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## EXECUTIVE SUMMARY


**Dunn, A., Horn, P.L., Cordue, P.L., & Kendrick, T.H. 2000: Stock assessment of hake (*Merluccius australis*) for the 1999–2000 fishing year.**

*New Zealand Fisheries Assessment Report 2000/50.* **50 p.**

This report presents the stock assessment of hake in New Zealand waters. The fisheries for hake are briefly described and the data on which the stock assessments are based are summarised. New catch at age data are determined for the commercial trawl fishery in HAK 4 and HAK 7 in the 1997–98 fishing year and catch at age data from a series of trawl surveys of the Southern Plateau (HAK 1) are re-evaluated. We also review estimates of natural mortality (*M*) of hake and conclude that the best estimates of *M* for hake are 0.20 $y^{-1}$ for males and 0.18 $y^{-1}$ for females.

Hake are currently managed as three separate stocks: HAK 1 (mainly the Sub-Antarctic QMAs), HAK 4 (Chatham Rise), and HAK 7 (west coast of the South Island). This report presents updated catch histories for all stocks, and updates the stock assessments for HAK 1 and HAK 4, with the stocks assessed separately. The stock assessment for the HAK 7 fishery was not updated.

The MIAEL estimation method was used for the stock assessments. For both HAK 1 and HAK 4 age data and abundance indices from trawl surveys were available. CPUE indices and a single year's commercial catch-at-age data collected by Ministry of Fisheries scientific observers were available for HAK 4.

The stock assessment for HAK 1 was very uncertain. Inconsistencies and poor precision in the age data and biomass indices resulted in clearly inadequate model fits. The uncertainty is compounded by the absence of any other biomass information, and hence no substantive conclusions can be drawn on the current status of this stock.

The stock assessment for HAK 4 was uncertain; biomass estimates of the stock could be determined only within wide ranges and the MIAEL performance indices were low to moderate. However, if the model assumptions are correct, and recent year class strengths are as strong as have been estimated, then current catch levels pose little risk to the stock in the near future.

The current delineation of the QMA boundary between HAK 1 and HAK 4 on the western Chatham Rise may be cause for concern. The recent changes in fisher behaviour (predominantly driven by changes in fishing practice in the hoki fishery) resulted in an increasingly large proportion of the HAK 1 TACC being fished on the western Chatham Rise — a region that is currently considered to be the HAK 4 stock. Movements of fishing effort between stocks, such as have occurred between HAK 1 and HAK 4, may result in an increased risk when assessing stock status.

## 1. INTRODUCTION

### 1.1 Description of the fishery

Hake (Figure 1) are widely distributed through the middle depths of the New Zealand EEZ mostly south of latitude 40° S (Anderson *et al.* 1998). Adults are mainly distributed from 250 to 800 m, though some have been found as deep as 1200 m, while juveniles (0+) are found in shallower inshore regions (under 250 m) (Hurst *et al.* 2000). Hake are taken by large trawlers, often as bycatch in fisheries targeting other species such as hoki and southern blue whiting, although target fisheries also exist. Present management practices divide the fishery into three main fish stocks: (a) the Challenger QMA (HAK 7), (b) the southeast (Chatham Rise) QMA (HAK 4), and (c) the remainder of the EEZ comprising the Auckland, Central, southeast (Coast), Southland, and Sub-Antarctic QMAs (HAK 1). In addition, an administrative management area exists for the Kermadec QMA (HAK 10), and there are no recorded landings from this area. The Fishery Management Areas (FMAs) are shown in Figure 2.

**Figure 1: A typical catch of hake, mixed with hoki, caught by R.V. *Tangaroa* on the west coast South Island, August 1999.**

The largest fishery is off the west coast of the South Island (HAK 7) where the largest catch (17 000 t) was recorded in 1977, before the establishment of the EEZ (Table 1). The 1998–99 TACC for HAK 7 was 6855 t out of a total for the EEZ of 13 997 t (Table 2). Reported landings from HAK 7 in 1997–98 were 7396 t. This fishery has generally consisted of bycatch in the much larger hoki fishery, but it has undergone a number of changes during the last decade. These include changes to the TACCs of both hake and hoki, and also changes in fishing practices such as gear used, tow duration, and strategies to limit hake bycatch. In some years, notably in 1992 and 1993, there has been a hake target fishery in September after the peak of the hoki fishery; over 2500 t of hake were taken in this target fishery during September 1993. Since then, however, there has been no significant target fishery in September. Bycatch levels of hake early in the 1994–95 and 1995–96 seasons were relatively high and the overall catch in each of these years (8840 t and 8657 t respectively) exceeded the TACC of 6855 t. Although the reported catch dropped to slightly below the TACC in 1996–97, this catch of hake again exceeded the TACC in 1997–98.

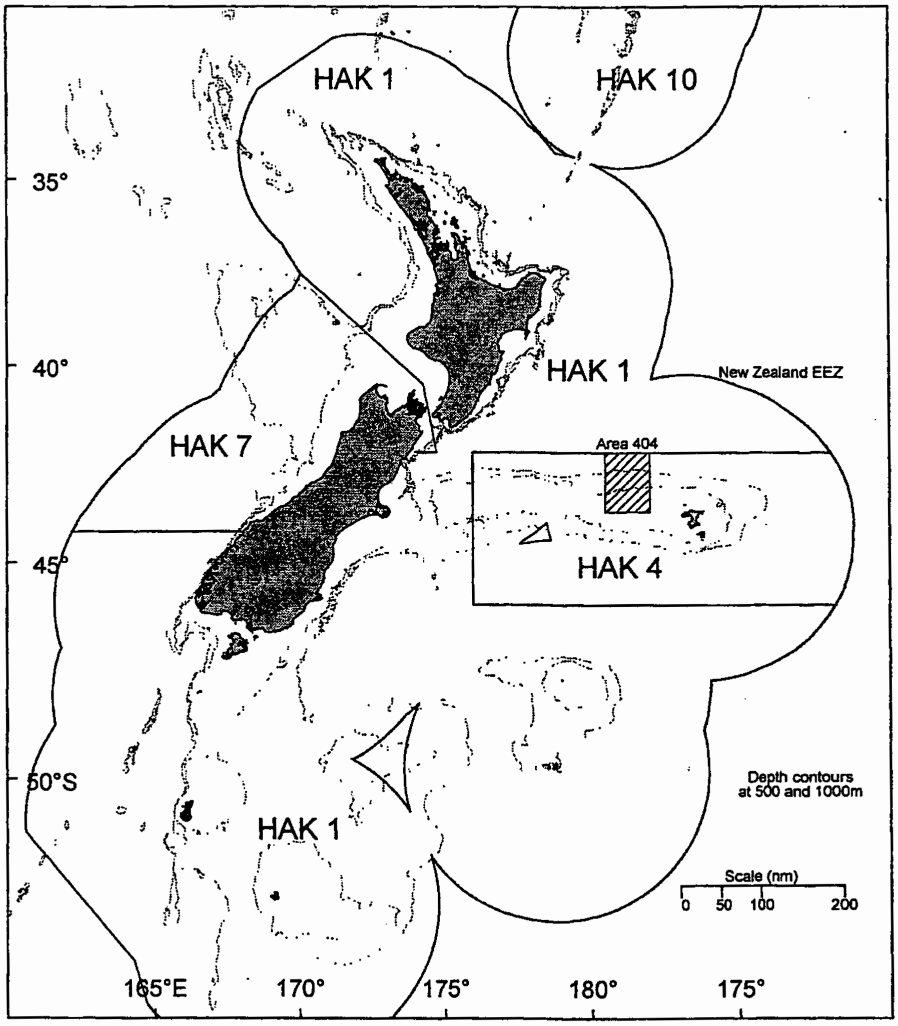


**Figure 2: Quota Management Areas (QMAs) for hake in the New Zealand EEZ. Statistical area 404 in HAK 4 is shown as the hashed region.**

In HAK 1 (where most of the catch originates from the Southern Plateau) and HAK 4 (Chatham Rise), hake have been caught mainly as bycatch by trawlers targeting hoki. However, in both areas some targeting of hake occurs, particularly in Statistical Area 404 for HAK 4 (Figure 2). Increases in TACCs from 2610 t to 3632 t in HAK 1, and from 1000 t to 3500 t in HAK 4, from the 1991–92 fishing year allowed the fleet to increase their landings of hake from these fish stocks. Catches have since risen to the levels of the new TACCs, and have remained at these levels for the past three years.

## 1.2 Literature review

Previous assessments of hake include those by Colman *et al.* (1991) for the 1991–92 fishing year, Colman & Vignaux (1992) for the 1992–93 fishing year, Colman (1997) for the 1997–98 fishing year, and Dunn (1998) for the 1998–99 fishing year.

Since 1991, time series of trawl surveys for inclusion in hake stock assessments have been carried out from R.V. *Tangaroa* in the Sub-Antarctic in November and December 1991, 1992, and 1993 (Chatterton & Hanchet 1994, Ingerson & Hanchet 1995, Ingerson *et al.* 1995) and in April–May 1992 (Schofield & Livingston 1994a), September–October 1992 (Schofield & Livingston 1994b), May–June 1993 (Schofield & Livingston 1994c), March–April 1996 (Colman 1996), and in April–May 1998 (Bagley & McMillan 1999). On the Chatham Rise, trawl surveys from the R.V. *Tangaroa* have been in January, from 1992 to 1998 (Horn 1994a, 1994b, Schofield & Horn 1994, Schofield & Livingston 1995, 1996, 1997, Bagley & Hurst 1998). Where these trawl surveys constitute comparable series the results are used as indicators of relative stock abundance in this assessment (*see* Section 3.3).

Since the previous stock assessment in 1998 (Dunn 1998), Horn (1998) published a study on the stock affinity for hake, revised the hake catch-at-age data, and provided updated productivity parameters for hake. Bull & Bagley (1999) investigated the effect of changes in the Chatham Rise trawl survey design on abundance indices and estimates of numbers of hake by age.

## 2. REVIEW OF THE FISHERY

### 2.1 TACCs, catch, landings, and effort data

Reported catches from 1975 to 1987–88 are shown in Table 1, and reported landings for each fish stock since 1983–84 and TACs since 1986–87 are shown in Table 2. Catches in the last three years were at their highest recorded levels in both HAK 1 and HAK 4. In HAK 7, catches in 1994–95 to 1997–98 were exceeded only in 1977.

Updated standardised CPUE indices (T. Kendrick, pers. com.) for HAK 4 are given in Table 3. Indices for HAK 1 are not available due to inadequate data (Kendrick 1998), and hence were not updated. The HAK 4 CPUE series shows a steady decline since the start of the series in 1991, with a recent rapid upturn since 1996–97.

### 2.2 Recreational and Maori customary fisheries

The recreational fishery for hake is negligible. The amount of hake caught by Maori is not known, but is believed to be negligible.

### 2.3 Other sources of fishing mortality

There is some evidence, from comparison of catches from vessels carrying observers with those not carrying observers, to suggest that catches of hake were not always fully reported in the past — particularly in HAK 7 in 1988–89 to 1990–91 when actual catches were probably considerably higher than reported catches. For these years the ratio of hake to hoki in the catch of vessels carrying observers was significantly higher (Colman & Vignaux 1992) than in the catch of vessels not carrying observers. The actual hake catch in HAK 7 for these years was estimated by multiplying the total hoki catch (which was assumed to be correctly reported by vessels both with and without observers) by the ratio of hake to hoki in the catch of vessels carrying observers. Reported and estimated catches for 1988–89 were respectively 6835 t and 8696 t; for 1989–90, 4903 t reported and 8741 t estimated; and for 1990–91, 6189 t reported and 8246 t estimated. More recently, the level of misreporting has not been estimated and is not known. No such corrections have been applied to either the HAK 1 or

HAK 4 fishery. In addition, there is likely to be some mortality associated with escapement from trawl nets, but its level is not known.

**Table 1: Reported hake catches (t) from 1975 to 1987–88. Data from 1975 to 1983 from MAF; data from 1983–84 to 1985–86 from FSU; data from 1986–87 to 1987–88 from QMS**

| | New Zealand | | | Foreign licensed | | | | |
|---|---|---|---|---|---|---|---|---|
| Fishing year | Domestic | Chartered | Total | Japan | Korea | USSR | Total | Total |
| 1975 [1] | 0 | 0 | 0 | 382 | 0 | 0 | 382 | 382 |
| 1976 [1] | 0 | 0 | 0 | 5 474 | 0 | 300 | 5 774 | 5 774 |
| 1977 [1] | 0 | 0 | 0 | 12 482 | 5 784 | 1 200 | 19 466 | 19 466 |
| 1978–79 [2] | 0 | 3 | 3 | 398 | 308 | 585 | 1 291 | 1 294 |
| 1979–80 [2] | 0 | 5 283 | 5 283 | 293 | 0 | 134 | 427 | 5 710 |
| 1980–81 [2] | | | | No data available | | | | |
| 1981–82 [2] | 0 | 3 513 | 3 513 | 268 | 9 | 44 | 321 | 3 834 |
| 1982–83 [2] | 38 | 2 107 | 2 145 | 203 | 53 | 0 | 255 | 2 400 |
| 1983 [3] | 2 | 1 006 | 1 008 | 382 | 67 | 2 | 451 | 1 459 |
| 1983–84 [4] | 196 | 1 212 | 1 408 | 522 | 76 | 5 | 603 | 2 011 |
| 1984–85 [4] | 265 | 1 318 | 1 583 | 400 | 35 | 16 | 451 | 2 034 |
| 1985–86 [4] | 241 | 2 104 | 2 345 | 465 | 52 | 13 | 530 | 2 875 |
| 1986–87 [4] | 229 | 3 666 | 3 895 | 234 | 1 | 1 | 236 | 4 131 |
| 1987–88 [4] | 122 | 4 334 | 4 456 | 231 | 1 | 1 | 233 | 4 689 |

1. Calendar year
2. 1 April to 31 March
3. 1 April to 30 September
4. 1 October to 30 September

**Table 2: Reported landings (t) of hake by fish stock from 1983–84 to 1998–99 and actual TACs (t) for 1986–87 to 1998–99 ( '–' indicates that the data are unavailable)**

| Fish stock | HAK 1 | | HAK 4 | | HAK 7 | | HAK 10 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| QMA(s) | 1, 2, 3, 5, 6, 8 & 9 | | 4 | | 7 | | 10 | | Total | |
| | Landings | TAC | Landings | TAC | Landings | TAC | Landings | TAC | Landings | TAC |
| 1983–84 [1] | 886 | – | 180 | – | 945 | – | 0 | – | 2 011 | – |
| 1984–85 [1] | 670 | – | 399 | – | 965 | – | 0 | – | 2 034 | – |
| 1985–86 [1] | 1 047 | – | 133 | – | 1 695 | – | 0 | – | 2 875 | – |
| 1986–87 [2] | 1 022 | 2 500 | 200 | 1 000 | 2 909 | 3 000 | 0 | 10 | 4 131 | 6 510 |
| 1987–88 [2] | 1 381 | 2 500 | 288 | 1 000 | 3 019 | 3 000 | 0 | 10 | 4 689 | 6 510 |
| 1988–89 [2] | 1 487 | 2 513 | 554 | 1 000 | 6 835 | 3 004 | 0 | 10 | 8 876 | 6 527 |
| 1989–90 [2] | 2 115 | 2 610 | 763 | 1 000 | 4 903 | 3 310 | 0 | 10 | 7 783 | 6 930 |
| 1990–91 [2] | 2 635 | 2 610 | 743 | 1 000 | 6 189 | 3 310 | 0 | 10 | 9 567 | 6 930 |
| 1991–92 [2] | 3 156 | 3 500 | 2 013 | 3 500 | 3 027 | 6 770 | 0 | 10 | 8 196 | 13 780 |
| 1992–93 [2] | 3 525 | 3 501 | 2 545 | 3 500 | 7 154 | 6 835 | 0 | 10 | 13 224 | 13 846 |
| 1993–94 [2] | 1 803 | 3 501 | 2 587 | 3 500 | 2 973 | 6 835 | 0 | 10 | 7 363 | 13 847 |
| 1994–95 [2] | 2 572 | 3 632 | 3 369 | 3 500 | 8 840 | 6 855 | 0 | 10 | 14 781 | 13 997 |
| 1995–96 [2] | 3 956 | 3 632 | 3 466 | 3 500 | 8 660 | 6 855 | 0 | 10 | 16 082 | 13 997 |
| 1996–97 [2] | 3 534 | 3 632 | 3 524 | 3 500 | 6 118 | 6 855 | 0 | 10 | 13 176 | 13 997 |
| 1997–98 [2] | 3 691 | 3 632 | 3 523 | 3 500 | 7 396 | 6 855 | 0 | 10 | 14 610 | 13 997 |
| 1998–99 | – | 3 632 | – | 3 500 | – | 6 855 | – | 10 | – | 13 997 |

1. FSU data
2. QMS data

**Table 3: HAK 4 CPUE indices by year (defined as running from July to June) and the year assumed in the stock assessment models**

| Year (July–June) | Model year | CPUE index |
|---|---|---|
| 1990–91 | 1990 | 0.575 |
| 1991–92 | 1991 | 0.430 |
| 1992–93 | 1992 | 0.484 |
| 1993–94 | 1993 | 0.419 |
| 1994–95 | 1994 | 0.487 |
| 1995–96 | 1995 | 0.324 |
| 1996–97 | 1996 | 0.715 |
| 1997–98 [1] | – | 1.000 |

1. The CPUE index for 1997–98 year was ignored in the stock assessment model as this value was based on incomplete data

## 3. BIOLOGY, STOCK STRUCTURE, AND RESOURCE SURVEYS

### 3.1 Biology

Horn (1997) validated the use of otoliths to age hake. Readings of otoliths from hake have been used to develop age-length keys to scale length frequency distributions for hake collected on a number of trawl surveys in HAK 1 and HAK 4 and by observers on vessels fishing in the HAK 4 fishery. The resulting age frequency distributions, scaled to the population sampled in the trawl surveys in HAK 1 and HAK 4, and to the total catch for the season in HAK 4, are shown in Appendix A as Figures A1, A2, and A3 with numbers of measurements given in Appendix A as Table A1. Relative observed proportions at age for selected ages from trawl surveys and observer data in HAK 1 and HAK 4 respectively, are shown in Figures 3 and 4.

The New Zealand hake reach a maximum age of at least 25 years of age. Males, which rarely exceed 100 cm total length (TL), do not grow as large as females, which can grow to 120 cm TL or more. Both sexes reach sexual maturity between 6 and 10 years of age, at lengths of about 67–75 cm TL (males) and 75–85 cm TL (females). Colman (1998) concluded that hake reached 50% maturity at between 6–8 years for HAK 1, and 7–8 years for HAK 4 (*see* Table 5).

Estimates of natural mortality (*M*) and the associated methodology are given in Appendix C: *M* is estimated as 0.18 $y^{-1}$ for females, and 0.20 $y^{-1}$ for males. Colman *et al.* (1991) previously estimated *M* as 0.20 $y^{-1}$ for females and 0.22 $y^{-1}$ for males using the maximum age method of Hoenig (1983) (where he defined the maximum ages at which 1% of the population survives in an unexploited stock as 23 years for females and 21 years for males). These are similar, but lower than values proposed by Horn (1997), who determined the age of hake by counting zones in sectioned otoliths, and suggested that it was likely that M was in the range 0.20–0.25 $y^{-1}$.

Data collected by observers on commercial trawlers and from trawl survey data suggest that there are at least three main spawning areas for hake. The best known area is off the west coast of the South Island, where the season can extend from June to October, usually with a peak in September. Spawning is also believed to occur to the west of the Chatham Islands during a prolonged period from at least November to January. Spawning on the Campbell Plateau, primarily to the northeast of the Auckland Islands, may occur from September to February with a peak in September–October. Spawning fish have been recorded occasionally on the Puysegur Bank, with a seasonality that appears similar to that on the Campbell Plateau.

Juvenile hake have been taken in coastal waters on both sides of the South Island and on the Campbell Plateau. They reach a length of about 15–20 cm TL at one year old, and about 35 cm TL at 2 years.

The biological parameters relevant to the stock assessment are given in Table 5.

### 3.2 Stock structure

There are three known hake spawning areas; off the west coast of the South Island, on the Chatham Rise, and on the Campbell Plateau. Juvenile hake are found in all three areas, there are differences in size frequency of hake between the west coast and other areas, and differences in growth parameters between all three areas (Horn 1997). There is some reason, therefore, to believe that at least three separate stocks may exist in the EEZ.

Analysis of morphometric data (Horn 1998) shows little difference between hake from the Chatham Rise and from the east coast of the North Island, but shows highly significant differences between these fish and those from the Sub-Antarctic, Puysegur, and on the west coast. The Puysegur fish are most similar to those from the west coast South Island, although, depending on which variables are used, they cannot always be distinguished from the Sub-Antarctic hake. However, the data are not unequivocal so the stock affinity is uncertain.

For the stock assessment models, the HAK 4 stock was considered to include the whole of the Chatham Rise (including the western end currently forming part of the HAK 1 management area). The HAK 1 stock was considered to contain hake in the Southland and Sub-Antarctic management areas: although fisheries management areas round the North Island are also included in HAK 1, catches of hake in these areas are very small.

### 3.3 Resource surveys

Trawl surveys have been carried out at depths of 300–800 m in HAK 1 and HAK 4 since 1991 by the NIWA research vessel R.V. *Tangaroa* with the same gear and similar survey designs. In HAK 4 there have been seven surveys at the same time of the year (January 1992–1998). However, although the survey designs for 1996–98 were similar, fewer deeper stations were sampled. In HAK 1 the three surveys were carried out in November–December 1991, 1992, and 1993 but the series was then terminated; there was evidence that hake in particular might be aggregated for spawning at that time of the year and that spawning aggregations had a high probability of being missed during a survey. Surveys in April 1992 and May 1993 formed the basis for a second series, repeated in April 1996 and again in April 1998, at which time of the year hake appear to be more evenly distributed through the survey area.

The two most recent surveys in HAK 1 (TAN9605 and TAN9805) increased the survey area in order to include deeper strata (800–1000 m). Earlier surveys of hake included only the depth range 300–800 m (with the occasional survey including 800–1000 m deep strata in the Puysegur region and on the Bounty Platform). Biomass estimates used in the stock assessment models are those for the 300–800 m depth range in order to maintain a consistent time series. These estimates of relative abundance are shown in Table 4. Table A2 shows the biomass estimates for HAK 1 from each of the surveys with different definitions of survey region, and Figure A4 shows the different definitions of survey regions.

