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EXECUTIVE SUMMARY

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Red cod (*Pseudophycis bachus*) stocks RCO 3 and RCO 7 were assessed using the single stock model and MIAEL estimation technique. Estimates were made of mid spawning season virgin biomass (B_0), mid spawning season current biomass (1998–99, B_{mid99}/B_0; 1999–2000 B_{mid00}/B_0), and beginning of season home ground total biomass (1999–2000, B_{beg00}). MCY and CAY were also estimated. This is the first stock assessment carried out for red cod.

RCO 3 basecase model input data included relative biomass indices and catch at age from five winter and three summer east coast South Island (ECSI) trawl surveys, catch at age from the ECSI red cod catch sampling programme (1990–93), and catch effort abundance indices from Catch Effort Landing Returns (CELR) and Trawl Catch Effort Processing Returns (TCEPR). Catch at age was estimated by applying age length keys from otolith readings scaled to length frequencies from trawl surveys and the catch sampling. A standardised Catch Per Unit effort (CPUE) analysis was carried out using (CELR) data (kg per day) and (TCEPR) data (kg per tow) with red cod specified as the target species.

RCO 7 basecase model input data included relative biomass indices and proportion at age from four west coast South Island (WCSI) trawl surveys, and catch effort abundance indices (CELR only). Proportion at age was estimated for all four surveys using the MIX analysis software. A standardised CPUE analysis was carried out using CELR data (kg per day) and TCEPR data (kg per tow). Specified target species for CELR data were red cod, flatfish, and barracouta, and for TCEPR no target species was specified with the requirement that red cod was in the top five species caught per tow.

The relationship between recruitment and climatic environmental variables was examined to determine if there was any causal link that might explain the variability in recruitment. The predictors sea surface temperature (SST) and Trough NW cluster, with a 14 month lag, explained 68% of variability in commercial catch in RCO 3, and SST and surface westerly wind, with a 14 month lag, explained 75% of variability in commercial catch for RCO 7. These predictor variables were used to predict an environmental abundance index for input into the MIAEL model sensitivity analysis.

Sensitivity runs were carried out for environmental abundance index (inclusion of the index), weighting of CPUE data, spawning period, r_{hm_mmax}, r_{hm_max}, mhigh, and M.

Year class strengths (YCS) were estimated for 1986 to 1998 for RCO 3 and 1989 to 1996 for RCO 7. For RCO 3 base case and all sensitivity analyses, except sensitivity 1 (environmental abundance index), recruitment was strongest in 1990, 1992, and 1996. The inclusion of the environmental abundance index in the model resulted in YCS estimates from 1994 to 1998 that were less than the base case. For RCO 7 base case and all sensitivity analyses, recruitment was strongest in 1990, 1992, and 1995, and sensitivity 1 (environmental abundance index) was similar to base case and other sensitivity runs.

RCO 3 and RCO 7 least squares estimates of all biomass estimates were the same as B_{max} in all runs. B_{max} is sensitive to r_{hm_mmax} with low values resulting in higher B_{max} estimates: however, sensitivity analyses with lower values of r_{hm_mmax} did not result in a least squares estimate of B_0 less than B_{max}. This may be caused by the flat nature of the trawl survey biomass estimates which result in the best fit at maximum B_0.

The MIAEL base case virgin biomass (B_0) estimate for RCO 3 was 58 000 t with sensitivity estimates ranging from 40 500 to 88 500 t. Estimates of basecase current biomass as a percentage of B_0 were 75% (B_{mid99}/B_0), and 49% (B_{mid00}/B_0) and beginning of season biomass (B_{beg00}) was 118 000 t. Performance indices were generally very low (all under 50%) indicating that the point estimates of biomass are not well estimated within their known range for these parameters. Estimates for current biomass (1998–99 and 1999–2000) are the lowest of all estimates for sensitivity 1 because RCO 3 estimated YCS are consistently low from 1994 to 1998.

The MIAEL base case virgin biomass (B_0) estimate for RCO 7 was 20 000 t with sensitivity estimates ranging from 13 500 to 37 500 t. Estimates of basecase current biomass as a percentage of B_0 were 49% (B_{mid99}/B_0), and 51% (B_{mid00}/B_0), and beginning of season biomass (B_{beg00}) was 57 500 t. Unlike RCO 3, sensitivity analyses did not affect estimates of B_0 greatly except for r_{hm_mmax}, when a lower value of 0.02 increased the B_0 estimate to 37 500 t. Performance indices were generally higher than RCO 3 indicating that the point estimates of biomass were, in some cases, well estimated within their known range for these parameters. The inclusion of the environment abundance index resulted in higher estimates of B_{mid00} and B_{mid99}.

Basecase MCY estimate for RCO 3 was 7173 t (range 2418–13 330 t) and RCO 7 was 2568 t (range 628–3452 t). Basecase CAY estimate for RCO 3 was 14 561 t (2624–37 976 t) and RCO 7 was 7084 t (260–9188 t). The environmental abundance index predicts that recruitment in RCO 3 has declined in recent years resulting in a lower estimate of CAY than the base case. For RCO 7 the environmental abundance index agrees with base case estimates of YCS, resulting in a similar estimate of CAY to the base case.

The assessment of RCO 3 is highly uncertain as estimates from sensitivity analyses vary widely and performance indices are generally very low (all under 50%), and least squares biomass estimates are at the upper bound.

RCO 7 performance indices are generally higher than RCO 3, but the assessment of RCO 7 is also highly uncertain. Sensitivity analyses have a wide range and least squares biomass estimates were all at the upper bound in all cases. Also for RCO 7 the most recent YCS estimated was for 1996 and these fish are no longer in the fishery. The YCS since 1996 is therefore based on the assumption of mean recruitment for each year and the estimates of B_{mid99} and B_{mid00} are probably driven by the CELR CPUE index and the recent high landings.

1. INTRODUCTION

1.1 Overview

There are now sufficient data on biomass and year class strength together with an understanding of red cod age, growth, and population dynamics, to be able to model the fishery and estimate current biomass and sustainable yields.

RCO 3 and RCO 7 stocks were assessed using the single stock model (Cordue 1998a) and MIAEL estimation technique (Cordue 1998b) and estimates of virgin biomass, MCY and CAY were determined. For RCO 3 the model input data included relative abundance indices and catch at age from eight east coast South Island trawl surveys, catch at age from the red cod catch sampling programme (1990–93) and catch effort abundance indices. For RCO 7 the model used relative abundance indices and catch at age from four west coast South Island trawl surveys and catch effort abundance indices. The relationship between recruitment and climatic environmental variables was examined to determine if there was any causal link that might explain the variability in recruitment (Beentjes & Renwick Unpubl. results). Low SST was found to be correlated with good recruitment and this was incorporated into the MIAEL model as a sensitivity analysis.

This is the third report on red cod stock assessment, following those by MacDiarmid (1988) and Beentjes (1992). There was little information available on the population dynamics of red cod in 1988 and the results of the report by Beentjes (1992) provided a starting point for considering stock assessment and management options. Ageing had not been validated at that time.

1.2 Description of the fishery

Red cod have been commercially fished since the early part of the 1900s, but a stable market developed only in the late 1960s when red cod became a major target species. In 1995, the estimated primary value of red cod was $7.7 million for the year and it ranked ninth in value out of 38 commercial finfish species (Fishing Industry Board 1993). Red cod is one of the major contributors to the total wet fish landings from Timaru and Lyttelton (RCO 3).

With the introduction of the QMS in 1986, landings of red cod by foreign licensed vessels declined substantially and were negligible by the 1990–91 fishing year (Beentjes 1992). The fishery is now dominated by the domestic inshore vessels (10–30 m length) and to a lesser extent by New Zealand chartered vessels.

About 98% of red cod landings are from RCO 3 and RCO 7, with the latter being about 30–50% of RCO 3 landings (Annala *et al.* 1999). The major red cod grounds in RCO 3 are around Banks Peninsula and Timaru (Fisheries Statistical Areas 20 and 22) and in RCO 7 off northern Westland and Buller (Fisheries Statistical Areas 34, 35, and 36) (Figure 1).

The red cod fishery is seasonal, usually beginning in November and running through to May or June with peak catches from the Canterbury Bight region around January and May. Red cod are commercially caught by bottom trawl, most commonly between 100 and 200 m although in some years the bulk of the catch has been taken in depths less than 100 m. Red cod distribution has also been shown to extend to mid water and at depths as great as 1000 m (Anderson *et al.* 1998, Bagley *et al.* 2000) although these fish are not targeted. During the peak red cod season, fishing is concentrated on dense aggregations of schooling red cod. These schools, most common off Banks Peninsula and Timaru, often occur near shoals of post larval pelagic *Munida gregaria*. Landings outside the period from December to June are usually non-targeted catch and may form a component of a mixed species trawl fishery.

1.3 Literature review

Early accounts of red cod biology are largely anecdotal but do provide some points for comparison (Thomson 1913, Graeme 1939).

Habib (1975) provided the only study on the biology of New Zealand red cod including taxonomy, feeding, reproductive biology, and growth. Unfortunately, the study was undertaken in a year characterised by very poor catches of red cod, length frequency analyses were not carried out separately for the sexes, and no attempt was made to validate age classes.

Walker (1972) studied the growth of the Australian rock cod, *Pseudophycis barbatus*: this is the only other ageing study on a species belonging to the same family as red cod, the morids.

MacDiarmid (1988) reviewed the history and current state of the fishery. Beentjes (1992) updated the 1988 report and presented results of the first two years of a four year red cod catch sampling programme (1990–93), and trawl surveys carried out on the east coast of the South Island in 1990 and 1991. The report also included analyses on ageing, catch at age analysis, growth, age and size composition of the commercial fishery, and total mortality. Horn (1995) validated ageing for red cod using data from east coast South Island trawl surveys and from the catch sampling programme (1990–93). Horn's methodology forms the basis for the catch at age analysis presented in this report.

2. REVIEW OF THE FISHERY

2.1 General

Commercial catches of red cod (*Pseudophycis bacchus*) have historically been highly variable and unpredictable both within and between seasons. The original TACC of 15 290 t for all fish stocks combined was based on the very high catch figure of 1984 with the rationale that this would provide the fishing sector with the flexibility to capitalise on years when red cod were plentiful. After relatively poor catching years in the late 1980s, catches have increased with TACCs exceeded in both RCO 3 and RCO 7 (Annala *et al.* 1999) on a number of occasions.

Red cod is a strongly recruitment driven fishery, with fluctuations in landings a result of variable recruitment, high mortality, fast growth, and relatively few year classes. Successful management of the red cod fishery depends upon being able to estimate red cod abundance in subsequent years. Preliminary analyses indicate a close relationship between year class strength of the 1+ fish (trawl survey data) and the commercial landings the following season (Annala & Sullivan 1996). Because there are only a few year classes in the fishery, a strong or weak year class can have a major impact on the fishery. Trawl surveys of the west coast and east coast South Island (winter time series) have been used to identify year class strength of pre-recruit 1+ fish which enter the commercial fishery mid season the following year. The more recent east coast summer trawl survey time series use a finer mesh codend and relative year class strength of 0+ age as well as 1+ fish can be determined.

The effect of environmental factors on the success of spawning and recruitment has not been investigated for red cod. With several time series of abundance indices now available, and an increasing array of ocean climate data becoming available, it is timely to examine whether any causal links exist between recruitment and environment. The establishment of any proven causal link may be useful in predicting red cod yields and as an integral part of any fishery model that might be used to estimate yields and ultimately in managing the fishery.

2.2 Landings and TACC

Landings fluctuate widely from year to year (Table 1, Figure 2), although landings have been higher and more stable in recent years for all stocks. The TACC was exceeded in RCO 3 by 2% in 1994–95 and 12% in 1998–99. The TACC for RCO 7 was exceeded in 1992–93 by 30%, and three years running from 1994–95 to 1996–97 by 14%, 19%, and 19%. There is no evidence to suggest that the overruns are due to changes in fleet structure or effort,: they are probably a reflection of good recruitment in recent years.

2.3 Recreational, traditional and Maori fisheries

Recreational surveys conducted in 1991–92 (Teirney *et al.* 1997) and 1996 (Bradford 1998) estimated that about 100 t of red cod are harvested annually by recreational fishers in RCO 3 and up to 40 t in RCO 7. There is no information on Maori customary harvest.

2.4 Stock structure

There is no information on stock structure of red cod and the number of stocks is unknown. When red cod were introduced into the QMS four fishstocks were designated: RCO1 - Auckland East and West; RCO2 - Central East and West; RCO 3 - Chathams, South-East Coast, Sub-Antarctic and Southland; RCO 7 - Challenger. These fishstocks reflect geographical boundaries and commercial fishing patterns rather than biologically distinct stocks.

3. RESEARCH

This section describes the methods used to determine red cod relative abundance indices from catch effort data, trawl surveys, catch-sampling and environmental data. These indices were input into the single stock model and MIAEL estimation model.

3.1 CPUE analyses

Catch and effort data were extracted from the Ministry of Fisheries catch effort database for 1988–89 to 1997–98 from the Catch Effort Landing Returns (CELR) and Trawl Catch Effort Processing Returns (TCEPR) because red cod is landed by both inshore and deepwater vessels. Catch effort data from Fisheries Statistics Unit (FSU) forms, which were used before 1988, were not examined. Standardised and unstandardised analyses of the CPUE data were carried out separately for each fishstock.

3.1.1 Selection of target species and data extraction

Summary data on estimated catches reported on CELR and TCEPR forms from a range of extracts were compared to find the most appropriate target species to specify in the extracts. The selection of the target species can have a significant effect on the results of a CPUE analysis and whether the data reflect abundance of the species of interest (Vignaux 1997). If more than one target species is selected, then the CPUE can be biased by the fishing characteristics used for species other than the species of interest.

RCO 3

When red cod was used as the only target species the proportion of the total red cod landings from RCO 3, from both CELR and TCEPR forms and excluding 1988–89, is between 46 and 68% (Table 2). In other words, this data captures between half and two thirds of the total commercial landings in RCO 3 and therefore should be acceptable to use in the analysis. The remainder is landed as bycatch when targeting other species. Between 44 and 83% of targeted red cod each year is caught by vessels that complete CELR forms, and accordingly 56–17% from vessels filling out TCEPR forms (Table 2). Therefore reporting of catch and effort information in the red cod fishery in RCO 3 uses both deepwater and inshore forms where the target species is red cod.

RCO 7

When red cod is selected as the target species, the proportion of the total red cod landings from RCO 7 from both CELR and TCEPR forms is between 0.7 and 38% (Table 3), mostly from CELR forms. This proportion was considered too low to proceed with red cod as the target species for RCO 7 for either CELR or TCEPR forms. To increase this proportion, equivalent data were extracted where red cod was in the top five species landed and the target species were examined. The key target species for CELR forms were red cod, barracouta, and flatfish which were then used as extraction criteria. A similar exercise was carried out for TCEPR data and key target species were barracouta, hoki, and jack mackerel, but it was decided not to use these as extraction criteria because there is a high risk of introducing bias due to the different fishing practices involved in these fisheries. Therefore for TCEPR forms in RCO 7 data were extracted for all cases where red cod was recorded in the top five species. The proportion of the total red cod landed catch in RCO 7 from both CELR and TCEPR forms then increased to between 66 and 84 % (excluding 1998–99), which was considered to be acceptable to use in the analysis (Table 4).

CELR data extraction

One entry of estimated catch per day is recorded on CELR forms and this may cover multiple tows.

The following variables were extracted from the CELR database for RCO 3 and RCO 7 for the fishing years 1988–89 to 1997–98 for each day's fishing:

RCO 3 – target species = red cod (zero catches included)
RCO 7 – target species = red cod, barracouta, and flatfish (zero catches included)

1. Date of days fishing
2. Tow position (statistical area)
3. Total towing time (h) that day
4. Number of shots/tows that day
5. Catch of red cod in tonnes (estimated greenweight from catch effort section of form)
6. Headline height (m)
7. Wingspread (m)
8. MFish vessel code
9. Vessel length (m)
10. Vessel tonnage (t)
11. Vessel breadth (m)
12. Vessel draught (m)
13. Engine power (kilowatts)

The data were intensively error checked and outliers were removed or corrected where:

1. Estimated catch was over 21 000 kg
2. Number of tows per day was over 10
3. Statistical area was outside the range 18–33
4. Wingspread was over 49 m (many cases where feet were probably used instead of metres)
5. Headline height was over 15 m
6. Tow time was > 24 h

In addition, the vessel data (variables 8–13) were examined for consistency of specifications between years. Often, the same vessel had been registered with different specifications such as power rating or tonnage for different years, and these were manually changed where appropriate. Vessel tonnage, draught, breadth, and power were plotted against length to find outliers and where appropriate corrections or deletions were made. The original number of cases was reduced from 27 151 cases to 27 041 for RCO 3, a loss of 0.4% of the data, and 49 263 cases to 49 247 for RCO 7, a loss of 0.03% of the data.

TCEPR data extraction

One entry of estimated catch per tow is recorded on TCEPR forms.

The following variables were extracted from the TCEPR database for RCO 3 and RCO 7 for the fishing years 1988–89 to 1997–98 for each tow:

RCO 3 – red cod target species (zero catches included)
RCO 7 – red cod in the top 5 species (no zero catches).

1. Date of tow
2. Latitude
3. Time at the end of the tow
4. Duration of tow (h)
5. Catch of red cod in tonnes (estimated greenweight from catch effort section of form)
6. Target species
7. Headline height (m)
8. Depth of bottom (m)
9. Depth of groundrope (m)
10. MFish vessel ID
11. Vessel length (m)
12. Vessel tonnage (t)
13. Vessel breadth (m)
14. Vessel draught (m)
15. Engine power (kilowatts)

The data were intensively error checked and outliers were removed or corrected where:

1. Estimated catch over 40 000 kg
2. Statistical area was outside the range 18–33
3. Wingspread over 75 m (many cases where feet were probably used instead of m)
4. Headline height over 15 m
5. Tow time over 12 h
6. Gear and bottom depth over 800 m
7. Outlier latitudes and longitudes

Vessel data were error checked and corrected as per the CELR data. The original number of cases was reduced from 13 491 to 13 379 for RCO 3, a loss of 0.8% of the data, and 5658 to 5642 for RCO 7, a loss of 0.3%.

3.1.2 Unstandardised CPUE analysis

RCO 3

CELR forms require only one entry of estimated catch per day with effort recorded as the total time trawling and the number of tows in that day. Therefore it is possible to calculate three indices of raw CPUE: kg per day, kg per hour and kg per tow (Appendix 1). Plots of CELR CPUE (kg per day) for RCO 3 and zero catches are shown in Figure 3. Plots of kg per hour and kg per tow were similar (not illustrated). The proportion of cases (= days) with zero catch ranged from 4 to 7 % (Appendix 1).

TCEPR forms require one entry of estimated catch per tow with effort recorded as the total time trawling for each tow. Therefore it is possible to calculate two indices of raw CPUE: kg per hour and kg per tow (Appendix 2). CPUE expressed as kg per tow along with zero catches are plotted in Figure 4. Zero catches were between 10 and 32%. CPUE for both CELR and TCEPR differ for the first four years after which there is a general upward trend, peaking in 1995–95 and declining thereafter. Data for 1988–89 are likely to have errors and may be incomplete as fishers changed from FSU to catch effort landing forms in

1988. The proportion of zero catches appears to be inversely related to CPUE for both CELR and TCEPR.

In RCO 3, 99% of the CELR data originates from only four statistical areas (18, 20, 22, 24) and 86% from statistical areas 20 and 22 (Table 5), the areas north and south of Banks Peninsula (*see* Figure 1). The TCEPR data shows a similar catch distribution, although statistical area 18 contributes very little to this data (Table 6).

RCO 7

Plots of CELR CPUE (kg per day) and zero catches from RCO 7 are shown in Figure 5 and raw data in Appendix 3, including kg per tow and kg per hour. Plots of kg per hour and kg per tow were similar (not illustrated). The proportion of days with zero catch ranged from 19 to 51% (Appendix 3). TCEPR CPUE expressed as kg per tow is plotted in Figure 6 and raw data in Appendix 4; note there are no zero catches because only landings with red cod in the top five species were extracted. CPUE for CELR tends to increase with a peak in 1992–93 followed by a general decline. TCEPR CPUE, in contrast, is relatively flat except for a sharp peak in 1991–92. The proportion of zero catches in the CELR CPUE appears to be inversely related to CPUE.

In RCO 7 the key statistical areas fished by vessels filling out CELR forms are 33–35 (south of Buller), 17 (western Cook Strait), and 38 (Golden Bay) (Figure 1, Table 7). TCEPR shows a similar catch, though statistical area 38 contributes very little and area 37 (north of Golden Bay) is a major contributor (Table 8).

3.1.3 Standardised CPUE analysis

Standardised CPUE analyses were conducted using the method described by Vignaux 1992. Using a stepwise regression procedure, the CPUE index was regressed against all predictor variables and the variable that explained the most variability in CPUE was included in the model. Iterations continued including the remaining variables stepwise until no more variability was explained by including additional variables into the model. The iterations were terminated when improvement in R^2 (multiple regression coefficient) with the addition of an extra variable was less than about 1%.

Catch data were first log transformed; logarithms of zero catches were taken by the addition of 10 kg to each zero catch record. Examination of the residuals from these regression analyses indicated that the model was biased by the inclusion of zeros and therefore only results from analyses excluding zero records are presented. Also, many of the zero catches when targeting red cod may have actually been greater than zero but did not make the top five species in the catch effort section of the form.

The results were converted to relative year indices using the regression coefficients.

RCO 3 CELR

Regression analysis of the RCO 3 CELR data was restricted to 1989–90 to 1997–98 (there were little 1988–89 data and they were prone to error), to records with headline height between 0.5 and 7.0 m, and to statistical areas 18, 20, 22, and 24 (bulk of catch from these areas). The total number of records included in the analysis was 26 874.

The CPUE index log (kg per day) was chosen for the CELR standardised analysis. The selection was arbitrary because raw CPUE trends for all three indices were similar (kg per day, kg per tow, or kg per hour). Predictor variables included in the model were year (fishing year), day of year (season), area (statistical area), towtime (towing duration), headline height, and vessel characteristics breadth, draught, length, tonnage, kilowatts (power), and volume (b*l*d). Variables fishing year and statistical area were included as categorical and all other variables as continuous. The form of the relationship between log CPUE and the continuous variables was examined and the polynomial with the most appropriate order was chosen. Third order polynomials were chosen for all continuous variables except season, which was of fourth order, and volume, which was linear.

Results of the stepwise selection are shown in Table 9 and the relative year indices in Table 10. The model explained 24% of the variability in CPUE and included the five variables day of year, tonnage, fishing year, towtime, and statistical area.

RCO 3 TCEPR

Regression analysis of the RCO 3 TCEPR data was restricted to records as per CELR data above, except that statistical areas were restricted to 20, 22, and 24: 13 379 records were included in the analysis.

The CPUE index log (kg per tow), rather than kg per day, was chosen for the TCEPR standardised analysis as catch is recorded for each tow. Kilograms per day is also the most commonly used CPUE index taken from TCEPR catch effort data. Predictor variables used were the same as for RCO 3 CELR data, but included gear depth and time of day, and excluded volume, which explained the least variability in the RCO 3 CELR model. Variables fishing year and statistical area were included as categorical and the all other variables were continuous. Third order polynomials were chosen for all continuous variables except season, which was of fourth order, and time of day, which was second order.

Results of the stepwise selections are shown in Table 11 and the relative year indices in Table 12. The model explained 13% of the variability in CPUE and included the five variables power, day of year, time of day, fishing year, and gear depth.

Plots of RCO 3 CELR and TCEPR year relative effects are shown in Figure 7. Comparison of the plots indicates that both CELR and TCEPR data follow a similar trend with CPUE peaking in 1994–95, and declining thereafter. CPUE track commercial catch in RCO 3 reasonably well for both CELR and TCEPR (Figure 8).

RCO 7 CELR

Regression analysis of the RCO 7 CELR data was restricted to records as per RCO 3 CELR data, except that statistical areas were restricted to 17, 33, 34, 35, and 38: 46 023 records were included in the analysis.

The CPUE index log (kg per day) was chosen for the CELR standardised analysis. Predictor variables used were the same as for RCO 3 CELR data but also included target species. Variables fishing year, statistical area, and target (target species = red cod, barracouta, flatfish) were included as categorical and the all other variables were continuous. The form of the relationship between log CPUE and the continuous variables was the same as for RCO 3 CELR.

Results of the stepwise selections are shown in Table 13 and the relative year indices in Table 14. The model explained 37% of the variability in CPUE and included the five variables breadth, area, fishing year, towtime, and target.

RCO 7 TCEPR

Regression analysis of the RCO 7 TCEPR data was restricted to records as per RCO 3 CELR data except that statistical areas were restricted to 17, 33, 34, 35, and 37: 4779 records were included in the analysis.

The CPUE index log (kg per tow) was chosen for the TCEPR standardised analysis. Predictor variables used were the same as for RCO 3 TCEPR data, but also included target (redefined as barracouta, hoki, jack mackerel, or others). Variables fishing year, statistical area, and target (target species) were included as categorical and all other variables were continuous. Third order polynomials were chosen for all continuous variables except season (fourth order) and towtime/gear depth (second order).

Results of the regression analyses are shown in Table 15 and the relative year indices in Table 16. The model explained 18% of the variability in CPUE and included the five variables area, target, length, fishing year, and time of day.

Plots of RCO 7 CELR and TCEPR year relative effects are shown in Figure 9. Comparison of the plots indicates that like the raw CELR and TCEPR CPUE analysis, results are dissimilar (*see* Figures 5 & 6). The TCEPR data are not considered to be as dependable given that, despite using all records where red cod was in the top five species caught, the number of records was still small (only 10% of CELR data). Also the main target species is hoki, which is caught at much greater depths than red cod. In addition, CPUE of CELR track commercial catch in RCO 7 reasonably well, whereas TCEPR do not. Assuming that red cod commercial catch is related to abundance, then CPUE for CELR may be a better index of abundance than TCEPR data and for this and the above reasons the latter was not included in the MIAEL model (Figure 10).

3.2 Resource surveys

3.2.1 West coast South Island trawl survey time series

A time series of four trawl surveys has been conducted in Golden and Tasman Bays, and along the west coast of the South Island from Farewell Spit to Haast in the depth range 20–400 m. The surveys were carried out in March-April in 1992, 1994, 1995, and 1997 (KAH9204, KAH9404, KAH9504, KAH9701) (Drummond & Stevenson 1995a, 1995b, 1996, Stevenson 1998). Red cod was included in the target species objectives and the surveys provided estimates of relative abundance and collected data on length frequency, length weight relationship and gonad condition as well as collecting otoliths for ageing. The results of these four surveys have been summarised by Stevenson & Hanchet (2000).

Scaled length frequencies for red cod from these surveys are shown in Figure 11. Red cod length frequency distributions from west coast South Island surveys are generally dominated by the 1+ age class (25–40 cm), with fewer 2+ fish (40–55 cm) and to a lesser extent 3+ fish (> 55 cm) constituting a second smaller mode (Horn 1995). 1994 was an exception with a relatively weak 1+ year class and a strong 2+ mode, the latter a result of a strong 1+ year class in 1993. The 0+ age class (10–20 cm) is also represented in some years and was relatively strong in 1995 and 1997, although 0+ fish age are probably not fully vulnerable to capture with the net used. The 1+ mode is generally about 30 cm and females appear to be marginally largerthan males.

