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# Stock assessment of hake (*Merluccius australis*) on the Chatham Rise (HAK 4) and off the west coast of South Island (HAK 7) for the 2012–13 fishing year

New Zealand Fisheries Assessment Report 2013/31

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## EXECUTIVE SUMMARY

**Horn, P.L. (2013). Stock assessment of hake (*Merluccius australis*) on the Chatham Rise (HAK 4) and off the west coast of South Island (HAK 7) for the 2012–13 fishing year.**

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This report summarises the stock assessment for the 2012–13 fishing year of two stocks of hake, the WCSI stock (Quota Management Area HAK 7) and the Chatham Rise stock (HAK 4 and part of HAK 1). Updated Bayesian assessments were conducted using the general-purpose stock assessment program CASAL v2.22. The assessment incorporated all relevant biological parameters, the commercial catch histories, updated CPUE series, and series of proportion-at-age data from the commercial trawl fisheries and research surveys. The analysis includes fishery data up to the end of the 2011–12 fishing year. New model input data and revised catch histories for all three hake stocks (Sub-Antarctic, Chatham Rise, and west coast South Island) are also reported here.

The stock assessment of hake on the Chatham Rise has been updated using a model without sex in the partition, with biomass fitting primarily to the summer research survey series. The stock status of hake on the Chatham Rise appears to be relatively clear. The stock has been steadily fished down throughout the 1990s, but spawning biomass ($B_{2012}$) is still estimated to be 47% of $B_0$. A strong year class spawned in 2002 (in contrast to generally poor spawning success in other years from 1995 to 2009) has resulted in a slight stock upturn. However, it is likely that an annual catch equal to the HAK 4 TACC (1800 t) over the next five years will result in a further stock decline. The stock is probably being well monitored by the January trawl survey series, which showed evidence of a uniform decline in biomass from 1992 to about 2005. The sensitivity analysis incorporating a CPUE series gave a slightly more optimistic estimate of stock status ($B_{2012}$ was 55% of $B_0$), but still indicated that stock status would decline over five years with an annual catch of 1800 t.

The stock assessment of hake off west coast South Island has been updated using a model without sex in the partition, with biomass fitting primarily to a trawl fishery CPUE series from 2001 to 2011. A pair of comparable trawl survey biomass indices (from 2000 and 2012) were also incorporated in the assessment. The base case model indicated that the spawning stock is currently at about 58% $B_0$, and that $B_0$ was about 89 000 t. Sensitivity model runs excluding the trawl survey data or estimating instantaneous natural mortality within the model did not markedly alter the absolute spawning stock biomass (SSB) estimates or the estimate of current SSB. All models projected an increase in SSB over the next five years with catches equal to those from recent years (4500 t), but a slight decline in biomass at a higher future catch level equal to the current TACC (7700 t). The assessment indicated that the stock had been steadily fished down throughout the 1990s, but that relatively good spawning success from 2004 to 2006 has resulted in recent growth in stock size. However, the assessment is clearly uncertain as it is based primarily on a CPUE series, although the three main input data series (CPUE, trawl survey, and commercial fishery catch-at-age) all indicate a $B_0$ value in a relatively narrow range.

# 1. INTRODUCTION

This report outlines the stock assessment of hake (*Merluccius australis*) stocks on the WCSI (Quota Management Area (QMA) HAK 7) and on the Chatham Rise (HAK 4 and part of HAK 1) with the inclusion of data up to the end of the 2011–12 fishing year. The current stock hypothesis for hake suggests that there are three separate hake stocks (Colman 1998); the west coast South Island stock (WCSI, the area of HAK 7 on the west coast South Island), the Sub-Antarctic stock (the area of HAK 1 that encompasses the Southern Plateau), and the Chatham Rise stock (HAK 4 and the area of HAK 1 on the western Chatham Rise).

The stock assessments of hake off WCSI and Chatham Rise are presented as Bayesian assessments implemented as single stock models using the general-purpose stock assessment program CASAL v2.22 (Bull et al. 2012). Estimates of the current stock status and projected stock status are provided.

This report fulfils Objective 3 of Project DEE201002HAKB "To update the stock assessment of hake, including biomass estimates and sustainable yields", funded by the Ministry for Primary Industries. Revised catch histories for all three hake stocks are reported here, as are any new model input data and research results. Although some of these data are not relevant to the assessment reported here, they are included to provide in one place an up-to-date summary of the available knowledge and literature on hake in New Zealand waters.

## 1.1 Description of the fishery

Hake are widely distributed through the middle depths of the New Zealand Exclusive Economic Zone (EEZ) mostly south of latitude 40° S (Anderson et al. 1998). Adults are mainly distributed in depths from 250 to 800 m although 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 (Devine 2009). Present management divides 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). An administrative fish stock exists in the Kermadec QMA (HAK 10) although there are no recorded landings from this area. The hake QMAs are shown in Figure 1.

The largest fishery has been off the west coast of the South Island (HAK 7) with the highest catch (17 000 t) recorded in 1977, immediately before the establishment of the EEZ. Currently, the TACC for HAK 7 is the largest, at 7700 t out of a total for the EEZ of 13 211 t. The WCSI hake fishery has generally consisted of bycatch in the much larger hoki fishery, but it has undergone a number of changes during the last decade (Devine 2009). 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, 1993, 2006, and 2009 there has been a hake target fishery in September after the peak of the hoki fishery is over (Ballara 2012).

On the Chatham Rise and in the Sub-Antarctic, hake have been caught mainly as bycatch by trawlers targeting hoki, although significant targeting occurs in both areas (Devine 2009). Increases in TACCs from 2610 t to 3500 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 the landings of hake from these fish stocks. Reported catches rose over a number of years to the levels of the new TACCs in both HAK 1 and HAK 4, with catches in HAK 1 remaining relatively steady since. The TACC for HAK 1 has risen in several small jumps since then to its current level of 3701 t. Landings from HAK 4 steadily declined from 1998–99 to a low of 811 t in 2002–03, but increased to 2275 t in 2003–04. However, from 2004–05, the TACC for HAK 4 was reduced from 3500 t to 1800 t with an overall TAC of 1818 t. Annual landings have been markedly lower than the new TACC since then. From 1 October 2005 the TACC for HAK 7 was increased to

7700 t with an overall TAC of 7777 t. This new catch limit was set equal to average annual catches over the previous 12 years, a catch level that is believed to be sustainable in the short term.

Dunn (2003a) found that area misreporting between the WCSI and the Chatham Rise fisheries occurred from 1994–95 to 2000–01. He estimated that between 16 and 23% (700–1000 t annually) of WCSI landings were misreported as deriving from Chatham Rise, predominantly in June, July, and September. Levels of misreporting before 1994–95 and after 2000–01, and between WCSI and Sub-Antarctic, were estimated as negligible, and there is no evidence of significant misreporting since 2001–02 (Devine 2009).

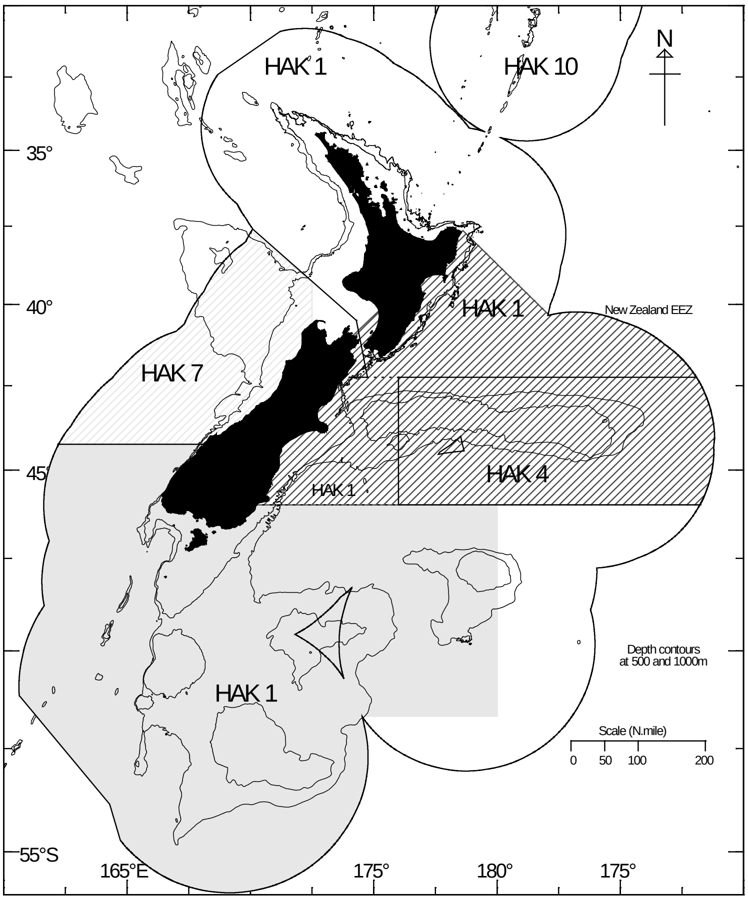



**Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, and 10; and the west coast South Island (light shading), Chatham Rise (dark shading), and Sub-Antarctic (medium shading) hake stock boundaries assumed in this report.**

## 1.2 Literature review

Previous assessments of hake, by fishing year, are as follows: 1991–92 (Colman et al. 1991), 1992–93 (Colman & Vignaux 1992), 1997–98 (Colman 1997), 1998–99 (Dunn 1998), 1999–2000 (Dunn et al. 2000), 2000–01 (Dunn 2001), 2002–03 (Dunn 2003b), 2003–04 (Dunn 2004a, 2004b), 2004–05 (Dunn et al. 2006), 2005–06 (Dunn 2006), 2006–07 (Horn & Dunn 2007), and 2007–08 (Horn 2008). The Bayesian stock assessment software CASAL (Bull et al. 2012) has been used for all assessments since 2002–03. The most recent assessments by stock are: Chatham Rise (Horn & Francis 2010), Sub-Antarctic (Horn 2013), and WCSI (Horn 2011).

Since 1991, resource surveys have been carried out from R.V. *Tangaroa* in the Sub-Antarctic in November–December 1991–1993, 2000–2009 and 2011, September–October 1992, and April–June 1992, 1993, 1996, and 1998. On Chatham Rise, a consistent time series of resource surveys from *Tangaroa* has been carried out in January 1992–2012. Appendix A gives more details about the surveys.

Standardised CPUE indices for the Sub-Antarctic stock only were updated to the 2009–10 fishing year by Ballara (2012), and for the WCSI and Chatham Rise stocks only by Ballara (in press), which includes a descriptive analysis of all New Zealand's hake fisheries up to the 2010–11 fishing year.

# 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 QMA since 1983–84 and TACCs since 1986–87 are shown in Table 2. Revised estimates of landings by QMA for 1989–90 to 2010–11 (Table 3) were derived by examining the reported tow-by-tow catches of hake and correcting for possible misreporting, using the method of Dunn (2003a).

Revised landings by biological stock are given in Table 4. The derivation of the catch from 1974–75 to 1988–89 was described for the Chatham Rise and Sub-Antarctic stocks by Dunn et al. (2000) and for WCSI by Dunn (2004b). Landings since 1989–90 from Chatham Rise and Sub-Antarctic and since 1991–92 for WCSI were obtained from the corrected data used to produce Table 3, but this time summing the landings reported in each of the three shaded areas shown on Figure 1. WCSI revised estimates for 1988–89 to 1990–91 are from Colman & Vignaux (1992), who estimated the actual hake catch in HAK 7 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.

**Table 1: Reported hake catches (t) from 1975 to 1987–88. Data from 1975 to 1983 from Ministry of Agriculture & Fisheries (Fisheries); data from 1983–84 to 1985–86 from Fisheries Statistics Unit; data from 1986–87 to 1987–88 from Quota Management System (QMS).**

| | New Zealand vessels | | | Foreign licensed vessels | | | | |
|---|---|---|---|---|---|---|---|---|
| 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 QMA from 1983–84 to 2010–11 and actual TACCs (t) for 1986–87 to 2010–11. Data from 1983–84 to 1985–86 from Fisheries Statistics Unit; data from 1986–87 to 2010–11 from Quota Management System (– indicates that the data are unavailable).**

| QMA | HAK 1 | | HAK 4 | | HAK 7 | | HAK 10 | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Landings | TACC | Landings | TACC | Landings | TACC | Landings | TACC | Landings | TACC |
| 1983–84 | 886 | – | 180 | – | 945 | – | 0 | – | 2 011 | – |
| 1984–85 | 670 | – | 399 | – | 965 | – | 0 | – | 2 034 | – |
| 1985–86 | 1 047 | – | 133 | – | 1 695 | – | 0 | – | 2 875 | – |
| 1986–87 | 1 022 | 2 500 | 200 | 1 000 | 2 909 | 3 000 | 0 | 10 | 4 131 | 6 510 |
| 1987–88 | 1 381 | 2 500 | 288 | 1 000 | 3 019 | 3 000 | 0 | 10 | 4 689 | 6 510 |
| 1988–89 | 1 487 | 2 513 | 554 | 1 000 | 6 835 | 3 004 | 0 | 10 | 8 876 | 6 527 |
| 1989–90 | 2 115 | 2 610 | 763 | 1 000 | 4 903 | 3 310 | 0 | 10 | 7 783 | 6 930 |
| 1990–91 | 2 603 | 2 610 | 743 | 1 000 | 6 148 | 3 310 | 0 | 10 | 9 567 | 6 930 |
| 1991–92 | 3 156 | 3 500 | 2 013 | 3 500 | 3 026 | 6 770 | 0 | 10 | 8 196 | 13 780 |
| 1992–93 | 3 525 | 3 501 | 2 546 | 3 500 | 7 154 | 6 835 | 0 | 10 | 13 224 | 13 846 |
| 1993–94 | 1 803 | 3 501 | 2 587 | 3 500 | 2 974 | 6 835 | 0 | 10 | 7 363 | 13 847 |
| 1994–95 | 2 572 | 3 632 | 3 369 | 3 500 | 8 841 | 6 855 | 0 | 10 | 14 781 | 13 997 |
| 1995–96 | 3 956 | 3 632 | 3 465 | 3 500 | 8 678 | 6 855 | 0 | 10 | 16 082 | 13 997 |
| 1996–97 | 3 534 | 3 632 | 3 524 | 3 500 | 6 118 | 6 855 | 0 | 10 | 13 176 | 13 997 |
| 1997–98 | 3 809 | 3 632 | 3 523 | 3 500 | 7 416 | 6 855 | 0 | 10 | 14 749 | 13 997 |
| 1998–99 | 3 845 | 3 632 | 3 324 | 3 500 | 8 165 | 6 855 | 0 | 10 | 15 333 | 13 997 |
| 1999–00 | 3 899 | 3 632 | 2 803 | 3 500 | 6 898 | 6 855 | 0 | 10 | 13 600 | 13 997 |
| 2000–01 | 3 504 | 3 632 | 2 472 | 3 500 | 8 134 | 6 855 | 0 | 10 | 14 110 | 13 997 |
| 2001–02 | 2 870 | 3 701 | 1 424 | 3 500 | 7 519 | 6 855 | 0 | 10 | 11 813 | 14 066 |
| 2002–03 | 3 336 | 3 701 | 811 | 3 500 | 7 433 | 6 855 | 0 | 10 | 11 581 | 14 066 |
| 2003–04 | 3 461 | 3 701 | 2 272 | 3 500 | 7 943 | 6 855 | 0 | 10 | 13 686 | 14 066 |
| 2004–05 | 4 797 | 3 701 | 1 266 | 1 800 | 7 316 | 6 855 | 0 | 10 | 13 377 | 12 366 |
| 2005–06 | 2 743 | 3 701 | 305 | 1 800 | 6 906 | 7 700 | 0 | 10 | 9 955 | 13 211 |
| 2006–07 | 2 025 | 3 701 | 900 | 1 800 | 7 668 | 7 700 | 0 | 10 | 10 592 | 13 211 |
| 2007–08 | 2 445 | 3 701 | 865 | 1 800 | 2 620 | 7 700 | 0 | 10 | 5 930 | 13 211 |
| 2008–09 | 3 415 | 3 701 | 856 | 1 800 | 5 954 | 7 700 | 0 | 10 | 10 226 | 13 211 |
| 2009–10 | 2 156 | 3 701 | 208 | 1 800 | 2 351 | 7 700 | 0 | 10 | 4 715 | 13 211 |
| 2010–11 | 1 904 | 3 701 | 179 | 1 800 | 3 754 | 7 700 | 0 | 10 | 5 838 | 13 211 |

**Table 3: Revised reported landings (t) by QMA 1989–90 to 2010–11 from Ballara (in press).**

| Fishing | | QMA | | Total |
|---|---|---|---|---|
| Year | HAK 1 | HAK 4 | HAK 7 | |
| 1989–90 | 2 115 | 763 | 4 903 | 7 781 |
| 1990–91 | 2 592 | 726 | 6 175 | 9 494 |
| 1991–92 | 3 141 | 2 007 | 3 048 | 8 196 |
| 1992–93 | 3 522 | 2 546 | 7 157 | 13 225 |
| 1993–94 | 1 787 | 2 587 | 2 990 | 7 364 |
| 1994–95 | 2 263 | 2 855 | 9 659 | 14 780 |
| 1995–96 | 3 805 | 3 028 | 9 153 | 15 987 |
| 1996–97 | 3 285 | 2 865 | 6 950 | 13 100 |
| 1997–98 | 3 659 | 3 237 | 7 686 | 14 581 |
| 1998–99 | 3 702 | 2 882 | 8 929 | 15 513 |
| 1999–00 | 3 747 | 2 447 | 7 086 | 13 280 |
| 2000–01 | 3 429 | 2 321 | 8 351 | 14 101 |
| 2001–02 | 2 865 | 1 420 | 7 499 | 11 784 |
| 2002–03 | 3 334 | 805 | 7 406 | 11 545 |
| 2003–04 | 3 455 | 2 254 | 7 943 | 13 652 |
| 2004–05 | 4 795 | 1 260 | 7 302 | 13 357 |
| 2005–06 | 2 742 | 305 | 6 897 | 9 944 |
| 2006–07 | 2 006 | 900 | 7 660 | 10 566 |
| 2007–08 | 2 442 | 865 | 2 615 | 5 922 |
| 2008–09 | 3 409 | 854 | 5 945 | 10 208 |
| 2009–10 | 2 156 | 208 | 2 340 | 4 704 |
| 2010–11 | 1 904 | 179 | 3 716 | 5 799 |

**Table 4: Estimated landings (t) from fishing years 1974–75 to 2010–11 for the Sub-Antarctic (Sub-A), Chatham Rise (Chat), and west coast South Island (WCSI) biological stocks (areas as defined in Figure 1).**

| Fishing yr | Sub-A | Chat | WCSI | Fishing yr | Sub-A | Chat | WCSI |
|---|---|---|---|---|---|---|---|
| 1974–75 | 120 | 191 | 71 | 1993–94 | 1 453 | 2 934 | 2 971 |
| 1975–76 | 281 | 488 | 5 005 | 1994–95 | 1 852 | 3 387 | 9 535 |
| 1976–77 | 372 | 1 288 | 17 806 | 1995–96 | 2 873 | 4 028 | 9 082 |
| 1977–78 | 762 | 34 | 498 | 1996–97 | 2 262 | 4 234 | 6 838 |
| 1978–79 | 364 | 609 | 4 737 | 1997–98 | 2 606 | 4 252 | 7 674 |
| 1979–80 | 350 | 750 | 3 600 | 1998–99 | 2 796 | 3 669 | 8 742 |
| 1980–81 | 272 | 997 | 2 565 | 1999–00 | 3 020 | 3 517 | 7 031 |
| 1981–82 | 179 | 596 | 1 625 | 2000–01 | 2 790 | 2 962 | 8 346 |
| 1982–83 | 448 | 302 | 745 | 2001–02 | 2 510 | 1 770 | 7 498 |
| 1983–84 | 722 | 344 | 945 | 2002–03 | 2 738 | 1 401 | 7 404 |
| 1984–85 | 525 | 544 | 965 | 2003–04 | 3 245 | 2 465 | 7 939 |
| 1985–86 | 818 | 362 | 1 918 | 2004–05 | 2 531 | 3 526 | 7 298 |
| 1986–87 | 713 | 509 | 3 755 | 2005–06 | 2 557 | 489 | 6 892 |
| 1987–88 | 1 095 | 574 | 3 009 | 2006–07 | 1 818 | 1 081 | 7 660 |
| 1988–89 | 1 237 | 804 | 8 696 | 2007–08 | 2 202 | 1 096 | 2 583 |
| 1989–90 | 1 927 | 950 | 8 741 | 2008–09 | 2 427 | 1 825 | 5 912 |
| 1990–91 | 2 370 | 931 | 8 246 | 2009–10 | 1 958 | 391 | 2 282 |
| 1991–92 | 2 750 | 2 418 | 3 001 | 2010–11 | 1 138 | 940 | 3 701 |
| 1992–93 | 3 269 | 2 798 | 7 059 | | | | |

## 2.2 Recreational and Maori customary fisheries

The recreational fishery for hake is believed to be 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 likely to be some mortality associated with escapement from trawl nets, but the level is not known and is assumed to be negligible.

# 3. BIOLOGY, STOCK STRUCTURE, AND ABUNDANCE INDICES

## 3.1 Biology

Data collected by observers on commercial trawlers and from resource surveys suggest that there are at least three main spawning areas for hake (Colman 1998). The best known area is off the west coast of the South Island, where the season can extend from June to October, possibly with a peak in September. Spawning also occurs to the west of the Chatham Islands during a prolonged period from at least September to January. Spawning fish have also been recorded occasionally near the Mernoo Bank. 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 also been recorded occasionally on the Puysegur Bank, with a seasonality that appears similar to that on the Campbell Plateau (Colman 1998).

Horn (1997) validated the use of otoliths to age hake. New Zealand hake reach a maximum age of at least 25 years. Males, which rarely exceed 100 cm total length, do not grow as large as females, which can grow to 120 cm total length or more. Readings of otoliths from hake have been used as age-length keys to scale up length frequency distributions for hake collected on resource surveys and from commercial fisheries on the Chatham Rise, Sub-Antarctic, and west coast South Island. The resulting age frequency distributions were reported by Horn & Sutton (2013).

Colman (1998) found that hake reach sexual maturity between 6 and 10 years of age, at total lengths of about 67–75 cm (males) and 75–85 cm (females); he concluded that hake reached 50% maturity at between 6 and 8 years in HAK 1, and 7–8 years in HAK 4. In assessments before 2005, the maturity ogive for the Chatham Rise and Sub-Antarctic was assumed from a combination of the estimates of Colman (1998) and model fits to the west coast South Island stock presented by Dunn (1998).

