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EXECUTIVE SUMMARY

Coburn, R.P.; Doonan, I.J.; McMillan, P.J. (2008). A stock assessment of smooth oreo in Southland (part of OEO 1 & OEO 3A).

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The biomass of smooth oreo in the Southland fishery (part of OEO 1 & OEO 3A) was estimated with Bayesian methods using a CASAL age-structured model. This is the second assessment of the stock and used 5 extra years of catch and observer length frequency data compared to the previous (2003) analysis. No fishery-independent data are available for this fishery so inputs for the model included catches, pre- and post-GPS standardised CPUE, and observer length frequency data. Model structure was changed from 2003 to incorporate a split of the data into deep and shallow fisheries because of a strong observed relationship between smaller fish in shallow water and large fish in deeper water.

Virgin mature biomass estimate for the accepted model was 18 000 t with a 90% C.I. of 16–22 000 t. Current mature biomass was 28% of the virgin mature biomass with a 90% C.I. of 19–41%. No yields were estimated because of the uncertainty of this assessment, i.e., standardised CPUE was assumed to index abundance.

Smooth oreo catch from Southland is about 480 t (mean of 2003–04 to 2005–06). There is an industry catch limit of 400 t for this fishery. It is uncertain if a catch of 400–500 t p.a. is sustainable, but it seems likely that the Southland fishery is small relative to the largest New Zealand smooth oreo fisheries, e.g., OEO 4.

1. INTRODUCTION

1.1 Objective

This work addresses the following objectives in the MFish project "Oreo stock assessment" (OEO2006/02).

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 Southland (part of OEO 1 & OEO 3A), including estimating biomass and sustainable yields.

1.2 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; QMA, Quota Management Area; DWWG, Deepwater Working Group.

1.3 General

This report presents a new stock assessment for the Southland smooth oreo fishery; it uses a CASAL population model employing Bayesian statistical techniques. Inputs are a catch history, standardised CPUE (as an index of abundance), and a time series of length frequency data from the fishery. B_0 (mature biomass) and the current mature biomass (as a percentage of B_0) and some auxiliary parameters were estimated. Yields were not calculated.

Previous oreo stock assessments, e.g., OEO 4 smooth oreo (Doonan et al. 2003) and Southland smooth oreo (Coburn et al. 2003), also used a similar CASAL population model employing Bayesian statistical techniques (Bull et al. 2005).

The Southland fishery is mostly within the Quota Management Area (QMA) OEO 1 but a small amount comes from OEO 3A. Southland has provided most of the OEO 1 smooth oreo catch and is the only component of the OEO 1 QMA that has been assessed. Catches from OEO 1 were variable and only infrequently close to the quota. In recent years the TACC was largely uncaught (Figure 1).

Following the 2003 assessment, industry adopted a voluntary catch limit of 400 t of smooth oreo in this area (Clement and Associates 2007), although the area definition varies somewhat from the assessment area used in the current study. Catches and effort have progressively reduced since 2003.

MFish commissioned NIWA to update the stock assessment of smooth oreo in the Southland fishery. The previous analysis was preformed on data up to the end of the 2000–01 fishing year and was presented by Coburn et al. (2003). Presentations of the revised model inputs were made to the Deep Water Working Group (DWWG) which requested a number of changes to the method. The standardised CPUE analyses was modified in several ways before being accepted, but of most impact was a decision to abandon the early/late fishery model used in the previous stock assessment (see Coburn et al. 2003) and develop a depth structured model. This model uses a single area but different selectivity for shallow and deep catches and means that all the model inputs required reworking, i.e., catch history, standardised CPUE, and length frequency data all needed to be structured by depth.

The new model made sense because the average size of fish in catches (determined from observer length frequency data) increased with depth fished (Figure 2). Catches shallower than 975 m rarely contain fish with a mean length over 37 cm, while beyond 975 m most catches have a mean length greater than 37 cm.

The split between the deep and shallow components of the fishery (975 m) was adopted mostly on the basis of Figure 2. This depth also corresponds with the saddle of the bimodal distribution of catch with respect to depth in the period 1989–90 to 2000–01 (see figure 6 of Coburn et al. 2003). This depth also serves to divide the catch history roughly into halves and was used by Coburn et al. (2003) as the stratum boundary in a post-stratification of length frequency data.

In the 2003 model the size structure with depth was accommodated through the early/late fishery division, which worked well enough because most early fishing was deep while late fishing was a fairly constant mix of shallow and deep. However, since about 2000 fishing was mainly deep so the old model is inappropriate. We could extend the early/late model by allowing the later selectivity to move in response to the mean catch depth and this option was investigated, but the new deep/shallow structure seems more practical and has the advantage that it is no longer necessary to create a simulated length frequency for the early fishery.

This report presents the final stock assessment agreed by the Deepwater Working Group (DWWG).

2. CATCH HISTORY

A catch history (Figure 3) was derived using declared catches of OEO from OEO 1 (see table 2, p. 548, Ministry of Fisheries 2007) and tow-by-tow records of catch from the assessment area (see Figure 4). The tow-by-tow data (see Section 3) 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, area, and depth 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. From 1983–84 onwards, each year's calculation was made independently. The catch history is also given in Table 1.

3. CATCH PER UNIT OF EFFORT

3.1 Background

Coburn & McMillan (2006) described unstandardised catch and effort data for the Southland smooth and black oreo fisheries as well as for the other New Zealand oreo fisheries. Recent smooth oreo standardised CPUE studies include those in Pukaki (Coburn et al. 2007) and in OEO 3A (Coburn et al. 2006).

Smooth oreo and black oreo are managed together despite the two species having different population sizes 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. 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. Hence, separate series of CPUE may be required through the history of the fishery. Recent oreo stock assessments split the time series of standardised CPUE based upon the timing of the adoption of 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).

3.2 Methods

3.2.1 General

The CPUE model was modified from Coburn et al. (2003) by restricting data to vessels with 3 years' involvement, dropping entirely one vessel that was very influential, and by discarding the final two years of data. Using only vessels that have 3 years involvement is motivated by the belief that minor players in the fishery may be of little value in deriving useful abundance information. The excluded influential vessel was removed because it displayed trends in catch rates that were at variance with the rest of the fleet. The last two years' data were discarded because they had few tows. This is a consequence of the reducing catches in this fishery.

In addition, the move to a depth-structured population model meant the CPUE analysis was modified with a depth-year interaction term so that separate indexes could be derived for the shallow and deep components of the fishery. This approach gives independent year effects for each depth-zone but allows the other effects, e.g., vessel, to be shared over all the data. We consider this preferable to a division of the data into separate shallow and deep analyses.

The pre-GPS series was left unmodified from 2003. This series was used as an index of the deep fishery, appropriate because most fishing in that period was deep. This pre-GPS series should be reworked in future to be consistent with the post-GPS analysis.

The assessment area was left the same as in the last analysis as no reason to change it emerged. Methods are similar to recent oreo CPUE and we adopted the bootstrap c.v.s as per Coburn et al. (2007). Records selected are all those tows that report a target species of SSO or BOE or OEO in the assessment area. Only the post-GPS index was calculated. Two part (positive catch and zero catch) models were used because typically more than 10% of records reported a zero catch of smooth oreo.

3.2.2 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 CPUE analysis used tow-by-tow estimates of catch, and all further reported catches or catch rates in this CPUE section are directly from these data and not adjusted to declared catches.

For the standardised analysis we used only those tow-by-tow records of fishing in a defined assessment area where the target species was SSO or BOE or OEO, i.e., a subset of the set mentioned above. This means there may be records with a zero catch of smooth oreo.

3.2.3 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, 1997a, 1999).

3.2.4 Assessment area

The assessment area was defined to enclose the main fishery and is shown in Figure 4 (vertices are 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), Coburn et al. (2003) provided more on this choice. It is not known what degree of mixing might occur between smooth oreo populations in the assessment area and those outside it.

3.2.5 Standardised CPUE

Predictor variables that were offered for selection in the regression models are listed in Table 2. Two innately categorical predictors were used: vessel had a category for each vessel; target species had categories for SSO, BOE, and OEO, (year is also in the model as an innately categorical variable, but it is not a standardising predictor). The other predictors were continuous, e.g., time of day. 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.

3.2.6 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. Because there was no additional data to work with, no attempt was made to revisit the pre-GPS analyses presented in Coburn et al. (2003). We present only the post-GPS analysis here.

3.2.7 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).

3.2.8 Two part models

Separate regression models were used to model the tows where there was a non-zero catch of smooth oreo (the positive catch regression), and all the tows where it is the success (i.e., a non-zero catch) only that is modeled (the zero catch regression). The zero catch regression does not consider how much smooth oreo was caught, only whether there was some or none.

The positive catch regression is a log linear model where log(CPUE) is regressed against the predictor variables. The zero catch regression is a generalised linear regression employing the logit link function where the response is a logical variable that is true for a non-zero catch and false for a zero catch. It fits as the probability of a non-zero (i.e., successful) catch. Mathematical details of the models were given by Vignaux (1994).

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. For the GLM regression, an R^2 equivalent is defined as (1 - deviance/null-deviance)*100. The base model has only the year * depth-zone interaction term and is the minimum model required from which we can extract a year effect for each depth-zone (termed the null model). Note that because information about the depth of tows is already included in the interaction term (year * depth-zone), depth is no longer a candidate variable in the model selection process.

3.2.9 Year effects

Because the models have a year * depth-zone interaction term, extracting the year effects is slightly different from most CPUE models. Coburn et al. (2006) described the method where models with interactions between year and depth and between year and subarea were examined as possible alternatives to the non-interaction model. The same method is used here.

3.2.10 Confidence interval

An estimate of confidence interval on the year effects was calculated using a bootstrap approach. Coburn et al. (2007) first explored this and considered several alternatives of which a nested resampling regime was favoured because it best mimics the fishing process, i.e., a set of vessels conducts a set of tows. This resamples the data first by vessel then by tow within vessel. Thus the resampled data vary in the number of records selected in each bootstrap iteration.

3.3 Results

3.3.1 Unstandardised CPUE

General description

Smooth oreo catch is distributed around the 1000 m depth contour off the southeast coast of the South Island (Figure 4). The distribution is distinct from that on the south Chatham Rise and from the Pukaki Rise fishery to the south. Our assessment area excludes the Waitaki Canyon at the northern tip of the distribution and also excludes a deep canyon at approximately longitude 172 E (Figure 4). The reasons for excluding these were given by Coburn et al. (2003).

Unstandardised CPUE for the pre-GPS period for all tows that targeted SSO or BOE or OEO from the assessment area are provided in Table 3. Effort (number of tows) overall is variable but has trended down markedly since a high of 677 in 2001–02. The number of vessels varied from a maximum of 18 in 1992–93 to 5 in 2005–06. Catches varied from a maximum of 1860 t in 2001–02 to 230 t in 2005–06. Mean catch per tow shows little consistent trend. The fraction of zero tows varied between 26 and 11% which is why we use two part models for the standardised analysis. The fraction of tows that target SSO varied from 8% to 74% with no clear trend.

Vessel, year structure

Few vessels maintained long periods of activity in this fishery. The average period of involvement in the post-GPS fishery is 3.3 years (Table 4). Only one vessel fished the entire period, but this vessel was excluded from the standardised CPUE analysis. Twenty-three vessels had at least 3 years' involvement. The pattern of turnover is typical of other oreo fisheries.

Catch by depth profile

The depth profile of catch is complex and changing (Figure 5). In the period before GPS most catch was taken deep however over the 1990s catch shifted into shallower water. Since about 2000–01 catch is again mainly from the deep.

3.3.2 The standardised CPUE

Selection of the positive catch model

The selected standardising predictors were (in the order of selection) vessel, axis-position (derived from the start position, see Coburn et al. (2003)), and day with a total R^2 of 18.7% (null model 6.9 %) (Table 5).

Selection of the zero catch model

The selected standardising predictors were (in the order of selection) vessel and target with a total R^2 of 13.2% (null model 3.6 %) (Table 6).

Index and c.v.s

Indices trend downward for both the shallow and deep depth-zones (Figure 6). However, there is much uncertainty in these indices, particularly for the deep. Actual values of indices and c.v.s are provided in Table 7.

4. OBSERVER LENGTH FREQUENCIES

4.1 Data

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 (Scientific Observer Programme, SOP). Since then various industry bodies have also collected similar information. This study examines length data collected only from SOP observers as earlier work (Coburn et al. 2003) suggested there appeared to be differences in data between the two sources. There has also been minimal collection of new data for this fishery by industry. Length frequency records from fishery observers are stored in the Empress database 'obs_lfs' maintained by NIWA (Sanders & Mackay 2000).

We extracted all SOP records where smooth oreo were measured from within the assessment area (see Figure 4). The distribution of samples by fishing year and depth-zone are shown in Table 8: 78 samples were shallow and 51 deep. Only 13 shallow and 4 deep samples were collected before 1999–2000.

The data were examined to identify any important covariates among the available information. Only depth emerged as important, consistent with both the earlier Southland and Pukaki analyses.

