



**Investigation of a minimum biomass model
for the assessment of hake (*Merluccius australis*)
on the west coast South Island (HAK7)**

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**Final Research Report for
Ministry of Fisheries Research Project HAK2003-01**

National Institute of Water and Atmospheric Research

April 2005

Final Research Report

- Report title:** Investigation of a minimum biomass model for the assessment of hake (*Merluccius australis*) on the west coast South Island (HAK 7)
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- 1. Date:** 1 April 2005
- 2. Contractor:** Ministry of Fisheries
- 3. Project Title:** Stock assessment of hake
- 4. Project Code:** HAK2003/01
- 5. Project Leader:** A. Dunn
- 6. Duration of Project:**
Start Date: October 2004
Finish Date: May 2006

7. Introduction

This report outlines a preliminary investigation of an assessment method using a minimum biomass model for the stock assessment of hake in the Quota Management Area (QMA) HAK 7 (Figure 1). I describe a modelling method, along with the key assumptions, and apply this as an illustrative model to the west coast South Island hake fishery.

The west coast South Island (HAK 7) stock is the largest fishery of the three hake stocks within the New Zealand EEZ, with catches up to almost 8000 t per annum in recent years. However, lack of abundance data have prevented any useful stock assessments for this stock. Information for the west coast South Island hake fishery is limited, with little fishery independent data available for formal stock assessment models.

The most recent work on this stock was by Dunn (1998), who attempted a MIAEL model using the least squares and MIAEL estimation techniques of Cordue (1995) with a single stock model as detailed in Cordue (1998). Dunn (1998) estimated that the virgin (equilibrium) spawning stock biomass was about 85 000 t (with range 42 000–185 000 t), but conclusions on current stock status were very uncertain, and further, that the estimates of stock status were unlikely to be reliable. Since then, no further work on the stock status of the west coast South Island hake fishery has been reported.

The current status of the west coast South Island hake fishery is unknown, and Annala et al. (2004) reported that “Estimates of current and reference biomass [for HAK 7] are not available. It is not known if recent catch trends and the current TACC are sustainable, or whether they will allow the stock to move towards a size that will support the MSY”.

This report investigates methods that may allow estimates of the minimum (equilibrium) virgin biomass (B_{\min}) consistent with the observed catch-at-age and the catch history to be determined. Further, the report provides an estimate of the maximum risk, under the assumption that the stock status cannot be less than B_{\min} , associated with an assumed level of future catch and an assumption of a maximum exploitation rate.

The work presented in this report arose out of concerns, expressed by members of the Ministry of Fisheries Middle Depths Fish Stock Assessment Working Group, that standard modelling approaches to the assessment of hake on the west coast South Island (HAK 7) would be unreliable as a basis for determining stock status. An alternative approach was mooted that suggested investigating minimum biomass methods as a basis for informing stock status discussions. This report fulfils Objective 5 of Project HAK2003/01 “To investigate alternative methods for the assessment of the west coast South Island (HAK 7) stock”.

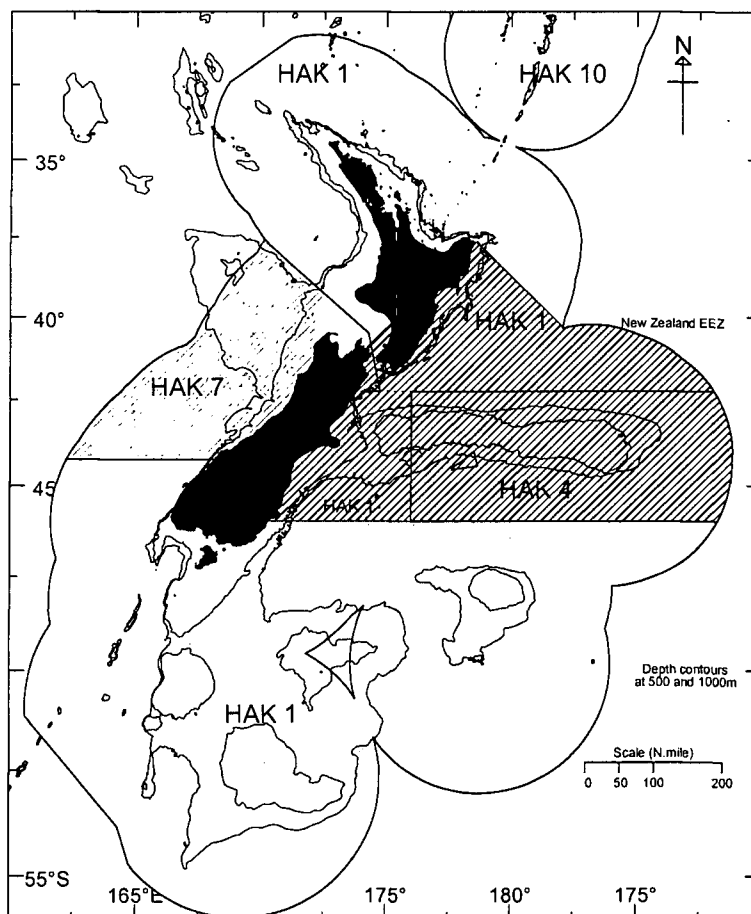


Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, & 10; and the west coast South Island (light shading), Chatham Rise (dark shading), and sub-Antarctic (medium shading) hake stock boundaries assumed in this report.

8. Description of the west coast South Island hake 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 (Phillips & Livingston 2004).

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. The TACC for HAK 7 is the largest, at 6855 t out of a total for the EEZ of 13 997 t. The west

coast South Island 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. These include changes to the TACCs of both hake and hoki, and also changes in fishing practices such as gear used, tow duration, and strategies to limit hake bycatch. In some years, notably in 1992 and 1993, there has been a hake target fishery in September after the peak of the hoki fishery is over; more than 2000 t of hake were taken in this target fishery during September 1993. Bycatch levels of hake early in the fishing season in the years 1994–95, 1995–96, and 1997–89 to 2000–01 were relatively high (Dunn 2004).

Previous assessments of HAK 7 include those by Colman et al. (1991) for the 1991–92 fishing year, Colman & Vignaux (1992) for the 1992–93 fishing year, Colman (1997) for the 1997–98 fishing year, and Dunn (1998) for the 1998–99 fishing year. However, such models have been suspected of being unreliable, and no information has been reported on whether the current catch would meet the sustainability criteria under the Fisheries Act (1996).

9. Methods

9.1 Introduction

Previous attempts at assessment of the west coast South Island hake stock have been considered to be unreliable, primarily as they used only commercial catch-at-age data to infer biomass trends. No series of biomass indices are available for the west coast South Island stock, and CPUE indices previously calculated for the stock have been highly suspect (Annala et al. 1999). In addition, the commercial catch-at-age data appear to suffer from a lack of obvious year class tracking (either because the commercial catch sampling of hake is inadequate to detect such trends, or, less likely, that west coast South Island hake have had very low recruitment variability).

This report investigates an approach that may allow estimates of the minimum (equilibrium) virgin biomass (B_{\min}) consistent with the observed catch-at-age and the catch history to be determined. Further, the report provides an estimate of the maximum risk, under the assumption that the stock status cannot be less than B_{\min} , associated with an assumed level of future catch and an assumption of a maximum exploitation rate.

This report considers two estimates for the assessment of the west coast South Island hake fishery;

- (i) estimates of the minimum virgin (equilibrium) spawning stock biomass (B_{\min}) consistent with the catch history and an assumption of the maximum possible exploitation rate, and
- (ii) estimates of the exploitation rate, and change in the exploitation rate, from a simple Chapman-Robson (1960) catch-curve analysis.

9.2 Minimum biomass assessment model

A minimum biomass model for the west coast South Island hake fishery was developed by estimating the minimum (equilibrium) virgin biomass (B_{\min}) that was consistent with the catch history and an assumption of the maximum exploitation rate. The development of such a model also requires additional assumptions on, for example, biological parameters, relative year class strength, and fishing selectivity. The modelling approach, model structure, and assumptions are described below.

9.2.1 Summary of available data

There are few fishery independent or abundance information for west coast South Island hake available for use in a formal assessment model. The largest quantity of data is from length and age-frequency estimates derived from catch sampling data collected by Ministry of Fisheries observers. Ministry of Fisheries observers have collected length and otolith data from vessels on the west coast South Island since 1989–90.

Periodic resource surveys of the west coast South Island occasionally collected and summarised data for hake, but have used differing vessels, methodologies, and sampling gear. In addition, few data from these resource surveys have been summarised, have reported length/age-frequency estimates, or have calculated biomass estimates. Data used in this analysis were restricted to the proportions-at-age for hake sampled by the research vessel *Wesermünde* in July and August 1979. Here, a sample of 500 otoliths collected from May to August 1979 off the west coast South Island were aged, and the length frequency data used to estimate the catch-at-age distribution.

Some additional length or age data may be available from the *Shinkai Maru* survey in 1976, the *James Cook* surveys in 1978 and 1979, the *Giljanes* survey in 1990, and the hoki *Tangaroa* survey in 2000. However, these data have not been compiled or analysed for hake, and hence have not been used in this analysis. Several years of inshore *Kaharoa* surveys on the west coast South Island have occasionally caught large numbers of juvenile hake (Stevenson & Hanchet 2000). The utility of this data as a recruitment index has not been investigated and, hence, have not been included within this analysis.

Macaulay & Dunn (Macaulay & Dunn 2000) conducted a feasibility study of the use of acoustic surveys for estimating hake abundance on the west coast South Island. They concluded that the acoustic survey method was potentially feasible, with aggregations of hake behaving in a manner amenable to acoustic survey. Since then, no further acoustic investigations have been made.

CPUE indices for the west coast South Island hake fishery were last estimated by Kendrick (1998), but were not considered to be a reliable index of abundance. Since then, CPUE indices for the west coast South Island have not been investigated. CPUE indices have not been included within this analysis.

9.2.2 Model structure

Modelling of the B_{\min} based estimates relies on an initial stock model. Here, the stock assessment model partitioned the population into two sexes and age groups 1–30, with the last age class considered a plus group. The west coast South Island stock was considered to reside in a single area (Colman 1998), with the proportion mature considered to be a constant proportion at age. The model was implemented in CASAL (Bull et al. 2004), as a Bayesian two-sex single-stock single-area model with three time steps.

The model's annual cycle was based on the fishing year, with the time steps describing the spawning, recruitment, fishing, and nominal age increment (Table 1). Note that model references to “year” within this document refer to the fishing year, and are labelled as the most recent calendar year, i.e., the fishing year 1998–99 is referred to as “1999”.

The model ran from 1975 to 2004, and was initialised assuming an equilibrium age structure at an unfished equilibrium biomass, i.e., a constant recruitment assumption. The spawning stock-recruitment relationship was assumed to be a Beverton-Holt relationship with steepness equal to 0.9.

