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# Migration patterns during the life-cycle of hoki (Macruronus novaezelandiae): an analysis of trawl survey data in New Zealand waters 1991-2002 

M.E. Livingston, B. Bull, D.W. Stevens

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Migration patterns during the life-cycle of hoki (Macruronus novaezelandiae): an analysis of trawl survey data from New Zealand waters 1991-2002.

M.E. Livingston, B. Bull, D.W. Stevens

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## 7. Executive Summary

Time series of trawl surveys of the Chatham Rise and Sub-Antarctic by Tangaroa show that juvenile hoki (Macruronus novaezelandiae) are consistently found in abundance on the Chatham Rise (200-500 m depth) from age 1 to 3 years. From age 4 to 8 years, numbers decline rapidly to a residual stock of older fish found in deeper water. A small number of juvenile hoki are also found at Puysegur Bank, but very few are found on the Campbell Plateau part of the Sub-Antarctic where a stock of hoki aged 5 years and over resides. Analysis of numbers at age data from the trawl survey series found that instantaneous rates of change in the numbers of hoki at age between surveys averaged 0.66 (males) and 0.44 (females) in fish aged 3 to 7 years on the Chatham Rise, almost double the estimates of natural mortality for hoki. In contrast, mean instantaneous rates of change in the Sub-Antarctic averaged -0.4 up to age 5 (males), and 1.2 up to age 7 (females), suggesting significant increases of hoki in the area rather than a decline. On a proportional basis, $80 \%$ or more of hoki aged 1-2 years occur on the Chatham Rise. Between ages 3 and 7 , this drops to $60-80 \%$. By age $8,35 \%$ or less fish are found on the Chatham Rise compared with $65 \%$ or more in the Sub-Antarctic.

Inshore surveys by Tangaroa and Kaharoa around both the North and South Islands recorded juvenile hoki ( $0-1$ years) in most areas around the South Island and the east coast North Island, but abundance estimates were extremely low compared with the Chatham Rise. The presence of $0-1$ year old hoki in inshore areas and their high abundance as $1+$ fish on the Chatham Rise supports the hypothesis that young hoki disperse from their spawning grounds north and south from the west coast South Island, and through Cook Strait to the Chatham Rise. The data show that very few 2 year old hoki occur outside the Chatham Rise, and support the hypothesis of one main nursery ground on the Chatham Rise. The small proportion of 2 year old hoki found at Puysegur during some Sub-Antarctic surveys may recruit directly to the Sub-Antarctic hoki population without moving to the to the Chatham Rise at any stage.

The results of our study strongly support the current hypothesis that most juvenile hoki reside on the Chatham Rise nursery ground, and a significant proportion move to the Sub-Antarctic as they approach maturity, with most movement between ages 3 and 7 years.

It was not possible to determine the season, the exact route followed, or the length of time required, for fish to move from the Chatham Rise to the Sub-Antarctic. Inference of length modes in the spawning fisheries and catch rate distributions at different times of year on the Chatham Rise and Sub-Antarctic identify seasonal movement in and out of these areas in relation to the winter spawning season, and it is possible that movement of new recruits to the Sub-Antarctic coincides with the maturation cycle, even enabling some fish to recruit via their spawning grounds.

In further support of the view that once hoki have recruited to the Sub-Antarctic they remain in that stock, a GAM analysis of length-at-age data found that the mean length at age was $9 \%$ higher in the SubAntarctic than on the Chatham Rise across all ages (2-12 years) for both sexes. It is not known if these differences reflect a tendency for larger hoki to move to the Sub-Antarctic and smaller fish remain on the Chatham Rise, or if there are genetic differences in growth rates between stocks.

The GAM analyses also showed that there has been a steady increase of almost $10 \%$ in mean fish length from the 1982 to the 1997 year class, across all ages, sexes and areas. This may be a direct result of the declining population abundance and could have an effect on age of maturity as well as age of recruitment into adult stocks.

## 8. Introduction

New.Zealand hoki (Macruronus novaezelandiae) are widely distributed throughout New Zealand's 200 mile Exclusive Economic Zone (EEZ) in depths of 200 to 800 m , and form New Zealand's largest fishery with annual commercial catches of 200000 t or more (Ballara et al. 2001). Hoki are currently assessed as 2 stocks: a western stock which spawns off the west coast of the South Island and resides for most of the year in the Sub-Antarctic south of New Zealand, and an eastern stock that spawns in Cook Strait and resides for most of the year on the Chatham Rise (Figure 1). Up until 1988, hoki were assessed as a single stock, but from 1989 on, this changed to 2 stocks (Annala et al. 2002). The stock structure was modified on the basis of research during the late 1980's following the discovery of a reasonably large spawning population in Cook Strait in 1987 that had different morphometrics and different growth rates from hoki on the west coast South Island spawning ground (Livingston 1990a, 1990b, Livingston \& Schofield 1996, Horn \& Sullivan 1996). The life-cycle of hoki was also developed at that time using distribution and abundance data from a range of trawl surveys (see section 1.1 below).

Although the 2 stocks do not appear to be genetically distinct (Smith et al 1996), the decision to assess them as separate stocks with $100 \%$ stock fidelity has continued since 1989 (Annala et al. 2002). However, research to verify this approach and ongoing data analysis to re-evaluate stock hypotheses have continued (e.g., Hicks \& Gilbert 2002). Recently, a study of the hoki commercial catches found support for the current life-cycle hypotheses and migration patterns of hoki (Bull \& Livingston 2000). In this paper, we investigate data from time series of research surveys where the relative abundance of individual year classes can be tracked within an area, and between areas. In particular, we wished to investigate the evidence for movement of hoki from the nursery grounds to the adult stock home grounds, but we also aimed to determine how well the distribution and abundance of hoki matches current hypotheses about the life-cycle and stock movements.

### 8.1 Stock movements and the life cycle of hoki

Length frequency and relative abundance data collected from random trawl surveys throughout the EEZ from the mid 1970s to the late 1980s consistently identified the Chatham Rise as the main nursery ground for immature hoki age 2-5 years, and the Campbell Plateau in the Sub-Antarctic as the main ground for adult hoki age 6 years and over (Kerstan \& Sahrhage 1980, Patchell 1982, van den Broek et al. 1984, Uozumi et al. 1987, Fenaughty \& Uozumi 1989, Livingston et al. 1991, Livingston \& Schofield 1993, 1995). Since 1987, two major spawning grounds for hoki, one centred off the west coast of the South Island (WCSI) and another centred in Cook Strait have been fished extensively. The current working hypothesis, developed from both commercial and research data, is that hoki spawned on either spawning ground migrate to a shared nursery ground on the Chatham Rise by 2 years old (Figure 2). As they mature (3-6 years), they move to deeper water forming the eastern stock on the Chatham Rise, and the western stock on the Campbell Plateau in Sub-Antarctic waters south of the South Island. They remain on their respective home grounds for the rest of their lives, apart from excursions to their spawning grounds (Figure 2). It is unknown if hoki from the two stocks have stock fidelity or not. Morphometric and growth rate parameters differ significantly between the two spawning populations supporting the concept of 2 mature-size stocks on different home grounds (Livingston \& Schofield 1996, Hom \& Sullivan 1996), but genetic techniques have not found any stock separation markers demonstrating stock fidelity (Smith et al 1980, Smith et al 1997). Micro-chemistry of the otoliths and otolith ring patterns have also failed to identify clear stock separation markers (Kalish et al. 1998, Hicks 2001).

### 8.1.1 Dispersion of pre-recruit hoki from spawning grounds to nursery grounds

Sampling of the upper water column using plankton nets and fine mesh midwater trawls have located $0+$ and 1 year old hoki in midwater around much of the coast of the South Island and in Cook Strait (Kerstan \& Sahrhage 1980; Patchell 1982; Kuruwa 1985, Murdoch et al. 1990). There is some evidence that $0+$ hoki spawned on the west coast South Island disperse both north and south from the spawning grounds during their first year (Patchell 1982). Trawl surveys that sample Puysegur Bank usually report the presence of 1 and 2 year old hoki, but generally their abundance is very low compared with the Chatham Rise. By 2 years old, hoki have adopted a demersal life-style, and the greatest abundance is found on the Chatham Rise and (Livingston \& Schofield 1996). Research surveys and commercial fishers have not found large quantities of hoki age 1-2 years on the Challenger Plateau (the only other major area of suitable depths) or around any other areas of coastal New Zealand (Bull \& Livingston 2000). The time series of trawl surveys by Tangaroa on the Chatham Rise and Sub-Antarctic, as well as surveys of Southland waters (also Tangaroa) and some coastal areas of New Zealand by Kaharoa allow a more thorough investigation of juvenile hoki distribution to determine dispersion patterns from spawning grounds to the Chatham Rise, and any other nursery grounds that are currently overlooked in the life-cycle of hoki.

### 8.1.2 Migration from the Chatham Rise to deeper waters and other home grounds

The hypothesis that most of the hoki seen in the Sub-Antarctic have moved there from the Chatham Rise was initially developed by comparing the size and age frequencies of hoki in the two areas. For example, in December 1989, a survey of the Chatham Rise by Amaltal Explorer found evidence of two relatively strong juvenile cohorts spawned in 1987 and 1988, aged 3 and 2 years old respectively (Figures 3a \& 3b). Another survey of the Chatham Rise two years later using Tangaroa found large numbers of the 1988 year class (now aged 4 years) still present, but proportionally far less of the 1987 year class (Figures 3a \& 3b). Surveys of the Sub-Antarctic during the same time period found that numbers of the 1987 year class in the area increased substantially (Figures 3a \& 3b). There was also evidence of recruitment of the 1987 year class into the west coast spawning fishery at age 3 in July 1990, and more substantially at age 4 in July 1991 as the fish reached the age or size of maturity to become part of the western spawning stock (Figures 4a \& 4b). These observations provide compelling circumstantial evidence that as hoki reach maturity, a substantial
proportion moves away from the Chatham Rise nursery grounds and recruits to the Sub-Antarctic home grounds. Trawl survey data collected by Tangaroa 1991-1995 using standardised sampling methods, gear and vessel further supported these observations, however, the analysis was limited because the time series were short, and age data were not available from each survey at that time (Livingston \& Schofield 1995b). Research surveys using Tangaroa and consistent survey methods now span an 11 year period, and provide numbers at age data allowing tracking of individual cohorts in each area to provide more insight into stock movements of hoki, and the age at which this occurs.

### 8.1.3 Annual spawning migrations

There is strong evidence from hoki target catch vessels and tuna vessels which catch hoki as a bycatch, of fish movement from the Sub-Antarctic to the west coast spawning grounds in May-June (Bull \& Livingston 2000). Trawl surveys of the Sub-Antarctic by Amaltal Explorer in summer and winter 1990 reported a marked drop in hoki biomass in winter consistent with the departure of fish to spawn elsewhere (Hurst \& Schofield 1995). There are no equivalent surveys of the Chatham Rise, however, a survey by Shinkai Maru in July 1986 found that hoki biomass was very low compared with April 1983 (Fenaughty \& Uozumi 1989, Livingston et al. 1991), and it is likely that spawners move from the Chatham Rises to spawn in Cook Strait at some time in autumn. The seasonal surveys of the Sub-Antarctic carried out by Tangaroa 1991-1993 provide an improved data set to quantify changes in the numbers of hoki at age throughout the year.

## 9. Objectives

The studies outlined above form the basis of most of the assumptions about the stock structure and lifecycle of hoki that are implicit in the models currently used for stock assessment (Annala et al 2002).

Use of the research vessel Tangaroa for trawl surveys of hoki on the Chatham Rise and Sub-Antarctic since 1991 has generated a new data series with substantially improved comparability. The study presented here (MFish Project Code HOK2000/01, Objective 6), had the following aims:
a) To determine how well the observed patterns [from trawl survey data] fit existing hypotheses about hoki distribution at different life cycle stages.
b) Define the age, and if possible the season, at which movements occur.

In this study, we used relative biomass, numbers at age and length frequency data from Tangaroa surveys to quantify changes in distribution of hoki at different stages of their life history, and address the issue of dispersion to the Sub-Antarctic from the Chatham Rise. The data were examined for signals on the age at which hoki appear on and disperse away from the Chatham Rise, the seasonality of dispersal and any differences between males and females. We also investigated length at age on the two home grounds. Possible variations in catchability with age and between areas are discussed. Time series of data collected by Kaharoa and Tangaroa surveys of some coastal regions of the North and South Islands for information regarding the size range and abundance of hoki found outside the principal spawning, nursery, and home grounds were collated.

## 10. Methods

### 10.1 Trawl survey time series

To track year classes on each home ground and infer arrivals and departures, we required time series of abundance data (biomass and numbers of fish at age) from both areas. Trawl surveys of the home grounds of mature-size hoki are believed to give the most accurate results when the fish have returned from spawning, and are widely dispersed within each home ground for feeding. Hoki are winter spawners and begin to migrate towards their spawning grounds in mid to late May, and do not return to the home grounds until mid-late October (Livingston et al. 1997). Most hoki trawl surveys have therefore taken place during summer. On the Chatham Rise there have been 11 annual surveys during January, from 1992 to 2002. Changing research requirements in the Sub-Antarctic resulted in three annual surveys during December from 1991 to 1993, and then two more in 2000 and 2001. In between, two surveys to primarily estimate hake abundance, but sampling the same depths as hoki surveys, were carried out in March (1996) and April (1998). Because of the seven-year break within the December time series from the Sub-Antarctic we have included these two autumn surveys of the Sub-Antarctic to improve continuity in the Sub-Antarctic time series, and we have assumed that spawning migrations out of the area had not yet begun (Livingston et al. 1997).