The method to generate suitable input for the population model from these data follows closely those of Coburn et al. (2007, section 5). The main difference is that in this case there was no post-stratification of the data because the population model is now explicitly depth structured, so post-stratifying the data (with respect to depth) is no longer necessary. Instead we calculated the length frequencies separately from the shallow and deep length frequency data.

Year groups of aggregated data were determined independently for the shallow and deep strata based on the available data (Table 8). There are four shallow year groups and two deep year groups.

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. Weighting by catch 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.

4.2 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. Year group sample size varied from 13 to 30 and a maximum of five consecutive years of data was spanned (Table 9). Combining length frequencies over a maximum period of 5 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 8 (the samples in 1986–87 and 1988–89 were discarded), and the year applied (Table 9) is the year in which the derived length frequency were used to represent the population in the model.

4.3 Bootstrap c.v.s

The above methods were used to derive the weighted, composite length frequencies for the four shallow and two deep year groups (Figure 7). 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. Coburn et al. (2007) provided greater detail on the bootstrapping method.

5. STOCK ASSESSMENT

5.1 Model structure

The model structure is similar to that used for the OEO 3A smooth oreo stock assessment 2005–06 (Doonan et al. 2005). The observational data were incorporated into an age-based Bayesian stock assessment with deterministic recruitment to estimate stock size. The stock was considered to reside in a single area, with a partition by age and sex, but not by maturity. Age groups were 5–70 years, with a plus group of 70+.

There is a single time step in the model, in which the order of processes is ageing, recruitment, maturation, and mortality (natural and fishing). It is assumed that 50% of the recruits are males, and that year class strengths over the years 1972–73 to 2001–02 are equal. Mortality was "instantaneous", i.e., half the natural mortality was applied, then all of the fishing mortality, then half the natural mortality. A maximum exploitation rate of 0.58 was permitted.

The values for the life history parameters were derived from oreo samples taken from a range of areas. The natural mortality estimate is from fish sampled from the Puysegur Bank fishery. The von Bertalanffy parameters and associated length-at-age c.v.s are from fish sampled from the Chatham Rise and Puysegur Bank fisheries (Doonan et al. 1997b). The mean length-at-age curves are plotted in Figure 8. The length-weight parameters are from research trawl samples from the south Chatham Rise (Doonan et al. 1995), while the recruitment steepness for the Beverton and Holt recruitment relationship is an assumed value.

The maturity ogive developed during the 2003 stock assessment of smooth oreo from south Chatham Rise Appendix 2, in Doonan et al. (2003) was used. The age at which 50% are mature is between 18 and 19 for males and between 25 and 26 years for females (Figure 9).

5.2 Methods

Parameters which were made free in the model were: (1) the virgin biomass (B_0), (2) the relativity constants (qs) which are involved in scaling the standardised CPUE indices to a biomass, (3) the parameters defining the curves for the fishing selectivitites. Selectivity for shallow was defined as a double normal and for the deep as logistic. The estimated parameters and their priors are summarised in Table 11.

The CPUE data are fitted with a lognormal error distribution. The length frequency data are fitted with a lognormal error distribution with a nominal process error of one added to the boot strap estimated c.v.s.

Maximum Posterior Density (MPD) estimates were found for the free parameters in the model. The stock assessment program CASAL v2.08 (Bull et al. 2005) was used to implement and fit the models (see Appendix A for the CASAL model files). The uncertainty in the estimates was evaluated by Markov Chain Monte Carlo (MCMC) simulations.

The following assumptions were made in this analysis.

1. The CPUE analysis indexed the abundance of smooth oreo in the assessment area (Figure 4) of OEO 1/3A.
2. The length frequency samples were representative of the catch.
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 assessment 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.

For further detail, the attached CASAL control files (Appendix A) together with the CASAL software documentation (Bull et al. 2005) provide a comprehensive record of the model specification and estimation procedures.

5.3 Results

5.3.1 Maximum posterior density (MPD)

The MPD run results including estimated parameters and objective function components are shown in Table 12. Virgin mature biomass, 16 800 t, is a little greater than that estimated from the base case model by Coburn et al. (2003) (15 300 t).

The selectivities ogives were plotted (Figure 10). Selectivity for the deep is to the right of that for the shallow as we would expect.

Estimated mature biomass has fallen, as have the vulnerable or selected biomass in both shallow and deep components (Figure 11). The rate of decline is noticeably greater in the deep than the shallow. However, the downward trend ends about 2004–05 and biomasses increase. Also shown are the fits of the CPUE indices. Shallow CPUE data fits well without any obvious residual pattern and no individual point falls outside the 2 s.e. bars. For deep CPUE, the pre-GPS series has a pattern in the residuals (model biomass does not drop fast enough to match the CPUE index) and one data point falls outside the 2 s.e. bars. For the deep CPUE post-GPS fit there is no trend in the residuals and all data points are within 2 s.e.

Mean fits to the length frequency data (Figure 12) reveal a general pattern of misfit to shallow data where the observed data have a more peaked distribution than the model. However, normalised standardised residuals rarely exceed one and the mean length of the model versus the observed data distributions are very close. For the deep, males appear to fit better than females. In particular the model fails to fit an observed modal peak of females at about 43 cm and there is a small divergence of model to observed mean lengths.

To meet the statistical assumptions of the model standardised residuals should be normally distributed. This requirement can be evaluated by plotting the residuals against a corresponding normal distribution. If residuals are perfectly normal the resultant plot (a Q-Q norm plot) will lie along a straight line. For the CPUE data (Figure 13) the post-GPS data look normally distributed, but the deep pre-GPS data depart slightly from normal. The length frequency data (Figure 14) again depart slightly.

Fits of the length frequency data for each individual year group (Figure 15) are shown with the bootstrap 2 s.e. confidence interval bars (i.e., no added process error). Generally the model distribution fits inside the envelope provided by the 2 s.e. bars. The main exceptions are the peaks of the female data in the first 3 shallow year groups and the last of the deep year groups. At least visually, the fits to the male data seem better that the female.

5.3.2 Monte Carlo Markov Chain (MCMC)

A Monte Carlo Markov Chain technique was used to explore the variation of quantities of interest; free parameters and key metrics. A chain of about 1.4 million iterations was generated. The first 100 000 iterations were discarded (burn-in) and every 1000^{th} point was thereafter retained for analyses, giving about 1300 points. Traces of the free parameter values over the chain length were plotted to check model results (Figure 16). These showed the desired well mixed pattern. In addition, we plotted running means and these converged nicely. Derived parameter values were generated from a random sample of 1000 points from the retained points. By way of example, Figure 16 plots the trace for mature current biomass (expressed as a percentage of virgin mature biomass).

To further establish the suitability of the MCMC method we ran a second and independent chain started from a different point. Traces of the free parameter values were plotted along with cumulative distributions of key metrics to compare with the first chain (Figure 17). These show very similar distributions suggesting the method is working correctly.

Table 13 summarises the distributions for the first chain for the free parameters as well as key derived quantities. For virgin mature biomass the median value is 17 400 tonnes, and a 90% c.i. is 15 600 to 21 700 tonnes. Current mature biomass expressed as a percentage of initial ranges from 18.6 to 41.0 (90% range). Current shallow vulnerable biomass expressed as a percentage of initial ranges from 55.5 to 72.9 (90% range) while current deep vulnerable biomass expressed as a percentage of initial ranges from 12.0 to 36.5 (90% range).

6. DISCUSSION

The only direct abundance information in this study is from the standardised CPUE, so the assumption that these index abundance is key to this analysis. This study alone can't confirm this assumption. However, a measure of confidence comes from the use of similar CPUE in several other oreo assessments including those with fishery-independent abundance information, e.g., acoustic biomass, e.g., see Doonan et al. (2003).

This analysis incorporates an additional five years' catch effort and length frequency data and is slightly more optimistic than the previous assessment. This model has allowed us to discard the simulated length frequency and incorporates more directly the dependence of fish size on depth. There is a visual improvement in fits to the length frequency data. This study suggests that the adoption of lower catches by the industry was appropriate. Increases in fish size caught and improvements in raw CPUE in the last few years are may be seen as additional benefits of the reduced catches.

While not presented here, several alternative models all reached similar bottom lines on B_0 and suggest the result is robust to changes in model detail. Looking ahead, moving to an area-based model seems advantageous. This will explicitly incorporate the unspoken assumption of movement of fish from shallow to deep as they age and allow meaningful measures of this process to be estimated. A candidate model of this sort used all recruitment to a shallow area with a logistic age-based one-way movement of fish to a deep area. Selectivity on the shallow area was logistic while in the deep all fish were selected. The assumptions need to be weighed up, but they seem to be supported by the observations (length frequencies) and this is a slightly more economical model (one less estimated parameter).

This candidate model gave essentially the same results as the model presented here so it could be argued its adoption is of purely academic interest. But, it seems likely that a movement to deeper water as fish age is a universal characteristic of smooth oreo so its estimation is worthwhile. A flaw with the current setup is that there is nothing to prevent 'holes' in the selectivity curves. This would suggest a cryptic biomass that is not vulnerable to the fishery. In the absence of direct evidence, accepting a model with a large cryptic biomass seems unwise. An area model, properly specified, will rule out this possibility.

Observers can collect otoliths as well as length frequencies, so an opportunity exists to add independent age structure data to validate this model.

In summary, the addition of five years' new information in concert with a better model structure supports the previous assessment and suggests that the current catches are reasonable.

7. ACKNOWLEDGMENTS

This research was carried out for the Ministry of Fisheries under Project OEO2006/02. We thank members of the 2006–07 DWWG for advice during the development of the model. Thanks to Kevin Sullivan of MFish for useful comments on the manuscript. Thanks to Andy McKenzie for providing the CASAL scripts and several tables and figures from the 2006–07 Pukaki smooth oreo assessment and to Mike Beardsell for editing.

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Table 1: A catch history of smooth oreo from the Southland fishery assessment area by depth-zone. Catches are rounded to the nearest 10 t.

Fishing year	Shallow	Deep	Fishing year	Shallow	Deep
1977–78	210	0	1992–93	410	250
1978–79	10	0	1993–94	220	150
1979–80	40	0	1994–95	80	150
1980–81	0	0	1995–96	600	500
1981–82	0	0	1996–97	440	70
1982–83	0	0	1997–98	320	230
1983–84	480	660	1998–99	480	620
1984–85	170	510	1999–00	650	480
1985–86	480	3 760	2000–01	400	610
1986–87	30	160	2001–02	580	1 470
1987–88	130	860	2002–03	130	1 320
1988–89	0	240	2003–04	330	420
1989–90	210	430	2004–05	140	290
1990–91	410	420	2005–06	120	140
1991–92	530	380			

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	2	Target species, SSO, BOE, or OEO.
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 (a measure of location, see Coburn et al. 2003 for detail), blocked into 8 bins.
Vessel	21	A parameter estimated for each vessel.

Table 3: Unstandardised CPUE for all tows in the assessment area that targeted SSO or BOE or OEO from 1992–93 to 2005–06. 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.

Fishing year	Number of tows	Number of vessels	SSO catch (t)	Mean catch per tow	Zero tows (%)	SSO target tows (%)
1992–93*	168	18	570	3.4	22	74
1993–94*	107	12	340	3.1	21	30
1994–95*	49	6	200	4.1	22	16
1995–96*	188	14	820	4.4	19	8
1996–97*	439	15	470	1.1	25	44
1997–98*	199	13	480	2.4	22	35
1998–99*	388	15	1 020	2.6	11	31
1999–00*	491	11	1 050	2.1	13	61
2000–01*	268	11	920	3.4	14	30
2001–02*	677	9	1 860	2.7	19	32
2002–03*	482	11	1 380	2.9	26	14
2003–04*	306	8	630	2.1	14	20
2004–05	153	5	350	2.3	16	31
2005–06	59	5	230	3.9	12	19

Table 4: Number of tows by fishing year and vessel. Same dataset as Table 3. 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. * indicates the vessel that was excluded from the standardised CPUE analysis because it was highly influential.

