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Comparisons of age and growth of blue cod within the Marlborough Sounds (BCO 7)

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To determine age and growth of blue cod in Marlborough Sounds.

8. Executive summary:

In 1995 and 1996 the Ministry of Fisheries contracted NIWA (CEBC02 & BCO9701) to "determine the size of blue cod in the Marlborough Sounds". The two major sounds, Queen Charlotte and Pelorus Sound, were each sampled for blue cod using a hierarchical sample design. Sites were randomly selected within four fishing areas within sampling stratum of each Sound over two years, 1995 and 1996. Otoliths were collected opportunistically throughout both the Queen Charlotte and Pelorus Sounds, with the number of otoliths collected between areas unbalanced. The current project sought to make use of available otoliths to determine and compare length at age growth models in areas where sufficient samples of otoliths allowed. Length frequency distributions of captured blue cod were also compared between strata.

In both the 1995 and 1996 surveys, 4007 blue cod were caught in the Marlborough Sounds; 2051 otoliths were collected. As the otoliths were not collected evenly across strata in either 1995 or 1996, only 1178 were selected for sectioning in the current study. Of these, 811 were males ranging in size between 18 and 47 cm, and 512 were females from 17 to 40 cm in total length.

Within each Sound, von Bertalanfffy growth curves were developed at three spatial scales (sites, areas, and strata) and compared using Kimura's likelihood method. Only a single comparison of growth was possible at the smallest spatial scale, which

showed no significant difference between growth models of male blue cod between sites. Comparisons of growth at the next spatial scale were possible among areas within five strata for males, and within three strata for females. Female blue cod showed no detectable difference in growth between areas or strata within either Pelorus or Queen Charlotte Sounds. In contrast, growth of males differed between strata within both Sounds, and may differ between areas of the extreme and outer Pelorus Sound strata. A gradient was also apparent, with male blue cod growing fastest in the extreme outer strata of both Pelorus and Queen Charlotte Sounds.

Comparisons of equivalent strata between Pelorus and Queen Charlotte Sounds showed similar growth of males in outer strata, but biologically faster male growth in the extreme outer Queen Charlotte Sound. While female growth showed statistically significant differences between both equivalent pairs of strata, these results were not biologically convincing.

Results are discussed in terms of fishing pressure, catch-per-unit-effort, sex ratios, female fecundity, and sex inversion.

9. Introduction

In the South Island, blue cod (*Parapercis colias*) are one of the most important inshore commercial and recreational fish species. Nationally, the commercial fishery in 1998/99 reported landings of 2130 t, with an approximate landed value of $2.6 million (Annala *et al.*, 1999). All major blue cod fisheries are in the South Island.

In the 1998/99 fishing year, commercial landings in Southland (BCO5) were 63% of the national total (1352 t), 25% came from the Chatham Islands (BCO4: 525 t), 8% from the east coast South Island (BCO 3: 161 t), and 3% from the South Island's north/west coast (BCO7: 59 t) (Annala *et al,* 1999).

The total annual recreational catch of blue cod is estimated to be about 706 t, with the South Island's BCO 7 (239 t), BCO 3 (151 t) and BCO 5 (139 t) accounting for 75% of the national total (Annala *et al.*, 1999). Blue cod is also an important species for Maori; however, no specific information is available on the levels of Maori customary catches.

The most recent assessment presented in the report from the 1999 Fishery Assessment Plenary indicates that for all Fish stocks, current TACCs and recent commercial catch levels are sustainable, and probably at levels which will allow the stocks to move towards a size that will support a maximum sustainable yield (MSY, See Annala *et al.*, 1999). However, for BCO 7, and especially the Marlborough Sounds, it is not known if recent catch levels are sustainable, or if they are at levels that will allow the stock to move towards a size that will support the MSY (Annala *et al.*, 1999). Further stock assessment is therefore required for this area.

Fundamental to a number of stock assessment techniques is the ability to age fish. This is an essential variable for determining the productivity of fish stocks and monitoring their responses to fishing. However, the paucity of information on age and growth of blue cod in BCO 7 limits stock assessment and causes uncertainty about the status of this resource (McGregor, 1988; Annala *et al.*, 1999).

NIWA has recently completed research validating ageing blue cod from otoliths (Carbines, 1998), but the behaviour of this species means that estimating growth is not straightforward. Because blue cod are a relatively sedentary species with a patchy distribution, they may form 'sub populations' with different growth rates within relatively small areas (Rapson, 1956; Mace & Johnston, 1983; Mutch, 1983, Carter, 1990; Carbines, 1998). The current study sought to determine the degree of spatial variability in growth rates of blue cod in the Marlborough Sounds, and to estimate growth over spatial areas most appropriate for stock assessment.

The estimation of fish growth is a complex topic. It requires the development of an ageing technique, validation of that technique, and the estimation age in natural populations (Secor *et al.*, 1995). Carter (1990) and Carbines (1998) have both used tetracycline marking to validate the annual periodicity of blue cod otolith ring formation, with Carbines (1998) showing an acceptable mean between – reader variation of 0.59 $\pm$. 0.03 years. This makes possible comparisons of growth between populations of blue cod using otoliths.

In 1995 and 1996, the Ministry of Fisheries contracted NIWA (CEBC02 & BCO9701) to "Determine the size of blue cod in the Marlborough Sounds" (Blackwell, 1997 & 1998). As an additional aspect of these studies, otoliths were collected throughout both the Queen Charlotte and Pelorus Sounds (Figure 1). However, projects CEBC02 and BCO9701 sought mainly to determine the size distribution of blue cod in the Marlborough Sounds, and otoliths were not collected for the purpose of determining age and growth within different areas. Consequently, otoliths were collected opportunistically, and the number collected between areas was unbalanced. The current project makes use of the available otolith set in order to determine length at age growth models in areas where sufficient samples of otoliths allowed.

Survey area

The Marlborough Sounds (Figure 1) is a series of drowned river valleys situated at the northeastern end of the South Island of New Zealand. The area comprises two major sounds: Queen Charlotte Sound bounded to the east by Arapawa Island, and Pelorus Sound bounded to the west by D'Urville Island. These sounds have different characters. Queen Charlotte Sound is characterized by a complex tidal current pattern with intrusions of cold nutrient rich water from the adjacent deep waters of Cook Strait (Heath 1974). Pelorus Sound is influenced by the effects of the warmer but less nutrient rich tidal current from Tasman Bay that enters through French Pass (Figure 1) and by the major freshwater influence of the Pelorus River (Heath 1974). Both Sounds have complex coastlines and provide a variety of habitats from sheltered reefs to exposed rocky coasts and offshore islands (Figure 1).

10. Programme Objectives

1. Determine the age and growth of blue cod (*Parapercis colias*).

Objectives for 1998–99

1. To determine age and growth of blue cod in Marlborough Sounds.

11. Methods

Sampling methodology and survey design in projects CEBC02 & BCO9701 for collecting blue cod in areas of the Marlborough Sounds

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.

The two major sounds, Queen Charlotte and Pelorus Sound, were sampled for blue cod using a hierarchical sample design with replicate fishing stations at each sampling site. Sites were randomly selected within four fishing areas nested within each of seven sampling stratum (Figure 1). For details on the stratum rationale and boundaries, see Appendix 1. Sampling was carried out over two years, 1995 (Blackwell, 1997) and 1996 (Blackwell, 1998).

During the 1995 survey, which concentrated on Queen Charlotte Sound, strata IQCH95, OQCH95, EQCH95 were surveyed, and strata OPEL95 and EOPE95 were surveyed in Pelorus Sound. During the 1996 survey, only strata in the Pelorus Sound were surveyed, and stratum OPEL96 and EOPE96 were re-surveyed (Figure 1).

Within each stratum, eight fishing areas of suitable rocky/rubble reef habitat were identified based upon marine charts and anecdotal evidence (C. Aston, commercial fisher, pers. comm. 1996). Of these eight sampling areas, four (A-D) were randomly 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 were sampled in the afternoon. For the areas re-sampled in the 1995 survey (EOPE & OPEL), the sample times allocated in 1995 was repeated in the 1996 survey.

Within each of these four fishing areas within a stratum, nine fishing stations were established, forming three replicates (a-c) at each of three sampling sites (1–3) randomly chosen within the available blue cod habitat.

Based on previous tagging studies of blue cod in the Marlborough Sounds, replicate sites are considered to be within the population mixing distance, sample areas were likely to experience only a small amount of migration, and strata are probably isolated without significant interaction (Rapson, 1956; Mace & Johnston, 1983).

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 hydraulic hauling gear for pot fishing. It also has a *Koden* colour depth sounder and a *Trimble* GPS system.

The nine pots used in the 1995 and 1996 surveys were modified commercial cod pots. These were rectangular in shape (1.87 x 1.40 x 0.93 m), constructed from a 40-mm diameter steel rod framework and covered with 60-cm nylon mesh. For the survey, the bottom and sides of pots were fitted with a 15 mm galvanised wire mesh inner liner. 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. As part of both the 1995 and 1996 surveys, two braided hand lines were also fished for 15 minutes at each station, using 6/0 Kale hooks and frozen pilchard bait. Otoliths were collected from fish caught by both pots and lines.

Catch and biological sampling

The length of blue cod (total length, to the nearest whole centimetre below actual length), weight (to the nearest 1.0 g), sex and gonad maturity stage (determined by dissection and visual examination) were measured and recorded for each blue cod. In addition, catch composition, abundance, catch per-unit effort (CPUE), environmental data, location, wind, cloud cover, water condition, and bottom type were recorded. For these data, see Blackwell (1997 & 1998).

The nonparametric Kolmogorov-Smirnov two sample test was used to pair-wise test differences between blue cod length frequency distributions from strata (Sokal & Rohlf, 1995).

Selection of otoliths

From 4007 blue cod caught in the 1995 and 1996 surveys, only 2051 otoliths were collected. However, these were not collected equally across areas of the Marlborough Sounds, and this restricted the development of growth models. A significant difference in growth demonstrated between male and female Southland blue cod (Carbines, 1998), also required that the two sexes be analysed separately. Otoliths were therefore selected for processing from areas with sufficient numbers covering a wide size range for each sex.

Processing and reading of otoliths

Throughout the 1995 and 1996 surveys, the largest pair of otolith, the sagittae, were removed by dissecting the cranial region, rinsed with water, air dried and stored in paper envelopes.

Once otoliths had been selected, they were embedded in araldite polymer resin and sectioned to approximately 250 μm thick along the transverse plane with a diamond-tipped cut-off wheel. The cut sections were then sanded with 600 grit sandpaper to remove saw marks and polished on a felt pad with 0.3-μm alumina suspension polishing compound. Sections were observed at 40 or 100x magnification under transmitted light with a compound microscope.