Relative biomass estimates and *c.v.s* for each survey (Table 17) are largely unchanged between years and there is no statistically significant trend in biomass (Stevenson & Hanchet2000).

3.2.2 East coast South Island winter trawl survey time series

A time series of five trawl surveys has been conducted on the east coast of the South Island from Waiau River to Shag Point in the depth range 30–400 m. The surveys were carried out in May-June 1991, 1992, 1993, 1994, and 1996 (KAH9105, KAH9205, KAH9306, KAH9406, KAH9606) (Beentjes & Wass 1994, Beentjes 1995a, 1995b, 1998a, 1998b). Red cod was the main target species and the surveys provided estimates of relative abundance and collected data on length frequency, length weight relationship and gonad condition as well as collecting otoliths for ageing. The results of these four surveys have been summarised by Beentjes & Stevenson (2000).

Scaled length frequencies for red cod from these surveys are shown in Figure 12. Red cod length frequency distributions from east coast South Island winter surveys are similar to those described above for the west coast, and are dominated in most years by 1+ fish (30–45 cm). Note that the age classes from east coast surveys are larger than the west coast surveys as a result of growth over several months. This is most obvious for the 1+ fish which have grown on average about 5 cm. The 0+ age class is not well represented in these surveys. 1993 and 1996 had relatively low numbers of 1+ fish.

Relative biomass estimates and *c.v.*s for each survey (Table 17) are largely unchanged between years and there is no statistically significant trend in biomass (Beentjes & Stevenson2000).

3.2.3 East coast South Island summer trawl survey time series

A time series of three surveys have been conducted on the east coast of the South Island from Waiau River to Shag Point in the depth range 15–400 m. This time series replaced the winter surveys which were discontinued after 1996. The surveys were carried out in December/January of 1996–97, 1997–98, and 1998–99 (KAH9618, KAH9704, KAH9809) (Stevenson 1997, Stevenson & Hurst 1998, Stevenson & Beentjes 1999). Red cod was included as a target species in the objectives and the surveys provided estimates of relative abundance and collected data on length frequency, length weight relationship, gonad condition as well as collecting otoliths for ageing.

Scaled length frequencies for red cod from these surveys are shown in Figure 13. Red cod length frequency distributions from east coast South Island summer surveys are similar to those described above for the west coast, except that fish from the same year class are smaller because these surveys take place in December-January. Length frequency distributions are dominated by the 1+ (15–30 cm) age class in 1997–98 and 1998–99 and by the 0+ fish (7–15 cm) in 1996–97. The net used a finer codend mesh than the winter surveys and 0+ fish are vulnerable to capture.

Biomass estimates and *c.v.*s for each survey are given in Table 17. The relative biomass estimates are all larger than the winter survey estimates, a result not unexpected given that the summer survey takes place in the peak of the red cod fishery season. There is considerable fluctuation in biomass estimates with a relatively low estimate for the second survey. Biomass estimates for some other key species were also low and unusual water temperatures were possibly the cause (Stevenson & Hurst 1998).

3.3 Red cod commercial catch sampling programme (1990–93)

3.3.1 Sampling procedure

A red cod catch sampling programme on the east coast of the South Island was carried out over four consecutive years between 1990 and 1993 (MAF Fisheries research programme SORCO1) The key objective was to determine length at age of red cod in the commercial fishery and ultimately to use this information in an age structured model for stock assessment. It was also envisaged that these data would reveal any trends in age composition over time because the strength of recruiting year classes is known to be highly variable. Data from the 1990 and 1991 seasons were presented by Beentjes (1992). Sampling involved the recording of length and sex as well as biological information on stomach contents, gonad stage, and the removal of otoliths for ageing. The double sample approach was used to sample landings (Quinn *et al.* 1983): from a random sample of 200 fish taken for length, a sub-sample of 20 randomly selected fish was sampled for age. Sampling occurred throughout the season but mainly between January and May. A summary of landings sampled is given in Table 18.

3.3.2 Analysis of sampling bias

Before using the catch sampling data to estimate catch at age for inclusion in the MIAEL estimation model, the data were first examined to determine if there was any sampling bias due to changes in the size and power of the fishing vessels or areas fished between seasons.

Red cod landings tend to show high heterogeneity in mean length and sex ratio (Figures 14 & 15). Within landings the mean length of males and females is similar, indicating that both sexes are the same age and probably dominated by one cohort. The between-landing variation in mean size is presumably due to the dominance of a single cohort in the catches, an indication that red cod school in cohorts, and that these cohort schools move around the fishing grounds. To guard against possible bias in sampling length frequency composition that might result from vessel size and thus power, vessel size was examined for each of the four years (Table 19). It was found that the sampled vessel size and the proportion of landings sampled from the different vessel sizes remained roughly constant between years. If there are differences in the size composition of red cod attributable to vessel size, these are common to all years.

Vessels under 43 m filling our CELR catch effort forms are required by MFish to provide statistical area position data but not latitude and longitude. As part of the red cod catch sampling programme approximate positions of sampled landings were requested from fishers and are available for some landings (91 of 124 landings in 1990). These data show that in all four years, effort has been spread throughout the main fishery in RCO 3 (Pegasus Bay to south of Timaru), and indicate that the between-landing heterogeneity in size composition has an inherent spatial component which is an integral part of this fishery. The assumption is that although heterogeneity exists in between landing data, landings are essentially random events and that given that sampling is adequate and robust, the sampled length frequency composition is representative of the fishery in RCO 3.

Nineteen landings from two vessels were sampled from Kaikoura in 1991. The length composition of these fish was markedly smaller than from the main fishery from Pegasus Bay to Timaru (Beentjes 1992). It is likely that the Kaikoura red cod fishery catches fish at different ages than the Pegasus Bay and Timaru fisheries. Therefore, given that sampling in Kaikoura occurred only in 1991, these data have been excluded from the length frequency and catch at age analyses. Further, to allow length frequency data to be validly compared between years, only landings from common months sampled were used, thus avoiding bias of seasonality in the data. Therefore only landings from January to May have been used to generate length frequency histograms and to determine catch at age.

The data were examined to determine the most appropriate stratification. Comparison of Timaru and Lyttelton landings showed no differences in average length or length at age, and therefore area stratification was not necessary (Beentjes 1992). Red cod, however, grow fast, and modal progression can be seen in the length frequency data within the season. It was therefore necessary to stratify by time, and accordingly the data were broken up into three blocks (January–February, March–April and May).

3.3.3 Catch sampling length frequency data

For each two month block (January–February, March–April, and May–June) length frequency data by sex were scaled to landing weight and coefficients of variation determined for each length interval (Figure 16). Mean weighted coefficients of variation (MWCV) are also shown indicating sampling precision for each strata. MWCVs were calculated by the following method:

$$\frac{\sum (c.v.\text{ at } ith \text{ length.No.fish measured at } ith \text{ length})}{\text{Total number of fish measured}}$$

MWCV ranged from 13.9 to 40.9% and was highest in 1991 when there were fewer landings than in other years (*see* Table 18). In addition, the exclusion of Kaikoura landings from our analyses in 1991 reduced the number of landings in the analysis from 54 to 35. Generally the *c.v.s* for most length frequency distributions are 10–20% over the bulk of the length classes, indicating an acceptable level of precision and that adequate landings were sampled.

3.4 Ageing

3.4.1 Preparation and reading

All otoliths collected from the red cod catch sampling programme (1990–93) and the east coast South Island trawl surveys in 1991, 1992, and 1993 were prepared at the time of collection by breaking mid length through the nucleus, and moulding in PS404 epoxy resin, broken surface down. A mould with 20 otoliths was then polished using several grades of sandpaper or sharpening stones. A final polish with "Brasso" or a similar polishing product produced a smooth, clean, unmarked surface. The block was then baked in an oven at 250° C for 10 to 15 min. Otoliths from all other trawl surveys were prepared using the standard method for finfish (Horn & Sullivan 1994).

Otoliths were read under a binocular microscope using reflected light. Best results were achieved using a directed light source at an angle of about 35–45° above the plane of the flat otolith surface. The surface of the otolith was coated in oil before reading to heighten the contrast between light and dark rings, making the otolith easier to read and interpret.

For the catch sampling programme, all otoliths were read where N < 160 for each of the three 2 monthly strata (January–February, March–April, May–June), for each of the four years. Where N > 160, a random selection of around 140 was taken using an otolith selection computer programme designed to sample otoliths from as many landings as possible by selecting about four otoliths per length class, per sex (Appendix 5). The programme also ensures that otoliths from the smallest and largest fish, which are usually underrepresented, are included.

For the east coast South Island summer and winter, and west coast South Island trawl surveys, all otoliths collected were prepared and read, except for the 1994 east coast South Island survey where 800 otoliths were collected; of these 800 otoliths, 400 were randomly selected for reading using the otolith selection programme (Appendix 6). One reader (principal reader) was responsible for reading all otoliths.

3.4.2 Within and between - reader comparisons

Red cod ageing has been validated by Horn (1995). To ensure that age readings of red cod otoliths by the principal reader were consistent with this ageing methodology, about 260 otoliths from the 1992 east South Island winter trawl survey (KAH9205) were read by the principal reader and by Horn and compared (Table 20). To check within-reader variability, these otoliths were also read twice (12 weeks apart) by the principal reader (Table 21). Agreement between the principle reader and Horn is about 90–100% with no apparent age bias. Within-reader agreement for the principal reader was 70–90% and reflected a change in interpretation by the reader with experience rather than actual within-reader error. All otolith readings used in this study were taken after the principal reader had achieved good agreement with Horn (*see* Table 20).

Von Bertalanffy growth parameters and 95% confidence intervals were determined for the length and age data from the west coast trawl surveys (KAH9504, KAH9701). Von Bertalanffy growth parameters for RCO 3 were taken from Horn (1995) (Table 22).

3.5 Estimation of proportion at age

3.5.1 Trawl surveys

Proportion at age was determined for all east coast South Island trawl surveys using otolith age readings (*see* Appendices 6 & 7) (Figure 17). Separate age length keys were constructed for males and females. Length frequency data were first scaled to population numbers using the Trawlsurvey Analysis Program (Vignaux 1994) and age length keys were then applied to the scaled length frequencies to estimate age distribution (Horn & Sullivan 1994) as follows:

$$A_t = \Sigma_x (L_x \, p_{tx})$$

Where A_t is the estimated proportion of fish of age t in the sample, L_x is the proportion of fish of length x in the length frequency, and p_{tx} is the proportion of aged fish of length x which were age t.

For west coast surveys, red cod otoliths were collected only on the 1995 and 1997 surveys (Appendix 6) and therefore proportion at age was estimated using MIX software (MacDonald & Green 1988, Sullivan &

Cordue 1994). The numbers of 0+, 1+, and 2+ and older fish, were estimated from scaled length frequency data for all four west coast South Island trawl surveys. Unsexed fish were prorated across both sexes in accordance with the sex ratio in the population as determined from the Trawlsurvey Analysis Program. It was generally close to half (Appendix 8).

3.5.2. Catch sampling

Catch at age was determined for the red cod catch sampling data in the following way. The length frequency data were stratified, as per the age data in two monthly blocks for each year, to account for rapid within-season growth (January–February, March–April, May–June). The length frequency data were then scaled up to the total landed weight of the sampled catch. Age length keys were estimated for these bimonthly strata and applied to the equivalent scaled length frequency data. The total catch at age for each year (between January and June) is the sum of the three bimonthly catch at age estimates. (Figure 18, Appendix 9). This method is known as Project and Add (Quinn *et al.* 1983).

3.6 Environmental-recruitment relationship

Climate and fisheries data were analysed in a two-stage exploratory process, using simple linear statistics throughout. Climate variables included sea surface temperature (SST), southern oscillation index (SOI), frequency of defined weather systems, river flow data, and mean sea level pressure (MSLP). The emphasis in the statistical analysis was on the commercial catch data (1970–71 to 1997–98) which were used as an estimate of abundance in the absence of any long-term year class strength index such as catch at age from trawl surveys. The catch data are characterised by peaks and troughs in catches, assumed to reflect changes in abundance driven by recruitment pulses. This assumption is given support by the catch effort analyses which indicate that annual indices of CPUE mirror annual commercial landings (*see* Figures 8 & 10). We also assume that the fishing rounds are a closed system and that red cod do not move in and out of the fishing grounds to any extent, i.e., availability between years does not vary. For instance, in years when catches are poor there are no corresponding increases in deep water catches (McDiarmid 1988, Beentjes 1992) and, at least for the east coast South Island, TCEPR CPUE is similar to that for CELR. Also the peaks and troughs in catches from the west coast fishery resemble those on the east coast, although they are thought to be independent, indicating that recruitment is being affected in a similar manner. The high variability in annual catches along with rapid growth and short life span make red cod a good candidate for detecting correlations between environmental factors and recruitment.

Consistently, the strongest correlations between red cod commercial catch and explanatory variables were with SST, over a wide range of time lags, for both RCO 3 and RCO 7.After SST, the next best "predictors" of catch variability were the frequencies of southwest and northeast flow patterns. The correlations generally operate in the sense that "colder is better": negative correlations with SST, positive with southwest weather types (stronger southwesterlies are cooler over New Zealand), negative with northeast weather types, and so on. The most useful variables are very similar to those found for southern gemfish off the west coast of the South Island (Renwick *et al.* 1998), although the sense of the correlations is opposite. An annual periodicity with time lag appeared in correlations with many variables. Climate indices from the late winter and spring 1 year before the catch year tended to be most highly correlated with catch, but often there were secondary maxima in the magnitude of the correlations 1 or 2 years farther back (i.e., 2 or 3 years prior to the catch year). The evolution of the correlation with lag is very similar for both fisheries and appears to be non-random. The maximum magnitude of the (negative) correlation occurs at 14 month lag for both fisheries, corresponding to August-January of the year before the catch year. There are subsequent local "peaks" in the correlations about 1 and 2 years before the 14-month value (at about 26 and 38 month lags). The commercial fishery is made up largely of 2 and 3-year-old fish, implying that juvenile fish (age about one year) are sensitive to environmental conditions.

From regression analysis, variables most strongly correlated with commercial catch were used to predict red cod abundance (environmental abundance index) for input into the MIAEL model. Lags of 14 and 26 months were tested and in both cases 14 month lag explained the most variability in commercial catches. For RCO 3, the predictors SST and Trough NW cluster, with a 14 month lag, explained 68% of variability in commercial catch. For RCO 7 the predictors SST and surface westerly wind, with a 14 month lag, explained 75% of variability in commercial catch. The resultant predicted index of abundance for each stock were used in the MIAEL model as sensitivity analyses (Figures 19 & 20, Appendix 10).

4. STOCK ASSESSMENT

This section describes the assessment of RCO 3 and RCO 7 stock using the single stock population model and MIAEL estimation technique (MIAEL stands for Minimum Integrated Average Expected Loss). Virgin biomass, current biomass (1998–99), and next year's biomass (1999–2000) were estimated for stocks RCO 3 and RCO 7. MCY, MAY, and CAY were also determined.

4.1 Model estimation method

Assessment of red cod was carried out separately for stocks RCO 3 and RCO 7 using a stock reduction technique. The estimation method is a two-step approach. The first step is a multi-parameter estimation in which unknown parameters relative year class strength, B_0, home ground selectivity, and trawl selectivity were estimated using the single stock least squares model (Cordue 1998a). In the second step, these parameters were fixed at their estimated least squares values, except B_0, and then used in the MIAEL estimation technique (Cordue 1998b) in a single parameter estimation of B_0 and performance index (a measure of the reliability with which the estimate is determined within its known range).

4.2 Model Input data

RCO 3

1. East coast South Island winter trawl surveys KAH9105, KAH9205, KAH9306, KAH9406, KAH9606 (Appendix 7). The period of the surveys was entered as second half pre-spawning season. Data were input into step one of the model as numbers at age and sex of 1+ and 2+ fish: *c.v.*s for the 0+, 3+, and 4+ fish were considered to be too high to use in the model. Model *c.v.*s for numbers at age were obtained by weighting a median *c.v.* of 25 by the number of tows and were 28, 25, 26, 23, and 23% respectively. Total biomass estimates from these surveys were used in the second step of the MIAEL estimation procedure (*see* Table 17). Model *c.v.*s for biomass were obtained by weighting a median *c.v.* of 35 (average performance) by the number of tows and were 38, 35, 36, 33, and 33%, respectively.

2 East coast South Island summer trawl surveys KAH9618, KAH9704, KAH9809 (Appendix 7). The period of the surveys was entered as corridor migrations and maturation. Data were input into step one of the model as numbers at age and sex of 0+, 1+, 2+, and 3+ and older fish: *c.v.*s for 4+ fish were considered to be too high to use in the model. The model does not cater for 0+ age groups and therefore the 0+ fish were entered as 1+ fish the following year. Model *c.v.*s for numbers at age were obtained by weighting a median *c.v.* of 25 (good performance) by the number of tows and were 25, 24, and 25 % respectively. Total biomass estimates from these surveys were used in the second step of the MIAEL estimation procedure (*see* Table 17). Model *c.v.*s for biomass were obtained by weighting a median *c.v.* of 25 (good performance) by the number of tows and were 25, 24, and 25%, respectively.

3. Catch at age for east coast South Island red cod catch sampling programme (1990–93) (Appendix 9). The period was entered as second half pre-spawning season. Data were input into step one of the model as proportion at age and sex of 1+, 2+, 3+, and 4+ fish in the catch. Model *c.v.*s for each year were obtained by weighting a median *c.v.* of 25 (good performance) by the number of samples and were 23, 32, 26, and 24% respectively. Catch sampling data were not used in the second step MIAEL estimation procedure.

4 Standardised CPUE data 1989–90 to 1997–98 (CELR and TCEPR). The period was entered as first half pre-spawning season. Data were input into steps one and two of the model as mature biomass (relative

year effects) and a median *c.v.* of 35% (convention) was applied to each year's CPUE data (*see* Tables 10 & 12).

5 The environmental abundance index determined from the relationship between environmental variables and actual commercial catch in RCO 3 for the fishing years 1970–71 to 1997–98 (Appendix 10). Variables most strongly correlated with commercial catch were used to predict abundance for input into the MIAEL model sensitivity analysis. The predictors SST and Trough NW cluster, with a 14 month lag, explained 68% of variability in commercial catch. Data were input into steps one and two as biomass and the period was entered as first half pre-spawning season. A median *c.v.* of 35% was applied to each yearly abundance estimate.

RCO 7

1 West coast South Island trawl surveys KAH9204, KAH9404, KAH9504, KAH9701. The period was entered as first half pre-spawning season. Data were input into the model as numbers at age and sex of 0+, 1+ and 2+ & older fish, determined from MIX analysis (Appendix 8). MIX analysis was used because otoliths were collected for only two of the four trawl surveys. The model does not cater for 0+ age groups and therefore the 0+ fish were entered as 1+ fish the following year. Model *c.v.*s for numbers at age were obtained by weighting a median *c.v.* of 25 (good performance) by the number of tows and were 25, 24, 25, and 26% respectively. Total biomass estimates from these surveys were used in the MIAEL estimation procedure (Table 17). Model *c.v.*s for biomass were obtained by weighting a median *c.v.* of 25 (good performance) by the number of tows and were 25, 24, 25, and 26%, respectively.

2 Standardised CPUE data 1989–90 to 1997–98 (CELR only). The period was entered as first half pre-spawning season. Data were input into steps one and two of the model as mature biomass (relative year effects) and a median *c.v.* of 35% (convention) was applied to each years CPUE data (*see* Table 14). TCEPR data were not included because it was considered that this index was not a good indicator of red cod abundance.

3 The environmental abundance index determined from the relationship between environmental variables and actual commercial catch in RCO 7 for the fishing years 1970–71 to 1997–98 (Appendix 10). Variables most strongly correlated with commercial catch were used to predict abundance for input into the MIAEL model sensitivity analysis. The predictors SST and surface westerly wind, with a 14 month lag, explained 75% of variability in commercial catch. A median *c.v.* of 35% was assigned to each yearly catch estimate. Data were input into steps one and two as biomass and the period was entered as first half pre-spawning season. A median *c.v.* of 35% was applied to each yearly abundance estimate.

Natural mortality estimates, length weights relationships, von Bertalanffy parameters, and maturity ogives for RCO 3 and RCO 7 and shown in Table 22.

4.3 Year class strength and parameter estimation

The model

Year class strengths were estimated for the years 1986 to 1998 (RCO 3) and 1989 to 1996 (RCO 7); these periods were defined by input data that included information on age classes. In both stocks the environmental abundance index was used only as a sensitivity analysis. Home ground fishing selectivity ogives (RCO 3 only) and trawl survey selectivity ogives were also estimated with a fixed maturity ogive (Table 22). Home ground selectivity was fixed for RCO 7 using proportions similar to RCO 3 rather than being estimated at each run because there were no fishing data to estimate this ogive. For missing age classes (3+ and 4+ fish) in the east coast South Island winter trawl surveys, age selectivities were assumed by the model to be the same as 2+ fish. Similarly for the summer surveys, the 4+ selectivities were assumed by the model to be the same as 3+ fish, and for the west coast South Island surveys, 3+ and 4+ selectivities were assumed by the model to be the same as 2+ fish. Bounds on the trawl survey selectivities and home ground selectivities were adjusted to achieve sensible results and/or to improve least squares model fits of the CPUE abundance indices and age classes from the catch sampling and trawl surveys. Initial estimates of YCS were considered to be too high and were encouraged to average about 1 (Hurst *et al.* 1999). For sensitivity analyses, selected parameters were changed and YCS re-estimated (Table 23). Once determined, these parameters were then used to obtain estimates of B_{min} and B_{max}, which are the lowest and highest values of virgin biomass that are consistent with the catch history.

An ageing error of ±10% was used (Horn 1995) and log-normal error structure was applied throughout. Beverton-Holt stock recruitment steepness criteria was taken as 0.75, which is a default value from Francis (1992).

The model allows for catches to be partitioned between pre-spawning and spawning periods. Red cod spawning grounds are unknown although they are thought to spawn in deep water (Beentjes 1992) and there is little fishing during the spawning season in August to October. All fishing therefore isassumed to take place on the home ground with no spawning season catch; spawning length was entered as zero in the model (Table 23). A sensitivity analysis was carried out assuming a spawning length of 0.1 and catches were partitioned between home ground (83.4%) and spawning ground (16.6%). These proportions were generated by dividing the total annual catch by twelve months and the catch for the spawning period was taken as the catch for 2 of the12 months. There are no commercial catch records from 1960 to 1970 and therefore catch for this period was estimated and set at about the mean annual catch for the 1970s (RCO 3 3000 t, RCO 7 600 t).

The maximum proportion of the beginning of season home ground biomass (r_{hm_max}) that could have been caught by the commercial fleet was set at (0.7) for RCO 3 and RCO 7. The minimum exploitation rate (r_{hm_mmx}) was set at 0.05 and represents an estimate of the minimum proportion of fish that could have been caught in the year of highest exploitation. Sensitivity analyseswere carried out with r_{hm_max} values of0.8. and 0.5 and a r_{hm_mmx} value of 0.02.

CPUE data was down-weighted to 0.5 because of the high frequency of errors generally associated with catch effort data and proportion or numbers at age data (trawl surveys and catch sampling) was given a weighting of 1. A sensitivity analysis was carried out with a weighting of 1.0 for CPUE data.

Instantaneous natural mortality (M) values were set at 0.75 for males and at 0.7 for females, which tend to live longer. It is based on the method of Vetter (1988) where maximum age observed in an exploited population was 4 and the proportion of the population that reaches this age was taken as 0.05.

Red cod have been shown to mature between 50 and 55 cm total length (Habib 1975). From our understanding of length at age (Horn 1995), it is likely that there are still some immature males as old as 3 and possibly 4. The highest age (mhigh) at which there were still immature fish was set at 4 for both sexes. This was decreased to 3 in a sensitivity analysis. The lowest age at which there might be mature fish (mlow) was set at 1, given that 1+ fish approach 50 cm in length near their October birthday.

4.4 Results

Estimated home ground fishing selectivities are shown in Table 24, andtrawl selectivites in Tables 25 and 26. For the basecase and most sensitivity analyses, home ground fishing selectivities suggest that 2+ fish are consistently the most vulnerable, followed closely by 3+ fish. For 3+ and 4+ fish there is also a tendency for males to be more vulnerable than females. Trawl survey selectivities for the ECSI winter surveys and WCSI surveys are largely constrained by the bounds which were imposed to encourage the best fits of the data to the model. The summer surveys are more representative and indicate that 1+ and 2+ fish are most vulnerable with a considerable reduction in vulnerability for 3+ and older fish.

YCS estimates for base case and sensitivity analyses are given in Tables 27 and 28. YCSs for the basecase and sensitivity 1 (environmental abundance index) for both stocks are plotted in Figure 21. For RCO 3 base case and all sensitivity analyses except sensitivity 1, recruitment was strongest in 1990 with secondary peaks in 1992 and 1996. For sensitivity 1 there is also a strong peak in 1987 but 1996 is weak. In other words, the inclusion of the environmental abundance index in the model indicates that YCS from 1994 to 1998 has been consistently poor and less than YCS estimates of the base case. For RCO 7 base case and all sensitivity analyses, recruitment was strongest in 1990, 1992, and 1995, and sensitivity 1 (environmental abundance index) was similar to base case and other sensitivity runs.

Least squares fits to the RCO 3 data are shown in Figure 22. Fits were reasonably good for CPUE indices, and the proportions at age from the catch sampling and trawl surveys with the exception of the 3+ age class from the summer trawl survey in which the fit was poor. The poor fit for the 3+ fish may be due to the pooling of the 3+ and older fish in the model (*see* input data). The least squares fit of the environmental abundance index in sensitivity 1 also is also reasonable. There are fewer model fits for RCO 7 as there was less input data (Figure 23). The best fits are for the 0+ fish with only average fits for CPUE indices and the 1+ year class. The 2+ year class has a poor fit. The poor fit for the 2+ fish may be due to the pooling of the 2+ and older fish in the model. The least squares fit of the environmental abundance index in sensitivity 1 is also reasonable.

4.5 Least squares biomass estimates

RCO 3 and RCO 7 least squares estimates of all biomass estimates were the same as B_{max} in all runs (Table 29 & 30). B_{max} is sensitive to r_{hm_mmax} with low values resulting in higher B_{max} estimates. In sensitivity analysis 8, r_{hm_mmax} was decreased from 0.05 to 0.02 resulting in an increased B_{max}, although least squares estimate of B_0 was still equal to B_{max}. Similarly increasing or decreasing r_{hme_max} (base case 0.7, sens2 0.8, sens9 0.5) did not result in a least squares estimate of B_0 less than B_{max}. This may be caused by the flat nature of the trawl survey biomass estimates which result in the best fit at maximum B_0.

Because RCO 3 estimated YCS for sensitivity 1 are consistently low from 1994 to 1998, least squares biomass estimates for current biomass (1998–99) and 1999–2000 biomass are the lowest of all estimates. RCO 7 estimated YCS for sensitivity 1 are similar to the basecase and estimates for current biomass (1998–99) and 1999–2000 biomass are those of the basecase.

