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EXECUTIVE SUMMARY

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The first stock assessment for the Southland smooth oreo fishery is presented. This is an old fishery with catch and effort data available from 1977–78 and mean annual catches of about 1000 t of smooth oreo. The stock assessment used a CASAL population model analysis. Two fisheries were modelled: an early fishery (before 1989–90) that was mainly Soviet and a late fishery (1989–90 on) consisting mainly of New Zealand vessels. There were no fishery-independent abundance estimates, so relative abundance estimates from pre- and post-GPS standardised CPUE analyses and length frequency data collected by MFish (SOP) and Orange Roughy Management Company (ORMC) observers were used in the assessment. Pre-GPS standardised CPUE showed a steep decline but the post-GPS standardised CPUE had a more gradual decline. The base case model run used the SOP length data because the ORMC length data was biased towards large fish.

The estimated median mature virgin biomass from the base case was 15 900 t (13 800–20 700 t for the 90% confidence interval). The long-term MCY estimate for the base case was 310 t. Biomass projections 5 and 10 years into the future suggest that annual catch levels of less than 400 t would be required to provide at least 50% probability of increasing the mature biomass. The base case analysis indicates that annual catches of about 1000 t (1998–99 to 2000–01) are unsustainable.

Conclusions from the assessment were as follows.

1. The Southland smooth oreo fishery is based on a small stock and recent catches may be unsustainable.
2. The length data for this fishery came from two sources, but only the SOP length data were acceptable for use in the stock assessment analyses and consequently the structure of all smooth oreo length data collected should be investigated for bias before they are used.
3. The stock assessment was sensitive to the error structure of the length data.
4. Direct ageing of samples collected from the fishery would eliminate the problem with length bias, but only if sampling for age is random.

1. INTRODUCTION

1.1 Objectives

This work addresses the following objectives in MFish project OEO2001/02, Oreo stock assessment.

Overall objective

1 To carry out a stock assessment of black oreo and smooth oreo, including estimating biomass and sustainable yields.

Specific objective

5 To carry out stock assessments of the following oreo fisheries: Southland (OEO 1 and 3A) black oreo, Southland (OEO 1 and 3A) smooth oreo, Pukaki Rise east (OEO 6) black oreo, Pukaki Rise east (OEO 6) smooth oreo, Bounty Plateau (OEO 6) smooth oreo.

1.2 Overview

This, the first stock assessment of the Southland smooth oreo fishery aimed to provide preliminary biomass estimates for the stock. No research surveys have been conducted in the area so data for this assessment were limited to fishery-dependent sources, i.e., catch per unit effort (CPUE), and length frequencies from observers including the MFish scientific observer programme (SOP) and recently from the fishing industry through the Orange Roughy Management Company (ORMC). Previous studies of the Southland fishery included a general description of the catch and effort data for black oreo and smooth oreo in this area over time (McMillan et al. 2002) and a CPUE study (Coburn et al. 2002) that provided more detailed description of the fishery for smooth oreo plus unstandardised and standardised CPUE analyses. That report demonstrated that there were sufficient good quality CPUE data for standardised CPUE analyses.

1.3 TACCs and catch data

The fishery off the Otago-Southland coast from about 45 to 48° S and from 169 to 172° E is referred to as the Southland oreo fishery (Figure 1). This is one of the oldest deepwater fisheries in New Zealand with oreo catches reported since 1978–79, (Table 1). Although it straddles the OEO 1 and OEO 3A boundaries it is mainly in OEO 1. It is smaller than the Chatham Rise fisheries (Annala et al. 2002), with mean annual catches for smooth oreo of less than 1000 t. Catches were variable in many years and don't appear to have been constrained by the OEO 1 TAC. Catches of smooth oreo from 1990–91 to 2001–01 (excluding 1991–92) were 456–1759 t. Other fisheries in OEO 1 developed later and include: Puysegur (mainly 1989–90 to 1994–95) and Snares (1990–91 on) (McMillan et al. 2002). A TAC of 4000 t was introduced for OEO 1 in 1986–87 and increased to 5033 in 1989 and then to 6044 t in 1992–93 under the "Adaptive Management Programme" (AMP) to encourage exploration of new areas. It returned to 5033 t in 1998–99 when the AMP was cancelled (Annala et al. 2002).

2. ASSESSMENT MODEL

2.1 Population dynamics

2.1.1 Partition of the population

The population model was age-based and also accounted for the sex and maturity of the fish. The partition is therefore age by sex by maturity. A new maturity ogive was used and was estimated from Chatham Rise research samples (Doonan et al. 2003). The depth distribution of catch was very different between the pre-GPS and post-GPS periods (see Figure 6), so the CPUE indices required different selectivity values because depth affects length and therefore the age distribution of the catch. A two-fishery model was employed by defining and analysing an early fishery, up to and including 1988–89, and a late fishery from 1989–90 onwards. An alternative method to deal with the different selectivity values would have been to analyse a shallow and a deep fishery with shallow and deep standardised CPUE. This would have required assumed rates of movement of fish between the shallow and deep fisheries. The early and late fishery approach was used as it appeared to be more straightforward.

2.1.2 Annual cycle

The model used an annual cycle with a single time step during which the following processes occurred: ageing, recruitment, maturation, natural mortality. The mature biomass was estimated in the middle of mortality.

2.2 Selectivities, ogives, assumptions

Recruitment was determined from the mature biomass with a Beverton & Holt relationship with steepness of 0.75. The length frequency data were fitted as proportion-at-age by sex derived by a logistic selectivity curve for each fishery with errors assumed to be log-normally distributed. The CPUE indices were fitted as relative indices of abundance with a logistic selectivity ogive for each fishery with errors assumed to be log-normally distributed. Catchability coefficients (q) for each CPUE relative abundance series were fitted as nuisance parameters. An exploitation constraint was applied to catches causing the objective function to be penalised if the model had insufficient fish to provide the reported catch history. The catch history entered the model as control data, i.e., they were taken as known.

Priors on selectivity parameters were uniform. The 50% value, a, ranged from 1 to 50, and the 95% value, b, from 0.1 to 35, expressed as ages (years). The age at which 95% of the population was selected was a + b. Doonan et al. (1997) estimated a knife-edge value of 50% selection as 21 years based on length frequency data from the Chatham Rise and Puysegur Bank fisheries. Catchability coefficients were given uniform priors from 1.0×10^{-8} to 1.0×10^{8}. The priors gave a very wide range around plausible values and were uninformative.

Smooth oreo catches had a positive relationship between depth and size (see Figure 5), i.e., larger fish were more prevalent in deeper water, so it was reasonable to expect that the late fishery would have a greater selectivity than the early fishery. This matched the observed CPUE trends because the decline in CPUE for the pre-GPS fishery was large and reflected the fishing-down of a part of the larger selected population of the post-GPS fishery.

A difficulty in the analysis was the lack of information about the selectivity of the early fishery due to the lack of length frequency samples: there were only three samples, all from deep tows (see Table 11). These were deemed insufficient to usefully inform the model and the modelling confirmed this. But in the absence of length data the model used the CPUE indices resulting in an unrealistically high selectivity value (50% at 35.5 cm), which essentially meant the pre-GPS CPUE was providing no information to the model and was therefore of little value.

The approach adopted to solve this problem was to simulate a length frequency for the early fishery using the data from the late fishery. The simulated length frequency combined the shallow and deep length frequencies using the fraction of catch from the shallow and deep parts of the early fishery (before 1989–90). The length data from the late fishery came from 1998–99 to 2000–01 and the date for the simulated length frequency was taken to be 1999–2000 and was assigned a nominal 10 t catch. The simulated length frequency enabled estimates of the selectivity of the early fishery to be made.

The following assumptions were made in this analysis.

1. The CPUE analysis indexed the abundance of smooth oreo in the study area (Figure 2) of OEO 1/3A.
2. The length frequency samples were representative of the population being fished.
3. The ranges used for the biological values covered their true values.
4. Recruitment was deterministic and followed a Beverton & Holt relationship with steepness of 0.75.
5. The population of smooth oreo in the study area was a discrete stock or production unit.
6. Catch overruns were 0% during the period of reported catch.
7. The catch histories were accurate.
8. The maximum fishing pressure U_{max} was 0.58.

2.3 Modelling methods, parameters, assumptions about parameters

The stock assessment analyses were conducted using CASAL (Bull et al. 2002). This was implemented as an age-structured population model that took account of the sex and maturity status of the fish and allowed inclusion of length frequency data. The Bayes estimator was employed. The population parameters used (Table 2) were mostly from Doonan et al. (1997) and were estimated from fish sampled on the Chatham Rise and Puysegur Bank fisheries.

3 OBSERVATIONS AND MODEL INPUTS

3.1 Catch history

A catch history was derived using declared catches of OEO from OEO 1 (Table 1) and tow-by-tow records of catch from the study area (Figure 2). The tow-by-tow data were used to estimate the species ratio (SSO/BOE) and therefore the SSO taken. It was assumed that the reported landings 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 is uncertainty about the actual SSO catch in the early years as little catch then was reported by species. There may be unreported catch from before records started, 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 figure 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 3.

3.2 Relative abundance estimates from CPUE analyses

Analyses of unstandardised CPUE were used to describe the fishery, to assess the quantity and quality of the data available for standardised CPUE analysis, and to define the study area to be used for the standardised analysis. The composition of the vessel fleet over time, and therefore continuity of the CPUE data, was analysed using a year-cross analysis. Data links between years were established where a vessel made at least 10 tows in each of the paired years. This gave the number of vessels that linked each pair of years across the dataset. Standardised CPUE indices were performed to provide indices that were assumed to index relative abundance of smooth oreo. The methods used for the CPUE analyses in the present study are largely the same as those used by McMillan et al. (2002) and Coburn et al. (2002). The changes include, first an extra year's data from the 2000–01 fishing year. The second change was that the study area (described below) was changed slightly from that used previously to achieve a more homogeneous and consistent time series of CPUE data over time. The third difference was a technical change in the way the year indices were derived from the standardised CPUE model and is described more fully below.

Study area

Boundary lines for the Southland smooth oreo fishery were determined after analysis of the unstandardised catch and CPUE data and resulted in a study area (Figure 2) that was modified from the previous CPUE study (figure 2 in Coburn et al. 2002). The Waitaki Canyon area data were excluded from the present analyses because although it is spatially contiguous with the rest of the Southland fishery, the catch history (figure 4 in Coburn et al. 2002) showed that it was dominated by one year. The fishery began in 1991–92 and was driven by the presence of a small orange roughy population, with the oreo being taken as bycatch. The remaining Southland fishery was a target oreo fishery and it seemed likely that the Southland stock assessment would be influenced by the single year of large catches from Waitaki, i.e., affecting both catch history and CPUE. After 1991–92 the Waitaki region was only lightly fished, and the spatial distribution of the oreo catch was similar to that before 1991–92. An area of recent fishing at about 47° S, 172° E was also excluded because it is spatially separated from the Southland fishery by about 30 nautical miles and because length frequency samples showed that fish from that area were generally much larger than those from the study area. This suggests limited mixing between these areas, hence including it could compromise this stock assessment.

