derived from each model and then normalised by dividing by their mean. An estimate of c.v. by year was calculated from the normalised values (c.v. = std.dev./mean for each year). We used the selected model form in each case, i.e., the model selection process was not undertaken for each re-sampled dataset. The second regime was to re-sample by vessel. Here each re-sample is a random sample with replacement from the set of vessels. This means that samples formed differ in the number of records they have. When a vessel was sampled more than once it was treated each time in the regression as a distinct vessel. The models were fitted, year indices derived, and c.v.s calculated as above. The final regime re-sampled both by vessel and tow. That is, we re-sampled first by vessel as above, then within each vessel we re-sampled by tow, i.e., nested re-sampling. Derivation of c.v. was as above.

3.2 Results

3.2.1 Unstandardised CPUE

General description

Smooth oreo are caught on the edge of the continental shelf at depths around 1000 m in New Zealand waters mainly south of Cook Strait and to the east of the main divide (extended down along the Macquarie Ridge). There are several discrete fisheries (Figure 1). In the last decade fishing has moved toward the southern regions away from the historical main Chatham Rise fisheries, and Pukaki Rise has emerged as an important source of catch (second only to OEO 4 in some years). We defined an assessment area around the fishery based on this distribution (Figure 1). A section of the boundary between OEO 1 and OEO 6 was employed as one side of this assessment area.

Catches from the area were reported from Soviet vessels (see Coburn et al. 2005) in the early to mid eighties when catch was mainly black oreo, with smaller amounts of smooth oreo and almost no orange roughy (Figure 2). Fishing then declined but catches resumed in 1995–96. These were mostly New Zealand vessels and initially they caught a lot of orange roughy with oreo apparently taken mainly as bycatch. Since 1995–96, orange roughy catch tailed off rapidly to almost nothing and by 1999–2000 the fishery was dominated by smooth oreo and black oreo, although the proportions changed year by year. Since 2000–01 there has been an increase of reported orange roughy catch.

Reported smooth oreo catch came from around the rim of the north and east slopes of the Pukaki Rise (Figure 3). Orange roughy catch had a more limited distribution, clustered mostly around 50° S, 176° E, and around 48° 30′ S, 175° E. The black oreo catch spatial distribution is less extensive than that of smooth oreo.

Plotted tow tracks suggest that most fishing occurs on discrete bottom features (Figure 4) and most tows are short. The relatively high value of orange roughy has tended to drive the exploitation of other deepwater species. The spatial distribution of smooth oreo and orange roughy catches by year is shown in Figure 5. Clear association of orange roughy and smooth oreo catch are seen in the initial years. However, as orange roughy catch fell, the smooth oreo catch distribution evolved, with vessels typically exploring more of the 1000 m margin, and gradually spreading along the north slope. The resurgence of orange roughy catch since 2001–02 in the same general area as smooth oreo catches appears unlinked to smooth oreo catch as the catch circles are not concentric, e.g., 1995–96 to 1998–99 contrasts with 2001–02 to 2004–05.

The data available for standardisation are summarised in Table 3. The assessment area was fished in the mid to late 1980s, but catches were then negligible until fishing resumed in the mid 1990s with a New Zealand fleet, and have been fairly steady since then. The New Zealand fleet has had about 10 vessels with effort ranging from about 300 to 700 tows per annum. Catch of smooth oreo since 1995–96 was fairly steady, about 1000 to 2000 t. Mean catch rates were fairly stable from 1995–96 to 2001–02 but have declined since then. The fraction of reported zero catches is low except for a few of the early years that were not included in the standardised analysis, and so only a positive catch model was used in standardisation (see methods). The years 1995–96 to 2004–05 were used for the standardising analyses because the data before this were inadequate (see Section 3.1).

Vessel, year structure

The post-GPS data were selected according to the methods above. The data are dominated by one vessel (vessel 5) that fished in every year and expended the greatest effort in 8 of the 10 years. Vessel 6 was also a major player (Table 4). Twelve vessels fished in at least 3 years in this series.

3.2.2 Initial model

Selection of the model

The selected standardising predictors were (in the order of selection) vessel, target, season, depth, and axis-position, with a total R^2 of 21.6% (null model 7.9%) (Table 5).

Index steps

Year effects calculated for each step of the model selection process are shown in Figure 6. The zero step is the null model with only the year included and no standardising covariates. The first standardising covariate, vessel, provides the bulk of the explaining power (R^2) of the model yet it has little effect on the year effect. However, when target was added the index shifted considerably, particularly in the initial few years, and had the effect of greatly increasing the decline seen in the series. Further steps (season, depth, axis-position) modify the index slightly, making the decline steeper.

Examination of alternative c.v.s

The alternative estimates of c.v.s from the methods outlined above are provided in Table 6. By comparison with the jackknife estimates the bootstrap c.v.s are generally more consistent from year to year. The results show that variability between vessels is much greater than variability between tows within vessels.

3.2.3 Final model

The initial model was presented to the Deepwater Working Group. They requested two changes: (1) that data from vessels with less than 3 years involvement in the standardised analysis period (1995–96 to 2004–05) be excluded from the model and that there be no aggregation of the remaining vessels; (2) that target be excluded as a candidate predictor as there may have been a change in the way in which target was reported within the time series. These changes were implemented and are reported here as the final model. Data from 12 vessels are included in this analysis (see Table 4).

Selection of the model

The selected standardising predictors were (in the order of selection) vessel, axis-position, depth, and season, with a total R^2 of 19.8% (null model 9.4%) (Table 7).

Year indices and bootstrap c.v.

The year index and bootstrap c.v.s are provided in Table 8 and can be seen in Figure 7. Over the period there is a clear downward trend, although from 1997–98 to 2001–02 the decline is small. The index value in the final year is less than one tenth of the 1995–96 value.

Non-year effects

Non-year effects are shown in Figure 8. The vessel effect appears roughly lognormal in distribution, i.e., as many vessels occur with double as those with half the average fishing power. The plot also illustrates the dominance of a single vessel. The axis-position effect depicts the patchiness both of effort and catch rates around the 1000 m margin. The depth effect shows that catch rates improve with depth with the exception of the shallowest depth bin. The season effect shows no clear seasonality of catchrates.

4. CATCH DEPTH

Two additional inputs were calculated as potentially useful to the stock assessment. The first, median catch depth, is the depth below which half the catch is taken. The second, interquartile catch depth, is the difference between the depth below which 25% of the catch is taken and the depth below which 75% of the catch is taken. Both have units of metres.

These quantities were calculated for each year of the catch history using a method similar to that used to derive the depth stratification breaks for the post-stratification of the length frequency data (see Section 5.2). That is, a smooth line is fitted to the cumulative distribution of catch by depth, this line is intersected at the appropriate quantile of catch, and depth is read off the other axis. These values are given in Table 9.

Because fish size in the catch is related to depth (see Section 5), median catch depth may relate to median fish size, while interquartile catch depth may relate to the spread of fish sizes.

5. OBSERVER LENGTH FREQUENCIES

5.1 Data

Length frequency records from fishery observers are stored in the Empress database 'obs_lfs' maintained by NIWA. These data were collected by the Scientific Observer Programme (SOP) run by the Ministry of Fisheries (MFish) and various fishing industry bodies, including the Orange Roughy Management Company (ORMC).

We extracted all records where smooth oreo were measured from within the assessment area (Figure 9). The distribution of samples by fishing year and by collector source, and an approximate smooth oreo catch estimate from the assessment area derived from tow by tow catch records (see Section 3) are shown in Table 10. About 300 samples were evenly divided between the SOP and ORMC. ORMC samples were collected from 1998–99 to 2002–03 and SOP samples were from 1996–97 to 2004–05. Samples cover the period of most catch but the early fishery was not sampled. The location of these samples and the overall distribution of the fishery are shown in Figure 9. Spatially at least, sampling appears fairly representative of the fishery.

Composite length frequency distributions (length frequency for short) were calculated for each year. Each sample was weighted by the catch weight of the tow from which the sample was taken. This was modified slightly by estimating the number of fish that would be in a unit weight of catch and multiplying by that. The intention behind this is that each measured fish carries the same weight into the composite length frequency. Samples with mainly small fish will take a proportionately greater weight than those with mainly large fish and this reflects the numbers of fish measured. Weighing by catch weight could be problematic if there were cases of small sized samples from large catches. This possibility was checked and found not to exist for these data.

Plots of composite weighted length frequencies by fishing year show noticeable trends over time (Figure 10). The distributions tend to spread out over time as more small and large fish are encountered, while the fraction of fish close to the mode declined. Most of this change seems to occur between 2001–02 and 2002–03.

5.2 Post-stratification

The stock assessment population model can include data representing the size structure of the catch. Ideal data would be a measurement of every fish caught. This is impractical, but sampling should reflect the fishery as best as possible.

These data are collected without a prescriptive sample programme, i.e., not strictly random. If we can identify systematic features of the data, we may improve their representativeness by post-stratifying them.

Regression techniques were used to model length frequency characteristics against available 'predictor' variables. The characters examined were mean length, standard deviation, and the fraction of male fish. We identified one important relationship: that mean length increases with depth (Figure 11).

The samples' distribution by depth was plotted relative to the fishery depth distribution (Figure 12) and suggested that the sampling was fairly representative of the fishery. Therefore, post-stratification is unlikely to much modify the results. Nevertheless we did post-stratify these data.

Post-stratification was achieved by dividing samples into three depth ranges (shallow, mid, and deep). The depth ranges were chosen by taking an overall distribution of catch by depth and splitting it into three even parts of catch (Figure 13). The depths derived for the breaks (rounded to 10 m) are 900 m and 990 m. Length frequencies were calculated for each depth range and then combined weighted by the catch weights in each depth range.

5.3 Year groups

Grouping of adjacent years was allowed in producing length frequencies for the population model. This ensured that each composite length frequency was based on sufficient length frequency samples to allow a bootstrap approach to estimating variance. A minimum of 30 samples was taken as a guideline. Combining length frequencies over a maximum period of 3 years was a balance between the rate of growth and the precision of length measurement (lengths are rounded down to the next whole centimetre). The year groups are given in Table 11 (the single sample in 1996–97 was discarded), and the year applied shown is the year in which the derived length frequency will be used to represent in the model. The guideline of 30 was easily exceeded in each year group.

