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A validated ageing method and updated stock assessment for white warehou (*Seriolella caerulea*) in New Zealand waters

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1. EXECUTIVE SUMMARY

White warehou (*Seriolella caerulea*) are seldom a target species, but are generally a bycatch of various target trawl fisheries, primarily those for hoki and silver warehou.

White warehou were aged from counts of zones in sectioned otoliths, a technique which was validated by examining the state of otolith margins from fish sampled regularly throughout the year. Von Bertalanffy parameters are presented for white warehou from the Chatham Rise and the Campbell Plateau, and indicated that there were no significant areal differences in growth. The fish grow rapidly up to the time of first spawning (about 3–4 years), but growth is negligible after about 8 years. A maximum age of 21 years was recorded. Females grow significantly faster than males. Best estimates of M were considered to be 0.25 for males and 0.20 for females.

Catch histories were formulated for three assumed biological stocks of white warehou (i.e., Chatham Rise, Campbell Plateau, and west coast South Island). No suitable series of relative abundance indices are available for any of the stocks. A model incorporating catch history and biological parameters was used to obtain bounds around virgin biomass and current biomass.

Mean landings levels from fishing years 1988–89 to 1997–98 were used to produce estimates of MCY for the three biological stocks.

2. INTRODUCTION

White warehou (*Seriolella caerulea*) are generally taken as bycatch from various target trawl fisheries, primarily those for hoki and silver warehou, but also hake, ling, and scampi. The fishery for this species has been described by Bagley & Hurst (1997).

Few publications have dealt with white warehou in any detail. Gavrilov (1976, 1979) and Gavrilov & Markina (1979) gave detailed accounts of the biology and distribution of this species in New Zealand waters. Bagley & Hurst (1997) synthesised all available biological data on white warehou from published and database sources to produce information on fish distribution, length-weight coefficients, length-at-age, spawning locations, size structure of populations, and length at maturity. Biomass estimates from trawl surveys were summarised, and stock boundaries were proposed. They also compiled catch histories from the early 1970s, and estimated maximum constant yields (MCY) based on an average catch history. However, Bagley & Hurst (1997) noted that the ageing method for white warehou had not been validated, the value of M used in the yield assessments was assumed the same as for silver warehou (*Seriolella punctata*), and that catch histories were uncertain. Subsequently, the estimates of MCY were not accepted by the Middle Depths Fishery Assessment Working Group (Annala *et al.* 1999).

This document presents a validated ageing method, and von Bertalanffy growth parameters, for white warehou. The three biological stocks as proposed by Bagley & Hurst (1997) (Figure 1) were modelled using the least squares, single-stock estimation techniques of Cordue (1995, 1998). Estimates of MCY based on average catch histories were updated.

3. COMMERCIAL FISHERY

3.1 Catch histories

White warehou were a non-QMS species, and therefore not subject to any catch restrictions, before the 1998–99 fishing year. Catch histories from 1970 to 1994–95 (by QMA where possible) were presented by Bagley & Hurst (1997). The accuracy of these data are influenced by two major complications: the reporting of all warehou species (white, silver, and blue) under a single code from 1970 to 1977; the misreporting of other warehou species as white warehou since 1986.

Reported landings of white warehou by QMA and fishing year since 1982–83 are presented in Table 1. Estimated catch histories for the three biological stocks proposed by Bagley & Hurst (1997) (*see* Section 4.2) are listed in Table 2. Landings from 1970 to 1977 were not reported by area, and those from 1970 and 1971 comprise catches by Japanese vessels only. To account for unreported Soviet landings, values for 1970 and 1971 were multiplied by 4. Annual landings from 1970 to 1977 were then allocated to area based on the proportions of reported landings by area over the years 1978 to 1983, i.e., 37% to WWA 1, 58% to WWA 5, and 5% to WWA 7.

White warehou was added to the QMS on 1 October 1998. The TACCs for 1998–99 were as follows: WWA 1 — 4 t, WWA 2 — 73 t, WWA 3 — 399 t, WWA 4 — 220 t, WWA 5 — 2127 t, WWA 6 — 490 t, WWA 7 — 60 t, WWA 8 — 1 t, WWA 9 and WWA 10 — 0 t. An allowance of 2 t was made for non-commercial catch in each of WWA 2–7, and therefore, TACs for these stocks are 2 t higher than the TACCs.

3.2 Illegal catch

When white warehou was a non-QMS species it provided the opportunity for misreporting the QMS species silver warehou. This is known to have been a significant problem, at least in 1988 (Bagley & Hurst 1997). Thus, reported landings since the inception of TACCs in 1986–87 may well be inflated. However, the true extent of misreporting is unknown, so the accuracy of the annual catch records cannot be determined.

3.3 Other sources of mortality

There is likely to be some mortality associated with escapement from trawl nets, but the level of this is not known. Small amounts of white warehou may also have been caught and discarded when the quantities were too small to process.

There are no known recreational or Maori customary fisheries for white warehou.

4. BIOLOGY

4.1 Stock assumptions

There is evidence for at least three spawning areas for white warehou in late winter to early spring (i.e., around the Mernoo Bank on the Chatham Rise, off the west coast of the South Island, and off Southland). These data led Bagley & Hurst (1997) to suggest the possibility of three separate biological stocks which could be divided into the following fishstock areas (*see* Figure 1): QMAs 1, 2, 3, 4, and 10 (WWA 1); QMAs 5 and 6 (WWA 5); and QMAs 7, 8, and 9 (WWA 7). This stock hypothesis is used in the current assessment.

4.2 Age validation and growth

4.2.1 Methods

Length frequency distributions from trawl surveys of the Chatham Rise, Campbell Plateau, and the Stewart-Snares shelf were created, following scaling by percentage sampled and area trawled, to represent the population of white warehou in the survey area available to the trawl. The distributions were examined for consistency of modal lengths in surveys conducted at the same time of the year, and for the progression of modes in survey series conducted at different times of the year. The progression of modes between years was also looked for.

Otoliths (sagittae) of white warehou have been collected sporadically from research and commercial landings since about 1992. Fork length (FL, rounded to the nearest centimetre below actual length) and sex were recorded for all fish from which otoliths were taken.

Otoliths for a validation study such as this would ideally be collected regularly over a 12-month period from fish known to make up a single stock. This was not possible for white warehou because of the sporadic nature of the otolith collection. Hence, otolith samples were compiled for each month from archived material collected from 1992 to 1998 (Table 3). Wherever possible, otoliths were selected to obtain at least 35 per month from a wide size range of fish. Otoliths from the three postulated stocks had to be used to make up the collection.

All selected otoliths were examined in cross-section following preparation by baking whole otoliths in an oven until amber coloured, embedding them in clear epoxy resin (Araldite K142), and cutting the otolith along the dorso-ventral axis through the nucleus using a rotary diamond edged saw. The prepared otolith cross-section was coated in paraffin oil, illuminated by reflected light with an incident angle of about 30°, and examined under a binocular microscope (x40). A pattern of dark brown (translucent) and light brown (opaque) zones was apparent. Subsequently in this paper, 'zone' refers to the paired structure of one opaque band inside one translucent band. The number of complete zones (i.e., zones with at least some opaque material outside them) was counted. Fish length and sex were unknown to the otolith reader.

To convert zone counts to estimates of age, it was necessary to validate the ageing method by determining when and how frequently the zones were laid down. To examine changes in otolith margin characteristics throughout the year, margins of otoliths from the validation samples in

Table 3 were classified as either translucent or opaque, and the number of complete zones was counted. Less than 2% of otoliths examined had a marginal state too indistinct to classify confidently, and all of these were from fish older than 10 years. The month of collection was unknown to the otolith reader.

Age-frequency distributions from two pairs of comparable trawl survey samples (Chatham Rise January 1997 and 1998), and Stewart-Snares shelf February–March 1993 and 1996) were examined to see whether the progression of any strong or weak year classes supported the ageing data derived from otoliths.

Von Bertalanffy growth curves were fitted to the age-length data from the Chatham Rise, and from the Campbell Plateau (including the Stewart-Snares shelf) using a non-linear least-squares regression procedure (SAS Institute 1988). Separate equations were derived for each sex.