Sections exhibited alternating opaque and translucent zones and age estimates were made by counting the number of annuli (opaque zones) from the distal to the proximal edge of the otolith section (Carbines, 1998). Light-translucent bands were used to define a complete dark band, i.e., an annuli was counted only if it had a light band on both sides (Carbines, 1998). The readability of each otolith was graded 1 (excellent) to 5 (very poor).

Comparing estimates of growth at each spatial scale

Starting at the smallest possible spatial scale (i.e., sites within areas), comparisons of growth were made where possible, and data progressively pooled to the next spatial scale. A significant result indicated that growth differed at that spatial scale, and non-significance showing no detectable differences. As the projects CEB02 and BCO9701 were conducted in separate years, a temporal comparison was also made within OPEL and EOPE, which were sampled in both years.

The most powerful technique for comparing growth is to fit an appropriate model to data sets and to then contrast the resulting parameter estimates (Rao, 1958). The most frequently used model to describe the mean growth in a population or sub population is the three parameter equation developed by von Bertalanffy (1936).

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

In this equation, L_t is the length at age t and L_∞ is the asymptotic mean length. K is the growth coefficient that determines the growth rate towards the maximum, and t_0 allows for apparent non-zero body lengths at age zero.

Two approaches can be taken in comparing von Bertalanfffy parameters between stocks. One approach is to use parameter estimates in hypothesis tests. Kinsley (1979), Gallucci & Quinn (1979), and Misra (1980, 1986) carried out univariate comparisons based on either the student's t-test or the χ^2-test. However, for simultaneous comparisons of two or all three of the von Bertalanfffy parameters, Kinsley (1979) and Bernard (1981) suggested a procedure based on Hotellings T^2 statistic.

The second approach, proposed by Kimura (1980), is based on the likelihood ratio statistic and has been shown to be a more reliable procedure for comparing growth models because it is not biased by the parameter effects component of non-linear data (Cerrato, 1990).

The method of comparing growth curves used here is derived from Kimura's (1980) method. A limitation is that the residuals must be additive and normally distributed. This is because the method relies on the fact that even with non-linear curves, if the errors are additive and normally distributed then the maximum likelihood estimator will produce identical results to those produced by the minimisation of the residual sum of squares (least squares method).

The basic strategy is to compare the quality of fit under different constraints. Assuming the two data sets to be compared are in fact different, two separate curves are fitted. This is the base case against which all other hypotheses are compared. Using this, the two curves are refitted under a variety of different constraints (e.g., the K values are equal in both curves). This leads to a new total sum of squared residuals, which is compared directly with the base case.

The statistical programme S plus was used to test for normality and view the residuals of the length at age data. Von Bertalanffy growth curves were then developed and compared using Kimura's (1980) likelihood method in 100 randomisation's of the length at age data. A 95% confidence interval (CI) was then estimated for each parameter using 600 randomisation's.

12. Results:

<u>Catch of blue cod in areas of the Marlborough Sounds</u>

A total of 2140 (1366 male & 774 female) blue cod were caught in 1995, and 1867 (1398 male & 498 female) in 1996. For more detailed information on the catch composition, CPUE, length frequency distribution, sex ratios, mortality, and yield per recruit, see Blackwell (1997 & 1998).

Sex ratio

The larger length classes (greater than or equal to 30 cm) tended to be dominated by males, whereas the smaller length classes tended to have a more even sex ratio (Figures 2 & 3). Male blue cod were more common in all strata sampled during 1996, and all but OQCH95 in 1995 (Figures 2 & 3). The overall percentage of males by sampling stratum varied from 44% in OQCH95 to 84% in EQCH95. In the 1995 survey, the ratio of female to male blue cod in Queen Charlotte Sound decreased from IQCH95 (1:1.61) to OQCH95 (1:0.78) and peeked in EQCH95 (1:5.16) (Figure 2). In Pelorus Sound, the same ratio increased from the OPEL95 (1:1.27) to EOPE95 (1:3.0) (Figure 2). In the 1996 survey, the ratio of females to males was similar between IPEL96 (1:2.2), MPEL96 (1:2.1) and OPEL96 (1:1.9), but was notably higher in EOPE96 (1:3.9) and DURV96 (1:3.4) (Figure 3).

Length frequency

The length frequency distribution of both male and female blue cod sampled in the three strata of Queen Charlotte Sound in 1995 are shown in Figure 2. While mean fish size in IQCH95 (31.14 cm for males, 30.17 cm for females) was larger than in OQCH95 (29.98 cm for males, 28.15 cm for females), there were no significant differences between the length frequency distributions of these strata for ether males (Kolmogorov-Smirnov test, $P>0.05$) or females (Kolmogorov-Smirnov test, $P>0.05$) (Figure 2). There were also no significant differences between the length frequency distributions of either male (Kolmogorov-Smirnov test, $P>0.05$) or female (Kolmogorov-Smirnov test, $P>0.05$) blue cod in IQCH95 and EQCH95 (Figure 2). However, the larger size of males in EQCH95 (means of 31.90 cm for males, 27.08 cm for females, See Figure 2) resulted in a significant difference compared to the male length frequency distribution of OQCH95 (Kolmogorov-Smirnov test, $P<0.05$). This was not significant for females (Kolmogorov-Smirnov test, $P>0.05$).

In Pelorus Sound (1995), mean size of male blue cod increased from OPEL95 (28.75 cm for males, 25.24 cm for females) to EOPE95 (30.30 cm for males, 25.30 cm for females), and a significant difference between the length frequency distributions of males in these strata (Kolmogorov-Smirnov test, $P<0.001$) confirmed this observation (Figure 2). Large numbers of small females in OPEL95 (Figure 2) also resulted in a significant difference in the length frequency distributions of females between these two strata (Kolmogorov-Smirnov test, $P<0.001$).

Comparing between the Pelorus and Queen Charlotte Sounds, the length frequency distributions of blue cod in the extreme outer strata (EOPE95 & EQCH95) were remarkably similar (Figure 2), and showed no significant differences between either males (Kolmogorov-Smirnov test, $P>0.05$) or females (Kolmogorov-Smirnov test, $P>0.05$). In contrast, the length frequency distributions of both males (Kolmogorov-Smirnov test, $P<0.001$) and females (Kolmogorov-Smirnov test, $P<0.001$) were significantly different between the outer strata of Pelorus (OPEL95) and Queen Charlotte Sounds (OQCH95), primarily due to proportionately larger numbers of small fish in OPEL95 (Figure 2).

In 1996, the mean size of blue cod was similar among IPEL96 (29.1 cm for males, 24.1 cm for females), MPEL96 (29.0 cm for males, 24.1 cm for females) and OPEL96 (29.9 cm for males, 27.2 cm for females), but larger in the strata of EOPE96 (31.0 cm for males, 26.6 cm for females) and DURV96 (31.8 cm for males, 27.7 cm for females) (Figure 3). However, in contrast to results from 1995, all pair-wise statistical examinations showed no significant differences in the length frequency distributions of either males (Kolmogorov-Smirnov test, $P>0.05$) or females (Kolmogorov-Smirnov test, $P>0.05$) between any of these strata.

Between the two years, the length frequency distribution of blue cod from the outer Pelorus Sound (OPEL) did not differ significantly for ether males (Kolmogorov-Smirnov test, $P>0.05$) or females (Kolmogorov-Smirnov test, $P>0.05$) (Figures 2 & 3). However, the length frequency distribution of blue cod in the extreme outer Pelorus Sound (EOPE) did differ significantly between years for males (Kolmogorov-Smirnov test, $P<0.001$), but not females (Kolmogorov-Smirnov test, $P>0.05$) (Figures 2 & 3).

Comparisons of blue cod growth within the Marlborough Sounds

Selected Otoliths

Of 4007 blue cod caught in the 1995 and 1996 surveys, only 2051 were otolithed by Blackwell (1997 & 1998). Otoliths were not collected evenly across all strata in either 1995 (IQCH95-89, OQCH95-269, EQCH95-178, OPEL95-240, EOPE95-289) or 1996 (IPEL96-81, MPEL96-228, OPEL96-233, EOPE96-167, DURV96-277).

From these, 1323 otoliths were selected for sectioning from strata containing high numbers of otoliths in at least two areas and a wide size range for both sexes (IQCH95-50 male, 32 female; OQCH95-100, 110; EQCH95-125, 40; OPEL95-110, 102; EOPE95-122, 38; OPEL96-126, 90; EOPE96-178, 100). After sectioning, a further 54 otoliths were rejected as unreadable, leaving 1178 readable blue cod otoliths. Of these 811 were males ranging in total length between 18 and 47 cm, and 512 were females from 17 to 40 cm in total length.

Growth comparisons

Statically significant comparisons between growth models must be interpreted not only in relation to the component model's ability to describe their data sets, but also with regard to the biological significance of any observed statistical difference. Consequently, the ability of each growth model to describe its length at age data is shown in Tables 1 and 2 using a 95% CI fitted to each variable, as well as the sample size and the length range from which data was derived. Data points were not plotted as figures became too cluttered to be useful.

Growth between sites

Only a single comparison of growth was possible at the smallest spatial scale, between sites. Growth models of males were compared between sites 1 and 3 within an area (Forsyth Island) in EOPE96 (Table 1 & Figure 4). Although the sample size of site 3 was small (n=32), and the 95% conference intervals (CI) were large for L_∞ and t_0 of site 1, there was no significant difference between growth models of male blue cod at this spatial scale (Table 1).

Growth among areas

Comparisons of growth at the next spatial scale were possible among areas within five strata for males (Table 1), and within three strata for females (Table 2).

Males

The extreme outer Pelorus Sound strata showed statistically significant differences between areas at the 1% level in both 1995 (EOPE95) and 1996 (EOPE96) (Table 1). Male growth in areas of the outer Pelorus Sound strata also differed, but only at the 5% level of significance in 1996 (OPEL96), and at the 10% level in 1995 (OPEL95) (Table 1).

While growth of male blue cod showed statistically significant differences between areas within some strata, Table 1 shows that sample sizes were small for most areas within strata EOPE95, and the 95% CI for all variables was high. These observations suggest that growth was not well described by the model, and therefore results should be treated with some caution. However, figure 5 shows that growth models of male blue cod in the three areas of EOPE95 were very different and probably biologically significant.

In the following year, growth of male blue cod in areas of EOPE96 were again statistically different, but in this comparison sample sizes were much larger and some smaller fish were present (Table 1). While this provided a better description of the data, some of the variables remained unstable (Table 1). The growth models in these areas overlap, but may have biologically significant differences between older fish (Figure 5).

