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Te Tautiaki i nga tini a Tangaroa

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on Snake Bank, Whangarei Harbour, 2004**

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EXECUTIVE SUMMARY

Watson, T.G.; Cryer, M.; Smith, M.D.; MacKay, G.; Tasker, R. (2005). Biomass survey and stock assessment of cockles on Snake Bank, Whangarei Harbour, 2004. *New Zealand Fisheries Assessment Report 2005/15* 36 p.

A stratified random survey of cockles, *Austrovenus stutchburyi*, on Snake Bank in March, 2004 produced an estimate of recruited biomass (30 mm or greater shell length, SL) of 546 t with a c.v. of 14%. This estimate is slightly higher than the 2001 and 2002 estimates (435 and 466 t, respectively, with c.v.s of 17–19%, the two lowest estimates on record) but smaller than that recorded in 2003 (889 t with a c.v. of 10%). Current biomass is about 23% of virgin biomass (cockles 30 mm shell length, SL, or larger). Incorporating information from this latest survey leads to estimates of MCY = 166 t and CAY (for 2004) = 160 t. These estimates of yield are smaller than the current TACC of 346 t, but are sensitive to the assumed size at recruitment to the fishery. At an assumed size at recruitment of 28 mm SL (which may be realistic given the size of cockles in the commercial catch), current recruited biomass was estimated to be 1009 t with a c.v. of at least 14%, about 40% of virgin biomass (cockles 28 mm SL or larger). Yield at an assumed size at recruitment of 28 mm SL was estimated as MCY = 268 t and CAY (for 2004) = 278 t. Only at an assumed size at recruitment of 25 mm was CAY as large as the current TACC of 346 t, and MCY was always smaller. These simple MCY and CAY estimates suggest that fishing at the level of the current TACC is not likely to be sustainable in the long term.

The stochastic, dynamic, length-based, observation-error, time-series model was extended by including estimates of the 2004 biomass and population length frequency distribution and 178 individual growth increments by length from 2003–04. Growth was fitted to each observed year and across all years for periods in which no growth data was available. Various scenarios were explored but none of our models successfully duplicated the observed trends in biomass and length frequency distribution. Results indicate the possibility of large annual variability in model parameters and in particular, mortality, growth, and recruitment. There are sufficient inconsistencies and conflicts in all versions of the length-based model for us to conclude that it does not provide a good description of the observed data. We are therefore, not confident that estimates of productivity, biomass, and yield made using the length based model are reliable, and suggest that the simpler estimates based on observed biomass and reference rates of fishing mortality are preferable in the short term.

1. INTRODUCTION

1.1 Overview

This report summarises research and fishery information for cockles, *Austrovenus stutchburyi*, on Snake Bank and elsewhere in Whangarei Harbour (Figure 1). The most recent biomass survey on Snake Bank (March 2004) is described and yield estimates for 2004 are derived using methods after Annala et al. (2003). A length-based model is in development and development up to and including 2004 are included. This work was funded by the Ministry of Fisheries under project COC2003/01.