The rate of instantaneous natural mortality (M) was estimated for white warehou using the equation $M = -\log_e(p)/A$ where p is the proportion of the population that reaches A or older (Hoenig 1983). Values of p of 0.01 and 0.05 are used here; in an unexploited stock, a p of 0.01 is usually used. Estimates of M were also derived from the largest available trawl survey sample (Chatham Rise, January 1998) using two methods: (a) that of Chapman & Robson (1960) where $M = \log_e[(1+a)/a]$ where a is the mean age of fish above recruitment age, and (b) the slope of the right hand limb of the catch curve using the regression model defined as R1 by Dunn *et al.* (1999).

4.2.2 Results

Length frequency distributions

Distributions of white warehou from surveys of the Chatham Rise conducted each January from 1992 to 1999 are shown in Figure 2. Modes occur at consistent positions in virtually all the distributions (i.e., 18–21, 30–32, 36–39, and 41–44 cm), so it is likely that the modes represent consecutive year classes. Distributions from three other surveys of the Chatham Rise conducted at different times of the year (Figure 3) show the smallest mode to progress from 21 cm in March to 27 cm in November. The growth of juvenile white warehou based on modal lengths is given in Table 4, after allocating a birthday of 1 August (from spawning season data in Bagley & Hurst 1997), and assuming that the size of this species at age 1 year is comparable to that of silver warehou (Horn & Sutton 1996).

Differences in year class strengths of juveniles are apparent within and between distributions from the Chatham Rise (Figures 2 and 3). However, there are no clear progressions of any particularly strong or weak year classes. For example, the strong 1+ and 2+ year classes in 1997 are not apparent in either the 1996 or 1998 distributions. Also, the smaller 1+ and larger 2+ modes in 1992 are followed by smaller 2+ and larger 3+ modes in 1993.

Length frequency distributions of white warehou from surveys of the Campbell Plateau and Stewart-Snares shelf were presented by Bagley & Hurst (1997), but were often based on small samples (i.e., less than 50 fish), resulting in poorly defined modes. Distributions with relatively clear modes of juvenile fish are plotted in Figure 4, and the estimated growth of the fish based on these modes is given in Table 4. The estimated growth data for this area are considered to be less reliable than that from the Chatham Rise because of the generally smaller sample sizes, and the lower number of surveys. However, the estimated growth rates from the two areas are quite similar.

Otolith interpretation

Otoliths of white warehou were found to be less clear than those from silver warehou or blue warehou. However, the interpretation of the zones was still relatively straightforward. Split zones were sometimes apparent, but they could generally be identified because of the regularly decreasing distances between true zones with increasing age. Some otoliths exhibited a clear double banding pattern (commonly adjacent to the sulcus) in older zones, but again the true interpretation was usually clear because of the regular overall zonation pattern. Both the split zones and the double banding pattern are characteristics that have been described previously from otoliths of silver warehou (Horn & Sutton 1996) and blue warehou (Bagley *et al.* 1998).

Marginal state

It was generally possible to determine whether an otolith margin was translucent or opaque, although some interpretations for older fish were difficult or impossible because of the narrowness of the margin or the indistinctness of the zonation pattern. Percentages of otoliths with translucent margins are shown in Figure 5. It is apparent that translucent material is initially laid down about April–May, that most otoliths have a translucent margin in late winter, and that most fish are laying down opaque material by November. These data support the hypothesis that one opaque and one translucent band (i.e., one complete zone) are laid down annually in the otoliths of white warehou.

White warehou probably spawn in New Zealand waters from about August to October (Bagley & Hurst 1997), so a 'birthday' of 1 August was chosen. As the translucent part of a zone appears to be complete by late spring (October–November), fish are about 1 year old on completion of the first translucent band. Hence, the number of complete zones, plus a correction for the time elapsed between 1 August and the date of sampling, was taken as the age of the fish.

Progression of year classes

Estimated proportion-at-age distributions from two pairs of comparable trawl surveys are presented in Figure 6. On the Stewart-Snares shelf, both distributions suggest that the 1986 and 1992 year classes (age classes 5 and 0 in 1993) were relatively strong, and the 1989 year class (age 3 in 1993) was relatively weak. No clear progressions of any age class are apparent in the Chatham Rise samples, although it is tentatively suggested that the 1992 year class (aged 4 in 1997 and 5 in 1998) is slightly stronger than average.

Growth parameters

Von Bertalanffy growth curve parameters (with asymptotic 95% confidence intervals) calculated from the otolith readings of fish from the Chatham Rise, and the Campbell Plateau area, separately by sex, are given in Table 5. Time of sampling, and hence, part-year growth, is incorporated in this analysis. These samples probably comprise data from the full life span of the species, i.e., 0 to 21 years. Comparisons of the von Bertalanffy parameters between areas, by sex, showed no significant differences, so single growth curves for each sex were calculated from all the data from the Chatham Rise and the Campbell Plateau combined (Table 5).

The calculated curves and raw data (corrected for part-year growth) are plotted in Figure 7. The curves fit the observed data reasonably well, although it is noted that most of the observed data points for fish aged older than 13 years are above the curve. Female white warehou grow significantly faster and reach a larger size than males. Male white warehou had a maximum age of 18 years, and females were aged to 21 years. Females may have a greater longevity than males; in all samples combined, proportions of fish aged 14 years or older were 3.2% and 6.3% for males and females respectively. The minimum age reached by the oldest 1% of the sampled fish was 15 years for males and 17 years for females.

4.2.3 Discussion of ageing data

The survey sampling technique (bottom trawl) is unlikely to comprehensively sample the whole white warehou population in the survey area because of the patchy distribution of the species, their semi-pelagic habitat, and the tendency of similar sized fish to school together.

Baked, sectioned otoliths of white warehou exhibit a pattern of zones each comprising one opaque and one translucent band, and the fish were aged from counts of the number of complete zones. Validation of this ageing method was achieved in general by showing that, for all fish combined, one translucent band was formed annually. It was not possible to validate the method for every year class individually because of insufficient sample sizes. It was also unfortunate that samples from different years had to be combined to complete this study as different climatic conditions between years could influence the time of formation of the otolith growth zones. The samples probably also comprise fish from different biological stocks if the current stock hypothesis is correct. Thus, it is pleasing that despite these possible complications, the annual cycle of change at the otolith margin is clear.

Like many teleosts, female white warehou are larger than males at corresponding ages after sexual maturity, and they have a significantly larger L_∞ value. Fish of both sexes have a relatively fast growth rate up to the time of first spawning (4–5 years). Growth then slows and is negligible after about 10 years. Similar growth characteristics have been shown for silver warehou (Horn & Sutton 1996) and blue warehou (Bagley *et al.* 1988).

A previous study of white warehou also indicated that the species was relatively fast growing, but had a maximum age of 12 years (Gavrilov 1976). However, the current study showed many fish aged older than 12 years, up to a maximum of 22 years. Differences in the ageing methods between studies are the most likely cause of the different estimates of maximum age. Gavrilov examined scales (and possibly whole otoliths), and it is likely that narrow zones on the margins of this material would be very difficult to distinguish. The problem of underestimating true age when counting zones on whole otoliths was demonstrated for silver warehou by Horn & Sutton (1996).

The sampled fish comprise a wide range of ages (0–21 years) and so the fitted von Bertalanffy parameters are considered to be reasonable descriptors of growth for this species.

4.3 Biological parameters

Estimates of instantaneous natural mortality (M) derived for white warehou are presented in Table 6. The Chapman-Robson and R1 regression estimates (where data from both sexes were combined), and the Hoenig estimates using $p = 0.01$ (with separate estimates for each sex), all fall in a relatively narrow range (0.26–0.31). However, none of these estimates account for the samples being taken from exploited populations (where total mortality will comprise a component attributable to fishing), so these values are probably overestimates of *M*. The Hoenig estimates using $p = 0.05$ produce lower estimates of *M*. For many marine teleosts, there is a trend for females to grow bigger, live slightly longer, and, hence, have lower vales of *M* than males of the same species (Pauly 1980). White warehou appear to be in this category. Based on the conclusions of Dunn *et al.* (1999), the most reliable estimates of total mortality are probably those derived using the Chapman-Robson and R1 regression methods. Consequently, some reduction of these values to allow for fishing mortality is required. Hence, it is suggested that point estimates of *M* for white warehou be set at 0.25 and 0.20 for males and females, respectively, and that a suitable sensitivity range for these values would be ± 0.05.