Growth of male blue cod in areas of the outer Pelorus Sound strata also differed, but only at the 5% level of significance in 1996 (OPEL96), and at the 10% level in 1995 (OPEL95) (Table 1). In both of these comparisons, several components of the model showed a large 95% CI and sample sizes were relatively small, especially in OPEL96 (Table 1). As these growth models also showed relatively little biological difference over the equivalent length ranges sampled (Figure 5), the observed difference in growth between these areas was not convincing.

The comparison of male blue cod growth between areas in OQCH95 showed no statistical difference (Table 1). Although several parameter 95% CI were wide (Table 1), the growth curves overlapped and supported the validity of a non-significant result (Figure 4).

Females

Growth models of females showed no statistically significant differences between any areas within strata (Table 2). However, the low numbers of female blue cod sampled meant that comparisons among areas could only be made in three strata (Table 2). The comparisons of female growth within EOPE96 and OPEL95 were made between some relatively poor component growth models compared to a somewhat more convincing comparison within OQCH95 (Table 2 & Figure 6).

Growth among strata

Comparisons of growth at the next spatial scale were possible among all selected strata in both Pelorus and Queen Charlotte Sounds for males (Table 1), and all but IQCH95 for females (Table 2).

Males

Comparisons of growth models for male blue cod in Queen Charlotte Sound showed statistically significant differences among the three strata (IQCH95, OQCH95 & EQCH95) at the 1% level of significance (Table 1). With relatively large sample sizes and length ranges, estimates of L_∞ were improved, but estimates of K and t_0 were still somewhat unstable (Table 1). However, differences between growth curves of strata in Queen Charlotte Sound seem to be biologically significant, with growth of older fish notably faster EQCH95 (Figure 7).

The two strata of Pelorus Sound also showed statistically significant differences between the growth of male blue cod at the 1% level in 1996, but only at the 10% level in 1995 (Table 1). Growth models gave a relatively good description of the data, and showed consistently faster growth in the extreme outer Pelorus Sound (Table 1). This difference in growth also appears to be biologically significant among older fish (Figure 7).

Both strata in the Pelorus Sound were sampled twice, once in 1995 and again in 1996. A temporal comparison between years showed no significant difference in the growth of male blue cod in the outer or extreme outer Pelorus Sound (Table 1). Spatially equivalent growth curves were consistent between years (Figure 7).

A comparison of equivalent strata between Pelorus and Queen Charlotte Sounds showed similar growth curves in the outer strata, but significantly faster growth to larger sizes in extreme outer Queen Charlotte Sound (Table 1). These observations appear to also be biologically significant (Figure 8).

Females

For female blue cod, comparisons of growth were also possible between all strata of both years in Pelorus Sound, and all strata except IQCH95 in Queen Charlotte Sound (Table 2). There were no statistically significant differences among strata within either the Queen Charlotte or Pelorus Sounds, but there were significant differences of equivalent strata between the two sounds (Table 2).

Within Queen Charlotte Sound, growth models appear to have provided a good description of female blue cod length at age data for both EQCH95 and OQCH95 (Table 2). Growth curves in these strata were also extremely similar over the available sample range, reinforcing the statistically non-significant result (Figure 7).

Within Pelorus Sound, models of female growth were not as successful at describing female blue cod length at age data, and estimates of L_∞ and t_0 in EOPE95 were both unstable and extrapolated well beyond the data range (Table 2). Allowing for these shortcomings, female blue cod growth curves in strata in the Pelorus Sound were remarkably similar over the available sample ranges (Figure 7).

Comparison between years showed no significant difference in the growth of female blue cod in both strata of the Pelorus Sound (Table 2 & Figure 7).

A comparison between equivalent strata of Pelorus and Queen Charlotte Sounds showed significant differences in both the outer and extreme outer strata of these Sounds (Figure 8, Table 2). However, the growth model was a poor fit for female blue cod length at age data in EOPE95 (Table 2). Also given the similarity of growth curves in the outer strata (Figure 8), the observed significant differences were not biologically convincing.

13. Conclusion

Catch per unit effort (CPUE) may provide a useful index of relative abundance for blue cod, and in the 1995 and 1996 blue cod surveys of the Marlborough Sounds. CPUE was proportionally lower in the inner strata (IQCH in 1995, IPEL in 1996) and higher in the outer strata of both Pelorus and Queen Charlotte Sounds (OQCH, EQCH, OPEL, and EOPE) (Blackwell, 1997 & 1998). Similar patterns occur between 1995 and 1996 for the OPEL and EOPE strata, and these trends have been attributed to over fishing and local depletion in the inner Marlborough Sounds (Blackwell, 1997 & 1998).

Blackwell (1997 & 1998) further suggested that a decreasing mean size along a gradient from extreme outer to inner Pelorus Sound is indicative of higher fishing pressure in inner Pelorus Sound. Pair-wise statistical examination of the 1995 length frequency distributions between the strata of Pelorus Sound showed a significant difference for both sexes between OPEL95 and EOPE95. However, Blackwell's (1997 & 1998) conclusion is not supported by the current study as no significant length frequency differences were detected between any Pelorus Sound strata in 1996. Significant differences in length frequency distributions of male blue cod were observed between outer and extreme outer strata of Queen Charlotte Sound. However, there was no gradient consistent with fishing pressure as blue cod were similar lengths between the Inner and Extreme Outer Queen Charlotte Sound strata.

Sex ratios however, follow a remarkably consistent trend of higher relative numbers of male blue cod in the extreme outer areas of both Pelorus and Queen Charlotte Sounds (Figures 2 & 3). Recreational fishing pressure may be responsible, as male blue cod grow faster, and become larger than females (Carbines, 1998), so are more likely to make up a larger proportion of the recreational catch. However, more information on the amount of recreational fishing in these areas is required.

Growth

Growth of blue cod has shown itself to be a complex issue. Not only does blue cod growth differ within geographical areas, but also variations in growth among geographical areas are not the same for both sexes. Female blue cod showed no detectable differences in growth among areas and strata within either Pelorus or Queen Charlotte Sounds (Table 2). In contrast, growth of males differed both statistically and biologically among strata within both Sounds, and may differ among areas within the outer and extreme outer Pelorus Sound strata (Table 1). A gradient was also apparent, with male blue cod growing fastest in the extreme outer strata in both Pelorus and Queen Charlotte Sounds (Figure 7).

Between equivalent strata of the Pelorus and Queen Charlotte Sounds there are biologically significant different growth rates of male blue cod between the extreme outer strata (Table 1), with faster growth in EQCH95 (Figure 8). Comparisons of female growth between equivalent strata of each sound did show statistically significant differences in both outer and extreme outer strata (Table 2). However, the poor fit of the model, and the similarity of growth curves over the available data range meant that these differences were not biologically convincing for female blue cod (Figure 8).

Comparisons between years also showed no convincing evidence of biologically significant differences for either male (Table 1) or female (Table 2) blue cod, suggesting some temporal stability in the results presented here (Figure 8).

Possible higher levels of fishing pressure in the inner areas of the Marlborough Sounds may have had the potential to select out faster growing fish. Consequently fishing pressure may be responsible for some growth differences observed in the Pelorus Sound in 1995. However, length frequency distributions of blue cod in Queen Charlotte Sound showed no statistically significant difference between the inner (IQCH95) and extreme outer (EPEL95) strata (Kolmogorov-Smirnov test, P>0.05), while an equivalent pair-wise comparison of male growth showed significantly faster growth in the extreme outer strata ($\chi^2 = 12.12_{(3)}$, p=0.007). Examples such as this suggest that the differences in blue cod growth demonstrated in this study are not simply an artefact of fishing pressure. While it is possible that fishing pressure may be responsible for some of the differences in growth observed between the outer and extreme outer areas of the Marlborough Sounds, differences in growth may also be attributed to differences in condition brought about by variations in the quality of habitat and/or food source.

The results of this study also suggest that females may be less likely to show significant changes in growth between samples because they have a slower growth rate to begin with (Carbines, 1998). This is perhaps the result of females investing more energy into reproduction than males, with the gonadosomatic index of females 2.4 times larger than that of males (Carbines, 1998). Therefore, variations in female condition may be harder to detect through measurements of growth than would be expected for males.

Blue cod have also been shown to be protogynous hermaphrodites, with a change in sex leading to an increase in growth (Carbines, 1998). It is therefore possible that larger lengths at age of male blue cod in the extreme outer strata of both sounds, are the results of an earlier onset of sex inversion in those areas. Changing sex at a younger age may be an adaptive mechanism for larger females to take advantage of better condition to provide more sperm to fertilise females that are more fecund. However, there is no evidence of this when comparing the relative mean size of female to male blue cod length in Queen Charlotte Sound (IQCH96-96.9%, OQCH96-93.9%, and EQCH96-84.9%). Nevertheless, this variable does suggest that in Pelorus Sound (IPEL96-82.8%, MPEL96-83.1%, OPEL96-91.1%, and DUR96-87.1%) males may be changing sex at a smaller size in the extreme outer areas.

The current study sought to determine the degree of spatial variability in growth rates of blue cod in the Marlborough Sounds, and to estimate growth over spatial areas most appropriate for stock assessment. Tagging studies of blue cod have concluded that the Marlborough Sounds supports a separate stock and that interactions among the strata of the current study are likely to be less than 4% over 2.25 years (Mace & Johnston, 1983). Given that the current study concluded that blue cod growth differs between these strata, it is further concluded that stock assessment may need to take these differences into account.

14. Publications

There are no publications from this project.

15. Data Storage

The data collected in this project are stored on the MFish "age" database housed at Greta Point.

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Appendix 1

Each major sound was divided into sampling strata based on the distance from the head of the sound, and on major topographical features. Greater Queen Charlotte Sound was divided into three strata, the Inner, Outer, and Extreme Outer sounds (Figure 1). The Inner Queen Charlotte (IQCH) stratum extended north-west from a line between Pihaka Point, Allports Island and The Snout, including the Bay of Many Coves. It was bounded in the north-east by a line from Hawes Rock to Dieffenbach Point (Figure 1). The area inland from Allports Island was not surveyed.

The Outer Queen Charlotte (OQCH) stratum extended north-east to a line between Ship Cove, Long Island and Cooper Point on Arapawa Island, and included Tory Channel (Figure 1). The Extreme Outer Queen Charlotte stratum included the exposed coastline of the Marlborough Sounds from Cape Jackson to Alligator Head (Figure 1).