The models used four selectivity ogives; male and female fishing selectivities, and male and female survey selectivities for resource survey series. Selectivities were assumed to either be logistic (with female selectivity curves estimated relative to male selectivity) or domed (parameterised by a double normal selectivity, with female selectivity curves estimated relative to male selectivity). Selectivity values for males at age were hence defined to have maximum selectivity at 1, and female selectivity set relative to males. Annual selectivity shifts were also used in alternative model runs that allowed the selectivity to ‘shift’ to the left or right with changes in an exogenous variable (for example, the mean depth or timing of the fishery). Recruitment was assumed to occur at the beginning of the first (summer) time step, and assumed to be 50:50 male to female.

Table 1: Annual cycle of the stock model, 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.

Step	Period	Processes	M^1	Age ²	Observations	
					Description	% M^3
1	Oct–Feb	Recruitment & spawning	0.42	0.25		
2	Mar–May	Fishing	0.25	0.50	Catch proportions-at-age	50
					Survey proportions-at-age	50
3	Jun–Sep	Increment age	0.33	0.00		

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. % M is the percentage of the natural mortality in each time step that was assumed to have taken place at the time each observation was made.

In total, five model runs were conducted (see Table 2). In the first (“initial”) model, and model runs 3–5, recruitment was parameterised as a year class strength multiplier (assumed to have mean equal to one over a defined range of years), multiplied by an average (unfished) recruitment (R_0) and a spawning stock-recruitment relationship. For the second model (“YCS”), year class strength multipliers were assumed to be constant and equal to 1. The third model scenario (“depth shifted”) assumed that the annual fishing selectivity was shifted by $a(E - \bar{E})$, where a is a shift factor and E was the mean depth fished (weighted by the catch) of all hake tows with each year, expressed in units of years per metre. The fourth (“domed”) and fifth (“domed-shift”) model runs utilised domed selectivities, with the latter also employing the same depth shift algorithm as described above.

Table 2: Model run labels and descriptions for the initial and alternative model runs.

Model run	Description
Initial	Initial model
YCS	Initial case, but assuming constant YCS
Depth shifted	Initial case, but with fishing selectivity shifted by mean depth fished each season
Domed	Initial case, but with domed fishing selectivity
Domed shift	Initial case, but with domed fishing selectivity and shifted by mean depth fished each season

9.2.3 Catch, biological parameters, and observations

The catch histories assumed in all model runs were the revised estimates of catch reported by Dunn (2003) and updated for 2002–03, with the assumption that the catch in 2003–04 was the same as that reported for 2002–03 (7432 t). Reported catches from 1974–75 are shown in Table 3. The West coast South Island estimates for 1989–90 and 1990–91 are taken from Colman & Vignaux (1992) who corrected for under-reporting in 1989–90 and 1990–91 using

estimates of landings from vessel trips with Ministry of Fisheries observers to correct catches from vessel trips that did not carry Ministry of Fisheries observers.

Table 3: Landings (t) 1974–75 to 2003–04 for the west coast South Island.

Fishing year	Landings	Fishing year	Landings	Fishing year	Landings
1974–75	71	1984–85	965	1994–95	9 537
1975–76	5 005	1985–86	1 918	1995–96	9 433
1976–77	17 806	1986–87	3 755	1996–97	7 008
1977–78	498	1987–88	3 009	1997–98	8 118
1978–79	4 737	1988–89	8 696	1998–99	9 117
1979–80	3 600	1989–90	8 741	1999–00	7 617
1980–81	2 565	1990–91	8 246	2000–01	8 761
1981–82	1 625	1991–92	3 027	2001–02	7 519
1982–83	745	1992–93	7 154	2002–03	7 432
1983–84	945	1993–94	2 974	2003–04	–

Note: West coast South Island revised estimates for 1989–90 and 1990–91 are taken from Colman & Vignaux (1992) who corrected for underreporting in 1989–90 and 1990–91, and not from Dunn (2003) who ignored such underreporting.

Estimates of known biological parameters and fixed biological parameters used in the assessments are given in Table 4. 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 $0.20\text{--}0.25 \text{ y}^{-1}$.

Variability was assumed in the von Bertalanffy age-length relationship (Horn 1998), with the variation assumed to be lognormal with a constant c.v. (coefficient of variation) of 0.1. The proportion of males at recruitment was assumed to be 0.5 of all recruits, as there was no external data from which to estimate this value.

Colman (1988) found that, in general, 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. We assume 50% maturity at ages between 6–7 with full maturity at age 9, where the relative proportions mature at age were those estimated by Dunn (1998) for the west coast South Island (Table 4).

Horn (1997) validated the use of otoliths to age hake. Readings of otoliths from hake have been used to develop age-length keys to scale length frequency distributions for hake collected from commercial fisheries on the west coast South Island; hence catch-at-age observations were available for commercial observer data from 1989–90. These data, along with the proportions-at-age data from the *Wesermünde* in 1979, were fitted to the model as proportions-at-age, where estimates of the proportions-at-age were estimated using the NIWA catch-at-age software by bootstrap (Bull & Dunn 2002). Age data from each year were compiled into year-specific age-length keys, and these were applied to the stratified, scaled length-frequency distributions to produce proportions-at-age distributions. Strata were determined using the tree-based regression methods described in Francis (2002), with three strata defined as (i) depth $\geq 620.5 \text{ m}$, (ii) depth $< 620.5 \text{ m}$ and latitude $\geq 42^\circ 33' \text{ S}$, and (iii) depth $< 620.5 \text{ m}$ and latitude $< 42^\circ 33' \text{ S}$. Tows where less than 5 fish were measured were ignored. 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. The resulting age frequency

distributions are shown in Appendix A as Figures A1–A2. Numbers of measurements are given in Appendix A in Table A1. The relative observed proportions-at-age data (for ages 3–20) from the observer data are shown in Figure 2.

Table 4: Estimates of biological parameters assumed for the stock model.

	Estimate	Source
<i>Natural mortality</i>		
Males	$M = 0.20$	(Dunn et al. 2000)
Females	$M = 0.18$	(Dunn et al. 2000)
<i>Weight = a · (length)^b (Weight in t, length in cm)</i>		
Males	$a = 3.95 \times 10^{-9}$	$b = 3.130$ (Horn 1998)
Females	$a = 1.86 \times 10^{-9}$	$b = 3.313$ (Horn 1998)
<i>von Bertalanffy growth parameters</i>		
Males	$k = 0.263$ $t_0 = -0.06$	$L_\infty = 90.8$ (Horn 1998)
Females	$k = 0.188$ $t_0 = -0.13$	$L_\infty = 115.0$ (Horn 1998)
<i>Maturity</i>		
Males	Ages 3–9 0.02, 0.07, 0.31, 0.78, 1.00, 1.00	
Females	Ages 3–9 0.02, 0.04, 0.07, 0.45, 0.86, 1.00	
Steepness (Beverton & Holt)	0.9	
Proportion spawning	1.0	
Proportion of recruits that are male	0.5	
Maximum exploitation rate (U_{max})	0.5	

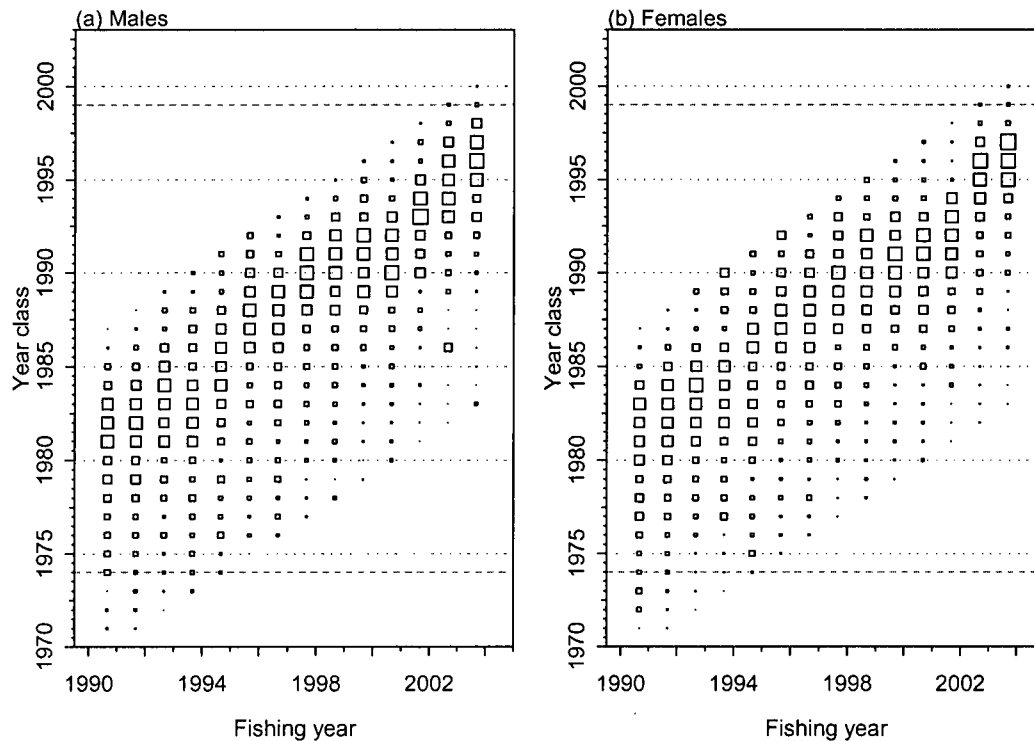


Figure 2: Age frequencies (ages 3 to 20) by year class and year (symbol area proportional to the proportions-at-age within sampling event) on the west coast South Island for commercial catch-at-age data (squares). Horizontal lines indicate the earliest (1974) and latest (1999) year class strengths estimated within the stock assessment model.

9.2.4 Model estimation

Model parameters were estimated using Bayesian estimation implemented using CASAL (Bull et al. 2004). However, only the mode of the joint posterior distribution (MPD) was estimated in preliminary runs. For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm.

Multinomial errors, with estimated sample sizes, were assumed for the proportions-at-age observations. Estimates of the sample size for the observations were made via a two-step process; (a) first, the sample sizes for the proportions-at-age data were derived by assuming the relationship between the observed proportions, E_i , and estimated c.v.s, c_i , followed that for a multinomial distribution with unknown sample size N_j . The estimated sample size was then derived using a robust non-linear least squares fit of $\log(c_i) \sim \log(P_i)$, and (b) by estimating an effective sample size, N' , by adding additional process error, N_{PE} , to the sample size calculated in (a) above, where,

$$N' = 1 / \left(\frac{1}{N} + \frac{1}{N_{PE}} \right)$$

i.e., from an initial MPD model fit, an estimate of the additional process error was made (in a manner similar to that outlined by McAllister & Ianelli 1997) by solving the following equation for N_{PE} ,

$$n = \sum_j \frac{(O_{ij} - E_{ij})^2}{E_{ij} (1 - E_{ij}) \left(\frac{1}{N_j} + \frac{1}{N_{PE}} \right)}$$

where n was the number of multinomial cells, O_{ij} was the observed proportions for age class i in year j , E_{ij} was the expected proportions, N_j was the effective sample size estimated in (a) above, and N_{PE} was the associated process error for that class of observations. Sample sizes for the initial model are given in Table 5. Estimated process errors for the initial, YCS, depth-shifted, domed, and domed-shift models were 254, 201, 247, 270, and 258 respectively.

