New Zealand Fisheries Assessment Research Document 92/16

Assessment of red cod based on recent trawl survey and catch sampling data

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September 1992

MAF Fisheries, N.Z. Ministry of Agriculture and Fisheries
This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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1. INTRODUCTION

1.1 Overview

Commercial catches of red cod (*Pseudophycis bacchus*) have historically been highly variable and unpredictable both within and between seasons. Until recently research on this species by MAF Fisheries had assumed a low priority and research on associated species had not provided reliable estimates of biomass or population dynamics. The original TACC of 15 290 t for all Fishstocks 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. 1984 however, proved to be an exceptional year in the red cod fishery and all subsequent catches have been substantially less than for the 1984 year. It was recognised that if yield estimates are to be provided there was a need for a research programme directed at investigating the reasons for the large yearly fluctuations in red cod landings. As a first step it was necessary to collect data on relative abundance, age and growth, mortality, reproduction, feeding habits, and the age structure of the commercial catch.

This is the second FARD on red cod. The first was produced in 1988 (MacDiarmid 1988) and essentially reviewed the history and then current state of the fishery; there was no research programme on red cod at that time. This document provides an update of the 1988 FARD and presents results of the red cod catch sampling programme and multi-species trawl surveys carried out on the southeast coast of the South Island in 1990 and 1991. The document provides recent data and analyses on ageing, growth, age and size composition of the commercial fishery, catch curve analysis, CPUE, relative abundance, length weight regression coefficients, yield per recruit, and mortality. There is little information available on the population dynamics of red cod and while more detailed analyses are necessary the document at least provides a starting point for considering management options for this species.

1.2 Summary of literature

Early accounts of red cod biology are largely anecdotal but do provide some points for comparison (Graeme 1939, 1954, Thomson 1892, 1913).

The PhD thesis of Habib (1975) provides the only study on the biology of New Zealand red cod. Habib addressed several aspects of the biology of red cod including taxonomy, feeding, reproductive biology, and growth. Red cod were found to reach maturity at around 50 cm (Habib 1975). 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.

Growth of the Australian rock cod, *Pseudophycis barbatus*, has been studied and provides the only other ageing study on a species belonging to the same family as red cod (Walker 1972).

2. REVIEW OF THE FISHERY

2.1 General

Red cod have been commercially fished since the early part of the 1900s but a stable market only developed in the late 1960s when red cod became a major target species. Before this time red cod was caught only as by-catch of fishing for more valuable species, and much of the red cod catch was dumped (Fenaughty & Bagley 1981). Dumping and under-reporting by Russian vessels was known to occur until the late 1970s. In 1990 red cod had an estimated primary value of $4.69 million for the year and ranked twelfth in value out of 36 commercial finfish species. In Timaru and Lyttelton red cod is now one of the major contributors to the total wet fish landings from these ports.

Landings fluctuate widely from year to year (Table 1, Figure 1) (i.e., five fold in the Canterbury Bight between 1983 and 1987) and it has generally been considered that these fluctuations are not due to availability since when domestic catches are low there is no corresponding increase in landings by deepwater fisheries (MacDiarmid 1988). The fluctuations are therefore thought to represent actual variation in yearly biomass as a result of high mortality, fast growth, and variable recruitment. Historical records and literature on red cod indicate that the average size of this species was considerably larger than is now caught (Thomson 1892, 1913). This would indicate that red cod may have been 'fished down' with few fish currently attaining the historical lengths and ages.

2.2 Landings

Red cod are currently targeted primarily by domestic trawlers, but are also a by-catch of deepwater fisheries off the southeast and southwest coasts of the South Island. All targeting of red cod is by bottom trawl although by-catch by other methods may occur.

In the early 1970s most red cod was landed by Japanese foreign licensed vessels with only small landings by New Zealand domestic vessels (Table 1). Korean and Russian vessels may have landed greater quantities than are shown in Table 1 as they did not record catches by species at this time. Total annual landings increased in successive years during this period and the foreign licensed vessels from Japan, Korea, and the then Soviet Union continued to dominate the red cod fishery.

In the 1978–79 season, with the introduction of the EEZ, domestic landings exceeded those by foreign vessels and chartered vessels were introduced to fish on behalf of New Zealand companies. Subsequently the proportion of the total landings by foreign licensed vessels continued to decline as New Zealand domestic and chartered vessels became more prominent in the red cod and other inshore fisheries (Figure 1).

With the introduction of the QMS in 1986 landings of red cod by foreign licensed vessels declined substantially and in the 1990–91 fishing year were negligible. The fishery is now dominated by the domestic fleet and to a lesser extent by New Zealand chartered vessels. In RCO 3, the major red cod area in New Zealand, 70–80% of the catch is landed by 12 domestic trawlers ranging from 18 to 20 m in length.

The major red cod grounds for domestic vessels are found around Banks Peninsula and Timaru (Fisheries Statistical Areas 020, 021, 022, and 023) and to a lesser extent off northern Westland and Buller (Fisheries Statistical Areas 034 and 035) (Figure 2, Appendix A). Largest catches of red cod by foreign licensed and New Zealand chartered vessels are from QMAs 3, 5, and 6 (Figure 3, Appendix B and C).

2.3 Seasonality

The domestic red cod fishery is seasonal, usually beginning in November and running through to May or June with peak catches from the Canterbury Bight region (statistical areas 022 and 023) around January and May (Figure 2). The fishery usually begins in the north of both the east and west coasts of the South Island and moves southward as the season progresses. Red cod are found most commonly at a depth of about 100 m, but are caught anywhere from 30 to 200 m and have been reported at depths of 750 m.

Primarily a bottom dwelling species, red cod may move vertically in the water column in response to movement of prey such as *Munida gregaria* (galatheid crab). 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 are often coincident with shoals of post larval pelagic *Munida gregaria* (*see* Zeldis (1985) for distribution patterns of *Munida gregaria*). At other times red cod disperse and target fishing becomes uneconomic. Landings outside the December to June period are usually non-targeted catch and may form a component of a mixed species trawl fishery.

Landings by deepwater vessels do not exhibit any clear seasonal pattern with catches spread throughout the year (Figure 3).

2.4 Distribution of catches in the Canterbury Bight

The catch rates of red cod by six domestic vessels filling out deepwater returns for the years 1983 to 1986 in RCO 3, are shown in Figure 4. There appear to be two major red cod grounds on this coast. The data indicate that red cod aggregate in the same general areas each year off Timaru and Banks Peninsula.

Records from the *W.J. Scott* surveys in the late 1970s (Fenaughty & Bagley 1981) indicate that red cod distribution changes with seasons: between June and September red cod were found in deeper water on the shelf slope.

2.5 Recreational, traditional and Maori fisheries

Maori and recreational fishers take red cod, particularly on the east coast of the South Island. Results from the 1987 National Marine Recreational Fishing Survey together with the 1990 South Recreational Survey indicate that red cod is the third most commonly caught recreational fish in the southern region. Consequently recreational catches may have more of an impact on the red cod fishery than was previously thought.

2.6 TACC

Red cod was introduced into the Quota Management System (QMS) in 1986. TACs were based on the landings of the catch history years 1983 to 1985. These years proved to be exceptionally good seasons for red cod and as a result the TAC was set at a level that far exceeds average annual landings. The net effect is that while the fishery may fluctuate up to five fold yearly, the TAC does not limit effort in this fishery. The TACC in RCO 3 was reduced in the 1989–90 fishing year by retiring crown held quota (921.2 t). Quota appeals however increased the TACC by 994.2 t off-setting the TACC reduction (Annala 1991).

2.7 CPUE analysis

Catch and effort generally track each other for vessels targeting red cod in RCO 3 (Figure 5). There has been no decline in catch per unit effort (CPUE) during years of high effort. CPUE peaked in 1983–84, although landings did not reflect this trend. During 1984–85 effort trebled and the highest ever red cod landings were recorded. This increased effort in 1984–85 may have been due in part to the high CPUE in the previous season and in anticipation of the introduction of the QMS in 1986.

The positive relationship between effort and CPUE is understandable when considered in the context of the fluctuating nature of this fishery. In a poor season, or period within a season, as catch rates decline so does effort. This is related to economic factors since red cod is a low value species and targeting becomes uneconomic when the species is not caught with minimum searching and in large quantities. Target fishing in RCO 3 is generally confined to the proven red cod grounds around Banks Peninsula and Timaru.

3. RESEARCH

3.1 Stock structure

There is no information on stock boundaries of red cod. When red cod were introduced into the QMS four Fishstocks were designated: RCO 1 – Auckland East and West, RCO 2 – 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.

3.2 Resource surveys

3.2.1 Trawl surveys 1990 (KAH9008) and 1991 (KAH9105)

Two phase random stratified trawl surveys were conducted in May 1990 and 1991 along the southeast coast of the South Island from Moeraki to Kaikoura in the depth range of 30–400 m. Sampling involved the recording of red cod weight (all red cod per tow and individual fish weights for sub-samples), length, sex, stomach contents, gonad stage, and the removal of otoliths for ageing studies. Data collected during these and future surveys will provide a time series which may be used to monitor the state of the red cod and other commercially important finfish species in this region. A cod-end mesh size of 60 mm was used allowing juvenile red cod to be retained in the net. The trawl surveys provide length frequency and age data on small red cod that are absent from the catch sampling programme as well as a relative biomass index. Few small red cod have been recorded from the catch sampling programme since the commercial cod end size is 100 mm and also because processing requirements discourage fishers from landing fish under 40 cm in length.

3.2.2 Other resource surveys

1 Hurst, R. (cruise leader, 1980–82). Series of *James Cook* trawl surveys in the Canterbury Bight targeting barracouta. Red cod caught as by-catch were measured but not sexed. Trip Codes – JCO8016, JCO8018, JCO8103, JCO8108, JCO8114, JCO8202, JCO8207, JCO8216, JCO8220.

2. Francis, M. (cruise leader, 1982–84). Series of *Kaharoa* trawl surveys from Golden Bay to Pegasus Bay targeting rig. Red cod caught as by-catch were measured but not sexed. Trip Codes – KAH8205, KAH8211, KAH8216(I), KAH8306, KAH8313, KAH8302, JCO8314, JCO8402.

3.* Fenaughty, J. and Bagley, N.W. 1981. *W.J. Scott* Canterbury Bight trawl surveys. Red cod were measured but not sexed.

4.* Hurst, R.J. Bagley, N.W. and Uozumi, Y. 1990. Trawl survey in Southern New Zealand. Red cod were measured but not sexed.

* see references

3.3 Southeast catch sampling programme

A catch sampling programme on the southeast coast of the South Island, was initiated in the 1989–90 red cod season. Sampling involves the recording of length, sex, stomach contents, gonad stage and the removal of otoliths for ageing. In 1989–90 and 1990–91, 124 and 55 samples (n = 200 fish per sample) respectively, were taken from commercial catches landed into Timaru, Lyttelton, and Kaikoura. A poor red cod season in 1990–91 saw fewer landings and consequently a reduction in the number of samples compared to 1989–90.

Sampling in the 1989–90 year was confined to Lyttelton and Timaru. Comparison of landings showed no differences in average length or length at age. The data were therefore stratified by time and not area.

In the 1990–91 season sampling also encompassed the Kaikoura area. Comparison of average landed length and length at age between the Kaikoura, Lyttelton, and Timaru samples indicated that Kaikoura red cod were generally smaller with slower growth than those fish from the south. Consequently samples in the 1990–91 season were stratified by area and by time. Area stratification was broken into two strata, 'Kaikoura' and 'South', the latter including samples from Lyttelton and Timaru.

3.4 Ageing

3.4.1 Ageing technique

Red cod otoliths are broken mid length exposing the nucleus, then moulded in PS404 epoxy resin, with the broken surface down. A mould with 20 otoliths is then polished using several grades of sandpaper or sharpening stones. A final polish with 'Brasso' or a similar polishing product produces a smooth clean unmarked surface. The block is then baked in an oven at 250 °C for 10 to 15 minutes. The otoliths are read under a binocular microscope using reflected light. Best results are achieved using a directed light source at an angle of about 35–45° above the plane of the flat otolith surface. Covering the surface of the otolith with water before reading cleans the surface and heightens contrast between light and dark rings, making the otolith easier to read and interpret.

3.4.2 Growth characteristics

von Bertalanffy growth parameters were determined by counting growth rings of the otoliths collected during the 1990 and 1991 trawl surveys (Saila *et al.* 1988 – FSAS Fishparm Programme). Fish representative of all sizes and ages were sampled in these surveys. The data collected from the catch sampling programme does not provide a sufficient size range to estimate growth parameters since small fish (<45 cm) are seldom landed. von Bertalanffy growth curves and mean length at age are shown in Figure 6.

The von Bertalanffy growth parameters are:

	males	**females**
L_{inf}	61.5	65.9
K	0.429	0.418
t_o	-0.456	-0.266

The von Bertalanffy growth curves indicate that female red cod have a larger L_{inf} than males. Red cod longer than 60 cm are predominantly female fish. Growth is initially rapid, growing up to 27 cm in the first year followed by annual increments of around 15 cm, 10 cm and 5 cm, depending on sex, spawning time and environmental conditions. The maximum age for red cod, based on growth ring counts, appears to be around 6 or 7 years. Growth rings become difficult to read after 3 or 4 years and thus the maximum ages may be underestimated by this technique. Walker (1972) found that the Australian rock cod, *Physiculus barbatus*, also a gadid, lived to about 6 or 7 years with one or two fish being as old as 11 years.

3.4.3 Validation of ageing

One method of validating ring counts, and thus the von Bertalanffy growth parameters, is by tracking a dominant year class through the fishery in successive years. It has not been possible to apply this technique to red cod since natural mortality is very high, red cod is short lived, and no dominant year classes have yet been identified. Generally it is possible to clearly identify only the 0+, 1+ and 2+ classes as modal peaks of older fish merge together and are difficult to interpret. Discrimination of the year classes becomes more difficult with age so validation is based primarily on young cohorts.

Length frequency data collected on the trawl surveys in 1990 and 1991 provide some validation of the growth parameters and thus the ageing accuracy (Figures 7 and 8). In 1991 there were two obvious peaks corresponding to the 0+ and 1+ year classes at lengths that would be predicted by the age/length growth curves derived from otolith ageing. The data from the 1990 trawl survey demonstrates the 1+ but not the 0+ year class.

The 0+, 1+, and occasionally 2+ year classes were also apparent in other surveys where length frequency data for red cod has been collected (Habib 1975, Hurst – barracouta trawl surveys 1980–82, Francis – rig surveys 1982–84). Red cod from these earlier resource surveys were not sexed and since growth rates of sexes are different only the first few years data are meaningful. A single modal peak at about 52 cm was observed in the Southland trawl survey in 1986 (Hurst *et al.* 1990). This would represent a population based around the 3+ and 4+ cohorts (assuming similar growth rates for these southern fish) and in this respect is no different from the Canterbury Bight population structure.

Modal progression analysis has also proved difficult except for the first 2 years. Length frequency data from the rig and barracouta surveys in the early 1980s does however provide validation that support the assumed growth rates and thus the aging (Figure 9). On these surveys length frequency data were collected over a series of months. The modal peaks have been plotted against time and this approximates the growth curve of 0+ and 1+ fish for that period.

Measurements of weight, length, and width have been recorded on the 1991 trawl survey otoliths as a means of validating the ring counts. Otolith growth is generally considered to continue even when adult size has been reached. Consequently, if older cohorts exist, it was hoped to reveal otolith weight classes corresponding to these cohorts. The preliminary results from this work reveal that the modal peaks observed in the length frequency data are mirrored in the otolith weights. There were however, no distinct modal peaks found that were not apparent in the length frequency data.