	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06
	8	2	–	–	–	–	–	–	–	–	–	–	–	–
	2	2	–	–	–	–	–	–	–	–	–	–	–	–
	4	4	–	–	–	–	–	–	–	–	–	–	–	–
	38	7	–	–	–	–	–	–	–	–	–	–	–	–
	3	14	5	–	–	–	–	–	–	–	–	–	–	–
	2	20	1	8	–	–	–	–	–	–	–	–	–	–
	42	18	–	14	93	–	–	–	–	–	–	–	–	–
	4	1	8	4	12	–	–	–	–	–	–	–	–	–
	7	–	–	2	2	–	–	–	–	–	–	–	–	–
	2	–	–	5	–	67	110	–	–	–	–	–	–	–
	1	–	–	–	–	–	13	–	–	–	–	–	–	–
	3	2	–	11	13	8	1	112	7	–	1	–	–	–
*	22	20	18	61	46	23	14	15	80	181	259	96	34	16
	–	16	–	4	8	–	–	–	–	–	–	–	–	–
	–	1	–	10	14	6	12	–	–	–	–	–	–	–
	–	–	8	20	11	6	–	–	–	–	–	–	–	–
	–	–	–	24	–	2	–	3	–	–	–	–	–	–
	–	–	–	23	2	20	27	39	7	–	–	–	–	2
	–	–	–	–	8	20	–	–	–	–	–	–	–	–
	–	–	–	–	1	1	–	–	–	–	–	–	–	–
	–	–	–	–	10	4	–	–	–	–	–	–	–	–
	–	–	–	–	203	–	1	5	–	–	–	–	–	–
	–	–	–	–	13	–	43	33	19	58	1	11	39	–
	–	–	–	–	–	33	7	20	3	16	17	–	–	–
	–	–	–	–	–	8	64	44	14	31	6	44	–	–
	–	–	–	–	–	–	6	–	1	–	7	–	–	–
	–	–	–	–	–	–	35	–	–	–	1	–	–	–
	–	–	–	–	–	–	34	1	–	117	22	3	–	–
	–	–	–	–	–	–	16	196	116	254	146	122	53	4
	–	–	–	–	–	–	–	23	2	4	–	9	3	–
	–	–	–	–	–	–	–	–	5	3	1	–	–	–
	–	–	–	–	–	–	–	–	14	13	21	2	–	–
	–	–	–	–	–	–	–	–	–	–	–	–	24	28

Table 5: R^2 (%) values for the stepwise model selection of variables for the positive catch 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. –, n.a.

	step1	step2	step3
Vessel	14.1	–	–
Axis position	10.9	17.0	–
Day	9.2	15.9	**18.7**
improvement	7.2	2.9	1.8

Table 6: R^2 (%) values for the stepwise model selection of variables for the zero catch 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. –, n.a.

	step1	step2
Vessel	11.2	–
Target	5.6	**13.2**
improvement	7.6	2.0

Table 7: CPUE indices and c.v.s (%).

	Shallow		Deep	
Fishing year	Index (kg/tow)	Bootstrap c.v. (%)	Index (kg/tow)	Bootstrap c.v. (%)
1992–93	1 489	57	1 401	73
1993–94	956	47	916	53
1994–95	1 521	72	428	121
1995–96	1 173	37	1 862	84
1996–97	511	84	2 117	41
1997–98	1 477	39	502	59
1998–99	939	42	915	50
1999–00	842	44	611	48
2000–01	758	46	385	72
2001–02	573	44	658	53
2002–03	303	48	406	76
2003–04	480	57	719	218

Table 8: Length frequency samples from the assessment area by fishing year and depth-zone. –, no data. a=1993–94 to 1997–98 ; b=1999–2000; c=2000–01 to 2001–02; d=2002–03 to 2005–06; e=1997–98 to 2001–02; f=2002–03 to 2004–05. –, no data.

Fishing year	Shallow	Year-group	Deep	Year-group
1986–87	–		1	
1988–89	–		2	
1993–94	2	a	–	
1994–95	3	a	–	
1995–96	2	a	–	
1996–97	4	a	–	
1997–98	2	a	1	e
1999–00	30	b	6	e
2000–01	4	c	–	
2001–02	18	c	20	e
2002–03	1	d	6	f
2003–04	2	d	10	f
2004–05	7	d	5	f
2005–06	3	d	–	

Table 9: Year group, year applied, and the total number of length frequencies for the shallow and deep year groups.

Year group	Year applied	No. of lfs
shallow		
a=1993–94 to 1997–98	1995–96	13
b=1999–2000	1999–00	30
c=2000–01 to 2001–02	2001–02	22
d=2002–03 to 2005–06	2004–05	13
Deep		
e=1997–98 to 2001–02	2001–02	27
f=2002–03 to 2004–05	2003–04	21

Table 10: Fixed life history parameters for smooth oreo.

Parameter	Symbol (unit)	Female	Male
Natural mortality	M (yr^{-1})	0.063	0.063
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-at-age c.v.		0.1	0.1
Length-weight parameters*	a	0.029	0.032
	b	2.90	2.87
Recruitment steepness		0.75	0.75

* $W(kg) = L(cm)^b$

Table 11: Estimated parameters and priors of the assessment model. U, uniform distribution.

Parameter	Number	Prior
Virgin mature biomass (B_0)	1	ln B_0 ~U[ln(100), ln (100 000)]
Catchability coefficients		
pre-GPS CPUE, deep	1	U[1e-8, 1e8]
post-GPS CPUE, shallow	1	U[1e-8, 1e8]
post-GPS CPUE, deep	1	U[1e-8, 1e8]
Age-based selectivity - shallow fishery, double normal		
Age at mode, (a1)	1	U[1, 50]
years to go from mode to half mode left, (sL)	1	U[0, 35]
years to go from mode to half mode right, (sR)	1	U[0, 35]
Age-based selectivity - deep fishery, logistic		
Age at 50% selected, (a50)	1	U[1, 50]
Extra years to go from 50 to 95% selected, (to95)	1	U[0.1, 35]

Table 12: MPD run results.

(a) Estimated parameters		value
Virgin mature biomass (B_0)		16800
Selectivity, shallow	a1	18.9
	sL	4.7
	sR	8.3
Selectivity, deep	a50	26.2
	to95	7.0

(b) objective function components	Value
Pre-GPS CPUE, deep	-0.9
Post-GPS CPUE, shallow	-5.0
Post-GPS CPUE, deep	-1.3
Shallow fishery length frequencies	50.7
Deep fishery length frequencies	29.9
Prior on virgin mature biomass	9.7
Total	83.1

Table 13: Bayesian estimates for the free parameters and for key derived metrics.

		5%	median	mean	95%	c.v. (%)
Free parameters						
Virgin mature biomass (B_0)		15 600	17 400	17 900	21 700	12
Selectivity, shallow	a1	17.2	19.0	19.0	21.0	6
	sL	3.9	4.8	4.8	5.8	12
	sR	5.9	8.3	8.4	11.2	20
Selectivity, deep	a50	22.1	26.0	26.2	30.8	10
	to95	1.9	7.1	7.0	11.0	37
Derived quantities						
Current mature biomass (% initial)		19	27	28	41	25
Current selected shallow biomass (% initial)		56	65	65	73	8
Current selected deep biomass (% initial)		12	20	22	36	36

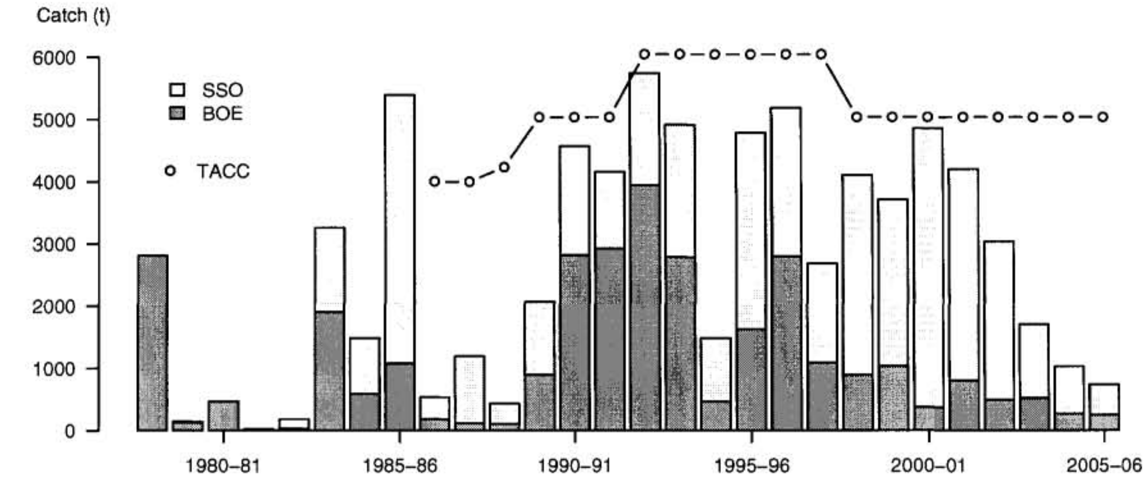

Figure 1: OEO 1 TACC and reported catches by species. The data are from tables 2 and 3 of the Oreo section of Ministry of Fisheries (2007). Catches are from Table 2 reported landings, and species breakdown are from Table 3. The 1983–83 catches were split 50:50 to the 1982–83 and 1983–84 fishing years. Years to 1982–83 are 1 April to 31 March; years from 1983–84 are 1 October to 30 September.

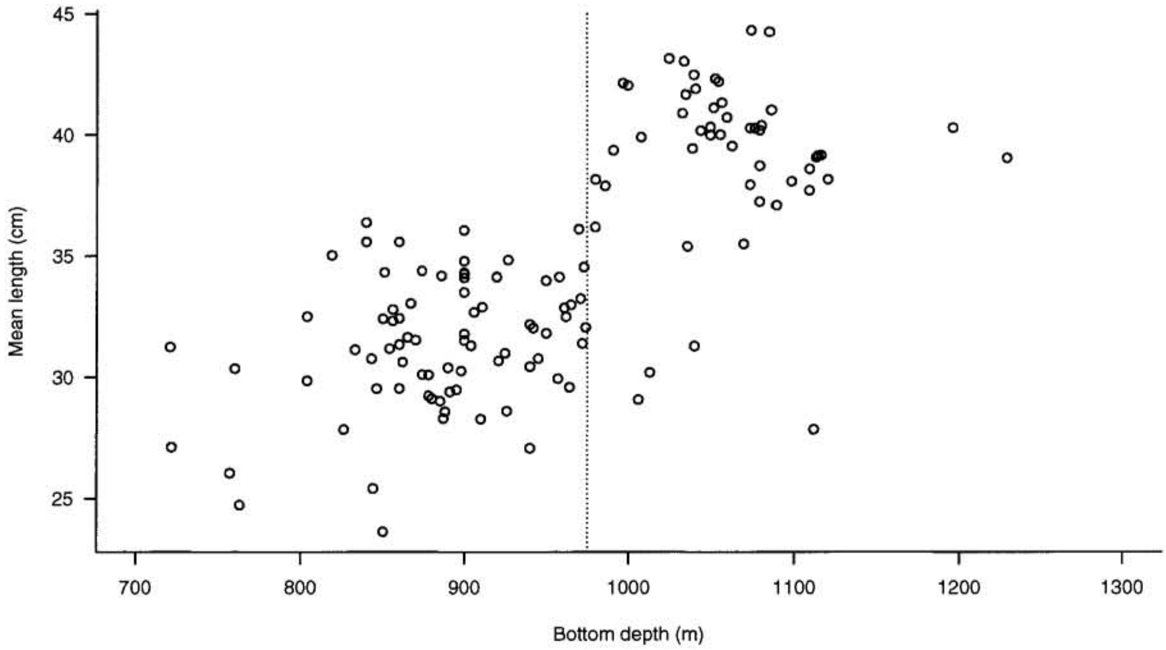

Figure 2: Smooth oreo mean length versus bottom depth from the Southland assessment area. Each point is the mean length of fish in an observer length frequency sample. The dotted vertical line is at 975 m.

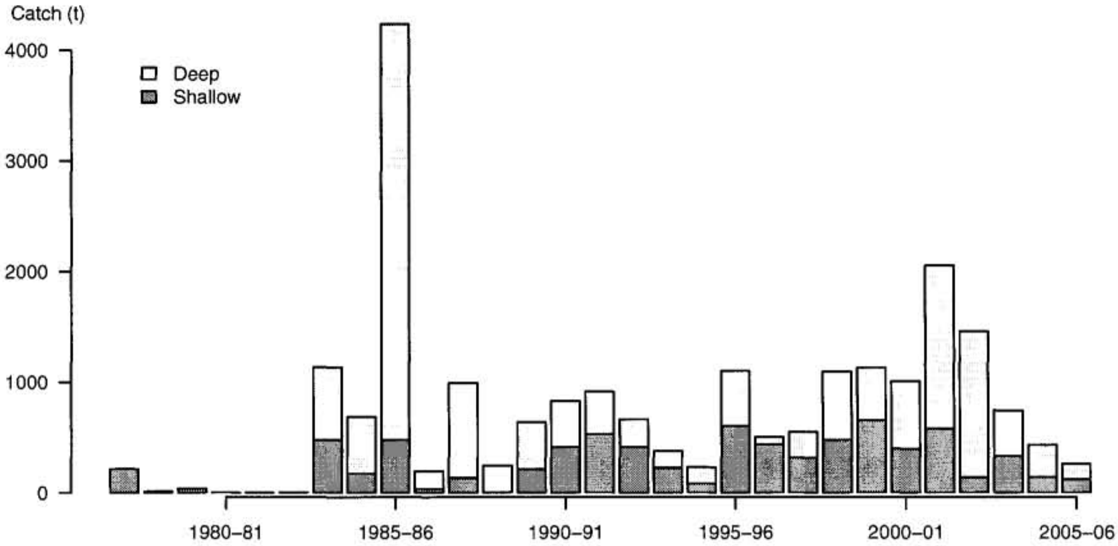

Figure 3: The catch history of smooth oreo from the assessment area by depth-zone (shallow < 975 m, deep >= 975 m).