Hoki are not caught in abundance on their spawning grounds outside the spawning season. Further, commercial catches outside the survey areas during the non-spawning season are generally low (Bull \& Livingston 2002). The dispersed summer populations on the Chatham Rise and Sub-Antarctic are therefore believed to represent together a large proportion of the hoki population in the EEZ. As well as documenting changes within in each survey area, we wanted to determine the overall changes seen in the EEZ. To do this, we used pairs of surveys carried out in the same season between the Chatham Rise and the Sub-Antarctic areas and summed the data, assuming no difference in catchability. The Sub-Antarctic surveys in December and the Chatham Rise surveys which followed in January, provided 5 pairs of surveys that could be summed (Table 1). However, we also used the March/April surveys of the SubAntarctic in 1996 and 1998 and paired them with January surveys in 1996 and 1998 respectively to obtain 2 more survey pairs.

To infer movement of fish in or out of an area, be it spawning migrations or recruitment of new fish into home ground stocks, seasonal surveys are required. The only time series designed to monitor seasonal changes in hoki populations has been conducted in the Sub-Antarctic. These took place in December 1991, April-May 1992, September 1992, December 1992, May 1993 and December 1993. The April/May surveys were conducted later than those in 1996 or 1998, and pinpointed the timing of the spawning migration out of the area in late May (Livingston et al. 1997). We used this seasonal time series to try and ascertain the season in which new fish recruit into this stock.

This study therefore used data from four sets of Tangaroa trawl surveys as follows, and summarised in Table 1:

1. A time series of 11 annual surveys on the Chatham Rise January 1992-2002.

These were analysed to determine the age at which juvenile abundance peaked, and the rate at which numbers at age declined relative to expected rates of decline (i.e., natural mortality) to determine the age at which dispersal elsewhere began.
2. A time series of 7 surveys in the Sub-Antarctic areas in December 1991-December 1993, March 1996, April 1998 and December 2000-2001.

These were analysed to determine the age structure of hoki in the area compared with the Chatham Rise, and the rate at which numbers of hoki increased relative to current estimates of natural mortality as they reached a mature size.
3. A time series of 7 paired surveys from the Chatham Rise (C.R.) and Sub-Antarctic (S.A.) December 1991 (S.A.) with January 1992 (C.R.), December 1992 (S.A.) with January 1993 (C.R.), December 1993 (S.A.) with January 1994 (C.R.), January 1996 (C.R.) with March 1996 (S.A.), January 1998 (C.R.) with April 1998 (S.A.), December 2000 (S.A.) with January 2001 (C.R.), December 2001 (S.A.) with January 2002 (C.R.).

These were summed as snapshot EEZ abundance at a time of year when hoki are at their most dispersed, to determine how numbers of fish at age in each area changed relative to each other.
4. A seasonal time series of surveys from the Sub-Antarctic carried out December 1991, May 1992, September 1992, December 1992, May 1993 and December 1993.

These were analysed for indicators of the timing of hoki movement into the Sub-Antarctic.

Each time series was analysed for trends in biomass, changes in numbers and proportions of hoki at age, and mean lengths at age within the context of current beliefs about the life history of hoki and stock migration. Instantaneous rates of change were calculated as indicators of how numbers of fish in each year class changed compared with what would be expected from mean estimates of natural mortality used for stock assessment (Annala et al. 2002).

To further examine hypotheses about the dispersion of 0 and 1 year old hoki to the Chatham Rise nursery ground, and also the movement of older hoki to areas other than deep water on the Chatham Rise or south to the Sub-Antarctic, survey data from other areas of New Zealand were analysed. Several time series of surveys have been conducted in inshore areas of New Zealand using Kaharoa and Tangaroa (Table 2). These surveys have fewer data points and cover relatively small areas compared with the home-ground surveys, and generally do not cover the full depth range of hoki (Table 2). Further, although consistent sampling gear was used within each series, the gear type differed between time series. Our analyses were therefore limited to describing the occurrence of hoki of different ages (inferred from length data) in these areas compared with the Chatham Rise and Sub-Antarctic home grounds.

### 10.2 Chatham Rise and Sub-Antarctic survey methodology

A stratified random sampling design (Francis 1989) was used in all surveys to sample the hoki population from $200-800 \mathrm{~m}$ depths on the Chatham Rise, and $300-800 \mathrm{~m}$ depths in the Sub-Antarctic (including Puysegur Bank, the Stewart and Snares Island shelf, the Auckland Islands shelf, the Campbell Island shelf, Pukaki Rise and the Campbell Plateau, see Figure 1). R.V. Tangaroa, with an 8 -seam winged bottom trawl net ( 60 mm mesh cod-end) was used for each survey. Following gear trials to optimise performance for sampling hoki, the gear was standardised and a consistent deployment procedure followed throughout each survey (Hurst et al. 1992). Both survey areas were subdivided into strata based on depth intervals and area, and tow positions were determined using a random generation program. Stratum details and number of tows in each survey are given in Table 1. On the Chatham Rise, station allocation was optimised for 2 -year-old hoki to improve sampling efficiency while maintaining low coefficients of variation (c.v.s).

The catch from each tow was sorted and weighed by species, and sub-sampled to obtain data on size distribution and sex ratios, according to the procedures outlined by Hurst et al. (1992).

### 10.3 Biomass estimation and numbers of hoki

Doorspread estimates of relative biomass and total population numbers of hoki were estimated using the area-swept method of Francis (1984, 1989). Calculations were done with the Trawlsurvey Analysis Program described by Vignaux (1994), assuming a value of 1.0 for vertical and areal availability, and vulnerability. Relative biomass data are presented as totals for each area, and also as sub-totals of 1 year olds (1+), 2 year olds (2+) and fish 3 years and older (3++). This was done by visually defining length
ranges of each age class from length frequency histograms. Since length modes of hoki 3 years and older merge, the biomass of age classes older than 2 years were not estimated. To track the relative abundance of individual year classes, estimates of numbers at age from otolith readings and age length keys for hoki were used.

Sub-samples from each survey were aged by the method described by Horn and Sullivan (1996). These data were also used to develop age-length keys. Where there were no fish in the sample of a given length, the age-length key was interpolated using nearby values of age. Numbers at age are presented for each year class up to 9 years, and as a plus group for fish aged 10 years and over (10+). The c.v.s presented combine both the error derived from the abundance estimates using the Trawlsurvey Analysis Program, and the ageing error.

The Chatham Rise and Sub-Antarctic time series were used to investigate the age at which hoki migrate from the Chatham Rise to the Sub-Antarctic. The seasonal time series was examined for signals on spawning migrations, and recruitment of mature-size hoki into the area.

All biomass estimates and numbers at age are relative, not absolute.

### 10.4 Length at age

We analysed individual cohort data to obtain length of fish at a true age in years, with the birthday of hoki set at $31^{\text {st }}$ July. For example, assuming that hoki reach age 1 on the $31^{\text {st }}$ of July, a $1+$ fish on the Chatham Rise in the following January has an age of 1 year 5 months. A GAM model (Hastie \& Tibshirani 1990) was fitted to the mean-length-at-age data using forward stepwise selection, with an F-test of residual deviance with an alpha level of 0.01 , and a formula:
$\log ($ mean length $) \sim$ lo(age,sex $)+$ area + year class
where lo is a loess smoother with a span of 0.5.

## 10.5 instantaneous rates of change in numbers of hoki by cohort

To infer deviation from expected changes in the abundance of a given year class over time, we wanted to compare observed change with total mortality (within this study, it was not possible to separate natural mortality from fishing mortality). To track changes in numbers of hoki within cohorts, we took natural logarithms of the change in the numbers of a given year class from year to year to estimate an instantaneous rate of change in the relative numbers of hoki within a given cohort. As with estimates of mortality, a negative value shows increasing numbers of fish between one year and the next, while a positive value shows decreasing numbers of fish. Annual estimates of instantaneous rates of change are presented by age for both areas separately and combined. When more than 12 months occurred between surveys (e.g., December 1993 to March 1996), we adjusted the calculation procedure accordingly.

### 10.6 Inshore survey methodology

Like the home ground trawl surveys, inshore surveys by both Tangaroa and Kaharoa have generally followed a stratified random design, however, depths sampled and the gear deployed varies widely between time series and the references given in Table 2 should be referred to for details. Generally, hoki were not sexed on Kaharoa surveys, and relatively few fish were measured, as hoki were not the species of interest in these surveys. Biomass estimation followed the same procedures described above. Length frequencies from Kaharoa surveys are presented as number of fish measured and scaled to catch, but from the Tangaroa Southland series, they are presented as population estimates.

## 11. Results

### 11.1 Chatham Rise abundance and age structure

January trawl surveys of the Chatham Rise confirm that the area is still the most important area for juvenile hoki, generally 1-3 years old (i.e., less than 65 cm total length) although when there has been poor recruitment and juvenile fish have weak year class strength, there are years where older fish predominate, e.g., surveys in 1992 and 2001 (Figures 5a, 5b). There has been a steady decline in the relative biomass of hoki (total and 3++) since 1993, apart from a small increase in 1996 and 1997 (Table 3a). Strong year classes spawned in 1987, 1988, and 1991-1994 show as large modal peaks in the length frequency histograms (Figures 5a, 5b) and in the numbers at age data (Figure 5c), but relatively weak to moderate recruitment in the intervening years has contributed to the overall decline.

The population estimates of numbers of hoki in age classes 1 to 9 years, and a plus group of fish age 10 years and over, provide a more detailed overview of how the numbers of hoki on the Chatham Rise decline with age (Table 4a). A plot of the data in Table 4a shows that the strong 1987 and 1988 year classes apparent as 3 and 4 year old fish in January 1992 can be tracked in each successive year until they reach the plus group (Figure 5c). Other relatively strong year classes such as the 1991-1994 group do not, however, sustain such high numbers, having all but disappeared from the Chatham Rise by age 5 (Figure 5c). This suggests that although the 1991-1994 year class are the strongest year classes in the Chatham Rise trawl survey series at ages 1 and 2 years, the 1987 and 1988 year classes may have been much stronger at that age. The changes in relative biomass and also numbers of fish at age from $1+$ to $2+$ were not consistent. The relative biomass of $2+$ hoki for a given year class was usually greater than that of $1+$ because of growth (Table 3a), however, numbers at age data show that some year classes were at there greatest number at age 1 (e.g., year classes age 1 in 1992, 1993, 1995, 1996, 1999, 2000) while others were highest at age 2 (e.g., 1994, 1997, 1998, 2001), (compare rows at age 1 and 2 of Table 4a; note that year classes track diagonally across the table). The variance associated with estimating the abundance of $1+$ hoki is invariably high (generally $20-30 \%$ ). The variability in catch rates which lead to high c.v.s is believed to reflect the schooling and pelagic behaviour of $1+$ hoki, while $2+$ hoki are more widely dispersed and have adopted a more demersal lifestyle. The instantaneous rate of change between $1+$ and $2+$ fish ranged from a large decline ( 0.77 ) to a large increase $(-0.75)$, however the mean rate was 0.04 , suggesting that on average, the rate of decline was much lower than mean natural mortality, and much lower than might be expected for such young fish (see Tables 10, 11). The low instantaneous rates of change may reflect ongoing movement of hoki on to the Chatham Rise from age 1 to age 2 , or movement to a demersal lifestyle (and therefore availability to the trawl), or increased selectivity because the fish escape through the meshes less as they become larger.

### 11.2 Sub-Antarctic abundance and age structure

Trawl surveys of the Sub-Antarctic confirm that the area is generally dominated by adult hoki at least 4 years old (i.e. more than 65 cm total length) although younger fish occur in some years (Figures 6a, 6b). The total biomass of hoki and the biomass of 3++ hoki peaked in December 1993, but have both declined steadily since (see Tables 3b, 4b). The strong 1987 year class identified at age 4on the Chatham Rise in January 1992 was also present in significant numbers in the Sub-Antarctic at age 4 in December 1991 (Figure 6c) and declined thereafter. The 1988 year class increased steadily in the Sub-Antarctic from age 3 through to age 5 before starting to decline (Figure 6c). The relatively strong 1991-1994 year classes were present as 2 and 3 year old fish in some surveys, particularly March 1996 (Figure 6c). Nevertheless, the number and proportion of young fish in the Sub-Antarctic was low compared with the Chatham Rise (Figures 7, 8). The 1992 year class was as strong at age 8 (December 2001) as the 1987 year class at age 8 in March 1996. Relatively weak to moderate recruitment since 1994 may have contributed to the overall decline in hoki abundance in the Sub-Antarctic.

The numbers of hoki aged 1-3 years were very low, but when present, the instantaneous rate of change between $1+$ and $2+$ fish ranged from a large decline (1.5) to a large increase ( -1.6 ), with a mean of -0.08 , (see Tables 12, 13). The low numbers of young fish and low instantaneous rates of change may reflect movement of hoki through to the Chatham Rise from age 1 to age 2.

### 11.3 Evidence for movement from the Chatham Rise to the Sub-Antarctic

Total hoki biomass on the Chatham Rise is considerably higher than in the Sub-Antarctic, in part because of the large number of $1+$ and $2+$ hoki in the population At age 3 and over, the biomass on the Chatham Rise is still relatively higher than in the Sub-Antarctic (Tables 3a, 3b). It is not until hoki reach age 8 or more that the numbers in the Sub-Antarctic exceeds that of the Chatham Rise (Tables 4a, 4b).

A summary of the numbers at age data from seven pairs of back to back surveys into population estimates of juvenile hoki ( $1-2$ years old), maturing hoki (3-7 years old) and adult hoki (8 years and older), shows how the relative proportions of different age-groups change in each area, as well as the overall decline in numbers with age group (Table 5 \& Figure 7). Proportionally, 80 to $100 \%$ of fish aged 1-2 years are located on the Chatham Rise, but this drops to about $60 \%$ of fish aged 3-7 years (Figure 8). Of fish aged 8 years or more, about $70 \%$ are found on the Sub-Antarctic, indicating a higher abundance of mature size hoki in the Sub-Antarctic than on the Chatham Rise.