Table 5: Number of tows, number of fish measured, and number of fish aged from observer sampled tows on the west coast South Island hake fishery, and the estimated sample size (N), and the effective sample size used for the multinomial likelihood (Effective N), with a process error of $N_{PE}=254$.

Year	Tows	No. fish measured		No. fish aged		Sample size	
		Male	Female	Male	Female	N	Effective N
1990	57	578	567	210	261	351	147
1991	146	2 288	1 653	286	358	540	173
1992	121	2 592	1 193	196	261	441	161
1993	93	2 129	979	188	163	303	138
1994	174	1 598	1 643	151	272	227	120
1995	152	2 528	2 769	271	342	386	153
1996	193	2 862	1 753	287	326	440	161
1997	234	3 286	1 720	262	198	414	157
1998	237	2 339	1 497	257	253	400	155
1999	307	4 186	3 744	269	240	728	188
2000	285	2 705	2 330	258	269	454	163
2001	192	1 529	1 723	176	280	412	157
2002	380	2 281	2 434	93	385	347	147
2003	296	1 917	2 063	227	234	674	184

Year class strengths were assumed known (and equal to one) for years prior to 1974 and after 1999, 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, in the projections, the assumption that the relative year class strengths were equal to one was relaxed. Here, relative year class strengths from 2000 were assumed to be unknown, with a lognormal distribution with mean 1.0 and standard deviation set equal to the standard deviation of the previously estimated year class strengths (or, in the “YCS” model run, equal to 0.9).

The assumed prior distributions used in the model were intended to be relatively uninformed or conservative. Priors for B_0 were assumed to be uniform-log, with bounds 2 500–250 000 t; priors for the relative year class strengths were assumed to be lognormal with mean 1.0 and c.v. 1.1; and priors on selectivity parameters were assumed to be uniform with arbitrary wide bounds. Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was strongly penalised. A small penalty was applied to the estimates of year class strengths to encourage estimates that average to 1.0.

MCMCs were estimated using a burn-in length of 1×10^6 iterations, with every 5000th sample taken from the next 5×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior). Convergence diagnostics for the MCMC for the parameters of the model were not formally investigated, but visual inspection suggested no strong evidence of lack of convergence. The MCMC trace for B_0 and B_{\min} is shown as Figure 3.

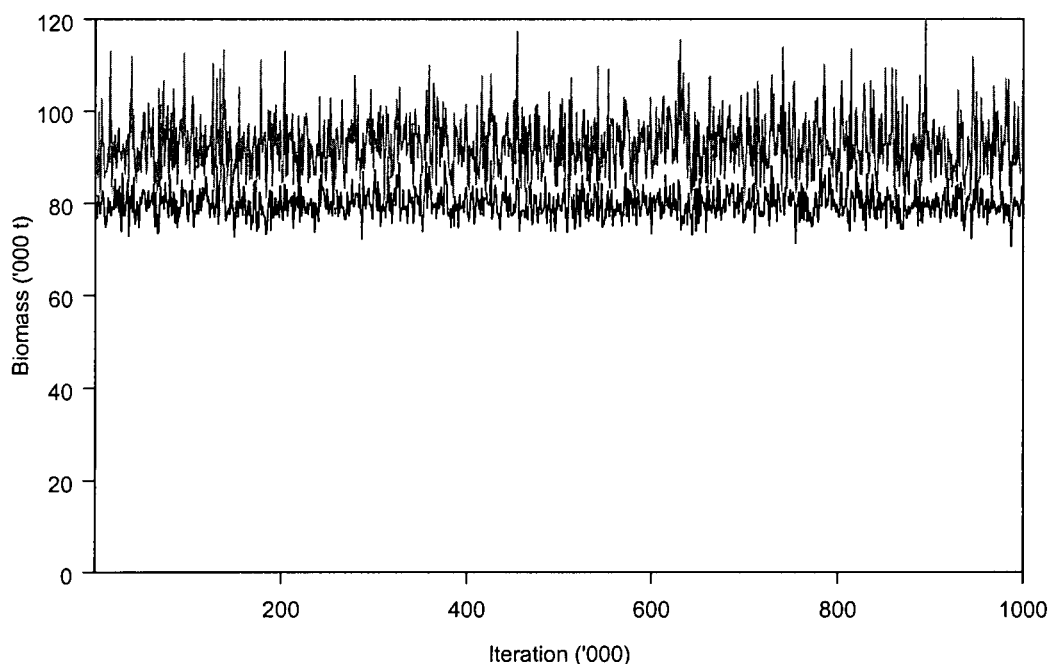


Figure 3: Trace diagnostic plot for initial case MCMC chain for estimates of B_0 (grey line) and B_{\min} (black line).

9.2.5 B_{\min} estimation

Model estimates derived from the MCMC estimation procedures described earlier were used to determine a minimum biomass consistent with the catch history and an assumption of the maximum possible exploitation rate (U_{\max}). The procedure was to find, for each sample from the posterior distribution, the value of B_{\min} such that when $B_0 = B_{\min}$ the maximum observed exploitation rate is equal to U_{\max} .

Here, the maximum exploitation rate was defined as the maximum fishing pressure (or catch proportion) where no more than the proportion U_{\max} can be taken from any element of the partition affected by the fishery in that time step. Clearly $0 \leq U_{\max} \leq 1$. For this report, the maximum exploitation rate was assumed to be $U_{\max} = 0.5$ for all catches that have been taken from the west coast South Island hake fishery. However, this constraint was relaxed for the projections, and a maximum exploitation rate for future years was defined as $U_{\max} = 1$.

The method of finding the minimum biomass was top trial candidate values of the initial equilibrium biomass from 40 000–120 000 t in 5000 t increments, and then calculate the resulting maximum value of the exploitation rate for each candidate. The estimated value of B_{\min} at each value of U_{\max} was then determined by linear interpolation of the relationship between the candidate values and the maximum calculated exploitation rate for each candidate.

The choice of the maximum exploitation rate has considerable impact on the conclusions that can be drawn from this type of analyses, and clearly, in a fuller analysis, the choice of U_{\max} and the sensitivity of model results to alternative values of U_{\max} would need to be fully investigated. The choice of 0.5 in this model is an arbitrary value, however, I note that the maximum observed exploitation rate estimated for the Chatham Rise fishery was about 0.4 (Dunn 2004).

9.3 Chapman-Robson catch curve analysis

Chapman Robson (1960) developed a method for the estimation of total mortality, Z , (i.e., natural mortality plus fishing mortality) from age frequency data that is easily calculated from catch-at-age data. The estimator is based on a minimum variance unbiased estimator for the related survival parameter, $S = e^{-Z}$, and is defined as

$$\hat{Z} = \log_e \left(\frac{1 + \bar{a} - 1/n}{\bar{a}} \right), \text{ with variance } \approx \frac{(1 - e^{-Z})^2}{ne^{-Z}}$$

where \bar{a} is the mean age (above the recruitment age) and n is the sample size.

Dunn et al. (2002) showed that the Chapman-Robson estimator performed better, on average, than regression based methods, for estimating Z . Here, this estimator is applied to the age frequency data from the catch proportions-at-age data from the west coast South Island hake fishery. Population model fits (see later) to the catch proportions-at-age data suggested that maximum selectivity occurs at about age 8–11 for males and females, and hence the age of full recruitment is defined at age = 9 (i.e., the age where recruitment is $\geq 90\%$). Table 6 shows the proportion of full recruitment, by age, for male and female hake under an assumption of a logistic fishery selectivity with parameters approximately equal to the initial case MPD model fits.

Table 6: Relative selectivity (scaled to maximum of 1) for male and female hake assuming a logistic selectivity function with male parameters $a_{50} = 7$ and $a_{t0.95} = 2.4$, and female parameters $a_{50} = 6.4$ and $a_{t0.95} = 2.4$

Age	5	6	7	8	9	10	11	12
Male	0.08	0.23	0.5	0.77	0.92	0.98	0.99	1.00
Female	0.15	0.38	0.68	0.88	0.96	0.99	1.00	1.00

10. Results

10.1 Minimum biomass assessment model

The initial case estimates of biomass, including B_{\min} estimates, were estimated using the biological parameters and model input parameters described earlier. Objective function values (negative log-likelihood) for each MPD model run are shown in Table 7. MCMC estimates of the posterior distribution were obtained for all 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. Summary plots of the initial case MPD model fits are given as Appendix B.

The estimated MCMC marginal posterior distributions for selected parameters are shown in Figure 4–Figure 9. Fishing selectivities for males and females were divergent; with the selectivities for males significantly higher than for females in all cases (Figure 4). While the relative proportions of male to females is unusual, the selectivities are representative of the input data; proportions of male fish in the catch suggest that 59% of the catch (by number) was male, though the ratio has declined in recent years (see Figure 10). Similar relative ratios of males to female selectivities were also found when domed selectivities were applied (Figure 5). Maximum selectivity was typically at about ages 8–10 for both males and females,

Year class strength estimates were poorly estimated for most years, particularly where only old or young fish were available to determine age class strength (Figure 6). In addition, it is difficult to determine any evidence of year classes tracking through the commercial catch proportions-at-age data.

Figure 7 shows the B_{\min} biomass trajectory for the initial case, projected forward until 2009. Here, under the assumption that the true virgin equilibrium biomass was equal to B_{\min} , the current biomass ($B_{\min,2004}$) was about 44% B_{\min} (95% credible intervals 36–55%) (Table 8). Estimated values of B_0 , B_{2004} , and B_{2004} as a percentage of B_0 are shown in Table 9. Model estimates of the current biomass are fairly uncertain, and suggest that current biomass was about 50% B_0 (with range between about 30–70%). Both the $B_{\min,2004}$ and B_{2004} estimates suggest that current biomass is not severely depleted, under the assumption that the maximum exploitation rate has not exceeded 0.5 (Figure 8). The relationship between the estimated minimum biomass and the exploitation rate is shown as Figure 9. Here, the minimum possible virgin equilibrium biomass (B_{\min}) is highly unlikely to be below about 60 000 t (i.e., when $U_{\max}=1$), and, under the assumption that the maximum exploitation rate was no more than 0.5, is likely to be more than 75 000 t.

Projections of the initial case with $B_0=B_{\min}$ suggest that the maximum probability that the spawning stock population will decline to below less than 20% B_{\min} is less than 10% for the next five years, assuming future catches equal to the current catch (Table 10). (Note that projections were carried out using the 2002–03 catch of 7532 t, rather than the current TACC of 6855 t). However, the probability of a continued decline in the population (assuming $B_0=B_{\min}$) is high, with strong evidence that current catch levels will continue to reduce the population in the short term (Table 11).

Alternative model runs suggested that there was considerable uncertainty in the shape of the selectivity function. For the “domed” scenario, selectivities were significantly dome shaped, with the maximum selectivity at ages 10–12, and rapidly declining right hand limbs (Figure 5). The initial case model fits showed considerable evidence of poor fit to observations of the number of older aged fish (Figure 11), with MCMC runs predicting greater numbers of fish aged over 15 and over 20 in the population than that supported by the catch proportions-at-age observations. However, domed selectivities appeared to fit the observations more closely, and gave more satisfactory diagnostics (Figure 12).