Data

All data were grouped by fishing year, i.e., 1 October to 30 September. 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. Initially, data from all tows that targeted or caught oreo (SSO, BOE, or OEO) were considered. The data were restricted to the study area (Figure 2). 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.

Unstandardised CPUE analyses

Analyses of numbers of vessels, number of tows, catches, mean catch per tow, and fraction of zero tows per year were carried out along with plots of location of tows and the spatial pattern of catch by species and year following the methods previously described by McMillan et al. (2002) and Coburn et al. (2002). Tows where smooth oreo, black oreo, or unspecified oreos were targeted or caught from 1977–78 to 2000–01 were plotted in Figure 1 and show the discrete Southland fishery separated from the west Chatham Rise oreo fishery to the north (OEO 3A) and the Pukaki Rise fishery to the southeast (OEO 6). Revised unstandardised mean catch per tow was higher in 2000–01 than in the previous four years (Table 4). Tow-by-tow oreo catch was not generally reported by species in the first four years of the series, so care is needed interpreting those rows of the table. The year-cross analysis (Table 5) showed that there were two sets of linked years with almost no continuity across the whole time period. The first set was from 1983–84 to 1988–89 and the second was from 1989–90 to 2000–01.

Standardised CPUE analyses

The standardised CPUE analyses were performed as described by Coburn et al. (2002) and used a two part model which separately analysed the tows which caught smooth oreo using a log-linear regression (referred to as the positive catch regression) and a binomial part which used a Generalised Linear Model with a logit link for the proportion of successful tows (referred to as the zero catch regression). The binomial part used all the tows, but considered only whether or not the species was caught and not the amount caught. The yearly indices from the two parts of the analysis (positive catch index and zero catch index) were multiplied together to give a combined index (after Vignaux 1994). The pre-GPS data covered the years from 1983–84 to 1987–88 and the post-GPS data covered 1992–93 to 2000–01.

Predictor variables in the regressions were all designated as categorical (Table 6). Numeric variables, e.g., depth, were converted into categorical variables by splitting the range into eight bins. Eight bins were chosen as sufficient to model any dependencies in the data (without prejudice as to the shape of any dependency) while ensuring that the resultant models were not over-parameterised. Bin widths were chosen to ensure that tow numbers in each bin were similar. Vessel entered as a categorical variable, except that vessels with fewer than 50 tows over the whole time period were all lumped into the same category. Tow position was reduced to a single predictor variable termed axis-position by projecting the start position of the tow on to an axis line drawn approximately northeast southwest through the fishery.

Data were excluded for any year where a single vessel caught 80% or more of the smooth oreo catch in that year, or where there were fewer than 50 catches of smooth oreo from all vessels fishing in that year. Separate analyses were performed on data from pre- and post-GPS periods to avoid problems of increased catch rates caused by the introduction and adoption of GPS demonstrated for OEO 4 smooth oreo by Coburn et al. (2001). Data from 1989–90 to 1991–92 were therefore discarded.

Plots of the smooth oreo combined indices where the data from one vessel at a time were dropped from the regression analyses showed that in the pre-GPS period no single vessel influenced the resulting trend (Figure 3). In the post-GPS, period the removal of one vessel made a big difference to the index in 1993–94 and 1995–96 (Figure 4). These effects produced high c.v. estimates in those years (see Table 10).

Deriving the annual index values

A new method for obtaining the annual index values was used that was intuitive and removed the arbitrary choice of reference year that our previous method required (for example see Coburn et al. 2002). The standardised CPUE model provides a series of annual index values that are used in the stock assessment as an index of abundance. Two methods currently used to calculate the index values (Vignaux 1994 and Francis 2001) were examined and a third approach was proposed and adopted.

This change is of purely technical interest in this study because it does not materially affect the derived index series that go into the stock assessment. The index series from the positive catch model is identical to that from the method used by Vignaux (1994): for the zero catch model, the index series is similar to the set of series that are created by varying the arbitrary choice of reference year.

The regression model allows prediction of the response variable, i.e., it predicts CPUE for any set of values of the predictors. Therefore, if the true year in the predictor data is replaced with year X in each observation, the regression model will predict CPUE for each observation as if it were made in year X. In other words, the observations are standardised to year X. The new method was to simply take the mean of these standardised predicted values as the index for year X. The resultant series is the mean CPUE, standardised with respect to year. The same method was applied to both the positive catch and zero catch models.

Advantages of this method compared to Vignaux (1994) include its intuitive description, ease of use, and straightforward extension to models involving a year interaction term. It provides a unique index independent of arbitrary choice of reference year and the index is expressed in the units of the CPUE data allowing possible comparison across analyses; in this case, for example, between the pre- and post-GPS analyses.

Jackknife c.v. estimates were made for the standardised CPUE indices using the method described by Doonan et al. (1995) except that the annual index values were calculated as above rather than with a specified reference year. A result of this change was that each year now has an estimated c.v. which can be passed directly into the stock assessment model. The previous method had a c.v. value of zero on the reference year and further manipulation was required to provide c.v.s for the stock assessment model.

The pre-GPS and post-GPS regression model results are given in Tables 7 and 8 and the indices and jackknife c.v. results in Tables 9 and 10. The pre-GPS combined indices showed a steep decline over time, although the post-GPS indices were more variable but overall showed a slight decline.

3.3 Length data analyses

The CASAL population model allowed a series of length-sex data to be fitted in the model assigned to a specific year and fishery. Smooth oreo length frequency data were obtained from the obs_lfs database maintained by NIWA, Greta Point (Sanders & Mackay 2001), and examined to determine if they were of sufficient quality and quantity to be used in the stock assessment.

Before the length frequency data were incorporated into the stock assessment model they were re-stratified by depth and weighted by the sample catch. The variability of the length data was expressed as c.v.s by length class derived from a linear regression of log c.v. (bootstrap c.v. values from the 1999–2000 length data) versus proportion at length. In the modelling, process error was always applied to all the length frequency inputs to the extent that the residuals became approximately standardised normal (see Francis 2003). Because process error was large relative to the above bootstrap derived c.v.s, the precise derivation of the latter was not critical.

The spatial distribution of samples where smooth oreo was measured approximately reflected the fishery catch (see Figure 2), but samples were mostly from just the last three years, 1998–99 to 2000–01 (Table 11). None of the earlier years reached the nominal threshold of five samples per year that was applied to another oreo assessment analysis (Hicks et al. 2002).

Initial examination of the combined SOP and ORMC data showed that the 2000–01 mean length increased by about 10 cm from the 1999–2000 value (Table 12) and that this could not be explained by spatial or depth differences in the sampling. Further investigation showed that length samples collected by ORMC observers from one vessel (vessel X) for 2000–01 appeared to be biased upwards. Data collected by ORMC observers on that vessel were eliminated from the analysis, because they were irreconcilable with the other data. A few samples from vessel X collected by SOP observers were retained.

Further exploratory data analysis showed that mean length approximated a step function with depth (Figure 5) and this was used to re-stratify the sample length frequencies to the catch. This was important because there was a major change in the distribution of catch with respect to depth over time (Figure 6). In the 1980s, nearly all the catch was taken in deep water, but in the 1990s the catch was split between deep and shallow water. The depth (to re-stratify) was the value that gave the highest R^2 estimate for a single step function fitted to mean length and depth. This value was 975 m, so the shallow stratum was defined as depths less than 975 m and the deep stratum as depths greater than or equal to 975 m.

In contrast to the SOP data, the ORMC data showed no differences in mean length with depth (Figure 7). There was a distinct gap of 1–2 cm between the SOP and ORMC mean length data from less than 1000 m. The gap appears to be due to about half the ORMC samples having means at the extreme high limit of the SOP means. For a slow growing species like smooth oreo this gap is a biologically significant difference. Therefore the ORMC length data are biased relative to the SOP data and consequently the two sets of length data were separated and only one of the sets was used in each model run. The SOP length data were chosen for the base case analysis because they appeared to be consistent with research length data. SOP length data have been collected since about 1985–86 and have not been shown to be biased.

3.4 Biological data

Biological parameters are given in Table 2.

3.5 Development of base case

There were two SOP length data only models and two ORMC length data only models reported. All except ORMC 2 were modelled as two fisheries, early and late. ORMC 2 was modelled as a single fishery and no length frequency data were applied to the early fishery because there was no strong evidence of a mean length-depth relationship from the ORMC samples, and therefore no reason to re-stratify the data. The data sources for the model runs are given in Table 13. Estimated model parameters and priors are given in Table 14.

3.6 Projections

The model was used to project stock status into the future using stochastic recruitment. Biomass projections for 5 and 10 years into the future were made under a range of constant catch regimes to determine the probability of the stock increasing. Projections were made based on a random subsample of 500 values from the posterior distribution. For each value the model was run into the future with the year class strength for the projected years randomised (mean = 1, s.d. = 0.65) and the ratio of SSB for the projected year to SSB for the current year recorded.

3.7 Biomass and yield estimates

The model was also used to estimate biomass, and generate yield estimates including $MCY_{long\text{-}term}$ and CAY. The prior chosen for B_0 (mature biomass in the virgin stock) was log-uniform because this was consistent with the assumption that any value of B_0 (x) had an equal likelihood that B_0 could be half or double the value. The lower bound selected (100 t) was arbitrary providing it was below the minimum B_0 required to sustain the recorded catch history because a penalty constraint on the objective function was used that effectively required that the recorded catch was available in the model to be taken. The upper bound was set at 100 000 t. A catch history of about 17 000 t deduced from this bound implied a current standing stock of at least 83 000 t, a lightly modified population. This seemed unlikely given the observed drop in standardised catch rates, the long period of unconstrained exploitation, and the lack of large fish in recent SOP samples. Therefore 100 000 t appeared to be a generous upper limit.

A Markov Chain Monte Carlo method was used to generate a Bayesian posterior distribution from the base case. A number of Markov Chain diagnostics were examined to evaluate the convergence of the chain.

MCY and CAY yields were estimated using the sample-based method based on a random sample of 350 points from the posterior distribution. In this analysis, MCY is the maximum constant catch that can be taken indefinitely so that the mature biomass does not fall below $20\%B_0$ more than 10% of the time. CAY is the maximum fishing mortality under the same condition. Estimates were made in CASAL by simulation under a range of catch or yield levels. The simulations used randomised year class strengths with an assumed log-normal distribution (mean = 1, $\sigma_r = 0.65$).

Sensitivity of biomass estimates

A number of sensitivity analyses were run to determine the effect of various factors on the biomass estimates. The CASAL model was allowed to estimate M, growth (L_∞, k), and recruitment deviates using either log-normal or "Coleraine" error structures for the length data.

4. RESULTS

4.1 MPD results

The Maximum Posterior Distribution (MPD) parameter values and results for each model run are given in Tables 15 and 16. As there was a range of different inputs in these alternative models, the total objective function value is not directly comparable from one to the other. However, the component parts are comparable when there is no change in the data or error structure of that component. For example, comparing runs SOP 1 and SOP 2, where the only change is an extra length frequency applied to the late fishery, showed that a small improvement in the fit of the post-GPS CPUE was observed (–6.5 to –6.6), plus a small downgrade in the fit for the pre-GPS CPUE (–2.3 to –1.9) and a small improvement in the fit for the early fishery length frequency (17.7 to 17.4).

