Abundance, size and age composition, and yield-per-recruit of blue cod in the Marlborough Sounds, September 1996

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Cover: Craig Aston, skipper of *Lady H.R.*, lifting a cod pot during the survey.
Photograph by Ron Blackwell

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Abstract

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Aspects of the biology of blue cod (*Parapercis colias*) from the Marlborough Sounds were investigated. Results of a pilot study of pot catching efficiency indicate that catch per unit effort data from the potting survey provide a satisfactory index of relative abundance. Patterns of relative abundance and size distribution between strata indicate that overfishing and local depletion may have occurred, particularly in the Inner Sounds. Examination of age and growth parameters indicated that males grow faster in both size and weight than females. Variability in the age at length data for males suggests a sex change from females to males (protogyny) may occur. Spawning fish were recovered in all strata surveyed, with size at maturity estimated at 23–26 cm for males and 21–26 cm for females. The September age structure is unimodal and dominated by 6–8 year old males. Few large females were present, in contrast to the female-dominated population structure found by trawl surveys in Tasman Bay during April 1994, 1995, and 1997.

Natural mortality (M) is estimated at 0.24–0.27, based on maximum ages of 20 years for females and 11 years for males. Although maximum yield-per-recruit may be attained by catching fish after 4 years of age and 25 cm in length, these data may be considered preliminary, as growth rates may be affected by possible sex change. Further work will be required to determine the nature and extent of protogyny in the Marlborough Sounds blue cod population.

Introduction

This report describes the second of two potting and lining surveys of blue cod carried out in September 1996 as part of the requirements of the Ministry of Fisheries contract CEBC02, "Determination of the size and age distribution and the reproductive biology of blue cod in the Marlborough Sounds".

Blue cod, *Parapercis colias,* is among the top three recreational target finfish species in the Central Region (Kilner & Bell 1992, Bell *et al.* 1993), and the most important recreational finfish species caught in the Marlborough Sounds (Blackwell 1997a, Hartill *et al.* 1998). It also supports a small commercial fishery (Warren 1994, Annala & Sullivan 1997). Recent concerns about the level of fishing pressure resulted in a reduction in the minimum legal size for recreational fishers from 33 to 28 cm in the Marlborough Sounds (Annala & Sullivan 1997). The Inshore Working Group highlighted the lack of current biological data necessary to review the most appropriate minimum legal size in this fishery. Blue cod may change sex from females to males (protogyny) but the length of time required for this transition or the processes controlling sex change are unknown and may be complex (Mutch 1983, Sadovy & Shapiro 1987).

These two surveys review the length distribution and relative abundance of blue cod in the Marlborough Sounds and provide background information for the management of this fishery. Blackwell (1997b) described the first (1995) survey in this series covering Queen Charlotte Sound and Outer Pelorus Sound.

This report reviews the size distribution and sex ratios of blue cod in the Marlborough Sounds. It extends the 1995 survey area to include Inner Pelorus Sound and D'Urville Island. It reviews the age structure of the Marlborough Sounds blue cod and presents the results of a yield per recruit analysis of this fishery.

A sub-objective of the blue cod contract involved the examination of pot catching efficiency. Field work was completed during April 1997, partly funded through a research grant from the Lotteries Grants Board. Blue cod behaviour in and around the pots was monitored using a remote underwater video camera and diver transects. Although preliminary data are discussed in this report where appropriate, the results will be reported separately.

Project objectives

1. To determine the size distribution of blue cod at selected sites throughout the Marlborough Sounds, and provide a baseline for future comparisons.

2. To review the relationship between length, reproductive state, and age of blue cod in the Marlborough Sounds, in order to determine yield per recruit and review the minimum legal size.

Sub-objective

3. To provide initial estimates of blue cod pot catching efficiency, which will enable the usefulness of CPUE data from the commercial pot fishery to be evaluated.

Project and voyage personnel

The blue cod potting and lining survey was carried out from 12 to 17 September 1996. The project leader was Ron Blackwell. Craig Aston was the skipper of the fishing vessel *Lady H.R.* chartered for the survey.

Methods

Survey area

The Marlborough Sounds (Figure 1) are a series of drowned river valleys at the northeastern end of the South Island of New Zealand. The area comprises two major systems: Queen Charlotte Sound. bounded to the east by Arapawa Island, and Pelorus Sound, bounded to the west by D'Urville Island.

Blue cod habitat within the Marlborough Sounds was assumed to include all possible sites over the rocky reefs and rubble banks that are commonly found off the headlands and drop-offs within a band 10–60 m in depth from the shoreline. Queen Charlotte Sound (Figure 2) was divided into three strata (Inner, Outer, and Extreme Outer) which were surveyed in 1995 (Blackwell 1997b). Pelorus Sound was divided into three strata (Inner, Mid, and Outer). Only the Mid and Outer areas were surveyed in 1995 (Blackwell 1997b).

Sampling methodology and survey design

The 1996 survey concentrated on Pelorus Sound (Figure 2) which was divided into five strata (Table 1). The Extreme Outer Pelorus (EOPE) and Outer Pelorus (OPEL) areas defined for the 1995 programme were re-surveyed. Inner Pelorus was divided into two strata: Inner (IPEL) and Mid Pelorus (MPEL). The region inside a line between Dillon Bell Point and Turn Point (*see* Figure 1) was included in the survey. A new stratum (DURV) included the east coast of D'Urville Island, the Rangitoto Islands, and the Trio Banks.

Sampling was undertaken during mid September 1996, the peak of the local spawning season (C. Aston, French Pass, commercial fisher, pers. comm., 1996), and generally followed the procedures developed during the September 1995 survey (Blackwell 1997b). The four sampling areas within EOPE and OPEL that were selected during the September 1995 survey were re-sampled to provide comparisons between sampling years.

For each of the three new strata, eight sampling areas of suitable rocky/rubble reef habitat were identified from marine charts and anecdotal advice (C. Aston, pers. comm., 1996). Four of these areas (A–D) were selected using random number tables.

To avoid any time bias, the time of sampling (morning or afternoon) was randomly allocated for each new sampling area. Two of the four sampling areas were sampled in the morning and two in the afternoon. For the areas repeated from the 1995 survey, the times used in the 1995 survey were repeated.

Within each of these four sampling areas, nine pots were set: three replicate pots (a–c) set at three sampling sites (1–3) randomly chosen within the available blue cod habitat.

As most recreational target fishing for blue cod in the Marlborough Sounds is by hand lining, two line fishing stations (g and h) were also established adjacent to the first and last pot stations (1a and 3c) within each sampling area.

Additional sampling stations were established at Bulwer (5E), Camp Bay (5F), Te Akaroa (5G), and French Pass (6H) where anecdotal information suggested that sufficient blue cod might not be available for adequate biological sampling, gonad maturity, and otolith collection. Line fishing stations were not routinely established at these additional sites. The data from these additional stations have not been included in catch rate analyses.

Vessel and gear specifications

The commercial fishing vessel *Lady H.R.* is 9.6 m in length, with a 3.2 m beam and a displacement of 10 t. It is powered by a Ford diesel generating 60 kW and fitted with power hauling gear for cod pot fishing. It has a Koden colour depth sounder. For the survey it was equipped with a voltage inverter to power the 5 kg and the 1 kg motion-compensating Seaway electronic scales and Trimble portable GPS system.

The nine pots used in the survey were modified to the same specifications as those used in the 1995 survey. Commercial rectangular cod pots (1.87 x 1.40 x 0.93 m) were constructed from a 40 mm diameter steel rod framework covered with 60 cm nylon mesh. The bottom and sides were fitted with a 15 mm galvanised wire mesh inner liner for the survey. Each pot had four entrances of 10 cm external diameter leading into a 20 cm long steel wire tube with an internal diameter of 8 cm. The internal entrance of this tube was provided with inward-facing wire spines. The bait (frozen pilchard, *Sardinops neopilchardus)* was enclosed in a 15 mm mesh bait bag attached to the inside bottom face of the pot.

At each handline station, two braided nylon handlines were fished for 15 min. Each line used two 6/0 Kale hooks and frozen pilchard bait.

Sampling procedure

All stations were occupied in daylight. For the area randomly selected for morning fishing, the nine pot stations were sequentially established between 0600 and 0800 hours. At each station, the vessel position was recorded by GPS. The pot was deemed to be fishing once the pot was deployed at the station and the float was detached from the vessel.

Each pot was fished for 1 hour. Whilst these pots were fishing, the vessel steamed back to a position adjacent to the initial potting stations to complete the first line fishing station. The vessel then completed the second line fishing station, adjacent to the final potting stations. After 1 hour, the pots were sequentially recovered and the catch was removed. The vessel then steamed to the second and subsequent sampling areas. Afternoon fishing continued until dusk.

Catch and biological sampling

Each station was numbered sequentially with pot stations starting at 1 and line fishing stations at 900. For each station, environmental data were recorded on to the standard NIWA research database recording forms (trawl survey forms, 1989 edition): location (date, latitude and longitude, depth, and times of set and haul); wind direction (degrees true), strength (Beaufort scale), cloud cover (1–8), water condition, and colour and height and direction of swell. Bottom type was recorded, based upon data from the depth sounder and on observations of the substrate attached to the pot upon recovery. Standard bottom type categories from the NIWA research database were used: 1, mud; 2, sand/mud; 3, sand/gravel; 7, rock/rubble.

The catch from each pot or line fishing station was sorted by species on deck and weighed (to the nearest 0.1 kg) using 5 kg electronic motion-compensating Seaway scales. The number and total weight by species were recorded. Non-QMS species were weighed and returned alive to the sea where possible. For all QMS species, length (to the nearest whole centimetre below actual length) and sex were recorded.

All blue cod were dissected to determine sex and gonad maturity Sex ratios (percentage of males) were determined for each sampling area. Biological data were collected for a subsample of 20 fish from each station. Individual fish length (total length, to the nearest whole centimetre below actual length), weight (to the nearest 1.0 g), sex, and gonad maturity stage were measured and recorded. Gonad samples of each maturation stage were collected for subsequent histological examination. The gonad stages were: 1, immature or resting; 2, maturing (oocytes visible in females); 3, mature (hyaline oocytes in females, milt expressable in males; 4, running ripe (eggs and milt freely flowing); 5, spent.

To determine the minimum length at sexual maturity by stratum, the minimum size of fish with stage 4 gonads was recorded. The presence of stage 4 gonads was regarded as a conservative estimate of sexual maturity as the presence of partially mature gonad may reflect a transition stage due to possible sex change.

Otoliths were collected from 20 blue cod from each 1 cm size class per sex and sampling stratum. A random sample of six otoliths was selected from each size and sex group. These otoliths were mounted in blocks of five in epoxy resin. A thin section was then cut from each block using a double-bladed diamond saw. The sections were polished and mounted on a microscope slide. They were viewed under a stereo microscope using x25 magnification and illumination from a cold light source. All otoliths were read twice, without reference to length and sex. Blue cod otolith age estimation is currently unvalidated. Final age estimates were determined by comparison with age and sex data and reference to estimates provided by other NIWA science staff (P. Horn and G. Carbines).

Data analysis

The data were edited in Nelson and entered on to the Greta Point research database (as LHR9601) following standard data checking procedures. The mean catch rate (kg per pot-hour) was calculated for the 36 main sampling stations within each stratum. Length frequency distributions were determined for each fishing method separately (all areas combined) and for each sample stratum (methods combined). Because the area fished by a pot or line is unknown, the length frequency data have not been scaled to the population.

Von Bertalanffy growth curves were fitted to the aged subsample of blue cod using Proc Nlin, a non-linear least squares curve fitting procedure (SAS 1989). As no commercial length frequency data are available for blue cod within the Marlborough Sounds, the 1996 survey length frequency data were combined with the weight and length at age data to estimate the age frequency distribution of the 1996 survey data. Data from the five strata were summed and weighted by the total weight of fish caught per stratum.

The yield-per-recruit for blue cod was estimated for the current minimum legal size (MLS) of 28 cm and for several management options. Details of the procedures followed are given in Appendix 1.

Results

Of 247 stations completed (Table 2), 207 were potting stations and 40 were line fishing stations. The station positions and catch data are given in Appendix 2. Line fishing stations at the Te Akaroa site (5G) were not completed because of timing constraints and they were surveyed on 16 December 1996. Although these data are listed in Appendix 2, they have not been included in the analysis. One cod pot was lost at Bulwer and the site was re-sampled. All other planned stations in the remaining strata were occupied.

Catch composition

Blue cod were taken at 205 of the 247 stations, and made up 71% (by weight) of the total survey catch of 1.1 t (Table 3). A total of 1867 blue cod were caught, 1369 males and 498 females. Carpet shark represented 10% and conger eel 9% of the catch by weight. The remainder of the catch comprised 12 species (Table 3) and made up a minor proportion of the landed weight. The size range and numbers taken of the major species are given in Table 4.

Catch rate

By method. Catches from the line fishing stations (Table 5) were low: 135 blue cod (88 males and 47 females, i.e., 68% males) were caught. A wide range of sizes of fish was caught from 16 to 38 cm (Figure 3). From the pot fishing stations (Table 5), a total of 1732 blue cod were caught (1281 male and 451 female) of which 75% were males. The modal length of pot-caught fish (Figure 3) is similar to that of line-caught fish, which suggests that similar sampling bias operates for both fishing methods. Mean lengths by fishing method are given in Table 5.

By stratum. The mean CPUE (catch per unit effort, expressed as kg per pot-hour fished) was examined for the 36 main potting stations in each stratum (Figure 4). For 1996, CPUE was highest for the DURV stratum (7.4 kg per pot hour) and lowest for IPEL (0.9 kg per pot hour). This low catch rate in IPEL is reflected in the high number of zero catches (zero catch occurred in 22 of the 44 stations – *see* Appendix 2), and is strongly suggestive of local depletion through the effects of high fishing pressure. The CPUE for EOPE and OPEL was comparable, and similar to the catch rates in the 1995 survey.

Length frequency

The unscaled length frequency distribution data (all methods combined) are shown in Figure 5. The larger length classes (greater than, or equal to 30 cm) tended to be dominated by males, whereas the smaller length classes (less than 29 cm) tended to have a more even sex ratio. The Pelorus strata had fish of 28–30 cm modal length whereas fish in the D'Urville stratum had a modal length of 30–32 cm. Smaller females were commonly found in IPEL and MPEL, whereas few small blue cod were caught in the DURV stratum. Few large fish (30 cm or over) were caught in the IPEL stratum.

The mean size (*see* Table 5) of both male and female blue cod increased from IPEL (29.1 cm for males, 24.1 cm for females) and MPEL (29.0 cm for males, 24.1 cm for females) to the two outer sounds strata: EOPE (31.0 cm for males, 26.6 cm for females) and DURV (31.8 cm for males, 27.7 cm for females). This is also suggestive of high fishing pressure in Inner Pelorus Sound.

Comparisons with 1995 sampling in OPEL and EOPE. The 1995 and 1996 length frequency data for OPEL and EOPE are shown in Figure 6. The length frequency distributions between the two years are similar for each area. From the movement in modal peaks for the EOPE data, a strong year class appears to be moving through the fishery. A growth rate of 1–2 cm per year is suggested for larger (30 cm and over) blue cod.

Sex ratio

Male blue cod were more common in all strata sampled during 1996. The overall percentage of males by sampling stratum (Table 6) varied from 66% in OPEL to 80% in EOPE. No consistent trends could be determined in the sex ratio data by size class.

Length at sexual maturity

The range of gonad maturity stages of male and female blue cod by length is given in Figure 7. The minimum length of male blue cod with stage 4 gonads ranged from 23 cm (DURV) to 26 cm (MPEL). Mature females ranged from 21 cm (OPEL) to 26 cm (EOPE). Running ripe fish (stage 4) were recovered in all strata. The paucity of spawning fish in IPEL, due perhaps to the low numbers sampled, may reflect heavy fishing pressure.

From Figure 8, a greater proportion of pre-spawning and spawning fish was found in DURV, whereas most fish in IPEL were not in spawning condition. This suggests that a pattern of increasing ripeness occurs (from stage 1, 2 to stage 3, 4) from IPEL to DURV.

Length and weight

The length frequency data for each survey year (Appendix 3) are very similar. Data have been combined (Figure 9) to derive overall length-weight regressions for males in the size range from 15 to 55 cm and for females from 12 to 45 cm.

Age and growth

A total of 250 otoliths, representing up to six blue cod per 1 cm size and sex class from 12 to 52 cm, was aged. Age estimates (Table 7) from the two readers showed good agreement, with a trend in underestimation apparent, particularly for older fish. Of the otoliths read, 84% differed by 1 year or less. Both readers noted the high variability in age estimates for males (Figure 10).

Growth curves. Von Bertalanffy growth parameters are shown in Table 8. Growth curves were fitted using the estimated length-age and length-weight parameters: males grow faster both in length (Figure 10) and in weight (Figure 11) than females. The poor fit of data to the growth curve for males is indicated by the spread of data points in Figure 10. The standard error of the estimate of L_∞ for males (43.511 in Table 8) was 11.677, and for females (38.072 in Table 8) was 1.780.

Age frequency distribution. The 1996 length frequency data were combined with the age-length key to estimate the numbers at age in the survey area (Table 9). The age structure was dominated by fish 6–7 years old. Up to age 5, sexes are equally abundant. From ages 6 to 9, males are dominant, and thereafter, sexes are equally abundant. It is unclear whether this is due to gear selectivity or to recent poor recruitment.

Natural mortality. Estimates of natural mortality (*M*) of 0.27 yr^{-1} for males and 0.24 yr^{-1} for females (*see* Table 9) have been obtained by assuming that 1% of a cohort of males reaches 17 years (A_m) and that 1% of a cohort of females reaches 19 years, using the formula

$$M = -\frac{\log_e(0.01)}{A_m}$$

(*see* Annala & Sullivan 1997). For modelling purposes it is assumed that all surviving males and females die at these ages.