Inclusion of a shift parameter (“depth-shifted” and “domed shift”) suggested that there appears to be some age/depth relationship, with the estimated increase in mean fish age about 7–8 years per 1000 m increase in depth (95% credible intervals 4–12 ykm⁻¹). However, all the sensitivity scenarios (except for the fixed YCS run) suggested a lower potential risk of current catches reducing the population below 20% B_0 than the initial case.

Table 7: Objective function values (negative log-likelihood) for MPD fits to the observations, priors, and penalties, and the total objective function (negative log-likelihood) value.

Component	Initial case	YCS	Depth shifted	Domed	Domed shift
Observations					
Catch proportions-at-age	954.4	921.3	938.0	962.8	941.2
Survey proportions-at-age	91.8	92.7	92.0	92.7	92.3
Priors					
B_0	11.4	11.4	11.4	11.5	11.5
a	–	–	0.0	–	0.0
YCS	1.8	–	1.8	1.8	1.8
Fishing selectivity (male)	0.0	0.0	0.0	0.0	0.0
Fishing selectivity (female)	0.0	0.0	0.0	0.0	0.0
Survey selectivity (male)	0.0	0.0	0.0	0.0	0.0
Survey selectivity (female)	0.0	0.0	0.0	0.0	0.0
Penalties					
Catch limit	0.0	0.0	0.0	0.0	0.0
YCS	0.4	–	0.4	0.4	0.4
Total	1059.8	1025.4	1043.6	1069.2	1047.2

Table 8: Bayesian median and 95% credible intervals of B_{\min} , $B_{\min_{2004}}$, and $B_{\min_{2004}}$ as a percentage of B_{\min} for the initial and sensitivity cases.

Model run	B_{\min}	$B_{\min_{2004}}$	$B_{\min_{2004}}$ (% B_{\min})
Initial case	79 630 (74 160–86 120)	35 260 (27 440–46 030)	44 (36–55)
YCS	79 910 (75 530–84 820)	26 690 (24 920–35 000)	37 (33–41)
Depth shifted	84 720 (77 880–92 890)	41 140 (29 750–54 760)	48 (37–60)
Domed	100 200 (89 680–114 260)	40 490 (35 590–51 290)	40 (34–52)
Domed shift	104 710 (95 150–116 390)	44 980 (36 690–60 010)	43 (35–55)

Table 9: Bayesian median and 95% credible intervals of B_0 , B_{2004} , and B_{2004} as a percentage of B_0 for the initial and sensitivity cases.

Model run	B_0	B_{2004}	B_{2004} (% B_0)
Initial case	92 280 (81 100–107 750)	49 210 (32 220–74 780)	53 (39–70)
YCS	90 760 (82 310–99 040)	41 230 (32 340–49 680)	45 (39–50)
Depth shifted	92 350 (79 790–106 920)	49 730 (30 550–74 790)	54 (38–70)
Domed	114 200 (99 370–152 870)	53 900 (34 670–101 650)	47 (33–70)
Domed shift	110 930 (97 900–135 080)	50 740 (34 220–86 050)	46 (34–65)

Table 10: Initial and sensitivity case estimates of the probability that the population will decline below 20% B_{\min} under an assumption of annual catch of 7532 t for the years 2005–2009.

Model scenario	Median B_{\min}	Year				
		2005	2006	2007	2008	2009
Initial case	79 630	0.00	0.00	0.01	0.03	0.06
YCS	79 910	0.00	0.00	0.00	0.04	0.16
Depth shifted	84 720	0.00	0.00	0.00	0.01	0.02
Domed	100 200	0.00	0.00	0.00	0.02	0.03
Domed shift	104 710	0.00	0.00	0.00	0.01	0.02

Table 11: Initial and sensitivity case estimates of the probability that the population will decline below $B_{\min,2004}$ under an assumption of annual catch of 7532 t for the years 2005–2009.

Model scenario	Median $B_{\min,2004}$ (t)	Year				
		2005	2006	2007	2008	2009
Initial case	35 260	0.57	0.89	0.91	0.89	0.88
YCS	29 690	0.93	0.84	0.74	0.71	0.70
Depth shifted	41 140	0.38	0.79	0.86	0.84	0.84
Domed	40 490	0.73	0.88	0.85	0.78	0.73
Domed shift	44 980	0.62	0.81	0.79	0.74	0.70

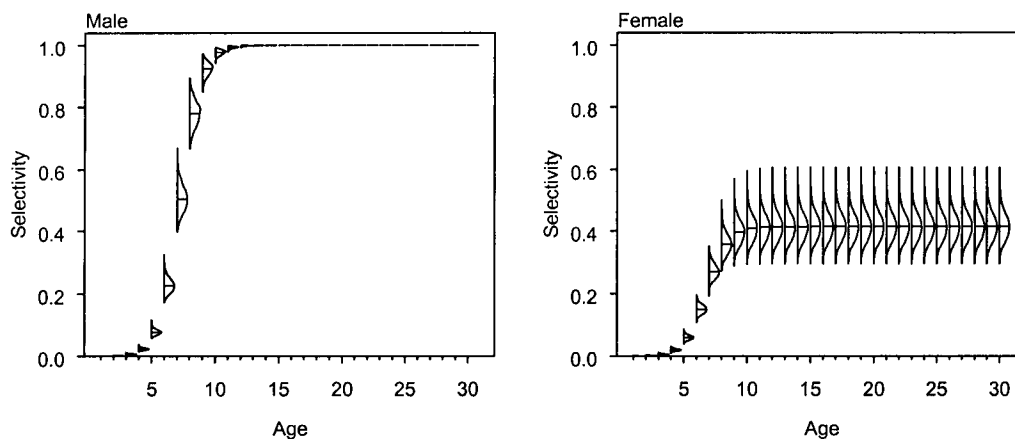


Figure 4: Estimated posterior distributions of relative fishing selectivity by age and sex, for the initial case. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

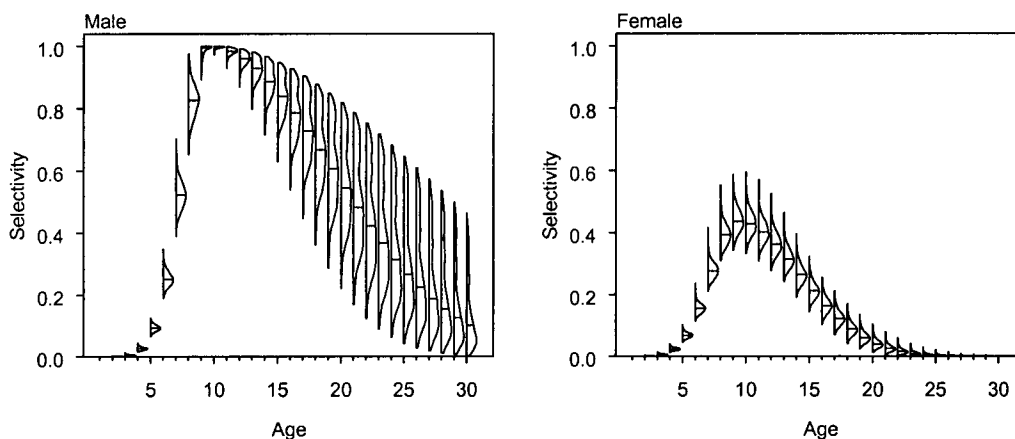


Figure 5: Estimated posterior distributions of relative fishing selectivity by age and sex, for the domed case. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

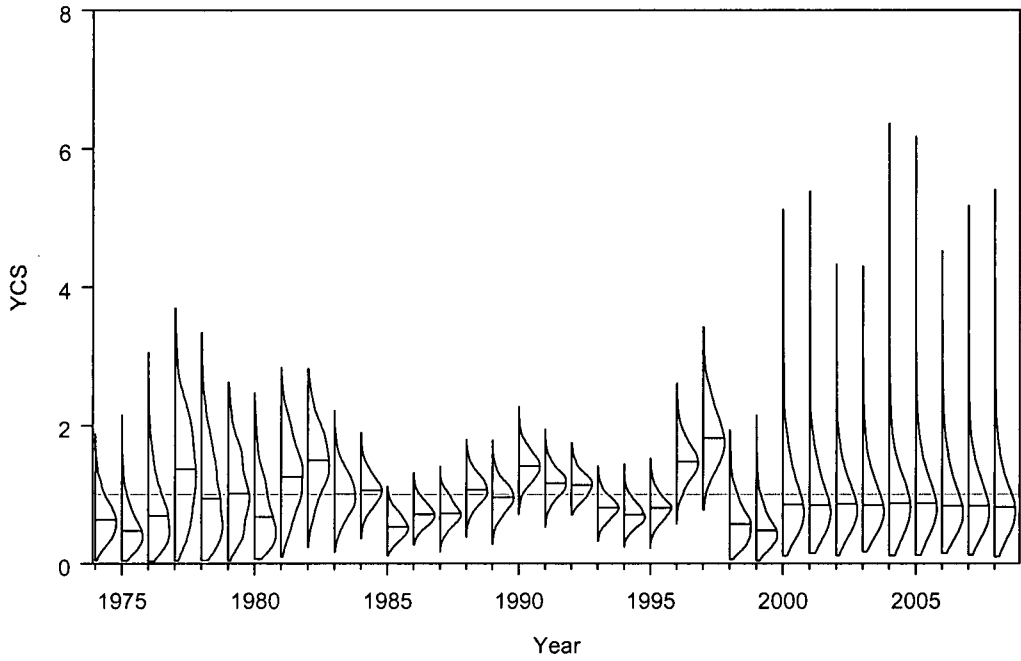


Figure 6: Estimated posterior distributions estimated and projected year class strengths for the initial case. The grey horizontal line indicates the mean year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

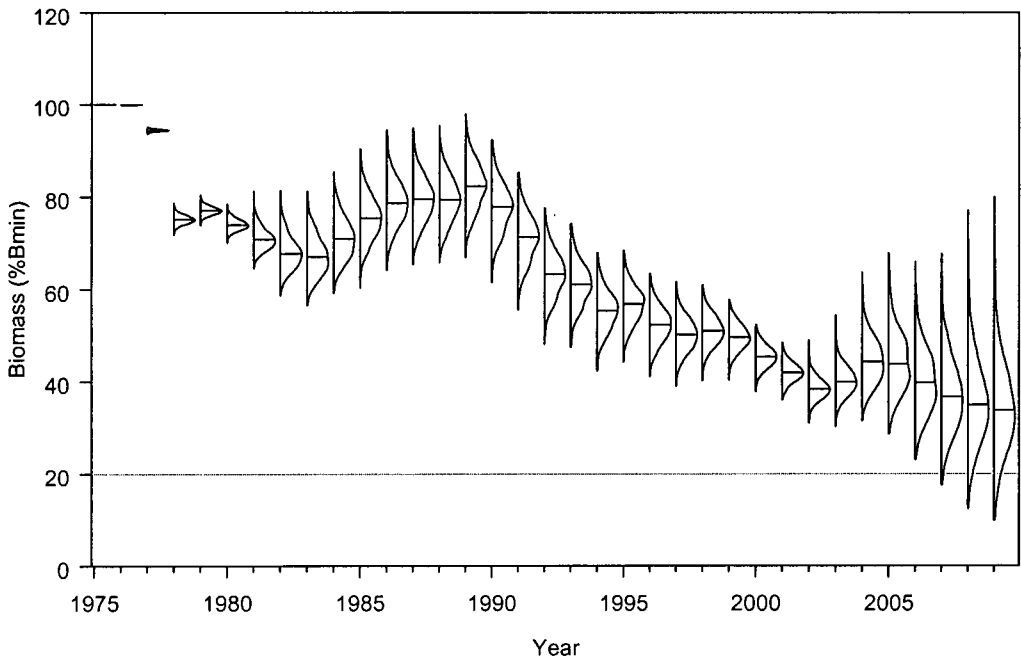


Figure 7: Estimated posterior distributions of minimum biomass trajectories for the initial case ($\%B_{\min}$). Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

