MINISTRY OF FISHERIES

Te Tautiaki i nga tini a Tangaroa

The observed sex ratios of hoki (*Macruronus novaezelandiae*) in New Zealand, 1983–99

M. E. Livingston
B. Bull
D. Gilbert

The observed sex ratios of hoki (*Macruronus novaezelandiae*) in New Zealand, 1983–99

M. E. Livingston
B. Bull
D. Gilbert

NIWA
PO Box 14 901
Wellington

EXECUTIVE SUMMARY

The proportions of male and female hoki in commercial trawl catches from two spawning grounds (West Coast South Island (WCSI) and Cook Strait), and trawl surveys of two non-spawning grounds (Chatham Rise and the Subantarctic), were examined for the period 1983 to 1999.

In each of the four areas studied, the observed proportion of male hoki declined with increasing age. Trawl surveys of the Chatham Rise and Subantarctic had similar mean proportions of males up to age 4 years, but after age 6 years, the relative proportion of males in the Subantarctic was higher than on the Chatham Rise. The relative proportions of males at age on the two spawning grounds were similar to each other. In the eastern stock of hoki, the proportions of males at age on the spawning grounds (Cook Strait) were consistently higher than on the home ground (Chatham Rise). In the western stock the proportions of males up to age 6 were consistently higher than on the home ground (Subantarctic), but from 7 years and older, ratios of males on both spawning and home grounds were similar. Males formed a higher proportion of hoki aged 4 and 5 years in December surveys of the Subantarctic compared with other seasons.

Within time series of data, some trends were apparent. On the WCSI the proportion of males decreased over time among year classes 7 and older within the commercial catch at age series. In the Subantarctic there was some evidence of a seasonal cycle in the proportion of males, the lowest coinciding with September when fish had not returned from their spawning grounds. In Cook Strait, little change was observed except for a slight increase in the proportion of males in the 5–8 year classes. On the Chatham Rise, a slight increase in the proportion of males in the 9–10 age classes within the January time series was observed. Changes in sex ratios between 1983 and 1999 show that relatively, males now form a lower proportion in the Subantarctic than they did in 1983, whereas on the Chatham Rise, they form a higher proportion now than in 1983.

An analysis to determine the effect of fish size on the rate of survival of individual cohorts from year to year showed that the size differences between male and female hoki alone do not explain the observed differences in sex ratios. Another analysis to estimate the total mortality of males and females gave such large differences between the two sexes that mortality differences were also considered unlikely to be the sole factor influencing observed sex ratios. We suggest that differences in the distribution of male and female hoki in the water column could account for some of the differences in observed sex ratios, and the apparently contradictory changes in sex ratios between areas.

We concluded that observed differences in hoki sex ratios reflected more than sex differences in growth rate and the ability of the larger females to out-swim trawl nets. We concluded that the observed sex ratios reflect differences in mortality rates between the sexes, (males > females), and differences in vertical availability (males higher in water column than females and therefore less available to bottom gear). Several hypotheses are proposed, and a range of sensitivity analyses for hoki stock assessment are discussed.

1. INTRODUCTION

Hoki are most abundant in waters 200–800 m deep around the South Island, and support an annual total catch of about 250 000 t (Annala *et al.* 1999). Large midwater trawlers operate on winter spawning grounds off the west coast of the South Island (WCSI) and in Cook Strait during winter (Figure 1). A substantial bottom trawl fishery for hoki operates during other seasons on the Chatham Rise and to a lesser extent in the Subantarctic (Auckland Islands and Campbell Islands Shelves, Pukaki Rise, and Campbell Plateau (Figure 1). The Chatham Rise is the main nursery ground for juvenile hoki age 2–4 years, and, as the fish reach sexual maturity, some recruit south to the Subantarctic which is the assumed home ground of the western stock, while others move to deeper water on the Chatham Rise, the assumed home ground of the eastern stock (Livingston & Schofield 1996a, Cordue 2000).

Female hoki grow to a greater size than males (Horn & Sullivan 1996) and sex ratios from trawl surveys of the Chatham Rise and Subantarctic have shown that the proportion of males in the catch declines with age (e.g., Livingston & Schofield 1993). It is currently assumed that most of the differences in observed sex ratios arise from the ability of the larger female hoki to better out-swim trawl gear than the smaller males, and in the stock assessment model there is a penalty function if female selectivities or vulnerabilities are higher than for males (Cordue 2000). However, there are other factors that could explain the observed differences in hoki sex ratios, such as different mortality rates and different vulnerabilities. If there are differences in male and female mortality rates, sex ratios will reflect actual differences in the numbers of fish at age. If there are differences in male and female catchability, then the sex ratios observed will reflect the bias in the way that hoki are sampled by the trawl rather than the abundance of each sex.

The model used for hoki assessment estimates catchability coefficients for each of the spawning grounds and home grounds (Cordue 1999). Improving understanding of the factors influencing the observed sex ratios is part of an overall objective to improve parameterisation of the model. Investigation of the observed differences in sex ratios between areas, and between trawl survey catches and commercial catches and incorporation of the results in the assessment models, was identified as an objective within the ongoing hoki population modelling and stock assessment research programme funded by MFish in 1998 (MFish Project HOK9801, Objective 6).

To meet the first part of Objective 6 above 'investigate the observed differences in sex ratios between areas and between trawl survey catches and commercial catches [of hoki]', the study reported here was commissioned to investigate observed sex ratios from the four main fishing grounds of hoki (i.e., Chatham Rise, Subantarctic, Cook Strait, and WCSI), and explore alternative hypotheses to explain these observations. Sex ratios from the principal time series of data from each area were also compared to explore differences between spawning and non-spawning hoki, trawl surveys and commercial data, eastern and western stock hoki, and any differences between pre-fishery data and recent data. To meet the second part of the objective, 'incorporation of the results in the stock assessment models' the results will be used in the next stock assessment for hoki, currently scheduled for 2001.

2. METHODS

2.1 Data sources

Tables A1–A5 of Appendix 1 give the raw data used. Numbers at age were derived either from otolith readings using the validated hoki ageing method of Horn & Sullivan (1996), or the length at age program MIX (MacDonald & Green 1988). Otolith data allowed numbers at age to be estimated for the first nine age classes individually, and a plus group for those 10 years or more. Age classes 10 years and over were combined because zeros were frequently encountered in older age classes. The MIX results provide numbers at age for the first five year classes individually, with a combined plus group of 6 years and over.

The proportions of male hoki out of the total number of hoki for individual age classes were estimated from each of the main data sets, as follows.

- WCSI commercial catch at age data (estimated from otolith readings and age length keys) from the winter spawning fishery on board sampling by Ministry of Fisheries scientific observers (*see* Figures 27, 28.)

- Subantarctic area commercial catch at age data (estimated from length frequency distribution using MIX software) collected opportunistically by the Ministry of Fisheries Scientific Observer Programme throughout the year.

- Subantarctic population numbers at age (otolith readings or MIX) estimated from a series of random trawl surveys covering 300–800 m in the Subantarctic (Table 1). It should be noted that some adjustments were made when plotting the proportions of males at age. Age class 1 data were omitted because of inadequate sampling in this age group; suspected ageing errors may have resulted in over-representation of the year class spawned in 1989, which follows a strong year class spawned in 1988 (Livingston & Schofield 1996b).

- Cook Strait commercial catch at age data (estimated from otolith readings and age length keys) from the winter spawning fishery as sampled by the Ministry of Fisheries Stock Monitoring Programme in the factory sheds when the fish are first landed.

- Chatham Rise area commercial catch at age (estimated from length frequency distribution using MIX software) collected by the Scientific Observer Programme opportunistically throughout the year.

- Chatham Rise population numbers at age (otolith readings or MIX) estimated from a series of random trawl surveys 200–800 m on the Chatham Rise (Table 1).

Numbers at age from surveys were scaled up to the population estimate from the individual surveys made using the area swept method of Francis (1984). Numbers at age from commercial fishery samples were scaled up to the total annual catch for that area. Standard errors (s.e.) were estimated for all proportions and are plotted as error bars (± 2 s.e.) where appropriate. For single records, standard errors were calculated by simulation. For means of multiple records, they were calculated as the sampling error of the mean, $s/\sqrt{n}$.

2.2 The effects of catchability on observed sex ratios

Observed differences between the proportions of male and female hoki in a catch may reflect bias in the way in which they are captured by the trawl rather than their relative abundance in the population. It is therefore important to consider the behaviour of the fish and its effect on catchability to understand observed sex ratios. Catchability, that is the behavioural factors influencing the proportion of a fish population, has three main components: areal availability, vertical availability, and vulnerability (*see* Hurst 1988). If male and female hoki behave differently from each other, their catchability may be different, and this could affect the relative proportions of each sex in the catch. For commercial catches, there may also be a selectivity factor that relates more to the way in which fish are targeted, for example if a particular size range is favoured for market purposes.

From the data available it is not possible to isolate and estimate the components of catchability from the effects of mortality. By exploring the effects of length and mortality on sex ratios, it is possible to make some judgement about appropriate bounds on catchability of male and female hoki for the model, and form some testable hypotheses about hoki behaviour.

5

2.3 Fish size and survival analysis

The size of a fish has an influence on how likely it is to be caught. When fish are small, they can escape through the meshes of a trawl (depending on mesh size), and as they grow bigger, they may be strong enough to out-swim the trawl and avoid capture. Because there are differences in the growth rates of male and female hoki (Horn & Sullivan 1996) their size differences at a given age may have an effect on the observed sex ratios. Mesh selection studies for hoki have shown that a codend of mesh size 60 mm, has a 50% retention size of 36 cm total length (TL). For a codend of mesh size 100 mm the 50% retention size is 60 cm TL (Hurst 1988). All commercial vessels use a codend mesh of 100 mm, except south of 53° S where they are permitted to use a mesh size of 60 mm. All research surveys use a codend mesh of 60 mm. Because the growth rates of male and female hoki do not diverge until after they reach 60 cm TL (Horn & Sullivan 1996), mesh selectivity is unlikely to be a significant factor affecting overall catchability. Any effects of size may therefore lie in the ability of females, as the larger fish, to better out-swim the gear than males.

We examined the effect of size on the relative abundance by comparing the relative numbers of males and females in fish of the same size. However, because the numbers of fish at a given size also reflect year class strength, we had to find a way of removing the effect of year class strength. The objective was to determine whether differences in survival between sexes could be attributed solely to differences in length. If the estimated survival rates at a given length differed between sexes, we would conclude that there was a between-sex difference in survival, or some aspect of catchability that increased with age, over and above the effect of length.

We estimated the survival of a cohort of fish from one year to the next as the numbers of that year class in the second year divided by the numbers of that year class in the first year. The survival of fish at a given age, in general, was estimated as the mean survival of cohorts at that age, averaging across pairs of consecutive years in a time series. The proportion of fish at each age that had survived from the preceding year was plotted for each sex against the mean length of each sex at that age in the time series. Survival of age class

$$ j = \frac{\displaystyle\sum_{k \text{ pairs of consecutive years } (i,i+1)} \left(\frac{n_{i+1,j+1}}{n_{ij}} \right)}{k} $$

where n_{ij} is the number of fish in year i of age j.

Mean length at age was determined from age length keys for each area (Horn & Sullivan 1996). Four main data sets were analysed in this way: catch at age data from the spawning fisheries of both WCSI and Cook Strait the Chatham Rise trawl surveys 1992–99, and the Subantarctic trawl surveys in December 1991–93. The WCSI spawning fishery had the largest and most consistent data set followed by Cook Strait. The trawl surveys, particularly from the Subantarctic, had much less data, but were included for comparison.

Technically, this is not a true survival analysis because it is based on commercial catch data and the catch-at-age of a given year class in a particular year is dependent not only on the abundance of the year class but on the level of fishing activity in that year. As a result, survival estimates can exceed 1 if there is high recruitment into the fishery, or if a given year class is exploited more heavily in one year than the one before. We tried to minimise the effects of variable recruitment by excluding data on fish age 4 years or younger. On the assumption that catches of both sexes and all ages are affected equally by changes in total catch level, the analysis was considered adequate for comparing survival rates between sexes and ages.

2.4 Effects of mortality on sex ratios

To explore the effects of mortality on sex ratios, we assumed that the observed proportions of male and female hoki reflect the underlying abundance of males relative to females. If the differences observed are solely a result of mortality, then it is possible to estimate approximately what the difference in mortality between the two sexes would have to be to explain the observed differences in proportions at age.

We assumed that the mortality was constant for each sex. If the proportion of males in an age class goes from p_a at age a, to p_{a+n} at age $a+n$, then

$$\frac{p_a N \exp[-n(Z_F + \delta)]}{(1 - p_a) N \exp[-nZ_F]} = \frac{p_{a+n}}{1 - p_{a+n}}$$

where N is the initial number in the cohort, Z_F is the mortality of females, and δ is the amount by which male mortality exceeds female mortality. Thus,

$$\delta = -\frac{1}{n} \ln\left[\frac{p_{a+n}(1 - p_a)}{p_a(1 - p_{a+n})}\right]$$

The δ parameter was estimated for all 4 areas.

2.5 Effects of fishing on sex ratios

Although there were few surveys before 1987, surveys conducted by *Shinkai Maru* in 1983 on both the Chatham Rise and in the Subantarctic, and also on the Chatham Rise in 1986, provide a comparison with the more recent surveys of these two areas by *Tangaroa* (*see* Table 1). There are no pre-fishery data for either of the spawning grounds. However, Ministry of Fisheries catch at age sampling programmes began in the early stages of the hoki fishery development, and any changes between 1988 and 99 could reflect the effects of fishing.

3. RESULTS

3.1 Chatham Rise sex ratios

The proportion of male hoki at age for each data set are given in Table 2. The age data (otolith readings) from the Chatham Rise January trawl survey series show that about 50% of the 1 and 2 year old hoki are male. At ages 3–6, males make up 40%, declining to less than 20% in the 10 year old plus group (Figure 2). These correspond closely to the proportions observed in earlier surveys by *Shinkai Maru* in March 1983 and July 1986 up to age 5, but the proportions of ages 6–9 years in March 1983 and 6–8 years in July 1986 were considerably lower (Figure 2). MIX data from the commercial catches by fishing year, 1992–97, on the Chatham Rise follow an almost identical pattern (Figure 2). The November-December 1989 proportions of males at age determined from MIX also show a lower proportion of males in the 6 plus group.

Within the January time series, there is some variation in the sex ratios (Figure 3). The start point at age 1 is almost identical in all years, with the spread of values widening thereafter. Most of the surveys individually follow a relatively smooth track, with progressively fewer males after age 6. The proportions in 1992 were the most variable, particularly in the younger age classes. MIX analyses of commercial catches from the Chatham Rise show a wide variation in the proportion of males caught in 1993 and 1997, but not in other years (Figure 4).

There do not appear to be any consistent changes in the relative proportions of individual age classes over the time period examined, except in the proportion of age class 5 which decreased from 1992 to 1999, and an overall increase in the proportion of male hoki age 6 and above between the earlier surveys in 1983 and 1986 and the series 1992–99 (Figures 5, 6).

3.2 Subantarctic sex ratios

The percentage of male hoki at age for each data set are given in Table 3. The proportion of males in research surveys for which otolith data were available show an overall decline with increasing age (Figure 7), but the decline is not as pronounced as on the Chatham Rise. There also seems to be more variation in the proportion of males in the younger year classes between surveys in different seasons than on the Chatham Rise. The average proportion of males in the December series and the commercial catch was about 55% up to age 5, and thereafter declined to about 38%, whereas in the autumn series (April, May, June), the proportion of male hoki was generally below 50% up to age 5, again declining to 30% by age 10 (Figure 7). The October-November survey in 1983 had similar proportions of males to the autumn series, but the September survey in 1992 had very low proportions of males (Figure 7). The proportion of males in the plus group of 6 years from July 1990 and the October-November surveys in 1989 and 1990 were among the lowest in the Subantarctic data set (Figure 7).

A comparison of individual surveys within the autumn series showed that the survey in 1993 had much lower proportions of male hoki age 2–5 than the other surveys (Figure 8). Since this is thought to be related to the timing of the 1993 survey, which ran into the prespawning migration out of the area, the survey in April-May 1993 was not considered to be representative of the series (Livingston at al. 1997) and was not used in the estimation of mean sex ratios from the Subantarctic. In December, the proportion of male hoki between ages 2 and 5 vary widely between surveys, but the peaks of each survey, which correspond to the proportion of males in the 1988 year class, increased by one year in successive surveys (Figure 9). In other words, the proportion of male hoki in the 1988 year class was higher than in the adjacent year classes as it progressed from 3 years old in 1991 to 5 years old in 1993 (Figure 9). Changes in the relative proportions of males for each age class show little variation over time in the younger 2–5 year classes (Figure 10), but there is a suggestion that the proportion of males was lower in 1992 than in other years, particularly September, among the older age classes (Figure 11).

The data from the Subantarctic surveys suggest much greater variability in the proportion of males in the younger year classes, and less of a decline in the proportion of males in the older year classes compared with the Chatham Rise. A comparison of the means from these time series shows that males tend to form a higher proportion of fish aged 2–5 in the Subantarctic in December, compared with April-May in the Subantarctic and on the Chatham Rise in January (Figure 12).

3.3 Cook Strait and West Coast sex ratios

The proportions of male hoki caught in both spawning fisheries are very similar (Tables 4, 5), averaging 50–70% in the 3–6 years age classes, and dropping to about 25% by age 11 (Figure 13). The proportion of males in the spawning fisheries is considerably higher than in the Chatham Rise surveys for a given age (Figure 14), but not higher than in the Subantarctic (Figure 15). The proportions of male hoki at age in the WCSI spawning fishery were almost identical to those in the Subantarctic December time series, but in the April-May Subantarctic series the proportion of males age 2–5 was lower (Figure 15).

Trends in the WCSI and Cook Strait fisheries show that young males have formed a much larger portion of the catch at age in the younger age classes than in the older age classes (Figures 16, 17). When plotted by age class, however, there is no trend among younger hoki (Figure 18), but the

decline in males among older hoki on the WCSI is clear (Figure. 19). No trends are apparent in the Cook Strait data (Figures 20, 21).

3.4 Fish size and survival analysis

Data that could be used for the survival analysis from the spawning fisheries comprise a time series of 10 consecutive years: the Chatham Rise, 8 years (January series) and the Subantarctic just 3 years (December series only). The plots of survival rates with length of fish from both spawning fisheries show a clear difference between male and female hoki, with the survival rate of males consistently lower than females of the same length in both (Figures 22, 23). The slopes of male and female survival rates were similar to each other within the same fishery, but differed between fisheries (Figures 22, 23). On the Chatham Rise, there was overlap between male and female survival rates although among larger fish, males typically had a lower survival rate than females at length (Figure 24). Unlike in the spawning fisheries, the slope of male survival rate at length was steeper than for females on the Chatham Rise (Figure 24). In the more limited data set from the Subantarctic, the males again had a consistently lower survival rate than females of the same length, although here, the relative steepness of the slopes was the reverse to that seen on the Chatham Rise (Figure 25), i.e. the survival rate of male hoki declined very little compared with females as their length increased. This result almost certainly reflects the variability in the data of this short time series (*see* Figure 9).