From 2005 to 2007, maturity ogives for the Chatham Rise and Sub-Antarctic stocks were fitted within the assessment model to data derived from resource survey samples with information on the gonosomatic index, gonad stage, and age (Horn & Dunn 2007, Horn 2008). Individual hake were classified as either immature or mature at sex and age, where maturity was determined from the gonad stage and gonosomatic index (GSI, the ratio of the gonad weight to body weight). Fish identified as stage 1 were classified as immature. Stage 2 fish were classified as immature or mature depending on the GSI index, using the definitions of Colman (1998) — i.e., classified as immature if GSI less than 0.005 (males) or GSI less than 0.015 (females), or mature if GSI at least 0.005 (males) or GSI at least 0.015 (females). Fish identified as stages 3–7 were classified as mature. From 2009 to 2011, fixed ogives as derived from the previously described model fitting procedure were used in the assessment models. In 2012, fixed ogives for all stocks were updated by fitting a logistic curve (from Bull et al. 2012) to the proportion mature at age data, by sex, with the fish classified as mature or immature as described above. The analysed data were derived from resource surveys over the following periods corresponding with likely spawning activity: Sub-Antarctic, October–February; Chatham Rise, November–January; WCSI, July–September. The proportions mature are listed in Table 5, with ogives plotted in Figure 2; values for combined sexes maturity were taken as the mean of the male and female values. Chatham Rise hake reach 50% maturity at about 5.5 years for males and 7 years for females, Sub-Antarctic hake at about 6 years for males and 6.5 years for females, and WCSI hake at about 4.5 years for males and 5 years for females.

Von Bertalanffy parameters were previously estimated using data up to 1997 (Horn 1998). The parameters for all three stocks were updated using all data available at February 2007 (Horn 2008).

Plots of the fitted curves on the raw data indicated that the von Bertalanffy model tended to underestimate the age of large fish. Consequently, the growth model of Schnute (1981) was fitted to the data sets (Table 5). This model appeared to better describe the growth of larger hake (Horn 2008), and the resulting parameters can be used in the CASAL stock assessment software. Most aged hake have been 3 years or older. However, juvenile hake have been taken in coastal waters on both sides of the South Island and on the Campbell Plateau. It is known that they reach a total length of about 15–20 cm at 1 year old, and about 35 cm total length at 2 years (Horn 1997).

Estimates of natural mortality ($M$) and the associated methodology were given by Dunn et al. (2000); $M$ was estimated as 0.18 $y^{-1}$ for females and 0.20 $y^{-1}$ for males. Colman et al. (1991) 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 they 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 to the values proposed by Horn (1997), who determined the age of hake by counting zones in sectioned otoliths and concluded from that study that it was likely that $M$ was in the range 0.20–0.25 $y^{-1}$. Up to 2011, constant values of $M$ were used in stock assessment models. However, because true $M$ is likely to vary with age, the assessments presented below estimate ogives for $M$ within the models (see Sections 5.4 and 6.4).

Dunn et al. (2010) found that the diet of hake on the Chatham Rise was dominated by teleost fishes, in particular Macrouridae. Macrouridae accounted for 44% of the prey weight and consisted of at least six species, of which javelinfish, *Lepidorhynchus denticulatus*, was most frequently identified. Hoki were less frequent prey, but being relatively large accounted for 37% of prey weight. Squids were found in 7% of the stomachs, and accounted for 5% of the prey weight. Crustacean prey were predominantly natant decapods, with pasiphaeid prawns occurring in 19% of the stomachs.

Length-weight relationships for hake from the Sub-Antarctic and Chatham Rise stocks were revised by Horn (2013) using all available length-weight data collected during trawl surveys since 1989. Following a trawl survey off WCSI in July-August 2012, parameters for hake from that stock were also revised. Parameters were calculated for males, females, and both sexes combined (Table 5). Sample sizes were large (2165 males, 1828 females) and all $r^2$ values were greater than 0.97.

**Table 5: Estimates of biological parameters for the three hake stocks.**

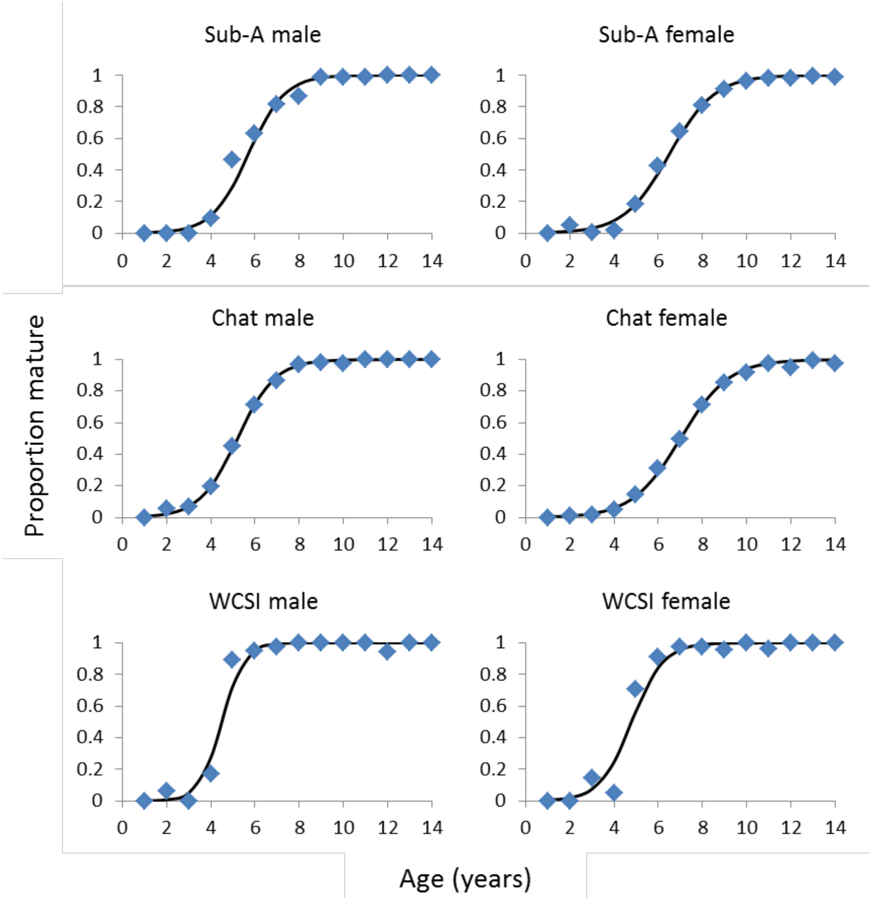
| | | Estimate | | | | Source |
|---|---|---|---|---|---|---|
| *Natural mortality* | | | | | | |
| | Males | $M$ = 0.20 | | | | (Dunn et al. 2000) |
| | Females | $M$ = 0.18 | | | | (Dunn et al. 2000) |
| *Weight = $a \cdot (length)^b$ (Weight in t, length in cm)* | | | | | | |
| Sub-Antarctic | Males | $a$ = 2.13 x$10^{-9}$ | $b$ = 3.281 | | | (Horn 2013) |
| | Females | $a$ = 1.83 x$10^{-9}$ | $b$ = 3.314 | | | (Horn 2013) |
| | Both sexes | $a$ = 1.95 x$10^{-9}$ | $b$ = 3.301 | | | (Horn 2013) |
| Chatham Rise | Males | $a$ = 2.56 x$10^{-9}$ | $b$ = 3.228 | | | (Horn 2013) |
| | Females | $a$ = 1.88 x$10^{-9}$ | $b$ = 3.305 | | | (Horn 2013) |
| | Both sexes | $a$ = 2.00 x$10^{-9}$ | $b$ = 3.288 | | | (Horn 2013) |
| WCSI | Males | $a$ = 2.85 x$10^{-9}$ | $b$ = 3.209 | | | (current study) |
| | Females | $a$ = 1.94 x$10^{-9}$ | $b$ = 3.307 | | | (current study) |
| | Both sexes | $a$ = 2.01 x$10^{-9}$ | $b$ = 3.294 | | | (current study) |
| *von Bertalanffy growth parameters* | | | | | | |
| Sub-Antarctic | Males | $k$ = 0.295 | $t_0$ = 0.06 | $L_\infty$ = 88.8 | | (Horn 2008) |
| | Females | $k$ = 0.220 | $t_0$ = 0.01 | $L_\infty$ = 107.3 | | (Horn 2008) |
| Chatham Rise | Males | $k$ = 0.330 | $t_0$ = 0.09 | $L_\infty$ = 85.3 | | (Horn 2008) |
| | Females | $k$ = 0.229 | $t_0$ = 0.01 | $L_\infty$ = 106.5 | | (Horn 2008) |
| WCSI | Males | $k$ = 0.357 | $t_0$ = 0.11 | $L_\infty$ = 82.3 | | (Horn 2008) |
| | Females | $k$ = 0.280 | $t_0$ = 0.08 | $L_\infty$ = 99.6 | | (Horn 2008) |
| *Schnute growth parameters* ($\tau_1$ = 1 and $\tau_2$ = 20 for all stocks) | | | | | | |
| Sub-Antarctic | Males | $y_1$ = 22.3 | $y_2$ = 89.8 | $a$ = 0.249 | $b$ = 1.243 | (Horn 2008) |
| | Females | $y_1$ = 22.9 | $y_2$ = 109.9 | $a$ = 0.147 | $b$ = 1.457 | (Horn 2008) |
| | Both sexes | $y_1$ = 22.8 | $y_2$ = 101.8 | $a$ = 0.179 | $b$ = 1.350 | (Horn 2013) |
| Chatham Rise | Males | $y_1$ = 24.6 | $y_2$ = 90.1 | $a$ = 0.184 | $b$ = 1.742 | (Horn 2008) |
| | Females | $y_1$ = 24.4 | $y_2$ = 114.5 | $a$ = 0.098 | $b$ = 1.764 | (Horn 2008) |
| | Both sexes | $y_1$ = 24.5 | $y_2$ = 104.8 | $a$ = 0.131 | $b$ = 1.700 | (Horn & Francis 2010) |
| WCSI | Males | $y_1$ = 23.7 | $y_2$ = 83.9 | $a$ = 0.278 | $b$ = 1.380 | (Horn 2008) |
| | Females | $y_1$ = 24.5 | $y_2$ = 103.6 | $a$ = 0.182 | $b$ = 1.510 | (Horn 2008) |
| | Both sexes | $y_1$ = 24.5 | $y_2$ = 98.5 | $a$ = 0.214 | $b$ = 1.570 | (Horn 2011) |

*Maturity ogives (proportion mature at age)*

| | Age | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SubAnt | Males | 0.01 | 0.04 | 0.11 | 0.30 | 0.59 | 0.83 | 0.94 | 0.98 | 0.99 | 1.00 | 1.00 | 1.00 |
| | Females | 0.01 | 0.03 | 0.08 | 0.19 | 0.38 | 0.62 | 0.81 | 0.92 | 0.97 | 0.99 | 1.00 | 1.00 |
| | Both | 0.01 | 0.03 | 0.09 | 0.24 | 0.49 | 0.73 | 0.88 | 0.95 | 0.98 | 0.99 | 1.00 | 1.00 |
| Chatham | Males | 0.02 | 0.07 | 0.20 | 0.44 | 0.72 | 0.89 | 0.96 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Females | 0.01 | 0.02 | 0.06 | 0.14 | 0.28 | 0.50 | 0.72 | 0.86 | 0.94 | 0.98 | 0.99 | 1.00 |
| | Both | 0.02 | 0.05 | 0.13 | 0.29 | 0.50 | 0.70 | 0.84 | 0.93 | 0.97 | 0.99 | 0.99 | 1.00 |
| WCSI | Males | 0.01 | 0.05 | 0.27 | 0.73 | 0.95 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Females | 0.02 | 0.07 | 0.25 | 0.57 | 0.84 | 0.96 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Both | 0.01 | 0.06 | 0.26 | 0.65 | 0.90 | 0.97 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

*Miscellaneous parameters*

| | |
|---|---|
| Steepness (Beverton & Holt stock-recruitment relationship) | 0.90 |
| Proportion spawning | 1.0 |
| Proportion of recruits that are male | 0.5 |
| Ageing error c.v. | 0.08 |
| Maximum exploitation rate ($U_{max}$) | 0.7 |



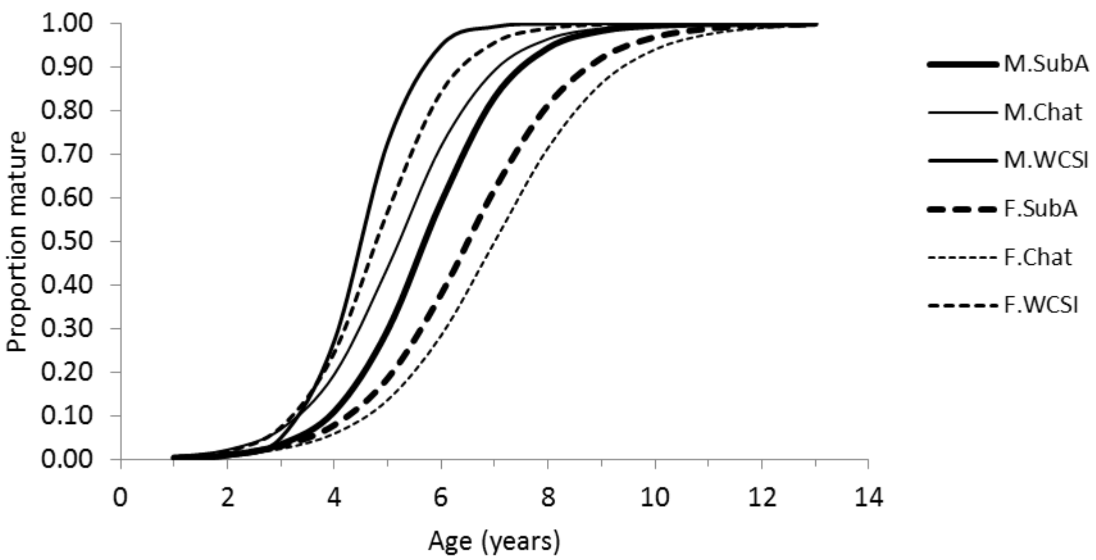




**Figure 2: Raw proportion mature at age data with fitted logistic ogives (upper panel), and a comparison plot (lower panel) of all estimated ogives by stock for male (M, solid lines) and female (F, broken lines) hake.**

## 3.2 Stock structure

There are at least three hake spawning areas: off the west coast of the South Island, on the Chatham Rise, and on the Campbell Plateau (Colman 1998). 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 reason, therefore, to believe that at least three separate stocks may exist in the EEZ.

Analysis of morphometric data (J.A. Colman, NIWA, unpublished data) showed little difference between hake from the Chatham Rise and from the east coast of the North Island, but 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 stock assessment models, the Chatham Rise stock was considered to include the whole of the Chatham Rise (HAK 4 and the western end of the Chatham Rise that forms part of the HAK 1 management area). The Sub-Antarctic stock was considered to contain hake in the remaining Puysegur, Southland, and Sub-Antarctic regions of the HAK 1 management area. The stock areas assumed for this report are shown earlier, in Figure 1.

## 3.3 Resource surveys

In the Sub-Antarctic, three resource surveys were carried out by *Tangaroa* with the same gear and similar survey designs in November–December 1991, 1992, and 1993, but the series was then terminated as 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. However, research interest in hoki in the Sub-Antarctic resulted in a return to the November–December survey annually from 2000 to 2009 and in 2011. Surveys by *Tangaroa* in April 1992, May 1993, April 1996, and April 1998 formed the basis for a second series, with hake appearing to be more evenly distributed through the survey area at that time of year. A single survey in September 1992 by *Tangaroa* was also completed. The biomass estimates from the Sub-Antarctic *Tangaroa* and 1989 *Amaltal Explorer* surveys are shown in Table 6 with further details given in Appendix A.

Sub-Antarctic surveys were conducted by *Shinkai Maru* (March–May 1982 and October–November 1983) and *Amaltal Explorer* (October–November 1989, July–August 1990, and November–December 1990). However, these vessels used different gear and had different performance characteristics (Livingston et al. 2002), so cannot be used as part of a consistent time series.

Resource surveys have been carried out at depths of 200–800 m on the Chatham Rise since 1992 by *Tangaroa* with the same gear and similar survey designs (see Appendix A). While the survey designs since 1992 have been similar, there was a reduction in the number of stations surveyed between 1996 and 1999, and some strata in the survey design used between 1996 and 1999 were merged (see Bull & Bagley 1999). The surveys since 2000 used a revised design, with some strata being split and additional stations added. Since 2000 some of the *Tangaroa* surveys included deepwater strata (i.e., 800–1300 m) on the Chatham Rise, although data from these strata were excluded from this analysis to maintain consistency in the time series.

Chatham Rise surveys were conducted by *Shinkai Maru* (March 1983 and June–July 1986) and *Amaltal Explorer* (November–December 1989). However, these surveys used a range of gear, survey methodologies, and survey designs (Livingston et al. 2002), and cannot be used as a consistent time series. The biomass estimates from Chatham Rise resource surveys are shown in Table 7 with further details in Appendix A. Catch distributions from these surveys are plotted by Stevens et al. (2011).

**Table 6: Research survey indices (and associated c.v.s) for the Sub-Antarctic stock.**

| Fishing | Vessel | Nov–Dec series[1] | | Apr–May series[2] | | Sep series[2] | |
|---|---|---|---|---|---|---|---|
| Year | | Biomass (t) | c.v. | Biomass (t) | c.v. | Biomass (t) | c.v. |
| 1989 | *Amaltal* | 2 660 | 0.21 | | | | |
| 1992 | *Tangaroa* | 5 686 | 0.43 | 5 028 | 0.15 | 3 760 | 0.15 |
| 1993 | *Tangaroa* | 1 944 | 0.12 | 3 221 | 0.14 | | |
| 1994 | *Tangaroa* | 2 567 | 0.12 | | | | |
| 1996 | *Tangaroa* | | | 2 026 | 0.12 | | |
| 1998 | *Tangaroa* | | | 2 554 | 0.18 | | |
| 2001 | *Tangaroa* | 2 657 | 0.16 | | | | |
| 2002 | *Tangaroa* | 2 170 | 0.20 | | | | |
| 2003 | *Tangaroa* | 1 777 | 0.16 | | | | |
| 2004 | *Tangaroa* | 1 672 | 0.23 | | | | |
| 2005 | *Tangaroa* | 1 694 | 0.21 | | | | |
| 2006 | *Tangaroa* | 1 459 | 0.17 | | | | |
| 2007 | *Tangaroa* | 1 530 | 0.17 | | | | |
| 2008 | *Tangaroa* | 2 470 | 0.15 | | | | |
| 2009 | *Tangaroa* | 2 162 | 0.17 | | | | |
| 2010 | *Tangaroa* | 1 442 | 0.20 | | | | |
| 2012 | *Tangaroa* | 2 004 | 0.23 | | | | |

Notes: (1) Series based on indices from 300–800 m core strata, including the 800–1000 m strata in Puysegur, but excluding Bounty Platform, (2) Series based on the biomass indices from 300–800 m core strata, excluding the 800–1000 m strata in Puysegur and the Bounty Platform.

Research surveys of hoki and hake have been conducted periodically off WCSI, but these have generally been ‘one-off’ surveys by different vessels (i.e., *Shinkai Maru* in 1976, *James Cook* in 1978–79, *Wesermünde* in 1979, and *Giljanes* in 1990) so any biomass estimates from them are not useful model inputs. However, a combined trawl and acoustic survey by *Tangaroa* in 2000 (O’Driscoll et al. 2004) was replicated (with some modifications) in winter 2012 (O’Driscoll et al. in prep.), so a two year comparable time series is available (Table 7). The biomass estimates from the two surveys were standardised using random day-time bottom trawl stations in strata 12A, B, and C, and 4A, B, and C, with stratum areas from the 2012 survey (O’Driscoll et al. in prep.). A long-running trawl survey series of inshore waters off WCSI by *Kaharoa* has not provided a useful index of hake biomass as it surveys no deeper than 400 m (Stevenson & Hanchet 2000). Age data, and consequent estimates of proportion-at-age, are available for the two comparable *Tangaroa* surveys. Proportion-at-age data are also available from the 1979 *Wesermünde* survey; these data are included in the assessment model with the WCSI commercial trawl fishery data set as the selectivity ogive for this vessel is likely to be more similar to the commercial fleet than to the *Tangaroa* survey gear (N. Bagley, NIWA, pers. comm.).

**Table 7: Research survey indices (and associated c.v.s) for the Chatham Rise and WCSI stocks.**

| | Chatham Rise | | | WCSI | | |
|---|---|---|---|---|---|---|
| Year | Vessel | Biomass (t) | c.v. | Vessel | Biomass (t) | c.v. |
| 1989 | *Amaltal Explorer* | 3 576 | 0.19 | | | |
| 1992 | *Tangaroa* | 4 180 | 0.15 | | | |
| 1993 | *Tangaroa* | 2 950 | 0.17 | | | |
| 1994 | *Tangaroa* | 3 353 | 0.10 | | | |
| 1995 | *Tangaroa* | 3 303 | 0.23 | | | |
| 1996 | *Tangaroa* | 2 457 | 0.13 | | | |
| 1997 | *Tangaroa* | 2 811 | 0.17 | | | |
| 1998 | *Tangaroa* | 2 873 | 0.18 | | | |
| 1999 | *Tangaroa* | 2 302 | 0.12 | | | |
| 2000 | *Tangaroa* | 2 090 | 0.09 | *Tangaroa* | 803 | 0.13 |
| 2001 | *Tangaroa* | 1 589 | 0.13 | | | |
| 2002 | *Tangaroa* | 1 567 | 0.15 | | | |
| 2003 | *Tangaroa* | 890 | 0.16 | | | |
| 2004 | *Tangaroa* | 1 547 | 0.17 | | | |
| 2005 | *Tangaroa* | 1 049 | 0.18 | | | |
| 2006 | *Tangaroa* | 1 384 | 0.19 | | | |
| 2007 | *Tangaroa* | 1 820 | 0.12 | | | |
| 2008 | *Tangaroa* | 1 257 | 0.13 | | | |
| 2009 | *Tangaroa* | 2 419 | 0.21 | | | |
| 2010 | *Tangaroa* | 1 700 | 0.25 | | | |
| 2011 | *Tangaroa* | 1 099 | 0.15 | | | |
| 2012 | *Tangaroa* | 1 292 | 0.15 | *Tangaroa* | 583 | 0.12 |

## 3.4 Observer age data

### 3.4.1 Chatham Rise

The fishery on the Chatham Rise was stratified using a tree-based regression on mean lengths of hake in tows where observers had measured five or more hake (Horn & Dunn 2007). The defined strata are shown in Figure 3. Mean fish length tends to increase from west to east, and with increasing depth. Area 404 is a known spawning ground. However, Horn & Francis (2010) showed that the two western fisheries had similar age-frequency distributions, and the two eastern fisheries were data poor. Consequently, they used two strata, eastern and western, divided at 178.1° E. Observer data from each fishery stratum were converted into catch-at-age distributions if there were at least 400 length measurements (from western strata) or 320 length measurements (from eastern strata), and the mean weighted c.v. over all age classes was less than 30%. The available data (described by Horn & Sutton (2013)) are from 1991–92 and 1993–94 to 2010–11. Although the observer length data from each year were partitioned into fisheries (i.e., two strata in each of the two fisheries, as shown in Figure 3), the age data from each year were not (i.e., a single age-length key was constructed for each year and applied to all available sets of length data from that year). Horn & Dunn (2007) showed that mean age at length did not differ between fisheries, so the use of a single age-length key per year has probably not biased the age distributions.