The weight of smooth oreo in the sampled catches, the total fishery smooth oreo catch, and their ratio are provided in Table 11. Even in the worst case, 2002–03 to 2004–05, 6% of the fishery was sampled. In the best case (2001–02) 24% of the fishery was sampled.

Post-stratification allowed a rebalancing of the samples to reflect the fishery. An impression of the degree of rebalancing that can be obtained is possible by comparing the distribution of samples by depth range in each year group (Table 12) with the distribution of catch in each depth range in each year applied (Table 13). Examination showed (consistent with the impression from Figure 12) that little rebalancing is possible.

5.4 Bootstrap c.v.s

The above methods were used to derive the weighted, post-stratified composite length frequencies for the four year groups (Figure 14). An estimate of c.v. for each length class was obtained by bootstrap re-sampling. Data were re-sampled with replacement 1000 times and the 1000 resultant length frequencies (in each year group) were examined to extract the c.v. of each length class. Re-sampling was conducted in a tiered or nested fashion. The first tier re-sampled by tow, the second by fish in tow. A comparison of other re-sampling regimes (by tow only, by fish only) showed that most of the variability in these data occurs between tows.

5.5 An all years composite length frequency

The Deepwater Working Group requested an overall length frequency be made available for the population model. This was achieved by combining the data from 1996–97 to 2004–05 as a single year group using the same process as described above for the derivation of the four year group length frequencies. The result is shown in Figure 15.

6. DISCUSSION

The selection of important predictors in the regression models was consistent with previous oreo CPUE studies, e.g., Coburn et al. (2001), Doonan et al. (2001). Vessel, target species, and depth are consistently selected in oreo CPUE models.

This study has not exhausted all possible analyses. The observation that dropping target species from the model raised the importance of axis-position suggests an aliasing effect, but it seems likely that there may be interaction between target species and area. From Figure 5 it is clear that, at least in the early years, there was considerable interaction between orange roughy and smooth oreo fishing on Pukaki Rise. When target species was used as a predictor variable in the regression model it increased the explained variance by more than 50% of the increase due to the vessel predictor variable (the target variable had 4 parameters, and vessel had 13). This analysis ignored tows where orange roughy was the target and no smooth oreo was recorded as we analysed only tows that caught smooth oreo. In addition, the final model ignored target species as a predictor variable. Perhaps a fuller examination of all deepwater tows in the area would be worthwhile.

The atypical catch rate in the shallowest depth bin was noted by the Deepwater Working Group and this was investigated by re-running the analysis with those data excluded. This had little effect on the resultant year index. This apparent anomaly remains unexplained.

Fishers often report that extreme weather in the region is the main reason it was not explored earlier and weather is still a difficulty. It may be that weather records such as wind speed could be included usefully in future regression analyses.

Some would argue that a single vessel is ideal for CPUE analyses because such an analysis would not require standardisation. This overlooks the likelihood that the vessel may change significantly at any point in the time series, e.g., new skipper, engines, trawl gear. Unless those factors are controlled, as in a research vessel, it seems better to have a group of vessels from which such changes probably occur in a more or less random fashion. So this analysis with one dominating vessel starts at a disadvantage. For this reason the examination of alternative c.v. estimates to the jackknife were useful.

Resampling by first vessel, then tow in vessel (i.e., nested) seems best to reflect the process by which fishing occurs. So we favour this over the jackknife method (which arguably has a similar rationale) *a priori*. Additionally, given the number of records each year we find the jackknife values implausibly small in a couple of years. Coefficients of variance estimated by bootstrapping tows only are much smaller than those where re-sampling includes vessel, but those estimates really depend on tows being independent, and previous studies have shown that these analyses are typically highly heteroskedastic with respect to vessel (Coburn et al. 2006).

The steepening of the index as terms are added to the model is consistent with a notion that fishers can learn about their fishery and, over time, enhance catch rates by deploying effort in more optimal ways. In this case the modifiers include target, season, depth, and axis-position. This pattern both characterises the fishery and imparts the value of producing standardised CPUE indices. It implies that the unstandardised index is likely to underestimate decline (or overestimate a rebuild) in a fishery.

The pattern of an evolving spread of fishing suggests the fishery stabilised only in 2002–03 after a period of exploration of new ground. That corresponds with the period when raw catch rates first show a clear decline (see Table 3).

The downward trend in the CPUE index is unequivocal. Whether or not these standardised CPUE series are proportional to population abundance cannot be ascertained from this study. External information is required; a stock assessment containing other independent data should address this question.

In summary, since 1995–96 the Pukaki Rise has become an important component of the New Zealand smooth oreo catch. The fishery is spread along about 600 km of continental slope, absolute catch rates were never high relative to other smooth oreo fisheries, and standardised catch rates dropped to less than a tenth of the initial value in only 10 years. These observations suggest that the biomass of smooth oreo there has already been modified considerably, and hence that the initial population can not have been very great. It seems unlikely that catches in the fishery will increase.

7. ACKNOWLEDGMENTS

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Table 1: Catch history of smooth oreo from the Pukaki Rise fishery assessment area. Catches are rounded to the nearest 10 t.

Year	Catch	Year	Catch
1980–81	30	1993–94	0
1981–82	20	1994–95	130
1982–83	0	1995–96	1 360
1983–84	640	1996–97	1 650
1984–85	340	1997–98	1 340
1985–86	10	1998–99	1 370
1986–87	0	1999–00	2 270
1987–88	180	2000–01	2 580
1988–89	0	2001–02	2 020
1989–90	0	2002–03	1 340
1990–91	10	2003–04	1 660
1991–92	0	2004–05	1 370
1992–93	70		

Table 2: Summary of non-year variables that could be selected in the initial regression model. All were categorical variables. Df is the number of parameters estimated for that variable; –, not available (depended on the dataset).

Variable	Df	Description
Target	4	Target species, SSO, BOE, OEO, ORH, or other.
Depth	7	Depth at start of a tow. Bins were defined to contain about the same number of tows.
Season	7	The fishing year blocked into 8 periods.
Time	7	Time of day when a tow started, blocked into 8 periods.
Axis-position	7	Axis-position of start of tow, blocked into 8 bins.
Vessel	–	A parameter estimated for each vessel with at least 50 tows. Vessels with fewer than 50 tows were grouped together.
Moon	7	Moon illumination, blocked into 8 bins.
Sun	7	Altitude of the sun, blocked into 8 bins.

Table 3: Unstandardised CPUE for all tows in the assessment area that targeted or caught smooth oreo from 1980–81 to 2004–05. Catch was rounded to the nearest 10 t. Zero tows is the fraction of tows with no smooth oreo catch reported. '*' those years that were used in the standardised analyses. '–' value not available.

Fishing year	Number of tows	Number of vessels	SSO catch (t)	Mean catch per tow	Zero tows (%)	SSO target tows (%)
1980–81	6	4	0	0.3	33	83
1981–82	42	4	40	1.0	21	33
1982–83	0	0	0	–	–	–
1983–84	111	9	550	5.0	6	53
1984–85	123	4	310	2.5	0	8
1985–86	20	2	10	0.7	0	20
1986–87	0	0	0	–	–	–
1987–88	14	1	230	16.5	21	100
1988–89	1	1	0	0.1	0	0
1989–90	5	2	0	0.1	0	80
1990–91	9	5	10	1.4	0	22
1991–92	4	2	0	0.3	0	0
1992–93	14	5	50	3.6	0	7
1993–94	1	1	0	2.0	0	0
1994–95	30	6	120	4.0	3	7
1995–96*	278	9	1 170	4.2	1	6
1996–97*	402	10	1 490	3.7	1	4
1997–98*	356	10	1 190	3.4	5	10
1998–99*	377	12	1 230	3.3	7	15
1999–00*	591	9	2 070	3.5	7	37
2000–01*	651	9	2 310	3.5	8	52
2001–02*	415	7	1 920	4.6	1	9
2002–03*	533	9	1 240	2.3	5	18
2003–04*	585	9	1 520	2.6	2	13
2004–05*	712	12	1 300	1.8	5	27

Table 4: Number of tows by fishing year for vessels in the initial standardised analysis dataset. Each row is a vessel; only vessels that fished in more than one year are shown. The vessels were sorted on their year of first and last appearance. –, indicates zero tows.

Vessel	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05
1	2	60	8	–	–	–	–	–	–	–
2	1	–	–	2	–	–	–	–	–	–
3	1	11	42	9	–	–	–	–	–	–
4	22	25	–	6	45	13	–	–	–	–
5	174	255	232	188	183	142	206	251	266	311
6	1	1	1	33	202	212	105	173	73	64
7	–	1	1	–	–	–	–	–	–	–
8	–	1	5	37	138	77	33	21	–	–
9	–	45	45	–	–	–	–	–	–	27
10	–	–	1	1	–	–	–	–	–	–
11	–	–	15	31	9	–	–	–	–	–
12	–	–	–	19	2	7	–	–	6	18
13	–	–	–	–	2	89	21	22	48	5
14	–	–	–	–	1	–	–	4	18	15
15	–	–	–	–	–	3	1	–	–	–
16	–	–	–	–	–	1	–	–	–	109
17	–	–	–	–	–	107	48	58	134	104
18	–	–	–	–	–	–	–	1	1	–
19	–	–	–	–	–	–	–	–	1	19
20	–	–	–	–	–	–	–	–	38	19

Table 5: R^2 (%) values for the stepwise model selection of variables for the initial analysis. New variables were added one at a time until R^2 failed to increase by more than 1 unit. At each iteration the variable that increased R^2 the most was added. Variables considered for the regression are given in Table 2.

	Step1	Step2	Step3	Step4	Step5
Vessel	14.2	–	–	–	–
Target	13.6	18.0	–	–	–
Season	9.8	15.7	19.4	–	–
Depth	10.1	15.3	19.0	20.5	–
Axis-position	10.5	15.9	19.0	20.4	21.6
Improvement	6.3	3.8	1.4	1.1	1.1

Table 6: Comparison of different c.v.s (%) on the initial model.