4.6 MIAEL biomass estimates

In the second step of the MIAEL estimation procedure the following biomass estimates and ranges were obtained:

- mid spawning season virgin biomass (B_0)
- mid spawning season current biomass (1998–99, B_{mid99}/B_0)
- beginning of season home ground total biomass (1999–2000, B_{beg00})
- mid spawning season current biomass for next year (1999–2000) (B_{mid00}/B_0)

To determine B_{mid00} an estimate of catch for the next year was required. The estimated catch used in 1999–2000 for RCO 3 was 9297 t and for RCO 7 was 2637, the mean catch over the last 10 years for each stock.

RCO 3

The MIAEL base case virgin biomass estimate for RCO 3 was 58 000 t with a performance index of 17%. Sensitivity estimates of virgin biomass ranged from 40 500 to 88 500 t. The largest estimates of B_0 were for sensitivity analyses 1 (environmental abundance index) and 8 (r_{hm_mmax} 0.02). Sensitivity analysis 1 also resulted in the highest performance index for B_0 estimates of 32 %. The model was also sensitive to changes in mortality, with higher mortality resulting in a lower B_0 estimate and vice versa. The inclusion of a spawning period resulted in the lowest estimate of B_0.

MIAEL basecase estimate of current biomass as a percentage of virgin biomass (B_{mid99}/B_0) is 75% with a performance index of 15%. Current biomass was most sensitive to the inclusion of the environmental abundance index which lowered the estimate to 47% of B_0 and gave the best performance index of 50%. Changing r_{hm_max} or r_{hm_mmax} also increases the estimate of current biomass.

Beginning of season biomass (B_{beg00}) was 118 000 t for the base case and all sensitivity analyses estimates were less than this, except for r_{hm_max} and r_{hm_mmax} sensitivities. Estimated biomass for the next fishing year (B_{mid00}) as a percentage of B_0 is 49% for the base case with a performance index of only 6%, indicating that the point estimate of B_{mid00} is generally not well known. Sensitivity analyses displayed a wide range of B_{mid00} estimates and performance indices. The most notable departures from the basecase were sensitivity 1 (environmental abundance index) where the B_{mid00} estimate is only 12% of B_0 with a performance index of 15%, and sensitivity 9 (r_{hm_max} 0.5), where the B_{mid00} estimate is 114% of B_0 with a performance index of 22%. In general, sensitivities for environmental abundance index, r_{hm_max}, and r_{hm_mmax} resulted in the highest performance indices, i.e., the biomass estimates are well estimated within their known range for these parameters.

Biomass trajectories for B_{min} and B_{max} and current and estimates of B_{mid99} and B_{mid00} for the base case and sensitivity 1 are shown in Figure 24. Trajectories for both runs are similar. The lack of data before 1970 results in flat trajectories for both B_{min} and B_{max}, which then decline in the mid 1970s until the early 1990s when there is marked increase followed by a decline in the late 1990s. The initial decline is probably caused by the development of the fishery in the 1970s and the increase in recent years due to good recruitment. Fishing pressure is unlikely to have changed recently, and the latest decline is probably due to recent poor recruitment. The sensitivity analysis 1 (environmental abundance index) indicates an even sharper decline in biomass in recent years and lower estimates of B_{mid99} and B_{mid00}. It also indicates that biomass estimates for 1999–2000 will be less than for 1998–99.

Lowering the r_{hm_mmax}, from 0.05 to 0.02 resulted in higher estimates of all biomasses as a result of the increased least squares estimate of B_{max}.

RCO 7

RCO 7 is a smaller stock than red cod and estimates of virgin biomass are about one-third that of RCO 3. The MIAEL base case virgin biomass estimate for RCO 7 was 20 000 t with a performance index of 55%. Sensitivity estimates of virgin biomass ranged from 13 500 to 37 500 t. Unlike RCO 3, sensitivity analyses did not affect estimates of B_0, greatly except for r_{hm_mmax} when a lower value of 0.02 increased the B_0 estimate to 37 500 t. Performance indices were high, indicating that the point estimates of biomass are well estimated within their known range for these parameters.

MIAEL basecase estimate of current biomass as a percentage of virgin biomass (B_{mid99}/B_0) is 49% with a performance index of 32%. All sensitivity analyses resulted in increased estimates of current biomass and, in particular, sensitivities for environmental abundance index, r_{hm_mmax}, (0.02), r_{hm_max} (0.5), and mortality, increased estimates of B_{mid99} substantially.

Beginning of season biomass (B_{beg00}) was 57 500 t for the base case with a performance index of 75%. Apart from spawning length and r_{hm_mmax}, (0.02), B_{beg00} was not affected greatly by sensitivity analyses. B_{mid00} was estimated at 51% of B_0 with a performance index of 49%. All sensitivity analysis estimates of B_{mid00} were greater than the base case with the exception of r_{hm_max} (0.8). Sensitivities for r_{hm_mmax}, (0.02) and the environmental abundance index resulted in the highest estimates of B_{mid00} at 85% and 84% of B_0 respectively.

Biomass trajectories for B_{min} and B_{max} and estimates of B_{mid99} and B_{mid00} for the base case and sensitivity 1 (environ) are shown in Figure 25. Trajectories for both runs are similar. There is a general similarity in shape to RCO 3 (see above for interpretation). However, both the base case and sensitivity analysis (environ/SST) have higher estimates of current biomass and next years biomass as a percent of B_0 (B_{mid99} and B_{mid00}). It also indicates that biomass estimates for 1999–2000 will be similar to those for 1998–99.

The inclusion of the environment abundance index resulted in higher estimates of B_{mid00} and B_{mid99}, and high performance indices indicating that the biomass estimates are well estimated within their known range for these parameters. Lowering the r_{hm_mmax} (0.02) resulted in higher estimates of all biomasses as a result of the increased B_{max}.

4.7 MIAEL estimation of Maximum Constant Yield (MCY)

The method to estimate MCY $= p.B_0$, where p is determined using the method of Francis (1992) such that biomass does not fall below 20% of B_0 more than 10% of the time. MCY for RCO 3 and RCO 7 was 7173 t and 2568 t for the base case, and 10 045 t and 2183 t for the sensitivity analysis that included the climatic abundance index (3129). The higher estimate of B_0 for the sensitivity analysis in RCO 3 has resulted in higher point estimate of MCY.

4.8 Estimation of Current Annual Yield (CAY)

The method of Francis (1992) was used to estimate the range and point estimates of CAY from the range (B_{min} and B_{max}) and point estimates (MIAEL) of B_{beg00} (Table 32). CAY estimates for RCO 3 are 14 561 t for the base case and 10 671 t for sensitivity analysis 1 (environ). The environmental abundance index predicts that recruitment has declined in recent years resulting in a lower estimate of CAY than the base case. CAY estimates for RCO 7 are 7084 t for the base case and 6099 t for sensitivity analysis 1 (environ). The environmental abundance index agrees with base case estimates of YCS, resulting in a similar estimate of CAY to the base case.

4.9 Yields and stock status

Based on the results of this assessment and given the parameter assumptions, a CAY strategy of harvesting would indicate that the fishery in RCO 3 for 1999–2000 can sustain catches at least at the level of landings for the 1998–99 year and in the long term MCY at a level about twice that documented by Annala *et al.* (1999) (MCY determined by the method c.*Yav* is 4400 t). However, the assessment of RCO 3 is highly uncertain as estimates from sensitivity analyses vary widely and performance indices are generally very low (all under 50%) indicating that the point estimates of biomass are not well estimated within their known range. Additionally, least squares biomass estimates are at the upper bound.

Based on the results of this assessment and given the parameter assumptions, a CAY strategy of harvesting would indicate that the fishery in RCO 7 in 1999–2000 can sustain catches roughly twice the level of landings for the 1998–99 year and in the long term, MCY at a about three times that documented by Annala *et al.* 1999 (MCY determined by the method c.*Yav* is 800 t). However, although point estimates of biomass were, in some cases, well estimated within their known range, the assessment of RCO 7 is also highly uncertain. Sensitivity analyses have a wide range and least squares biomass estimates were all at the upper bound. For RCO 7 the most recent YCS estimated was for 1996 and these fish are no longer in the fishery. The YCS since 1996 is therefore based on the assumption of mean recruitment for each year and the estimates of B_{mid99} and B_{mid00} are probably driven by the CELR CPUE index and the recent high landings.

The higher performance indices of RCO 7 compared to RCO 3 is partly due to the difference in biomass. At low biomasses, relative indices are more informative than at high biomasses because the catch history causes a relatively larger decline and relative abundance indices are more likely to track biomass.

5. MANAGEMENT IMPLICATIONS

Given the uncertainty of the assessment for both RCO 3 and RCO 7 stocks it is not possible to conclude whether current landings or the current TACCs are sustainable.

The last five fishing years have seen the most sustained period of consistently high annual landings in the RCO 3 fishery since catch records began, indicating that recruitment has also been strong before and during this period. Our YCS estimates could only be made as far back as 1986, but indicate good recruitment in the 1990s compared to the late 1980s. Recruitment appears to be weaker in the last two years (1997 and 1998) indicating that poor catches can be expected in 1999–2000 and 2000–01. The modelled relationship between environmental variables and recruitment also predicts that commercial catches in these years will be low.

Annual landings in RCO 7 have been consistently high since 1991–92, indicating a sustained period of strong recruitment. There are fewer YCS estimates for RCO 7 and these go back only as far as 1989, extending to 1996, so it is not possible to compare with recruitment in the mid 1980s. However, like RCO 3, the modelled relationship between environmental variables and recruitment for RCO 7 also predicts that commercial catches in 1999–2000 and 2000–01 will be low.

This assessment is based on the assumption that RCO 3 and RCO 7 stocks do not mix and are separate populations. It does appear that YCS on the whole is tracking in a similar manner, and has resulted in similar peaks and troughs in annual landings. This suggests that recruitment is being affected in the same way in these stocks, a conclusion reached by the study on the relationship between environmental variables and recruitment.

In both RCO 3 and RCO 7 there is a strong correlation between recruitment and environmental variables (mainly SST) with a periodic 14 month time lag. The stock assessment model was sensitive to inclusion of the environment abundance index and for RCO 3 this index predicted a sharp decline in recruitment in recent years, reflected in the substantially lower estimates of CAY than the base case (27% lower). The relationship between recruitment and environmental variables for RCO 7, when included in the stock assessment model, has the same prediction of YCS as all other runs and the estimates of CAY are only 14% less than the base case.

If the red cod fishery is to be managed on a CAY basis, a future assessment with greater certainty in yields will be required. The performance of the model is limited bythe few YCSs that it was able to estimate. The current fishing year (1999–2000) shows early signs of being poor compared to previous seasons and if this is so then it would be useful to collect length frequency data from the commercial catch to monitor thepotential decrease in biomass. It will be important to continue both the east coast and west coast South Island trawl surveys on an annual basis to collect data on 0+ and 1+ age classes for input into future models.

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Table 1: Reported landings (t) of red cod from fishstocks RCO 3 and RCO 7. Data historically expressed by calendar year or part thereof (Annala *et al.* 1999); before 1983–84 catches have been converted to fishing year on the basis of the mean percent landed by month from the years 1983–84 to 1990–91

Fishing year	RCO 3 (t)	TAC	RCO 7 (t)	TAC
1970–71	1 814	–	534	–
1971–72	1 890	–	548	–
1972–73	2 567	–	755	–
1973–74	3 553	–	1 043	
1974–75	2 208	–	711	–
1975–76	3 854	–	1 142	–
1976–77	9 619	–	2 869	–
1977–78	7 610	–	2 779	–
1978–79	5 987	–	1 698	–
1979–80	5 637	–	1 637	–
1980–81	3 219	–	696	–
1981–82	3 854	–	1 220	–
1982–83	6 305	–	1 514	–
1983–84	9 357	–	3 051	–
1984–85	3 300	–	1 442	–
1985–86	9 346	–	408	–
1986–87	3 300	11 960	619	2 940
1987–88	2 878	12 182	1 605	2 982
1988–89	7 732	12 362	1 345	3 057
1989–90	6 589	13 018	800	3 125
1990–91	4 630	12 299	839	3 125
1991–92	6 500	12 299	2 220	3 125
1992–93	9 633	12 389	4 083	3 125
1993–94	7 977	12 389	2 992	3 125
1994–95	12 603	12 389	3 569	3 125
1995–96	11 038	12 389	3 728	3 125
1996–97	10 042	12 389	3 694	3 125
1997–98	9 972	12 389	2 700	3 125
1998–99	13 926	12 389	2 055	3 125

Table 2: Estimated catch from CELR and TCEPR forms and proportion of landings reported by these forms for 1988–89 to 1997–98 in RCO 3. Target species is red cod

Year	CELR (kg)	TCEPR (kg)	TOTAL (kg)	RCO 3 catch (kg)	Percent RCO 3	Percent CELR
1988–89	45584	185703	231287	7732000	3.0	19.7
1989–90	2062182	945097	3007279	6589000	45.6	68.6
1990–91	2021949	413511	2435460	4630000	52.6	83.0
1991–92	1952711	1718910	3671621	6500000	56.5	53.2
1992–93	2722228	3439012	6161240	9633000	64.0	44.2
1993–94	3322439	1982833	5305272	7977000	66.5	62.6
1994–95	5306608	2891304	8197912	12603000	65.0	64.7
1995–96	3596356	3640671	7237027	11038000	65.6	49.7
1996–97	4180063	2609459	6789522	10042000	67.6	61.6
1997–98	3531329	2547371	6078700	10000000	60.8	58.1

Table 3: Estimated catch from CELR and TCEPR forms and proportion of landings reported by these forms for 1988–89 to 1997–98 in RCO 7. Target species is red cod

Year	CELR (kg)	TCEPR (kg)	TOTAL (kg)	RCO 7 catch (kg)	Percent RCO 7	Percent CELR
1988–89	9769	300	10069	1345000	0.7	97.0
1989–90	83920	2750	86670	800000	10.8	96.8
1990–91	132344	–	132344	839000	15.8	100.0
1991–92	554551	285200	839751	2220000	37.8	66.0
1992–93	1059614	21070	1080684	4083000	26.5	98.1
1993–94	452110	58500	510610	2992000	17.1	88.5
1994–95	710076	12960	723036	3569000	20.3	98.2
1995–96	465835	26360	492195	3728000	13.2	94.6
1996–97	359523	22300	381823	3694000	10.3	94.2
1997–98	275200	10410	285610	2649000	10.8	96.4

Table 4: Estimated catch from CELR and TCEPR forms and proportion of landings reported by these forms for 1988–89 to 1997–98 in RCO 7. Target species for CELR forms is red cod, barracouta and flatfish; and for TCEPR, when red cod is in the top five species

Year	CELR (kg)	TCEPR (kg)	TOTAL (kg)	RCO 7 catch (kg)	Percent RCO 7	Percent CELR
1988–89	51187	108581	159768	1345000	11.9	32.0
1989–90	375485	155219	530704	800000	66.3	70.8
1990–91	342622	317429	660051	839000	78.7	51.9
1991–92	1196063	676524	1872587	2220000	84.4	63.9
1992–93	2769133	522835	3291968	4083000	80.6	84.1
1993–94	1958862	444083	2402945	2992000	80.3	81.5
1994–95	2103482	412306	2515788	3569000	70.5	83.6
1995–96	2049232	572113	2621345	3728000	70.3	78.2
1996–97	2307063	312192	2619255	3694000	70.9	88.1
1997–98	1370146	255818	1625964	2649000	61.4	84.3

Table 5: Summary of catch by statistical area in RCO 3. All data from CELR forms for 1988–89 to 1997–98. Target species is red cod

Statistical area	Days	Total catch (kg)	Mean (kg)	Percent catch by area
18	1974	1818061	921	6.5
19	14	16430	1174	0.1
20	7162	7551978	1054	27.0
21	29	22540	777	0.1
22	14233	16586467	1165	59.3
23	3	1860	620	< 0.1
24	3096	1668392	539	6.0
25	45	27439	610	0.1
26	314	229877	732	0.8
27	9	4059	451	< 0.1
30	131	49048	374	0.2
31	1	400	400	< 0.1
32	29	9360	323	< 0.1
unknown	1	5248	–	< 0.1
Totals	**27041**	**27991159**		

Table 6: Summary of catch by statistical area in RCO 3. All data from TCEPR forms for 1988–89 to 1997–98. Target species is red cod

Statistical area	Days	Total catch (kg)	Mean (kg)	Percent catch by area
18	340	262588	772	1.3
19	1	0	0	0.0
20	2897	3340401	1153	16.6
21	267	152530	571	0.8
22	7508	12159805	1620	60.4
23	10	8620	862	< 0.1
24	1386	3151845	2274	15.7
25	9	5300	589	< 0.1
26	197	272200	1382	1.4
27	134	203390	1518	1.0
28	93	71130	765	0.4
29	4	2242	561	< 0.1
30	525	493405	940	2.5
Totals	**13371**	**20123456**		

Table 7: Summary of catch by statistical area in RCO 7. All data from CELR forms for 1988–89 to 1997–98. Target species are red cod, barracouta, and flatfish

Statistical area	Days	Total catch (kg)	Mean (kg)	Percent catch by area
17	8222	2086770	254	14.5
33	2871	1149011	400	8.0
34	12082	4715151	390	32.7
35	5672	2513804	443	17.4
36	612	195092	319	1.4
37	1593	551436	346	3.8
38	18118	3226780	178	22.3
Totals	**49170**	**14438044**		

Table 8: Summary of catch by statistical area in RCO 7. All data from TCEPR forms for 1988–89 to 1997–98. Where red cod is in the top five species

Statistical area	Days	Total catch (kg)	Mean (kg)	Percent catch by area
17	1176	547183	465	14.5
33	350	270286	772	7.2
34	1178	1017274	864	27.0
35	1262	1134592	899	30.1
36	254	99503	392	2.6
37	1136	569328	501	15.1
38	267	132535	496	3.5
Totals	**5623**	**3770701**		

Table 9: Stepwise selection matrix for predictor variables in RCO 3 CELR CPUE data. Zero catch records excluded

Variable	r^2 at iteration				
	1	2	3	4	5
Day of year	0.1309				
Tonnage	0.1010	0.197			
Year	0.0261	0.1504	0.2203		
Towtime	0.0135	0.1372	0.2148	0.2353	
Area	0.0455	0.1512	0.2020	0.2252	0.2435
Headline	0.0549	0.1631	0.2030	0.2258	0.2422
Breadth	0.0992	0.1952	0.2024	0.2252	0.2419
Draught	0.0719	0.1764	0.1982	0.2213	0.2361
Length	0.0975	0.1916	0.2034	0.2268	0.2428
Kilowatts	0.0933	0.1941	0.2037	0.2263	0.2407
Volume	0.0772	0.1801	0.1980	0.2212	0.2363

Table 10: Relative year effects for RCO 3 CELR CPUE data. Base case is 1990 (= 1989–90). s.e., standard error

Year	Year effect	s.e.
1990	1	0
1991	0.7336	0.0324
1992	0.7487	0.0305
1993	0.8146	0.0322
1994	0.9122	0.0352
1995	1.2209	0.0456
1996	1.1612	0.0457
1997	0.8502	0.0328
1998	0.6526	0.0256

Table 11: Stepwise selection matrix for predictor variables in RCO 3 TCEPR CPUE data. Zero catch records excluded

Variable	r^2 at iteration				
	1	2	3	4	5
Kilowatts	0.0352				
Day of year	0.0307	0.0742			
Time of day	0.0128	0.062	0.1046		
Year	0.0236	0.0622	0.0939	0.1199	
Gear depth	0.0184	0.0421	0.0867	0.1128	0.128
Area	0.0077	0.0382	0.0763	0.1065	0.1214
Headline	0.0016	0.0406	0.0799	0.1091	0.1243
Breadth	0.0304	0.0415	0.0806	0.1083	0.1218
Draught	0.0150	0.0409	0.0784	0.1075	0.1221
Length	0.0326	0.0389	0.0777	0.1074	0.1243
Tonnage	0.0301	0.0377	0.0776	0.1065	0.1218
Towtime	0.0019	0.0439	0.0807	0.1057	0.1212

Table 12: Relative year effects for RCO 3 TCEPR CPUE data. Base case was 1990 (= 1989–90). s.e., standard error

Year	Year effect	s.e.
1990	1	0
1991	0.7262	0.0667
1992	0.9488	0.0651
1993	1.2372	0.0810
1994	1.2736	0.0889
1995	1.6295	0.1188
1996	1.3929	0.0909
1997	1.0256	0.0702
1998	1.0149	0.0709

Table 13: Stepwise selection matrix for predictor variables in RCO 7 CELR CPUE data. Zero catch records excluded

Variable	r^2 at iteration				
	1	2	3	4	5
Breadth	0.1782				
Area	0.0925	0.2392			
Year	0.0598	0.2278	0.2938		
Towtime	0.1082	0.2315	0.2795	0.3339	
Target	0.0805	0.2034	0.2654	0.3244	0.3707
Day of year	0.0079	0.1854	0.2394	0.3030	0.3430
Headline	0.0284	0.1782	0.2418	0.2972	0.3370
Draught	0.1670	0.1943	0.2500	0.3054	0.3434
Length	0.1526	0.1829	0.2482	0.3026	0.3427
Tonnage	0.1689	0.1930	0.2524	0.3057	0.3460
Kilowatts	0.1471	0.1896	0.2603	0.3150	0.3531
Volume	0.1149	0.1824	0.2437	0.2986	0.3387

Table 14: Relative year effects for RCO 7 CELR CPUE data. Base case is 1990 (= 1989–90). s.e., standard error

Year	Year effect	s.e.
1990	1	0
1991	0.9031	0.0349
1992	1.7317	0.0618
1993	2.4287	0.0794
1994	2.9812	0.1015
1995	2.7135	0.0897
1996	3.0518	0.1021
1997	3.0271	0.1003
1998	2.5362	0.0880

Table 15: Relative year effects for RCO 7 TCPER CPUE data. Base case is 1990 (= 1989–90). s.e., standard error

Variable	r^2 at iteration				
	1	2	3	4	5
Area	0.0810				
Target	0.0762	0.11			
Length	0.0682	0.1019	0.1434		
Year	0.0628	0.1030	0.1320	0.1625	
Time of day	0.0302	0.1028	0.1239	0.1581	0.1772
Day of year	0.0555	0.0993	0.1351	0.1585	0.1744
Headline	0.0429	0.0878	0.1205	0.1492	0.1730
Breadth	0.0101	0.0975	0.1407	0.1494	0.1681
Draught	0.0071	0.0868	0.1191	0.1443	0.1641
Tonnage	0.0034	0.0899	0.1261	0.1485	0.1670
Kilowatts	0.0147	0.0906	0.1221	0.1487	0.1697
Tow time	0.0313	0.0812	0.1102	0.1437	0.1627
Gear depth	0.0201	0.1037	0.1153	0.1494	0.1703

Table 16: Relative year effects for RCO 7 TCEPR CPUE data. Base case is 1990 (= 1989–90). s.e., standard error

Year	Year effect	s.e.
1990	1	0
1991	1.3363	0.1225
1992	2.1151	0.1958
1993	1.4375	0.1194
1994	1.2534	0.1050
1995	1.0363	0.0853
1996	1.4651	0.1158
1997	1.3790	0.1251
1998	1.2438	0.1139

Table 17: Estimated biomass and *c.v.s* from west coast and east coast South Island trawl survey series. *c.v.*, coefficient of variation

Stock	Area	Voyage	Date	Biomass (t)	*c.v.* (%)
RCO 7	West coast South Island	KAH9204	Feb–Mar 92	2 719	13
		KAH9404	Feb–Mar 94	3 169	18
		KAH9504	Feb–Mar 95	3 123	15
		KAH9701	Feb–Mar 97	2 546	23
RCO 3	East coast South Island (winter)	KAH9105	May–Jun 91	3 760	33
		KAH9205	May–Jun 92	4 527	40
		KAH9306	May–Jun 93	5 601	29
		KAH9406	May–Jun 94	5 637	31
		KAH9606	May–Jun 96	4 619	30
RCO 3	East coast South Island (summer)	KAH9618	Dec 96–Jan 97	10 634	23
		KAH9704	Dec 97–Jan 98	7 536	23
		KAH9809	Dec 98–Jan 99	12 823	17

Table 18: summary data of landings for red cod commercial catch sampling programme on the east coast South Island. 1990 = 1989–90 fishing year

Season	Sampling period	No.landings sampled	Landing weights sampled (t)	Percent RCO 3 sampled	Total fish measured	Otoliths collected
1990	Jan 90–Jun 90	124	622.5	9.4	25 799	2 296
1991	Nov 90–May 91	54	241.7	5.2	11 341	1 074
1992	Jan 92–May 92	64	308.3	4.7	13 332	1 409
1993	Jan 93–Jun 93	78	453.1	4.6	13 235	1 560
Totals		320	1625.6		63707	6339

Table 19: Vessel size specifications for red cod catch sampling programme. Mean size is calculated from the number of landings where a single vessel may have more than one landing. s.d., standard deviation

Year	Number of landings	Number of vessels	Mean vessel length (m)	s.d.	Length range (m)
1990	124	27	18.9	4.4	11.6–26
1991	54	11	16.9	4.9	9.9–25.6
1992	64	18	20.9	4.8	13–27.2
1993	78	19	19.0	4.2	13.1–27.2

Table 20: Between-reader comparison of 262 otoliths from south-east South Island winter trawl survey (KAH9205). Age, age at second reading by principal reader; Diff, the extent to which this reading differed from that of reader 2; Sim, the percentage of fish by age for which both readings were the same. After Horn (1995)

	Age					
	0	1	2	3	4	Total
Diff						
2+	0	0	0	0	0	0
1+	2	4	1	2	0	9
0	58	100	70	16	2	246
1-		6	1	0	0	7
Sim %	97	91	97	89	100	94

Table 21: Within-reader comparison of 257 otoliths from south-east South Island winter trawl survey (KAH9205). Age, age at first reading; Diff, the extent to which the first reading differed from the first; Sim, the percentage of fish by age for which both readings were the same. After Horn (1995)

	Age				
	0	1	2	3	Total
Diff					
2+		1	1		
1+	29	9	11	1	50
0	58	75	62	6	201
1-	–	0	5	1	6
Sim %	67	89	79	75	75

Table 22: Biological parameters used in the red cod assessment

Natural mortality M (Beentjes 1992)

Males	Females
0.75	0.7

Length weight relationship. weight = a(length)^b: (weight in g and length in cm total length)

	a	b
RCO 3	0.0057	3.147
RCO 7	0.0124	2.910

Von bertalanffy growth parameters (with 95% confidence intervals). RCO 3 from Horn (1995), RCO7 from this study

		Males		Females	
RCO 3	L_∞	*68.5*	*(62.8–74.1)*	*76.5*	*(69.5–83.4)*
	K	0.47	(0.37–0.57)	0.41	(0.32–0.50)
	t_0	0.06	(-0.09– +0.21)	-0.03	(-0.18– +0.12)
	N	229		320	

		Males		Females	
RCO 7	L_∞	68.2	(54.8–81.7)	79.6	(67.8–91.4)
	K	0.53	(0.24–0.82)	0.49	(0.29–0.70)
	t_0	0.22	(-0.14– +0.59)	0.2	(-0.09– +0.48)
	N	282		352	