Yield-per-recruit. The input parameters used for the yield-per-recruit (YPR) analysis are given in Table 8. The catch equations and modelling approach are given in Appendix 1. It was assumed that each cohort of fish contains equal numbers of males and females at age 4, but that half of the females (one quarter of the cohort) become males during their sixth year. It is likely that this is an underestimate of the variability in the sex reversal process as protogyny may be influenced by fishing pressure, but there are insufficient data on which to base a more complex model. For modelling purposes, it is assumed that at age 6 the protogynous fish have a mean length intermediate between that of the male and female growth curves, but that thereafter they follow the male growth curve (*see* Figure 10).

Yield per recruit estimates have been made for various levels of fishing mortality and various minimum legal sizes (MLS) (*see* Appendix 1). It is assumed that the same fishing mortality applies to all ages and both sexes. Fishing-induced mortality on fish under the MLS is assumed to be zero (i.e., small fish returned to the sea all survive). The distribution of size at age (by sex) was obtained by applying the age -ength key to the length frequency sample. For various values of MLS, the proportion of fish greater than or equal to the MLS (partial recruitment factor) was calculated (Figure 12). The effects on the estimates of any selective removal of larger fish by current fishing has been ignored. The relatively small subsample of aged fish resulted in an implausible set of partial recruitment estimates. For modelling purposes, the estimated partial recruitments have been replaced by plausible and consistent straight line relationships (*see* Figure 12).

Figure 13 shows the yield-per-recruit estimates for various values of F and for the partial recruitment factors corresponding to minimum legal sizes of 25, 28, 30, and 33 cm. These estimates are the weights in kilograms obtained by applying a constant fishing mortality to a stock at equilibrium per blue cod attaining 4 years.

The highest yield per recruit was obtained at the smallest MLS (28 cm), which suggests that the maximum yield is obtained by catching fish as soon as they have attained an age of 4 years. Estimates of $F_{0.1}$ yield for these minimum legal sizes are:

$F_{0.1}$	cm
0.32	25
0.37	28
0.41	30
0.49	33

Discussion

Blue cod pot CPUE provides a useful index of relative abundance in the Marlborough Sounds. There were large differences between lightly fished and heavily fished strata. CPUE was low in the inner sounds (IQCH in 1995, IPEL in 1996) and high in the outer areas of both sounds (OQCH, EQCH, OPEL, and EOPE). CPUE was highest in the remote D'Urville Island stratum sampled during 1996. Similar patterns occur in relative abundance between 1995 and 1996 for the OPEL and EOPE strata and these trends are consistent with the concerns of overfishing and local depletion in the inner Marlborough Sounds raised by many groups of fishers.

Pot CPUE data may be affected by the effectiveness of the fishing gear used (Furevik 1994). Entry and escapement behaviour is closely related to pot design (Furevik 1994, Fogarty & Addison 1997). Pot catching efficiency, in terms of species composition and size of fish, is highly species specific

(Furevik 1994) and may be influenced by mesh size, soak time, behaviour of fish inside the pot, state of the tide, and the bait used (Fogarty & Addison 1997). Whitelaw *et al.* (1991) found that only 60% of fish that entered commercial traps were retained during a 1–2 hour soak time. Fogarty & Addison (1997) reviewed pot fishing model and noted that catch rate was not generally a linear function of soak time, but a complex interplay of capture and escapement processes. Pot design, fishing time, bait, and soak time were standardised for both survey years. As size selectivity appeared to be consistent (indicated by the similarity in size distribution and mean size between potting and line fishing methods), it is assumed that a similar catching bias operated between fishing years and fishing methods.

Pot catching efficiency may also be influenced by the radius within which fish are attracted to the bait (Eggers *et al.* 1982) and trapped fish may attract other fish to the pots (Fogarty & Addison 1997). In a pilot study of pot effectiveness (Blackwell *et al.*, unpublished results) a correlation of 0.98 was determined, from 15 replicate pots, between the number retained and the mean density of blue cod 0–10 m from the pot as determined by diver observation of four transects per pot. Blue cod appeared to be attracted to the pots from a distance of 30–40 m. From the video camera observations of the pots, little aggressive behaviour was observed, in contrast to other studies (Furevik 1994), and escapement appeared to be low. The pots retained a wide size range of fish — blue cod of 14–51 cm as well as triplefins and blennies.

The length frequency data also indicate that high fishing pressure occurs in the inner Marlborough Sounds as an increase in mean size occurred along a gradient from Inner to Outer Pelorus and D'Urville Island in 1996 and similar trends can be seen in the 1995 data (Blackwell 1997b) for Queen Charlotte Sound.

Few females were caught and few large females were sampled in the 1995 and 1996 September potting surveys, which contrasts to data from previous summer trawl surveys of Tasman Bay (Drummond & Stevenson 1995a, 1995b, 1996, Stevenson 1998). Length frequencies in 1994 were bimodal and dominated by females in length classes 16–45 cm. In the 1995 and 1997 surveys, more females were recovered overall, but they were smaller than in 1994 (16–39 cm in 1995 and 24–43 cm in 1997).

The apparent lack of younger cohorts observed during the April 1995 and 1997 trawl surveys and from the 1995 and 1996 potting surveys contrasts with the 1994 survey data and suggests that recruitment may be variable, or that migration may occur out into deeper waters (Rapson 1956, Robertson 1973). Evidence for such migration of blue cod in the Marlborough Sounds is equivocal. Rapson (1956) found spawning blue cod on the Trio Banks and proposed that they had migrated from the inner sounds to spawn. The presence of spawning blue cod in all strata during 1995 and 1996, the low numbers of females recorded from the Trio Banks, and the stage 1 males in the DURV stratum all suggest that the observed pattern of increasing gonad ripeness between IPEL and DURV relates to timing differences in spawning rather than to migration. Mace & Johnston (1983) found that most blue cod remained close to where they had been tagged and none of the fish larger than 30 cm had moved away.

Blue cod are generally considered to be protogynous hermaphrodites (Rapson 1956, Mutch 1983, Pankhurst & Conroy 1987), though little research has been carried out on the nature and extent of such a sex change. Shapiro (1986) and Siau (1994) noted that in most protogynous species the transition from ovary to testis occurred outside the breeding season, usually soon after spawning. Blue cod gonads were clearly differentiated during September 1995 and 1996, which represented the peak of the spawning season. Running ripe fish were present in all strata during both survey years.

Sadovy & Shapiro (1987) noted that some protogynous species contain both primary and secondary males, the latter derived from females that change sex after initial sexual maturity as males. Where the proportion of primary males is high, bimodality in the size frequency distributions is obscured as males occupy all size ranges. Primary males may form up to 50% of such a population. Many of the males sampled in IPEL and MPEL were at a low stage 1 of gonad maturation for their length, in comparison to DURV where most males were sexually mature (stages 3 and 4). Some of these immature males may have previously matured as females, but detailed histological examination is required to determine the proportion of such secondary males in the population.

If blue cod do change sex from males to females, the change may be related to length, rather than to age. The variability in the length at age data for males suggests that such a change may be influenced by other factors such as the overall density of blue cod and fishing mortality, sex ratio and differential growth rates, and natural mortality, as well as by sex or age-related differential migration (Cole & Robertson 1988). The interactions of these factors may be complex (Sadovy & Shapiro 1987, Hunstman & Schaaf 1994) and protogyny may occur only under certain conditions. As sex change is likely to occur outside the spawning season (Sadovy & Shapiro 1987), histological sampling of gonad condition and maturity may be required throughout the year to determine the level of protogyny in blue cod. Further tagging work is required to determine the existence of differential migration of blue cod, and the possible effect on the age and sex structure of the Marlborough Sounds blue cod population.

A conservative estimate of the minimum size at sexual maturity was obtained by determining the minimum size at which mature, running ripe (stage 4) gonads occur (23–26 cm for male, 21–26 cm for females). From the proportions of gonad maturation, an increase in ripeness is suggested from the Inner Pelorus, through the Outer Sounds, to D'Urville Island. As no stage 5 gonads were observed during September 1996, spawning may have been later than in 1995.

Unvalidated age estimates from the survey data extend the maximum ages from 12–17 years (Annala & Sullivan 1997) to 20 years for females and 11 years for males. The resulting estimates of M of 0.24 yr^{-1} for females and 0.27 yr^{-1} for males are lower than previous estimates of 0.27–0.38 yr^{-1} (Annala & Sullivan 1997). The break and burn method of otolith preparation used in the earlier studies (Johnston & Clarke 1982) may have an error of $\pm$ 2 years in comparison with the thin section method (P. Horn, NIWA, Nelson, pers. comm.). As differential growth rates occur between male and female blue cod, aggregated age-at-length data as used by Johnston & Clarke (1982) and Rapson (1956) may be invalid.

The 1996 age frequency data indicate that similar numbers of males and females are present up to about 35 cm, which represents ages of 5+ for males and 6+ for females. Males are more common in age classes 6–9, but sex ratios are similar for age classes 10–14 years. Most older fish (over 15 years) are female because of their greater longevity. These data are consistent with a possible sex change at about 35 cm in length at age 6–8 years, but the sex ratios may be confounded by strong recruitment of 6+ fish.

The yield-per-recruit analysis suggests that for all maximum legal sizes considered, yield per recruit is maximised at a very large (infinite) fishing mortality. This is the consequence of growth from age 4 being slow relative to natural mortality and insufficient to compensate for losses from natural mortality. Maximum yield per recruit would be attained by catching fish as soon as possible after reaching 4 years of age. However, because the yield per recruit curves are very flat, a yield very close to the maximum could be achieved at moderate fishing mortality. Secondly, increasing MLS above 25 cm reduces yield per recruit, due again to the slow rate of growth after age 4. Protecting 25 cm fish does not result in higher yield because these fish do not grow fast enough to compensate for losses from natural mortality. These yield-per-recruit results can be considered preliminary, however, as they may be influenced by the effects of protogyny on growth and survival of male and female blue cod.

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Table 1: **Stratification used in the survey**

Stratum code	**Area**		**Location of area**
EOPE	4A1–4A3		Forsyth Island
	4B1–4B3		Chetwode Islands
	4C1–4C3		Clay Point
	4D1–4D3		Harris Bay
OPEL	5A1–5A3		The Reef
	5B1–5B3		Boat Rock point
	5C1–5C3		Katira Point
	5D1–5D3		Duffer's Reef
	5E1–5E3	*	Bulwer
	5F1–5F3	*	Camp Bay
	5G1–5G3	*	Te Akaroa
DURV	6A1–6A3		Rangitoto Islands
	6B1–6B3		West Trio Bank
	6C1–6C3		East Trio Bank
	6D1–6D3		Penguin Bay
	6H1–6H3	*	French Pass
IPEL	7A1–7A3		Jacob's Bay
	7B1–7B3		Mary's Bay
	7C1–7C3		Te Puraka Point
	7D1–7D3		Te Rawa Point
MPEL	8A1–8C3		Kauauroa Point
	8B1–8B3		Rams Head
	8C1–8C3		Maud Island
	8D1–8D3		Tapapa Point

* Denotes additional sampling site (see text)

Table 2 : **Numbers of stations sampled per stratum and site**

Stratum	Area		Region	Main pot sites	Extra pot sites	Line sites
EOPE	4		Extreme Outer Pelorus			
	4A	*	Forsyth Island	9	0	2
	4B	*	Chetwode Islands	9	0	2
	4C	*	Clay Point	9	0	2
	4D	*	Harris Bay	9	0	2
			Total	36	0	8
OPEL	5		Outer Pelorus			
	5A	*	The Reef	9	0	2
	5B	*	Boat Rock Point	9	0	2
	5C	*	Katira Point	9	0	2
	5D	*	Duffer's Reef	9	3	2
	5E	*	Bulwer	0	3	0
	5F	*	Camp Bay	0	3	0
	5G	*	Te Akaroa	0	3	0
			Total	36	9	8
DURV	6		D'Urville Island			
	6A		Rangitoto Islands	9	0	2
	6B		West Trio Bank	9	0	2
	6C		East Trio Bank	9	0	2
	6D		Penguin Bay	9	3	2
	6H	*	French Pass	0	3	0
			Total	36	6	8
IPEL	7		Inner Pelorus			
	7A		Jacob's Bay	9	0	2
	7B		Mary's Bay	9	0	2
	7C		Te Puraka Point	9	3	2
	7D		Te Rawa	9	3	2
			Total	36	6	8
MPEL	8		Mid Pelorus			
	8A		Kauauroa Point	9	0	2
	8B		Rams Head	9	0	2
	8C		Maud Island	9	3	2
	8D		Tapapa Point	9	3	2
			Total	36	6	8
Total				180	27	40

* Denotes stations resampled from 1995

***Table 3*: Species caught, and total and percentage occurrence at 247 stations**

Common name	Scientific name	Catch (kg)	Percent by weight	Occurrence by station	Depth (m) Min	Depth (m) Max
Blue cod	*Parapercis colias*	769.5	71.1	205	5	51
Carpet shark	*Cephaloscyllium isabellum*	105.2	9.7	32	13	51
Conger eel	*Conger verreauxi*	93.1	8.6	10	18	44
Red cod	*Pseudophycis bachus*	34	3.1	28	9	46
Octopus	*Octopus cordiformis*	30.2	2.8	11	7	37
Sea perch	*Helicolenus percoides*	24.8	2.3	29	11	49
Hagfish	*Eptatretus cirrhatus*	6.8	0.6	12	13	42
Tarakihi	*Nemadactylus macropterus*	5	0.5	10	11	40
Spotty	*Notolabrus celidotus*	3.5	0.3	17	9	27
Leatherjacket	*Parika scaber*	3	0.3	9	13	31
Barracouta	*Thyrsites atun*	2.5	0.2	1	27	27
Brittle star	*Pectinura maculata*	1.8	0.2	12	11	27
Eleven armed starfish	*Coscinasterias calamaria*	1.4	0.1	5	16	37
Bastard red cod	*Pseudophycis breviuscula*	0.6	0.1	1	15	15
Trumpeter	*Latris lineata*	0.6	0.1	1	18	18
Total landings by weight		1 082.0				

***Table 4*: Maximum and minimum lengths of main fish species caught**

Common name	Length min	Length max	Number caught
Barracouta	86	86	1
Blue cod	14	51	1 856
Bastard red cod	36	36	1
Leatherjacket	17	29	10
Red cod	22	59	51
Sea perch	21	35	37
Spotty	12	26	21
Tarakihi	20	31	18
Trumpeter	27	32	3

Table 5: **Numbers and mean length of blue cod caught by pots, by stratum and area, and the numbers and mean length of line caught fish per stratum**

Stratum	Area	Region	Numbers of blue cod			Mean length of blue cod			
			Males	Females	Total	Males	C.I. *	emale	C.I.*
EOPE	4	Extreme Outer Pelorus							
	A	Forsyth Island	35	3	38	32.14	1.40	28.00	3.04
	B	Chetwode Islands	51	8	59	30.68	0.92	26.25	1.44
	C	Clay Point	60	19	79	31.43	0.82	27.77	0.88
	D	Harris Bay	29	8	37	31.75	1.44	27.62	3.21
		Pots overall	175	38	213	31.41	0.54	27.43	0.90
		Lines overall	28	14	42	28.75	1.32	24.57	1.28
		Total	203	52	255	31.04	0.50	26.64	0.82
OPEL	5	Outer Pelorus							
	A	The Reef	54	26	80	30.85	1.21	26.92	1.76
	B	Boat Rock Point	44	42	86	30.16	0.81	27.57	1.06
	C	Katira Point	44	14	58	27.81	0.86	28.28	1.34
	D	Duffer's Reef	53	29	82	30.05	1.02	27.20	1.34
	E	Bulwer	6	3	9	27.83	2.40	23.66	2.40
	F	Camp Bay	5	7	12	33.00	3.62	30.42	2.56
	G	Te Akaroa	41	9	50	30.02	1.20	25.00	4.10
		Pots overall	247	130	377	29.85	0.46	27.32	0.68
		Lines overall	13	6	19	30.53	1.60	25.00	3.80
		Total	260	136	396	29.88	0.46	27.22	0.66
DURV	6	D'Urville Island							
	A	Rangitoto Islands	176	18	194	31.39	0.46	28.05	1.97
	B	West Trio Banks	142	56	198	31.82	0.64	27.89	0.58
	C	East Trio Banks	168	27	195	32.77	0..58	27.96	1.04
	D	Penguin Bay	104	59	163	31.78	0.74	27.86	0.90
	E	French Pass	6	5	11	32.00	2.78	27.80	1.60
		Pots overall	596	165	761	31.85	0.68	27.54	0.81
		Lines overall	43	21	64	30.60	1.06	26.05	1.01
		Total	639	186	825	31.86	0.28	27.69	0.42
IPEL	7	Inner Pelorus							
	A	Jacob's Bay	18	10	28	28.61	1.74	23.90	3.10
	B	Mary's Bay	33	15	48	28.12	1.18	23.00	1.82
	C	Te Puraka Point	11	4	15	33.36	3.40	30.50	3.68
	D	Te Rawa	6	2	8	29.66	1.52	26.00	6.00
		Pots overall	68	31	99	29.23	1.00	24.45	1.64
		Lines overall	3	1	4	28.33	0.66	12.00	0.00
		Total	71	32	103	29.19	0.97	24.19	1.68
MPEL	8	Mid Pelorus							
	A	Kauauroa Point	57	16	73	29.38	0.88	25.43	2.26
	B	Rams Head	39	11	50	29.15	1.26	24.72	2.38
	C	Maud Island	46	46	92	25.87	1.30	24.34	1.32
	D	Tapapa Point	53	14	67	31.24	0.94	26.50	2.04
		Pots overall	195	87	282	29.23	1.00	24.45	1.64
		Lines overall	1	5	6	29.00	0.00	26.80	2.02
		Total	196	92	288	29.01	0.60	25.02	0.90

* where C.I. = 2 s.e.