3.5 Length frequency data

3.5.1 Trawl surveys (KAH9008, KAH9105)

A strong 1+ cohort and with a modal peak of about 36 cm for both sexes was observed in the 1990 length frequency histograms (Figure 7). There was also a strong modal peak at about 52 cm and 55 cm for males and females, respectively. The second modal peak is composed of a range of year classes from 3+ to 6+ and possibly older. The 2+ cohort was not a strong year class but can be observed between the 1+ and 3+ to 6+ peak at about 46 cm for males and 49 cm for females.

A very strong 1+ cohort with a modal peak of about 36 cm and the 0+ cohorts represented by a smaller peak at around 20 cm for both sexes was observed in the 1991 length frequency histograms (Figure 8). The relative strength of the 0+ cohort cannot be gauged from this data since little is known about the distribution of juvenile red cod. There are also smaller modal peaks at 45 & 49 cm, 49 & 51 cm, 53 & 59 cm (male and female length respectively) that may represent the 2+, 3+ and 4+ cohorts. These data are consistent with the von Bertalanffy growth parameters indicating that after the first year females grow faster than males

Length frequency data from the trawl surveys (KAH9008 and KAH9105) indicate that within one year the age composition of the fishery has changed substantially. In 1990 the 1+ cohort appeared in similar numbers to the older years classes while in 1991 the 1+ cohort was the dominant year class. Comparison of this cohort between years shows that in 1991 the 1+ cohort was 10 times as large as that in 1990 while older cohorts were relatively similar in abundance between years. This provides evidence for good recruitment in the spring of 1990. The change in length frequency and age structure of the fishery within a single year is characteristic of a fast growing short-lived species.

These data suggest that commercial catches in 1991–92 would be predominantly 2+ fish. Preliminary catch sampling results from the 1991–92 season support this hypothesis with approximately 90% of all fish landed being in the size range 40–50 cm, lengths corresponding to the 2+ cohorts.

3.5.2 Catch sampling

1989–90 season: The growth of a cohort during the season was difficult to track by examining the monthly length frequency histograms (Figure 10). The large single mode shown in the histograms consists of several cohorts, and thus the peak may shift to the left or right depending on which cohort is being landed in the largest quantities. This may be due to fishing on different schools comprising fish of different ages (see section 3.8 – schooling behaviour). If the age composition is examined by month, the 3+ are the dominant cohort in both February and June. The modal peaks of females are predominantly larger than males, confirming that females grow faster than males.

1990–91 season: Again, the growth of a single cohort through the season could not be followed using modal progression. The length frequency data from the 'South Stratum' indicate that fish were of similar size to 1989–90 with different cohorts prevailing in different months (Figure 11). The size distribution pattern of males and females was similar to 1989–90 with the female modal peaks larger than male peaks.

Similar conclusions can be drawn for the 'Kaikoura stratum' (Figure 12).

3.6 Size and age composition of the commercial fishery

3.6.1 Catch sampling (1989–90 fishing season)

Age length keys were estimated for each month and the length frequency data stratified by month and scaled up to the commercial catches. The combined age/length keys and scaled numbers per month were used to determine total numbers at age in the commercial fishery in this season (Figure 13).

The commercial fishery was dominated by only two year classes, the 3 and 4 year olds. These year classes contributed 81% of both sexes caught in this season with the 3 year old fish contributing 50%.

3.6.2 Catch sampling (1990–91 fishing season)

South stratum – A similar age distribution to the previous season was observed (Figure 13). Again the 3 and 4 year old fish were the dominant year classes comprising 83% and 89% of males and females respectively.

Kaikoura stratum – The commercial fishery in the Kaikoura region usually begins earlier than in the south with 3 year olds comprising the majority of the catch. Unlike the south however, 2 year old fish were also a major component of the fishery (Figure 13).

3.7 Sex ratio

Sex ratios varied considerably between samples (Figures 14, 15, and 16), but did indicate that females are more commonly caught earlier in the season than are males. At the beginning of the season the ratio of females:males was over 3:1, declining toward a 1:1 ratio at the end of the season. This was especially evident during the 1990–91 season when sampling began three months earlier than in the 1989–90 season. The sex ratios on both trawl surveys were very close to 1:1 which is the same ratio observed from the catch sampling at this time of year.

3.8 Schooling behaviour

Examination of sex ratios indicates that occasional landings yielded virtually all females and, less frequently, all males (Figures 14, 15 and 16) indicating that sex may be a factor in schooling behaviour. There was a very strong correlation between size of males and females from the same landing indicating that red cod school in cohorts. The average length of females was always larger than males, consistent with the growth differences between sexes.

3.9 Mortality

An estimate of instantaneous total mortality (Z) was obtained from a catch curve analysis of numbers at age. The number of fish at each age was calculated from an age length key scaled up to the commercial catch. A regression equation was fitted to the natural log of total numbers at each age. The slope of this line was taken as the total mortality. Values of Z for the south stratum are given below for the last two seasons. Z was not estimated for Kaikoura since sample size was considered to be inadequate.

	1989–90	1990–91
males	1.56	1.42
females	1.67	1.64

Larger fish are more difficult to age and consequently red cod may live to older ages than those estimated. Total mortality would therefore not be as high as has been calculated.

Natural mortality was estimated using the formula $M = \log_e 100 / A_{max}$ (Sparre *et al.* 1989), where A_{max} is the maximum age to which 1% of the population survives in an unexploited stock. For both sexes $A_{max} = 6$ years, so $M = 0.76$.

3.10 Spawning

Red cod from the Canterbury Bight spawn from August to October with spawning occurring correspondingly later the higher the latitude (Thomson 1892, 1913, Graham 1939, Habib 1975). Spawning period may, however, be more variable since some fish examined in January 1992 appeared to be in the ripe pre-spawning condition. If the timing of the spawning does vary between seasons then year class sizes will be more difficult to track. Spawning aggregations or grounds have not been located but are believed to be in deeper water. Similarly, there are no known red cod nursery grounds although juveniles have been caught in deep water after the spawning period. Plankton studies have failed to find red cod eggs or larvae over the continental shelf and it is likely that these stages exist in deeper waters.

3.11 Recruitment

The results from this study indicate that recruitment is highly variable. A strong year class such as the 1+ cohort observed on the 1991 trawl survey is expected to have a major impact on the fishery over the next few years. Years of exceptionally good catches such as in 1984–85 are probably due to several consecutive years of good spawning and/or recruitment.

Habib (1975) estimated that red cod first spawn at a size of around 50 cm. This size would equate to an age of three years. If this is correct, then a considerable proportion of the red cod catch would be caught before it had spawned. Age at maturity has not been determined from this study since neither the trawl surveys nor the catch sampling overlap with the spawning period of October.

3.12 Feeding

Analysis of red cod stomach contents from the 1990 and 1991 trawl surveys showed that *Munida* was the most common food item, accounting for an average 55% of stomach contents by volume. Fish and crustacea were two other common food items represented at 17% and 12% by volume, respectively. Stomachs were found to contain greater volumes of food in the freshest state before midday. This indicates that feeding occurs predominantly in the early morning period.

3.13 Biomass estimates

Relative biomass has been estimated for the southeast coast from the 1990 and 1991 trawl surveys (Empress 'Trawlsurvey Programme').

	1990	CV	1991	CV
Biomass Estimate (tonnes)	1940	22%	4147	33%

The 1990 trawl survey was a pilot programme aimed at assessing the feasibility of surveying red cod. In 1991 a new, purpose designed and built net was employed resulting in more efficient gear deployment. The time series of these southeast trawl surveys will therefore be taken from 1991 and in future the same net and gear specifications will be used on all inshore trawl surveys in this area.

3.14 Length weight relationship

From data collected on the 1990 and 1991 trawl surveys the following length weight relationships for red cod were determined from $W = aL^b$ (where W = weight (g), L = total length (cm).

	a	b
males	0.014495	2.892
females	0.007453	3.059
combined	0.009249	3.001

3.15 Yield per recruit

The sensitivity of yield per recruit to different levels of natural mortality (M) between 0.3 and 0.6 was examined. This range is less than the value of 0.76 obtained from the catch curve analysis. However, this is a reasonable assumption given that the population is heavily exploited to the point that older age classes may not be present, older fish are more difficult to age and may be underestimated (ring counts up to 9 were recorded in a few fish), and Z is likely to be variable and highly dependent on the strength of individual year classes. A baseline estimate of M of 0.4 has been used for the yield per recruit analyses.

The sensitivity of $F_{0.1}$ to varying levels of M was examined under constant recruitment (steepness = 1) assumptions. At M = 0.4, $F_{0.1}$ was 0.47 with an equilibrium stock size occurring at 33.9% B_0 (Table 2). The recruitment ogive assumes 5% recruit at age 1, 50% at age 2 , 95% at age 3 and 100% at age 4 and over for both sexes.

Because recruitment in red cod is considered to be variable, a Beverton Holt stock recruitment relationship was incorporated into the analysis. Steepness values of 0.75 and 0.95 were tested against the baseline M of 0.4. (Table 2). Using a value of 0.75, now considered to be the default value for steepness (Francis 1992), the equilibrium stock size at $F_{0.1}$ occurs at 26.8% B_0. The relationship of yield per recruit and equilibrium biomass against fishing mortality is shown in Figure 17.

4. MANAGEMENT IMPLICATIONS

Fluctuations in annual landings of red cod are apparently due to fast growth, short lifespan and few year classes comprising the fishery, compounded by variable recruitment. The high variability in annual catches appears to be related to abundance rather than availability. The current TACC was set on catches of several exceptionally good years providing fishers with the flexibility to capitalise on years of high abundance. There has not been a season comparable to the that of 1984–85 and the TACC has consequently never been a constraining factor.

Catches are usually close to MCY estimates (Annala 1991) and current catch levels appear to be sustainable. The high M value combined with fast growth would indicate that a high fishing mortality could be applied. CAY estimates are not yet available for red cod since trawl survey estimates of biomass are only relative indices and have yet to be related to virgin biomass. A stock reduction analysis based on the method of Francis (1990) could be carried out to calculate biomass and CAY. This method is highly dependent on accurate age estimates since it utilises growth, mortality, and recruitment parameters.

Future management could be based on a CAY harvesting strategy in which biomass and yields are predicted for the following year. Because recruitment appears highly variable, annual trawl surveys could be used to estimate pre-recruit abundance. The on-going catch sampling programme should provide data on which to calculate fishing mortality and biomass using the VPA technique.

5. ACKNOWLEDGMENTS

The following packing houses are acknowledged for their cooperation and assistance in allowing MAF Fisheries South to catch sample landings of red cod: Sanford South Island Ltd, Timaru; Deepcove Fisheries Ltd, Timaru; Independent Fisheries Ltd, Christchurch; United Fisheries Ltd, Christchurch; Virgo (Pacific) Fishing Co., Kaikoura. Thanks also to the commercial fishers for providing details of landings.

Thanks to MAF Fisheries South staff for general input, assistance, and encouragement.

I thank the following for their input into this study: Graeme McGregor for valuable discussions, assistance, and management of the catch sampling programme; Kevin Sullivan for advice and assistance in computing and analysis; Mike Coakley for persevering with the catch sampling programme for the last three seasons and providing data of a consistently high standard.

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Table 1. Reported annual catch (tonnes) of red cod, by nation from 1970 to 1990/91.

	New Zealand		Foreign Licensed				
Fishing Year	**Domestic**	**Chartered**	**Japan**	**Korea**	**USSR**	**Total**	**TOTAL**
1970	760		995			995	1 755
1971	393		2 140			2 140	2 533
1972	301		2 082		<100	2 182	2 483
1973	736		2 747		<100	2 847	3 583
1974	1 876		2 950		<100	3 050	4 926
1975	721		2 131		<100	2 231	2 952
1976	948		4 001		600	4 601	5 549
1977	2 690		8 001	<1 358*	2 200	<11 559	14 249
1978/79	5 343	124	2 560	151	51	2 762	8 229
1979/80	5 638	883	537	259	116	912	7 433
1981/82	3 210	387	474	70	102	646	4 243
1982/83	4 342	406	764	675	52	1 493	6 241
1983-83	3 751	390	149	401	3	553	4 694
1983/84	10 189	1 764	1 364	480	49	1 893	13 846
1984/85	14 097	2 381	978	829	7	1 814	18 292
1985/86	9 035	1 014	739	147	5	891	10 940
1986/87	2 620	1 089	197	4	59	261	3 969
1987/88	3 637	894	17	26	4	47	4 577
1988/89	6 323	2 939	23	6		29	9 291
1989/90	5 799	1 695	7			8	7 502
1990/91	4 503	1 063	1			1	5 567

1970 - 1977 = calender years
1978/79 - 1982/83 = 1 April - 31 March
1980/81 - no fishing returns processed this year
1983/83 = 1 April - 30 September
1983/84 - 90/91 = 1 October - 30 September
* Principally ribaldo and red cod
86/87 to 90/91 = QMS data
1970-1977 = FSU data

Table 2. Yield per recruit for red cod based on the parameters shown below under a range of M where recruitment is assumed to be constant, and when M=0.4 and the stock recruitment relationship (SRR) steepness is varied.

Recruitment constant, SRR steepness = 1

M	$F_{0.1}$	YPR	Yield (% biomass)	Equilibrium Biomass ($\%B_o$)
0.3	0.35	410	12.5	34.9
0.4	0.47	320	16.6	33.9
0.5	0.61	259	21.0	32.5
0.5	0.76	214	25.8	31.7

SRR Steepness = 0.95

M	$F_{0.1}$	YPR	Yield (% biomass)	Equilibrium Biomass ($\%B_o$)
0.4	0.47	320	16.1	32.8

SRR Steepness = 0.75

M	$F_{0.1}$	YPR	Yield (% biomass)	Equilibrium Biomass ($\%B_o$)
0.4	0.47	320	13.1	26.8

Input Parameters

	males	females
L_{inf}	61.5	65.9
K	0.429	0.418
T_o	-0.456	-0.266
a	0.014495	0.007453
b	2.892	3.059

Appendix A.