Maturity ogives for males and females for RCO 3 and RCO 7. *, base case and all sensitivity analyses except sensitivity 3. Ogives represent change in maturity from previous value

Age	All*	sens3
1	0.1	0.1
2	0.2	0.5
3	0.9	1
4	1	–

Recruitment parameters

Beverton holt stock recruitment relationship 0.75 (Beentjes 1992)

Table 23: **Base case and sensitivity analyses parameters used in the MIAEL analysis for RCO 3 and RCO 7. Maturity ogives fixed for all runs (*see* Table 22), home ground selectivity estimated for RCO 3 and fixed for RCO 7, trawl survey vulnerabilities estimated for all trawl surveys**

Parameter	base case	sens1	sens2	sens3	sens4	sens5	sens6	sens7	sens8	sens9
environ		included								
cpue wt	0.5						1			
sp_length	0					0.1				
r_{hm_max}	0.7		0.8							0.5
r_{hm_mmx}	0.05								0.02	
pspawn	1									
clow	1									
chigh	1									
ogive	1									
mlow	1									
mhigh	4			3						
M (m,f)	0.75, 0.7				0.9, 0.85			0.65, 0.6		
steep	0.75									
age wt	1									

where:

environ	environmental prediction of catch as an index of abundance
cpue wt	CPUE was down weighted to 0.5
sp_length	Proportion of year spent spawning
r_{hm_max}	Max possible catch on pre-spawning ground as ratio of total pre-spawning biomass (at start of pre-spawning season)
r_{hm_mmx}	Home ground minmax rate–absolute minimum proportion of fish that could have been caught in the year of highest exploitation.
pspawn	Proportion of mature fish that spawn
clow	Low age for juyeniles leaving corridor
chigh	High age for juveniles leaving the corridor
ogive	Corridor ogive
mlow	Lowest maturity age
mhigh	Highest age at which there are still some immature fish
M	Instanteous mortality rate
steep	Steepness parameter for the Beverton Holt equation
age wt	Catch at age data weighted at 1

Table 24: Home ground selectivity ogives for base case and sensitivity runs for RCO 3 and RCO 7

RCO 3 (estimated for all runs)

Age	Base case		sens1		sens2		sens3		sens4		sens5		sens6	
	male	female	male	female	male	female	male	female	male	female	male	female	male	female
1	0.01	0.01	0.5	0.5	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.5	0.5
2	1.5	1.5	1.5	1.5	1.5	1.3	1.5	1.4	1.4	1.5	1.5	1.5	1.5	1.5
3	1.5	1.5	1	1	1.5	1.2	1.5	1.5	1.5	1.5	1.5	1.5	1	1
4	1	0.8	1	0.8	1	0.8	1	0.8	1	0.8	1	0.8	1	0.8

Age	sens7		sens8		sens9	
	male	female	male	female	male	female
1	0.01	0.01	0.01	0.01	0.01	0.01
2	1.5	1.5	1.5	1.4	1.5	1.5
3	1.5	0.7	1.5	1.4	1.5	1.2
4	1	0.8	1	0.8	1	0.8

RCO 7 (fixed for all runs)

Age	Base case	
	male	female
1	0.1	0.1
2	0.8	0.8
3	1	1
4	1	1

Table 25: RCO 3 basecase least squares estimates of *qs* (proportionality constant) with upper and lower bounds, and trawl survey vulnerabilities at sex and age for the east coast South Island winter and summer trawl surveys

Abundance index and age group	Estimated *qs*	Lower bounds	Upper bounds
Winter trawl surveys (1, 2 yr)	1.000	0.10	1.0
Summer trawl surveys (0 yr)	0.046	0.01	1.0
Summer trawl surveys (1, 2, 3+ yr)	0.108	0.01	1.0

Estimated vulnerabilities for east coast South Island winter trawl surveys

Age	Males	Females
1	0.590	0.450
2	1.000	1.200
3	1.000	1.200 (assumed by model to be the same as 2 yr olds)
4	1.000	1.200 (assumed by model to be the same as 2 yr olds)

Estimated vulnerabilities for east coast South Island summer trawl surveys

Age	Males	Females
0	8.927	6.681 (input in the model as 1 year olds)
1	8.927	6.681
2	6.179	8.057
3	1.000	1.200
4	1.000	1.200 (assumed by model to be the same as 3 yr olds)

Standardised to the male age 2. The corresponding estimated q is 0.67 (0.108*6.179)

Age	Males	Females
1	1.440	1.080
2	1.000	1.300
3	0.160	0.190

Table 26: RCO 7 basecase least squares estimates of *qs* (proportionality constant) with upper and lower bounds and trawl survey vulnerabilities at sex and age for the west coast South Island trawl surveys

Abundance index and age group	Estimated *qs*	Lower bounds	Upper bounds
West coast trawl survey (0 yr)	0.312	0.01	10.0
West coast trawl survey (1, 2+ yr)	0.186	0.01	10.0

Estimated vulnerabilities for west coast South Island trawl surveys

Age	Males	Females
0	0.192	0.216 (input in the model as 1 year olds)
1	0.192	0.216
2	1.000	0.623
3	1.000	0.623 (assumed by model to be the same as 2 yr olds)
4	1.000	0.623 (assumed by model to be the same as 2 yr olds)

Table 27: Estimated year class strengths (YCS) for base case and sensitivity runs for RCO 3. rsd, recruitment variability

Year	base case	sens1	sens2	sens3	sens4	sens5	sens6	sens7	sens8	sens9
1986	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1987	1.06	2.92	1.06	0.99	0.78	1.19	1.10	1.22	1.07	1.09
1988	0.50	0.32	0.51	0.50	0.48	0.41	0.46	0.50	0.50	0.49
1989	1.36	1.13	1.42	1.59	1.13	1.03	1.28	1.33	1.35	1.31
1990	3.27	3.33	3.29	2.89	2.74	3.23	2.94	3.32	3.23	3.15
1991	1.43	1.00	1.46	1.42	1.38	1.03	1.43	1.35	1.41	1.33
1992	2.56	2.81	2.46	2.52	1.90	2.92	2.52	2.77	2.55	2.61
1993	2.16	1.39	2.19	1.90	2.05	1.61	2.27	2.12	2.13	2.03
1994	0.89	0.66	0.87	0.97	0.78	0.75	0.95	0.86	0.89	0.84
1995	1.40	0.45	1.42	1.34	1.20	1.81	1.48	1.46	1.38	1.27
1996	1.80	0.65	1.55	1.63	1.48	2.18	1.83	1.84	1.78	2.46
1997	0.59	0.19	0.52	0.59	0.56	0.60	0.59	0.55	0.60	0.73
1998	0.38	0.14	0.37	0.40	0.41	0.38	0.38	0.40	0.39	0.42
Mean YCS	1.34	1.15	1.32	1.29	1.15	1.32	1.33	1.36	1.33	1.36
rsd	1.47	1.6	1.4	1.45	1.42	1.48	1.47	1.46	1.44	1.47

Table 28: Estimated year class strengths (YCS) for base case and sensitivity runs for RCO 7. rsd, recruitment variability

	base case	sens1	sens2	sens3	sens4	sens5	sens6	sens7	sens8	sens9
1989	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1990	3.17	3.50	3.17	3.18	2.99	3.17	3.42	3.22	3.22	3.22
1991	0.08	0.13	0.08	0.09	0.18	0.08	0.13	0.08	0.08	0.08
1992	3.15	4.11	3.15	3.21	2.79	3.14	3.49	3.24	3.24	3.24
1993	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01
1994	0.23	0.38	0.23	0.24	0.51	0.23	0.37	0.22	0.22	0.22
1995	2.62	2.43	2.62	2.59	2.44	2.62	2.46	2.58	2.58	2.58
1996	0.23	0.31	0.23	0.23	0.46	0.23	0.32	0.22	0.22	0.22
Mean YCS	1.19	1.36	1.19	1.19	1.18	1.19	1.28	1.20	1.20	1.20
rsd	2.40	2.35	2.40	2.40	1.03	2.40	2.32	2.41	2.41	2.41

Table 29: RCO 3 least squares (LS) and bestk estimates of biomass, and MIAEL estimates of p, biomass, and performance index (PI) for base case and sensitivity analyses. Parameters are defined in Table 23. Bestk and MIAEL estimates have been rounded to the nearest 500 t

Estimate	Run	B_{min}	B_{max}	LS	bestk	p	MIAEL	PI (%)
B_0	**Base**	**19500**	**107500**	**107500**	**40500**	**0.26**	**58000**	**17**
	sens 1 $_{environ}$	22805	143271	143271	50000	0.37	84500	32
	sens 2 $r_{hm\_max=0.8}$	19500	107428	107428	40500	0.28	59500	20
	sens 3 $_{mhigh=3}$	22000	124699	124699	46500	0.21	63000	12
	sens 4 $_{M=0.9,\ 0.85}$	16000	81352	81352	32500	0.20	42000	11
	sens 5 $_{sp\_length=0.1}$	20926	63490	63490	34500	0.20	40500	9
	sens 6 $_{cpue\ wt=1.0}$	19500	107500	107500	40500	0.22	55500	13
	sens 7 $_{M=0.65,\ 0.6}$	23000	129035	129035	48500	0.25	68500	16
	sens 8 $r_{hm\_mmax=0.02}$	19500	259254	259254	54500	0.16	88500	11
	sens 9 $r_{hm\_max=0.5}$	19500	107402	107402	40500	0.25	57500	16
B_{mid99} (% B_0)	**Base**	**25**	**135**	**135**	**52**	**0.28**	**75**	**15**
	sens 1 $_{environ}$	4	74	74	12	0.56	47	50
	sens 2 $r_{hm\_max=0.8}$	29	131	131	56	0.43	88	29
	sens 3 $_{mhigh=3}$	20	132	132	44	0.17	59	7
	sens 4 $_{M=0.9,\ 0.85}$	21	109	109	43	0.17	54	6
	sens 5 $_{sp\_length=0.1}$	26	130	131	52	0.18	66	7
	sens 6 $_{cpue\ wt=1.0}$	24	139	139	51	0.18	67	7
	sens 7 $_{M=0.65,\ 0.6}$	23	141	141	50	0.27	74	13
	sens 8 $r_{hm\_mmax=0.02}$	25	144	144	53	0.37	87	24
	sens 9 $r_{hm\_max=0.5}$	33	138	138	62	0.32	86	18
B_{beg00}	**Base**	**22279**	**322120**	**322120**	**64000**	**0.21**	**118000**	**15**
	sens 1 $_{environ}$	3924	186052	186052	15500	0.42	87000	43
	sens 2 $r_{hm\_max=0.8}$	22642	299079	299079	63000	0.27	127000	22
	sens 3 $_{mhigh=3}$	17987	306045	306045	54000	0.12	84500	7
	sens 4 $_{M=0.9,\ 0.85}$	21645	250424	250424	58000	0.15	87000	9
	sens 5 $_{sp\_length=0.1}$	24757	189074	189074	58000	0.16	79000	8
	sens 6 $_{cpue\ wt=1.0}$	21874	329345	329345	63500	0.15	103500	9
	sens 7 $_{M=0.65,\ 0.6}$	20129	351147	351147	61000	0.19	116000	13
	sens 8 $r_{hm\_mmax=0.02}$	22606	811818	811818	83500	0.10	156000	7
	sens 9 $r_{hm\_max=0.5}$	30643	371635	371635	83500	0.22	147000	16
B_{mid00} (% B_0)	**Base**	**14**	**126**	**126**	**35**	**0.16**	**49**	**6**
	sens 1 $_{environ}$	1	55	55	2	0.18	12	15
	sens 2 $r_{hm\_max=0.8}$	15	117	117	35	0.38	66	25
	sens 3 $_{mhigh=3}$	7	112	112	21	0.30	23	1
	sens 4 $_{M=0.9,\ 0.85}$	9	98	98	24	0.07	29	2
	sens 5 $_{sp\_length=0.1}$	20	128	128	44	0.18	59	7
	sens 6 $_{cpue\ wt=1.0}$	14	130	130	35	0.09	44	3
	sens 7 $_{M=0.65,\ 0.6}$	13	133	133	34	0.15	48	6
	sens 8 $r_{hm\_mmax=0.02}$	15	136	136	37	0.30	67	19
	sens 9 $r_{hm\_max=0.5}$	32	146	146	62	0.29	86	15

Table 30: RCO 7 least squares (LS) and bestk estimates of biomass, and MIAEL estimates of p, biomass, and performance index (PI) for base case and sensitivity analyses. Parameters are defined in Table 23. Bestk and MIAEL estimates have been rounded to the nearest 500 t

Esimate	Run	B_{min}	B_{max}	LS	bestk	p	MIAEL	PI (%)
B_0	**Base**	**4895**	**26887**	**26887**	**10000**	**0.59**	**20000**	**55**
	sens 1 $_{environ}$	4450	22212	22212	8000	0.62	17000	59
	sens 2 $r_{hm\_max=0.8}$	4909	26806	26806	10000	0.59	20000	55
	sens 3 $_{mhigh=3}$	5641	31251	31251	12000	0.59	23500	56
	sens 4 $_{M=0.9,\ 0.85}$	4081	22350	22350	8500	0.50	15500	46
	sens 5 $_{sp\_length=0.1}$	6445	17240	17240	10000	0.50	13500	40
	sens 6 $_{cpue\ wt=1.0}$	4819	23764	23764	9500	0.49	16500	44
	sens 7 $_{M=0.65,\ 0.6}$	6278	29981	29981	12500	0.52	21500	46
	sens 8 $r_{hm\_mmax=0.02}$	6340	71777	71777	17000	0.38	37500	36
	sens 9 $r_{hm\_max=0.5}$	6445	29931	29931	12500	0.51	21500	45
B_{mid99} (%B_0)	**Base**	**1**	**111**	**111**	**5**	**0.42**	**49**	**32**
	sens 1 $_{environ}$	2	113	113	8	0.80	92	92
	sens 2 $r_{hm\_max=0.8}$	1	111	111	5	0.45	53	33
	sens 3 $_{mhigh=3}$	1	103	103	5	0.48	52	37
	sens 4 $_{M=0.9,\ 0.85}$	2	115	115	8	0.84	98	82
	sens 5 $_{sp\_length=0.1}$	33	99	99	54	0.65	83	56
	sens 6 $_{cpue\ wt=1.0}$	2	111	111	8	0.81	91	74
	sens 7 $_{M=0.65,\ 0.6}$	2	108	108	8	0.80	88	71
	sens 8 $r_{hm\_mmax=0.02}$	2	119	119	8	0.84	102	80
	sens 9 $r_{hm\_max=0.5}$	6	108	108	18	0.89	98	85
B_{beg00}	**Base**	**2125**	**74691**	**74691**	**8000**	**0.74**	**57500**	**75**
	sens 1 $_{environ}$	3017	63281	63281	9500	0.74	49500	76
	sens 2 $r_{hm\_max=0.8}$	2310	74444	74444	8500	0.73	56500	75
	sens 3 $_{mhigh=3}$	2652	74504	74504	9000	0.73	57000	75
	sens 4 $_{M=0.9,\ 0.85}$	2393	84121	84121	9000	0.70	61500	73
	sens 5 $_{sp\_length=0.1}$	8458	43340	43340	17000	0.55	31500	49
	sens 6 $_{cpue\ wt=1.0}$	2862	67125	67125	9500	0.64	46500	66
	sens 7 $_{M=0.65,\ 0.6}$	2293	69414	69414	8000	0.69	50500	71
	sens 8 $r_{hm\_mmax=0.02}$	2444	176615	176615	10500	0.48	91000	53
	sens 9 $r_{hm\_max=0.5}$	3355	69285	69285	10500	0.65	48500	66
B_{mid00} (%B_0)	**Base**	**1**	**85**	**85**	**5**	**0.58**	**51**	**49**
	sens 1 $_{environ}$	1	87	87	5	0.96	84	93
	sens 2 $r_{hm\_max=0.8}$	1	85	85	5	0.27	26	19
	sens 3 $_{mhigh=3}$	1	84	84	5	0.69	59	61
	sens 4 $_{M=0.9,\ 0.85}$	1	89	89	4	0.85	76	83
	sens 5 $_{sp\_length=0.1}$	15	74	74	30	0.65	59	56
	sens 6 $_{cpue\ wt=1.0}$	1	86	86	4	0.82	71	77
	sens 7 $_{M=0.65,\ 0.6}$	1	85	85	4	0.87	75	84
	sens 8 $r_{hm\_mmax=0.02}$	1	95	95	5	0.90	85	86
	sens 9 $r_{hm\_max=0.5}$	2	85	85	8	0.87	75	85

Table 31: Maximum constant yield (MCY) estimates for RCO 3 and RCO 7. B_{MCY} (%B_0) is the mean mid season spawning biomass as percent of B_0 when fishing at MCY; MCY (%B_0), MCY catch as a percent of B_0; PI, performance index

Fishstock	Run	B_{MCY} (%B_0)	MCY (%B_0)	MCY (t)	MCY Range	PI %
RCO 3	base case	71.3	12.4	7 173	2 418–13 330	17
RCO 3	sens 1 $_{environ/SST}$	71.5	11.9	10 045	2 713–17 049	32
RCO 7	base case	71.6	12.8	2 568	628–3 452	55
	sens 1 $_{environ/SST}$	71.6	12.8	2 183	571–3 442	59

Table 32: Current annual yield (CAY) estimates for RCO 3 and RCO 7. B_{MAY} (% B_0), maximum average yield as a percent of B_0 if fishing at CAY; MAY (%B_0), maximum average yield as a percent of B0; PI, performance index

Fishstock	Run	B_{MAY} (% B0)	MAY (% B0)	CAY (t)	Range	PI (%)
RCO 3	base case	47.4	24.1	14 561	2 624–37 976	15
	sens 1 $_{environ/SST}$	46.0	23.4	10 671	488–22 737	43
RCO 7	base case	46.4	25.9	7 084	260–9 188	75
	sens 1 $_{environ/SST}$	46.4	25.9	6 099	373–7 789	76

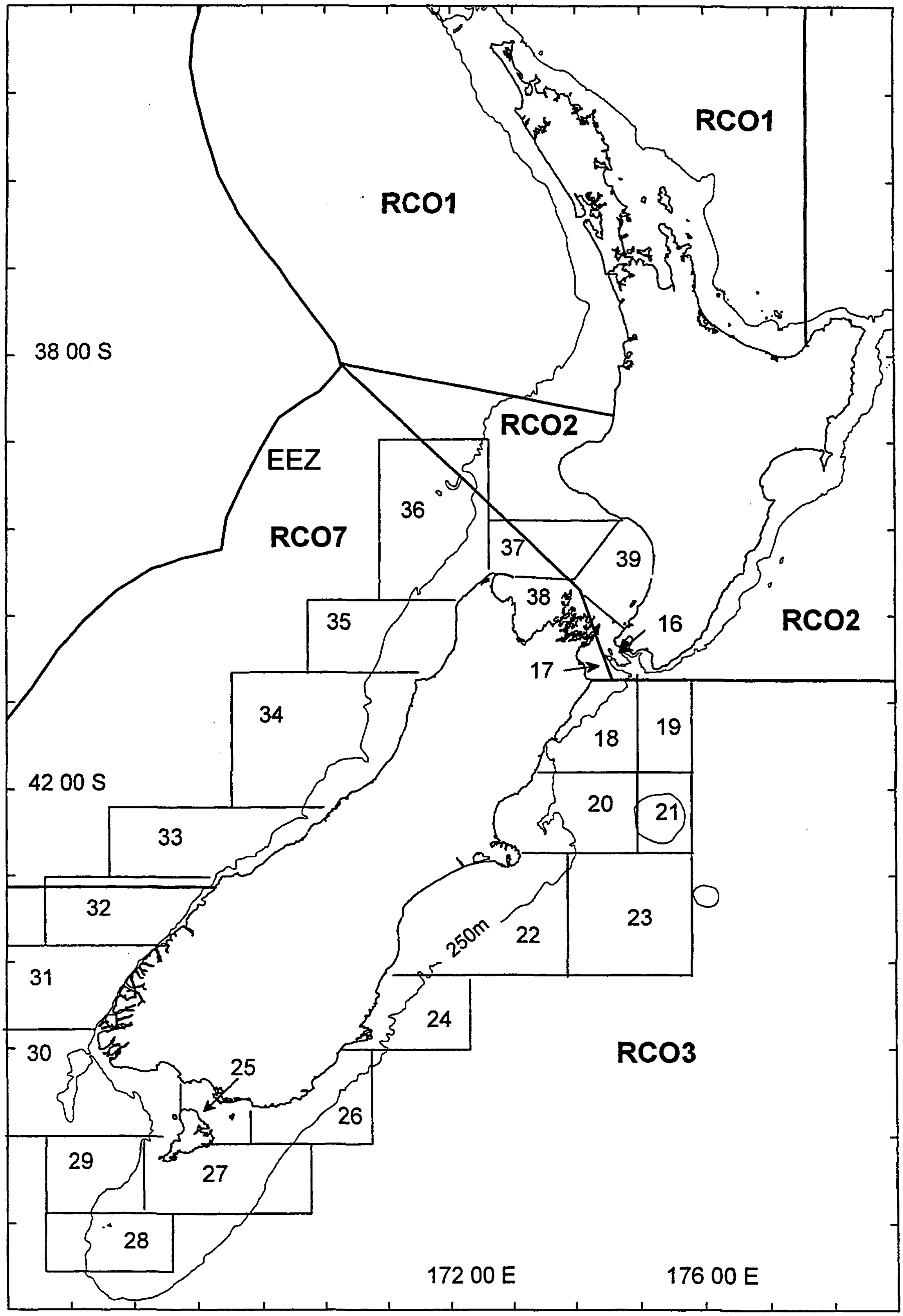


Figure 1: Key statistical areas in RCO 3 and RCO 7 and quota management areas for red cod.

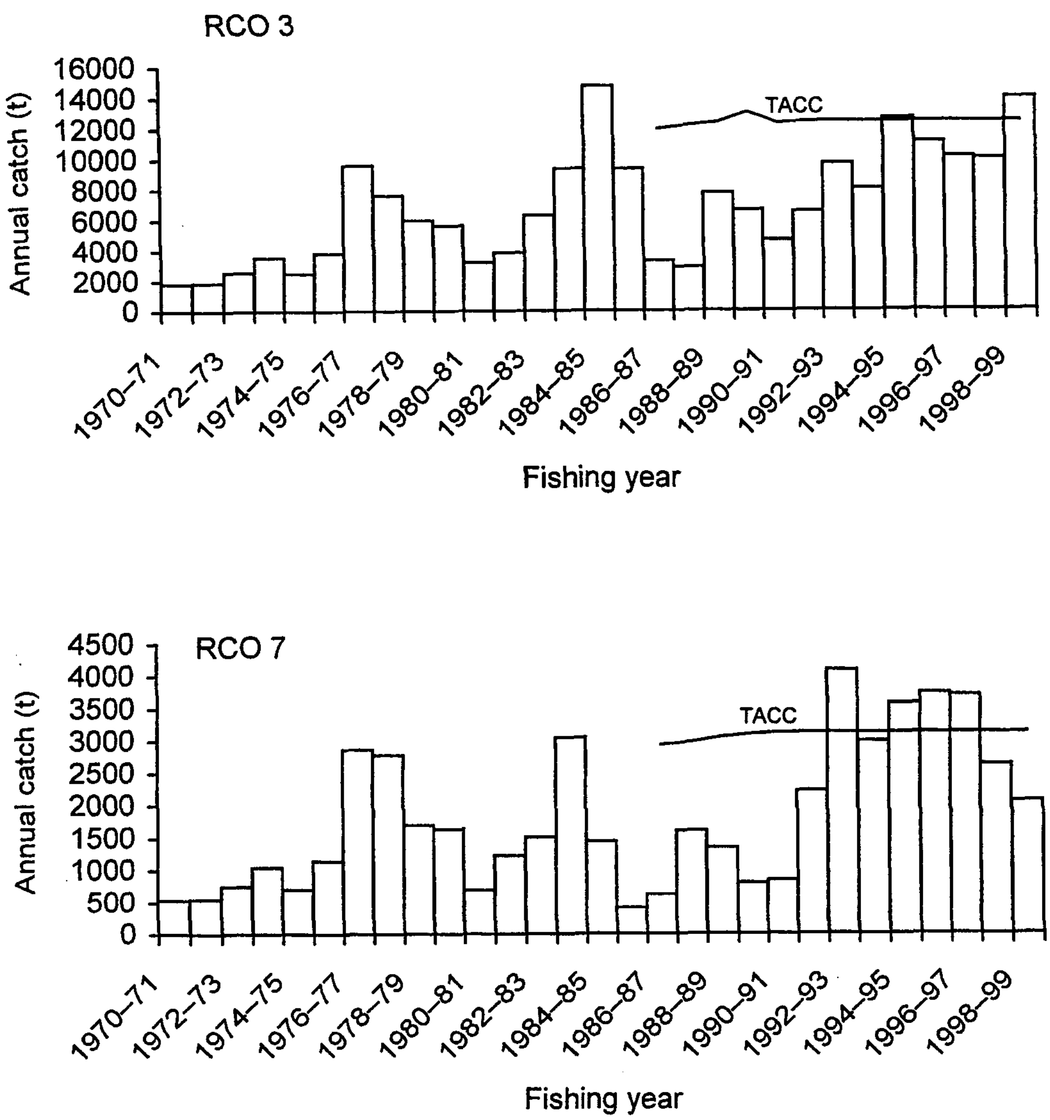


Figure 2: Annual catches of red cod (RCO 3 and RCO 7) from 1970–71 to 1998–99 and TACC.

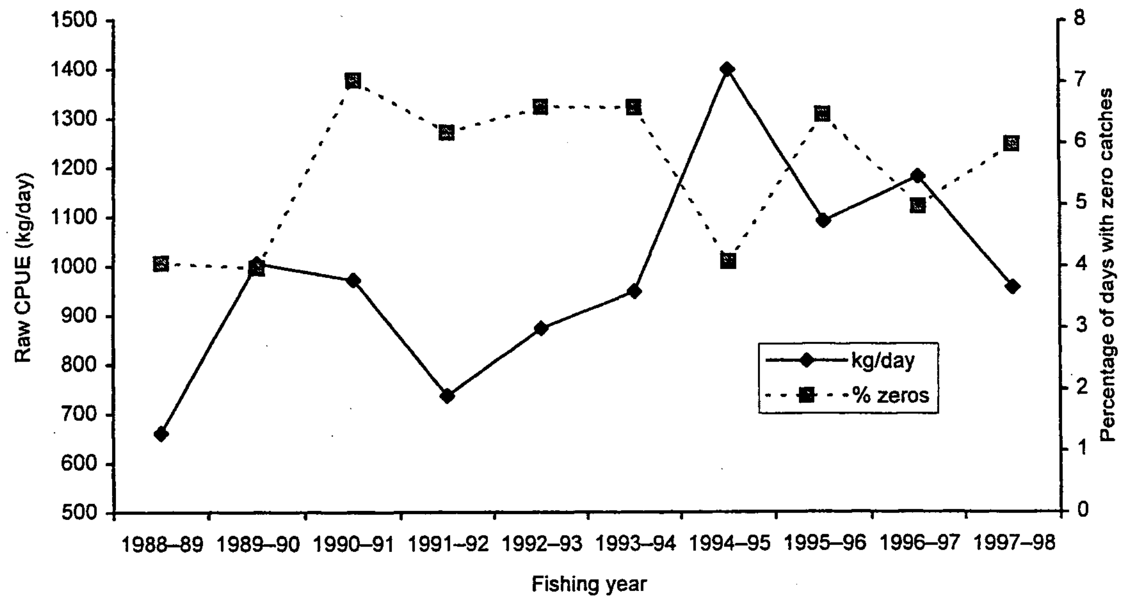


Figure 3: Raw CPUE data (kg/day) and zero catches for CELR forms in RCO 3 from 1988–89 to 1997–98. Target species is red cod.