Table 6 **: Sex ratios of blue cod by length class**

Area	Location	Length (cm)	No. Males	No. Females	Percentage male
4	EOPE	<18	0	0	0
		19–30	95	49	66
		31–35	88	1	99
		>35	20	2	91
		Total	203	52	80
5	OPEL	<18	0	1	0
		19–30	143	110	57
		31–35	101	21	83
		>35	16	4	80
		Total	260	136	66
6	DURV	<18	0	0	0
		19–30	220	162	58
		31–35	330	23	93
		>35	89	1	99
		Total	639	186	77
7	IPEL	<18	0	2	0
		19–30	47	27	64
		31–35	20	3	87
		>35	4	0	100
		Total	71	32	69
8	MPEL	<18	1	4	20
		19–30	127	81	61
		31–35	56	6	90
		>35	12	1	92
		Total	196	92	68

Table 7 **: Frequency of agreement of all otolith ages between two readers by age. R1–R2, differences in ages between readers 1 and 2 (i.e., 0 implies exact agreement between the two readers)**

	Age recorded by reader 1																		
R1–R2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18+	Total
-2							1	1										1	3
-1		1	2	0	4	4	1	2			1	1							16
0	1	11	16	10	10	10	23	10	5	4	3	3	0	1	1	0	0	1	109
+1		2	4	8	5	1	11	19	6	9	3	1	1			1		3	74
+2					6	1	1	4	0	2	3	1				0	1		19
+3							1	4	2		2	1				2		1	13
>+3											1	2							3

***Table 8*: Estimates of biological parameters used in the YPR model. Protogynous fish are assumed to switch from female to male parameters during their sixth year as described in the text**

Parameter		Male	Female	Protogynous
von Bertalanffy, L_{inf}	cm	43.511	38.072 cm	
von Bertalanffy, k	cm	0.152	0.146	
von Bertalanffy, t_0	y-1	-0.600	-0.988	
Length-weight, a		0.007	0.117	
Length-weight, b		2.225	3.087	
Maximum age, am	y	17	19	
Natural mortality, M	y-1	0.270	0.240	
Proportion at age 4, p		0.500	0.250	0.250

***Table 9*: Estimated numbers at age in the survey area by combining the 1996 length frequency sample and age-length key**

	Male		Female	
Age	Frequency	c.v.	Frequency	c.v.
1	0.000	0.000	1.000	1.001
2	2.667	1.110	15.000	0.367
3	15.333	0.432	9.800	0.637
4	15.400	0.520	19.533	0.405
5	36.400	0.278	47.833	0.527
6	235.467	0.297	87.750	0.353
7	411.450	0.184	141.833	0.239
8	417.667	0.202	54.250	0.260
9	97.250	0.424	31.500	0.757
10	16.350	0.414	15.750	0.522
11	7.100	0.573	13.000	0.593
12	6.750	0.759	9.000	0.540
13	19.167	0.930	0.000	0.000
14	0.000	0.000	3.000	1.009
15	1.000	1.308	0.500	1.689
16	0.000	0.000	3.000	0.781
17	0.000	0.000	2.250	1.082

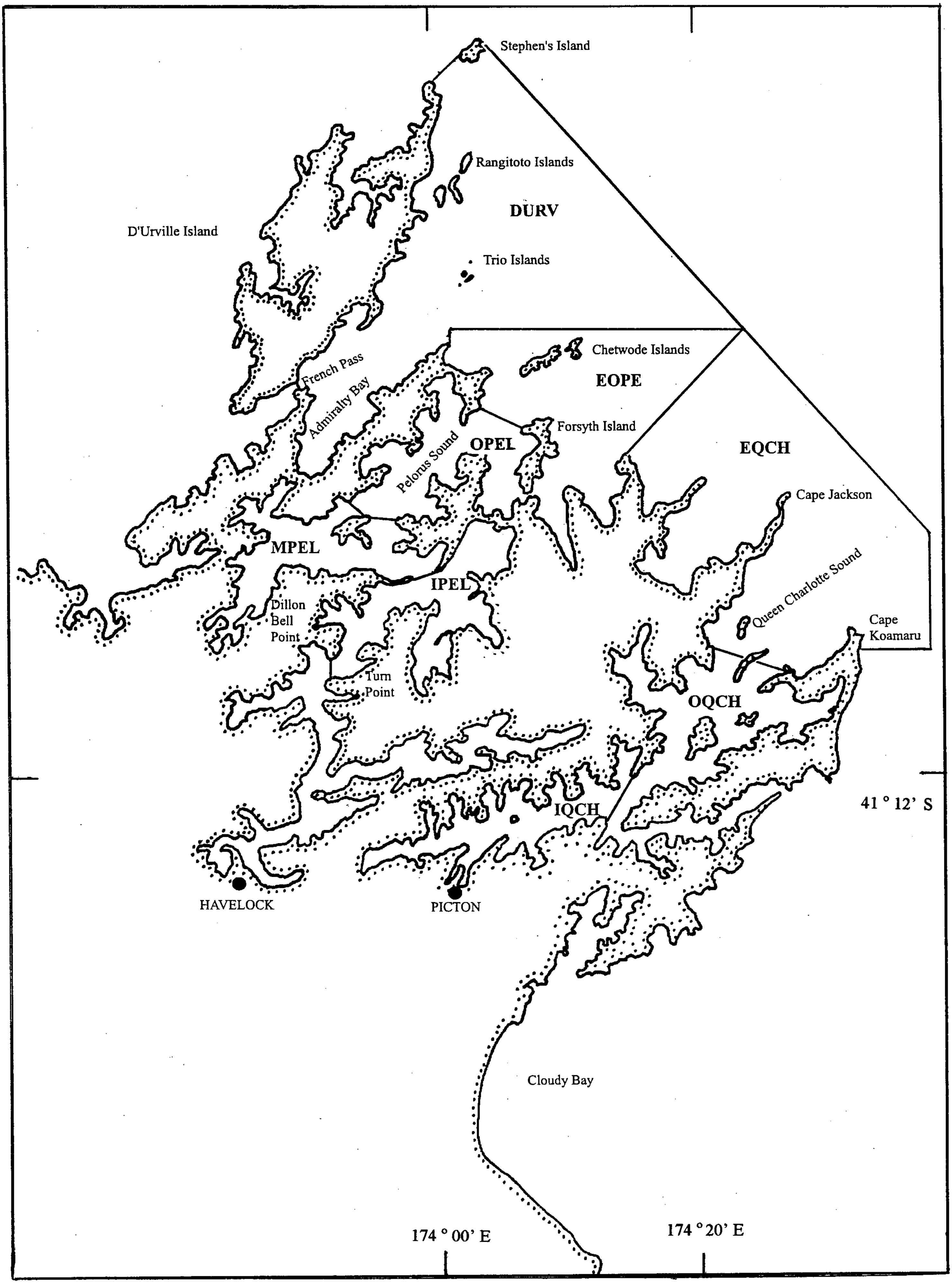


***Figure 1*: Marlborough Sounds survey area, showing strata:** DURV (D'Urville Island) EOPE (Extreme Outer Pelorus Sound, OPEL (Outer Pelorus Sound, MPEL (Mid Pelorus Sound), IPEL (Inner Pelorus Sound).

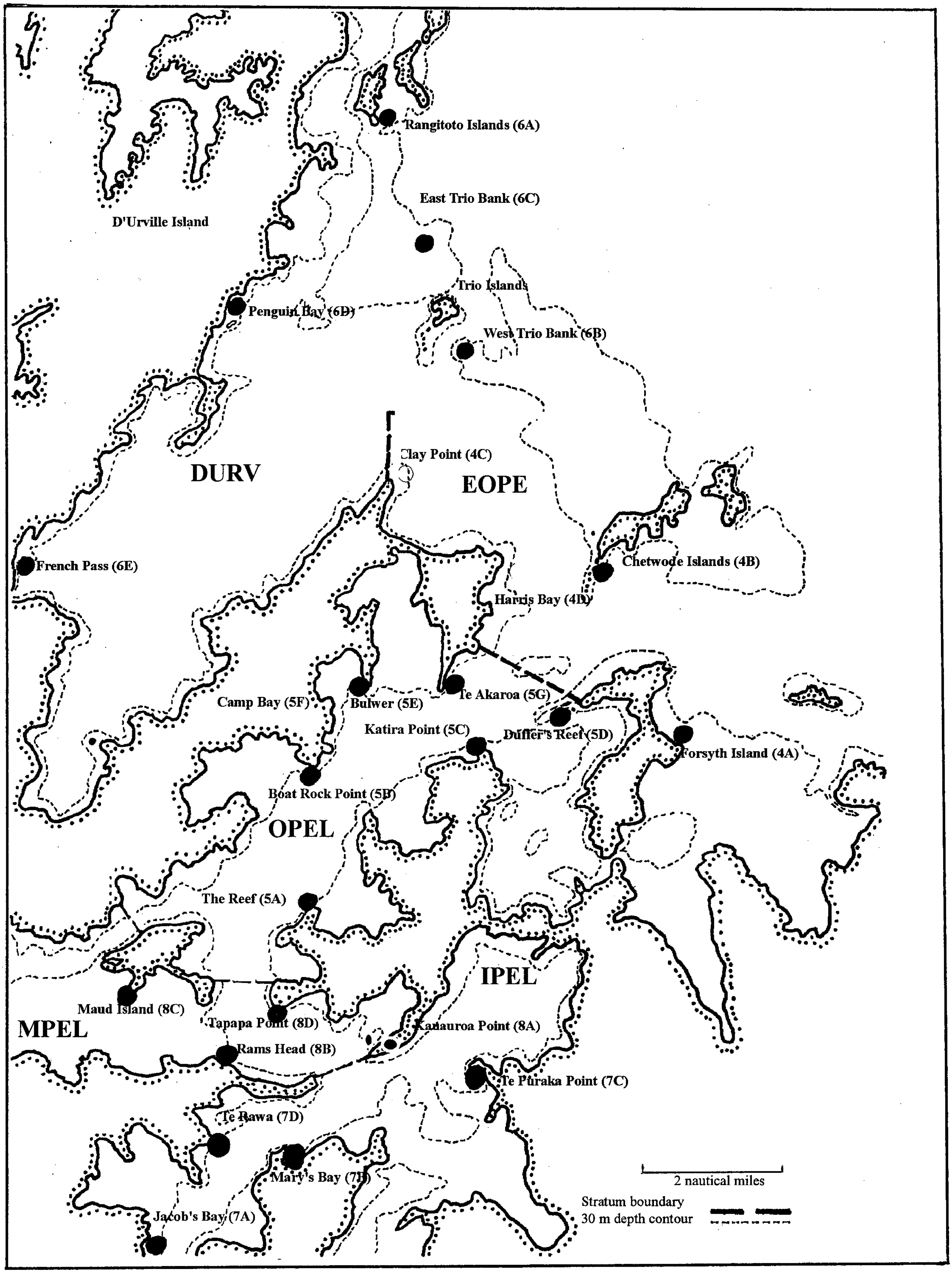


Figure 2: **Stratum boundaries and sampling areas**
Stratum codes are given in Figure 1.

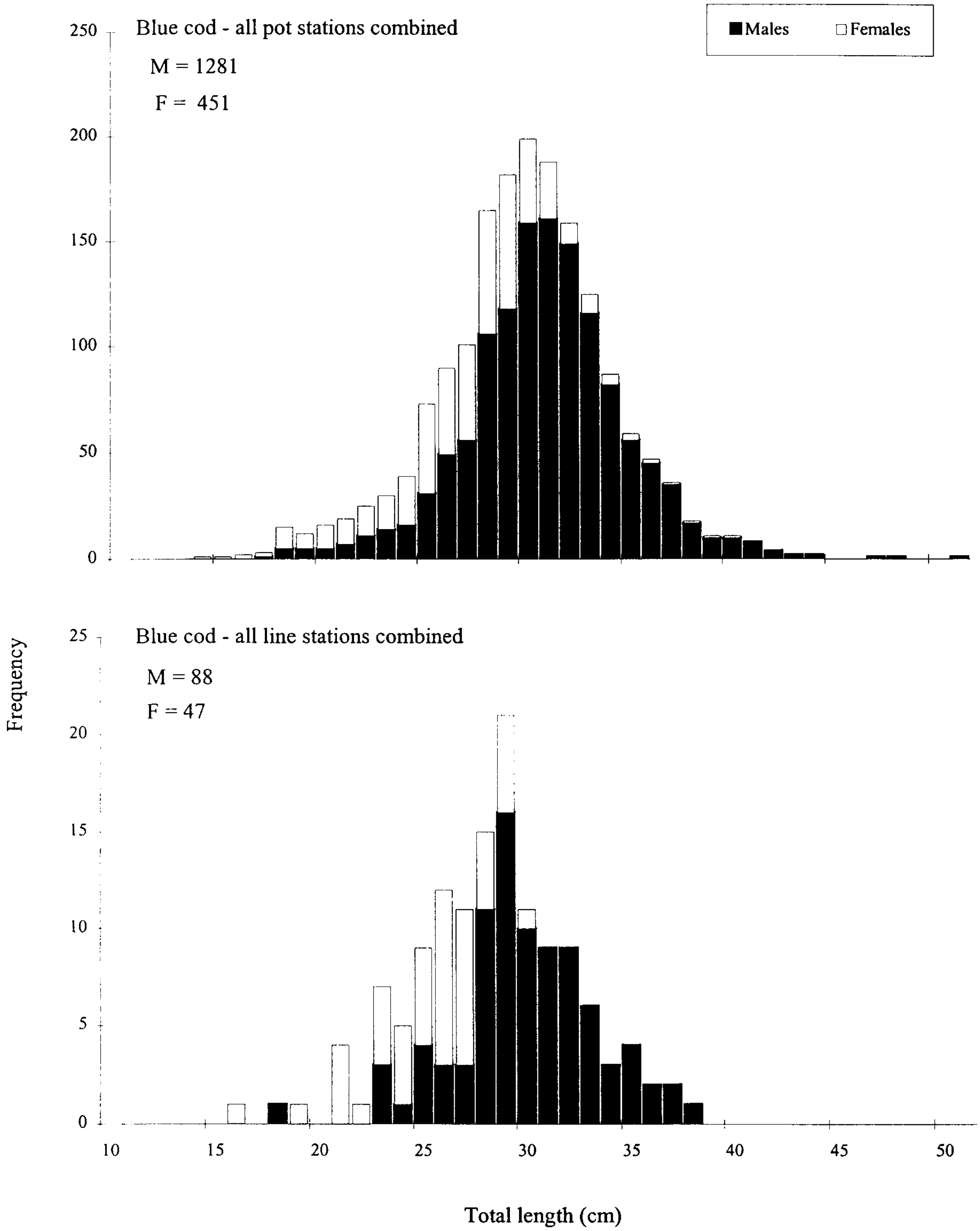


Figure 3: **Length frequency distribution of blue cod by fishing method. Frequency of male and female blue cod are actual numbers measured.**

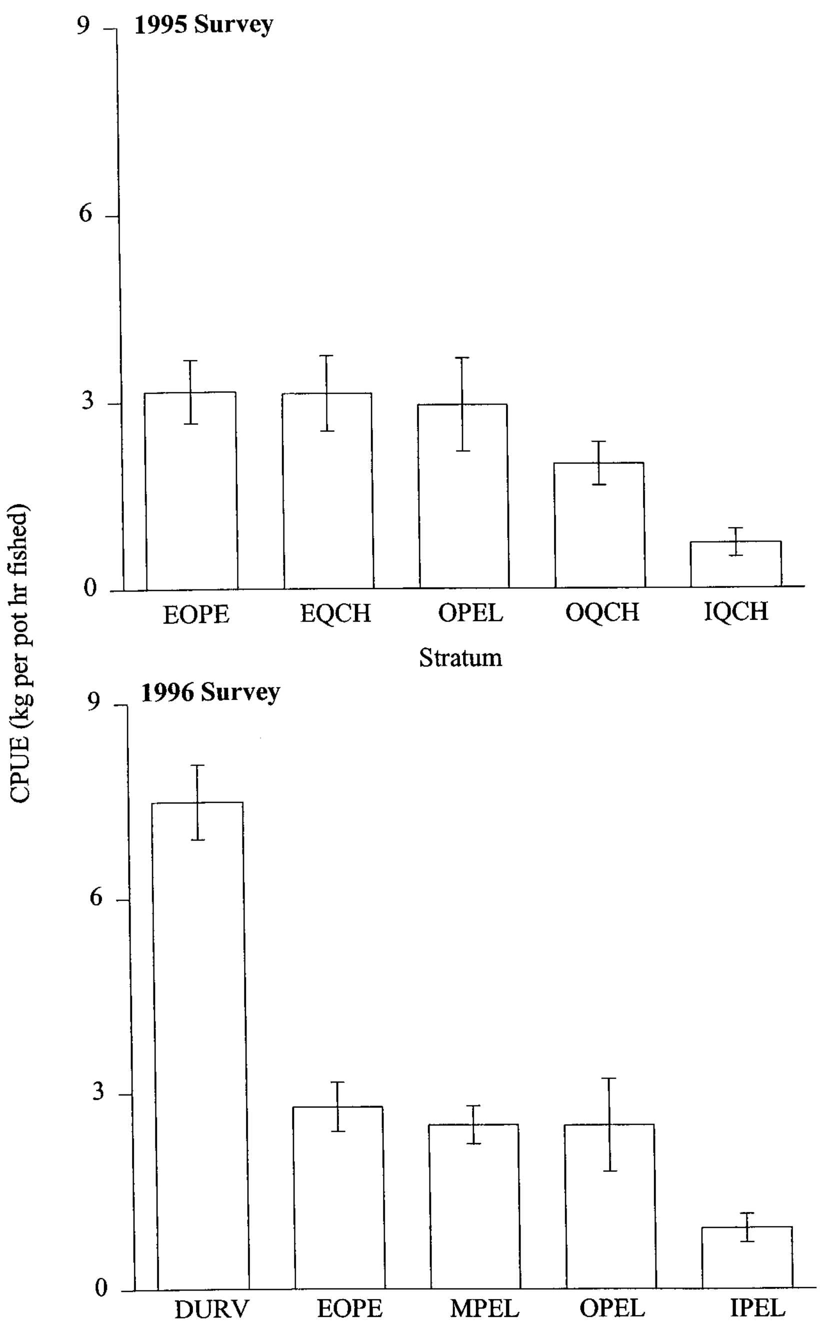


***Figure 4*: CPUE from 1995 and 1996 surveys. Stratum codes are given in Figure 1. Strata EOPE and OPEL were sampled in both survey years.**