Catch(t) of red cod by the domestic fleet (deepwater and inshore) by area and month from 1983/84 to 1990/91 (49-52 no significant catch)

Domestic Fishing Areas

	1-15	18-19	20-21	22-23	24	25-30	31-33	34	35	16-17 & 36-48	Undefined	Total	%
1983/84													
Oct	6	50	33	6	0	11	9	68	12	16	31	242	2.4
Nov	13	56	34	22	0	7	9	49	10	13	17	230	2.3
Dec	10	26	112	159	1	11	7	55	8	8	51	448	4.4
Jan	10	40	198	551	1	12	15	59	91	11	87	1075	10.6
Feb	4	24	257	646	5	28	21	72	124	20	274	1475	14.5
Mar	6	28	134	816	4	44	58	157	36	25	124	1432	14.1
Apr	12	24	198	457	8	23	18	94	57	77	173	1141	11.2
May	9	18	129	412	11	38	9	99	55	454	166	1400	13.8
Jun	8	15	97	741	13	49	6	120	70	205	198	1522	15.0
Jul	16	18	28	66	12	8	20	55	71	115	67	476	4.7
Aug	14	11	14	6	2	12	90	196	9	34	11	399	3.9
Sep	10	12	32	7	0	42	30	128	2	26	32	321	3.2
Total	118	322	1266	3889	57	285	292	1152	545	1004	1231	10161	
%	1.2	3.2	12.5	38.3	0.6	2.8	2.9	11.3	5.4	9.9	12.1		

	1-15	18-19	20-21	22-23	24	25-30	31-33	34	35	16-17 & 36-48	Undefined	Total	%
1984/85													
Oct	15	39	50	13	2	35	4	26	15	41	19	259	1.8
Nov	22	98	128	336	3	29	1	39	32	32	45	765	5.4
Dec	3	44	474	271	21	36	1	13	20	31	92	1006	7.1
Jan	7	56	343	643	8	31	0	3	17	19	150	1277	9.1
Feb	5	36	257	469	6	25	2	20	52	18	67	957	6.8
Mar	3	26	425	1035	15	14	4	30	90	90	204	1936	13.7
Apr	1	15	311	1186	6	16	2	54	46	114	241	1992	14.1
May	5	25	145	1735	35	15	5	55	41	104	550	2715	19.3
Jun	5	2	128	1108	56	18	0	84	42	72	275	1790	12.7
Jul	2	1	34	546	4	12	1	17	5	43	176	841	6.0
Aug	6	0	18	4	3	58	10	24	3	57	68	251	1.8
Sep	9	0	21	3	1	140	14	24	0	20	68	300	2.1
Total	83	342	2334	7349	160	429	44	389	363	641	1955	14089	
%	0.6	2.4	16.6	52.2	1.1	3.0	0.3	2.8	2.6	4.5	13.9		

	1-15	18-19	20-21	22-23	24	25-30	31-33	34	35	16-17 & 36-48	Undefined	Total	%
1985/86													
Oct	3	5	43	57	3	17	1	7	0	9	12	157	1.7
Nov	8	21	282	420	6	18	6	8	0	10	34	813	9.0
Dec	4	30	257	390	8	19	0	3	0	7	209	927	10.3
Jan	1	5	463	1274	1	10	5	0	0	16	237	2012	22.3
Feb	1	34	647	718	4	33	5	0	0	23	139	1604	17.8
Mar	2	13	248	385	7	41	1	0	1	6	65	769	8.5
Apr	1	1	153	686	11	40	2	0	1	14	129	1038	11.5
May	1	1	78	454	79	32	0	2	0	14	103	764	8.5
Jun	1	1	39	294	20	8	0	2	0	12	120	497	5.5
Jul	1	1	31	58	18	18	1	3	0	9	49	189	2.1
Aug	1	1	17	43	3	2	23	30	0	11	25	156	1.7
Sep	1	1	46	17	3	7	4	2	0	6	12	99	1.1
Total	25	114	2304	4796	163	245	48	57	2	137	1134	9025	
%	0.3	1.3	25.5	53.1	1.8	2.7	0.5	0.6	0.0	1.5	12.6		

	1-15	18-19	20-21	22-23	24	25-30	31-33	34	35	16-17 & 36-48	Undefined	Total	%
1986/87													
Oct	0.7	1.9	20.5	10.4	3	1.9	0.8	0.4	0	2.1	7	48.7	2.0
Nov	1	1.1	32.1	87.4	11.3	3.3	2.5	4.7	0	1.9	38.1	183.4	7.6
Dec	0.7	1.6	44.8	148.5	5.1	15.1	1.8	14.4	0	1.9	65	298.9	12.4
Jan	1.9	4.7	166.1	327	23.1	5.3	3.8	6.6	0	0.8	63.3	602.6	24.9
Feb	1.4	0.6	67	172.9	3.5	8.9	4.7	0.9	0	7.2	66.7	333.8	13.8
Mar	0.9	0.2	12.6	144.7	5.5	8.1	5.5	16.5	5.6	3.5	34	237.1	9.8
Apr	1.3	0.1	12.4	56.9	9.2	24.3	10.8	6.3	0.8	8.2	42.9	173.2	7.2
May	3.5	0.2	15.5	112.4	21.3	5.5	0.7	5.3	1.1	17.3	46	228.8	9.5
Jun	0.7	0.4	7.8	52.2	4.1	5.8	0.6	6.2	1.5	5.6	37.9	122.8	5.1
Jul	7.8	3.4	11.5	4.2	2.7	4.2	12.1	1.8	1	0.8	12.4	61.9	2.6
Aug	1.1	1.9	20	2.3	0.6	5.2	6.6	39.9	0.8	6.3	9.7	94.4	3.9
Sep	0.2	1.7	7.1	1	0.3	6.4	2.2	7.9	0.2	2.6	0.8	30.4	1.3
Total	21.2	17.8	417.4	1119.9	89.7	94	52.1	110.9	11	58.2	423.8	2416	
%	0.9	0.7	17.3	46.4	3.7	3.9	2.2	4.6	0.5	2.4	17.5		

	1-15	18-19	20-21	22-23	24	25-30	31-33	34	35	16-17 & 36-48	Undefined	Total	%
1987/88													
Oct	0.5	6.7	13.6	10.1	0.4	3.9	2.7	5.4	0	2.9	5.1	51.3	2.0
Nov	1.6	14	13.1	16.5	0.8	2.4	1.9	21.5	14.2	5	4.8	95.8	3.7
Dec	0.9	7	49.7	108.4	14.8	2.5	3.9	32.7	2.3	5.4	23.3	250.9	9.7
Jan	3.2	1.9	111	108.7	51.6	3.1	5.9	9.5	2.5	10.2	41.1	348.7	13.5
Feb	1.1	16.1	35.4	24.9	22.7	1	6.3	17	12.5	7.6	24.4	169	6.5
Mar	1.6	5.8	27.3	63	17.6	1.5	5.2	32	20.3	6	72.2	252.5	9.8
Apr	2.3	2.1	16.8	143.9	5.6	2.2	6.7	56.3	97.5	17.8	52.1	403.3	15.6
May	2	0.5	30.1	113.8	16.2	1.9	10	29.2	41.6	9.3	59.8	314.4	12.2
Jun	1.3	1.4	24.8	86	3.6	0.1	0.9	17.4	8.3	6.7	26.5	177	6.8
Jul	3.6	0.8	14.8	10.4	6	51.6	0.9	8.2	0.9	13.2	12.2	122.6	4.7
Aug	124.4	4.9	5.6	17.3	0.6	53	27.2	11.6	1.4	2.9	7.8	256.7	9.9
Sep	2.5	12.9	12.9	43.3	0.01	11.1	8.3	23.1	0.3	9.4	21.1	144.91	5.6
Total	145	74.1	355.1	746.3	139.91	134.3	79.9	263.9	201.8	96.4	350.4	2587.1	
%	5.6	2.9	13.7	28.8	5.4	5.2	3.1	10.2	7.8	3.7	13.5		

	1-15	18-19	20-21	22-23	24	25-30	31-33	34	35	16-17 & 36-48	Undefined	Total	%
1988/89													
Oct	0.2	17.5	7.9	8.9	0.2	4.9	0.1	0	0	0.5	18.7	58.9	1.1
Nov	0.1	8	19.2	4.2	0	18.8	0	1.7	3.7	0.2	142.6	198.5	3.5
Dec	4.5	17.4	61.4	9	6.9	0.2	0	1.7	0	4.9	245.8	351.8	6.3
Jan	5.8	7.8	58.4	117.7	0	3.7	0	0	0	0.3	719	912.7	16.3
Feb	34.6	4.4	60.2	201.1	3.8	1.3	0.1	0.5	2.2	1.3	488.9	798.4	14.3
Mar	7.6	10.2	54.5	116.8	0.6	4.4	0	1.7	2.2	0.9	227.6	426.5	7.6
Apr	13.6	17.4	110.2	301.8	8.5	6.9	0	1.3	6.1	5.2	557.2	1028.2	18.4
May	17.8	9.4	114.3	446.8	4	1.5	0	6.8	15.9	3.3	350.5	970.3	17.3
Jun	23.7	2	78.2	293.2	9.9	0.3	0	1.9	5.9	1.5	117.5	534.1	9.5
Jul	1.2	0.3	8	44.1	5.1	4.8	0	8.5	13.9	5.1	12.3	103.3	1.8
Aug	1.2	1.1	9.7	10.3	4.5	43.8	7.2	12.6	6.5	12	5.7	114.6	2.0
Sep	3.7	4.2	28.1	30.3	0.7	6.2	1.9	11.5	2.1	4.5	3.8	97	1.7
Total	114	99.7	610.1	1584.2	44.2	96.8	9.3	48.2	58.5	39.7	2889.6	5594.3	
%	2.0	1.8	10.9	28.3	0.8	1.7	0.2	0.9	1.0	0.7	51.7		

	1-15	18-19	20-21	22-23	24	25-30	31-33	34	35	16-17 & 36-48	Undefined	Total	%
1989/90													
Oct	3.7	3.7	43.6	43.9	3.5	13.2	0.8	5.8	1.2	3.8	3.6	126.8	2.7
Nov	18.2	6.7	82.5	247.9	8.7	17.4	2.5	15.3	6	19.5	8	432.7	9.3
Dec	41.9	22.6	99.2	437.3	11.6	7.6	1.5	13.9	7.9	6.7	34.1	684.3	14.6
Jan	32.5	13.9	163.3	246.1	19.9	8.1	1.7	10.6	4.6	12.5	4.5	517.7	11.1
Feb	35.9	4.9	80.4	253.4	15.4	11.3	0.3	4.9	14.9	10.5	0.5	432.4	9.3
Mar	9.9	17.7	192	215.2	21.2	12.1	2.1	19.1	18.4	32.8	4.3	544.8	11.7
Apr	4.9	17.3	152.5	254.6	9.4	9.1	3.2	19.8	5.1	47.8	2.7	526.4	11.3
May	16.4	28.5	197.7	305.9	28.9	12	0.3	1.9	0.3	16.1	4.9	612.9	13.1
Jun	27.6	3	86.1	208.2	91	12.8	5.5	23.8	7	9	0.5	474.5	10.2
Jul	5.7	1.4	7.9	60.2	14.7	18.5	1.8	5.6	2.6	16.2	0.7	135.3	2.9
Aug	7.4	3.1	3.5	11.5	2.4	12.7	23.6	33	1.6	11.6	0.3	110.7	2.4
Sep	1.2	4.9	7.4	4.9	1.1	4.1	24.1	18.1	0.1	6.9	0.3	73.1	1.6
Total	205.3	127.7	1116.1	2289.1	227.8	138.9	67.4	171.8	69.7	193.4	64.4	4671.6	
%	4.4	2.7	23.9	49.0	4.9	3.0	1.4	3.7	1.5	4.1	1.4		

	1-15	18-19	20-21	22-23	24	25-30	31-33	34	35	16-17 & 36-48	Undefined	Total	%
1990/91													
Oct	0.8	6.2	6.7	76.4	1.1	5.1	0.4	6.5	3.9	7.8	1.1	116	3.4
Nov	0.8	16	52.6	218.5	4.9	10.3	1.1	9.9	10.1	9.3	0.7	334.2	9.7
Dec	1.1	37.9	122.8	62	4.9	6.3	0	1.5	0.4	8.7	0.6	246.2	7.1
Jan	0.6	14	210.1	202.3	15.4	6.4	3.4	4.3	0.9	10.2	1.8	469.4	13.6
Feb	1.2	5.9	135.1	381	61.2	4.3	3.6	4	1	20.6	1.8	619.7	18.0
Mar	19.4	1.8	33.1	181.3	47.6	4.3	20.8	9.2	5.1	6.7	0.7	330	9.6
Apr	1.7	6.7	15.4	372.9	54.9	2.9	5.8	11	12.7	9.7	1.9	495.6	14.4
May	11.1	10.9	105.9	175.2	49.8	2.5	3.3	20	7.9	26.9	1.7	415.2	12.0
Jun	1.3	4.1	5.1	48.2	48.4	3.4	9.1	15.9	10.6	8.2	5.3	159.6	4.6
Jul	3.7	10.7	3.8	12.5	7.2	2.9	4.1	20.3	13.1	7.5	2.5	88.3	2.6
Aug	2.8	3.4	0.5	2.3	0.6	8	27.7	4.9	1	5.1	3.5	59.8	1.7
Sep	1.9	3.5	8.7	4.9	1	2.2	42.3	41.2	7.3	2.6	2.3	117.9	3.4
Total	46.4	121.1	699.8	1737.5	297	58.6	121.6	148.7	74	123.3	23.9	3451.9	
%	1.3	3.5	20.3	50.3	8.6	1.7	3.5	4.3	2.1	3.6	0.7		

Appendix B.

Catch (t) of red cod by deepwater (NZ chartered and foreign licensed) vessels by QMA and by month from 1983/84 to 1990/91.

1983/84	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8&9	Unknown	Total	%
Oct	7.7	23.0	371.0	42.0	2.0	1.9	0.0	446.0	0.12
Nov	9.7	3.0	288.0	6.8	0.0	9.5	0.0	317.0	0.09
Dec	11.0	2.0	78.0	85.0	2.0	20.0	0.0	196.0	0.05
Jan	2.1	34.0	70.4	82.0	0.1	22.0	0.0	211.0	0.06
Feb	0.0	366.0	16.4	57.2	0.0	18.0	0.0	458.0	0.12
Mar	0.0	0.4	35.0	205.6	0.0	17.0	0.0	258.0	0.07
Apr	4.9	4.4	305.0	204.9	0.0	1.7	0.0	521.0	0.14
May	0.2	0.3	197.0	258.4	0.0	2.3	0.0	458.0	0.13
Jun	29.4	10.0	62.0	50.0	0.0	6.7	0.0	158.0	0.04
Jul	0.6	40.0	23.7	96.2	0.2	0.0	0.0	161.0	0.04
Aug	12.7	20.0	325.0	40.8	9.3	0.2	0.0	408.0	0.11
Sep	9.7	3.8	21.3	7.8	23.0	1.7	0.0	67.0	0.02
Total	88.0	507.0	1793.0	1137.0	33.0	101.0	0.0	**3659.0**	
%	0.02	0.14	0.49	0.31	0.01	0.03	0.00		

1984/85	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8&9	Unknown	Total	%
Oct	23.8	2.4	74.9	0.5	0.0	2.2	0.0	103.8	0.02
Nov	11.7	11.0	71.0	31.9	0.0	3.1	0.0	128.7	0.03
Dec	0.3	31.0	136.0	181.6	0.0	15.0	0.0	363.9	0.09
Jan	5.6	9.2	189.0	125.0	0.0	23.0	0.0	351.8	0.08
Feb	0.0	4.8	272.0	194.0	0.0	0.0	0.0	470.8	0.11
Mar	2.5	10.0	178.0	83.0	0.0	0.0	0.0	273.5	0.06
Apr	0.0	7.5	208.0	152.7	0.0	1.4	0.0	369.6	0.09
May	0.4	3.8	166.0	91.4	0.0	1.3	0.0	262.9	0.06
Jun	2.0	29.0	283.0	29.6	0.0	1.2	0.0	344.8	0.08
Jul	3.1	22.0	529.0	82.8	0.0	1.5	0.0	638.4	0.15
Aug	65.0	1.9	164.0	8.8	2.2	0.1	0.0	242.0	0.06
Sep	43.0	15.0	566.4	8.7	0.6	0.0	0.0	633.7	0.15
Total	157.4	147.6	2837.3	990.0	2.8	48.8	0.0	**4184.0**	
%	0.04	0.03	0.68	0.24	0.00	0.01	0.00		