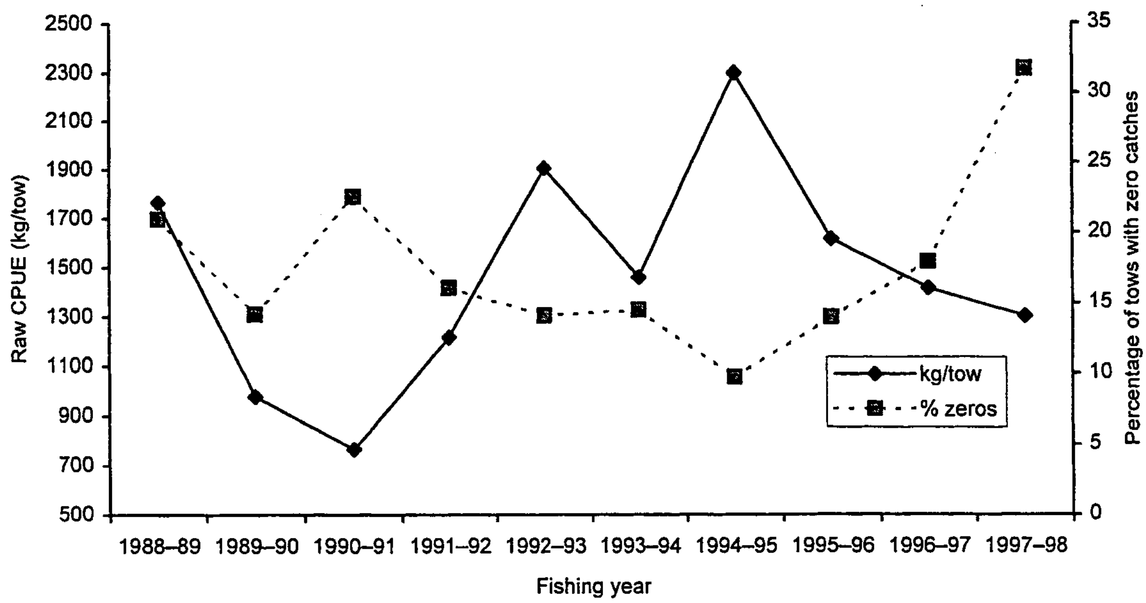


Figure 4: Raw CPUE data (kg/tow) and zero catches for TCEPR forms in RCO 3 from 1988–89 to 1997–98. Target species is red cod.

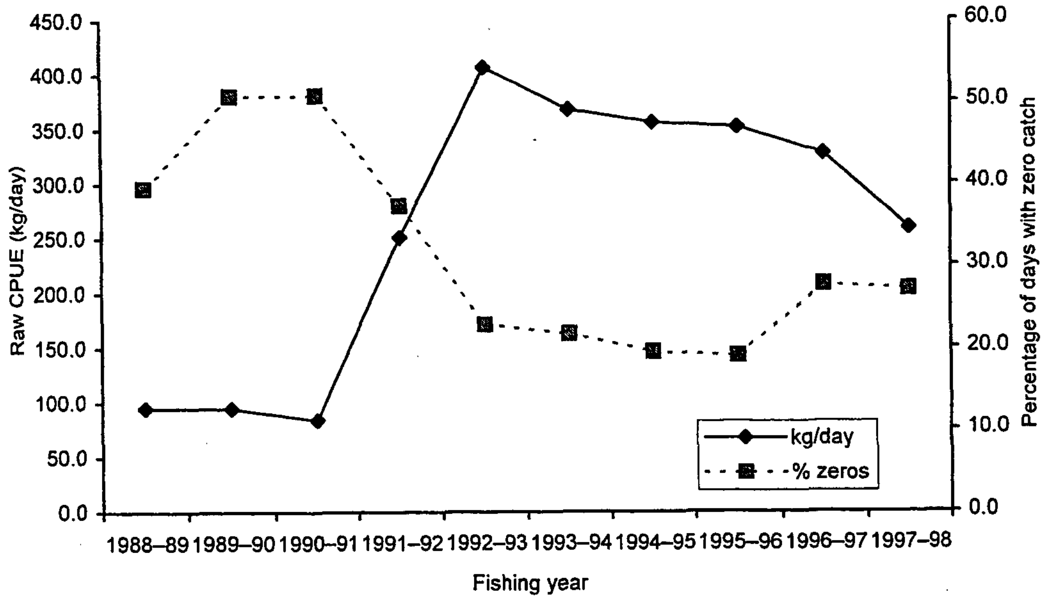


Figure 5: Raw CPUE data (kg/day) and zero catches for CELR forms in RCO 7 from 1988–89 to 1997–98. Target species is red cod, barracouta, and flatfish.

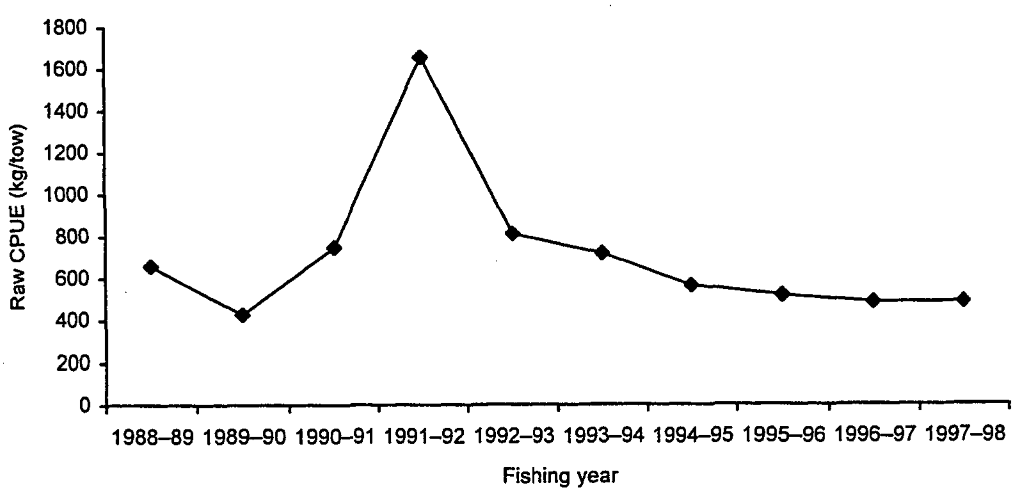


Figure 6: Raw CPUE data (kg/tow) for TCEPR forms in RCO 7 from 1988–89 to 1997–98, where red cod was in the top five species.

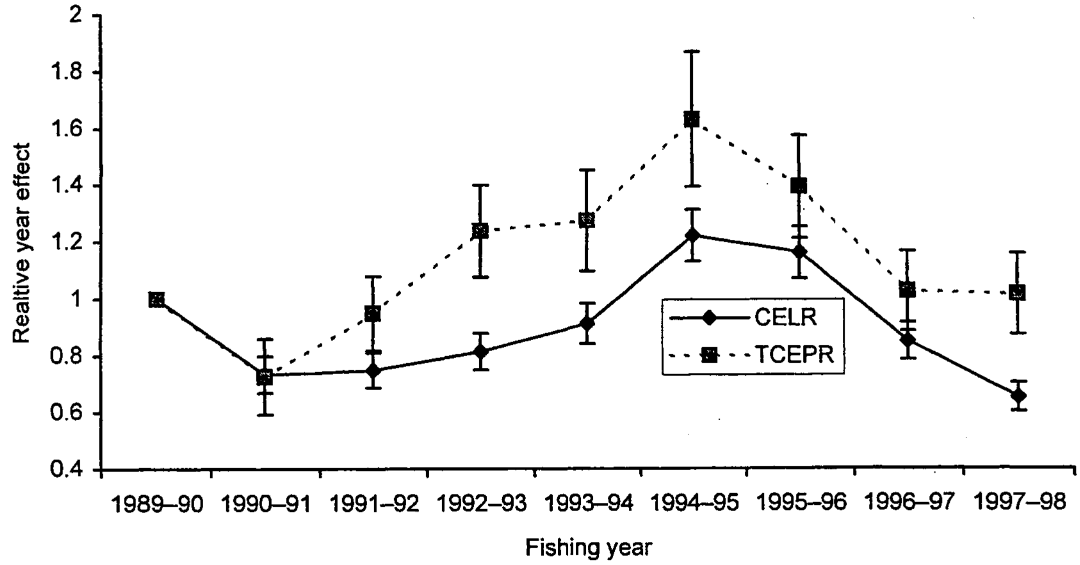


Figure 7: Relative year effect for CELR and TCEPR forms in RCO 3 from 1989–90 to 1997–98. CELR data derived from kg/day where target species is red cod. TCEPR data derived from kg/tow where target species is red cod. Error bars are ± 2 standard errors.

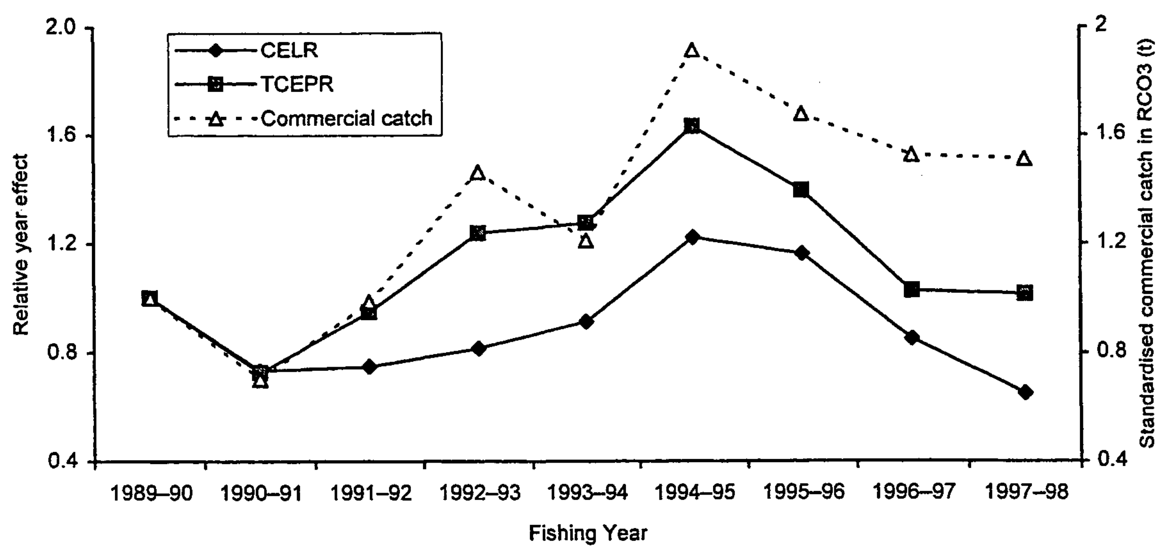


Figure 8: Relative year effect for CELR and TCEPR forms in RCO 3 from 1989–90 to 1997–98 with standardised commercial catch in RCO 3 for comparison (catch divided by catch in 1989–90).

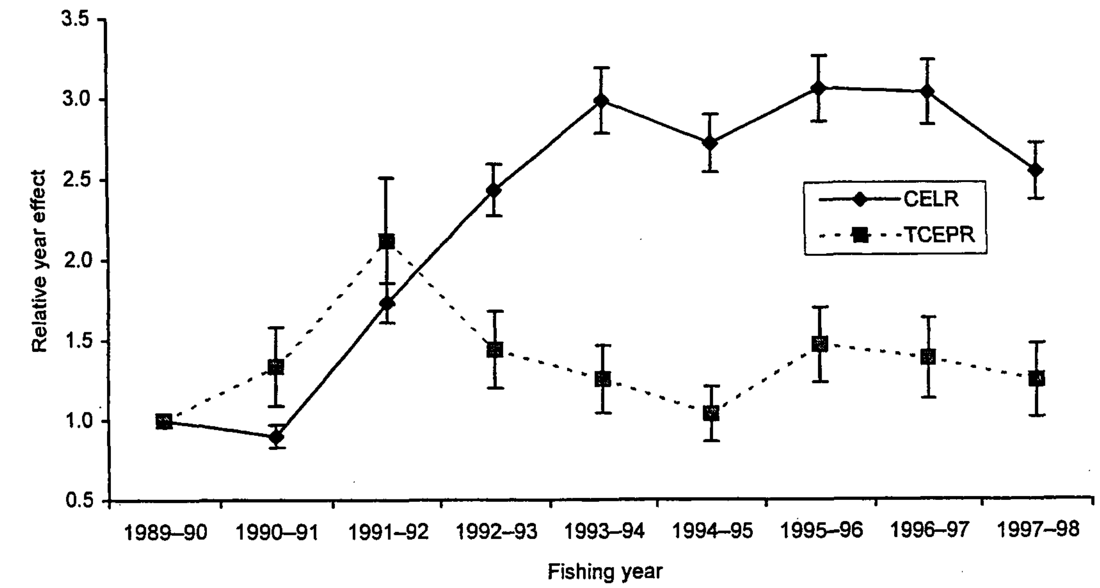


Figure 9: Relative year effect for CELR and TCEPR forms in RCO 7 from 1989–90 to 1997–98. CELR data derived from kg/day where target species is red cod, barracouta, and flatfish. TCEPR data derived from kg/tow where red cod is in top five species. Error bars are ± 2 standard errors.

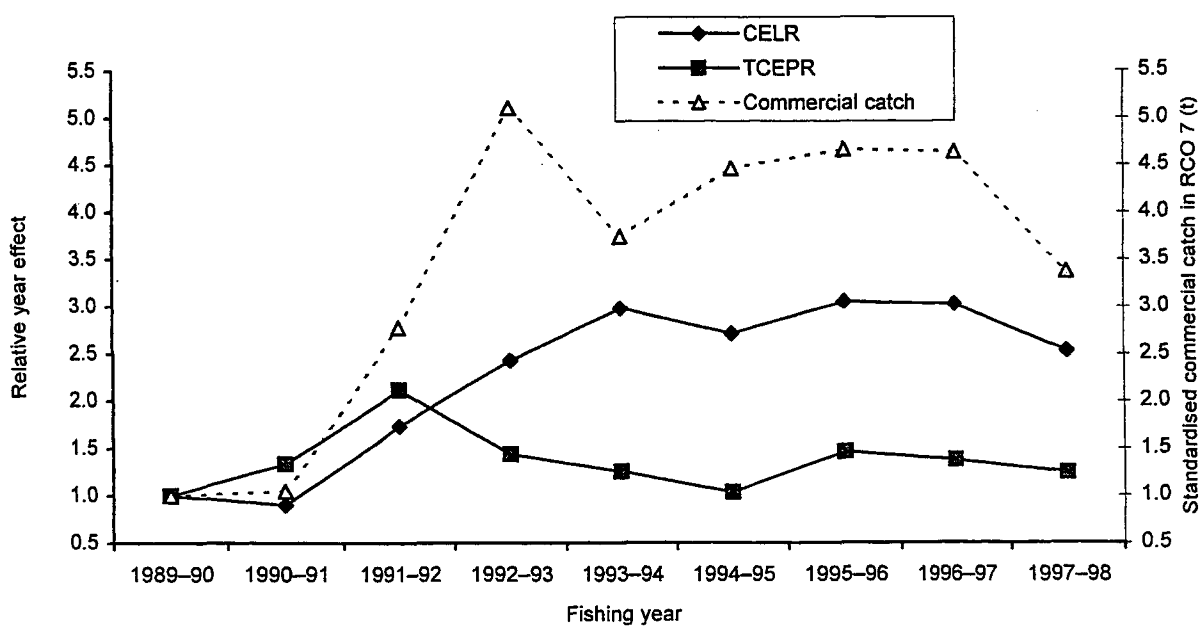


Figure 10: Relative year effect for CELR and TCEPR forms in RCO 7 from 1989–90 to 1997–98 with standardised commercial catch in RCO 7 for comparison (catch divided by catch in 1989–90).

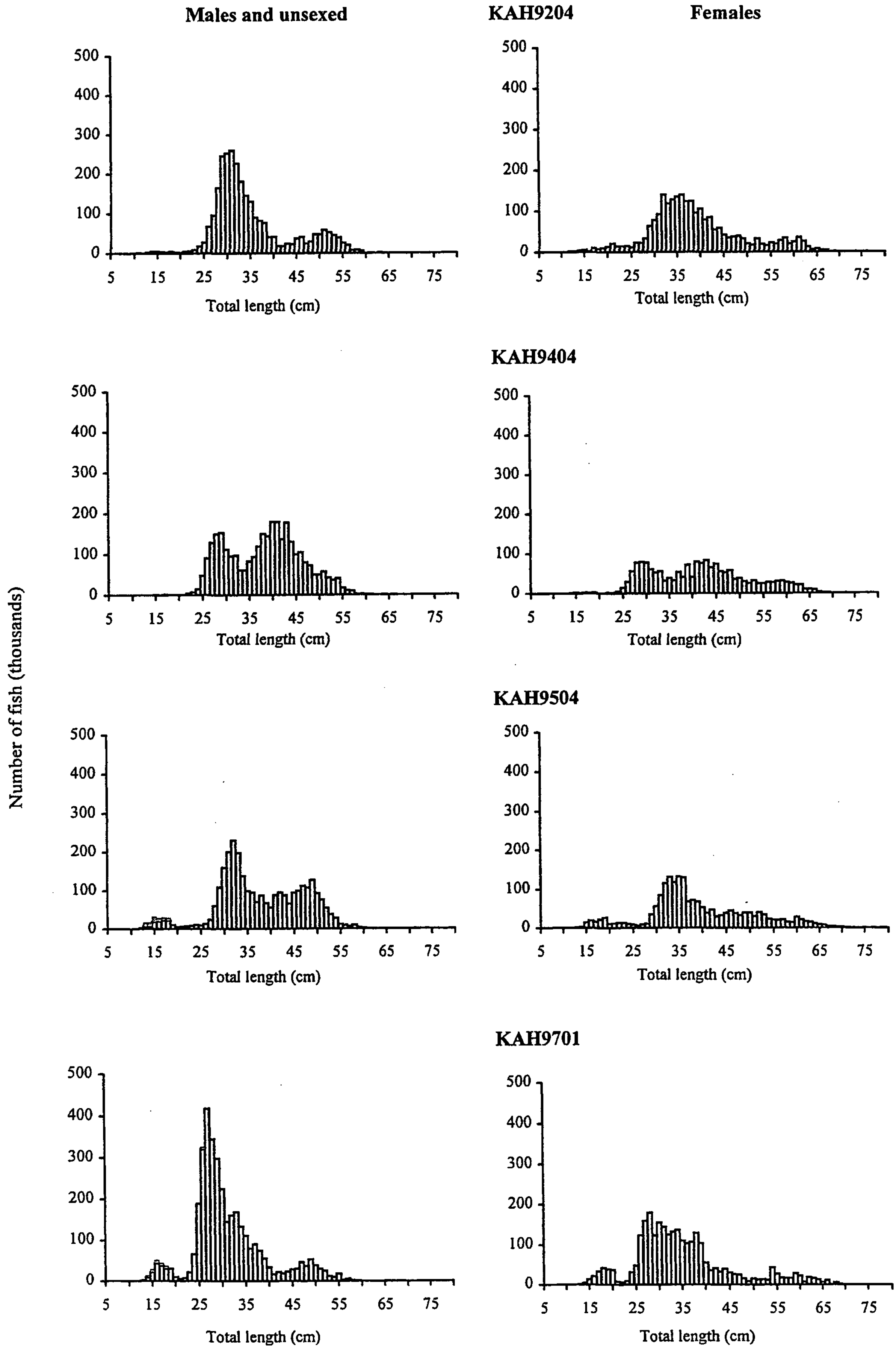


Figure 11: Scaled length frequencies from west coast South Island trawl surveys.

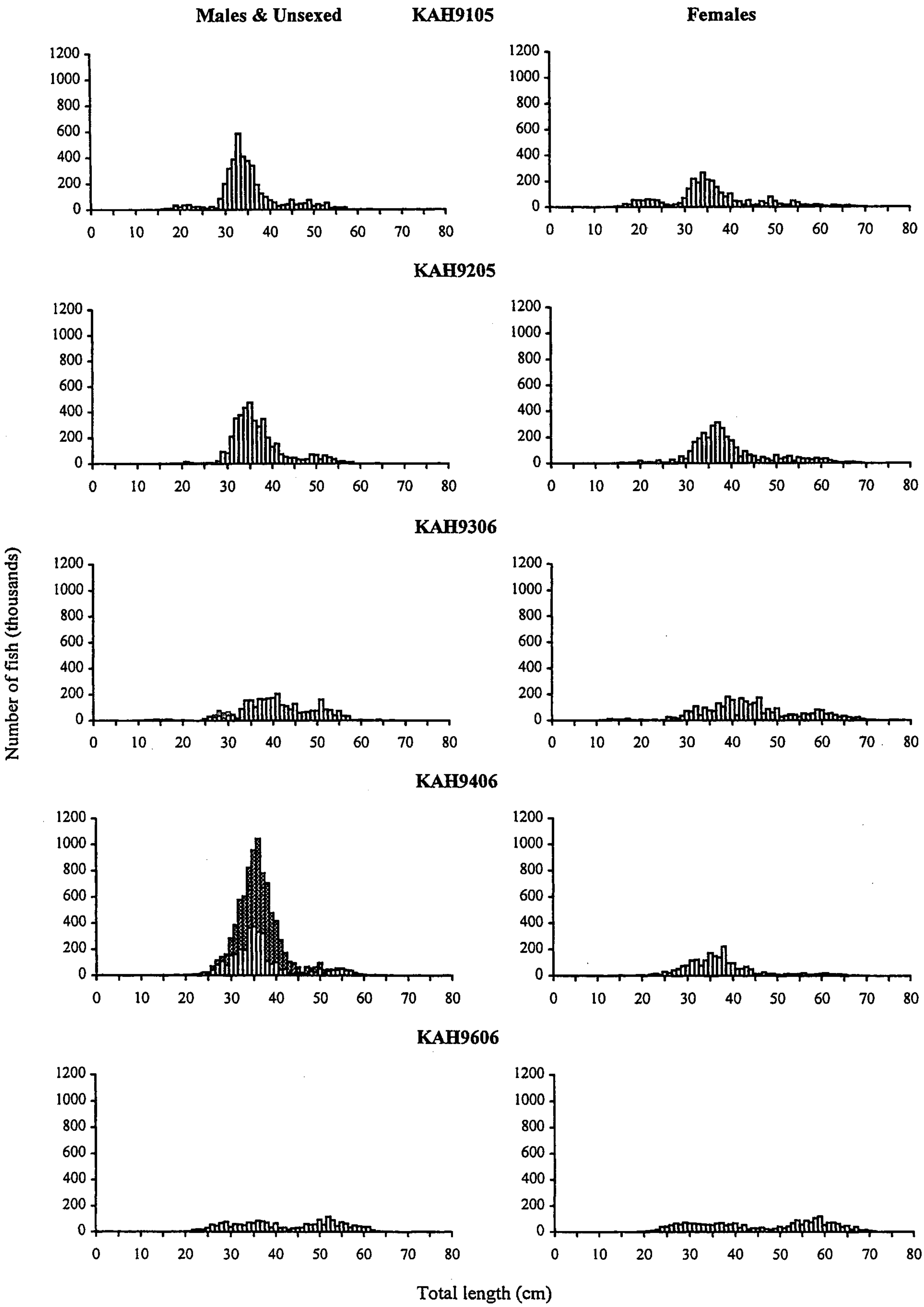


Figure 12: Red cod length frequencies from east coast South Island winter trawl surveys.

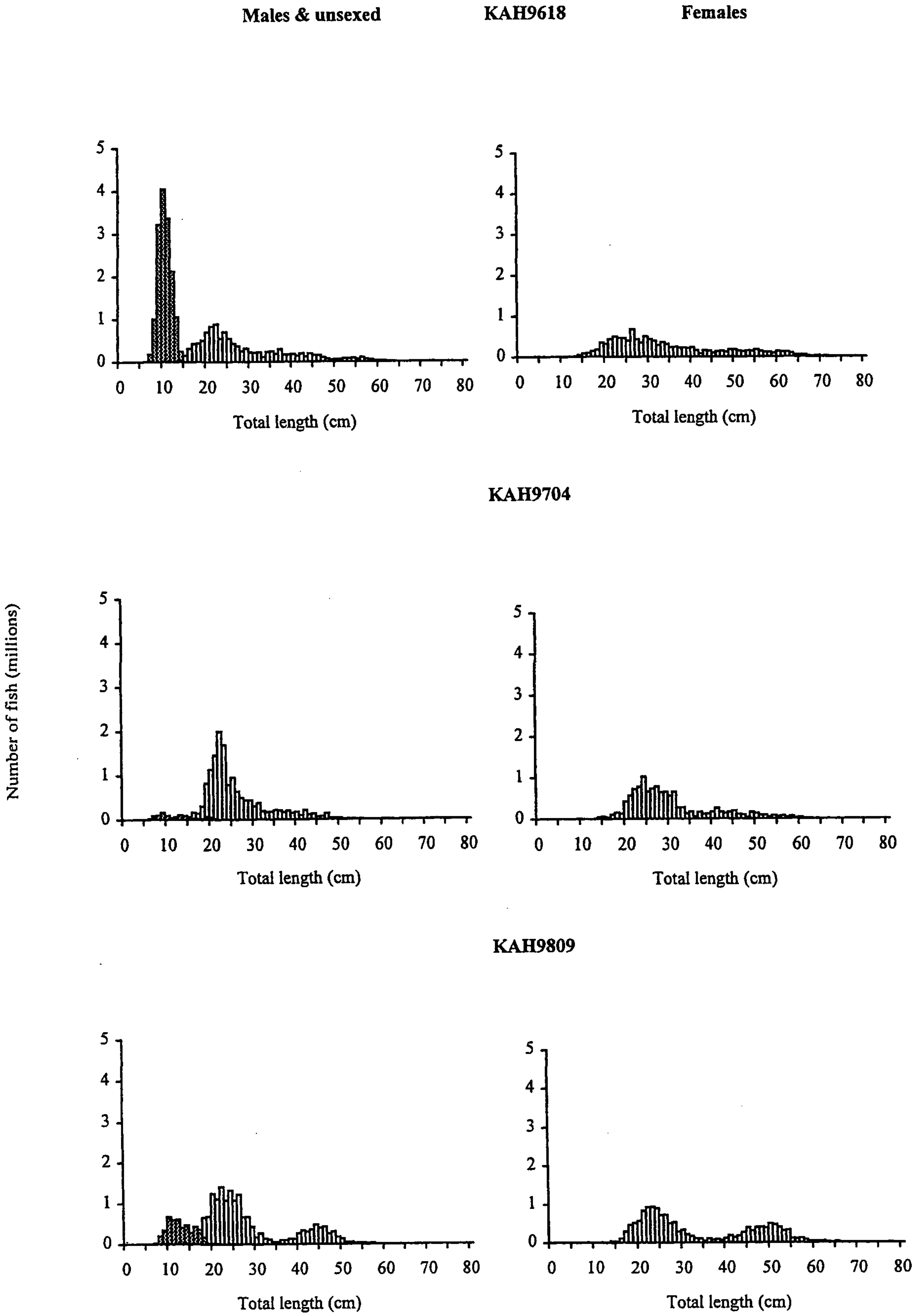


Figure 13: Red cod scaled length frequencies from east coast South Island summer trawl surveys.