3.5 Mortality

In Cook Strait and the WCSI spawning fisheries, full recruitment was assumed to have occurred by age 6 y. The mean proportions of males at this age were about 0.55 and 0.45, respectively (*see* Figure 13): these fall to 0.26 and 0.25 at age 11+ y. Hence δ for Cook Strait is 0.26 y^{-1} and for WCSI 0.18 y^{-1}. Although the data sets are broadly consistent, the values imply that male mortality would have to be about double that of females. This seems somewhat implausible.

The expected total mortality rates after recruitment should be the same in the home grounds as on the respective spawning grounds, where these fish are assumed to migrate to spawn. This is so for the Chatham Rise and Cook Strait with δ of 0.25 y^{-1} and 0.26 y^{-1} respectively. However, δ at 0.12 y^{-1} in the Subantarctic is 33% less than the value for WCSI (0.18 y^{-1}) due to the higher proportion of males at age 10+ y. This difference could be explained if a higher proportion of males than females at age go to spawn. Another explanation is that males are more vulnerable than females on the spawning grounds due to some difference in their spawning behaviour.

3.6 Sex ratios in the pre-fishery and current fishery

The proportion of males at age on the Chatham Rise in both 1983 and 1986 was similar to that of recent surveys for age classes 1–5 y, but in older age classes the earlier surveys had a lower proportion of males in the catch (*see* Figure 2). In the Subantarctic, a survey in 1983 gave higher proportions of males in the older age classes compared with more recent surveys (*see* Figure 7). If we assume that these changes reflect the effects of fishing, then we might conclude that adult females have been exploited more than males on the Chatham Rise ground, while males have been exploited more than females on the Subantarctic ground. The data from early years are, however, limited.

4. DISCUSSION

It is clear that the observed proportion of male hoki declines with increasing age in the data sets from each of the four areas studied. It is also clear that irrespective of year, trawl surveys of the Chatham Rise and Subantarctic had similar mean proportions of males at age to each other, except in the older age groups where the proportion of males was higher in the Subantarctic than on the Chatham Rise,

and the proportion of males at age in the two spawning fisheries was almost identical. There was a difference in the proportion of males between spawning and non-spawning grounds, with higher proportions of males at all ages on the spawning grounds, particularly among younger age classes.

The key issue is how much of the observed difference in proportions of male and female hoki with age and between areas is a result of differences in catchability, or of real differences in the abundance of each sex as a consequence of different mortalities.

4.1 Vulnerability – the effect of size

In most finfish species, females outgrow males, and outlive them as well. The accepted rationale is that because larger fish can swim faster, females are better able to escape predators and trawl nets, and hence have both lower natural mortality and lower fishing mortality. If larger hoki are better able to avoid the gear, then the vulnerability of females could be expected to be lower than that of males because females grow larger than males (Horn & Sullivan 1996). If this were the only factor affecting observed sex ratios, then for a given length, we would expect the survival of each sex to be similar.

The survival analysis showed that the observed survival rate of female hoki is higher than that of male hoki of a similar length in each study area. The 'survival' levels were generally higher for Cook Strait than for WCSI, but this is merely an artefact of steadily increasing catches over the time series (Figure 26). The Chatham Rise and Subantarctic data show a similar result to the spawning fisheries, although the slopes of survival rate with length for each sex are less consistent (*see* Figures 24, 25). Although the survival rate of male hoki from the Subantarctic surveys was less than that of females at a given size, it showed almost no decline with increasing size, unlike the other data sets. We believe that this is likely to be a function of the low number of data points or pairs in the series. Female hoki from the Subantarctic showed anomalously high survival rates of up to 4. This is a result of variable recruitment of hoki into the area (*see* Figure 9).

Overall, we conclude that something other than length (and therefore vulnerability) is affecting the estimated relative survival of male hoki. The observed survival rate does not necessarily reflect actual survival rate. It could just as equally reflect differences in catchability, particularly vertical availability.

4.2 Vulnerability of spawning and non-spawning hoki

When hoki spawn, they do not feed. They typically form dense aggregations near the bottom by day and higher in the water column by night. This behaviour renders spawning fish more vulnerable to trawl nets than on the home grounds, because of their increased density and their focus on spawning rather than escaping predation. The difference in vulnerability between spawning grounds and feeding grounds cannot be measured directly, but if males and females exhibit similar changes in behaviour, the relative proportions of each sex should be similar in each area. The proportion of male hoki at age was consistently higher in both spawning fisheries compared with the feeding grounds. As size alone cannot explain the difference, it is likely that vertical and areal availability play a role in the observed differences.

4.3 Areal and vertical availability

Male hoki recruit to adult fisheries and begin to spawn at an earlier age than females (Sullivan & Cordue 1990, Livingston and Schofield 1996a). Further, young males are more evident in length frequency distributions of the spawning fisheries in recent years than females (Ballara *et al.* 2000, and Figures 27, 28). There is also some evidence to suggest that male hoki spend longer on the spawning grounds than females (Langley 1993). Changes in the relative proportions of male and female hoki during the winter spawning period suggest that more males migrate away from the Chatham Rise and

the Subantarctic to spawn (Kerstan & Sahrhage 1980, Hurst & Schofield 1995). This is supported by the relatively lower proportions of male hoki in the September 1992 survey of the Subantarctic, when few spawners would have returned from their July-August spawning on the WCSI (*see* Figure 7). All of the above would subject males to higher rates of M and F than females. A higher mortality and higher areal availability of males than females could also occur if proportionally more males migrate to the spawning grounds in a given year. Early recruitment of male hoki and a higher frequency of spawning could also lead to differences in catchability between areas as the areal availability would differ from that of females. Thus, if the abundance of young males is greater in the spawning fisheries, their areal availability in the spawning fisheries will be higher than on the home grounds. In the Atlantic cod spawning fishery, evidence of early arrival of males on the spawning grounds has been found (Morgan & Trippel 1996).

4.4 Mortality

The presumed migration from the Chatham Rise to the Subantarctic usually occurs after age 3 y, although the numbers of younger hoki appearing in trawl surveys since December 1992 has been higher, suggesting earlier migration in recent years. Proportions of males are about 50% in both areas at age 3 y, but increase to about 60% at ages 4–5 y at times (*see* Figure 7). Even if migration occurs at different ages for males and females, similar natural mortalities in both areas would imply that the proportions of males amongst old fish should be similar. In the Chatham Rise data, the proportion of males falls from about 0.50 at age 3 y to 0.15 at age 10+ y (*see* Figure 12): the comparable proportions in the Subantarctic are 0.55 and 0.35. Hence δ is 0.25 y^{-1} on the Chatham Rise and is 0.12 y^{-1} in the Subantarctic. Both the differences in 10+ y proportions and the implied natural mortality rate indicate that there is some other factor at work. A partial explanation may be that more males of each cohort migrate from the Chatham Rise to the Subantarctic. This would cause the systematic differences between the proportions of males on the Chatham Rise and the Subantarctic at the older ages. Another way that systematic differences between the two areas could occur is if there is a sex difference in catchability, whereby females have a higher catchability than males, but that the differences are more extreme on the Chatham Rise than in the Subantarctic. The observed differences in sex ratios with age would not, therefore, reflect the true abundance of male relative to females.

Inasmuch as we were able to establish that size differences alone cannot explain the differences between male and female proportions at age, we can also say that something other than natural mortality is influencing the observed because they differ between the spawning grounds and the two home grounds. Consider areal availability and vulnerability arising from different schooling behaviour. The observed decline in the proportion of males on the Chatham Rise is greater than in the Subantarctic, yet the same sampling methods, vessel, and gear have been used in both areas. Male hoki may be more dispersed on the Chatham Rise than in the Subantarctic (so they have a relatively lower vulnerability), or the numbers of males that move off the Chatham Rise and recruit to the Subantarctic may be greater than females. Neither rationale is intuitively more likely than the other. There is a third explanation, which relates to the vertical availability of hoki on the Chatham Rise and in the Subantarctic. If male hoki were inclined to be higher in the water column than females, for example, as smaller fish they may need to rise higher in the water column to capture smaller prey than females, the availability of females to bottom trawling would be greater than males. If this scenario were true, it is possible that as females increase in size relative to males the difference in vulnerability increases with age. This type of behavioural difference could be enhanced by differences in bottom topography and the depths at which larger fish tend to occur. There are substantial differences in bottom topography and hydrography between the Chatham Rise and the Subantarctic. The Chatham Rise has far less flat ground, and always has an abundance of active ocean fronts due to the meeting of the warm northern Subtropical water mass with the cooler Subantarctic water along the Subtropical Front (Carter *et al.* 1998). The Subantarctic is much flatter, and the hydrographic environment is more uniform with little front activity in most of the area. If we speculate that male and female hoki behave differently, for example, if males feed higher in the water column than females, then we could see a difference in male catchability between the two areas. Hypotheses about the distribution of male and

female hoki with respect to topography and hydrology in the two areas could be tested by exploring the spatial distribution of male and female hoki within survey areas.

4.5 Changes from 1983 to 1999

Comparing surveys of the Chatham Rise and Subantarctic by *Shinkai Maru* in 1983 with more recent surveys by *Tangaroa* shows that the proportion of males in the Subantarctic is less now than in 1983, while on the Chatham Rise it appears to be higher.

There is a difference in fishing power between *Shinkai Maru* and *Tangaroa* (Hurst & Schofield 1990), but if this were the reason for a change in proportion of males, then we would expect the same trend in each area, not opposing trends. An alternative explanation is that the changes are real and reflect differential fishing mortality between the two areas. At first glance, this seems unlikely. However, let us consider the changes in sex ratios over time in the spawning fisheries, in which those from the Cook Strait fishery are the same stock as the Chatham Rise hoki (i.e., eastern stock), and those from the WCSI are the same stock as the Subantarctic hoki (western stock). Overall, there has been little change in the proportions of males taken at all ages in the Cook Strait fishery (*see* Figures 20, 21). In the WCSI fishery, there has been a steady decline in the proportion of males in age classes 7–11+ y from 1988 to 1999 (*see* Figure 19). In the western stock, most of the fishing exploitation has to date been on the spawning population on the WCSI rather than the assumed home ground in the Subantarctic. In the eastern stock, exploitation of Cook Strait and Chatham Rise has been steadily increasing, but at a similar rate (Figure 26). One interpretation could be that exploitation of males from the western spawning stock has had a selective effect leading to their decline, while in the eastern stock, any spawning exploitation effects have been masked by a higher selective effect for females, leading to the relative decline in females on the Chatham Rise.

5. CONCLUSIONS

It seems to us that to explain the differences in sex ratios in terms of mortality alone requires too great a difference in mortality between males and females. We can accept that there may be a higher mortality of males if they recruit to spawning fisheries at a younger age, and if they spawn more often than females. We also accept that males may be more vulnerable to natural predators and trawl nets than the larger females, but we believe that some other factor may be involved. We suspect that the vertical distribution of male and female hoki in the water column may be sufficiently different to bias the sampling towards females when using a bottom trawl.

We propose the following hypotheses, which, if true, would contribute to the observed decline in proportion of male hoki with increasing age: males have a higher natural mortality then females; males migrate earlier than females from the Chatham Rise to the Subantarctic leading to a higher area availability of young males in the Subantarctic; more males than females spawn in a given year leading to a higher area availability of males on the spawning ground; males are more vulnerable than females because of their smaller size; and males may be vertically less available to bottom trawls than females, particularly on the Chatham Rise.

6. IMPLICATIONS FOR ASSESSMENT MODELS

The relative proportions of male and female hoki change from 50% of each sex at age 1 y to 15–30% males and 70–85% females at age 10. We believe that these changes reflect combined differences in mortality (males > females) and vertical availability (males higher in water column than females and therefore less available) between the two sexes. We recommend that sensitivity analyses be carried out to test the effect of different sources of mortality and vertical availability (i.e., catchability) on the assessment. The data should be explored to better estimate and resolve the range of δ (the amount by which male mortality exceeds female mortality). We also recommend the hypothesis that males are

higher in the water column than females be tested, and data from past surveys be explored to determine the distribution of male and female hoki in relation to depth, topography, and hydrography in the Chatham Rise and Subantarctic survey areas. Existing stomach content data could be explored for signals about changes in feeding habits with size and or between sexes.

The results of the study suggest that males in the WCSI spawning fisheries may be more vulnerable than females. This may be due to more males than females going to spawn, or an increased vulnerability to the trawl gear due to some difference in schooling behaviour. It is recommended that the latter effect be explored further by examining the sex proportion data from bottom tows and midwater tows in the WCSI spawning fishery. We also recommend that sex ratios in relation to depth of the gear be analysed for Cook Strait.

The relative possibility that the relative proportion of males in a cohort may be determined early in life. For example, the proportion of males in the 1986 cohort was consistently higher than the average proportion of males at age both as juveniles on the Chatham Rise and later in the Subantarctic (see Figures 3, 9). Other cohorts were consistently lower. This should be examined further to see if it relates in some way to year class strength or some other factor such as climate. Setting bounds on catchability is beyond the scope of the current study, but we suggest that stock assessment models for hoki should consider the following.

- Catchability should be allowed to vary between sexes. The problem is, if the sex ratios reflect large differences in mortality, then the catchability of males may be higher than that of females. If, however, the sex ratios reflect a bias in the catch due to differences in fish distribution in the water column, then the catchability of males is necessarily lower than that of females. Bounds must therefore include differences in both directions.

- If sex differences in catchability are related to vertical availability, they may also vary depending on the gear being used; hence the relative selectivities (catchability by commercial catch) and relative vulnerabilities (catchability by trawl survey) should be allowed to vary independently.

- The model should allow sex differences in M or F to be greater than they are currently.

- The model should allow for the migration of male hoki off the Chatham Rise at a younger age than females. The model should also allow for male hoki to spawn more frequently than females.

- It would also be useful to examine plots of residuals from stock assessment model fits to these data. We should also determine if the estimated sex-specific selectivity, migration, and maturity regimes are both plausible and consistent with these data (see Cordue 1999).

7. ACKNOWLEDGMENTS

8. REFERENCES

Annala. J.H., Sullivan, K.J., Bagley, N. & O'Brien, C.J. (Comps.) 1999: Report from the Fishery Assessment Plenary, April 1999: stock assessment and yield estimates. 430 p. Unpublished report held in NIWA library, Wellington.

Bagley, N.W. & Livingston, M.E. 2000: Trawl survey of hoki and middle depth species on the Chatham Rise, January 1999 (TAN9901). NIWA Technical Report 81. 52 p.

Bagley, N.W. & Hurst, R.J. 1998: Trawl survey of hoki and middle depth species on the Chatham Rise, January 1998. NIWA Technical Report 44. 54 p.

Bagley, N.W. & McMillan, P. J. 1999: Trawl survey of hake and middle depth species in the Southland and Sub-Antarctic areas April-May 1998 (TAN9805). *NIWA Technical Report 52* 48 p.

Ballara, S.L., Cordue, P.L. Bagley, N., & Livingston, M.E. 2000: A review of the 1997-98 hoki fishery and assessment of hoki stocks for 1999. *N.Z Fisheries Assessment Report 2000/8*. 65 p.

Carter, L., Garlick, R.D., Sutton, P., Chiswell, S., Oien, N.A., & Stanton, B.R., 1998: Ocean Circulation New Zealand. *NIWA Chart Miscellaneous Series 76*.

Chatterton, T.D. & Hanchet, S.M. 1994: Trawl survey of hoki and associated species in the Southland and Sub-Antarctic areas, November-December 1991 (TAN9105). *N.Z Fisheries Data Report No. 41*. 55 p.

Chatterton, T.D., Hanchet, S.M., & Horn, P.L. 1993: Preliminary results of trawl surveys on hoki and other middle depth species in the Southland/Sub-Antarctic area and on the Chatham Rise, spring-summer 1992-93. MAF Fisheries Greta Point Internal Report No. 205. 26 p. Unpublished report held in NIWA library, Wellington.

Colman, J.A. 1996: Trawl survey of middle depth species in the Southland and Sub-Antarctic areas, March-April 1996 (TAN9605). *N.Z Fisheries Technical Report 83*. 40 p.

Cordue, P.L. 2000: MIAEL estimation of biomass and fishery indicators for the 1999 assessment of hoki stocks. *N.Z Fisheries Assessment Report 2000/10*. 69 p.

Cordue, P.L. 1999: MIAEL estimation of biomass and fishery indicators for the 1998 assessment of hoki stocks. N.Z. Fisheries Assessment Research Document 99/1. 64 p. Unpublished report held in NIWA library, Wellington.

Fenaughty, J.M. & Uozumi, Y. 1989: A survey of demersal fishstocks on the Chatham Rise, New Zealand, March 1983. *N.Z Fisheries Technical Report No. 12*. 42 p.

Francis, R.I.C.C. 1984: An adaptive strategy for stratified random trawl surveys. *New Zealand Journal of Marine and Freshwater Research 18*: 59-71.

Hatanaka, H., Uozumi, Y., Fukui, J., Aizawa, M., & Livingston, M.E. 1989: Trawl survey of hoki and other slope fish on the Chatham Rise, New Zealand, November-December 1983. *N.Z Fisheries Technical Report No. 17*. 31 p.

Horn, P.L. 1994a: Trawl survey of hoki and middle depth species on the Chatham Rise, December 1991-January 1992 (TAN9106). *N.Z Fisheries Data Report No. 43*. 38 p.

Horn, P.L. 1994b: Trawl survey of hoki and middle depth species on the Chatham Rise, December 1992-February 1993 (TAN9219). *N.Z Fisheries Data Report No. 44*. 43 p.

Horn, P.L. & Sullivan, K.J. 1996b: Validated aging methodology using otoliths, and growth parameters for hoki *(Macruronus novaezelandiae)* in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research 30*: 161-174.

Hurst, R.J. 1988: The estimation of catchability in the interpretation of bottom trawl survey data. Fisheries Research Centre Internal Report No. 109. 53 p. Unpublished report held in NIWA library, Wellington.

Hurst, R.J. & Schofield, K.A. 1990: Preliminary biomass estimates of hoki and selected species from trawl surveys of Southland/Sub-Antarctic and the Chatham Rise, October-December 1989, and comparison with previous *Shinkai Maru* surveys. N.Z. Fisheries Assessment Research Document 90/6. 23 p. Unpublished report held in NIWA library, Wellington.

Hurst, R.J. & Schofield, K.A. 1995: Winter and summer trawl surveys of hoki and associated species in the Southland and Sub-Antarctic areas 1990. *N.Z Fisheries Technical Report No. 43*. 55 p.

Ingerson, J.K.V. & Hanchet, S.M. 1995: Trawl survey of hoki and associated species in the Southland and Sub-Antarctic areas, November-December 1993 (TAN9310). *N.Z Fisheries Data Report No. 67*. 44 p.