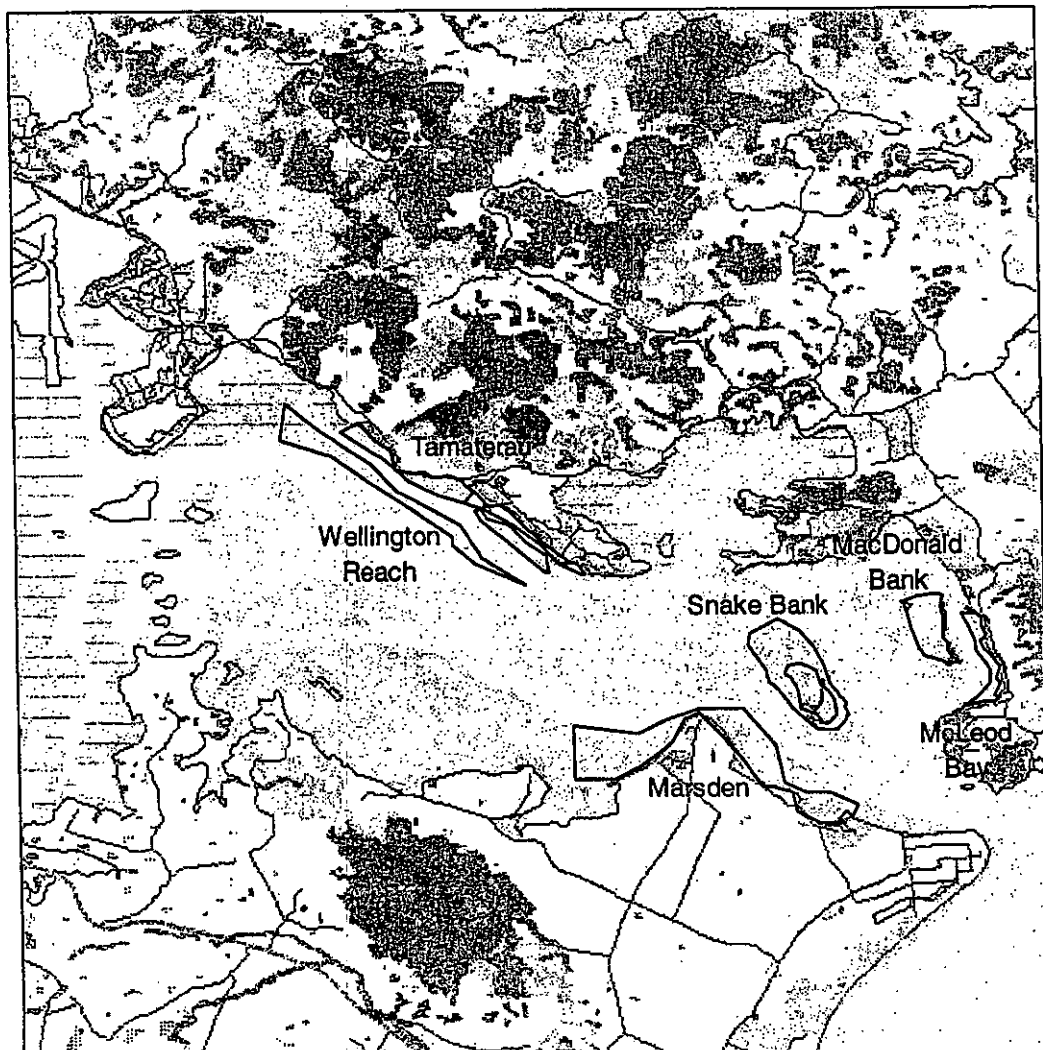


Figure 1: Beaches and banks within Whangarei Harbour that support appreciable numbers of cockles (as at July 2002, Cryer et al. 2002b). Sampling strata are delineated by solid lines. The outline of Snake Bank has subsequently moved.

1.2 Description of the fishery

Commercial picking in Whangarei Harbour began in the early 1980s and is undertaken year round, with no particular seasonality. Commercial fishers are restricted to hand gathering, but they routinely use simple implements such as "hand sorters" to separate cockles of desirable size from smaller

animals and silt. There is some amateur and customary interest in cockles, and all fishers favour larger cockles over smaller ones.

1.3 Literature review

General reviews of the fishery and cockle biology were given by Cryer (1997) and Annala et al. (2003). Since Cryer (1997), biomass estimates have been generated for Snake Bank by Morrison & Cryer (1999), Morrison (2000), Morrison & Parkinson (2001), Cryer & Parkinson (2001), and Cryer et al. (2002a). Estimates for cockles in other parts of the harbour were made by Morrison & Parkinson (2001) (MacDonald Bank) and Cryer et al. (2002b) (MacDonald Bank and all other areas shown in Figure 1). A length-based model based on that for paua (Breen et al. 2000) was developed for cockles by P. Breen (2000, unpublished results), and refined by McKenzie et al. (2003) and Cryer et al. (2004), although the fit to the observed data was poor at all three iterations.

2. REVIEW OF THE FISHERY

2.1 TACCs, catch, landings, and effort data

Commercial catch statistics for Snake Bank (Table 1) are unreliable (probably underestimates) before 1986 but, as a guide, it is thought that over 150 t of Snake Bank cockles were exported in 1982. However, there is evidence that cockles have been gathered commercially elsewhere in Whangarei Harbour and, thus, landings from Snake Bank may be over- or under-reported.

Table 1: Reported commercial landings of cockles from Snake Bank since 1986–87 (from Licensed Fish Receiver Returns after Annala et al. (2003). *, a TACC of 346 t was established in October 2002 when COC 1A entered the QMS.

Year	Landings (t)	Limit (t)	Year	Landings (t)	Limit (t)
1986–87	114	584	1995–96	495	584
1987–88	128	584	1996–97	457	584
1988–89	255	584	1997–98	439	584
1989–90	426	584	1998–99	472	584
1990–91	396	584	1999–00	505	584
1991–92	537	584	2000–01	423	584
1992–93	316	584	2001–02	423	584
1993–94	566	584	2002–03	346	*346
1994–95	501	584	2003–04	-	346

Until 30 September 2002 (after which date this fishery was introduced to the QMS with a TACC of 346 t), there were eight permit holders, each allowed a maximum of 200 kg (all weights in this report are greenweight) per day. If all permit holders took their limit every day a maximum of 584 t could be taken in a 365 day year. Landings of less than 200 t before 1988–89 rose to 537 t in 1991–92 (about 92% of the theoretical maximum). Landings for the 1992–93 fishing year were much reduced (about 316 t) following an extended closure for biotoxin contamination, but the fishery averaged 400–500 t between 1994 and 2002–03. Effort and catch-per-unit-effort data are not presented for this fishery because there are major problems with the reported information that render them uninformative.