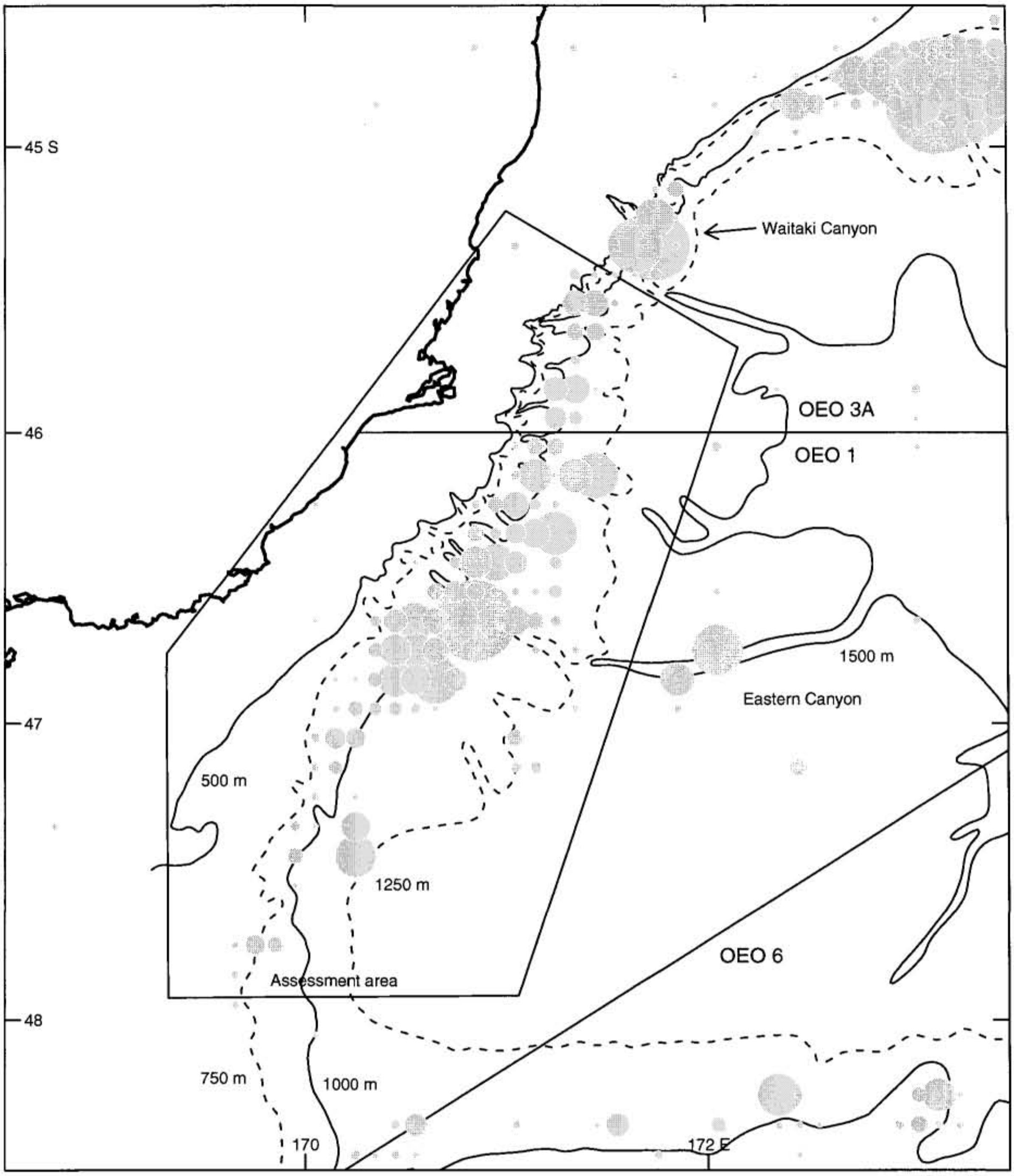

Figure 4: Smooth oreo estimated catch from all years to (and including) 2005–06. The area was divided into cells that are 0.1 degrees square and catches were summed for each cell. Circles proportional in area to the catch are plotted centred on the cells. Catches less than 10 tonnes per cell are not shown. Circles are layered so smaller circles are never hidden by larger ones. The assessment area and bottom topography are also shown.

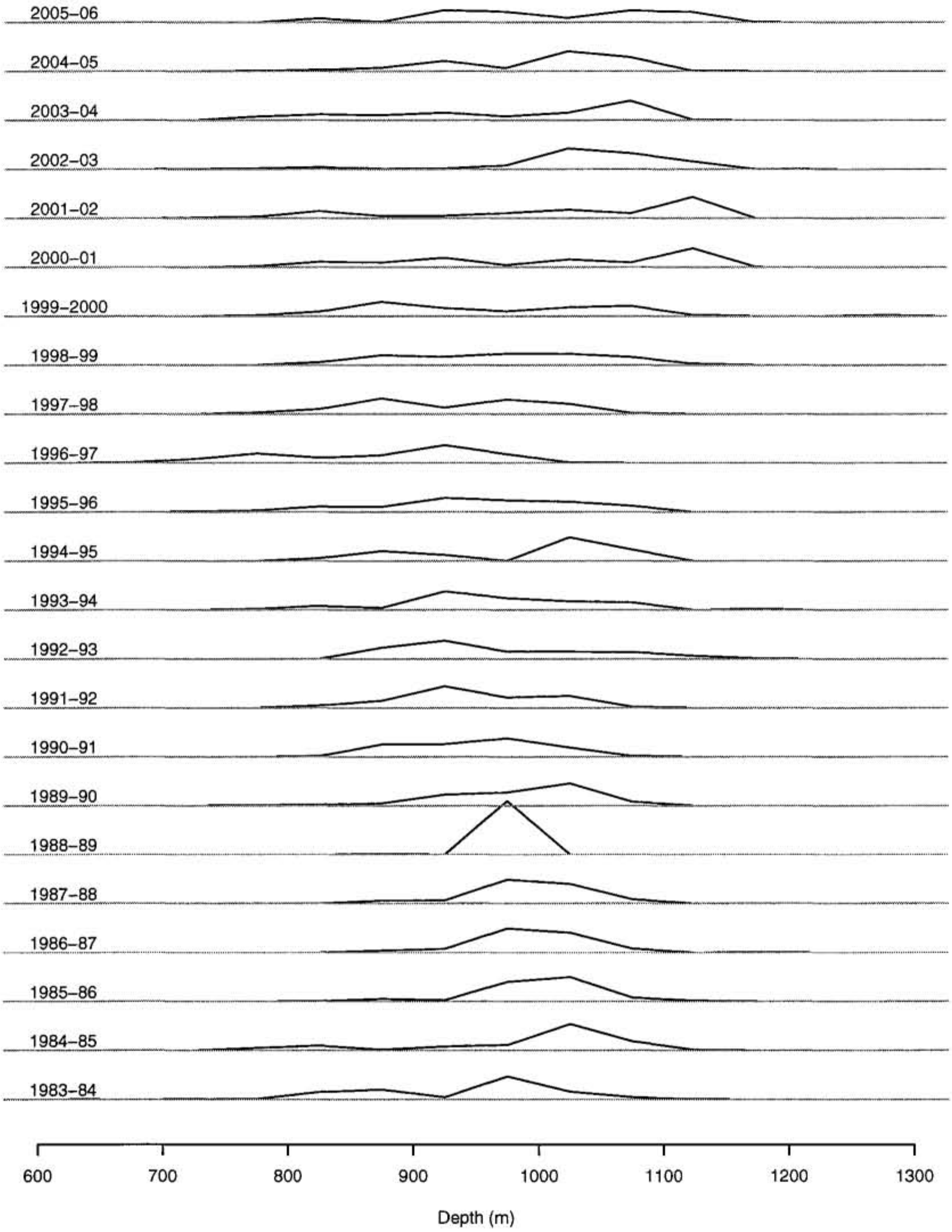

Figure 5: Smooth oreo catch distribution by depth for years 1983–84 to 2005–06 (solid horizontal line). Smooth oreo catch fraction was calculated by 50 m depth bins and plotted at bin mid point (hence area under each profile is the same). Note data before 1983–84 are not shown as there were only trivial catches then.

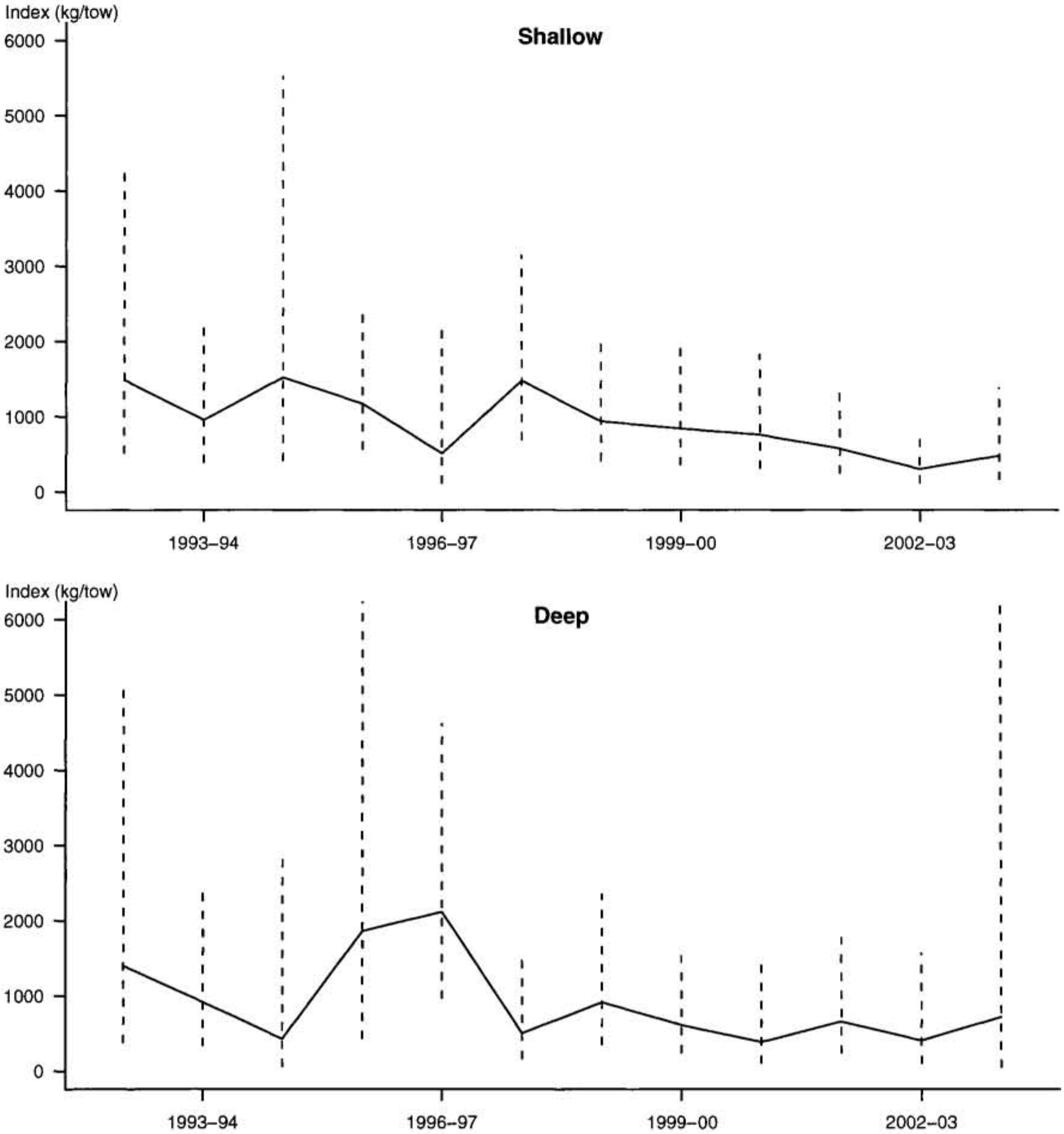

Figure 6: Year indices with +/- 2 s.e. based on the nested bootstrap for the shallow and deep depth-zones.