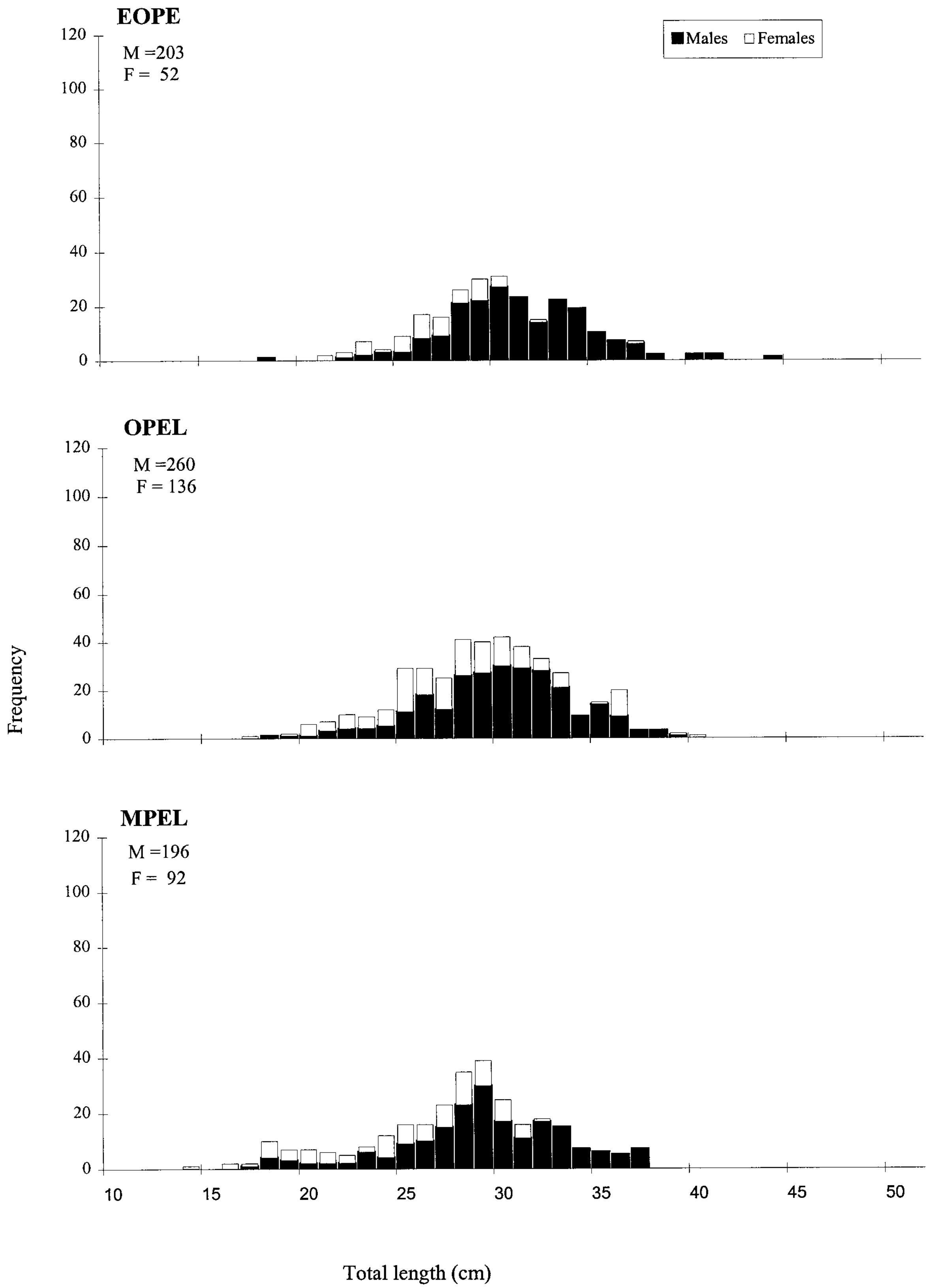


Figure 5: Length frequency distribution of blue cod by stratum, both methods combined. Frequency of male and female blue cod are actual numbers measured. Stratum codes are given in Figure 1.

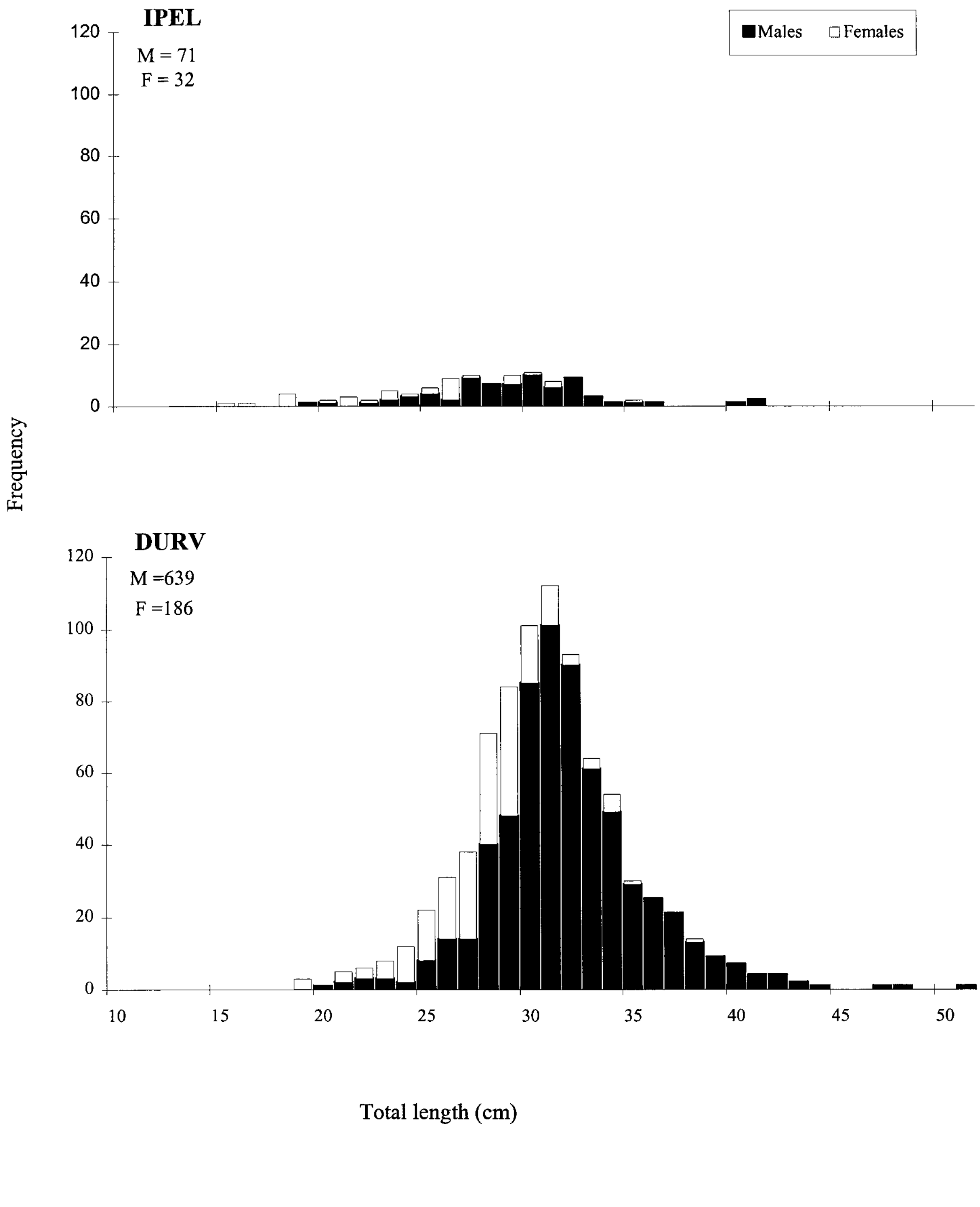


Figure 5:*—continued.*

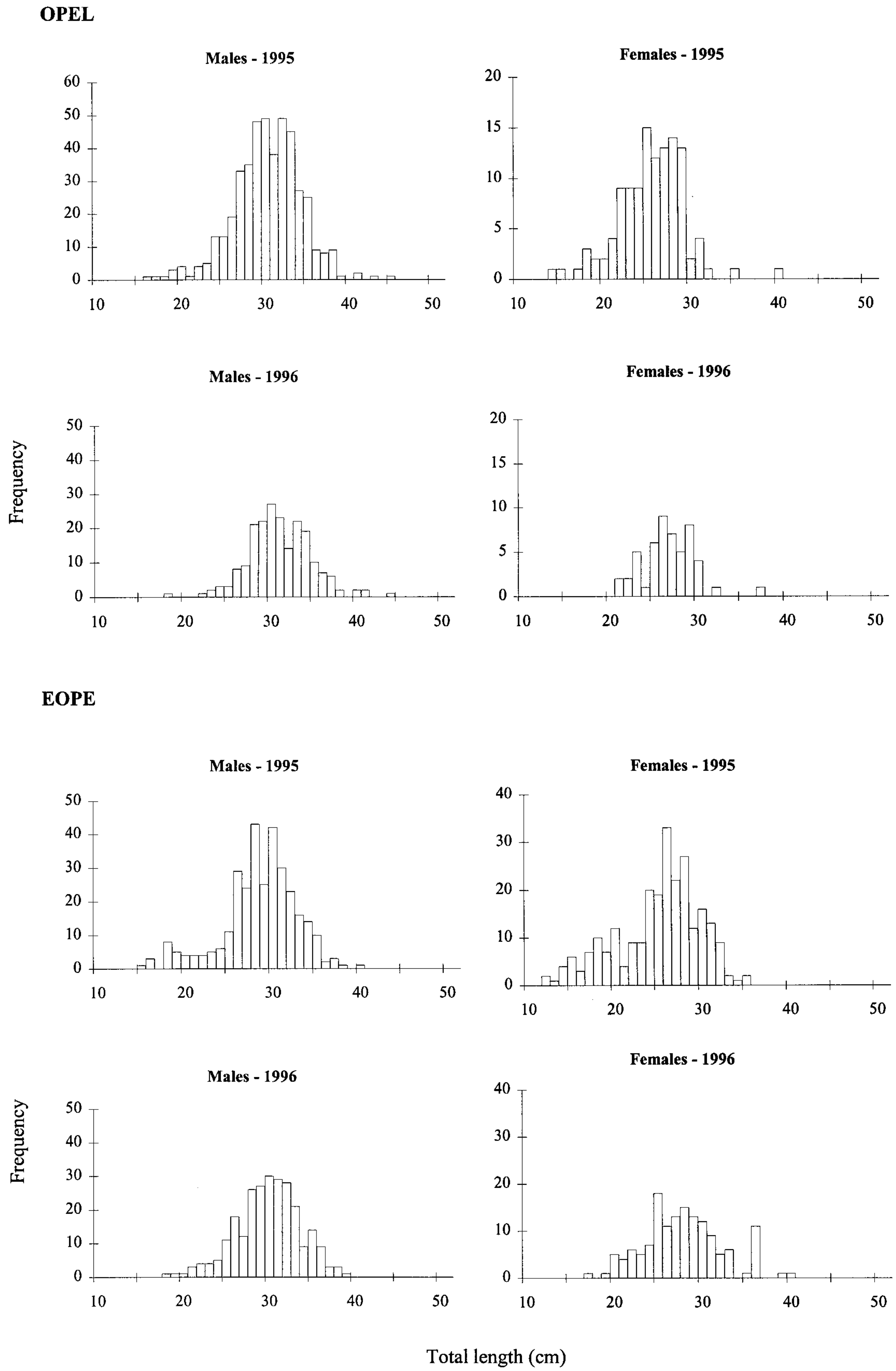


***Figure 6*: Length frequency distribution by sex for EOPE and OPEL.**
36 stations per stratum sampled in 1996 and 72 stations per stratum in 1995.
Stratum codes are given in Figure 1.

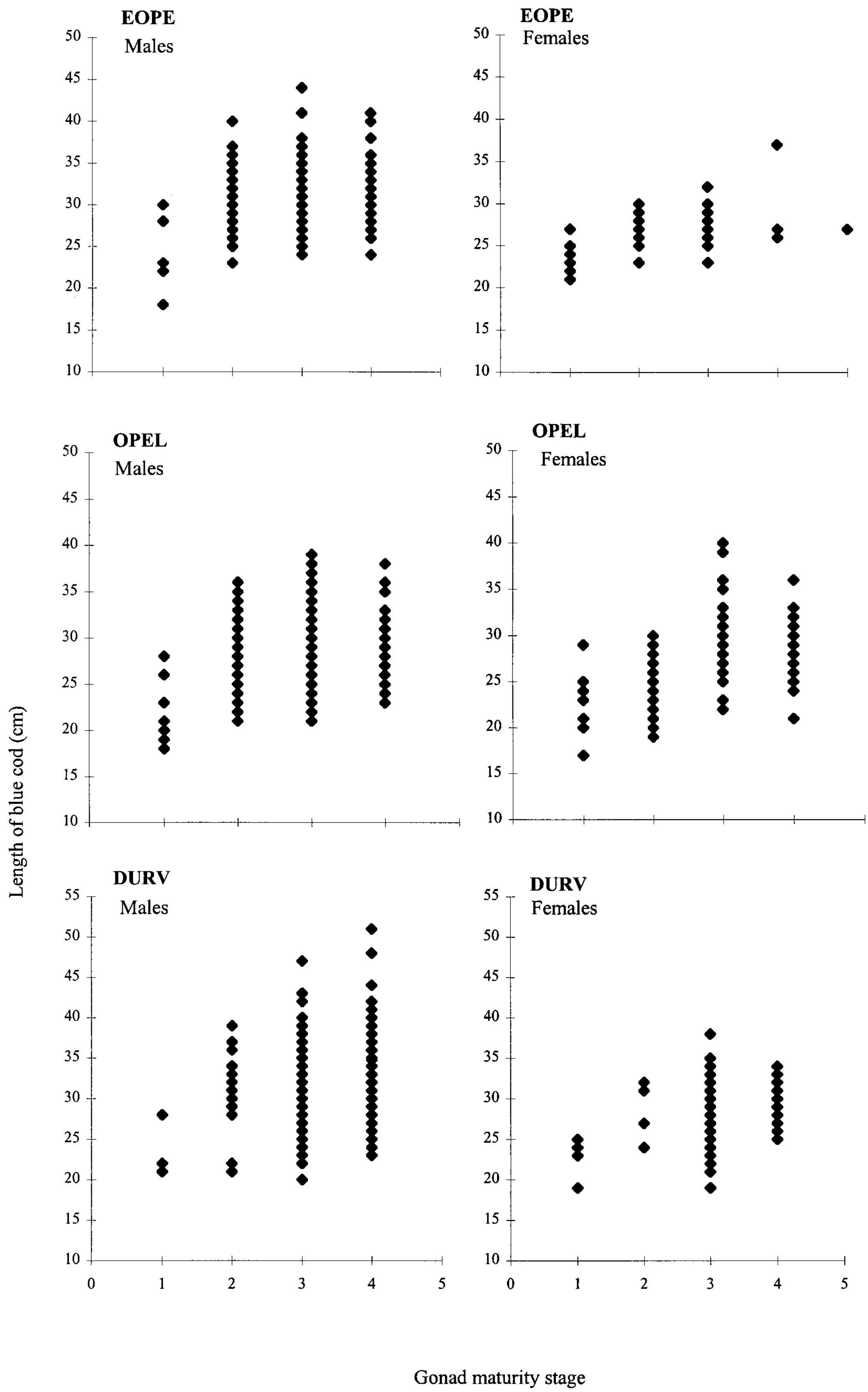


Figure 7: **Blue cod length and gonad maturity stage by sampling stratum. Stratum codes are given in Figure 1.**