The data fitted the base case model except for the 1986–87 pre-GPS CPUE data which fell below the biomass trajectories (Figure 8). The post-GPS CPUE series fitted the model better than the pre-GPS CPUE series (Figure 8). The fits of the length data to the base case model and absolute residuals are shown in Figure 9. The observed data had a higher peak frequency compared to the model curves for males and females and the secondary peak of large females was not modelled well, but overall the fits are reasonable. The Q-Q normal plots of the residuals for the length and CPUE data (Figures 10 and 11) are approximately standard normal (as they are assumed to be in the model).

A comparison of results for the SOP 2 and ORMC 1 runs showed the differences due to the source of length data. The ORMC length data resulted in fish being recruited to the fishery at an earlier age (especially for the early fishery) and there were also no differences in selectivity between the early and late fisheries. The ORMC 1 50% and 95% selectivity values for the early fishery were about 7 years and 12 years respectively lower than the values for the SOP 2 run (see Table 15). This reflected the differences in the length distributions versus depth for the ORMC and SOP length data.

Mature and vulnerable B_0 estimates were low for all runs (12 000–16 000 t) but the ORMC runs invoked the exploitation constraint on the late fishery so the ORMC runs are less plausible than the SOP runs that did not invoke the exploitation constraint (Table 16). The overall fit to the common data was the same for SOP 1 and SOP 2, but SOP 2 was chosen as the base case because it included more of the length data.

4.2 Bayesian estimates

The Markov Chain Monte Carlo analysis produced a total chain length of 500 000. The first 10 000 points were discarded (burn-in) and then every 100^{th} point was retained. Convergence diagnostics were run on a final chain length of 4900 points. Autocorrelations, and single chain convergence tests of Geweke (1992) and Heidelberger & Welch (1983), were applied to the chain to test for non-convergence. The tests used a significance level of 0.05 and the diagnostics were calculated using the Bayesian Analysis Output software (Smith, B.J., 2001. Bayesian output analysis program. Version 1.00 user's manual. Unpublished manuscript. 45 p. University of Iowa College of Public Health. http://www.public-health.uiowa.edu/boa). Table 17 shows that the MCMC runs converged. Summary statistics of the posterior distribution of the base case are given in Table 18 and show the tight distributions resulting from low c.v. estimates.

There were strong correlations between the selectivity parameters, i.e., between the early fishery age at 50% selection and the early fishery extra years to get to 95% selection and between the late fishery age at 50% selection and the late fishery extra years to get to 95% selection (Figure 12). These correlations were not a concern as the Markov Chain converged. A plot of the posterior distribution of virgin biomass for the base case showed that most of the estimates were between about 13 000 and 21 000 t (Figure 13). Plots of the posterior distribution of the fishery selectivity parameters for the base case showed symmetrical distributions (Figure 14). The base case posterior distributions of the derived quantities, current mature biomass, and current vulnerable biomass as a percentage of virgin biomass are shown in Figure 15: most of the mature biomass estimates were between about 20 and 40 $\%B_0$, while the vulnerable estimates were mostly between about 20 and 50 $\%B_0$.

4.3 Sensitivity of M estimates

Allowing the CASAL model to estimate M for the base case produced a value that was slightly lower (0.052) than the fixed life history parameter value (0.063, see Table 2). This result was in contrast to increased estimates of M from previous stock assessments of OEO 3A black oreo (Hicks et al. 2002) and OEO 4 smooth oreo (Starr & Magnusson, unpublished Working Group document 2002/56) that used the "Coleraine" error distribution for the length frequency data. The estimate of M for the base case increased when the Coleraine length data error structure was employed in the CASAL model to estimate M (Table 19). We think this effect is because the Coleraine error distribution closely fits the tails of the length distributions at the expense of the more frequent length data in the centre of the length distribution.

4.4 Biomass and yield estimates –base case

The posterior distribution of mature B_0 from the Markov Chain analysis for the SOP 2 model run provided a sample of 5000 values, mostly between 13 000 and 21 000 t (Figure 13). Biomass and yield estimates are given in Table 20.

4.5 Biomass projections – base case

Table 21 records the fraction of points from the posterior distribution where the biomass for the projected year is greater than the biomass for the current year, i.e., the probability of increasing the mature biomass.

5. DISCUSSION AND CONCLUSIONS

There were numerous uncertainties in this assessment but it seems unlikely that any of these would change the main conclusion that Southland smooth oreo is a small stock. The base case analysis suggested that the virgin biomass of the stock was probably 13 800–20 700 t (90% confidence interval). In contrast B_0 estimates of 76 500–92 500 t were made for OEO 3A smooth oreo and 100 000–148 000 t for OEO 4 smooth oreo (Annala et al. 2002). A previous preliminary CASAL assessment did not use the length data and produced B_0 estimates that were poorly determined with a 95% highest probability density interval for the posterior distribution of 11 500–73 800 t.

The assessment suggests that the recent annual catches of about 1000 t (1998–99 to 2000–01) are not sustainable. The base case long-term MCY estimate was 310 t and 5- and 10-year biomass projections into the future suggested that an annual catch of less than 400 t was required to provide at least a 50% chance that the mature biomass will increase. This assessment is consistent with the experience for other smooth oreo fisheries and is a consequence of the slow-growth and low productivity of the species (Annala et al. 2002).

Conclusions from the assessment were as follows.

1. The Southland smooth oreo fishery is based on a small stock and recent catches may be unsustainable.

2. The length data for this fishery came from two sources, but only the SOP length data were acceptable for use in the stock assessment analyses and consequently the structure of all smooth oreo length data collected should be investigated for bias before they are used.
3. The stock assessment was sensitive to the error structure of the length data.
4. Direct ageing of samples collected from the fishery would eliminate the problem with length bias, but only if sampling for age is random.

An alternative approach to future modelling of this stock could involve investigating a deep and a shallow model instead of the early and late fisheries. This would require a new standardised CPUE analysis and would benefit from continued collection of good quality (unbiased) length data from a range of depths.

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Table 1: Total reported landings (t) for all oreo species for oreo management area OEO 1 from 1978–79 to 2000–01 and TACs (t) from 1986–87 to 2000–01. –, no value. From McMillan et al. (2002).

	OEO 1	
Fishing year	Landings	TAC
1978–79*	2 808	–
1979–80*	143	–
1980–81*	467	–
1981–82*	21	–
1982–83*	162	–
1983–83#	39	–
1983–84†	3 241	–
1984–85†	1 480	–
1985–86†	5 390	–
1986–87†	532	4 000
1987–88†	1 193	4 000
1988–89†	432	4 233
1989–90†	2 069	5 033
1990–91†	4 563	5 033
1991–92†	4 156	5 033
1992–93†	5 739	6 044
1993–94†	4 910	6 044
1994–95†	1 483	6 044
1995–96†	4 783	6 044
1996–97†	5 181	6 044
1997–98†	2 681	6 044
1998–99†	4 102	5 033
1999–00†	3 711	5 033
2000–01†	4 852	5 033

Source: FSU from 1978–79 to 1987–88; QMS/ITD from 1988–89 to 2000–01. *, 1 April to 31 March; #, 1 April to 30 September; †, 1 October to 30 September.

Table 2: Life history parameters for smooth oreo. –, not estimated.

Parameter	Symbol (unit)	Female	Male
Natural mortality	M (yr^{-1})	0.063	0.063
Age at recruitment	A_r (yr)	21	21
Age at maturity	A_m (yr)	31	–
von Bertalanffy parameters	L_∞ (cm, TL)	50.8	43.6
	k (yr^{-1})	0.047	0.067
	t_0 (yr)	-2.9	-1.6
Length-weight parameters	a	0.029	0.032
	b	2.90	2.87
Recruitment variability		0.65	0.65
Recruitment steepness		0.75	0.75
Length at recruitment	(cm, TL)	34	–
Length at maturity	(cm, TL)	40	–

Table 3: Catch history of smooth oreo from the study area. Catches are rounded to the nearest 10 t.

Year	1978–79	1979–80	1980–81	1981–82	1982–83	1983–84	1984–85	1985–86	1986–87	1987–88
Catch	200	10	30	0	10	1 130	690	4 230	190	990
Year	1988–89	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98
Catch	240	640	830	910	660	370	230	1 100	500	550
Year	1998–99	1999–00	2000–01							
Catch	1 090	1 130	1 010							

Table 4: Smooth oreo catch (t) and unstandardised CPUE for all tows in the study area that targeted SSO or BOE or OEO. Years are fishing years (1 October – 30 September). –, data from fewer than 4 vessels.

Year	No. of tows	No. of vessels	Catch	Mean catch per tow	Zero catch tows (%)
1977–78	314	6	0	0.0	100
1978–79	–	–	10	–	–
1979–80	85	5	0	0.0	99
1982–83	–	–	0	–	–
1983–84	501	9	1 280	2.6	50
1984–85	240	16	880	3.6	27
1985–86	810	14	4 580	5.7	19
1986–87	100	6	150	1.5	29
1987–88	218	12	910	4.2	38
1988–89	27	6	130	4.7	59
1989–90	160	9	580	3.6	11
1990–91	143	7	650	4.5	16
1991–92	127	12	720	5.6	11
1992–93	168	18	570	3.4	22
1993–94	107	12	340	3.1	21
1994–95	49	6	200	4.1	22
1995–96	188	14	820	4.4	19
1996–97	439	15	470	1.1	25
1997–98	199	13	480	2.4	22
1998–99	388	15	1 020	2.6	11
1999–00	491	11	1 050	2.1	13
2000–01	264	10	920	3.5	14

Table 5: ***Year-cross table for the study area.*** **This shows the number of vessels that linked each pair of years, e.g., two vessels linked 1984–85 to 1986–87, hence the table is symmetric. A link was established when a vessel made at least 10 tows in each of the paired years. –, no link.**

	1983–84	1984–85	1985–86	1986–87	1987–88	1988–89	1989–90	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01
1983–84		2	2	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–
1984–85	2		5	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–
1985–86	2	5		4	1	–	–	–	–	–	–	–	1	1	–	–	1	–
1986–87	1	2	4		–	–	–	–	–	–	–	–	1	1	–	–	1	–
1987–88	1	1	1	–		1	–	1	1	1	–	–	–	–	–	–	–	–
1988–89	–	–	–	–	1		1	–	1	–	1	–	–	–	–	–	–	–
1989–90	–	–	–	–	–	1		1	1	1	2	–	1	1	–	–	–	–
1990–91	–	–	–	–	1	–	1		1	2	1	1	1	1	1	1	1	1
1991–92	–	–	–	–	1	1	1	1		3	1	–	–	–	–	–	–	–
1992–93	–	–	–	–	1	–	1	2	3		2	1	2	2	1	1	1	1
1993–94	–	–	–	–	–	1	2	1	1	2		1	2	2	1	1	1	1
1994–95	–	–	–	–	–	–	–	1	–	1	1		1	1	1	1	1	1
1995–96	–	–	1	1	–	–	1	1	–	2	2	1		5	2	3	3	1
1996–97	–	–	1	1	–	–	1	1	–	2	2	1	5		1	3	3	2
1997–98	–	–	–	–	–	–	–	1	–	1	1	1	2	1		3	3	1
1998–99	–	–	–	–	–	–	–	1	–	1	1	1	3	3	3		5	4
1999–00	–	–	1	1	–	–	–	1	–	1	1	1	3	3	3	5		4
2000–01	–	–	–	–	–	–	–	1	–	1	1	1	1	2	1	4	4	

Table 6: Summary of non-year variables that could be selected in the regression models. All were categorical variables. Df is the number of parameters to be estimated for that variable; –, not available: it depends on the dataset.