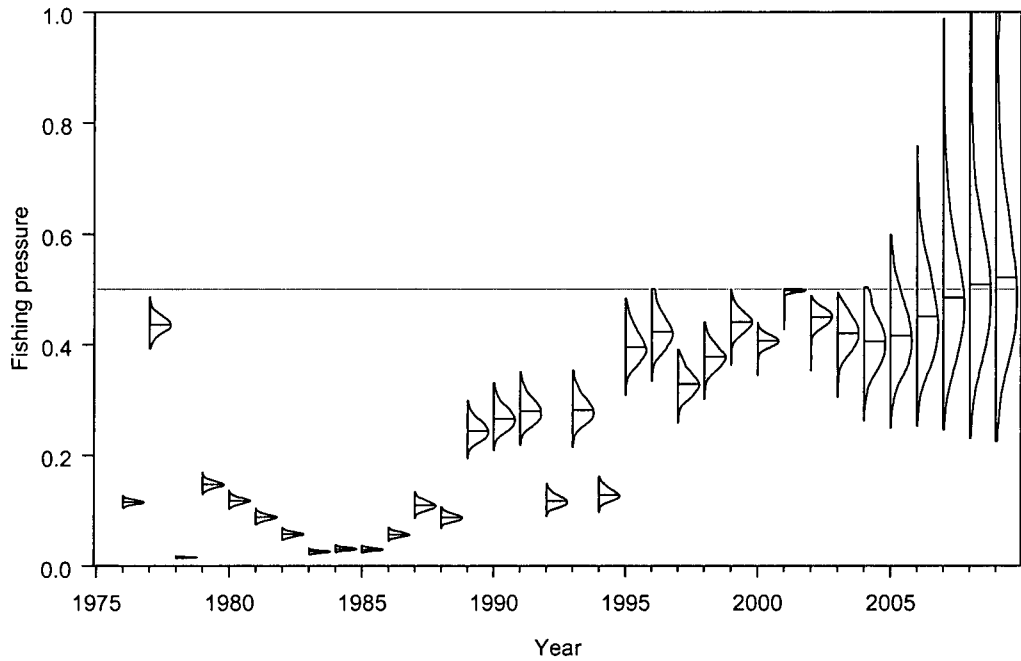


Figure 8: Estimated posterior distributions of minimum biomass exploitation rates for the initial case B_{\min} model. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

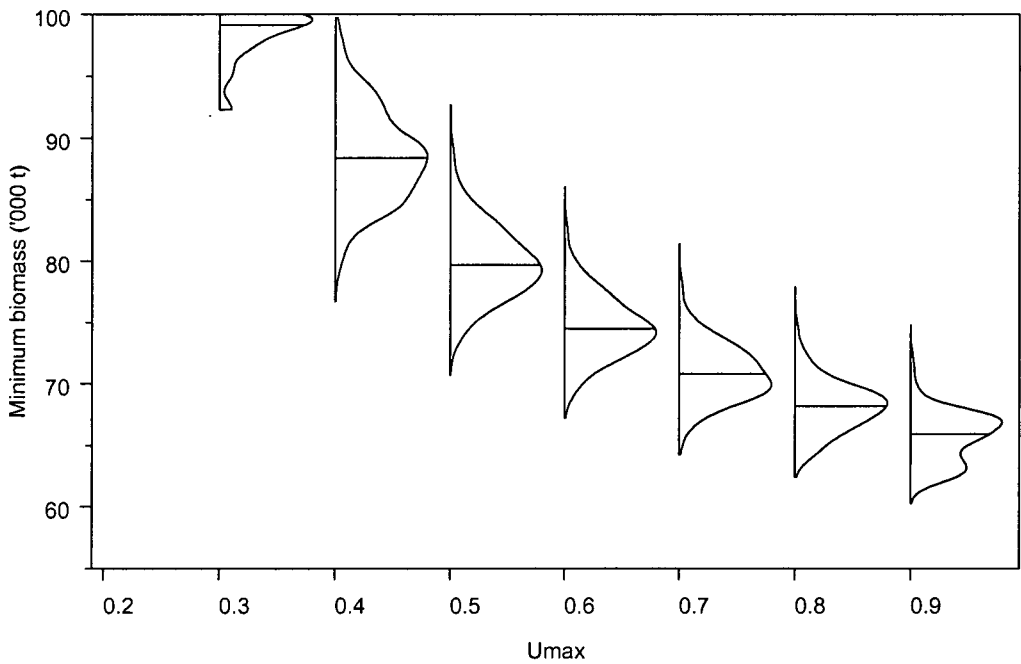


Figure 9: Estimated posterior distributions of minimum biomass for chosen values of the maximum exploitation rates for the initial case. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

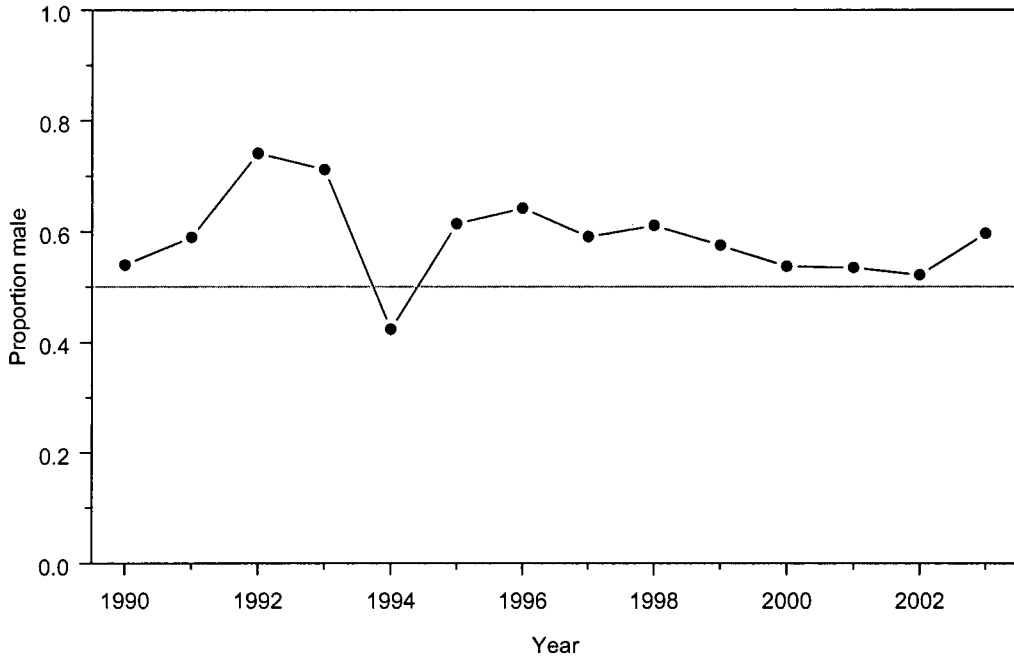


Figure 10: Proportion of fish that were male (by number), as estimated from the catch proportions-at-age data, for the years 1990 to 2003.

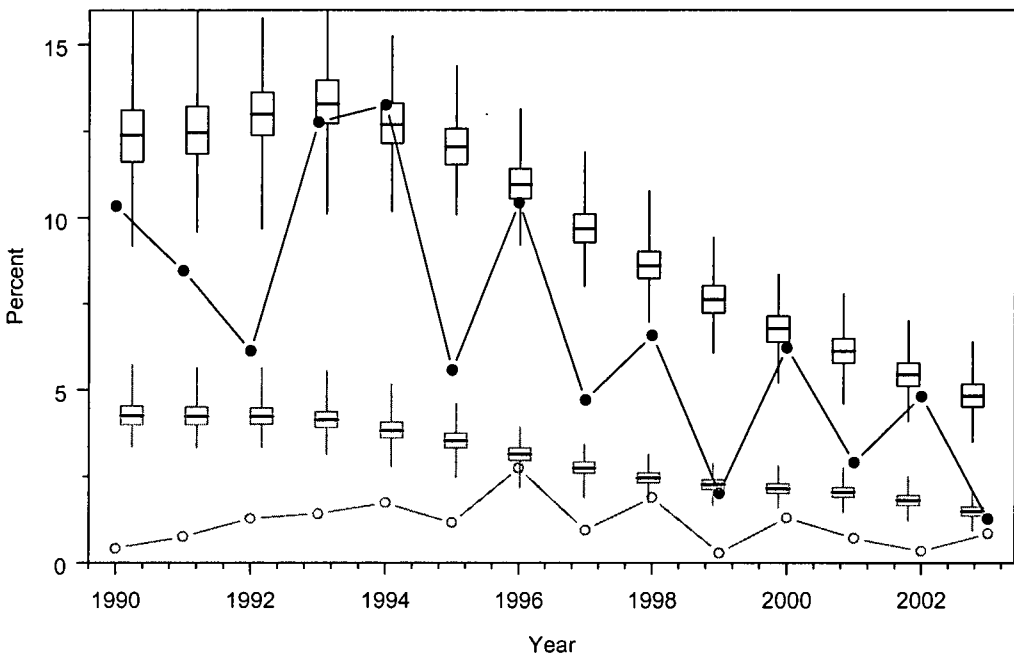


Figure 11: Observed proportion of fish in the catch ≥ 15 years of age (black lines with closed circles) and ≥ 20 years of age (grey lines with open circles), and the distribution of the initial model estimates of the proportion of fish age ≥ 15 (black box plots, showing median, inter-quartile range, and the range) the proportion of fish age ≥ 20 (grey box plots, showing median, inter-quartile range, and the range).