Ingerson, J.K.V., Hanchet, S.M., & Chatterton, T.D. 1995: Trawl survey of hoki and associated species in the Southland and Sub-Antarctic areas, November-December 1992 (TAN9211). *N.Z Fisheries Data Report No. 66*. 43 p.

Kerstan, M. & Sahrhage, D. 1980: Biological investigations on fish stocks in the waters off New Zealand. *Mitteilungen aus dem Institut für Seefischerei der Bundesforschungsanstalt für Fischerei, Hamburg, No. 29*. 187 p.

Langley, A.D. 1993: Spawning dynamics of hoki in the Hokitika Canyon. *N.Z Fisheries Technical Report No. 34*. 29 p.

Livingston, M.E. & Schofield, K.A. 1993: Trawl survey of hoki and associated species south of New Zealand, October-November 1989. *N.Z Fisheries Technical Report No. 36*. 39 p.

Livingston, M.E. & Schofield, K.A. 1995: Trawl survey of hoki and associated species on the Chatham Rise, November-December 1989. *N.Z. Fisheries Technical Report No. 41.* 31 p.

Livingston, M.E. & Schofield, K.A. 1996a: Stock discrimination of hoki (*Macruronus novaezelandiae*, Merlucciidae) in New Zealand waters using morphometrics. *N.Z. Journal of Marine and Freshwater Research 30*: 197–208.

Livingston, M.E. & Schofield, K.A. 1996b: Annual changes in the abundance of hoki year classes on the Chatham Rise (January 1992–95) and the Southern Plateau (December 1991–93). N.Z. Fisheries Assessment Research Document 96/14. 35 p. Unpublished report held in NIWA library, Wellington.

Livingston, M.E., Uozumi, Y., & Berben, P.H. 1991: Abundance, distribution, and spawning condition of hoki and other mid-slope fish on the Chatham Rise, July 1986. *N.Z. Fisheries Technical Report No. 25.* 47 p.

Livingston, M.E., Vignaux, M., & Schofield, K.A. 1997: Estimating the annual proportion of non-spawning adults in New Zealand hoki, *Macruronus novaezelandiae. Fishery Bulletin 95*: 99–113.

MacDonald, P.D. & Green, P.E.J. 1988: User's guide to program MIX: an interactive program for fitting mixtures of distributions. Ichthus Data Systems, Ontario. 60 p.

Morgan, M.J., & Trippel, E.A. 1996: Skewed sex ratios in spawning shoals of Atlantic cod (*Gadus morhua*). *ICES Journal of Marine Science 53*: 820–826.

Schofield, K.A. & Horn, P.L. 1994: Trawl survey of hoki and middle depth species on the Chatham Rise, January 1994 (TAN9401). *N.Z. Fisheries Data Report No. 53.* 54 p.

Schofield, K.A. & Livingston, M.E. 1994a: Trawl survey of hoki and associated species in the Southland and Sub-Antarctic areas, April-May 1992 (TAN9204). *N.Z. Fisheries Data Report No. 45.* 38 p.

Schofield, K.A. & Livingston, M.E. 1994b: Trawl survey of hoki and associated species in the Southland and Sub-Antarctic areas, September-October 1992 (TAN9209). *N.Z. Fisheries Data Report No. 46.* 43 p.

Schofield, K.A. & Livingston, M.E. 1994c: Trawl survey of hoki and associated species in the Southland and Sub-Antarctic areas, May-June 1993 (TAN9304). *N.Z. Fisheries Data Report No. 47.* 39 p.

Schofield, K.A. & Livingston, M.E. 1995: Trawl survey of hoki and middle depth species on the Chatham Rise, January 1995 (TAN9501). *N.Z. Fisheries Data Report No.59.* 53 p.

Schofield, K.A. & Livingston, M.E. 1996: Trawl survey of hoki and middle depth species on the Chatham Rise, January 1996 (TAN9601). *N.Z. Fisheries Data Report No. 71.* 50 p.

Schofield, K.A. & Livingston, M.E. 1997: Trawl survey of hoki and middle depth species on the Chatham Rise, January 1997 (TAN9701). *NIWA Technical Report 6.* 52 p.

Sullivan, K.J. & Cordue, P.L. 1990: Hoki stock assessment 1990. N.Z. Fisheries Assessment Research Document 90/5. 30 p. Unpublished report held in NIWA library, Wellington.

Table 1:   Trawl surveys of the Chatham rise and Subantarctic used for sex ratio analysis.

Date of survey	Vessel	Reference source
Chatham Rise		
March 1983	*Shinkai Maru*	Fenaughty & Uozumi 1989
July 1986	*Shinkai Maru*	Livingston *et al.* 1991
November-December 1989	*Amaltal Explorer*	Livingston & Schofield 1995
January 1992	*Tangaroa*	Horn 1994a
January 1993	*Tangaroa*	Horn 1994b
January 1994	*Tangaroa*	Schofield & Horn 1994
January 1995	*Tangaroa*	Schofield & Livingston 1995
January 1996	*Tangaroa*	Schofield & Livingston 1996
January 1997	*Tangaroa*	Schofield & Livingston 1997
January 1998	*Tangaroa*	Bagley & Hurst 1998
January 1999	*Tangaroa*	Bagley & Livingston 2000
Subantarctic		
October-November 1983	*Shinkai Maru*	Hatanaka *et al.* 1989
October-November 1989	*Amaltal Explorer*	Livingston & Schofield 1993
July 1990	*Amaltal Explorer*	Hurst & Schofield 1990
November-December 1990	*Amaltal Explorer*	Hurst & Schofield 1990
December 1991	*Tangaroa*	Chatterton & Hanchet 1994
December 1992	*Tangaroa*	Ingerson *et al.* 1995
December 1993	*Tangaroa*	Ingerson & Hanchet 1995
April-May 1992	*Tangaroa*	Schofield & Livingston 1994a
September 1992	*Tangaroa*	Schofield & Livingston 1994b
May-June 1993	*Tangaroa*	Schofield & Livingston 1994c
April-May 1996	*Tangaroa*	Colman 1996
April 1998	*Tangaroa*	Bagley & McMillan 1999

Table 2: Percentage of male hoki out of total male and female hoki in each age class, Chatham Rise (*see* Appendix 1 for numbers at age; Fishing year, 1 October-30 September; +, plus group of that year and all older fish).

	1	2	3	4	5	6	7	8	Age (years) 9	10+
Surveys (otoliths)										
March 1983	48	46	53	30	49	22	8	21	3	54
July 1986	46	51	39	41	50	28	17	15	24	15
January 1992	50	32	52	43	65	26	33	22	20	7
January 1993	50	52	44	52	40	59	43	39	14	10
January 1994	52	49	59	41	48	39	48	23	28	19
January 1995	48	50	50	34	35	48	40	33	25	18
January 1996	49	57	46	37	43	50	42	25	0	9
January 1997	48	50	59	38	40	53	44	36	20	19
January 1998	49	55	49	37	40	38	21	40	38	19
January 1999	52	57	43	44	30	42	23	30	40	14

	2	3	4	Age (years) 5	6+
Survey (MIX)					
Nov-Dec 1989	50	54	37	36	19

Commercial catch by fishing year (MIX)

	2	3	4	5	6+
1992–93	44	50	48	35	16
1993–94	42	80	14	37	20
1994–95	45	41	38	43	34
1995–96	45	51	44	37	40
1996–97	50	51	51	55	28
1997–98	45	31	75	30	48

Table 3: Percentage of male hoki out of total male and female hoki in each age class, in the Subantarctic (*see* Appendix 1 for numbers at age; Fishing Year 1, October-30 September; +, plus group of that year and all older fish).

									Age (years)	
	1	2	3	4	5	6	7	8	9	10+
Surveys (otoliths)										
Oct-Nov 1983	100	44	31	38	50	49	39	48	43	33
Dec 1991	51	100	58	44	50	49	36	37	28	41
Dec 1992	44	40	75	85	48	17	30	36	31	41
Dec 1993	48	53	50	70	63	42	53	24	31	35
Apr/May 1992	50	50	62	44	40	36	33	44	41	18
May-Jun 1993	50	0	25	33	33	57	33	35	51	42
Apr-May 1996	53	58	53	57	38	35	38	32	29	26
Apr 1998	71	40	47	44	48	47	50	26	21	28
Sep 1992	100	nil	nil	33	36	25	23	25	32	21

					Age (years)	
	1	2	3	4	5	6+
Surveys (MIX)						
Jul-Aug 1990		50	51	44	45	27
Oct-Nov 1989		50	57	50	49	32
Oct-Nov 1990		56	51	40	52	21

Commercial catch by fishing year (MIX)

	1	2	3	4	5	6+
1992–93		0	67	62	46	35
1993–94		0	73	62	56	21
1994–95		46	29	63	62	46
1995–96		53	45	54	96	38
1996–97		50	44	63	56	51
1997–98		63	67	58	46	26

Table 4: Percentage of male hoki out of total male and female hoki in the Cook Strait commercial catch, 1988–98 (*see* Appendix 1 for numbers at age; Fishing Year, 1 October-30 September; +, plus group of that year and all older fish).

								Age (years)	
	3	4	5	6	7	8	9	10	11+
1988–89	54	48	44	44	36	36	29	26	26
1989–90	70	68	48	60	56	29	29	19	29
1990–91	81	75	61	61	53	45	51	31	38
1991–92	62	71	76	53	45	39	38	23	28
1992–93	95	57	47	48	50	43	34	27	29
1993–94	63	44	59	56	50	27	36	32	27
1994–95	53	64	60	57	55	43	40	27	25
1995–96	67	65	61	56	59	44	30	19	26
1996–97	73	68	63	49	55	43	28	19	14
1997–98	62	55	66	62	49	51	46	34	24
1998–99	76	61	60	46	35	31	28	19	23

Table 5: Percentage of male hoki out of total male and female hoki in the west coast South Island commercial catch, 1988–98 (*see* Appendix 1 for numbers at age; Fishing Year, 1 October-30 September; +, plus group of that year and all older fish).

								Age (years)	
	3	4	5	6	7	8	9	10	11+
1988–89	0	72	65	62	58	44	42	32	25
1989–90	67	35	69	61	46	50	40	22	26
1990–91	72	60	49	44	48	45	35	22	35
1991–92	63	78	57	33	37	38	32	22	14
1992–93	33	61	52	41	40	33	30	36	29
1993–94	75	91	73	52	28	29	26	29	24
1994–95	76	54	37	55	38	42	38	21	19
1995–96	77	75	52	39	33	37	24	26	13
1996–97	76	74	64	39	33	23	29	17	32
1997–98	71	68	62	45	48	24	22	36	7
1998–99	72	75	59	51	37	26	26	37	44
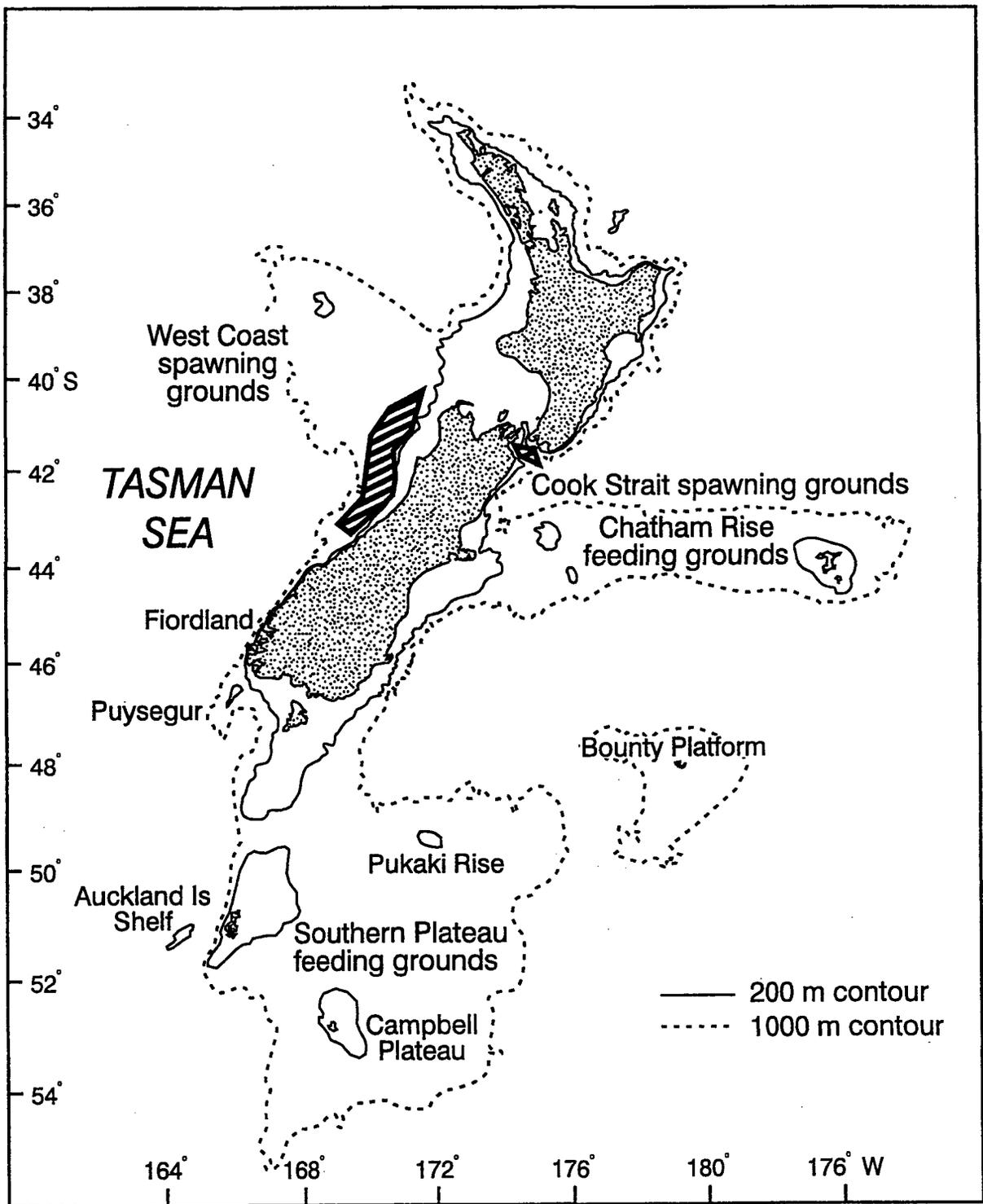
Figure 1: Distribution map to show principal spawning and feeding grounds (home grounds) of New Zealand hoki.
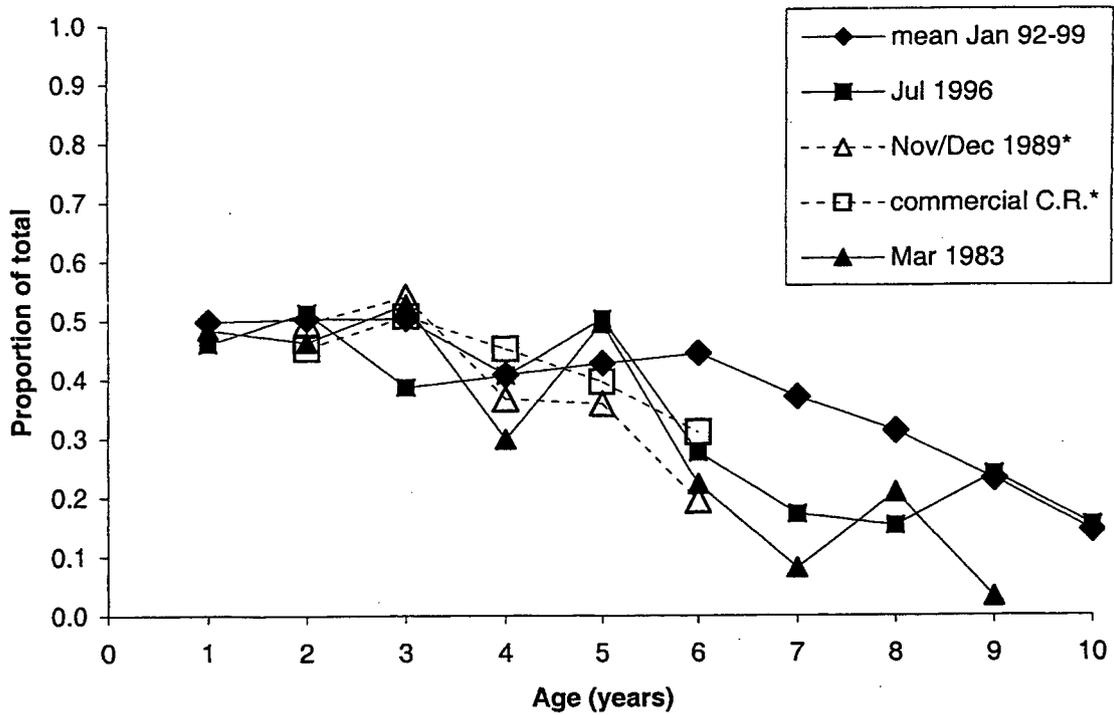
Figure 2: Mean proportion of male hoki on the Chatham Rise in January (mean of trawl survey catch at age 1992-99), July 1986, November - December 1989 and the annual Chatham Rise commercial catch, Fishing years 1992-97.
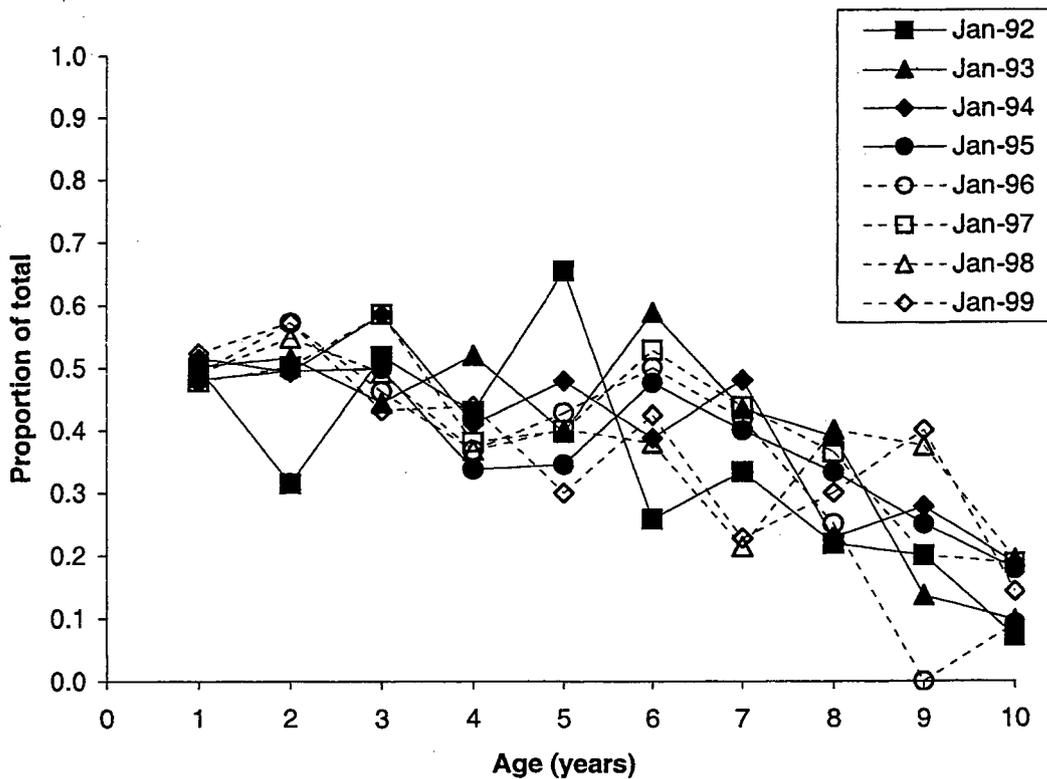