1985/86	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8&9	Unknown	Total	%
Oct	20.7	0.3	356.7	2.2	0.0	0.0	0.0	380.1	0.20
Nov	15.5	2.9	73.6	13.6	0.9	0.5	0.0	107.1	0.06
Dec	16.6	16.4	55.5	48.2	0.0	0.2	0.0	137.1	0.07
Jan	47.7	0.6	124.4	45.3	0.0	0.0	0.0	218.1	0.11
Feb	30.2	1.6	114.6	93.5	0.0	0.0	0.0	240.0	0.13
Mar	24.6	8.0	106.4	68.7	0.0	0.0	0.0	207.8	0.11
Apr	23.5	12.9	54.2	53.0	0.0	0.0	0.0	143.7	0.08
May	33.1	29.9	30.4	29.3	1.6	0.7	0.0	125.2	0.07
Jun	2.1	12.1	0.7	3.8	0.0	0.3	0.0	19.3	0.01
Jul	0.0	0.0	2.1	7.9	0.3	0.0	0.0	10.4	0.01
Aug	0.3	0.0	11.8	3.3	116.7	0.0	0.0	132.2	0.07
Sep	34.8	1.0	72.5	11.2	60.0	0.0	0.0	179.7	0.09
Total	249.4	86.2	1003.5	380.4	179.7	1.9	0.0	**1901.2**	
%	0.13	0.04	0.53	0.20	0.09	0.00	0.00		

1986/87	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8&9	Unknown	Total	%
Oct	26.3	15.9	127.3	11.1	0.0	0.0	0.0	180.7	0.17
Nov	16.2	0.4	31.5	0.5	1.0	4.5	0.0	54.2	0.05
Dec	14.1	3.0	22.0	15.3	0.0	0.4	0.0	55.0	0.05
Jan	3.3	7.7	8.3	34.4	0.2	0.1	0.0	54.1	0.05
Feb	0.5	0.0	40.2	43.1	0.0	0.0	0.0	83.8	0.08
Mar	4.4	2.7	10.7	99.1	0.3	0.0	0.0	117.4	0.11
Apr	57.3	3.4	29.2	105.2	4.5	1.8	0.0	201.5	0.19
May	51.9	3.2	3.3	50.9	0.7	0.7	0.0	110.9	0.10
Jun	19.9	1.6	5.7	0.0	0.1	0.1	0.0	27.6	0.03
Jul	0.0	0.3	0.0	0.0	0.7	0.2	0.0	1.2	0.00
Aug	0.0	0.0	5.4	1.3	2.4	0.0	0.0	9.2	0.01
Sep	346.0	1.7	99.6	9.6	29.1	0.0	0.0	174.9	0.16
Total	228.8	40.2	383.7	370.7	39.1	8.0	0.0	**1070.8**	
%	0.21	0.04	0.36	0.35	0.04	0.01	0.00		

1987/88	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8&9	Unknown	Total	%
Oct	15.4	1.9	38.3	12.0	0.1	0.1	0.0	68.0	0.07
Nov	39.2	2.6	37.0	2.1	0.7	0.1	0.0	81.7	0.09
Dec	44.3	4.1	34.2	0.8	0.8	1.6	0.0	86.0	0.09
Jan	155.8	5.0	109.3	0.8	1.0	3.6	0.0	275.8	0.29
Feb	8.4	1.5	9.6	0.1	0.0	0.2	0.0	20.0	0.02
Mar	26.8	0.0	1.7	31.2	0.2	0.6	0.0	60.8	0.06
Apr	12.4	7.0	2.6	20.5	4.1	1.4	0.0	48.3	0.05
May	48.6	4.1	4.0	0.2	27.9	18.6	0.0	103.6	0.11
Jun	34.2	9.1	0.7	0.0	29.0	49.4	0.0	122.6	0.13
Jul	0.0	0.0	0.0	0.0	1.1	1.0	0.0	2.1	0.00
Aug	0.0	0.0	1.6	0.7	22.3	0.0	0.0	24.7	0.03
Sep	6.7	1.1	25.2	1.1	29.6	0.0	0.0	63.9	0.07
Total	392.5	36.8	264.7	69.9	117.4	76.8	0.0	**958.3**	
%	0.41	0.04	0.28	0.07	0.12	0.08	0.00		

1988/89	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8&9	Unknown	Total	%
Oct	40.9	8.5	10.0	0.3	3.1	0.2	0.0	63.0	0.09
Nov	15.7	3.5	19.7	0.1	0.2	0.8	0.0	40.0	0.06
Dec	1.7	0.0	36.7	0.0	0.9	1.2	0.0	40.5	0.06
Jan	2.3	0.0	23.2	5.4	1.9	2.9	0.0	35.7	0.05
Feb	2.7	0.0	6.1	6.9	2.3	0.0	0.0	18.0	0.03
Mar	0.0	0.0	3.8	54.9	0.1	0.1	0.0	58.9	0.08
Apr	1.2	0.6	8.0	57.6	0.8	0.3	0.0	68.5	0.10
May	19.5	0.1	14.9	6.6	4.7	1.4	0.0	47.2	0.07
Jun	59.5	5.1	8.1	0.8	10.2	13.4	0.0	97.1	0.14
Jul	0.5	0.2	8.0	0.0	8.9	0.0	0.0	17.6	0.03
Aug	0.0	0.0	15.9	0.0	34.7	0.0	0.0	50.6	0.07
Sep	33.5	0.0	68.6	0.2	53.9	0.0	0.0	156.2	0.23
Total	177.5	18.0	223.0	132.8	121.7	20.3	0.0	**693.2**	
%	0.26	0.03	0.32	0.19	0.18	0.03	0.00		

1989/90	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8&9	Unknown	Total	%
Oct	13.9	0.0	8.5	0.0	0.4	0.6	0.0	23.4	0.03
Nov	1.0	0.5	69.8	12.8	0.2	0.6	0.7	85.7	0.10
Dec	3.9	0.0	9.9	0.0	0.0	0.2	0.0	14.2	0.02
Jan	0.0	0.0	14.5	2.5	0.1	0.0	0.0	17.2	0.02
Feb	1.1	0.5	30.2	16.6	0.9	0.4	0.3	50.1	0.06
Mar	43.1	4.2	19.4	25.6	1.3	0.5	0.0	94.3	0.11
Apr	59.3	14.4	7.6	2.2	7.1	8.5	0.0	99.3	0.12
May	166.1	6.3	2.3	0.3	16.7	0.2	0.0	191.9	0.23
Jun	43.1	4.5	6.3	0.0	7.2	0.9	0.0	62.3	0.07
Jul	0.8	0.4	0.2	0.0	12.9	0.0	0.0	14.4	0.13
Aug	15.9	3.2	8.3	0.0	60.0	0.0	0.0	87.5	0.13
Sep	56.3	8.3	24.4	0.3	22.0	0.0	0.0	111.5	0.13
Total	404.5	42.3	201.4	60.3	128.8	11.9	1.0	**851.8**	
%	0.47	0.05	0.24	0.07	0.15	0.01	0.00		

1990/91	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8&9	Unknown	Total	%
Oct	237.1	3.9	25.8	0.0	0.1	0.0	0.0	266.9	0.21
Nov	55.1	10.2	48.4	0.4	0.0	0.0	0.0	114.1	0.09
Dec	31.6	15.7	13.1	9.2	0.0	0.0	0.0	69.8	0.06
Jan	18.9	12.7	25.1	0.4	0.0	0.4	0.0	58.1	0.05
Feb	3.3	1.8	8.0	0.3	0.0	0.1	0.0	13.6	0.01
Mar	3.2	0.0	14.0	23.4	1.1	1.7	0.0	43.9	0.03
Apr	0.0	0.0	3.7	63.7	0.0	0.0	0.0	67.5	0.05
May	49.3	14.6	5.5	25.9	7.0	0.1	0.0	102.6	0.08
Jun	50.6	46.2	0.1	0.5	5.1	0.8	0.0	103.5	0.08
Jul	24.2	4.1	0.5	0.0	3.9	0.2	0.0	33.0	0.03
Aug	2.8	9.1	0.4	0.6	248.6	0.0	0.0	261.2	0.21
Sep	70.7	10.8	34.5	0.0	16.6	1.7	0.0	134.4	0.11
Total	546.8	129.1	179.1	124.4	282.4	5.0	0.0	**1268.6**	
%	0.43	0.10	0.14	0.10	0.22	0.00	0.00		

Appendix C.

Summary of red cod catch (t) by deepwater trawl (NZ chartered and foreign licensed vessels) by QMA by fishing year from 1978/79 to 1990/91.

	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8&9	Unknown	Total
1978/79	1 162	34	569	739	122	259	6	2 891
1979/80	570	320	441	395	21	47		1 794
1980/81*								
1981/82	80	114	248	559	16	27		1 044
1982/83	98	89	370	1 320	8	15		1 900
1983-83	97	97	280	445	15	10	1	945
1983/84	89	507	1 791	1 138	33	101		3 659
1984/85	157	149	2 837	982	3	49	11	4 188
1985/86	106	86	1 151	381	174	7		1 905
1986/87	228	40	383	371	39	8		1 069
1987/88	392	37	264	70	117	77		957
1988/89	177	18	223	133	121	20		692
1989/90	404	42	201	60	129	12	1	849
1990/91	547	129	179	124	282	5		1 266

1980/81 = no fishing returns processed this year
1978/79 - 1982/83 = fishing year 1 April - 31 March
1983-83 = fishing year 1 April - 30 September
1983/84-1990/91 = fishing year 1 October - 30 September

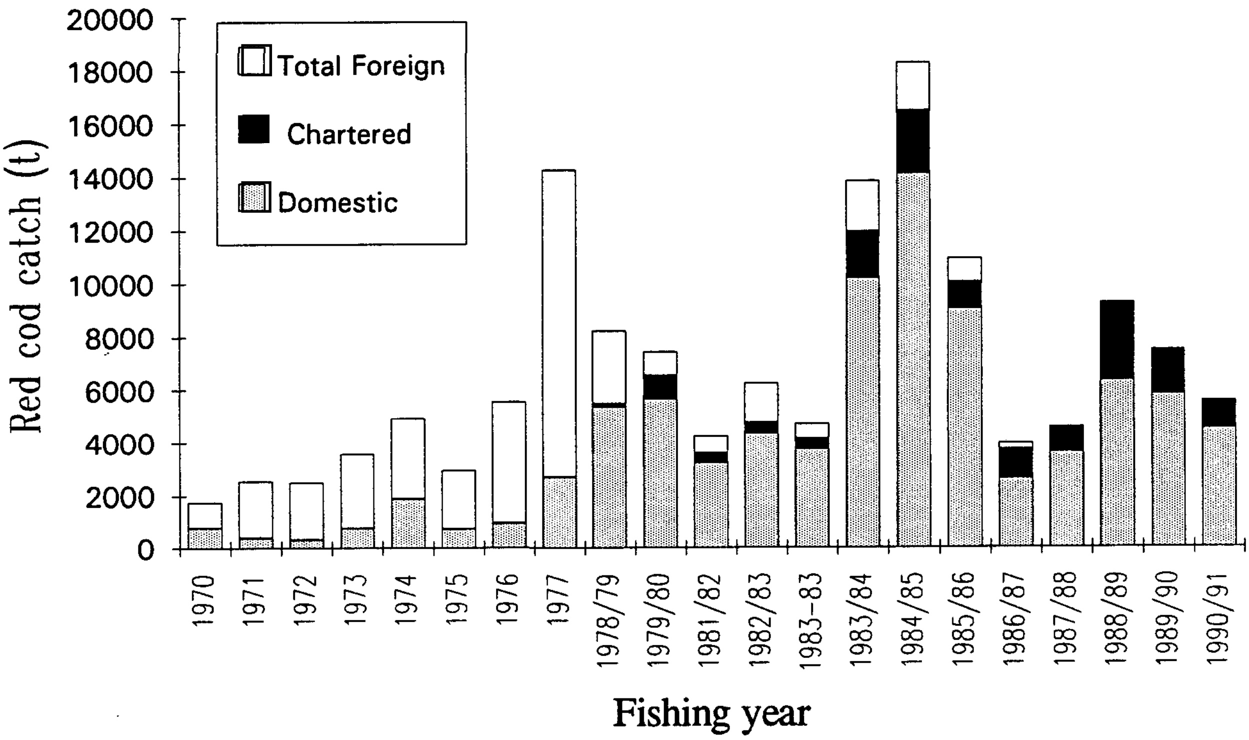


Figure 1. Proportion of red cod catch by foreign, chartered and domestic vessels from 1970 to 1990/91.

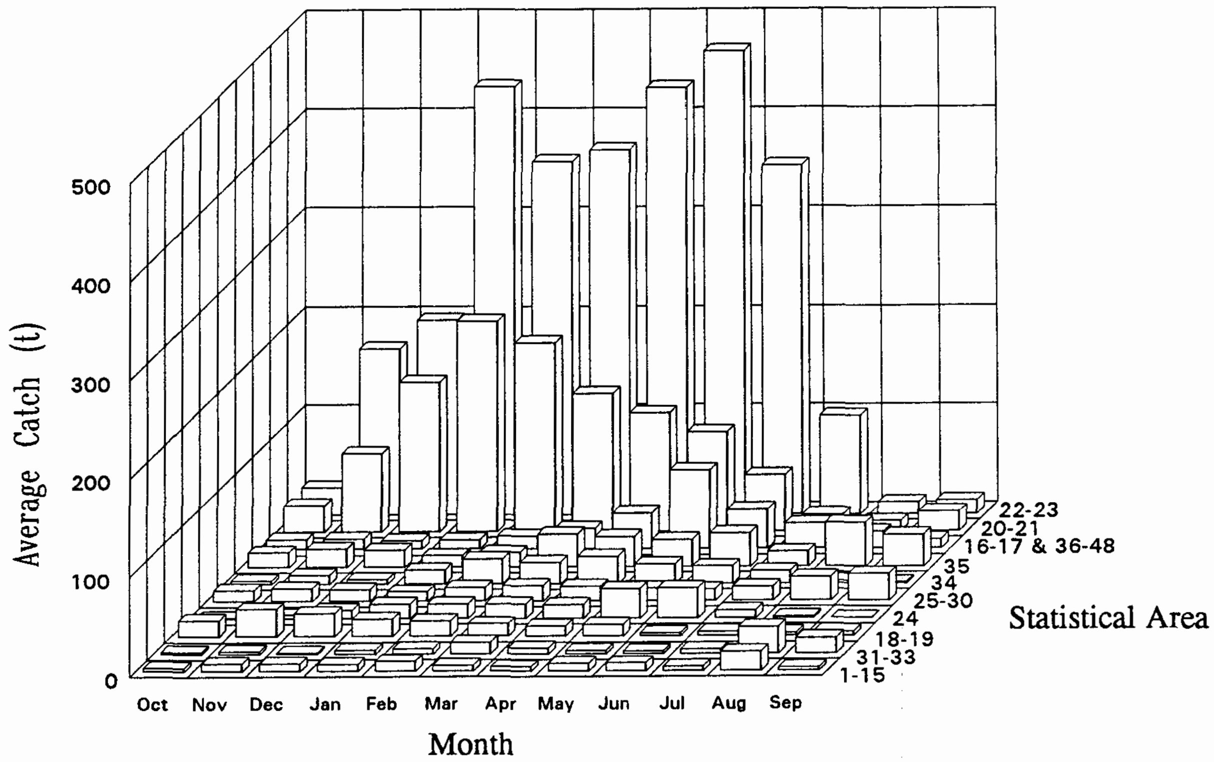


Figure 2. Average red cod catch for the period 1983/84 to 1990/91 for domestic trawl (deepwater & inshore) by month and by statistical area. NB: statistical areas are ranked in order of total catch. (Figure in based on data in Appendix A).