**Table 4: Biomass indices (t) and coefficients of variation (*c.v.*) from R.V. *Tangaroa* trawl surveys in depths of 300–800 m for HAK 1 and 200–800 m HAK 4. (These estimates assume that the areal availability, vertical availability, and vulnerability are equal to one.)**

| Fish stock (area) | Voyage code | Date | Biomass | *c.v.* | Reference |
|---|---|---|---|---|---|
| HAK 1 | TAN9105 | Nov–Dec 91 | 5 553 | 0.44 | (Chatterton & Hanchet 1994) |
| (Southland and | TAN9211 | Nov–Dec 92 | 1 822 | 0.12 | (Ingerson *et al.* 1995) |
| Sub-Antarctic) | TAN9310 | Nov–Dec 93 | 2 586 | 0.12 | (Ingerson & Hanchet 1995) |
| | TAN9204 | Apr–May 92 | 5 028 | 0.15 | (Schofield & Livingston 1994a) |
| | TAN9304 | May–Jun 93 | 3 221 | 0.14 | (Schofield & Livingston 1994c) |
| | TAN9605 | Mar–Apr 96 | 2 046 | 0.12 | (Colman 1996) |
| | TAN9805 | Apr–May 98 | 2 554 | 0.18 | (Bagley & McMillan 1999) |
| | TAN9209 | Sep–Oct 92 | 3 760 | 0.15 | (Schofield & Livingston 1994b) |
| HAK 4 | TAN9106 | Dec–Jan 92 | 4 180 | 0.15 | (Horn 1994a) |
| (Chatham Rise) | TAN9212 | Dec–Feb 93 | 2 950 | 0.17 | (Horn 1994b) |
| | TAN9401 | Jan 94 | 3 353 | 0.10 | (Schofield & Horn 1994) |
| | TAN9501 | Jan 95 | 3 303 | 0.23 | (Schofield & Livingston 1995) |
| | TAN9601 | Jan 96 | 2 457 | 0.13 | (Schofield & Livingston 1996) |
| | TAN9701 | Jan 97 | 2 811 | 0.17 | (Schofield & Livingston 1997) |
| | TAN9801 | Jan 98 | 2 873 | 0.18 | (Bagley & Hurst 1998) |

**Table 5: Estimates of biological parameters**

| Fish stock | | | Estimate | | | | Source |
|---|---|---|---|---|---|---|---|
| *Natural mortality (M)* | | | | | | | |
| | | | Males | | | Females | |
| HAK 1 | | | 0.20 | | | 0.18 | (*see* Appendix C) |
| HAK 4 | | | 0.20 | | | 0.18 | (*see* Appendix C) |
| *Weight = a·(length)$^b$ (Weight in g, length in cm)* | | | | | | | |
| | | | Males | | | Females | |
| HAK 1 | a = 0.00395 | b = 3.130 | | a = 0.00186 | b = 3.313 | | (Horn 1998) |
| HAK 4 | a = 0.00249 | b = 3.234 | | a = 0.00170 | b = 3.328 | | (Horn 1998) |
| *Von-Bertalanffy growth parameters* | | | | | | | |
| | | | Males | | | Females | |
| | K | $T_0$ | $L_{inf}$ | K | $t_0$ | $L_{inf}$ | |
| HAK 1 | 0.263 | –0.06 | 90.8 | 0.188 | –0.13 | 115.0 | (Horn 1998) |
| HAK 4 | 0.277 | –0.11 | 90.3 | 0.202 | –0.20 | 113.4 | (Horn 1998) |
| *Age at 50% maturity* | | | | | | | |
| | | | Males | | | Females | |
| HAK 1 | | | 6–7 | | | 7–8 | (Colman 1998) |
| HAK 4 | | | 7 | | | 8 | (Colman 1998) |

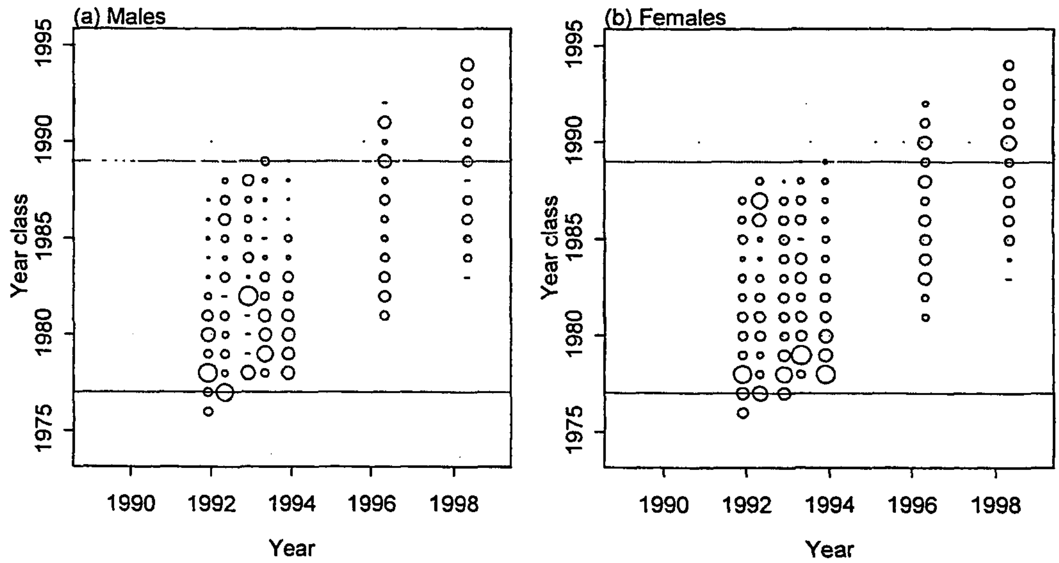


**Figure 3: Age frequencies (ages 3 to 14) by year class and year (symbol area proportional to the proportions at age within sampling event) in the HAK 1 trawl surveys for (a) males, and (b) females. Zero values are represented by a dash, and horizontal lines indicate the earliest (1977) and latest (1989) year class strengths estimated in the stock assessment model.**

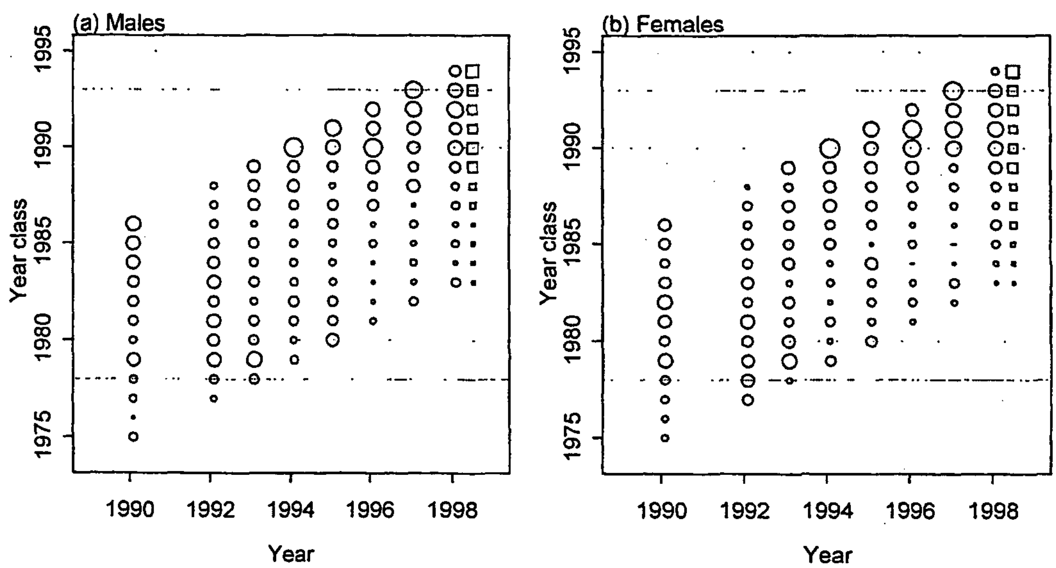


**Figure 4: Age frequencies (ages 3 to 14) by year class and year (symbol area proportional to the proportions at age within sampling event) in the HAK 4 trawl surveys (circles) and commercial catch-at-age data (squares) for (a) males, and (b) females. Zero values are represented by a dash, and horizontal lines indicate the earliest (1978) and latest (1993) year class strengths estimated in the stock assessment model.**

# 4. MODEL STRUCTURE AND BIOMASS ESTIMATES

## 4.1 Model methods, input parameters, and assumptions

Estimates of midseason virgin biomass ($B_0$), 1999 midseason biomass ($B_{mid99}$), estimates of 2000 beginning of year biomass ($B_{beg00}$), and 2000 midseason biomass ($B_{mid00}$) were obtained using the least squares and MIAEL estimation techniques of Cordue (1995), using the single stock model as detailed by Cordue (1998). Minor modifications to the model used for this assessment were described in detail by Cordue (2000). In brief, these consisted of introducing penalty functions to the home ground selectivity and trawl survey catchability estimates, so that the selectivities by age were encouraged to be cubic polynomials with female selectivity less than male selectivity at age. In addition, the mean of estimated relative year class strengths were encouraged so as to equal one.

Relative abundance indices were available for HAK 1 and HAK 4 from the results of trawl surveys (*see* Section 3.3). CPUE indices (Section 2.1) and a single year's commercial catch-at-age data collected by Ministry of Fisheries scientific observers were available for HAK 4 only.

Catch data are available for each year since 1975. Because there is some evidence that hake on the western end of the Chatham Rise should be included with these on the rest of the Rise, catches in HAK 1 and HAK 4 have been adjusted by moving catches recorded from the western end of the rise from HAK 1 into HAK 4. This has the effect of raising the recorded catches in HAK 4 and reducing them in HAK 1 — with a marked effect in more recent years. These estimates update those presented in previous years assessments, with landings estimated using the recorded location of individual catches from TCEPR records (Bull & Bagley 1999). The catch histories used in the stock assessments are given in Table A3.

Estimates of biological parameters and of model parameters used in the assessments are given in Tables 5 and 6 respectively. The proportion spawning is assumed to be 1.0 in the absence of data to estimate this parameter.

The maximum exploitation rate is assumed to be 0.4 on the home ground ($r_{hm\_max}$) for HAK 1 and HAK 4. The value of $r_{hm\_max}$ determines $B_{min}$, the lowest value of $B_0$ that is consistent with the catch history. An instantaneous spawning season was assumed for both HAK 1 and HAK 4, with all catch assumed to be taken from the home ground. Hence, no assumption for the maximum exploitation rate for the spawning ground was required.

The minimax exploitation rate on the home ground ($r_{hm\_mmx}$) is the lowest value that the exploitation rate is believed to have been in the year that the catch was highest (*see* Table 6). As for the maximum exploitation rate, the assumption of an instantaneous spawning season with no associated catch meant that no assumptions of the minimax exploitation on the spawning ground were required. Assumptions about $r_{hm\_mmx}$ determine the value of $B_{max}$, the highest level that is believed to be feasible for $B_0$. The values of $B_{min}$ and $B_{max}$ are used as bounds for estimates of $B_0$ for the MIAEL estimation.

The maturity ogive represents the proportion of fish (in the virgin stock) at each age which are estimated to be mature. Maturity values at age for HAK 1 and HAK 4 were assumed known, and were based on preliminary fits to the 1998 HAK 7 assessment (Dunn 1998), using the commercial catch-at-age data, under an assumption that all the year class strengths were 1 (*see* Table 6).

The selectivity ogive represents the proportion of fish at each age that are vulnerable to the fishing process. The home ground selectivity for HAK 4 was estimated within the model using penalty functions to encourage the estimated selectivities to be cubic polynomials, with female selectivity less than male selectivity at age. No data were available to estimate the HAK 1 home ground selectivity, and hence the home ground selectivity was assumed (*see* Table 6).

The corridor ogive describes the movement of juvenile fish from the nursery ground to the home ground and was assumed to be 1 for both male and female fish aged 1+, i.e., all juvenile fish were assumed to move onto the home ground immediately following hatching.

The mean *c.v.* for trawl surveys was assigned a value of 0.35 for HAK 1, and either 0.25, 0.30, or 0.35 for HAK 4 (depending on whether or not the trawl survey in a particular year was optimised for hake as well as the number of stations in the survey). Trawl survey catchability ogives were estimated in the model, using similar constraints as for the home ground selectivities. Estimated values of the catchability constant ($q$) were also calculated.

Observer age frequency data (HAK 4) were assigned a *c.v.* of 0.35. CPUE indices (HAK 4) were assigned a *c.v.* of 0.35 and given a relative weighting in the model of 0.5. Estimated values of the catchability constant $q$ were also calculated.

**Table 6: Model input parameters (base case), HAK 1 and HAK 4**

| Parameter | | Fish stock | Value |
|---|---|---|---|
| Steepness (Beverton & Holt stock-recruitment relationship) | | HAK 1 & 4 | 0.90 |
| Recruitment variability | | HAK 1 & 4 | 0.6 |
| Proportion spawning | | HAK 1 & 4 | 1.0 |
| Spawning season length | | HAK 1 & 4 | 0 |
| Juvenile corridor ogive (for ages 1+) | | HAK 1 & 4 | 1.0 |
| Natural mortality ($M$) | Male | HAK 1 & 4 | 0.20 |
| | Female | HAK 1 & 4 | 0.18 |
| Maximum exploitation on the home ground ($r_{hm\_max}$) | | HAK 1 & 4 | 0.4 |
| Minimax exploitation the on home ground ($r_{hm\_mmx}$) | | HAK 1 & 4 | 0.02 |
| Maturity ogive (for ages 4–8 & 9+) | Male | HAK 1 & 4 | 0.02, 0.07, 0.31, 0.78, 1.00, 1.00 |
| | Female | HAK 1 & 4 | 0.02, 0.04, 0.07, 0.45, 0.86, 1.00 |
| Ageing error | | HAK 1 & 4 | ± 15% for ages ≥ 3 |
| Home ground selectivity (for males and females aged 1–8 & 9+) | | HAK 1 | 0.01, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 0.9, 1.0 |
| Model *c.v.* for trawl surveys | | HAK 1 | 0.35 |
| | | HAK 4 | 0.25 (TAN9212, TAN9401, TAN9501)<br>0.30 (TAN9106, TAN9801)<br>0.35 (TAN9601, TAN9701) |
| Model *c.v.* for observer age data | | HAK 4 | 0.35 |
| Model *c.v.* for CPUE indices | | HAK 4 | 0.35 |
| Relative weights CPUE : trawl survey : observer data | | HAK 4 | 0.5 : 1.0 : 1.0 |

Modelling was conducted in two steps. The first step used the estimated numbers-at-age data derived from the trawl survey and proportions-at-age from the scientific observer commercial catch-at-age data. Least squares estimates (LSQ estimates) of $B_0$, year class strength, home ground selectivity (in the case of HAK 4) and trawl survey catchabilities were determined.

These estimates were used with the model to calculate a LSQ estimate of $B_{beg00}$, $B_{mid99}$, and $B_{mid00}$. The LSQ estimates are reported for each stock below. The second step used the MIAEL estimation procedure to calculate a "MIAEL least squares estimate" (MIAEL LSQ estimate) and a MIAEL estimate for $B_0$, $B_{beg00}$, $B_{mid99}$, and $B_{mid00}$. At this step, biomass indices from the respective trawl surveys replaced the numbers-at-age estimates, and the estimated proportions-at-age data from the commercial catch-at-age data were removed. The model was refitted and the MIAEL LSQ estimates of $B_0$, $B_{beg00}$, $B_{mid99}$, and $B_{mid00}$ determined. MIAEL estimation was conducted on these revised estimates to obtain estimates of the respective parameters and the subsequent MIAEL performance indices.

Also from the first step, the LSQ estimates of the nuisance parameters and biomass are presented with bootstrap 95% confidence intervals for the base case assessments for HAK 4 only. Bootstrap estimates were generated using the original model structure by: (1) using the estimated parameters, running the model to get an estimate of the true biomass, numbers at age, and selectivity parameters for which there are observations; (2) using the assumed *c.v.*s and distributional assumptions in the model to generate a simulated data set; and (3) refit the model using the simulated data as the observed data. In addition, home ground selectivity ogives and trawl survey catchabilities were constrained to lie between 0.01 and 5 by age, and relative year class strengths were constrained to lie between 0.01 and 10. No bounds for virgin biomass were imposed: 1000 bootstrap samples were generated, and 95% percentile confidence intervals generated.

## 4.2 Biomass estimates for HAK 1 (Southland and Sub-Antarctic)

Base case estimates of HAK 1 biomass were estimated using the biological parameters (Table 5) and model input parameters (Table 6), with relative year class strength and trawl survey catchabilities estimated without bounds. In addition to the base case, four sensitivity analyses were also carried out (Table 7). As the base case assessment suggested a shallow ogive for the trawl survey catchability for the two surveys combined, the catchability was fixed to have a constantly increasing ogive by age (and hereafter called fixed catchability). The effect of the strong assumptions of natural mortality ($M = 0.20$ $y^{-1}$ and 0.18 $y^{-1}$ for males and females respectively) was investigated by sensitivity analyses where $M$ was assumed to be higher (high $M$, where $M = 0.26$ $y^{-1}$ and 0.23 $y^{-1}$) and lower (low M, $M = 0.18$ $y^{-1}$ and 0.15 $y^{-1}$). The effect of assuming a single catchability ogive for both the trawl survey series was investigated by allowing a separate ogive for each (separate ogives).

**Table 7: Description of the base case and the sensitivity analyses for HAK 1, and the resulting least squares estimate (LSQ) of $B_0$ and model residual sum of squares (SSQ)**

| Sensitivity | Description | LSQ | SSQ |
|---|---|---|---|
| Base | Base case | 18 064 | 63.8 |
| Fixed catchability | Fixed trawl survey catchability ogive | 52 175 | 67.9 |
| High $M$ | Assumed that male $M = 0.26$ and female $M = 0.23$ | 20 921 | 63.4 |
| Low $M$ | Assumed that male $M = 0.18$ and female $M = 0.15$ | 18 884 | 63.7 |
| Separate ogives | Separate catchability ogives for both trawl surveys | 20 417 | 60.9 |

The estimates of nuisance parameters are shown in Appendix A. Table A4 shows the estimated values of the trawl survey catchability coefficients ($q$s). Figures A5 to A9 show the estimates of year class strengths and trawl survey catchabilities, and the assumed maturity ogive and home ground selectivities, for the base case and each of the sensitivity analyses. The LSQ, MIAEL LSQ, and MIAEL estimates of biomass for the base and sensitivity analyses are given in Table 9, and estimates of relative year class strengths are given in Table 8.

Model diagnostics for the HAK 1 data showed evidence of departure from assumptions of constant variance and normally distributed errors (Figure 5), and hence poor fit. In addition, the diagnostics suggested that the zero values in the observed numbers-at-age data may have had undue influence on the resulting model fits. The high observed variation in the age estimates, derived from the trawl survey data (*see* Figure 3), along with low proportions of hake in the lower age classes, suggested that the input data for the model were also highly uncertain (resulting from the small, often inconsistent, samples of hake caught in trawl surveys on the Sub-Antarctic).

MIAEL estimates of biomass had low performance indices and tended to be higher than the LSQ estimates. The MIAEL estimate of current biomass ($B_{mid99}$) was 15% $B_0$ (range 2–88%), although the performance index for this parameter was moderate (46 ± 24%). Estimated relative year class strengths given in Table 8, and LSQ and MIAEL estimates of biomass for the sensitivities are given in Table 9. The LSQ trajectories, along with the bounds $B_{min}$ and $B_{max}$ are shown in Figure 6 for the base and sensitivity analyses.

Because of the uncertainty in the trawl survey age data and biomass indices and in assumptions of the biological parameters, the uncertainty associated with this assessment should be considered to be high. As the only information on stock status results from these data, no substantive conclusions can be drawn about the current status of this stock.