A plot of the mean numbers at age from the paired surveys shows how juveniles are clearly present and caught by Tangaroa gear on the Chatham Rise in large numbers from age 1 to 4 , whereas they are caught in very low numbers in the Sub-Antarctic using the same gear (Figure 9, top panel). If we simply sum the numbers of fish at age from the Chatham Rise and the Sub-Antarctic (Table 6), and then express the data as proportion of each age class on the Chatham Rise out of the total, (Table 7), the age at which both male and female hoki become less than $50 \%$ on the Chatham Rise, and more than $50 \%$ on the Sub-Antarctic is between 5 and 6 years. Figure 10 also shows that there is a steep decline in the numbers of fish at age on the Chatham Rise to age 6 , which then levels off, while in the Sub-Antarctic, the number of fish increases slowly to age 8 for females, and age 5 for males before a decline in numbers is seen. Separating the mean values by sex, and plotting them as proportions, the crossover point at which the proportion of fish in the Sub-Antarctic is more than $50 \%$ is at about 6 years old for both male and female hoki (Figure 9; lower panels). The switch from Chatham Rise to the Sub-Antarctic seems to begin at about age 4 and continues until at least age 8 (Figure 9, lower panels). Both sexes follow the same patterns, although there is a slight indication that proportionally more males at age 4 appear in the Sub-Antarctic than females.

### 11.4. Instantaneous rates of change in the numbers of hoki compared with estimates of natural mortality

The age at which greatest change in estimated numbers at age of individual year classes occurs in both areas varied among individual year classes (Figure 10). The 1987 year class was most abundant in the Sub-Antarctic at age 4, Dec 1991 whereas the 1988 year class was most abundant at age 5, Dec 1993, (Tables 8,9). The decline in numbers of both these year classes between age 1 and 2 is unknown because the Tangaroa time series did not begin until December 1991, however, on the Chatham Rise their rate of decline is rapid from age 4 to age 6 (Figure 11). Later year classes such as the 1991 year class show a steep decline from age 1 to age 2 and again to age 3, whereas the 1992 and 1994 year classes show their steepest decline at ages 3 and 4 on the Chatham Rise (Figure 11).

If we compare the total abundance of the strong 1987 and 1988 pair of year classes with the 1991 and 1992 pair of year classes, we see that at ages 3 and 4, the $1987 / 1988$ pair totalled about 160 million respectively, and while the 1991/1992 pair totalled about 153 million (Figure 12). Within 2 years, the 1987/1888 pair declined to about 78 million, whereas the 1991/1992 pair had declined much more rapidly to 38 million (Figure 12).

The instantaneous rates of change in numbers of hoki by year class on the Chatham Rise show high annual values from 2 year olds through to the older plus groups (Tables 10, 11). Female decline rates are lower than males, but both are about twice the natural mortality rates estimated for hoki in the stock assessment model. In the Sub-Antarctic, the numbers of fish within each cohort give rise to instantaneous rates of change that are either negative or very low (Tables 12,13 ) and do not reach anything close to the estimated natural mortality until age 8 or 9 years in females, and 5 or 6 years in males.

These observations lead us to suspect that in addition to natural mortality and fishing mortality, there is also movement of hoki off the Chatham Rise from age 2 to age 8, and an influx of hoki to the SubAntarctic during these years.

The instantaneous rates of change between years for the two areas combined give the rates of decline much closer to the estimates of mortality for hoki (Tables 14, 15). Ignoring the changes from ages 1 to 3 years (as hoki may not be fully selected in this size range), the rates of decline among females and males is high until about age 5 or 6 , but thereafter, males maintain a high rate of decline whereas the rate lessens for females (Tables 14, 15). Between ages 5 and 9 years, the curves for males and females follow a ' $U$ ' shape with increasing mortality as the fish reach 9 years (Figure 12).

There is some variability in the rate of decline of individual year classes on the Chatham Rise, and their subsequent increase on the Sub-Antarctic. Some year classes declined significantly from their third year while others show a large decline from age 4 onwards (see Tables 9,10 ). It is not clear that that males decline at a faster rate than females, although their initial appearance in spawning fisheries and to some extent in the Sub-Antarctic does occur a year earlier than females.

Patterns of change on the Sub-Antarctic were less clear than on the Chatham Rise. Some year classes seemed to increase in number between years while others decreased (Tables 12, 13). Instantaneous rates of change within individual year classes however showed a net gain in the numbers of fish, particularly age 4 to 5 among females and 3 to 4 among males (see Table 6). The increase in numbers did not match the decline in numbers on the Chatham Rise.

The instantaneous rates of change within individual year classes from back to back surveys again varied among individual year classes (Tables 14, 15). Among males and females, this was highly variable from year to year, showing positive values in some years and negative in others (Tables 14, 15). Between age 2 and 3, mean change was almost zero for males and negative for females, but once again highly variable from year to year (Tables 14, 15). Mean rates of change for hoki age 3 to 7 years, i.e. those hoki best sampled by the trawl, were 0.44 for males and 0.36 for females (Tables 14, 15). Mean changes over the full age range were 0.35 for males and 0.23 for females.

### 11.5 Seasonal changes in the Sub-Antarctic

### 11.5.1 Spawning migrations

The length frequency histograms from the seasonal time series have a small juvenile component (less than 65 cm total length) and a dominant component among mature sized fish (over 65 cm total length, Figures 13a, 13b). The numbers of mature sized fish diminishes on the left-hand limb between December 1991 and April 1992, and then both limbs decline substantially between April and September 1992 (Figures 13a, 13b). The numbers of fish at age given in Table 16, and in Figure 13c, show that between December 1991 and April 1992, it is mostly 3-4 year old fish that diminished, not the older fish, whereas by September the decline was across all age classes. Numbers of fish in all age classes had increased again by December 1992 (Figure 13c). The second sequence from December 1992 to May-June 1993, however shows a drop in fish numbers across all age classes 4 to 10+, increasing again in December 1993 (Figure 13c). This pattern suggests that the younger fish (3-6 years) begin to move away from the area to spawn before mid-April, while older fish 7 years and over, begin to move later in May. The sequence also suggests that hoki continue to leave after April-May and although spawning activity on the west coast South Island
has largely ceased by September, the low numbers of fish present during September in the SubAntarctic indicate that few fish have returned by that time (Figure 13c).

Significant declines in fish numbers were observed between December 1991 and May 1992, May 1992 and September 1992, and December 1992 and May 1993 (Table 16, Figure 13). The losses between December and May coincide with the time of departure (late May) for the spawning grounds. Increases in numbers of fish that may reflect hoki recruitment to the Sub-Antarctic were only seen for the 1988, and 1989 year classes (Table 16). Other increases over and above returning spawners were apparent for the 1986, 1985, 1984 and 1983 year classes between September and December in 1992, and again in December 1993 (Figure 13c). No particular time period when recruitment to the Sub-Antarctic occurs stood out from the present data set.

### 11.3.2 Recruitment to the Sub-Antarctic

If we compare the juvenile modes ( 1 and 2 year olds) within the seasonal sequence of surveys 1991-93, there are a small number of 1 year old fish (1990 year class) evident in December 1991 and April 1992 which do not increase in subsequent surveys. The 1991 year class, can however be seen even as $0+$ fish (just under 30 cm total length) as unsexed fish in April 1992 (Figure 13a), and in increasing numbers right through to December 1993 as 2 year olds in both sexes (Figures 13a, 13b). Although this increase could be interpreted as evidence of movement of the 1991 year class into the area, it is possible that these fish remained in the Sub-Antarctic, recruiting directly from the west coast or Puysegur spawning grounds, and are showing an increase as a result of increased availability to the trawl gear. There is little increase in the 1991 year class between May-June 1993 and December 1993. Age 2 and 3 year old hoki were often absent or present in low numbers irrespective of season. The increase in numbers of the 1988 year class at 4 years old between December 1992 and December 1993 (Figure 13c) is more likely to be a result of movement of hoki into the area, as fish of this age are already fully selected by the Tangaroa trawl gear, however, the data give little information on which part of the year fish undergo the migration. It is not clear whether these fish move directly from the Chatham Rise, or if they move via the spawning grounds. There was quite an increase in the number of male 1988 year class hoki on the west coast between the spawning seasons of 1992 and 1993 (see Figure 4a), so it is possible that recruitment to the adult stock occurs via the spawning grounds.

### 11.6 Growth rates of hoki

Plots of the mean length at age (to the nearest month) for year classes 1982-1996 shows that SubAntarctic hoki are consistently larger than Chatham Rise hoki from age 5 on (Figure 14). A plot of mean fish length relative to the 1982 year class shows an increasing trend in fish size over the 1982-1997 year classes (Figure 15). Although the overall difference is less than $10 \%$ over the 15 year period, if it continues, there may be an effect on the age of movement to home grounds, and of first spawning.

An arbitrary growth curve has been fitted for each sex and modified by applying a multiplicative area effect i.e. fish taken in the Sub-Antarctic have a mean length approximately $9 \%$ more than those taken on the Chatham Rise, at a given age and sex. There is also a multiplicative year class effect, i.e. fish of the 1991 year class have a mean length approximately $7 \%$ higher than the 1982 year class, for a given sex and area.

There was no statistically significant evidence for multiplicative area effects between ages or sexes, or year class effects differing between areas, ages, or sexes. This analysis adds little to our understanding about migration.

### 11.7 Catch rates by depth and area

The mean catch rates of hoki declined with increasing depths, on the Chatham Rise. From 200 to 400 m , catch rates were quite variable as these depths are most influenced by the relative abundance of 1 and 2 year old fish (Table 17). The steepest declines in catch rates in the 2 deeper zones ( $400-600$ and $600-$ 800 m ) occurred from 1997 to 2000 , with some indication of a flattening out of the decline in the most recent years (Figure 16). Catch rates in the Sub-Antarctic were generally lower than the Chatham Rise within equivalent depth zones, and show a decline since 1996 (Figure 16, Table 17).

A plot of mean catch rate per tow from all surveys combined shows that catch rates on the Chatham Rise are highest in $300-550 \mathrm{~m}$ depths, while in the Sub-Antarctic they are highest in $400-700 \mathrm{~m}$ depths (Figure 17). Catch rates of $1+$ and $2+$ hoki are greatest in the shallower depth zones on the Chatham Rise, and vary with year class strength (Figure 18a). Catch rates of $3++$ hoki have declined at all depths within the time series (Figure 18a). Catch rates of $1+$ and $2+$ hoki in the Sub-Antarctic are 2 orders of magnitude lower than on the Chatham Rise (Figure 18b). Catch rates of $3++$ hoki in the Sub-Antarctic have declined in recent years, and are only slightly lower than catch rates on the Chatham Rise (Figures 18a, 18b). The mean length of hoki increases with depth from 350 m to 800 m on the Chatham Rise (Figure 19). Smaller fish tend to occur in shallower water in the Sub-Antarctic as well, but there is little overall change in fish length with depth in the Sub-Antarctic (Figure 19).

### 11.8 Inshore surveys and the distribution of 0-1 year old hoki

Biomass estimates of hoki from inshore trawl surveys were substantially lower than the Chatham Rise or Sub-Antarctic (compare Tables 3 \& 18). Even the Southland surveys which overlap with the SubAntarctic surveys in depths of $300-600 \mathrm{~m}$ at Puysegur and around the edge of the Stewart and Snares Island Shelf, had relatively low hoki biomass (mean 10697 t , Table 18). The lowest biomass was in the March-April series in Tasman and Golden Bays (Table 18) where small amounts of $0+$ hoki were found (Table 19). The May-June east coast South Island series also had a low hoki biomass (mean 233 t ), but in summer yielded much higher estimates (mean 2720 t , Table 18). The difference applied to all age classes. Mature-size fish may have moved to spawning grounds in winter, but the reason for more $1+$ and $2+$ hoki in summer compared with winter is unclear. Collectively, mean hoki biomass from the coastal surveys (excluding Southland and winter east coast South Island) summed to 6112 t , about $3 \%$ of the mean biomass estimated from Chatham Rise and Sub-Antarctic surveys combined (190 218 t ). When Southland surveys were included, mean inshore biomass of hoki increased to about $9 \%$ of the total biomass estimated from Chatham Rise and Sub-Antarctic surveys. Most of the biomass of hoki in Southland was $1+$ fish, and represented about $25 \%$ of the mean biomass of $1+$ hoki on the Chatham Rise over the same time period (i.e., January 1993-96). The mean biomass of 2+ hoki in Southland was only $12 \%$ of $2+$ biomass on the Chatham Rise over the same time period.
$0+$ hoki were not found in quantity anywhere except the west coast South Island (Table 19). This is partly because the fish are pelagic and are not well sampled by bottom trawl gear. Very small amounts of $0+$ fish were seen in surveys of Tasman and Golden Bays, and the east coast North Island (Table 19). $1+$ hoki are relatively pelagic, but were caught in larger quantities by the bottom trawl in Southland and summer surveys of the east coast South Island (Table 19). Some were also caught off the west coast South Island, but in less quantity than $0+$ hoki. Very small amounts of $1+$ hoki were caught off the east coast North Island. 2+ hoki were caught during Southland and east coast South Island surveys, and very small amounts are caught off the east coast North Island (Table 19). Biomass estimates of $2+$ hoki were lower than estimates for $1+$ hoki in 1993 and 1994 Southland surveys (Table 19). Hoki aged 3 years and over were caught in all inshore surveys except Tasman and Golden Bays. The mean biomass of $3++$ hoki from all inshore surveys combined was less than $1 \%$ of the mean biomass of $3++$ hoki from the home ground surveys.

The inshore surveys used bottom sampling gear, which is not ideal for estimating the biomass of $0+$ and $1+$ hoki that occur mostly up in the water column. Coefficients of variation were high for these age classes, and relative abundance will have been considerably underestimated. Further, the full
depth range of hoki was not sampled and may have underestimated the abundance of larger hoki that are bottom orientated. Larger hoki, over 70 cm total length, have been typically found in deepwater surveys ( $400-1200 \mathrm{~m}$ ) around most of the North Island (Clark \& King 1989, Livingston \& Stevens 2002), and also off the east coast of the South Island (Figures 20-22).