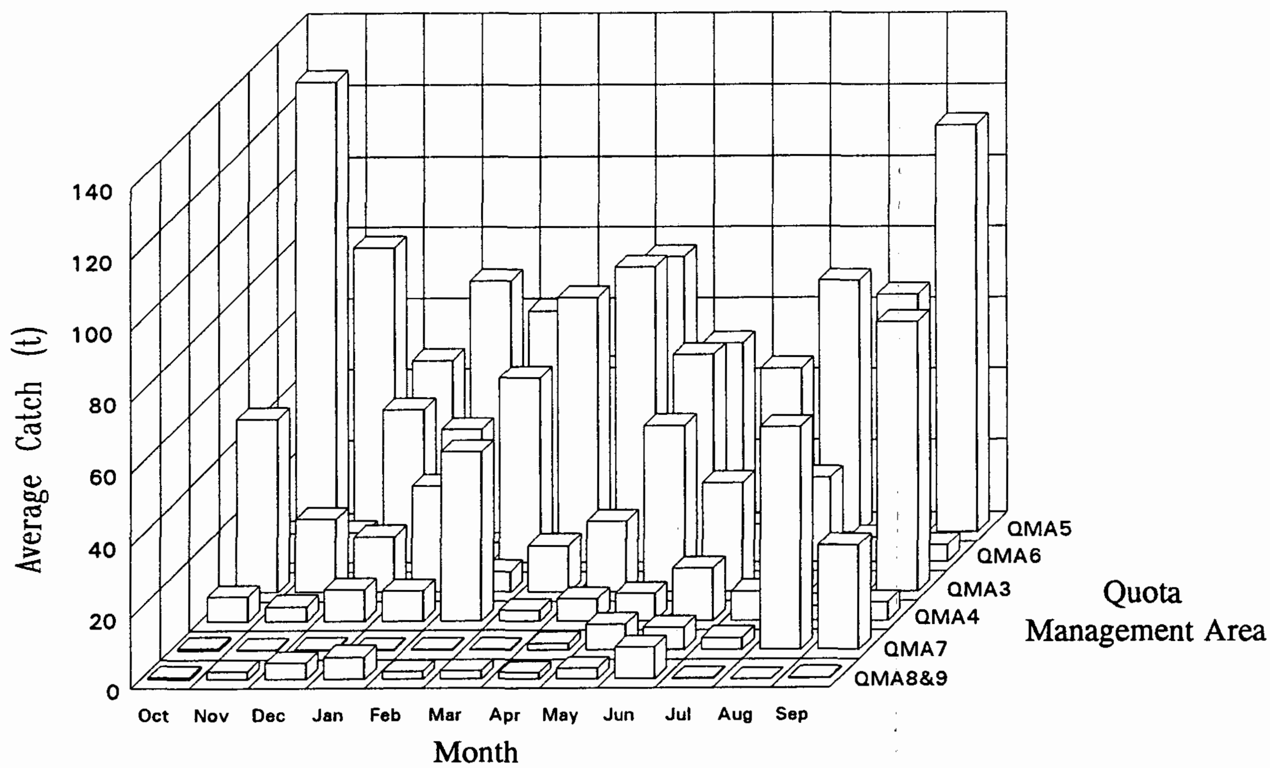
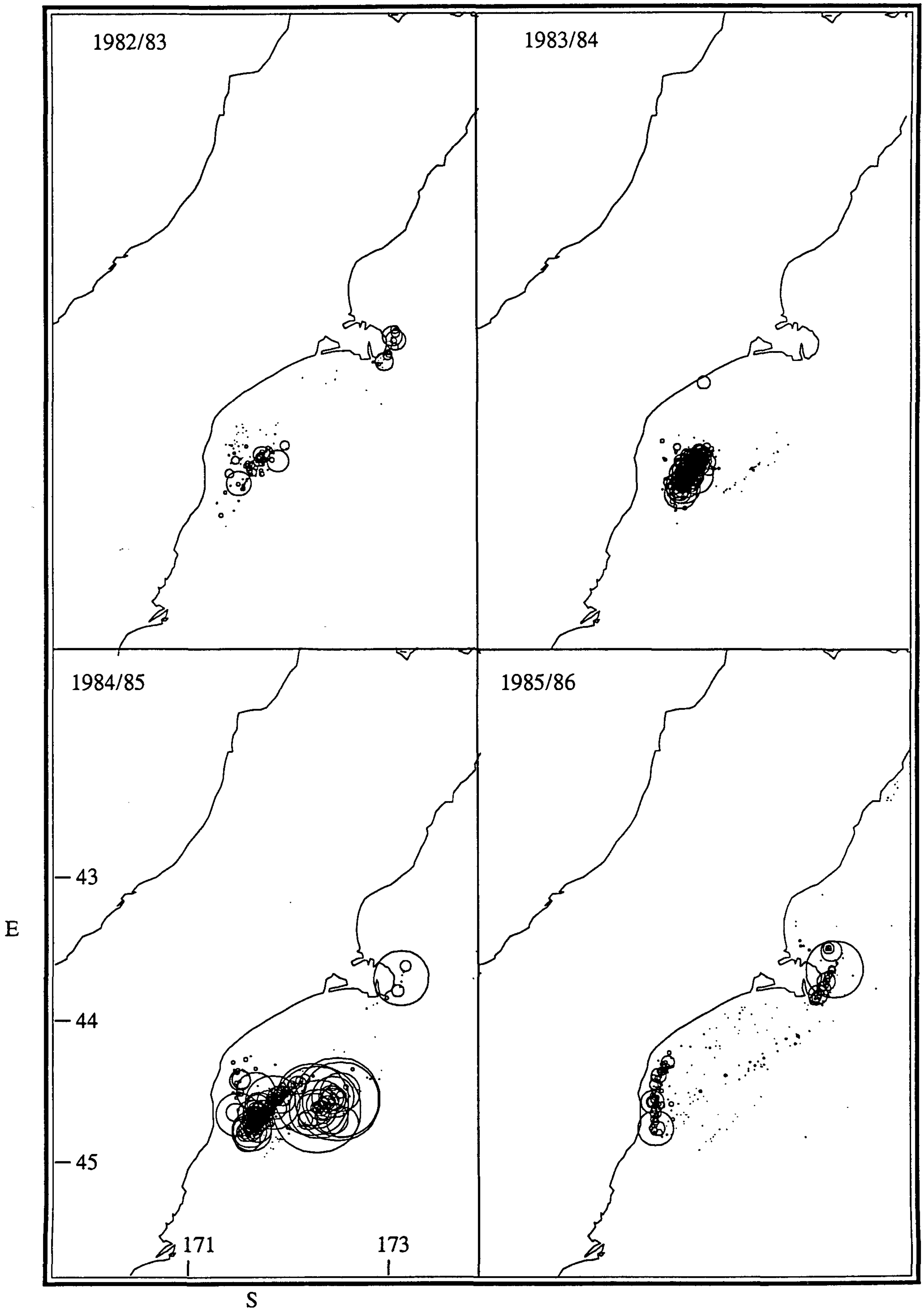


Figure 3. Average red cod catch for the period 1983/84 to 1990/91 for deepwater trawl (NZ chartered & foreign licensed) by month and by QMA. NB: QMA's are ranked in order of total catch. (Figure is based on data in Appendix B).

Figure 4.

Red cod catch rates in the Canterbury Bight from 1982/83 to 1985/86. FSU deepwater log-book data from six domestic vessels. Circles are proportional to catch rate (tonnes/hour).



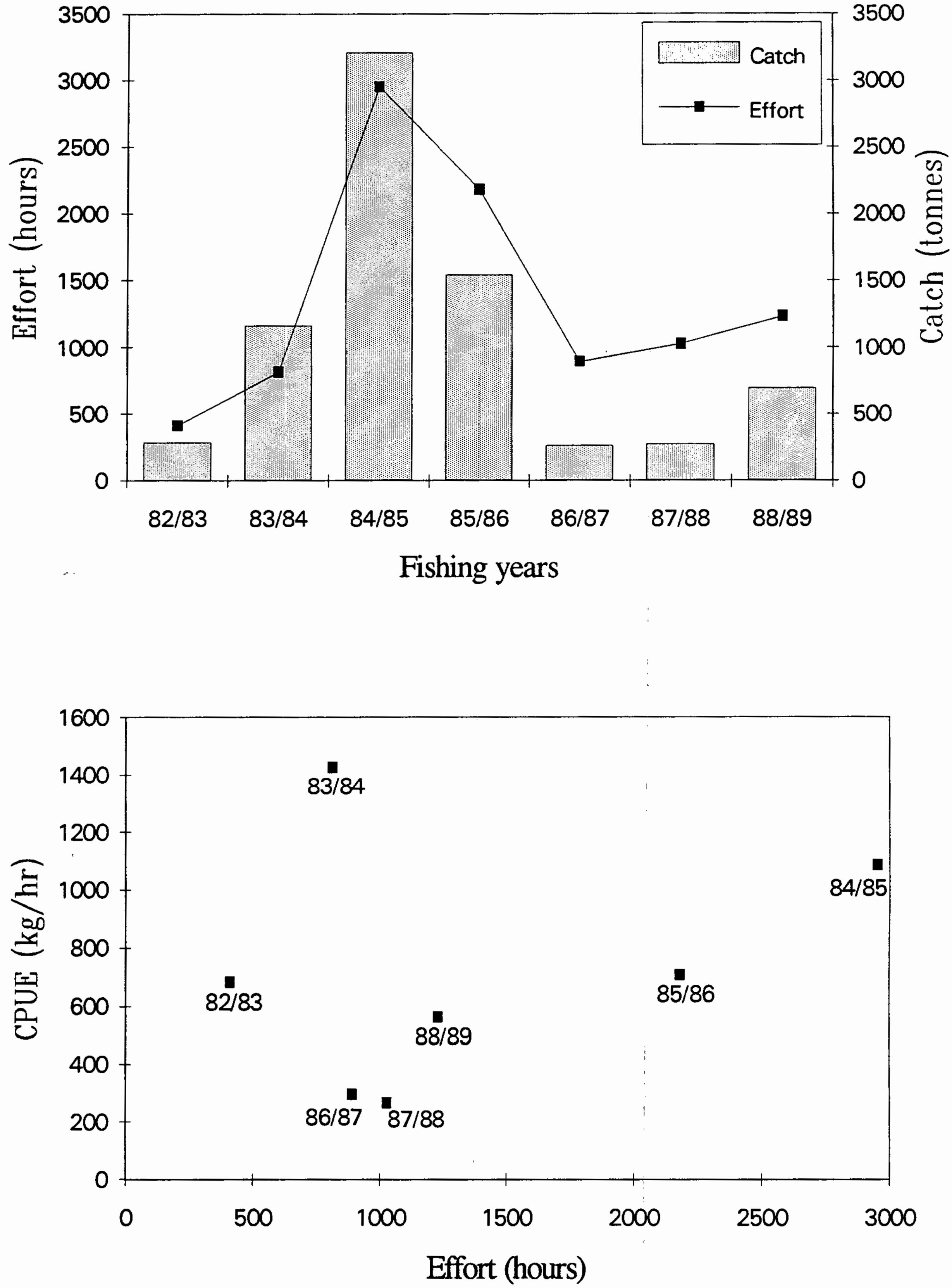
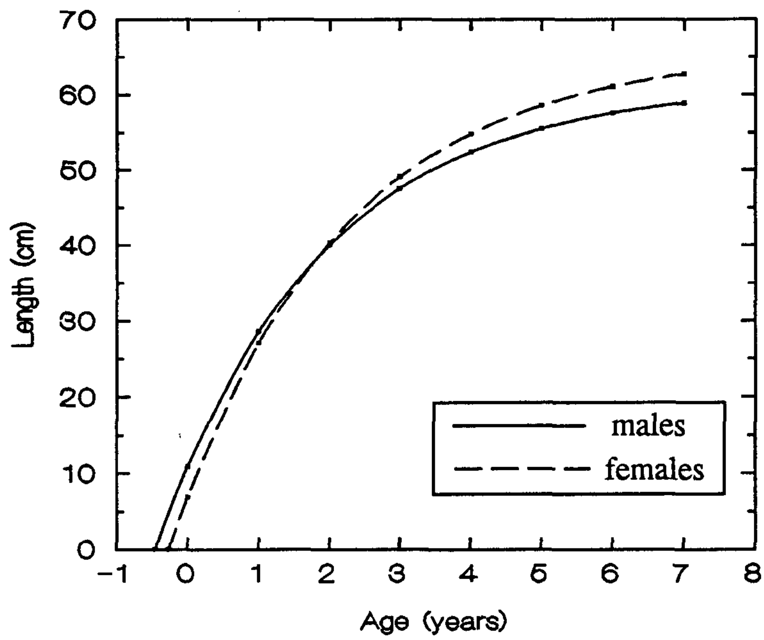


Figure 5. Above: Catch and effort for targeted red cod between 1982/83 and 1988/89.
Below: CPUE against effort for the same period.

von Bertalanffy growth curves



Mean length at age

	Males			Females		
Age:	$\bar{x}$	S.E.	N	$\bar{x}$	S.E.	N
0.7	20.6	0.59	36	21.2	0.37	89
1.7	35.5	0.38	124	36.1	0.41	128
2.7	46.9	0.73	67	48.3	0.86	76
3.7	52.0	0.42	74	56.7	0.39	123
4.7	54.7	0.43	47	60.0	0.38	93
5.7	59.5	0.69	19	63.6	0.68	26
6.7	60.5	0.50	4	68.7	1.12	7

Figure 6. von Bertalanffy growth curves for red cod. Below are the mean lengths at age. (Data is from the trawl surveys KAH9008 and KAH9105).

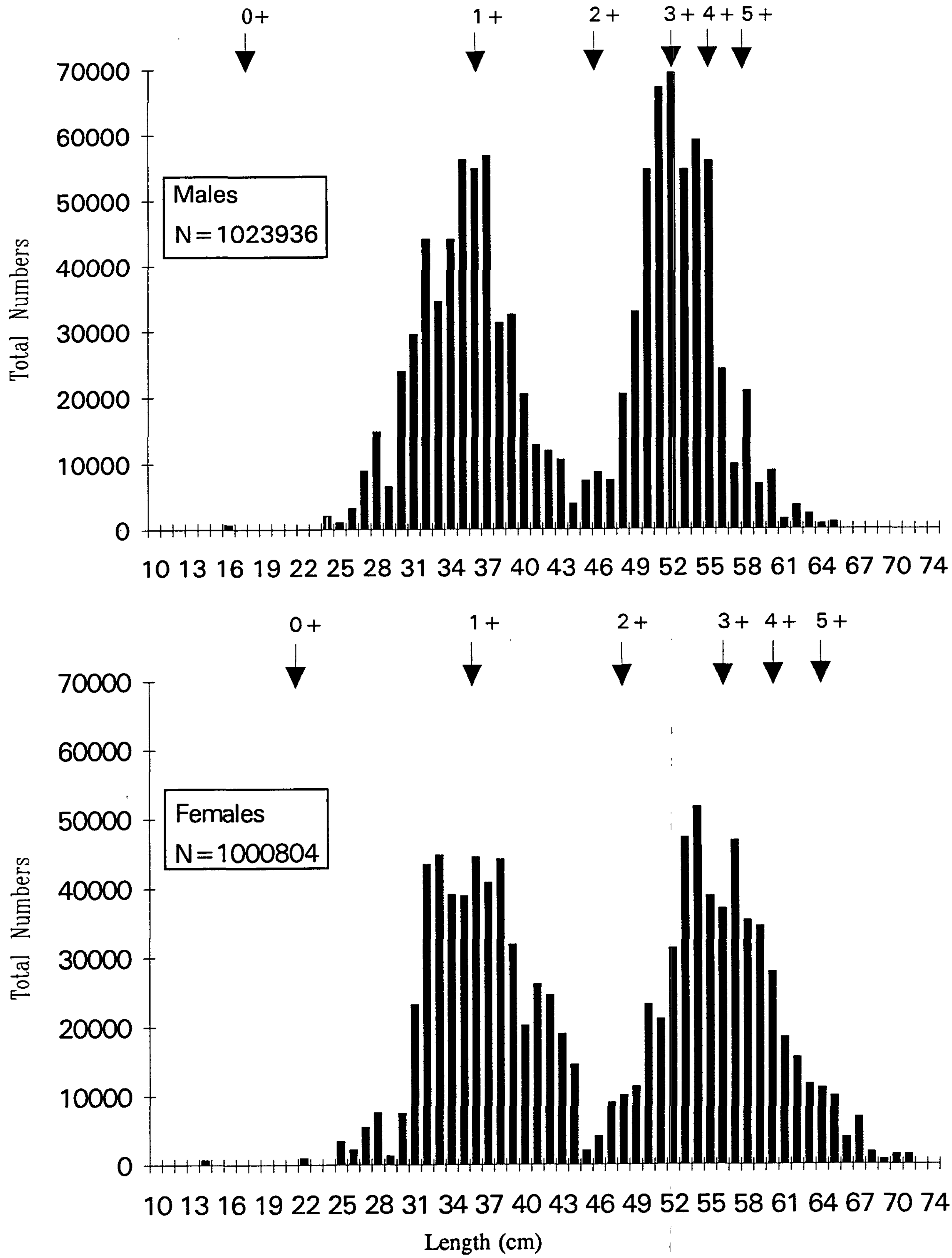


Figure 7. Weighted length frequencies for red cod south east trawl survey, KAH9008, May 1990. Mean length at age is shown above the histograms.