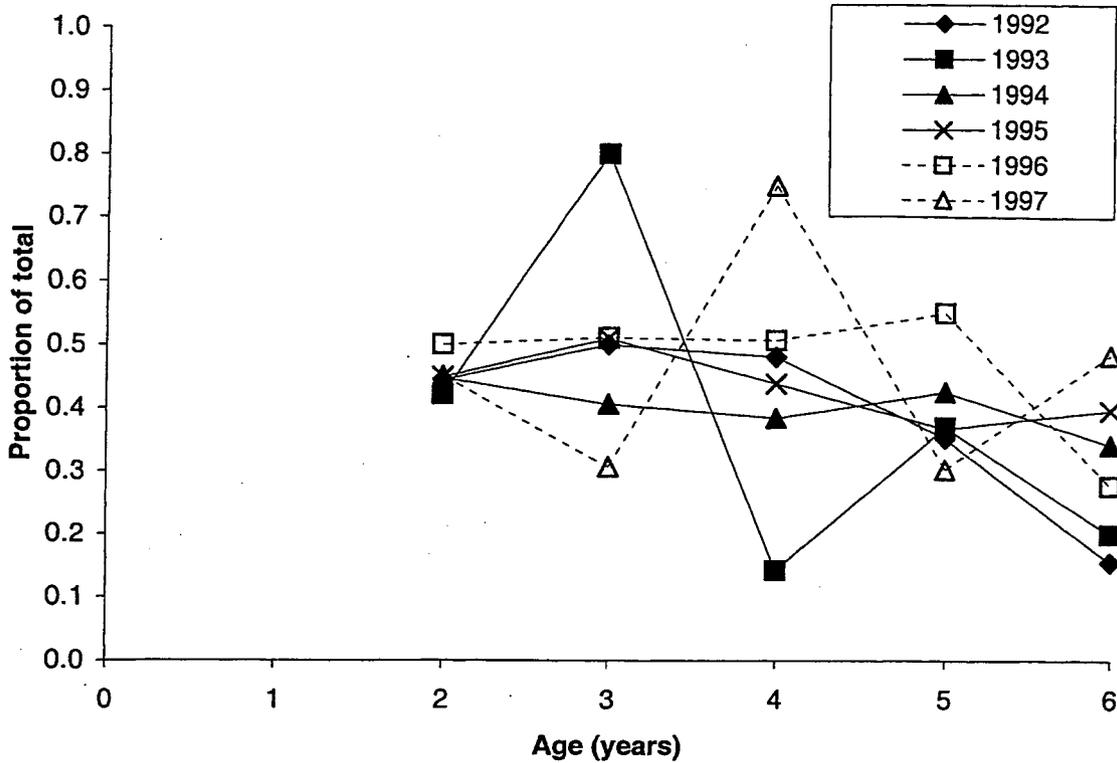Figure 3: Proportion of male hoki at age for individual surveys of the Chatham Rise from January 1992 to 1999.

Figure 4: Proportion of male hoki at age derived from MIX estimates of the commercial catch on the Chatham Rise in fishing years 1992-93 to 1997-98.
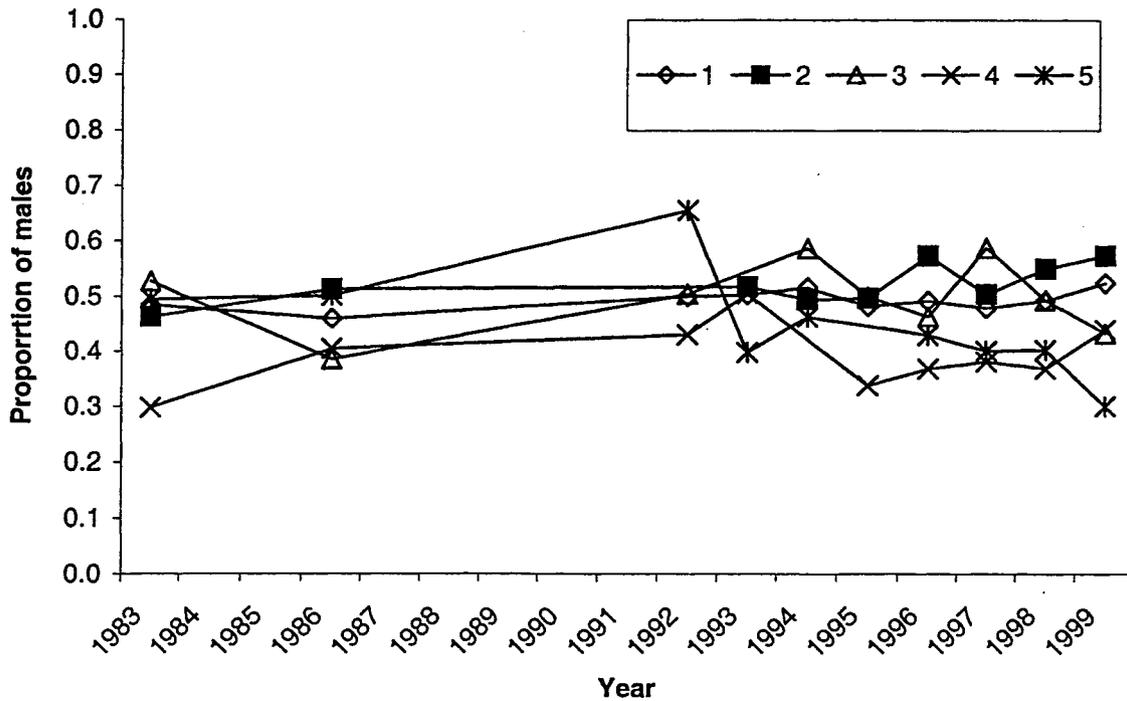
Figure 5: The proportion of males at age for ages 1-5 years on the Chatham Rise, March 1983, July 1986, and January 1992-99 (trawl surveys).
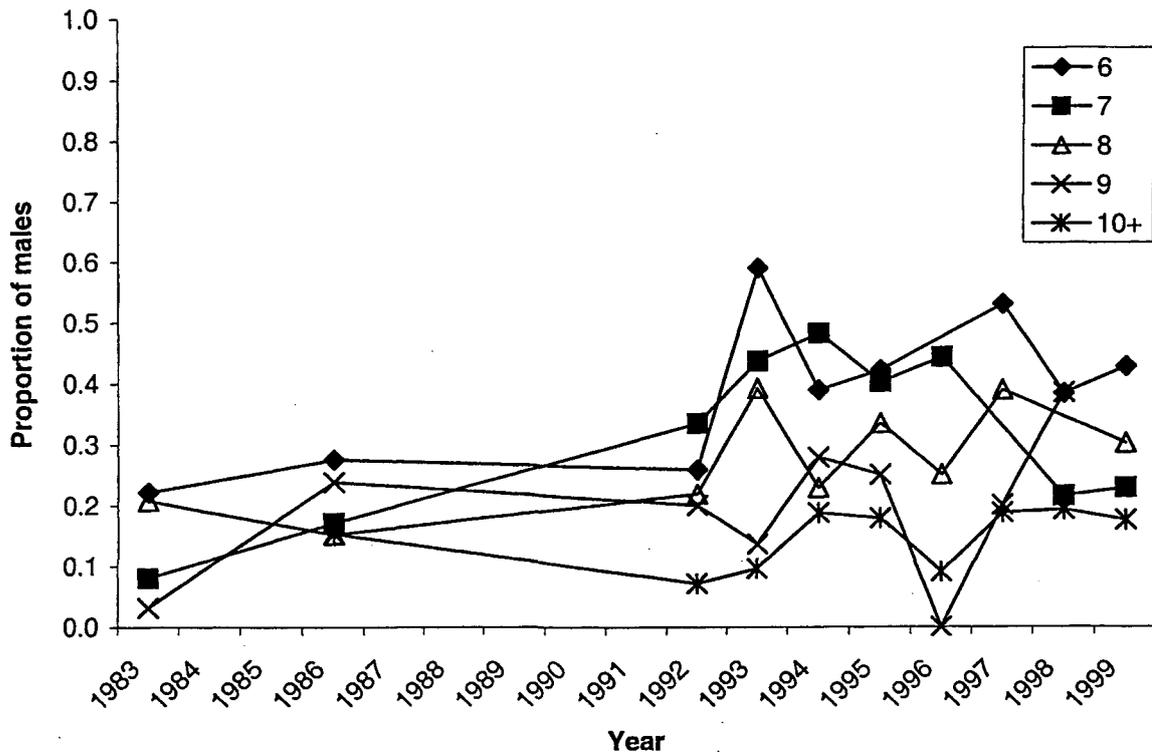
Figure 6: The proportion of male hoki at age for age classes 6-10+ from trawl surveys of
the Chatham Rise, March 1983, July 1986, January 1992-99.
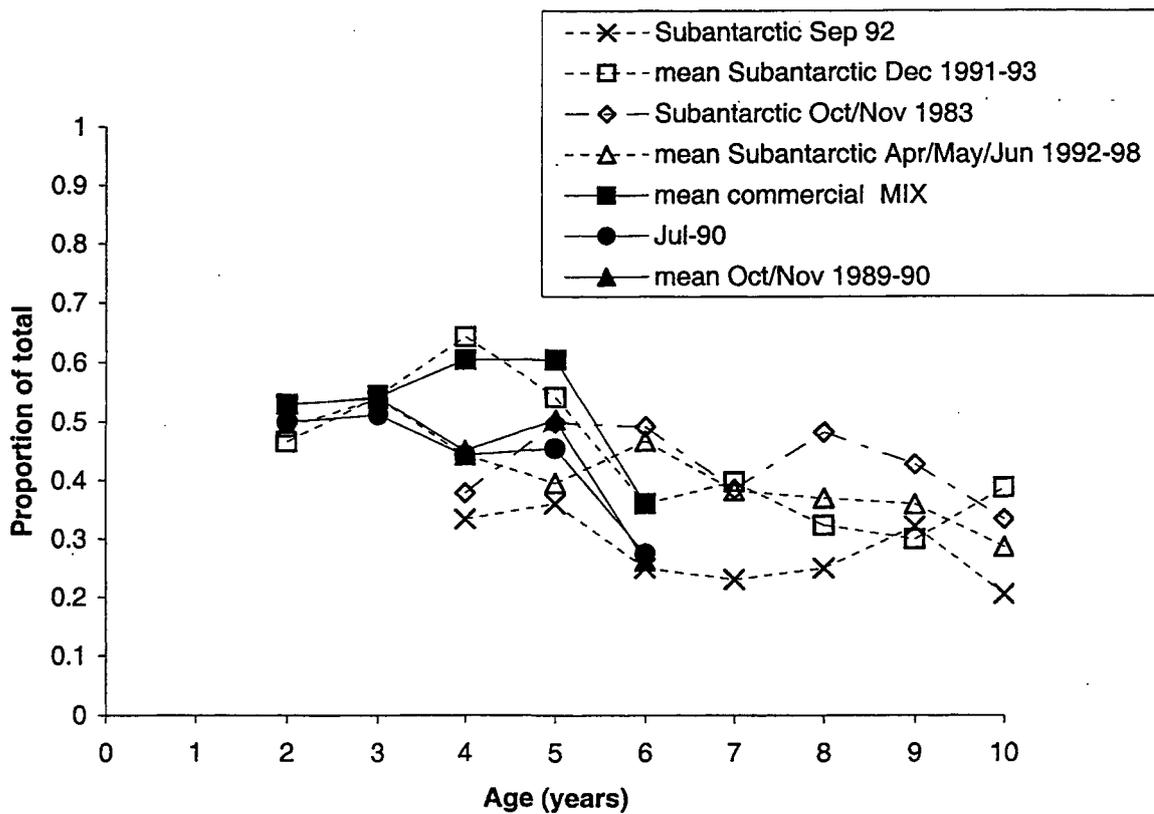
Figure 7: Mean proportion of male hoki at age from trawl surveys of the Subantarctic in
October/November 1983, September 1993, April/May 1992-98 and Dec 1991-93, (otolith
readings), October/November 1989-90, July 1990 and commercial catch 1992-97 (MIX)
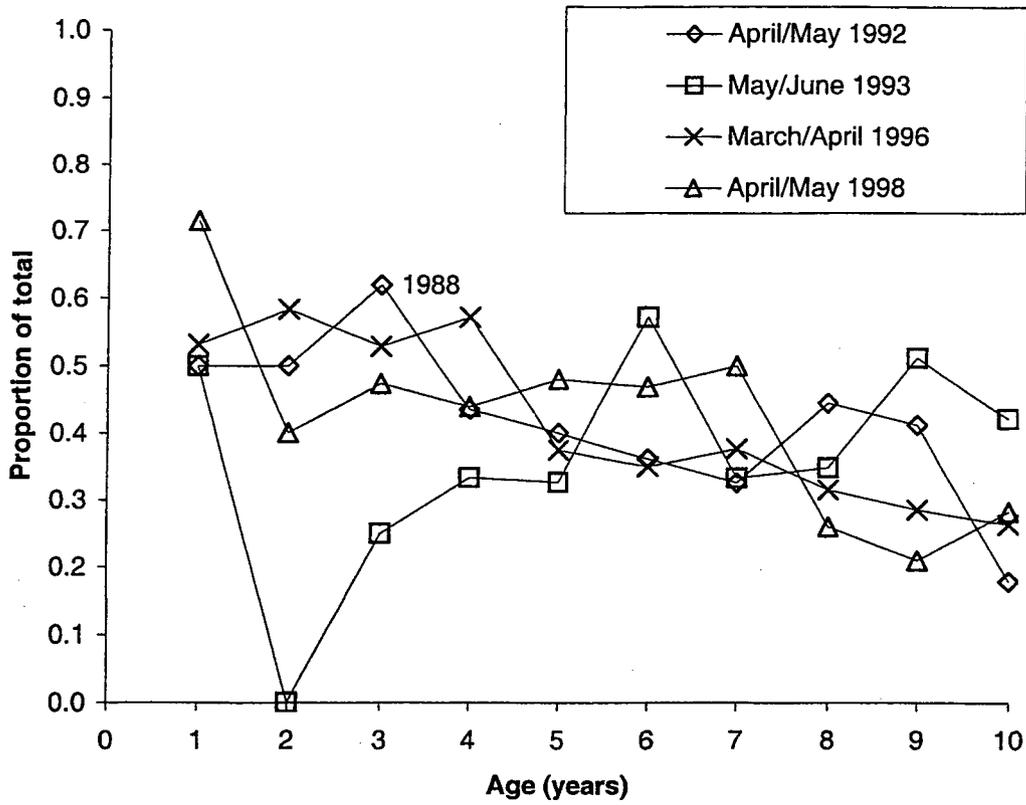
Figure 8: Mean proportion of male hoki at age from each trawl survey of the Subantarctic in autumn 1992-98 (otolith readings).
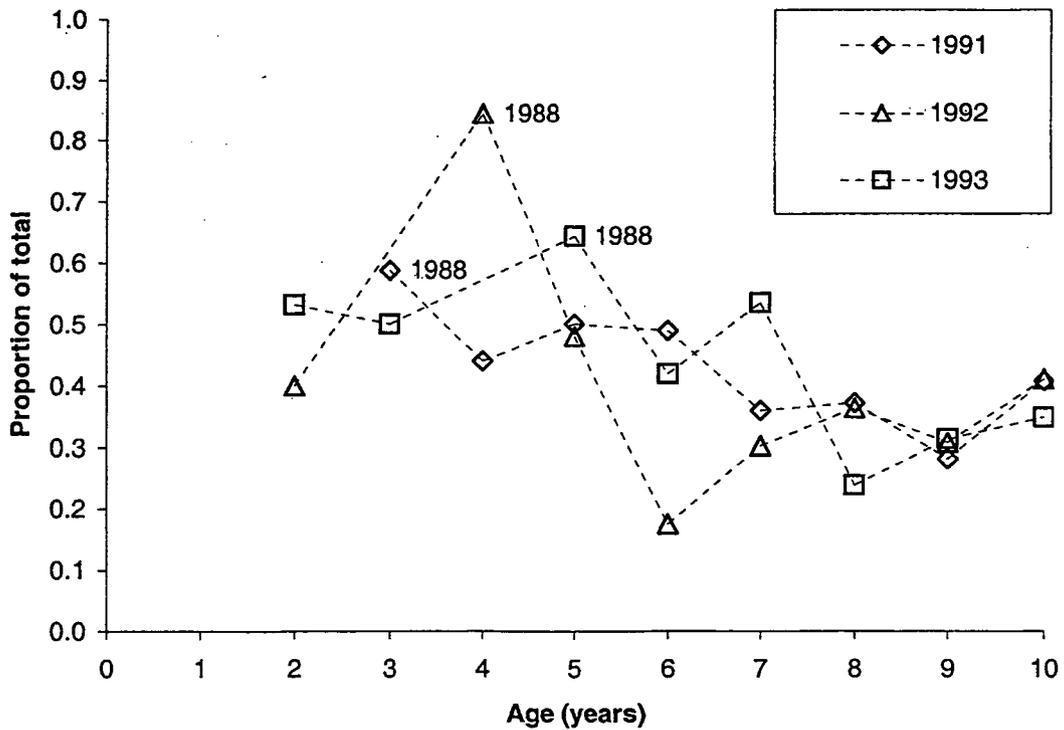
Figure 9: Mean proportion of male hoki at age from each trawl survey of the Subantarctic in December 1991-93 (otolith readings).
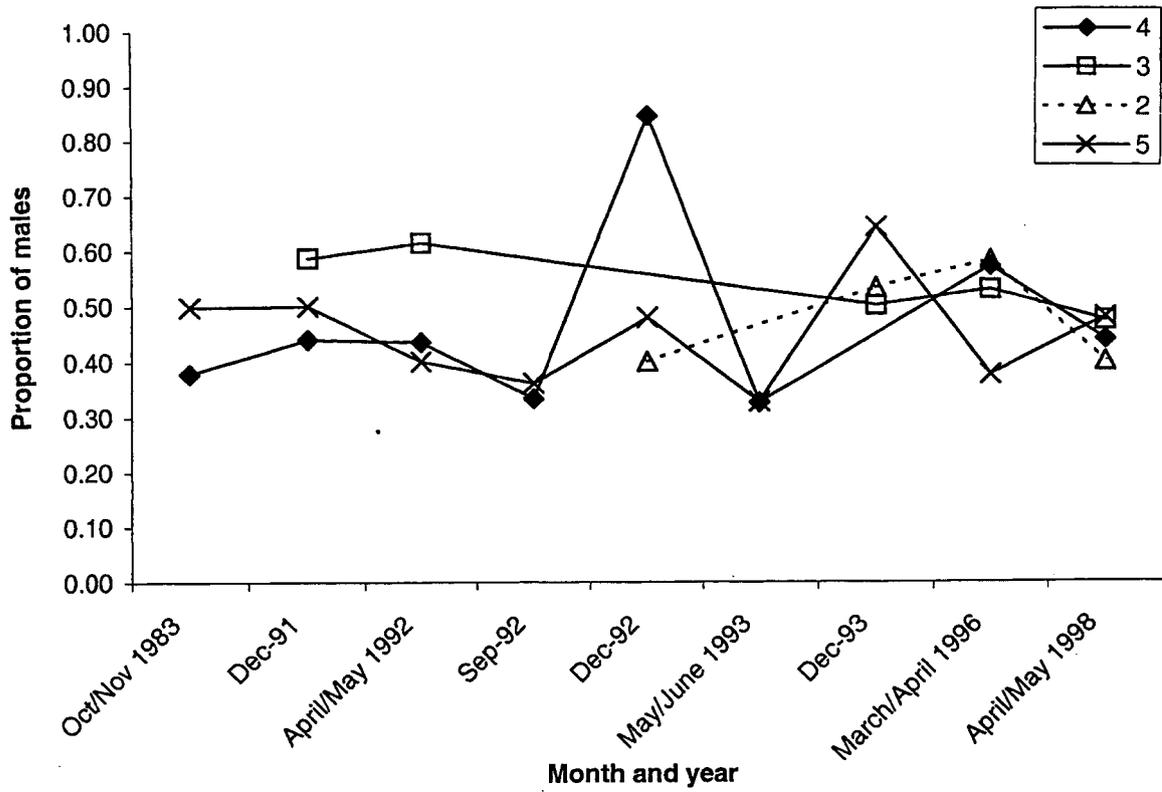
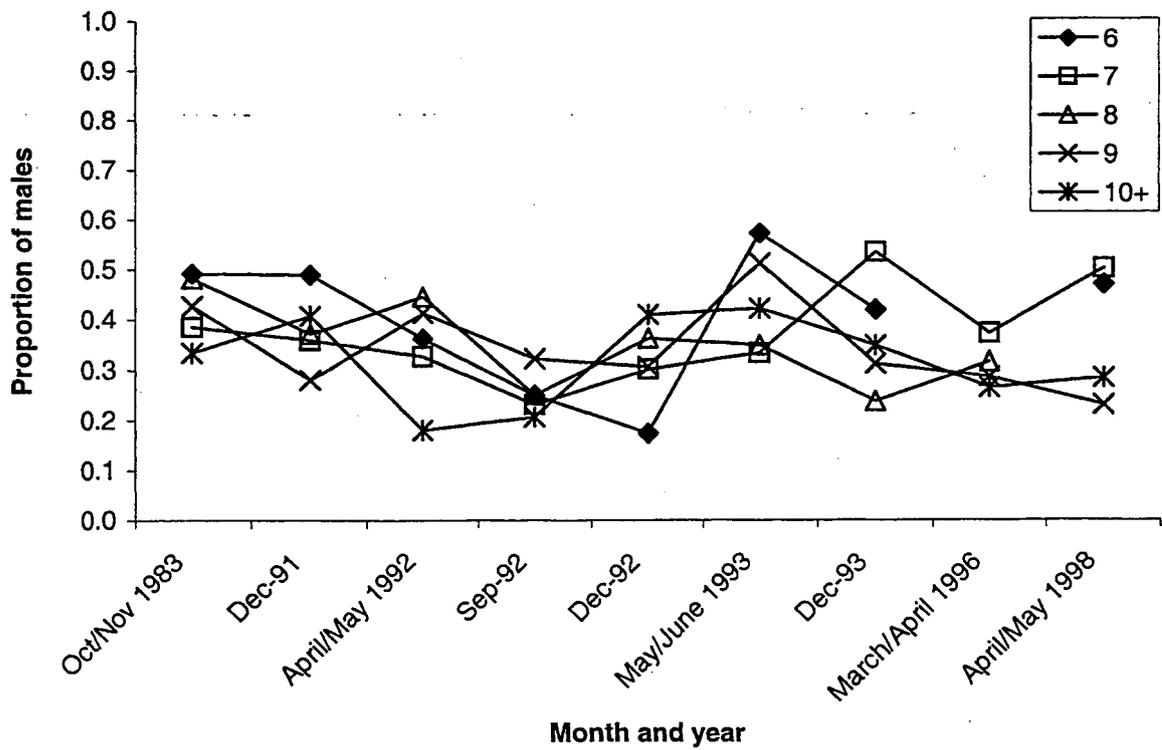**Figure 10: Proportion of male hoki in age classes 2-5 years in surveys of the Subantarctic 1983-98.**