The Middle Depth Species Fisheries Assessment Working Group concluded that the available data were not strong enough to establish a sexual difference in *M*. It was requested that modelling be conducted using a value of 0.25 for both sexes, with sensitivity tests of ± 0.05.

Length-weight coefficients were presented by Bagley & Hurst (1997). However, the parameters for WWA 1 and WWA 5 are re-calculated here as a considerable quantity of additional data from recent trawl surveys is available (Table 7). No data are available to calculate length-weight coefficients for white warehou off the west coast of the South Island (WWA 7), so the relationship for those fish is assumed to equal the "All fish" relationship from WWA 1.

Lengths at onset of maturity, 50% maturity, and 100% maturity are estimated to be 35, 40, and 45 cm, respectively, for both sexes (from Bagley & Hurst 1997). Using these lengths and the calculated von Bertalanffy growth equations, it is deduced that both sexes start to mature at age 2, are 50% mature at age 3–4, and fully mature by age 6. A maturity ogive was derived on this basis (Table 8).

5. STOCK ASSESSMENT

5.1 Model inputs

The three proposed biological stocks of white warehou were modelled using the least squares, single-stock estimation techniques of Cordue (1995, 1998). Although the single stock model has the facility to allow the specification of spawning and non-spawning components of catch, all white warehou stocks were modelled assuming a spawning season of zero length, with all catch taken from the home ground. The model year was set to begin at 1 October. Catch data were available for each year from 1970, with zero landings assumed for all previous years. Catch histories are presented in Table 2.

The only relative abundance indices available are those from various trawl survey series of the Chatham Rise and Campbell Plateau areas (Table 9). Bagley & Hurst (1997) considered that none of these data (up to 1996) were useful as series of relative abundance indices because of the generally clumped distribution of the species and the relatively low density of stations in the wide area surveys. Consequently, biomass estimates tended to vary greatly and often have high *c.v.s*. Results from surveys subsequent to 1996 (three on the Chatham Rise and one on the Campbell Plateau) exhibit a continuation of this trend, so the data are still not considered to be useful as relative abundance indices.

Estimates of biological parameters and of model parameters used in the assessments are given in Tables 7 and 8 respectively. A steepness parameter (from the Beverton and Holt stock-recruitment relationship) of 0.9 was assumed, and a sensitivity test using 0.75 was run. The proportion spawning is assumed to be 0.9 in the absence of data. Sensitivity tests using the point estimate of $M \pm 0.05$ were conducted. Based on observer length-frequency data indicating that white warehou recruit to the fishery between lengths of about 20 and 40 cm, the ogive for home ground selectivity was assumed to be the same as the maturity ogive.

The maximum exploitation rate (r_{max}) in any year for all stocks was taken as 0.5, with 0.3 tested in sensitivity runs. The value of r_{max} determines B_{min}, the lowest value of B_0 that is consistent with the catch history.

The minimum exploitation rate (r_{mmx}) is the lowest value that the exploitation rate could have been in the year that the exploitation was highest. A value of 0.03 was used in the base case for all stocks, with sensitivity runs using 0.01. Assumptions about r_{mmx} determine the value of B_{max}, the highest level that is believed to be feasible for B_0. The values of B_{min} and B_{max} are used as bounds for estimates of B_0.

7.2 Biomass estimation

Bounds around the mid-spawning season virgin biomass (B_0) and mid-spawning season mature biomass for 1999–2000 (B_{mid00}) were obtained for the three stocks (Table 10). Biomass trajectories for the three stocks are shown in Figure 8.

Estimates of B_0 were found to be relatively insensitive to the tested changes in *M*, steepness, and r_{max}, but, as expected, the tested reduction in r_{mmx} markedly increased B_{max}. The bounds around B_{mid00} were most sensitive to changes in r_{max} and r_{mmx}, and relatively insensitive to changes in the other parameters.

7.3 Estimation of Maximum Constant Yield (MCY)

The only method appropriate for estimation of MCY was MCY = $c.Y_{av}$, where $c = 0.8$ (based on an *M* in the range 0.16 to 0.25) and Y_{av} is the average catch over an appropriate period (method 4 of Annala *et al.* 1999). The range of years chosen for the catch history should ideally represent a period of stable effort, but this is not feasible as white warehou is primarily a bycatch of fisheries for other species such as hoki, hake, and silver warehou. Therefore, the fishing years 1988–89 to 1997–98 were chosen, as they represent a relatively stable period of management for these other target fisheries. Problems associated with these years include some likely misreporting of silver warehou as white warehou in the 1980s, and more target fishing on hoki outside the spawning season in the 1990s. Estimates of MCY are given in Table 11. The mean landings levels do at least give indications of yields which appear to have been sustained over a relatively long time. CAY was not estimated because no biomass estimates are available.

7.4 Management implications

Target fishing for this species is minimal in all stock areas, generally constituting less than 10% of annual landings.

It is not known whether any of the stocks are likely to be below levels that would support the MSY. The likely effects on the stocks of current catch levels are also unknown. However, the wide bounds around the estimates, and subsequent high levels of uncertainty about the assessment, have been stressed above.

8. ACKNOWLEDGMENTS

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9. REFERENCES

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

Bagley, N.W. & Hurst, R.J. 1997: A summary of biology and commercial landings, and a stock assessment of white warehou, *Seriolella caerulea* Guichenot, 1848 (Stromateoidei: Centrolophidae) in New Zealand waters. *N.Z. Fisheries Assessment Research Document 97/13.* 34 p.

Bagley, N.W., Ballara, S.L., Horn, P.L., & Hurst, R.J. 1998: A summary of commercial landings and a validated ageing method for blue warehou, *Seriolella brama* (Centrolophidae), in New Zealand waters, and a stock assessment of the Southern (WAR 3) Fishstock. *N.Z. Fisheries Assessment Research Document 98/20.* 46 p.

Chapman, D.G. & Robson, D.S. 1960: The analysis of a catch curve. *Biometrics 16*: 354–368.

Cordue, P.L. 1995: MIAEL estimation of biomass and fishery indicators for the 1995 assessment of hoki stocks. *N.Z. Fisheries Assessment Research Document 95/13.* 38 p.

Cordue, P.L. 1998: An evaluation of alternative stock reduction estimators of year class strength and an assessment of the frequency of Chatham Rise trawl surveys of juvenile hoki required for stock assessment. *N.Z. Fisheries Assessment Research Document 98/12.* 44 p.

Dunn, A., Francis, R.I.C.C., & Doonan, I.J. 1999: The sensitivity of some catch curve estimators of mortality to stochastic noise, error, and selectivity. *N.Z. Fisheries Assessment Research Document 99/5.* 23 p.

Gavrilov, G.M. 1976: Age and growth in the white (*Seriolella tinro* Gavrilov) and the common warehou (*Seriolella brama*) of the New Zealand Plateau. *Issledovanya po Biologii Ryb I Promyslovoi Okeanografii* [*Studies in Fish Biology and Fisheries Oceanography*] 1976: 52–57. (In Russian.)

Gavrilov, G.M. 1979: *Seriolella* of the New Zealand plateau. Report of the Pacific Ocean Scientific Research Institute of Fisheries and Oceanography (TINRO). [In Russian. English translation held in NIWA library, Wellington.]

Gavrilov, G.M. & Markina, N.P. 1979: The feeding ecology of fishes of the genus *Seriolella* (fam. Nomeidae) on the New Zealand plateau. *Journal of Ichthyology 19(6)*: 128–135.

Hoenig, J.M. 1983: Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin 82*: 898–902.

Horn, P.L. & Sutton, C.P. 1996: Validated ages, growth, and productivity parameters for silver warehou (*Seriolella punctata*) off the south and east coasts of South Island, New Zealand. *N.Z. Journal of Marine and Freshwater Research 30*: 301–312.

Pauly, D. 1980: On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *Journal du Conseil International pour l'Exploration de la Mer 39*: 175–192.

SAS Institute 1988: SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc., Cary, NC. 1028 p.