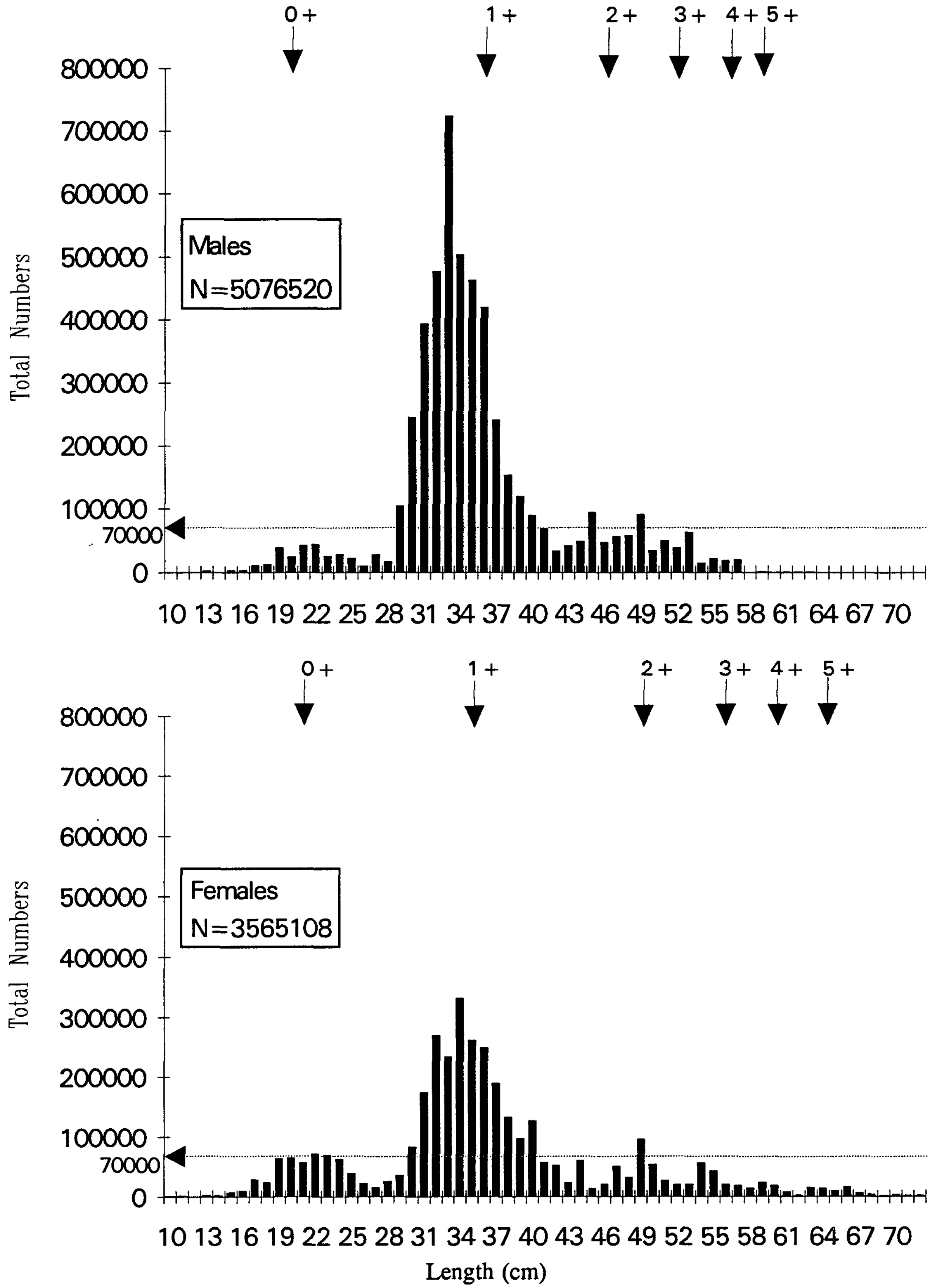
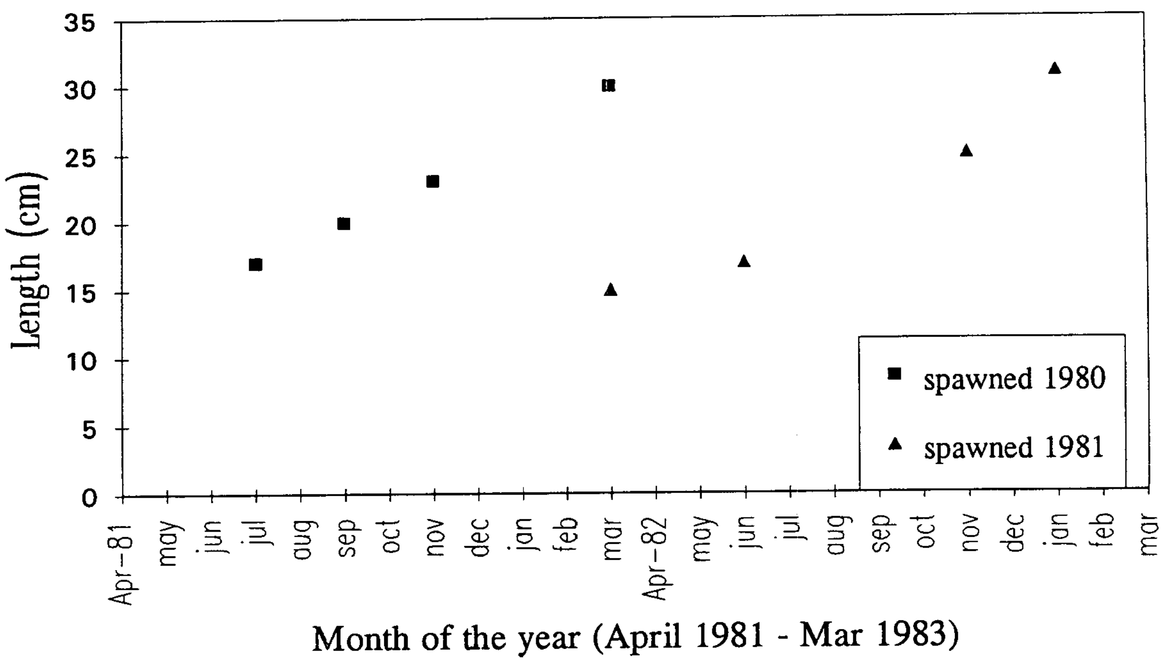


Figure 8. Weighted length frequencies for red cod south east trawl survey, KAH9105, May 1991. Mean length at age is shown above the histograms. Dotted line indicates relative scale of length frequency data in Figure 7.



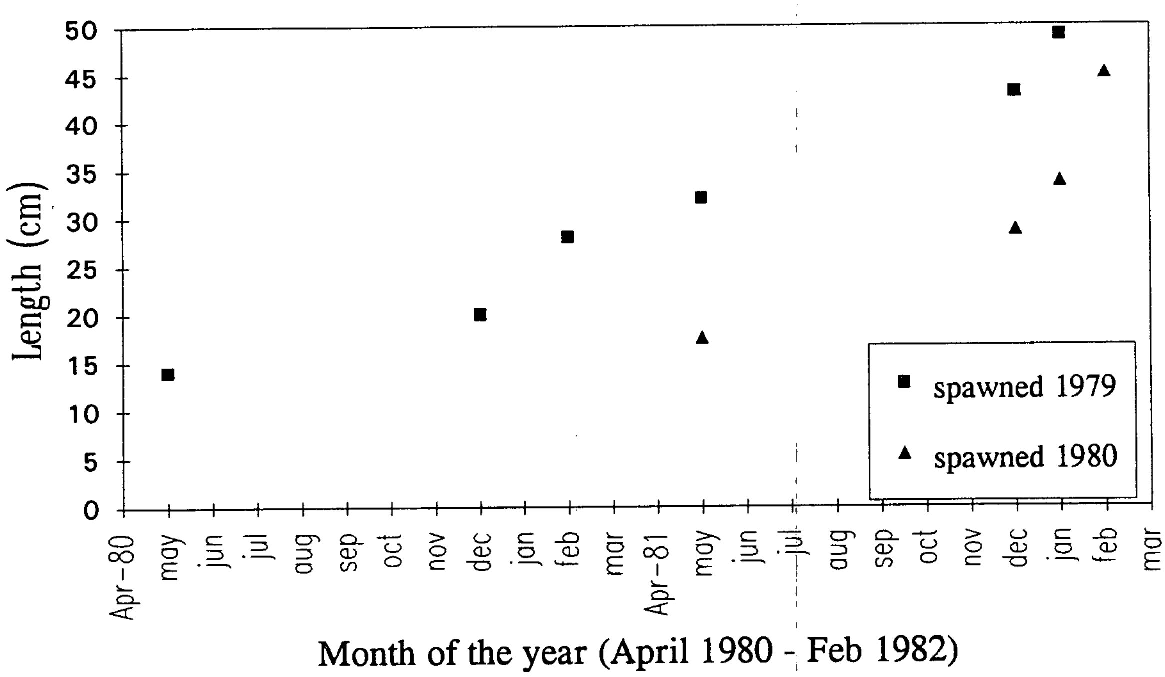


Figure 9. Growth of 0+/1+ cohorts over time. Points represent peaks of modes assumed to be cohorts. Top data from rig surveys. Bottom data from barracouta trawl surveys (see section 3.2.2 Other Resource Surveys for details).

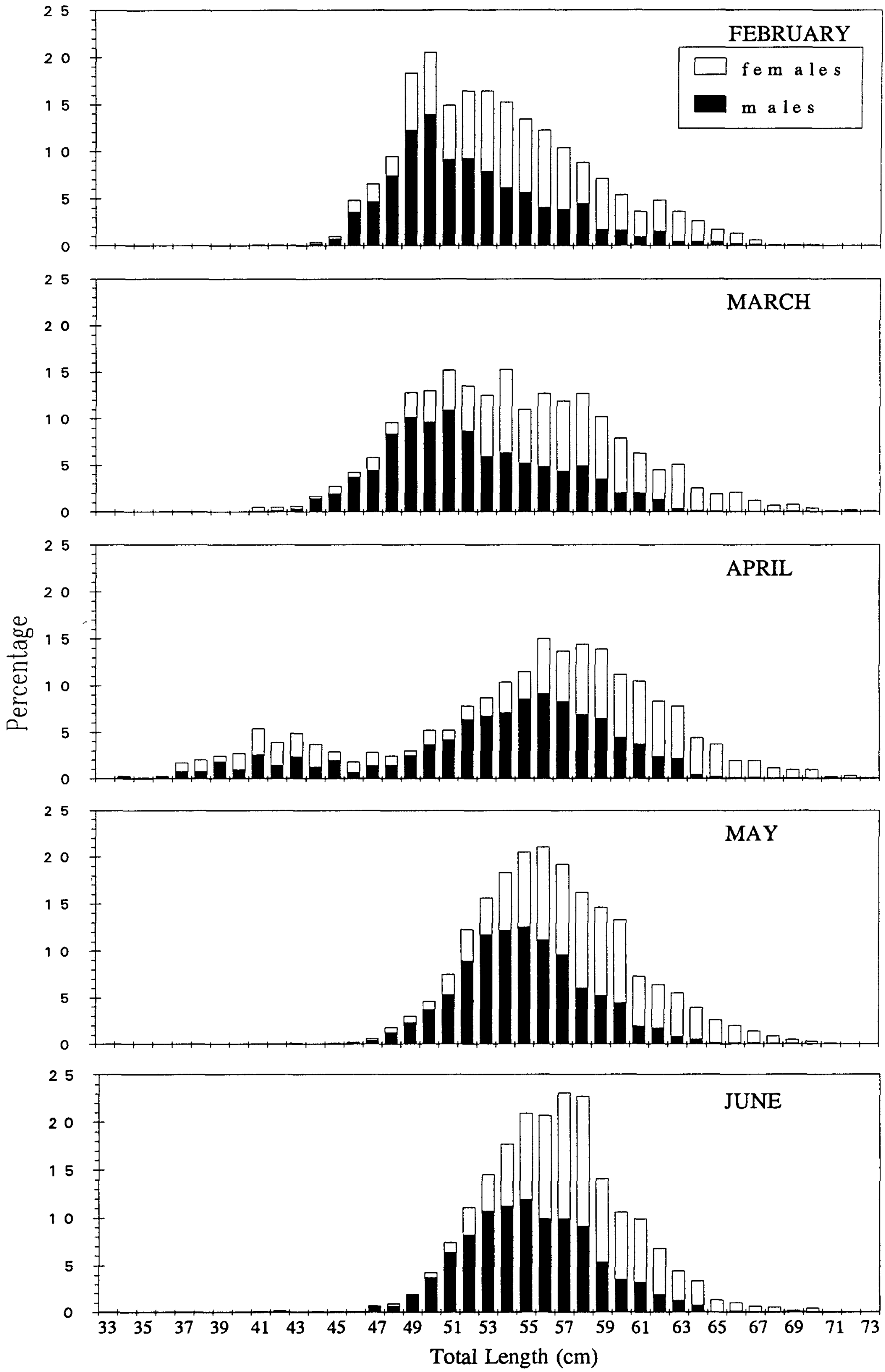


Figure 10. Weighted length frequencies for male and female red cod (catch sampling 1989/90).