Fishing year	Jackknife	Bootstrap tow	Bootstrap vessel	Bootstrap vessel, tow
1995–96	149	8	36	37
1996–97	127	8	37	37
1997–98	22	10	56	63
1998–99	24	12	29	33
1999–00	47	10	43	47
2000–01	30	10	38	44
2001–02	19	11	34	34
2002–03	8	10	34	38
2003–04	13	11	42	40
2004–05	100	10	70	69

Table 7: R^2 (%) values for the stepwise model selection of variables for the final analysis. New variables were added one at a time until R^2 failed to increase by more than 1 unit. At each iteration the variable that increased R^2 the most was added. Variables considered for the regression are given in Table 2.

	Step1	Step2	Step3	Step4
Vessel	15.2	–	–	–
Axis-position	11.3	16.9	–	–
Depth	11.8	16.6	18.3	–
Season	11.2	16.8	18.3	19.8
Improvement	5.8	1.7	1.5	1.5

Table 8: Index and c.v. from final model.

Fishing year	Index (kg/tow)	Bootstrap vessel, tow c.v. (%)
1995–96	3 339	32
1996–97	2 266	42
1997–98	1 421	42
1998–99	1 143	24
1999–00	969	27
2000–01	1 260	32
2001–02	1 247	27
2002–03	804	45
2003–04	735	83
2004–05	243	77

Table 9: Catch depth (m). '-' insufficient data to derive value.

Fishing year	Median	Interquartile	Fishing year	Median	Interquartile
1980–81	898	-	1993–94	-	-
1981–82	916	-	1994–95	918	13
1982–83	-	-	1995–96	911	62
1983–84	988	22	1996–97	909	77
1984–85	981	55	1997–98	901	111
1985–86	973	28	1998–99	896	98
1986–87	-	-	1999–00	937	171
1987–88	1093	9	2000–01	961	139
1988–89	-	-	2001–02	1008	138
1989–90	-	-	2002–03	994	115
1990–91	887	315	2003–04	933	123
1991–92	923	67	2004–05	972	158
1992–93	964	74			

Table 10: Length frequency samples from the assessment area by fishing year and source. –, no data. Also approximate estimated catch (rounded to 100 t)

Year	Catch (t)	ORMC	SOP	All	Fish measured
1983–84	600	–	–	–	
1984–85	300	–	–	–	
1985–86	–	–	–	–	
1986–87	–	–	–	–	
1987–88	200	–	–	–	
1988–89	–	–	–	–	
1989–90	–	–	–	–	
1990–91	–	–	–	–	
1991–92	–	–	–	–	
1992–93	100	–	–	–	
1993–94	–	–	–	–	
1994–95	100	–	–	–	
1995–96	1 200	–	–	–	
1996–97	1 500	–	1	1	40
1997–98	1 200	–	15	15	1 535
1998–99	1 200	64	9	73	6 747
1990–2000	2 100	5	36	41	4 470
2000–01	2 300	37	17	54	4 482
2001–02	1 900	42	22	64	6 230
2002–03	1 200	4	12	16	1 628
2003–04	1 500	–	19	19	1 619
2004–05	1 300	–	19	19	1 489
Totals		152	150	302	28 240

Table 11: Year group, year applied, and the number of length frequencies. Smooth oreo sample catch weight, fishery catch and sample catch as percentage of the fishery.

Year group	Year applied	No. of lfs	Catch sampled (t)	Fishery catch (t)	% fishery sampled
1997–98 to 1998–99	1998–99	88	350	2 420	15
1999–2000 to 2000–01	2000–01	95	770	4 380	18
2001–02	2001–02	64	460	1 920	24
2002–03 to 2004–05	2003–04	54	230	4 060	6

Table 12: Fraction of samples within year group and depth zone.

Year group	Shallow	Mid	Deep
1997–98 to 1998–99	0.4	0.5	0.1
1999–2000 to 2000–01	0.3	0.3	0.4
2001–02	0.3	0.2	0.5
2002–03 to 2004–05	0.4	0.3	0.2

Table 13: Fraction of catch in each depth zone for each year applied.

Year applied	Shallow	Mid	Deep
1998–99	0.5	0.4	0.1
2000–01	0.3	0.3	0.4
2001–02	0.2	0.2	0.6
2003–04	0.3	0.4	0.3

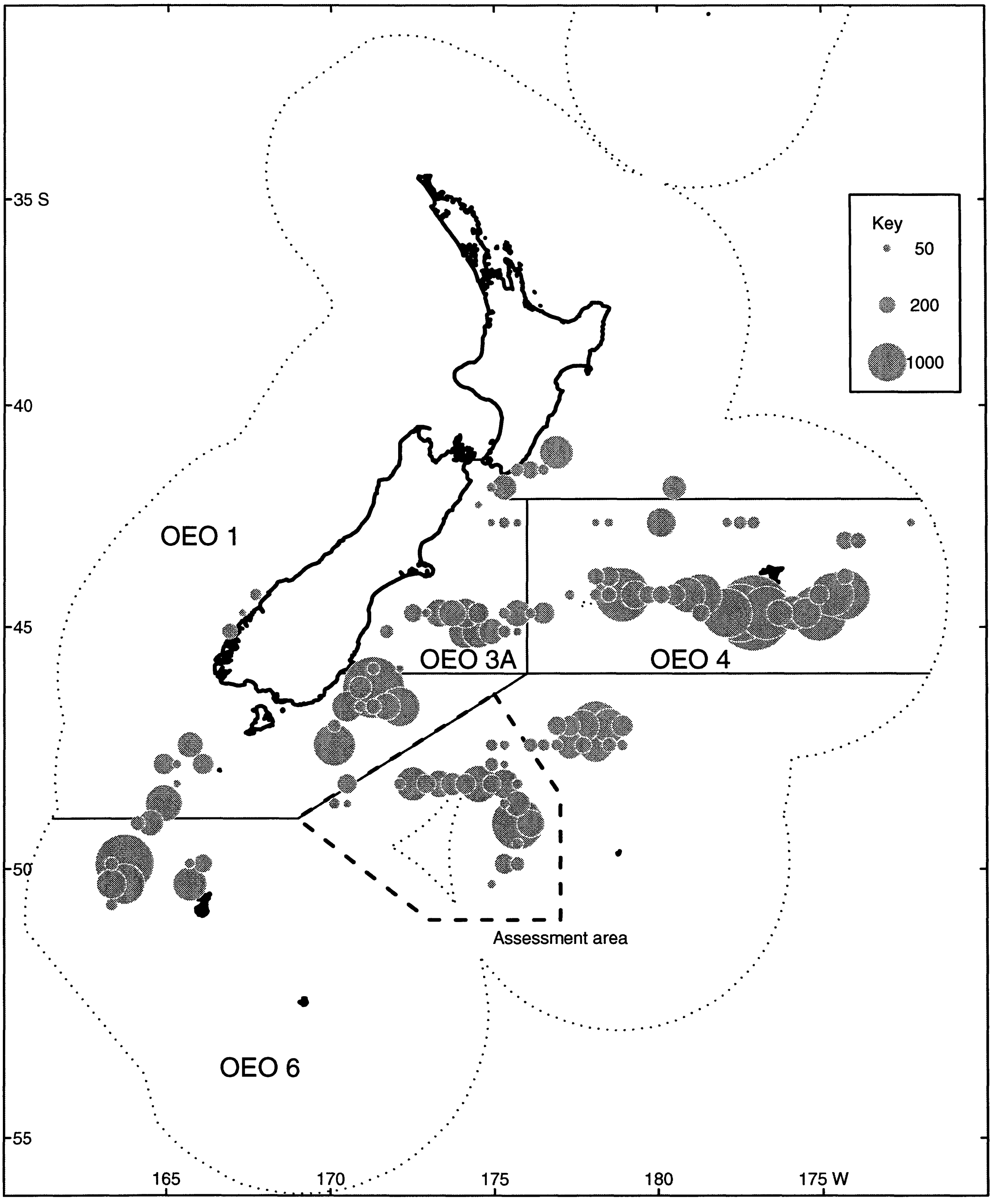

Figure 1: Smooth oreo estimated catch from 2000–01 to 2004–05. The area was divided into cells that are 0.4 degrees square and catches were summed for each cell. Circles proportional in area to the catch are plotted centreed on the cells (see key upper right). Catches less than 40 tonnes per cell are not shown. Circles are layered so smaller circles are never hidden by larger ones. The assessment area is also shown (dashed line).

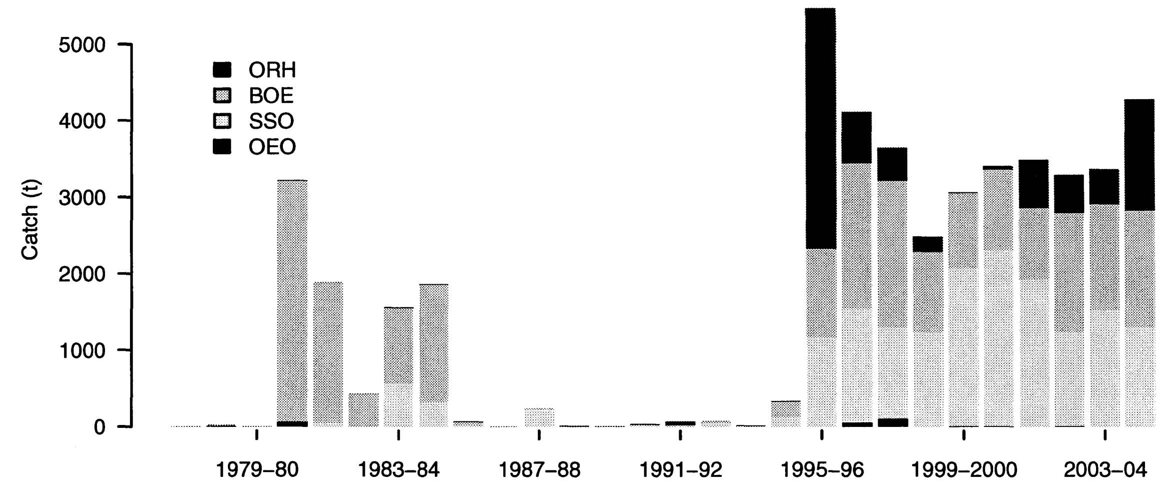

Figure 2: Smooth oreo (SSO), black oreo (BOE), unspecified oreo (OEO), and orange roughy (ORH) estimated catches by fishing year for the assessment area (see Figure 1).