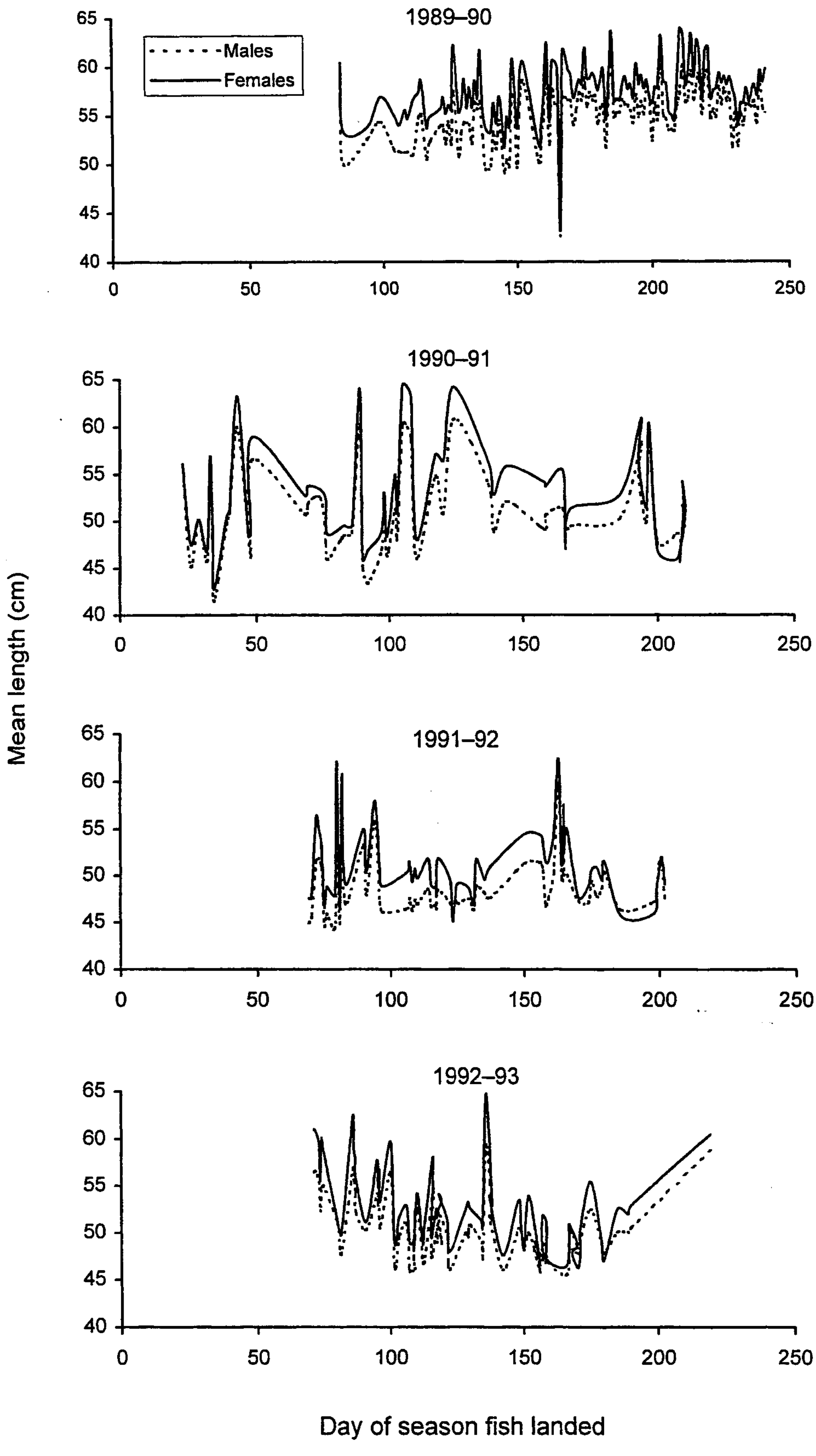


Figure 14: Mean length of landed red cod by day of fishing season (day 1 = 1 November). Includes Kaikoura landings in 1991.

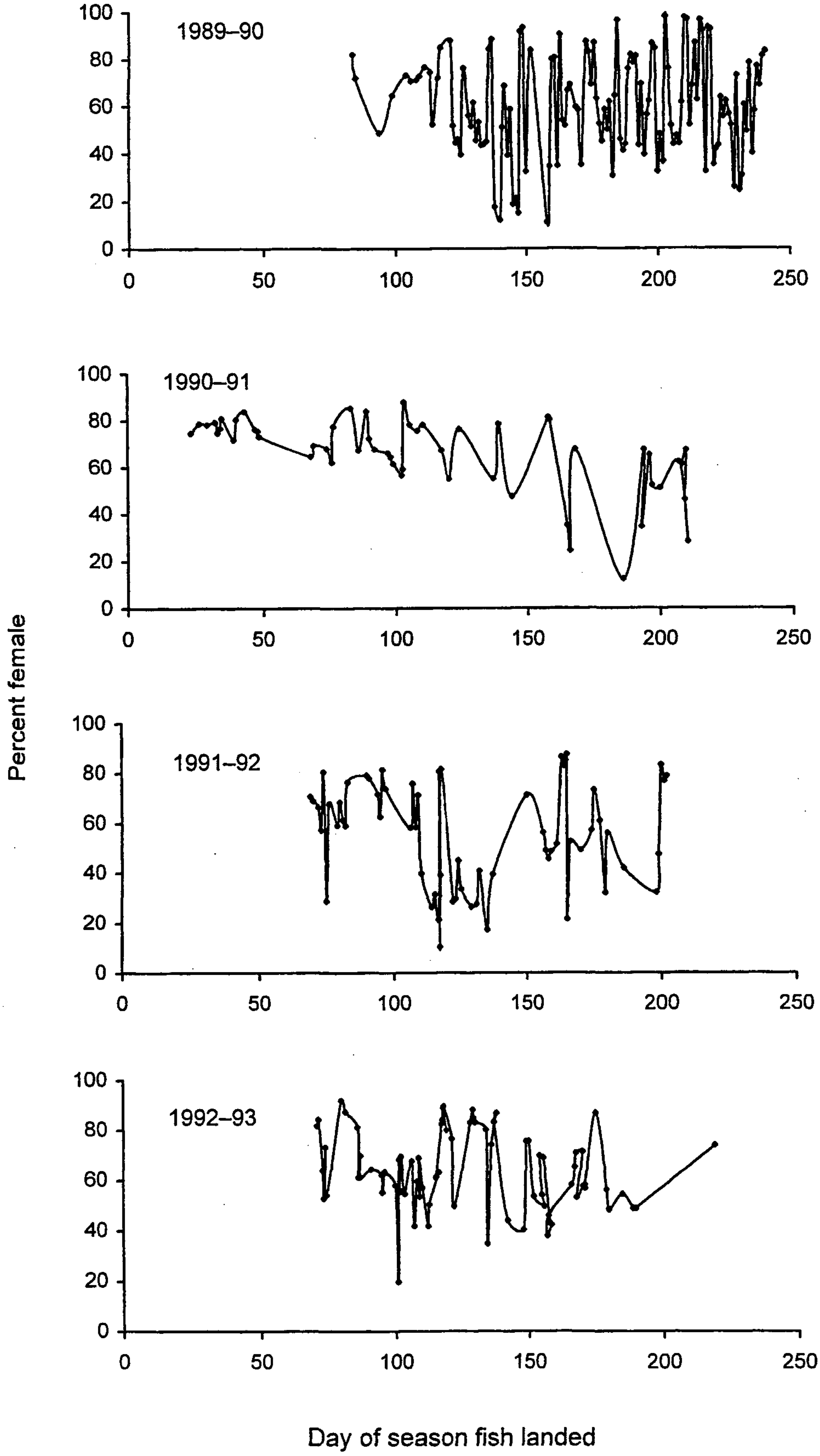


Figure 15: Percent female in red cod landings by day of fishing season (day 1 = 1 November). Includes Kaikoura landings in 1991.

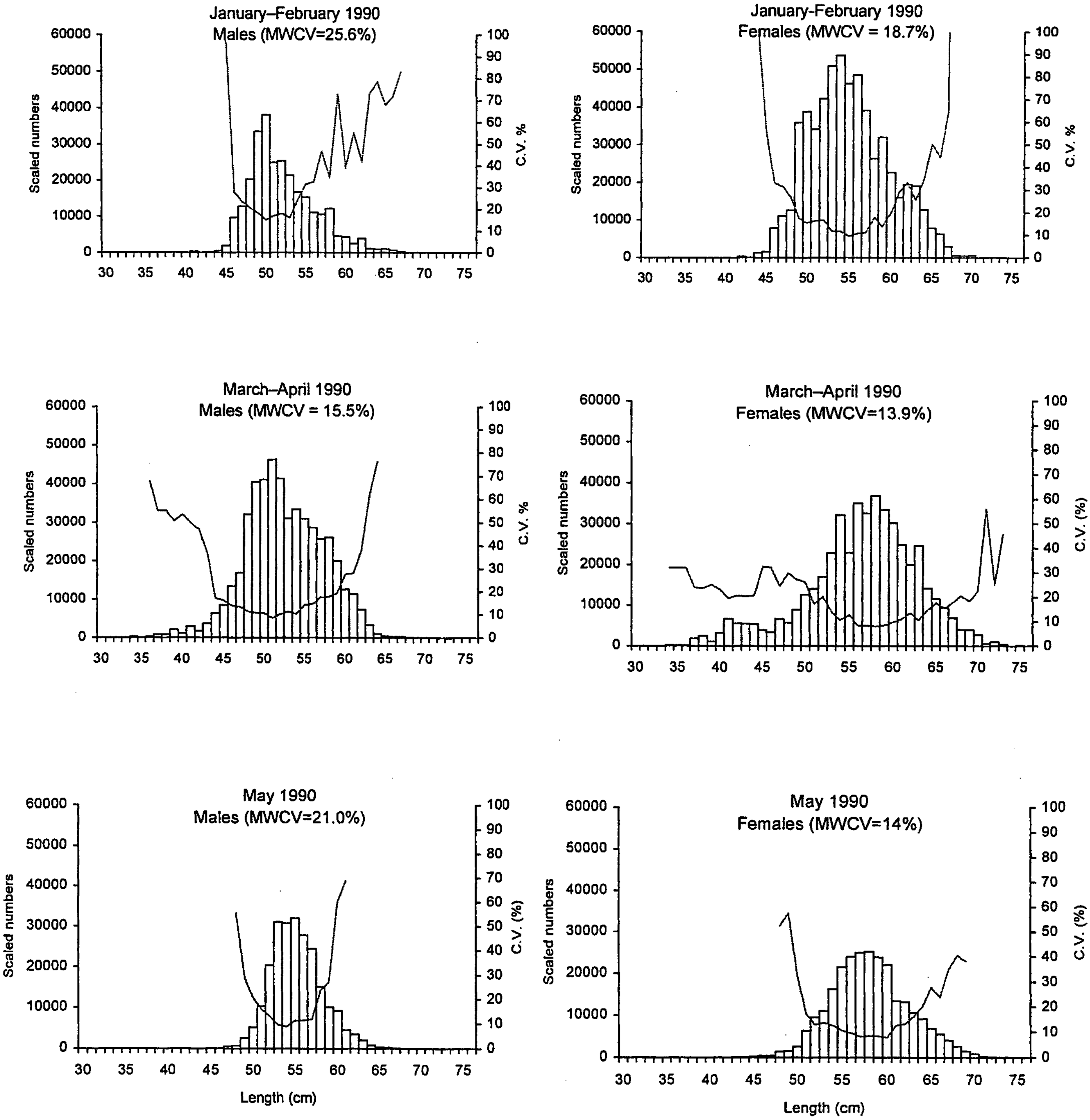


Figure 16: Red cod scaled length frequency distributions and *c.v.*s for catch sampling programme (1990–93). MWCV, mean weighted coefficient of variation.

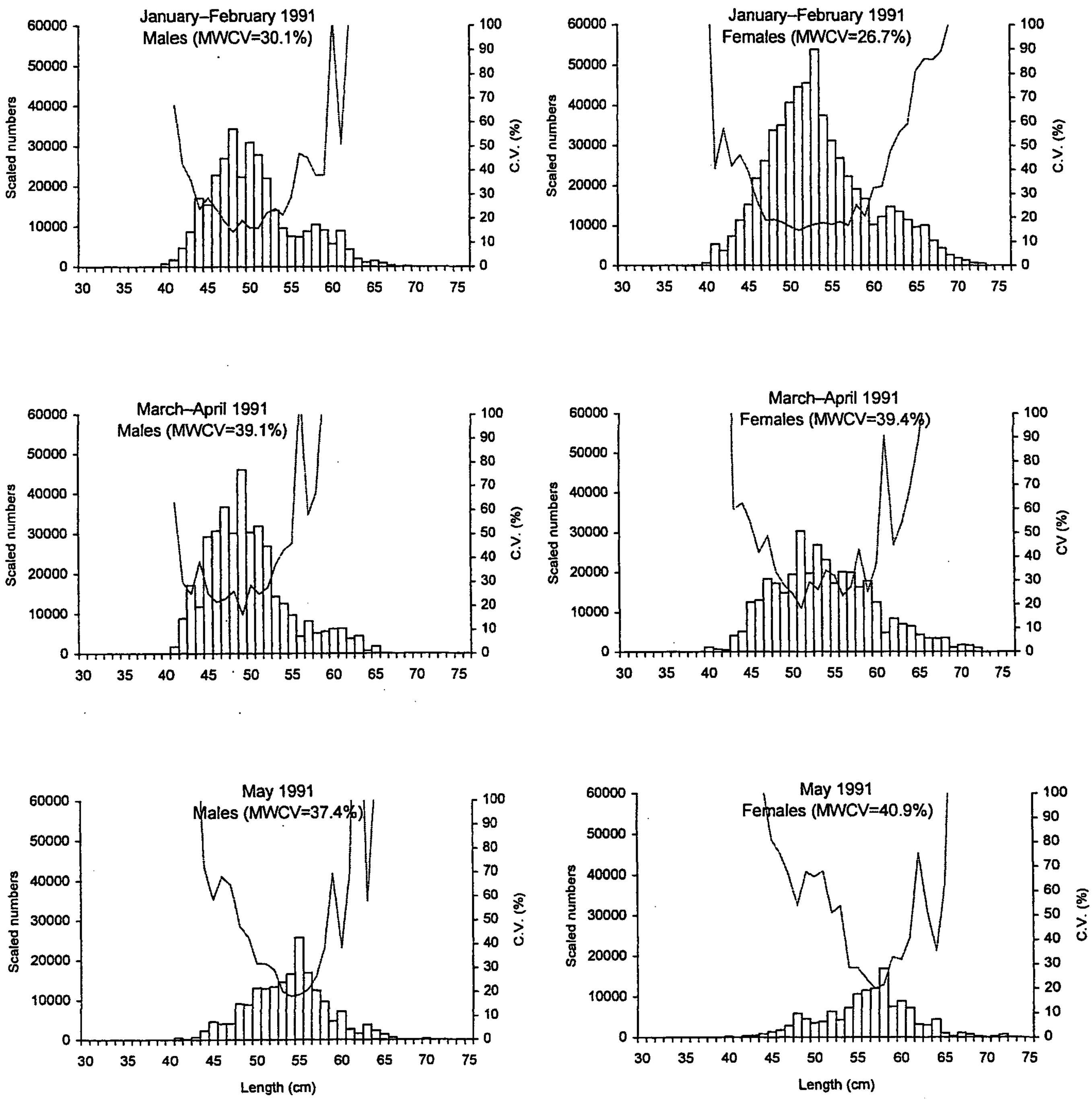


Figure 16–*continued*

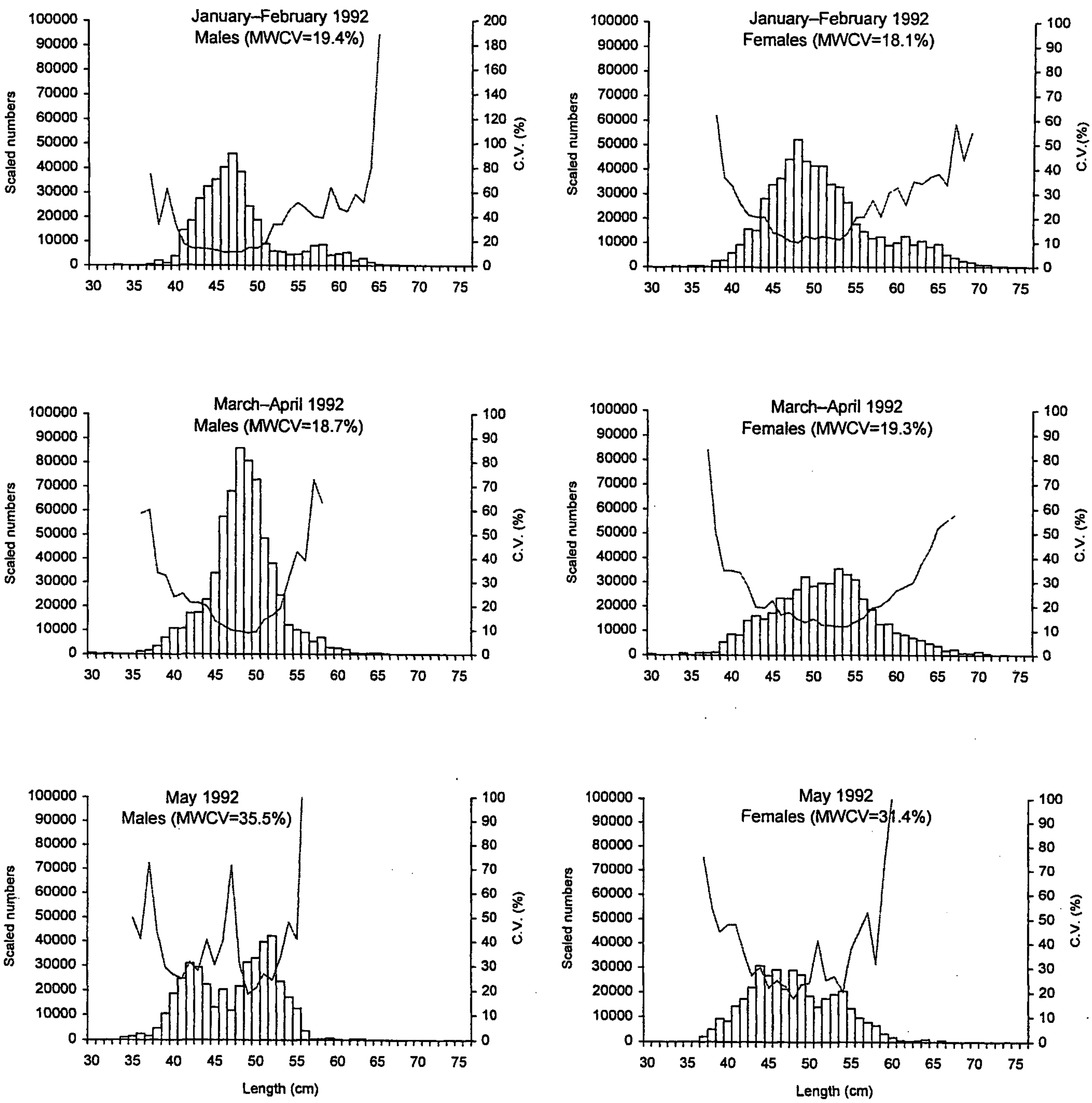


Figure 16–*continued*

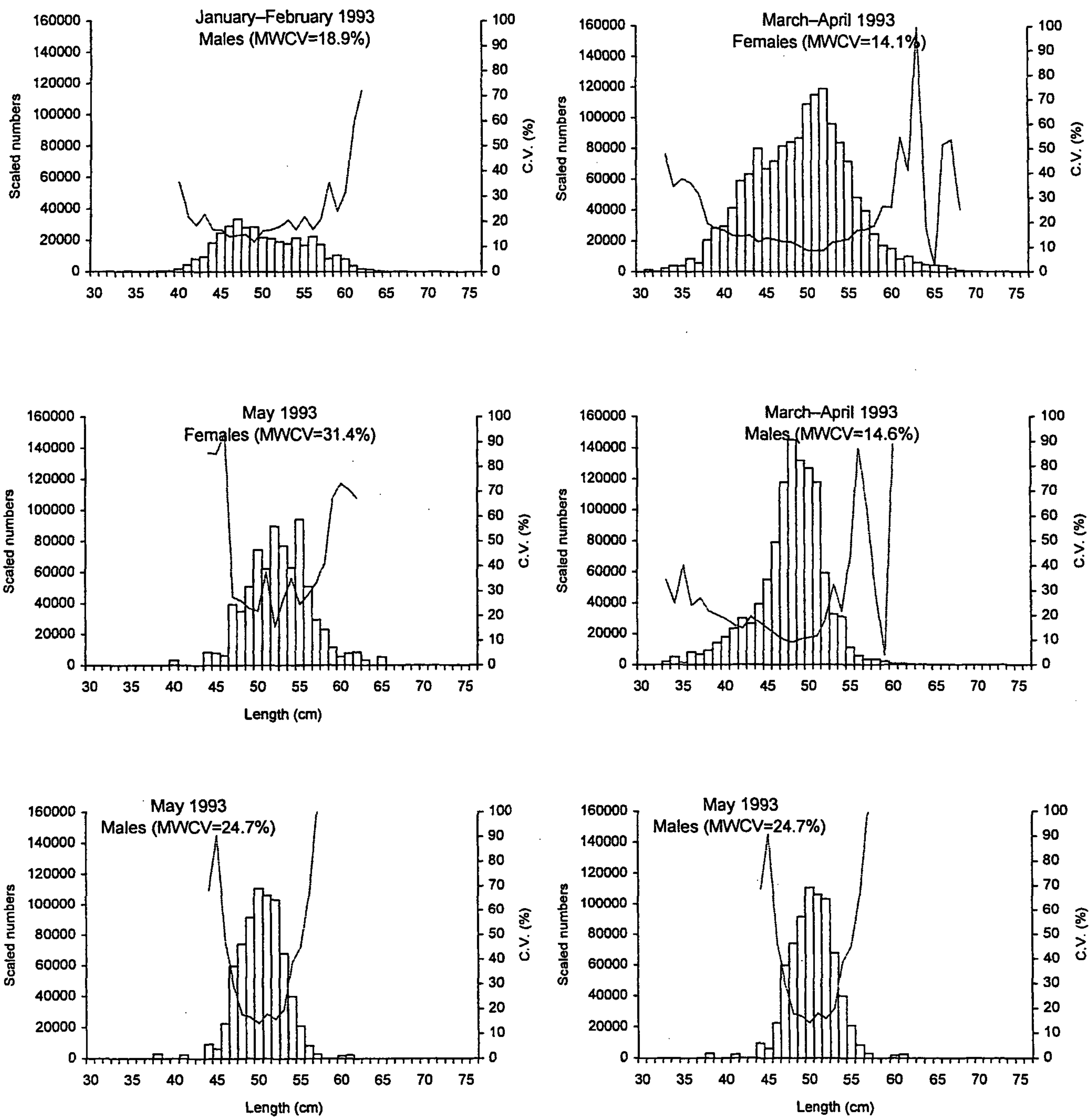


Figure 16–*continued*

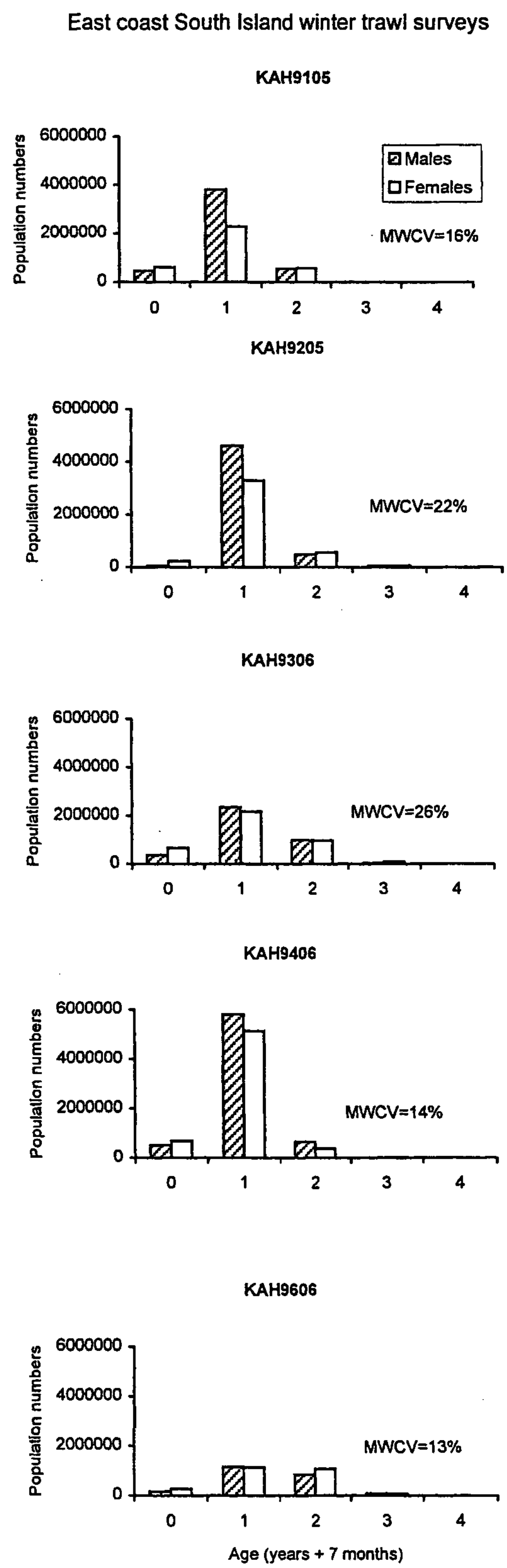


Figure17: Catch at age for east coast South Island winter and summer trawl surveys (from otoliths), and west coast South Island trawl surveys (MIX analysis). MWCV, mean weighted coefficient of variation.