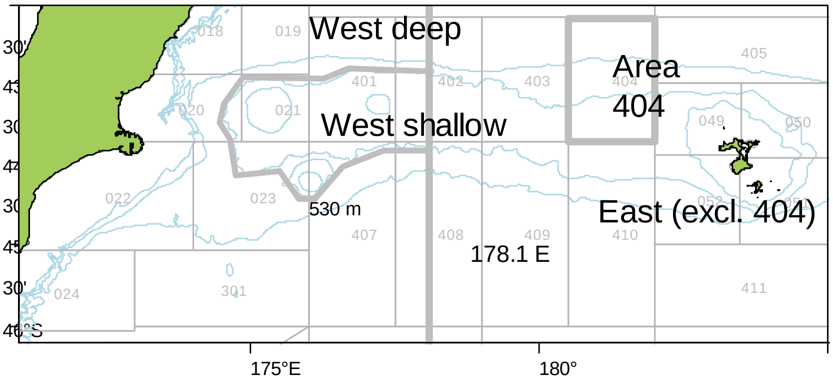



**Figure 3: Fishery strata defined for the Chatham Rise hake fishery. Large numbers show longitudes or depths of fishery boundaries; small numbers denote statistical areas. The stratum boundary defined by depth (530 m) is shown only approximately. Isobaths at 1000, 500, and 250 m are also shown.**

### 3.4.2 Sub-Antarctic

The Sub-Antarctic hake observer data were found to be best stratified into the four areas shown in Figure 4 (Horn 2008). Most of the hake target fishing, and most of the catch (average 94% per year), is associated with the Snares-Pukaki area. Puysegur is the next most important area with about 3% of the catch. Available observer data are also concentrated in the Snares-Pukaki region, but it is clear that the smaller fisheries (particularly the Campbell Island area) can often be over-sampled in most years. Consequently, the Sub-Antarctic observer data are analysed as one major and three very minor fisheries, with a single fishery ogive. However, because of clear differences in mean fish length between the fisheries (Horn 2008), it is important to use the four fishery strata when calculating catch-at-age distributions. Without stratification, the frequent over-sampling in the minor fisheries could strongly bias the catch-at-age distributions. However, it is satisfactory to apply a single age-length key to the scaled length-frequency distributions for each fishery to produce the catch-at-age data. Catch-at-age distributions from the Sub-Antarctic trawl fishery are available from all but three years from 1989–90 to 2010–11 (Horn & Sutton 2013).

### 3.4.3 WCSI

The fishery off WCSI was stratified using a tree-based regression on mean lengths of hake in tows where observers had measured five or more hake (Horn & Dunn 2007). A single catch-at-age distribution was estimated for each year, stratified as shown in Figure 4. Catch-at-age distributions from the WCSI trawl fishery are available from 1978–79 and all years from 1989–90 to 2010–11 (Horn & Sutton 2013).

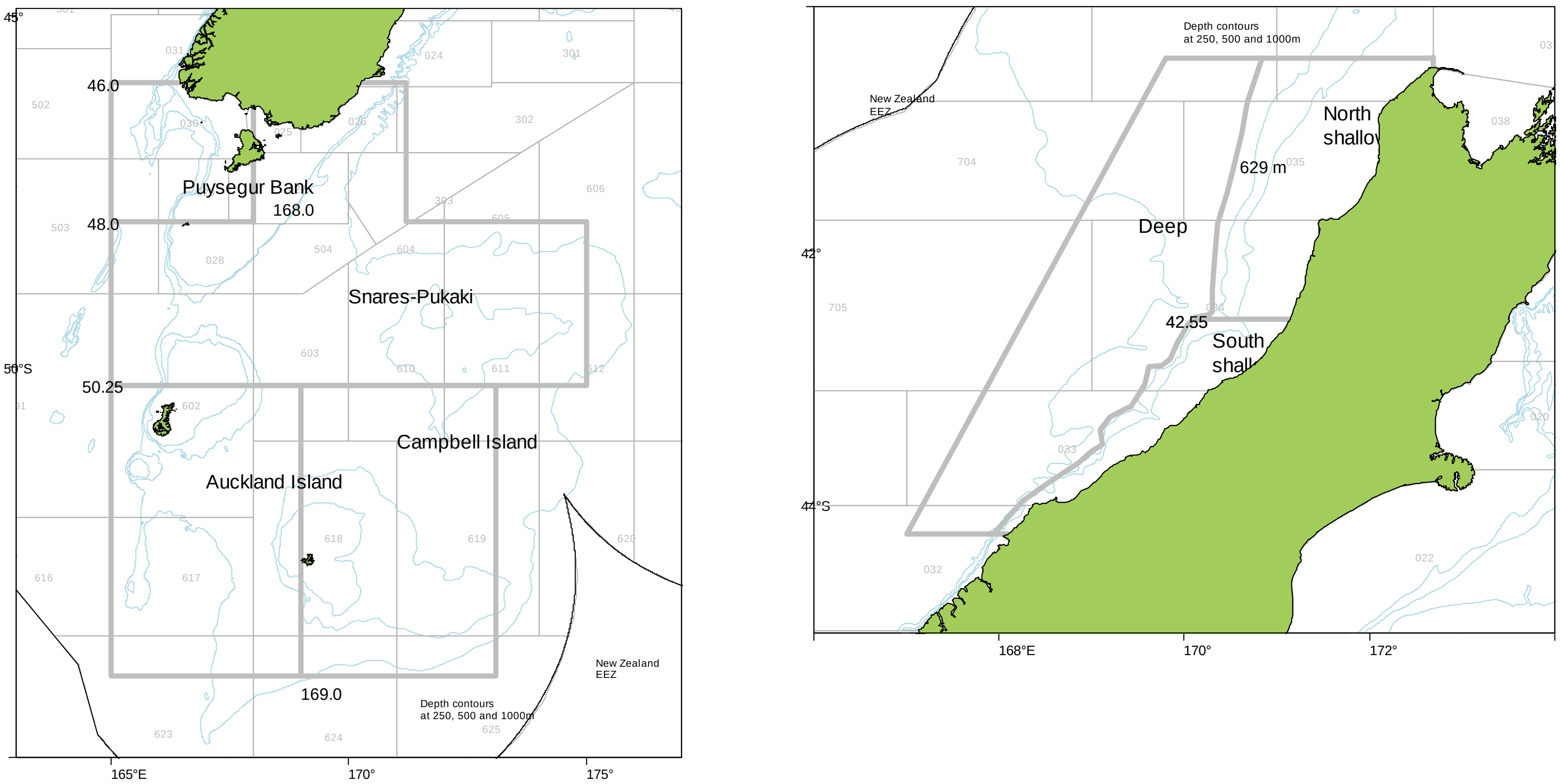



**Figure 4: Fishery strata defined for the Sub-Antarctic (left panel) and WCSI (right panel) hake fisheries. Large numbers show latitudes, longitudes, or depths of fishery boundaries; small numbers denote statistical areas. The WCSI stratum boundary defined by depth (629 m) is shown only approximately. Isobaths at 1000, 500, and 250 m are also shown.**

## 3.5 CPUE indices

As the Chatham Rise and WCSI assessments are being completed under the current project, standardised CPUE series from these areas only were updated using data to the end of the 2010–11 fishing year (Ballara in press). Series were produced for the separate eastern and western fisheries on the Chatham Rise using QMS data, and for the WCSI winter fishery using both QMS and observer data. The Middle Depth Species Fisheries Assessment Working Group selected two of the series for inclusion in assessment modelling (Table 8). For the Chatham Rise, the series analysing the daily processed catch from the eastern fishery was selected; the western fishery series were rejected because there were unexplained differences between the daily processed and tow-by-tow indices. For the WCSI, the series analysing observer estimated tow-by-tow data from 2001 to 2011 was selected. It was believed that this series, incorporating catch data after the establishment of the deemed value system, was the least likely to be biased owing to variation in fishing behaviour and catch reporting behaviour (Ballara in press).

**Table 8: Hake CPUE indices (and associated c.v.s) used in assessments of the Chatham Rise and WCSI hake stocks (from Ballara in press).**

| | Chatham east | | WCSI observer | |
|---|---|---|---|---|
| Year | Index | c.v. | Index | c.v. |
| 1989–90 | 2.08 | 0.12 | – | – |
| 1990–91 | 1.79 | 0.10 | – | – |
| 1991–92 | 1.20 | 0.08 | – | – |
| 1992–93 | 1.19 | 0.06 | – | – |
| 1993–94 | 1.38 | 0.06 | – | – |
| 1994–95 | 0.97 | 0.04 | – | – |
| 1995–96 | 1.28 | 0.06 | – | – |
| 1996–97 | 1.22 | 0.05 | – | – |
| 1997–98 | 0.95 | 0.04 | – | – |
| 1998–99 | 0.88 | 0.04 | – | – |
| 1999–00 | 1.21 | 0.04 | – | – |
| 2000–01 | 1.04 | 0.04 | 1.17 | 0.04 |
| 2001–02 | 0.83 | 0.04 | 1.55 | 0.04 |
| 2002–03 | 0.68 | 0.04 | 1.11 | 0.04 |
| 2003–04 | 0.75 | 0.04 | 0.95 | 0.04 |
| 2004–05 | 0.50 | 0.04 | 0.85 | 0.04 |
| 2005–06 | 0.48 | 0.06 | 0.79 | 0.04 |
| 2006–07 | 0.75 | 0.05 | 0.64 | 0.04 |
| 2007–08 | 0.77 | 0.05 | 0.44 | 0.04 |
| 2008–09 | 0.81 | 0.06 | 0.61 | 0.04 |
| 2009–10 | 0.70 | 0.06 | 0.68 | 0.05 |
| 2010–11 | 0.57 | 0.06 | 0.88 | 0.05 |

## 4. MODEL STRUCTURE, INPUTS, AND ESTIMATION

Updated assessments of the Chatham Rise and west coast South Island (WCSI) stocks are presented here. As in the most recent previous assessments of these stocks (Horn & Francis 2010, Horn 2011, 2013) the assessment models partitioned the population into age groups 1–30, with the last age class considered a plus group. Sex was not in the partition. For Chatham Rise, the model's annual cycle was based on a year beginning on 1 September and divided the year into three steps (Table 9). The fishing year (starting 1 October) is not used in this assessment because landings peaks tend to occur from September to January, so it is logical to include the September catch with landings from the five months immediately following it, rather than with catches taken about seven months previously (Horn & Francis 2010). For WCSI, the model's annual cycle was based on a year beginning on 1 November and divided into two steps (Table 9). The fishing year is not used in this assessment because landings peaks tend to occur from June to October, so it is logical to include the October catch with landings from the four months immediately preceeding it, rather than with catches taken about eight months later. Note that model references to "year" within this document are labelled as the most recent calendar year, e.g., the year 1 September 1998 to 31 August 1999 for Chatham Rise is referred to as "1999".

**Table 9: Annual cycle of the Chatham Rise and WCSI stock models, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.**

| | | | | | Observations | |
|---|---|---|---|---|---|---|
| **Chatham Rise** | | | | | | |
| Step | Period | Processes | $M^1$ | Age[2] | Description | $\%Z^3$ |
| 1 | Sep–Feb | Fishing, recruitment, and spawning | 0.42 | 0.25 | January resource survey | 100 |
| 2 | Mar–May | None | 0.25 | 0.50 | | |
| 3 | Jun–Aug | Increment age | 0.33 | 0.00 | | |
| **WCSI** | | | | | | |
| 1 | Nov–May | Recruitment | 0.42 | 0.50 | | |
| 2 | Jun–Oct | Fishing, spawning and increment age | 0.58 | 0.00 | Proportions-at-age<br>Winter resource survey | 50 |

1. *M* is the proportion of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction, used for determining length-at-age, that was assumed to occur in that time step.
3. %*Z* is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

For all models discussed below, assumed values of fixed biological parameters are given in Table 5. A Beverton-Holt stock-recruitment relationship, with steepness 0.9, was assumed. Variability in the Schnute age-length relationship was assumed to be lognormal with a constant c.v. of 0.1. The maximum exploitation rate was assumed to be 0.7 for the stock. The choice of the maximum exploitation rate has the effect of determining the minimum possible virgin biomass allowed by the model, given the observed catch history. This value was set relatively high as there was little external information from which to determine it.

Biomass estimates from the resource surveys were used as relative biomass indices, with associated c.v.s estimated from the survey analysis (Table 7). The survey catchability constant ($q$) was assumed to be constant across all years in the survey series. Catch-at-age observations were available for each research survey, from commercial observer data for the fishery, and (for WCSI) for the research voyage by *Wesermünde* in 1979. The error distributions assumed were multinomial for the proportions-at-age and proportions-at-length data, and lognormal for all other data. An additional process error c.v. of 0.2 was added to the trawl survey biomass index following Francis et al. (2001), and process error c.v.s for the CPUE series were estimated following Francis (2011). The multinomial observation error effective sample sizes for the at-age data were adjusted using the reweighting procedure of Francis (2011). Ageing error was assumed to occur for the observed proportions-at-age data, by assuming a discrete normally distributed error with c.v. 0.08.

Year class strengths were assumed known (and equal to one) for years before 1975 and after 2009 (Chatham Rise), and before 1973 and after 2007 (WCSI), when inadequate or no catch-at-age data were available. Otherwise, year class strengths were estimated under the assumption that the estimates from the model must average one. However, for the Chatham Rise stock, Horn & Francis (2010) had shown that is was necessary to smooth the year class estimates from 1974 to 1983 to preclude the estimation of widely fluctuating strong and weak year classes that were not supported by the available data. (It was suspected that the estimated strong year classes were an artefact, the consequence of a tendency for models which assume ageing error to estimate high variability in year-class strength in periods with few data.) The same smoothing process was included in the Chatham Rise model presented below. The Haist parameterisation for year class multipliers is used here (see Bull et al. (2012) for details).

For the Chatham Rise stock, the catch history assumed in all model runs was derived as follows. Using the grooming algorithms of Dunn (2003a), landings of hake reported on TCEPR and CELR forms from 1989–90 to 2010–11 were allocated to month and fishery (based on reported date, location, and depth). Annual totals for each fishery were obtained by summing the monthly totals, but, for reasons described above, using a September to August year. Thus, catch histories for model years 1990 to 2011 were produced. At the same time, catch histories for FMA 3 and FMA 4 were also produced. For each year from 1990 to 2011, the proportions of the FMA 3 catch made up by the ‘west shallow’ and ‘west deep’ fisheries were calculated, as were the proportions of the FMA 4 landings made up by the ‘east’ fishery. Means over all years indicated that the ‘west shallow’ and ‘west deep’ fisheries accounted for landings of 99% and 75% respectively of the FMA 3 total, and that the ‘east’ fishery took landings equivalent to 83% respectively of the FMA 4 total. [Note that the percentages for ‘west’ and ‘east’ do not equate to 100% because the western fisheries include an area greater than FMA 3, and the eastern fishery comprises an area smaller than FMA 4.] Dunn et al. (2006) had produced estimates of total Chatham Rise hake catch from 1975 to 1989, and the FMA 4 catch from 1984 to 1989. Estimates of FMA 4 catch before 1984 were obtained primarily from Colman & Livingston (1988). Hence, estimates of hake catch from FMA 3 and FMA 4 from 1975 to 1989 were available or could be derived. To estimate catch by fishery from 1975 to 1989, the percentages presented above were applied to the FMA 3 or FMA 4 landings. The catch in 2008–09 was estimated based largely on patterns of catch from the previous year. Catch histories by fishery are presented in Table 10.

For the WCSI stock, the catch history assumed in all model runs is as estimated for the WCSI section of HAK 7 by fishing year up to 1990–91, and by the year commencing 1 November from 1991–92 (Table 11).

**Table 10: Estimated catch (t) by FMA (3 and 4) from the Chatham Rise stock, and total catch, by fishing year, and estimated catch (t) by fishery for the model years. Note that from 1989–90 totals by fishing year and model year differ because the September catch has been shifted from the fishing year into the following model year. Landings from the most recent year are estimated assuming catch patterns similar to the previous year.**

| Fishing year | FMA 3 | FMA 4 | Total | Model year | West | East | Total |
|---|---|---|---|---|---|---|---|
| 1974–75 | 50 | 141 | 191 | 1975 | 80 | 111 | 191 |
| 1975–76 | 88 | 400 | 488 | 1976 | 152 | 336 | 488 |
| 1976–77 | 37 | 1 251 | 1 288 | 1977 | 74 | 1 214 | 1 288 |
| 1977–78 | 24 | 10 | 34 | 1978 | 28 | 6 | 34 |
| 1978–79 | 55 | 554 | 609 | 1979 | 103 | 506 | 609 |
| 1979–80 | 350 | 400 | 750 | 1980 | 481 | 269 | 750 |
| 1980–81 | 840 | 157 | 997 | 1981 | 914 | 83 | 997 |
| 1981–82 | 290 | 306 | 596 | 1982 | 393 | 203 | 596 |
| 1982–83 | 102 | 200 | 302 | 1983 | 154 | 148 | 302 |
| 1983–84 | 164 | 180 | 344 | 1984 | 224 | 120 | 344 |
| 1984–85 | 145 | 399 | 544 | 1985 | 232 | 312 | 544 |
| 1985–86 | 229 | 133 | 362 | 1986 | 282 | 80 | 362 |
| 1986–87 | 309 | 200 | 509 | 1987 | 387 | 122 | 509 |
| 1987–88 | 286 | 288 | 574 | 1988 | 385 | 189 | 574 |
| 1988–89 | 250 | 554 | 804 | 1989 | 386 | 418 | 804 |
| 1989–90 | 196 | 763 | 959 | 1990 | 309 | 689 | 998 |
| 1990–91 | 207 | 698 | 905 | 1991 | 409 | 503 | 912 |
| 1991–92 | 402 | 2 012 | 2 414 | 1992 | 718 | 1 087 | 1 805 |
| 1992–93 | 266 | 2 542 | 2 808 | 1993 | 656 | 1 996 | 2 652 |
| 1993–94 | 350 | 2 583 | 2 933 | 1994 | 368 | 2 912 | 3 280 |
| 1994–95 | 452 | 2 934 | 3 386 | 1995 | 597 | 2 903 | 3 500 |
| 1995–96 | 875 | 3 038 | 3 913 | 1996 | 1353 | 2 483 | 3 836 |
| 1996–97 | 924 | 2 737 | 3 661 | 1997 | 1475 | 1 820 | 3 295 |
| 1997–98 | 1 000 | 2 983 | 3 983 | 1998 | 1424 | 1 124 | 2 547 |
| 1998–99 | 831 | 2 541 | 3 372 | 1999 | 1169 | 3 339 | 4 509 |
| 1999–00 | 640 | 2 302 | 2 942 | 2000 | 1155 | 2 130 | 3 285 |
| 2000–01 | 435 | 2 069 | 2 504 | 2001 | 1208 | 1 700 | 2 908 |
| 2001–02 | 355 | 1 414 | 1 769 | 2002 | 454 | 1 058 | 1 512 |
| 2002–03 | 602 | 812 | 1 414 | 2003 | 497 | 718 | 1 215 |
| 2003–04 | 210 | 2 281 | 2 491 | 2004 | 687 | 1 983 | 2 671 |
| 2004–05 | 2 485 | 1 268 | 3 753 | 2005 | 2585 | 1 434 | 4 019 |
| 2005–06 | 54 | 305 | 359 | 2006 | 184 | 255 | 440 |
| 2006–07 | 181 | 900 | 1 081 | 2007 | 270 | 683 | 953 |
| 2007–08 | 233 | 865 | 1 098 | 2008 | 259 | 901 | 1 159 |
| 2008–09 | 971 | 854 | 1 825 | 2009 | 1069 | 832 | 1 902 |
| 2009–10 | 183 | 208 | 391 | 2010 | 231 | 159 | 390 |
| 2010–11 | 772 | 179 | 951 | 2011 | 822 | 118 | 940 |
| 2011–12 | – | – | – | 2012 | 800 | 150 | 950 |

**Table 11: Reported catch (t) from FMA 7 and estimated catch from the WCSI biological stock (area as defined in Figure 1), by fishing year, and estimated catch (t) for the model years. Note that from 1991–92 totals by fishing year and model year often differ because the October catch has been shifted from the fishing year into the previous model year. The catch from the most recent year is estimated assuming catch patterns similar to recent previous years.**

| Fishing year | FMA 7 | WCSI | Model year | WCSI |
|---|---|---|---|---|
| 1974–75 | 71 | 71 | 1975 | 71 |
| 1975–76 | 5 005 | 5 005 | 1976 | 5 005 |
| 1976–77 | 17 806 | 17 806 | 1977 | 17 806 |
| 1977–78 | 498 | 498 | 1978 | 498 |
| 1978–79 | 4 737 | 4 737 | 1979 | 4 737 |
| 1979–80 | 3 600 | 3 600 | 1980 | 3 600 |
| 1980–81 | 2 565 | 2 565 | 1981 | 2 565 |
| 1981–82 | 1 625 | 1 625 | 1982 | 1 625 |
| 1982–83 | 745 | 745 | 1983 | 745 |
| 1983–84 | 945 | 945 | 1984 | 945 |
| 1984–85 | 965 | 965 | 1985 | 965 |
| 1985–86 | 1 918 | 1 918 | 1986 | 1 918 |
| 1986–87 | 3 755 | 3 755 | 1987 | 3 755 |
| 1987–88 | 3 009 | 3 009 | 1988 | 3 009 |
| 1988–89 | 8 696 | 8 696 | 1989 | 8 696 |
| 1989–90 | 4 903 | 8 741 | 1990 | 8 741 |
| 1990–91 | 6 175 | 8 246 | 1991 | 8 246 |
| 1991–92 | 3 048 | 3 001 | 1992 | 3 004 |
| 1992–93 | 7 157 | 7 059 | 1993 | 7 056 |
| 1993–94 | 2 990 | 2 971 | 1994 | 2 987 |
| 1994–95 | 9 659 | 9 535 | 1995 | 9 604 |
| 1995–96 | 9 153 | 9 082 | 1996 | 9 053 |
| 1996–97 | 6 950 | 6 838 | 1997 | 6 877 |
| 1997–98 | 7 686 | 7 674 | 1998 | 7 674 |
| 1998–99 | 8 929 | 8 742 | 1999 | 8 842 |
| 1999–00 | 7 086 | 7 031 | 2000 | 6 907 |
| 2000–01 | 8 351 | 8 346 | 2001 | 8 277 |
| 2001–02 | 7 499 | 7 498 | 2002 | 7 590 |
| 2002–03 | 7 406 | 7 404 | 2003 | 7 590 |
| 2003–04 | 7 943 | 7 939 | 2004 | 7 915 |
| 2004–05 | 7 302 | 7 298 | 2005 | 7 336 |
| 2005–06 | 6 897 | 6 892 | 2006 | 6 659 |
| 2006–07 | 7 660 | 7 660 | 2007 | 7 664 |
| 2007–08 | 2 615 | 2 583 | 2008 | 2 529 |
| 2008–09 | 5 945 | 5 912 | 2009 | 5 914 |
| 2009–10 | 2 340 | 2 282 | 2010 | 2 400 |
| 2010–11 | 3 716 | 3 701 | 2011 | 3 620 |
| 2011–12 | – | – | 2012 | 3 600 |

## 4.1 Prior distributions and penalty functions

The assumed prior distributions used in the Chatham Rise and WCSI assessments are given in Table 12. The priors for $B_0$ and year class strengths were intended to be relatively uninformed, and had wide bounds.