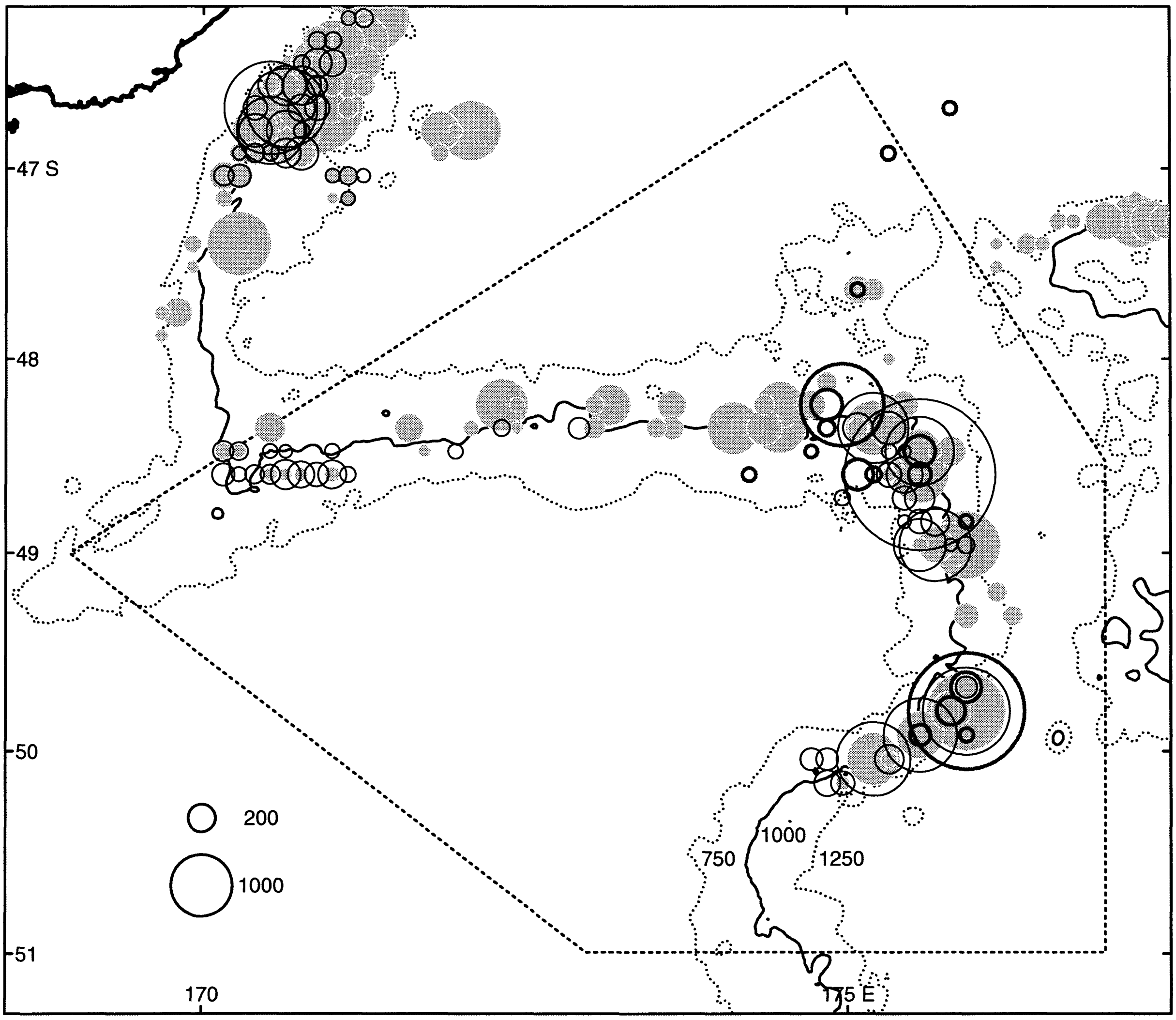

Figure 3: Smooth oreo, black oreo, and orange roughy catches from 1980–81 to 2004–05 from the assessment area and its surrounds. Cells are 0.12 by 0.12 degree (see lower left for scale). The threshold value for a cell is 40 tonnes. Smooth oreo are filled circles as described in Figure 1, black oreo are thin lined open circles, and orange roughy are thick lined circles. Depth contours in metres are shown at 750, 1000, and 1250.

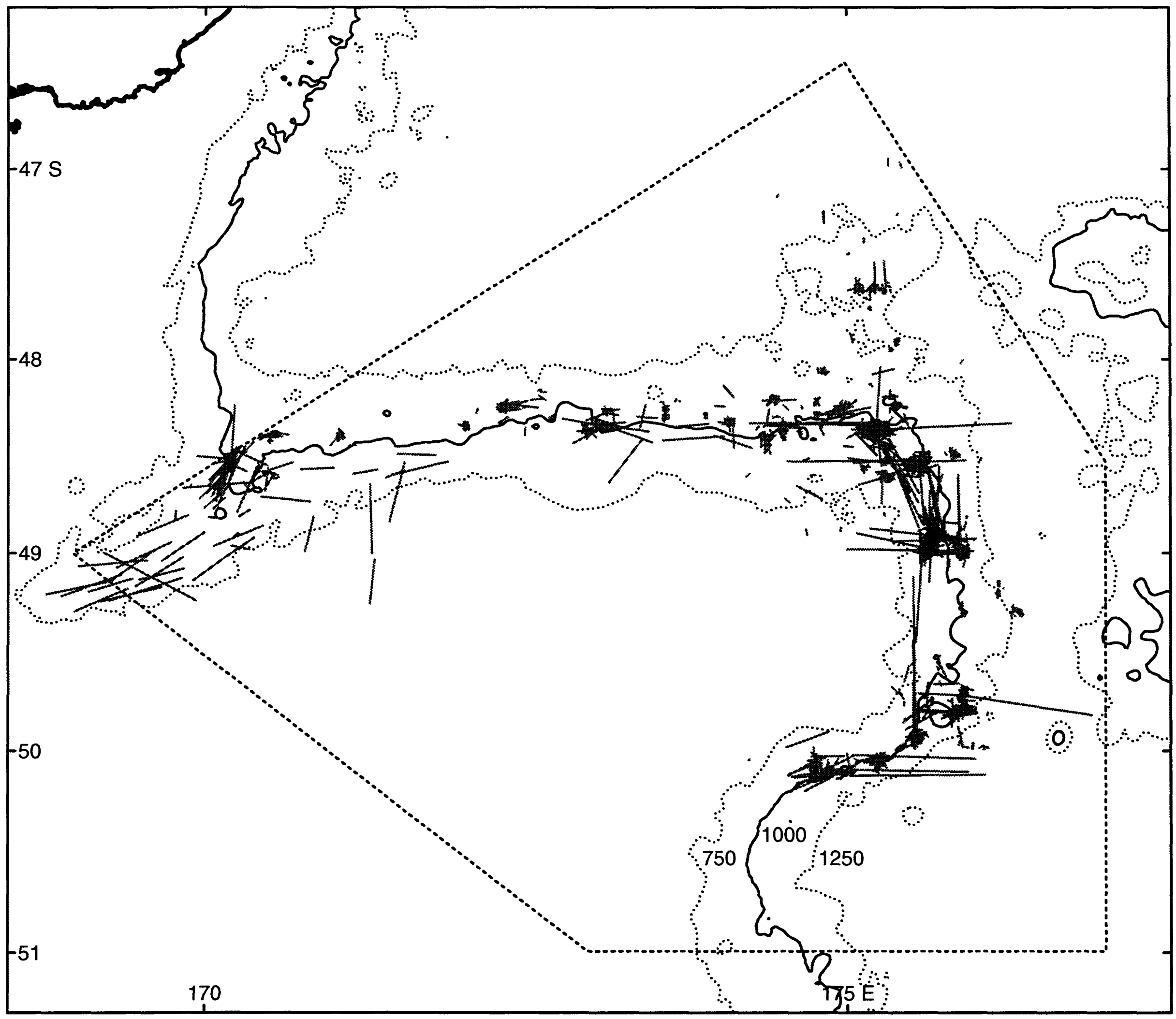

Figure 4: Tow tracks where the start position was reported inside the assessment area and where smooth oreo catch was reported caught since 1989. Start and end positions were jittered by +/- 0.5 minute. Tows where the distance from the reported start position to the end position exceeded 100 km are assumed to contain reporting errors and are not shown.