Length frequency histograms from the inshore surveys confirm that $0+$ fish ( $15-30 \mathrm{~cm}$ ) typically occurred off the south east coast of the North Island ( $20-400 \mathrm{~m}$ ), in Tasman Bay and Golden Bay ( $20-60 \mathrm{~m}$ ), and off the west coast of the South Island ( $20-400 \mathrm{~m}$; Figures. 20-22). Juvenile hoki $1+$ $3+$ were typically caught off the east coast of the South Island, ( $30-400 \mathrm{~m}$ ), off Southland ( $30-$ $600 \mathrm{~m})$, the north east coast of the North Island ( $200-600 \mathrm{~m}$ ) and the south east coast of the North Island ( $200-600 \mathrm{~m}$ ).

When plotted sequentially within years, it was possible to identify matching length modes for specific year classes between surveys, in spite of the differences in gear used. Surveys during 1994 clearly show the presence of $1+$ and $2+$ hoki, i.e. the 1992 and 1991 year classes on the Chatham Rise, off Southland and the south east coast of the North Island (Figure 20). The $0+$ year class spawned in 1993 is also evident off the south east coast of the North Island, the west coast of the South Island and in Tasman and Golden Bays (Figure 20). Surveys from 1995 show a strong presence of $1+$ and $2+$ fish on the Chatham Rise and Southland, and to a limited extent off the south and north east coasts of the North Island (Figure 21). 0+ hoki show up strongly on the WCSI, Tasman and Golden Bays and in surveys of the south east coast of the North Island. Of interest is an additional, small modal peak at about 25 cm total length seen off the east coast of the North Island. This may represent successful spawning at both the beginning and end of the spawning season, resulting in a bimodal distribution for the 1994 year class. Surveys from 1996 also show the presence of the 1995 year class as $0+$ fish off the east coast South Island in May, and again in December as $1+$ (Figure 22).

The inshore surveys show that $0+$ hoki move away from spawning grounds to reach Southland, the Chatham Rise, east coast South Island and east coast North Island by age $1+$. The relative abundance of $1+$ hoki in these areas suggest that while the majority reached the Chatham Rise at age 1+, a portion (average $25 \%$ ) reached the Southland area. By age $2+$, this had dropped to $11 \%$, suggesting that either offshore movement outside the Southland area, or even to the Chatham.Rise had occurred. Since very few 2+ hoki were recorded in Sub-Antarctic surveys, and the instantaneous rate of change in numbers of hoki between age $1+$ and $2+$ on the Chatham Rise were indicative of net increase to the area, it is possible that some of the hoki seen as $1+$ fish in the Southland areas moved to the Chatham Rise by age $2+$.

## 12. Discussion

The biomass of hoki estimated from summer time series of the Chatham Rise and Sub-Antarctic declined by at least $50 \%$ in both areas since trawl surveys with Tangaroa were initiated (Tables 3a, 3b). There has been a steady increase in the annual catch of hoki on the Chatham Rise, from about 12500 t in 1991-92 to 74000 t by 1997-98 (Annala et al. 2002). In all, an estimated catch of 519000 t of hoki have been caught on the Chatham Rise within the period of the survey series. There has also been a steady annual catch of hoki from the Sub-Antarctic within the survey time period, totalling 234500 t from 1991-92 to 2000-01 (Annala et al. 2002).

Biomass levels of $1+$ and $2+$ hoki are much higher on the Chatham Rise than the Sub-Antarctic, although fluctuations in year class strength cause wide variations in biomass of these juveniles (Tables 3a, 3b). The biomass of $3++$ (i.e. all hoki aged 3 years or older) hoki is quite similar between the two areas, but the age structure is quite different (Tables $4 \mathrm{a}, 4 \mathrm{~b}$ ). As a proportion, $80 \%$ of hoki aged $1-2$ years are found on the Chatham Rise, and just $20 \%$ in the Sub-Antarctic. For hoki aged 3-7 years, $60-80 \%$ are still found on the Chatham Rise, and it is only among fish aged 8 years or more that there is a major change, with only 20$30 \%$ found on the Chatham Rise and $70-80 \%$ found in the Sub-Antarctic (Table 5 \& Figure 8). The numbers of hoki on the Chatham Rise drops steadily from age 1 to 6 , levelling off thereafter, whereas in the Sub-Antarctic, numbers of hoki increase slightly up to age 5 , declining thereafter among males, but
continuing to increase slightly among females (Figure 9, top panel). The age at which the $50 \%$ swap-over occurs between areas is from 5 to 6 years old for both male and female hoki (Figure 9 bottom 2 panels). The average age at which the change occurs is similar for both sexes, although at age 4 , relatively more males appear to be already in the Sub-Antarctic compared with females (Figure 9, compare middle and lower panels).

Instantaneous rates of change in numbers of age within year classes were high on the Chatham Rise, indicating a rapid rate of decline from age 2 on (Tables $10 \& 11$ ), whereas in the Sub-Antarctic they were low or even negative, indicating an increase in numbers of fish from year to year until age 5 (males) and age 8 (females), (Tables $12 \& 13$ ). When back to back pairs of surveys were added, mean instantaneous rates of change for year classes aged 3-7 years were quite close to estimates of mortality for hoki ( 0.35 males, 0.28 females, Annala et al. 2002), (Tables 14 \& 15).

The seasonal series of surveys carried out Dec 1991 to Dec 1993 provide support for movement in and out of the Sub-Antarctic in relation to spawning, but they provide insufficient information in the series about the timing of any new arrivals into the Sub-Antarctic. There are no seasonal data available from the Chatham Rise from Tangaroa surveys, but early work from the Wesermünde and Shinkai Maru suggested a build up of hoki at the western end of the Chatham Rise during March-April (Kerstan \& Sahrhage 1980, Kuruwa 1985). At the time of that research, it was assumed that this related to spawning migrations to the west coast South Island as spawning in Cook Strait had not yet been discovered (Livingston 1990a). It is possible and likely that such a build up is related to both spawning and recruitment to other areas, but the data are insufficient to determine destinations or arrival times. The sequential partitioning of time steps in the hoki stock assessment model currently has movement of hoki from the Chatham Rise nursery to the Sub-Antarctic western home ground at the same time as spawning migrations to both Cook Strait and the west coast South Island from April to June (Annala et al. 2002). The results from this study do not result in any adjustment to this time step.

While migration of hoki from the Chatham Rise to the Sub-Antarctic to form the western stock as they reach maturity is our best interpretation of the data presented, we considered alternative scenarios that could give rise to similar observations:

Scenario 1. The catchability of hoki in all trawl surveys is extremely low ( $<0.01 \%$ ):
This could render any observed changes or trends as unreliable indicators about the age distribution of hoki in the two areas.

We believe that this is unlikely because there is little acoustic evidence for large numbers of hoki, aged 2-13 years, in mid-water on the Chatham Rise. (O'Driscoll 2002).

Scenario 2. The selectivity of hoki differs between the Chatham Rise and the Sub-Antarctic:
If juvenile hoki on the Chatham Rise were more vulnerable to Tangaroa nets than in the SubAntarctic, they would be substantially underestimated in the Sub-Antarctic. If vulnerability decreased with age on the Chatham Rise, but increased in the Sub-Antarctic, the different rates of change seen across all age groups in the two areas can be explained without movement between the two areas.

We believe that this is unlikely because strong year classes seen as 1 and 2 year olds in the surveys track into the commercial catches in both survey areas and in the spawning fisheries (O'Driscoll et al. 2002). The correlation between the abundance of a year class as 1 year olds, and the same year class in the following year as 2 year olds, is also very high (Francis et al. in press). Further, observed numbers at age of hoki from trawl surveys are not inconsistent with model estimates of expected in trawl surveys (Figure 23).

It is unlikely that the trawl selectivity in one area would be the exact opposite of the other if the same sampling tool were used in both areas. Juvenile hoki are occasionally caught at Puysegur and around the edge of the Stewart and Snares shelf during Sub-Antarctic surveys, showing that they are vulnerable to the gear in these areas. It is possible that the efficiency of the trawl at catching larger hoki may not be as high as for younger fish recruited to the bottom ( 2 years and older), but the same trends in efficiency would be expected, rather than opposite ones.

Scenario 3. The Chatham Rise and the Sub-Antarctic represent a small proportion of the total hoki stock: If hoki occur in abundance outside these survey areas, then the surveys may represent anomalous changes in the distribution and abundance of fish from year to year. For example, if the population of juvenile hoki in inshore areas of New Zealand, or offshore in mid-wateris very large compared to the Chatham Rise, then numbers on the Chatham Rise may not be representative of the stock. Further, if the majority of hoki move offshore into mid-water as they mature, rather than to demersal habitats in depths of $400-800 \mathrm{~m}$, then the trawl survey biomass estimates of mature-sized fish may be non-representative of the population as a whole.

We know from deep water trawl surveys, and commercial catches that hoki do occur outside the survey areas (Bull \& Livingston 2000). While this means that the surveys on the Chatham Rise and SubAntarctic underestimate the relative stock sizes of hoki, the catches in other areas are low and are not indicative of a large unexploited population. The proportion of the total stock distributed outside the survey areas is the key here.

The numbers of $1+$ and $2+$ hoki on the Chatham Rise were overwhelmingly high compared with estimates from inshore surveys, but again, populations in these areas are probably underestimated. There are also many areas of the EEZ that have not been surveyed. For example, Fiordland has never been surveyed for juvenile hoki, yet land-based seabirds such as penguins and shags in Fiordland and Stewart Island are reported to feed extensively on $0+$ hoki. Further offshore in mid-water, there have been anecdotal reports of hoki catches before and after spawning migrations, and there is evidence of hoki as a small bycatch of the tuna boats which operate over depths of $2000-4000 \mathrm{~m}$ off Puysegur and over the Bounty Trough (Bull \& Livingston 2000). Recent anecdotal reports indicate that commercial vessels have also located ripening hoki along the narrow shelf inshore along the Fiordland coastline, suggesting that some hoki migrate closer to land. Large hoki are also caught in bottom trawls in depths greater than 800 m along the southern edge of the Challenger Plateau, the Campbell Plateau, MacQuarrie Ridge and the Chatham Rise as bycatch in the orange roughy fisheries. Thus far, the biomass of hoki in these deeper areas is estimated to be a small fraction of the total population, but as with the inshore surveys, the sampling gear being used is not designed to catch hoki, and may underestimate hoki biomass in these areas.

The issue of changing catchability with age, between years and perhaps between areas, is probably more important. Without an understanding of how this varies, the interpretation of hoki migration patterns from trawl surveys is potentially weakened. Our view acknowledges that although catchability may be a major source of error, the observed changes in the distribution of hoki at age described in this report provide strong support for the current working hypotheses about the dispersion and migration patterns within the current view of the life-cycle of hoki.

## 13. Conclusions

In conclusion, the trawl survey data presented here provide evidence that juvenile hoki disperse as $0+$ fish from the spawning grounds to reach Southland and the Chathàm Rise by age $1+$. The $1+$ hoki in Southland may move further offshore to the Sub-Antarctic by age $2+$, or may move to the Chatham Rise. Biomass of $2+$ hoki in the Sub-Antarctic is low, and we believe that it is unlikely that a large number of juvenile hoki are present in the Sub-Antarctic area and unavailable to the trawl, when the same vessel and gear can catch them in both areas. The data do however suggest that in some years a small proportion of
juveniles ( 0 and 1 years) may not move to the Chatham Rise nursery grounds at all, for example, the 1991 year class seen as $1+$ fish in December 1992 and again as $2+$ in 1993.

Some year classes begin to move off the Chatham Rise as early as age 2, and appear in the Sub-Antarctic as early as age 3 (Figure 9, top panel). Proportionally, however, most change within the two areas occurs at ages 4-8, although this varies with individual year classes. These data therefore provide strong support for the hypothesis that the Chatham Rise is the main nursery ground for juvenile hoki, and that a large proportion of fish move from the Chatham Rise to the Sub-Antarctic as they reach maturity.

Conclusions regarding migration patterns and the life cycle of hoki are summarised below:

- $0+$ hoki mainly disperse to Southland (25\%) and the Chatham Rise (75\%) by age $1+$. By age $2+$, $84 \%$ of hoki biomass was on the Chatham Rise
- The Chatham Rise is the main nursery ground for hoki age 1-3 years in the EEZ.
- There is a possibility that a proportion of the juvenile hoki at Puysegur (aged 1-2 years) recruit directly to the Sub-Antarctic adult population.
- Instantaneous rates of change in fish numbers age 3-7 years on the Chatham Rise show a decline roughly double that of estimated natural mortality, while in the Sub-Antarctic, they indicate an influx of fish to the area.
- Some year classes appear to leave the Chatham Rise as early as 2 years, but most appear to depart at 4-8 years.
- Although the biomass of hoki on the Chatham Rise, and the number of fish up to age 7 is higher than in the Sub-Antarctic, from age 8 on, the Sub-Antarctic population size is greater than the Chatham Rise population.
- The differences in age structure and changes in numbers of fish at age between the two areas strongly support the current hypothesis that a large proportion of hoki recruit from the Chatham Rise to the Sub-Antarctic between the ages of 3 and 7 years.
- The consistent difference in size at age between the two home grounds supports the hypothesis used in stock assessment, that once recruited, hoki retain fidelity to their adult stocks.
- Growth (length at age) of hoki in both areas has increased by almost $10 \%$ over the time series investigated.
- The timing of recruitment to the Sub-Antarctic could not be determined from the data available, but it is possible that recruitment occurs via the spawning grounds. The spawning migration away from the Sub-Antarctic appears to begin in late May- early June, and the return does not occur until after mid-September-early October.
- Alternative scenarios to explain hoki distribution have little feasibility. However, it is acknowledged that some hoki are dispersed beyond the areas currently surveyed, and this may be worthy of further investigation.
- Catchability and selectivity differences between areas are of concern and need to be determined more accurately to resolve relative population size and age structure in the 2 survey areas.