**Table 8: Estimated year class strengths (YCS)[1] for the base case and the sensitivity analyses for HAK 1 (*refer* to Table 7 for descriptions of the sensitivity analyses)**

| Year | Base | Fixed catchability | High *M* | Low *M* | Separate ogives |
|---|---|---|---|---|---|
| 1977 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1978 | 2.43 | 5.24 | 3.46 | 2.26 | 2.41 |
| 1979 | 0.22 | 0.30 | 0.16 | 0.25 | 0.01 |
| 1980 | 0.69 | 1.13 | 0.78 | 0.69 | 0.01 |
| 1981 | 0.89 | 0.70 | 0.90 | 0.82 | 2.41 |
| 1982 | 2.35 | 1.20 | 2.25 | 2.22 | 1.83 |
| 1983 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1984 | 1.06 | 0.57 | 0.95 | 1.10 | 0.84 |
| 1985 | 1.48 | 0.46 | 1.24 | 1.54 | 1.62 |
| 1986 | 0.01 | 0.14 | 0.01 | 0.01 | 0.01 |
| 1987 | 1.50 | 0.86 | 1.30 | 1.54 | 1.95 |
| 1988 | 1.10 | 0.76 | 0.90 | 1.15 | 1.34 |
| 1989 | 1.10 | 1.46 | 0.85 | 1.28 | 0.59 |
| Mean YCS | 0.99 | 0.99 | 0.99 | 0.99 | 1.00 |

1. Year class strengths not estimated were assumed to be 1.

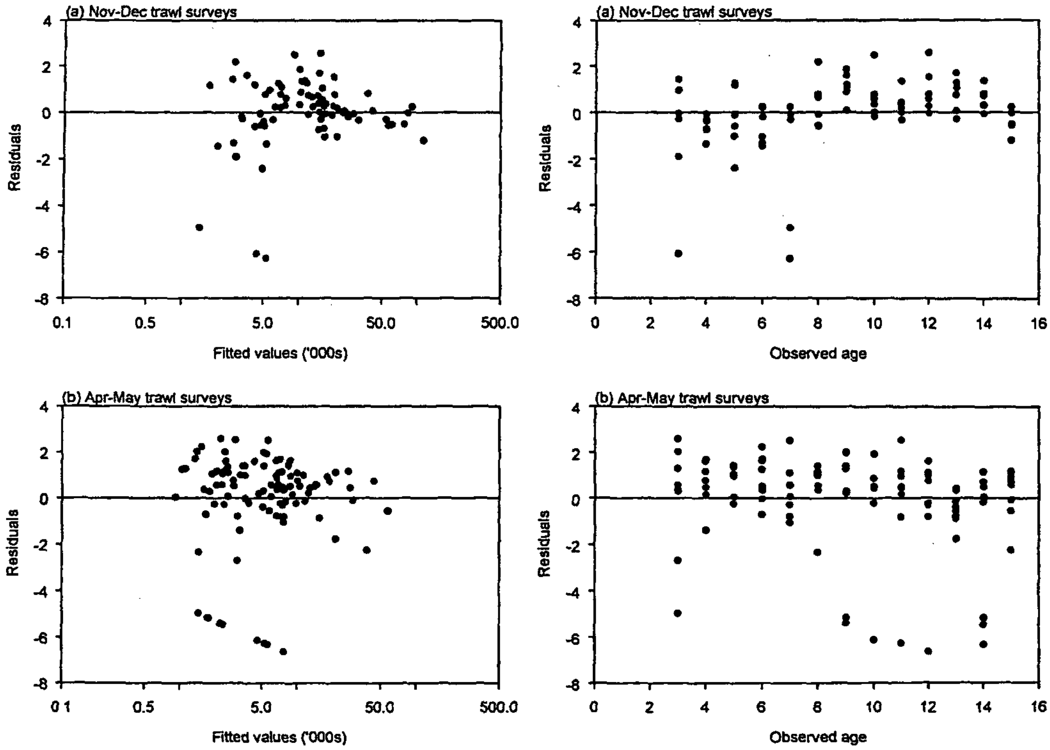


**Figure 5: Diagnostic plots for the base case assessment for HAK 1 showing fitted values against standardised residuals (left side graphs) and observed age against standardised residuals (right side graphs) for (a) Nov-Dec trawl surveys, and (b) Apr-May trawl surveys.**

**Table 9: HAK 1 least squares (LSQ), bounds, MIAEL least squares, and MIAEL estimates of biomass, and performance indices (with approximate 95% confidence range) for the base case and sensitivity analyses. Estimates are presented either in tonnes ($B_0$ and $B_{beg00}$) or as %$B_0$ ($B_{mid99}$ and $B_{mid00}$)**

| Parameter | Sensitivity | LSQ | Bounds ($B_{min}$–$B_{max}$) | MIAEL LSQ | MIAEL | Performance Index (%) |
|---|---|---|---|---|---|---|
| $B_0$ | Base | 18 064 | 12 950–98 400 | 16 864 | 27 236 | 17 (±7) |
| | Fixed catchability | 52 175 | 13 900–110 350 | 21 532 | 30 105 | 20 (±7) |
| | High *M* | 20 921 | 10 350–84 100 | 15 641 | 22 404 | 21 (±7) |
| | Low *M* | 18 884 | 14 900–109 200 | 18 524 | 30 955 | 16 (±6) |
| | Separate ogives | 20 417 | 12 800–95 750 | 16 604 | 26 814 | 17 (±6) |
| $B_{mid99}$ | Base | 27% | 2–87% | 22% | 15% | 43 (±7) |
| | Fixed catchability | 65% | 2–78% | 30% | 20% | 52 (±6) |
| | High *M* | 43% | 1–81% | 26% | 17% | 54 (±9) |
| | Low *M* | 22% | 3–89% | 20% | 15% | 39 (±7) |
| | Separate ogives | 65% | 2–88% | 21% | 15% | 44 (±8) |
| $B_{beg00}$ | Base | 15 155 | 4 625–155 919 | 12 877 | 15 627 | 30 |
| $B_{mid00}$ | Base | 23% | 4–87% | 18% | 15% | 29 (±8) |

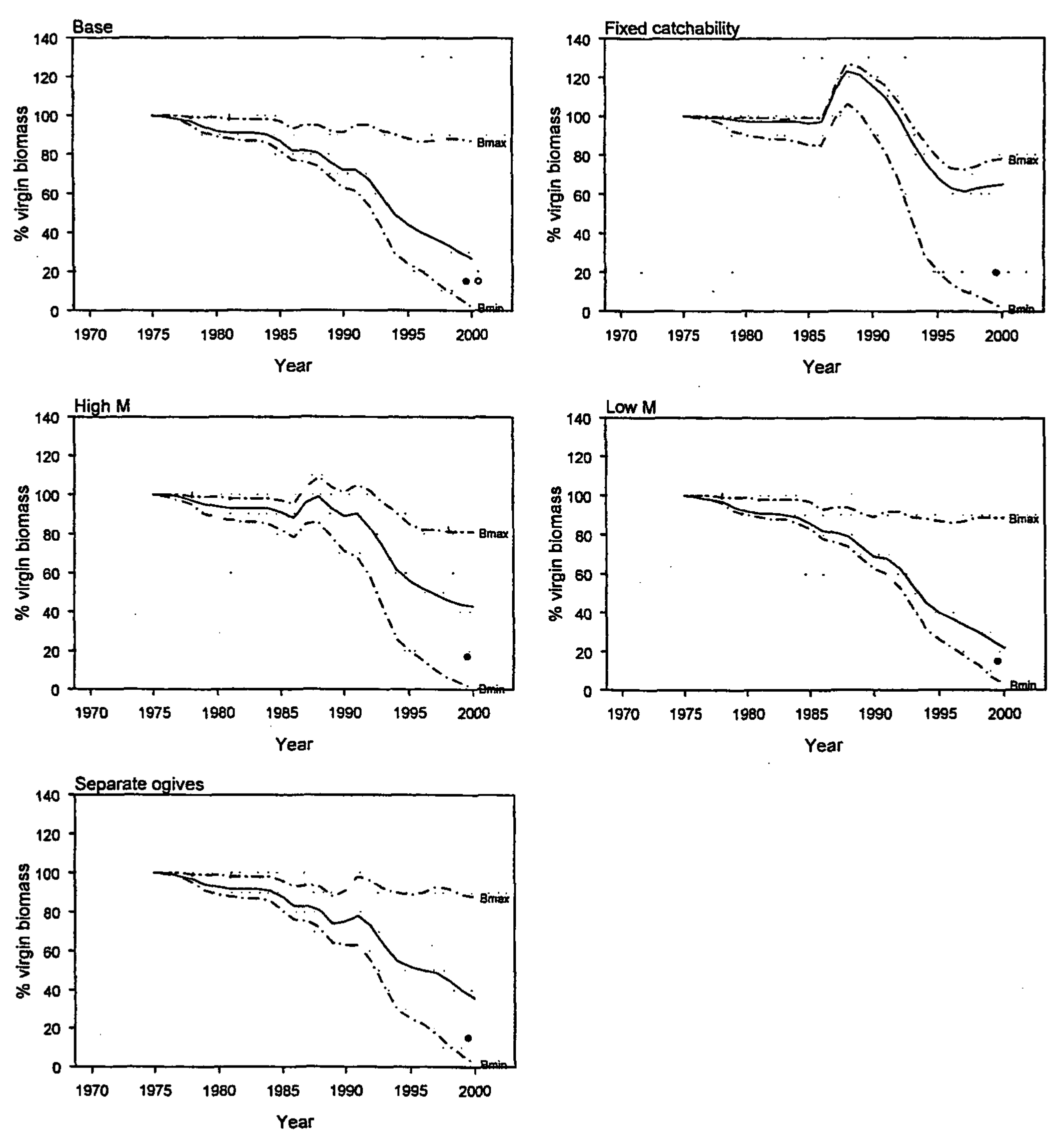


**Figure 6: Estimated biomass trajectories for HAK 1 for $B_0$ at $B_{max}$ and $B_{min}$ for the base case and each of the sensitivity analyses. The positions of the current biomass ($B_{mid99}$) and base case only projected biomass ($B_{mid00}$) as estimated by the MIAEL method are also shown (filled circle and open circle respectively).**

## 4.3 Biomass estimates for HAK 4 (Chatham Rise)

Base case estimates of HAK 4 biomass were obtained using the biological parameters (*see* Table 5) and model input parameters (*see* Table 6) above, and the estimates of relative year class strength, home ground selectivity, and trawl survey catchability were estimated without bounds. Several sensitivity analyses were also carried out. The sensitivity analyses are described in Table 10, together with the least squares estimate of $B_0$ and the associated residual sum of squares. Estimates of nuisance parameters are shown in Appendix A. Table A5 shows the estimated values of the trawl survey and CPUE catchability coefficients ($q$s). Figures A10 to A16 show the estimates of year class strengths, home ground selectivities, trawl survey catchabilities, and the assumed maturity ogive for the base case and the sensitivity analyses.

Estimated relative year class strengths for the base and sensitivity analyses are given in Table 11. Least squares and MIAEL estimates of biomass for the base case are given in Table 12.

Model diagnostics for the HAK 4 model are shown in Figure 7. In addition to MIAEL estimates, least squares simulations of virgin biomass, biomass trajectories, relative year class strengths, home ground selectivities, and trawl survey catchability were done. These estimates (and bootstrap 95% confidence intervals) are given as Figure 8.

Least squares simulations for HAK 4 suggested that the current biomass ($B_{mid99}$) was 30–87% $B_0$ (5 700–31 000 t). Simulations were carried out as described earlier. The simulations suggested great uncertainty in estimates of home ground selectivities, although trawl survey catchability estimates appeared consistent, as did the estimates of relative year class strength.

MIAEL estimates of biomass were higher than that for the LSQ (as can seen by the difference in the point estimates of current biomass $B_{mid99}$ of 64% as against 49%). Differences between the LSQ and MIAEL LSQ estimates derive from the two step procedure. The removal of the numbers-at-age data and subsequent inclusion of biomass indices coerced the MIAEL LSQ estimates to the upper bound ($B_{max}$).

Model fits for the HAK 4 data appeared better than for HAK 1 (*see* Figure 7), and the associated sums of squares values were correspondingly smaller (*see* Table 10) The fewer zero values within the numbers-at-age data derived from trawl surveys appeared to have less influence on overall fit. Sensitivity analyses appeared consistent, with the MIAEL estimates of biomass having moderate performance indices (*see* Table 12). Current biomass ($B_{mid99}$) is estimated to be 64% $B_0$ (range 8–86%; performance index 59±6%). Estimated recruitment to this stock appears to have been relatively weak through most of the 1980s following a strong year class in 1979, though recent estimated year class strengths are high.

Least squares and MIAEL estimates of biomass for the sensitivities are given in Table 12, with estimated relative year class strengths given in Table 11. The least squares trajectories, along with the bounds $B_{min}$ and $B_{max}$ are shown in Figure 9 for the base case and the sensitivity analyses.

**Table 10: Description of the base case and the sensitivity analyses for HAK 4, and the resulting least squares estimate (LSQ) of $B_0$ (t) and model residual sum of squares (SSQ)**

| Sensitivity | Description | LSQ | SSQ |
|---|---|---|---|
| Base | Base case | 37 784 | 44.8 |
| Adjusted 11+F | Adjusted zero values of 11+ Female trawl survey observations upwards | 36 786 | 26.0 |
| High $M$ | Assumed that male $M = 0.26$ and female $M = 0.23$ | 44 279 | 43.2 |
| Low $M$ | Assumed that male $M = 0.18$ and female $M = 0.15$ | 41 445 | 45.9 |
| Excluding CPUE | Excluded CPUE from estimation model | 33 150 | 42.2 |
| Increased SO weight | Increased the relative weights of the scientific observer commercial catch-at-age (SO) data so that the relative weights of CPUE : trawl survey : observer data were 0.5 : 1.0 : 2.0 | 35 359 | 46.6 |
| Increased age *c.v.* | Increased the assumed *c.v.* on age observations to 0.5 for observer data, and 0.35, 0.40, and 0.45 for trawl survey data. | 35 993 | 46.2 |

**Table 11: Estimated year class strengths (YCS)[1] for the base case and the sensitivity analyses for HAK 4** (*refer* to Table 10 for descriptions of the sensitivity analyses)

| Year | Base | Adjusted 11+F | High *M* | Low *M* | Excluding CPUE | Increased SO weight | Increased age *c.v.* |
|---|---|---|---|---|---|---|---|
| 1978 | 0.52 | 0.47 | 0.65 | 0.50 | 0.53 | 0.43 | 0.39 |
| 1979 | 1.70 | 1.59 | 1.77 | 1.73 | 1.78 | 1.56 | 1.78 |
| 1980 | 0.91 | 0.82 | 0.92 | 0.94 | 0.93 | 0.84 | 0.86 |
| 1981 | 1.03 | 0.98 | 1.01 | 1.06 | 1.07 | 0.98 | 0.94 |
| 1982 | 0.85 | 0.67 | 0.91 | 0.90 | 0.88 | 0.83 | 1.22 |
| 1983 | 0.66 | 0.69 | 0.61 | 0.65 | 0.68 | 0.66 | 0.53 |
| 1984 | 0.37 | 0.45 | 0.36 | 0.38 | 0.37 | 0.41 | 0.24 |
| 1985 | 0.49 | 0.56 | 0.49 | 0.49 | 0.49 | 0.52 | 0.82 |
| 1986 | 0.39 | 0.43 | 0.37 | 0.38 | 0.38 | 0.42 | 0.14 |
| 1987 | 0.81 | 0.82 | 0.80 | 0.81 | 0.78 | 0.86 | 0.99 |
| 1988 | 0.47 | 0.51 | 0.44 | 0.47 | 0.45 | 0.49 | 0.41 |
| 1989 | 1.19 | 1.24 | 1.11 | 1.19 | 1.13 | 1.31 | 1.20 |
| 1990 | 2.15 | 2.23 | 2.03 | 2.16 | 2.02 | 2.19 | 2.17 |
| 1991 | 1.58 | 1.62 | 1.55 | 1.56 | 1.53 | 1.61 | 1.51 |
| 1992 | 1.49 | 1.53 | 1.51 | 1.46 | 1.50 | 1.55 | 1.49 |
| 1993 | 1.45 | 1.50 | 1.50 | 1.42 | 1.55 | 1.42 | 1.40 |
| Mean YCS | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

1. Year class strengths not estimated were assumed to be 1.

**Table 12: HAK 4 least squares (LSQ), bounds, MIAEL least squares, and MIAEL estimates of biomass, and performance indices (with approximate 95% confidence range) for the base case and sensitivity analyses. Estimates are presented either in tonnes ($B_0$ and $B_{beg00}$) or as %$B_0$ ($B_{mid99}$ and $B_{mid00}$)**

| Parameter | Sensitivity | LSQ | Bounds ($B_{min}$–$B_{max}$) | MIAEL LSQ | MIAEL | Performance Index (%) |
|---|---|---|---|---|---|---|
| $B_0$ | Base | 37 784 | 19 900–142 750 | 142 509 | 82 442 | 32 (±5) |
| | Adjusted 11+F | 36 786 | 19 640–140 455 | 132 926 | 110 475 | 36 (±1) |
| | High *M* | 44 279 | 14 976–111 555 | 111 532 | 67 867 | 38 (±4) |
| | Low *M* | 41 445 | 23 455–161 916 | 161 728 | 90 923 | 28 (±5) |
| | Excluding CPUE | 33 150 | 19 700–144 200 | 142 351 | 81 640 | 32 (±5) |
| | Increased SO weight | 35 359 | 19 640–140 250 | 138 064 | 80 877 | 33 (±4) |
| | Increased age *c.v.* | 35 993 | 19 740–141 900 | 141 108 | 104 808 | 27 (±1) |
| $B_{mid99}$ | Base | 49% | 8–86% | 86% | 64% | 59 (±6) |
| | Adjusted 11+F | 49% | 8–88% | 87% | 67% | 59 (±5) |
| | High *M* | 65% | 6–87% | 87% | 68% | 67 (±4) |
| | Low *M* | 46% | 10–85% | 85% | 60% | 51 (±7) |
| | Excluding CPUE | 40% | 7–84% | 84% | 64% | 62 (±5) |
| | Increased SO weight | 47% | 8–88% | 88% | 66% | 60 (±5) |
| | Increased age *c.v.* | 47% | 9–87% | 87% | 58% | 43 (±10) |
| $B_{beg00}$ | Base | 46 189 | 8 404–252 048 | 251 578 | 125 579 | 43 |
| $B_{mid00}$ | Base | 49% | 5–92% | 92% | 64% | 54 (±10) |

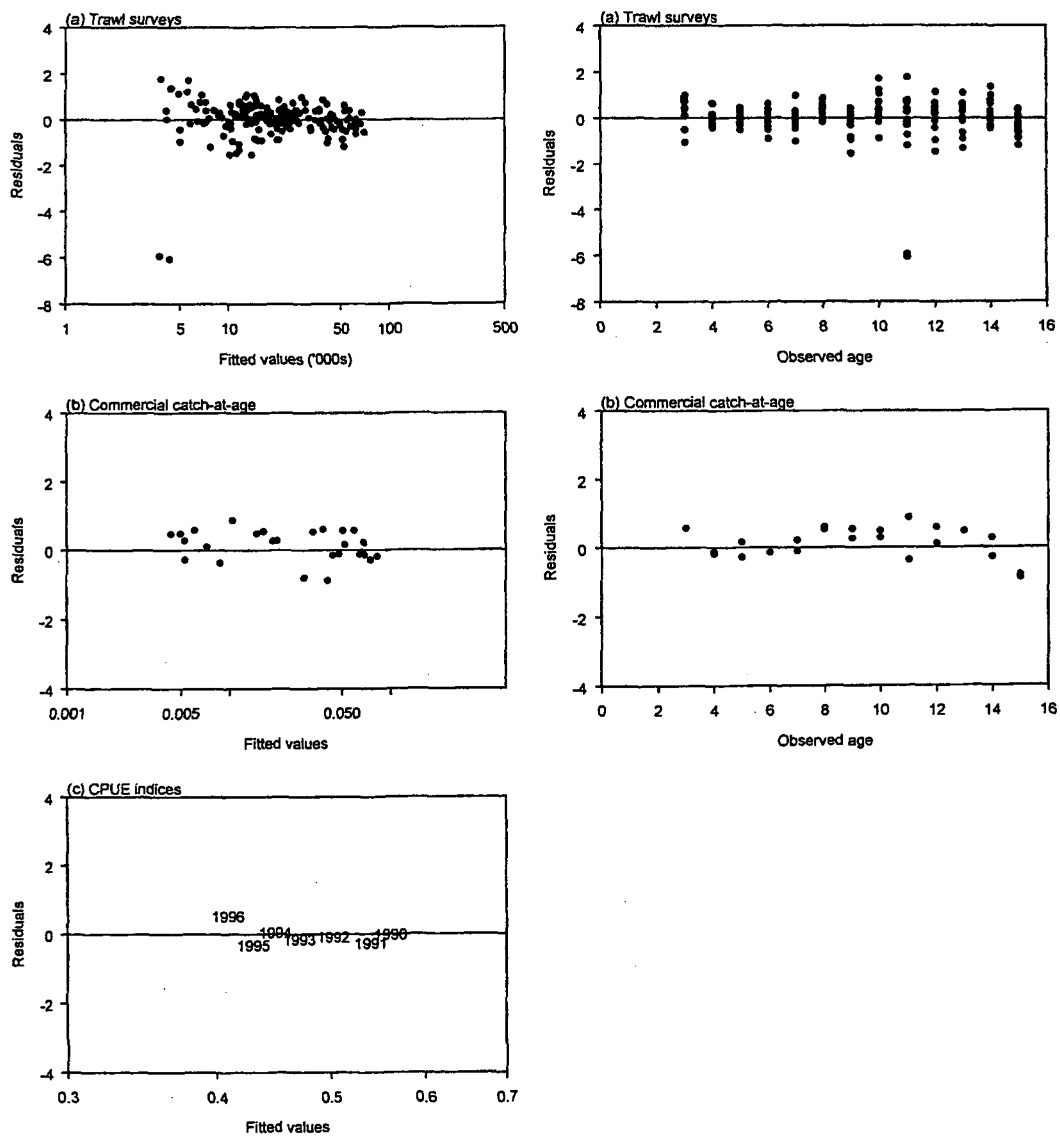


**Figure 7: Diagnostic plots for the base case assessment for HAK 4, showing fitted values against standardised residuals (left side graphs) and observed age against standardised residuals (right side graphs) for (a) trawl surveys, (b) scientific observer commercial catch-at-age data, and (c) CPUE indices (with points marked by year).**

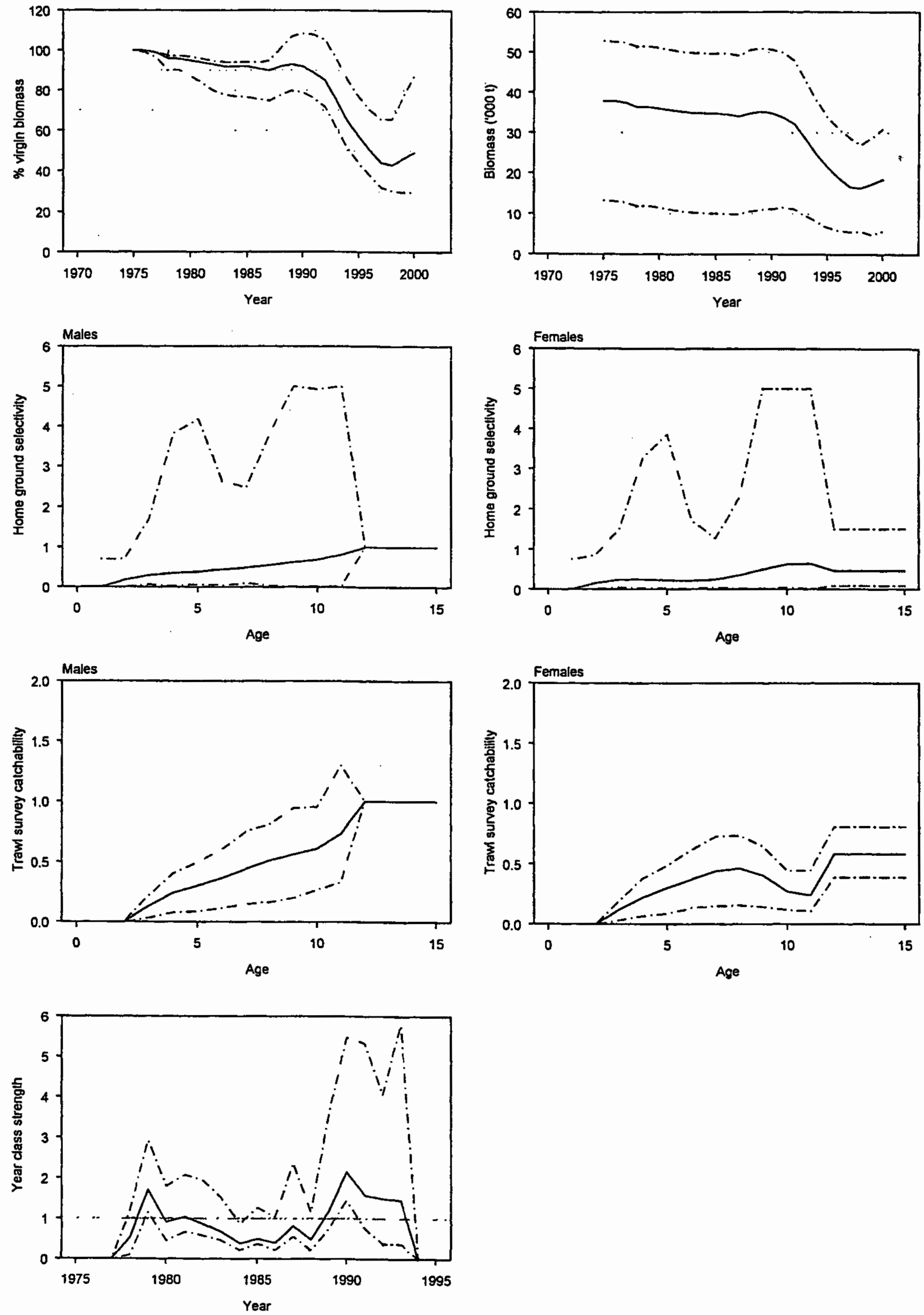


**Figure 8: Least squares estimates (LSQ) and bootstrap 95% confidence intervals of virgin biomass, biomass trajectories, home ground selectivities, trawl survey catchabilities, and relative year class strengths for HAK 4 (base case).**