2.2 Other information

Snake Bank is not the only cockle bed in Whangarei Harbour, but it is the only bed open for commercial fishing. The others are on the mainland, notably Marsden Bay, and other sandbanks, notably MacDonald Bank, and many hold cockles (Cryer et al. 2002b). There is good evidence that commercial gathering, at least on an exploratory scale, has occurred on MacDonald Bank in recent years.

2.3 Recreational and Maori customary fisheries

In common with many other intertidal shellfish, cockles are very important to Maori as a traditional food. However, no quantitative information on the level of customary take is available. Cockles are also taken by amateur fishers; cockles of about 30 mm or larger SL are acceptable (see Hartill & Cryer (2000) for estimates of amateur selectivity at four Auckland beaches). Recreational or customary catch are thought to be very small compared with commercial landings (e.g., Annala et al. 2003). In 1993–94, amateur harvest in QMA 1 was estimated by telephone and diary surveys to be about 2 million cockles (Teirney et al. 1997). A 1996 national recreational diary survey estimated the number of cockles taken in QMA 1 to be 569 000 (Bradford 1998). It is not clear to what extent these estimates include customary take. An assumed mean weight of 25 g (as for cockles 30 mm SL or more from the 1992 Snake Bank survey) leads to an estimated QMA 1 recreational harvest of 55 t in 1993–94 (about 1 t of which came from Whangarei Harbour), and 14 t in 1996 (Table 2).

Table 2: Estimated numbers of cockles harvested by recreational fishers in QMA 1, and the corresponding harvest tonnage based on an assumed mean weight of 25 g. Figures were extracted from a telephone and diary survey in 1993–94, and the national recreational diary survey in the 1996 calendar year.

Year	QMA 1 harvest (millions)	QMA 1 harvest (t)	c.v.	Whangarei harvest (t)
1993–94	2.14	55	0.18	1
1996	0.57	14	0.18	–

2.4 Other sources of fishing mortality

There have been sporadic suggestions of illegal fishing or over-catching of daily limits, but none has been supported by quantitative information. It has also been suggested that some methods of harvesting (such as brooms, rakes, and “hand sorters”) cause some mortality, particularly of small cockles, but this proposition has not been tested.

3. RESEARCH

3.1 Stock structure

Little is known of the stock structure of New Zealand cockles. It is assumed for management that cockles on Snake Bank are separate from cockles in other parts of Whangarei Harbour and elsewhere in QMA 1. However, the extended planktonic phase in cockles (a few weeks) suggests that the Snake Bank population is not likely to be reproductively isolated from the rest of the harbour. This may provide some protection against recruitment overfishing if there are productive spawning populations nearby.

Nevertheless, it has been demonstrated for this bank that settlement of juvenile cockles can be reduced by the removal of a large proportion of the adults (Martin 1984). Conversely, length frequency distributions from periodic biomass surveys suggest little recruitment to the Snake Bank population when adult biomass was close to virgin in 1982–85 (see Figure 6). This suggests that there may be some optimal level of adult biomass for spat settlement and eventual recruitment. It would appear prudent, therefore, to be cautious in reducing the biomass of adult cockles. If adult biomass is driven too low, then recruitment overfishing of this population could occur (via a “bottleneck” at spat settlement) despite the availability of large numbers of larvae.

3.2 Resource surveys

3.2.1 Historical Information for Snake Bank

Biomass surveys have been conducted periodically on Snake Bank since 1982. Early surveys were based on a permanent grid with 50 m intersection spacings and typically had 150–200 sites. Surveys since 1998 have had 50–65 sites in various single phase stratified random designs constrained to keep sites at least 50 m apart (Table 3).

Table 3: Estimates of biomass (t) of cockles on Snake Bank for surveys (N, number of sites) between 1982 and 2003. Biomass estimates marked (*) were made using length frequency distributions and length-weight regressions, others by direct weighing of samples sorted into three size classes. Two alternative biomass estimates are presented for 1988 because the survey was abandoned part-way through, “a” assuming the distribution of biomass in 1988 was the same as in 1991, and “b” assuming the distribution in 1988 was the same as in 1985. The 2001 result comes from the second of two surveys, the first having produced unacceptably imprecise results.