Table 1: Reported landings (t) of white warehou by QMA and fishing year, from 1982–83 to 1997–98. There are no landings reported from QMAs 9 and 10. Total includes landings from outside the EEZ and where no QMA was reported

Year	QMA								Total
	1	2	3	4	5	6	7	8	
1982–83	0	35	179	69	248	7	24	<1	562
1983–84	0	28	111	33	282	24	29	<1	510
1984–85	0	2	123	39	150	12	15	<1	342
1985–86	0	5	589	61	277	43	81	<1	1 058
1986–87	0	10	239	29	167	114	15	<1	573
1987–88	<1	9	431	26	113	20	28	<1	629
1988–89	6	1	118	43	843	16	10	0	1 040
1989–90	1	9	484	16	555	291	83	0	1 438
1990–91	2	11	696	80	630	390	74	1	1 884
1991–92	6	22	597	117	978	1 571	52	0	3 342
1992–93	2	13	281	106	560	645	125	2	1 733
1993–94	6	34	197	23	1 235	592	69	0	2 164
1994–95	4	41	327	243	1 936	185	80	0	2 817
1995–96	1	73	377	142	1 584	51	67	<1	2 295
1996–97	3	88	467	218	2 186	484	57	<1	3 522
1997–98	2	31	516	153	1 217	126	98	<1	2 155

Table 2: Estimated catch histories (t) of white warehou from 1970 to 2000, for the three postulated biological stocks: WWA 1 (QMAs 1–4, and 10), WWA 5 (QMAs 5 and 6), and WWA 7 (QMAs 7–9). Data sources: 1970 to 1983 from MAF; 1984 to 1986 from FSU; 1987 to 1998 from QMS; 1999 and 2000 set at about the mean of 1996–98 levels

Year	WWA 1	WWA 5	WWA 7	Year	WWA 1	WWA 5	WWA 7
1970	25	40	3	1990	510	846	83
1971	37	58	5	1991	789	1 020	75
1972	563	883	76	1992	742	2 549	52
1973	609	955	82	1993	402	1 205	127
1974	634	994	86	1994	260	1 827	69
1975	552	866	75	1995	615	2 121	80
1976	739	1 159	100	1996	593	1 635	67
1977	738	1 157	100	1997	776	2 670	57
1978	32	258	26	1998	702	1 343	98
1979	245	508	42	1999	700	1 900	80
1980	170	470	30	2000	700	1 900	80
1981	96	435	11				
1982	464	385	33				
1983	283	255	24				
1984	172	306	30				
1985	164	162	16				
1986	655	320	81				
1987	278	281	16				
1988	467	133	28				
1989	168	859	10				

Table 3: Details of monthly otolith samples examined to determine marginal state, and to provide data to calculate growth parameters. Source: TS, trawl survey; SOP, scientific observer programme. *n*, sample size of marginal state data; *N*, number of successfully aged fish

Month	Area	Source	*n*	*N*	Years sampled
January	Chatham Rise	TS	68	444	1994, 1996, 1997, 1998
February	Stewart-Snares shelf	TS	55	55	1993, 1996
March	Stewart-Snares shelf	TS	20	20	1996
	Stewart-Snares shelf	SOP	14	14	1998
April	Campbell Plateau	TS	95	117	1998
May	Chatham Rise	SOP	31	34	1993, 1998
June–August	West coast South Island	SOP	19	22	1993, 1996, 1998
September	Chatham Rise	SOP	4	5	1996
	Campbell Plateau	SOP	37	37	1992, 1997, 1998
October	Chatham Rise	SOP	38	39	1996, 1997, 1998
November	Chatham Rise	SOP	34	35	1998
December	Chatham Rise	TS	8	40	1995
	Chatham Rise	SOP	22	24	1997, 1998
	Stewart-Snares shelf	SOP	9	9	1997, 1998

Table 4: Estimated growth of white warehou based on modal lengths in length frequency distributions

	Chatham Rise			Campbell Plateau	
Month	Age (years)	Length (cm)	Month	Age (years)	Length (cm)
January	0.45	19	Apr-May	0.75	25–27
March	0.65	21	Jul-Aug	0.90	25
July	0.90	24	Nov-Dec	1.35	27–28
November	1.30	27	Feb-Mar	1.60	33
January	1.45	31	Apr-May	1.75	34–37
January	2.45	38	Nov-Dec	1.90	34
January	3.45	43			

Table 5: Von Bertalanffy parameters (with 95% confidence intervals), by sex, for white warehou from the Chatham Rise, Campbell Plateau (including the Stewart-Snares shelf), and both these areas combined. Unsexed juvenile fish were included in the analyses for both sexes

Sex	*n*	L_∞		*k*		t_0	
Chatham Rise (WWA 1)							
Male	346	53.7	(53.0–54.3)	0.342	(0.319–0.366)	–1.11	(–1.27 to –0.94)
Female	279	56.8	(56.0–57.6)	0.288	(0.267–0.310)	–1.33	(–1.53 to –1.14)
Campbell Plateau (WWA 5)							
Male	149	54.8	(53.5–56.1)	0.325	(0.287–0.362)	–1.31	(–1.53 to –1.08)
Female	109	59.2	(57.6–60.7)	0.252	(0.217–0.286)	–1.63	(–1.96 to –1.29)
Combined							
Male	495	54.0	(53.5–54.6)	0.329	(0.310–0.348)	–1.24	(–1.38 to –1.11)
Female	388	57.8	(57.0–58.5)	0.270	(0.252–0.288)	–1.48	(–1.65 to –1.31)

Table 6: Estimates of instantaneous natural mortality (*M*) derived from various estimation methods and samples

Method	Sample	*M*	Method reference
Hoenig: $p = 0.05$	All aged fish	0.25 (male) 0.20 (female)	Hoenig (1983)
Hoenig: $p = 0.01$	All aged fish	0.31 (male) 0.27 (female)	Hoenig (1983)
Chapman-Robson	1998 Chatham Rise	0.26 (sexes combined)	Chapman & Robson (1960)
Regression R1	1998 Chatham Rise	0.28 (sexes combined)	Dunn *et al.* (1999)

Table 7: Estimates of biological parameters used in stock modelling

Fishstock Estimate

1. Natural mortality (M)

	Male	Female
All	0.25	0.25

2. Weight = a (length)^b (Weight in g, length in cm total length)

	Sex	*a*	*b*	*n*	Range
WWA 1	Male	0.0247	2.981	459	18–59
	Female	0.0177	3.069	360	19–62
	All	0.0200	3.037	829	16–62
WWA 5	Male	0.0138	3.132	231	20–60
	Female	0.0106	3.197	131	20–62
	All	0.0111	3.188	406	20–62
WWA 7	All	0.0200	3.037	–	–

3. von Bertalanffy growth parameters

	Females			Males		
	k	t_0	L_∞	k	t_0	L_∞
All	0.270	–1.48	57.8	0.329	–1.24	54.0

Table 8: Model input parameters for the white warehou assessments

Parameter	Estimate
Steepness	0.9
Recruitment variability	0.6
Proportion spawning	0.9
Spawning season length	0.0
Maximum exploitation (r_{max})	0.5
Minimum exploitation at highest catch (r_{mmx})	0.03

Maturity ogive	Age	2	3	4	5	6
	Male	0.1	0.4	0.7	0.9	1.00
	Female	0.1	0.4	0.7	0.9	1.00

Table 9: Doorspread biomass estimates (t) and *c.v.*s (%), and sex ratios of white warehou from random stratified trawl surveys, 1982 to 1999. –, sample not sexed