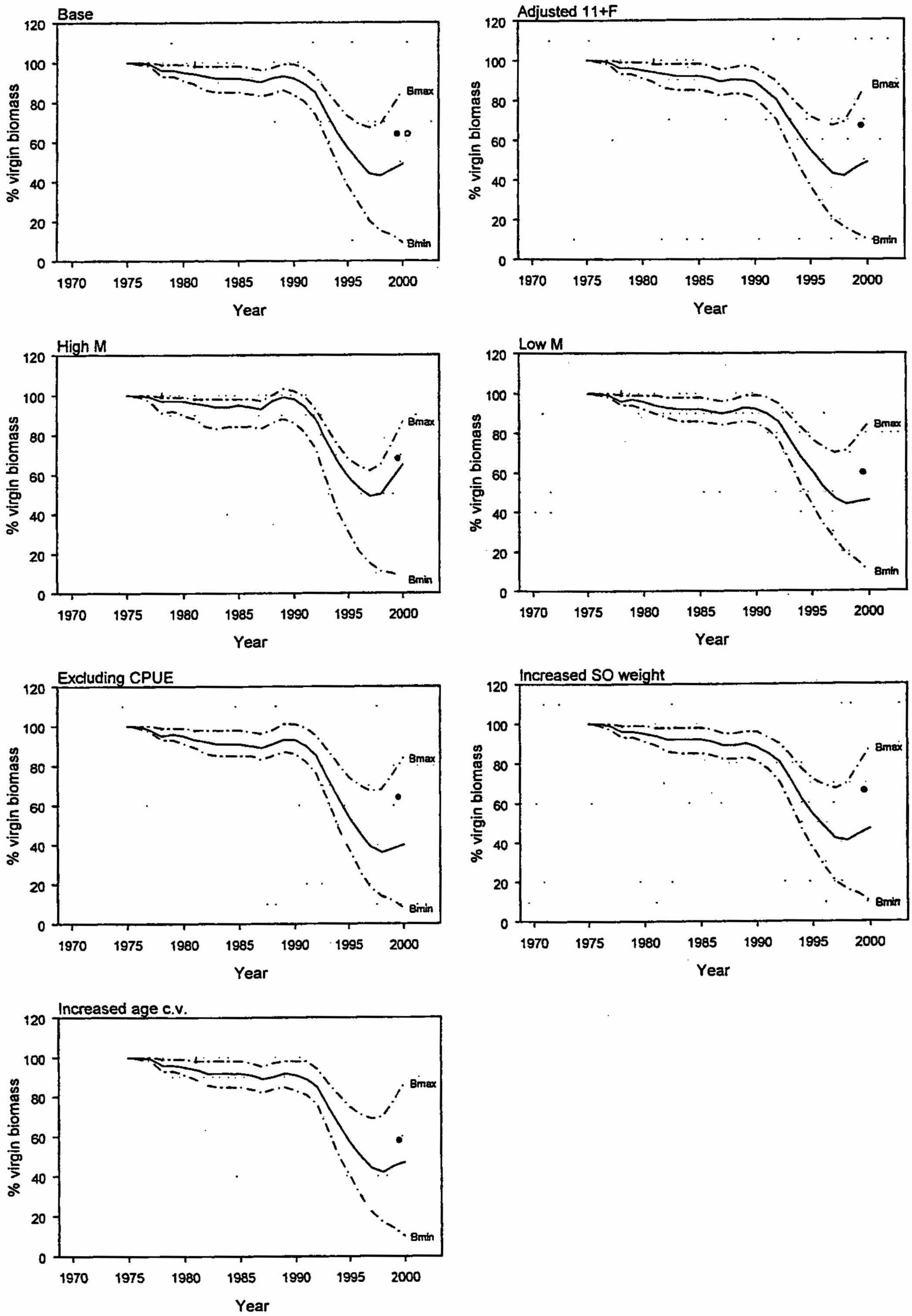


**Figure 9: Estimated biomass trajectories for HAK 4 for $B_0$ at $B_{max}$ and $B_{min}$ for the base case and each of the sensitivity analyses. The positions of the current biomass ($B_{mid99}$) and base case only projected biomass ($B_{mid00}$) as estimated by the MIAEL method are also shown (filled circle and open circle respectively).**

## 5. YIELD ESTIMATES

### 5.1 Estimation of Maximum Constant Yield (MCY)

The method used to estimate MCY was MCY = $\rho B_0$, where $\rho$ is determined for each stock using the simulation method described by Francis (1992), and is such that the projected biomass is below 20% $B_0$ exactly 10% of the time. $B_0$ is estimated by the MIAEL method of Cordue (1995), with associated performance indices indicating how well MCY is estimated within the given range of values. Estimates of MCY for each area are given in Table 13.

**Table 13: Estimates of $B_{MCY}$ (as % $B_0$), MCY (as %$B_0$), and MCY(t)**

| Fish stock | Sensitivity | $B_{MCY}$ (%$B_0$) | MCY (%$B_0$) | MCY range | MCY | MIAEL ($B_0$) | Performance Index (%) |
|---|---|---|---|---|---|---|---|
| HAK 1 | Base | 36.7 | 7.1 | 917–6 970 | 1 929 | 27 236 | 17 (±7) |
| | Fixed catchability | 36.6 | 7.1 | 985–7 817 | 2 132 | 30 105 | 20 (±7) |
| | High *M* | 36.5 | 9.4 | 973–7 910 | 2 107 | 22 404 | 21 (±7) |
| | Low *M* | 36.0 | 6.0 | 887–6 504 | 1 844 | 30 955 | 16 (±6) |
| | Separate ogives | 36.8 | 7.1 | 907–6 783 | 1 899 | 26 814 | 17 (±6) |
| HAK 4 | Base | 36.7 | 7.1 | 1 421–10 194 | 5 887 | 82 442 | 32 (±5) |
| | Adjusted 11+F | 36.9 | 7.2 | 1 404–10 044 | 7 900 | 110 475 | 36 (±1) |
| | High *M* | 37.0 | 9.8 | 1 475–10 986 | 6 683 | 67 867 | 38 (±4) |
| | Low *M* | 36.2 | 5.8 | 1 371–9 467 | 5 316 | 90 923 | 28 (±5) |
| | Excluding CPUE | 37.0 | 7.2 | 1 415–10 358 | 5 864 | 81 640 | 32 (±5) |
| | Increased SO weight | 36.2 | 7.1 | 1 402–10 011 | 5 773 | 80 877 | 33 (±4) |
| | Increased age *c.v.* | 36.5 | 7.2 | 1 429–10 273 | 7 588 | 104 808 | 27 (±1) |

### 5.2 Estimation of Current Annual Yield (CAY)

The simulation method of Francis (1992) was also used to estimate CAY from the MIAEL estimates of current biomass ($B_{beg00}$) given in Table 12. Estimates are given in Table 14. In addition, estimates of equilibrium biomass for MCY and MAY (as a proportion of $B_0$) are given in Table 13 and Table 14.

**Table 14: Estimates of $B_{MAY}$ (as % $B_0$), MAY (as %$B_0$) and CAY(t)**

| Fish stock | Sensitivity | $B_{MAY}$ (%$B_0$) | MAY (%$B_0$) | CAY range | CAY | MIAEL ($B_{beg00}$) | Performance Index (%) |
|---|---|---|---|---|---|---|---|
| HAK 1 | Base | 27.0 | 8.5 | 479–15 871 | 1 625 | 15 627 | 30 |
| HAK 4 | Base | 27.6 | 8.4 | 854–28 725 | 12 754 | 125 579 | 43 |

## 6. MANAGEMENT IMPLICATIONS

The stock assessment for HAK 1 was uncertain. Inconsistencies and poor precision in the age data and biomass indices resulted in clearly inadequate model estimates. The uncertainty is compounded by the absence of any other biomass information, and hence no substantive conclusions can be drawn on the current status of this stock.

The stock assessment for HAK 4 was uncertain; biomass estimates of the stock could be determined only within wide ranges and the MIAEL performance indices were low to moderate. However, if the model assumptions are correct, and the recent estimated year class strengths are as strong as have been estimated, then current catch levels pose little risk to the stock in the near future.

The current delineation of the QMA boundary between HAK 1 and HAK 4 on the western Chatham Rise may be cause for concern. The recent changes in fisher behaviour (predominantly driven by changes in fishing practice in the hoki fishery) has resulted in an increasingly large proportion of the HAK 1 TACC being fished on the western Chatham Rise, a region that is currently considered to be the HAK 4 stock. Movements of fishing effort between stocks, such as have occurred between HAK 1 and HAK 4, may result in an increased risk when assessing stock status.

## 7. ACKNOWLEDGMENTS

Many NIWA staff and Ministry of Fisheries scientific observers were involved in the collection of data at sea. Rosie Hurst provided invaluable advice and helpful interpretations that contributed to substantial improvements to the work. Neil Bagley provided the reinterpretation of the trawl survey biomass estimates, updating and correcting previously reported data. The project was funded by the Ministry of Fisheries under project code MID9801.

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## Appendix A: Supplementary tables and figures for the stock assessment

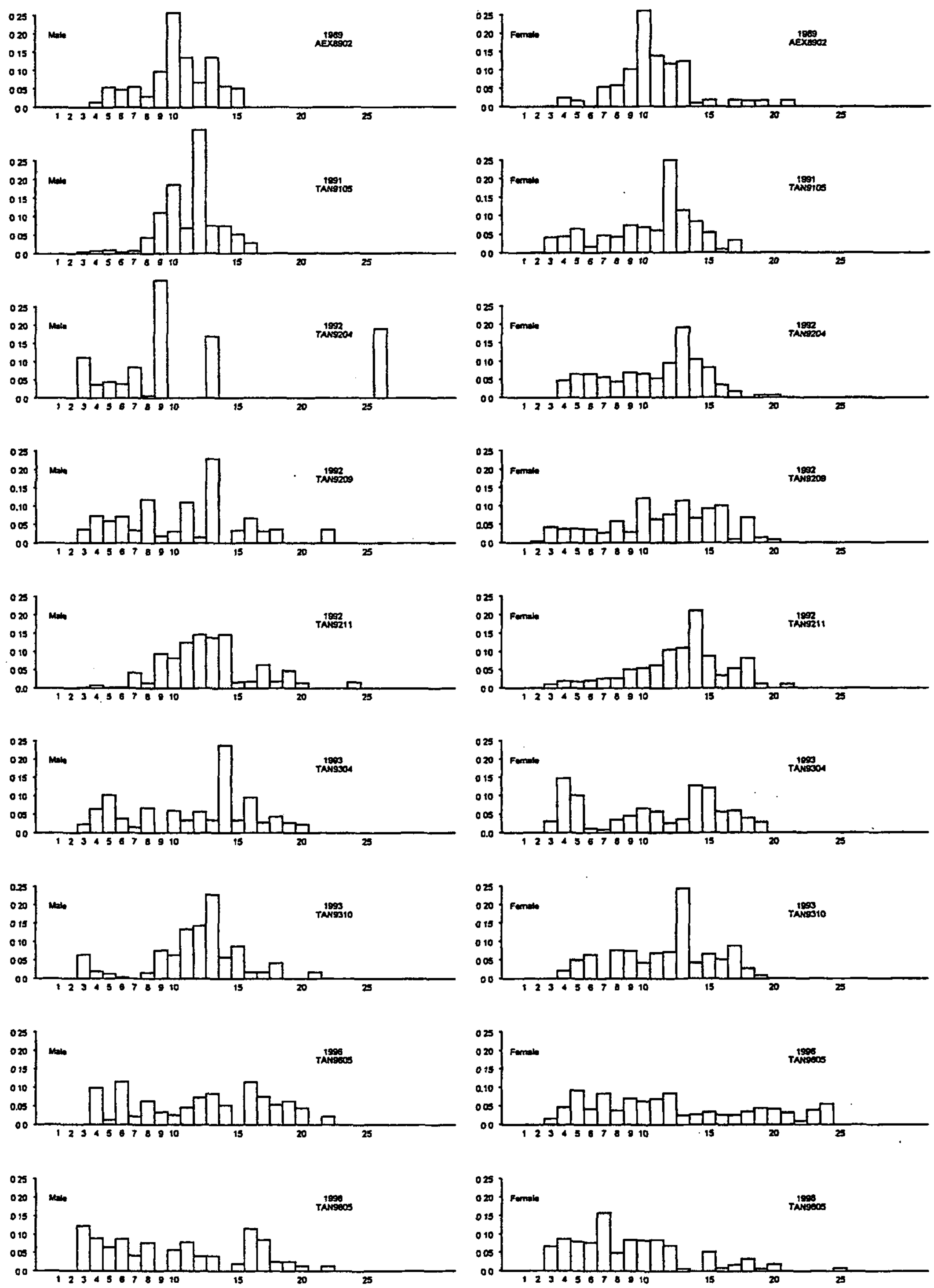

**Figure A1: Age frequencies of hake taken in trawl surveys in HAK 1 (300–800 m), 1990–96.**

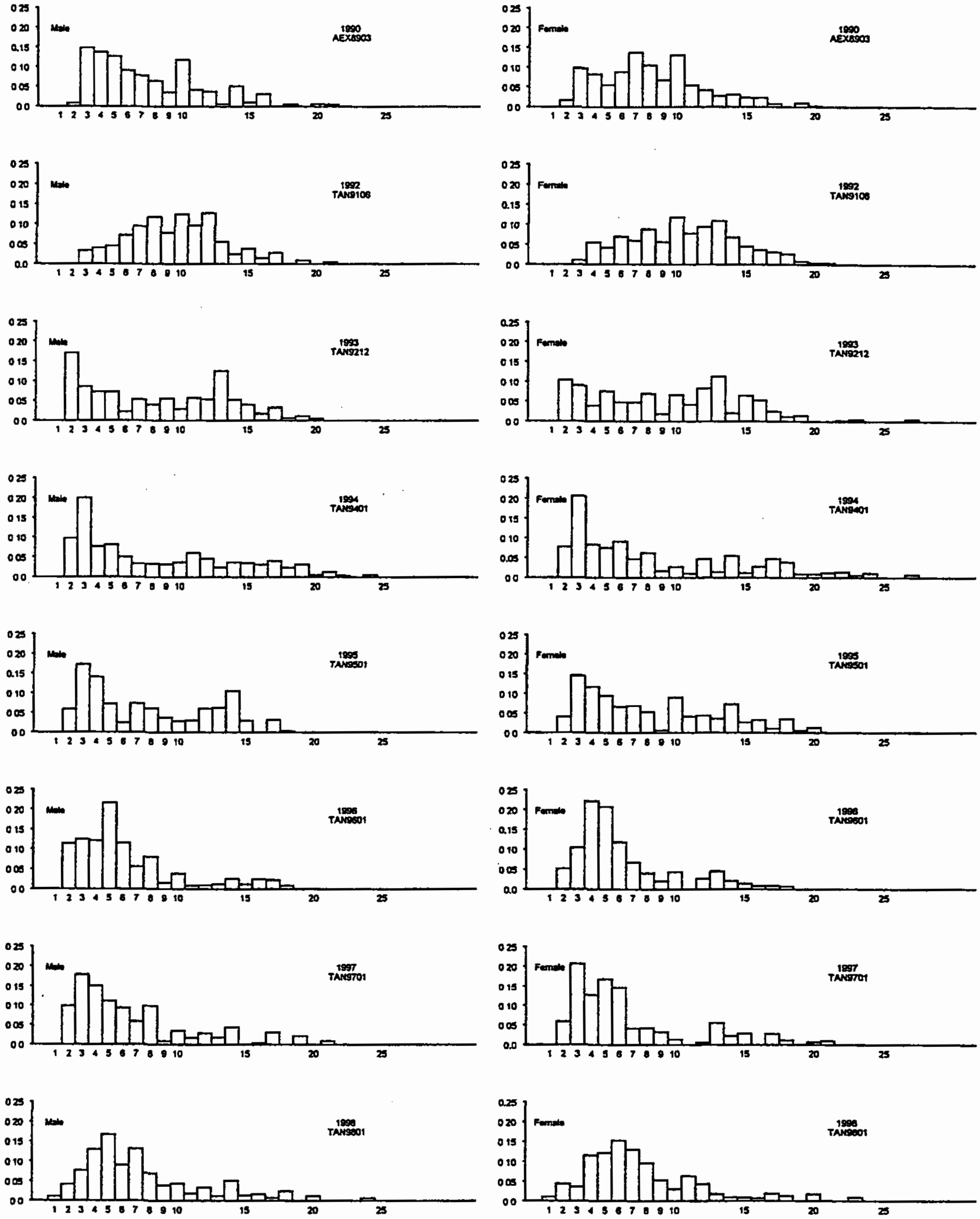

Figure A2: Age frequencies of hake taken in January trawl surveys in HAK 4, 1990–98.

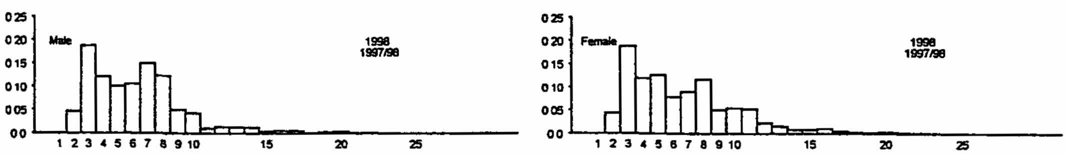

Figure A3: Age frequencies of hake from commercial catch-at-age data in the HAK 4 trawl fishery, 1998.

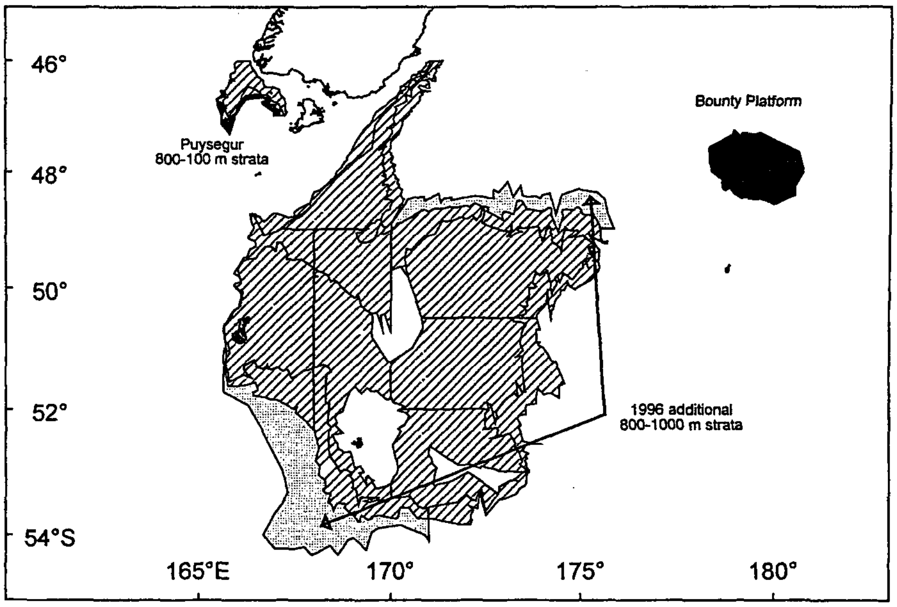


**Figure A4: The 1991 survey region (hashed), Puysegur 800–1000 m strata (dark grey), Bounty Platform (dark grey) and 1996 800–1000 m strata (light grey) for HAK 1.**

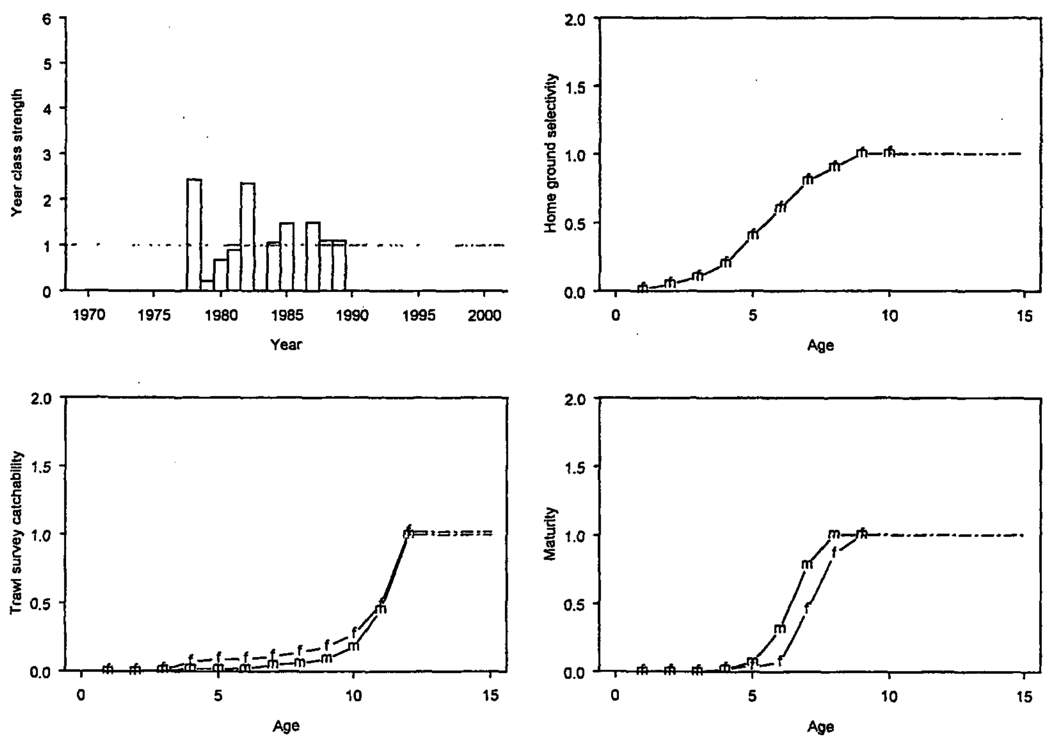


**Figure A5: Estimated relative year class strengths, assumed home ground selectivities, estimated trawl survey catchabilities, and the assumed maturity ogive for HAK 1 (base case) by sex (m = male and f = female). Note that the 1977 estimated YCS = 0.01.**