Year	N	Total		< 30 mm SL		≥ 30 mm SL		≥ 35 mm SL	
		Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.
1982	199	2 556	–	* 216	–	* 2 340	–	1 825	~0.10
1983	187	2 509	–	* 321	–	* 2 188	–	1 700	~0.10
1985	136	2 009	0.08	* 347	~0.10	1 662	0.08	1 174	~0.10
1988 a	53	–	–	–	–	1 140	> 0.15	–	–
1988 b	53	–	–	–	–	744	> 0.15	–	–
1991	158	1 447	0.09	686	0.10	761	0.10	197	0.12
1992	191	1 642	0.08	862	0.10	780	0.08	172	0.11
1995	181	2 480	0.07	1 002	0.09	1 478	0.07	317	0.12
1996	193	1 755	0.07	959	0.09	796	0.08	157	0.11
1998	53	2 401	0.18	1 520	0.20	880	0.17	114	0.20
1999	47	3 486	0.12	2 165	0.12	1 321	0.14	194	0.32
2000	50	1 906	0.23	1 336	0.24	570	0.25	89	0.32
2001	51	1 405	0.17	970	0.18	435	0.17	40	0.29
2002	53	1 618	0.14	1 152	0.15	466	0.19	44	0.29
2003	60	2 135	0.08	1 246	0.12	889	0.10	115	0.14
2004	65	1 910	0.15	1 364	0.17	546	0.14	59	0.22

3.2.2 2004 Snake Bank survey methods

Stratification was revised in 2001 and 2003, and again in 2004 because the northern part of the high density area (and, probably, the whole bank) appears to have been moving slowly east since about 1999 (Figure 4). The location of the high density area in March 2004 was estimated before sampling

started by walking the perimeter of the bank at a low (but not extreme) tide and periodically recording positions using a high-precision (but non-differential) hand-held GPS (previous high density strata have been similar to the boundary of the bank at low tide). Starting on 13 March, 2004, 65 randomly-located sites (50 in the high density stratum and 15 in the low density stratum, all zeroes, Figure 2) were visited in turn, using GPS. At each site, a square quadrat of 0.5 * 0.5 m (0.25 m²) was thrown haphazardly onto the bank. All sediment beneath the quadrat was excavated to the anaerobic layer (generally to a depth of about 100 mm, but sometimes considerably deeper) by hand, including in the samples any animals directly under the south- and west-facing sides (to account for any “edge effect”). Cockles were extracted from the sediment using a metal sieve of 5 mm square aperture agitated in water. Except for those sites where more than about 200 cockles were taken, all cockles were measured (SL) to the next whole millimetre down, and the aggregate weight of cockles in each of three size classes (< 30 mm, 30–34 mm, ≥ 35 mm SL) determined by direct weighing. Where more than about 200 cockles were taken, the sample was roughly halved. One half chosen at random was measured, the other half was counted. Standing biomass per unit area was estimated by scaling recorded weights by the inverse of the sampled fraction, then to a square metre of sediment.

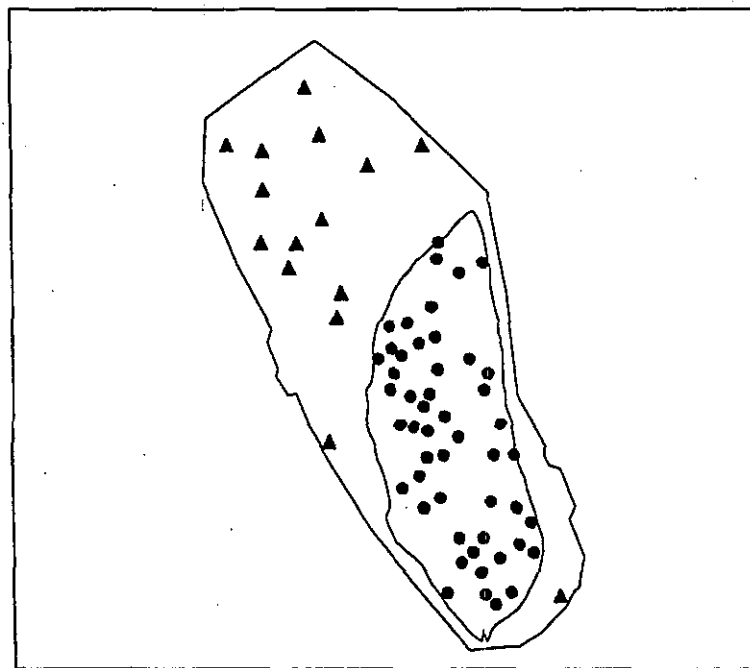


Figure 2: Design of the survey conducted in April 2004 on Snake Bank, Whangarei Harbour. Filled circles indicate site positions in the HIGH density and triangles in the LOW density strata. The boundary of the “Low” density area is likely to be inaccurate because it has not been measured since the movement of the “High” density area was mooted by Cryer et al. (2002a).

The overall mean biomass of cockles (for a given size range) was estimated using the weighted average of the stratum estimates of mean biomass, weights being proportional to the relative area of each stratum:

$$\bar{x}_y = \sum_{i=1}^n W_i \bar{x}_i \quad (1)$$

where \bar{x}_y is the overall mean biomass, W_i is the relative area and \bar{x}_i the mean biomass in stratum i . The variance for this mean was estimated using:

$$s_y^2 = \sum_{i=1}^n W_i^2 s_i^2 / n_i \quad (2)$$

where s_y^2 is the variance of the estimated mean biomass, s_i^2 is the sampling variance in stratum i , and n_i is the number of samples taken in stratum i . (Snedecor & Cochran 1989). No finite correction term was applied because the sampling fraction was negligible (less than 0.1% of the total area).