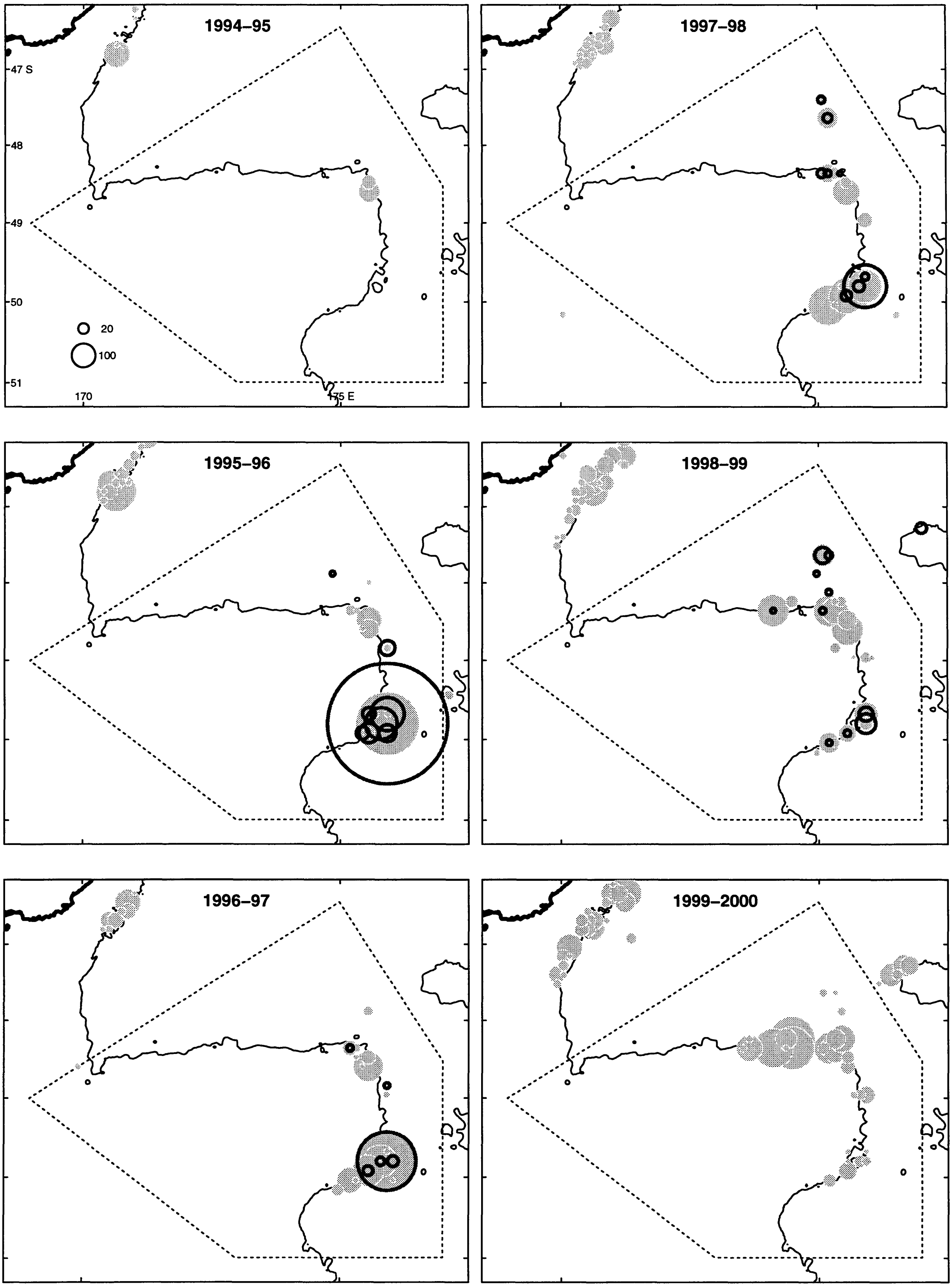

Figure 5, part 1: Smooth oreo and orange roughy catches for each fishing year from 1994–95 to 1999–2000. Cells are 0.12 by 0.12 degree (see lower left on 1994–95 for scale). The threshold value for a cell is 4 tonnes. Smooth oreo are filled circles and orange roughy are thick lined open circles. The 1000 m depth contour is shown. See Figure 3 for details, except threshold now set at 4 tonnes.

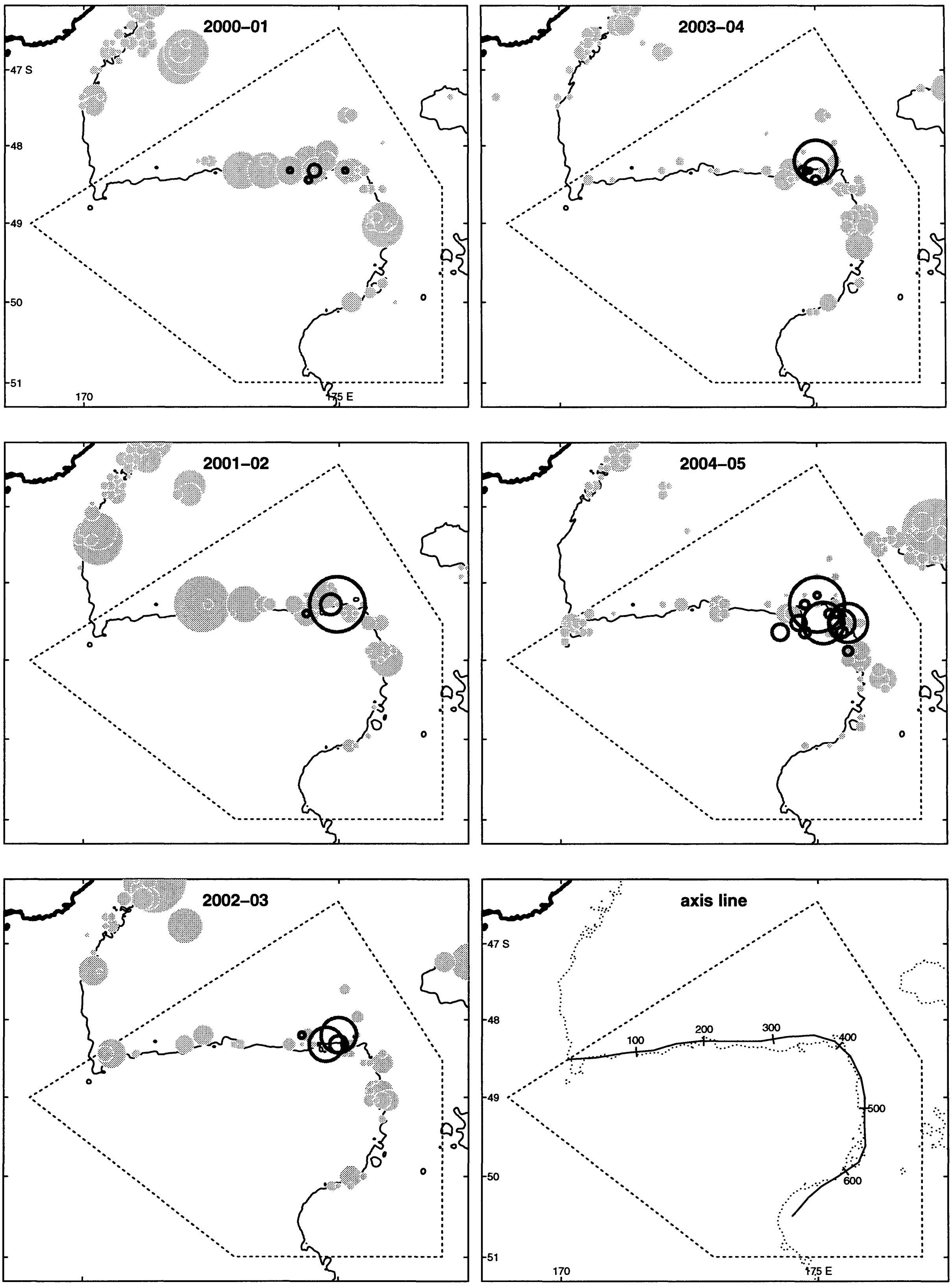

Figure 5, part 2: Smooth oreo and orange roughy catches for each fishing year from 2000–01 to 2004–05. Cells are 0.12 by 0.12 degree. The threshold value for a cell is 4 tonnes (see Figure 5, part 1 for scale). Smooth oreo are filled circles and orange roughy are thick lined open circles. Also shown (bottom right) is the axis line used to project positions onto the axis-position marked at every 100 km.

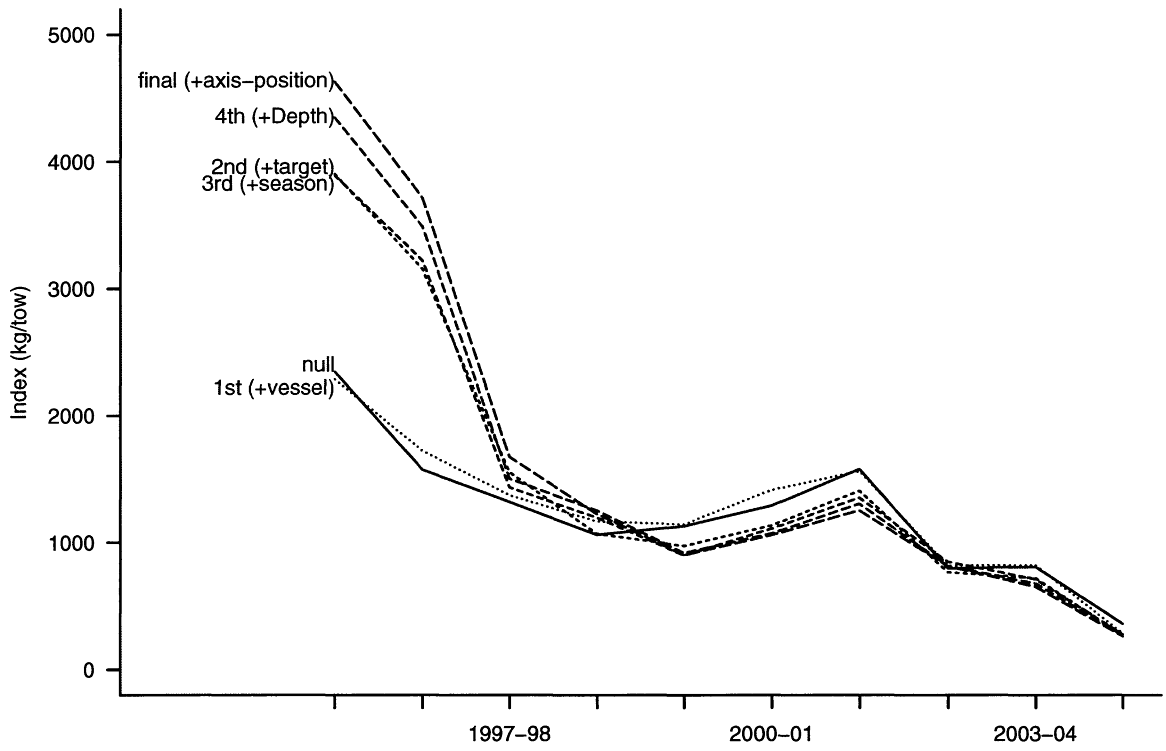

Figure 6: The indices from the standardising steps for the initial analysis. The null model index is shown with a solid line. The indices from the steps are shown with progressively longer dashes.