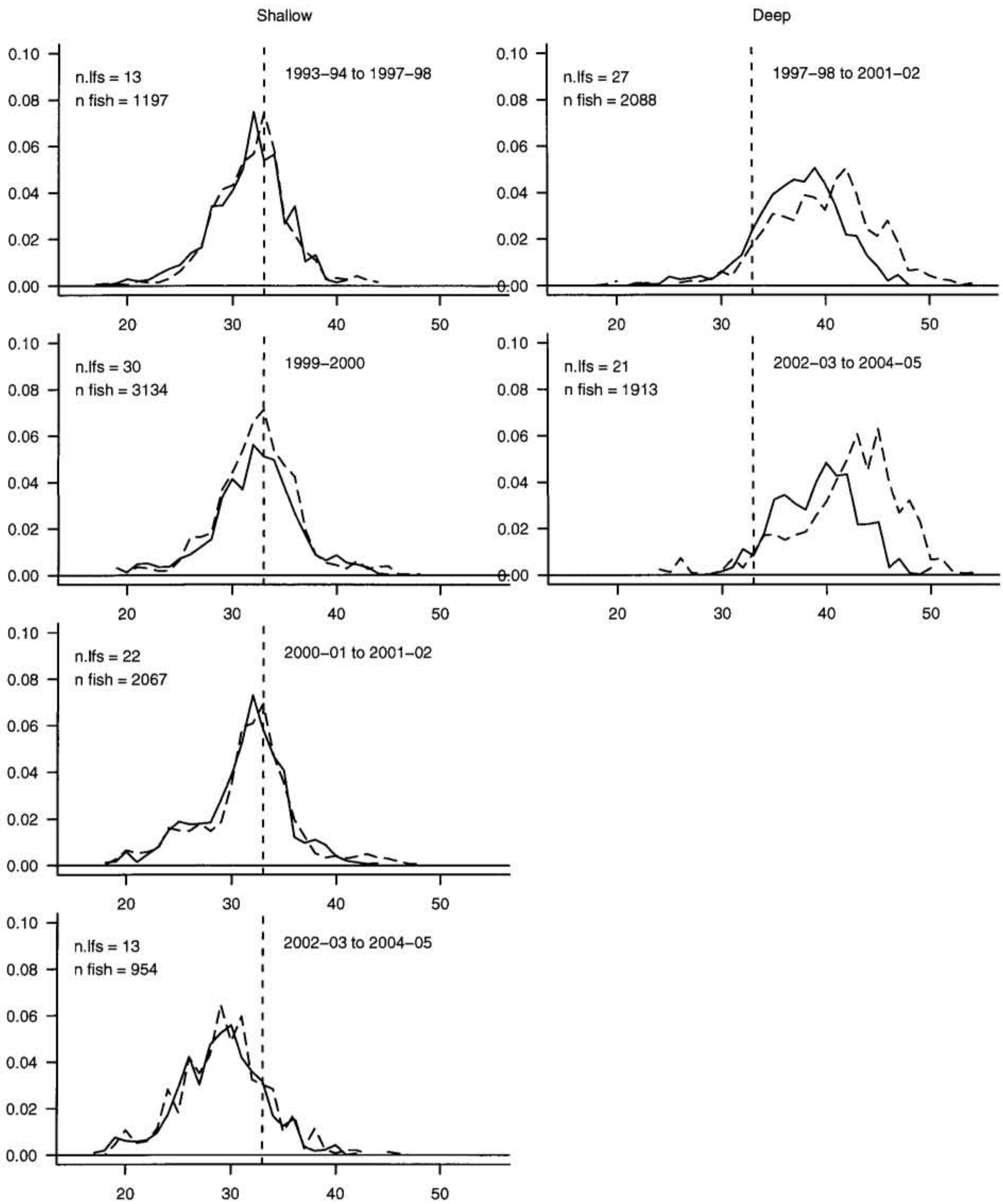

Figure 7: Smooth oreo composite length frequencies by year groups (males solid line, females dashed line). Left hand panels for shallow fishery, right hand panels for deep fishery. Also shown are the number of length frequency samples in each composite (n.lfs) and the number of fish measured (n.fish). The vertical dashed line is at 33 cm simply as a visual reference; it is not used in the model.

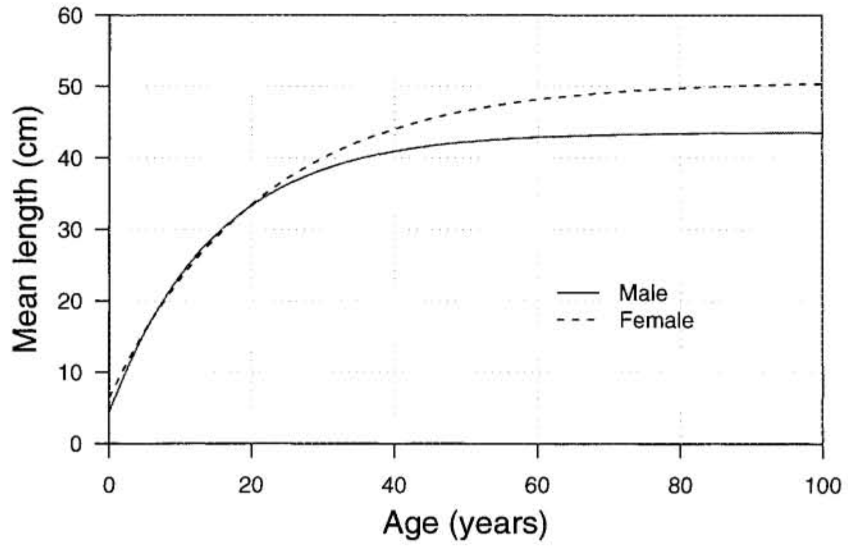

Figure 8: Mean length-at-age for smooth oreo (male and female).

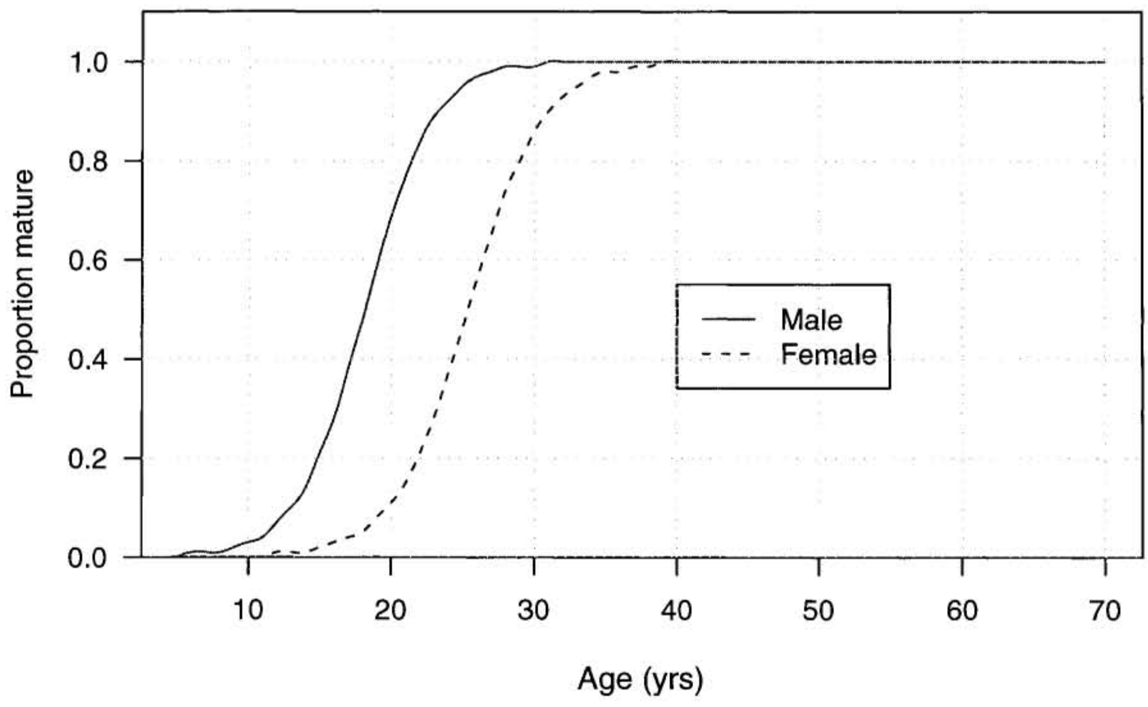

Figure 9: Proportion mature by age (male and female).

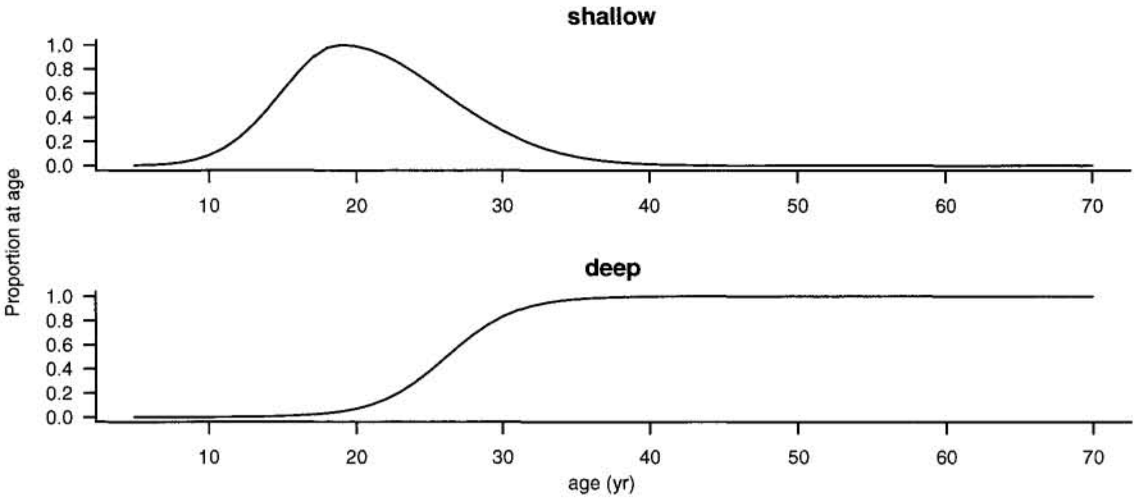

Figure 10: Model selectivity ogives for the shallow (top) and deep (bottom) fisheries.

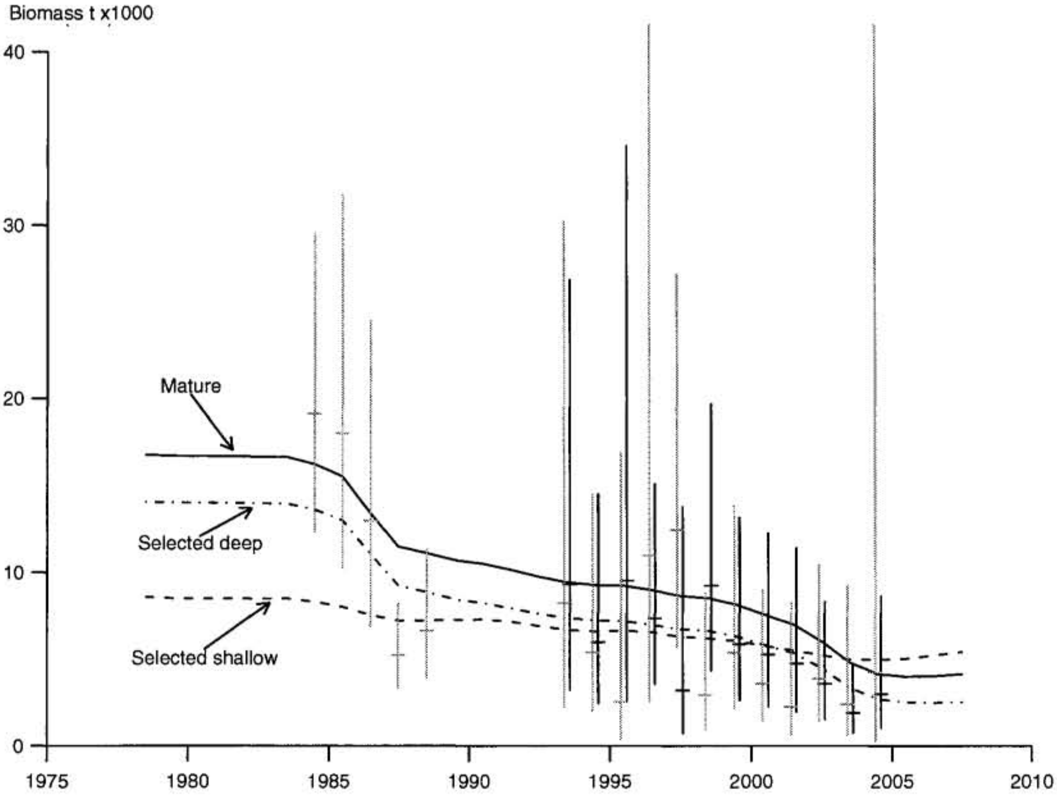

Figure 11: Mature biomass and selected biomass for the shallow and deep fisheries. Also shown are the CPUE indices from the pre- and post-GPS analysis for the deep fishery (in gray) and the post-GPS analyses for the shallow fishery (in black). CPUE indices are shown with +/- 2 s.e. confidence interval indicated by the vertical lines (the post-GPS CPUE data are slightly offset to avoid over plotting). The CPUE data were scaled by catchability coefficients to match the biomass scale.