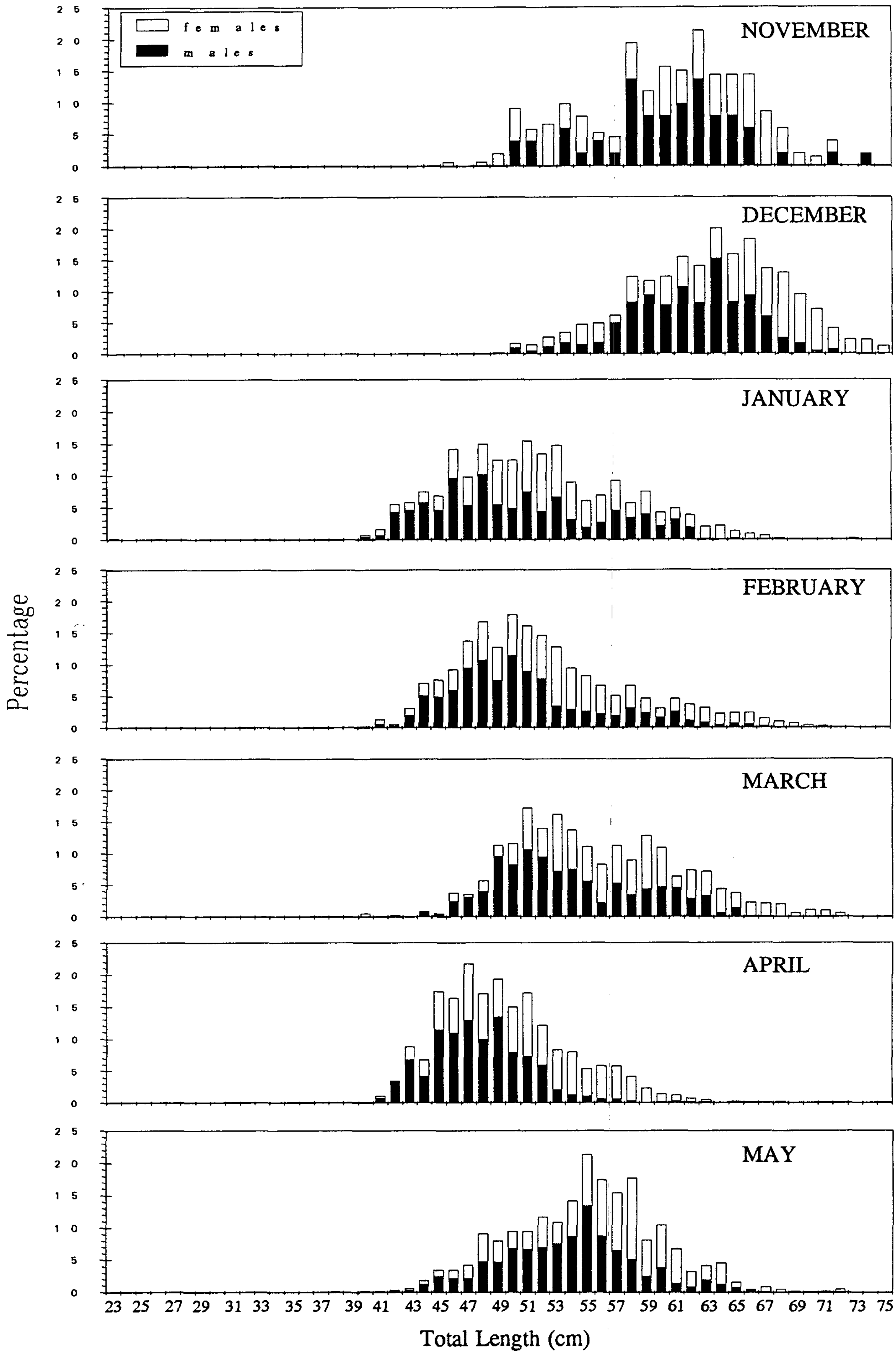


Figure 11. Weighted length frequencies for male and female red cod (catch sampling 1990/91: south stratum).

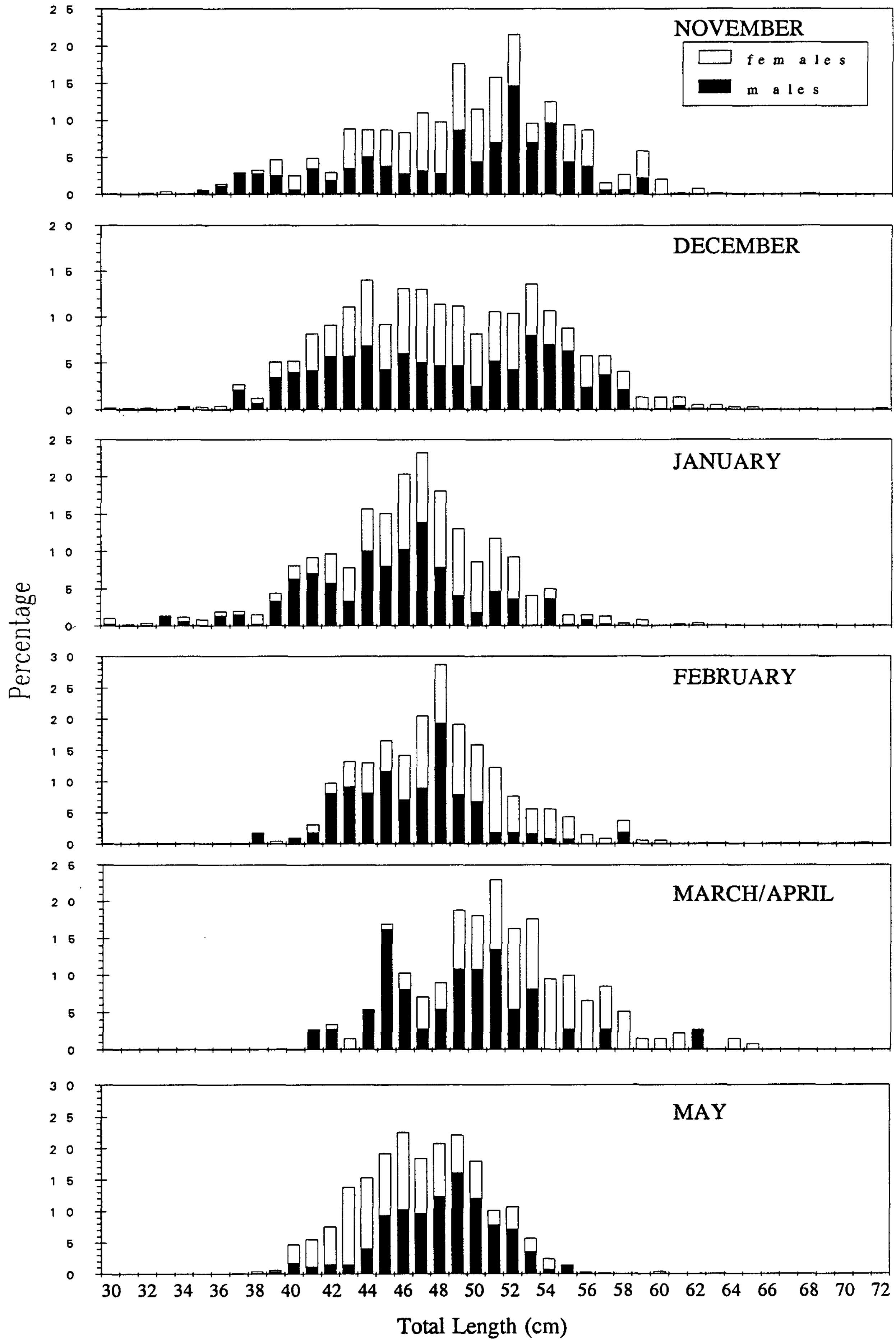


Figure 12. Weighted length frequencies for male and female red cod (catch sampling 1990/91: Kaikoura stratum)

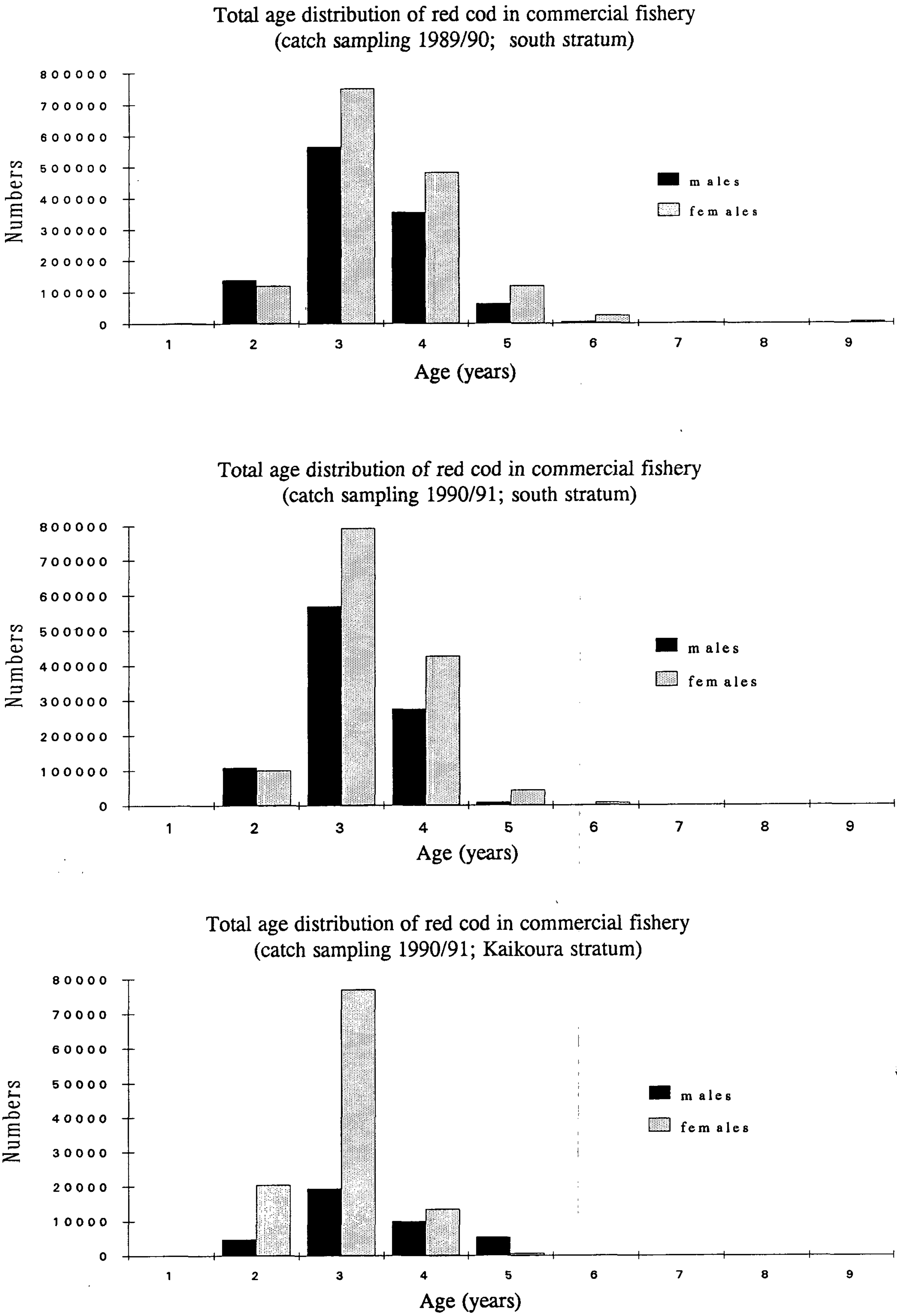
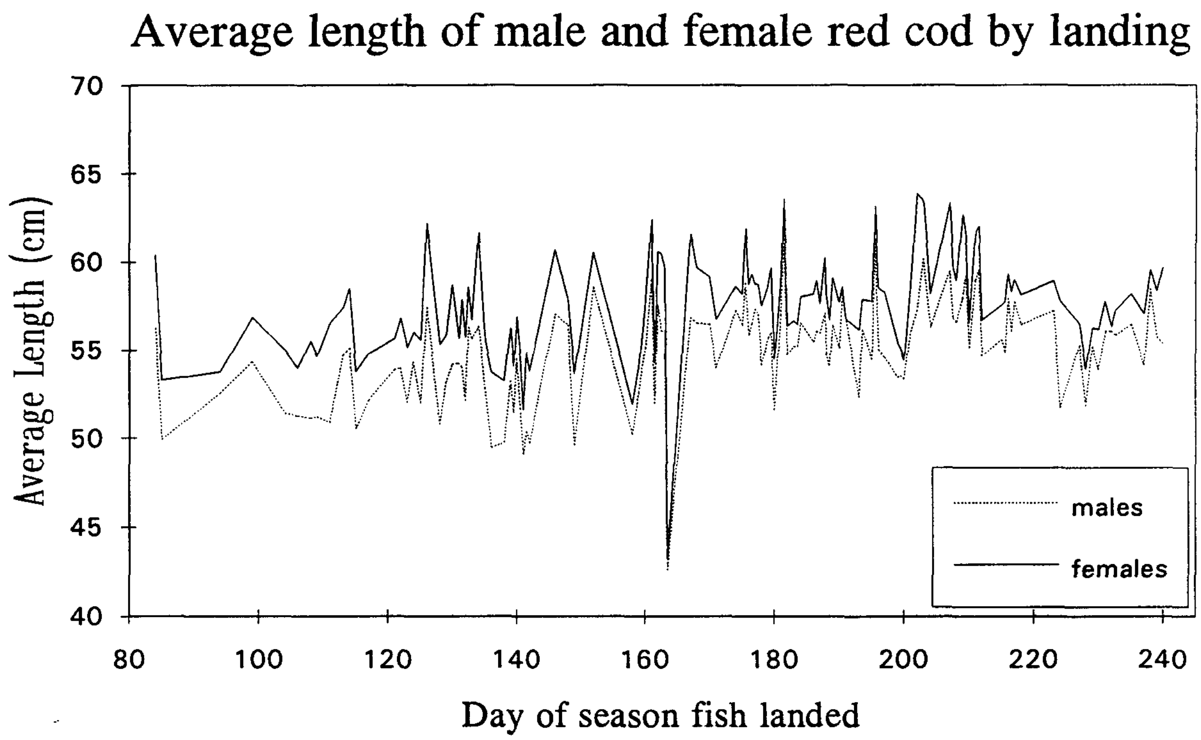


Figure 13. Age distribution for red cod in the commercial fishery for the 1989/90 and 1990/91 seasons.