East coast South Island summer trawl surveys

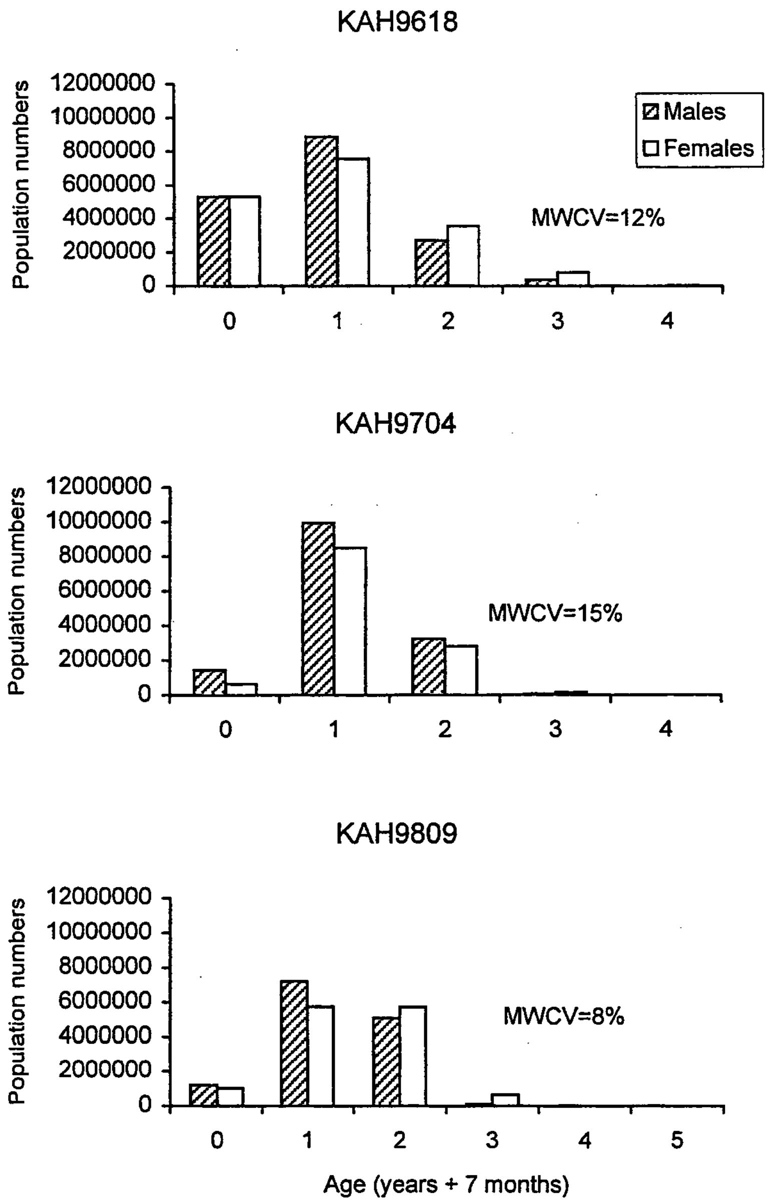


Figure 17 *–continued*

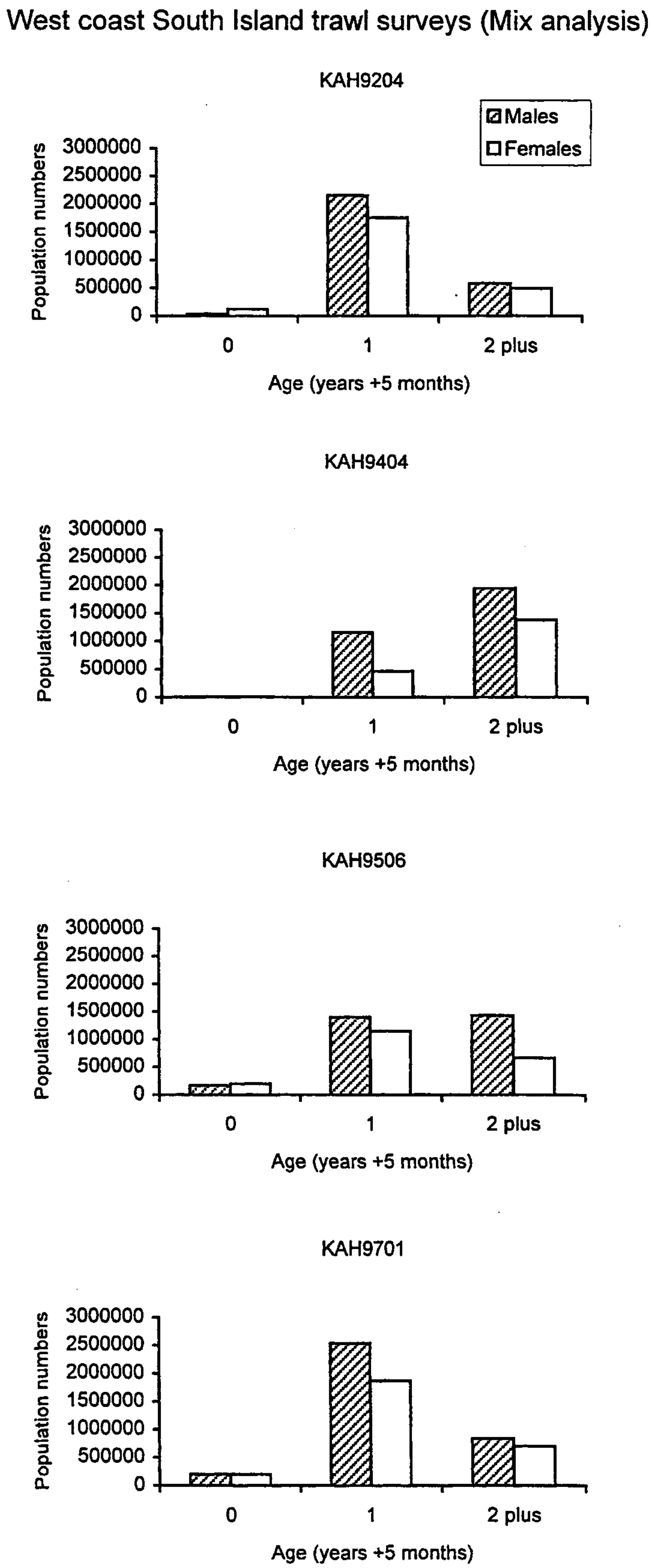


Figure 17 *–continued*

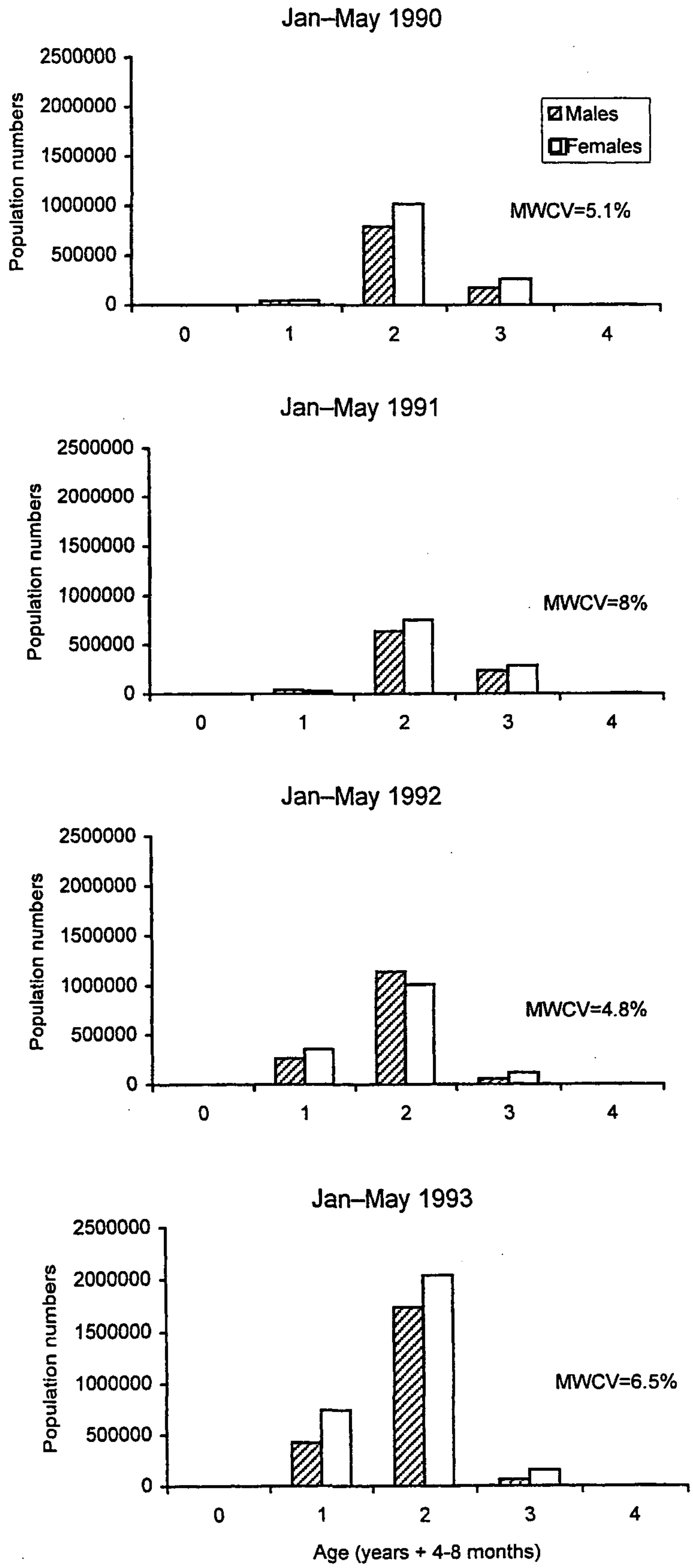


Figure 18: Catch at age for red cod from catch sampling programme 1990–93. MWCV, mean weighted coefficient of variation.

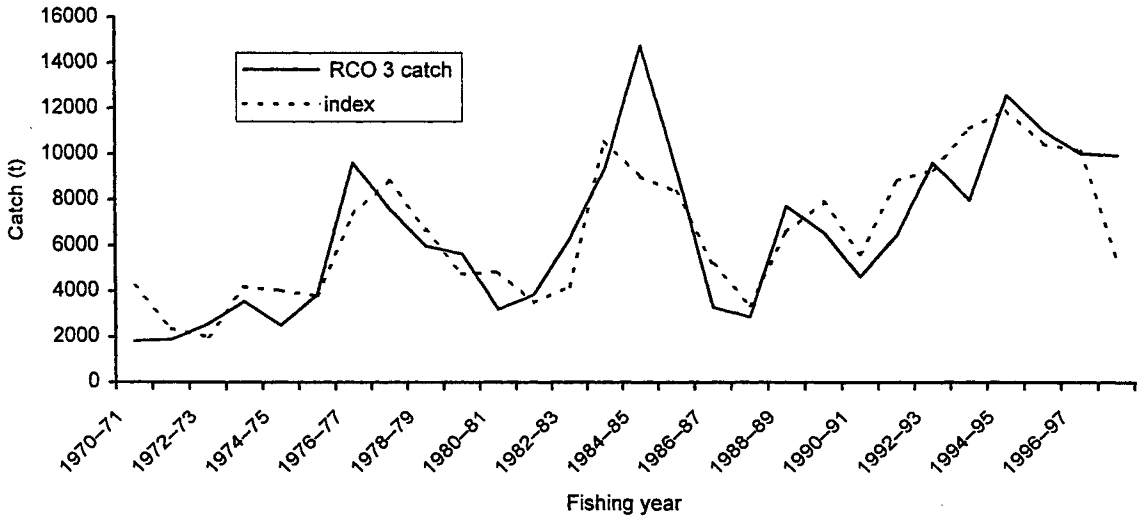


Figure 19: Commercial landings of red cod in RCO 3 and predicted environmental abundance index. The index was predicted from the regression model of environmental variables (SST and Trough NW cluster, with a 14 month lag) against commercial catch.

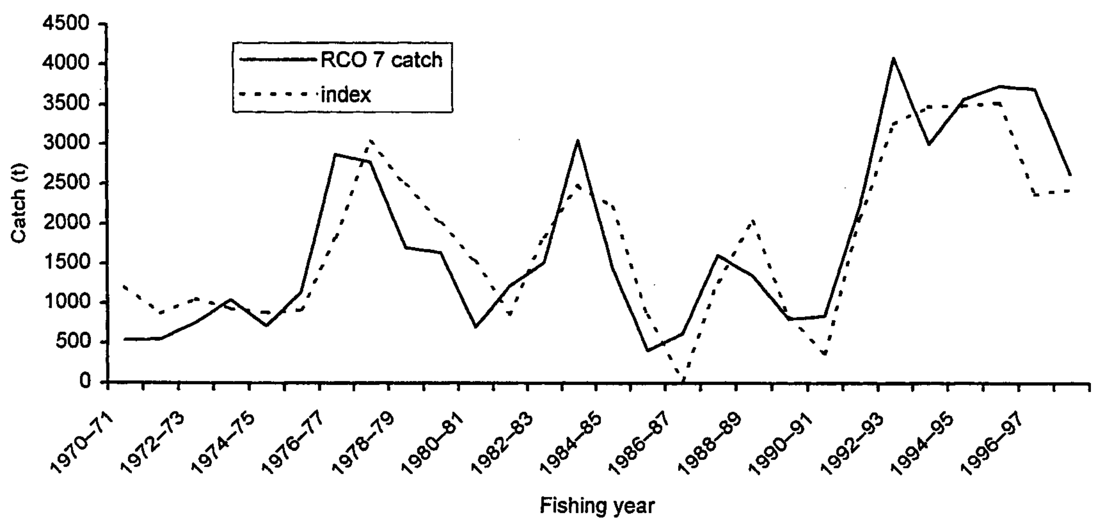
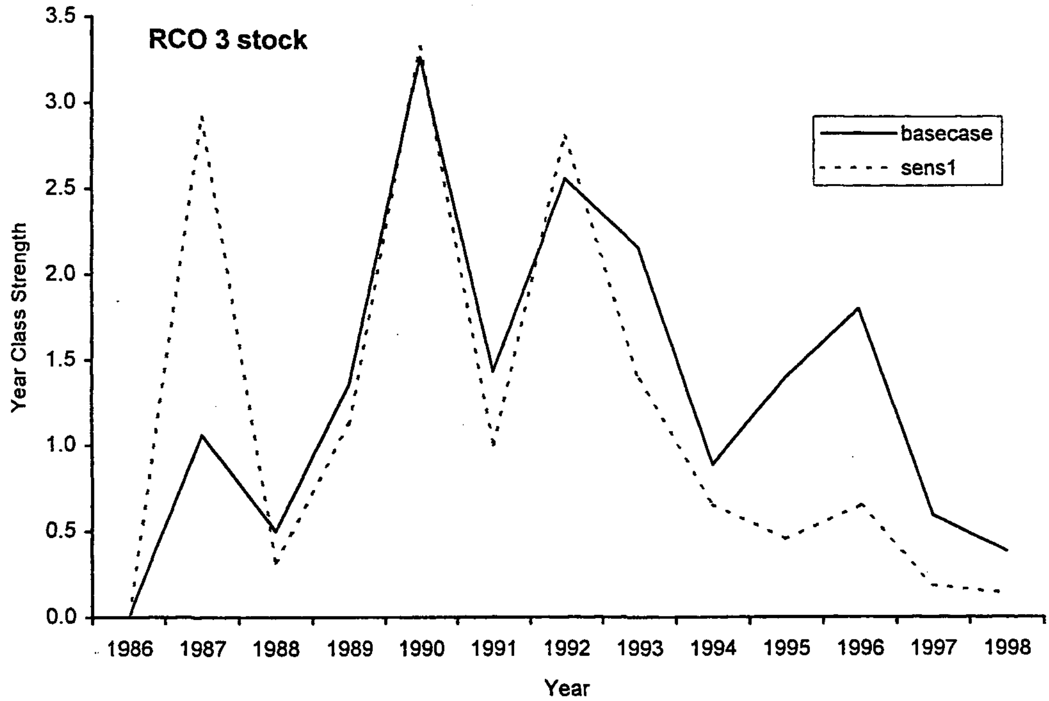


Figure 20: Commercial landings of red cod in RCO 7 and predicted environmental abundance index. The index was predicted from the regression model of environmental variables (SST and surface westerly, with a 14 month lag) against commercial catch.



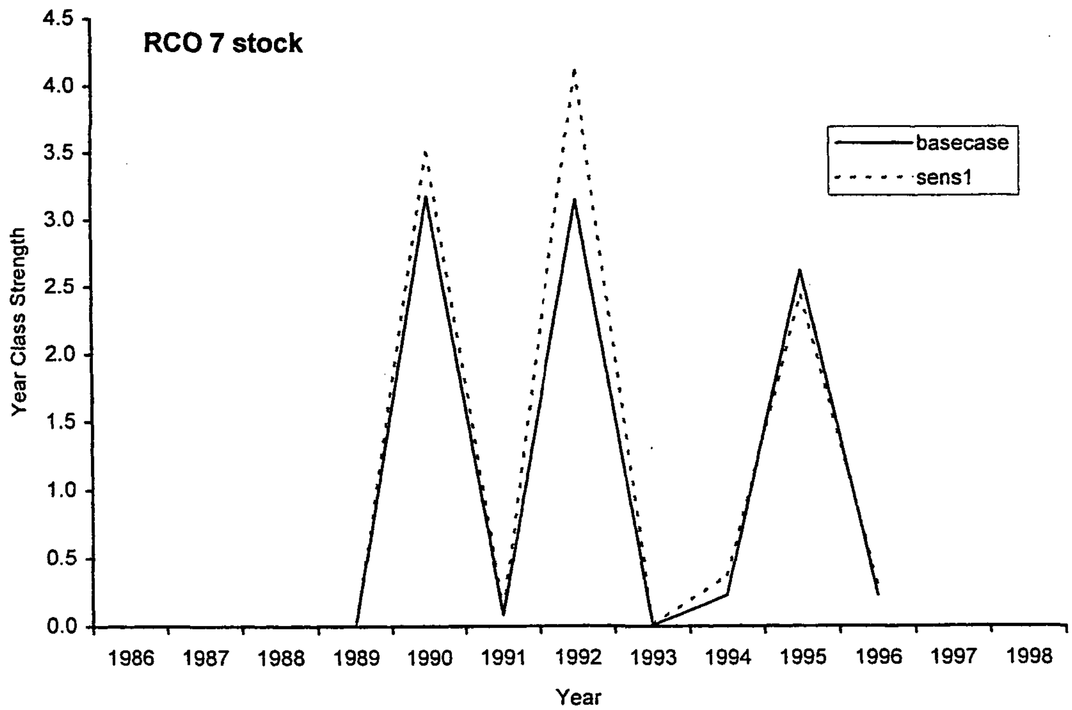


Figure 21: Estimated year class strengths for RCO 3 (1986–98) and RCO 7 (1989–96) using least squares single stock method. Only the basecase and sensitivity 1 (environ) are shown.

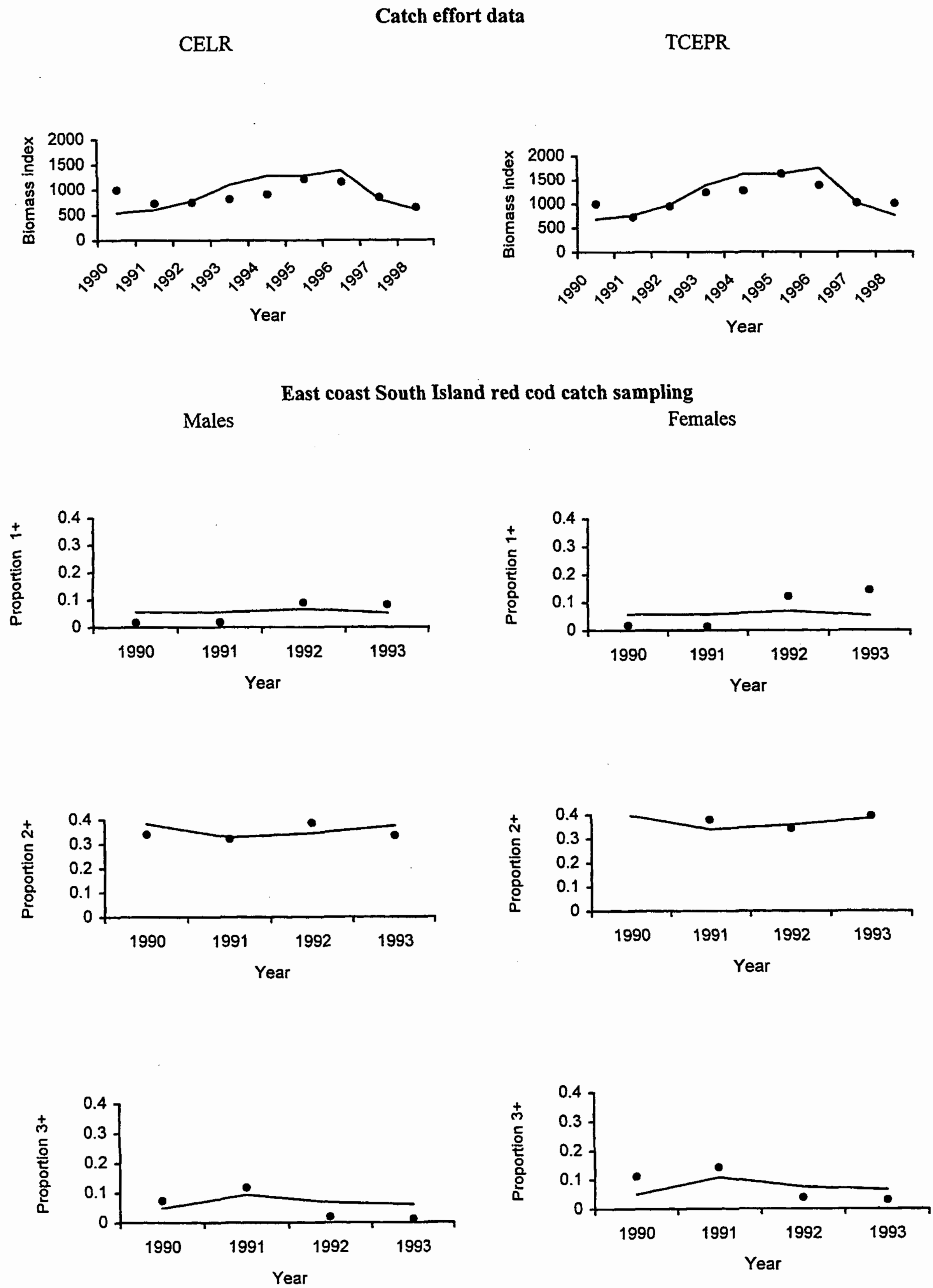
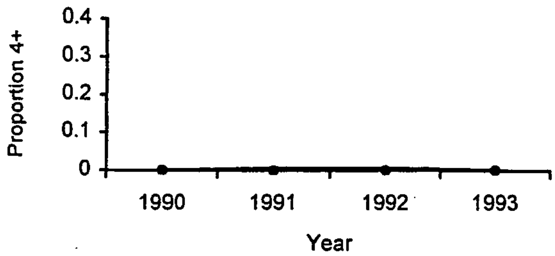


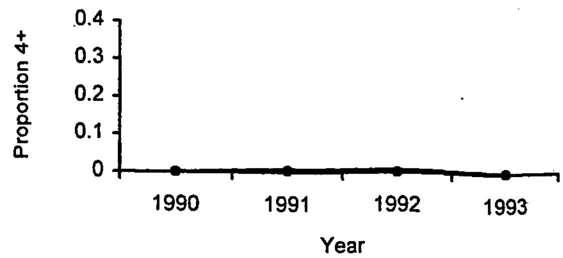
Figure 22: RCO 3 base case least squares fits to CPUE data, catch sampling proportion at age, trawl surveys number at age, and environment abundance index (sens1). Circles, observed; line, predicted.