Site length frequency distributions were estimated by scaling the recorded length frequency distributions by the inverse of the sampled fraction at each site and to a square metre of sediment. Stratum length frequency distributions were estimated as the average site length frequency distribution for that stratum scaled by the stratum area (m^2). The population length frequency was estimated by adding the stratum length frequency distributions.

3.2.3 2004 Snake Bank survey results

The March 2004 survey produced an estimated recruited biomass (30 mm SL or more) of 546 t with a c.v. of 13.8% (see Table 3). Restricting the estimate of recruited biomass to cockles longer than 35 mm SL produced a biomass estimate of 59 t with a c.v. of 22.1%. These estimates are slightly higher than those recorded in 2001 and 2002 (which were the lowest on record) but substantially lower than those in 2003 (Figure 3). Total biomass was estimated to be 1 910 t with a c.v. of 14.6%, about 36% higher than the 2001 estimate (1 405 t, the lowest on record). The biomass of cockles smaller than 30 mm SL was estimated to be 1 364 t with a c.v. of 17.2%, considerably higher than in the 1980s, but similar to the average since 1990 of 1190 t (c.v. 12%).

Cockles 30 mm SL or greater were distributed throughout the high density stratum in 2004 but we found no cockles in the low density stratum (from fifteen stations). The location of the top of the bank (and, we assume, the high density area for cockles in 2004, Figure 4) confirms that the bank is moving eastward as suggested by Cryer et al. (2002a) and Cryer et al. (2003). This movement caused poor survey precision and equivocal results in the first of two surveys in (April) 2001 and requires careful monitoring if future surveys are not to be jeopardised.

The estimated population length frequency distribution in 2004 had a well-defined mode at 28 mm SL (Figure 5) and, because the entire population was inside the high density stratum, the population length frequency is the same as that for the high density stratum. The 2004 length frequency distribution continued the recent pattern of domination by cockles just under 30 mm SL. However, the paucity of small cockles (≤ 20 mm) compared with many surveys in the 1990s (Figure 6) suggests relatively poor recruitment to the recruited biomass for the near future.

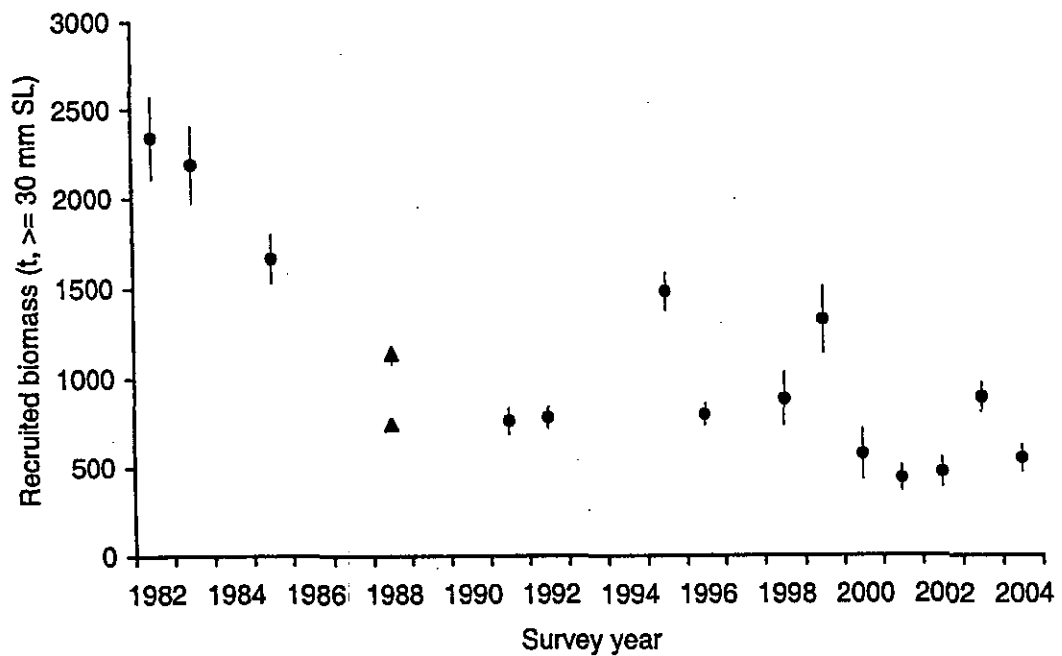


Figure 3: Estimated recruited biomass of cockles (30 mm or more SL, \pm one standard error) on Snake Bank from surveys between 1982 and 2003. The 1988 grid survey was abandoned part-way through and its analysis is complicated; two alternative analytical approaches are plotted as triangles. The 2001 result comes from the second of two surveys, the first having produced unacceptably imprecise results.