Greater Pelorus Sound was divided into five strata, the Inner, Mid, Outer, Extreme Outer and D'Urville Island (Figure 1). The Inner Pelorus (IPEL) stratum extended north along Popoure Reach from a line between Dillon Bell Point and Yncya Bay, to a line between Tawero Point and Whakamawahi Point (Figure 1). The mid Pelorus (MPEL) stratum extended north to a line between Tapapa Point and Maud Island including Tawhitinui Reach (Figure 1). The Outer Pelorus (OPEL) stratum extended northeast along Waitata Reach to a line between East Entry and West Entry Points (Figure 1). The Extreme Outer Pelorus (EOPE) stratum included the exposed coastline of the Marlborough Sounds from Guards Bay to Clay Point, including the Chetwode Islands (Figure 1). The D'Urville stratum included the waters of Admiralty Bay and the western side of D'Urville Island to Cape Stephens including the Trio and Rangitoto Islands (Figure 1).

Table 1: Growth models (von Bertalanffy) and likelihood comparisons for male blue cod. Parameter estimates, 95% confidence intervals, sample size, and length range are shown. The symbol * indicates the model was unable to fit data.

							Likelihood ratio tests					
	L_∞	95% CI	K	95% CI	t_0	95% CI	$\chi 2$	d.f.	p	n	Min	Max
EOPE95	42.34	37.73-93.53	0.16	0.03-0.29	-1.87	-8.63-0.40	28.05	6	<0.001	102	23	41
Forsyth Island (A)	41.67	35.41-122.63	0.24	0.02-0.74	-0.07	-8.33-2.56				28	23	40
Chetwode Island (B)	42.99	32.32-93.80	0.13	0.03-0.82	-2.94	-10.15-2.46				49	23	37
Clay Point (C)	44.53	38.67-145.64	0.15	0.02-0.34	-0.52	-5.01-2.55				25	24	41
Harris Bay (D)	*		*		*					20	23	40
EOPE96	39.30	36.52-48.55	0.28	0.12-0.43	0.46	-2.45-1.63	13.06	3	0.004	157	20	41
Forsyth Island (A)	38.38	35.63-55.76	0.29	0.07-0.51	0.11	-5.46-1.71				95	24	41
Chetwode Island (B)	42.49	35.98-125.75	0.25	0.03-0.54	1.05	-2.60-2.46				62	21	40
Clay Point (C)	*		*		*					15	20	38
Harris Bay (D)	*		*		*					6	20	38
Forsyth Island (A)	*38.39*	*35.48-53.48*	*0.30*	*0.08-0.50*	*0.17*	*-4.76-1.72*	*6.44*	*3*	*0.092*	*93*	*24*	*41*
Site 1	*40.57*	*31.56-97.73*	*0.19*	*0.03-1.15*	*-1.77*	*-9.01-2.63*				*61*	*24*	*38*
Site 2	*		*		*					*2*	*31*	*33*
Site 3	*36.23*	*34.16-39.59*	*0.81*	*0.30-3.60*	*3.36*	*0.78-4.61*				*32*	*25*	*41*
OPEL95	34.30	33.02-35.89	0.46	0.29-0.69	1.14	-0.51-2.12	6.56	3	0.087	74	20	39
The Reef (A)	*		*		*					32	25	38
Boat Rock Point (B)	37.58	32.48-106.74	0.29	0.04-0.65	0.41	-2.39-1.71				34	20	39
Duffers Reef (D)	34.77	32.45-51.34	0.27	0.03-6.40	-2.72	-28.13-4.66				40	25	36
Bulwer (E)	*		*		*					4	20	24
Camp Bay (F)	*		*		*					0		
OPEL96	34.89	33.09-37.43	0.36	0.25-0.53	0.84	-0.30-1.79	13.01	6	0.043	89	18	39
The Reef (A)	*		*		*					26	22	39
Boat Rock Point (B)	33.22	31.43-52.17	0.43	0.05-1.07	0.80	-12.92-3.34				24	25	34
Katira Point (C)	*		*		*					7	19	26
Duffers Reef (D)	38.18	33.72-69.97	0.19	0.05-0.47	-0.75	-5.56-2.36				27	21	36
Bulwer (E)	*		*		*					0		
Camp Bay (F)	*		*		*					4	31	37
Te Akaroa (G)	35.05	32.53-42.92	0.43	0.15-0.84	1.37	-2.08-2.76				38	18	36
EQCH95	*		*		*		*	*	*	*	*	*
Stella Roch (A)	*		*		*					34	29	47
The Twins (B)	*		*		*					11	26	38
Cape Jackson (C)	49.10	43.10-72.78	0.15	0.06-0.23	-0.77	-3.01-0.40				63	20	42
Alligator Head (D)	*		*		*					17	24	40
OQCH95	32.44	30.74-40.90	0.66	0.09-1.88	1.41	-8.07-3.00	2.75	3	0.432	73	21	40
Tory Channel (A)	30.94	29.48-35.21	1.74	0.25-8.01	2.94	-3.85-3.81				43	25	36
Hawes Rock (B)	*		*		*					22	27	37
Resolution Bay (C)	34.48	31.23-83.42	0.36	0.03-1.05	0.10	-12.30-2.06				30	21	40
Pickersgill Island (D)	*		*		*					5	25	36
Arapara Island (E)	*		*		*					0		
Queen Charlotte Sound 1995	62.96	39.99-155.61	0.06	0.01-0.22	-5.38	-10.01--0.72	23.29	6	<0.001	275	20	47
EQCH95	50.16	40.84-67.85	0.12	0.06-0.25	-1.92	-4.53-0.21				125	20	47
OQCH95	33.65	30.79-68.79	0.43	0.03-1.52	0.97	-12.35-2.79				100	21	40
IQCH95	41.35	30.70-88.04	0.13	0.02-6.52	-5.20	-13.33-3.71				50	24	40
Pelorus Sound 1995	37.78	36.06-41.25	0.27	0.17-0.35	-0.01	-1.73-0.69	6.83	3	0.077	232	20	41
EOPE95	42.81	38.53-90.59	0.16	0.03-0.27	-1.56	-7.47-0.39				122	23	41
OPEL95	34.97	33.71-36.91	0.41	0.29-0.53	0.89	0.11-1.34				110	20	39
Pelorus Sound 1996	38.21	36.68-40.45	0.27	0.21-0.33	0.18	-0.529-0.76	17.11	3	<0.001	304	18	41
EOPE96	41.88	38.21-51.09	0.22	0.12-0.33	-0.02	-1.65-1.05				178	20	41
OPEL96	37.57	35.67-40.81	0.25	0.17-0.32	-0.23	-1.42-0.56				125	18	39
Outer Pelorus Sound	36.24	35.018-37.86	0.31	0.24-0.38	0.31	-0.39-0.80	7.19	3	0.066	236	18	39
OPEL95	34.97	33.71-36.91	0.41	0.29-0.53	0.89	0.11-1.34				110	20	39
OPEL96	37.57	35.67-40.81	0.25	0.17-0.32	-0.23	-1.42-0.56				125	18	39
Extreme Outer Pelorus	40.84	38.43-45.72	0.22	0.14-0.29	-0.29	-1.67-0.66	5.79	3	0.122	300	20	41
EOPE95	42.81	38.53-90.59	0.16	0.03-0.27	-1.56	-7.47-0.39				122	23	41
EOPE96	41.88	38.21-51.09	0.22	0.12-0.33	-0.02	-1.65-1.05				178	20	41
Outer Strata	34.33	33.04-36.36	0.43	0.29-0.57	0.75	-0.67-1.30	3.10	3	0.376	210	20	40
OPEL95	34.97	33.71-36.91	0.41	0.29-0.53	0.89	0.11-1.34				110	20	39
OQCH95	33.65	30.79-68.79	0.43	0.03-1.52	0.97	-12.35-2.79				100	21	40
Extreme Outer Strata	47.90	41.43-74.39	0.12	0.05-0.21	-2.24	-5.65--0.45	21.17	3	<0.001	247	20	47
EOPE95	42.81	38.53-90.59	0.16	0.03-0.27	-1.56	-7.47-0.39				122	23	41
EQCH95	50.16	40.84-67.85	0.12	0.06-0.25	-1.92	-4.53-0.21				125	20	47

Table 2: Growth models (von Bertalanffy) and likelihood comparisons for female blue cod. Parameter estimates, 95% confidence intervals, sample size, and length range are shown. The symbol * indicates the model was unable to fit data.