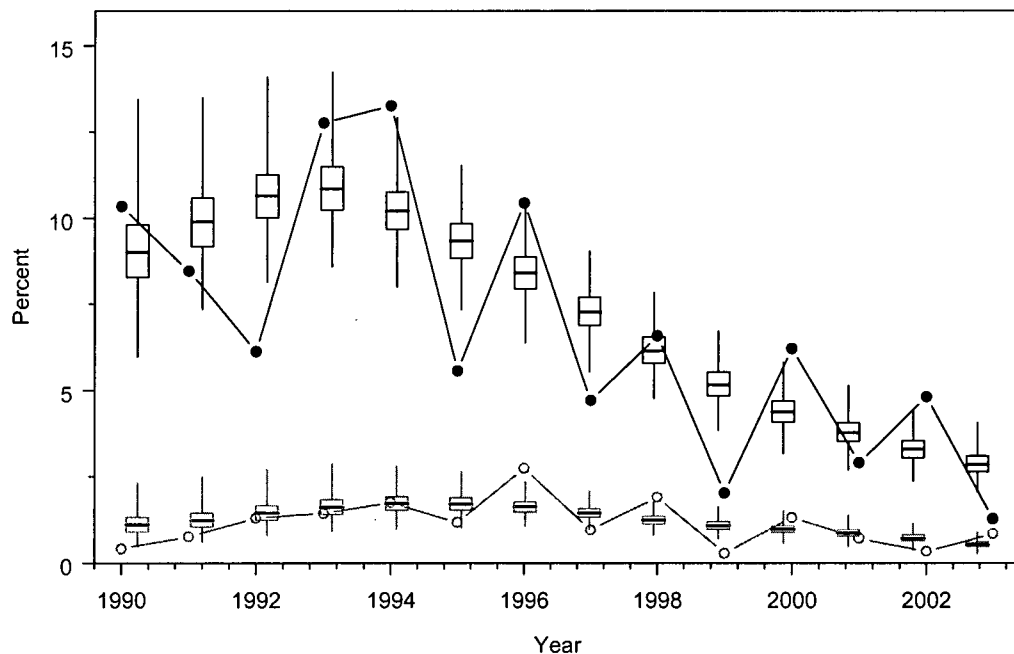


Figure 12: Observed proportion of fish in the catch ≥ 15 years of age (black lines with closed circles) and ≥ 20 years of age (grey lines with open circles), and the distribution of the domed model estimates of the proportion of fish age ≥ 15 (black box plots, showing median, inter-quartile range, and the range) the proportion of fish age ≥ 20 (grey box plots, showing median, inter-quartile range, and the range).

10.2 Chapman-Robson estimates of Z

Chapman-Robson estimates of the total mortality from catch proportions-at-age are shown in Table 12 and Figure 13. Mortality estimates for males and females suggested that the total fishing mortality (F) ranged from about 0.1 y^{-1} in the early 1990s, to about $0.2\text{--}0.3 \text{ y}^{-1}$ in more recent years, i.e., the level of fishing mortality has recently increased significantly. “Initial” model estimates of fishing mortality (although not strictly comparable due to the differing assumptions), are similar to that of the Chapman-Robson (if an appropriate time lag is taken into account in the comparison) (see Figure 13).

10.3 Estimates of sustainable yields

Estimates of sustainable yields were carried out for the initial case model and for the B_{\min} initial case model (i.e., the B_{\min} model assumed that $B_0=B_{\min}$). Yield estimates were based on the 1000 samples from the Bayesian posterior for each stock, with yield estimates based on stochastic simulations run over 100 years. The method used to estimate MAY and CAY was used the simulation method described by Francis (1992), and is such that catch is maximised so that the projected biomass is below $20\% B_0$ exactly 10% of the time. The estimates of B_{MAY} , MAY, and CAY are given in Table 13.

Table 12: Chapman-Robson estimates of Z (y^{-1}) (and hence F , assuming $M = 0.20 y^{-1}$ for males, and $0.18 y^{-1}$ for females) from the commercial catch-at-age composition, with an assumption of full recruitment at age 9.

Year	Z			F		
	Male	Female	Total	Male	Female	Total
1990	0.32	0.29	0.30	0.12	0.11	0.11
1991	0.33	0.35	0.34	0.13	0.17	0.15
1992	0.32	0.41	0.33	0.12	0.23	0.14
1993	0.28	0.31	0.28	0.08	0.13	0.09
1994	0.28	0.24	0.26	0.08	0.06	0.07
1995	0.26	0.33	0.29	0.06	0.15	0.10
1996	0.23	0.32	0.25	0.03	0.14	0.06
1997	0.34	0.34	0.34	0.14	0.16	0.15
1998	0.30	0.34	0.32	0.10	0.16	0.13
1999	0.47	0.49	0.48	0.27	0.31	0.29
2000	0.39	0.40	0.40	0.19	0.22	0.21
2001	0.43	0.41	0.42	0.23	0.23	0.23
2002	0.37	0.38	0.38	0.17	0.20	0.19
2003	0.44	0.48	0.45	0.24	0.30	0.26

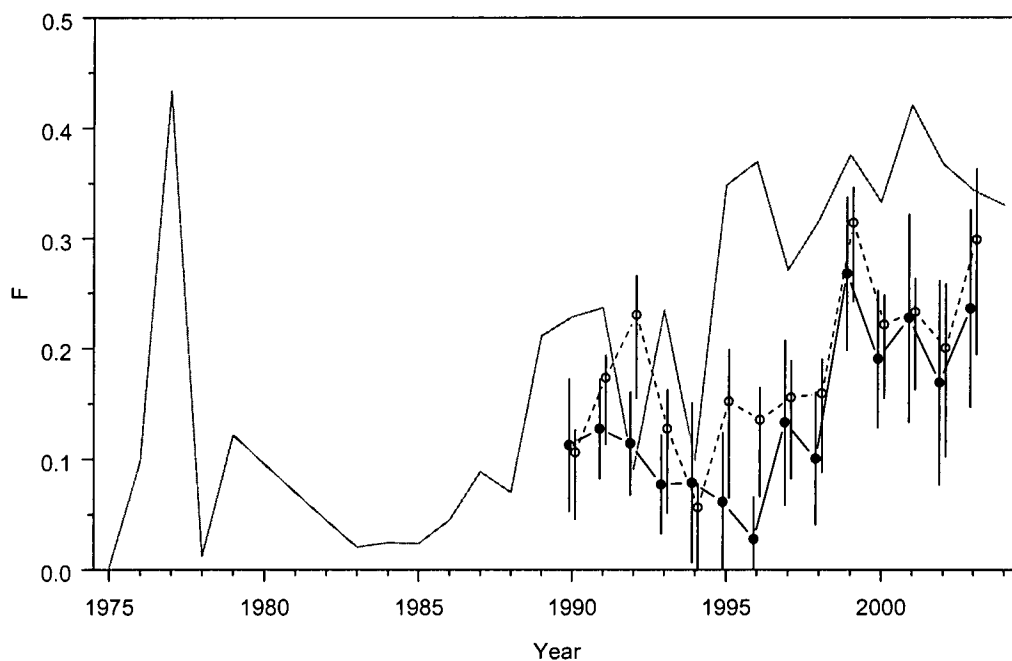


Figure 13: Chapman-Robson estimates of F (assuming $M = 0.20 y^{-1}$ for males and $0.18 y^{-1}$ for females) for (a) males (solid lines and filled circles), and (b) females (dashed lines and open circles), with an assumption of full recruitment at age 9 for age data from 1990 to 2003. Grey lines show the MPD initial model estimated exploitation rate (y^{-1}) for the catch over the beginning of season vulnerable biomass.

Table 13: Yield estimates and associated parameters for the initial model, and the initial B_{\min} model.

Model run	B_{MAY} (t)	MAY (t)	CAY (t)
Initial model	25 320	8 380	16 660
Initial B_{\min} model	21 790	7 230	11 680

11. Discussion

Minimum biomass approaches to the stock assessment of west coast South Island hake appear to provide some useful information on the likely stock status. This analysis suggests that there is some evidence that the current catch (i.e., 7532 t) is unlikely to reduce the population to below 20% B_0 in the short term, if the model assumptions of the maximum exploitation rate are correct. The analyses also suggest that the current catch would likely result in a decrease in population size in the near future, although the current stock size could plausibly be as high as 40–50% B_0 .

The sustainable yield estimates for the initial case suggested that current catches are about the level of the long-term MCY — if the initial model estimates of current stock status were correct. However, if true state were approximated by the initial B_{\min} model, then current catches are above the level of long-term yields (but about the level of the TACC at 6855 t).

However, there were some indications of poor model fits to the catch proportions-at-age data. Model fits to the proportion of fish over 15 years and over 20 years lend some weight to the suggestion that selectivity patterns may be more complex than has been assumed. Modelling alternative selectivity assumptions, including changing patterns of selectivity over time, may provide better fits to the data, and lead to more robust estimates of population size.

In addition, the definition of the maximum exploitation rate introduces some definitional complications, which can lead to problems in the interpretation of these results. In this model, the relative selectivity of female fish, at age, is estimated to be lower than that for males (i.e., about half for ages above 10). Hence, the calculation of the exploitation rate (i.e., the catch divided by the vulnerable biomass), ignores a substantial number of female fish at or above the recruited age. Thus, depending on how the “exploitable” biomass is calculated, very different estimates of the exploitation rate can be calculated for identical population states. The effect of this complication can be seen in Figure 9, where the posterior distribution of minimum biomass for various values of the maximum exploitation rate appear to move towards an asymptote above about 0.6. Here, because female fish are estimated to be less vulnerable than male fish, at age, a significant proportion of the population is always assumed to be invulnerable to exploitation. An alternative approach may be to determine the exploitation rate as the catch over mid-season spawning stock biomass.

Simple catch-curve (Chapman-Robson) analyses suggested that historical level of fishing mortality had been relatively light, at about $F=0.1 \text{ y}^{-1}$, but had increased in recent years to between 0.2–0.3 y^{-1} . Such estimates are not inconsistent with the initial case model (although both methods make similar assumptions about relative vulnerability). While there is a lack of abundance indices (for example resource survey or CPUE indices), a time series of catch proportions-at-age data allow a reasonable estimate to be made of the likely minimum level of current biomass. However, these models do rely on the assumption of the maximum possible exploitation rate and the definition of that rate, within the fishery.

Other available data for the west coast South Island hake fishery include periodic resource surveys on hake and hoki (e.g., *Shinkai Maru* survey in 1976, the *James Cook* surveys in 1978 and 1979, the *Giljanes* survey in 1990, the *Tangaroa* hoki survey in 2000, and the hake acoustic feasibility study in 1999), and the west coast South Island inshore survey (*Kaharoa* surveys on the west coast South Island). CPUE indices for the west coast South Island hake fishery were last estimated by Kendrick (1998), but were not considered to be a reliable index of abundance. Data from these sources may provide additional information to include within the current modelling approach.

It is possible that additional work on CPUE indices may provide a useful index of abundance by, for example, only investigating Ministry of Fisheries observed vessels, focusing on core

vessels, or investigating alternative CPUE modelling methodologies (e.g., Tweedie or mixed effects models), as has been attempted for other hake stocks (Phillips & Livingston 2004), toothfish (Phillips et al. 2004), or hoki (Dunn & Livingston 2004).

Some validation is required of the models presented here. Simulation studies (i.e., operating versus estimation model) of the adequacy of catch-at-age data to model stock status, the accuracy of B_{\min} estimates using the procedure outlined here, and the uncertainty associated with such approaches may provide a more quantitative basis for the interpretation of B_{\min} estimators.