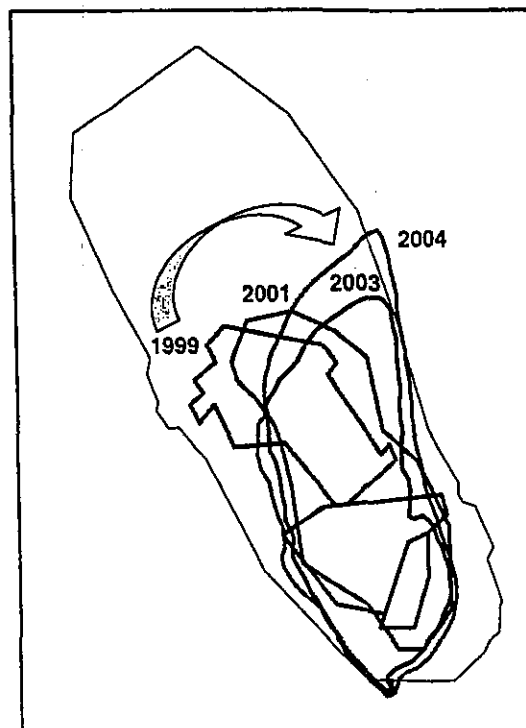


Figure 4: Location of the high density sampling strata on Snake Bank between 1999 and 2004 showing movement to the east, at least for the northern part of the stratum. The 1999 stratification was a modified version of the 1998 stratification which, in turn, was based on the average distribution of cockles 1985-96.

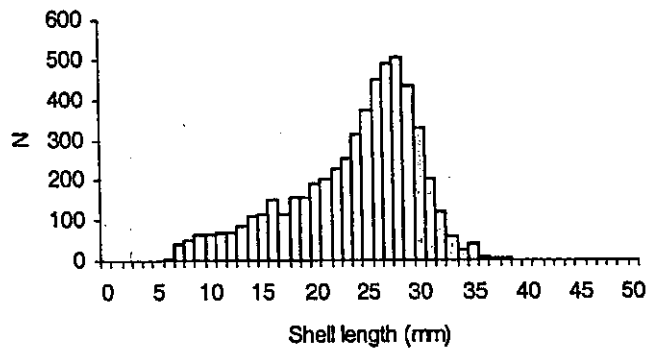


Figure 5: Estimated sample length frequency distribution of cockles in March 2004 ($N = 5490$). Data are not shown separately for the high and low density strata because no cockles were found in the latter. Shaded bars represent cockles of 30 mm SL or bigger, the assumed size at recruitment to the fishery.