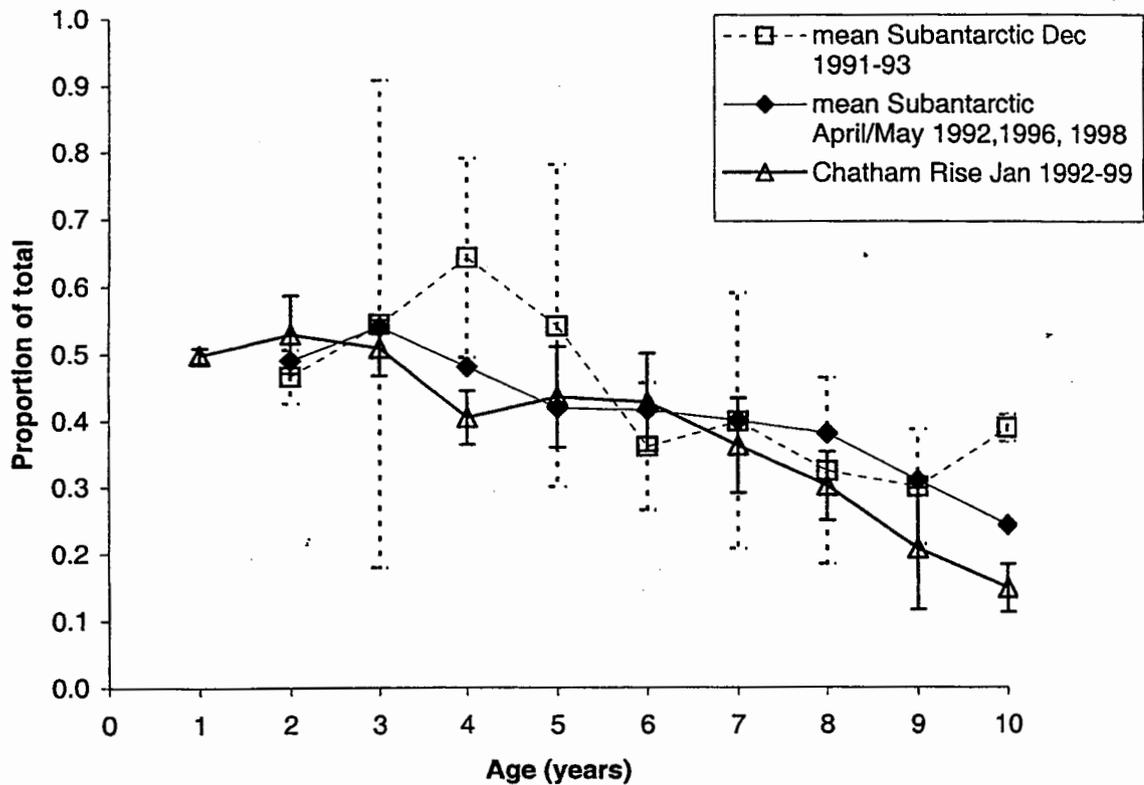**Figure 11: Proportion of males in age classes 6-10+ in surveys of the Subantarctic 1983-98.**

Figure 12: Mean proportion of male hoki at age from trawl surveys of the Subantarctic in April/May 1992-98 and December 1991-93 (otolith readings).
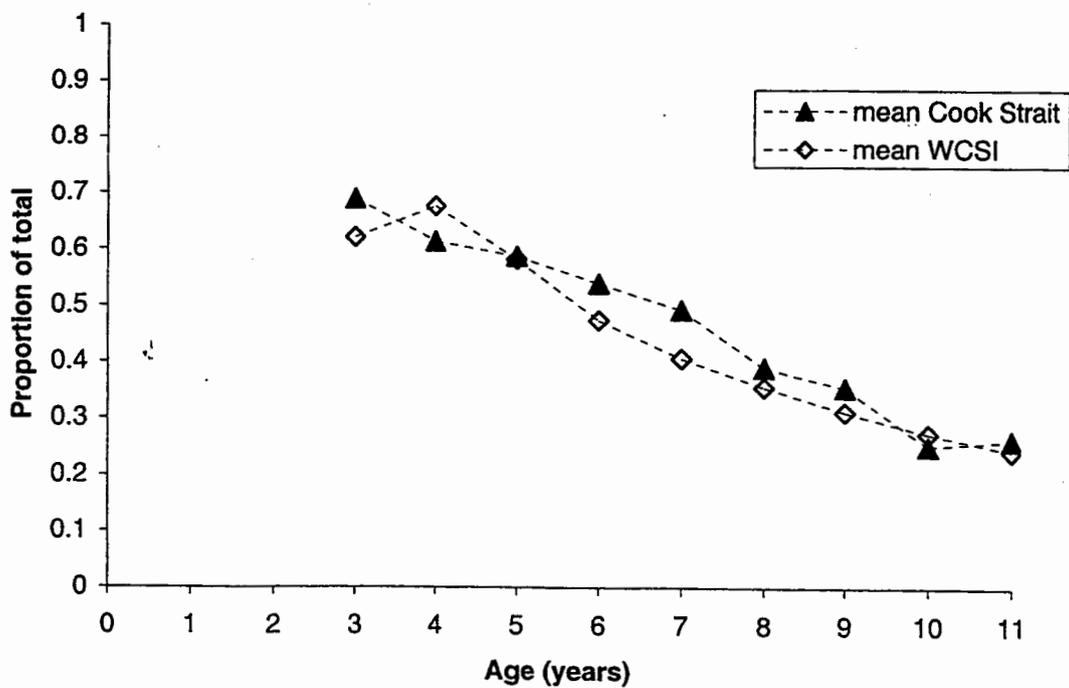

Figure 13: Mean proportion of male hoki from catch at age data in the spawning fisheries of Cook Strait and the west coast South Island (WCSI), 1988-98.
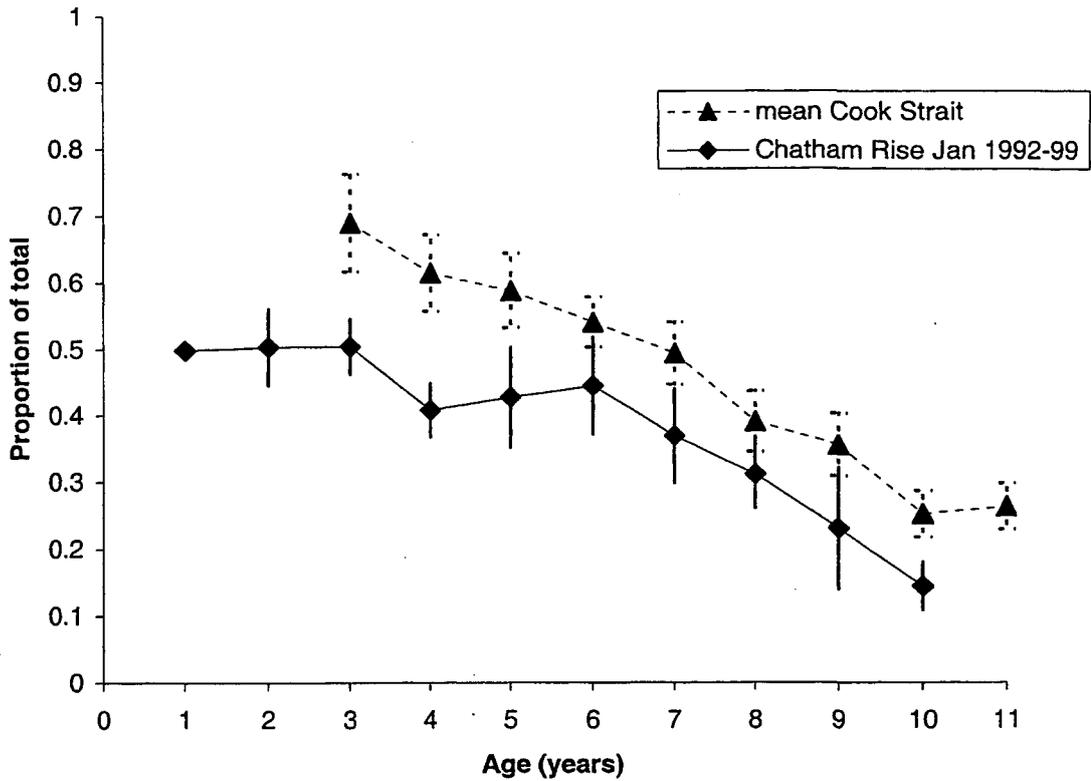
Figure 14: Mean proportion of male hoki from catch at age data in the spawning fishery of Cook Strait, 1988-98, and the Chatham Rise surveys, 1992-99.
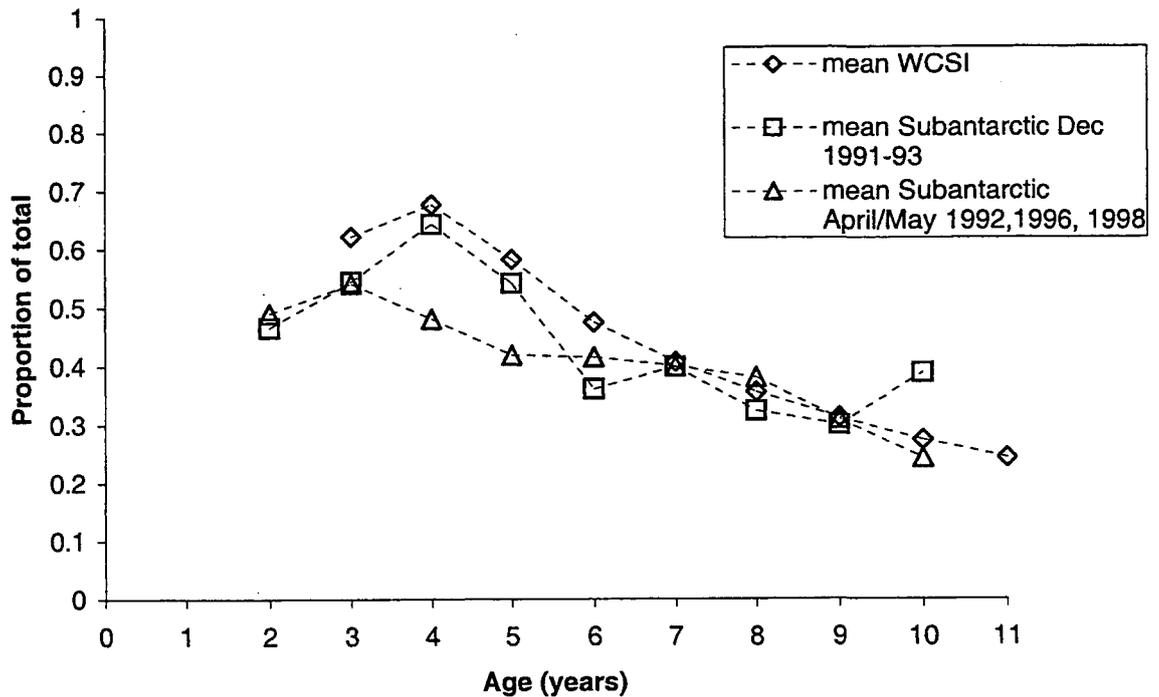