							Likelihood ratio tests					
	L_∞	95% CI	K	95% CI	t_0	95% CI	$\chi 2$	d.f.	p	n	Min	Max
EOPE95	*		*		*		*	*	*	*	*	*
Forsyth Island (A)	*		*		*					3	25	30
Chetwode Island (B)	*		*		*					9	22	29
Clay Point (C)	28.76	28.08-31.64	1.12	0.14-6.27	3.01	-6.33-4.70				19	25	32
Harris Bay (D)	*		*		*					7	23	37
EOPE96	34.37	28.76-79.64	0.15	0.02-0.49	-3.45	-13.21-0.87	4.14	3	0.247	75	20	32
Forsyth Island (A)	45.51	28.37-88.39	0.05	0.01-0.66	-12.97	-21.13-1.05				26	23	32
Chetwode Island (B)	*		*		*					15	22	29
Clay Point (C)	37.89	28.80-89.11	0.12	0.02-0.52	-3.52	-9.72-1.60				49	20	31
Harris Bay (D)	*		*		*					10	20	31
OPEL95	31.52	28.73-51.20	0.28	0.07-0.56	-0.86	-7.24-1.26	5.37	3	0.146	71	18	32
The Reef (A)	30.82	28.39-43.84	0.38	0.10-1.74	-0.06	-4.50-3.26				35	20	32
Boat Rock Point (B)	36.71	27.46-98.39	0.14	0.02-0.65	-3.30	-10.73-1.44				36	18	32
Katira Point (C)	*		*		*					15	24	31
Duffers Reef (D)	*		*		*					9	20	28
OPEL96	*		*		*		*	*	*	*	*	*
The Reef (A)	*		*		*					18	17	36
Boat Rock Point (B)	31.02	29.23-34.09	0.48	0.14-1.05	1.65	-3.51-3.31				24	20	33
Katira Point (C)	*		*		*					7	24	32
Duffers Reef (D)	*		*		*					31	21	39
Bulwer (E)	*		*		*					2	22	23
Camp Bay (F)	*		*		*					3	28	31
Te Akaroa (G)	*		*		*					5	21	40
EQCH95	*		*		*		*	*	*	*	*	*
Stella Roch (A)	*		*		*					2	30	30
The Twins (B)	*		*		*					2	22	27
Cape Jackson (C)	34.09	30.01-87.85	0.36	0.05-1.49	0.73	-2.05-3.17				19	20	33
Alligator Head (D)	*		*		*					17	23	30
OQCH95	31.83	30.84-33.68	0.37	0.22-0.63	-0.28	-2.57-1.5	1.47	3	0.690	82	21	36
Tory Channel (A)	*		*		*					13	22	30
Hawes Rock (B)	31.55	30.48-53.88	0.40	0.02-1.01	-0.26	-33.36-2.46				44	24	36
Resolution Bay (C)	32.59	29.99-40.55	0.30	0.09-0.65	-0.85	-6.14-1.57				38	21	36
Pickersgill Island (D)	*		*		*					14	23	36
Arapara Island (E)	*		*		*					1	32	32
Queen Charlotte Sound	32.18	31.17-33.88	0.31	0.20-0.43	-0.73	-2.56-0.45	0.63	3	0.891	150	20	36
EQCH95	30.82	28.81-36.88	0.45	0.18-0.95	0.33	-2.02-1.90				40	20	33
OQCH95	32.40	31.20-34.64	0.29	0.17-0.45	-1.12	-4.01-0.73				110	21	36
IQCH95	*		*		*					32	26	37
Pelorus Sound 1995	30.89	29.14-38.36	0.34	0.13-0.54	-0.15	-3.23-1.03	2.51	3	0.473	140	18	37
EOPE95	50.48	28.39-138.78	0.06	0.01-0.88	-6.18	-10.37-2.39				38	22	37
OPEL95	30.12	28.75-32.62	0.39	0.24-0.59	0.14	-1.50-1.11				102	18	32
Pelorus Sound 1996	33.22	30.90-39.46	0.20	0.11-0.28	-2.02	-4.29--0.83	3.56	3	0.314	190	17	40
EOPE96	33.89	28.47-73.30	0.16	0.03-0.43	-3.51	-11.08--0.11				100	20	32
OPEL96	32.87	30.78-37.78	0.23	0.13-0.35	-1.27	-3.12-0.18				90	17	40
Outer Pelorus Sound	32.19	30.56-34.97	0.26	0.18-0.36	-0.97	-2.21-0.04	2.71	3	0.439	192	17	40
OPEL95	30.12	28.75-32.62	0.39	0.24-0.59	0.14	-1.50-1.11				102	18	32
OPEL96	33.89	28.47-73.30	0.16	0.03-0.43	-3.51	-11.08--0.11				90	17	40
Extreme Outer Pelorus	39.72	29.78-106.65	0.10	0.02-0.34	-5.09	-11.35--0.41	4.25	3	0.236	138	20	37
EOPE95	50.48	28.39-138.78	0.06	0.01-0.88	-6.18	-10.37-2.39				38	22	37
EOPE96	33.89	28.47-73.30	0.16	0.03-0.43	-3.51	-11.08--0.11				100	20	32
Outer Strata	31.79	30.61-33.35	0.31	0.22-0.43	-0.51	-1.87-0.54	14.14	3	0.003	212	18	36
OPEL95	30.12	28.75-32.62	0.39	0.24-0.59	0.14	-1.50-1.11				102	18	32
OQCH95	32.40	31.20-34.64	0.29	0.17-0.45	-1.12	-4.01-0.73				110	21	36
Extreme Outer Strata	31.71	28.77-96.37	0.31	0.02-0.73	-0.74	-11.46-1.44	10.61	3	0.014	247	20	37
EOPE95	50.48	28.39-138.78	0.06	0.01-0.88	-6.18	-10.37-2.39				38	22	37
EQCH95	30.82	28.81-36.88	0.45	0.18-0.95	0.33	-2.02-1.90				40	20	33

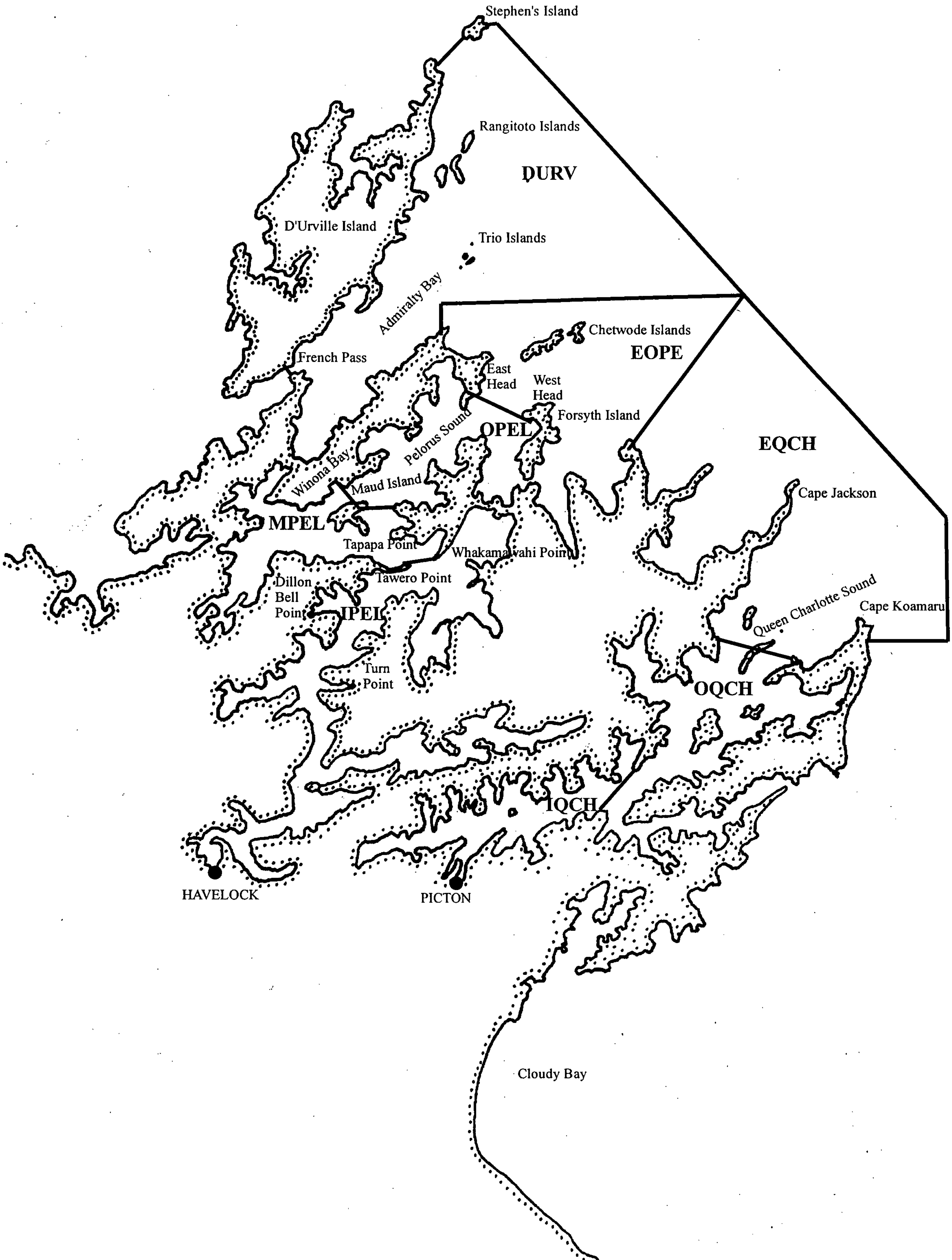


Figure 1: Marlborough Sounds survey area, showing strata: Pelorus Sound, DURV (D'Urville Island) EOPE (Extreme Outer Pelorus Sound), OPEL (Outer Pelorus Sound), MPEL (Mid Pelorus Sound). Queen Charlotte Sound: EQCH (Extreme Outer Queen Charlotte Sound), OQCH (Outer Queen Charlotte Sound), IQCH (Inner Queen Charlotte Sound).

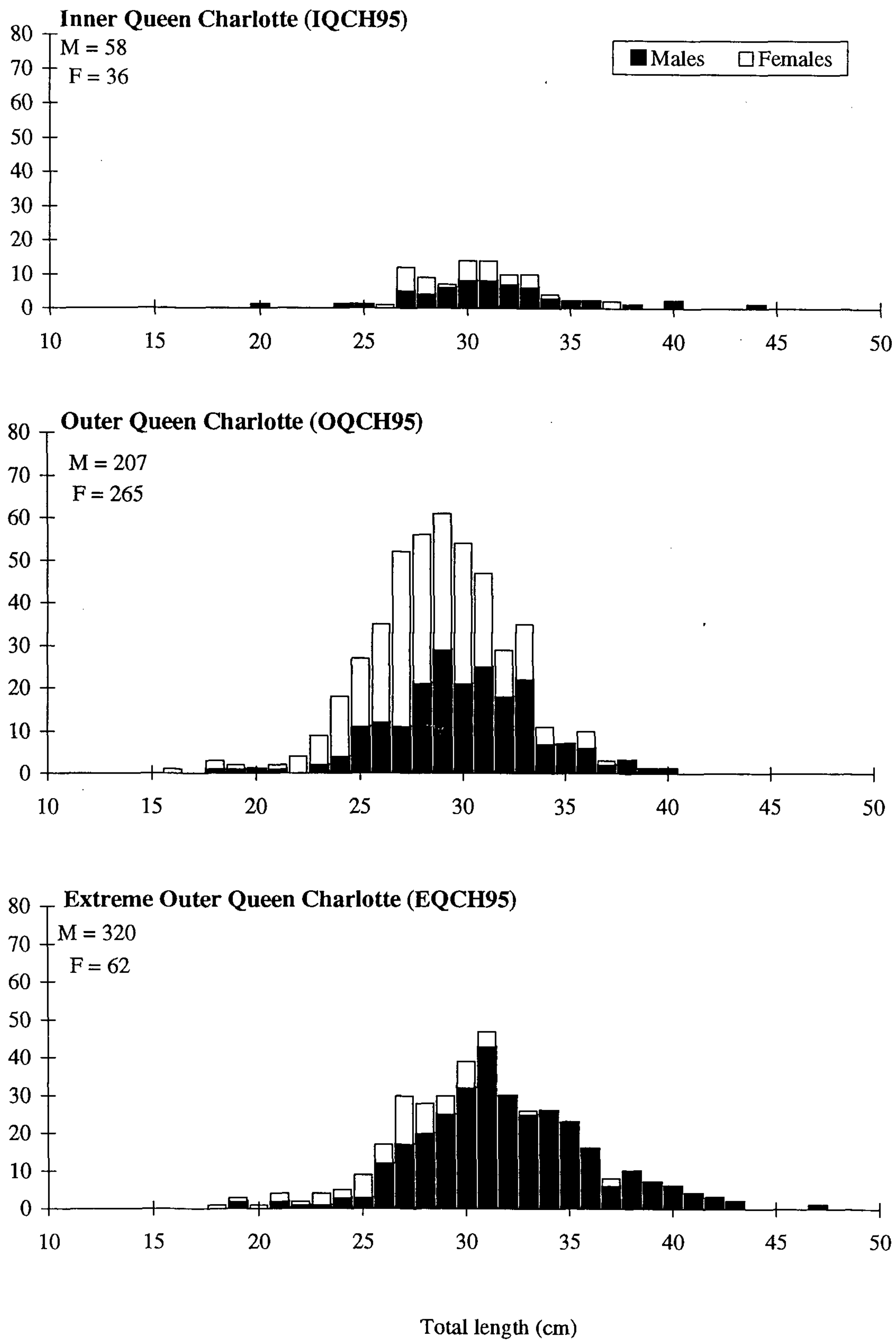


Figure 2: Length frequency distribution of blue cod by stratum in 1995. Frequency of male (black) and female (white) blue cod are actual numbers measured. Stratum are shown in Figure 1.