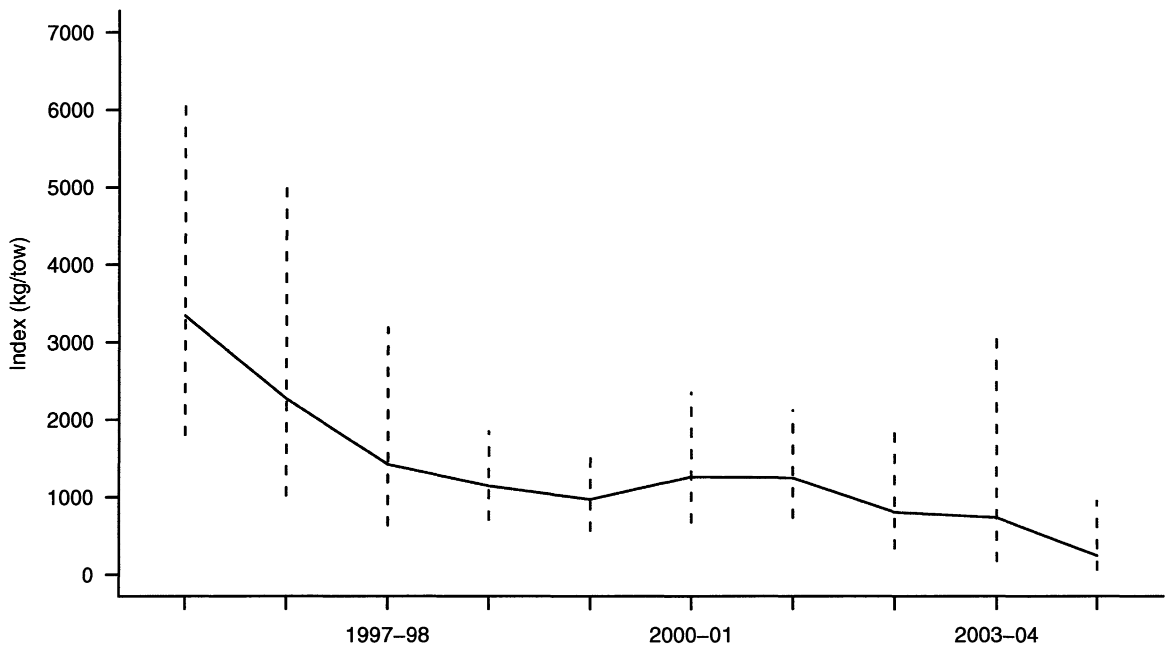

Figure 7: Final model year index with +/- 2 s.e. based on the nested bootstrap.

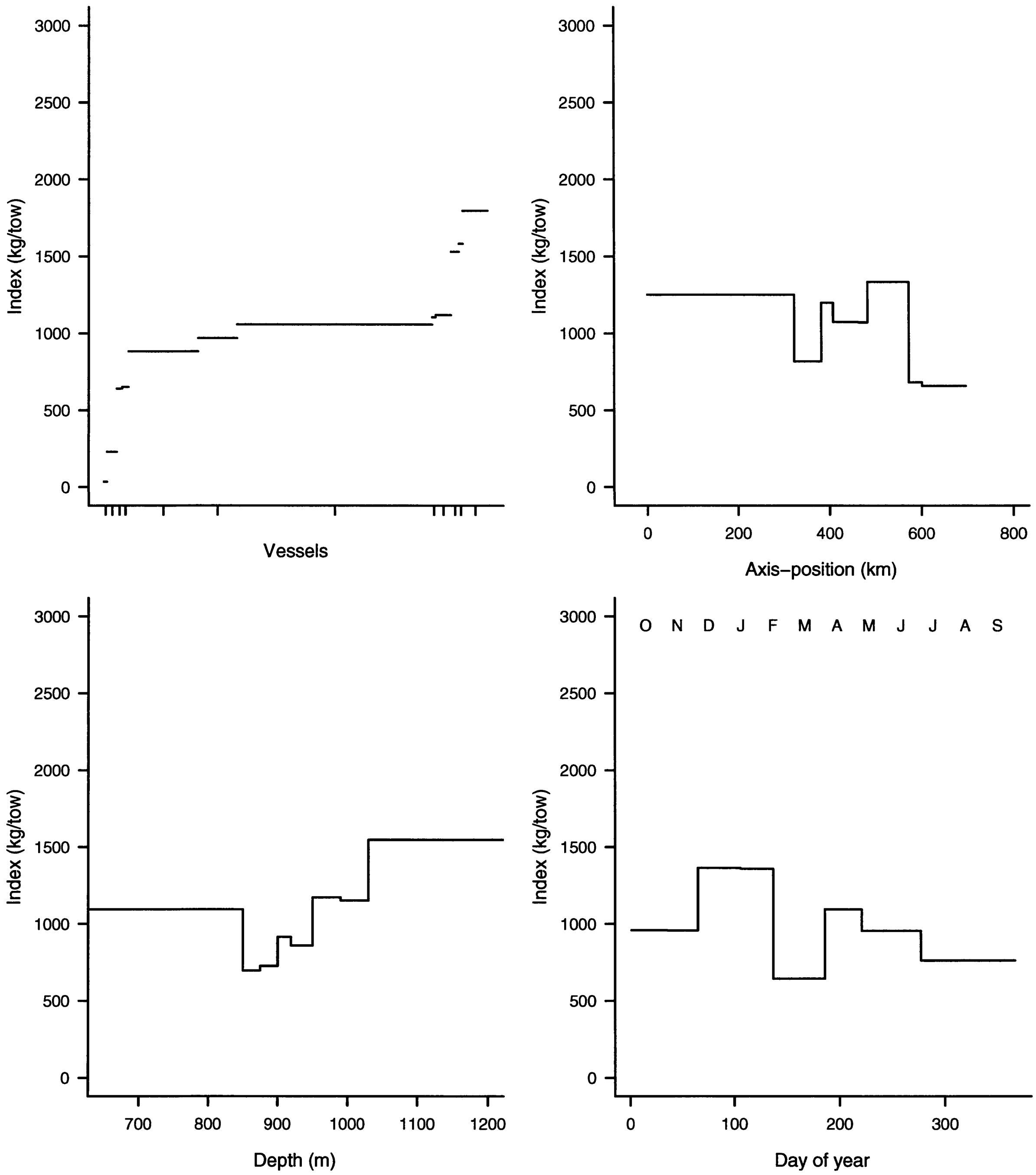

Figure 8: Non-year effects from the final model. The vessel effect: horizontal lines show the effect value for each vessel category. The width of each step is proportional to the number of records in each category. The axis-position effect: steps show the effect value at each of the eight bins. The depth effect: steps show the effect value at each of the eight bins. The season effect: steps show the effect value at each of the eight bins (0 = 1 October, months are indicated with characters at the top of the plot).

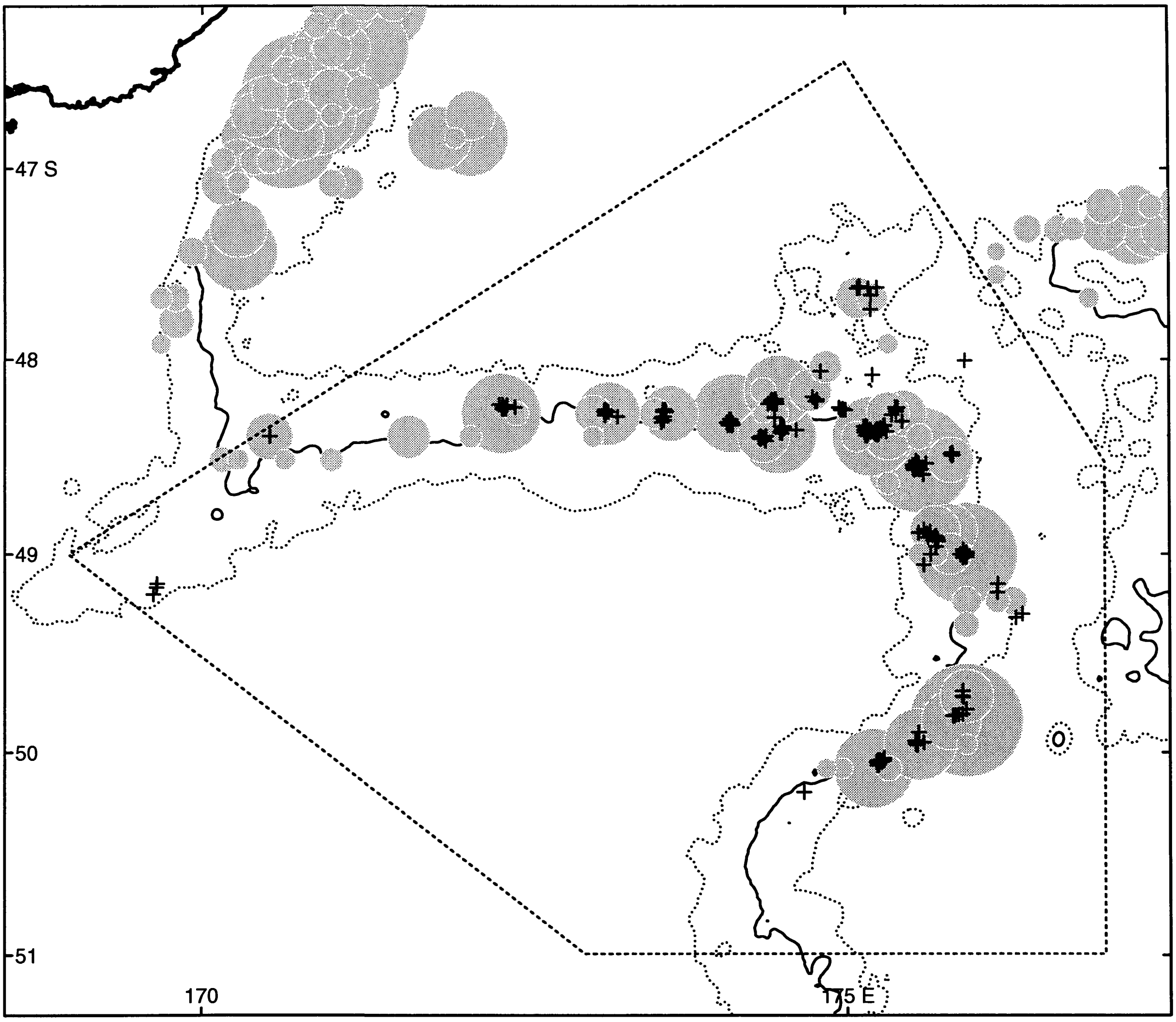

Figure 9: Pukaki Rise smooth oreo fishery catches from 1983-84 to 2004-05 binned as per Figure 1. Locations of observer length frequency samples are shown with crosses. Depth contours at 750, 1000, and 1250 m are shown.