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Table 1: Survey dates and station numbers (core strata only) from Tangaroa summer and seasonal surveys of the Chatham Rise and Sub-Antarctic, 1991-2002. (-, no survey.)

| Chatham Rise summer series |  |  |  |  |  |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Survey date | Jan | Jan | Jan | Jan | Jan | Jan | Jan | Jan | Jan | Jan | Jan |
|  | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
| No. stations | 184 | 194 | 162 | 122 | 89 | 103 | 91 | 100 | 128 | 119 | 110 |
|  |  |  |  |  |  |  |  |  |  |  |  |
| Sub-Antarctic summer series |  |  |  |  |  |  |  |  |  | Dec | Dec |
| Survey date | Dec | Dec | Dec | - | Mar | - | Apr | - | - | 2000 | 2001 |
|  | 1991 | 1992 | 1993 |  | 1996 |  | 1998 |  |  | 87 | 85 |


| Sub-Antarctic seasonal series |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| Survey date | Dec | May | Sep | Dec | May | Dec |
|  | 1991 | 1992 | 1992 | 1992 | 1993 | 1993 |
| No. stations | 150 | 90 | 95 | 149 | 100 | 130 |

Table 2: List of survey time series that provide hoki length frequency data from inshore areas not covered by the main surveys.
Trip code $\quad$ Survey type
EAST COAST NORTH ISLAND

EAST COAST NORTH ISLAND

| kah9301 | scampi relative biomass series |
| :--- | :--- |
| kah9401 | scampi relative biomass series |
| kah9501 | scampi relative biomass series |
| kah9604 | scampi gear selectivity trials |
|  |  |
| kah9304 | inshore relative biomass series |
| kah9402 | inshore relative biomass series |
| kah9502 | inshore relative biomass series |
| kah9602 | inshore relative biomass series |
| EAST COAST | SOUTH ISLAND |
| kah9105 | inshore relative biomass series |
| kah9205 | inshore relative biomass series |
| kah9306 | inshore relative biomass series |
| kah9406 | inshore relative biomass series |
| kah9606 | inshore relative biomass series |
| kah9618 | inshore relative biomass series |
| kah9704 | inshore relative biomass series |
| kah9809 | inshore relative biomass series |
| kah9917 | inshore relative biomass series |
| SOUTHLAND |  |
| tan9301 | inshore random trawl survey |
| tan9402 | inshore random trawl survey |
| tan9502 | inshore random trawl survey |
| tan9604 | inshore random trawl survey |

Table 3a: Relative biomass estimates ( $t$ in thousands) of hoki in $\mathbf{2 0 0 - 8 0 0} \mathbf{m}$ depths from Chatham Rise trawl surveys listed in Table 1. (c.v, coefficient of variation; 3++ all hoki aged 3 years and older.)

| Survey | 1+hoki |  |  | 2+hoki |  |  | $3++$ hoki |  |  | Total hoki |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\begin{array}{r} 1+\text { year } \\ \text { class } \end{array}$ | t | c. $\mathbf{Y}$ | $\begin{gathered} \hline 2+\text { year } \\ \text { class } \end{gathered}$ | t | c.v | t | c.v | t | c.v |
| Jan-92 | 1990 | 2.8 | (27.9) | 1989 | 1.2 | (18.1) | 116.1 | (7.8) | 120.2 | (9.7) |
| Jan-93 | 1991 | 32.9 | (33.4) | 1990 | 2.6 | (25.1) | 150.1 | (8.9) | 185.6 | (10.3) |
| Jan-94 | 1992 | 14.6 | (20.0) | 1991 | 44.7 | (18.0) | 86.2 | (9.0) | 145.6 | (9.8) |
| Jan-95 | 1993 | 6.6 | (13.0) | 1992 | 44.9 | (11.0) | 69.0 | (9.0) | 120.4 | (7.6) |
| Jan-96 | 1994 | 27.6 | (24.0) | 1993 | 15.0 | (13.0) | 106.6 | (10.0) | 152.8 | (9.8) |
| Jan-97 | 1995 | 3.2 | (40.0) | 1994 | 62.7 | (12.0) | 92.1 | (8.0) | 158.0 | (8.4) |
| Jan-98 | 1996 | 4.5 | (33.0) | 1995 | 6.9 | (18.0) | 75.6 | (11.0) | 86.7 | (10.9) |
| Jan-99 | 1997 | 25.6 | (30.4) | 1996 | 16.5 | (18.9) | 67.0 | (9.9) | 109.3 | (11.6) |
| Jan-00 | 1998 | 14.4 | (32.4) | 1997 | 28.2 | (20.7) | 29.5 | (9.3) | 71.7 | (12.3) |
| Jan-01 | 1999 | 0.4 | (74.6) | 1998 | 24.2 | (17.8) | 35.7 | (9.2) | 60.3 | (9.7) |
| Jan-02 | 2000 | 22.4 | (25.9) | 1999 | 1.2 | (21.2) | 50.7 | (12.3) | 74.4 | (11.4) |

Table 3b: Relative biomass estimates (t in thousands) of hoki in 300-800 m depths from SubAntarctic trawl surveys listed in Table 1. (c.v, coefficient of variation; $3++$ all hoki aged 3 years and older.)

| Survey | 1+ hoki |  |  |  | 2+ hoki |  | 3 ++ hoki |  | Total hoki |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1+ year class | t | c.v | $\begin{array}{r} 2+\text { year } \\ \text { class } \end{array}$ | t | c.v | t | c.v | t | c.v |
| Dec-91 | 1990 | 0.7 | (86.9) | 1989 | 0.2 | (55.9) | 79.4 | (6.6) | 80.3 | (6.8) |
| May-92 | 1990 | 0.8 | (39.4) | 1989 | 1.4 | (13.1) | 65.6 | (8.5) | 67.8 | (8.3) |
| Sep-92 | 1992 | 0.1 | (94.1) | 1991 | 0.007 | (58.2) | 34.1 | (14.2) | 34.3 | (14.2) |
| Dec-92 | 1991 | 0.2 | (66.1) | 1990 | 0.21 | (89.8) | 86.9 | (6.1) | 87.4 | (6.1) |
| May-93 | 1991 | 1.8 | (76.1) | 1990 | 0.198 | (33.4) | 51.4 | (10.4) | 53.5 | (10.5) |
| Dec-93 | 1992 | 1.1 | (97.8) | 1991 | 3.7 | (48.5) | 94.9 | (8.9) | 99.7 | (9.2) |
| Apr-96 | 1994 | 1.7 | (58.1) | 1993 | 3.2 | (41.1) | 85.4 | (9.0) | 90.4 | (9.7) |
| Apr-98 | 1996 | 0.16 | (62.3) | 1995 | 0.55 | (27.4) | 67.1 | (10.8) | 67.8 | (10.7) |
| Dec-00 | 1999 | 0.07 | (98.5) | 1998 | 0.026 | (51.4) | 55.6 | (12.6) | 55.6 | (12.6) |
| Dec-01 | 2000 | 0.23 | (49.1) | 1999 | 0.078 | (45.7) | 37.8 | (15.6) | 38.2 | (16.0) |

Table 4a: Population estimates of numbers of hoki by age class (in millions) from summer surveys of the Chatham Rise 1992-2002. (+indicates a plus group of fish the age given and older.) Note that individual year classes can be tracked diagonally across the table as they increase in age.

Males

|  | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Age |  |  |  |  |  |  |  |  |  |  |  |
| 1 | 6.7 | 87.2 | 45.4 | 17 | 93.8 | 7.7 | 10.9 | 38.1 | 40.2 | 0.7 | 31.4 |
| 2 | 1.8 | 3.1 | 53.6 | 47.9 | 24.6 | 83.5 | 8.4 | 16.6 | 28 | 26.3 | 1.5 |
| 3 | 37.8 | 8.0 | 2.4 | 20 | 40.8 | 9.9 | 34.7 | 11.2 | 3.5 | 9.6 | 9.6 |
| 4 | 22.8 | 35.9 | 4.6 | 2.4 | 8.4 | 12.3 | 4.2 | 19.2 | 1.7 | 0.9 | 10.8 |
| 5 | 3.6 | 20.8 | 16 | 2.8 | 1.2 | 11 | 4.1 | 1.5 | 2.5 | 0.7 | 2.1 |
| 6 | 0.8 | 2.0 | 7.4 | 5.0 | 1.8 | 1.9 | 2.4 | 2.8 | 0.9 | 1.2 | 0.2 |
| 7 | 1.3 | 2.0 | 1.2 | 4.4 | 4.1 | 1.4 | 0.3 | 1.0 | 1.0 | 0.3 | 0.7 |
| 8 | 0.7 | 1.6 | 0.8 | 0.2 | 1.1 | 2.7 | 0.4 | 0.3 | 0.4 | 0.5 | 0.1 |
| 9 | 0.2 | 0.3 | 0.5 | 0.4 | 0.0 | 1.0 | 0.9 | 0.2 | 0.1 | 0.2 | 0.1 |
| $10+$ | 0.2 | 0.3 | 0.9 | 0.5 | 0.2 | 0.6 | 0.5 | 0.5 | 0.2 | 0.2 | 0.1 |

$\begin{array}{llllllllllll}\text { Total } & 75.9 & 161.2 & 132.8 & 100.6 & 176 & 132 & 66.8 & 91.4 & 78.4 & 40.6 & 56.6\end{array}$

Females

| 1 | 6.7 | 86.4 | 42.7 | 18.1 | 96.9 | 8.4 | 11.3 | 34.7 | 37.1 | 0.7 | 43.0 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 2 | 3.9 | 2.9 | 55 | 48.6 | 18.4 | 82.7 | 6.9 | 12.4 | 30.4 | 24.4 | 1.5 |
| 3 | 35.1 | 10 | 1.7 | 20.1 | 47.4 | 7.0 | 35.8 | 14.7 | 4.5 | 13.1 | 9.9 |
| 4 | 30.2 | 33.2 | 6.6 | 4.7 | 14.4 | 20 | 7.2 | 24.6 | 1.9 | 1.6 | 13.5 |
| 5 | 1.9 | 31.5 | 17.4 | 4.3 | 1.6 | 16.5 | 6.1 | 3.5 | 5.3 | 1.5 | 2.9 |
| 6 | 2.3 | 1.4 | 11.7 | 5.5 | 1.8 | 1.7 | 3.9 | 3.8 | 2.2 | 2.8 | 0.4 |
| 7 | 2.6 | 2.6 | 1.3 | 6.6 | 5.7 | 1.8 | 1.1 | 3.4 | 1.5 | 0.5 | 1.7 |
| 8 | 2.5 | 2.5 | 2.7 | 0.4 | 3.3 | 4.7 | 0.6 | 0.7 | 0.7 | 1.5 | 0.6 |
| 9 | 0.8 | 1.9 | 1.3 | 1.2 | 0.2 | 4.0 | 1.5 | 0.3 | 0.3 | 0.5 | 1.0 |
| $10+$ | 2.6 | 2.8 | 3.9 | 2.3 | 2.0 | 2.6 | 2.1 | 3.0 | 1.4 | 1.1 | 2.5 |
|  |  |  |  |  |  |  |  |  |  |  |  |
| Total | 88.6 | 175.2 | 144.3 | 111.8 | 191.7 | 149.4 | 76.5 | 101.1 | 85.4 | 47.7 | 76.9 |

Table 4b: Population estimates of numbers of hoki by age class (in millions) from summer surveys of the Sub-Antarctic, 1991-2001. (+ indicates a plus group of fish the age given and older.) Note that individual year classes can be tracked diagonally across the table as they increase in age.

Males
Dec-91 Dec-92 Dec-93 Mar-96 Mar-98 Dec-00 Dec-01

| Age |  |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 1 | 1.8 | 0.8 | 1.0 | 7.6 | 0.5 | 0.2 | 0.5 |
| 2 | 0.2 | 0.4 | 4.2 | 8.1 | 0.6 | 0.1 | 0.2 |
| 3 | 5.2 | 0.3 | 0.2 | 13.8 | 4.5 | 0.8 | 1.5 |
| 4 | 10.9 | 5.1 | 1.9 | 8.8 | 2.9 | 0.7 | 0.6 |
| 5 | 1.0 | 9.3 | 9.6 | 0.3 | 6.1 | 0.9 | 0.8 |
| 6 | 2.1 | 0.4 | 5.3 | 0.7 | 3.7 | 2.8 | 0.8 |
| 7 | 3.7 | 2.2 | 0.8 | 2.6 | 0.8 | 1.7 | 1.5 |
| 8 | 2.0 | 4.6 | 1.4 | 2.9 | 0.5 | 3.3 | 1.3 |
| 9 | 0.7 | 2.3 | 3.4 | 0.2 | 0.8 | 1.7 | 1.5 |
| $10+$ | 1.3 | 1.7 | 3.3 | 1.4 | 1.5 | 0.6 | 0.9 |
| Total | 28.9 | 27.1 | 31.1 | 46.4 | 21.9 | 12.8 | 9.5 |

Females

| 1 | 1.7 | 1.0 | 1.1 | 6.7 | 0.2 | 0.2 | 0.5 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 2 | 0.0 | 0.6 | 3.7 | 5.8 | 0.8 | 0.0 | 0.1 |
| 3 | 3.8 | 0.1 | 0.2 | 12.3 | 4.3 | 0.7 | 0.8 |
| 4 | 14 | 0.9 | 0.8 | 6.6 | 2.8 | 1.2 | 0.5 |
| 5 | 1.0 | 10.1 | 5.6 | 0.5 | 7.0 | 1.3 | 1.2 |
| 6 | 2.2 | 1.9 | 7.4 | 1.3 | 4.9 | 4.3 | 1.5 |
| 7 | 6.8 | 5.1 | 0.7 | 4.3 | 1.4 | 3.8 | 3.2 |
| 8 | 3.4 | 8.1 | 4.5 | 6.3 | 1.1 | 5.9 | 2.5 |
| 9 | 1.8 | 5.2 | 7.5 | 0.5 | 3.1 | 3.2 | 2.2 |
| $10+$ | 3.7 | 4.9 | 8.6 | 3.9 | 4.4 | 2.4 | 2.8 |
| Total | 38.4 | 37.9 | 40.1 | 48.2 | 30.0 | 23.0 | 15.3 |