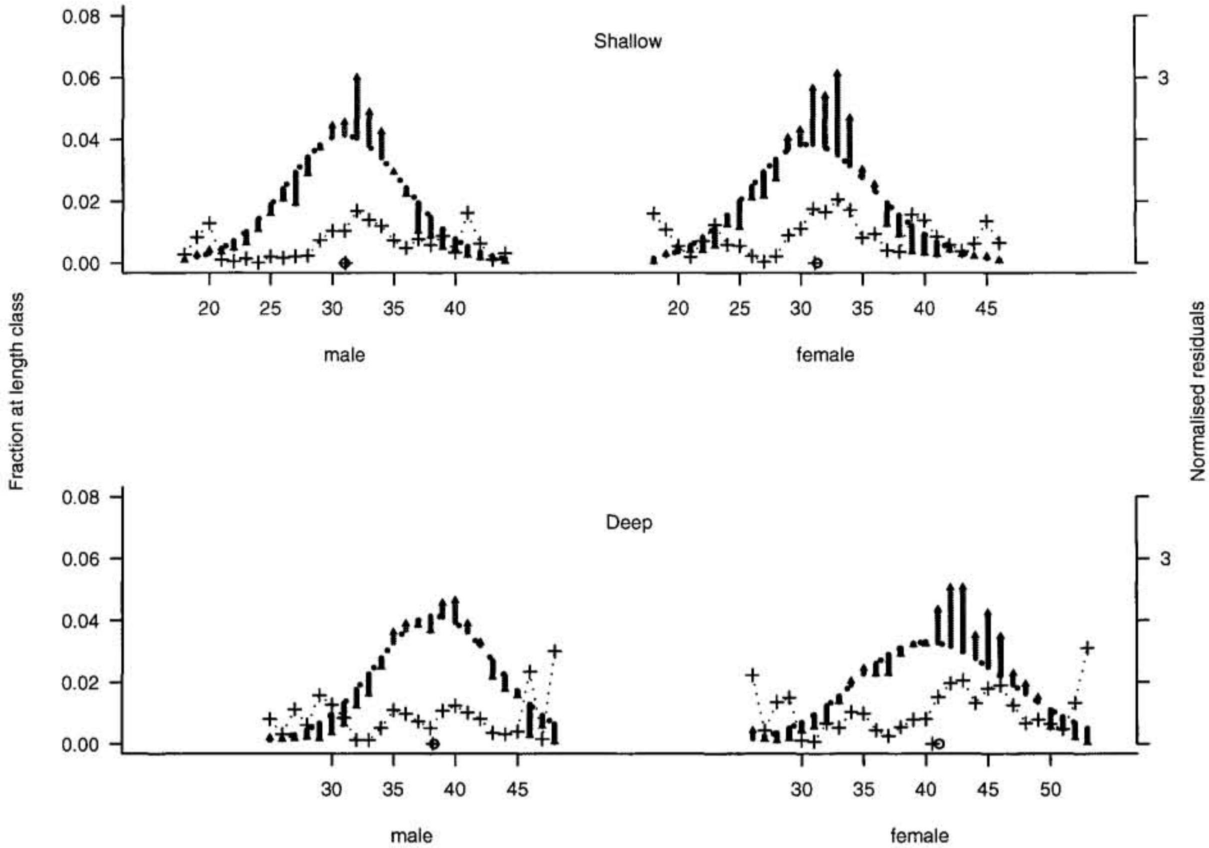

Figure 12: Average fits of length frequency data for the shallow and deep fisheries. Mean expected model values over the time series (4 year groups for shallow, 2 year groups for deep) are shown along with the corresponding observation data. Arrows show the residuals. Also shown (right hand axis) are standardised residuals (+). In addition overall means of the distributions are shown on the y=0 line; 0 for observation, + for model expected values.

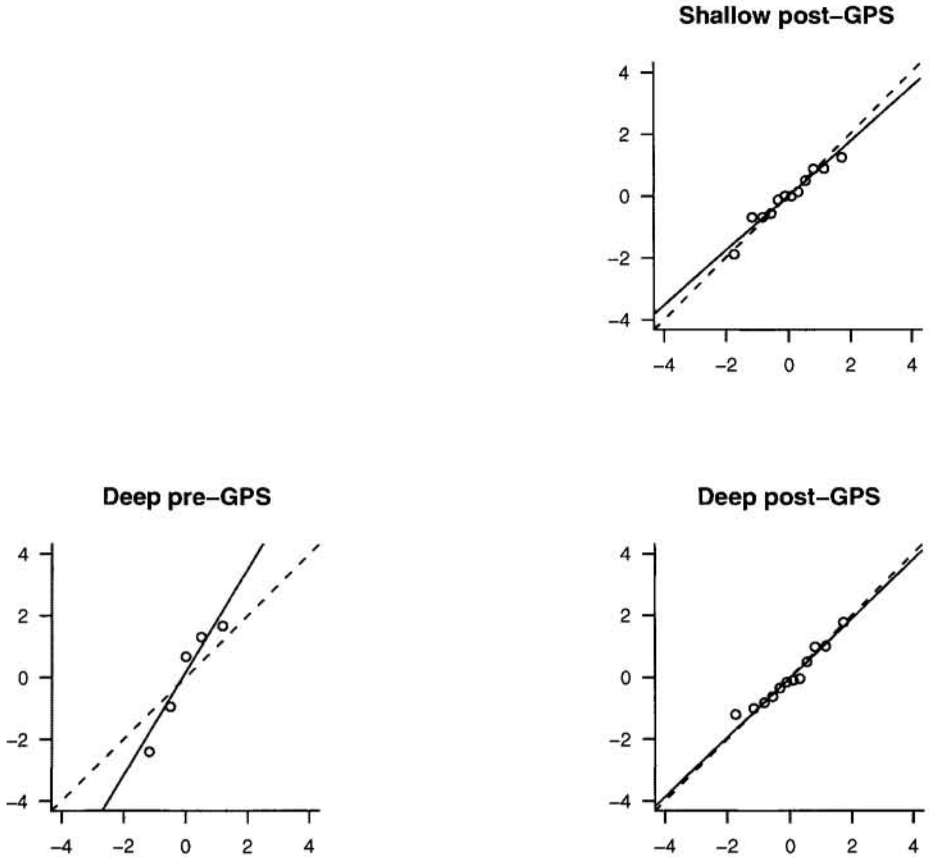

Figure 13: Quantile - quantile normal plots of the standardised residuals of the stock assessment model CPUE data. The residuals (y-axis) are plotted against the normal distribution (x-axis), the dashed lines lie through the origin with a slope of one, the solid line is fitted through the 1st and 3rd quartiles of the residuals.

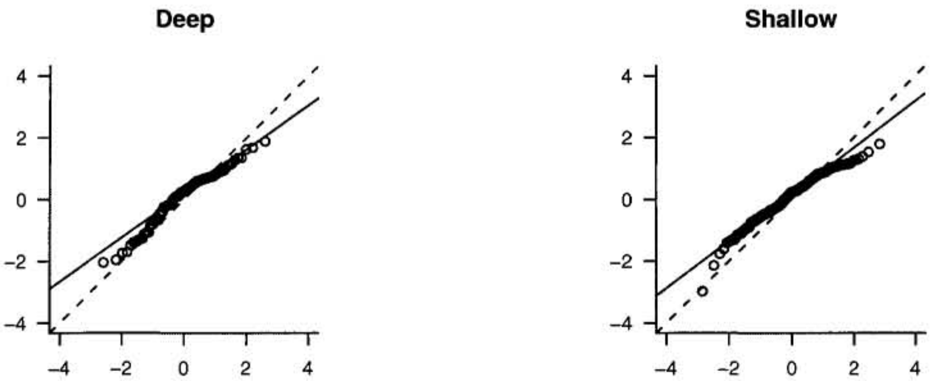

Figure 14: Quantile - quantile normal plots of the standardised residuals of the stock assessment model length frequency data. All data (males, females, all year groups) are aggregated for each group, i.e., shallow (right panel), deep (left panel). The residuals (y-axis) are plotted against the normal distribution (x-axis), the dashed lines lie through the origin with a slope of one, the solid line is fitted through the 1st and 3rd quartiles of the residuals.

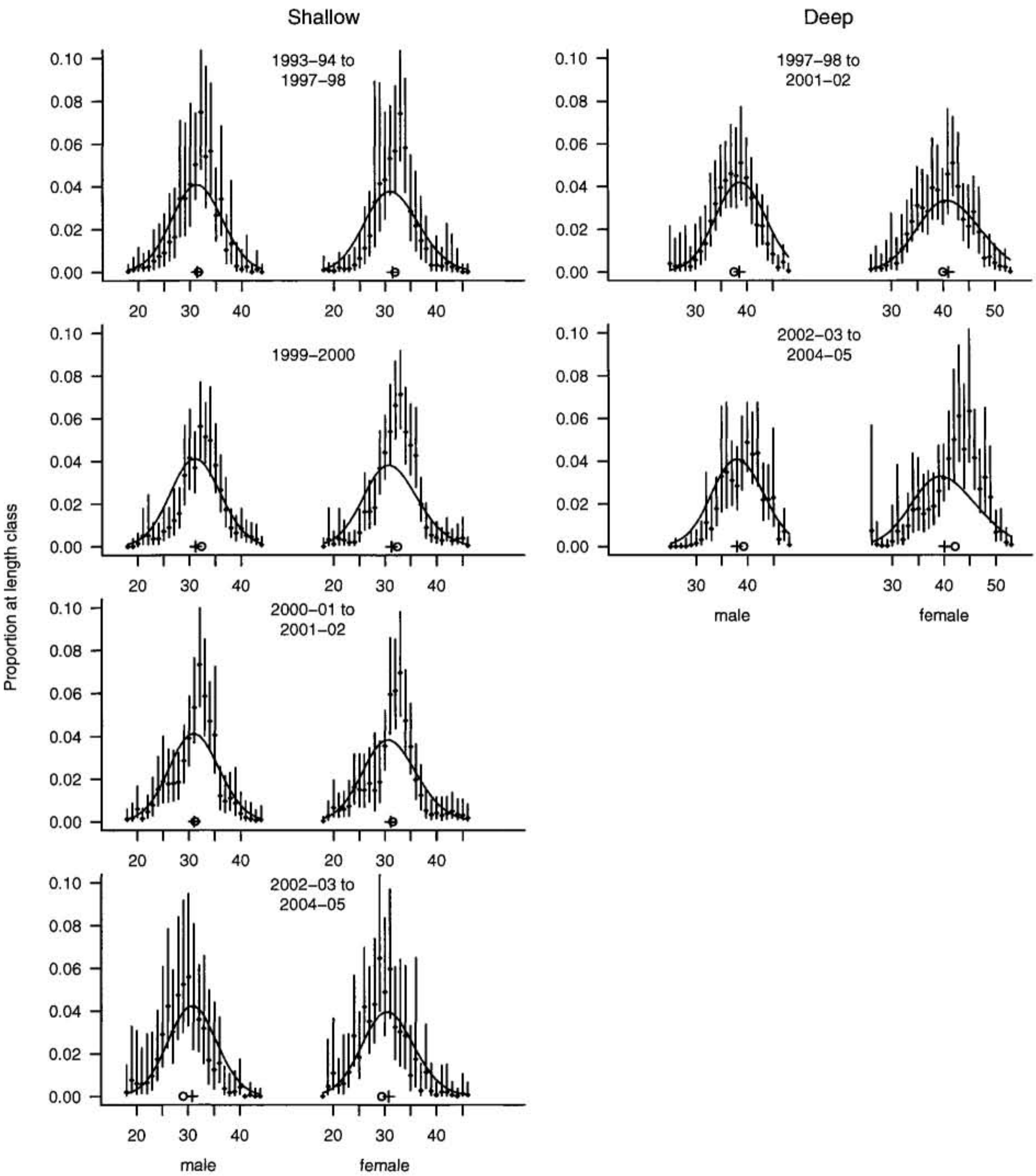

Figure 15: All observer length frequency observed data (diamonds) versus model (solid line). Vertical lines are 2 s.e. from the boot strap c.v.s (note that process error is added to these data in the model). o and + on the y=0 line are the observed mean length and model mean length respectively.