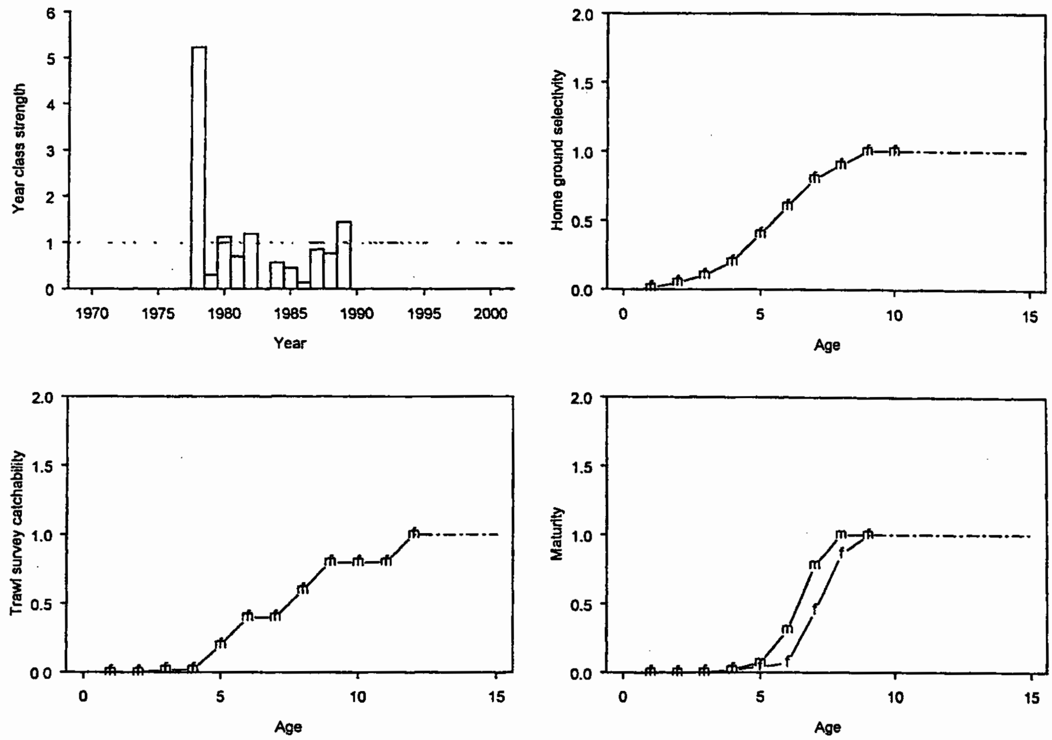


**Figure A6: Estimated relative year class strengths, assumed home ground selectivities, estimated trawl survey catchabilities, and the assumed maturity ogive for HAK 1 (Fixed catchability) by sex (m = male and f = female). Note that the 1977 estimated YCS = 0.01.**

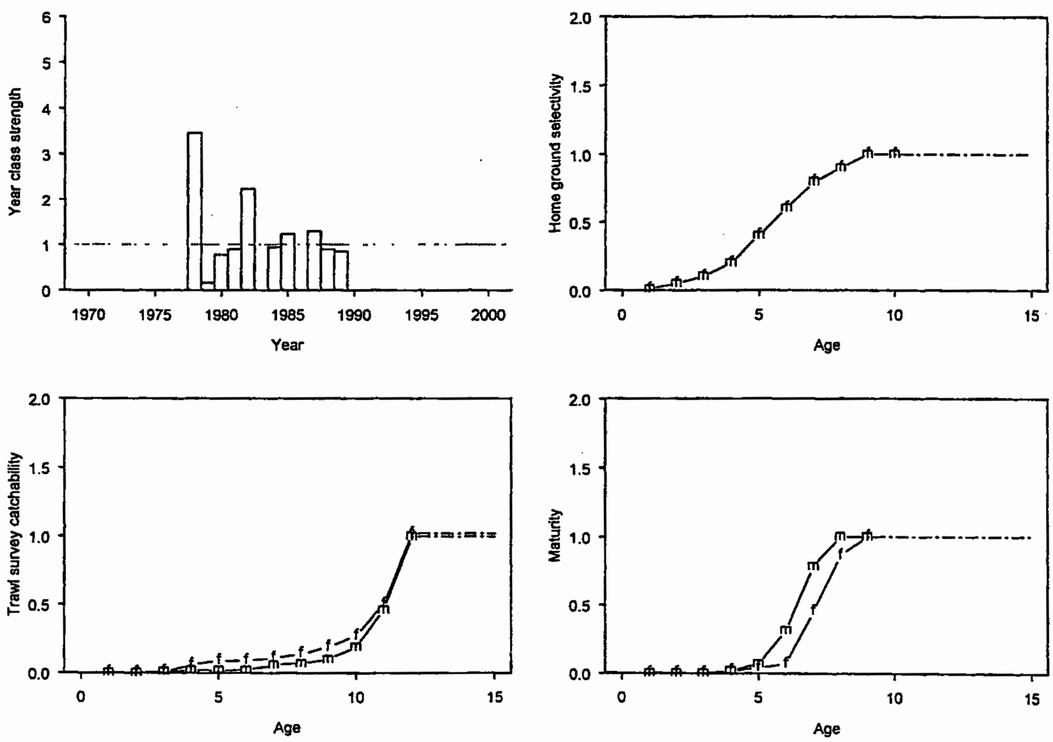


**Figure A7: Estimated relative year class strengths, assumed home ground selectivities, estimated trawl survey catchabilities, and the assumed maturity ogive for HAK 1 (High *M*) by sex (m = male and f = female). Note that the 1977 estimated YCS = 0.01.**

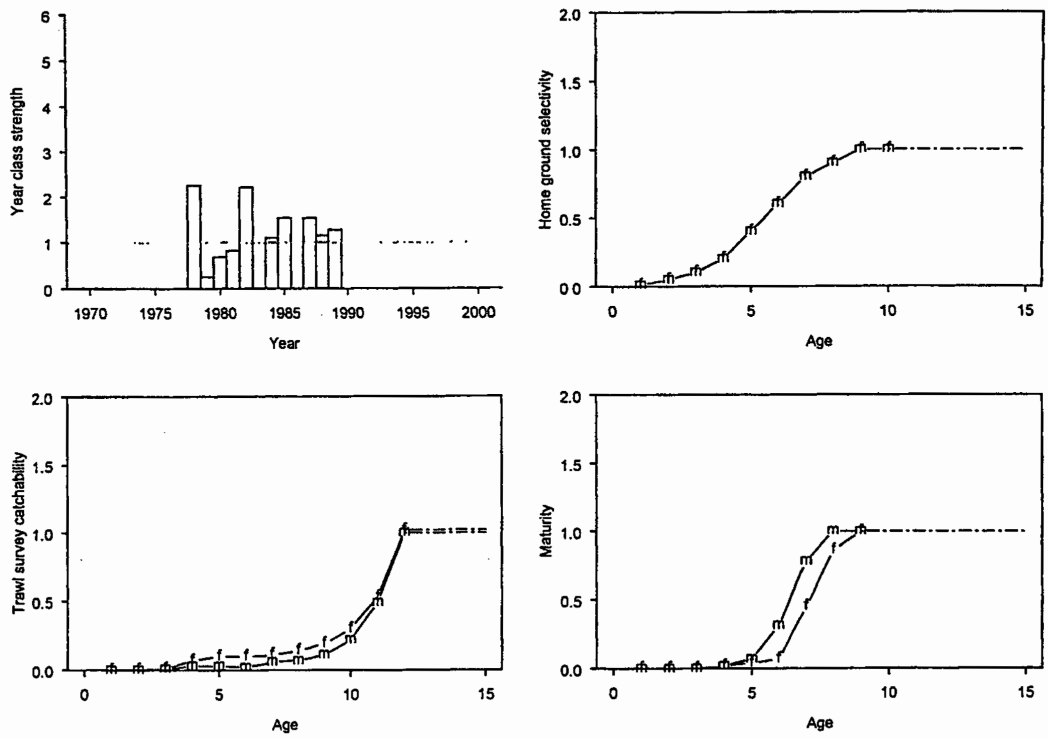


**Figure A8: Estimated relative year class strengths, assumed home ground selectivities, estimated trawl survey catchabilities, and the assumed maturity ogive for HAK 1 (Low *M*) by sex (m = male and f = female). Note that the 1977 estimated YCS = 0.01.**

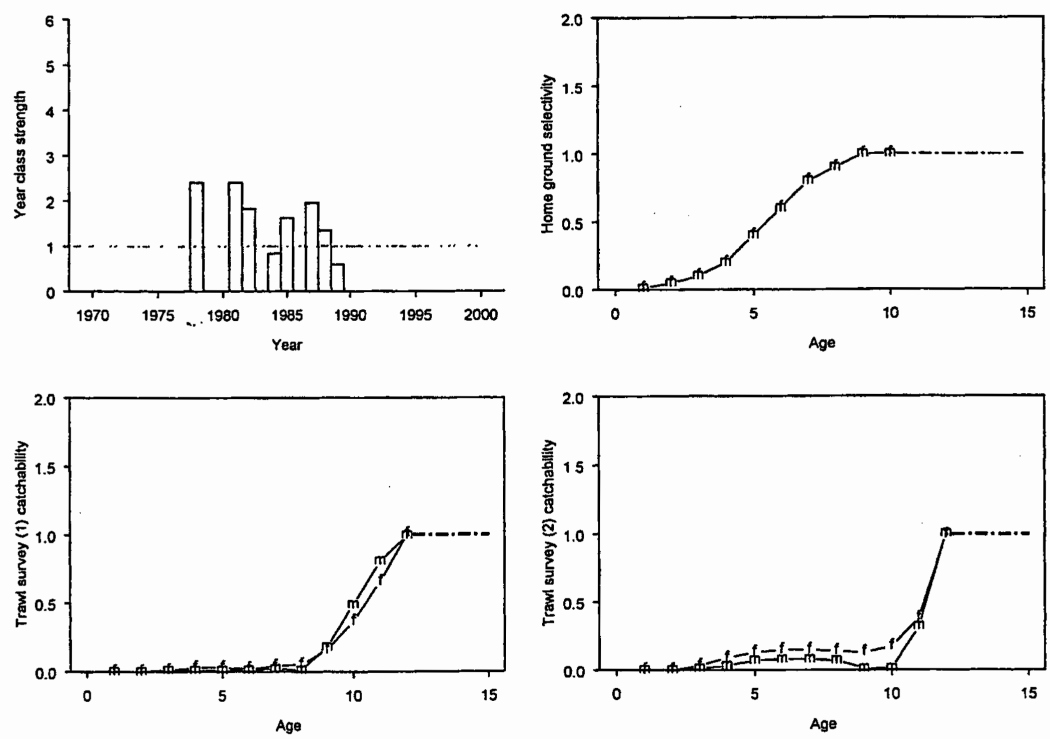


**Figure A9: Estimated relative year class strengths, assumed home ground selectivities, and the two estimated trawl survey catchabilities for HAK 1 (Separate ogives) by sex (m = male and f = female). Note that the 1977 estimated YCS = 0.01.**

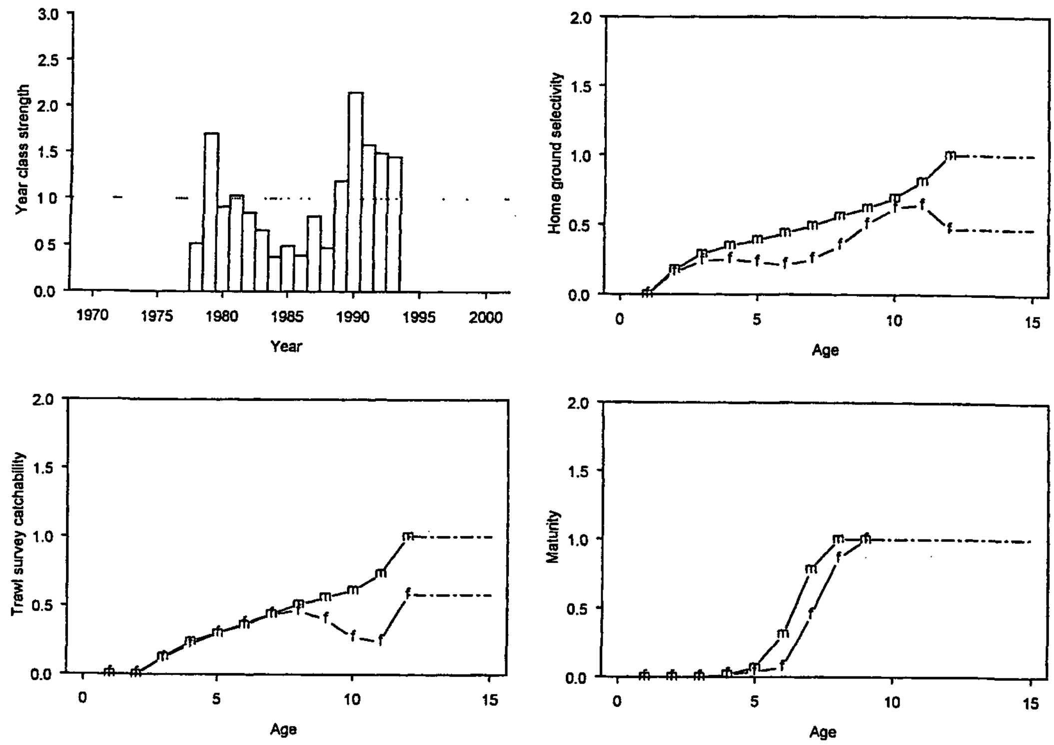


**Figure A10: Estimated relative year class strengths, home ground selectivities, trawl survey catchabilities, and the assumed maturity ogive for HAK 4 (base case) by sex (m = male and f = female).**

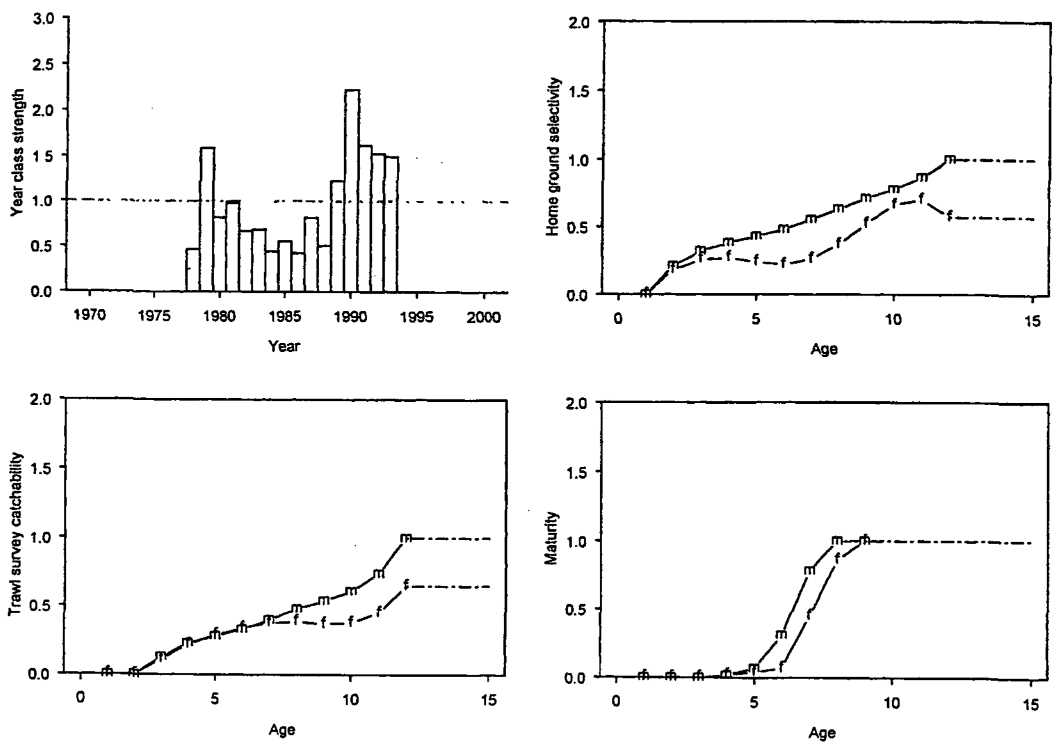


**Figure A11: Estimated relative year class strengths, home ground selectivities, trawl survey catchabilities, and the assumed maturity ogive for HAK 4 (Adjusted 11+ F) by sex (m = male and f = female).**

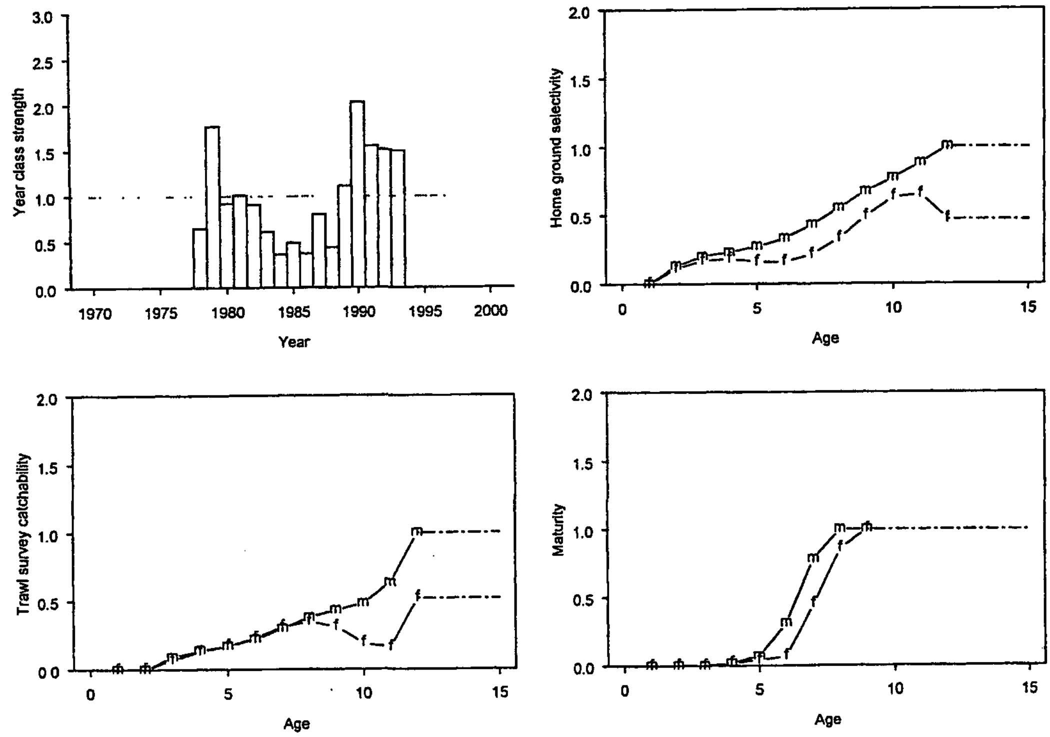


**Figure A12: Estimated relative year class strengths, home ground selectivities, trawl survey catchabilities, and the assumed maturity ogive for HAK 4 (High *M*) by sex (m = male and f = female).**

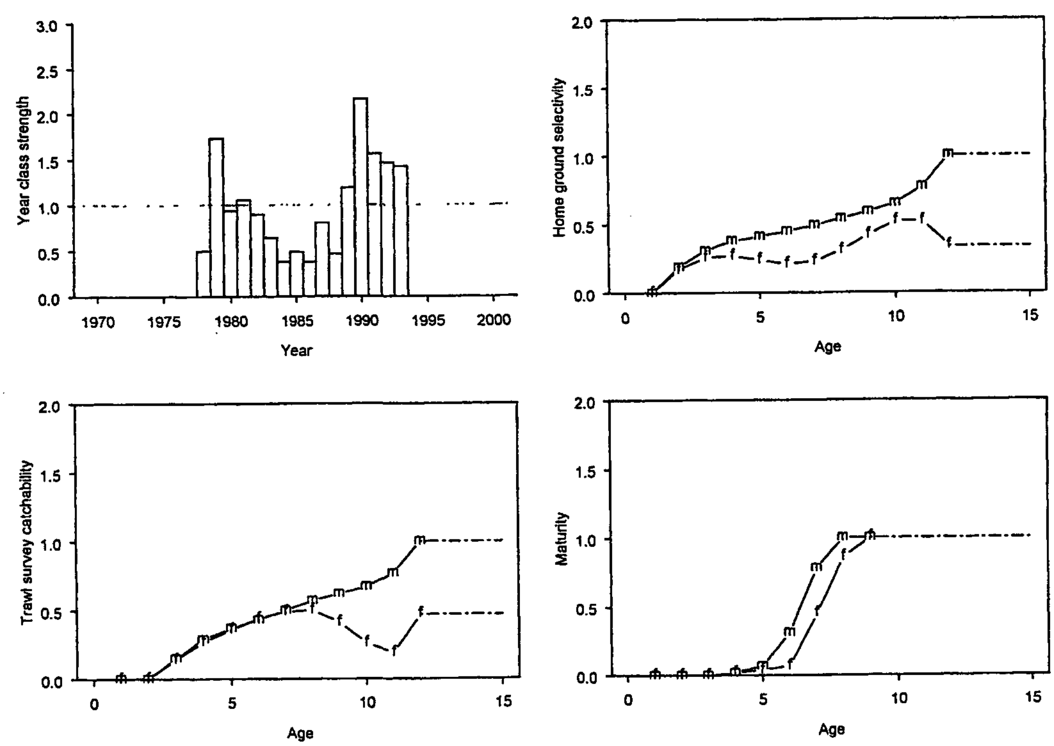


**Figure A13: Estimated relative year class strengths, home ground selectivities, trawl survey catchabilities, and the assumed maturity ogive for HAK 4 (Low *M*) by sex (m = male and f = female).**