The prior for the Chatham Rise survey *q* was informative and was estimated by assuming that the catchability constant was the product of areal availability, vertical availability, and vulnerability. This same $q$ prior was used in the previous Chatham Rise hake assessment (Horn & Dunn 2007). A simple simulation was conducted that estimated a distribution of possible values for the catchability constant by assuming that each of these factors was independent and uniformly distributed. A prior was then determined by assuming that the resulting, sampled, distribution was lognormally distributed. Values assumed for the parameters were areal availability (0.50–1.00), vertical availability (0.50–1.00), and vulnerability (0.01–0.50). The resulting (approximate lognormal) distribution had mean 0.16 and c.v. 0.79, with bounds assumed to be 0.01 and 0.40. Priors for the trawl fishery selectivity parameters were assumed to be uniform. Priors for the trawl survey selectivity parameters were assumed to have a normal-by-stdev distribution, with a very tight distribution set for age at full selectivity (a1, see Figure 10), but an essentially uniform distribution for parameters aL and aR. The values of survey catchability constants are dependent on the selectivity parameters, and the absolute catchability can be determined by the product of the selectivity by age and sex, and the catchability constant $q$.

**Table 12: The assumed priors assumed for key distributions (when estimated). The parameters are mean (in natural space) and c.v. for lognormal priors, and mean (in natural space) and standard deviation for normal-by-stdev priors.**

| Stock | Parameter | Distribution | Parameters | | Bounds | |
|---|---|---|---|---|---|---|
| Chatham Rise | $B_0$ | Uniform-log | – | – | 10 000 | 250 000 |
| | Survey $q$ | Lognormal | 0.16 | 0.79 | 0.01 | 0.40 |
| | YCS | Lognormal | 1.0 | 1.1 | 0.01 | 100 |
| | Selectivity (fishery) | Uniform | – | – | 1 | 25–200* |
| | Selectivity (survey, a1)[#] | Normal-by-stdev | 8 | 1 | 1 | 25 |
| | Selectivity (survey, aL, aR) | Normal-by-stdev | 10 | 500 | 1 | 50–200* |
| WCSI | $B_0$ | Uniform-log | – | – | 5 000 | 250 000 |
| | YCS | Lognormal | 1.0 | 1.1 | 0.01 | 100 |
| | Survey $q$ | Lognormal | 0.09 | 0.79 | 0.01 | 0.25 |
| | Selectivity | Uniform | – | – | 1 | 25–200* |

* A range of maximum values was used for the upper bound.
[#] The informed prior on the Chatham Rise survey a1 parameter was not used in all model runs.

For the WCSI assessment, priors for all selectivity parameters were assumed to be uniform. The prior for the WCSI survey $q$ was informative and was estimated using the Chatham Rise hake survey priors as a starting point because the survey series in both areas used the same vessel and fishing gear. However, the WCSI survey area in the 200–800 m depth range in strata 0004 A–C and 0012 A–C comprised 12 928 $km^2$ (O'Driscoll et al. in prep.); seabed area in that depth range in the entire HAK 7 biological stock area (excluding the Challenger Plateau) is estimated to be about 24 000 $km^2$. So because biomass from only 54% of the WCSI hake habitat was included in the indices, the Chatham Rise prior on $\mu$ was modified accordingly (i.e., $0.16 \times 0.54 = 0.09$), and the bounds were also reduced from [0.01, 0.40] to [0.01, 0.25].

Penalty functions were used in the assessments of both stocks to constrain the model so that any combination of parameters that resulted in a stock size that was so low that the historical catch could not have been taken was strongly penalised, and to ensure that all estimated year class strengths averaged 1. For the Chatham Rise stock they were also used to smooth the year class strengths estimated over the period 1974 to 1983.

## 5. MODEL ESTIMATES FOR CHATHAM RISE HAKE

### 5.1 Developing a 'base' model

Some initial investigations were completed to develop a 'base' model. The summer trawl survey series exhibits a relatively smooth trend over time, and so is probably a reasonable index of relative abundance. Consequently, in the model development stage it was assumed that any 'good' assessment model should fit the survey series well. Model parameters were estimated using Bayesian estimation implemented using the CASAL software. However, only the mode of the joint posterior distribution (MPD) was estimated in these initial runs. Full details of the CASAL algorithms, software, and methods were detailed by Bull et al. (2012).

An initial model (model 1) was set up, with the partition excluding sex and maturity. The model used three selectivity ogives: survey selectivities for the January *Tangaroa* resource survey series, and selectivities for each of the two commercial fisheries (i.e., west, east). Selectivities were assumed constant over all years in the fisheries or the survey series. All selectivity ogives were estimated using the double-normal parameterisation. A constant value of 0.19 was used for *M*. No CPUE series was incorporated. The survey biomass was reasonably well fitted (Figure 5).

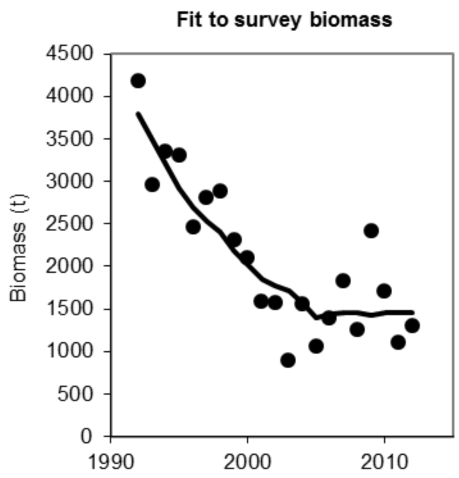



**Figure 5: Fits to the research survey biomass, from model 1.**

A second model (model 2) examined the effect of estimating natural mortality as an age-dependent ogive. This was the same as model 1 except that *M* was estimated as a double-exponential ogive, and the selectivity ogive for the eastern fishery was fitted as a logistic curve. Relative to model 1, the resulting fit to the survey biomass series was virtually identical, the biomass trajectory was little different, and there were no improvements in the fits to any data sources (total objective function was 757.6 compared to 757.4). The estimated *M* ogive was logical, although perhaps a little higher than might be expected (Figure 6).

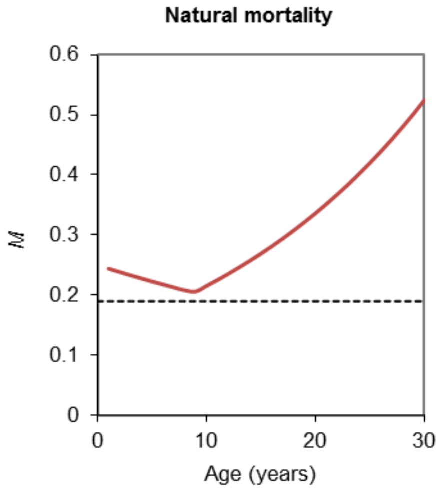



**Figure 6: Estimated natural mortality ogive (red line) from model 2, with the default constant value of 0.19 shown as a dashed line.**

The usefulness of the chosen CPUE series was investigated by including it in the initial model (model 3). The fit to the CPUE was good, but inclusion of this data set did result in a slightly worse fit to the trawl biomass series (i.e., an increase in the objective function of about 2) (see Figure 12). It also resulted in an elevation of the biomass trajectory (Figure 7). Clearly, the signal from the CPUE does not strongly conflict with the signal from the research survey series.

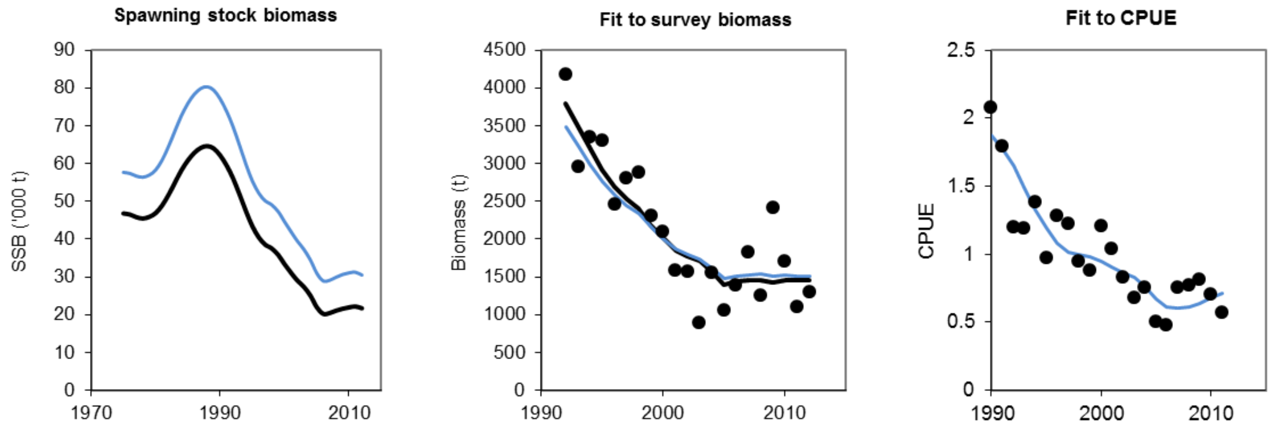



**Figure 7: Estimated spawning stock biomass, and fits to the research survey biomass and eastern fishery CPUE series from model 3 (blue lines), with the trajectory and fit from model 1 shown as black lines.**

A likelihood profile for model 3 showed that the research survey encourages a $B_0$ of about 40 000 t, CPUE encourages a high biomass, and the age data sets variously encourage low, moderate and high values of $B_0$ (Figure 8). The CPUE, survey age data, and eastern fishery age data all quite strongly discourage a $B_0$ less than about 40 000 t.

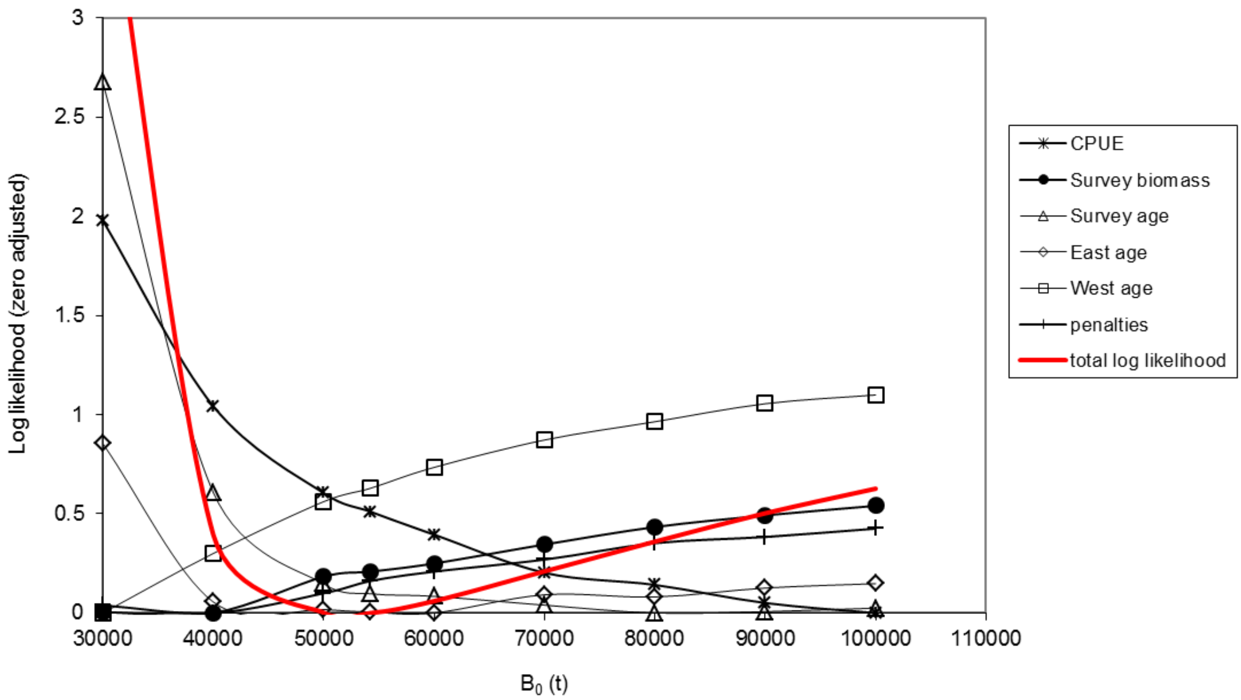



**Figure 8: Likelihood profile on $B_0$ for model 3, showing both the total likelihood (red line) and those for individual data series.**

It was apparent that the estimated selectivity ogive for the research survey was not satisfactory in any of models 1–3. Age at full selectivity was about 13 years (Figure 9), yet most of the fish taken in the survey are aged 3–12 years. An examination of the survey age distributions indicated that age at full selectivity was probably around 8 years, and was definitely less than 10. Consequently, an additional model was tested (model 4); it was identical to model 1 except that it had a tight normal prior on age at full selectivity (a1) strongly encouraging a value of 8 ± 2 years (Figure 10). The estimated research selectivity ogive reached a peak at about 9 years (Figure 11). The fits to the trawl survey age data were slightly degraded (an increase in the objective function of about 2), and the fit to the survey biomass altered slightly (Figure 11) but resulted in little change to the objective function (an increase of 0.2). The fits in model 4 to the three sets of at-age data were generally satisfactory in most years (Figures 12–14). However, despite the enforced difference in the survey selectivity ogive, there was little difference between models 1 and 4 in the fits obtained to the survey at-age data (Figure 12).

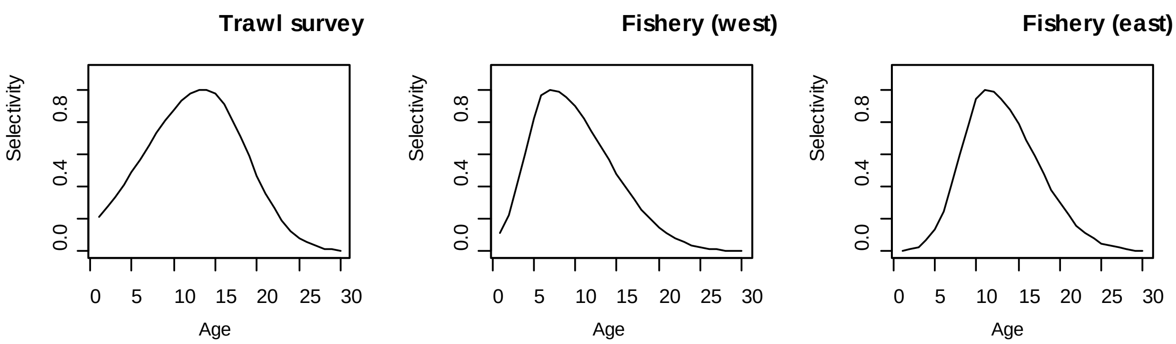



**Figure 9: Estimated selectivity ogives for the research survey and two commercial fisheries from model 1.**

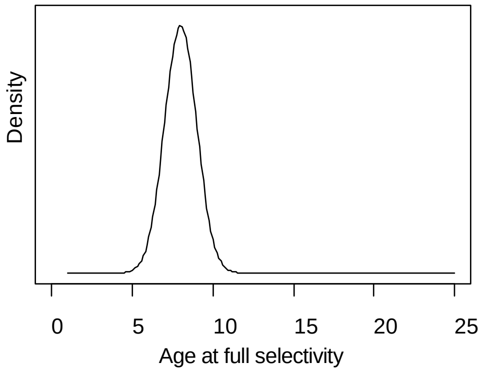



**Figure 10: Distribution of the prior on age at full selectivity (a1) for the research survey selectivity ogive used in model 4.**

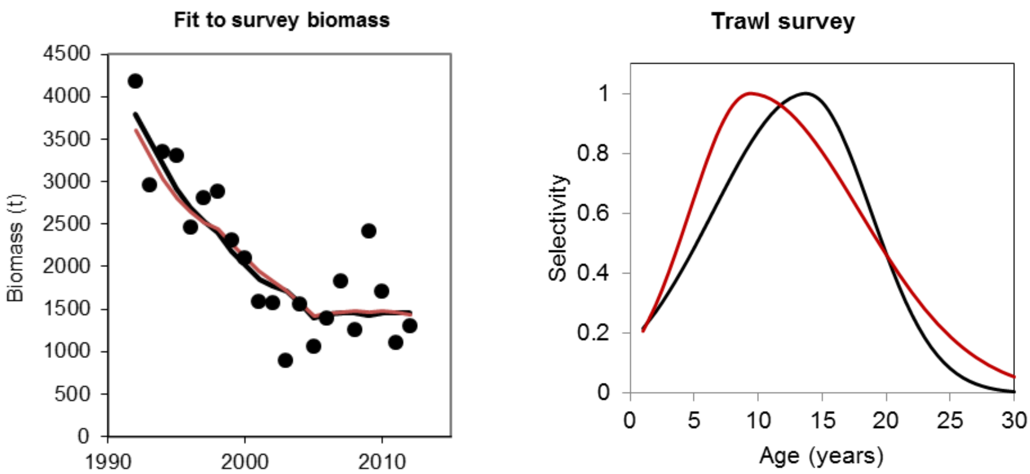



**Figure 11: Model fits to the research survey biomass (left panel) for model 4 (red line) and model 1 (black line), and estimated survey selectivity ogives (right panel) from model 4 (red line) and model 1 (black line).**

Following the investigations above with MPD model fits the Working Group concluded that the best base case model for MCMC estimation was model 4 (‘Base case’). Three sensitivities to the base case were fully investigated. They were:

- Model 1, with the unconstrained trawl survey ogive, the model most similar to the base case in the previous assessment of this stock (‘Free survey ogive’),
- The ‘base case’ model but with *M* estimated as an age-dependent double exponential function (‘Estimate *M*’), and
- The ‘base case’ model with the inclusion of the CPUE series (‘CPUE’).

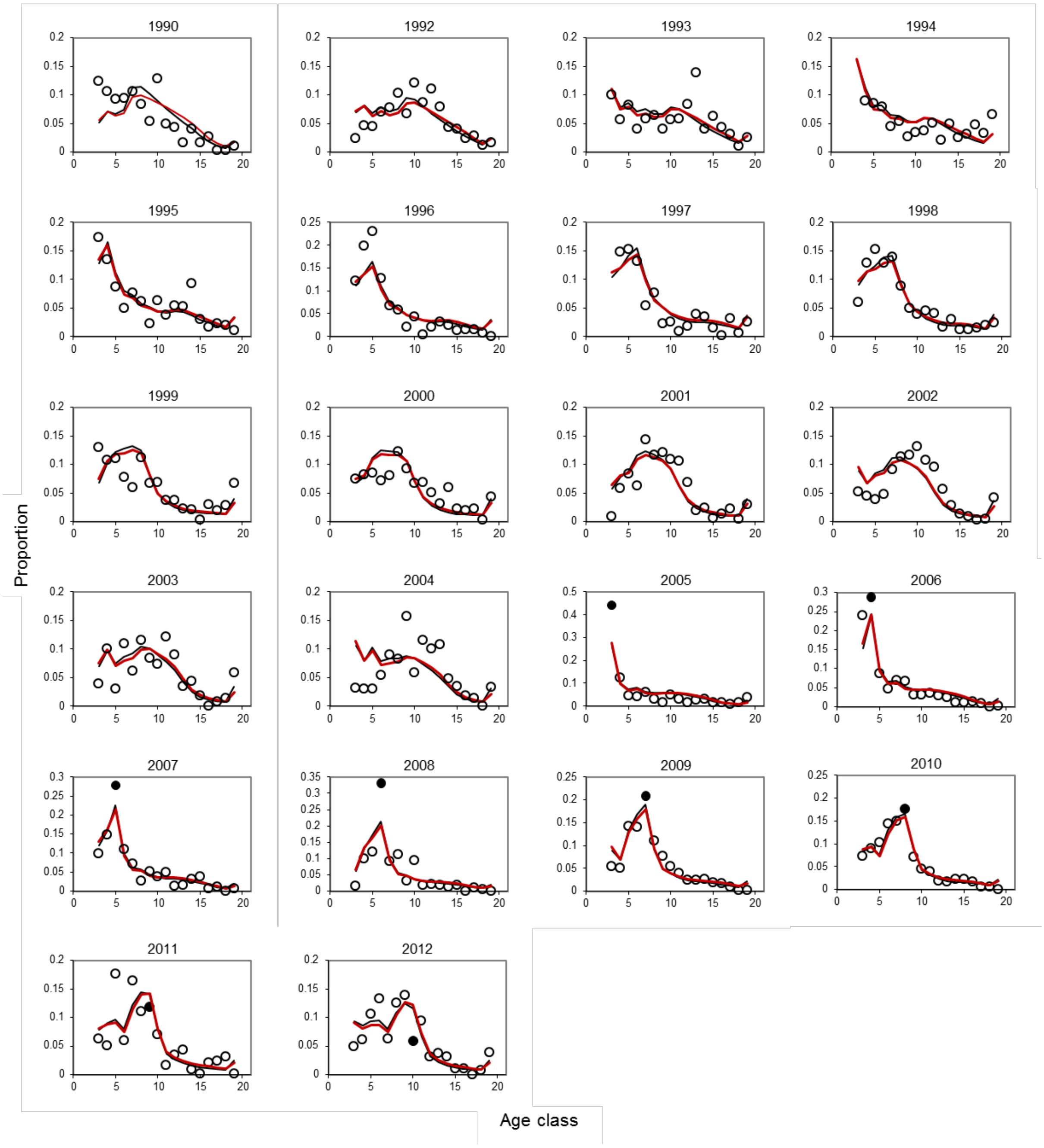



**Figure 12: Fits from model 4 (black lines) and model 1 (red lines) to the trawl survey proportion-at-age distributions (circles). The strong 2002 year class is shown as filled circles.**

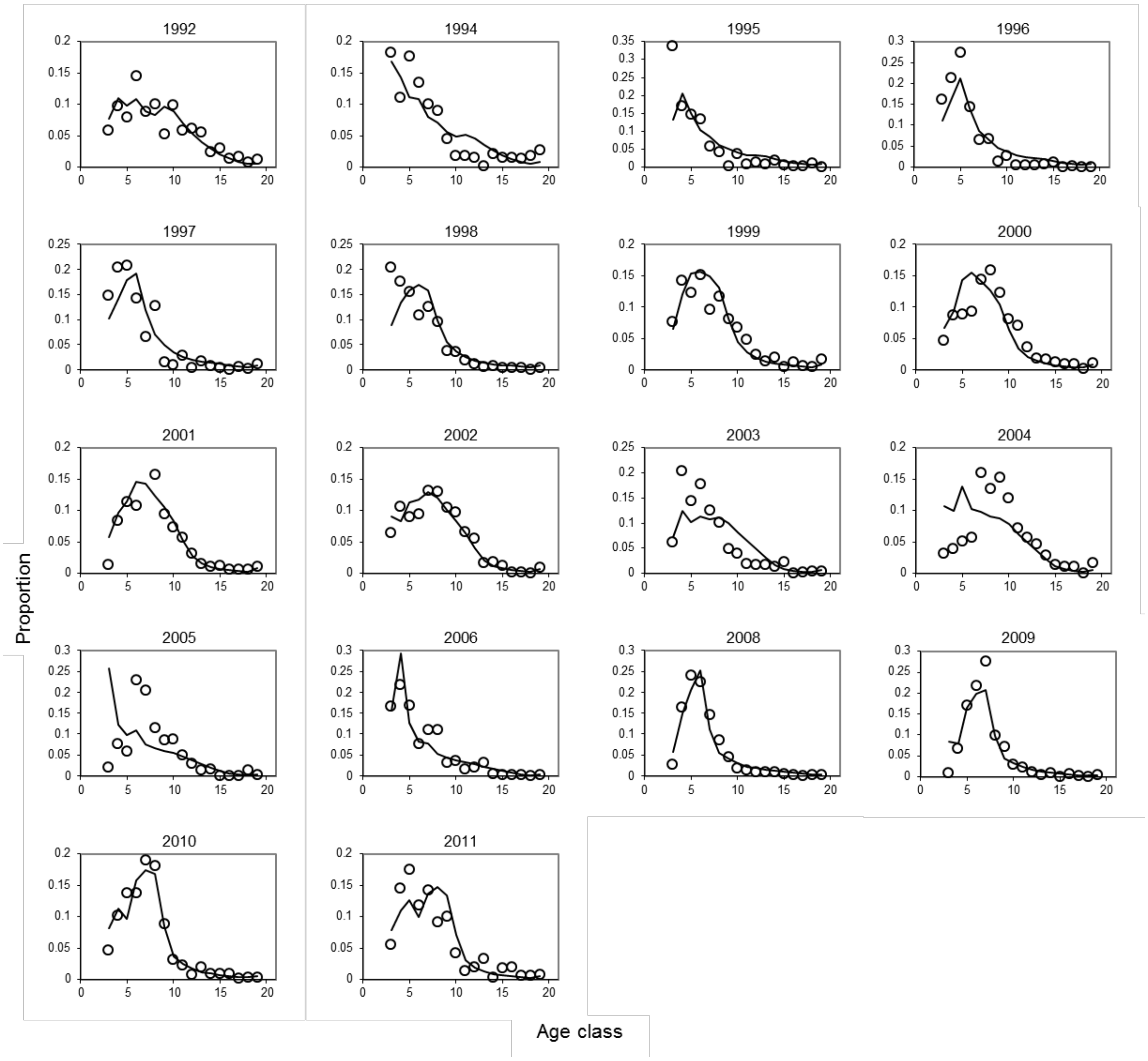



**Figure 13: Fits (lines) to the western trawl fishery proportion-at-age distributions (circles), from model 4.**


**Figure 14: Fits (lines) to the eastern trawl fishery proportion-at-age distributions (circles), from model 4.**

## 5.2 Model estimation using MCMC

Model parameters were estimated using Bayesian estimation implemented using the CASAL software. For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm. MCMCs were estimated using $3x10^6$ iterations, a burn-in length of $5x10^5$ iterations, and with every $2500^{th}$ sample kept from the final $2.5x10^6$ iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior). Year class strengths were estimated as in the MPD runs except that values for 2010–11 were no longer fixed at 1.