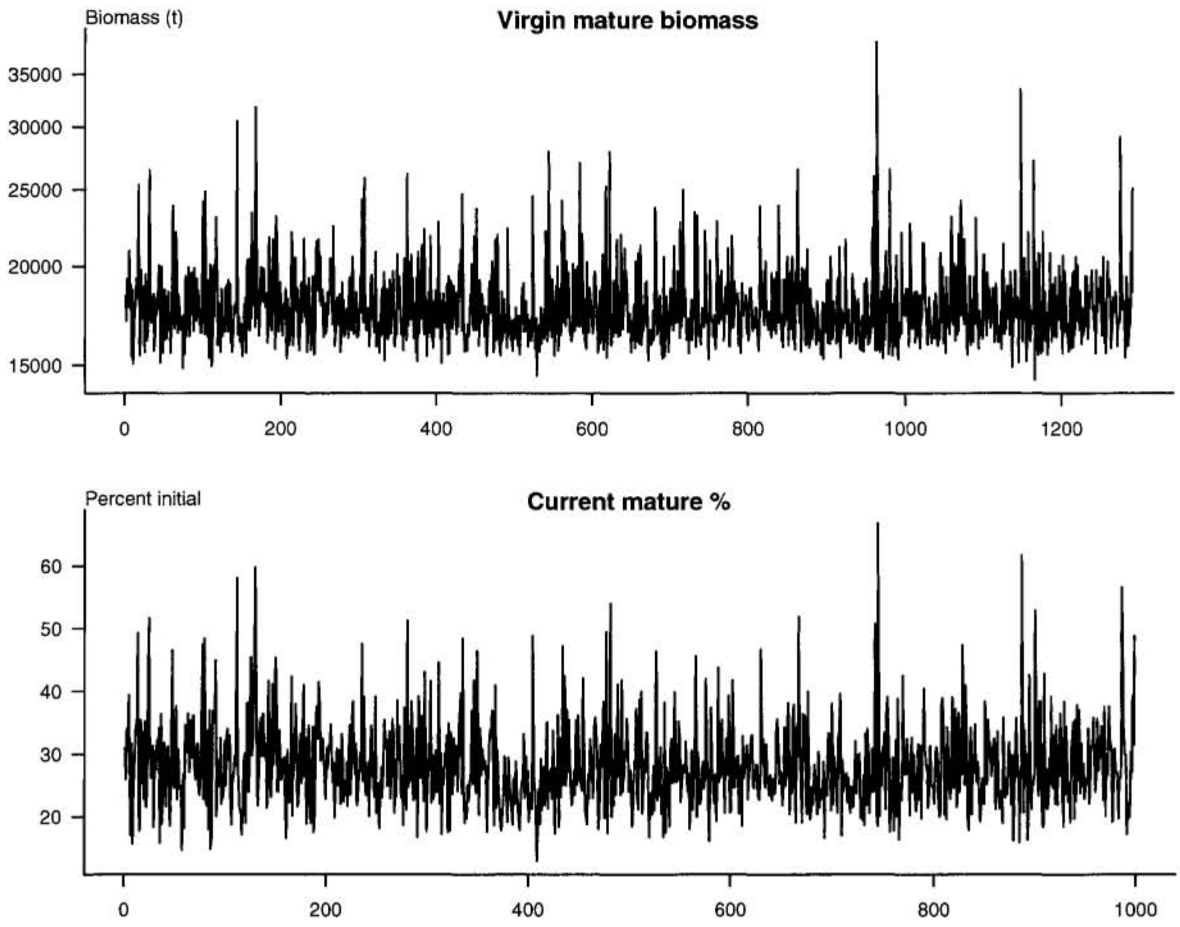

Figure 16: The key MCMC traces. Virgin mature biomass (upper panel) and current mature biomass as a % of initial (lower panel).

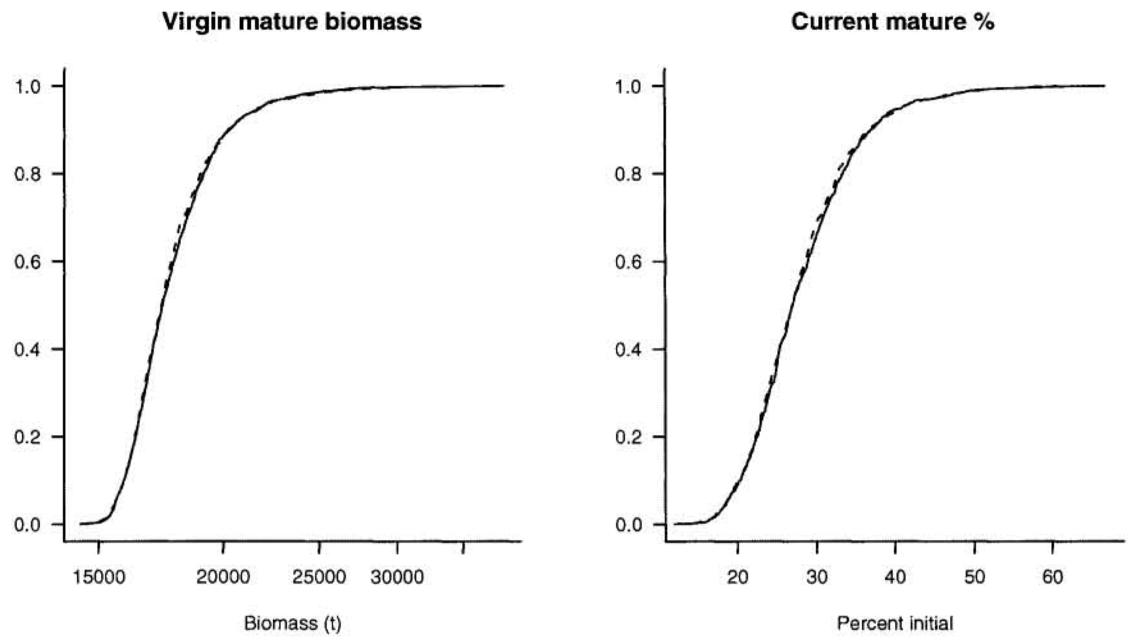

Figure 17: Cumulative distributions of key metrics from two independent chains (solid line, first chain; dashed line, second chain). Virgin mature biomass (left panel), current mature biomass as % of initial (right panel).

APPENDIX A: CASAL MODEL FILES

The following are the CASAL files for the stock assessment model.

The population file

```
@initialization
B0 40000

#PARTITION
@size_based false

@min_age 5
@max_age 70
@plus_group true

@sex_partition true

@mature_partition False
@n_areas 1


#TIME SEQUENCE
@initial 1978
@current 2007
@final 2012

@annual_cycle
time_steps 1
recruitment_time 1
aging_time 1
M_props 1
fishery_names     fish_shallow    fish_deep
fishery_times 1         1
n_maturations 1
maturation_times 1
spawning_time 1
spawning_p 1
spawning_part_mort 0.5

baranov false

#RECRUITMENT

@y_enter 5

@recruitment
SR BH
steepness  0.75


YCS_years 1973   1974   1975   1976   1977   1978   1979   1980    1981
1982     1983     1984     1985     1986     1987     1988     1989     1990
1991     1992     1993     1994     1995     1996     1997     1998     1999
2000     2001     2002
YCS          1       1       1       1       1       1       1       1        1
1        1        1        1        1        1        1        1        1        1
```

```
1       1       1       1       1       1       1       1       1       1
1

p_male 0.5

sigma_r 0.65

@randomisation_method lognormal

@natural_mortality
male     0.063
female   0.063

@fishery fish_shallow


years      1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
2006 2007
catches     210   10   40    0    0    0  480  170  480   30  130    0  210
410  530  410  220   80  600  440  320  480  650  400  580  130  330  140
120  120


selectivity trawl_shallow
U_max 0.58

@fishery fish_deep

years      1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
2006 2007
catches       0    0    0    0    0    0  660  510 3760  160  860  240  430
420  380  250  150  150  500   70  230  620  480  610 1470 1320  420  290
140  140


selectivity trawl_deep
U_max 0.58


@selectivity_names    trawl_shallow   trawl_deep

@selectivity trawl_shallow
all double_normal     25    5    5


@selectivity trawl_deep
all logistic    20.4527     5.114431


#SIZE AT AGE
@size_at_age_type von_Bert
@size_at_age_dist normal
@size_at_age
k_male 0.067
t0_male -1.6
Linf_male 43.6
cv_male 0.1
k_female 0.047
t0_female -2.9
```

```
Linf_female 50.8
cv_female 0.1


#MATURATION

@maturity_props

male allvalues 0  0.01  0.01  0.01  0.02  0.03  0.04  0.07  0.1   0.14
0.21  0.28  0.38  0.48  0.59  0.69  0.77  0.84  0.89  0.92  0.95  0.97
0.98  0.99  0.99  0.99  1   1   1   1   1   1   1   1   1  1  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  1


female allvalues 0  0     0     0     0     0     0     0.01  0.01  0.01
0.02  0.03  0.04  0.05  0.08  0.11  0.15  0.21  0.28  0.37  0.46  0.56
0.65  0.74  0.8   0.86  0.9 0.93 0.95 0.97 0.98 0.98 0.99 0.99 1  1  1  1
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1  1  1


@size_weight
a_male     3.2e-08
b_male     2.87
a_female   2.9e-08
b_female   2.90
```