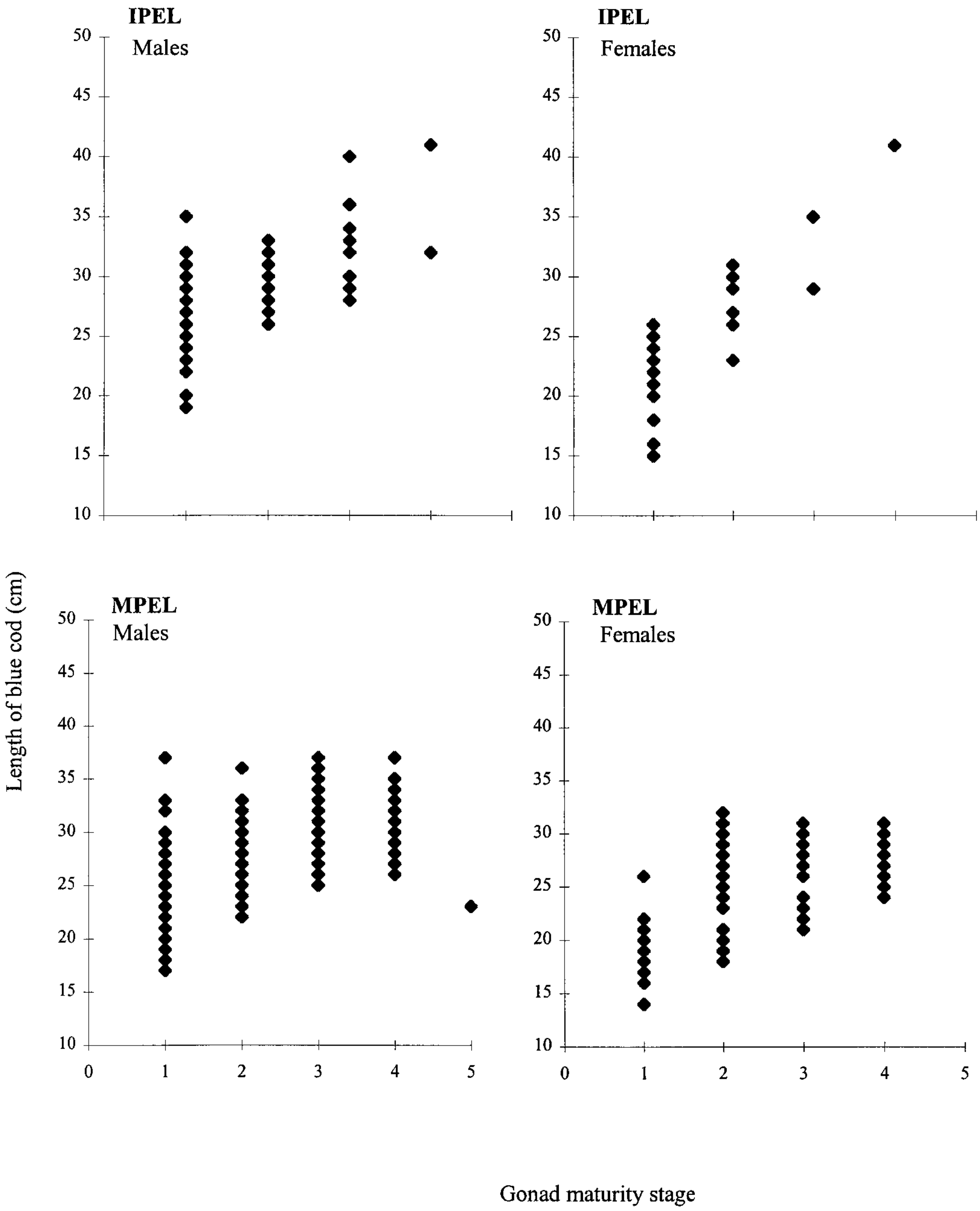


***Figure 7*: — continued.**

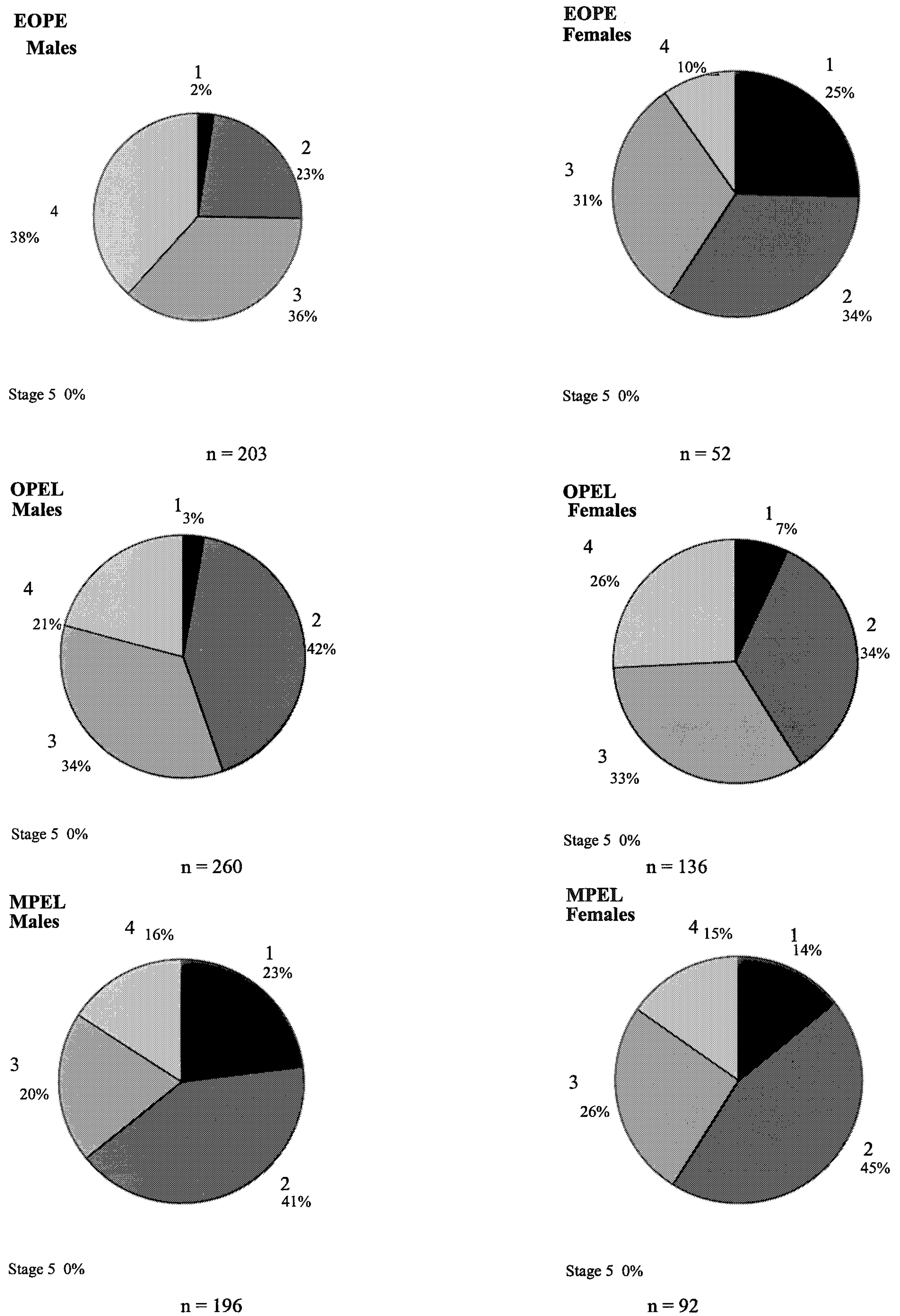


Figure 8: Relative sexual maturity stages by sampling stratum. Stratum codes are given in Figure 1.

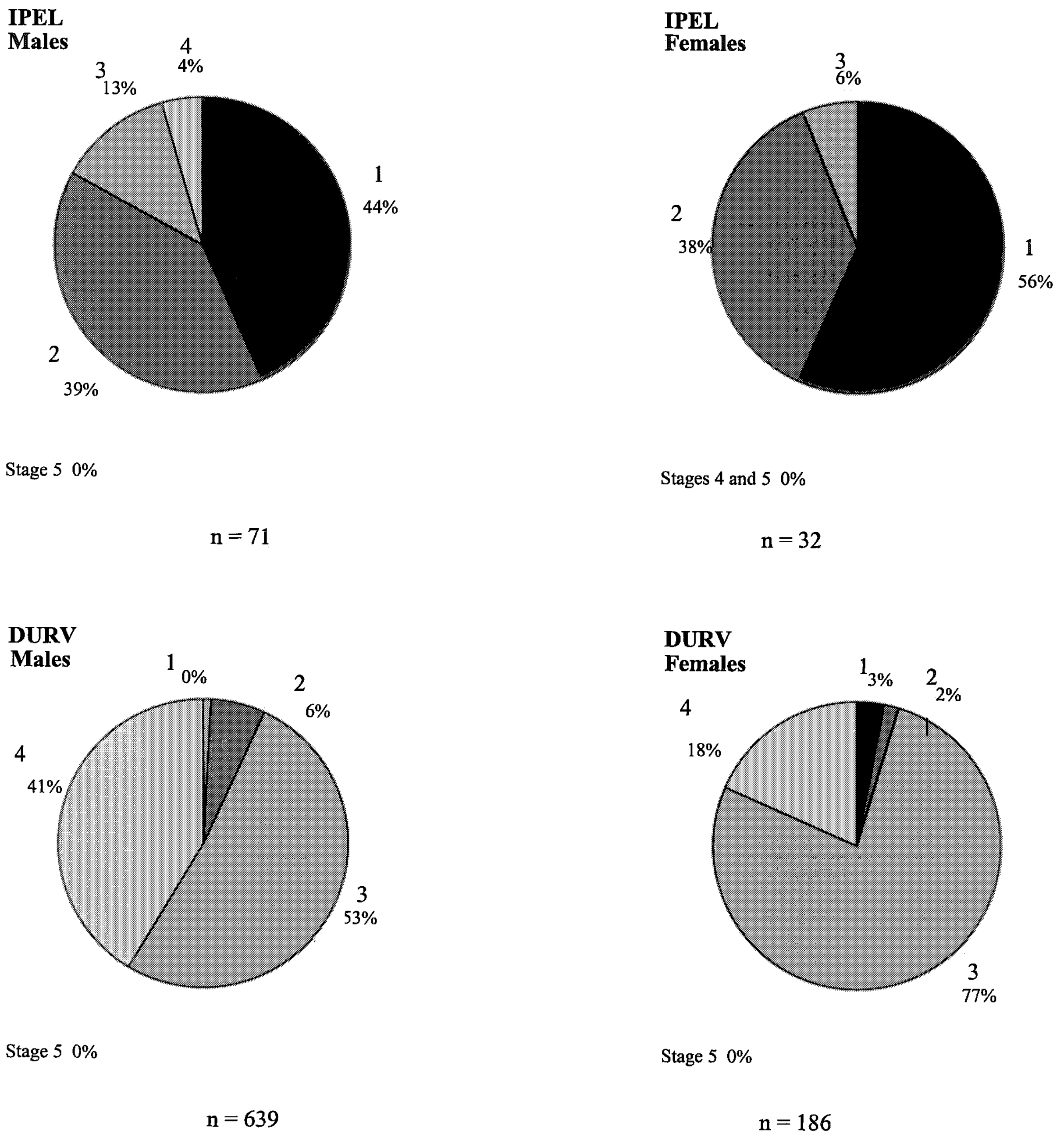


Figure 8: – ***continued.***

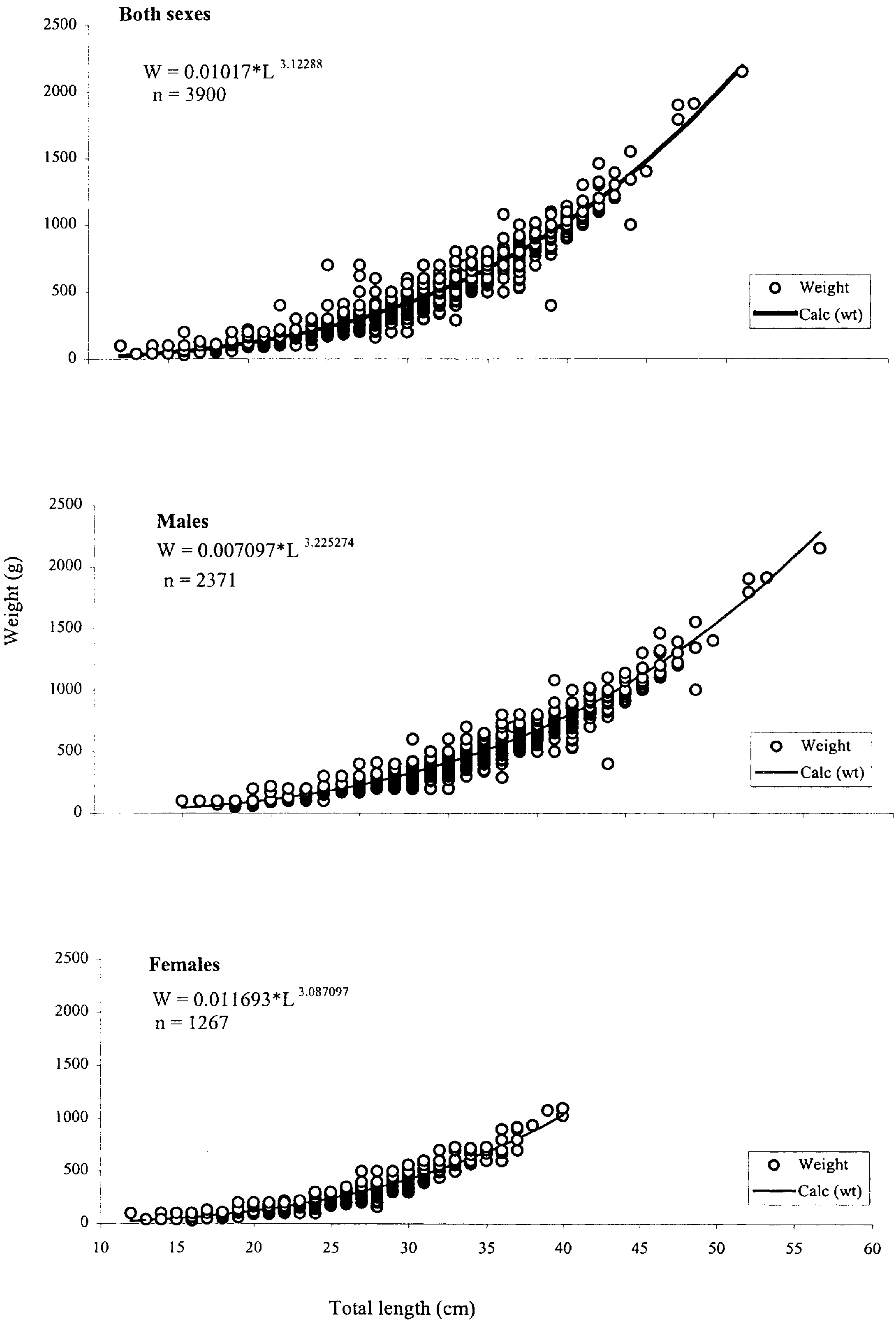


***Figure 9*: Length-weight relationships for 1995 and 1996 surveys.**

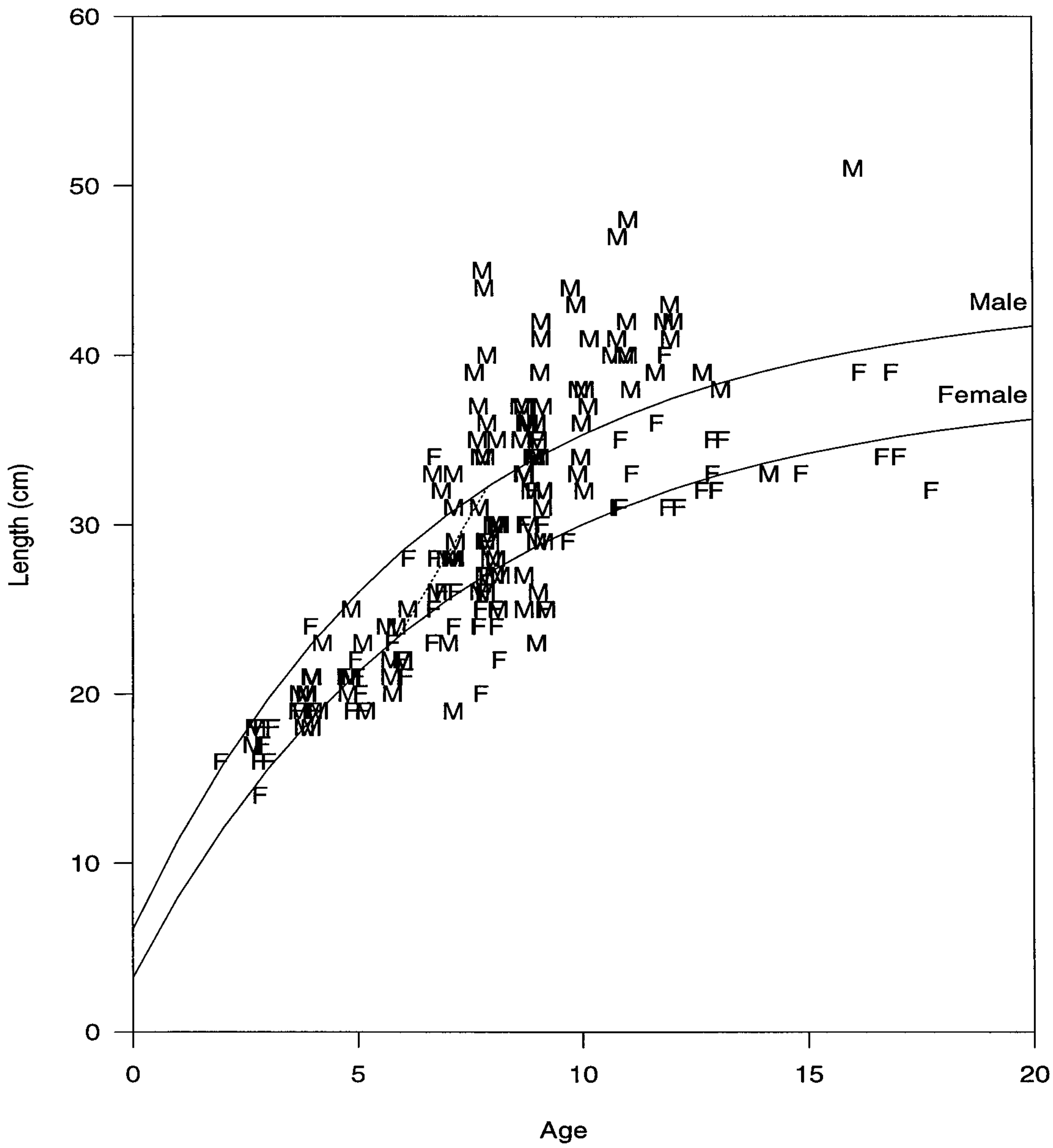


Figure 10: **Age subsample of blue cod. "M" denotes male and "F" denotes female. The sample was taken in September and all ages (y) are plotted with a decimal part of 0.9 (e.g. a fish of 5 complete years is plotted at age 5.9). Points have also been jittered within (-0.3, +0.3) y for separation. Male and female von Bertalanffy curves fitted to this data have been plotted. The dashed line indicates the modelled growth path of protogynous fish changing sex during their 6th year.**