## 5.3 MCMC estimates

Base case estimates of spawning stock biomass were made using the biological parameters (see Table 5) and model input parameters described earlier. Three sensitivities were investigated. Estimates of the posterior distribution were obtained and are presented below. In addition, MCMC estimates of the median posterior and 95% percentile credible intervals are reported for the key output parameters. The MCMC chains for estimates of $B_0$ and $B_{2012}$ from the base case appear moderately well converged (Figure 15). The distributions of estimates of $B_0$ and $B_{2012}$ (as $\%B_0$) from the base model are consistent between the first, middle, and last thirds of the chain (Figure 15), and hence convergence is probably adequate for stock assessment purposes.

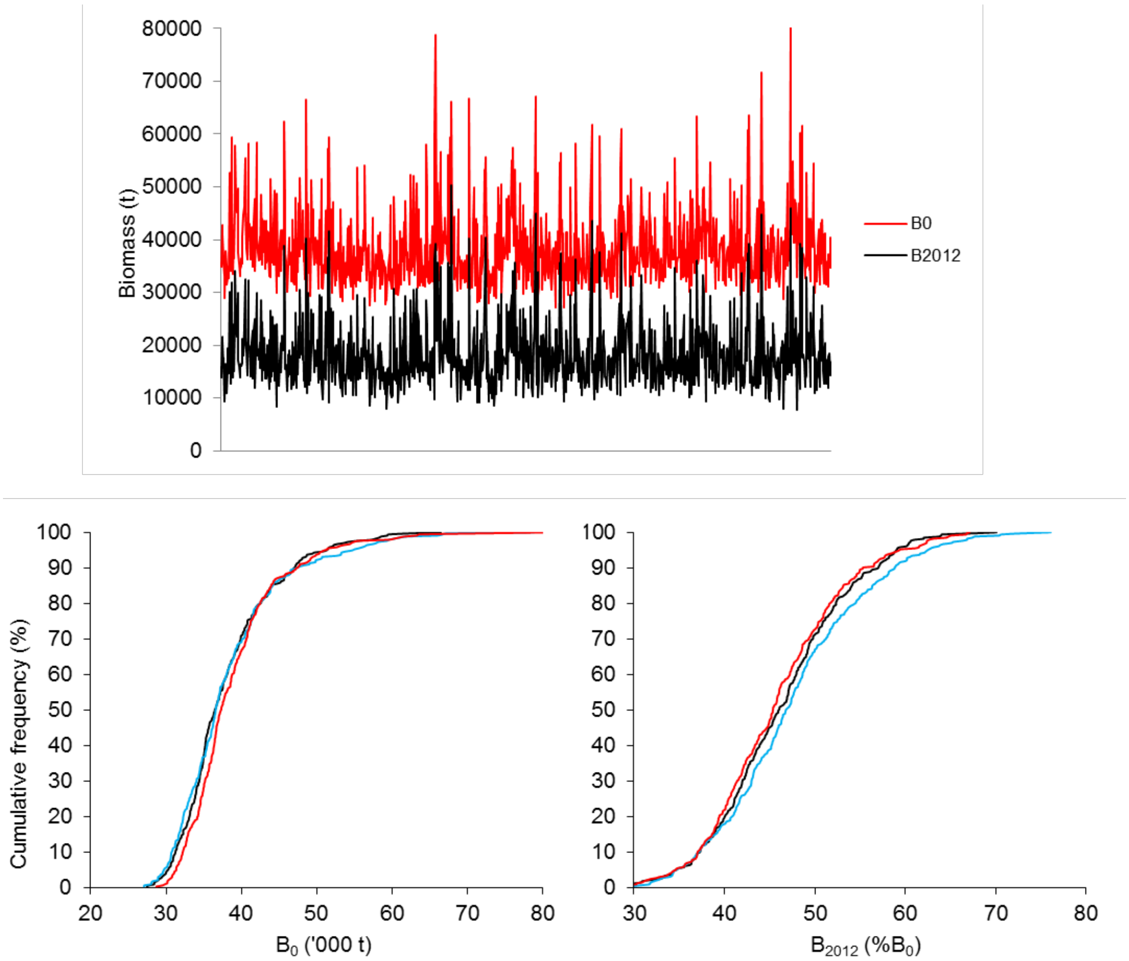



**Figure 15: Trace diagnostic plot of the MCMC chains for estimates of $B_0$ and $B_{2012}$ for the base model run (upper panel). MCMC diagnostic plots showing the cumulative frequencies of $B_0$ and $B_{2012}$ ($\%B_0$) for the first (black line), middle (blue line), and last (red line) third of the MCMC chain for the base model (lower panel).**

The estimated MCMC marginal posterior distributions for selected parameters from the base case model are shown in Figures 16–20. The estimated research survey catchability constant is estimated to be about 0.09, suggesting that the absolute catchability of the survey series is moderately low, although consistent with the prior (Figure 16). The fit to the research series in this model run is reasonably good (see Figure 11). The resource survey and fishery selectivity ogives all had relatively wide bounds after age at peak selectivity (Figure 17). The survey ogive was essentially logistic (even though fitted as double normal) and had hake fully selected by the research gear from about age 9. Recall that age at full selectivity for the trawl survey was strongly influenced by tight priors (see section 5.3). Fishing selectivities indicated that hake were fully selected in the western fisheries by about age 6 years, compared to age 11 in the eastern fishery; this is logical given that the eastern fishery concentrates more on the spawning (i.e., older) biomass. There is no information outside the model that allows the shape of the estimated selectivity ogives to be verified.

It had been shown previously (Horn & Francis 2010) that year class strength estimates were poorly estimated for years where only older fish were available to determine age class strength (i.e., before 1984). Consequently, these year class strength estimates were smoothed, and are indicative of a period of generally higher than average spawning success (Figure 18). More recent year class strengths appear to be moderately well estimated, being relatively strong in the early 1990s, followed by a period of steadily declining spawning success to 2001. The 2002 year class was strong, but it has been followed by more relatively weak year classes. The strength of the 2002 year class is strongly supported by consistent data from the research survey series age distributions (see Figure 12). The 2011 year class is estimated to be strong, but it is based on sparse data, and the size of very young year classes can be strongly influenced by small changes in the selectivity ogives.

Estimated spawning stock biomass for the Chatham stock increased throughout the 1980s owing to the relatively good spawning success during the late 1970s (Figure 19). Biomass then steadily declined from 1989 to 2005 owing to higher levels of exploitation and generally poor spawning success. The slight increase since 2005 is a consequence of the strong 2002 year class. Lower bounds for the spawning biomass estimates are reasonably tight, but less so for the upper bounds. Current stock size is about 47% of $B_0$ with a 95% credible interval of 35–63% (see Figure 19 and Table 13.) Exploitation rates (catch over vulnerable biomass) were very low up to the early 1990s, then were moderate (0.10–0.25 $yr^{-1}$) for about 12 years, but low again since 2006 (Figure 20).

**Table 13: Bayesian median and 95% credible intervals of $B_0$, $B_{2012}$, and $B_{2012}$ as a percentage of $B_0$ for the Chatham Rise model runs.**

| Model run | $B_0$ | $B_{2012}$ | $B_{2012}$ (%$B_0$) |
|---|---|---|---|
| Base case | 37 000 (30 110–67 000) | 17 250 (11 010–41 550) | 46.8 (35.3–63.4) |
| Free survey ogive | 29 460 (26 540–34 160) | 12 320 (8 850–17 270) | 41.8 (32.7–52.4) |
| Estimate *M* | 39 810 (32 550–60 790) | 18 140 (11 040–36 570) | 45.1 (33.0–61.7) |
| CPUE | 52 720 (36 270–95 190) | 28 970 (16 670–59 990) | 54.8 (45.1–65.1) |

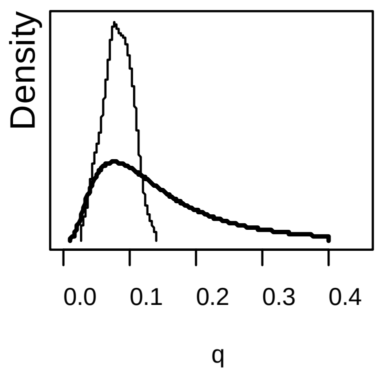



**Figure 16: Base case — Estimated posterior distribution (thin line) and prior (thick line) of survey catchability constant *q* for the Chatham Rise January resource survey series.**


**Figure 17: Base case — Estimated median selectivity ogives (with 95% credible intervals shown as dashed lines) for the trawl survey series, the western fishery and the eastern fishery, for the Chatham Rise stock.**

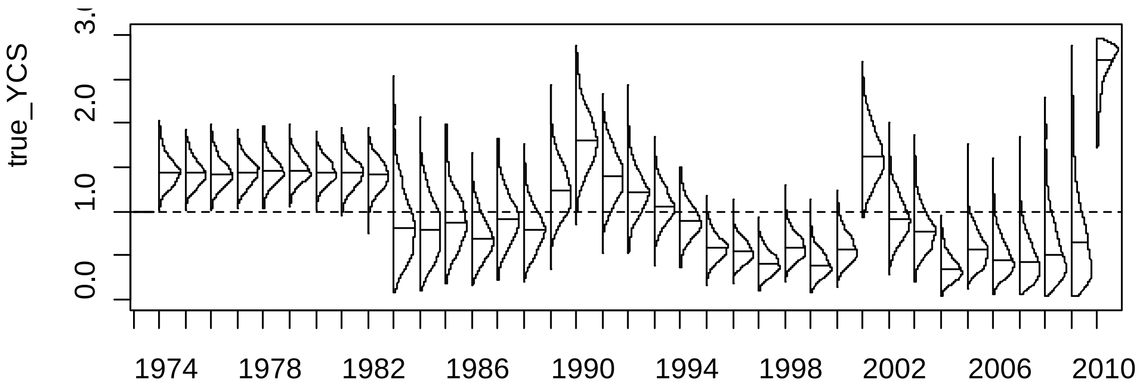



**Figure 18: Base case — Estimated posterior distributions of year class strengths for the Chatham Rise stock. The dashed horizontal line indicates the year class strength of one. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.**

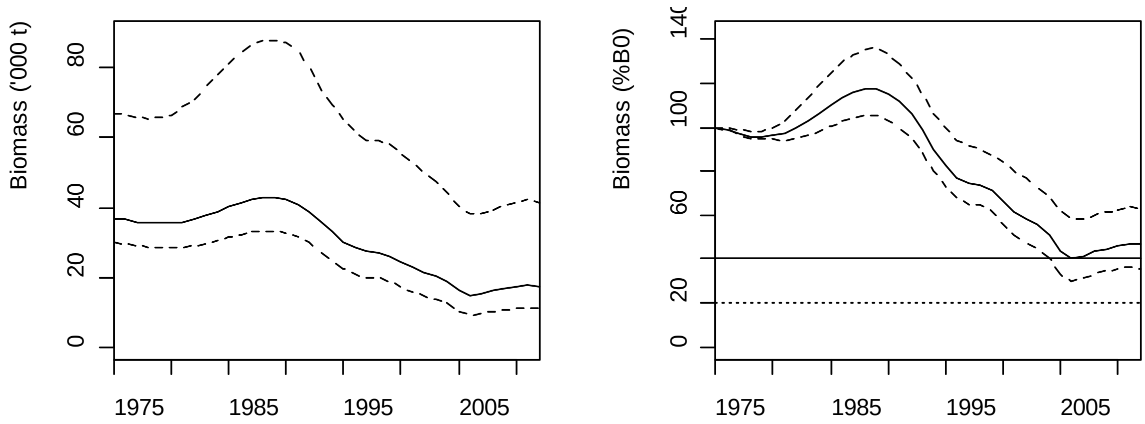



**Figure 19: Base case — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute spawning biomass and biomass as a percentage of $B_0$, for the Chatham Rise stock. Horizontal lines in the right panel show the management target of 40% $B_0$ and the soft limit of 20% $B_0$.**

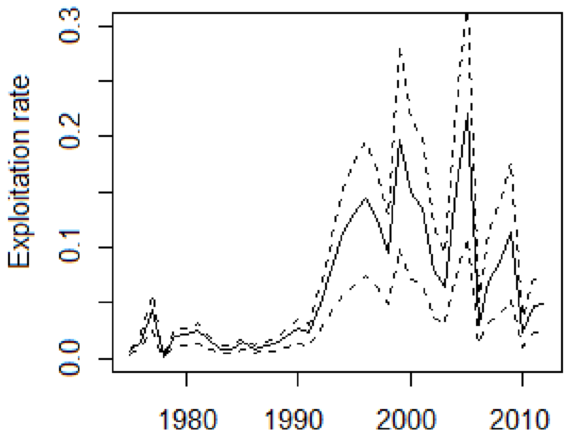



**Figure 20: Base case — Estimated median trajectory of exploitation rate (with 95% credible intervals shown as dashed lines).**

The 'Free survey ogive' sensitivity run differed from the base case in that the trawl survey selectivity ogive parameters had the same priors as the fishery ogive (i.e., all uniform). The estimated MCMC marginal posterior distributions for selected parameters from the free survey ogive model are shown in Figures 21–23. This model indicated lower absolute spawning biomass levels than the base case. Consequently, the estimated research survey catchability constant of about 19% suggests that the absolute catchability of the trawl survey series is higher than that estimated in the base case, though it is not as consistent with the prior (Figure 21). Fishery selectivity ogives were essentially logistic (they were domed in the MPD runs), and the trawl survey ogive was domed and suffered from the problem of the age at full selectivity being older than most of the fish caught in the survey (Figure 22). In the western fishery, hake were fully selected from age 6, while full selectivity did not occur until about age 11 in the eastern fishery.

There was little difference between the base case and free survey ogive models in the estimated pattern or absolute size of year class strengths. Trends in biomass were also similar between models. However, absolute biomass was lower in the free survey ogive model, and current stock status ($B_{2012}$ at 42% of $B_0$) was more pessimistic (Figure 23, Table 13).

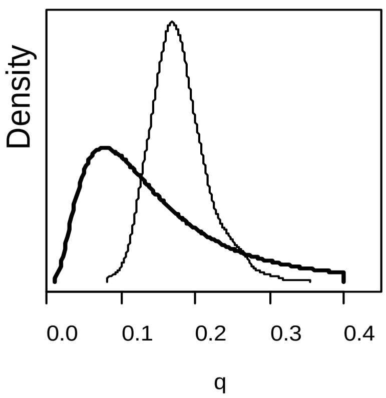



**Figure 21: Free survey ogive — Estimated posterior distribution (thin line) and prior (thick line) of survey catchability constant *q* for the Chatham Rise January resource survey series.**


**Figure 22: Free survey ogive — Estimated median selectivity ogives (with 95% credible intervals shown as dashed lines) for the trawl survey series, the western fishery and the eastern fishery.**

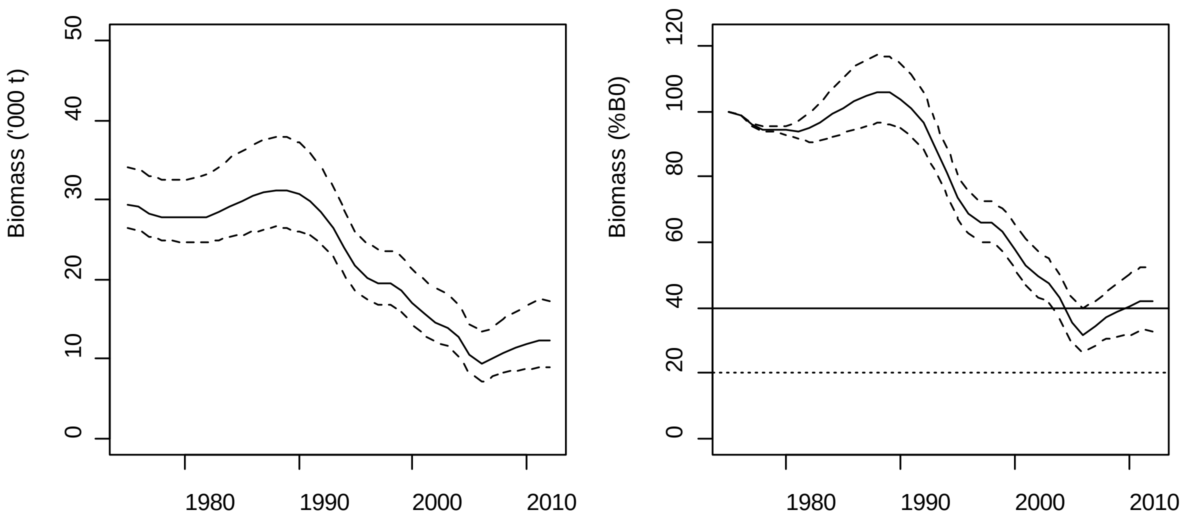



**Figure 23: Free survey ogive — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute spawning biomass and biomass as a percentage of $B_0$, for the Chatham Rise stock. Horizontal lines in the right panel show the management target of 40% $B_0$ and the soft limit of 20% $B_0$.**

The ‘Estimate *M*’ sensitivity run differed from the base case in that *M* was estimated using the double-exponential parameterisation (rather than be assumed constant at 0.19), and the eastern trawl fishery ogive was fitted as a logistic function. The estimated *M* ogive was unsatisfactorily low at ages younger than about 7 years (Figure 24). This resulted in selectivity ogives for the trawl survey and western fishery that were unreasonably high at young ages (Figure 25). However, the biomass trajectory, and estimates of absolute spawning biomass and stock status were little different to those from the base case (Table 13).

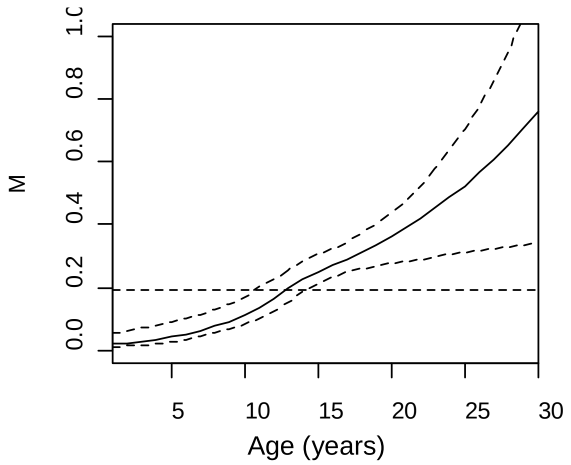



**Figure 24: Estimate *M* — Estimated median relationship of *M* at age (Year), with 95% credible intervals shown as dashed lines, for the Chatham Rise stock. The horizontal dashed line shows the constant value of *M* (0.19) used in other model runs.**


**Figure 25: Estimate *M* — Estimated median selectivity ogives (with 95% credible intervals shown as dashed lines) for the trawl survey series, the western fishery and the eastern fishery.**

The ‘CPUE’ sensitivity run differed from the base case in that the eastern trawl fishery CPUE was included as an additional relative abundance series. The estimated year class strengths were little different to those from the base case. The fishery selectivity ogives were similar to those from the base case, although they had narrower confidence bounds, and the median trawl survey selectivity ogive was domed (rather than being essentially logistic) (Figure 26).


**Figure 26: CPUE — Estimated median selectivity ogives (with 95% credible intervals shown as dashed lines) for the trawl survey series, the western fishery and the eastern fishery.**

The CPUE series was well-fitted (see Figure 7), but the inclusion of CPUE in the model did result in a slight degradation of the fits to the survey biomass series (the objective function increased by about 1). The biomass trends were similar to the base model, but with an overall flatter trajectory, and with relatively wide confidence bounds (Figure 27). However, relative to the base case, absolute spawning biomass estimates are markedly higher, as is current stock size (Table 13).