Figure 15: Mean proportion of male hoki from catch at age data in the spawning fishery of the west coast South Island (WCSI), 1988-98, and surveys of the Subantarctic, Dec 1991-93, April-May 1992-98.
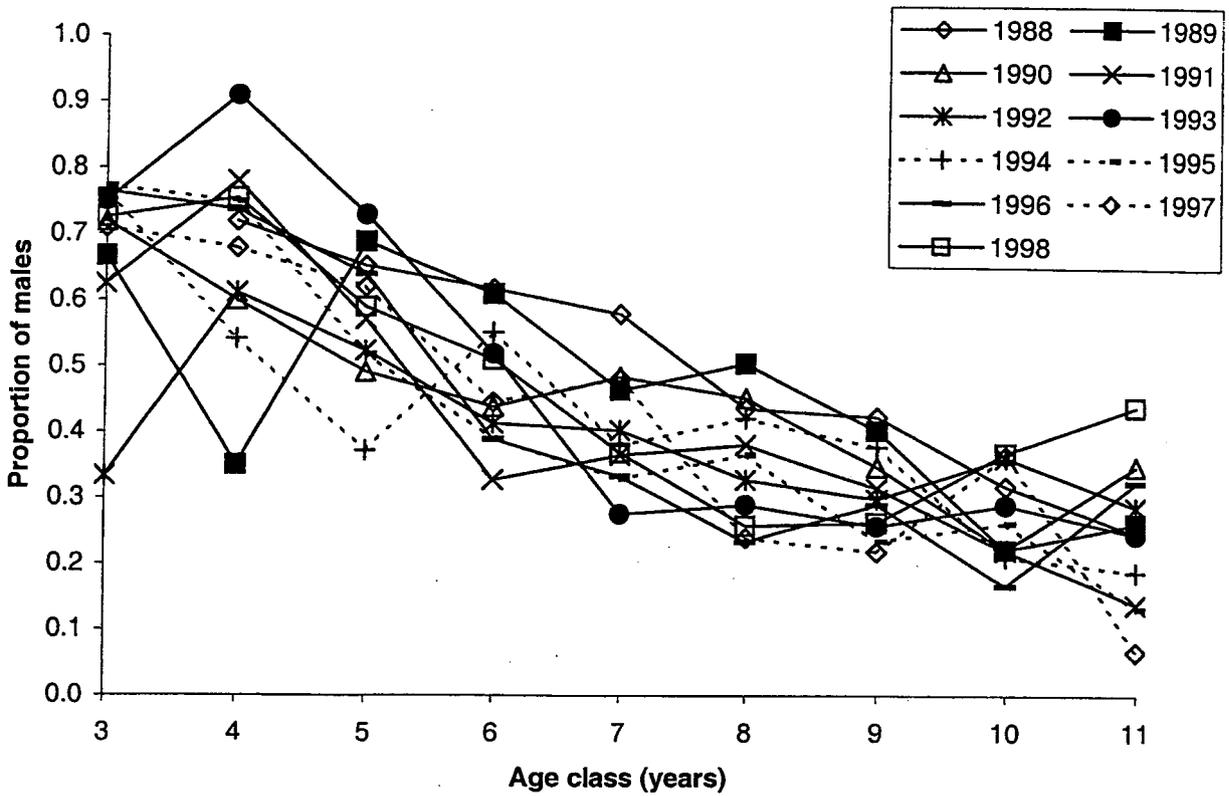
Figure 16: Proportion of male hoki at age from the west coast South Island spawning fishery, 1988-98.
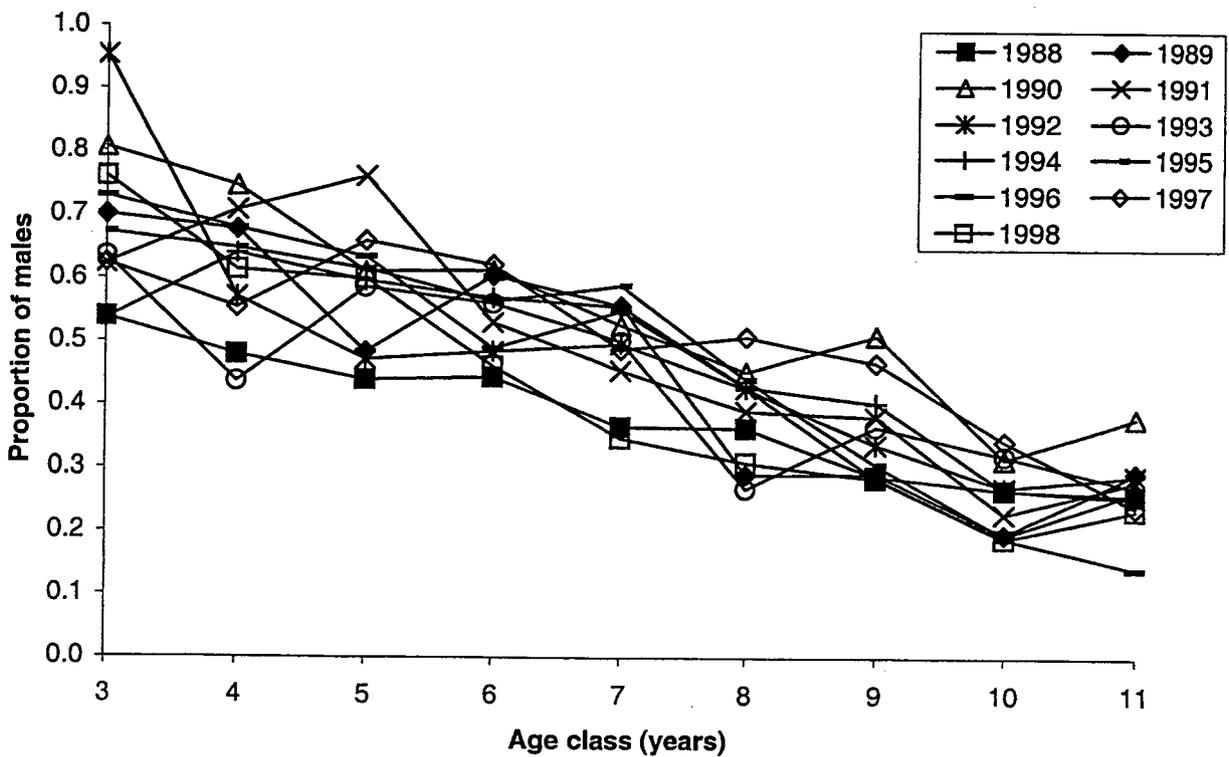

Figure 17. Proportion of male hoki at age in the Cook Strait fishery 1988-98.

Figure 18: Proportion of male hoki in age classes 3-6 years in the west coast South Island fishery, 1988-98.
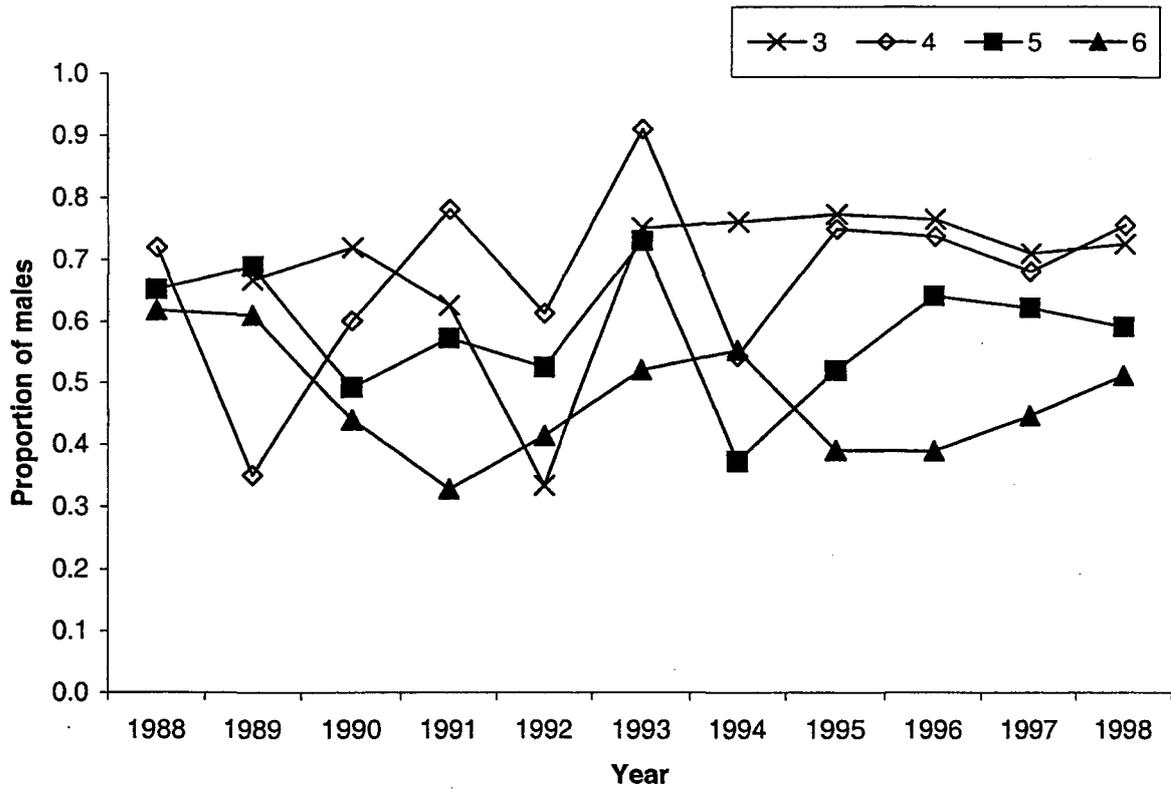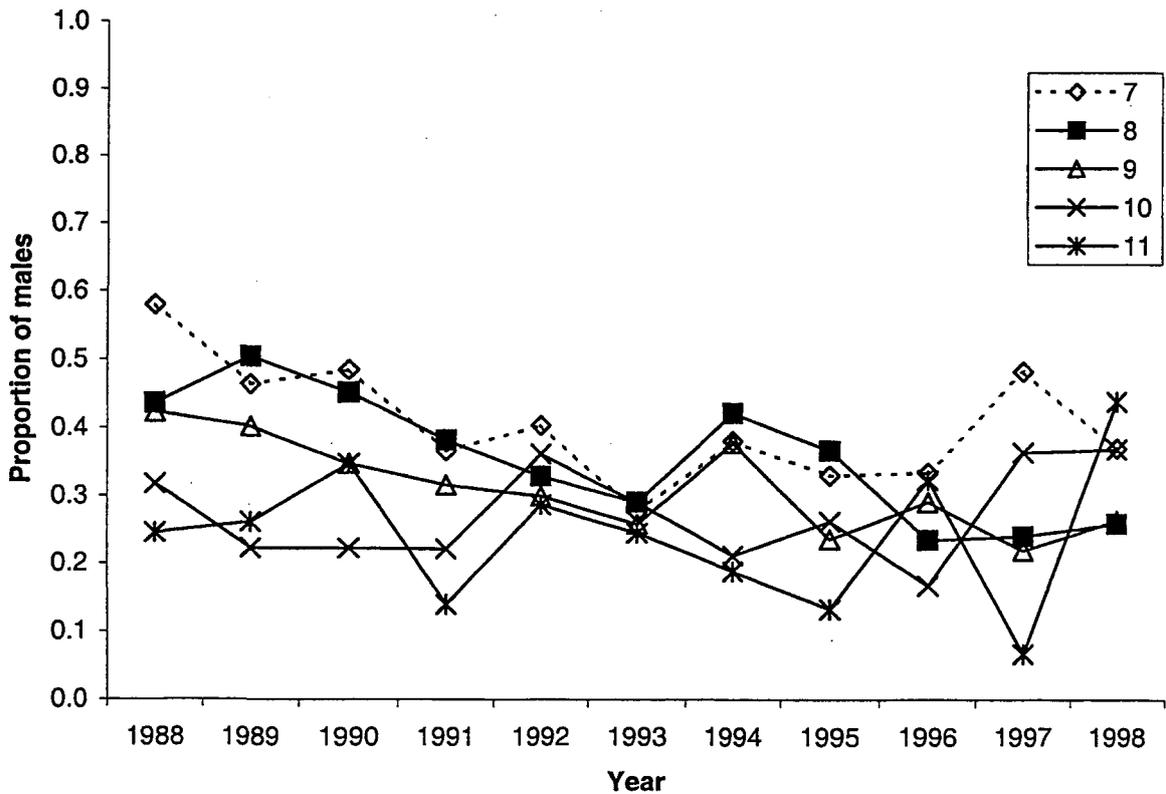

Figure 19: Proportion of male hoki in age classes 7-11 years in the west coast South Island fishery, 1988-98.
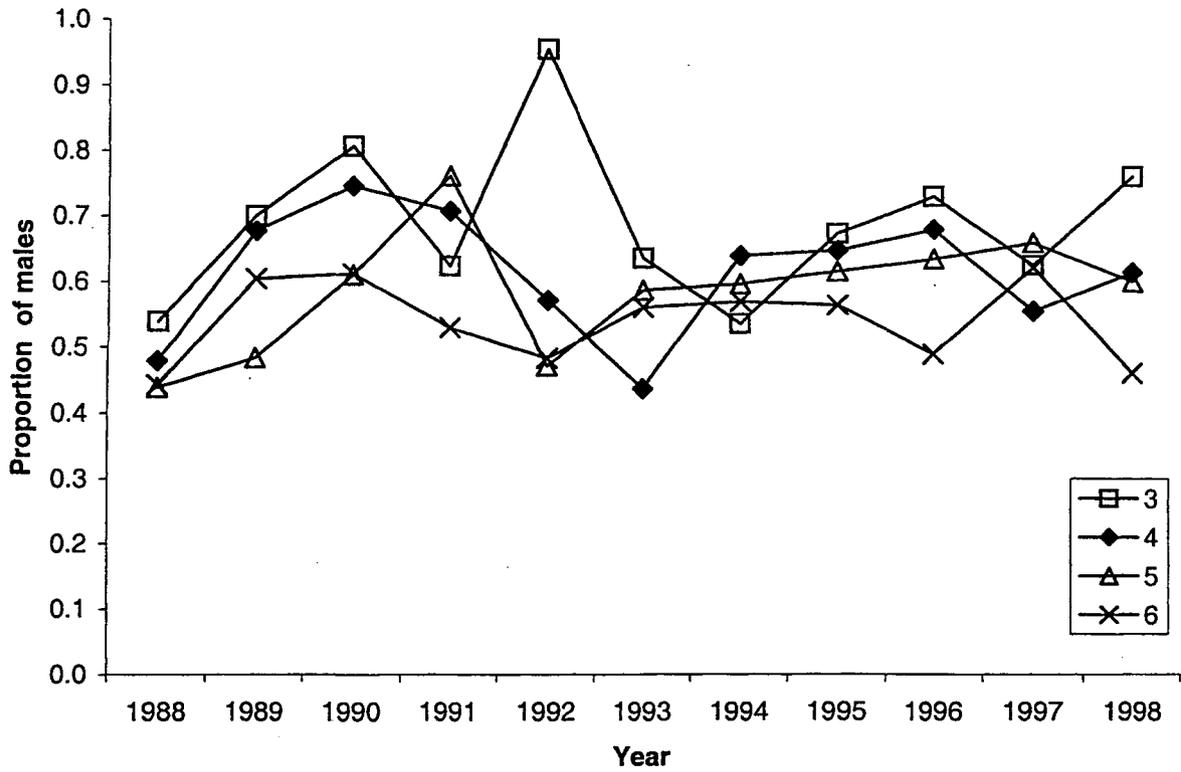
Figure 20: The proportion of male hoki age 3-6 years in the Cook Strait fishery 1988-98.
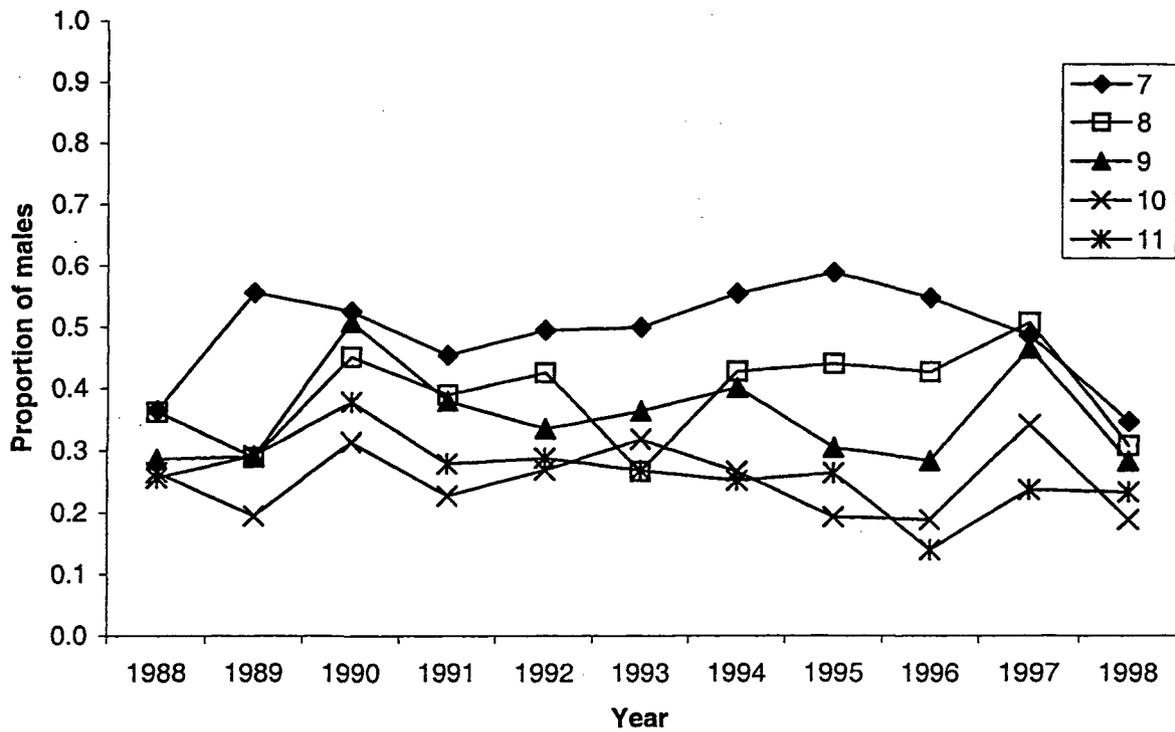
Figure 21: Proportion of males in age classes 7-11+ years in the Cook Strait fishery, 1988-98.
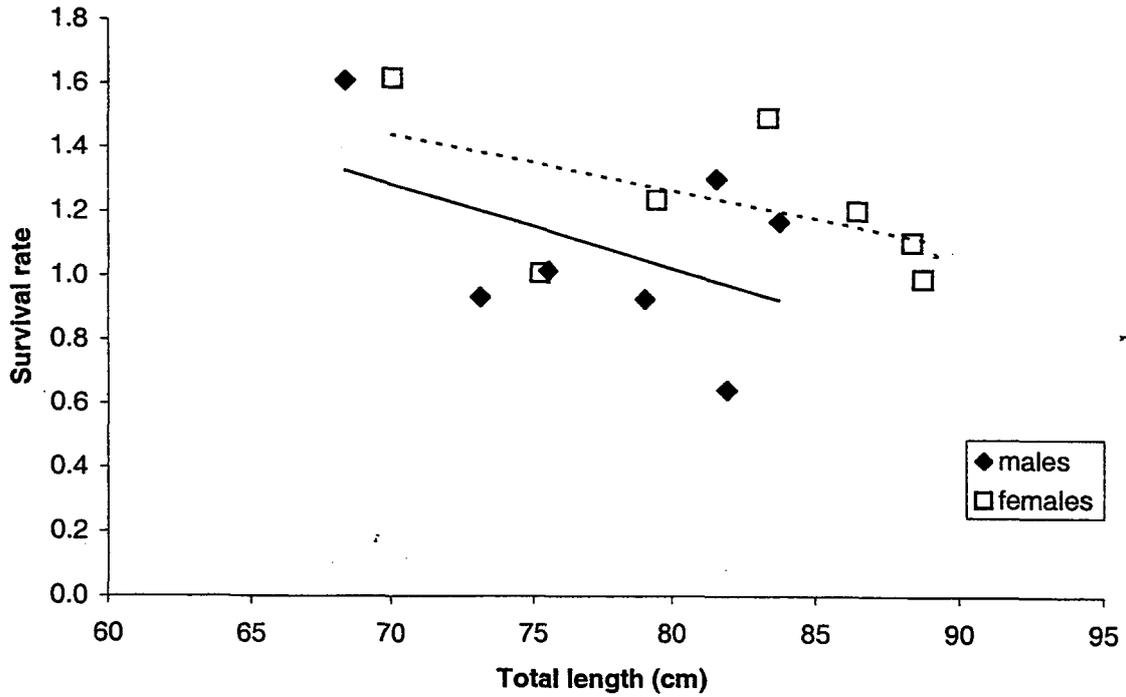
Figure 22: Survival rates of male and female hoki with mean length in the Cook Strait spawning fishery, 1988-99. (Note: survival rates > 1 may indicate recruitment into the fishery, or changes in catchability between cohorts.)
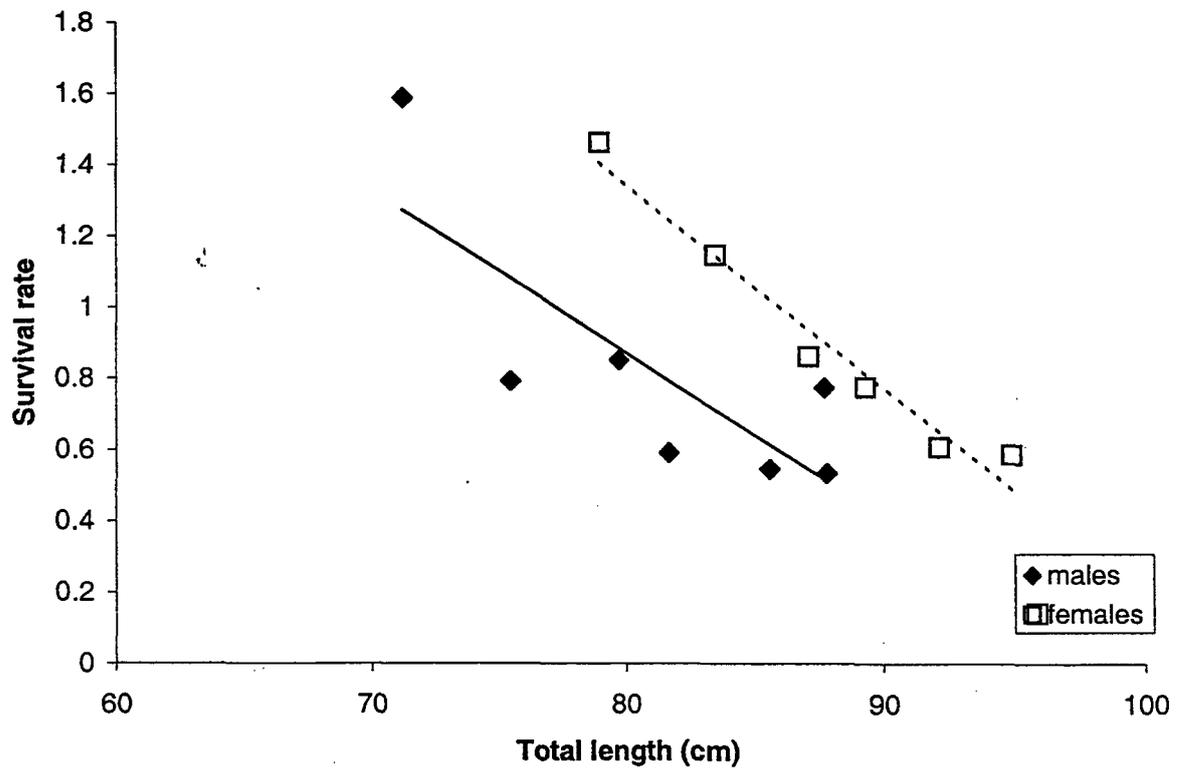
Figure 23: Survival rate of male and female hoki with length in the west coast spawning fishery, 1988-99. (Note: survival rates > 1 may indicate recruitment into the fishery, or changes in catchability between cohorts.)