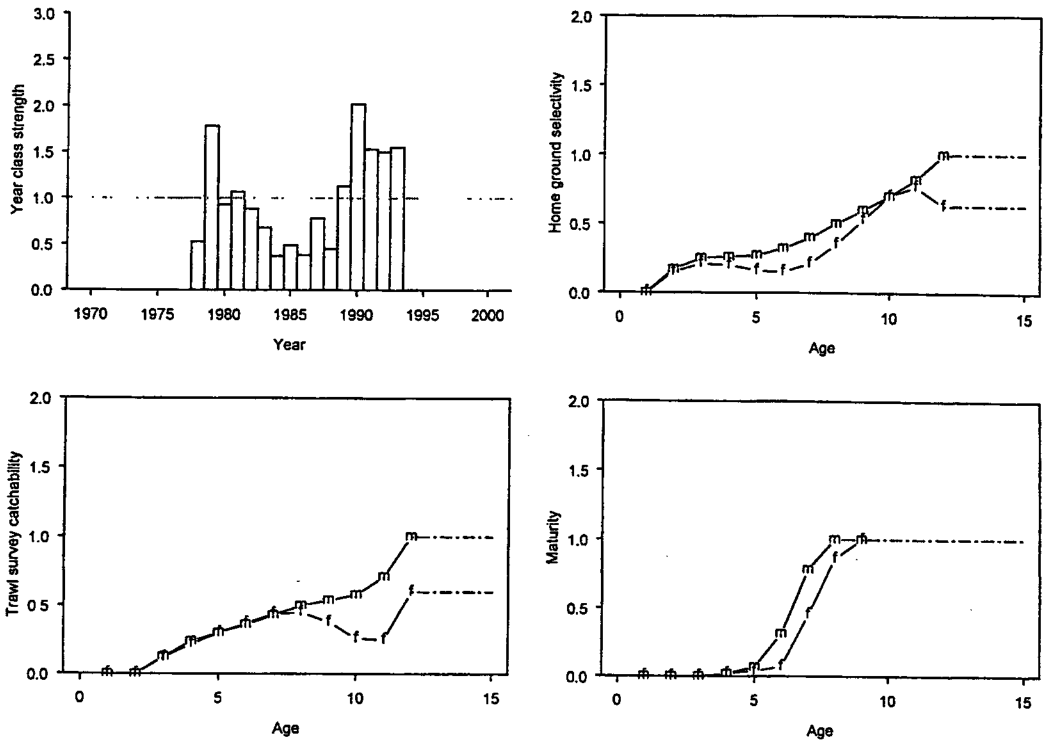


**Figure A14: Estimated relative year class strengths, home ground selectivities, trawl survey catchabilities, and the assumed maturity ogive for HAK 4 (Excluding CPUE) by sex (m = male and f = female).**

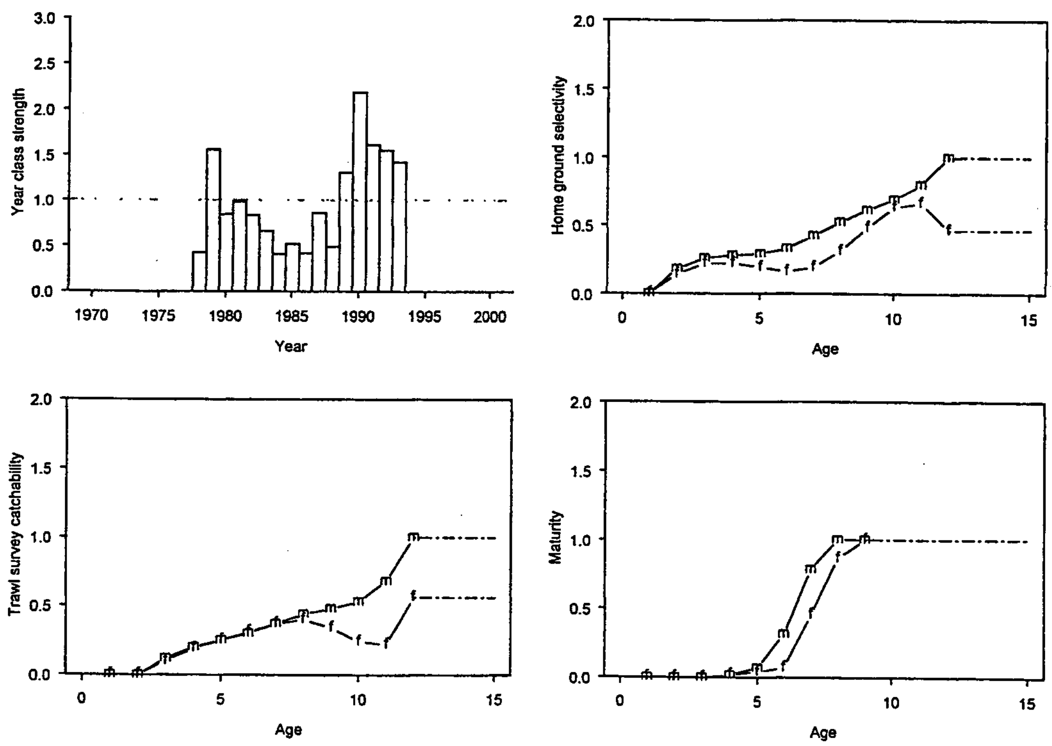


**Figure A15: Estimated relative year class strengths, home ground selectivities, trawl survey catchabilities, and the assumed maturity ogive for HAK 4 (Increased SO weight) by sex (m = male and f = female).**

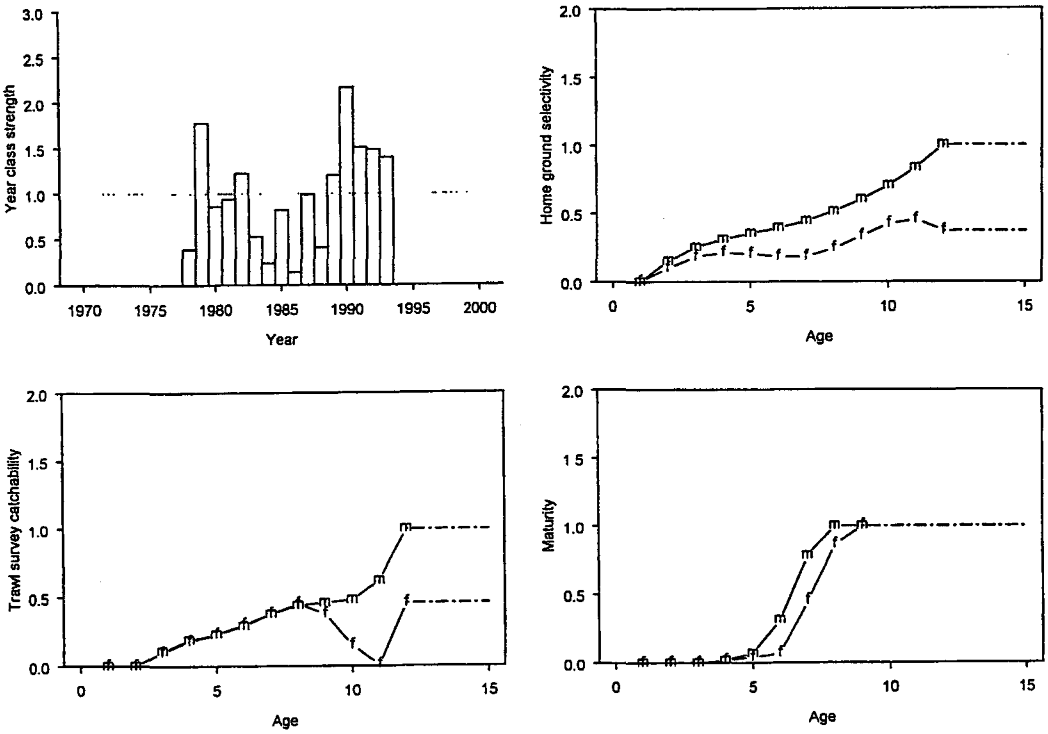


**Figure A16: Estimated relative year class strengths, home ground selectivities, trawl survey catchabilities, and the assumed maturity ogive for HAK 4 (Increased age *c.v.*) by sex (m = male and f = female).**

**Table A1: Numbers of measured and aged fish by data source for male and female hake, and the number of sampled tows and estimated mean weighted *c.v.* by age**

| | | Males | | Females | | | |
|---|---|---|---|---|---|---|---|
| Fish stock | Description | Measured | Aged | Measured | Aged | Shots/tows | Mean *c.v.* |
| HAK 1 | AEX8902 | 45 | 43 | 75 | 64 | 34 | 0.55 |
| | TAN9105 | 337 | 110 | 332 | 213 | 62 | 0.55 |
| | TAN9211 | 113 | 40 | 262 | 166 | 54 | 0.49 |
| | TAN9310 | 169 | 87 | 377 | 179 | 64 | 0.48 |
| | TAN9204 | 60 | 58 | 113 | 103 | 48 | 0.43 |
| | TAN9209 | 76 | 60 | 141 | 108 | 44 | 0.52 |
| | TAN9304 | 36 | 36 | 124 | 121 | 54 | 0.46 |
| | TAN9605 | 127 | 72 | 253 | 127 | 59 | 0.60 |
| | TAN9805 | 104 | 89 | 214 | 186 | 46 | 0.51 |
| HAK 4 | AEX8903 | 220 | 146 | 212 | 173 | 68 | 0.40 |
| | TAN9106 | 322 | 228 | 305 | 225 | 124 | 0.34 |
| | TAN9212 | 243 | 199 | 275 | 221 | 127 | 0.36 |
| | TAN9401 | 293 | 178 | 355 | 216 | 125 | 0.41 |
| | TAN9501 | 201 | 166 | 229 | 188 | 88 | 0.42 |
| | TAN9601 | 149 | 109 | 200 | 160 | 56 | 0.40 |
| | TAN9701 | 149 | 141 | 159 | 147 | 77 | 0.39 |
| | TAN9801 | 137 | 132 | 142 | 137 | 55 | 0.50 |
| | Observer data 1997–98 | 3 514 | 255 | 3 489 | 254 | 561 | 0.21 |

**Table A2: Biomass indices (t) and coefficients of variation (*c.v.*) from R.V. *Tangaroa* trawl surveys in the Sub-Antarctic region under different definitions of the survey region. (These** estimates assume that the areal availability, vertical availability and vulnerability are equal to one.)

| | | Reported biomass [1] | | 300–800 m survey regions [2] | | 1991 equivalent survey [3] | | 1996 equivalent survey [4] | |
|---|---|---|---|---|---|---|---|---|---|
| Voyage code | Date | Biomass | *c.v.* | Biomass | *c.v.* | Biomass | *c.v.* | Biomass | *c.v.* |
| TAN9105 | Nov–Dec 1991 | 5 686 | 0.43 | 5 553 | 0.44 | 5 686 | 0.43 | – | – |
| TAN9211 | Nov–Dec 1992 | 1 944 | 0.12 | 1 822 | 0.12 | 1 944 | 0.12 | – | – |
| TAN9310 | Nov–Dec 1993 | 2 572 | 0.12 | 2 286 | 0.12 | 2 567 | 0.12 | – | – |
| TAN9204 | Apr–May 1992 | 5 028 | 0.15 | 5 028 | 0.15 | – | – | – | – |
| TAN9304 | May–Jun 1993 | 3 602 | 0.14 | 3 221 [5] | 0.14 | – | – | – | – |
| TAN9605 | Mar–Apr 1996 | 2 850 | 0.19 | 2 046 | 0.12 | 2 281 | 0.11 | 2 846 [6] | 0.12 |
| TAN9805 | Apr–May 1998 | 3 946 | 0.16 | 2 554 | 0.18 | 2 643 | 0.17 | 3 946 | 0.16 |
| TAN9209 | Sep–Oct 1992 | 3 762 | 0.15 | 3 760 [6] | 0.15 | – | – | – | – |

1. The biomass and *c.v.* reported in the published voyage data report
2. The biomass and *c.v.* calculated from source records using the equivalent 1991 region, but excluding the 800–1000 m strata in Puysegur region and all Bounty Platform strata.
3. The biomass and *c.v.* calculated from source records using the equivalent 1991 region, including the 800–1000 m strata in Puysegur region and all Bounty Platform strata.
4. The biomass and *c.v.* calculated from source records using the equivalent 1996 region (which includes the 800–1000 m strata in Puysegur region) but excluding all Bounty Platform strata. (The 1996 region added additional 800–1000 m strata to the north and to the south of the Sub-Antarctic rise to the 1991 region).
5. Doorspread data not recorded for this survey. Analysis of source data with average of all other survey doorspread estimates resulted in a new estimate of biomass
6. Analysis of source data with a revised estimate of trawl doorspread resulted in a new estimate of biomass

**Table A3: Catch histories (tonnes per year) for HAK 1 and HAK 4. Actual recorded landings (Record.), adjusted landings assumed in previous stock assessments (Prev.) and adjusted landings (Adj.) for HAK 1 (excluding the western end of the Chatham Rise) and HAK 4 (including the western end of the Chatham Rise)**

| Fishing | HAK 1 | | | HAK 4 | | | |
|---|---|---|---|---|---|---|---|
| Year | Record. | Prev. | Adj. | Record. | Prev. | Adj. | Method |
| 1974–75 | 120 | 120 | 120 | 191 | 191 | 191 | Not adjusted |
| 1975–76 | 281 | 281 | 281 | 488 | 488 | 488 | Not adjusted |
| 1976–77 | 372 | 372 | 372 | 1 288 | 1 288 | 1 288 | Not adjusted |
| 1977–78 | 762 | 762 | 762 | 34 | 34 | 34 | Not adjusted |
| 1978–79 | 364 | 364 | 364 | 609 | 609 | 609 | Not adjusted |
| 1979–80 | 350 | 350 | 350 | 750 | 750 | 750 | Not adjusted |
| 1980–81 | 272 | 272 | 272 | 997 | 997 | 997 | Not adjusted |
| 1981–82 | 179 | 179 | 179 | 596 | 596 | 596 | Not adjusted |
| 1982–83 | 448 | 448 | 448 | 302 | 302 | 302 | Not adjusted |
| 1983–84 | 886 | 772 | 722 | 180 | 344 | 344 | From investigating catch positions [1] |
| 1984–85 | 670 | 525 | 525 | 399 | 544 | 544 | From investigating catch positions [1] |
| 1985–86 | 1 047 | 818 | 818 | 133 | 362 | 362 | From investigating catch positions [1] |
| 1986–87 | 1 022 | 713 | 713 | 200 | 509 | 509 | From investigating catch positions [1] |
| 1987–88 | 1 381 | 1 095 | 1 095 | 288 | 574 | 574 | From investigating catch positions [1] |
| 1988–89 | 1 487 | 1 237 | 1 237 | 554 | 804 | 804 | Assumed 250 t error [1] |
| 1989–90 | 2 115 | 1 865 | 1 522 | 763 | 1 013 | 977 | From investigating TCEPR records [2] |
| 1990–91 | 2 635 | 2 456 | 1 756 | 743 | 922 | 991 | From investigating TCEPR records [2] |
| 1991–92 | 3 156 | 2 814 | 2 464 | 2 013 | 2 355 | 2 454 | From investigating TCEPR records [2] |
| 1992–93 | 3 525 | 3 312 | 3 206 | 2 545 | 2 758 | 2 775 | From investigating TCEPR records [2] |
| 1993–94 | 1 803 | 1 525 | 1 586 | 2 587 | 2 865 | 2 898 | From investigating TCEPR records [2] |
| 1994–95 | 2 572 | 2 321 | 2 019 | 3 369 | 3 619 | 4 094 | From investigating TCEPR records [2] |
| 1995–96 | 3 956 | 3 706 | 2 479 | 3 466 | 3 716 | 4 760 | From investigating TCEPR records [2] |
| 1996–97 | 3 534 | 3 290 | 2 293 | 3 524 | 3 774 | 4 761 | From investigating TCEPR records [2] |
| 1997–98 | 3 691 | 3 381 | 2 486 | 3 523 | 3 750 | 4 673 | From investigating TCEPR records [2] |
| 1998–99 | 3 632 | 3 381 | 2 432 | 3 500 | 3 750 | 4 700 | Anticipated quota adjusted by 1 200 t |
| 1999–00 | 3 632 | – | 2 432 | 3 500 | – | 4 700 | Anticipated quota adjusted by 1 200 t |

1. *see* Colman (1997)
2. *see* Bull & Bagley (1999)

**Table A4: Estimated trawl survey catchability coefficients ($q$) for the base case and the sensitivity analyses for HAK 1**

| Fish stock | Sensitivity | Trawl survey $q$ (Nov–Dec) | Trawl survey $q$ (Apr–May) |
|---|---|---|---|
| HAK 1 | Base | 0.452 | 0.276 |
| | Fixed catchability | 0.063 | 0.033 |
| | High $M$ | 0.292 | 0.173 |
| | Low $M$ | 0.478 | 0.294 |
| | Separate ogives | 0.517 | 0.231 |

**Table A5: Estimated trawl survey catchability coefficients ($q$) and estimated CPUE catchability coefficient ($q$) for the base case and the sensitivity analyses for HAK 4**

| Fish stock | Sensitivity | Trawl survey $q$ | CPUE $q$ |
|---|---|---|---|
| HAK 4 | Base | 0.144 | 0.0000239 |
| | Adjusted 11+F | 0.157 | 0.0000230 |
| | High $M$ | 0.129 | 0.0000192 |
| | Low $M$ | 0.149 | 0.0000260 |
| | Excluding CPUE | 0.169 | – |
| | Increased SO weight | 0.173 | 0.0000278 |
| | Increased age *c.v.* | 0.189 | 0.0000301 |

## Appendix B: Catch at age data

### B1. INTRODUCTION

New catch at age data are determined for the commercial trawl fishery in HAK 4 and HAK 7 in the 1997–98 fishing year (Project MID 9801, Objective 1). In addition, catch at age data from a series of trawl surveys of the Southern Plateau (HAK 1) are re-evaluated (Project MID 9801, Objective 3). Details of the sampling and preparation methodology, and results are given below.

### B2. CATCH AT AGE DATA FOR HAK 4 AND HAK 7

Otoliths were selected from the samples collected from the commercial catch by scientific observers so that the length and sex distribution of the aged fish was approximately proportional to the scaled length frequency of the whole catch in the sampled period. In addition, all otoliths in the extreme right hand tail of the length frequency (where that number made up about 1.5% of all available otoliths) were sampled. This sampling method provides an efficient estimate of the age-length key, but also aims to reduce the *c.v.*s associated with older age classes. Otoliths were prepared and read (by a reader familiar with hake otoliths) using the validated method of Horn (1997).

The sampling period for the HAK 4 otoliths was from November 1997 to April 1998. Sampling intensity was relatively consistent during this period. For HAK 7, otoliths were sampled during a shorter period from July to early September 1998.

Age-length keys were determined for each stock, and separately for each sex (*see* Table B1). The target coefficient of variation across all age classes (30%) was met for both samples.

### B3. CATCH AT AGE DATA FOR HAK 1

Otoliths from a series of four comparable trawl surveys (1992, 1993, 1996, 1998) had previously been read, but by three different readers. As there were some inconsistencies in the progression of strong and weak year classes between these samples, it was proposed to have a single reader familiar with hake otoliths re-read all the samples using the method of Horn (1997). For each survey, all available otoliths were read, and the resulting data were applied to the scaled length frequency from the trawl survey to produce a revised catch at age distribution (Table B2).

The new catch at age distributions are only slightly different to those calculated initially (see Horn 1998). It is likely that apparent inconsistencies between samples are exaggerated by small sample sizes (and is demonstrated in the high estimate of mean weighted *c.v.*s over all age classes).