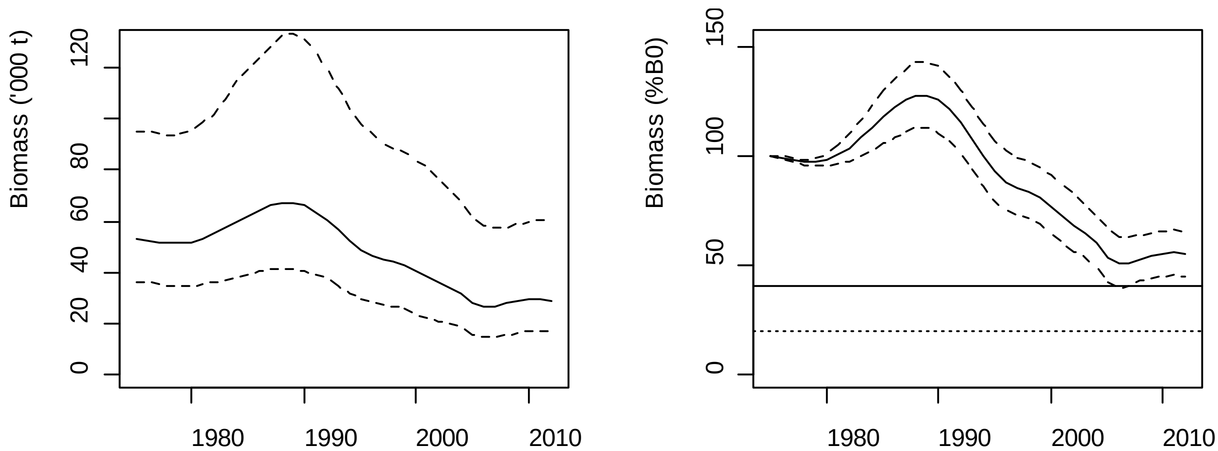



**Figure 27: CPUE — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute spawning biomass and biomass as a percentage of $B_0$, for the Chatham Rise stock. Horizontal lines in the right panel show the management target of 40% $B_0$ and the soft limit of 20% $B_0$.**

## 5.4 Biomass projections

Spawning stock biomass projections from all models were made assuming a future catch of 1800 t annually from 2013 to 2017. That catch level is the TACC for HAK 4. It is higher than recent annual landings from the stock (they have averaged about 1070 t in the last five years), but lower than what could be taken (if all the HAK 4 TACC plus some HAK 1 catch from the western Rise was taken). Projections were also made for the base and free survey ogive models assuming a future annual catch of 1100 t (i.e., close to the recent average).

In the projections, relative year class strengths from 2010 onwards were selected randomly from the previously estimated year class strengths from 1984 to 2009.

Projections from the base case model suggested that spawning biomass will decline to about 38% of $B_0$ by 2017 (Table 14, Figure 28). Biomass was also projected to decline under the other three model scenarios, with the CPUE model producing the most optimistic outcome and the free survey ogive model being the most pessimistic (Table 14).

**Table 14: Bayesian median and 95% credible intervals of projected $B_{2017}$, $B_{2017}$ as a percentage of $B_0$, and $B_{2017}/B_{2012}$ (%) for the Chatham Rise model runs.**

| Model run | Future catch (t) | $B_{2017}$ | $B_{2017}$ (%$B_0$) | $B_{2017}/B_{2012}$ (%) |
|---|---|---|---|---|
| Base | 1 800 | 13 930 (6 990–35 800) | 38.1 (22.0–57.2) | 80 (56–109) |
| | 1 100 | 16 300 (9 450–39 040) | 44.0 (29.9–63.5) | 93 (72–121) |
| Free survey ogive | 1 800 | 8 190 (4 210–14 880) | 28.0 (15.4–46.0) | 66 (41–99) |
| | 1 100 | 10 490 (6 510–16 780) | 35.1 (23.6–51.6) | 85 (64–114) |
| Estimate *M* | 1 800 | 14 210 (6 800–31 120) | 35.4 (19.6–56.3) | 78 (55–103) |
| CPUE | 1 800 | 24 690 (12 200–56 200) | 46.6 (31.9–62.7) | 84 (66–111) |

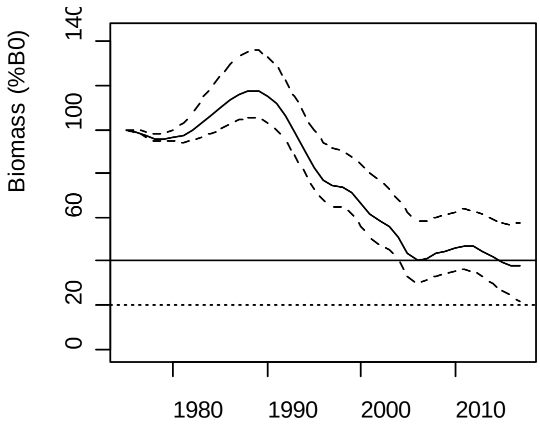



**Figure 28: Base case — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for spawning biomass as a percentage of $B_0$, for the Chatham Rise stock, projected to 2017 with future catches assumed to be 1800 t annually. Horizontal lines show the management target of 40% $B_0$ and the soft limit of 20% $B_0$.**

## 5.5 Management biomass targets

Probabilities that current and projected spawning biomass will drop below selected management reference points (i.e., target, 40%$B_0$; soft limit, 20%$B_0$; hard limit, 10%$B_0$) are shown for the base model and all sensitivity runs in Table 15. The base model indicates that it is extremely unlikely (i.e., about a 1% chance) that $B_{2017}$ will be lower than the soft target of 20%$B_0$.

**Table 15: Probabilities that current ($B_{2012}$) and projected ($B_{2017}$) spawning biomass will be less than 40%, 20% or 10% of $B_0$. Projected biomass probabilities are presented for a future annual catch of 1800 t.**

| Model run | Biomass | Management reference points | | |
|---|---|---|---|---|
| | | 40% $B_0$ | 20% $B_0$ | 10% $B_0$ |
| Base case | $B_{2012}$ | 0.144 | 0.000 | 0.000 |
| | $B_{2017}$, 1800 t catch | 0.587 | 0.011 | 0.000 |
| Free survey ogive | $B_{2012}$ | 0.350 | 0.000 | 0.000 |
| | $B_{2017}$, 1800 t catch | 0.909 | 0.138 | 0.003 |
| Estimate *M* | $B_{2012}$ | 0.219 | 0.000 | 0.000 |
| | $B_{2017}$, 1800 t catch | 0.693 | 0.031 | 0.000 |
| CPUE | $B_{2012}$ | 0.000 | 0.000 | 0.000 |
| | $B_{2017}$, 1800 t catch | 0.211 | 0.000 | 0.000 |

# 6. MODEL ESTIMATES FOR WCSI HAKE

## 6.1 Developing a 'base' model

Some initial investigations were completed to develop a 'base' model. In these preliminary models, the only parameters estimated were $B_0$, year class strengths, selectivity parameters, and (where CPUE was used) CPUE catchability.

An initial model (model 1) was set up, with the partition excluding sex and maturity. The model used a single selectivity ogive for the commercial fishery estimated using the double-normal parameterisation. Selectivity was assumed constant over all years. The CPUE series was incorporated, and comprised the only index of relative abundance. A constant value of 0.19 was used for *M*. The CPUE series was well fitted (Figure 29).

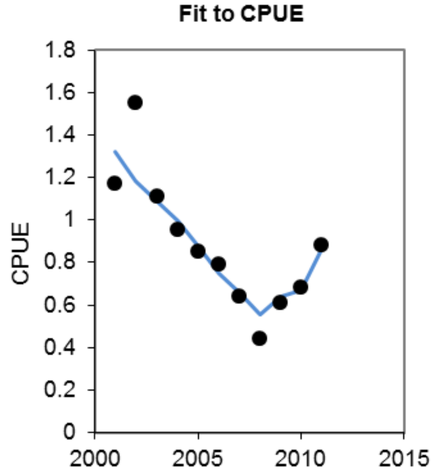



**Figure 29: Fits to the trawl fishery CPUE series, from model 1.**

The inclusion of the biomass survey data was tested in model 2. This was the same as model 1 except that research biomass indices and proportions-at-age data were included, with survey selectivity estimated as a double-normal ogive. The biomass indices were well fitted (Figure 30) and, relative to model 1, there were negligible changes in the biomass trajectory or in the fits to the fishery age data.

The impact of estimating an ogive for natural mortality was investigated in model 3. This was the same as model 2 except that *M* was estimated as a double-exponential ogive. Relative to model 2, the resulting fit to the CPUE series was virtually identical, the biomass trajectory was little different, and there was a slight improvement in the fits to the fishery age data (the objective function decreased by about 3). The estimated *M* ogive was logical (Figure 31). The model 2 fits to all the available age data are shown in Figures 32 and 33.

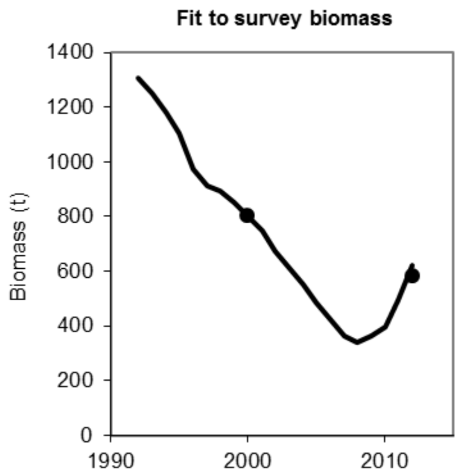



**Figure 30: Fits to the two research biomass indices, from model 2.**

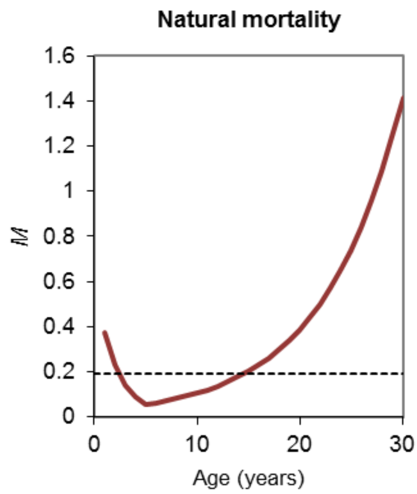



**Figure 31: Estimated natural mortality ogive (solid line) from model 3, with the default constant value of 0.19 shown as a dashed line.**

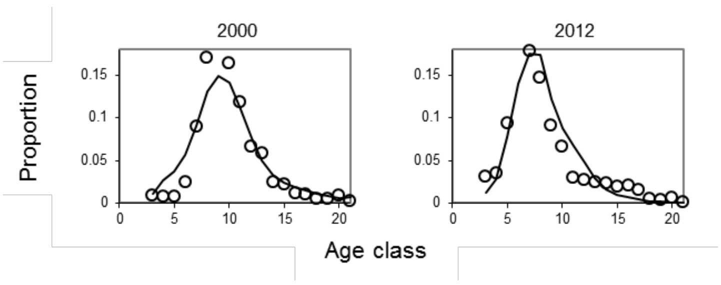



**Figure 32: Fits (lines) to the two research survey proportion-at-age distributions (circles), from model 2.**

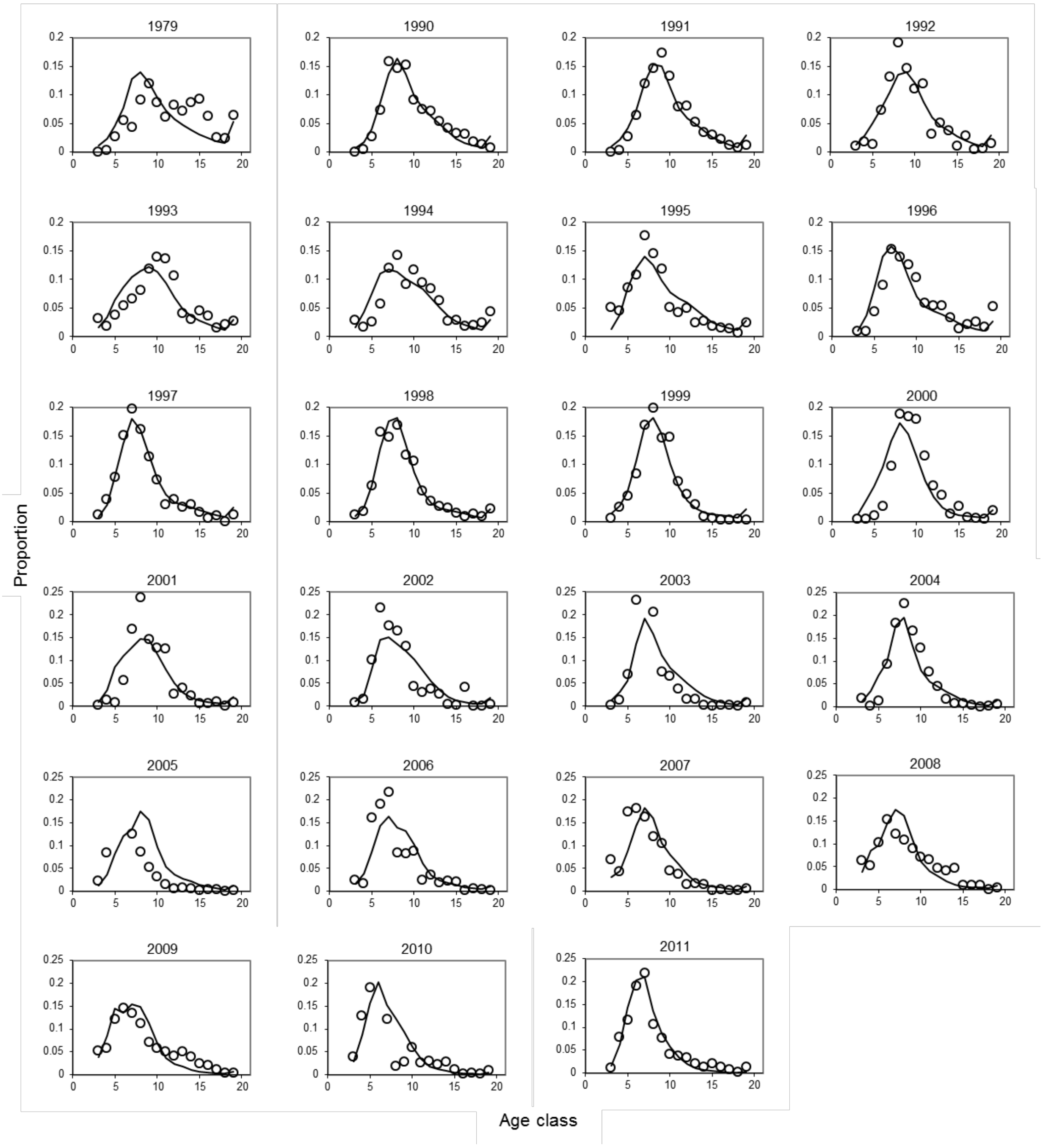



**Figure 33: Fits (lines) to the trawl fishery proportion-at-age distributions (circles), from model 2.**

A likelihood profile on $B_0$ from model 3 (Figure 34) showed that the research survey biomass and age data and the CPUE discourage a $B_0$ less that about 80 000 t, and that all data inputs encourage a $B_0$ in the range from 80 000 to 100 000 t.

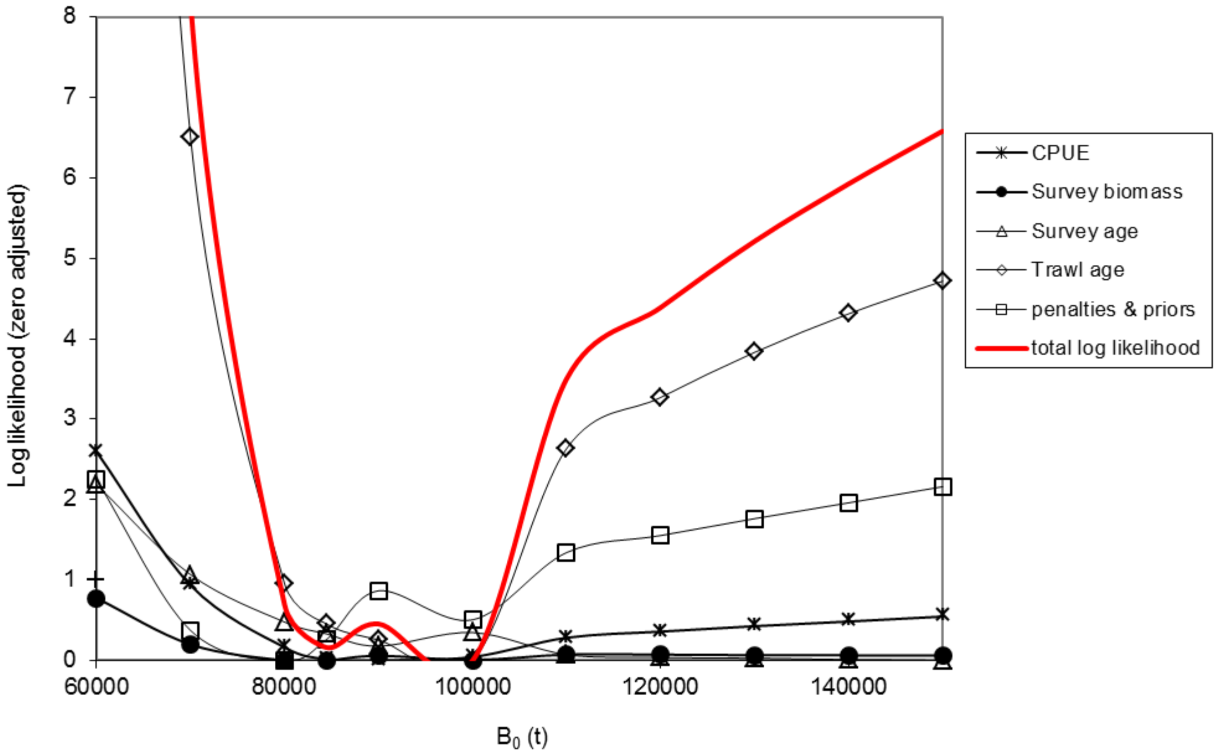



**Figure 34: Likelihood profile on $B_0$ for model 3, showing both the total likelihood (red line) and those for individual data series.**

Following the investigations above with MPD model fits it was concluded that the best base case model for MCMC estimation was model 2 (CPUE and survey data, with a constant *M*). Sensitivities to that model investigated the effect of estimating *M* (model 3), and the effect of excluding the research survey data (i.e., relying entirely on CPUE as an index of relative abundance, model 1).

## 6.2 Model estimation using MCMC

Model parameters were estimated using Bayesian estimation implemented using the CASAL software. For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm. MCMCs were estimated using $3\text{x}10^6$ iterations, a burn-in length of $5\text{x}10^5$ iterations, and with every $2500^{th}$ sample kept from the final $2.5\text{x}10^6$ iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior).

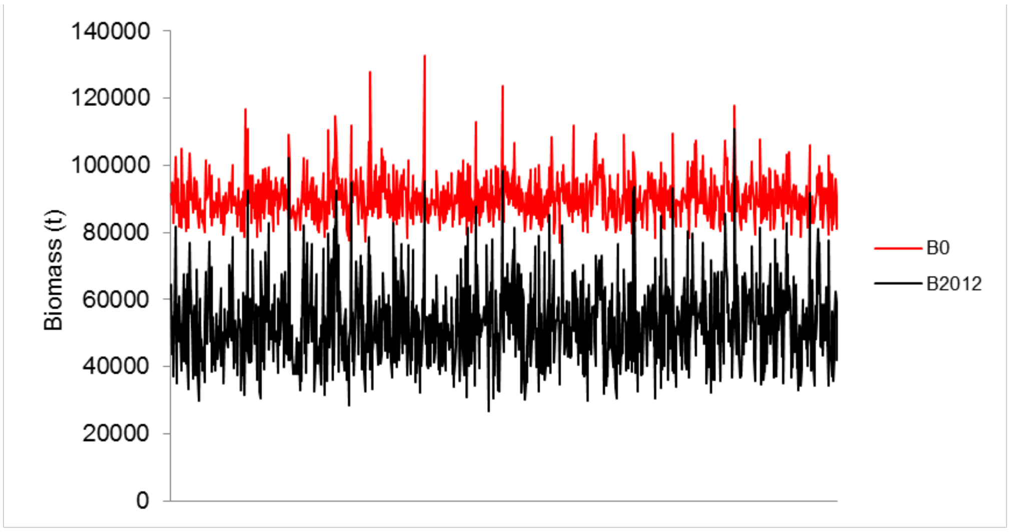
## 6.3 MCMC estimates

Estimates of spawning biomass were made using the biological parameters (see Table 5) and model input parameters described earlier. MCMC estimates of the posterior distribution were obtained for all three model runs, and are presented below. In addition, MCMC estimates of the median posterior and 95% percentile credible intervals are reported for the key output parameters. The MCMC chains for estimates of $B_0$ and $B_{2012}$ from the base model appear moderately well converged (Figure 35). The distributions of estimates of $B_0$ and $B_{2012}$ (as $\%B_0$) from the base model are consistent between the first, middle, and last thirds of the chain (Figure 35), and hence convergence is probably adequate for stock assessment purposes.

The estimated MCMC marginal posterior distributions for selected parameters from the base case model are shown in Figures 36–40. The median selectivity ogives for both the survey and the fishery were approximately logistic shaped, but their bounds were relatively wide (Figure 36). The ogives suggested that hake were fully selected by the fishery by about age 9, and slightly older in the survey. There is no information outside the model that allows the shape of the estimated selectivity ogives to be verified. The estimated research survey catchability constant is estimated to be about 0.04, suggesting that the absolute catchability of the survey series is low, although consistent with the prior (Figure 37).

Year class strength estimates were moderately well estimated for all years (Figure 38). Variation in year class strength does not appear to be great; virtually all median estimates are between 0.5 and 2.

Estimated spawning biomass for the WCSI stock declined throughout the late 1970s owing to relatively high catch levels, then increased through the mid 1980s concurrent with a marked decline in catch (Figure 39). Spawning biomass then steadily declined from 1988 to 2007 owing to higher levels of exploitation and the recruitment of year classes that were generally of below-average strength. The slight increase since 2005 is a consequence of the recruitment of four year classes since 2004 that are estimated to be of above average strength. Bounds around the biomass estimates are reasonably tight, with current stock size being about 58% of $B_0$ (95% credible interval 43–77%) (see Figure 39 and Table 16). Exploitation rates (catch over vulnerable biomass) were less (often much less) than 0.2 up to 1995 (except in 1977), but have been moderate (0.2–0.4 $yr^{-1}$) from 1996 to 2007 (Figure 40). The exploitation rate has dropped again in recent years.