Figure 24: Survival rates of male and female hoki at length from surveys of the Chatham Rise in January 1992-99.

Figure 25: Survival rates of male and female hoki from surveys of the Subantarctic, December 1991-93. (Note: survival rates > 1 may indicate recruitment into the area, or changes in catchability between cohorts.)
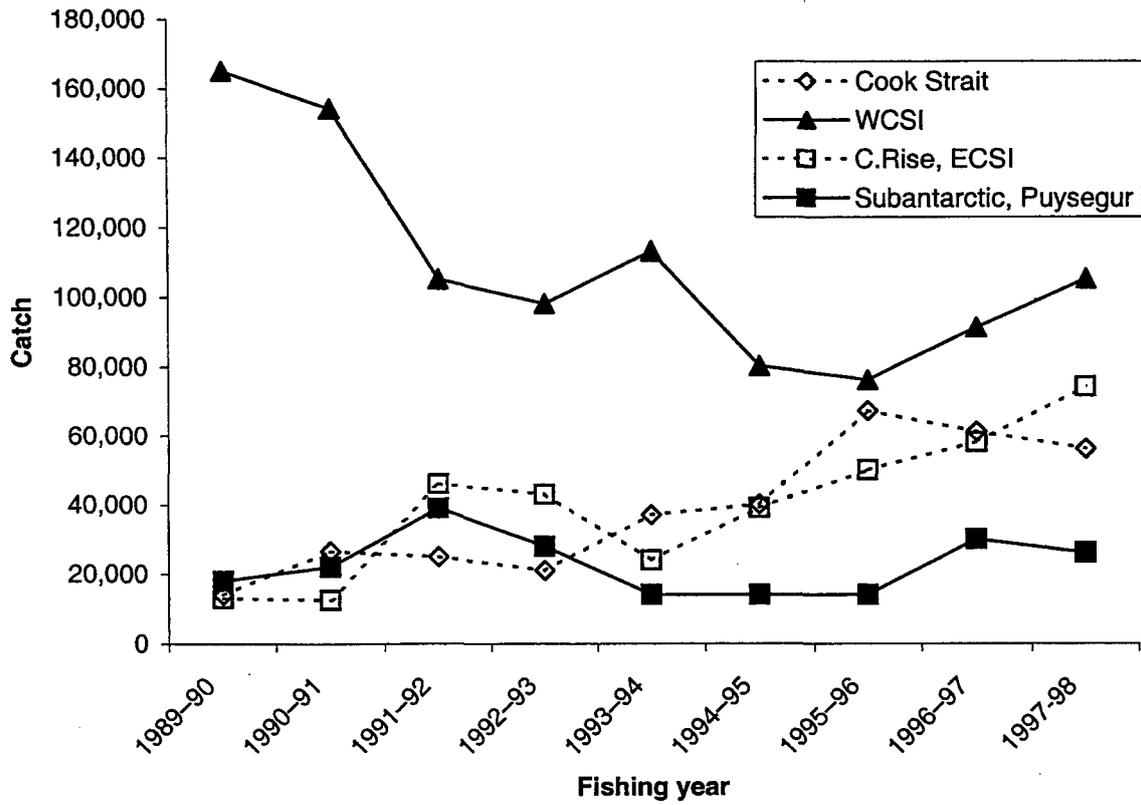
Figure 26: Annual catch (t) of hoki in Cook Strait and west coast South Island (WCSI), Subantarctic, Puysegur, Chatham Rise, and east coast of the South Island (ECSI), 1989-1998.

Appendix 1: Data used for sex ratio analyses (source Cordue 1999)

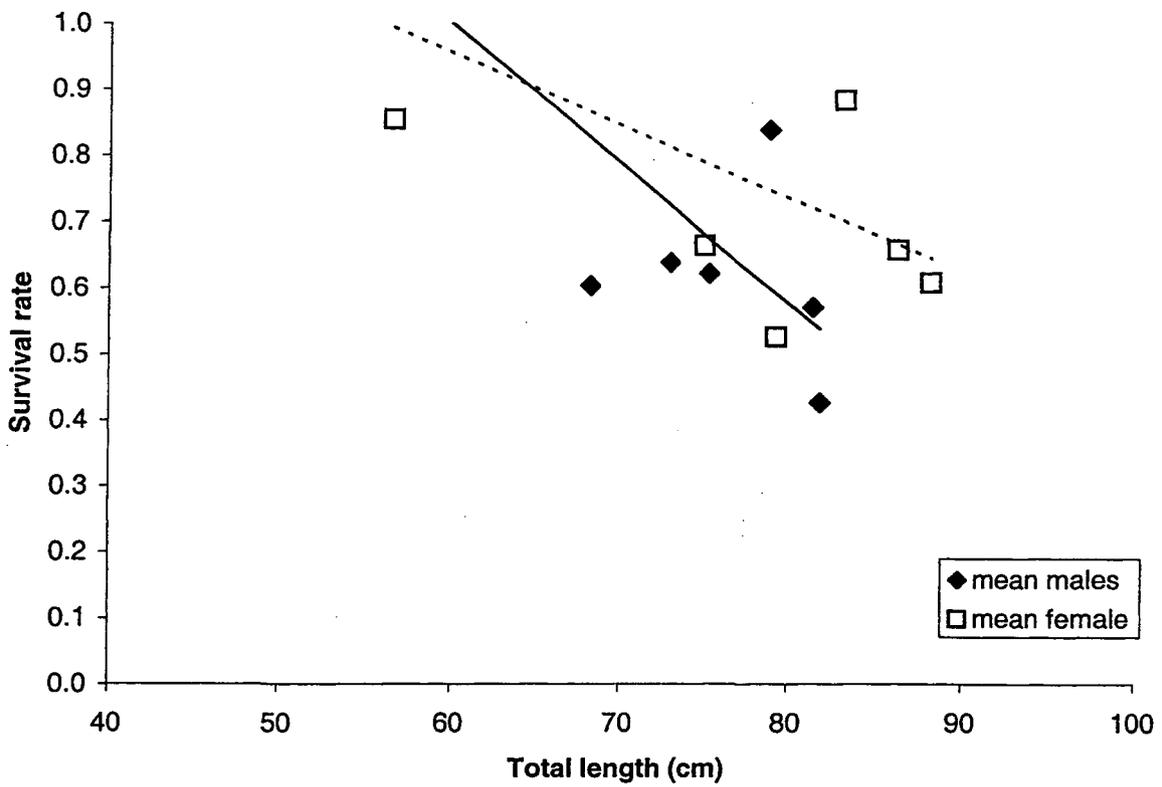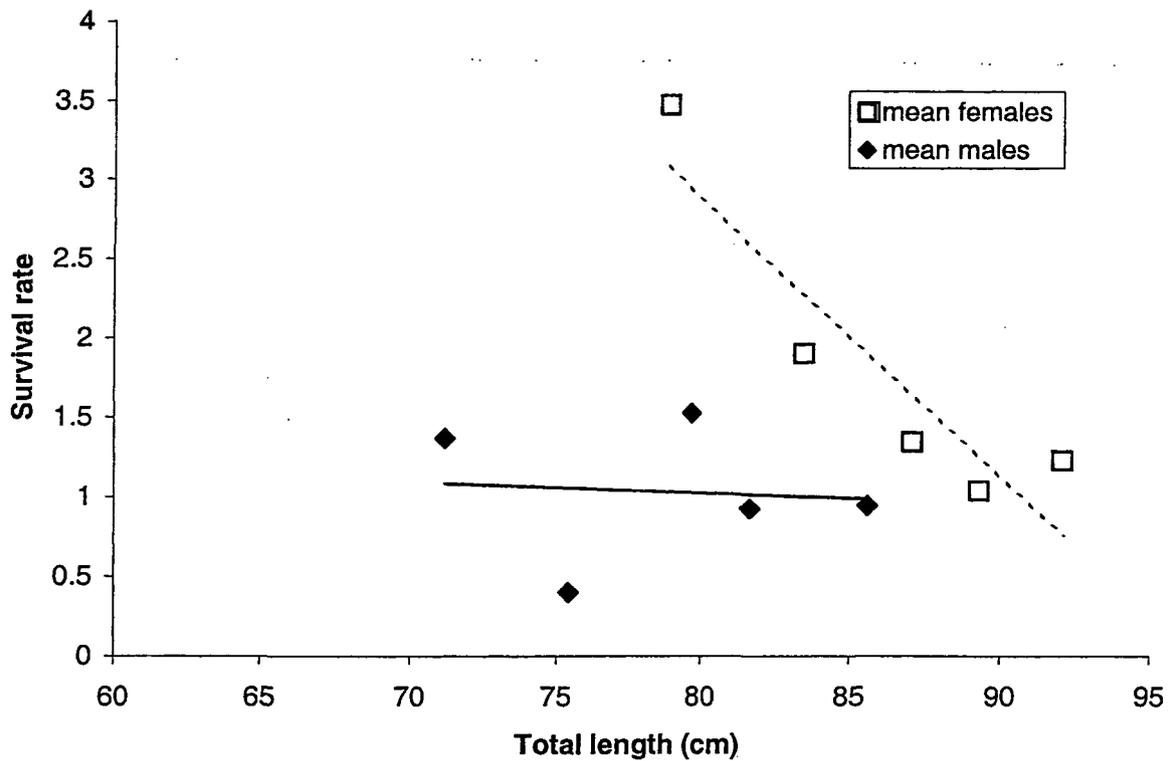**Table A1:Estimated numbers at age (millions) on the Chatham Rise, March 1983 (Otoliths, *Shinkai Maru* trawl survey). (Coefficients of variation italicised.)**

									Age (years)	
	1	2	3	4	5	6	7	8	9	10+
Males										
1983	24.2	50.2	90.3	27.2	14.2	2.4	0.39	1.3	0.189	8.9
	0.000	*0.022*	*0.047*	*0.150*	*0.177*	*0.327*	*0.707*	*0.305*	*0.707*	*0.000*
Females										
1983	25.8	58.4	81.1	64.1	14.5	8.3	4.4	4.9	5.8	7.5
	0.000	*0.032*	*0.069*	*0.090*	*0.162*	*0.221*	*0.250*	*0.209*	*0.145*	*0.424*

Table A2:Estimated numbers at age (millions) on the Chatham Rise, July 1986 (otoliths, *Shinkai Maru* trawl survey). (Coefficients of variation italicised.)

									Age (years)	
	1	2	3	4	5	6	7	8	9	10+
Males										
1986	1.9	162.4	51.9	6.6	9.0	3.4	2.1	2.6	2.9	1.4
	0.000	*0.021*	*0.079*	*0.230*	*0.257*	*0.235*	*0.270*	*0.307*	*0.348*	*0.452*
Females										
1986	2.3	154.1	82.5	9.6	9.0	8.9	10.1	14.5	9.3	7.9
	0.000	*0.044*	*0.085*	*0.205*	*0.176*	*0.175*	*0.123*	*0.125*	*0.139*	*0.215*

Appendix 1: (*continued*)

Table A3: Estimated numbers at age (millions) on the Chatham Rise, January 1992–99 (otoliths, *Tangaroa* trawl surveys). (Coefficients of variation italicised.)

	1	2	3	4	5	6	7	8	Age (years) 9	10+
Males										
1992	6.7	1.8	37.8	22.8	3.6	0.8	1.3	0.7	0.2	0.2
	0.001	*0.147*	*0.048*	*0.067*	*0.184*	*0.261*	*0.22*	*0.204*	*0.432*	*0.574*
1993	87.2	3.1	8.0	35.9	20.8	2.0	2.0	1.6	0.3	0.3
	0.001	*0.001*	*0.11*	*0.049*	*0.077*	*0.247*	*0.244*	*0.276*	*0.36*	*0.445*
1994	45.4	53.6	2.4	4.6	16.0	7.4	1.2	0.8	0.5	0.9
	0.001	*0.005*	*0.215*	*0.137*	*0.065*	*0.112*	*0.32*	*0.27*	*0.218*	*0.468*
1995	17.1	47.9	20.0	2.4	2.8	5.0	4.4	0.2	0.4	0.5
	0	*0.018*	*0.049*	*0.185*	*0.137*	*0.109*	*0.102*	*0.355*	*0.315*	*0.563*
1996	93.6	24.6	40.8	8.4	1.2	1.8	4.1	1.1	0.0	0.2
	0.001	*0.097*	*0.061*	*0.1*	*0.339*	*0.175*	*0.162*	*0.192*	*0.755*	*0.557*
1997	7.7	83.5	9.9	12.3	11.0	1.9	1.4	2.7	1.0	0.6
	0.002	*0.007*	*0.081*	*0.106*	*0.122*	*0.285*	*0.199*	*0.188*	*0.234*	*0.571*
1998	10.9	8.4	34.7	4.2	4.1	2.4	0.3	0.4	0.9	0.5
	0.098	*0.156*	*0.056*	*0.252*	*0.208*	*0.208*	*0.489*	*0.386*	*0.248*	*0.690*
1999	38.1	16.6	11.2	19.2	1.5	2.8	1.0	0.3	0.2	0.5
	0.114	*0.107*	*0.155*	*0.088*	*0.340*	*0.348*	*0.600*	*0.463*	*0.712*	*0.998*
Females										
1992	6.7	3.9	35.1	30.2	1.9	2.3	2.6	2.5	0.8	2.6
	0.001	*0.162*	*0.051*	*0.059*	*0.291*	*0.224*	*0.158*	*0.136*	*0.28*	*0.447*
1993	86.4	2.9	10.0	33.2	31.5	1.4	2.6	2.5	1.9	2.8
	0.001	*0.175*	*0.088*	*0.083*	*0.088*	*0.352*	*0.262*	*0.227*	*0.216*	*0.445*
1994	42.7	55.0	1.7	6.6	17.4	11.7	1.3	2.7	1.3	3.9
	0.001	*0.001*	*0.155*	*0.115*	*0.068*	*0.09*	*0.289*	*0.184*	*0.252*	*0.431*
1995	18.4	48.6	20.1	4.7	5.3	5.5	6.6	0.4	1.2	2.3
	0.000	*0.021*	*0.076*	*0.234*	*0.192*	*0.105*	*0.091*	*0.312*	*0.203*	*0.485*
1996	96.9	18.4	47.4	14.4	1.6	1.8	5.7	3.3	0.2	2.0
	0.001	*0.12*	*0.051*	*0.075*	*0.323*	*0.184*	*0.131*	*0.135*	*0.441*	*0.539*
1997	8.4	82.7	7.0	20.0	16.5	1.7	1.8	4.7	4.0	2.6
	0.002	*0.01*	*0.213*	*0.107*	*0.119*	*0.402*	*0.21*	*0.118*	*0.16*	*0.459*
1998	11.3	6.9	35.8	7.2	6.1	3.9	1.1	0.6	1.5	2.1
	0.085	*0.157*	*0.053*	*0.173*	*0.121*	*0.173*	*0.266*	*0.321*	*0.233*	*0.405*
1999	34.7	12.4	14.7	24.6	3.5	3.8	3.4	0.7	0.3	3.0
	0.081	*0.117*	*0.125*	*0.086*	*0.302*	*0.252*	*0.189*	*0.374*	*1.272*	*0.336*

Table A4: Estimated numbers at age (millions) on the Chatham Rise, November-December 1989 (MIX, *Amaltal Explorer* trawl survey; coefficients of variation, 5.5 for all age classes)

	2	3	4	Age (years) 5	6+
Males					
1989	38.3	13.8	5.3	4.4	3.3
Females					
1989	39.0	11.8	9.2	7.9	13.7

Appendix 1: (*continued*)

Table A5:Estimated proportion at age and sex in the Chatham Rise commercial catch, Fishing years 1992–97. (MIX, *n*, number of length frequency samples per year; Fishing year, 1 October-30 September; +, plus group of that year and all older fish; coefficients of variation, 5.5 for all age classes.)