Variable	Df	Description
Target	2	Target species, SSO, BOE, or OEO.
Depth	7	Depth at start of a tow. Bins were defined to contain about the same number of tows.
Season	7	The fishing year divided into 8 periods.
Time	7	Time of day when a tow started, blocked into 8 periods.
Axis-position	7	Position of start of tow, blocked into 8 cells.
Vessel	–	A parameter estimated for each vessel with at least 50 tows. Vessels with less than 50 tows were grouped together.

Table 7: Smooth oreo pre-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo. New variables were added one at a time until R^2 (%) or its equivalent failed to increase by more than 1%. At each iteration the variable that increased R^2 the most was added. Variables considered for the positive and zero catch analyses are given in Table 6.

(a) Positive-catch model R^2 values (%)

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Vessel	27.4					
Target	20.3	34.6				
Year	6.1	31.8	38.9			
Axis-position	18.4	30.7	36.6	40.8		
Time	9.6	29.9	36.2	40.8	42.4	
Depth	15.0	30.5	37.0	40.7	42.3	43.9
Improvement	27.4	7.2	4.3	2.0	1.6	1.4

(b) Zero-catch GLM R^2 values (% null deviance explained)

	Step 1	Step 2
Vessel	14.5	
Target	0.8	16.1
Improvement	14.5	1.6

Table 8: Smooth oreo post-GPS. Stepwise selection of variables for the positive catch regression and the zero catch GLM for all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo. New variables were added one at a time until R^2 (%) or its equivalent failed to increase by more than 1%. At each iteration the variable that increased R^2 the most was added. Variables considered for the positive and zero catch analyses are given in Table 6.

(a) Positive-catch model R^2 values (%)

	Step 1	Step 2	Step 3	Step 4	Step 5
Vessel	11.3				
Axis-position	5.9	14.5			
Year	7.7	13.9	16.2		
Time	5.0	13.6	16.1	17.6	
Target	2.3	12.6	15.2	16.9	18.8
Improvement	11.3	3.2	1.7	1.4	1.2

(b) Zero-catch GLM R^2 values (% null deviance explained)

	Step 1	Step 2	Step 3	Step 4
Vessel	4.6			
Axis-position	3.0	6.1		
Year	2.2	6.0	7.7	
Target	1.6	5.8	6.9	8.8
Improvement	4.6	1.5	1.6	1.1

Table 9: Smooth oreo pre-GPS positive catch, zero catch, combined index estimates by year, and jackknife c.v. estimates on the combined index from analysis of all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo.

	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1983–84	4 507	0.69	3 111	22
1984–85	4 149	0.71	2 937	29
1985–86	2 980	0.71	2 112	33
1986–87	1 299	0.66	852	23
1987–88	1 714	0.63	1 082	27

Table 10: Smooth oreo post-GPS positive catch, zero catch, combined index estimates by year, and jackknife c.v. estimates on the combined index from analysis of all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo.

	Positive index	Zero index	Combined index	Jackknife c.v. (%)
1992–93	1 556	0.74	1 150	39
1993–94	1 252	0.79	994	78
1995–96	1 703	0.86	1 470	103
1996–97	648	0.73	474	84
1997–98	1 255	0.83	1 037	27
1998–99	918	0.89	821	17
1999–00	1 031	0.82	849	21
2000–01	902	0.90	808	38

Table 11: Summary of length frequency data for smooth oreo available for the study area. The table shows the number of tows sampled by year, source, and depth zone (deep >= 975 m). Note that ORMC samples from vessel X were excluded. –, no data.

	SOP		ORMC	
Year	Shallow	Deep	Shallow	Deep
1986–87	–	1	–	–
1988–89	–	2	–	–
1993–94	2	–	–	–
1994–95	3	–	–	–
1995–96	2	–	–	–
1996–97	4	–	–	–
1997–98	2	1	–	–
1998–99	–	–	12	19
1999–00	30	6	–	3
2000–01	4	–	1	1

Table 12: Combined annual SOP and ORMC mean length data (cm, TL). All data were scaled by the catch weight. N, number of fish sampled.

Years	Mean length	n
1989–90 to 1997–98	32.4	1 397
1998–99	33.7	3 449
1999–00	32.9	3 896
2000–01	42.7	1 689

Table 13: CASAL stock assessment model runs. †, simulated length frequency. –, not applicable. The base case (SOP 2) is in bold. Deep, only the data from the deep. The annual length data are summarised in Table 11. 1993–97 is the years from 1993–94 to 1996–97 and 1999–01 is 1999–2000 and 2000–01.

Run			Length data				CPUE	Early fishery
	Early	Years used	Years applied	Late	Years used	Years applied		
SOP 1	Yes †	1997–98 & 1999–00	1999–00	Yes	1997–98 & 1999–00	1999–00	Pre- & post-GPS	Yes
SOP 2	**Yes †**	**1997–98 & 1999–00**	**1999–00**	**Yes**	**1997–98 & 1999–00 1993–97 & 1997–98 deep & 1999–00 deep**	**1999–00 1995–96**	**Pre- & post-GPS**	**Yes**
ORMC 1	Yes †	1998–99	1998–99	Yes	1998–99 & 1999–01	1998–99 & 1999–00	Pre- & post-GPS	Yes
ORMC 2	No	–	–	Yes	1998–99 & 1999–01	1998–99 & 1999–00	Post-GPS	No

Table 14: Estimated parameters and priors of the assessment model. U, uniform distribution.

Parameter	Number	Prior
Virgin biomass	1	ln B_0 ~U[ln(100), ln (100 000)]
Catchability coefficient [pre-GPS CPUE]	1	U[1e-8, 1e8]
Catchability coefficient [post-GPS CPUE]	1	U[1e-8, 1e8]
Age-based selectivity - commercial fishery		
Age at 50% selected (Early.50 & Late.50)	2	U[1, 50]
Extra years to go from 50 to 95% selected (Early.95 & Late.95)	2	U[0.1, 35]

Table 15: Results. MPD model free parameter values and objective function components for runs ORMC 1 & 2 and SOP 1 & 2 (see Table 13 for description of runs). For run ORMC 2 "late" should be read as "all" because that run used only a single fishery model. All other runs used a two fisheries model (early and late). Priors that made no contribution to the objective function value in any case were not reported. NA, not applicable. The base case (SOP 2) is in bold.

Length data source	SOP 1	**SOP 2**	ORMC 1	ORMC 2
Free parameters				
B_0 (t)	15 140	**15 300**	12 150	12 140
Selectivity early 50% (year)	23.7	**22.0**	15.4	NA
Selectivity early 95% (year)	9.9	**8.8**	3.1	NA
Selectivity late 50% (year)	17.9	**16.5**	15.4	14.9
Selectivity late 95% (year)	6.8	**5.7**	3.8	3.2
Objective function components				
CPUE pre-GPS	–2.3	**–1.9**	–2.7	NA
CPUE post-GPS	–6.5	**–6.6**	–5.4	–5.5
Early LFs	17.7	**17.4**	11.2	NA
Late LFs	8.8	**18.3**	90.5	90.9
Prior on B_0	9.6	**9.6**	9.4	9.4
Exploitation constraint early	0.0	**0.0**	0.0	NA
Exploitation constraint late	0.0	**0.0**	1.0	0.5
Total objective function value	27.3	**36.8**	104.0	95.3

Table 16: Results. MPD model biomass estimates for runs ORMC 1 & 2 and SOP 1 & 2 (see Table 13 for description of runs). The base case (SOP 2) is in bold.

Run	SOP 1	SOP 2	ORMC 1	ORMC 2
Mid-year, mature				
B_0	15 000	**15 200**	12 000	12 100
B_{2002}	4 000	**4 100**	1 000	900
B_{2002}/B_0	27%	**27%**	8%	8%
Mid-year, vulnerable				
B_0	15 100	**16 000**	13 100	13 300
B_{2002}	4 000	**4 500**	1 200	1 300
B_{2002}/B_0	26%	**28%**	9%	9%

Table 17: Convergence tests carried out on the MCMC chain. See Table 14 for parameter descriptions.

	Heidleberger and Welch test		Geweke test
Parameter	Stationarity	Halfwidth.	P value
B_0	Passed	Passed	0.25
Age at 50% selected (early)	Passed	Passed	0.67
Extra years to 95% selected (early)	Passed	Passed	0.97
Age at 50% selected (late)	Passed	Passed	0.66
Extra years to 95% selected (late)	Passed	Passed	0.65

Table 18: Bayesian estimates: summary statistics of the posterior distributions for the base case. See Table 14 for parameter descriptions.

	0.05 quantile	Median	Mean	0.95 quantile	C.v.(%)
B_0	13 800	15 900	16 500	20 800	15
Age at 50% selected (early)	14.7	16.5	16.6	18.8	7
Extra years to 95% selected (early)	4.1	5.9	6.0	8.0	20
Age at 50% selected (late)	18.5	22.5	23.0	29.0	14
Extra years to 95% selected (late)	6.6	9.5	9.8	13.9	23

Table 19: Biomass sensitivity estimates. Estimates of M for the base case (SOP 2) in bold. M was either fixed or estimated by the CASAL model using either log-normal or "Coleraine" length data error structure estimates. OFV, objective function value.

M source	Error structure	M value	OFV
Fixed	**Log-normal**	**0.063**	**36.8**
Estimated	Log-normal	0.052	35.6
Fixed	Coleraine	0.063	-414.8
Estimated	Coleraine	0.11	-416.3

Table 20: Biomass and yield estimates (t).

(a) Mid-year biomass estimates

	Median	90% C.I.
Mature virgin	15 900	13 800–20 700
Mature 2001–02 mid-year	4 800	2 800–9 500
Mature 2001–02 mid-year (% B_0)	30	20–46
Vulnerable virgin	16 700	13 900–22 400
Vulnerable 2001–02 mid-year	5 300	2 800–10 800
Vulnerable 2001–02 mid-year (% B_0)	32	21–48

	Mean
B_{MCY}	†7 800
B_{MAY}	†4 300

† mid-year vulnerable biomass.

(b) Yield estimates

	Mean
$MCY_{long-term}$	310
CAY	440

Table 21: Biomass projections. Probability of the mature biomass increasing at 5 and 10 years into the future under a range of constant annual catch levels.