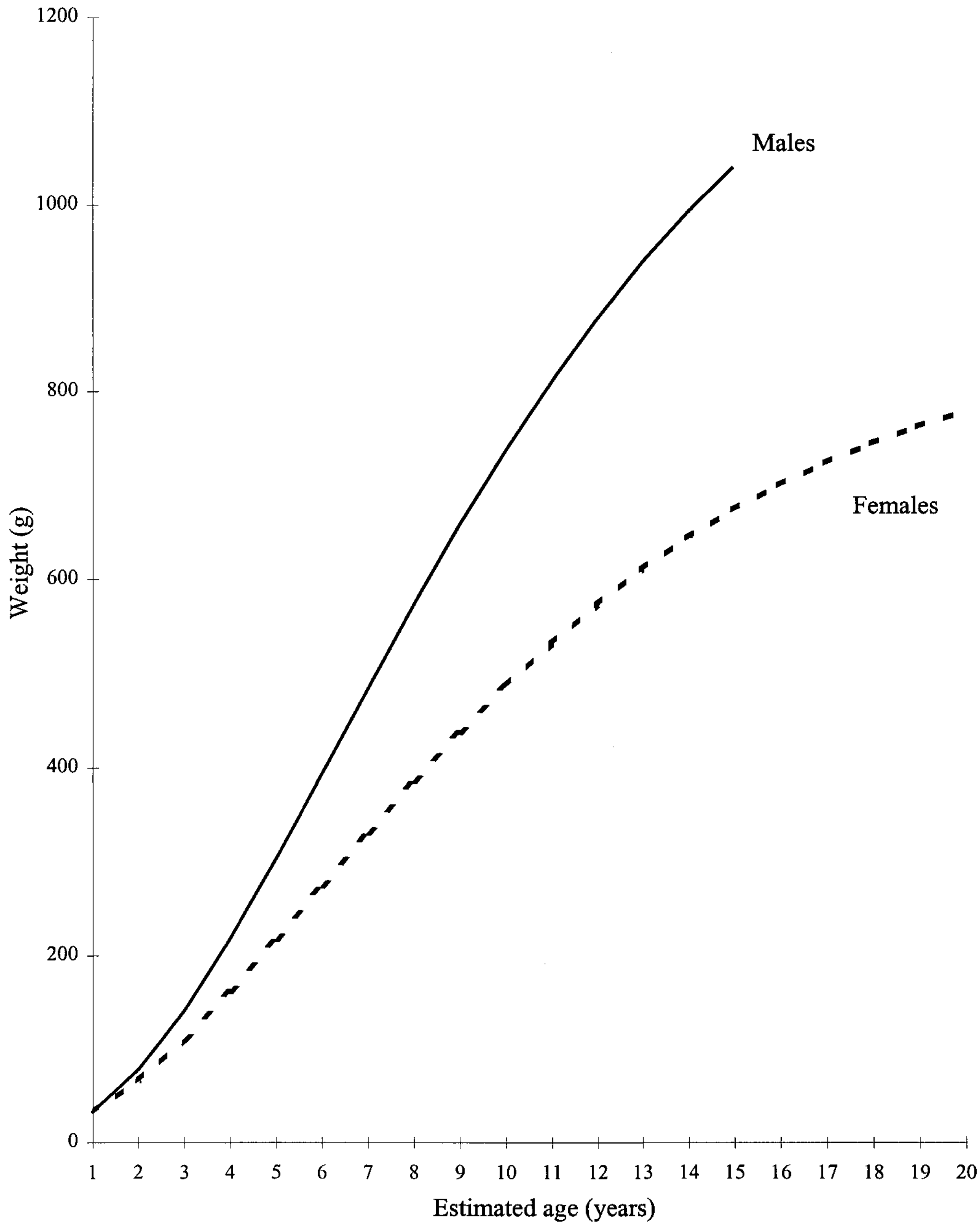
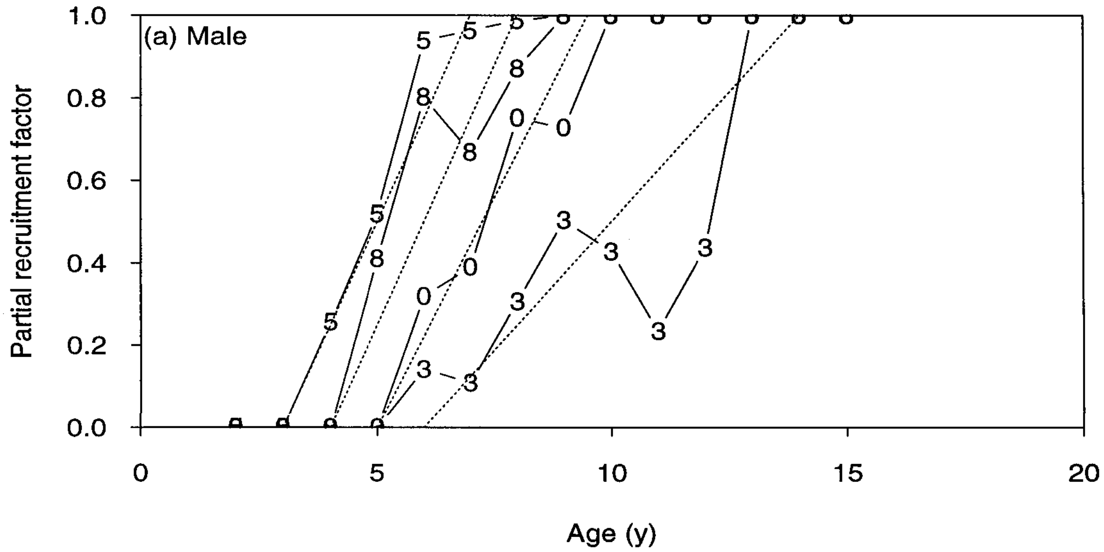


***Figure 11*: Weight at age relationship for the aged subsample of blue cod. The graph combines the Von Bertalanffy growth parameters and the length-weight relationship from the 1995 and 1996 survey years.**



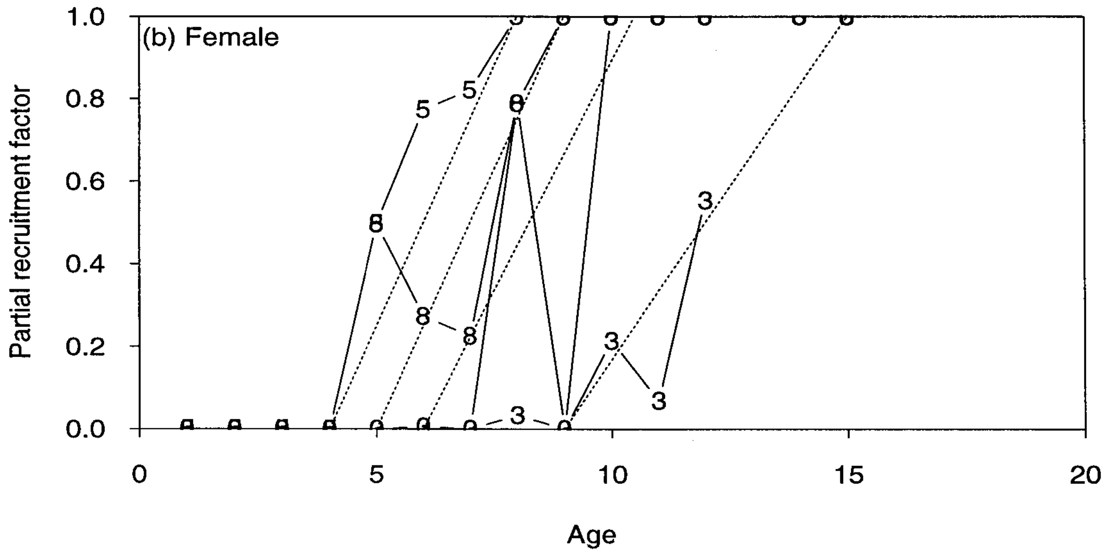


***Figure 12 (a), (b)*: Partial recruitment factors (proportion of fish in sample at least equal to the minimum legal sizes, MLS) by sex and age (y) for various MLSs. "5", "8", "0" and "3" denote MLS of 25, 28, 30 and 33 cm, respectively. The dashed lines are the corresponding partial recruitment factor relationships used to estimate yield per recruit.**

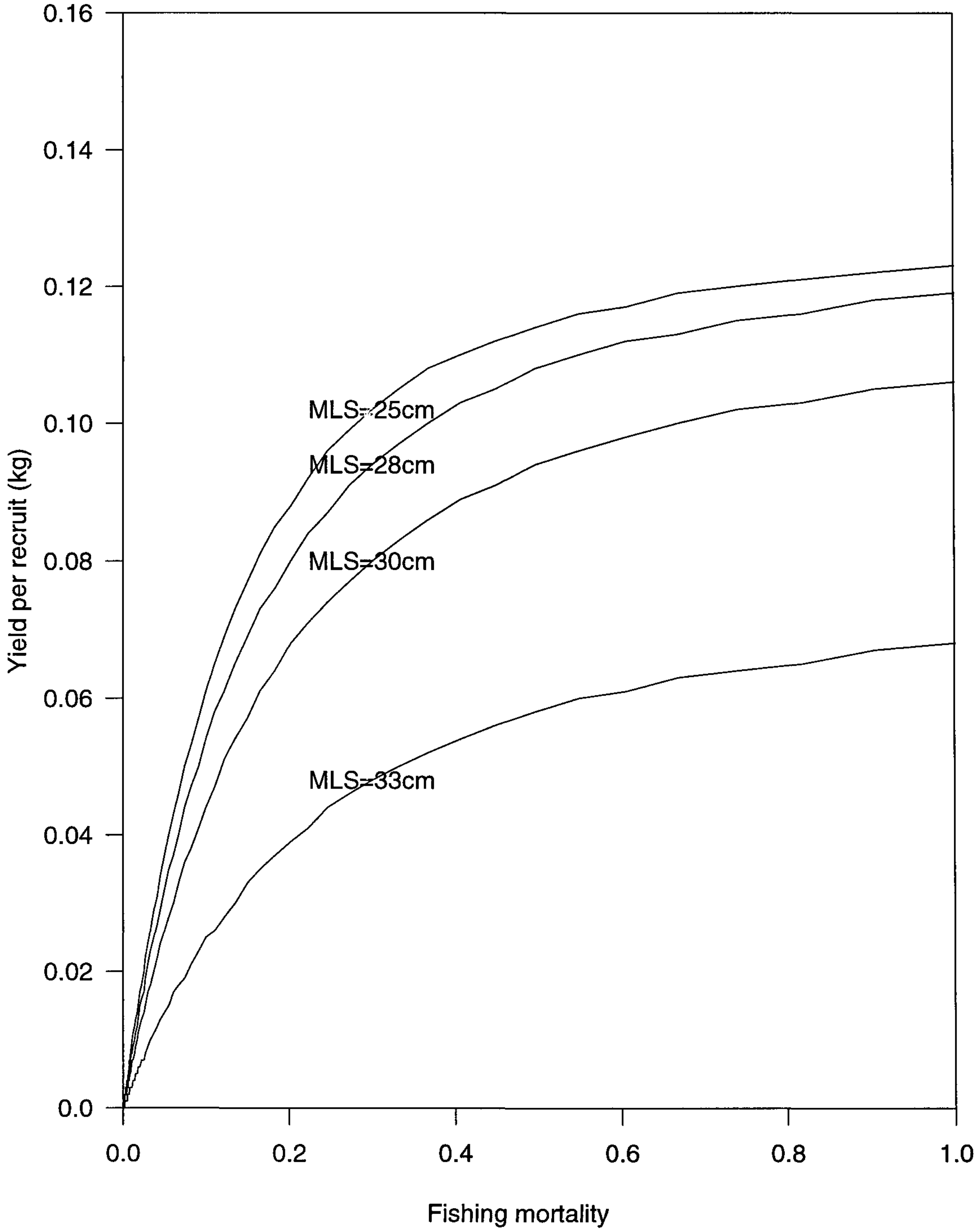


Figure 13: **Yield-per-recruit at various minimum legal sizes (MLS) by fishing mortality. Units are kilograms per fish attaining years of age.**

Appendix 1: Derivation of deterministic yield and stock biomass equations

For clarity, the catch equations assume that both males and females have the same parameters. The sexes are separated later.

Let L_∞, k, and t_0 be the von Bertalanffy growth parameters.
Let a and b be the length weight relationship parameters.
Let L_i be the start of year length of a fish aged i years.
Let w_i be the start of year weight of a fish aged i years.
Let M and F be the natural and fishing mortality rates.
Let a_r and a_m be the age of youngest recruitment and maximum ages, respectively.
Let s_i, the partial recruitment factor, be the proportion of fish aged i years which are recruited

$$s_i \geq s_{i-1},$$
$$0 < s_i \leq 1, \; a_r \leq i \leq a_m$$
$$s_{a_r-1} = 0.$$

Let R_0 be the number of recruits for a virgin stock.
Let B_0 be the virgin mid-year recruited stock biomass.
Let B be the equilibrium mid-year recruited stock biomass (a function of F).
Let Y be the equilibrium catch (a function of F).
Let R be the equilibrium number of start of year a_r-year-olds (a function of F).

Then, length at age, i, is given by,

$$L_i = L_\infty (1 - \exp[-k(i - t_0)])$$

and weight at age, i, is given by,

$$w_i = a\, L_i^b$$

To calculate the equilibrium mid-year stock biomass we must allow for the progressive recruitment according to the s_i factors. Consider i-year-olds in a particular year:
the proportion s_{a_r} of them recruited at age a_r and by mid year has suffered (i-a_r+½) years of natural plus fishing mortality;the proportion (s_{a_r+1}-s_{a_r}) recruited at age a_r+1 and by mid year has suffered 1 year of natural mortality and (i-(a_r+1)+½) years of natural plus fishing mortality; the proportion (s_j-s_{j-1}) recruited at age j and by mid year has suffered (j-a_r) years of natural mortality and (i-j+½) years of natural plus fishing mortality, which means that the proportion exp[(j-a_r)M].exp[(i-j+½)(F+M)] has survived by mid year.

Collecting the M and the F terms, and summing over i and j, the mid year stock biomass is given by,

$$B = R\left[\sum_{i=a_r}^{a_m} w_i \sum_{j=a_r}^{i} (s_j - s_{j-1}) \exp[-(i - a_r + \tfrac{1}{2})M - (i - j + \tfrac{1}{2})F] + P_1\right]$$

$$= R\left[\sum_{i=a_r}^{a_m} w_i \exp[-(i - a_r + \tfrac{1}{2})M - (i + \tfrac{1}{2})F] \sum_{j=a_r}^{i} (s_j - s_{j-1}) \exp[jF] + P_1\right] \quad \textbf{(1)}$$

The P_1 term relates to the *plus group*. It is assumed that all fish die at the end of their a_m th year (no plus group) so that P_1 is zero.

The software commonly used in New Zealand (*pmod*) ignores growth of fish during the year when calculating mid-year stock biomass. A slightly better assumption which I have used here is to replace w_i by $(w_i + w_{i+1})/2)$.

By setting F to 0 in equation **(1)** for a virgin stock, and simplifying the partial recruitment factor summations, we have,

$$B_0 = R_0 \left[\sum_{i=a_r}^{a_m} s_i w_i \exp[-(i - a_r + \tfrac{1}{2})M] + P_2 \right]$$

Again, the plus group term, P_2 is here assumed to be zero.
Therefore the virgin number of recruits,

$$R_0 = \frac{B_0}{\sum_{i=a_r}^{a_m} s_i w_i \exp[-(i - a_r + \tfrac{1}{2})M] + P_2} \qquad \textbf{(2)}$$

For yield per recruit estimates, or if recruitment is independent of stock biomass, we can take R_0 to be the annual number of recruits

The Baranov equation gives the equilibrium catch,

$$Y = \frac{F(1 - \exp[-(F + M)])R_0}{F + M} \left[\sum_{i=a_r}^{a_m} w_i \exp[-(i - a_r)M - iF] \sum_{j=a_r}^{i} (s_j - s_{j-1}) \exp[jF] + \exp[-\tfrac{1}{2}(F + M)] P_1 \right] \qquad \textbf{(3)}$$

The yield per recruit is obtained by dividing both sides of equation **(3)** by R_0.

The sexes (male, female and protogynous) have different growth, natural mortality and partial recruitment factors, so equation **(3)** must be replaced by an equation of three parts

$$Y = Y_M + Y_F + Y_P = p_M R_0 \{...\} + p_F R_0 \{...\} + p_T R_0 \{...\} \qquad \textbf{(4)}$$

where each term is similar to the right hand side of equation **(3)**, with R_0 replaced by the corresponding pR_0 and with the parameters corresponding to each sex type. Again the yield per recruit is obtained by dividing both sides of equation **(4)** by R_0.