	_____Age (years)_____				
	2	3	4	5	6+
Males					
1992–93	0.004	0.001	0.330	0.070	0.014
1993–94	0.016	0.004	0.004	0.282	0.030
1994–95	0.038	0.117	0.010	0.040	0.173
1995–96	0.057	0.180	0.075	0.051	0.084
1996–97	0.074	0.220	0.078	0.028	0.023
1997–98	0.136	0.119	0.153	0.023	0.015
Females					
1992–93	0.005	0.001	0.357	0.129	0.076
1993–94	0.022	0.001	0.024	0.480	0.120
1994–95	0.047	0.171	0.016	0.054	0.333
1995–96	0.070	0.173	0.096	0.088	0.128
1996–97	0.074	0.210	0.076	0.023	0.060
1997–98	0.166	0.268	0.051	0.053	0.016

Table A6:Estimated numbers at age (millions) in the Subantarctic, October-November 1983 (otoliths, *Shinkai Maru* trawl survey). (Coefficients of variation italicised.)

	1	2	3	4	5	6	7	8	Age (years) 9	10+
Males										
1983	0.005	0.083	0.050	5.1	13.9	18.2	13.4	13.7	5.5	10.7
	0.000	*0.000*	*0.000*	*0.148*	*0.222*	*0.177*	*0.163*	*0.131*	*0.159*	*0.242*
Females										
1983	0	0.105	0.110	8.4	14.0	18.8	21.7	14.8	7.4	21.4
	0.000	*0.000*	*0.000*	*0.057*	*0.175*	*0.139*	*0.107*	*0.106*	*0.120*	*0.107*

Table A7:Estimated numbers at age (millions) in the Subantarctic, December 1991–93 (otoliths, *Tangaroa* trawl surveys). (Coefficients of variation italicised.)

	1	2	3	4	5	6	7	8	Age (years) 9	10+
Males										
1991	1.8	0.2	5.2	11.0	1.0	2.1	3.8	2.0	0.7	1.3
	0.003	*0.004*	*0.082*	*0.052*	*0.289*	*0.17*	*0.111*	*0.145*	*0.242*	*0.541*
1992	0.8	0.4	0.3	5.1	9.3	0.4	2.2	4.6	2.3	1.8
	0.004	*0.023*	*0.219*	*0.075*	*0.067*	*0.444*	*0.201*	*0.107*	*0.167*	*0.61*
1993	1.0	4.2	0.2	1.9	9.6	5.4	0.8	1.4	3.4	3.3
	0.104	*0.101*	*0.002*	*0.179*	*0.065*	*0.117*	*0.345*	*0.233*	*0.125*	*0.578*
Females										
1991	1.7	0.0	3.8	14.0	1.0	2.2	6.8	3.4	1.8	1.9
	0.003	*0.004*	*0.112*	*0.042*	*0.281*	*0.181*	*0.085*	*0.123*	*0.188*	*0.314*
1992	1.0	0.6	0.1	0.9	10.1	1.9	5.1	8.1	5.2	2.6
	0.004	*0.004*	*0.002*	*0.196*	*0.08*	*0.268*	*0.156*	*0.113*	*0.142*	*0.52*
1993	1.1	3.7	0.2	0.8	5.6	7.5	0.7	4.5	7.5	6.2
	0.005	*0.002*	*0.002*	*0.197*	*0.095*	*0.092*	*0.391*	*0.142*	*0.1*	*0.492*

Table A8:Estimated numbers at age (millions) in the Subantarctic, April/May 1992–93, 1996 (otoliths, *Tangaroa* trawl surveys). (Coefficients of variation italicised.)

									Age (years)	
	1	2	3	4	5	6	7	8	9	10+
Males										
1992	1.1	0.1	2.6	5.7	0.4	1.3	3	2.8	0.7	0.7
	0.002	*0.001*	*0.002*	*0.119*	*0.081*	*0.495*	*0.248*	*0.134*	*0.146*	*0.681*
1993	4.3	0	0.1	1.3	3.4	0.4	0.9	2.3	2.3	1.6
	0.536	*0.121*	*0.203*	*0.111*	*0.076*	*0.323*	*0.205*	*0.122*	*0.118*	*0.405*
1996	7.6	8.1	13.8	8.8	0.3	0.7	2.6	2.9	0.2	1.4
	0.003	*0.053*	*0.053*	*0.069*	*0.397*	*0.224*	*0.11*	*0.096*	*0.457*	*0.567*
1998	0.5	0.6	4.5	2.9	6.1	3.7	0.8	0.6	0.8	1.5
	0.562	*0.202*	*0.089*	*0.161*	*0.096*	*0.130*	*0.281*	*0.308*	*0.229*	*0.369*
Females										
1992	1.1	0.1	1.6	7.4	0.6	2.3	6.2	3.5	1	3.2
	0.001	*0.319*	*0.146*	*0.051*	*0.339*	*0.141*	*0.063*	*0.099*	*0.19*	*0.481*
1993	4.3	0.1	0.3	2.6	7	0.3	1.8	4.3	2.2	2.2
	0.005	*0.004*	*0.064*	*0.063*	*0.036*	*0.226*	*0.094*	*0.052*	*0.076*	*0.369*
1996	6.7	5.8	12.3	6.6	0.5	1.3	4.3	6.3	0.5	3.9
	0.003	*0.016*	*0.054*	*0.102*	*0.219*	*0.211*	*0.108*	*0.08*	*0.372*	*0.589*
1998	0.2	0.9	5	3.7	6.6	4.2	0.8	1.7	3	3.8
	0.637	*0.139*	*0.079*	*0.117*	*0.069*	*0.080*	*0.146*	*0.162*	*0.100*	*0.205*

Table A9:Estimated numbers at age (millions) in the Subantarctic, September 1992 (otoliths, *Tangaroa* trawl survey; coefficients of variation italicised; 0.0, numbers < 0.05).

									Age (years)	
	1	2	3	4	5	6	7	8	9	10+
Males										
1992	0.1	0.0	0.0	0.5	2.2	0.2	0.3	1.0	0.9	0.7
	0.004	*0.237*	*0.378*	*0.129*	*0.061*	*0.318*	*0.216*	*0.118*	*0.122*	*0.127*
Females										
1992	0.0	0.0	0.0	1.0	3.9	0.6	1.0	3.0	1.9	2.7
	0.003	*0.253*	*0.205*	*0.153*	*0.070*	*0.356*	*0.228*	*0.111*	*0.147*	*0.084*

Table A10: Estimated numbers at age (millions) in the Subantarctic, July-August 1990 (MIX, *Amaltal Explorer* trawl survey; coefficient of variation, 5.5 for all age classes).

					Age (years)	
	1	2	3	4	5	6+
Males						
1990		0.1	6.9	6.2	1.5	4.5
Females						
1990		0.1	6.6	7.8	1.8	11.9

Appendix 1: (*continued*)

Table A11: **Estimated numbers at age (millions) in the Subantarctic, October-November 1989-90 (MIX;** *Amaltal Explorer* **trawl surveys; coefficient of variation, 5.5 for all age classes).**

					Age (years)	
	1	2	3	4	5	6+
Males						
1989		1.0	0.4	0.9	11.9	5.6
1990		1.4	3.3	1.2	5.8	4.2
Females						
1989		1.0	0.3	0.9	12.5	12.0
1990		1.1	3.2	1.8	5.4	16.1

Table A12: **Estimated proportion at age and sex in the Subantarctic commercial catch, Fishing years 1992-97 (MIX; n, number of length frequency samples per year; coefficient of variation, 5.5 for all age classes ; Fishing year, 1 October-30 September; +, plus group of that year and all older fish).**

					Age (years)	
	1	2	3	4	5	6+	n
Males							
1992-93		0.000	0.002	0.168	0.050	0.215	267
1993-94		0.000	0.016	0.165	0.170	0.074	187
1994-95		0.006	0.034	0.027	0.265	0.178	100
1995-96		0.017	0.065	0.088	0.023	0.240	50
1996-97		0.012	0.046	0.228	0.128	0.146	114
1997-98		0.005	0.144	0.182	0.103	0.061	68
Females							
1992-93		0.001	0.001	0.102	0.059	0.404	267
1993-94		0.003	0.006	0.102	0.134	0.277	187
1994-95		0.007	0.083	0.016	0.162	0.210	100
1995-96		0.015	0.079	0.074	0.001	0.398	50
1996-97		0.012	0.058	0.132	0.100	0.138	114
1997-98		0.003	0.070	0.133	0.119	0.177	68

(0.000 = proportion < 0.0005)

Table A13: **Estimated numbers at age (millions) off Southland, February-March 1993-96 (length mode;** *Tangaroa* **trawl surveys).**

	Age (years)	
	1	2
Males		
1993	19.0	0.6
1994	28.3	6.8
1995	1.8	1.3
1996	3.7	5.0
Females		
1993	23.9	0.8
1994	26.3	6.0
1995	1.6	1.0
1996	3.3	5.1

Appendix 1: (*continued*)

Table A14: Estimated numbers (millions) at age in the Cook Strait commercial catch, Fishing years 1988–98 (spawning season, otoliths). (Coefficients of variation italicised; +, plus group of that year and all older fish.)

	3	4	5	6	7	8	9	Age (years) 10	11+
Males									
1988	0.02	0.06	0.07	0.04	0.05	0.04	0.05	0.05	0.04
	0.436	*0.195*	*0.16*	*0.2*	*0.171*	*0.202*	*0.173*	*0.176*	*0.22*
1989	0.26	0.47	0.38	0.40	0.16	0.08	0.08	0.11	0.17
	0.176	*0.124*	*0.143*	*0.152*	*0.264*	*0.339*	*0.428*	*0.299*	*0.22*
1990	0.47	0.92	0.71	0.82	0.47	0.21	0.40	0.12	0.39
	0.126	*0.122*	*0.158*	*0.148*	*0.204*	*0.301*	*0.205*	*0.4*	*0.231*
1991	1.00	3.75	2.13	0.79	0.87	0.74	0.29	0.21	0.12
	0.17	*0.079*	*0.106*	*0.178*	*0.173*	*0.199*	*0.332*	*0.345*	*0.481*
1992	0.27	1.62	2.60	0.40	0.68	0.83	0.33	0.20	0.16
	0.231	*0.091*	*0.07*	*0.213*	*0.159*	*0.138*	*0.23*	*0.268*	*0.334*
1993	0.04	0.78	2.39	2.17	0.20	0.28	0.36	0.15	0.08
	0.411	*0.152*	*0.095*	*0.101*	*0.298*	*0.238*	*0.249*	*0.304*	*0.338*
1994	0.26	0.76	2.62	2.68	3.02	0.24	0.50	0.19	0.14
	0.182	*0.205*	*0.12*	*0.112*	*0.097*	*0.383*	*0.297*	*0.372*	*0.366*
1995	0.53	1.24	0.96	1.33	2.82	1.92	0.20	0.27	0.22
	0.13	*0.11*	*0.174*	*0.158*	*0.092*	*0.114*	*0.412*	*0.262*	*0.303*
1996	2.21	3.79	2.42	0.55	2.50	2.89	1.61	0.11	0.21
	0.102	*0.091*	*0.134*	*0.29*	*0.132*	*0.117*	*0.158*	*0.574*	*0.455*
1997	1.79	4.01	4.27	4.01	0.55	1.71	1.84	1.09	0.16
	0.117	*0.118*	*0.13*	*0.118*	*0.305*	*0.179*	*0.144*	*0.183*	*0.562*
1998	3.76	3.07	3.04	0.94	0.81	0.27	0.85	0.58	0.39
	0.068	*0.116*	*0.11*	*0.201*	*0.217*	*0.351*	*0.19*	*0.219*	*0.256*
Females									
1988	0.01	0.07	0.08	0.05	0.09	0.06	0.13	0.13	0.10
	0.269	*0.175*	*0.154*	*0.226*	*0.161*	*0.191*	*0.126*	*0.123*	*0.14*
1989	0.11	0.23	0.41	0.26	0.13	0.20	0.20	0.44	0.41
	0.658	*0.275*	*0.147*	*0.201*	*0.313*	*0.205*	*0.201*	*0.134*	*0.143*
1990	0.11	0.32	0.46	0.52	0.43	0.26	0.39	0.27	0.64
	0.308	*0.2*	*0.164*	*0.171*	*0.197*	*0.225*	*0.199*	*0.216*	*0.151*
1991	0.61	1.56	0.67	0.71	1.05	1.17	0.47	0.71	0.30
	0.19	*0.118*	*0.174*	*0.173*	*0.139*	*0.133*	*0.214*	*0.178*	*0.272*
1992	0.01	1.22	2.92	0.43	0.70	1.12	0.66	0.54	0.40
	0.605	*0.122*	*0.07*	*0.25*	*0.168*	*0.136*	*0.186*	*0.215*	*0.227*
1993	0.02	1.01	1.69	1.71	0.20	0.78	0.64	0.31	0.23
	0.494	*0.105*	*0.107*	*0.109*	*0.351*	*0.165*	*0.184*	*0.207*	*0.336*
1994	0.23	0.43	1.78	2.04	2.42	0.32	0.75	0.53	0.41
	0.109	*0.276*	*0.126*	*0.133*	*0.104*	*0.304*	*0.176*	*0.184*	*0.215*
1995	0.26	0.68	0.60	1.04	1.97	2.46	0.46	1.13	0.61
	0.298	*0.136*	*0.175*	*0.163*	*0.111*	*0.099*	*0.251*	*0.161*	*0.193*
1996	0.82	1.80	1.40	0.58	2.06	3.89	4.08	0.49	1.32
	0.203	*0.11*	*0.15*	*0.305*	*0.157*	*0.115*	*0.11*	*0.331*	*0.202*
1997	1.08	3.24	2.22	2.46	0.58	1.66	2.12	2.10	0.52
	0.125	*0.089*	*0.155*	*0.147*	*0.344*	*0.171*	*0.137*	*0.15*	*0.312*
1998	1.19	1.94	2.04	1.10	1.54	0.62	2.17	2.52	1.30
	0.142	*0.11*	*0.11*	*0.197*	*0.161*	*0.284*	*0.151*	*0.137*	*0.164*

Appendix 1: (*continued*)

Table A15: Estimated numbers (millions) at age and sex in the west coast South Island commercial catch, 1988–98 (spawning season, otoliths). (Coefficients of variation italicised; +, plus group of that year and all older fish.)

								Age (years)	
	3	4	5	6	7	8	9	10	11
Males									
1988	0.000	0.041	0.060	0.084	0.080	0.051	0.033	0.033	0.038
	0.324	*0.119*	*0.132*	*0.115*	*0.125*	*0.165*	*0.185*	*0.189*	*0.188*
1989	0.002	0.007	0.073	0.161	0.07	0.061	0.039	0.014	0.024
	0.310	*0.183*	*0.136*	*0.089*	*0.163*	*0.158*	*0.207*	*0.339*	*0.261*
1990	0.023	0.009	0.028	0.078	0.138	0.047	0.041	0.012	0.025
	0.057	*0.264*	*0.199*	*0.128*	*0.101*	*0.182*	*0.215*	*0.320*	*0.268*
1991	0.025	0.135	0.024	0.038	0.072	0.069	0.029	0.013	0.009
	0.161	*0.051*	*0.194*	*0.157*	*0.109*	*0.107*	*0.191*	*0.249*	*0.304*
1992	0.002	0.052	0.189	0.019	0.056	0.043	0.026	0.022	0.014
	0.198	*0.138*	*0.055*	*0.305*	*0.196*	*0.139*	*0.184*	*0.191*	*0.225*
1993	0.003	0.02	0.14	0.227	0.008	0.029	0.017	0.013	0.011
	0.346	*0.254*	*0.093*	*0.066*	*0.438*	*0.221*	*0.287*	*0.261*	*0.424*
1994	0.095	0.013	0.029	0.107	0.139	0.008	0.023	0.008	0.006
	0.044	*0.181*	*0.234*	*0.130*	*0.098*	*0.516*	*0.279*	*0.364*	*0.282*
1995	0.105	0.146	0.014	0.023	0.06	0.067	0.004	0.017	0.007
	0.042	*0.041*	*0.261*	*0.200*	*0.100*	*0.090*	*0.410*	*0.229*	*0.323*
1996	0.147	0.416	0.192	0.012	0.047	0.053	0.052	0.002	0.014
	0.091	*0.052*	*0.094*	*0.419*	*0.142*	*0.146*	*0.141*	*0.692*	*0.303*
1997	0.056	0.161	0.134	0.089	0.013	0.018	0.014	0.02	0.001
	0.084	*0.075*	*0.105*	*0.133*	*0.383*	*0.270*	*0.250*	*0.245*	*0.712*
1998	0.064	0.089	0.153	0.082	0.046	0.011	0.019	0.019	0.019
	0.108	*0.105*	*0.080*	*0.128*	*0.154*	*0.390*	*0.281*	*0.198*	*0.482*
Females									
1988	0.000	0.016	0.032	0.052	0.058	0.066	0.045	0.071	0.056
	0.400	*0.180*	*0.168*	*0.147*	*0.143*	*0.123*	*0.167*	*0.127*	*0.139*
1989	0.001	0.013	0.033	0.103	0.081	0.06	0.058	0.049	0.035
	0.454	*0.185*	*0.201*	*0.110*	*0.145*	*0.168*	*0.182*	*0.185*	*0.201*
1990	0.009	0.006	0.029	0.1	0.147	0.057	0.077	0.042	0.024
	0.107	*0.225*	*0.205*	*0.136*	*0.108*	*0.187*	*0.162*	*0.215*	*0.253*
1991	0.015	0.038	0.018	0.078	0.125	0.112	0.063	0.046	0.033
	0.171	*0.104*	*0.224*	*0.117*	*0.091*	*0.100*	*0.140*	*0.166*	*0.187*
1992	0.004	0.033	0.172	0.027	0.083	0.088	0.061	0.039	0.019
	0.344	*0.173*	*0.066*	*0.320*	*0.144*	*0.103*	*0.113*	*0.187*	*0.194*
1993	0.001	0.002	0.052	0.21	0.021	0.071	0.049	0.032	0.015
	1.006	*0.300*	*0.147*	*0.054*	*0.254*	*0.119*	*0.129*	*0.154*	*0.227*
1994	0.03	0.011	0.049	0.087	0.227	0.011	0.038	0.03	0.022
	0.070	*0.125*	*0.159*	*0.153*	*0.075*	*0.438*	*0.236*	*0.244*	*0.246*
1995	0.031	0.049	0.013	0.036	0.122	0.116	0.013	0.048	0.03
	0.102	*0.076*	*0.179*	*0.149*	*0.079*	*0.086*	*0.256*	*0.143*	*0.159*
1996	0.054	0.182	0.138	0.026	0.115	0.21	0.158	0.011	0.041
	0.096	*0.052*	*0.079*	*0.260*	*0.147*	*0.100*	*0.120*	*0.525*	*0.222*
1997	0.023	0.076	0.082	0.111	0.014	0.057	0.05	0.035	0.006
	0.126	*0.094*	*0.117*	*0.092*	*0.312*	*0.140*	*0.146*	*0.167*	*0.404*
1998	0.024	0.029	0.106	0.079	0.079	0.033	0.053	0.033	0.024
	0.104	*0.151*	*0.081*	*0.123*	*0.132*	*0.222*	*0.147*	*0.183*	*0.218*