Vessel	Tripcode	Station density (km^2/station)	Biomass (t)	*c.v.*	Sex ratio M : F	Date
Chatham Rise						
Shinkai Maru	SHI8301	1 158	2 220	27	–	March 1983
Shinkai Maru	SHI8304	1 293	8 959	41	–	November/December 1983
Shinkai Maru	SHI8602	1 337	3 791	30	1.2	June/July 1986
Amaltal Explorer	AEX8903	1 171	3 175	30	1.2	November/December 1989
Tangaroa	TAN9106	738	2 170	30	1.2	December/January 1992
Tangaroa	TAN9212	717	2 940	46	1.1	December/January 1993
Tangaroa	TAN9401	848	1 572	27	1.4	January 1994
Tangaroa	TAN9501	1 144	731	25	1.0	January 1995
Tangaroa	TAN9601	1 569	533	24	1.2	December/January 1996
Tangaroa	TAN9701	1 355	2 287	20	1.0	January 1997
Tangaroa	TAN9801	1 533	1 017	23	1.1	January 1998
Tangaroa	TAN9901	1 395	3 136	41	1.6	January 1999
Southern N.Z. **a) QMA 5 and 6**						
Shinkai Maru	SHI8201	1 578	2 800	26	–	March/April 1982
Shinkai Maru	SHI8303	1 882	2 500		–	October/November 1983
Amaltal Explorer	AEX8902	2 547	877	79	1.0	October/November 1989
Amaltal Explorer	AEX9001	2 406	172	24	1.3	July/August 1990
Amaltal Explorer	AEX9002	1 869	5 200	74	1.4	October/November 1990
Tangaroa	TAN9105	1 787	1 422	5	2.5	November/December 1991
Tangaroa	TAN9204	2 992	256	30	0.9	April/May 1992
Tangaroa	TAN9209	2 578	348	55	0.7	September/October 1992
Tangaroa	TAN9211	1 721	277	26	1.5	November/December 1992
Tangaroa	TAN9304	2 630	904	24	2.0	May/June 1993
Tangaroa	TAN9310	1 995	284	28	1.2	November/December 1993
Tangaroa	TAN9605	3 188	239	31	1.5	March/April 1996
Tangaroa	TAN9805	4 219	2 887	68	2.3	April 1998
b) QMA 5 only						
Shinkai Maru	SHI8601	952	81	79	1.8	June 1986
Akebono Maru No.3	AKE8601	386	9 227	93	4.2	November 1986
Tangaroa	TAN9301	446	18	34	2.3	February/March 1993
Tangaroa	TAN9402	384	46	49	2.0	February/March 1994
Tangaroa	TAN9502	331	2	76	2.6	February/March 1995
Tangaroa	TAN9604	401	102	87	2.1	February/March 1996

Table 10: Bounds around B_0 (t) and B_{mid00} (as a % of B_0) for the WWA 1 (Chatham Rise), WWA 5 (Campbell Plateau), and WWA 7 (west coast South Island) stocks. Results from the base case and sensitivity model runs are presented

Stock	Model run	B_0	B_{mid00}
WWA 1	Base case	2 820 – 14 790	1.9 – 81.8
	$r_{max} = 0.3$	3 160 – 14 790	10.9 – 81.8
	$r_{mmx} = 0.01$	2 820 – 42 010	1.9 – 93.6
	$M = 0.30$	2 300 – 12 850	1.4 – 82.2
	$M = 0.20$	3 500 – 17 020	2.2 – 80.9
	Steepness = 0.75	3 160 – 14 920	2.5 – 81.1
WWA 5	Base case	7 690 – 50 750	2.3 – 85.3
	$r_{max} = 0.3$	8 850 – 50 750	13.3 – 85.3
	$r_{mmx} = 0.01$	7 690 – 144 500	2.3 – 94.9
	$M = 0.30$	6 360 – 44 380	1.6 – 85.7
	$M = 0.20$	9 320 – 57 900	2.7 – 84.7
	Steepness = 0.75	8 230 – 50 910	2.5 – 84.9
WWA 7	Base case	350 – 2 330	2.2 – 86.1
	$r_{max} = 0.3$	380 – 2 330	9.2 – 86.1
	$r_{mmx} = 0.01$	350 – 6 740	2.2 – 95.2
	$M = 0.30$	280 – 2 030	1.0 – 86.5
	$M = 0.20$	430 – 2 670	2.0 – 85.3
	Steepness = 0.75	390 – 2 340	2.2 – 85.5

Table 11: Estimates of MCY (rounded to the nearest 5 t) based on an average catch history from fishing years 1988–89 to 1997–98 (MCY = $c.Y_{av}$)

Stock	QMAs	MCY
WWA1	1, 2, 3, 4, & 10	0.8 * 556 t = 445 t
WWA5	5 & 6	0.8 * 1608 t = 1285 t
WWA7	7, 8, & 9	0.8 * 72 t = 60 t

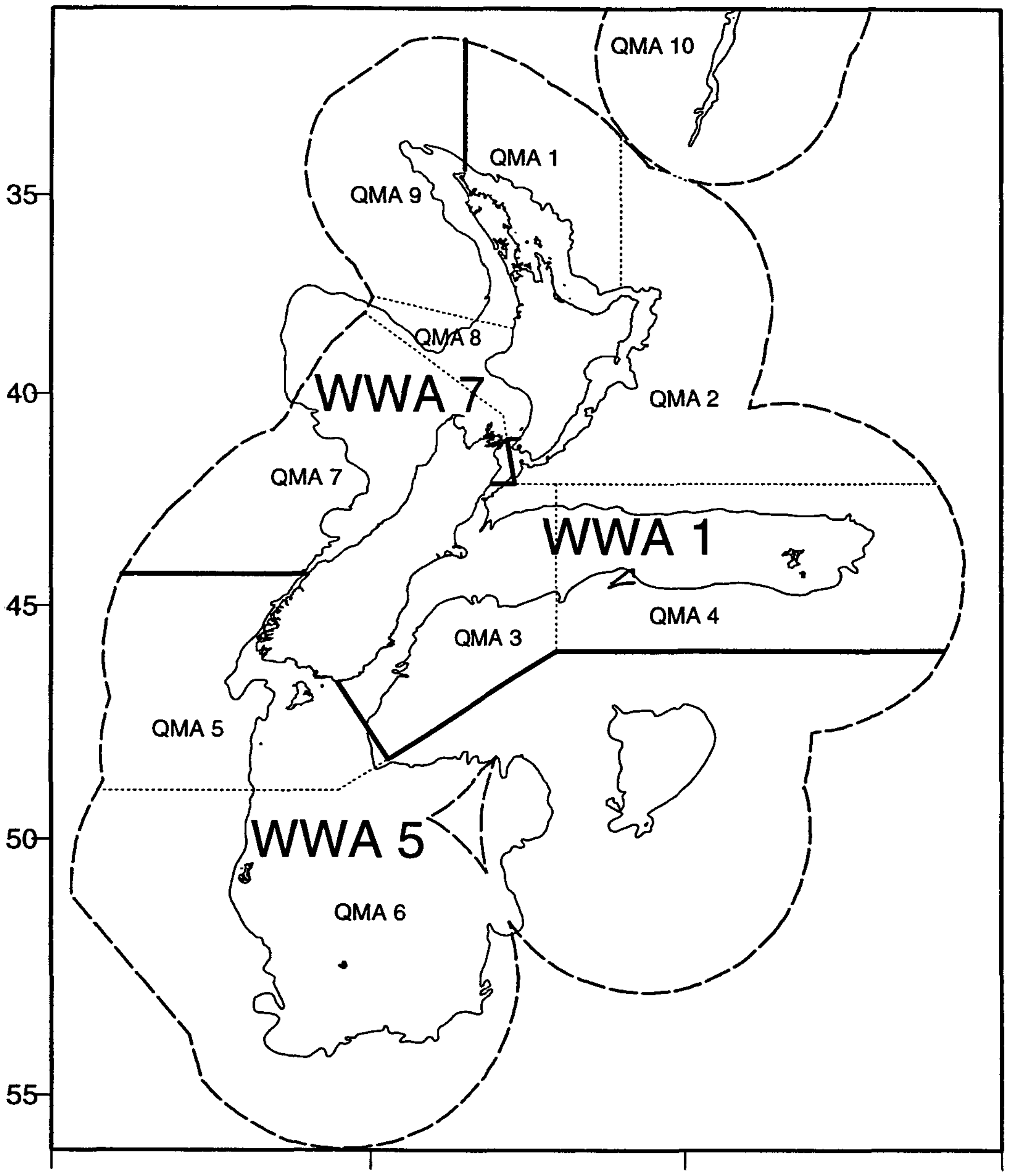

Figure 1: QMA boundaries, areas of postulated biological stocks WWA 1, WWA 5, and WWA 7, and the 1000 m isobath.