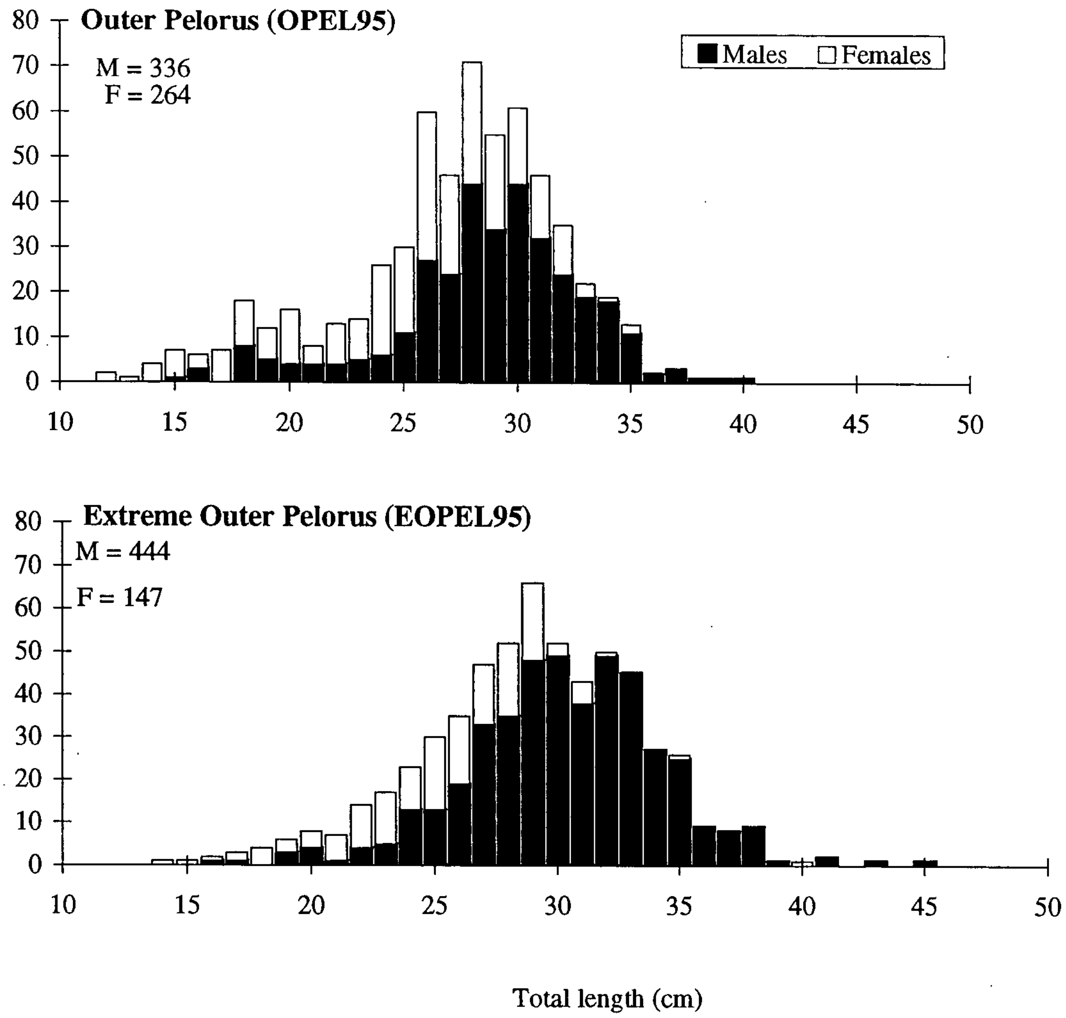


Figure 2 — *continued*

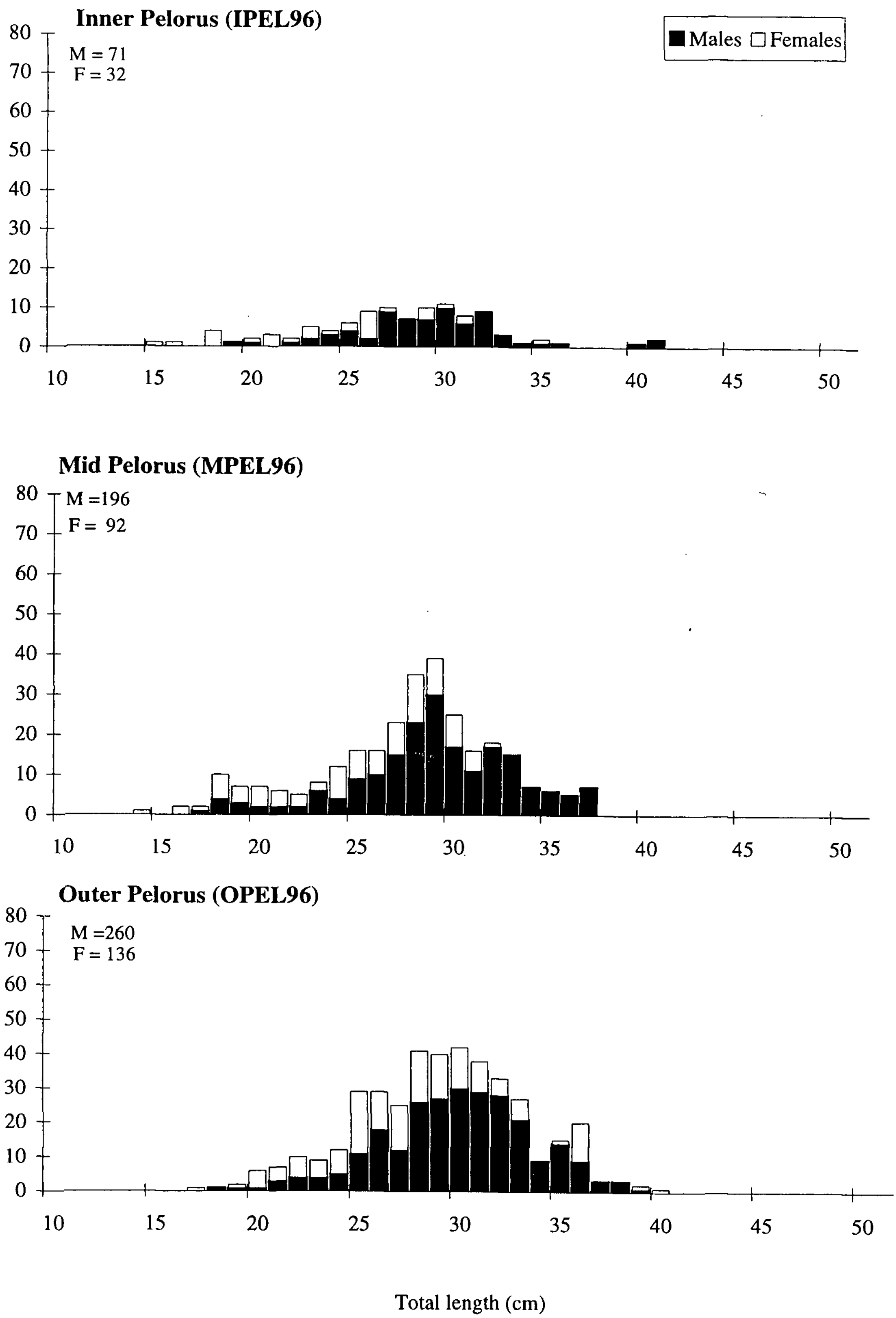


Figure 3: Length frequency distribution of blue cod by stratum in 1996. Frequency of male (black) and female (white) blue cod are actual numbers measured. Stratum are given in Figure 1.