Catch (t)	Probability	
	5 years	10 years
1 010	0	0
800	0	0
600	0	0
500	0	0
400	0	0.44
300	0.58	1
200	1	1

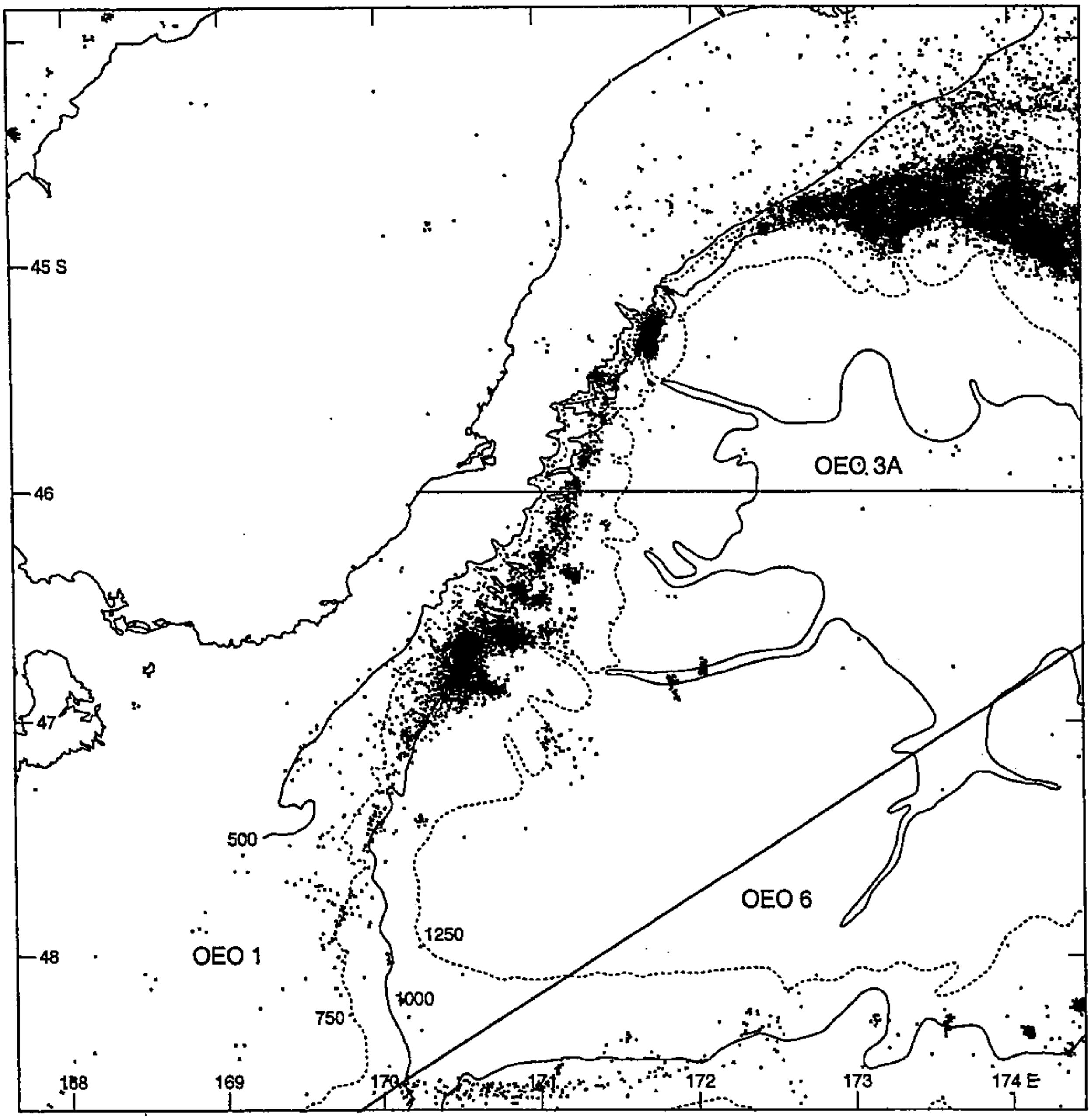

Figure 1: The Southland oreo fishery off the Otago-Southland coast (about 45 to 48° S and 169 to 172° E, see study area, Figure 2) showing the oreo management areas. The grey dots are the locations of commercial tows where oreo (SSO, BOE, OEO) was targeted or caught from 1977–78 to 2000–01. Depth contours are shown at 500, 750, 1000, 1250, and 1500 m

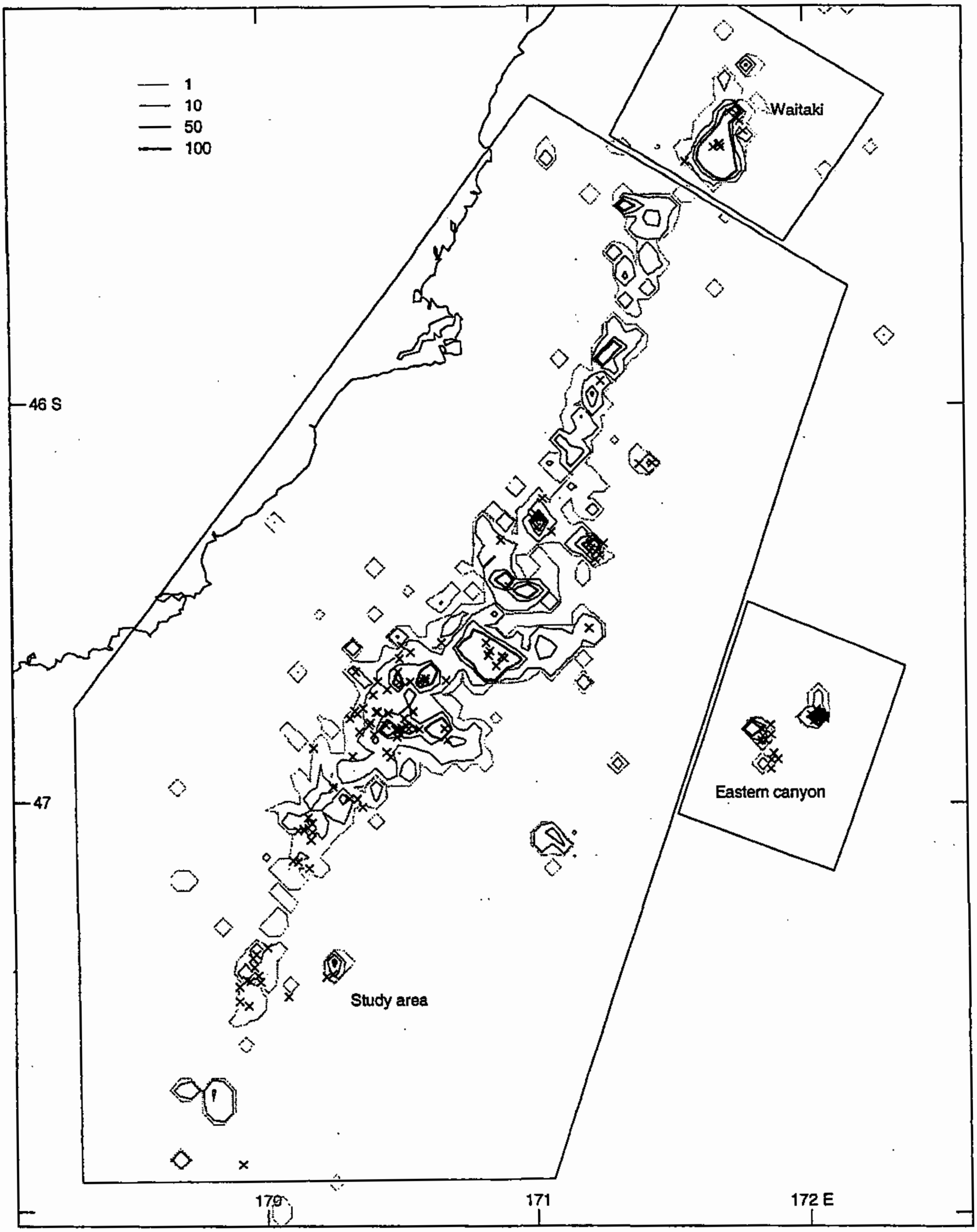

Figure 2: The Southland fishery study area (large polygon) with small polygons around the Waitaki and eastern canyon areas (not included in this study). Smooth oreo catch contours from 1977–78 to 2000–01 were plotted by summing the catches over a roughly square grid with cell size of about 10km². The contours are at 1, 10, 50 and 100 t per cell (therefore approximately 0.1, 1, 5, and 10 t per km²). The study area polygon has corners at 45° 13.6' S, 171° 0.3' E; 45° 42.3' S, 172° 9.4' E; 47° 55.2' S, 171° 3.7' E; 47° 55.6' S 169° 19.2' E; 46° 45.8' S 169° 18.5' E. Xs mark the location of length frequency samples of smooth oreo.

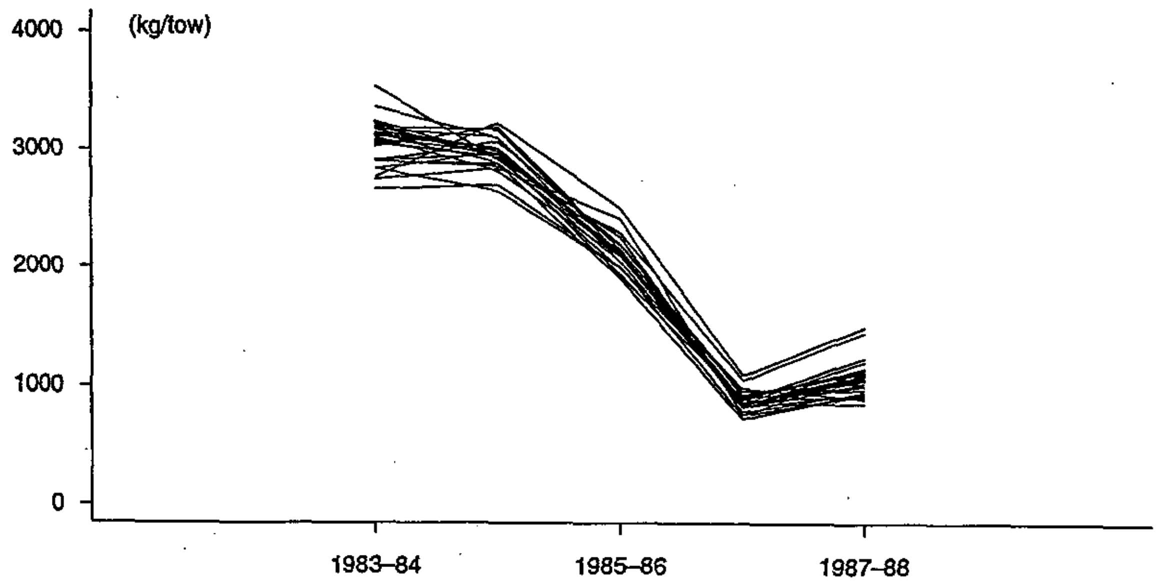

Figure 3: Smooth oreo combined CPUE indices for the pre-GPS period showing the effect of dropping one vessel at a time from the regression analysis.