The same fishing mortality, F, is assumed throughout to apply to all ages and all sex types. The yield per recruit for various values of F and the partial recruitment factors corresponding to various minimum legal sizes are obtained by substituting these parameter values into equation **(4)**.

Appendix 2 : **Summary of station data, where bottom type 2 = sand, 4 = sandy/mud, 7= rock/rubble.**

Station no.	Start Time NZST)	Method	Location	Latitude ° ' S	Longitude ° ' E	Area	Stratu	Site	Pot	Depth (m)	Bottom type	No. BCO
1	0640	pot	Rangitoto	40.47.22	173.58.12	DURV	A	1	a	26	4	20
2	0642	pot	Rangitoto	40.47.22	173.58.12	DURV	A	1	b	37	4	46
3	0644	pot	Rangitoto	40.47.22	173.58.12	DURV	A	1	c	49	4	17
4	0654	pot	Rangitoto	40.47.09	173.58.27	DURV	A	2	a	26	4	23
5	0657	pot	Rangitoto	40.47.09	173.58.27	DURV	A	2	b	20	0	14
6	0659	pot	Rangitoto	40.47.09	173.58.27	DURV	A	2	c	20	0	24
7	0703	pot	Rangitoto	40.47.02	173.59.24	DURV	A	3	a	27	7	33
8	0708	pot	Rangitoto	40.47.02	173.59.24	DURV	A	3	b	35	7	3
9	0710	pot	Rangitoto	40.47.02	173.59.24	DURV	A	3	c	38	7	14
901	0724	line	Rangitoto	40.47.14	173.58.10	DURV	A	1	g	15	4	23
902	0746	line	Rangitoto	40.46.41	173.58.73	DURV	A	2	g	15	4	5
12	1003	pot	WestTrioBank	40.49.24	173.58.92	DURV	B	1	a	27	4	24
13	1005	pot	WestTrioBank	40.49.24	173.58.92	DURV	B	1	b	26	4	6
14	1007	pot	WestTrioBank	40.49.24	173.58.92	DURV	B	1	c	26	4	10
15	1009	pot	WestTrioBank	40.49.99	173.58.96	DURV	B	2	a	27	4	19
16	1010	pot	WestTrioBank	40.49.99	173.58.96	DURV	B	2	b	27	4	23
17	1011	pot	WestTrioBank	40.49.99	173.58.96	DURV	B	2	c	27	4	24
18	1015	pot	WestTrioBank	40.50.43	173.59.02	DURV	B	3	a	37	4	16
19	1016	pot	WestTrioBank	40.50.43	173.59.02	DURV	B	3	b	42	4	54
20	1018	pot	WestTrioBank	40.50.43	173.59.02	DURV	B	3	c	48	4	22
903	1022	line	WestTrioBank	40.50.43	173.59.02	DURV	B	3	g	37	4	6
904	1448	line	WestTrioBank	40.50.09	173.59.08	DURV	B	2	g	27	4	1
23	1515	pot	EastTrioBank	40.51.14	174.00.37	DURV	C	1	a	40	2	19
24	1516	pot	EastTrioBank	40.51.14	174.00.37	DURV	C	1	b	35	2	27
25	1517	pot	EastTrioBank	40.51.14	174.00.37	DURV	C	1	c	35	2	20
26	1519	pot	EastTrioBank	40.51.18	174.00.29	DURV	C	2	a	29	2	26
27	1521	pot	EastTrioBank	40.51.18	174.00.29	DURV	C	2	b	35	2	16
28	1522	pot	EastTrioBank	40.51.18	174.00.29	DURV	C	2	c	29	2	21
29	1526	pot	EastTrioBank	40.51.57	173.59.85	DURV	C	3	a	38	2	23
30	1527	pot	EastTrioBank	40.51.57	173.59.85	DURV	C	3	b	44	2	4
31	1529	pot	EastTrioBank	40.51.57	173.59.85	DURV	C	3	c	51	2	39
905	1533	line	EastTrioBank	40.51.32	173.51.32	DURV	C	3	g	31	2	5
999	1533	line	EastTrioBank	40.51.32	173.51.32	DURV	C	3	h	31	2	0
33	2000	pot	FrenchPass	41.55.80	173.50.60	DURV	H	1	a	46	2	3
34	2001	pot	FrenchPass	41.55.80	173.50.60	DURV	H	1	b	37	2	4
35	2005	pot	FrenchPass	41.55.80	173.50.60	DURV	H	1	c	27	2	4
36	0740	pot	PenguinBay	40.50.56	173.54.84	DURV	D	1	a	24	7	29
37	0741	pot	PenguinBay	40.50.56	173.54.84	DURV	D	1	b	16	7	31
38	0745	pot	PenguinBay	40.50.56	173.54.84	DURV	D	1	c	18	7	10
39	0752	pot	PenguinBay	40.50.21	173.55.08	DURV	D	2	a	22	7	0
40	0756	pot	PenguinBay	40.50.21	173.55.08	DURV	D	2	b	27	7	0
41	0759	pot	PenguinBay	40.50.21	173.55.08	DURV	D	2	c	24	7	22
42	0805	pot	PenguinBay	40.50.01	173.55.02	DURV	D	3	a	31	7	15
43	0808	pot	PenguinBay	40.50.01	173.55.02	DURV	D	3	b	22	7	51
44	0811	pot	PenguinBay	40.50.01	173.55.02	DURV	D	3	c	24	7	5
906	1152	line	PenguinBay	40.50.01	173.55.02	DURV	D	3	g	22	7	17
907	1237	line	PenguinBay	40.50.01	173.55.03	DURV	D	2	g	27	7	7
47	1436	pot	Chetwode	40.54.66	174.03.52	EOPE	B	1	a	31	7	1
48	1438	pot	Chetwode	40.54.66	174.03.52	EOPE	B	1	b	24	7	15
49	1440	pot	Chetwode	40.54.66	174.03.52	EOPE	B	1	c	20	7	8
50	1444	pot	Chetwode	40.54.41	174.03.92	EOPE	B	2	a	22	7	11
51	1446	pot	Chetwode	40.54.41	174.03.92	EOPE	B	2	b	20	7	0
52	1447	pot	Chetwode	40.54.41	174.03.92	EOPE	B	2	c	35	7	5
53	1450	pot	Chetwode	40.54.31	174.04.20	EOPE	B	3	a	20	7	9

Appendix **2:– continued.**

Station no.	Start Time NZST)	Method	Location	Latitude ° ' S	Longitude ° ' E	Area	Stratu	Site	Pot	Depth (m)	Bottom type	No. BCO
54	1452	pot	Chetwode	40.54.31	174.04.20	EOPE	B	3	b	16	7	4
55	1454	pot	Chetwode	40.54.31	174.04.20	EOPE	B	3	c	11	7	6
908	1452	line	Chetwode	40.54.31	174.04.20	EOPE	B	3	g	16	2	0
909	1520	pot	Chetwode	40.54.52	174.04.06	EOPE	B	2	g	13	7	4
56	1800	line	Bulwer	40.56.87	173.58.10	OPEL	E	1	a	27	7	0
57	1805	line	Bulwer	40.56.87	173.58.10	OPEL	E	1	b	20	7	2
58	1810	line	Bulwer	40.56.87	173.58.10	OPEL	E	1	c	15	7	0
59	0758	pot	Forsyth	40.56.87	174.00.21	EOPE	A	1	a	22	7	7
60	0800	pot	Forsyth	40.56.87	174.00.21	EOPE	A	1	b	16	7	5
61	0802	pot	Forsyth	40.56.87	174.00.21	EOPE	A	1	c	13	7	5
62	0804	pot	Forsyth	40.56.04	174.05.00	EOPE	A	2	a	15	7	4
63	0805	pot	Forsyth	40.56.04	174.05.00	EOPE	A	2	b	11	2	0
64	0806	pot	Forsyth	40.56.04	174.05.00	EOPE	A	2	c	13	7	11
65	0813	pot	Forsyth	40.56.84	174.05.00	EOPE	A	3	a	13	7	2
66	0814	pot	Forsyth	40.56.84	174.05.00	EOPE	A	3	b	13	7	6
67	0817	pot	Forsyth	40.56.84	174.05.00	EOPE	A	3	c	18	2	0
910	0824	line	Forsyth	40.56.84	174.05.00	EOPE	A	2	g	13	7	1
911	0835	line	Forsyth	40.56.84	174.05.00	EOPE	A	1	g	15	7	1
68	1017	pot	Duffers	40.57.45	174.02.21	OPEL	D	1	a	29	7	1
69	1018	pot	Duffers	40.57.45	174.02.21	OPEL	D	1	b	26	7	15
70	1020	pot	Duffers	40.57.45	174.02.21	OPEL	D	1	c	24	7	0
71	1024	pot	Duffers	40.57.22	174.02.80	OPEL	D	2	a	22	7	17
72	1026	pot	Duffers	40.57.22	174.02.80	OPEL	D	2	b	26	7	2
73	1028	pot	Duffers	40.57.22	174.02.80	OPEL	D	2	c	16	7	19
74	1032	pot	Duffers	40.57.15	174.03.44	OPEL	D	3	a	27	7	7
75	1034	pot	Duffers	40.57.15	174.03.44	OPEL	D	3	b	22	7	21
76	1036	pot	Duffers	40.57.15	174.03.44	OPEL	D	3	c	35	7	0
912	1037	line	Duffers	40.57.19	174.03.55	OPEL	D	3	g	29	7	8
913	1110	line	Duffers	40.57.18	174.03.43	OPEL	D	2	g	13	7	6
77	1300	pot	TeAkaroa	40.56.86	173.59.92	OPEL	G	1	a	15	7	10
78	1302	pot	TeAkaroa	40.56.86	173.59.92	OPEL	G	1	b	13	7	6
79	1303	pot	TeAkaroa	40.56.86	173.59.92	OPEL	G	1	c	27	7	7
80	1306	pot	TeAkaroa	40.56.44	174.00.29	OPEL	G	2	a	20	7	1
81	1308	pot	TeAkaroa	40.56.44	174.00.29	OPEL	G	2	b	18	7	9
82	1309	pot	TeAkaroa	40.56.44	174.00.29	OPEL	G	2	c	22	7	7
83	1312	pot	TeAkaroa	40.56.21	174.00.72	OPEL	G	3	a	26	7	1
84	1312	pot	TeAkaroa	40.56.21	174.00.72	OPEL	G	3	b	22	7	7
85	1315	line	TeAkaroa	40.56.21	174.00.72	OPEL	G	3	c	37	7	2
914	1320	line	TeAkaroa	40.56.21	174.00.72	OPEL	G	3	g	35	7	2
915	1355	line	TeAkaroa	40.56.44	174.00.10	OPEL	G	2	g	20	7	1
86	1552	pot	BoatRockPt	40.58.40	173.56.75	OPEL	B	1	a	37	7	2
87	1553	pot	BoatRockPt	40.58.40	173.56.75	OPEL	B	1	b	29	7	7
88	1554	pot	BoatRockPt	40.58.40	173.56.75	OPEL	B	1	c	29	7	9
89	1557	pot	BoatRockPt	40.58.40	173.56.75	OPEL	B	2	a	27	7	5
90	1558	pot	BoatRockPt	40.58.40	173.56.75	OPEL	B	2	b	20	7	7
91	1600	pot	BoatRockPt	40.58.40	173.56.75	OPEL	B	2	c	27	7	15
92	1603	pot	BoatRockPt	40.58.10	173.57.32	OPEL	B	3	a	26	7	10
93	1605	pot	BoatRockPt	40.58.10	173.57.32	OPEL	B	3	b	22	7	15

Appendix 2 :– continued.

Station no.	Start Time Method NZST)		Location	Latitude ° ' S	Longitude ° ' E	Area	Stratu	Site	Pot	Depth (m)	Bottom type	No. BCO
94	1606	pot	BoatRockPt	40.58.10	173.57.32	OPEL	B	3	c	22	7	16
916	1611	line	BoatRockPt	40.57.95	173.57.45	OPEL	B	3	g	20	7	1
917	1645	line	BoatRockPt	40.57.95	173.57.45	OPEL	B	2	g	20	7	0
95	1753	pot	CampBay	40.57.28	173.57.52	OPEL	F	1	a	27	2	1
96	1755	pot	CampBay	40.57.28	173.57.52	OPEL	F	1	b	27	2	8
97	1800	pot	CampBay	40.57.28	173.57.52	OPEL	F	1	c	27	2	3
98	0738	pot	TheReef	41.00.40	173.57.10	OPEL	A	1	a	26	7	16
99	0740	pot	TheReef	41.00.40	173.57.10	OPEL	A	1	b	26	7	10
100	0741	pot	TheReef	41.00.40	173.57.10	OPEL	A	1	c	26	7	22
101	0744	pot	TheReef	41.00.78	173.56.84	OPEL	A	2	a	15	7	5
102	0746	pot	TheReef	41.00.78	173.56.84	OPEL	A	2	b	16	7	3
103	0747	pot	TheReef	41.00.07	173.56.84	OPEL	A	2	c	15	7	7
104	0750	pot	TheReef	41.00.97	173.56.53	OPEL	A	3	a	18	7	5
105	0752	pot	TheReef	41.00.97	173.56.53	OPEL	A	3	b	20	7	7
106	0753	pot	TheReef	41.00.97	173.56.53	OPEL	A	3	c	24	7	5
918	0756	line	TheReef	41.01.00	173.56.40	OPEL	A	3	g	18	7	0
919	0830	line	TheReef	41.00.81	173.56.85	OPEL	A	2	g	15	7	0
107	1009	pot	TapaapaPt	41.02.51	173.56.23	MPEL	D	1	a	33	7	4
108	1011	pot	TapaapaPt	41.02.51	173.56.23	MPEL	D	1	b	22	7	24
109	1012	pot	TapaapaPt	41.02.51	173.56.23	MPEL	D	1	c	29	7	7
110	1014	pot	TapaapaPt	41.02.37	173.56.60	MPEL	D	2	a	22	7	7
111	1015	pot	TapaapaPt	41.02.37	173.56.60	MPEL	D	2	b	15	7	14
112	1016	pot	TapaapaPt	41.02.37	173.56.60	MPEL	D	2	c	18	7	0
113	1021	pot	TapaapaPt	41.02.50	173.57.30	MPEL	D	3	a	22	7	4
114	1022	pot	TapaapaPt	41.02.50	173.57.30	MPEL	D	3	b	20	7	3
115	1025	pot	TapaapaPt	41.02.50	173.57.30	MPEL	D	3	c	20	7	4
920	1030	line	TapaapaPt	41.02.49	173.57.30	MPEL	D	3	g	20	7	0
921	1120	line	TapaapaPt	41.02.34	173.56.58	MPEL	D	2	g	20	7	0
116	1311	pot	MarysBay	41.05.10	173.55.94	IPEL	B	1	a	18	7	2
117	1312	pot	MarysBay	41.05.10	173.55.94	IPEL	B	1	b	18	7	2
118	1313	pot	MarysBay	41.05.10	173.55.94	IPEL	B	1	c	16	7	12
119	1316	pot	MarysBay	41.05.34	173.55.89	IPEL	B	2	a	15	7	2
120	1317	pot	MarysBay	41.05.34	173.55.89	IPEL	B	2	c	11	7	18
121	1319	pot	MarysBay	41.05.34	173.55.89	IPEL	B	2	c	11	7	4
122	1323	pot	MarysBay	41.05.56	173.55.69	IPEL	B	3	a	11	7	2
123	1325	pot	MarysBay	41.05.56	173.55.69	IPEL	B	3	b	18	7	3
124	1327	pot	MarysBay	41.05.56	173.55.69	IPEL	B	3	c	15	7	4
922	1330	line	MarysBay	41.05.73	173.55.60	IPEL	B	3	g	13	7	0
923	1405	line	MarysBay	41.05.38	173.55.88	IPEL	B	2	g	9	7	2
125	1541	pot	JacobsBay	41.07.28	173.53.03	IPEL	A	1	a	20	8	2
126	1542	pot	JacobsBay	41.07.28	173.53.03	IPEL	A	1	b	11	7	6
127	1544	pot	JacobsBay	41.07.28	173.53.03	IPEL	A	1	c	11	7	3
128	1547	pot	JacobsBay	41.06.89	173.53.18	IPEL	A	2	a	16	7	1
129	1548	pot	JacobsBay	41.06.89	173.53.18	IPEL	A	2	b	13	7	4
130	1549	pot	JacobsBay	41.06.89	173.53.18	IPEL	A	2	c	11	7	6
131	1550	pot	JacobsBay	41.06.66	173.53.25	IPEL	A	3	a	13	2	0
132	1552	pot	JacobsBay	41.06.66	173.53.25	IPEL	A	3	b	15	7	3
133	1553	pot	JacobsBay	41.06.66	173.53.25	IPEL	A	3	c	11	7	3
924	1555	line	JacobsBay	41.06.51	173.53.36	IPEL	A	3	g	18	7	0
925	1630	line	JacobsBay	41.06.89	173.53.20	IPEL	A	2	g	13	7	0
134	1750	pot	TeRawa	41.04.89	173.54.58	IPEL	D	1	a	11	7	0