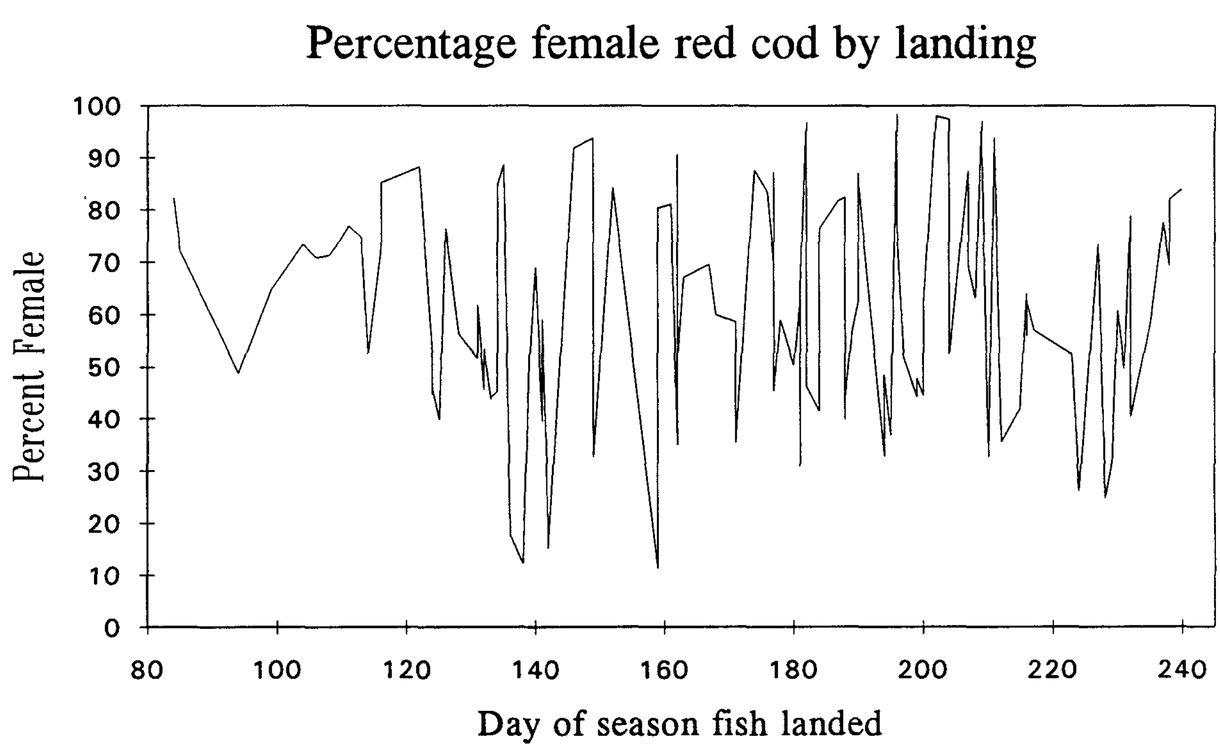
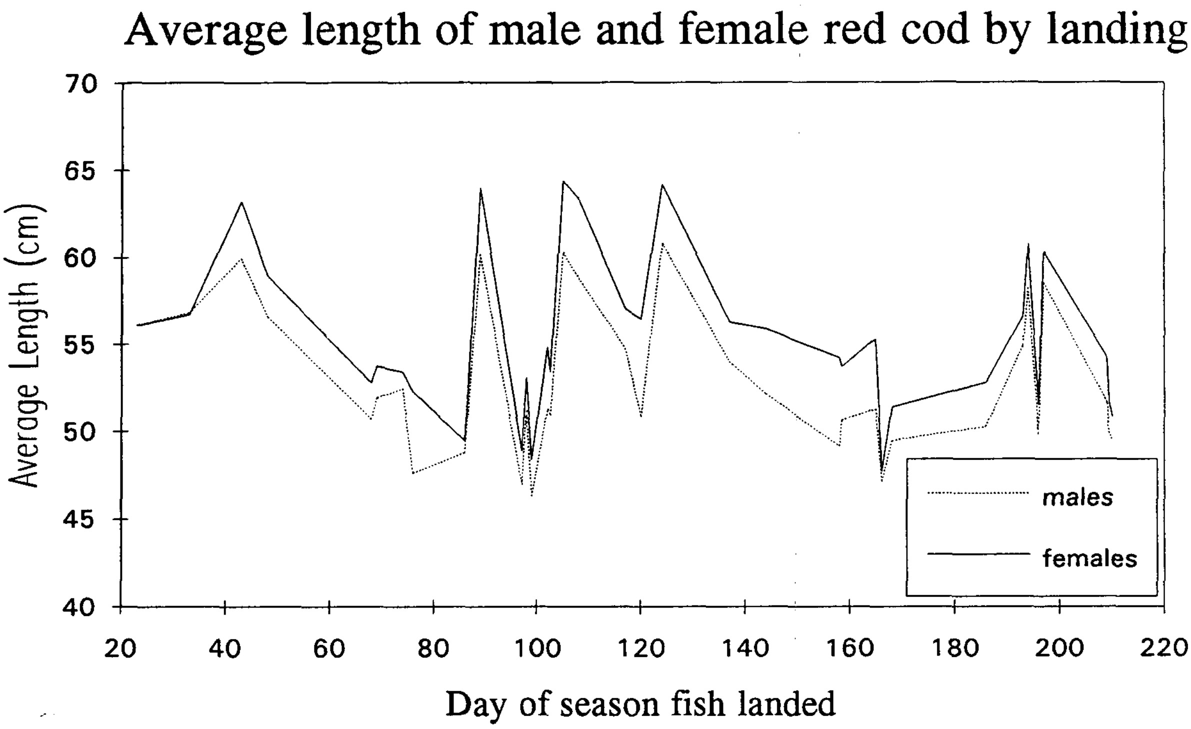


Figure 14. Average lengths and percent female red cod by vessel landing through the red cod fishing season (catch sampling: south 1989/90; day 1 = 1 November).



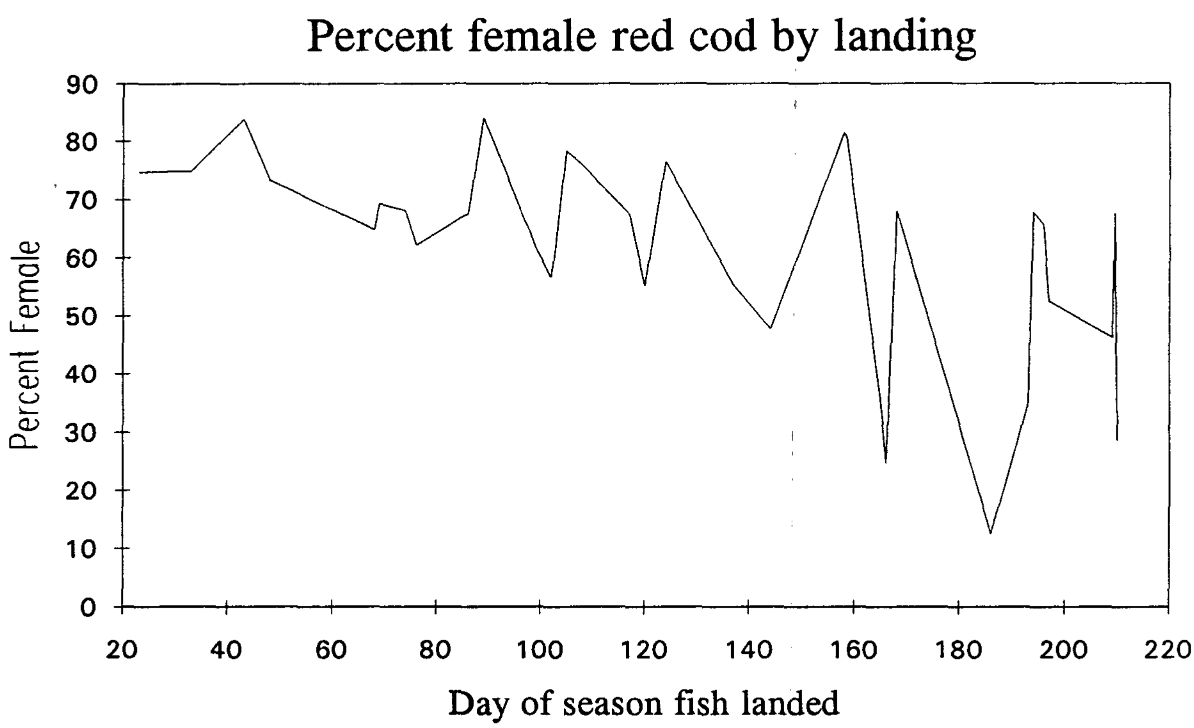
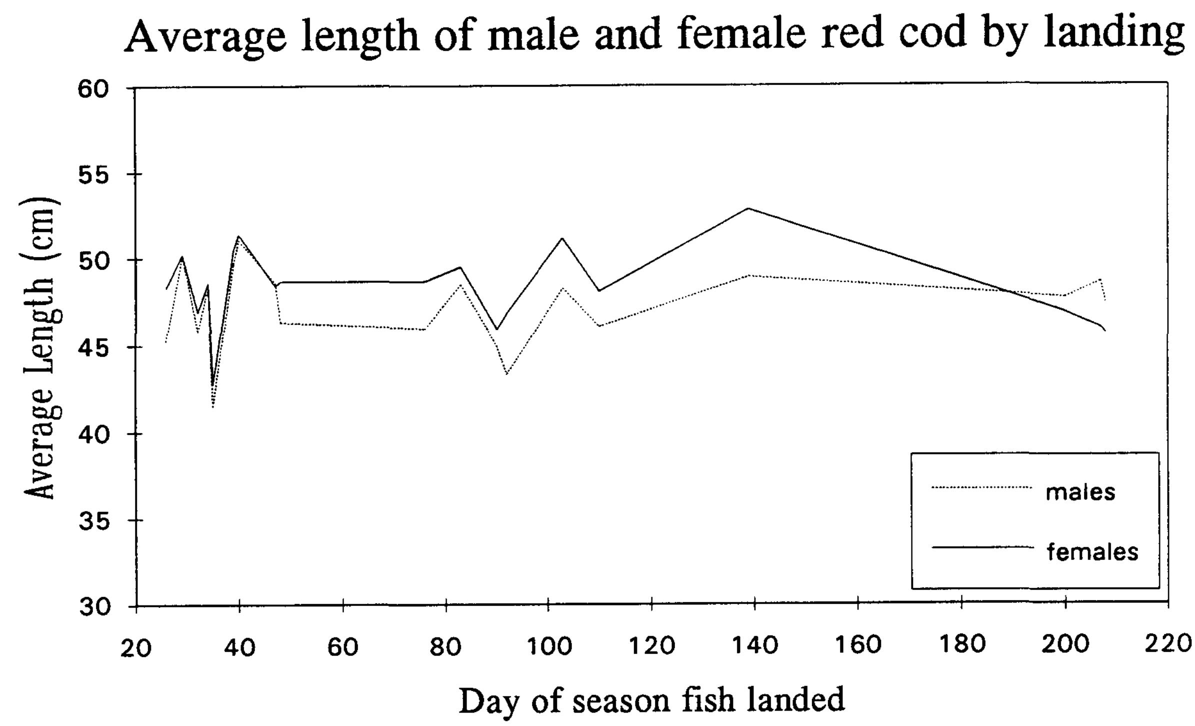


Figure 15. Average lengths and percent female red cod by vessel landing through the red cod fishing season (catch sampling: south 1990/91; day 1 = 1 November).



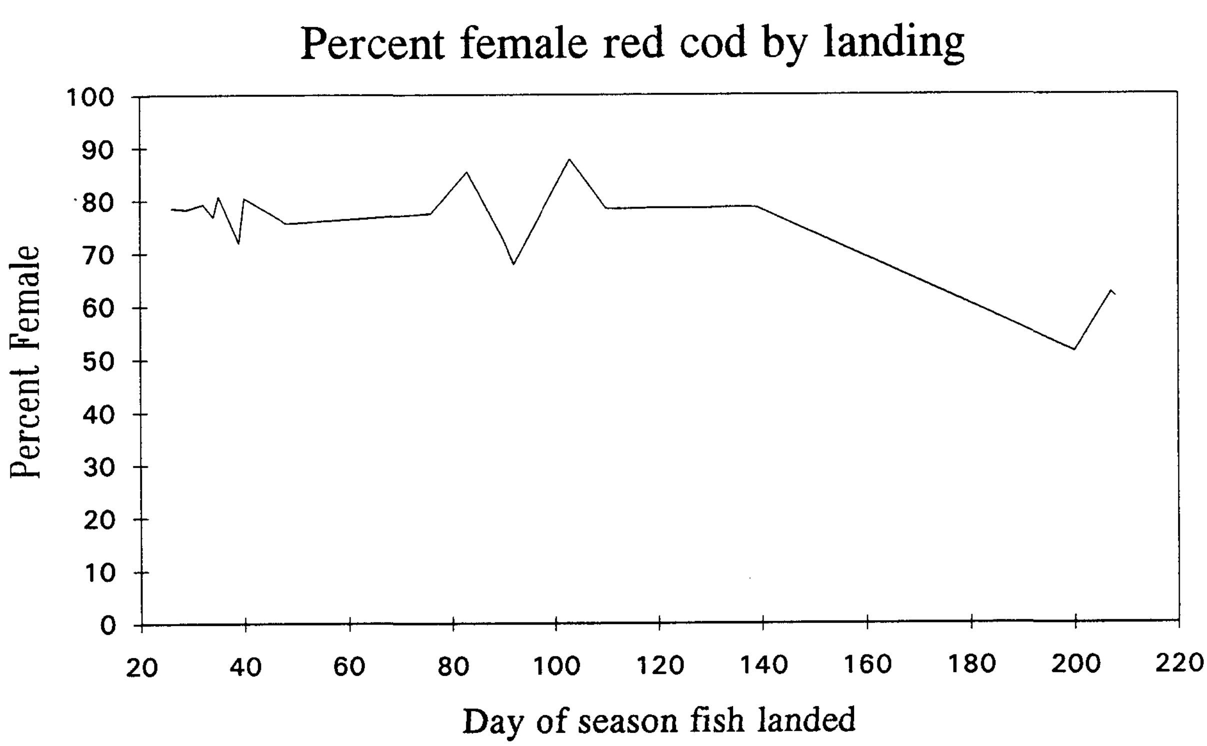


Figure 16. Average lengths and percent female red cod by vessel landing through the red cod fishing season (catch sampling; Kaikoura 1990/91; day = 1 November).

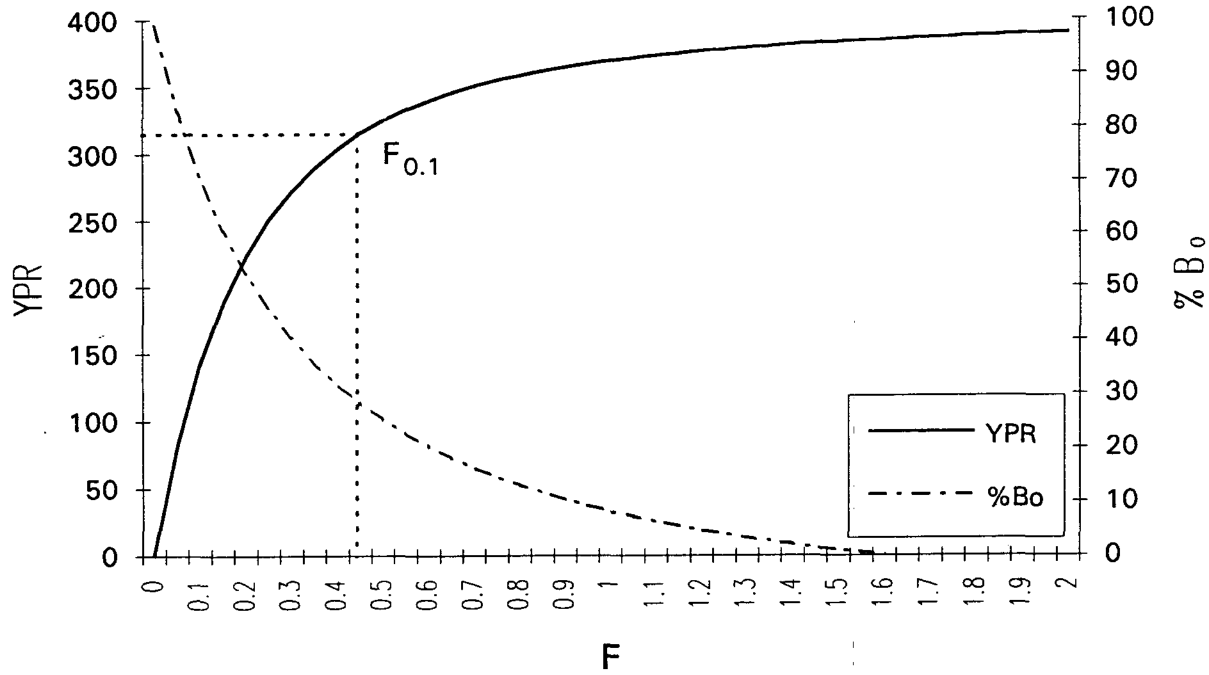


Figure 17. Yield per recruit and equilibrium biomass (% B_o) plotted against fishing mortality. $F_{0.1}$ corresponds to an instantaneous rate of fishing mortality of 0.47, M=0.4, SRR steepness =0.75.