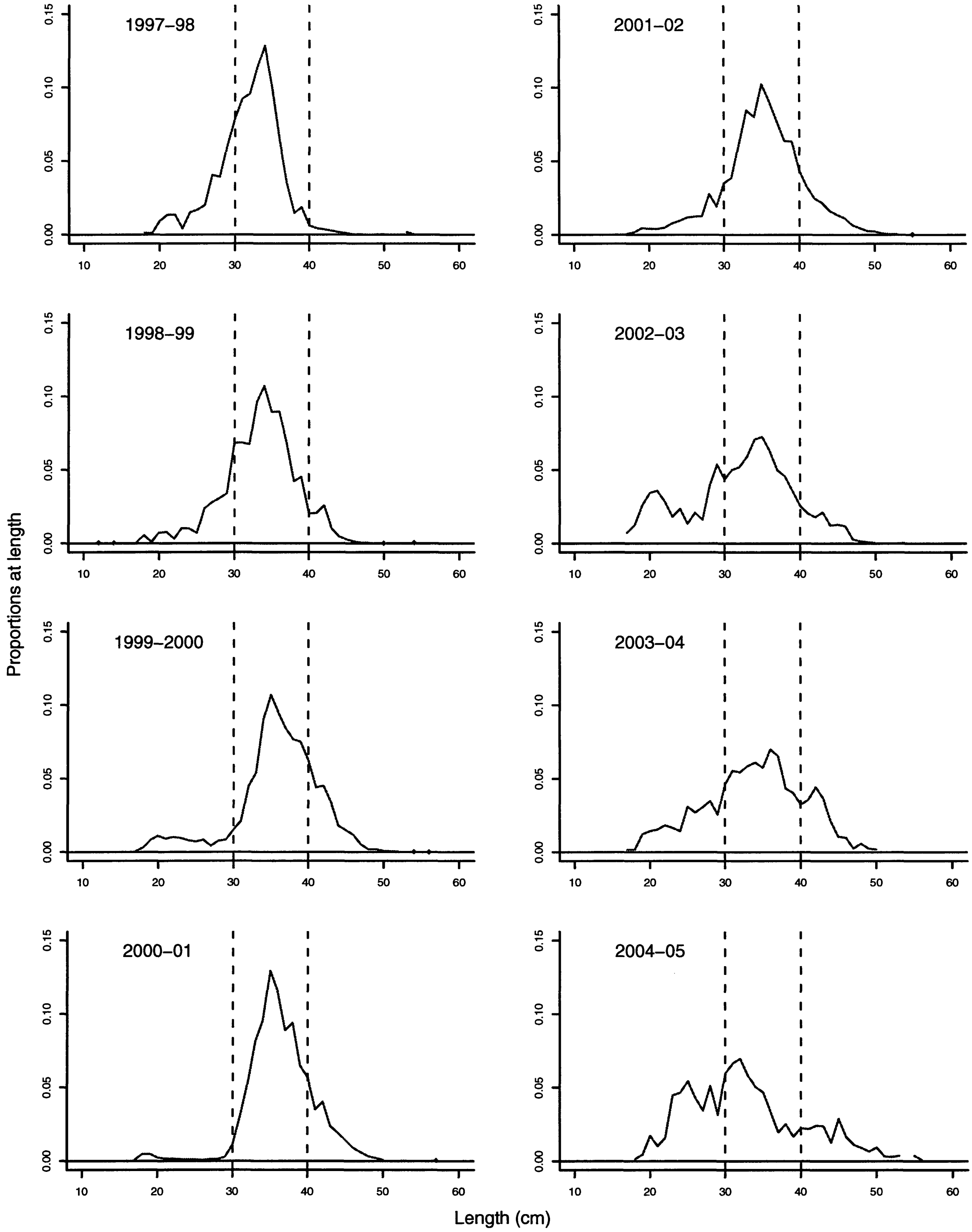

Figure 10: Smooth oreo catch weighted composite length frequencies by fishing year (not post-stratified).

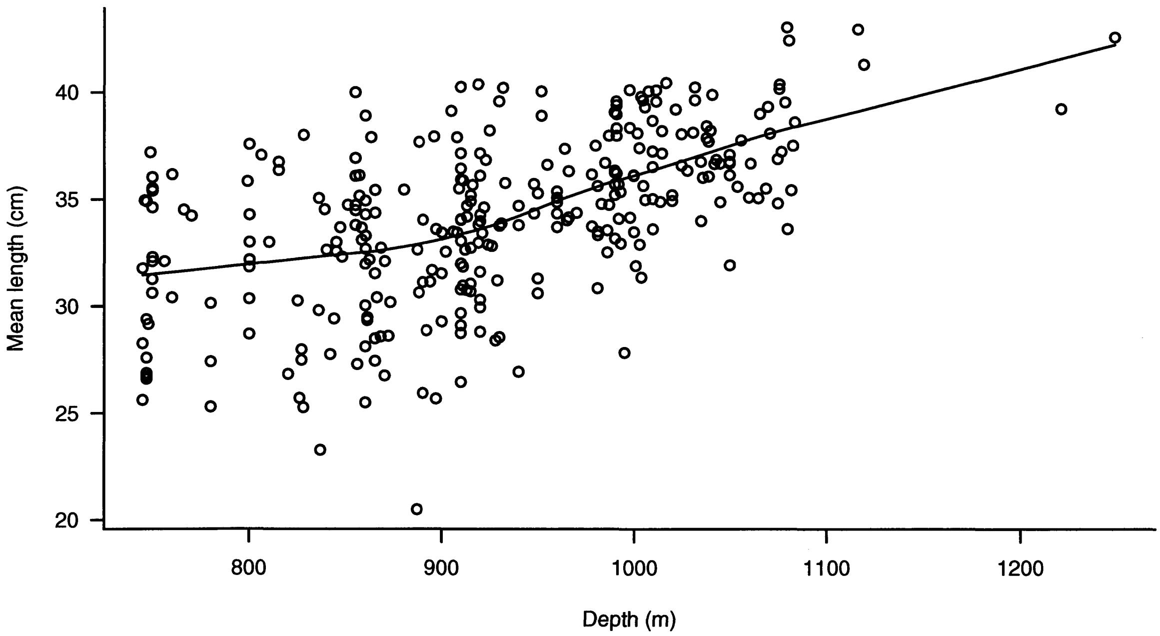

Figure 11: Smooth oreo mean length versus bottom depth. The solid line is a local regression fit. Each point is the mean length of fish in an observer length frequency sample.

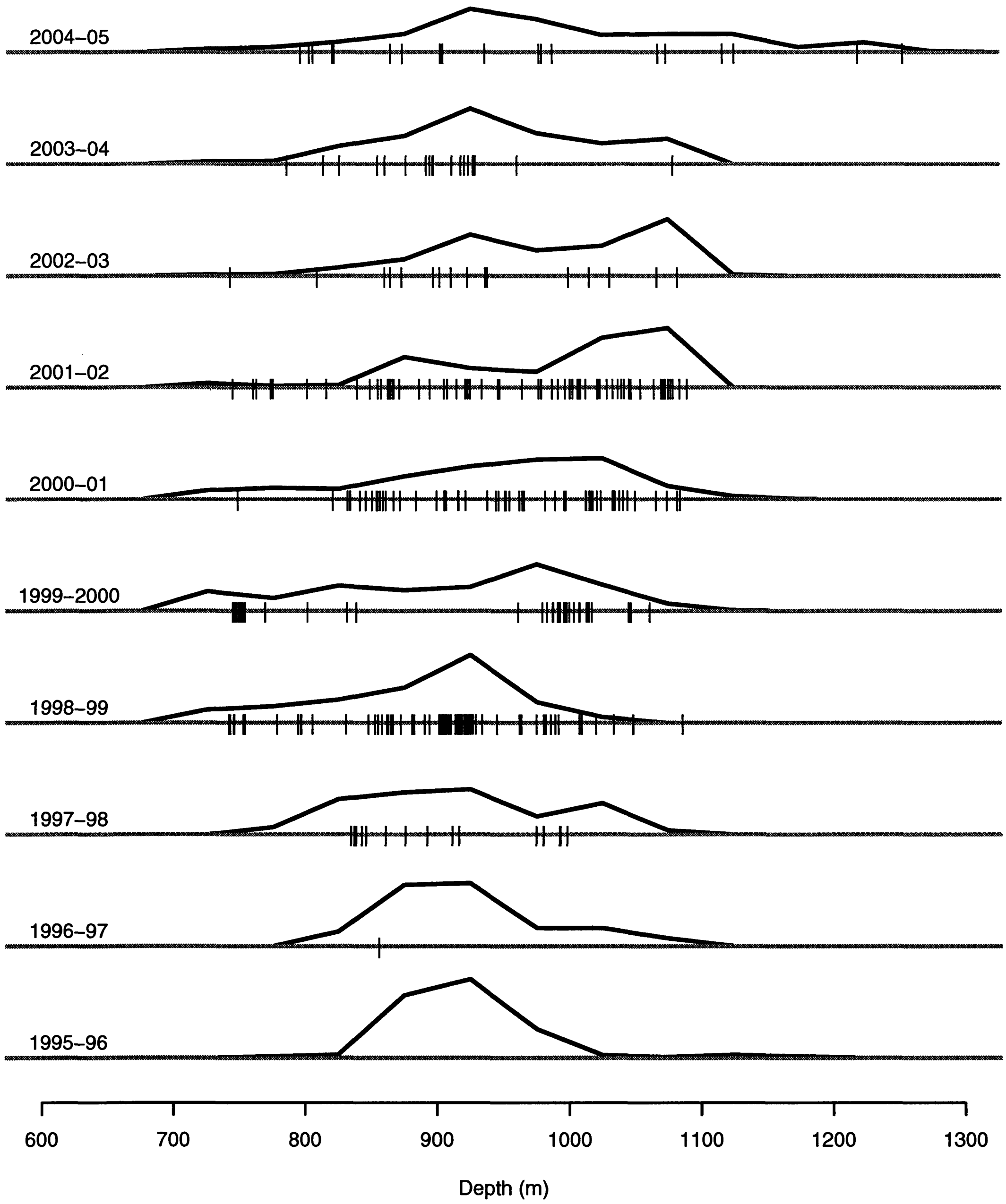

Figure 12: Smooth oreo catch distribution by depth for years 1995–96 to 2004–05 (solid horizontal line), with the length frequency sample distribution shown as vertical dashes.