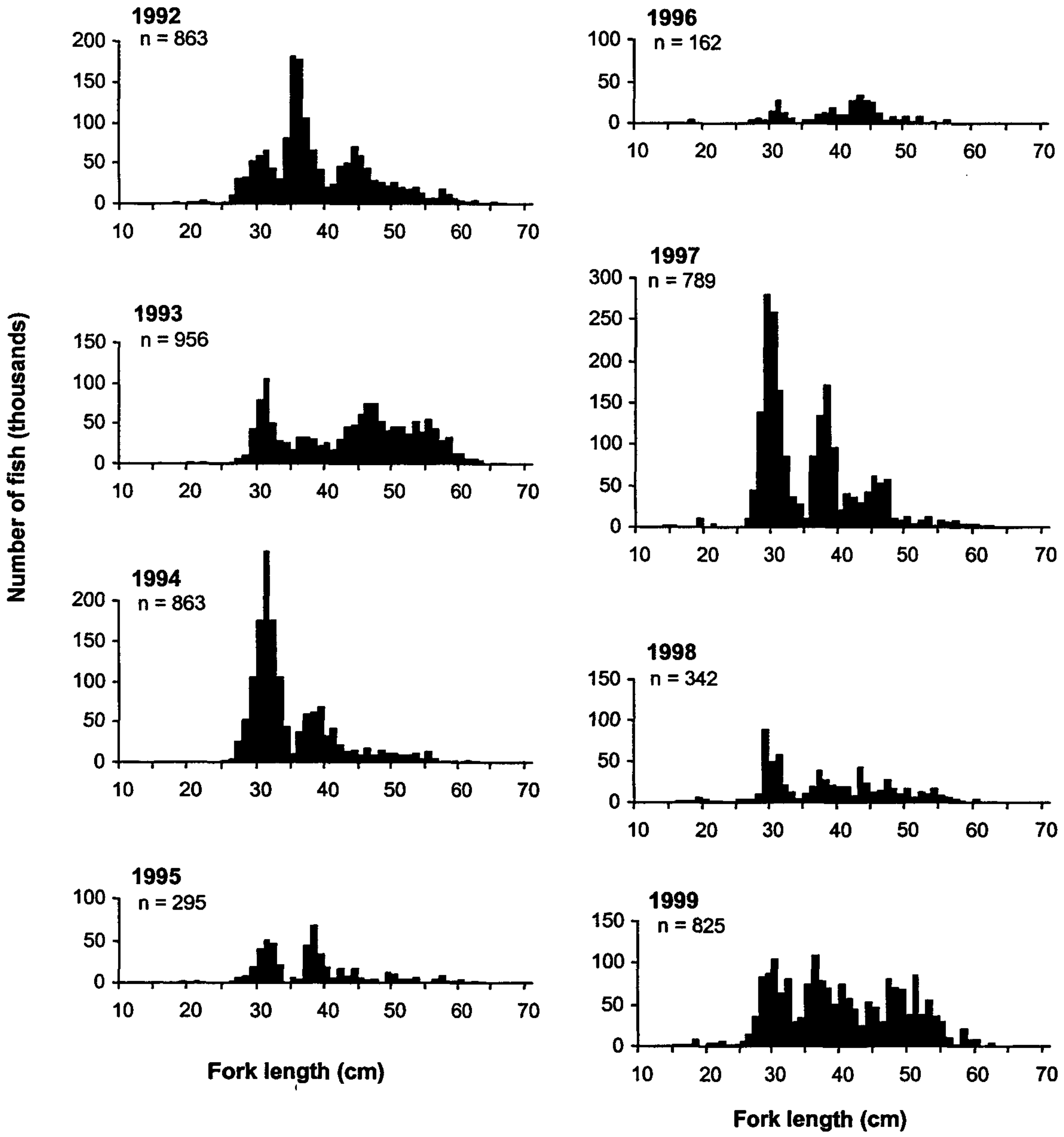

Figure 2: Scaled length frequency distributions of white warehou (sexes combined) from *Tangaroa* trawl surveys on the Chatham Rise, January 1992 to 1999. n, number of fish measured.

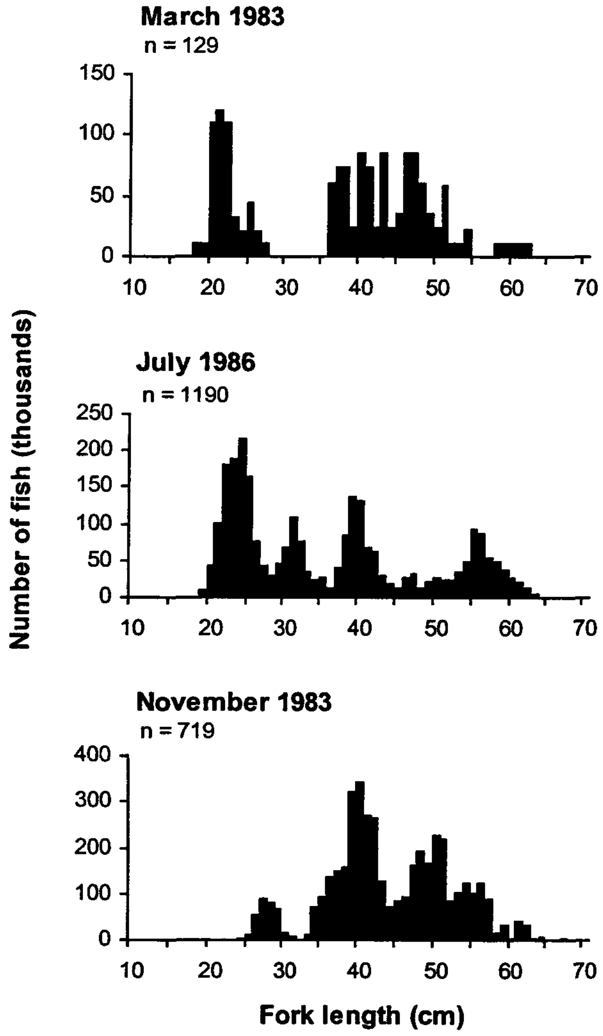

Figure 3: Scaled length frequency distributions of white warehou (sexes combined) from *Shinkai Maru* trawl surveys on the Chatham Rise, in 1983 and 1986. n, number of fish measured.