Table 5: Relative numbers of hoki at age from Chatham Rise and Sub-Antarctic paired summer surveys, grouped as juveniles (1-2 years), maturing adults 3-7 years old and adults over 7 years old.

| Year | 1992 | 1993 | 1994 | 1996 | 1998 | 2001 | 2002 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Juveniles 1 \& 2 yrs |  |  |  |  |  |  |  |
| Total Chatham Rise | 19.1 | 179.6 | 196.7 | 233.7 | 37.5 | 52.1 | 77.3 |
| Total Sub-Antarctic | 3.7 | 2.8 | 10.0 | 28.2 | 2.1 | 0.5 | 1.3 |
| \% juv. < 3 yrs on C.R. | 0.8 | 1.0 | 1.0 | 0.9 | 0.9 | 1.0 | 1.0 |
| \% juv. < 3 yrs on S.A. | 0.2 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 |
|  |  |  |  |  |  |  |  |
| Maturing (3-7yrs) |  |  |  |  |  |  |  |
| Total Chatham Rise | 138.4 | 147.4 | 70.3 | 127.2 | 99.8 | 32.2 | 51.8 |
| Total Sub-Antarctic | 50.7 | 35.4 | 32.5 | 51.2 | 38.4 | 18.2 | 12.2 |
| \% m. adult > 3-7 yrs on | 0.7 | 0.8 | 0.7 | 0.7 | 0.7 | 0.6 | 0.8 |
| C.R. |  |  |  |  |  |  | 0.3 |
| \% m. adult > 3-7 yrs on | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.2 |
| S.A. |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| Adults (> 8yrs) | 7.0 | 9.4 | 10.1 | 6.8 | 6.0 | 4.0 | 4.4 |
| Total Chatham Rise | 12.9 | 26.8 | 28.7 | 15.2 | 11.4 | 17.1 | 11.3 |
| Total Sub-Antarctic | 0.35 | 0.26 | 0.26 | 0.31 | 0.34 | 0.19 | 0.28 |
| \% adult > 7 yrs on C.R. | 0.65 |  |  |  |  |  |  |
| \% adult > 7 yrs on S.A. | 0.65 | 0.74 | 0.74 | 0.69 | 0.66 | 0.81 | 0.72 |

Table 6: Numbers of hoki at age (in millions) summed from paired summer surveys of the Chatham Rise and Sub-Antarctic summed by age class. ( + , plus group including age given and older.) Note that individual year classes can be tracked diagonally downwards across the table as they increase in age.


Table 7: Proportion of hoki on the Chatham Rise out of summed total from paired surveys, by age class. (+, plus group of age given and older.)

| Males |  |  |  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Year | 1992 | 1993 | 1994 | 1996 | 1998 | 2001 | 2002 |
| Age |  |  |  |  |  |  |  |
| 1 | 0.788 | 0.991 | 0.978 | 0.925 | 0.956 | 0.778 | 0.983 |
| 2 | 0.900 | 0.886 | 0.927 | 0.752 | 0.933 | 0.996 | 0.872 |
| 3 | 0.879 | 0.964 | 0.923 | 0.747 | 0.885 | 0.923 | 0.865 |
| 4 | 0.677 | 0.876 | 0.708 | 0.488 | 0.592 | 0.563 | 0.947 |
| 5 | 0.783 | 0.691 | 0.625 | 0.800 | 0.402 | 0.438 | 0.736 |
| 6 | 0.276 | 0.833 | 0.583 | 0.720 | 0.393 | 0.300 | 0.193 |
| 7 | 0.260 | 0.476 | 0.600 | 0.612 | 0.273 | 0.150 | 0.322 |
| 8 | 0.259 | 0.258 | 0.364 | 0.275 | 0.444 | 0.132 | 0.075 |
| 9 | 0.222 | 0.115 | 0.128 | 0.000 | 0.529 | 0.105 | 0.056 |
| $10+$ | 0.133 | 0.150 | 0.214 | 0.125 | 0.250 | 0.250 | 0.063 |
| Females |  |  |  |  |  |  |  |
| 1 | 0.798 | 0.989 | 0.975 | 0.935 | 0.983 | 0.778 | 0.990 |
| 2 | 1.000 | 0.829 | 0.937 | 0.760 | 0.896 | 1.000 | 0.914 |
| 3 | 0.902 | 0.990 | 0.895 | 0.794 | 0.893 | 0.949 | 0.929 |
| 4 | 0.683 | 0.974 | 0.892 | 0.686 | 0.720 | 0.571 | 0.962 |
| 5 | 0.655 | 0.757 | 0.757 | 0.762 | 0.466 | 0.536 | 0.709 |
| 6 | 0.511 | 0.424 | 0.613 | 0.581 | 0.443 | 0.394 | 0.194 |
| 7 | 0.277 | 0.338 | 0.650 | 0.570 | 0.440 | 0.116 | 0.344 |
| 8 | 0.424 | 0.236 | 0.375 | 0.344 | 0.353 | 0.203 | 0.196 |
| 9 | 0.308 | 0.268 | 0.148 | 0.286 | 0.326 | 0.135 | 0.300 |
| $10+$ | 0.138 | 0.220 | 0.231 | 0.294 | 0.303 | 0.095 | 0.228 |

Table 8: Numbers at age of male hoki by cohort (labeled by year spawned) from trawl surveys of the Chatham Rise and Sub-Antarctic. (Values at bottom of each column are for a plus group of fish 10 years and older.)

| Chatham Rise | 1992 |  |  |  |  |  |  |  |  | Survey year |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year class |  | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
| 2001 |  |  |  |  |  |  |  |  |  |  |  |
| 2000 |  |  |  |  |  |  |  |  |  |  | 31.4 |
| 1999 |  |  |  |  |  |  |  |  |  | 0.7 | 1.5 |
| 1998 |  |  |  |  |  |  |  |  | 40.2 | 26.3 | 9.6 |
| 1997 |  |  |  |  |  |  |  | 38.1 | 28.0 | 9.6 | 10.8 |
| 1996 |  |  |  |  |  |  | 10.9 | 16.6 | 3.5 | 0.9 | 2.1 |
| 1995 |  |  |  |  |  | 7.7 | 8.4 | 11.2 | 1.7 | 0.7 | 0.2 |
| 1994 |  | . |  |  | 93.8 | 83.5 | 34.7 | 19.2 | 2.5 | 1.2 | 0.7 |
| 1993 |  |  |  | 17.0 | 24.6 | 9.9 | 4.2 | 1.5 | 0.9 | 0.3 | 0.1 |
| 1992 |  |  | 45.4 | 47.9 | 40.8 | 12.3 | 4.1 | 2.8 | 1.0 | 0.5 | 0.1 |
| 1991 |  | 87.2 | 53.6 | 20.0 | 8.4 | 11.0 | 2.4 | 1.0 | 0.4 | 0.2 | 0.2 |
| 1990 | 6.7 | 3.1 | 2.4 | 2.4 | 1.2 | 1.9 | 0.3 | 0.3 | 0.1 | 0.2 |  |
| 1989 | 1.8 | 8.0 | 4.6 | 2.8 | 1.8 | 1.4 | 0.4 | 0.2 | . 0.2 |  |  |
| 1988 | 37.8 | 35.9 | 16.0 | 5.0 | 4.1 | 2.7 | 0.9 | 0.5 |  |  |  |
| 1987 | 22.8 | 20.8 | 7.4 | 4.4 | 1.1 | 1.0 | 0.5 |  |  |  |  |
| 1986 | 3.6 | 2.0 | 1.2 | 0.2 | 0.0 | 0.6 |  |  |  |  |  |
| 1985 | 0.8 | 2.0 | 0.8 | 0.4 | 0.2 |  |  |  |  |  |  |
| 1984 | 1.3 | 1.6 | 0.5 | 0.5 |  |  |  |  |  |  |  |
| 1983 | 0.7 | 0.3 | 0.9 |  |  |  |  |  |  |  |  |
| 1982 | 0.2 | 0.3 |  |  |  |  |  |  |  |  |  |
| 1981 | 0.2 |  |  |  |  |  |  |  |  |  |  |


| Sub-Antarctic |  |  |  |  |  |  |  |  |  | Surv | year |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year class | 1991 | 1992 | 1993 |  | 1996 |  | 1998 |  |  | 2000 | 2001 |
| 2001 |  |  |  |  |  |  |  |  |  |  |  |
| 2000 |  |  |  |  |  |  |  |  |  |  | 0.5 |
| 1999 |  |  |  |  |  |  |  |  |  | 0.2 | 0.2 |
| 1998 |  |  |  |  |  |  |  |  | - | 0.1 | 1.5 |
| 1997 |  |  |  |  |  |  |  | - | - | 0.8 | 0.6 |
| 1996 |  |  |  |  |  |  | 0.5 | - | - | 0.7 | 0.8 |
| 1995 |  |  |  |  |  | - | 0.6 | - | - | 0.9 | 0.8 |
| 1994 |  |  |  |  | 7.6 | - | 4.5 | - | - | 2.8 | 1.5 |
| 1993 |  |  |  | - | 8.1 | - | 2.9 | - | - | 1.7 | 1.3 |
| 1992 |  |  | 1.0 | - | 13.8 | - | 6.1 | - | - | 3.3 | 1.5 |
| 1991 |  | 0.8 | 4.2 | - | 8.8 | - | 3.7 | - | - | 1.7 | 0.9 |
| 1990 | 1.8 | 0.4 | 0.2 | - | 0.3 | - | 0.8 | - | - | 0.6 |  |
| 1989 | 0.2 | 0.3 | 1.9 | - | 0.7 | - | 0.5 | - | - |  |  |
| 1988 | 5.2 | 5.1 | 9.6 | - | 2.6 | - | 0.8 | - |  |  |  |
| 1987 | 10.9 | 9.3 | 5.3 | - | 2.9 | - | 1.5 |  |  |  |  |
| 1986 | 1.0 | 0.4 | 0.8 | - | 0.2 | - |  |  |  |  |  |
| 1985 | 2.1 | 2.2 | 1.4 | - | 1.4 |  |  |  |  |  |  |
| 1984 | 3.7 | 4.6 | 3.4 | - |  |  |  |  |  |  |  |
| 1983 | 2.0 | 2.3 | 3.3 |  |  |  |  |  |  |  |  |
| 1982 | 0.7 | 1.7 |  |  |  |  |  |  |  |  |  |
| 1981 | 1.3 |  |  |  |  |  |  |  |  |  |  |

Table 9: Numbers at age of female hoki by cohort (labeled by year spawned) from trawl surveys of the Chatham Rise and Sub-Antarctic. (Values at bottom of each column represent a plus group of fish 10 years and older.)

| Year class |  |  |  |  |  |  |  |  |  | Survey year |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
| 2001 |  |  |  |  |  |  |  |  |  |  |  |
| 2000 |  |  |  |  |  |  |  |  |  |  | 43.0 |
| 1999 |  |  |  |  |  |  |  |  |  | 0.7 | 1.5 |
| 1998 |  |  |  |  |  |  |  |  | 37.1 | 24.4 | 9.9 |
| 1997 |  |  |  |  |  |  |  | 34.7 | 30.4 | 13.1 | 13.5 |
| 1996 |  |  |  |  |  |  | 11.3 | 12.4 | 4.5 | 1.6 | 2.9 |
| 1995 |  |  |  |  |  | 8.4 | 6.9 | 14.7 | 1.9 | 1.5 | 0.4 |
| 1994 |  |  |  |  | 96.9 | 82.7 | 35.8 | 24.6 | 5.3 | 2.8 | 1.7 |
| 1993 |  |  |  | 18.1 | 18.4 | 7.0 | 7.2 | 3.5 | 2.2 | 0.5 | 0.6 |
| 1992 |  |  | 42.7 | 48.6 | 47.4 | 20.0 | 6.1 | 3.8 | 1.5 | 1.5 | 1.0 |
| 1991 |  | 86.4 | 55.0 | 20.1 | 14.4 | 16.5 | 3.9 | 3.4 | 0.7 | 0.5 | 2.5 |
| 1990 | 6.7 | 2.9 | 1.7 | 4.7 | 1.6 | 1.7 | 1.1 | 0.7 | 0.3 | 1.1 |  |
| 1989 | 3.9 | 10.0 | 6.6 | 4.3 | 1.8 | 1.8 | 0.6 | 0.3 | 1.4 |  |  |
| 1988 | 35.1 | 33.2 | 17.4 | 5.5 | 5.7 | 4.7 | 1.5 | 3.0 |  |  |  |
| 1987 | 30.2 | 31.5 | 11.7 | 6.6 | 3.3 | 4.0 | 1.2 |  |  |  |  |
| 1986 | 1.9 | 1.4 | 1.3 | 0.4 | 0.2 | 2.6 |  |  |  |  |  |
| 1985 | 2.3 | 2.6 | 2.7 | 1.2 | 2.0 |  |  |  |  |  |  |
| 1984 | 2.6 | 2.5 | 1.3 | 2.3 |  |  |  |  |  |  |  |
| 1983 | 2.5 | 1.9 | 3.9 |  |  |  |  |  |  |  |  |
| 1982 | 0.8 | 2.8 |  |  |  |  |  |  |  |  |  |
| 1981 | 2.6 |  |  |  |  |  |  |  |  |  |  |


| Sub-Antarctic |  |  |  |  |  |  |  |  |  | Surveyyear |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year class | 1991 | 1992 | 1993 |  | 1996 |  | 1998 |  |  | 2000 | 2001 |
| 2001 |  |  |  |  |  |  |  |  |  |  |  |
| 2000 |  |  |  |  |  |  |  |  |  |  | 0.5 |
| 1999 |  |  |  |  |  |  |  |  |  | 0.2 | 0.1 |
| 1998 |  |  |  |  |  |  |  |  | - | 0.0 | 0.8 |
| 1997 |  |  |  |  |  |  |  | - | - | 0.7 | 0.5 |
| 1996 |  |  |  |  |  |  | 0.2 | - | - | 1.2 | 1.2 |
| 1995 |  |  |  |  |  | - | 0.8 | - | - | 1.3 | 1.5 |
| 1994 |  |  |  |  | 6.7 | - | 4.3 | - | - | 4.3 | 3.2 |
| 1993 |  |  |  | - | 5.8 | - | 2.8 | - | - | 3.8 | 2.5 |
| 1992 |  |  | 1.1 | - | 12.3 | - | 7.0 | - | - | 5.9 | 2.2 |
| 1991 |  | 1.0 | 3.7 | - | 6.6 | - | 4.9 | - | - | 3.2 | 2.8 |
| 1990 | 1.7 | 0.6 | 0.2 | - | 0.5 | - | 1.4 | - | - | 2.4 |  |
| 1989 | 0.0 | 0.1 | 0.8 | - | 1.3 | - | 1.1 | - | - |  |  |
| 1988 | 3.8 | 0.9 | 5.6 | - | 4.3 | - | 3.1 | - |  |  |  |
| 1987 | 14.0 | 10.1 | 7.4 | - | 6.3 | - | 4.4 |  |  |  |  |
| 1986 | 1.0 | 1.9 | 0.7 | - | 0.5 | - |  |  |  |  |  |
| 1985 | 2.2 | 5.1 | 4.5 | - | 3.9 |  |  |  |  |  |  |
| 1984 | 6.8 | 8.1 | 7.5 | - |  |  |  |  |  |  |  |
| 1983 | 3.4 | 5.2 | 8.6 |  |  |  |  |  |  |  |  |
| 1982 | 1.8 | 4.9 |  |  |  |  |  |  |  |  |  |
| 1981 | 3.7 |  |  |  |  |  |  |  |  |  |  |

Table 10: Observed rate of change (expressed as an instantaneous rate) in numbers of male hoki from trawl surveys of the Chatham Rise.