The estimation file

```
@estimator Bayes
@max_iters 300
@max_evals 1000


#MCMC

@MCMC
start 0                     # 0 implies start chain at point estimate
length 100000000               # 100M
keep 1000                   # keep every 100th sample
burn_in 100                 # burn in for 1000*100=100k steps of the chain
subsample_size      1000
systematic True             # if False then randomly sample from the chain
adaptive_stepsize  True
adapt_at 50000 100000


# shallow cpue

@relative_abundance CPUE_shallow_postGPS
q CPUE_shallow_postGPS

years 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
step 1
proportion_mortality 0.5
biomass true
ogive trawl_shallow
```

```
dist lognormal

1993 1489
1994  956
1995 1521
1996 1173
1997  511
1998 1477
1999  939
2000  842
2001  758
2002  573
2003  303
2004  480

cv_1993 0.568
cv_1994 0.466
cv_1995 0.718
cv_1996 0.372
cv_1997 0.839
cv_1998 0.391
cv_1999 0.420
cv_2000 0.442
cv_2001 0.460
cv_2002 0.440
cv_2003 0.482
cv_2004 0.567


# deep cpue

@relative_abundance CPUE_deep_preGPS
q CPUE_deep_preGPS
years 1984 1985 1986 1987 1988
step 1
proportion_mortality 0.5
biomass true
ogive trawl_deep
dist lognormal

1984            3111
1985            2937
1986            2112
1987             852
1988            1082
cv_1984           .221
cv_1985           .288
cv_1986           .325
cv_1987           .228
cv_1988           .270


@relative_abundance CPUE_deep_postGPS
q CPUE_deep_postGPS

years 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
step 1
proportion_mortality 0.5
biomass true
ogive trawl_deep
```

```
dist lognormal

1993 1401
1994  916
1995  428
1996 1862
1997 2117
1998  502
1999  915
2000  611
2001  385
2002  658
2003  406
2004  719

cv_1993 0.725
cv_1994 0.525
cv_1995 1.214
cv_1996 0.835
cv_1997 0.405
cv_1998 0.590
cv_1999 0.499
cv_2000 0.484
cv_2001 0.720
cv_2002 0.528
cv_2003 0.759
cv_2004 2.179


@catch_limit_penalty
label exploitation_constraint_shallow
fishery fish_shallow
log_scale 1
multiplier 100

@catch_limit_penalty
label exploitation_constraint_deep
fishery fish_deep
log_scale 1
multiplier 100


@estimate
parameter initialization.B0
lower_bound 1e2
upper_bound 1e5
prior uniform-log


@estimate
parameter selectivity[trawl_shallow].all
lower_bound      1       0       0
upper_bound     50      35      35
prior uniform


@estimate
parameter selectivity[trawl_deep].all
lower_bound  1      0.1
```

```
upper_bound 50      35
prior uniform


# Q's

#shallow

@estimate
parameter q[CPUE_shallow_postGPS].q
lower_bound 1e-8
upper_bound 1e8
prior uniform

#deep

@estimate
parameter q[CPUE_deep_preGPS].q
lower_bound 1e-8
upper_bound 1e8
prior uniform

@estimate
parameter q[CPUE_deep_postGPS].q
lower_bound 1e-8
upper_bound 1e8
prior uniform



# shallow lfs

@catch_at fish_shallow_LFs

fishery fish_shallow
at_size true
plus_group false
dist lognormal
cv_process_error  1

years         1996 2000 2002 2005
sexed         TRUE
class_mins    17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
min_class     2 2
max_class     28 30

# 94-98
#                  m18          m19          m20          m21          m22
m23         m24          m25         m26         m27         m28         m29
m30        m31        m32         m33         m34        m35         m36
m37        m38          m39          m40          m41          m42          m43
m44          f18          f19           f20          f21          f22
f23          f24          f25         f26         f27         f28         f29
f30        f31         f32        f33         f34         f35         f36
f37        f38          f39          f40          f41          f42          f43
f44          f45          f46
1996     0.0003223924 0.001267201 0.002943964 0.002062271 0.002627337
0.005167165 0.007424196 0.009037915 0.01411939 0.01642090 0.03434551
0.03456256 0.0411006 0.05034918 0.0748373 0.05391306 0.05658938 0.0267197
0.03434235 0.01044656 0.01330300 0.002836196 0.001439109 0.002531074
```

```
0.0001000273 0.001265537 0.0001000273 0.001070402 0.000772114 0.0005117993
0.002067516 0.001400984 0.001601519 0.003240725 0.006414487 0.01131723
0.01708113 0.03278438 0.04151911 0.04326374 0.05321422 0.05678419 0.0742151
0.05828682 0.02854517 0.02179877 0.01483820 0.01103526 0.003234509
0.003399725 0.002767066 0.004259382 0.002531074 0.001671417 0.0001000273
0.0001000273
cvs_1996 1.8587284968 1.020758688 0.778571112 0.818260913 0.753365266
0.758225806 0.602674813 0.596639953 0.50509108 0.45762709 0.37489814
0.36278656 0.3343367 0.19684518 0.2220328 0.29532292 0.22578788 0.3068688
0.35484427 0.49956272 0.63763697 0.928794083 1.299196337 1.227622064
5.0000000000 1.373496121 5.0000000000 1.236799698 1.039862137 1.3856638868
0.852949673 0.986712039 0.950578101 0.692923237 0.576835305 0.52825595
0.41167397 0.53487801 0.39264153 0.27916547 0.19242568 0.21666739 0.1773387
0.22389061 0.33593704 0.40201770 0.45761336 0.45350911 0.789838304
0.952858200 0.808461890 1.011457133 1.257295980 1.187884121 5.0000000000
5.0000000000
# 00
#                m18          m19         m20          m21          m22
m23        m24         m25         m26        m27         m28         m29
m30        m31        m32        m33        m34        m35        m36
m37        m38        m39         m40         m41         m42         m43
m44          f18          f19          f20          f21          f22        f23
f24         f25        f26        f27        f28         f29        f30
f31        f32        f33        f34        f35        f36        f37
f38         f39          f40          f41          f42          f43          f44
f45         f46
2000     6.111253e-05 0.0001001385 0.001395929 0.004927252 0.005083096
0.003578599 0.00369668 0.007182073 0.008982015 0.01221682 0.01549691
0.03338544 0.04152692 0.03690521 0.05624481 0.05131215 0.04973952
0.03819811 0.02654243 0.01744278 0.00878825 0.00642502 0.008641273
0.005372903 0.004657393 0.003497613 0.0008882902 0.0001001385 0.003264296
0.001210119 0.003617727 0.002980523 0.0018563 0.002059071 0.006560859
0.01642517 0.01647153 0.01823421 0.03673004 0.0441983 0.05394246 0.06617044
0.07136708 0.05380553 0.04740339 0.04264415 0.01979607 0.008968902
0.005455242 0.004340880 0.002975593 0.006216815 0.002762551 0.003692475
0.003953765 0.000507607
cvs_2000 1.630932e+00 5.0000000000 0.878840874 0.715114457 0.918818091
0.620625942 0.58364577 0.472190957 0.365550407 0.41413369 0.29418086
0.26950153 0.22065428 0.18940812 0.15850716 0.13599194 0.20562682
0.20669741 0.24235909 0.31433654 0.36090689 0.42749365 0.375190332
0.434364803 0.457988353 0.586876333 1.0061484926 5.0000000000 1.036201549
1.087733677 0.942575351 0.801840464 0.6883144 0.720532387 0.525166950
0.38512796 0.32218546 0.28533078 0.19652018 0.1665253 0.17269068 0.13650009
0.12655169 0.16462085 0.17292731 0.21423133 0.24919404 0.429204247
0.436787680 0.520584702 0.575920539 0.403969084 0.581316095 0.555165926
0.680107982 1.469773305
# 01-02
#                m18          m19         m20          m21          m22
m23        m24        m25        m26        m27        m28        m29
m30        m31       m32        m33        m34        m35        m36
m37        m38         m39         m40         m41         m42          m43
m44          f18          f19          f20          f21          f22
f23        f24        f25        f26        f27        f28        f29
f30        f31        f32        f33        f34        f35        f36
f37         f38          f39          f40          f41          f42          f43
f44         f45          f46
2002     0.001250662 0.001714201 0.005951095 0.001432794 0.004697221
0.00785178 0.01516695 0.01894303 0.01769787 0.01799179 0.01851653
0.02859822 0.03917359 0.05313734 0.0732505 0.05847823 0.04687191 0.04072553
0.01217657 0.00967871 0.01111012 0.008782985 0.003905889 0.001967669
0.001291806 0.0006459032 0.0009114924 0.0002731545 0.002739579 0.006550546
```

```
0.005292487 0.005815049 0.007174439 0.01617386 0.01514113 0.01488033
0.01803030 0.01478710 0.01872582 0.03564036 0.05940471 0.06108063
0.06954916 0.04712073 0.03523191 0.01970189 0.01234324 0.005243422
0.003337071 0.00407708 0.003008221 0.003845515 0.004885717 0.003357221
0.002936344 0.001732585
cvs_2002 0.921492026 0.953844910 0.551025011 0.848745686 0.515185671
0.51860806 0.36089618 0.38738327 0.33518721 0.31667137 0.28338813
0.22813207 0.20356846 0.18325353 0.1553827 0.18944761 0.16580198 0.29435372
0.38868287 0.41562268 0.37677973 0.567887079 0.697279016 0.940247683
1.232024387 1.4634783505 1.4131916133 1.3532245659 0.695577197 0.584408095
0.485514661 0.466751533 0.519500985 0.34492234 0.38425040 0.39213503
0.33462616 0.55383427 0.36278228 0.19097562 0.18618883 0.16806944
0.17304989 0.20619406 0.22681587 0.31500901 0.40027562 0.562720272
0.609288306 0.55738149 0.754158526 0.604148205 0.550566164 0.625090466
0.701839985 0.914440653
# 03-06
#                 m18         m19         m20         m21         m22
m23        m24        m25        m26        m27        m28        m29
m30        m31        m32        m33        m34        m35        m36
m37         m38         m39         m40         m41         m42
m43          m44          f18          f19          f20          f21
f22        f23        f24        f25        f26        f27        f28
f29        f30        f31        f32        f33        f34         f35
f36         f37         f38         f39          f40          f41          f42
f43          f44          f45          f46
2005     0.002062008 0.007627369 0.006124048 0.005773341 0.006373135
0.00957861 0.01736209 0.02907196 0.04228412 0.03025056 0.04738902
0.05243423 0.05586312 0.04199229 0.03593409 0.03168657 0.01686099
0.01246113 0.01558271 0.003590334 0.001773881 0.002177419 0.004277417
3.220405e-05 0.0006851717 0.0001000892 0.0001000892 3.220405e-05
0.004648336 0.01078347 0.005152792 0.005962254 0.01132473 0.02826364
0.01831096 0.04200874 0.03512971 0.04305463 0.0646999 0.04892880 0.05968711
0.03244597 0.03031341 0.02840913 0.009829481 0.01737302 0.002747492
0.01131799 0.002491257 0.0006851717 0.002055515 0.002055515 0.0006851717
0.0001000892 0.001370343 0.0006851717
cvs_2005 1.272729937 0.837573485 0.958909480 0.773196340 0.884889390
0.61915566 0.43839239 0.38057215 0.31575578 0.34575246 0.29165093
0.28464244 0.26908456 0.33467755 0.27293535 0.37663169 0.58221790
0.69910824 0.45341293 0.762488621 1.107802592 1.026577513 0.795226384
2.010616e+00 1.5756236761 5.0000000000 5.0000000000 2.148223e+00
1.065258074 0.66959401 0.674158979 0.919385008 0.50057677 0.35627934
0.39898693 0.25685453 0.27777580 0.27548384 0.2440788 0.27241757 0.24619949
0.32073984 0.38880465 0.39784185 0.667944561 0.73765765 1.039019151
0.58890347 1.141125778 1.5866288285 1.257411252 1.300201766 1.6526250292
5.0000000000 1.344560937 1.6073443131


# deep lfs    (excludes the 87-89 stuff)

@catch_at fish_deep_LFs

fishery fish_deep
at_size true
plus_group false
dist lognormal
cv_process_error  1

# deep ('cept 87-89)

years        2002 2004
```

```
sexed         TRUE
class_mins    17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
min_class     9 10
max_class     32 37

# 98-02
#                m25          m26          m27          m28          m29
m30        m31        m32        m33        m34        m35        m36
m37        m38        m39        m40        m41        m42        m43
m44        m45        m46        m47        m48        f26
f27        f28        f29        f30        f31        f32        f33
f34        f35        f36        f37        f38        f39        f40
f41        f42        f43        f44        f45        f46        f47
f48        f49        f50        f51        f52        f53
2002    0.003923032 0.002782255 0.003269193 0.004173382 0.002545667
0.005563615 0.009607327 0.0132713 0.02384355 0.03200729 0.03952626
0.04293824 0.04597882 0.04505892 0.0511242 0.04411066 0.03475616 0.02200649
0.02151526 0.01305606 0.008356341 0.002111384 0.004630582 0.0004520466
0.001307677 0.002044966 0.001724928 0.003060294 0.006196589 0.00407257
0.01061576 0.01778319 0.02358365 0.03112549 0.03001357 0.02827338
0.03932983 0.03823076 0.03282264 0.04582696 0.05104669 0.04006391
0.02464625 0.02147363 0.02819596 0.01880514 0.00650749 0.007041593
0.004301804 0.002776326 0.002259147 0.0002617793
cvs_2002 1.033365644 1.057450148 1.046114004 0.979609707 0.890271912
0.785472589 0.523097172 0.4411252 0.33891048 0.24545142 0.20504533
0.17659937 0.20489652 0.20289339 0.2088263 0.17788041 0.21537813 0.31841641
0.26111819 0.44867229 0.386600519 0.729725030 0.533077370 1.4561086093
1.138022204 1.093907425 0.925586244 0.920687809 0.864983373 0.76884103
0.48872029 0.32239016 0.25125972 0.23145089 0.23572175 0.23645379
0.23453154 0.22084387 0.19426079 0.25956434 0.17754978 0.24689937
0.26176160 0.32644700 0.23442277 0.38683306 0.48858592 0.479473600
0.605565850 0.714904335 0.893252018 1.3886060887
# 03-05
#                m25          m26          m27          m28          m29
m30        m31        m32        m33        m34        m35        m36
m37        m38        m39        m40        m41        m42        m43
m44        m45        m46        m47        m48        f26        f27
f28        f29        f30        f31        f32        f33        f34
f35        f36        f37        f38        f39        f40        f41
f42        f43        f44        f45        f46        f47        f48
f49        f50        f51        f52        f53
2004    2.346159e-05 0.0001008835 0.0001547382 0.0001008835 0.0006761274
0.001577330 0.003282624 0.0112543 0.008358128 0.01774173 0.03275244
0.03479255 0.03091678 0.02832881 0.0400459 0.04871872 0.04308727 0.04371146
0.02182321 0.02206656 0.02289992 0.003329067 0.006985828 0.0007839834
0.00734718 0.001069792 0.0003627223 0.0002871194 0.002315634 0.007041475
0.003113827 0.009544308 0.01711796 0.01766228 0.01520788 0.01732848
0.01873773 0.02586829 0.03191223 0.04114089 0.05005194 0.06123614
0.04552184 0.06339318 0.04149275 0.02697716 0.03233906 0.02305891
0.006642579 0.007110882 0.001821091 0.0007839834
cvs_2004 7.141454e+00 5.0000000000 1.5286032145 5.0000000000 1.6652087869
0.925252052 0.715896111 0.6102210 0.551816281 0.30844394 0.35869189
0.33989752 0.23624745 0.25269402 0.2119542 0.16317384 0.18996278 0.21992311
0.29589079 0.27717880 0.46312032 0.656709445 0.490580665 1.1137823587
1.35873218 1.748976513 1.5947063875 1.7685309382 1.431737812 1.021006769
0.652654090 0.505848169 0.49335623 0.44574858 0.41186269 0.36755191
0.30751641 0.30802407 0.20391803 0.21859478 0.25755040 0.21763543
0.26086179 0.23988098 0.22138869 0.26476900 0.35990491 0.36622099
0.491227029 0.475781897 0.922248211 1.1337667325
```

The output file

```
@print

# estimation section stuff
parameters 0
estimation_section 1
fits 1
fits_every_eval 0
resids    1
normalised_resids    1
objective_every_eval 0
parameters_every_eval 0
parameter_vector_every_eval 0 # switched this off for MCMC

# population section stuff
#annual_cycle 1
requests 0
initial_state 0
state_annually 0
state_every_step 0
final_state 0
results 1
#to view the fishing pressure need to switch q off

yields 1

@quantities

ogive_arguments  selectivity[trawl_shallow].all
selectivity[trawl_deep].all

ogive_parameters   selectivity[trawl_shallow].all
selectivity[trawl_deep].all


fishing_pressures    True
#vector_parameters      fishery.catches


@abundance mature_biomass
years     1978   1979   1980   1981   1982   1983   1984   1985   1986
1987   1988   1989   1990   1991   1992   1993   1994   1995   1996   1997
1998   1999   2000   2001   2002   2003   2004   2005   2006   2007
step 1
proportion_mortality 0.5
mature_only   true
biomass      true



# Vulnerable biomass shallow fishery
@abundance vulnerable_biomass_shallow
biomass True
ogive trawl_shallow
proportion_mortality 0.5
step 1
```

```
years      1978   1979   1980   1981   1982   1983   1984   1985   1986
1987   1988   1989   1990   1991   1992   1993   1994   1995   1996   1997
1998   1999   2000   2001   2002   2003   2004   2005   2006   2007

# Vulnerable biomass deep fishery
@abundance vulnerable_biomass_deep
biomass True
ogive trawl_deep
proportion_mortality 0.5
step 1
years      1978   1979   1980   1981   1982   1983   1984   1985   1986
1987   1988   1989   1990   1991   1992   1993   1994   1995   1996   1997
1998   1999   2000   2001   2002   2003   2004   2005   2006   2007

@MCY_CAY_mortality_rate exploitation_rate

@catch_split          0        1
```