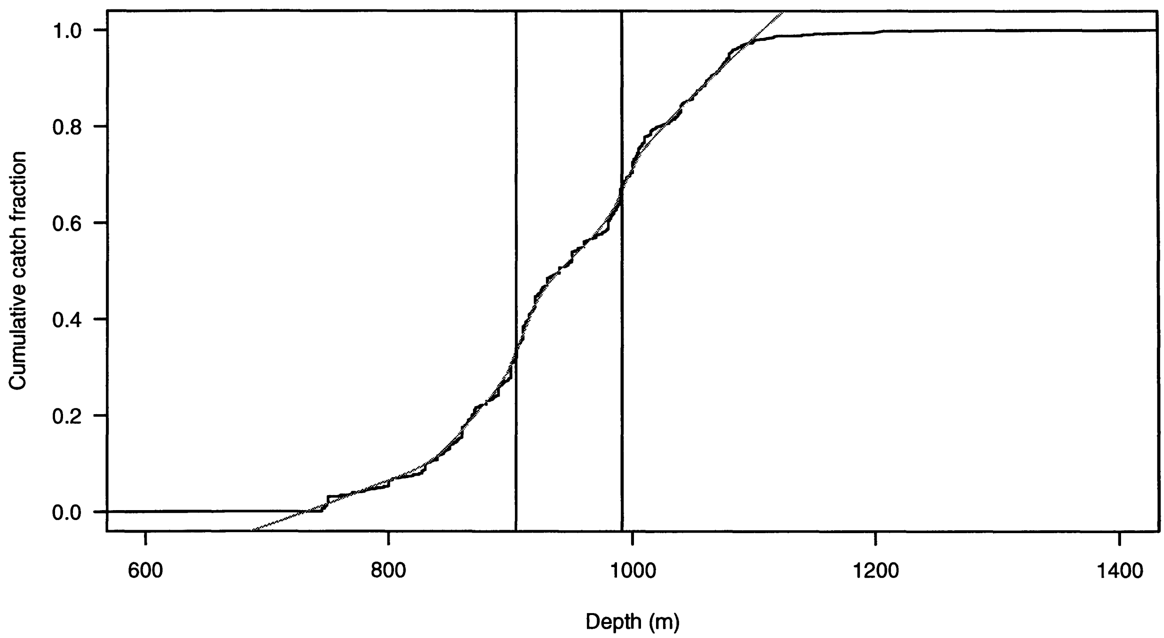

Figure 13: Cumulative catch curve for length frequency post-stratafication (see Section 5.2). The vertical lines divide the catch into three equal parts.

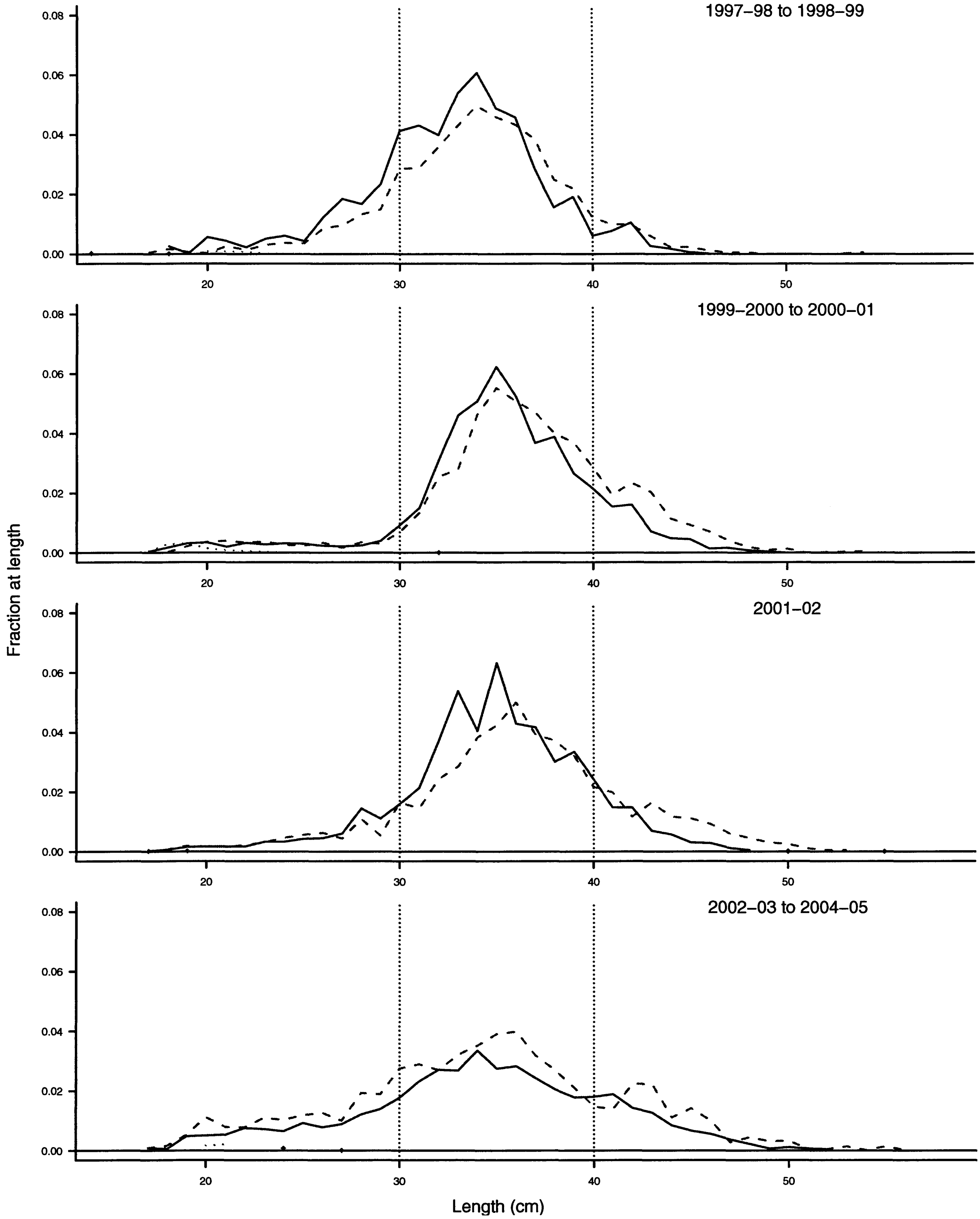

Figure 14: Smooth oreo post-stratified length frequencies by year groups (males solid line, females dashed line).

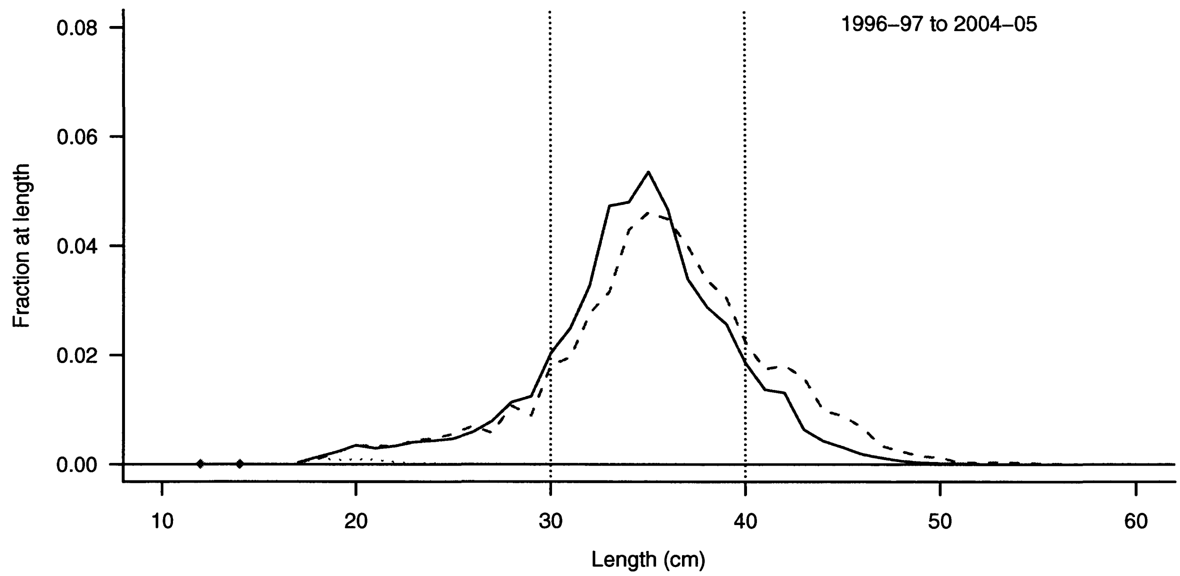

Figure 15: Smooth oreo post-stratified length frequencies combining all years, (males solid line, females dashed line).