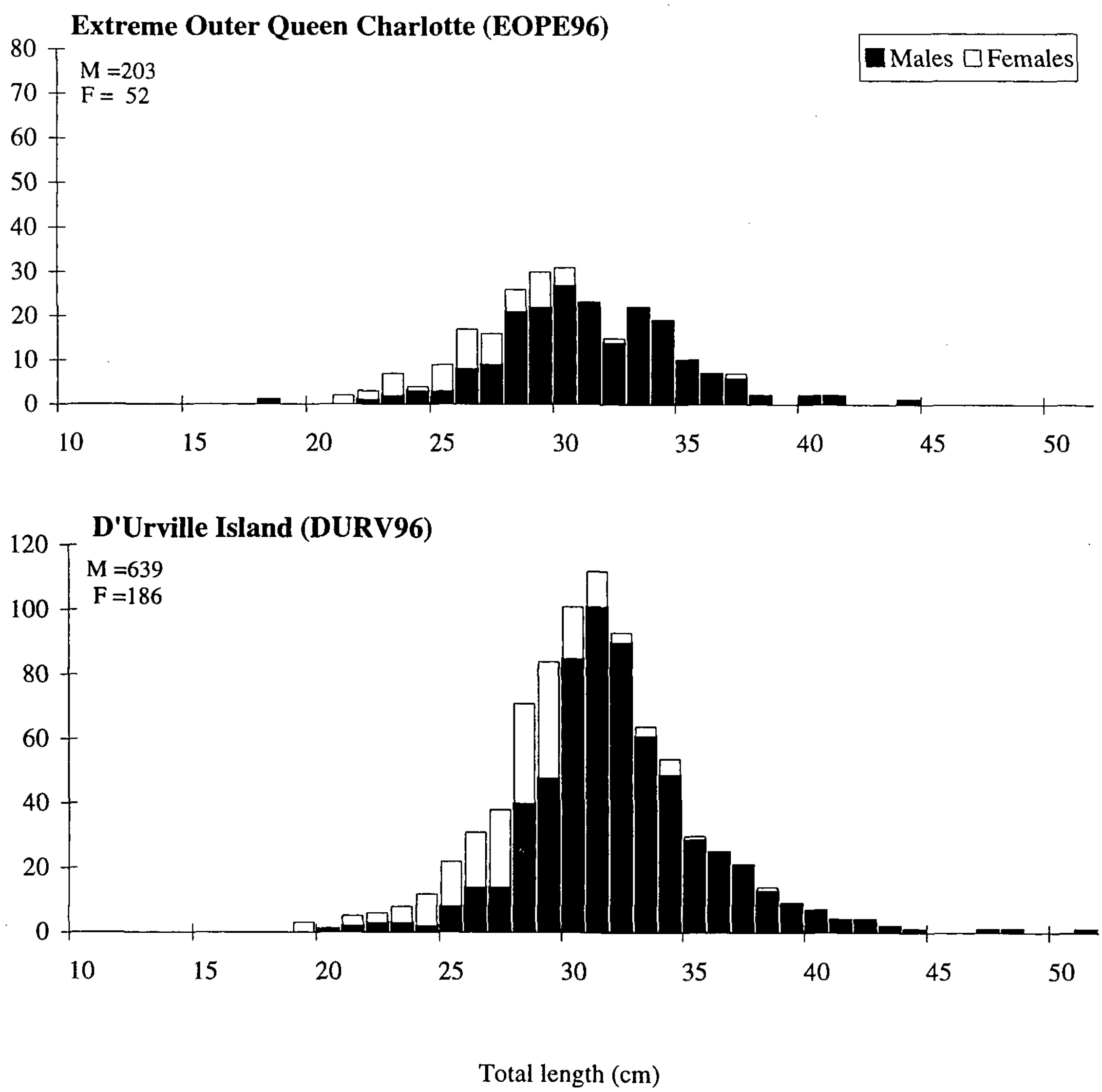


Figure 3:—*continued.*

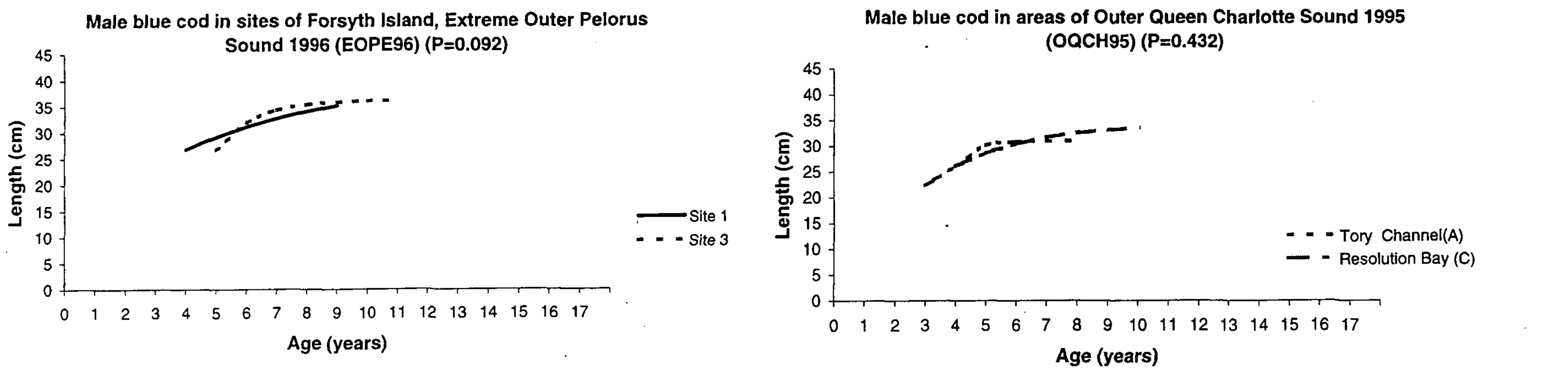


Figure 4: Von Bertalanffy growth models fitted to the data range of male blue cod from sites within the Forsyth Island area of the Extreme outer Pelorus Sound in 1995, and of areas in the outer Queen Charlotte Sound stratum in 1996. P-values of likelihood comparisons of growth models are shown in brackets, for a full description see Table 1. Strata are shown in Figure 1.

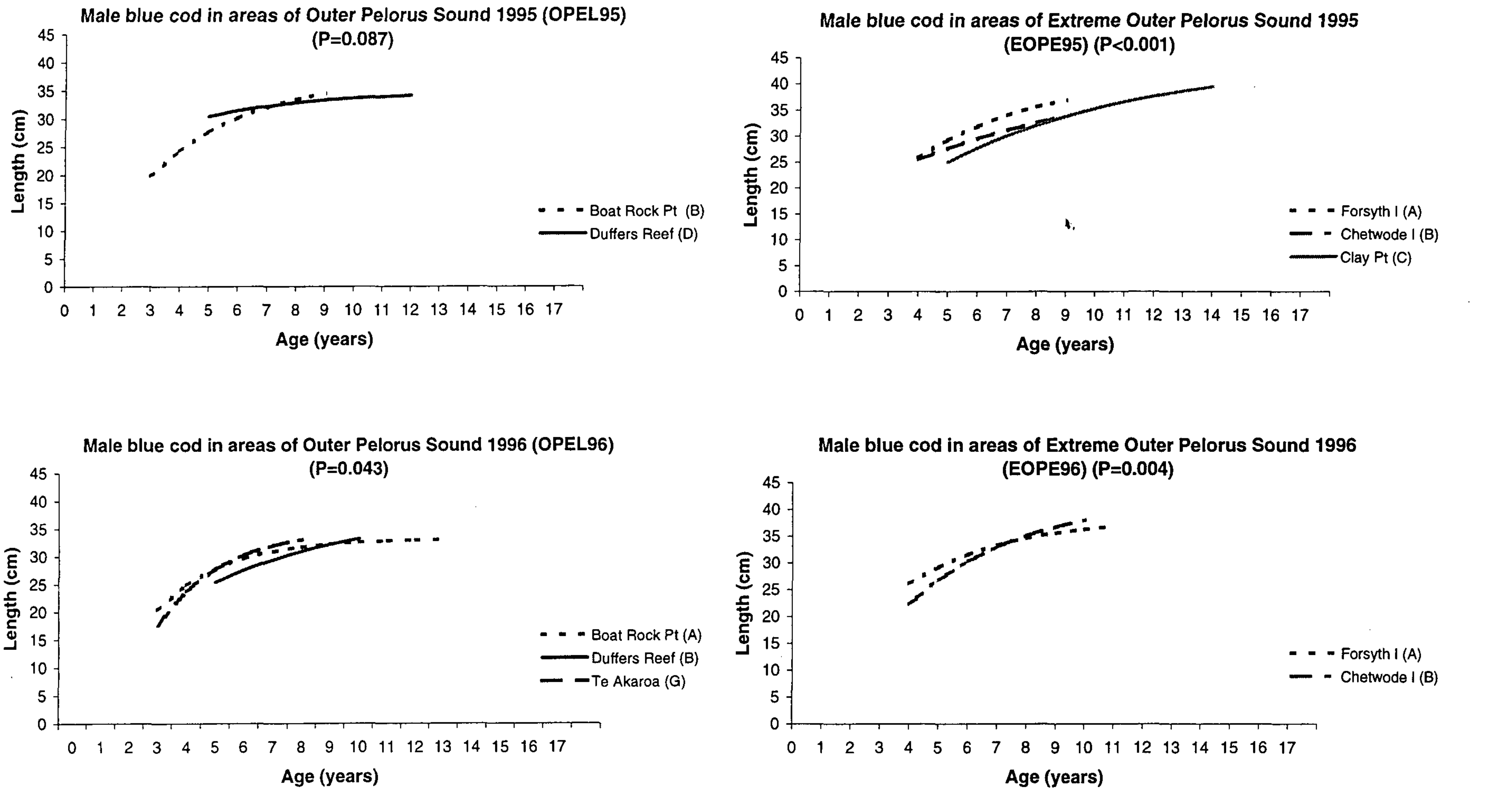
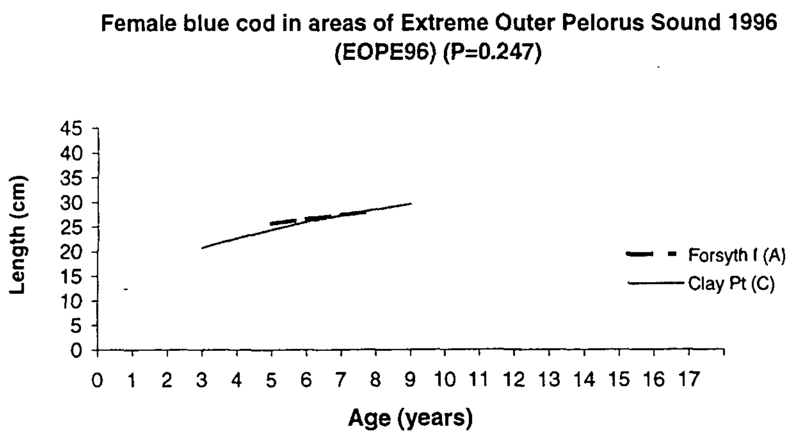
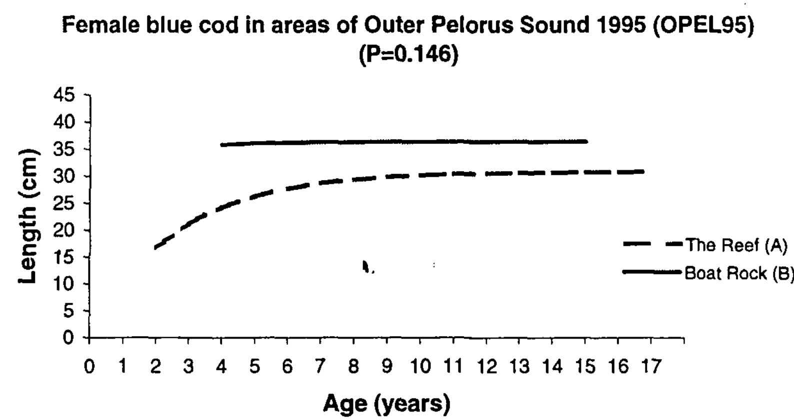


Figure 5: Von Bertalanffy growth models fitted to the data range of male blue cod of areas within strata of Pelorus Sound sampled in 1995 and 1996. P-values of likelihood comparisons of growth models are shown in brackets, for a full description see Table 1. Strata are shown in Figure 1.