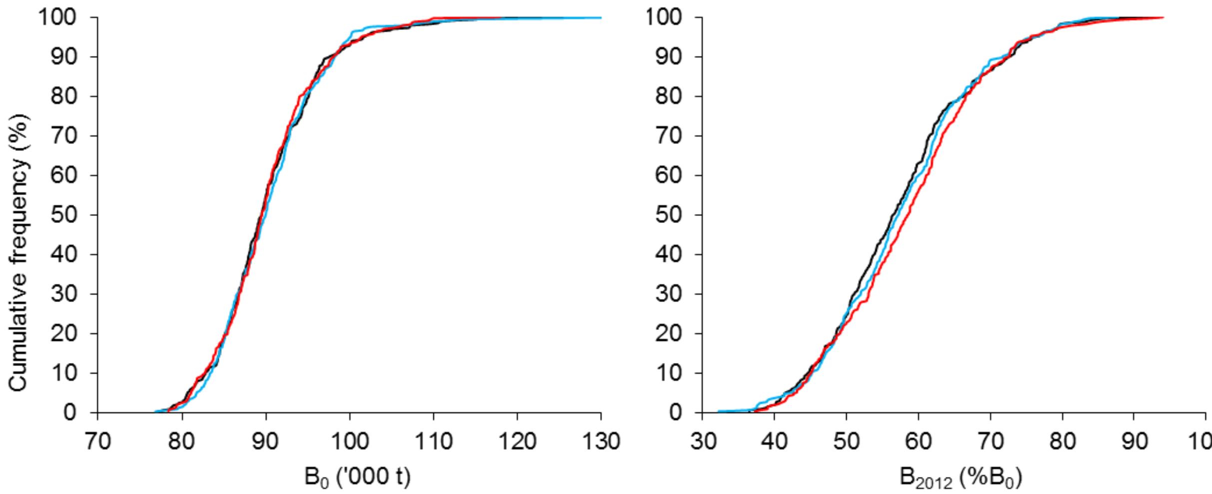



**Figure 35: Trace diagnostic plot of the MCMC chains for estimates of $B_0$ and $B_{2012}$ for the base model run (upper panel). MCMC diagnostic plots showing the cumulative frequencies of $B_0$ and $B_{2012}$ (%$B_0$) for the first (black line), middle (blue line), and last (red line) third of the MCMC chain for the base model (lower panel).**

**Table 16: Bayesian median and 95% credible intervals of $B_0$, $B_{2012}$, and $B_{2012}$ as a percentage of $B_0$ for all model runs.**

| Model run | $B_0$ | | $B_{2012}$ | | $B_{2012}$ (%$B_0$) | |
|---|---|---|---|---|---|---|
| Base case | 88 920 | (80 660–101 210) | 51 190 | (35 850–74 790) | 57.7 | (43.1–77.4) |
| Estimate *M* | 88 360 | (78 790–114 920) | 48 190 | (29 260–90 800) | 54.2 | (35.8–86.4) |
| No survey | 89 640 | (80 320–106 360) | 51 870 | (32 990–81 160) | 57.4 | (40.2–79.5) |

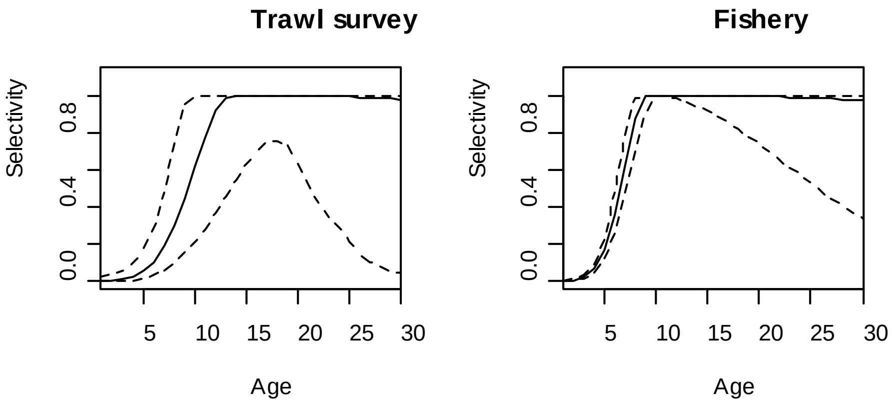



**Figure 36: Base case — Estimated median selectivity ogive (with 95% credible intervals shown as dashed lines) for the trawl survey and the commercial trawl fishery.**

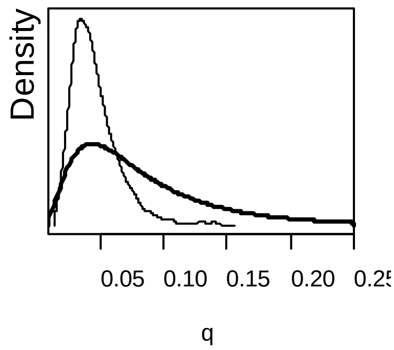



**Figure 37: Base case — Estimated posterior distribution (thin line) and prior (thick line) of survey catchability constant *q* for the WCSI winter resource survey series.**

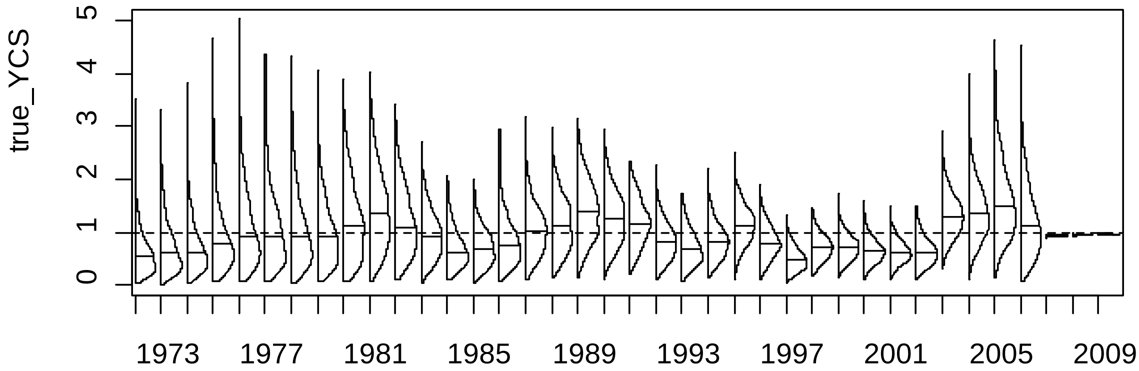



**Figure 38: Base case — Estimated posterior distributions of year class strengths. The dashed horizontal line indicates the year class strength of one. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.**

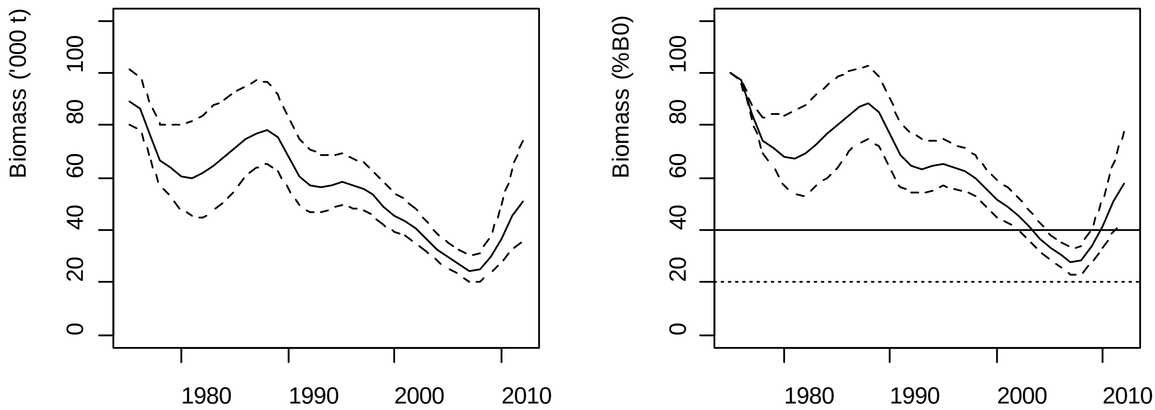



**Figure 39: Base case — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute spawning biomass and biomass as a percentage of $B_0$. Horizontal lines in the right panel show the management target of 40% $B_0$ and the soft limit of 20% $B_0$.**

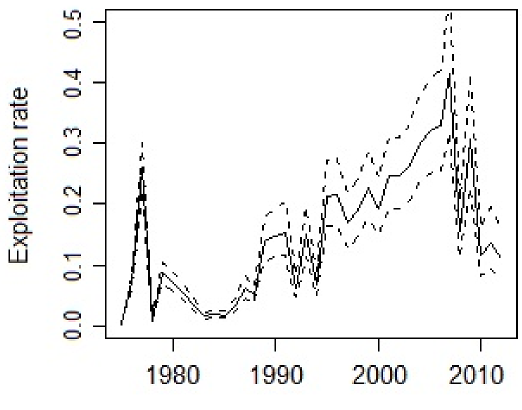



**Figure 40: Base case — Estimated median trajectory of exploitation rate (with 95% credible intervals shown as dashed lines).**

One sensitivity run investigated the effects of estimating *M* in the model (the 'Estimate *M*' model). The estimated MCMC marginal posterior distributions for selected parameters are shown in Figures 41–43. The selectivity ogives were little different to those from the base model (Figure 41). The estimated year class strength pattern and exploitation trajectory were also negligibly different. The estimated *M* ogive was logical, being highest for very young and very old fish, and lowest at about the age of maturity (Figure 42).

Trends in biomass were quite similar between the base and estimate *M* models (Table 16; Figure 43, compared with Figure 39). However, because of the extra uncertainty added when *M* is not constant, the bounds around the trajectory are wider when *M* is estimated. Estimated stock status is also slightly more pessimistic.

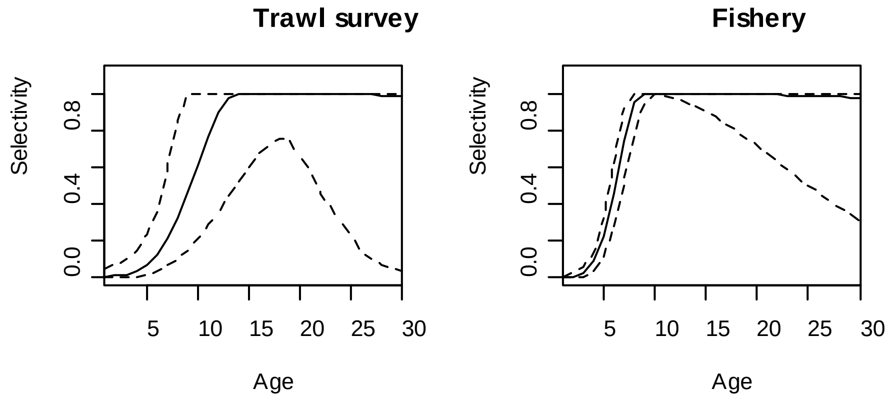



**Figure 41: Estimate *M* — Estimated median selectivity ogives (with 95% credible intervals shown as dashed lines) for the WCSI stock.**

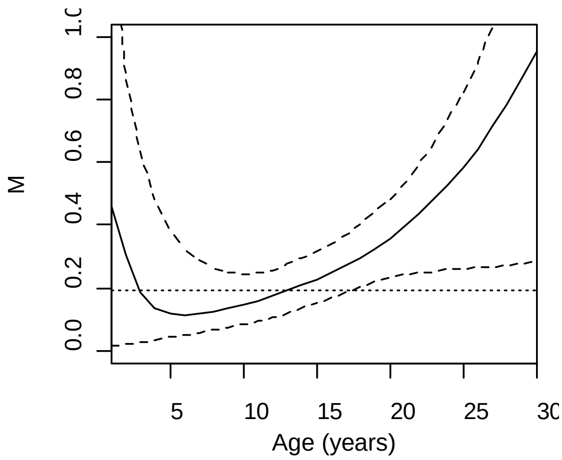



**Figure 42: Estimate *M* — Estimated natural mortality ogive (with 95% credible intervals shown as dashed lines) for the WCSI stock. The horizontal dotted line shows the constant value of *M* (0.19) used in other model runs.**

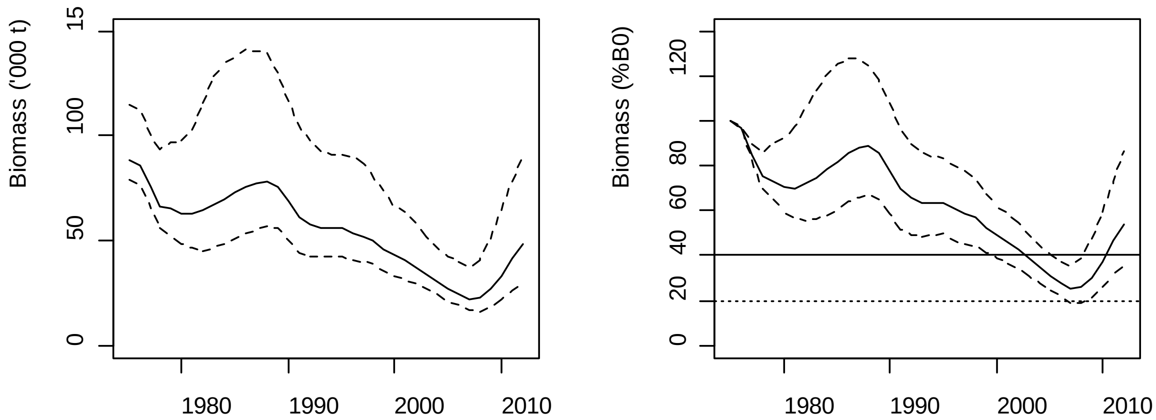



**Figure 43: Estimate *M* — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute spawning biomass and biomass as a percentage of $B_0$, for the WCSI stock. Horizontal lines in the right panel show the management target of 40% $B_0$ and the soft limit of 20% $B_0$.**

The final sensitivity run examined the effect of ignoring the survey data (biomass and proportions-at-age), and thus relying solely on the CPUE to index relative abundance. This model produced results little different to those from the base run (see Table 16, Figure 44).

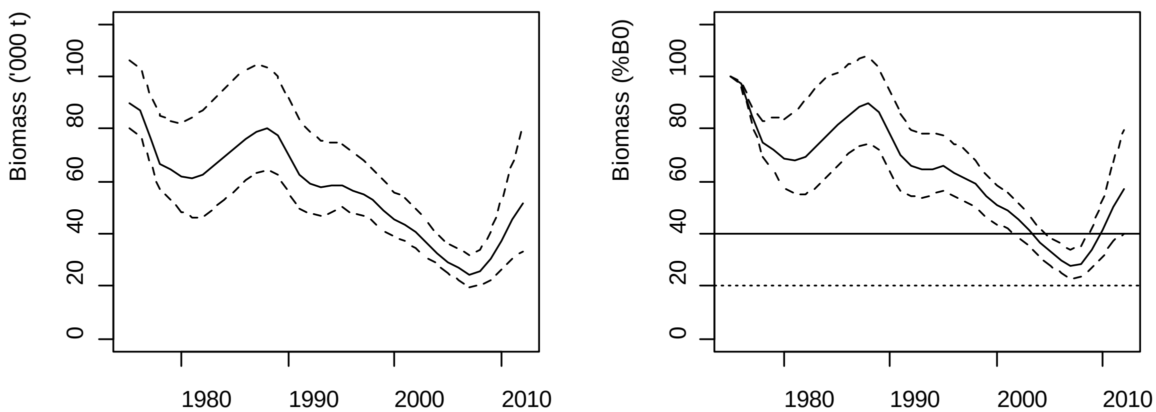



**Figure 44: No survey — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute spawning biomass and biomass as a percentage of $B_0$, for the WCSI stock.**

## 6.4 Biomass projections

Projections of spawning biomass from the base case and two sensitivity models were made under two assumed future catch scenarios (4500 t or 7700 t annually from 2013 to 2017). The low catch scenario (4500 t) approximates the catch level from recent years; the actual catch from 2011–12 was 4460 t (author's unpublished data)). The high catch scenario (7700 t) is the highest likely level of catch as it equates to the HAK 7 TACC.

Year class strengths from 2008 onwards were selected randomly from the previously estimated year class strengths from 1995 to 2006.

Projections from all the models suggested that spawning biomass will increase slightly at the lower projected catch level to be about 60% of $B_0$ by 2017, or decrease slighty to about 47% of $B_0$ at the higher catch level (Table 17, Figures 45 and 46). However, these projections are quite uncertain as indicated by the rapidly spreading confidence intervals after 2012.

**Table 17: Bayesian median and 95% credible intervals of projected $B_{2017}$, $B_{2017}$ as a percentage of $B_0$, and $B_{2017}/B_{2012}$ (%) for all model runs, under two future annual catch scenarios.**

| Model run | Future catch (t) | $B_{2017}$ | | $B_{2017}$ (%$B_0$) | | $B_{2017}/B_{2012}$ (%) | |
|---|---|---|---|---|---|---|---|
| Base case | 4 500 | 54 320 | (33 010–92 820) | 61.2 | (39.2–97.7) | 107 | (78–146) |
| | 7 700 | 41 990 | (22 740–79 420) | 47.4 | (27.4–83.9) | 83 | (56–122) |
| Estimate *M* | 4 500 | 54 810 | (30 520–104 150) | 61.1 | (36.2–101.4) | 114 | (81–158) |
| | 7 700 | 43 310 | (17 390–93 410) | 48.1 | (20.8–89.1) | 88 | (55–130) |
| No survey | 4 500 | 56 010 | (31 210–92 360) | 59.6 | (37.4–95.1) | 105 | (79–141) |
| | 7 700 | 43 160 | (20 530–81 220) | 48.1 | (24.2–84.1) | 85 | (55–122) |

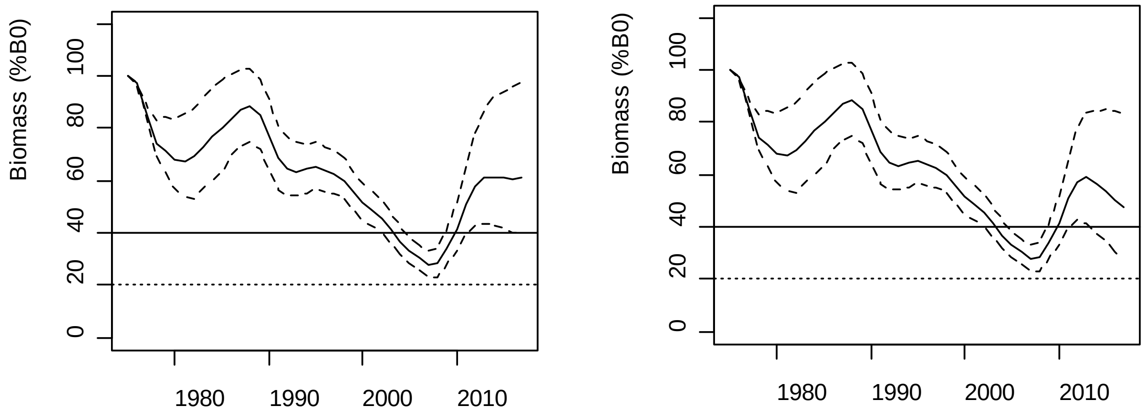



**Figure 45: Base case — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for spawning biomass as a percentage of $B_0$, projected to 2017 with future catches assumed to be 4500 t (left panel) or 7700 t (right panel) annually. Horizontal lines show the management target of 40% $B_0$ and the soft limit of 20% $B_0$.**

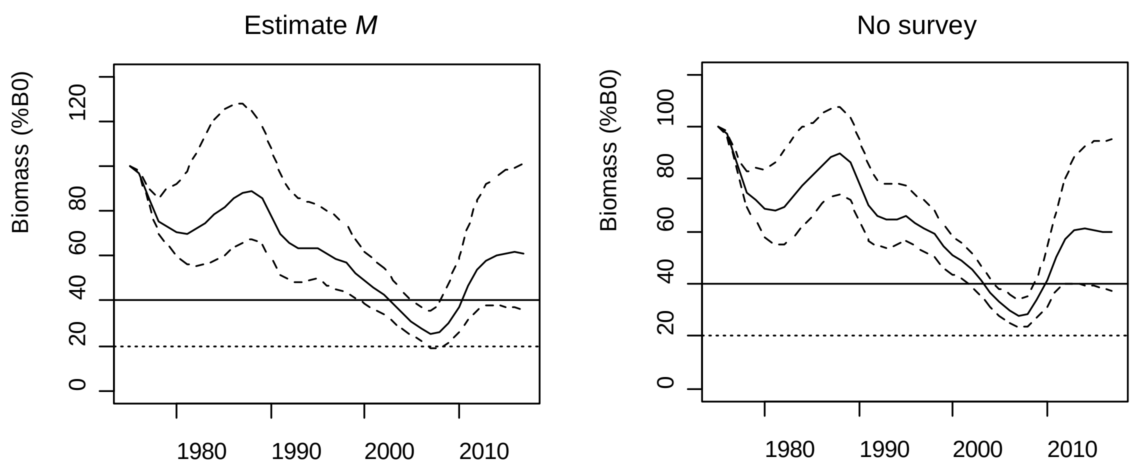



**Figure 46: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for spawning biomass as a percentage of $B_0$, for the two sensitivity models (Estimate *M*, No survey), projected to 2017 with future catches assumed to be 4500 t annually. Horizontal lines show the management target of 40% $B_0$ and the soft limit of 20% $B_0$.**

## 6.5 Management biomass targets

Probabilities that current and projected spawning biomass will drop below selected management reference points (i.e., target, 40%$B_0$; soft limit, 20%$B_0$; hard limit, 10%$B_0$) are shown for the base model and both sensitivity runs in Table 18. It appears extremely unlikely (i.e., less than 1%) that $B_{2017}$ will be lower than the soft target of 20%$B_0$.

**Table 18: Probabilities that current ($B_{2012}$) and projected ($B_{2017}$) spawning biomass will be less than 40%, 20% or 10% of $B_0$. Projected biomass probabilities are presented for two scenarios of future annual catch (i.e., 4500 t, and 7700 t).**

| Model run | Biomass | Management reference points | | |
|---|---|---|---|---|
| | | 40% $B_0$ | 20% $B_0$ | 10% $B_0$ |
| Base | $B_{2012}$ | 0.008 | 0.000 | 0.000 |
| | $B_{2017}$, 4500 t catch | 0.031 | 0.000 | 0.000 |
| | $B_{2017}$, 7700 t catch | 0.272 | 0.001 | 0.000 |
| Estimate *M* | $B_{2012}$ | 0.082 | 0.000 | 0.000 |
| | $B_{2017}$, 4500 t catch | 0.044 | 0.000 | 0.000 |
| | $B_{2017}$, 7700 t catch | 0.292 | 0.022 | 0.000 |
| No survey | $B_{2012}$ | 0.028 | 0.000 | 0.000 |
| | $B_{2017}$, 4500 t catch | 0.038 | 0.000 | 0.000 |
| | $B_{2017}$, 7700 t catch | 0.277 | 0.007 | 0.000 |

# 7. DISCUSSION

## 7.1 Chatham Rise

The base case model estimates that the Chatham Rise spawning stock is currently at about 47% $B_0$, and that continued fishing at catch levels somewhat higher than has occurred recently is likely to cause the stock to decline slowly. All model runs presented are indicative of a current stock status above the management target of 40% $B_0$.

There are several significant differences between the Chatham Rise base model presented above for the 2012–13 fishing year and that reported by Horn & Francis (2010) for the 2009–10 fishing year. First, there are new data (primarily three biomass survey indices, but also some western commercial fishery and survey catch-at-age data). Second, the error structure applied to the at-age data has been changed from lognormal to multinomial. Third, the weighting given to each of the data sets has been modified according to the process of Francis (2011). Finally, the age at full selectivity for the trawl survey has been constrained within a 'logical' range rather than being allowed to be higher than the age of most of the fish caught in the survey series. Both models gave very similar results, the current assessment estimates a lower $B_0$ than the 2009 assessment (37 000 t compared with 41 000 t), and lower stock status in 2009 (44% $B_0$ compared with 47% $B_0$), but identical estimates of 'current' status (47% $B_0$).

Information about the stock status of hake on the Chatham Rise appears reasonably strong. Biomass estimates from the Chatham Rise research trawl series strongly suggest a uniform decline in biomass from the start of the series to the mid 2000s, with biomass in 2005 at about one-third of the level in the early 1990s. Estimates of year class strengths on the Chatham Rise clearly indicate lower than average spawning success in recent years except for 2002. However, this single strong year class has resulted in an upturn in the survey estimates of biomass. All model runs produced almost identical patterns of year class strengths.