12. Acknowledgments

I thank the many NIWA staff and Ministry of Fisheries scientific observers who were involved in the collection of data at sea. Darren Stevens prepared and aged the otolith samples, and Neville Phillips derived the age frequencies from the Ministry of Fisheries observer data. Dave Gilbert and Chris Francis provided advice on aspects of population models and their implementation in CASAL. I thank Rosie Hurst and Stuart Hanchet for providing a number of helpful comments on the draft manuscript. The project was funded by the Ministry of Fisheries under project code HAK 2003/01.

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Appendix A: Summaries of the proportions-at-age data from resource surveys and fishery observer sampling in the west coast South Island hake fishery.

Table A1: Numbers of measured and aged fish by data source for male and female hake, and the number of sampled tows by age for the west coast South Island.

Source	Males		Females		Tows
	Measured	Aged	Measured	Aged	
WES7904	2 331	289	1 865	206	30
Commercial catch 1989-90	578	210	567	261	57
Commercial catch 1990-91	2 288	286	1 653	358	146
Commercial catch 1991-92	2 592	196	1 193	261	121
Commercial catch 1992-93	2 129	188	979	163	93
Commercial catch 1993-94	1 598	151	1 643	272	174
Commercial catch 1994-95	2 528	271	2 769	342	152
Commercial catch 1995-96	2 862	287	1 753	326	193
Commercial catch 1996-97	3 286	262	1 720	198	234
Commercial catch 1997-98	2 339	257	1 497	253	237
Commercial catch 1998-99	4 186	269	3 744	240	307
Commercial catch 1999-00	2 705	258	2 330	269	285
Commercial catch 2000-01	1 529	176	1 723	280	192
Commercial catch 2001-02	2 281	93	2 434	385	380
Commercial catch 2002-03	1 917	227	2 063	234	296

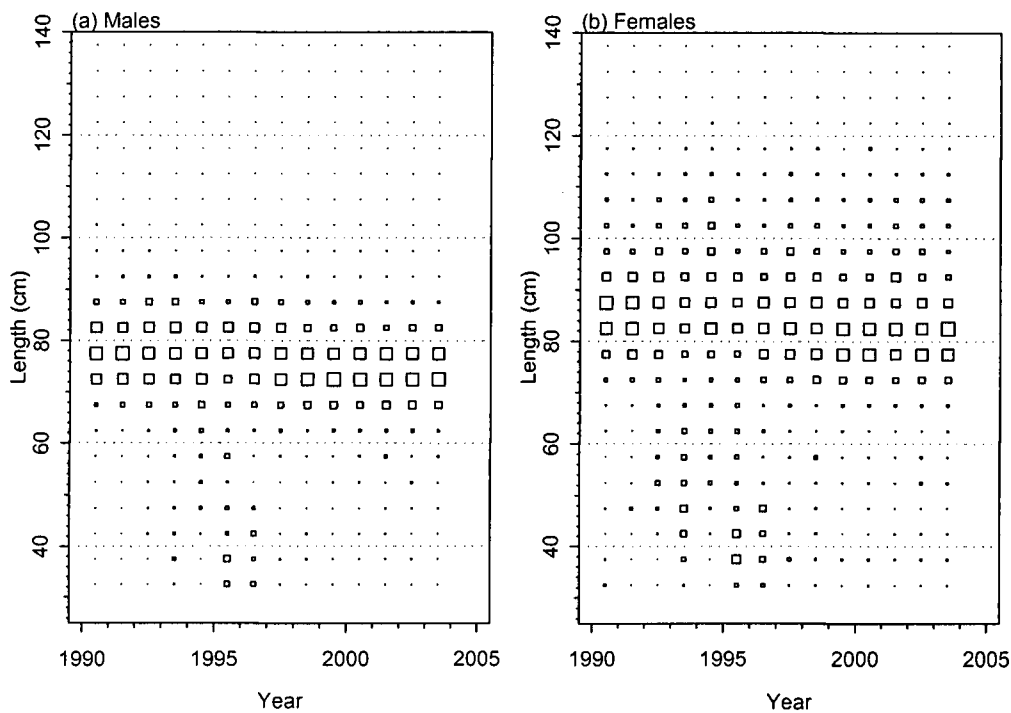


Figure A1: Length frequencies by year (symbol area proportional to the proportions-at-length within sampling event) in the west coast South Island for commercial catch-at-age data. Zero values are represented by a dash.

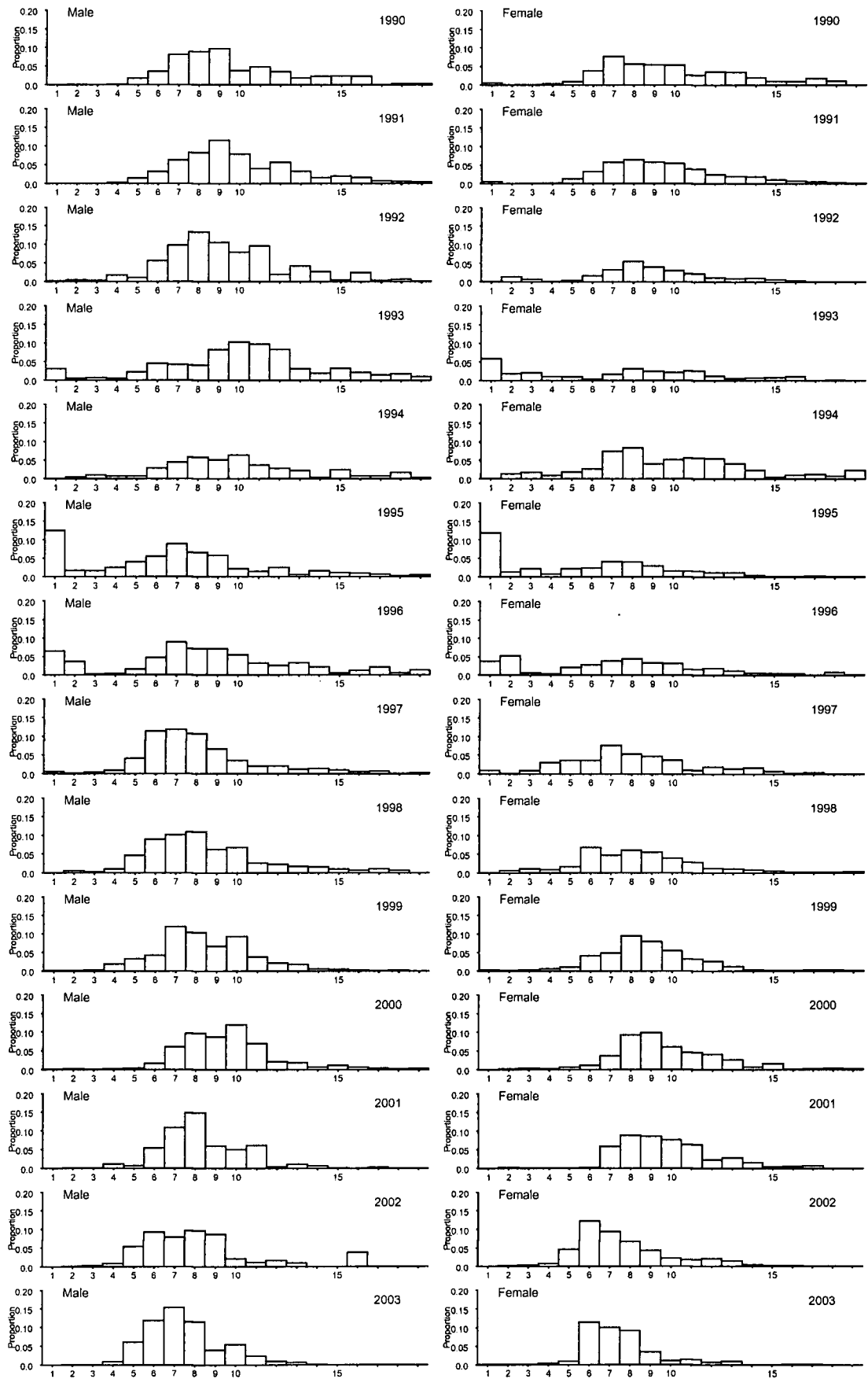


Figure A2: Age frequencies of hake (ages 1 to 19) from commercial catch-at-age data in the west coast South Island trawl fishery, 1989–90 to 2002–03.

Appendix B: Summary of the initial model MPD fits

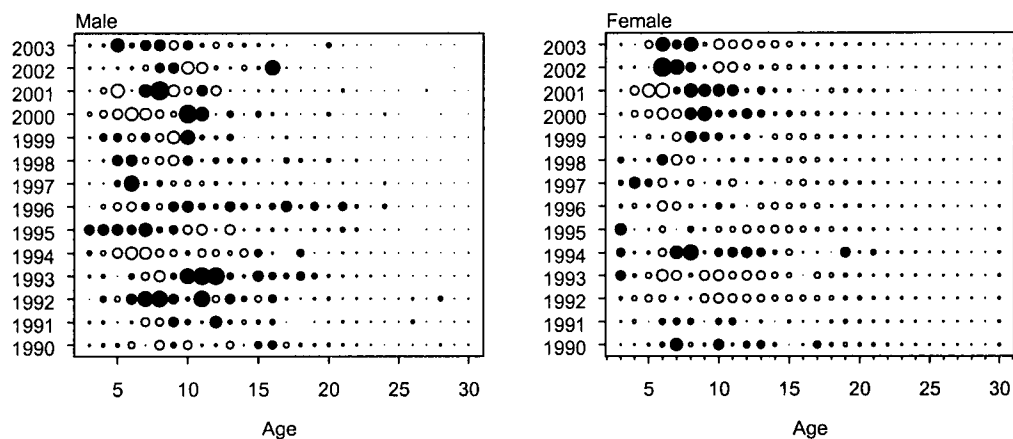


Figure B1: Initial model MPD residual values for the proportions-at-age data for fishery observer sampling series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

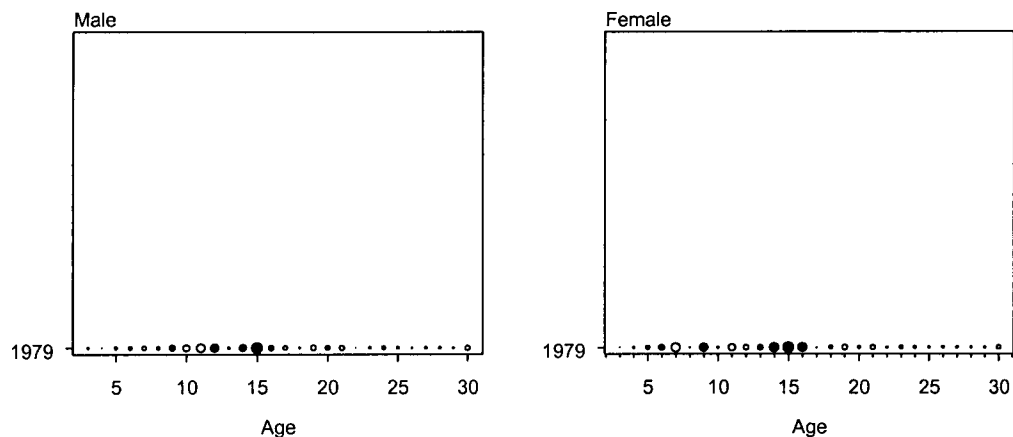


Figure B2: Initial model MPD residual values for the proportions-at-age data for *Wesermünde* resource survey. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