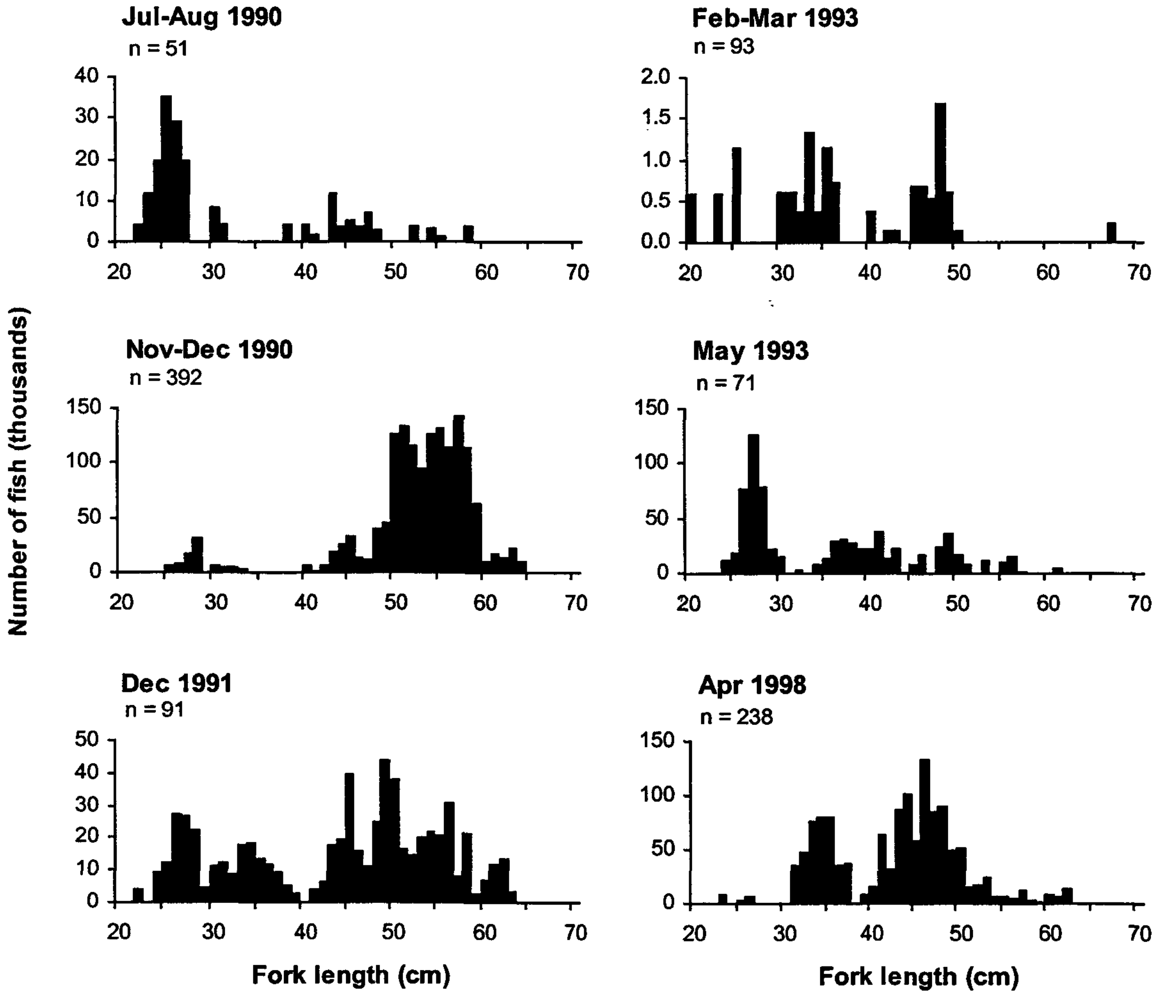

Figure 4: Scaled length frequency distributions of white warehou (sexes combined) from trawl surveys of the Stewart-Snares shelf (Feb-Mar 1993) and the Campbell Plateau (all other surveys), from 1990 to 1998. Surveys were by *Amaltal Explorer* (1990) and *Tangaroa* (1991–1998). n, number of fish measured.

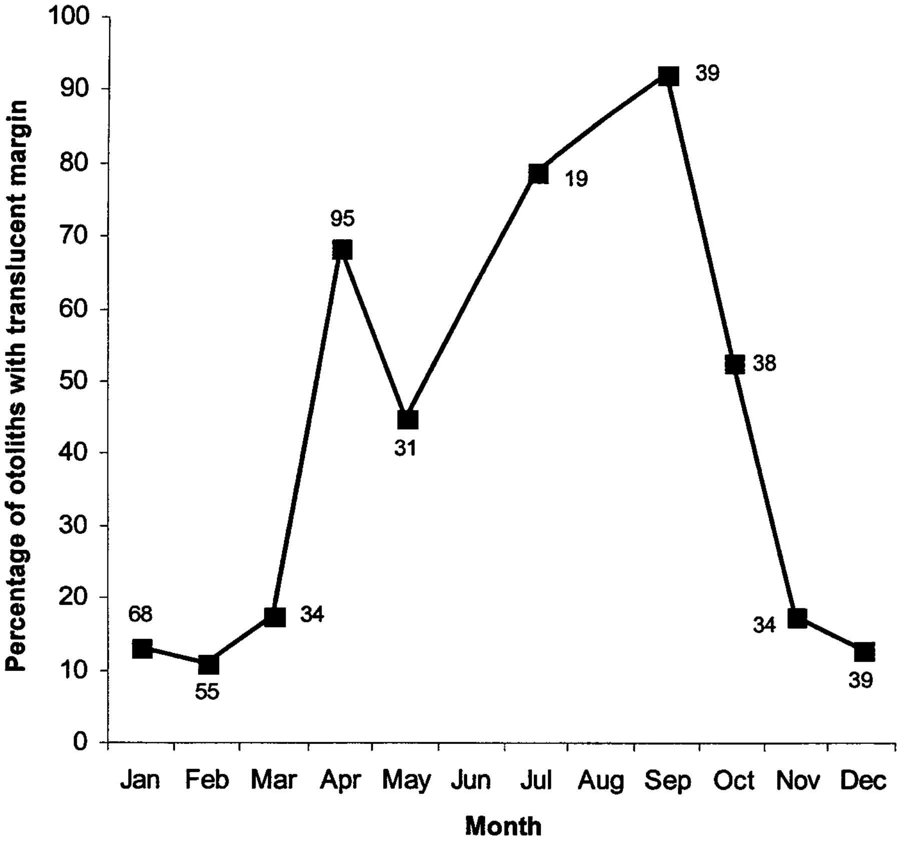

Figure 5: Seasonal change in the percentage of white warehou otoliths with a translucent margin. Numbers adjacent to symbols denote sample size. For details of area and year of sample collection, see Table 3.

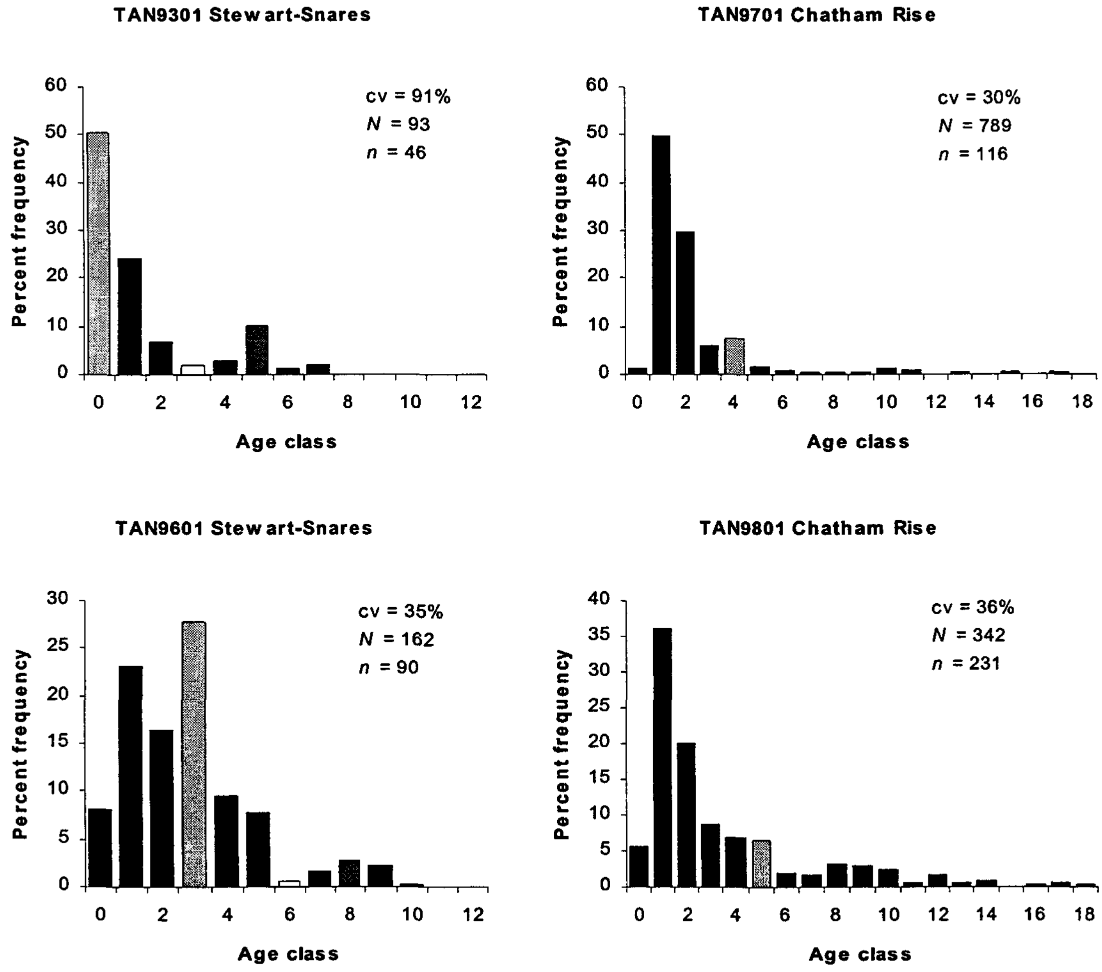

Figure 6: Estimated proportion at age distributions (sexes combined) from two pairs of comparable trawl surveys conducted on the Stewart-Snares shelf in 1993 and 1996, and on the Chatham Rise in 1997 and 1998. Similarly shaded bars represent individual years classes. cv, mean weighted cv over all age classes; *N*, number of fish measured; *n*, number of fish aged.