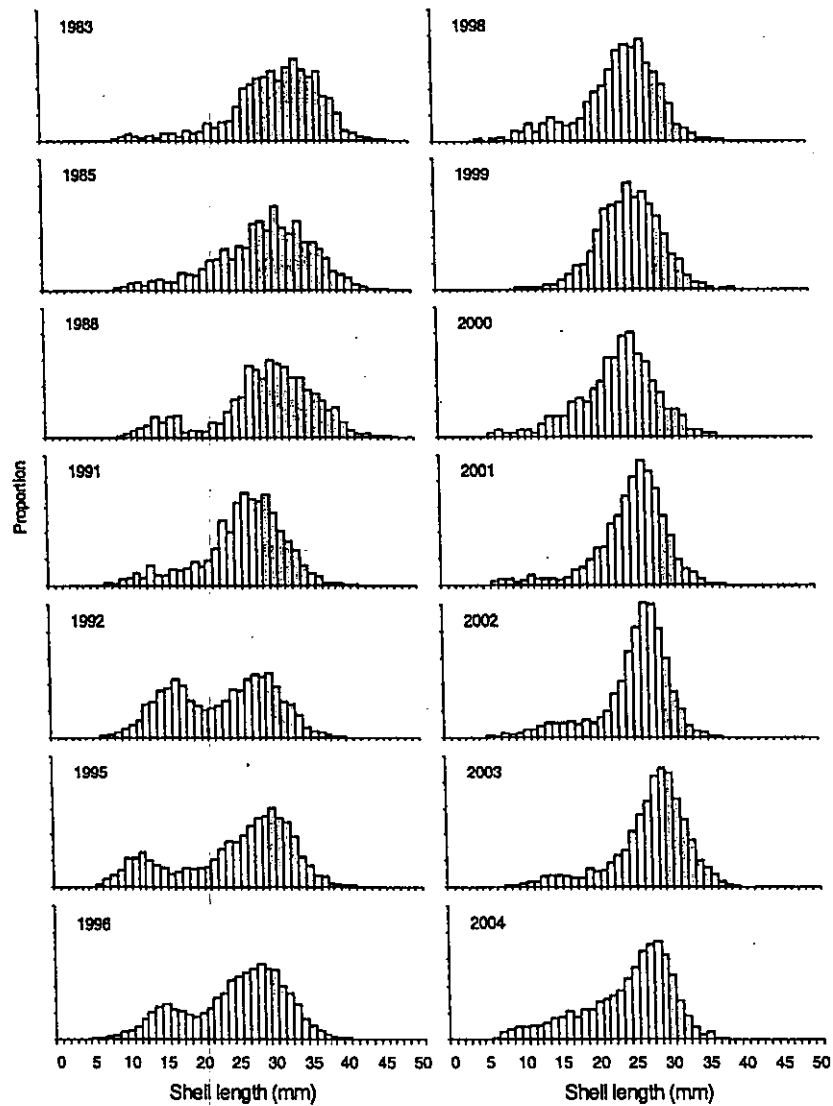


Figure 6: Estimated population length frequency distribution of cockles on Snake Bank, 1983–2003. Shaded bars represent cockles of 30 mm SL or bigger, the assumed size at recruitment to the fishery.

3.2.4 Sensitivity of Snake Bank biomass estimates to the assumed size at recruitment

Actual (aggregate) weights were measured for size classes < 30 , $30\text{--}34$, and ≥ 35 mm SL, and these allow direct estimation of recruited biomass only for assumed sizes at recruitment of 30 and 35 mm SL. In recent years, fishers have taken a greater proportion of cockles smaller than 30 mm SL (Figure 7), occasionally taking cockles as small as 25 mm SL. Recruited biomass in 2004 was, therefore, estimated for assumed sizes at recruitment of 28 mm and 25 mm SL using the estimated 2004 population length frequency distribution and a length-weight regression.

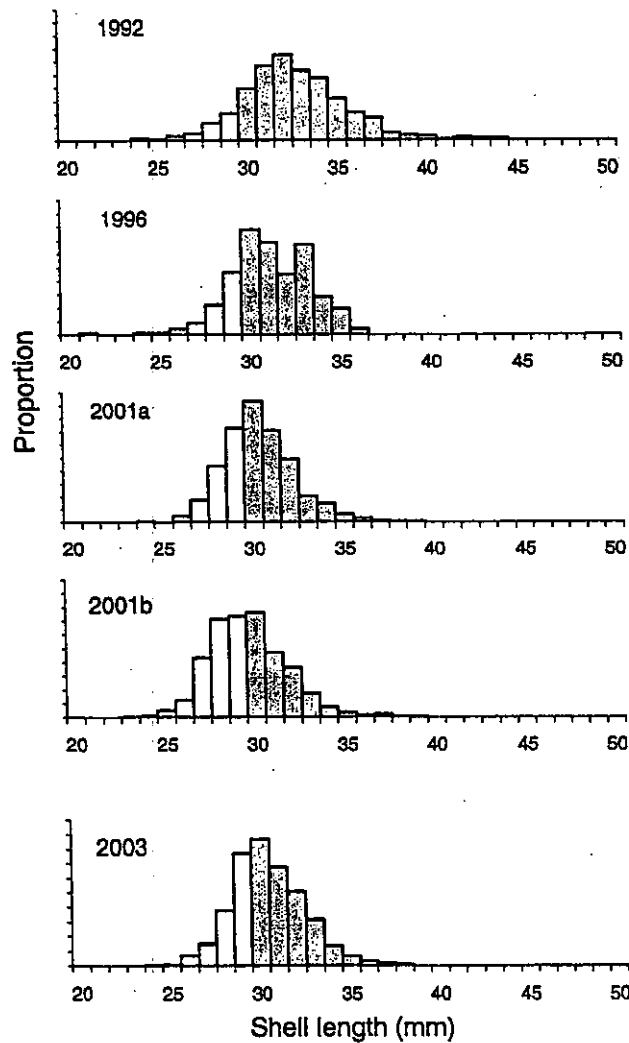


Figure 7: Estimated length frequency distribution of cockles in the commercial harvest from Snake Bank in 1992 ($n = 1006$), 1996 ($n = 267$), and 2001 (a = summer, $n = 1397$; b = winter, $n = 1454$) and 2003 ($n = 1264$). The shaded part of each histogram contains animals 30 mm SL and larger (the nominal size at recruitment to the fishery).

The estimated recruited biomass in 2004 at an assumed size of recruitment to the fishery of 28 mm SL was 1009 t (Table 4). At assumed sizes of recruitment to the fishery of 25 and 20 mm SL, it was 1500 t and 1768 t, respectively. We have not formally estimated c.v.s for these estimates but all would probably be similar to the c.v. on the estimate at 30 mm SL.

Table 4: Estimated recruited biomass of cockles on Snake Bank in 2002–2004 for different assumed shell lengths (SL) at recruitment to the fishery.