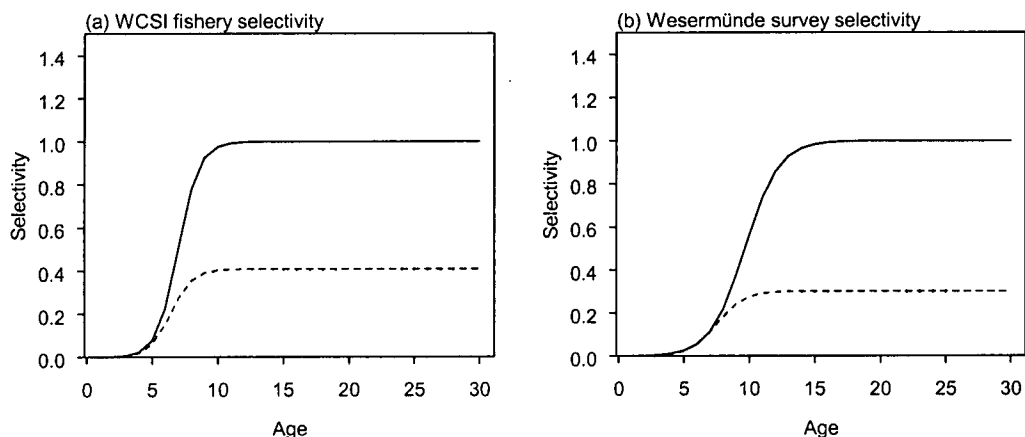


Figure B3: Initial model MPD estimated selectivities for the (a) west coast South Island hake fishery proportions-at-age, and (b) the 1979 *Wesermünde* resource survey proportions-at-age (solid lines for males and dashed lines for females).

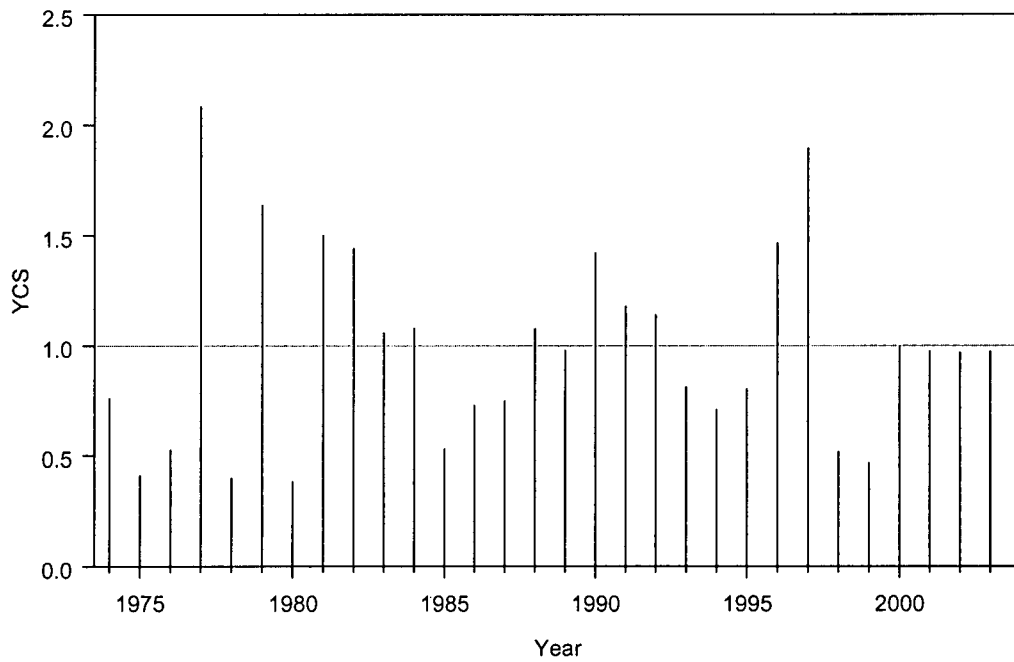


Figure B4: Initial model MPD relative year class strengths for the west coast South Island hake fishery (values after 1999 are fixed).

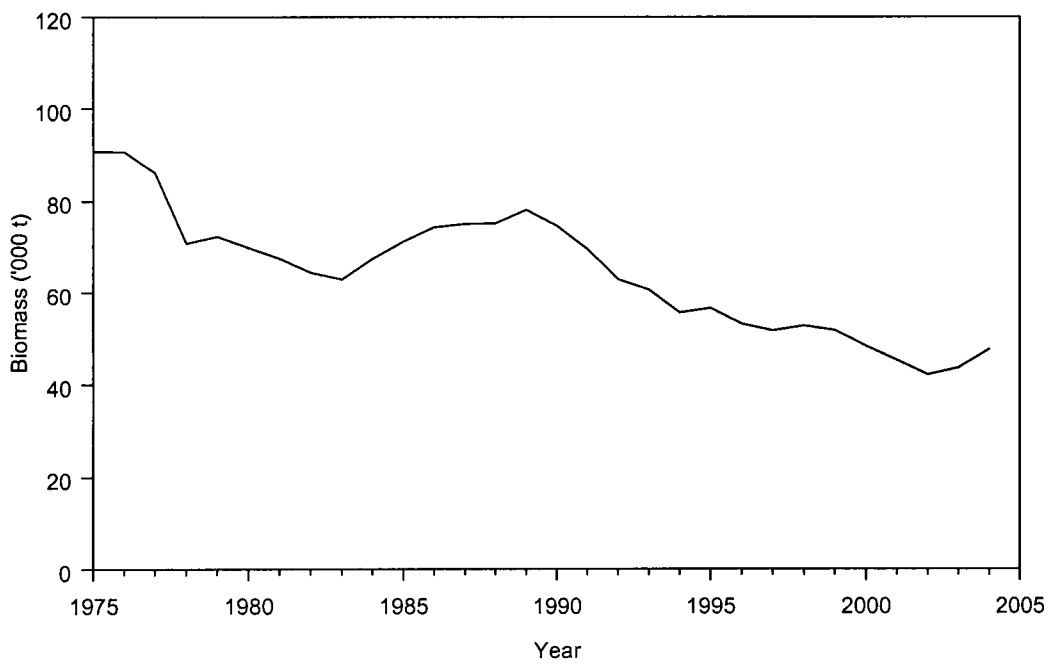


Figure B5: Initial model MPD spawning stock biomass for the west coast South Island hake fishery.

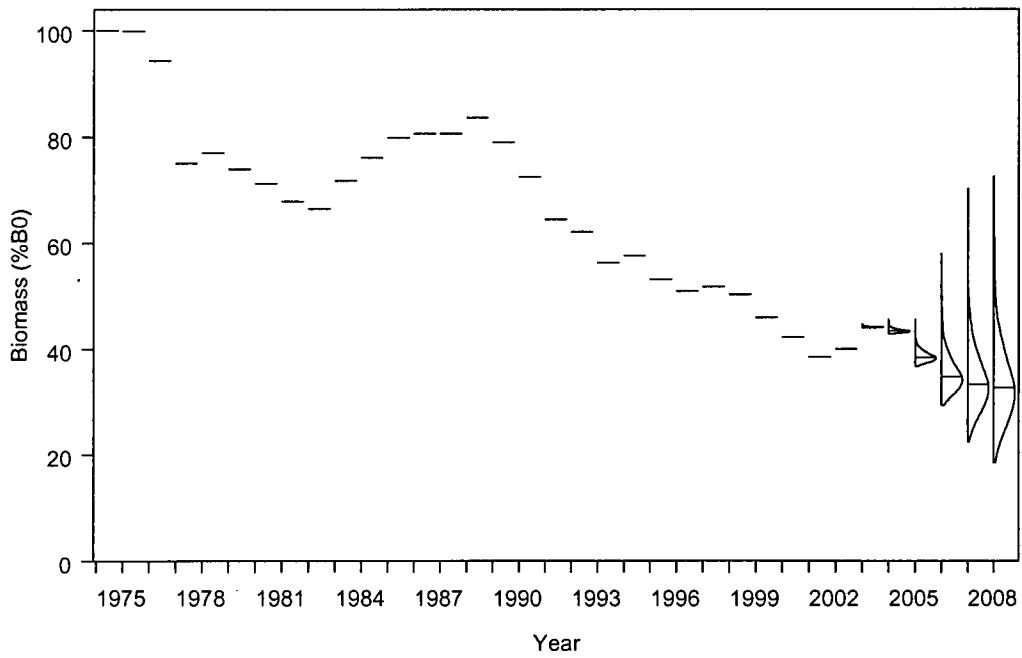


Figure B6: Initial model MPD projected spawning stock biomass ($\%B_{\min}$) for the west coast South Island hake fishery.

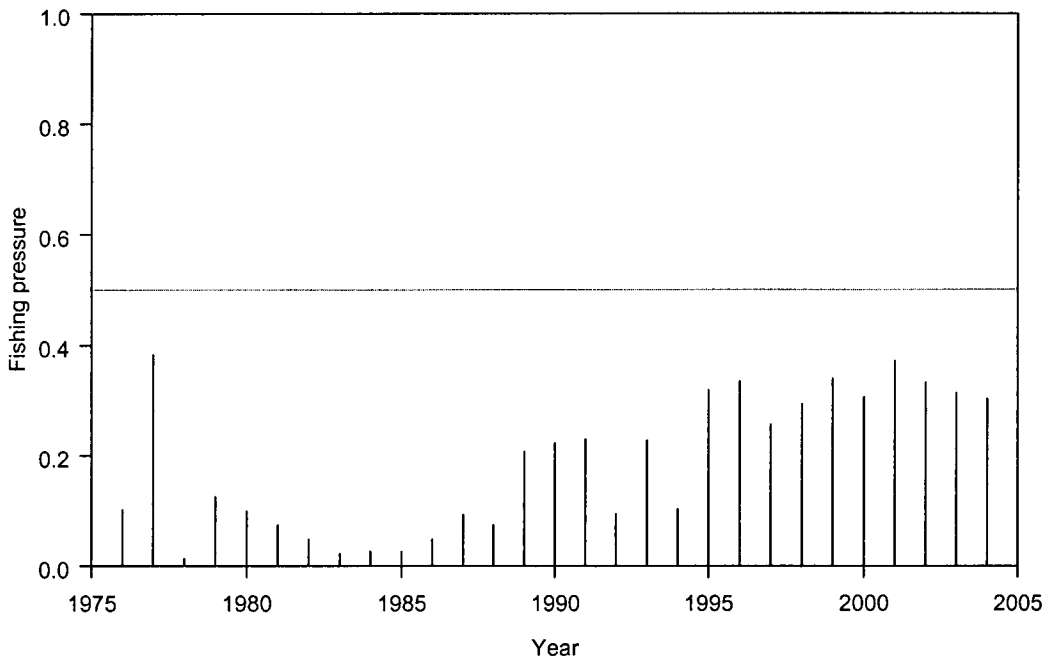


Figure B7: Initial model MPD estimated and projected exploitation rates for the west coast South Island hake fishery.