**Table B1: Calculated catch at age, by sex, for hake in HAK 4 and HAK 7 from commercial trawl fisheries in the 1997–98 fishing year. Numbers of males and females have been scaled to total commercial trawl catch. Summary statistics show the total number of fish, by sex, that were measured or successfully aged, the number of trawl shots that were sampled, and the mean weighted *c.v.* across all age classes for the catch at age data**

| | | | | HAK4 | | | | HAK7 |
|---|---|---|---|---|---|---|---|---|
| Age | Males | *c.v.* | Females | *c.v.* | Males | *c.v.* | Females | *c.v.* |
| 1 | 0 | 0.00 | 88 | 0.00 | 7 160 | 0.18 | 8 603 | 0.18 |
| 2 | 36 954 | 0.25 | 29 154 | 0.20 | 3 402 | 1.29 | 10 594 | 0.21 |
| 3 | 149 562 | 0.13 | 126 625 | 0.13 | 17 528 | 0.54 | 13 195 | 0.68 |
| 4 | 96 497 | 0.18 | 80 551 | 0.18 | 84 377 | 0.24 | 32 278 | 0.40 |
| 5 | 80 506 | 0.20 | 85 235 | 0.17 | 162 891 | 0.18 | 119 887 | 0.17 |
| 6 | 84 312 | 0.18 | 53 165 | 0.22 | 186 337 | 0.17 | 85 223 | 0.22 |
| 7 | 119 560 | 0.16 | 60 304 | 0.20 | 197 861 | 0.16 | 109 576 | 0.17 |
| 8 | 98 038 | 0.16 | 78 507 | 0.16 | 111 528 | 0.24 | 98 094 | 0.18 |
| 9 | 39 981 | 0.25 | 33 945 | 0.24 | 122 637 | 0.22 | 73 410 | 0.20 |
| 10 | 34 226 | 0.28 | 36 780 | 0.23 | 46 900 | 0.37 | 53 198 | 0.23 |
| 11 | 8 554 | 0.52 | 35 346 | 0.24 | 41 812 | 0.39 | 22 363 | 0.35 |
| 12 | 10 918 | 0.45 | 15 036 | 0.34 | 30 596 | 0.42 | 21 572 | 0.35 |
| 13 | 10 614 | 0.43 | 10 194 | 0.28 | 30 538 | 0.33 | 16 834 | 0.45 |
| 14 | 9 994 | 0.50 | 5 638 | 0.57 | 18 244 | 0.46 | 8 756 | 0.64 |
| 15 | 3 336 | 0.76 | 5 599 | 0.50 | 11 555 | 0.54 | 3 732 | 0.67 |
| 16 | 4 242 | 0.73 | 6 998 | 0.35 | 20 688 | 0.47 | 4 183 | 0.52 |
| 17 | 4 473 | 0.65 | 3 531 | 0.58 | 10 973 | 0.98 | 4 721 | 0.73 |
| 18 | 160 | 6.41 | 2 038 | 0.64 | 0 | 0.00 | 4 891 | 0.61 |
| 19 | 2 114 | 0.64 | 1 560 | 0.62 | 11 909 | 0.61 | 3 410 | 0.82 |
| 20 | 3 147 | 0.95 | 2 469 | 0.50 | 2 876 | 0.99 | 0 | 0.00 |
| 21 | 500 | 1.51 | 1 694 | 0.58 | 5 820 | 0.74 | 0 | 0.00 |
| 22 | 926 | 1.05 | 542 | 0.00 | 1 819 | 1.23 | 1 238 | 1.08 |
| 23 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| 24 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 2 345 | 0.51 |
| 25 | 55 | 12.04 | 0 | 0.00 | 0 | 0.00 | 4 258 | 0.96 |
| Measured males | | | | 3 514 | | | | 2 354 |
| Measured females | | | | 3 489 | | | | 1 539 |
| Aged males | | | | 255 | | | | 240 |
| Aged females | | | | 254 | | | | 228 |
| Sampled tows | | | | 561 | | | | 268 |
| Mean *c.v.* | | | | 21 | | | | 25 |

**Table B2: Revised catch at age, by sex, for hake from a series of comparable trawl surveys in the Southern Plateau. Numbers have been scaled to total population in the survey area. Summary statistics show the total number of fish, by sex, that were measured or successfully aged, the number of trawl shots that were sampled, and the mean weighted *c.v.* across all age classes for the catch at age data**

| | | TAN9204 | | TAN9304 | | TAN9605 | | TAN9805 | |
|---|---|---|---|---|---|---|---|---|---|
| | Age | Number | *c.v.* | Number | *c.v.* | Number | *c.v.* | Number | *c.v.* |
| Male | 2 | 0 | 0.00 | 0 | 0.00 | 349 | 1.03 | 0 | 0.00 |
| | 3 | 434 | 1.22 | 3 526 | 0.47 | 10 634 | 0.44 | 11 318 | 0.20 |
| | 4 | 1 367 | 0.99 | 7 081 | 0.35 | 24 262 | 0.36 | 21 888 | 0.40 |
| | 5 | 434 | 1.22 | 5 683 | 0.45 | 13 460 | 0.56 | 14 494 | 0.89 |
| | 6 | 484 | 1.47 | 6 924 | 0.66 | 23 033 | 0.40 | 24 593 | 0.39 |
| | 7 | 7 897 | 0.65 | 3 346 | 0.99 | 7 455 | 0.67 | 10 643 | 0.62 |
| | 8 | 2 681 | 1.26 | 11 560 | 0.47 | 16 529 | 0.56 | 27 364 | 0.36 |
| | 9 | 17 376 | 0.50 | 1 859 | 0.95 | 10 974 | 0.71 | 9 103 | 0.73 |
| | 10 | 15 098 | 0.63 | 3 082 | 0.98 | 7 590 | 0.78 | 20 144 | 0.47 |
| | 11 | 23 020 | 0.40 | 10 802 | 0.77 | 14 127 | 0.58 | 13 527 | 0.64 |
| | 12 | 26 984 | 0.36 | 1 441 | 1.76 | 9 057 | 0.39 | 13 369 | 0.72 |
| | 13 | 25 292 | 0.39 | 22 365 | 0.43 | 26 785 | 0.39 | 13 541 | 1.14 |
| | 14 | 27 078 | 0.36 | 0 | 0.00 | 9 036 | 0.76 | 6 112 | 0.70 |
| | 15 | 3 048 | 0.98 | 3 341 | 0.52 | 0 | 0.00 | 3 306 | 1.01 |
| | 16 | 3 252 | 1.11 | 6 464 | 0.81 | 24 998 | 0.45 | 23 190 | 0.63 |
| | 17 | 11 828 | 0.73 | 3 134 | 1.01 | 21 812 | 0.34 | 14 236 | 0.76 |
| | 18 | 3 252 | 1.11 | 3 518 | 1.14 | 14 896 | 0.56 | 11 851 | 0.73 |
| | 19 | 8 771 | 0.73 | 0 | 0.00 | 9 765 | 0.89 | 6 762 | 0.98 |
| | 20 | 2 660 | 0.95 | 0 | 0.00 | 5 458 | 0.50 | 9 471 | 0.88 |
| | 21 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | 22 | 0 | 0.00 | 3 526 | 0.47 | 6 576 | 0.70 | 5 963 | 1.27 |
| | 23 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | 24 | 3 048 | 0.98 | 0 | 0.00 | 0 | 0.00 | 4 015 | 2.95 |
| | 25 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | 26 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | 27 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | 28 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 4 015 | 2.95 |
| Female | 2 | 0 | 0.00 | 1 794 | 0.71 | 697 | 0.65 | 0 | 0.00 |
| | 3 | 4 445 | 1.46 | 16 588 | 0.49 | 7 880 | 0.65 | 44 579 | 0.26 |
| | 4 | 8 026 | 0.38 | 14 429 | 0.54 | 39 411 | 0.25 | 75 498 | 0.24 |
| | 5 | 7 399 | 1.28 | 15 116 | 0.51 | 49 159 | 0.20 | 53 714 | 0.26 |
| | 6 | 8 560 | 1.06 | 14 118 | 0.52 | 17 095 | 0.42 | 55 359 | 0.37 |
| | 7 | 11 295 | 0.57 | 10 639 | 0.64 | 28 525 | 0.32 | 90 149 | 0.34 |
| | 8 | 11 058 | 0.69 | 22 584 | 0.41 | 14 468 | 0.47 | 25 412 | 0.70 |
| | 9 | 20 617 | 0.45 | 11 124 | 0.69 | 20 430 | 0.46 | 52 121 | 0.41 |
| | 10 | 21 740 | 0.53 | 46 964 | 0.41 | 22 276 | 0.39 | 42 516 | 0.44 |
| | 11 | 25 497 | 0.47 | 24 757 | 0.52 | 18 127 | 0.70 | 42 199 | 0.47 |
| | 12 | 42 617 | 0.32 | 30 296 | 0.50 | 24 941 | 0.53 | 39 385 | 0.42 |
| | 13 | 44 480 | 0.39 | 44 643 | 0.36 | 7 737 | 0.72 | 4 802 | 1.26 |
| | 14 | 85 582 | 0.26 | 25 965 | 0.61 | 10 239 | 0.57 | 0 | 0.00 |
| | 15 | 35 357 | 0.49 | 36 495 | 0.44 | 9 620 | 0.51 | 32 585 | 0.54 |
| | 16 | 14 104 | 0.78 | 39 551 | 0.49 | 11 105 | 0.33 | 6 948 | 0.86 |
| | 17 | 22 077 | 0.50 | 3 279 | 0.89 | 7 680 | 0.78 | 9 551 | 0.57 |
| | 18 | 33 269 | 0.47 | 26 577 | 0.50 | 12 270 | 0.77 | 18 645 | 0.73 |
| | 19 | 4 769 | 1.17 | 5 350 | 0.92 | 14 516 | 0.64 | 4 802 | 1.26 |
| | 20 | 0 | 0.00 | 2 989 | 0.92 | 10 489 | 0.67 | 11 823 | 0.53 |
| | 21 | 4 336 | 0.66 | 0 | 0.00 | 7 902 | 0.43 | 0 | 0.00 |
| | 22 | 0 | 0.00 | 0 | 0.00 | 3 123 | 1.20 | 0 | 0.00 |
| | 23 | 0 | 0.00 | 0 | 0.00 | 9 881 | 0.70 | 0 | 0.00 |
| | 24 | 0 | 0.00 | 0 | 0.00 | 13 955 | 0.59 | 2 460 | 2.84 |
| | 25 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 3 584 | 1.38 |
| Measured males | | | 60 | | 36 | | 127 | | 104 |
| Measured females | | | 113 | | 124 | | 253 | | 214 |
| Aged males | | | 58 | | 36 | | 72 | | 89 |
| Aged females | | | 103 | | 121 | | 127 | | 186 |
| Sampled tows | | | 48 | | 54 | | 59 | | 46 |
| Mean c.v. | | | 49 | | 52 | | 48 | | 51 |

## Appendix C: *A review of the estimate of natural mortality for hake*

### C1. INTRODUCTION

This appendix reviews the estimate of natural mortality (*M*) of hake (Project MID 9801, Objective 5). Data and the methods of analysis are described, and we conclude that the best estimates of *M* for hake are 0.20 $y^{-1}$ for males and 0.18 $y^{-1}$ for females.

### C2. METHODS

Numerous sets of age data, represented as catch-at-age distributions, were available for hake from various areas and years (Horn 1998). Two additional data sets have since been created; one for commercial landings from the Chatham Rise in the 1997–98 fishing year, and the other for a trawl survey in 1979 off the west coast of the South Island (WCSI) described below.

A sample of 500 otoliths collected from May to August 1979 off WCSI were aged, and the data used to estimate the catch-at-age distribution of the spawning population of hake sampled by the research vessel *Wesermünde* in July and August 1979. A sample of 4334 hake were measured during this survey. It can be assumed that this sample is fairly representative of the age structure of an unexploited population, as significant fishing did not occur off WCSI until 1976 (Colman *et al.* 1991).

Available sets of catch-at-age data were collated by fish stock, sex, and sampling method. Numbers at age were then summed across each age class to produce a single distribution for each sex in each fish stock, by sampling method. Where several years of data are combined in this way it has the effect of smoothing the data and reducing the influence of any particularly weak or strong year classes. To examine whether recent higher levels of exploitation have had any influence on the estimates of mortality, the parameters were re-calculated after the data had been further split into samples collected before or after February 1993.

Estimates of instantaneous natural mortality (*M*) were derived using the three following methods.

1. $$M = -\frac{\log_e(p)}{A}$$

   where $p$ is the proportion of the population that reaches age $A$ or older (Hoenig 1983). Values of $p$ of 0.01 and 0.05 were used here. In an unexploited population, a $p$ of 0.01 is usually used. This method assumes that all age classes in the population are fully vulnerable to the sampling technique. This assumption does not hold for hake; in all samples, some of the younger age classes are not fully recruited. To correct for this, an age at recruitment $R$ was chosen, the proportion $p$ of the fully recruited population (i.e., aged $R$ or older) that reaches age $A$ or older is calculated, and the denominator in Hoenig's equation is replace by $A$–$R$+1. This is subsequently referred to as the $A_{max}$ estimator.

2. $$M = \log_e\left(\frac{1+a-1/n}{a}\right)$$

   where $a$ is the mean age above recruitment age and $n$ is the sample size (Chapman & Robson 1960). For this estimator, age at recruitment ($R$) should be the age at which 100% of fish are vulnerable to the sampling method (rather than the often used age at 50% recruitment). This is subsequently referred to as the CR estimator. A 95% confidence interval around this estimator is $\pm 2*\sqrt{\text{var}}$, where var = $(1-e^{-CR})^2/(ne^{-CR})$.

3. $M$ is minus the slope of the right hand limb (i.e., points where age is $R$ or older) of the relationship between age and the natural logarithm of the frequency of fish in that age class (Ricker 1975). The regression model defined as R1 by Dunn *et al.* (1999) was used here, i.e., reject all fish of ages greater than $i_{max}$, where $i_{max}$ is the greatest age for which $N_i \geq 1$ for all $i \leq i_{max}$. This is subsequently referred to as the R1 estimator. A 95% confidence interval around this estimator was taken as ± 2*SE of the slope.

All three methods estimate instantaneous total mortality ($Z$), rather than $M$. However, if it can be assumed for any particular sample that exploitation (i.e., instantaneous fishing mortality, $F$) has been negligible, then $Z$ will approximate $M$.

All three estimators require the initial determination of an age at full recruitment ($R$). It was not possible to use a single, consistent age at full recruitment for all samples from all areas, owing to differences in sampling methods (i.e., research trawl with 60 mm mesh codend, commercial trawl with 100 mm mesh codend), and seasons (i.e., primarily a spawning population off WCSI, but generally non-spawning populations in other areas). However, for valid comparisons between estimates from an individual sample, it is important to use the same age at recruitment in all estimators.

## C3. RESULTS

Details of the sets of samples used in this analysis, and the chosen ages at recruitment ($R$), are given in Table C1. There was considerable uncertainty about the age at recruitment for the fish from HAK 1 and HAK 4. Some samples indicated that hake as young as 3 or 4 years old may be fully recruited. However, because the results of all estimators are sensitive to the chosen $R$, it was considered prudent to select higher values, thereby increasing the likelihood that only fully recruited year classes are used in the estimations. The values chosen here vary between fish stocks, but were the lowest age that appeared to be fully recruited in all samples from a particular stock.

Catch curve plots, and calculated regression lines of the right hand limbs of these distributions, are presented in Figures C1, C2, C3, C4, and C5. Estimates of $Z$ using the three estimators are summarised in Table C1. The estimates have a very wide range, both within and between samples and estimation methods.

For HAK 1 (Southern Plateau), there were large differences between the earlier and later periods of exploitation in the CR and $A_{max}$ estimates, with the earlier period having the greater rate of total mortality. The catch curves (Figure C1) also exhibit a marked difference in shape between periods. This may be due to seasonal differences in the timing of the sets of surveys; most of the 1989–92 surveys were conducted around December, but those from 1993–98 were conducted around April.

**Table C1: Details of samples of catch-at-age data, by fish stock and sampling period, and estimates of $Z$ ($y^{-1}$) from these samples. Method: RT, research trawl; CT, commercial trawl. $N$, number of samples; $R$, age at recruitment. For the CR and R1 estimators, 95% confidence intervals are plus or minus the value in brackets. For the $A_{max}$ estimator, two values of $p$ (0.01, 0.05) were used. –, estimate not calculated**

| Fish stock | Method | Period | N | R | Z (male) CR | | R1 | | $A_{max (0.01)}$ | $A_{max (0.05)}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| HAK 1 | RT | 1989–98 | 9 | 12 | 0.33 | (0.03) | 0.34 | (0.10) | 0.31 | 0.33 |
| (Southern | RT | 1989–92 | 5 | 12 | 0.50 | (0.06) | 0.49 | (0.05) | 0.35 | 0.42 |
| Plateau) | RT | 1993–98 | 4 | 12 | 0.22 | (0.03) | 0.07 | (0.17) | 0.27 | 0.27 |
| HAK 4 | RT | 1989–98 | 8 | 10 | 0.26 | (0.01) | 0.32 | (0.08) | 0.38 | 0.30 |
| (Chatham | RT | 1989–93 | 3 | 10 | 0.32 | (0.03) | 0.33 | (0.06) | 0.38 | 0.37 |
| Rise) | RT | 1994–98 | 5 | 10 | 0.22 | (0.02) | 0.25 | (0.09) | 0.35 | 0.30 |
| | CT | 1998 | 1 | 10 | 0.32 | (0.04) | 0.29 | (0.12) | 0.35 | 0.27 |
| HAK 7 | RT | 1979 | 1 | 9 | 0.19 | (0.02) | 0.21 | (0.07) | 0.22 | – |
| (WCSI) | CT | 1990–98 | 9 | 9 | 0.29 | (0.01) | 0.33 | (0.06) | 0.31 | 0.27 |
| | CT | 1990–92 | 3 | 9 | 0.32 | (0.03) | 0.41 | (0.06) | 0.26 | 0.33 |
| | CT | 1993–98 | 6 | 9 | 0.28 | (0.02) | 0.35 | (0.06) | 0.33 | 0.27 |
| | | | | | **Z (female) CR** | | **R1** | | **$A_{max (0.01)}$** | **$A_{max (0.05)}$** |
| HAK 1 | RT | 1989–98 | 9 | 12 | 0.31 | (0.02) | 0.36 | (0.08) | 0.35 | 0.33 |
| (Southern | RT | 1989–92 | 5 | 12 | 0.39 | (0.03) | 0.47 | (0.17) | 0.46 | 0.42 |
| Plateau) | RT | 1993–98 | 4 | 12 | 0.24 | (0.02) | 0.25 | (0.08) | 0.35 | 0.27 |
| HAK 4 | RT | 1989–98 | 8 | 10 | 0.24 | (0.01) | 0.28 | (0.04) | 0.33 | 0.27 |
| (Chatham | RT | 1989–93 | 3 | 10 | 0.29 | (0.02) | 0.38 | (0.08) | 0.38 | 0.33 |
| Rise) | RT | 1994–98 | 5 | 10 | 0.21 | (0.01) | 0.21 | (0.06) | 0.31 | 0.25 |
| | CT | 1998 | 1 | 10 | 0.36 | (0.05) | 0.31 | (0.05) | 0.38 | 0.33 |
| HAK 7 | RT | 1979 | 1 | 9 | 0.23 | (0.03) | 0.25 | (0.11) | 0.27 | – |
| (WCSI) | CT | 1990–98 | 9 | 9 | 0.32 | (0.01) | 0.35 | (0.03) | 0.35 | 0.33 |
| | CT | 1990–92 | 3 | 9 | 0.32 | (0.02) | 0.38 | (0.08) | 0.38 | 0.33 |
| | CT | 1993–98 | 6 | 9 | 0.31 | (0.02) | 0.32 | (0.04) | 0.33 | 0.30 |

Estimates of $Z$ for HAK 4 (Chatham Rise) derived from research trawl surveys exhibit quite similar trends to those for HAK 1, although the differences between comparable estimates from the earlier and later periods of exploitation are not as extreme as for HAK 1. Again, the catch curves are markedly different between the earlier and later periods (Figure C2). All the Chatham Rise surveys were conducted around December–January, so seasonal differences in availability are unlikely to explain the catch curve differences in this stock. The estimates of $Z$ from the single 1998 commercial trawl sample (Figure C3) are consistently higher than for the research samples taken from 1994–98.

The 1979 research sample from HAK 7 (WCSI) is the only data set that can be assumed to be from a population that had not been exploited for many years. All estimates of $Z$ are quite consistent within sexes (0.19–0.22 $y^{-1}$ for males, 0.23–0.27 $y^{-1}$ for females), although the correlation coefficients for the R1 regressions are not high (Figure C4). Because this sample is assumed to be from an unexploited population, the $A_{max}$ estimate is derived only using $p$ of 0.01. The commercial trawl samples from HAK 7 appear to have a consistent catch curve shape and age at recruitment over the entire sampled period (Figure C5). As with the HAK 1 and HAK 4 samples, estimates of $Z$ appear to be higher in the early 1990s than in the latter part of that decade. All estimates of $Z$ from the commercial catch are higher than those from the research sample taken in 1979.

Comparisons between sexes of estimates of *Z* derived from the same data set and estimation method exhibit some trends (though it is noted that for the CR and R1 estimators, the 95% confidence intervals of comparable pairs overlap in all but two cases). For all the HAK 7 samples, there is a consistent tendency for *Z* to be less for males than for females. For the HAK 4 research samples, comparable estimates are generally higher for males. However, in the HAK 4 commercial sample, all estimates of *Z* are higher for females. For HAK 1, there is no trend apparent.

## C4. DISCUSSION

Dunn *et al.* (1999) compared the merits of estimating *M* using the CR estimator and various regression methods (including R1). They concluded that CR was the most accurate estimator, with R1 being the best of the regression estimators. They did not examine any $A_{max}$ estimators. The reported values of variance for the CR and R1 estimators are likely to be underestimates because their calculation assumes no ageing error, constant recruitment, a constant *M*, and little sampling variability. None of these assumptions are likely to be true.

Clearly, estimates derived using all three methods can vary (sometimes quite markedly) given uncertainties in some parameters. The CR estimator is sensitive to the choice of age of recruitment. The R1 estimate can be influenced by where the right limb of the catch curve is started (i.e., the choice of age of recruitment), or by a single outlying point in the data series. To demonstrate the dependence of *Z* on the selected age at recruitment, results using the three estimation methods are presented for the HAK 7 research trawl data set (Figure C6). The R1 estimators for both sexes appear to have a point of inflexion at about recruitment age 10, but then peak at about age 15 before declining. The information in Figure C6, and some of the right hand limbs of the catch curves in Figures C1–C5 (which are better modelled by a downward curve rather than a straight line), raise the possibility that *M* is either not constant after recruitment, or that selectivity declines with age.

All estimates of *Z* for HAK 1 and HAK 4 from research trawl surveys are based on sets of relatively imprecise age data; mean weighted *c.v.*s over all age classes are in the range of 40–55% for HAK 1 and 34–50% for HAK 4 (Horn 1998). There also appear to be some unexplained differences in the catch curves between the two periods into which the data were split, which complicates the choice of an age at recruitment. Owing to these factors, these data sets are considered to provide unreliable estimates of *Z*. The general change in shape of the catch curves between the two periods indicates either a greater relative abundance, or increased vulnerability to the trawl, of younger year classes in the latter period. This correlates with a possible drop in abundance of old hake on the Chatham Rise since 1995 (Bull & Bagley 1999), and with stock modelling results, which suggested relatively strong recruitment in all fish stocks since about 1994–96, and subsequent increases in biomass (Dunn 1998).

Mean weighted *c.v.*s over all age classes for the commercial trawl samples from HAK 7 and HAK 4 range from 21 to 31% (Horn 1998). The research trawl data from HAK 7 have a *c.v.* of 36%. Thus, these data sets probably provide the most reliable estimates of *Z*.

The estimates of *Z* based on commercially caught hake are all likely to contain a non-trivial component of *F*, as landings of hake over 500 t have been taken annually from HAK 7 since 1976 and from HAK 4 since 1989 (Annala *et al.* 1998). Estimates of *Z* from these samples using the CR and R1 methods range from 0.28 $y^{-1}$ to 0.41 $y^{-1}$. Using the $A_{max}$ method and a *p* of 0.05 gave a range of 0.27 $y^{-1}$ to 0.33 $y^{-1}$. Although the $A_{max}$ estimate may be a better estimate of $M$ than those from CR and R1 because it does account for some component of fishing mortality, the true extent of $F$ is unknown, so the chosen $p$ may be inappropriate.