Table 11: Observed rate of change (expressed as an instantaneous rate) in numbers of female hoki from trawl surveys of the Chatham Rise.


Table 12: Observed rate of change (expressed as an instantaneous rate) in numbers of male hoki from summer trawl surveys of the Sub-Antarctic. (-, no data.)

|  | Survey |  |  |  |  |  |  | Date |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Age in years | 91 to 92 | 92 to 93 | 93 to 96 | 96 to 98 | 98 to 00 | 00 to 01 | Mean |  |
|  |  |  |  |  |  |  |  |  |
| 1+ to $2+$ | 1.50 | -1.66 | - | - | - | -0.08 | -0.08 |  |
| 2+ to $3+$ | -0.41 | 0.69 | -1.97 | 0.26 | - | -2.71 | -0.83 |  |
| 3+ to 4+ | 0.02 | -1.85 | -0.55 | 0.51 | -0.12 | 0.27 | -0.29 |  |
| 4+ to $5+$ | 0.16 | -0.63 | -0.30 | 0.41 | -0.15 | -0.07 | -0.10 |  |
| 5+ to $6+$ | 0.92 | 0.56 | 0.75 | 0.43 | 0.17 | 0.15 | 0.50 |  |
| 6+ to 7+ | -0.05 | -0.69 | 0.98 | -0.49 | 0.19 | 0.64 | 0.10 |  |
| 7+ to $8+$ | -0.22 | 0.45 | 0.45 | 0.17 | 0.22 | 0.28 | 0.23 |  |
| 8+ to $9+$ | -0.14 | 0.30 | 1.04 | 0.59 | 0.28 | 0.82 | 0.48 |  |
| 9+ to $10++$ | -0.89 | -0.36 | 0.00 | 0.33 | 0.10 | 0.63 | -0.03 |  |

Table 13: Observed rate of change (expressed as an instantaneous rate) in numbers of female hoki from summer trawl surveys of the Sub-Antarctic. (-, no data.)

|  | Survey |  |  |  |  |  |  | Date |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Age in years | 91 to 92 | 92 to 93 | 93 to 96 | 96 to 98 | 98 to 00 | 00 to 01 | Mean |  |
|  |  |  |  |  |  |  |  |  |
| 1+ to $2+$ | 1.04 | -1.31 | - | - | - | - | -0.13 |  |
| $2+$ to $3+$ | -16.22 | 1.10 | -1.81 | 0.22 | - | 0.39 | -3.27 |  |
| 3+ to $4+$ | 1.44 | -2.08 | -0.43 | 0.36 | -0.65 | -13.55 | -2.48 |  |
| 4+ to $5+$ | 0.33 | -1.83 | -0.69 | 0.28 | -0.18 | 0.28 | -0.30 |  |
| 5+ to $6+$ | -0.64 | 0.31 | -0.36 | 0.15 | 0.00 | 0.01 | -0.09 |  |
| $6+$ to $7+$ | -0.84 | 1.00 | 0.20 | -0.51 | -0.11 | -0.13 | -0.07 |  |
| $7+$ to $8+$ | -0.17 | 0.13 | 0.12 | 0.08 | 0.06 | 0.31 | 0.09 |  |
| $8+$ to $9+$ | -0.42 | 0.08 | 0.25 | 0.16 | 0.15 | 0.40 | 0.10 |  |
| $9+$ to $10++$ | -1.00 | -0.50 | 0.10 | 0.20 | -0.20 | 0.10 | -0.22 |  |

Table 14: Observed rate of change (expressed as an instantaneous rate) in numbers of male hoki by age class for paired surveys of the Chatham Rise and the Sub-Antarctic. (-, no data.)

|  | Survey |  |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Age in years | 91 to 92 | 92 to 93 | 93 to 96 | 96 to 98 | 98 to 00 | 00 to 01 | Mean |  |
|  |  |  |  |  |  |  |  |  |
| 1+ to $2+$ | 0.89 | 0.42 | - | - | - | -0.63 | 0.22 |  |
| 2+ to $3+$ | -1.42 | 0.30 | -0.12 | 0.48 | - | 0.87 | 0.02 |  |
| 3+ to 4+ | 0.05 | 0.24 | 0.91 | 0.76 | 0.71 | -0.10 | 0.43 |  |
| 4+ to $5+$ | 0.11 | 0.47 | 0.41 | 0.84 | 0.63 | -0.58 | 0.31 |  |
| 5+ to $6+$ | 0.65 | 0.86 | 0.72 | 0.52 | 0.83 | 0.51 | 0.68 |  |
| 6+ to $7+$ | -0.37 | 0.18 | 1.01 | 0.16 | 0.46 | 0.61 | 0.34 |  |
| 7+ to $8+$ | -0.22 | 0.65 | 0.87 | 0.51 | 0.36 | 0.37 | 0.42 |  |
| 8+ to $9+$ | 0.04 | 0.46 | 1.73 | 0.69 | 0.42 | 0.90 | 0.71 |  |
| 9+ to $10++$ | -0.80 | -0.48 | 0.24 | 0.35 | 0.12 | 0.60 | 0.00 |  |

Table 15: Observed rate of change (expressed as an instantaneous rate) in numbers of female hoki by age class for paired surveys of the Chatham Rise and the Sub-Antarctic. ( - , no data.)

|  | Survey |  |  |  |  |  |  | Date |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Age in years | 91 to92 | 92 to93 | 93 to 96 | 96 to 98 | 98 to 00 | 00 to 01 | Mean |  |
|  |  |  |  |  |  |  |  |  |
| 1+ to $2+$ | 0.88 | 0.40 | - | - | - | -0.03 | 0.42 |  |
| 2+ to $3+$ | -0.95 | 0.61 | -0.23 | 1.10 | - | -0.83 | -0.06 |  |
| 3+ to 4+ | 0.13 | 0.31 | 0.77 | 0.50 | 0.21 | 0.91 | 0.47 |  |
| 4+ to $5+$ | 0.06 | 0.39 | -0.08 | 0.85 | 1.10 | 0.34 | 0.44 |  |
| 5+ to $6+$ | -0.13 | 0.78 | 0.65 | 0.63 | 0.25 | -0.15 | 0.34 |  |
| 6+ to 7+ | -0.54 | 0.50 | 0.62 | 0.02 | 0.26 | 0.34 | 0.20 |  |
| 7+ to 8+ | -0.12 | 0.07 | 0.52 | 0.09 | 0.21 | 0.38 | 0.19 |  |
| 8+ to $9+$ | -0.19 | 0.19 | 0.79 | 0.45 | 0.14 | 0.35 | 0.29 |  |
| 9+ to $10+$ | 0.00 | 0.20 | 0.79 | 0.55 | 0.50 | 1.06 | 0.52 |  |
| 10+ to $11++$ | -1.16 | -0.95 | 0.71 | -0.59 | 0.11 | -1.04 | -0.49 |  |

Table 16: Population estimates of numbers of hoki by age class (in millions) from seasonal surveys of the Sub-Antarctic, 1991-93. ( + , a plus group of fish the age given and older.)

| Males | Dec-91 | Apr-92 | Sep-92 | Dec-92 | Apr-93 | Dec-93 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| 1 |  |  |  |  |  |  |
| 2 | 1.8 | 1.1 | 0.1 | 0.8 | 4.3 | 1.0 |
| 3 | 0.2 | 0.1 | 0.0 | 0.4 | 0.0 | 4.2 |
| 4 | 5.2 | 2.6 | 0.0 | 0.3 | 0.0 | 0.2 |
| 5 | 10.9 | 5.7 | 0.5 | 5.1 | 1.4 | 1.9 |
| 6 | 1.0 | 0.4 | 2.2 | 9.3 | 3.4 | 9.6 |
| 7 | 2.1 | 1.3 | 0.2 | 0.4 | 0.4 | 5.3 |
| 8 | 3.7 | 3.0 | 0.3 | 2.2 | 0.9 | 0.8 |
| 9 | 2.0 | 2.8 | 1.0 | 4.6 | 2.3 | 1.4 |
| $10+$ | 0.7 | 0.7 | 0.9 | 2.3 | 2.3 | 3.4 |
|  | 1.3 | 0.7 | 0.7 | 1.7 | 1.6 | 3.3 |
| Total |  |  |  |  |  |  |
|  | 28.9 | 18.4 | 5.8 | 27.1 | 16.6 | 31.1 |
| Females |  |  |  |  |  |  |
|  | 1.7 | 1.1 | 0.1 | 1.0 | 4.3 | 1.1 |
| 1 | 0.0 | 0.1 | 0.0 | 0.6 | 0.1 | 3.7 |
| 2 | 3.8 | 1.6 | 0.0 | 0.1 | 0.0 | 0.2 |
| 3 | 14 | 7.4 | 1.0 | 0.9 | 2.9 | 0.8 |
| 4 | 1.0 | 0.6 | 3.9 | 10.1 | 7.0 | 5.6 |
| 5 | 2.2 | 2.3 | 0.6 | 1.9 | 0.3 | 7.4 |
| 6 | 6.8 | 6.2 | 1.0 | 5.1 | 1.8 | 0.7 |
| 7 | 3.4 | 3.5 | 3.0 | 8.1 | 4.3 | 4.5 |
| 8 | 1.8 | 1.0 | 1.9 | 5.2 | 2.2 | 7.5 |
| 9 | 2.7 | 3.2 | 2.7 | 4.9 | 2.2 | 5.0 |
| $10+$ | 37.4 | 27 | 14.1 | 37.9 | 25.1 | 36.5 |
| Total |  |  |  |  |  |  |

Table 17. Mean catch rates of hoki ( $\mathbf{k g} . \mathrm{km}^{2}$ ) by depth zone in surveys of the Chatham Rise and Sub-Antarctic ( $n$ number of stations).

## Chatham Rise Surveys



Sub-Antarctic surveys


Table 18. Total biomass estimates (t) of hoki from coastal surveys

Trip code
Survey type

## EAST COAST NORTH ISLAND

| kah9301 | scampi relative biomass series |
| :--- | ---: |
| kah9401 | scampi relative biomass series |
| kah9501 | scampi relative biomass series |
| kah9604 | scampi gear selectivity trials |

kah9304 inshore relative biomass series
kah9402 inshore relative biomass series
kah9502 inshore relative biomass series
kah9602 inshore relative biomass series

Date Depth range Hoki biomass
c.v. (\%)
(m)
(t)

| Jan 1993 | $200-800$ | - | - |
| ---: | ---: | ---: | ---: |
| Jan 1994 | $200-600$ | - | - |
| Jan 1995 | $200-600$ | - | - |
| Apr 1996 | $200-600$ | - | - |
|  |  |  |  |
| ar-Apr 1993 | $20-400$ | 543 | 24 |
| b-Mar 1994 | $20-400$ | 2729 | 47 |
| b-Mar 1995 | $20-400$ | 2937 | 42 |
|  | $20-400$ | 1411 | 50 |
|  |  | 1905 |  |

EAST COAST SOUTH ISLAND
kah9105 inshore relative biomass series
kah9205 inshore relative biomass series
kah9306 inshore relative biomass series
kah9406 inshore relative biomass series
kah9606 inshore relative biomass series
Mean biomass
kah9618 inshore relative biomass series
kah9704 inshore relative biomass series
kah9809 inshore relative biomass series
kah9917 inshore relative biomass series
Mean biomass

## SOUTHLAND

| $\tan 9301$ | inshore random trawl survey |
| :--- | :--- |
| $\tan 9402$ | inshore random trawl survey |
| $\tan 9502$ | inshore random trawl survey |
| $\tan 9604$ | inshore random trawl survey |


| Feb-Mar 1993 | $30-600$ | 11395 | 29 |
| :--- | ---: | ---: | ---: |
| Feb-Mar 1994 | $30-600$ | 18784 | 40 |
| Feb-Mar 1995 | $30-600$ | 2893 | 33 |
| Feb-Mar 1996 | $30-600$ | 9717 | 16 |