The series of year class strengths from 1995 to 2010 (excluding 2002) were estimated to be weaker than average. However, even a more extended series where year class strengths were based on reasonable quantities of at-age data (i.e., 1984 to 2010) has only six years above average. For spawning biomass projections, future year class strengths were sampled randomly from those estimated over the 26-year period from 1984 to 2009. Consequently, average year class strengths after 2010 would have continued the generally 'lower than average' trend. If actual year class strengths after 2010 improve on the recent trend then the projected biomasses reported here will be overly pessimistic. Future biomass is also dependent on future catches. Future catch scenarios of 1100 t or 1800 t annually (equal to the HAK 4 TACC) were modelled; average annual catch in the last five years has been 1070 t. However, all runs indicated a decline in spawning biomass. It is therefore concluded that biomass in this stock will increase only if future annual catches remain significantly lower than 1800 t (and probably lower than 1100 t) and/or if at least some future year class strengths are stronger than the recent average.

However, estimates of stock size and projected stock status rely on the shape of the selectivity ogives. All ogives were estimated using the double-normal parameterisation, and, for the base case and CPUE model runs, all but one were clearly bell-shaped (see Figures 17 and 26). The rate of natural mortality (*M*) was assumed constant in all but the estimate *M* model, but in reality it is likely to vary with age, being relatively greater for very young and very old fish. The assumption of constant *M* will also influence the shapes of the selectivity ogives, as relatively high natural mortality at older ages will be manifested as relatively lower selectivity at those ages. However, an attempt to estimate an age-dependent *M* ogive did not produce a useful result.

Estimates of resource survey catchability (*q*s) are moderately low in the base case assessment (i.e., about 0.08), and even lower in the CPUE sensitivity run (i.e., about 0.05). It is not known if the catchability of the trawl survey series is as low as estimated by the model, but hake are believed to be relatively more abundant over rough ground (that would be avoided during a trawl survey), and it is known that hake tend to school off the bottom, particularly during their spring–summer spawning season, hence reducing their availability to the bottom trawl. However, the Chatham Rise trawl survey series does appear to be providing a relatively precise index of relative abundance for this stock. The series declined steadily, but not radically, from 1992 to about 2005, and has since shown a slight but variable recovery (which is supported by the appearance of a strong year class). There has been little year-to-year variation in the biomass indices, i.e., the series is relatively smooth.

Two CPUE series were available (i.e., for the eastern and western fisheries). The eastern (spawning) fishery series does mirror the estimated biomass reasonably, so it may be reliable and was incorporated in one of the sensitivity models. However, the western fishery series markedly increased around 1994–96 (Ballara in press) which is totally at odds with the research biomass series. It is most likely that this increase was a consequence of some currently unknown change in fishing behaviour or catch reporting behaviour. Consequently, it was not included in any assessment model.

The structural assumptions of the model reported here are likely to lead to the Bayesian posteriors of stock status underestimating the true level of uncertainty. The projected stock status relies on adequate estimation of recent year class strengths and recruitment. The sample sizes of age data from the resource survey are generally small, and the commercial catch proportions-at-age distributions can be sporadic (particularly for the eastern fishery) and based on relatively small samples. Consequently, the projections of future stock status are likely to underestimate the true level of uncertainty. It is particularly unfortunate that the most productive fishery centred on Statistical Area 404 is the worst sampled.

The assessment for Chatham Rise hake has been updated, and is indicative of a stock that has been steadily fished down throughout the 1990s, but that is likely to be above the management target of 40% $B_0$ set for this species. Recruitment of the strong 2002 year class has slowed the rate of stock decline, but future annual catches of around the recent average (i.e., 1100 t) is still likely to result in a decline in spawning biomass over the next five years (see Table 14). It is likely that the stock is being well monitored by the January trawl survey series. There are probably no current sustainability issues for this hake stock, but continued monitoring is important as any increase in catches or continued poor spawning success could drive the spawning biomass towards the soft limit of 20% $B_0$.

### 7.2 West coast South Island

Previous assessments of the HAK 7 (west coast South Island) stock have been complicated because there were no reliable indices of relative abundance (Dunn 2004a, Horn 2011). While CPUE series have been produced previously (e.g., Ballara & Horn 2011) the trends in these series have generally not been logical and it was concluded that catch rates of hake off WCSI are influenced more by fisher behaviour than by abundance of the species. Consequently, adding the available CPUE to the model would probably be misleading (Horn 2011). Several 'one-off' research surveys of hoki and hake have been conducted by different vessels off WCSI, but these provide no useful relative biomass series. A long-running trawl survey series of inshore waters off WCSI by *Kaharoa* does not provide a useful index of hake biomass as it surveys no deeper than 400 m (Stevenson & Hanchet 2000). Consequently, the last HAK 7 assessment included only biological parameters, a catch history, and proportion-at-age data from the commercial fishery since 1990 and the *Wesermünde* survey in 1979 (Horn 2011). While catch-at-age data can provide information on trends in biomass, they are likely to be much more informative when tuned using a relative abundance series. The Middle Depth Species Fisheries Assessment Working Group considered that the 2010 assessment was too unreliable to be reported in the 2011 Plenary Document.

The assessment presented above differed significantly from the 2010 assessment in two respects. First, it included a CPUE series that was considered to be reliable. That series commenced when the deemed value scheme was introduced (2001), and so was believed to be less biased by changes in fishing practice and catch reporting behaviour that had confounded longer CPUE series. Second, it included two comparable trawl biomass indices from surveys that had covered a large proportion of the likely hake habitat off WCSI. The base case model included both the CPUE and survey abundance series, with a sensitivity model run to investigate the effect of excluding the survey biomass index. An additional sensitivity model incorporated both abundance index series, but estimated natural mortality within the model.

The base case model indicates that the WCSI spawning stock is currently at about 58% $B_0$, and that continued fishing at recent catch levels is likely to allow stock size to increase slowly. The two sensitivity model runs produced estimates of $B_0$ and current spawning biomass that were little different to those from the base case. The most pessimistic of the model runs (estimate *M*) indicated that there was an 8% chance of current spawning biomass being lower than 40% of $B_0$, and less than a 5% chance of biomass in 2017 being less than 40% of $B_0$ with future catches equal to those from recent years (i.e., 4500 t annually). Even if future annual catches were as high as the TACC (7700 t), the base model indicated that there was still only a 0.1% chance that biomass would be driven as low as the soft management limit of 20% $B_0$.

Estimated year class strengths often have quite wide 95% bounds, particularly at the start and the end of the estimated series. However, the median estimates suggest that variation in year class strength is not great for this stock; only one of the estimates from 1973 to 2007 are outside the range 0.5–2 (i.e., 1998 is lower). A greater level of year class strength variation, but still relatively low, was also estimated for the hake stock on the Chatham Rise. However, it is not possible to tell whether the low variability in WCSI year class strengths is correct (i.e., the actual variability is low) or is a consequence of uninformative data (e.g., the year-class signal in the observer data could be poor either because these data are not representative of the catch, or because it is masked by year-to-year variation in selectivity).

The structural assumptions of the model reported here are likely to lead to the Bayesian posteriors of stock status underestimating the true level of uncertainty. The projected stock status relies on adequate estimation of recent year class strengths and recruitment. The commercial catch proportions-at-age distributions (which drive the year class strength estimates) are not collected systematically over time or space. Although the stratification used in the analyses of these data coupled with the removal of sex from the partition is believed to produce reasonable estimates of catch-at-age for the fishery, the projections of future stock status based on these data are likely to underestimate the true level of uncertainty.

The assessment for WCSI hake has been updated, and is indicative of a stock that has been steadily fished down throughout the 1990s. However, it is very likely to be currently above the management target of 40% $B_0$ set by the Ministry for Primary Industries. This is the first time that this stock has been assessed using what are believed to be reliable indices of relative abundance. The three input data series used in this assessment (i.e., CPUE, trawl survey biomass, and commercial fishery catch-at-age) are all indicative of a level of virgin spawning biomass in the relatively narrow range of 80 000 to 100 000 t. Recruitment of the relatively strong 2004 to 2006 year classes has resulted in recent growth in stock size. Future annual catches similar to those from recent years are likely to result in a continued slight growth in biomass over the next five years, and even future catches as high as the TACC have a relatively low probability (i.e., less than 30%) of reducing spawning biomass to the management target of 40% of $B_0$. Although the assessment is clearly uncertain, as it is based primarily on a CPUE series, there are probably no current sustainability issues for this hake stock. Improved confidence in the assessment of this hake stock will probably be achieved if the winter research survey series is continued.

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## APPENDIX 1: RESOURCE SURVEY BIOMASS INDICES FOR HAKE IN HAK 1 AND HAK 4

**Table A1: Biomass indices (t) and coefficients of variation (c.v.) for hake from resource surveys of the Sub-Antarctic.** (These estimates assume that the areal availability, vertical availability, and vulnerability are equal to one.)

| Vessel | Date | Trip code | Depth | | Biomass | c.v. | Reference |
|---|---|---|---|---|---|---|---|
| *Wesermünde* | Mar–May 1979 | | – | 1 | – | – | Kerstan & Sahrhage 1980 |
| *Wesermünde* | Oct–Dec 1979 | | – | 1 | – | – | Kerstan & Sahrhage 1980 |
| *Shinkai Maru* | Mar–Apr 1982 | SHI8201 | 200–800 | | 6 045 | 0.15 | N.W. Bagley, NIWA, pers. comm. |
| *Shinkai Maru* | Oct–Nov 1983 | SHI8303 | 200–800 | | 11 282 | 0.22 | N.W. Bagley, NIWA, pers. comm. |
| *Amaltal Explorer* | Oct–Nov 1989 | AEX8902 | 200–800 | | 2 660 | 0.21 | Livingston & Schofield 1993 |
| *Amaltal Explorer* | Jul–Aug 1990 | AEX9001 | 300–800 | | 4 343 | 0.19 | Hurst & Schofield 1995 |
| *Amaltal Explorer* | Nov–Dec 1990 | AEX9002 | 300–800 | | 2 460 | 0.16 | N.W. Bagley, NIWA, pers. comm. |
| *Tangaroa* | Nov–Dec 1991 | TAN9105 | Reported | 2 | 5 686 | 0.43 | Chatterton & Hanchet 1994 |
| | | | 300–800 | 3 | 5 553 | 0.44 | O'Driscoll & Bagley 2001 |
| | | | 1991 area | 4 | 5 686 | 0.43 | O'Driscoll & Bagley 2001 |
| | | | 1996 area | 5 | – | – | |
| *Tangaroa* | Apr–May 1992 | TAN9204 | Reported | 2 | 5 028 | 0.15 | Schofield & Livingston 1994a |
| | | | 300–800 | 3 | 5 028 | 0.15 | O'Driscoll & Bagley 2001 |
| | | | 1991 area | 4 | – | – | |
| | | | 1996 area | 5 | – | – | |
| *Tangaroa* | Sep–Oct 1992 | TAN9209 | Reported | 2 | 3 762 | 0.15 | Schofield & Livingston 1994b |
| | | | 300–800 | 3, 7 | 3 760 | 0.15 | O'Driscoll & Bagley 2001 |
| | | | 1991 area | 4 | – | – | |
| | | | 1996 area | 5 | – | – | |
| *Tangaroa* | Nov–Dec 1992 | TAN9211 | Reported | 2 | 1 944 | 0.12 | Ingerson et al. 1995 |
| | | | 300–800 | 3 | 1 822 | 0.12 | O'Driscoll & Bagley 2001 |
| | | | 1991 area | 4 | 1 944 | 0.12 | O'Driscoll & Bagley 2001 |
| | | | 1996 area | 5 | – | – | |
| *Tangaroa* | May–Jun 1993 | TAN9304[6] | Reported | 2 | 3 602 | 0.14 | Schofield & Livingston 1994c |
| | | | 300–800 | 3 | 3 221 | 0.14 | O'Driscoll & Bagley 2001 |
| | | | 1991 area | 4 | – | – | |
| | | | 1996 area | 5 | – | – | |

**Table A1 ctd.**

| Vessel | Date | Trip code | Depth | Biomass | c.v. | Reference |
|---|---|---|---|---|---|---|
| *Tangaroa* | Nov–Dec 1993 | TAN9310 | Reported [2] | 2 572 | 0.12 | Ingerson & Hanchet 1995 |
| | | | 300–800 [3] | 2 286 | 0.12 | O'Driscoll & Bagley 2001 |
| | | | 1991 area [4] | 2 567 | 0.12 | O'Driscoll & Bagley 2001 |
| | | | 1996 area [5] | – | – | |
| *Tangaroa* | Mar–Apr 1996 | TAN9605 | Reported [2] | 3 946 | 0.16 | Colman 1996 |
| | | | 300–800 [3] | 2 026 | 0.12 | O'Driscoll & Bagley 2001 |
| | | | 1991 area [4] | 2 281 | 0.17 | O'Driscoll & Bagley 2001 |
| | | | 1996 area [5] | 2 825 | 0.12 | O'Driscoll & Bagley 2001 |
| *Tangaroa* | Apr–May 1998 | TAN9805 | Reported [2] | 2 554 | 0.18 | Bagley & McMillan 1999 |
| | | | 300–800 [3] | 2 554 | 0.18 | O'Driscoll & Bagley 2001 |
| | | | 1991 area [4] | 2 643 | 0.17 | O'Driscoll & Bagley 2001 |
| | | | 1996 area [5] | 3 898 | 0.16 | O'Driscoll & Bagley 2001 |
| *Tangaroa* | Nov–Dec 2000 | TAN0012 | 300–800 [3] | 2 194 | 0.17 | O'Driscoll et al. 2002 |
| | | | 1991 area [4] | 2 657 | 0.16 | O'Driscoll et al. 2002 |
| | | | 1996 area [5] | 3 103 | 0.14 | O'Driscoll et al. 2002 |
| *Tangaroa* | Nov–Dec 2001 | TAN0118 | 300–800 [3] | 1 831 | 0.24 | O'Driscoll & Bagley 2003a |
| | | | 1991 area [4] | 2 170 | 0.20 | O'Driscoll & Bagley 2003a |
| | | | 1996 area [5] | 2 360 | 0.19 | O'Driscoll & Bagley 2003a |
| *Tangaroa* | Nov–Dec 2002 | TAN0219 | 300–800 [3] | 1 283 | 0.20 | O'Driscoll & Bagley 2003b |
| | | | 1991 area [4] | 1 777 | 0.16 | O'Driscoll & Bagley 2003b |
| | | | 1996 area [5] | 2 037 | 0.16 | O'Driscoll & Bagley 2003b |
| *Tangaroa* | Nov–Dec 2003 | TAN0317 | 300–800 [3] | 1 335 | 0.24 | O'Driscoll & Bagley 2004 |
| | | | 1991 area [4] | 1 672 | 0.23 | O'Driscoll & Bagley 2004 |
| | | | 1996 area [7] | 1 898 | 0.21 | O'Driscoll & Bagley 2004 |
| *Tangaroa* | Nov–Dec 2004 | TAN0414 | 300–800 [3] | 1 250 | 0.27 | O'Driscoll & Bagley 2006a |
| | | | 1991 area [4] | 1 694 | 0.21 | O'Driscoll & Bagley 2006a |
| | | | 1996 area [7] | 1 774 | 0.20 | O'Driscoll & Bagley 2006a |
| *Tangaroa* | Nov–Dec 2005 | TAN0515 | 300–800 [3] | 1 133 | 0.20 | O'Driscoll & Bagley 2006b |
| | | | 1991 area [4] | 1 459 | 0.17 | O'Driscoll & Bagley 2006b |
| | | | 1996 area [7] | 1 624 | 0.17 | O'Driscoll & Bagley 2006b |

**Table A1 ctd.**

| Vessel | Date | Trip code | Depth | Biomass | c.v. | Reference |
|---|---|---|---|---|---|---|
| *Tangaroa* | Nov–Dec 2006 | TAN0617 | 300–800 [3] | 998 | 0.22 | O'Driscoll & Bagley 2008 |
| | | | 1991 area [4] | 1 530 | 0.17 | O'Driscoll & Bagley 2008 |
| | | | 1996 area [7] | 1 588 | 0.16 | O'Driscoll & Bagley 2008 |
| *Tangaroa* | Nov–Dec 2007 | TAN0714 | 300–800 [3] | 2 188 | 0.17 | Bagley et al. 2009 |
| | | | 1991 area [4] | 2 470 | 0.15 | Bagley et al. 2009 |
| | | | 1996 area [7] | 2 622 | 0.15 | Bagley et al. 2009 |
| *Tangaroa* | Nov–Dec 2008 | TAN0813 | 300–800 [3] | 1 074 | 0.23 | O'Driscoll & Bagley 2009 |
| | | | 1991 area [4] | 2 162 | 0.17 | O'Driscoll & Bagley 2009 |
| | | | 1996 area [7] | 2 355 | 0.16 | O'Driscoll & Bagley 2009 |
| *Tangaroa* | Nov–Dec 2009 | TAN0911 | 300–800 [3] | 992 | 0.22 | Bagley & O'Driscoll 2012 |
| | | | 1991 area [4] | 1 442 | 0.20 | Bagley & O'Driscoll 2012 |
| | | | 1996 area [7] | 1 602 | 0.18 | Bagley & O'Driscoll 2012 |
| *Tangaroa* | Nov–Dec 2009 | TAN1117 | 300–800 [3] | 1 434 | 0.30 | Bagley et al. 2013 |
| | | | 1996 area [7] | 2 004 | 0.23 | Bagley et al. 2013 |

1. Although surveys by *Wesermünde* were carried out in the Sub-Antarctic in 1979, biomass estimates for hake were not calculated.
2. The depth range, biomass and c.v. in the original report.
3. The biomass and c.v. calculated from source records using the equivalent 1991 region, but excluding both the 800–1000 m strata in Puysegur region and the Bounty Platform strata.
4. The biomass and c.v. calculated from source records using the equivalent 1991 region, which includes the 800–1000 m strata in Puysegur region but excludes the Bounty Platform strata.
5. 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 excludes the Bounty Platform strata. (The 1996 region added additional 800–1000 m strata to the north and to the south of the Sub-Antarctic to the 1991 region).
6. 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.
7. 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 excludes the Bounty Platform strata. (The 1996 region added additional 800–1000 m strata to the north and to the south of the Sub-Antarctic to the 1991 region). However, in 2003, stratum 26 (the most southern 800–1000 m strata) was not surveyed. In previous years this stratum yielded either a very low or zero hake biomass. The yield in 2003 from stratum 26 was assumed to be zero.

**Table A2: Biomass indices (t) and coefficients of variation (c.v.) for hake from resource surveys of the Chatham Rise.** (These estimates assume that the areal availability, vertical availability, and vulnerability are equal to one.)

| Vessel | Date | Trip code | Depth | | Biomass | c.v. | Reference |
|---|---|---|---|---|---|---|---|
| *Wesermünde* | Mar–May 1979 | | – | [1] | – | – | Kerstan & Sahrhage 1980 |
| *Wesermünde* | Oct Dec 1979 | | – | [1] | – | – | Kerstan & Sahrhage 1980 |
| *Shinkai Maru* | Mar 1983 | SHI8301 | 200–800 | | 11 327 | 0.12 | N.W. Bagley, NIWA, pers. comm. |
| *Shinkai Maru* | Nov–Dec 1983 | SHI8304 | 200–800 | [2] | 8 160 | 0.12 | N.W. Bagley, NIWA, pers. comm. |
| *Shinkai Maru* | Jul 1986 | SHI8602 | 200–800 | | 7 630 | 0.13 | N.W. Bagley, NIWA, pers. comm. |
| *Amaltal Explorer* | Nov–Dec 1989 | AEX8903 | 200–800 | | 3 576 | 0.19 | N.W. Bagley, NIWA, pers. comm. |
| *Tangaroa* | Jan 1992 | TAN9106 | 200–800 | | 4 180 | 0.15 | Horn 1994a |
| *Tangaroa* | Jan 1993 | TAN9212 | 200–800 | | 2 950 | 0.17 | Horn 1994b |
| *Tangaroa* | Jan 1994 | TAN9401 | 200–800 | | 3 353 | 0.10 | Schofield & Horn 1994 |
| *Tangaroa* | Jan 1995 | TAN9501 | 200–800 | | 3 303 | 0.23 | Schofield & Livingston 1995 |
| *Tangaroa* | Jan 1996 | TAN9601 | 200–800 | | 2 457 | 0.13 | Schofield & Livingston 1996 |
| *Tangaroa* | Jan 1997 | TAN9701 | 200–800 | | 2 811 | 0.17 | Schofield & Livingston 1997 |
| *Tangaroa* | Jan 1998 | TAN9801 | 200–800 | | 2 873 | 0.18 | Bagley & Hurst 1998 |
| *Tangaroa* | Jan 1999 | TAN9901 | 200–800 | | 2 302 | 0.12 | Bagley & Livingston 2000 |
| *Tangaroa* | Jan 2000 | TAN0001 | 200–800 | | 2 090 | 0.09 | Stevens et al. 2001 |
| | | | 200–1000 | | 2 152 | 0.09 | Stevens et al. 2001 |
| *Tangaroa* | Jan 2001 | TAN0101 | 200–800 | | 1 589 | 0.13 | Stevens et al. 2002 |
| *Tangaroa* | Jan 2002 | TAN0201 | 200–800 | | 1 567 | 0.15 | Stevens & Livingston 2003 |
| | | | 200–1000 | | 1 905 | 0.13 | Stevens & Livingston 2003 |
| *Tangaroa* | Jan 2003 | TAN0301 | 200–800 | | 888 | 0.16 | Livingston et al. 2004 |
| *Tangaroa* | Jan 2004 | TAN0401 | 200–800 | | 1 547 | 0.17 | Livingston & Stevens 2005 |
| *Tangaroa* | Jan 2005 | TAN0501 | 200–800 | | 1 048 | 0.18 | Stevens & O'Driscoll 2006 |
| *Tangaroa* | Jan 2006 | TAN0601 | 200–800 | | 1 384 | 0.19 | Stevens & O'Driscoll 2007 |
| *Tangaroa* | Jan 2007 | TAN0701 | 200–800 | | 1 824 | 0.12 | Stevens et al. 2008 |
| | | | 200–1000 | | 1 976 | 0.12 | Stevens et al. 2008 |
| *Tangaroa* | Jan 2008 | TAN0801 | 200–800 | | 1 257 | 0.13 | Stevens et al. 2009a |
| | | | 200–1000 | | 1 323 | 0.13 | Stevens et al. 2009a |
| *Tangaroa* | Jan 2009 | TAN0901 | 200–800 | | 2 419 | 0.21 | Stevens et al. 2009b |
| *Tangaroa* | Jan 2010 | TAN1001 | 200–800 | | 1 701 | 0.25 | Stevens et al. 2011 |
| | | | 200–1300 | | 1 862 | 0.25 | Stevens et al. 2011 |

**Table A2 ctd.**

| | | | | | | |
|---|---|---|---|---|---|---|
| *Tangaroa* | Jan 2011 | TAN1101 | 200–800 | 1 099 | 0.15 | Stevens et al. 2012 |
| | | | 200–1300 | 1 201 | 0.14 | Stevens et al. 2012 |
| *Tangaroa* | Jan 2012 | TAN1201 | 200–800 | 1 292 | 0.15 | Stevens et al. in press |
| | | | 200–1300 | 1 493 | 0.13 | Stevens et al. in press |

1. Although surveys by *Wesermünde* were carried out on the Chatham Rise in 1979, biomass estimates for hake were not calculated.
2. East of 176º E only.