The estimates of $Z$ based on data collected during research surveys in 1979 probably include a negligible component of $F$, and can be assumed to represent $M$. The estimates obtained using the three methods are very consistent (within sexes); 0.19–0.22 $y^{-1}$ for males, and 0.23–0.27 $y^{-1}$ for females. The best estimates of $M$ (following the recommendation of Dunn *et al.* 1999) are those derived from the CR estimator, i.e., 0.19 $y^{-1}$ for males and 0.23 $y^{-1}$ for females. The R1 estimates are probably also reasonable.

The conclusion that different sexes of the same species experience different rates of natural mortality is not uncommon (Pauly 1980), and this has been the situation in recent hake assessments (Annala *et al.* 1998). Estimates of $M$ for hake were calculated by Colman *et al.* (1991), using the $A_{max}$ estimator, and data derived from samples of otoliths collected in 1976 from HAK 4 and HAK 7. Raw age data for hake from the two areas were combined (it was not stated how much data came from each area), and it was concluded that "very few seem to survive beyond about age 23 (females) or 21 (males)". Applying these ages to Hoenig's (1983) equation, assuming $p = 0.01$, gave estimates of $M$ of 0.20 $y^{-1}$ and 0.22 $y^{-1}$ for females and males, respectively. Where there is an apparent difference in $M$ between sexes for a particular marine fish species, it appears almost universal that the value for females will be lower than that for males, i.e., the longevity of females is greater (Pauly 1980).

Results from the current study suggest that the longevity of male hake is greater than that for females in HAK 7, but that female hake tend to live longer in HAK 4 (although statistically significant differences in $Z$ between sexes have not been demonstrated in this study). Different levels of $M$ for fish of the same sex, living in such close proximity, would not be expected. However, differences in fishing patterns between areas, and fish behaviour between sexes could explain the conflicting estimates of longevity. The HAK 7 fishery essentially targets a spawning population, but the number of males in the landings is almost always greater than the number of females (*see* Horn 1998). From 1990 to 1998, it is estimated that males made up 48–68% of the catch (mean = 58%), and they constituted 57% of the 1979 sample. The fishery in HAK 4 targets some spawning concentrations, but also the dispersed population outside the spawning season. Fish are fully recruited into this fishery perhaps as early as age 3 (*see* Figure C3). The trawl surveys target the dispersed population. The sex ratio of landings from HAK 4 is generally evenly balanced. From the trawl surveys, the proportion of males ranged from 43 to 51%, with a mean of 48%. From commercial landings in the 1990s (using data from five fishing years when over 1200 fish were measured each year), the proportion of males ranged from 44 to 53%, with a mean of 48% (unpublished data from the Ministry of Fisheries *obs_lfs* database).

A possible interpretation of these data is that where the whole population is sampled, males and females occur in about the same proportions, although males may be slightly less abundant than females (thus, having a lower maximum age, and higher $M$). In the spawning aggregations, males are relatively more abundant than females, perhaps because females spend less time on the spawning grounds than males, or a smaller proportion of the older females go to spawn each year. In this situation, females could appear to have a lower maximum age than males.

It is suggested that because the HAK 4 research samples are from the whole population, then the trend of a higher $M$ for males apparent there is probably applicable to all populations. Comparisons between sexes of the HAK 4 samples indicate that $M$ for males should be about 0.01 to 0.05 $y^{-1}$ higher than for females. The problem then exists of how to modify the estimates derived from the unexploited spawning population in HAK 7 to recognise the likely lower maximum age of males in an overall population. Since males numerically dominate the catch, it is assumed that male fish over the age of recruitment are fully represented in the samples, so the estimate of $M$ derived for these fish is applicable to males for the whole population. The CR and R1 estimates (0.19 $y^{-1}$ and 0.21 $y^{-1}$, respectively) suggest a likely $M$ of 0.20 $y^{-1}$ for male hake. Given the conclusion above that $M$ for female hake should be slightly lower than that for males, a value of 0.18 $y^{-1}$ is suggested.

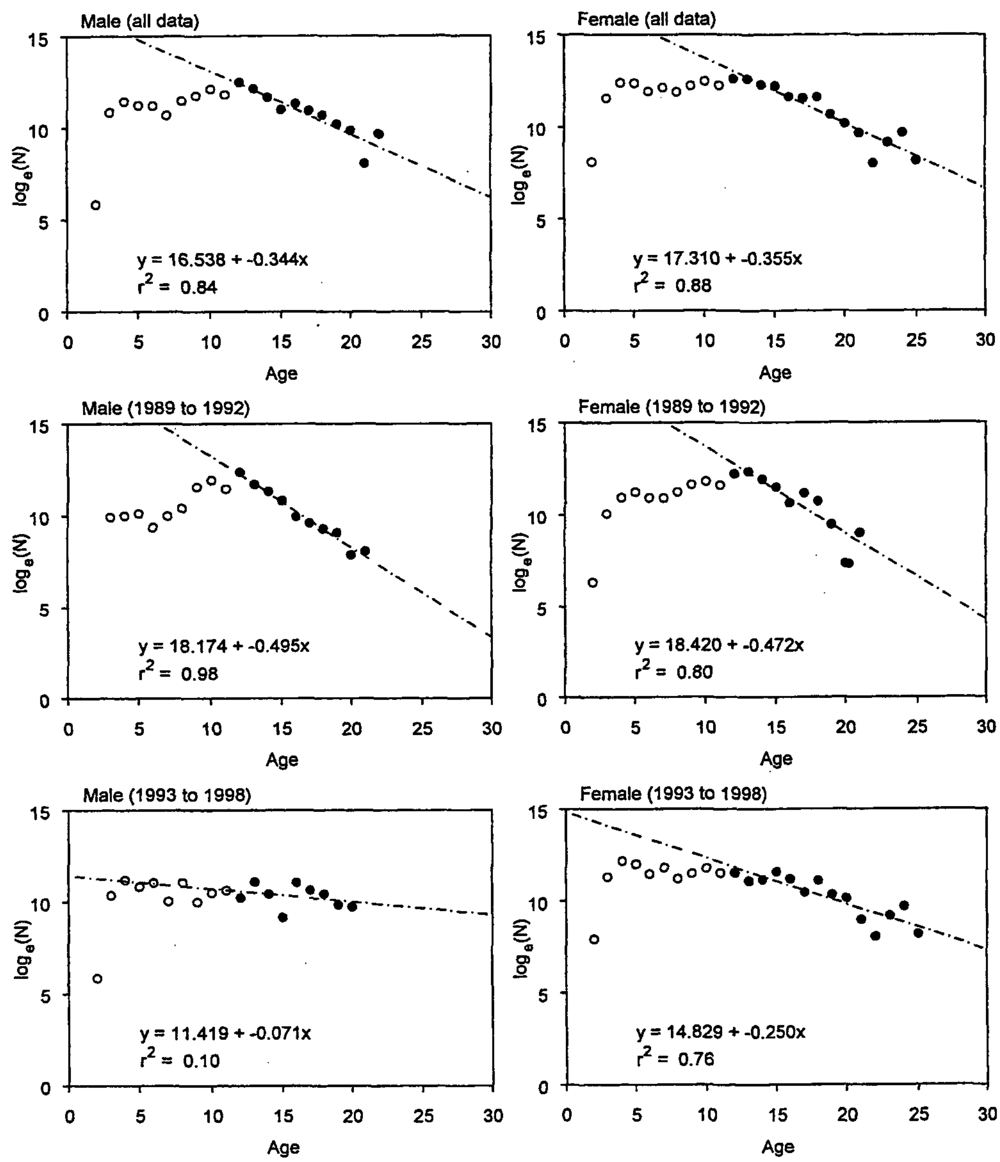


**Figure C1: Estimated catch-at-age, by sex, for samples of hake taken in trawl surveys of the Sub-Antarctic, from 1989 to 1998. Lines are the least squares linear regressions fitted to the data points represented by filled circles.**

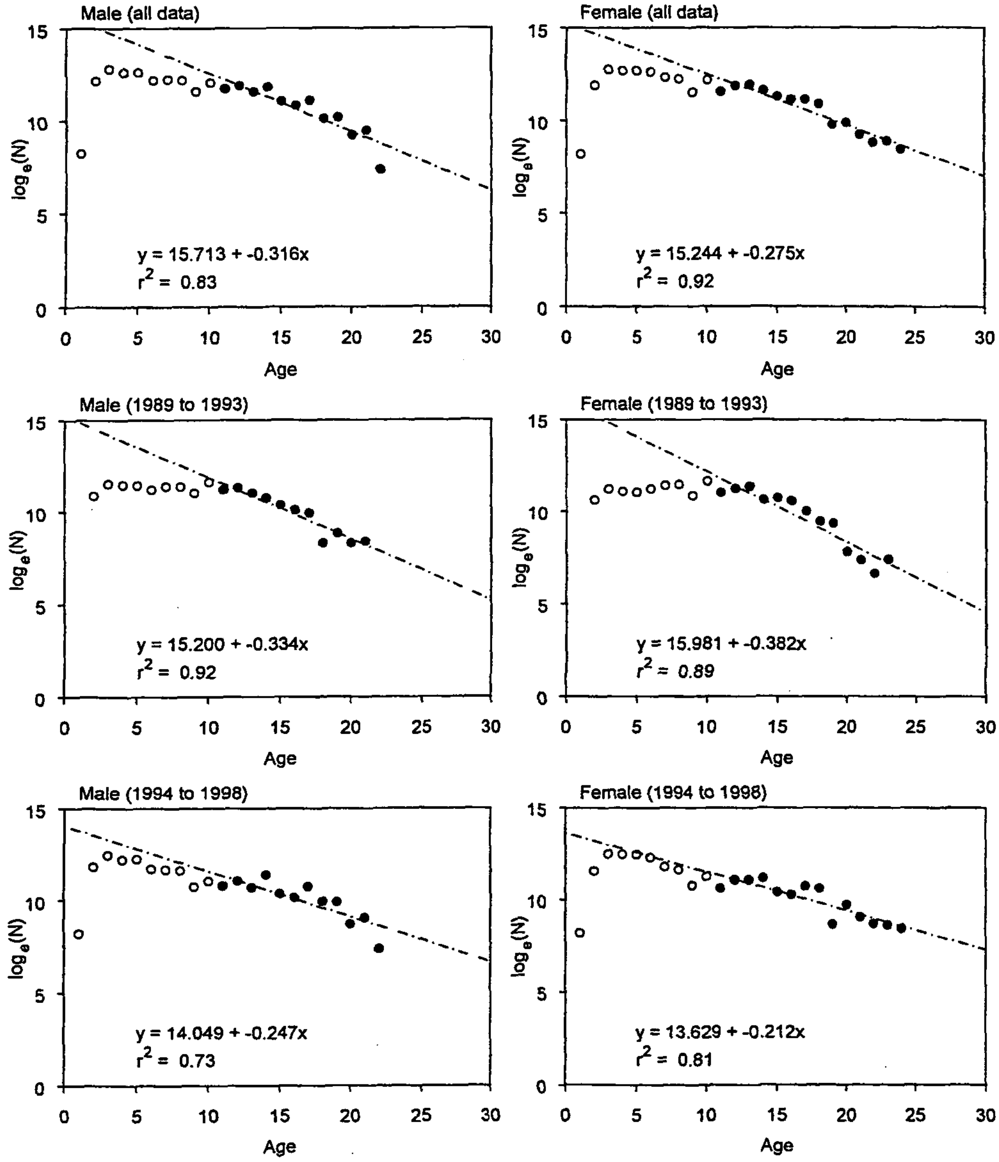


**Figure C2: Estimated catch-at-age, by sex, for samples of hake taken in trawl surveys of the Chatham Rise, from 1989 to 1998. Lines are the least squares linear regressions fitted to the data points represented by filled circles.**

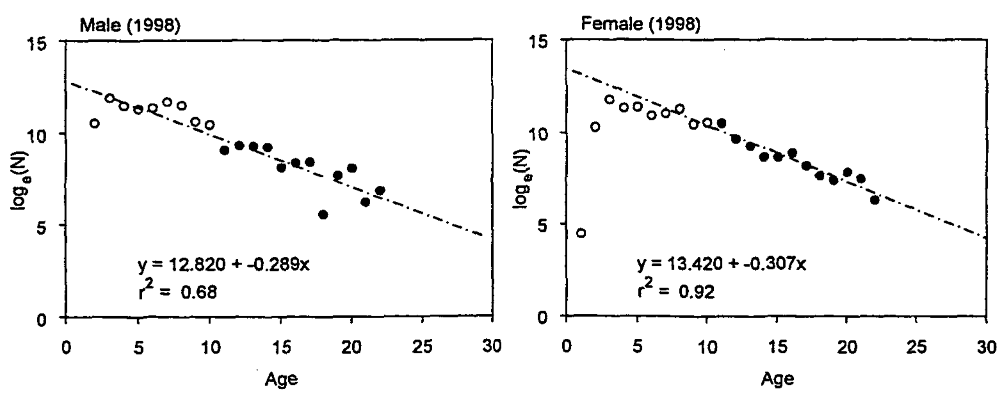


**Figure C3: Estimated catch-at-age, by sex, for samples of hake taken by commercial trawls on the Chatham Rise in 1997–98. Lines are the least squares linear regressions fitted to the data points represented by filled circles.**

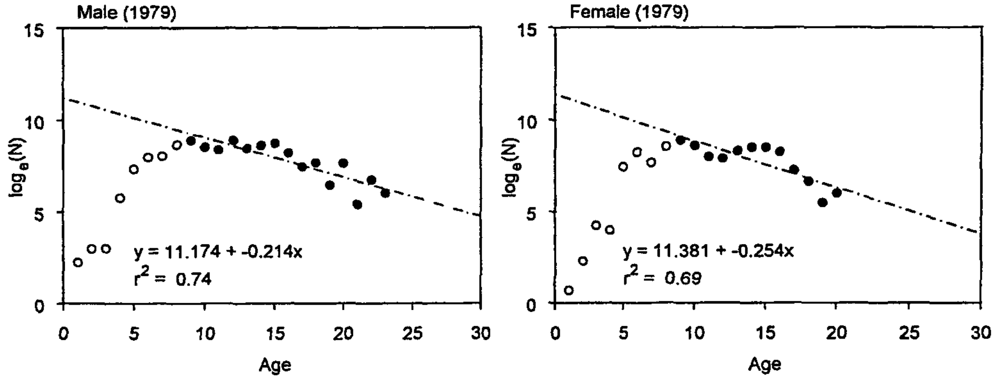


**Figure C4: Estimated catch-at-age, by sex, for samples of hake taken in a trawl survey off the west coast South Island in 1979 (WES7904). Lines are the least squares linear regressions fitted to the data points represented by filled circles.**

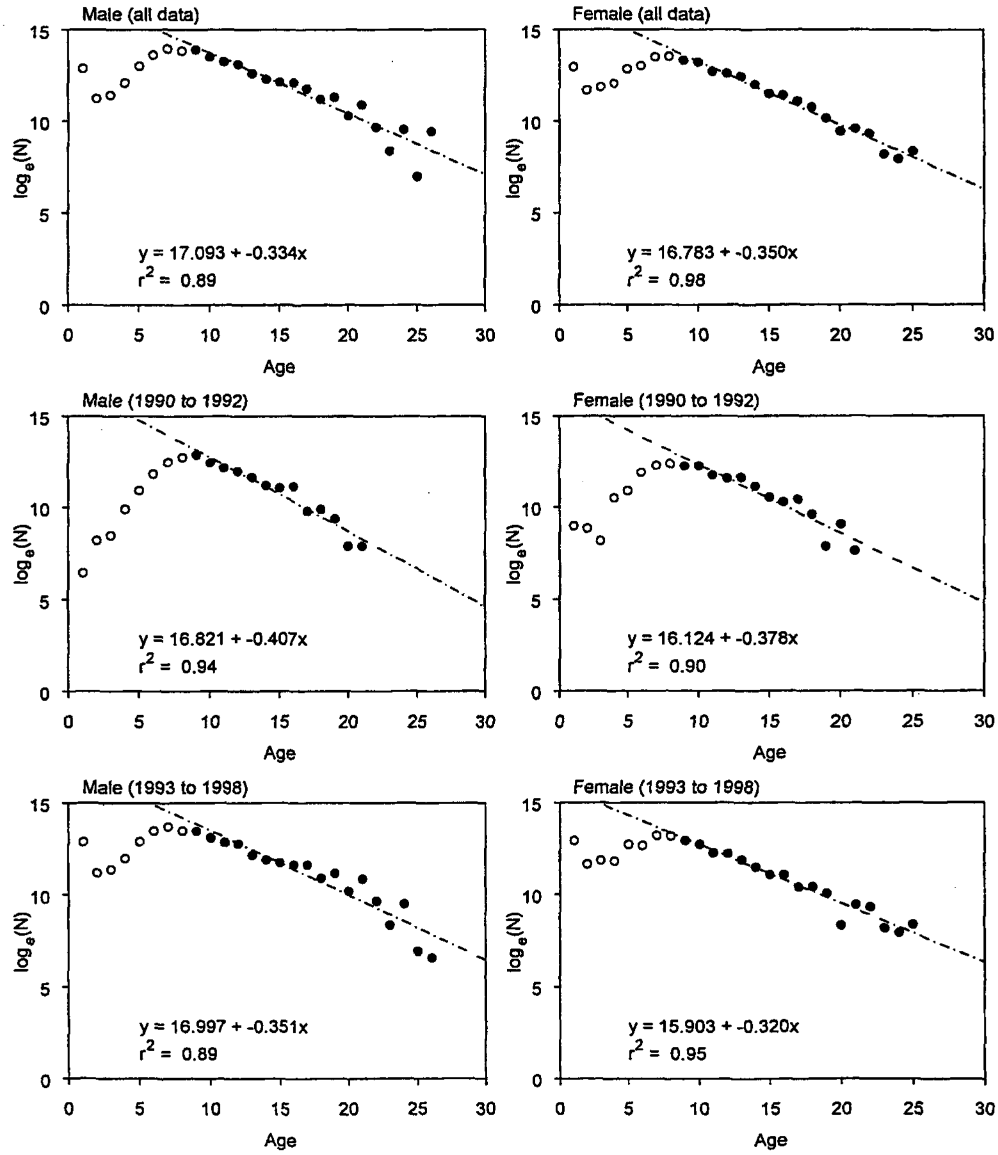


**Figure C5: Estimated catch-at-age, by sex, for samples of hake taken by commercial trawls on the west coast South Island from 1990 to 1998. Lines are the least squares linear regressions fitted to the data points represented by filled circles.**

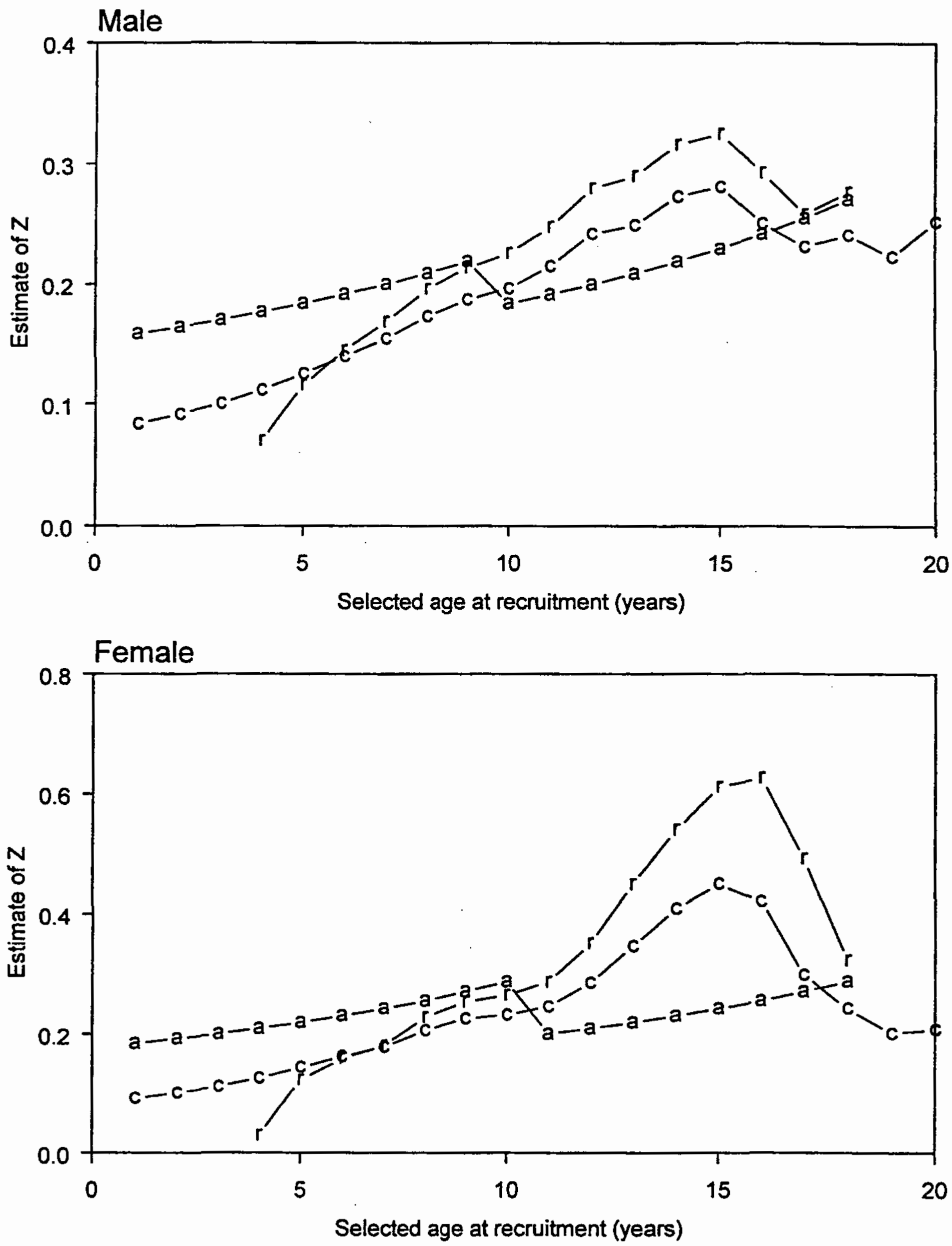


**Figure C6: Estimates of $Z$ using the three estimation methods (a = $A_{max}$, c = Chapman Robson, and R1= regression) and a range of ages at recruitment, for male and female fish from the HAK 7 research trawl data set (1979). For the $A_{max}$ estimator, $p$ = 0.01.**