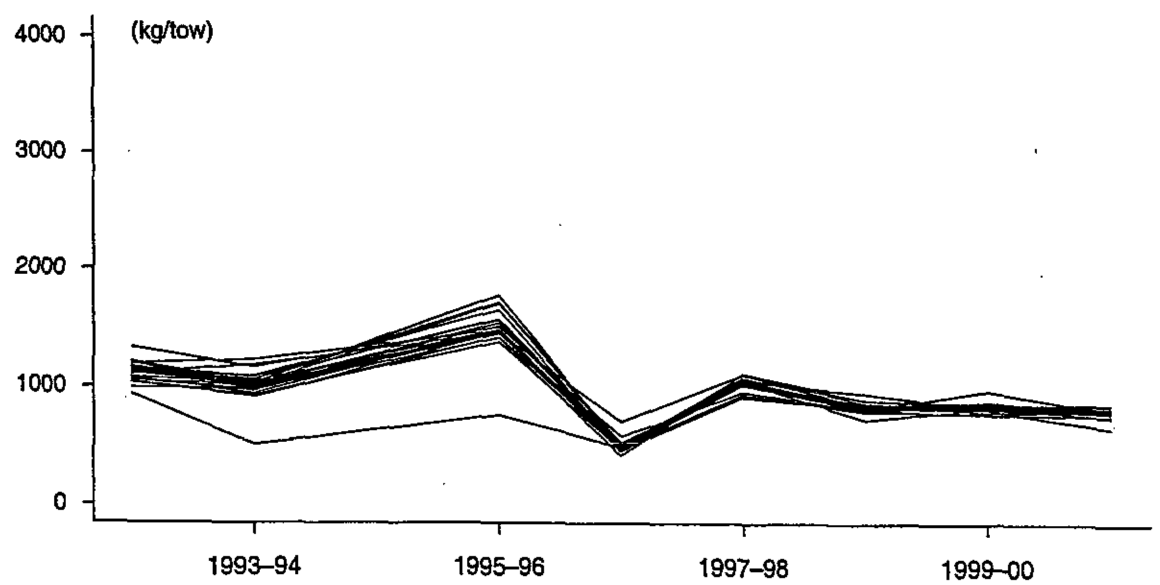

Figure 4: Smooth oreo combined CPUE indices for the post-GPS period showing the effect of dropping one vessel at a time from the regression analysis.

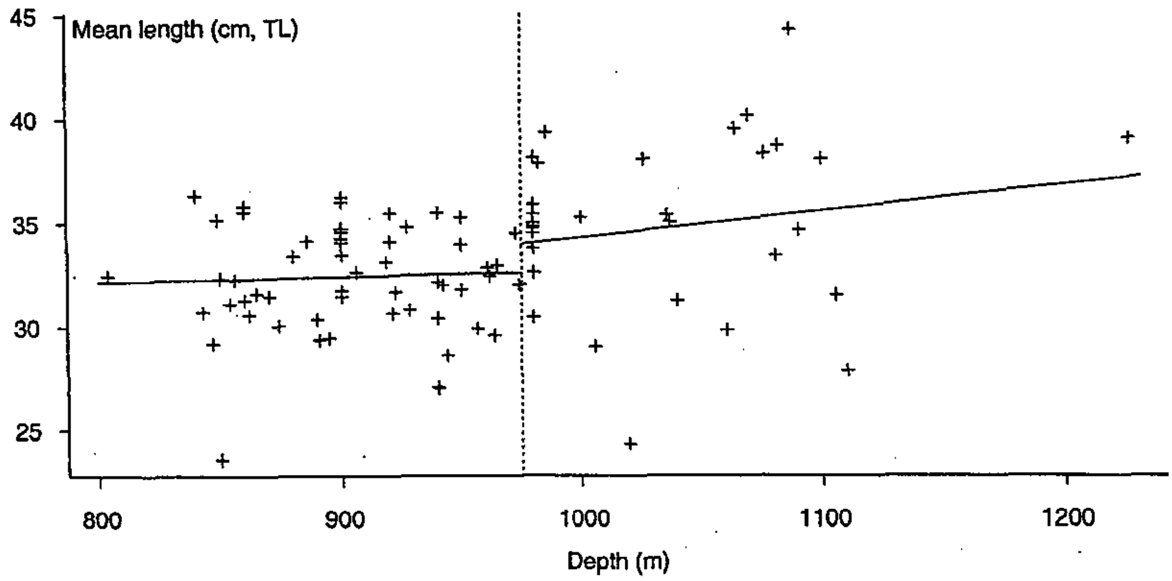

Figure 5: The relationship between mean length and depth for smooth oreo length frequency samples from the study area. The approximately horizontal lines show a linear regression fit to the data from each side of the vertical line at 975 m. Samples collected from vessel X by ORMC observers were excluded.

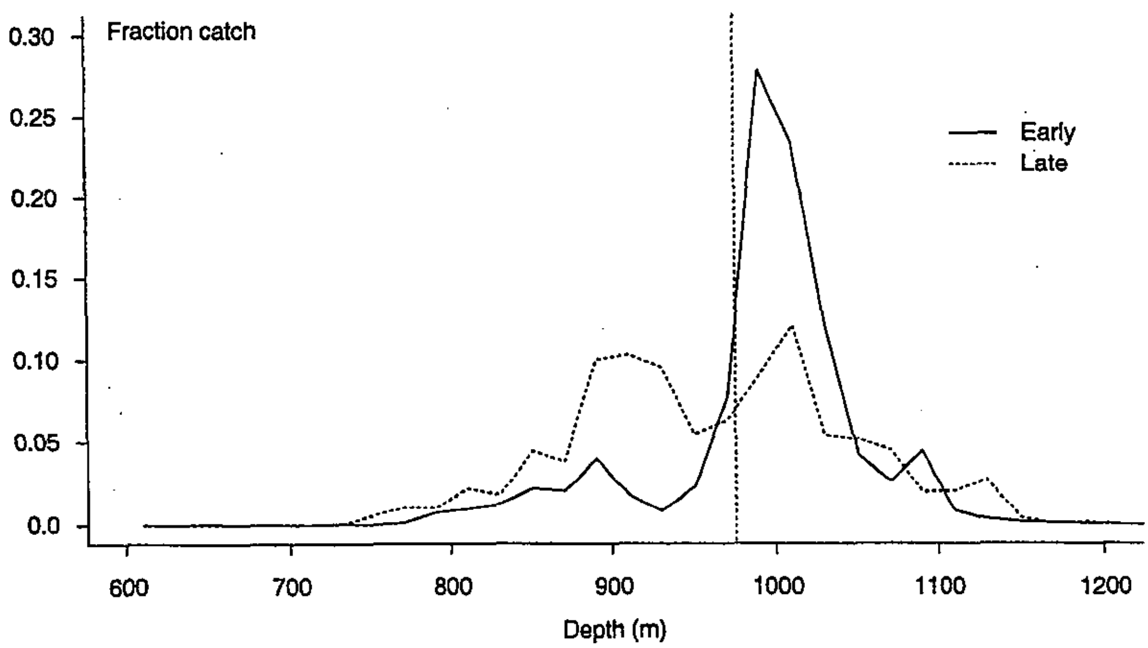

Figure 6: Distribution of smooth oreo catch (t) from the study area by depth for the early (pre 1989–90) and late (1989–90 onwards) fishery. The vertical line is at 975 m. Catches were summed in bins of 20 m width spanning the data. The plotted line connects those data at each bin centre. Pre-GPS is the period before 1989–90 and post-GPS after 1991–92. These periods identify closely with the early and late fisheries.

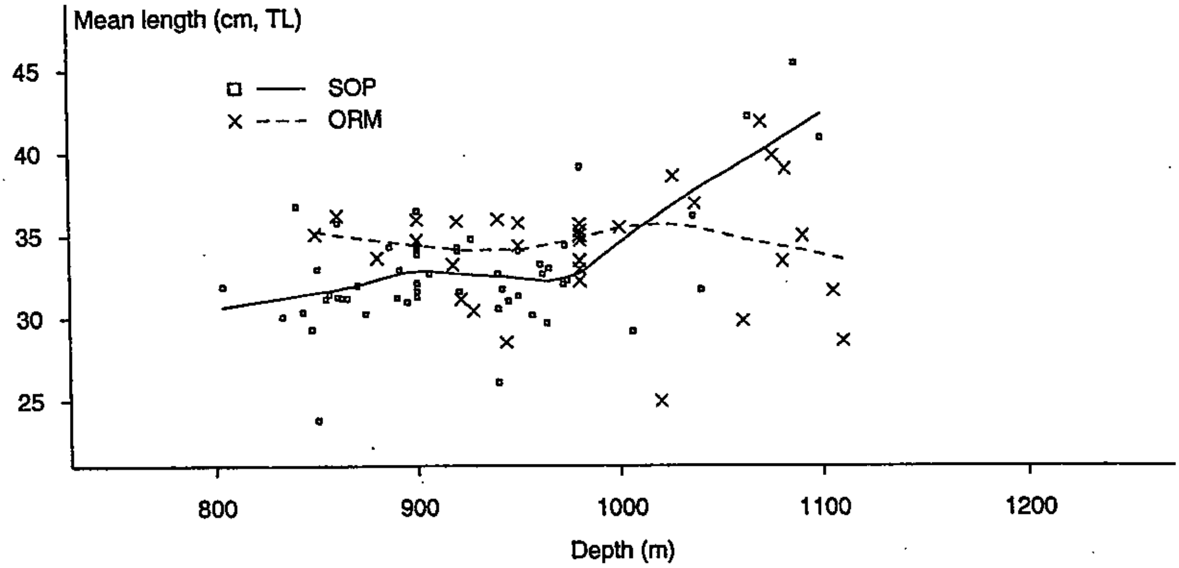

Figure 7: Mean length plotted against depth for female smooth oreo (male plot was very similar). Local regression lines were fitted to data from the SOP and ORMC separately.