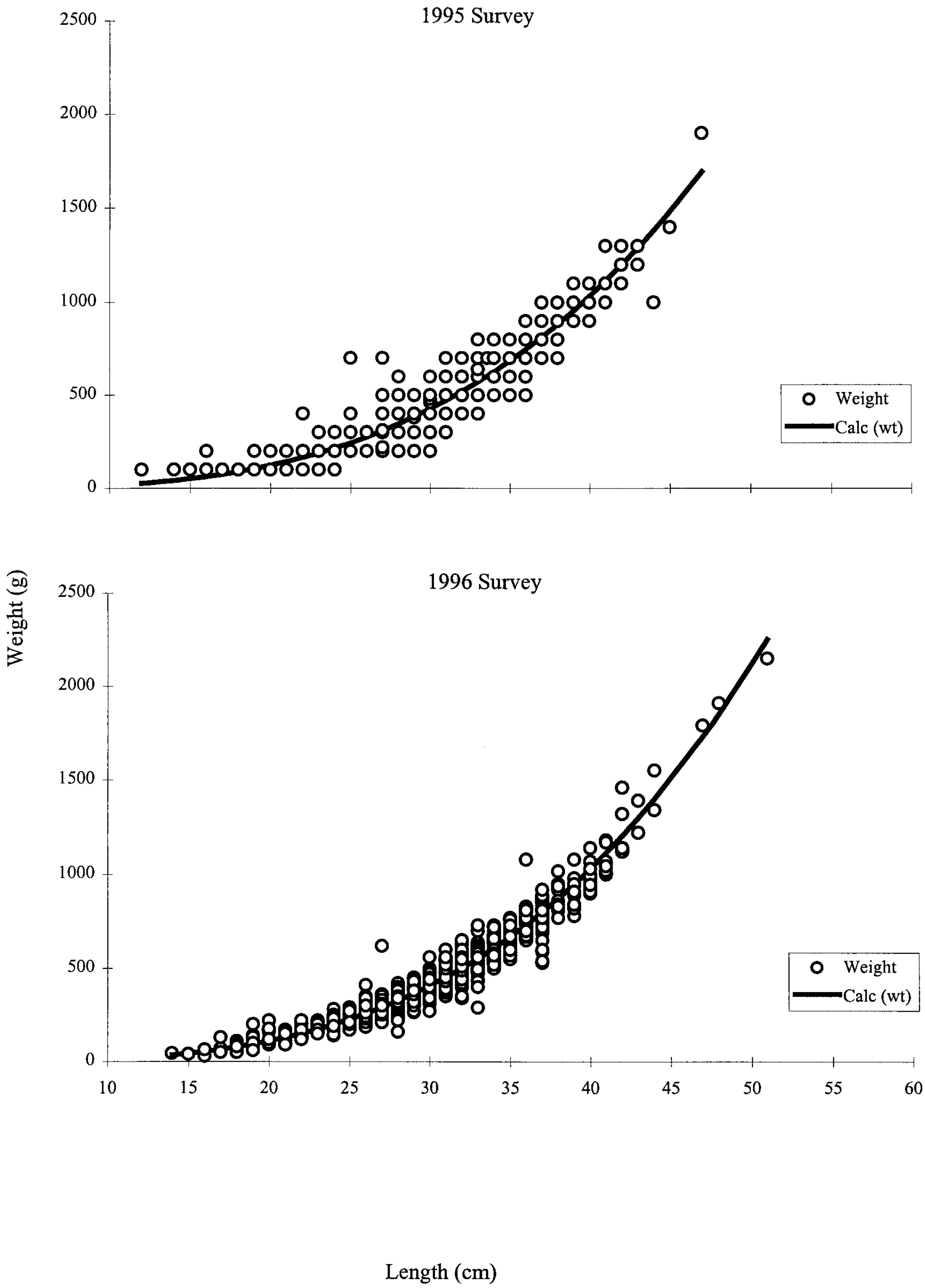
Appendix 2:– continued.

Station no.	Start Time NZST)	Method	Location	Latitude ° ' S	Longitude ° ' E	Area	Stratu	Site	Pot	Depth (m)	Bottom type	No. BCO
135	1751	pot	TeRawa	41.04.89	173.54.58	IPEL	D	1	b	11	7	2
136	1753	pot	TeRawa	41.04.89	173.54.58	IPEL	D	1	c	11	7	2
137	1756	pot	JacobsBay	41.04.78	173.54.74	IPEL	G	1	d	11	7	1
138	1757	pot	TeRawa	41.04.78	173.54.74	IPEL	D	2	a	11	7	1
139	1758	pot	TeRawa	41.04.78	173.54.74	IPEL	D	2	b	10	7	0
140	1759	pot	TeRawa	41.04.64	173.54.69	IPEL	D	2	c	10	7	1
141	1800	pot	TeRawa	41.04.64	173.54.69	IPEL	D	3	a	11	7	1
142	1801	pot	TeRawa	41.04.64	173.54.69	IPEL	D	3	b	11	7	0
143	1802	pot	TeRawa	41.04.64	173.54.69	IPEL	D	3	c	11	7	0
940	1500	line	TeRawa	41.04.64	173.54.69	IPEL	D	3	g	11	7	4
941	1530	line	TeRawa	41.04.64	173.54.69	IPEL	D	2	g	11	7	7
144	0737	pot	TePurakaPt	41.03.36	174.00.74	IPEL	C	1	a	11	7	0
145	0738	pot	TePurakaPt	41.03.36	174.00.74	IPEL	C	1	b	15	7	0
146	0739	pot	TePurakaPt	41.03.36	174.00.74	IPEL	C	1	c	18	7	0
147	0742	pot	TePurakaPt	41.03.39	174.00.69	IPEL	C	2	a	16	7	0
148	0743	pot	TePurakaPt	41.03.39	174.00.69	IPEL	C	2	b	15	7	4
149	0745	pot	TePurakaPt	41.03.39	174.00.69	IPEL	C	2	c	15	7	0
150	0749	pot	TePurakaPt	41.03.84	174.01.02	IPEL	C	3	a	11	7	3
151	0750	pot	TePurakaPt	41.03.84	174.01.02	IPEL	C	3	b	11	7	4
152	0751	pot	TePurakaPt	41.03.84	174.01.02	IPEL	C	3	b	9	7	4
926	0800	line	TePurakaPt	41.03.99	174.01.09	IPEL	C	3	g	15	7	1
927	0820	line	TePurakaPt	41.03.52	174.00.75	IPEL	C	2	g	16	7	1
153	0941	pot	KauauroaBy	41.03.42	173.58.25	MPEL	A	1	a	26	5	5
154	0943	pot	KauauroaBy	41.03.42	173.58.25	MPEL	A	1	b	18	7	10
155	0945	pot	KauauroaBy	41.03.42	173.58.25	MPEL	A	1	c	18	7	10
156	0948	pot	KauauroaBy	41.03.21	173.58.43	MPEL	A	2	a	13	7	7
157	0949	pot	KauauroaBy	41.03.21	173.58.43	MPEL	A	2	b	15	7	10
158	0950	pot	KauauroaBy	41.03.21	173.58.43	MPEL	A	2	c	11	7	6
159	0954	pot	KauauroaBy	41.02.94	173.58.81	MPEL	A	3	a	15	7	5
160	0956	pot	KauauroaBy	41.02.94	173.58.81	MPEL	A	3	b	15	7	15
161	0957	pot	KauauroaBy	41.02.94	173.58.81	MPEL	A	3	c	15	7	5
928	1000	line	KauauroaBy	41.02.87	173.58.86	MPEL	A	3	g	13	7	1
929	1030	line	KauauroaBy	41.03.16	173.58.49	MPEL	A	2	g	11	7	0
162	1144	pot	RamsHead	41.03.47	173.55.17	MPEL	B	1	a	15	7	1
163	1146	pot	RamsHead	41.03.47	173.55.17	MPEL	B	1	b	13	7	8
164	1147	pot	RamsHead	41.03.47	173.55.17	MPEL	B	1	c	24	7	6
165	1151	pot	RamsHead	41.03.29	173.54.82	MPEL	B	2	a	13	7	4
166	1152	pot	RamsHead	41.03.29	173.54.82	MPEL	B	2	b	15	7	6
167	1153	pot	RamsHead	41.03.29	173.54.82	MPEL	B	2	c	16	7	1
168	1155	pot	RamsHead	41.03.32	173.54.53	MPEL	B	3	a	9	7	13
169	1156	pot	RamsHead	41.03.32	173.54.53	MPEL	B	3	b	11	7	2
170	1158	pot	RamsHead	41.03.32	173.54.53	MPEL	B	3	c	11	7	9
930	1200	line	RamsHead	40.41.56	175.13.32	MPEL	B	3	g	9	7	0
931	1240	line	RamsHead	41.03.36	173.54.91	MPEL	B	2	g	24	7	0
171	1420	pot	MaudIsl	41.02.43	173.54.61	MPEL	C	1	a	18	7	10
172	1422	pot	MaudIsl	41.02.43	173.54.61	MPEL	C	1	b	20	7	11
173	1424	pot	MaudIsl	41.02.43	173.54.61	MPEL	C	1	c	18	7	15

Appendix 2 **:– continued.**

Station no.	Start Time NZST)	Method	Location	Latitude ° ' S	Longitude ° ' E	Area	Stratu	Site	Pot	Depth (m)	Bottom type	No. BCO
174	1427	pot	MaudIsl	41.02.32	173.54.38	MPEL	C	2	a	20	7	27
175	1428	pot	MaudIsl	41.02.32	173.54.38	MPEL	C	2	b	20	7	7
176	1429	pot	MaudIsl	41.02.32	173.54.38	MPEL	C	2	c	18	7	10
177	1433	pot	MaudIsl	41.02.32	173.54.38	MPEL	C	3	a	20	7	1
178	1434	pot	MaudIsl	41.02.32	173.54.38	MPEL	C	3	b	18	7	4
179	1435	pot	MaudIsl	41.02.32	173.54.38	MPEL	C	3	c	18	7	8
932	1445	line	MaudIsl	41.02.32	173.54.38	MPEL	C	3	g	18	7	3
933	1515	line	MaudIsl	41.02.26	173.54.37	MPEL	C	2	g	20	7	2
279	1712	pot	KatiraBay	40.57.85	174.00.90	OPEL	C	1	a	16	7	5
180	1713	pot	KatiraBay	40.57.85	174.00.90	OPEL	C	1	b	11	7	20
181	1714	pot	KatiraBay	40.57.85	174.00.90	OPEL	C	1	c	11	7	0
182	1715	pot	KatiraBay	40.57.85	174.00.90	OPEL	C	2	a	20	7	12
183	1716	pot	KatiraBay	40.57.85	174.00.90	OPEL	C	2	b	20	7	8
184	1718	pot	KatiraBay	40.57.85	174.00.90	OPEL	C	2	c	20	7	3
185	1721	pot	KatiraBay	40.57.85	174.00.90	OPEL	C	3	a	9	7	6
186	1722	pot	KatiraBay	40.57.85	174.00.90	OPEL	C	3	b	11	7	2
187	1723	pot	KatiraBay	40.57.85	174.00.90	OPEL	C	3	c	13	7	2
934	1725	line	KatiraBay	40.57.85	174.00.90	OPEL	C	3	g	13	7	1
935	1800	line	KatiraBay	40.57.85	174.00.90	OPEL	C	2	g	20	7	0
188	1915	pot	Bulwer	40.56.88	173.58.21	OPEL	E	2	a	15	7	4
189	1916	pot	Bulwer	40.56.88	173.58.21	OPEL	E	2	b	15	7	3
190	1917	pot	Bulwer	40.56.88	173.58.21	OPEL	E	2	c	15	7	0
191	0812	pot	HarrisBay	40.55.56	174.01.19	EOPE	D	1	a	18	7	6
192	0814	pot	HarrisBay	40.55.56	174.01.19	EOPE	D	1	b	15	7	8
193	0920	pot	HarrisBay	40.55.56	174.01.19	EOPE	D	1	c	38	7	5
194	0817	pot	HarrisBay	40.55.39	174.01.04	EOPE	D	2	a	9	7	4
195	0818	pot	HarrisBay	40.55.39	174.01.04	EOPE	D	2	b	7	7	3
196	0819	pot	HarrisBay	40.55.39	174.01.04	EOPE	D	2	c	5	7	5
197	0824	pot	HarrisBay	40.55.24	174.01.00	EOPE	D	3	a	7	7	0
198	0825	pot	HarrisBay	40.55.24	174.01.00	EOPE	D	3	b	7	7	5
199	0826	pot	HarrisBay	40.55.24	174.01.00	EOPE	D	3	c	7	7	1
936	0830	line	HarrisBay	40.55.24	174.01.00	EOPE	D	3	g	7	7	8
937	1000	line	HarrisBay	40.55.40	174.01.16	EOPE	D	2	g	7	7	3
200	1113	pot	ClayPt	40.53.41	174.01.06	EOPE	C	1	a	37	7	7
201	1115	pot	ClayPt	40.53.41	174.01.06	EOPE	C	1	b	20	7	9
202	1218	pot	ClayPt	40.53.41	174.01.06	EOPE	C	1	c	37	7	2
203	1118	pot	ClayPt	40.53.58	173.58.76	EOPE	C	2	a	22	7	1
204	1119	pot	ClayPt	40.53.58	173.58.76	EOPE	C	2	b	18	7	25
205	1121	pot	ClayPt	40.53.58	173.58.76	EOPE	C	2	c	11	7	8
206	1123	pot	ClayPt	40.53.41	174.01.06	EOPE	C	3	a	18	7	7
207	1124	pot	ClayPt	40.53.41	174.01.06	EOPE	C	3	b	20	7	11
208	1126	pot	ClayPt	40.53.41	174.01.06	EOPE	C	3	c	26	7	10
938	1155	line	ClayPt	40.54.03	173.58.49	EOPE	C	1	g	37	7	3
939	1250	line	ClayPt	40.53.58	173.58.76	EOPE	C	2	g	22	7	11

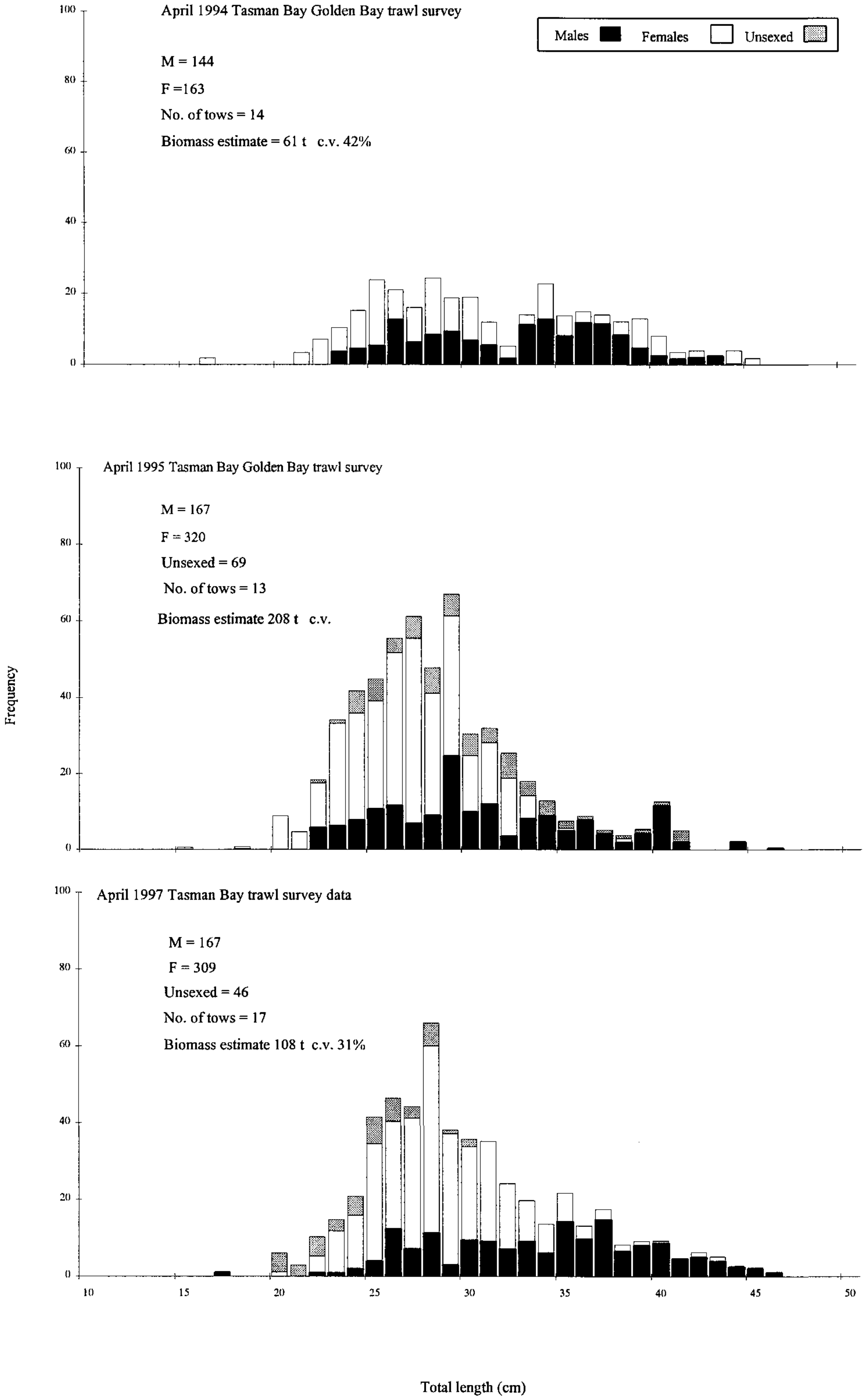
Appendix 3: Length and weight data from the 1995 and 1996 surveys.



1995 data **Weight = 0.01017 length** $^{3.122889}$

1996 data **Weight = 0.007047 length** $^{3.223463}$

Appendix 4: **Length frequency data and biomass estimates from recent trawl surveys. Frequency of males and females is the number of fish caught.**



Source: April 1994 survey: Drummond & Stevenson (1995b)
April 1995 survey: Drummond & Stevenson (1996)
April 1997 survey: Stevenson (1997)