East coast South Island red cod catch sampling

Males

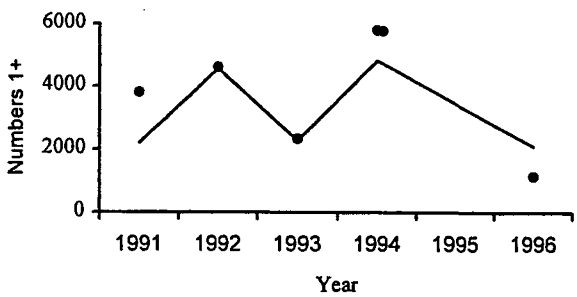


Females

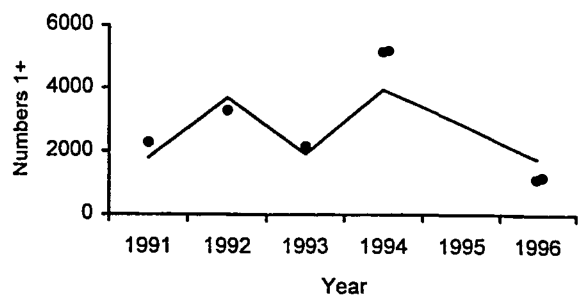


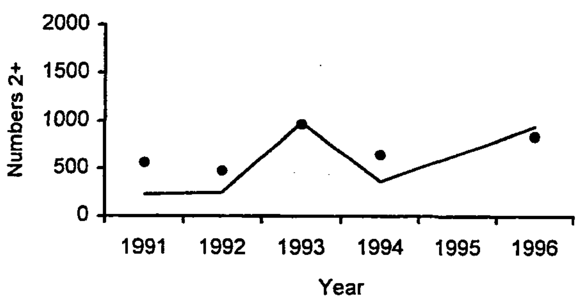
East coast South Island winter trawl surveys (1991, 1992, 1993, 1994, 1996)

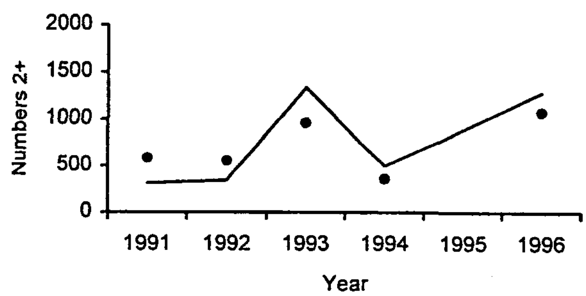
Males



Females

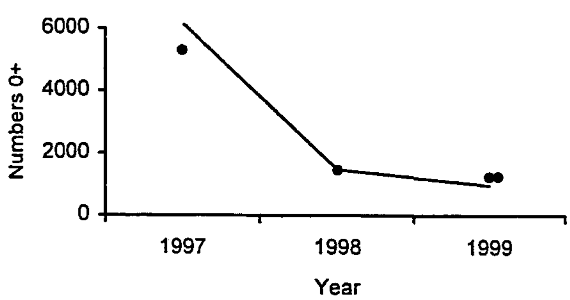






East coast South Island summer trawl surveys (1997, 1998, 1999)

Males



Females

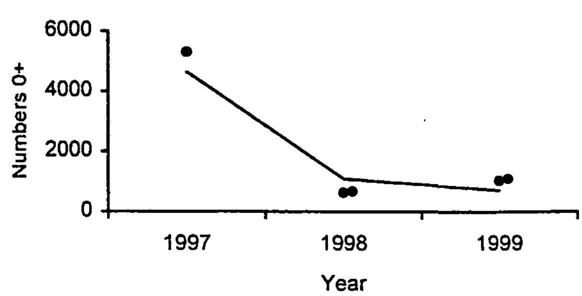
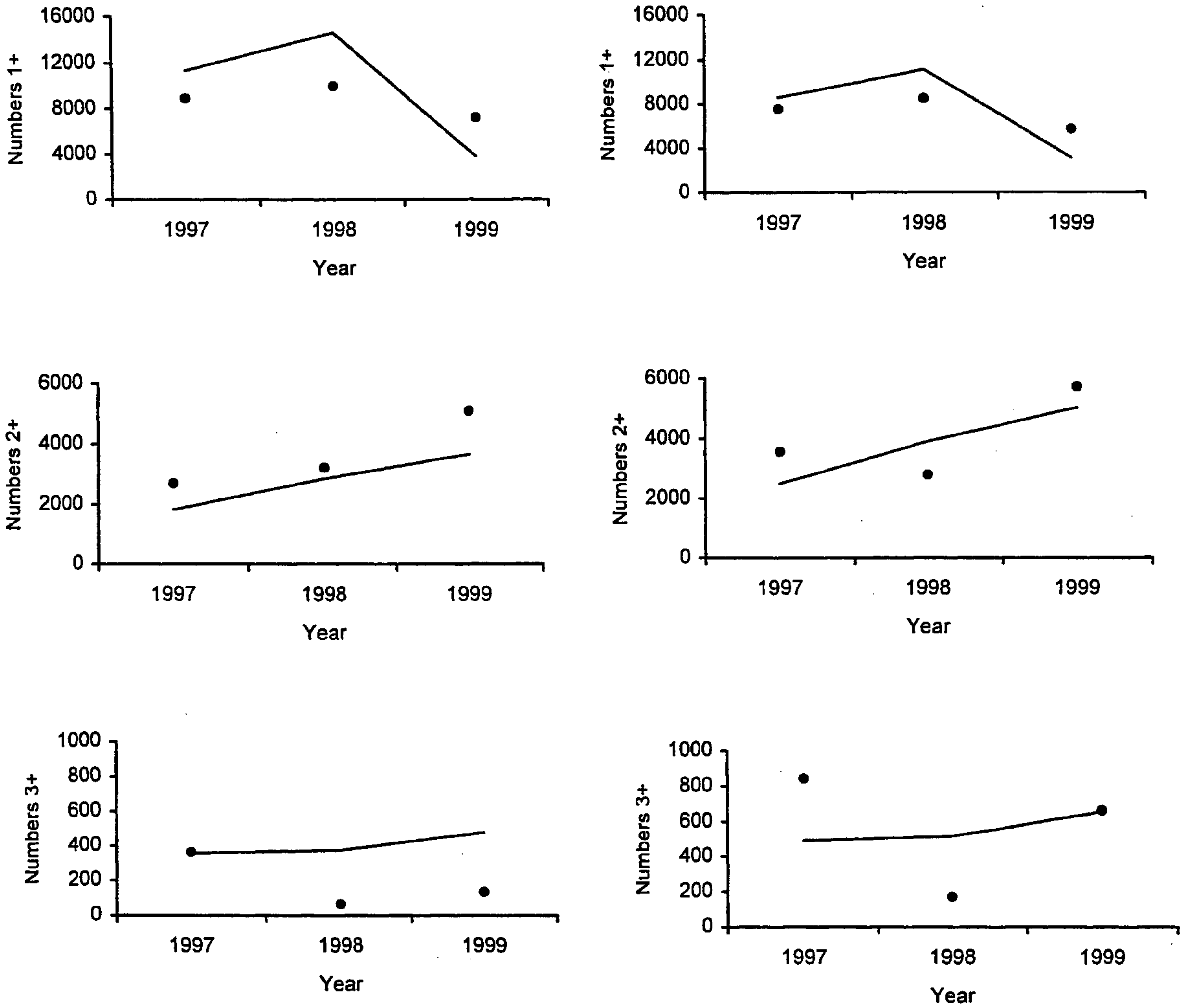


Figure 22–***continued***

East coast South Island summer trawl surveys (1997,1998,1999)

Males | Females



Environmental abundance index (from sensitivity 1)

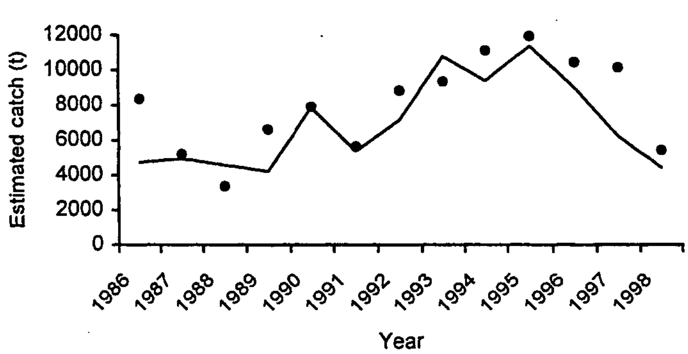


Figure 22–*continued*

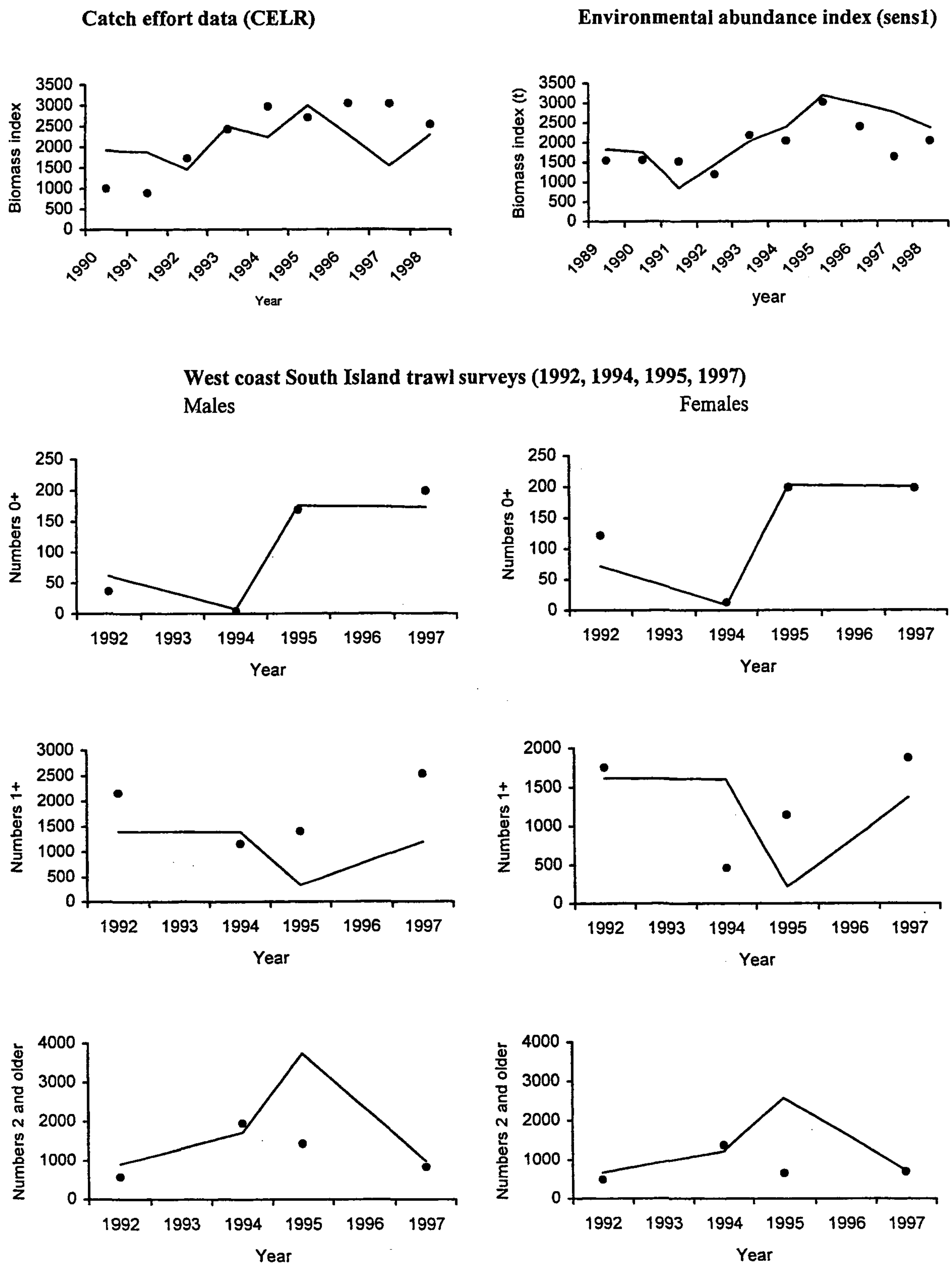
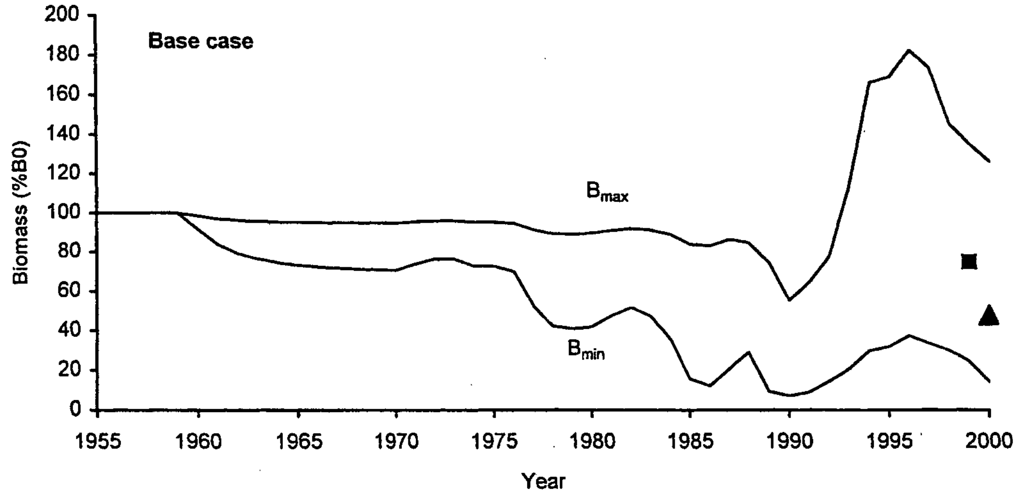


Figure 23: RCO 7 base case least squares fits to CPUE data, catch sampling proportion at age, trawl surveys number at age, and environment abundance index (sens1). Circles, observed; line, predicted.



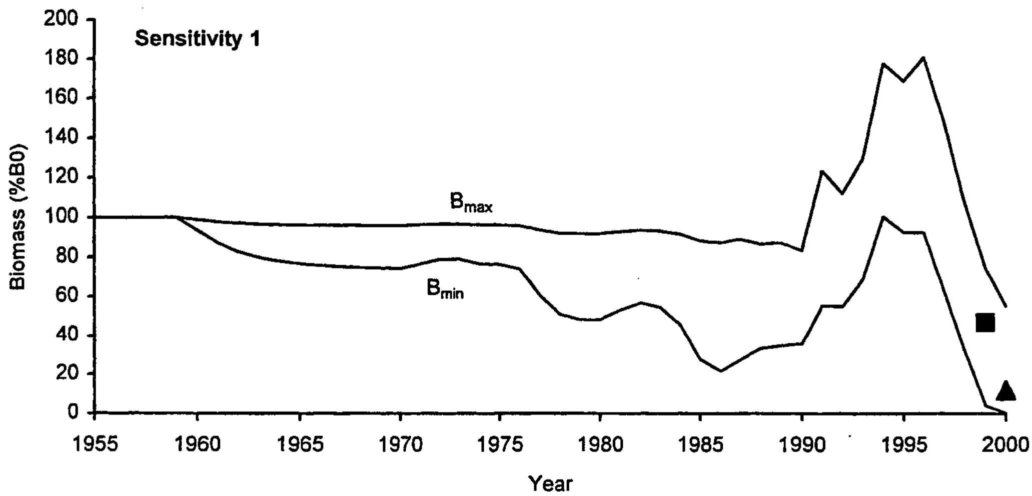
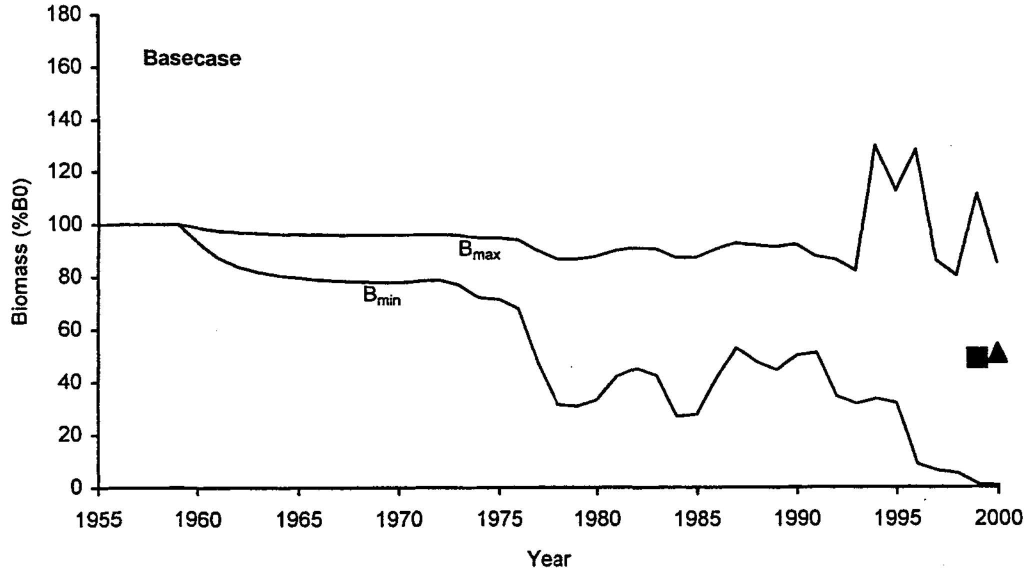


Figure 24: RCO 3 biomass trajectories for B_{min} and B_{max} for base case and sensitivity 1(environ). Square, B_{mid99}; triangle B_{mid00}.



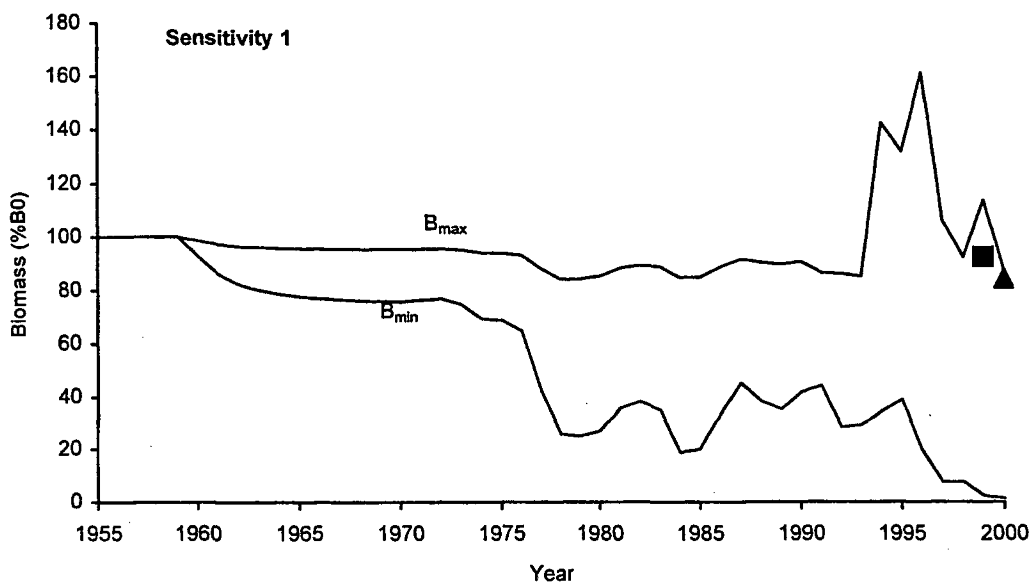


Figure 25: RCO 7 biomass trajectories for B_{min} and B_{max} for base case and sensitivity 1(environ). Square, B_{mid99}; triangle B_{mid00}.

Appendix 1: Red cod raw CPUE data from CELR forms in RCO 3. Target species red cod. Proportion of zeros refers to days with zero catch

Year	Catch (kg)	Days	No. Tows	Hours	kg/day	kg/tow	kg/hour	prop zeros
1988–89	45584	69	173	566	660.6	263.5	80.5	4.0
1989–90	2060392	2051	5519	17277	1004.6	373.3	119.3	4.0
1990–91	1993559	2053	5675	18139	971.0	351.3	109.9	7.0
1991–92	1943017	2638	7317	25213	736.5	265.5	77.1	6.2
1992–93	2642337	3027	8280	29616	872.9	319.1	89.2	6.6
1993–94	3256762	3436	8967	28375	947.8	363.2	114.8	6.6
1994–95	5227016	3737	9540	31478	1398.7	547.9	166.1	4.1
1995–96	3371382	3092	7947	26301	1090.4	424.2	128.2	6.5
1996–97	3885646	3290	9145	28568	1181.0	424.9	136.0	5.0
1997–98	3167654	3311	9838	29457	956.7	322.0	107.5	6.0

Appendix 2: Red cod raw CPUE data from TCEPR forms in RCO 3. Target species is red cod. Proportion of zeros refers to tows with zero catch

Year	Catch (kg)	Tows	Minutes	kg/tow	kg/hour	prop zeros
1988–89	185453	105	347.8	1766.2	533.2	21.0
1989–90	938342	959	3686.4	978.5	254.5	14.2
1990–91	407631	532	2315.5	766.2	176.0	22.6
1991–92	1691985	1391	5841.3	1216.4	289.7	16.0
1992–93	3410534	1790	7265.0	1905.3	469.4	14.1
1993–94	1966653	1347	4634.7	1460.0	424.3	14.5
1994–95	2811854	1225	4663.2	2295.4	603.0	9.7
1995–96	3481611	2157	7047.3	1614.1	494.0	14.0
1996–97	2583569	1826	5464.6	1414.9	472.8	17.9
1997–98	2529577	1940	5560.9	1303.9	454.9	31.8

Appendix 3: Red cod raw CPUE data from CELR forms in RCO7. Target species is red cod, barracouta, and flatfish. Proportion of zeros refers to days with zero catch

Year	Catch (kg)	Days	No. Tows	Hours	kg/day	kg/tow	kg/hour	prop zeros
1988–89	51182	537	1561	4287	95.3	32.8	11.9	39.5
1989–90	365939	3854	11999	31501	95.0	30.5	11.6	50.8
1990–91	342102	4068	12964	34586	84.1	26.4	9.9	50.8
1991–92	1167603	4648	14850	43328	251.2	78.6	26.9	37.3
1992–93	2727490	6710	22267	65010	406.5	122.5	42.0	22.8
1993–94	1888088	5131	16227	43962	368.0	116.4	42.9	21.7
1994–95	2093095	5879	18304	48324	356.0	114.4	43.3	19.5
1995–96	1980445	5633	17229	47883	351.6	114.9	41.4	19.0
1996–97	2241883	6848	21225	62164	327.4	105.6	36.1	27.7
1997–98	1333130	5145	15544	44461	259.1	85.8	30.0	27.1

Appendix 4: Red cod raw CPUE data from TCEPR forms in RCO 7. Red cod in top five species

Year	Catch (kg)	Tows	Hours	Kg/tow	Kg/hour
1988–89	108581	165	616	658	176
1989–90	154879	363	1410	427	110
1990–91	310429	416	1451	746	214
1991–92	662664	401	1918	1653	345
1992–93	518835	642	2862	808	181
1993–94	442083	619	2857	714	155
1994–95	412056	732	3009	563	137
1995–96	572113	1111	3901	515	147
1996–97	307774	638	1685	482	183
1997–98	253484	525	1586	483	160

Appendix 5: Numbers of otoliths collected for each of the three time strata for each year of the red cod catch sampling programme

Year	Strata	Total males collected	Number read	Sample method	Total females collected	Number read	Sample method
1990	Jan–Feb	69	69	all	190	140	sub-sample
	Mar–Apr	464	134	sub-sample	535	141	sub-sample
	May–Jun	376	134	sub-sample	662	133	sub-sample
1991	Jan–Feb	111	111	all	188	188	all
	Mar–Apr	65	65	all	95	95	all
	May–Jun	86	86	all	74	74	all
1992	Jan–Feb	255	143	sub-sample	337	147	sub-sample
	Mar–Apr	319	136	sub-sample	260	131	sub-sample
	May–Jun	53	53	all	66	66	all
1993	Jan–Feb	296	147	sub-sample	484	139	sub-sample
	Mar–Apr	267	138	sub-sample	433	132	sub-sample
	May–Jun	38	38	all	42	42	all

Appendix 6: Number of otoliths collected, prepared and read from South Island trawl surveys. SI; South Island. * 1990 survey not included in the assessment

Trawl survey series	Voyage trip code	Total collected	Total prepared and read	Males	Females	Unsexed
Winter east coast SI	*KAH9008	423	–	–	–	–
	KAH9105	455	455	194	261	0
	KAH9205	258	258	83	175	0
	KAH9306	382	382	158	212	12
	KAH9406	800	400	200	200	0
	KAH9606	204	204	82	121	1
Summer east coast SI	KAH9618	398	398	175	204	19
	KAH9704	325	325	139	172	14
	KAH9809	351	351	148	201	2
West coast SI	KAH9204	0	–	–	–	–
	KAH9404	0	–	–	–	–
	KAH9504	377	375	171	204	0
	KAH9701	361	361	158	203	0

Appendix 7: Estimated catch at age (numbers) for east coast South Island trawl surveys. *c.v.*, coefficient of variation per age class; MWCV, mean weighted *c.v.*

East coast South Island winter surveys.

KAH9105, MWCV=16%

Age	Males	*c.v.*	Females	*c.v.*
0	459060	0.56	615818	0.26
1	3812031	0.07	2277542	0.07
2	560923	0.30	585435	0.32
3	9761	14.36	17346	1.68
4	0	–	1404	0.46
Totals	4841775		3497544	

KAH9205, MWCV=23%

Age	Males	*c.v.*	Females	*c.v.*
0	60344	4.11	230446	1.03
1	4605561	0.11	3302084	0.12
2	473285	0.78	555061	0.22
3	52366	2.27	62616	1.30
4	0	–	8309	0.95
Totals	5191555		4158516	

KAH9306, MWCV=26%

Age	Males	*c.v.*	Females	*c.v.*
0	352743	1.10	653867	0.89
1	2346446	0.07	2158043	0.10
2	966067	0.40	963585	0.15
3	42081	1.25	86896	0.35
4	0	–	0	–
Totals	3707337		3862391	

KAH9406, MWCV=14%

Age	Males	*c.v.*	Females	*c.v.*
0	506812	0.26	679996	1.26
1	5798291	0.04	5134813	0.06
2	644886	0.27	362323	0.34
3	1031	32.74	19939	1.80
4	0	–	0	–
Totals	6951020		6197070	

Appendix 7– ***continued***

KAH9606, MWCV=13%

Age	Males	*c.v.*	Females	*c.v.*
0	160725	0.35	268760	0.20
1	1158024	0.07	1138494	0.08
2	844513	0.13	1077548	0.14
3	86122	0.67	62020	0.57
4	0	–	3845	0.90
Totals	2249384		2550667	

East coast South Island summer surveys.

KAH9618, MWCV=12%

Age	Males	*c.v.*	Females	*c.v.*
0	5302351	0.08	5293558	0.08
1	8874009	0.06	7567307	0.07
2	2693099	0.23	3564591	0.12
3	362533	1.07	810132	0.80
4	0	–	32946	1.24
Totals	17231992		17268533	

KAH9704, MWCV=15%

Age	Males	*c.v.*	Females	*c.v.*
0	1450246	0.51	640090	0.37
1	9949776	0.09	8507897	0.06
2	3214015	0.23	2797580	0.22
3	65703	0.70	168798	0.74
4	0	–	4405	2.08
Totals	14679740		12118768	

KAH9809, MWCV=8%

Age	Males	*c.v.*	Females	*c.v.*
0	1237350	0.21	1041665	0.13
1	7187135	0.06	5733486	0.06
2	5096204	0.05	5719133	0.06
3	117730	0.49	655387	0.49
4	13368	0.98	6936	1.20
5	3882	2.42	0	–
Totals	13655668		13156605	

Appendix 8: Numbers at age for west coast South Island trawl surveys from Mix analysis

	Males			Females		
Survey	0+	1+	2 & older	0+	1+	2 & older
KAH9204	36790	2158477	581303	121564	1753885	495146
KAH9404	4571	1156599	1948552	12641	464862	1381425
KAH9504	168007	1398457	1430979	199065	1146569	661068
KAH9701	198942	2536925	837720	197730	1873662	695223

Appendix 9: Estimated catch at age (numbers) for red cod catch sampling for years 1990–93, January to June. *c.v.*, coefficient of variation; MWCV, mean weighted *c.v.*

1990, MWCV=5.1%

Age	Males	*c.v.*	Females	*c.v.*
1	39035	0.277	41414	0.140
2	790355	0.036	1018710	0.029
3	170336	0.119	259355	0.087
4	0	–	2155	0.596
Totals	999725		1321635	

1991, MWCV=8.0%

Age	Males	*c.v.*	Females	*c.v.*
1	38374	0.225	28801	0.327
2	634593	0.053	747907	0.050
3	231592	0.142	281562	0.108
4	416	3.152	9016	0.525
Totals	904975		1067286	

1992, MWCV=4.8%

Age	Males	*c.v.*	Females	*c.v.*
1	263039	0.091	355745	0.072
2	1136182	0.032	1007710	0.029
3	55625	0.227	113974	0.107
4	0	–	4233	0.438
Totals	1454845		1481662	

1993, MWCV=6.5%

Age	Males	*c.v.*	Females	*c.v.*
1	426059	0.158	742397	0.092
2	1731991	0.048	2036546	0.039
3	63987	0.225	158006	0.120
4	0	–	2260	1.310
Totals	2222036		2939209	

Appendix 10: Commercial landings of red cod in RCO 3 and RCO 7 and predicted catch from environmental-recruitment relationship. For RCO 3 the predictors SST and Trough NW cluster, with a 14 month lag, explained 68% of variability in commercial catch. For RCO 7 the predictors SST and surface westerly wind, with a 14 month lag, explained 75% of variability in commercial catch

	RCO 3		RCO 7	
Fishing year	Catch (t)	Predicted catch (t)	Catch (t)	Predicted catch (t)
1970–71	1815	4224	534	1207
1971–72	1890	2369	548	868
1972–73	2567	2000	755	1056
1973–74	3553	4186	1043	933
1974–75	2508	4038	711	880
1975–76	3854	3789	1142	915
1976–77	9619	7355	2869	1830
1977–78	7610	8815	2779	3030
1978–79	5987	6690	1698	2495
1979–80	5637	4742	1637	2011
1980–81	3219	4857	696	1526
1981–82	3854	3495	1220	864
1982–83	6305	4209	1514	1842
1983–84	9357	10589	3051	2481
1984–85	14751	9009	1442	2220
1985–86	9346	8359	408	847
1986–87	3300	5202	619	35
1987–88	2878	3387	1605	1278
1988–89	7732	6614	1345	2034
1989–90	6589	7907	800	821
1990–91	4630	5636	839	367
1991–92	6500	8827	2220	2080
1992–93	9633	9336	4083	3252
1993–94	7977	11128	2992	3476
1994–95	12603	11944	3569	3493
1995–96	11038	10454	3728	3525
1996–97	10042	10168	3694	2365
1997–98	9954	5420	2621	2428