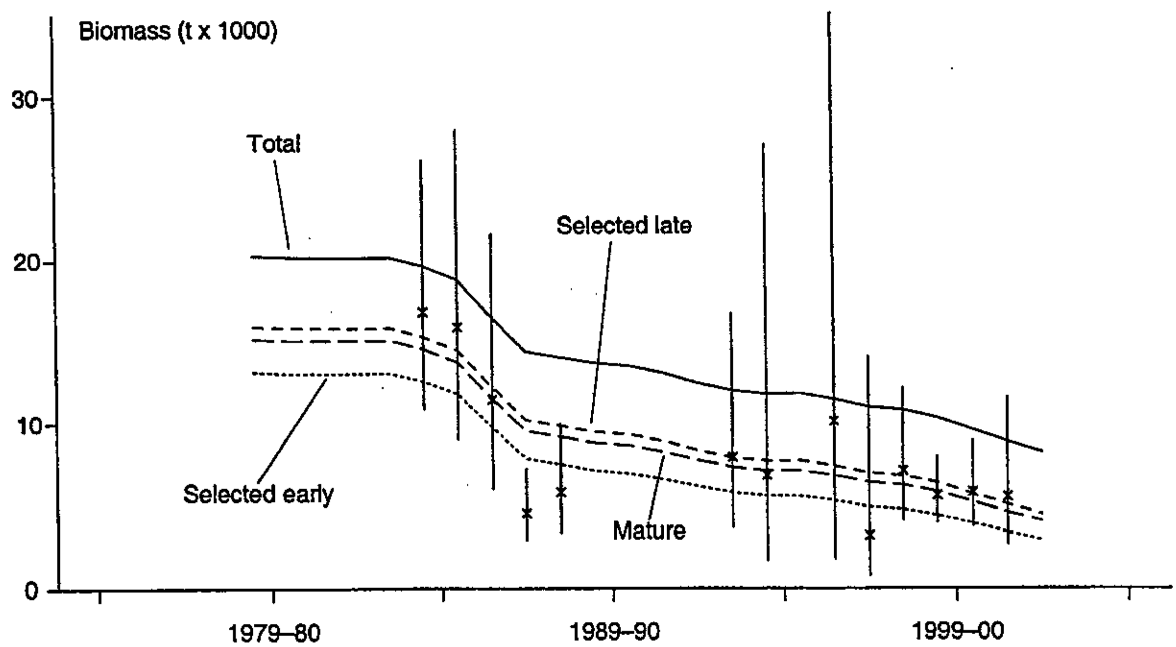

Figure 8: Biomass trajectories from the base case. Total biomass, mature biomass, and selected biomass for the early (before 1989–90) and selected biomass for the late fishery (from 1989–90 on) are shown. Also shown are the CPUE indices from the pre- and post-GPS analyses with 2 s.e. confidence interval indicated by the vertical lines.

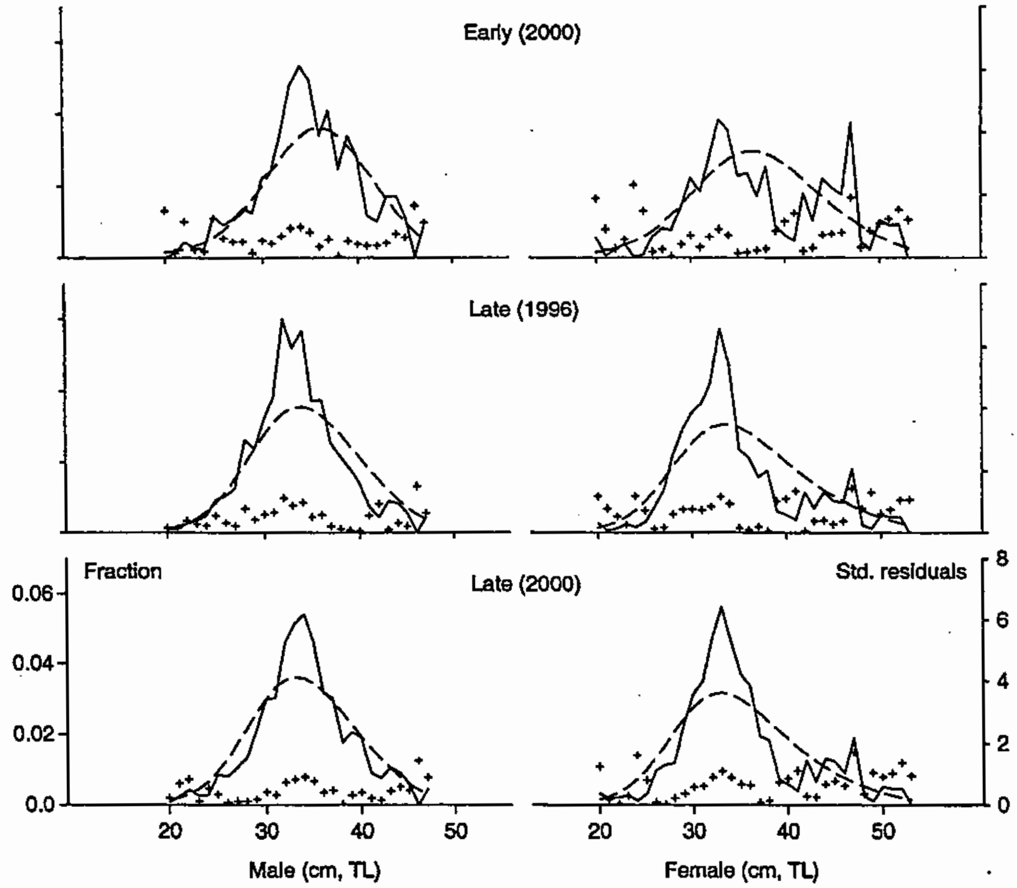

Figure 9: Length frequencies (solid line) and model fit (dashed line) from the base case model. Also shown are the absolute standardised residuals (+). The three pairs of plots from top to bottom correspond to the three plots in Figure 10 left to right.

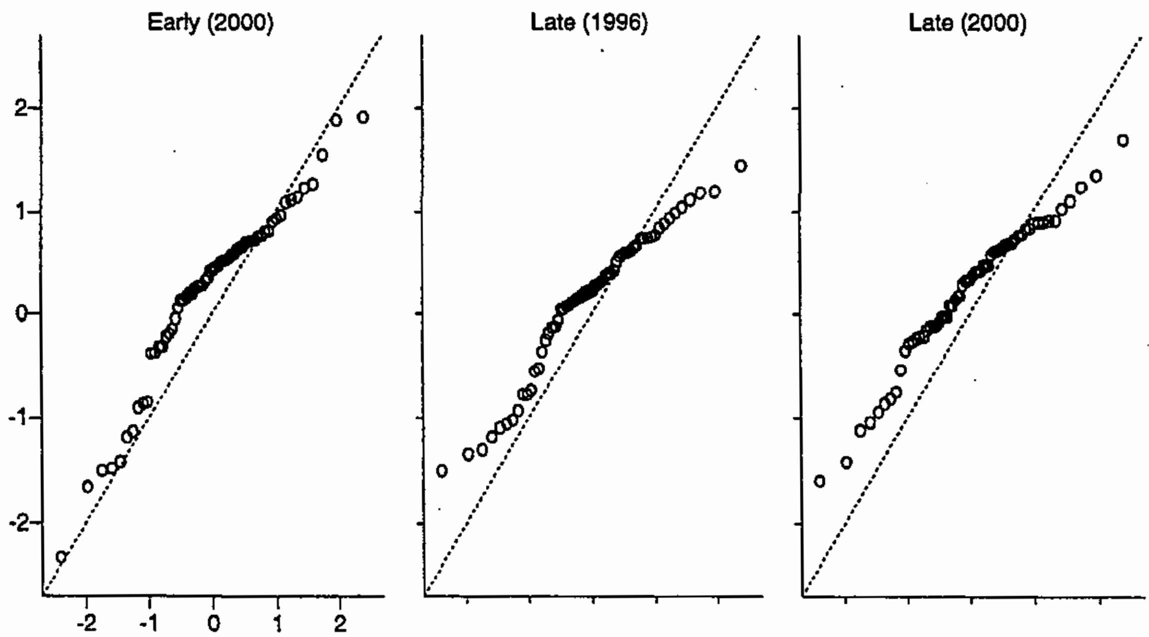

Figure 10: Q-Q normal plots of the standardised residuals of the length frequency data in the base case. The residuals (y-axis), are mapped against the normal distribution (x-axis). From left to right: the length frequencies for the early fishery applied in 1999–2000; length frequencies for the late fishery applied in 1995–96; length frequencies for the late fishery applied in 1999–2000. The diagonal line is through the origin and the slope is one.

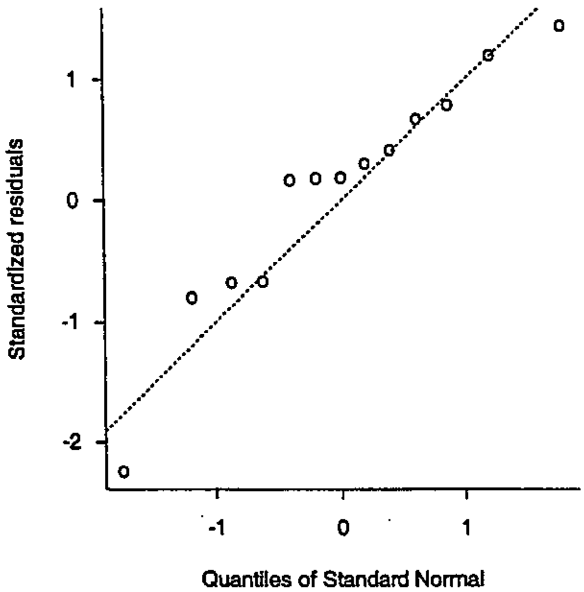

Figure 11: Q-Q normal plot for all the normalised residuals from the two CPUE indices. The dashed line is the 1:1 line.

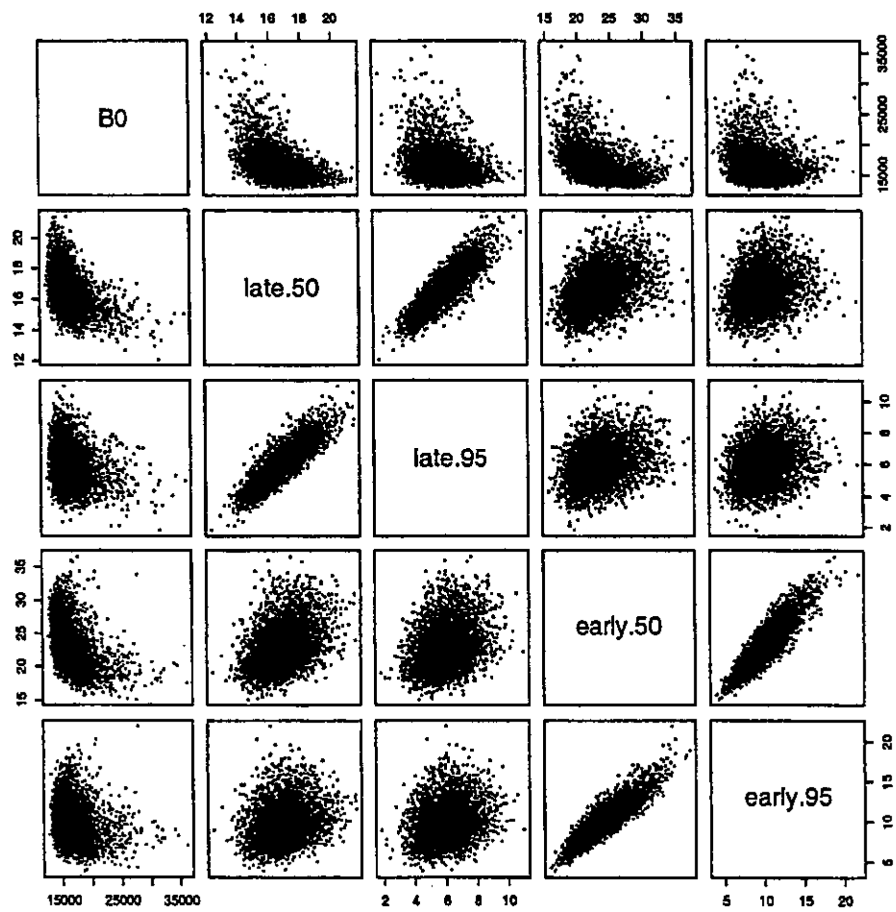

Figure 12: Pairwise plots of MCMC parameter estimates. See parameter definitions in Table 14.