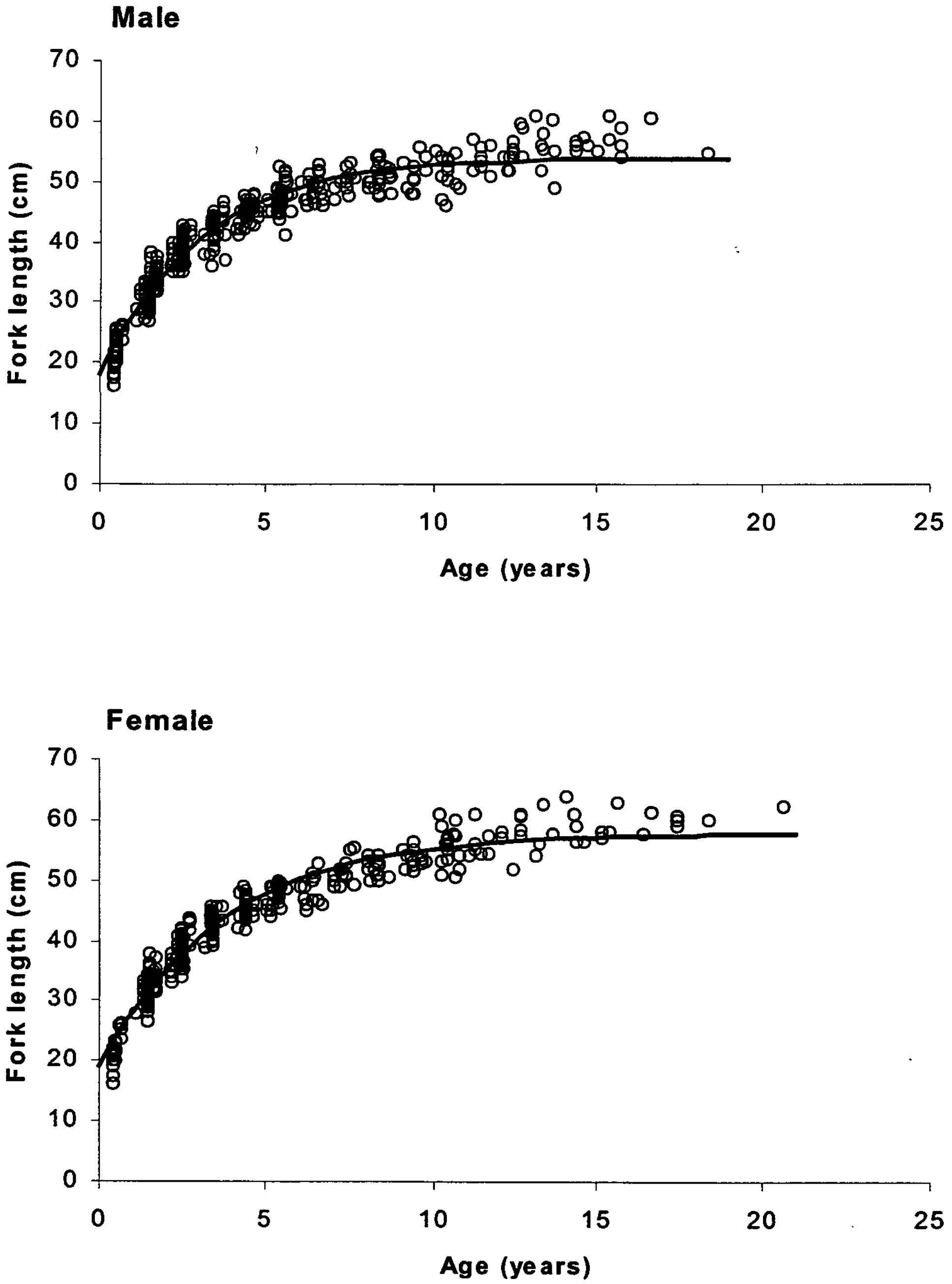

Figure 7: Raw age-length data and calculated von Bertalanffy growth curves, by sex, for white warehou from the Chatham Rise and Campbell Plateau combined.

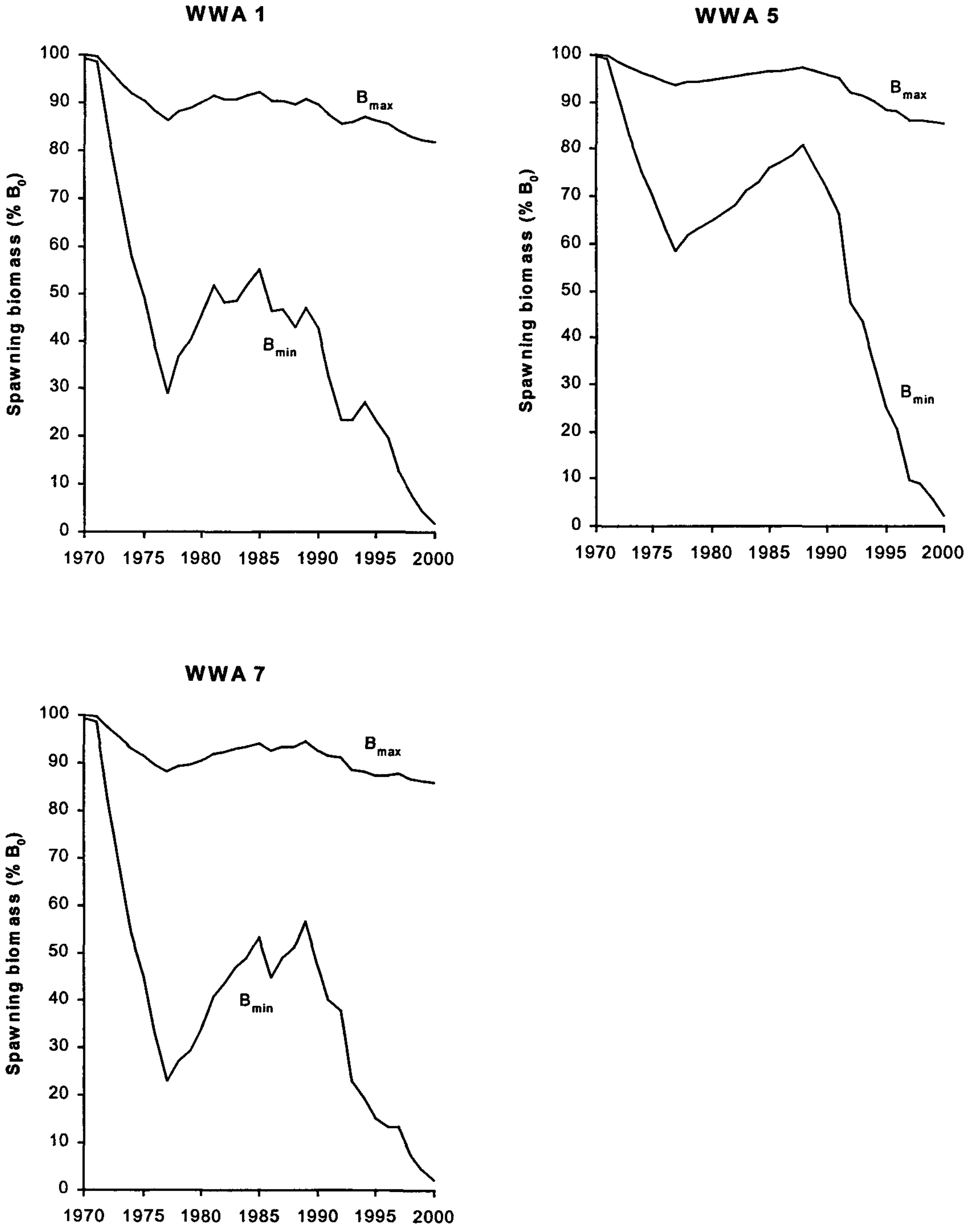

Figure 8: Estimated biomass trajectories for B_0 at B_{max} and B_{min}, from the base case model runs for the three biological stocks.