WEST COAST SOUTH ISLAND, TARANAKI BIGHT

| kah9204 | inshore relative biomass series | Mar-Apr 1992 | $20-400$ | 395 | 17 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| kah9404 | inshore relative biomass series | Mar-Apr 1994 | $20-400$ | 825 | 49 |
| kah9504 | inshore relative biomass series | Mar-Apr 1995 | $20-400$ | 3604 | 21 |
| kah9701 | inshore relative biomass series | Mar-Apr 1997 | $20-400$ | 1100 | 25 |
| Mean biomass |  |  |  | $\mathbf{1 4 8 1}$ |  |

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| kah9204 | inshore relative biomass series | Mar-Apr 1992 | $20-400$ | 10 | 96 |
| :--- | :--- | :--- | ---: | ---: | ---: |
| kah9404 | inshore relative biomass series | Mar-Apr 1994 | $20-400$ | 1 | 93 |
| kah9504 | inshore relative biomass series | Mar-Apr 1995 | $20-400$ | 13 | 44 |
| kah9701 | inshore relative biomass series | Mar-Apr 1997 | $.20-400$ | $<0.5$ | 79 |
| Mean biomass |  |  |  |  | $\mathbf{6 . 1}$ |

Table 19. Estimated biomass ( $t$ ) of hoki by age classes $1+2+$ and $3++$ from inshore surveys.

| Trip code | Date | Depth range <br> $(\mathbf{m})$ | $\mathbf{0 +}$ | $\mathbf{1 +}$ | $\mathbf{2 +}$ | $\mathbf{3 + +}$ |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
|  |  |  |  |  |  |  |
| EAST COAST NORTH ISLAND |  |  |  |  |  |  |
| kah9304 | Mar-Apr 1993 | $20-400$ | 0.2 | 0.7 | 2.5 | 539 |
| kah9402 | Feb-Mar 1994 | $20-400$ | 10.6 | 74.9 | 136.8 | 2506 |
| kah9502 | Feb-Mar 1995 | $20-400$ | 4.7 | 5 | 15.1 | 2912 |
| kah9602 | Feb-Mar 1996 | $20-400$ | 0.1 | 0.6 | 3.0 | 1407 |
| Mean biomass |  |  | $\mathbf{4}$ | $\mathbf{2 0}$ | $\mathbf{3 9}$ | $\mathbf{1 8 4 1}$ |


| EAST COAST SOUTH ISLAND |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| kah9105 | May-Jun 1991 | 30-400 | - | - | - | 61 |
| kah9205 | May-Jun 1992 | 30-400 | - | - | - | 108 |
| kah9306 | May-Jun 1993 | 30-400 | $<0.5$ | 28 | 48 | 336 |
| kah9406 | May-Jun 1994 | 30-400 | - | - | - | 125 |
| kah9606 | May-Jun 1996 | 30-400 | 4 | 5 | 4 | 447 |
| Mean biomass |  |  | 2 | 17 | 26 | 215 |
| kah9618 | Dec-Jan 1996 | 10-400 | - | 323 | 1399 | 1384 |
| kah9704 | Dec-Jan 1997 | 10-400 | - | 31 | 1035 | 1123 |
| kah9809 | Dec-Jan 1998 | 10-400 | - | 2631 | 758 | 4054 |
| kah9917 | Dec-Jan 1999 | 10-400 | - | 17 | 540 | 216 |
| Mean biomass |  |  | - | 751 | 933 | 1694 |
| SOUTHLAND 2373 |  |  |  |  |  |  |
| $\tan 9301$ | Feb-Mar 1993 | 30-600 | - | 8338 | 684 | 2373 |
| $\tan 9402$ | Feb-Mar 1994 | 30-600 | - | 11516 | 5087 | 2181 |
| $\tan 9502$ | Feb-Mar 1995 | 30-600 | - | 641 | 1041 | 1211 |
| $\tan 9604$ | Feb-Mar 1996 | 30-600 | - | 1521 | 4232 | 3964 |
| Mean biomass |  |  | - | 5504 | 2761 | 2432 |


| WEST COAST SOUTH ISLAND |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| kah9204 | Mar-Apr 1992 | $20-400$ | 205 | 119 | - | 71 |
| kah9404 | Mar-Apr 1994 | $20-400$ | 243 | 359 | - | 223 |
| kah9504 | Mar-Apr 1995 | $20-400$ | 2643 | 504 | - | 457 |
| kah9701 | Mar-Apr 1997 | $20-400$ | 563 | 182 | - | 355 |
| Mean biomass |  |  | 914 | 291 | - | 277 |

TASMAN BAY \& GOLDEN BAY

| kah9204 | Mar-Apr 1992 | $20-400$ | 10 | - | - | - |
| :--- | :--- | :--- | ---: | :--- | :--- | :--- |
| kah9404 | Mar-Apr 1994 | $20-400$ | 1 | - | - | - |
| kah9504 | Mar-Apr 1995 | $20-400$ | 13 | - | - | - |
| kah9701 | Mar-Apr 1997 | $20-400$ | 0 | - | - | - |
| Mean biomass |  |  | 6 | - | - | - |



Figure 1. Spawning grounds and home grounds of western and eastern stocks of hoki.


Figure 2. Current view of the life-cycle of hoki



$2-1990$ (Nov-Dec)
Amaltal Explorer


Figure 3a. Length frequency histograms of male and unsexed hoki from trawl surveys of the Chatham Rise and Sub-Antarctic to show the decline in the presence of the 1987 and 1988 year classes on the Chatham Rise, and their increase in the Sub-Antarctic, within the same time period.


Figure 3b. Length frequency histograms of female hoki from trawl surveys of the Chatham Rise and Sub-Antarctic to show the decline in the presence of the 1987 and 1988 year classes on the Chatham Rise, and their increase in the Sub-Antarctic, within the same time period.


Figure 4a. Numbers of male hoki at age (scaled to catch) showing entry of the 1987 and 1988 cohorts (white bars) and the 1991-1994 cohorts (black bars) into the West Coast spawning fishery. (n number of otoliths read.)


Figure 4b. Numbers of female hoki at age (scaled to catch) showing entry of the 1987 and 1988 cohorts (white bars) and the 1991-1994 cohorts (black bars) into the West Coast spawning fishery. (n number of otoliths read.)


Figure 5a. Length frequencies of male hoki (scaled to catch and area swept) from summer trawl surveys of the Chatham Rise 1992-2002. (n, estimated male population; c.v., coefficient of variation; no., number of fish measured.)


Figure 5b. Length frequencies of female hoki (scaled to catçh and area swept) from summer trawl surveys of the Chatham Rise 1992-2002. (n, estimated female population; c.v., coefficient of variation; no., number of fish measured.)



Figure 6a. Length frequencies of male hoki (scaled to catch and area swept) from summer trawl surveys of the Sub-Antarctic 1991-2001. ( $n$, estimated male population; c.v., coefficient of variation; no., number of fish measured.)


Figure 6b. Length frequencies of female hoki (scaled to catch and area swept) from summer trawl surveys of the Sub-Antarctic 1991-2001. (n, estimated female population; c.v., coefficient of variation; no., number of fish measured.)

December 1991


December 1992


December 1993


April 1998


December 2000


December 2001



Figure 6c. Numbers at age of male hoki (white bars) and female hoki (black bars) from trawl surveys in the summer time series of the Sub-Antarctic 1991-2001. (Note: summers are referenced to adjacent January surveys on the Chatham Rise.)!

Juvenile hoki



Adult hoki


Figure 7. Estimated population numbers of juvenile (1 \& 2 years), recruiting ( $3-7$ years) and adult ( 8 years and over) hoki from pairs of trawl surveys from the summer series of the Chatham Rise (CR) and Sub-Antarctic (SA).

Juvenile hoki


Recruiting hoki


Adult hoki


Figure 8. Proportions of estimated population numbers of juvenile (1 \& 2 years), recruiting (3-7 years) and adult (8 years and over) hoki from pairs of trawl surveys from the summer series of the Chatham Rise (CR, white bars) and Sub-Antarctic (SA, black bars). (Note: proportions sum to $\mathbf{1}$ for each pair of surveys.)


Figure 9. Top panel: Mean numbers of male and female hoki by age class from 7 pairs of summer trawl surveys on the Chatham Rise (CR) and the Sub-Antarctic (SA). Middle and lower panels: Mean proportions of female hoki and male hoki by age class from the same 7 pairs of summer surveys.


SUMMER 1993 Chatham Rise \& Sub-Antarctic


SUMMER 1994 Chatham Rise \& Sub-Antarctic


Figure 10. Population estimates of hoki at age from Tangaroa trawl surveys of the Chatham Rise and Sub-Antarctic. (Text boxes indicate year class, numbers are numbers of hoki in millions, bracket totals are the total numbers of hoki for the year classes indicated from both areas combined.)


SUMMER 1996 Chatham Rise \& Sub-Antarctic


SUMMER 1997 Chatham Rise only


Figure 10. Continued. (Text boxes indicate year class, numbers are numbers of hoki in millions, bracket totals are the total numbers of hoki for the year classes indicated from both areas combined.)


SUMMER 1999 Chatham Rise only


SUMMER 2000 Chatham Rise only


Figure 10. Continued. (Text boxes indicate year class, numbers are numbers of hoki in millions, bracket totals are the total numbers of hoki for the year classes indicated from both areas combined.)

SUMMER 2001 Chatham Rise \& Sub-Antarctic


SUMMER 2002 Chatham Rise \& Sub-Antarctic


Figure 10. Continued. (Text boxes indicate year class, numbers are numbers of hoki in millions, bracket totals are the total numbers of hoki for the year classes indicated from both areas combined.)


Figure 11. Change in numbers of hoki in year classes 1985-1994 from surveys of the Chatham Rise (C) and Sub-Antarctic (S).


Figure 11. Continued.


Figure 12. Mean instantaneous rates of changes in numbers of hoki between age classes, estimated from pairs of summer surveys of the Chatham Rise and Sub-Antarctic. ( $C$ catchability, $M$ mortality.)


Figure 13a. Length frequency histograms of male hoki (scaled to catch and area swept) from the seasonal time series of surveys of the Sub-Antarctic. ( $n$, estimated male population; c.v., coefficient of variation; no., number of fish measured.)


Figure 13b. Length frequency histograms of female hoki (scaled to catch and area swept) from the seasonal time series of surveys of the Sub-Antarctic. ( $n$, estimated male population; c.v., coefficient of variation; no., number of fish measured.)

## December 1991



April-May 1992


December 1992


May-June 1993


September 1992


December 1992


December 1993


Figure 13c. Numbers at age of male hoki (white bars) and female hoki (black bars) from trawl surveys in the seasonal time series of the Sub-Antarctic 1991-1993.


Figure 14. Mean length (cm) at age (to nearest month) of individual year classes 1982-1996 from trawl surveys of the Chatham Rise (C) and the Sub-Antarctic (S).


Figure 14. Continued.


Figure 14. Continued.


Figure 34. Continued.


Figure 14. Continued.


Figure 15. Increasing trend in the size of year classes 1982-1997 relative to the 1982 year class.


Sub-Antarctic


Figure 16. Mean catch rates of hoki in different depth zones from surveys of the Chatham Rise and Sub-Antarctic.


Figure 17. Mean catch rates of hoki by depth from Chatham Rise and Sub-Antarctic surveys. (n, number of tows.)


Figure 18a. Mean catch rates of $1+, 2+$, and $3++$ ( 3 years and over) hoki by depth zone during trawl surveys of the Chatham Rise.

Mean catch rate of 1 thoki by depth zone


Mean catch rate of $2+$ hoki by depth zone



Figure 18b. Mean catch rates of $1+, 2+$, and $3++$ ( 3 years and over) hoki by depth zone during trawl surveys of the Sub-Antarctic.


Figure 19. Mean length of hoki with depth of tow from surveys of the Chatham Rise and SubAntarctic. (n, number of tows.)


Figure 20. Size distributions of hoki (all fish combined) from 1994 surveys by Kaharoa and Tangaroa. (* estimated population numbers of fish, CR Chatham Rise, ECSI east coast South Island, NECNI north east coast North Island, SECNI south east coast North Island, STHLND Southland, TB \& GB Tasman Bay and Golden Bay, WCSI west coast South Island. Depth range in metres, cod-end mesh size in millimeters and gear type given. Year classes also indicated where known.)


Figure 21. Size distributions of hoki (all fish combined) from 1995 surveys by Kaharoa and Tangaroa. (* estimated population numbers of fish, CR Chatham Rise, ECSI east coast South Island, NECNI north east coast North Island, SECNI south east coast North Island, STHLND Southland, TB \& GB Tasman Bay and Golden Bay, WCSI west coast South Island. Depth range in metres, cod-end mesh size in millimeters and gear type given. Year classes also indicated where known.)


Figure 22. Size distributions of hoki (all fish combined) from 1996 surveys by Kaharoa and Tangaroa. (* estimated population numbers of fish, CR Chatham Rise, ECSI east coast South Island, NECNI north east coast North Island, SECNI south east coast North Island, STHLND Southland. Depth range in metres, cod-end mesh size in millimeters and gear type given. Year classes also indicated where known.)


Figure 23. Comparison of observed survey numbers of hoki at age 1 and 8 years (Chatham Rise) and age 8 years (Sub-Antarctic) with expected numbers from assumptions used in run 6.2 of the 2002 hoki stock assessment model (Francis et al. in press).

## 16. Publications

It is proposed that the main findings from this report (with permission from MFish) and from the document by Bull \& Livingston (2000), be put into 3 journal publications with draft titles and possible authors as follows:

1. The life-cycle and movements of hoki (Macruronus novaezelandiae) stocks in New Zealand waters. (Authors Livingston, Bull, Stevens)
2. Growth rate changes in New Zealand hoki (Macruronus novaezelandiae) stocks since 1982. (Livingston, Bull)
3. The biological rationale for assessing New Zealand hoki (Macruronus novaezelandiae) as two stocks. (Livingston)

## 17. Data Storage

The data extracted for this project are stored on the Trawlsurvey Database held at NIWA, Wellington.