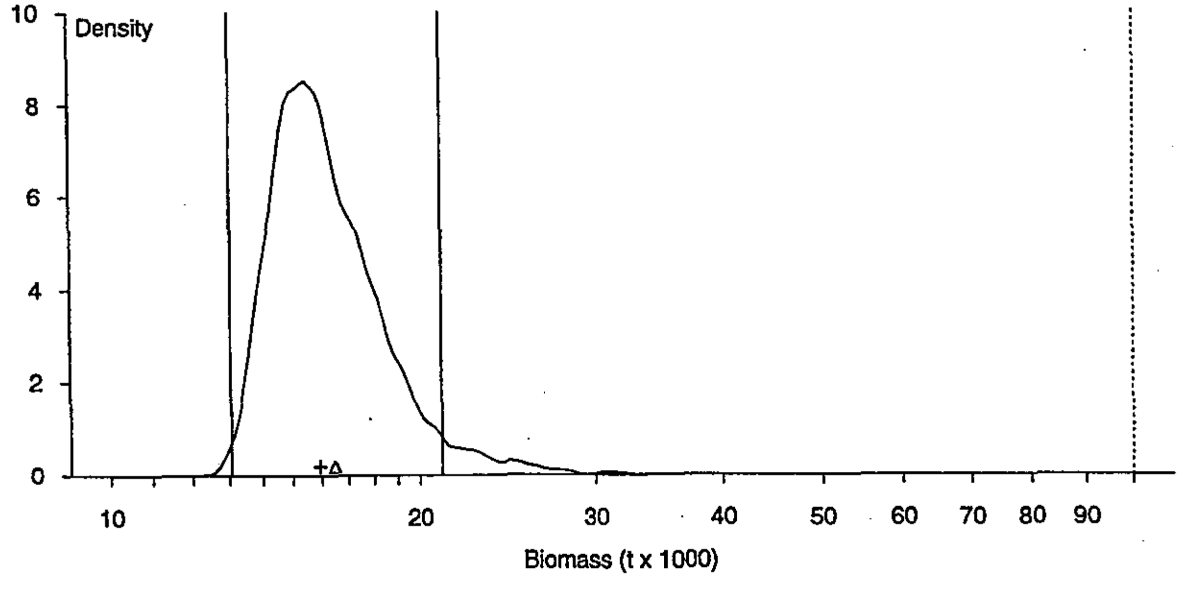

Figure 13: The posterior distribution of B_0 for the base case (SOP 2). The mean value is shown as a triangle and the median as a plus sign. The x-axis is a log scale. The two solid vertical lines show the 95% HPD. The vertical dashed line is the upper limit on the B_0 prior (100 000 t).

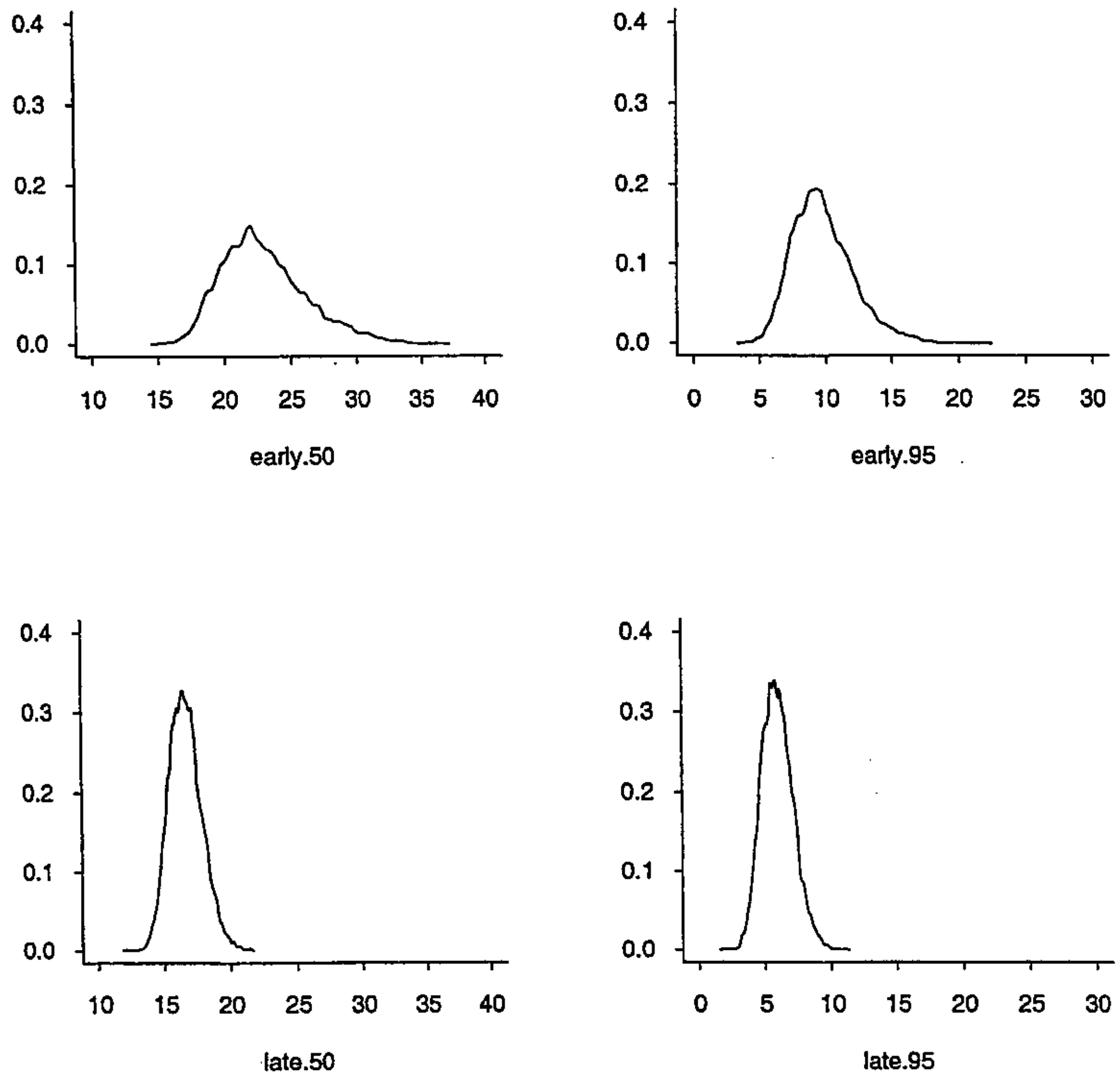

Figure 14: Posterior distribution plots for the early fishery selectivity, age at 50% selection (top left); early fishery selectivity, for ages from 50% to 95% selection (top right); late fishery selectivity, age at 50% selection (bottom left); late fishery selectivity, for ages from 50% to 95% selection (bottom right). See parameter definitions in Table 14.

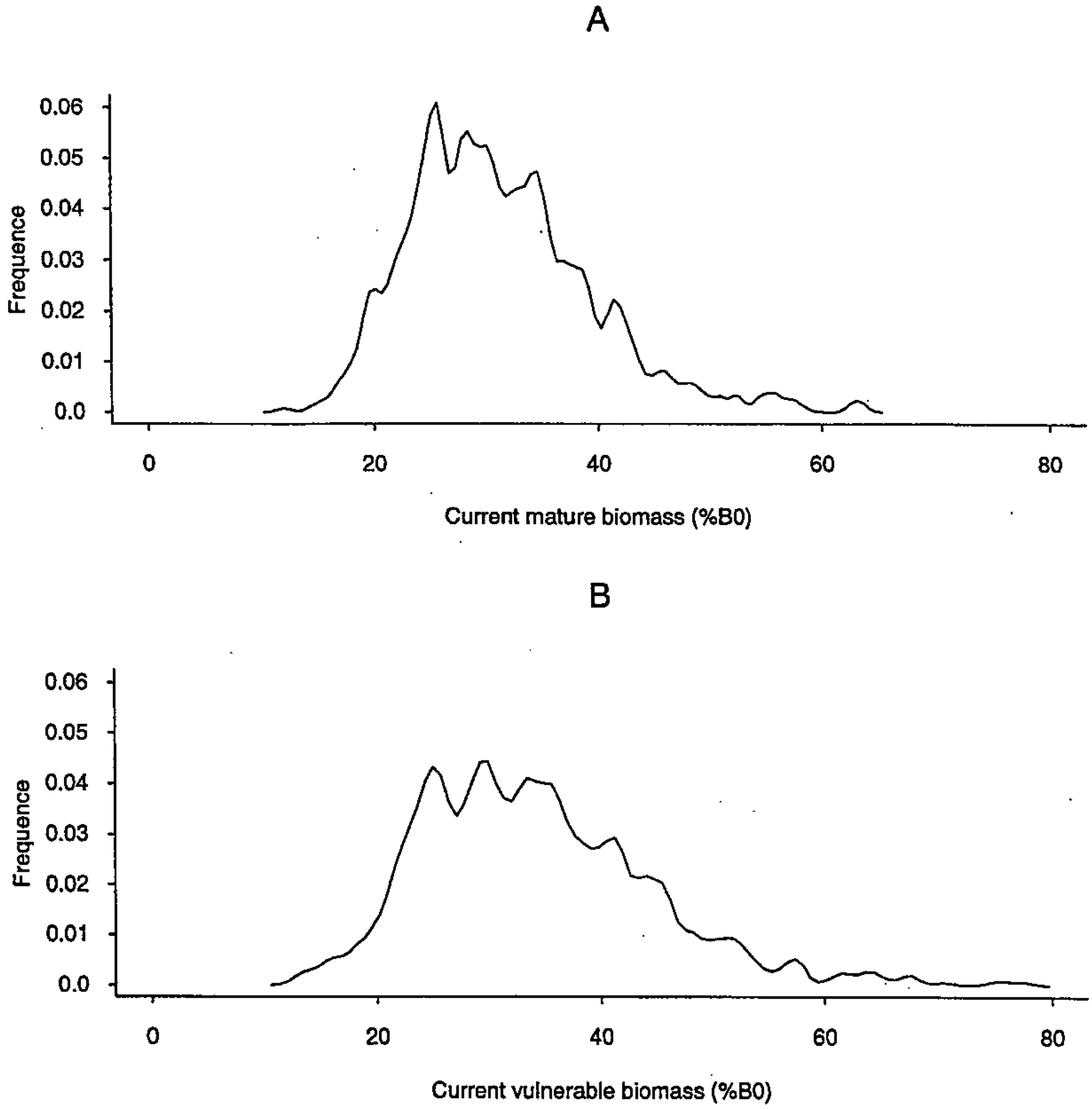

Figure 15: Posterior distribution of the derived parameters: current mature biomass as a percentage of the virgin biomass (A) and current vulnerable biomass as a percentage of the virgin biomass (B).