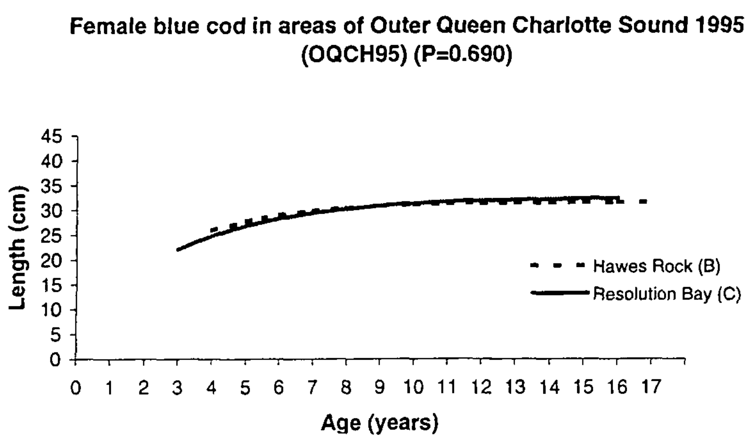


Figure 6: **Von Bertalanffy growth models fitted to the data range of female blue cod of areas within strata of Queen Charlotte (1995) and Pelorus Sounds (1995 & 1996). P-values of likelihood comparisons of growth models are shown in brackets, for a full description see Table 2. Strata are shown in Figure 1.**

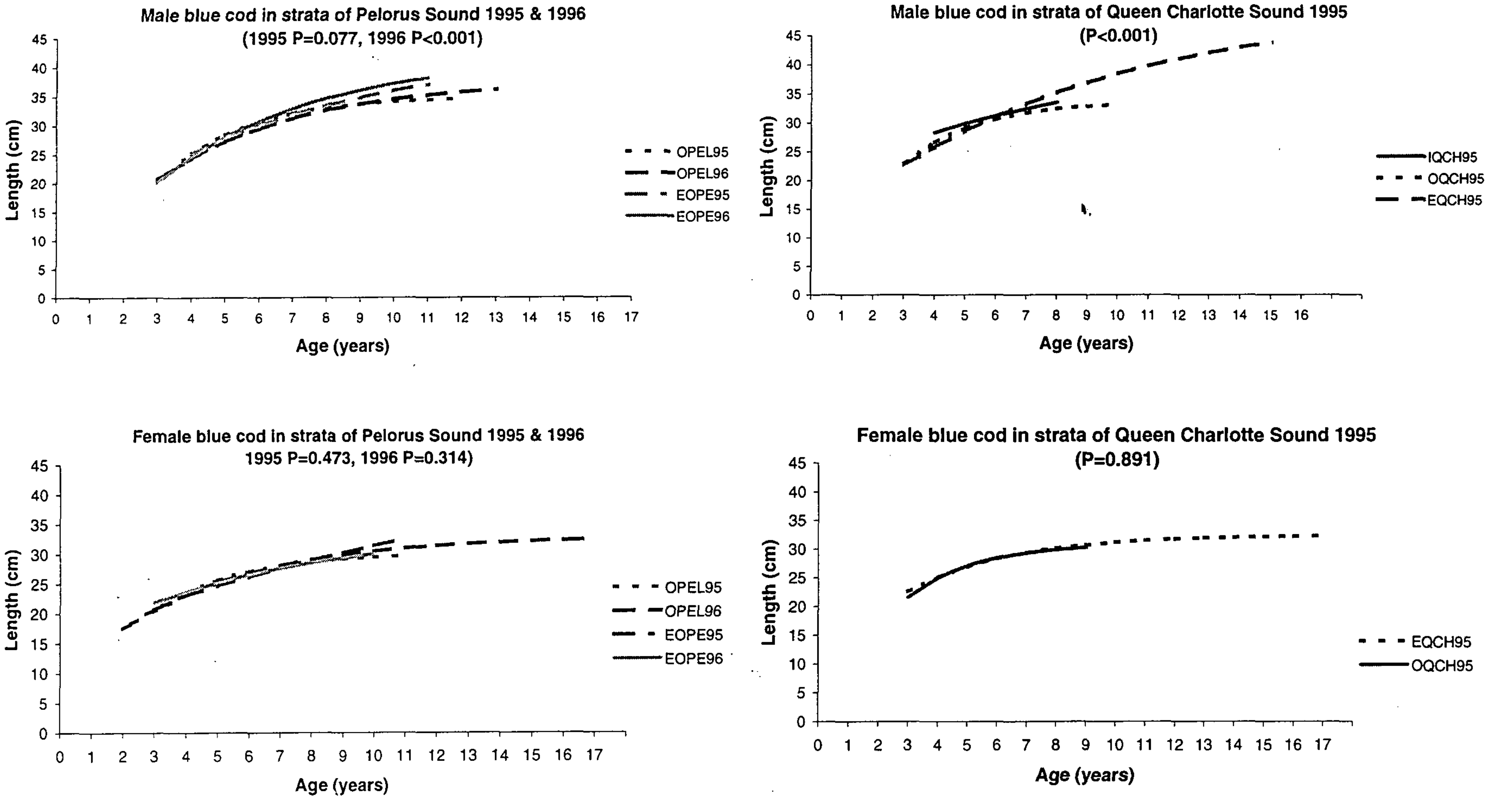


Figure 7: Von Bertalanffy growth models fitted to the data range of both male and female blue cod in strata of Pelorus and Queen Charlotte Sounds sampled in 1995 and 1996. OPEL95 = Outer Pelorus Sound 1995, OPEL96 = Outer Pelorus Sound 1996, EOPE95 = Extreme Outer Pelorus Sound 1995, OPEL96 = Extreme Outer Pelorus Sound 1996. IQCH95 = Inner Queen Charlotte Sound 1995, OQCH = Outer Queen Charlotte Sound 1995, EQCH = Extreme Outer Queen Charlotte Sound 1995. P-values of likelihood comparisons of growth models are shown in brackets, for a full description see Table 1. Strata are shown in Figure 1.

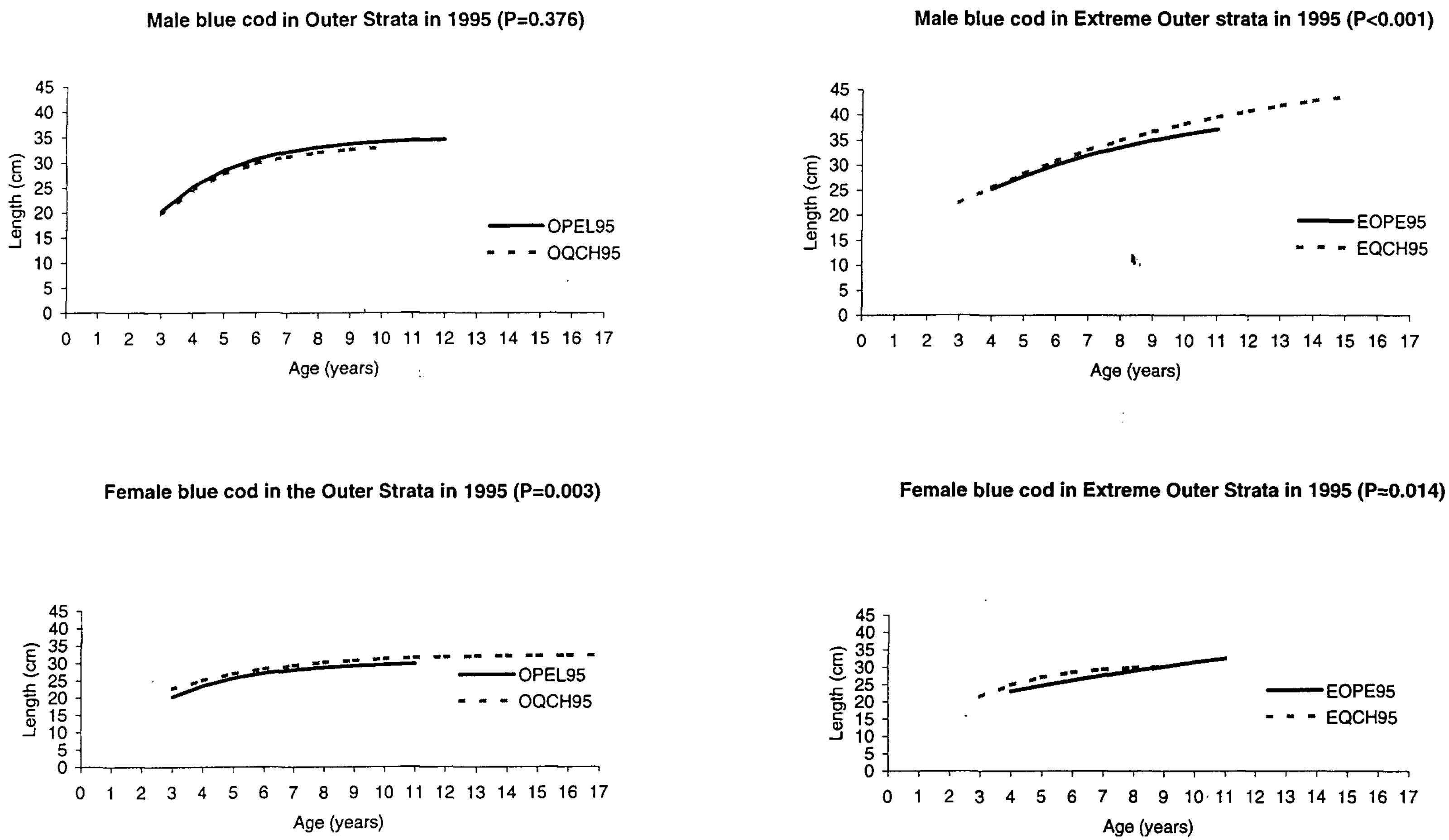


Figure 8: Von Bertalanffy growth models fitted to the data range of both male and female blue cod in equivalent strata of Pelorus and Queen Charlotte Sounds sampled in 1995. OPEL95 = Outer Pelorus Sound 1995, EOPE95 = Extreme Outer Pelorus Sound 1995, OQCH95 = Outer Queen Charlotte Sound 1995, EOPE95 = Extreme Outer Queen Charlotte Sound 1995. P-values of likelihood comparisons of growth models are shown in brackets, for a full description see Tables 1 & 2. Strata are shown in Figure 1.