Assumed L_{recr} (mm)	Rationale	2004 (t)	2004 c.v.	2003 (t)	2003 c.v.	2002 (t)
30	Historical assumption	546	0.14	889	0.10	466
28	Recent selectivity	1 009	–	1 258	–	913
25	Smallest in catch	1 500	–	1 519	–	1 381
20	Reproductive maturity	1 768	–	1 613	–	1 574

3.2.5 Biomass in other parts of Whangarei Harbour (2002)

Cryer et al. (2002b) described surveys of cockle beds in parts of Whangarei Harbour other than Snake Bank. Their survey was conducted in June 2002 and is best compared with the survey of Snake Bank in late March 2002 (Cryer et al. 2002a). At that time, appreciable numbers of cockles of a size of interest to fishers were found only on Snake Bank, MacDonald Bank, and in Marsden Bay. Some other areas held mostly small cockles. The distribution of recruited biomass among strata, the total biomass, and the estimated precision of these estimates were all sensitive to changes in the assumed size at recruitment. If only cockles of 35 mm SL or bigger were included, more than half of the recruited biomass was in Marsden Bay in 2002. As the assumed size at recruitment was decreased, the biomass was spread among progressively more strata. At an assumed size at recruitment of 30 mm SL (as for Snake Bank), the total recruited biomass in areas other than Snake Bank was estimated to be 881 t (c.v. = 33%), spread roughly 60:40 between MacDonald Bank and Marsden Bay. At an assumed size at recruitment of 20 mm SL (similar to the size at biological maturity, Larcombe 1971), the total recruited biomass in areas other than Snake Bank was estimated to be 3243 t (c.v. = 15%); about three-quarters was on MacDonald Bank. The March 2002 survey of 53 sites on Snake Bank produced an estimated recruited biomass (30 mm or more SL) of 466 t with a c.v. of 18.9% (Cryer et al. 2002a). Restricting the estimate of recruited biomass to cockles over 35 mm SL produced a biomass estimate of 44 t with a c.v. of 29%, longer than 20 mm SL a biomass estimate of 1574 t with a c.v. of 14%, and total biomass was estimated to be 1618 t with a c.v. of 14%. Thus, in 2002, Snake Bank contained 25% of the biomass of very large cockles (35 mm SL or larger), 35% of the traditionally accepted recruited biomass (30 mm SL or larger), 33% of the biologically mature cockles (20 mm SL or larger), and 31% of the (sampled) cockle biomass in Whangarei Harbour.

3.3 Other studies

The relationship between length and weight is important for cockles because length-weight regressions are used to assess the sensitivity of biomass estimates to the assumed size at recruitment to the fishery. Several regressions have been derived (Table 5, including references) and there has been considerable variation between them. It is not known whether this variation is random, or a result of variation among locations, years, or tidal height.

Experimental work on Snake Bank led to estimates of absolute mortality of 17–30% per annum of instantaneous mortality (M) of 0.19–0.35, with a midpoint of $M = 0.28$ (after Cryer 1997). The estimated mortality rates for cockles over 30 mm SL were slightly greater at 19–37% per annum, (M of 0.21–0.46 with a midpoint of 0.33). This higher estimate was caused by relatively high mortality rates for cockles bigger than 35 mm SL and, as these are uncommon, $M = 0.30$ (range 0.20–0.40) is usually assumed for yield-per-recruit modelling (Cryer 1997) and yield calculations.

Analysis of roughly quarterly length frequency distributions between 1992 and 1996 on Snake Bank using MULTIFAN software generated an estimate of the von Bertalanffy slope parameter of $K = 1.02$,

suggesting rapid growth (about 2 y) to the size of interest to fishers (Cryer & Holdsworth 1993, Cryer 1997). This is much faster growth than in previous tagging studies by Martin (1984), who suggested cockles could take up to 4 or 5 years to attain 30 mm SL. A March 2001 notch tagging study on Snake Bank (191 returns, with 184 positive increments, Figure 8) was analysed using Gulland's method (e.g., Ricker 1975) and generated estimates of the von Bertalanffy parameters $L_{\infty} = 35.7$ mm SL and $K = 0.31$ (for that year), a much shallower growth curve than suggested by the length frequency analysis, and similar to the earlier estimates of Martin (1984).

Table 5: Length weight regressions ($W = aL^b$) for cockles on Snake Bank (weight in g, length in mm). Locations relate to the area on Snake Bank from which the cockles were collected.

Year	Location	a	b	n	Reference
1992	Random	0.00110	2.721	607	Cryer & Holdsworth (1993)
1995	Random	0.00015	3.285	226	Annala & Sullivan (1996)
1996	Mid-tide	0.00018	3.253	240	Cryer (1997)
1996	Lagoon	0.00037	3.060	204	Cryer (1997)
1998	Mid-tide	0.00018	3.275	103	Morrison & Cryer (1999)
1999	Lagoon	0.00009	3.450	114	Morrison (2000)
1999	Mid-tide	0.00010	3.445	122	Morrison (2000)
2001	Random	0.00017	3.246	193	Cryer et al. (2002a)

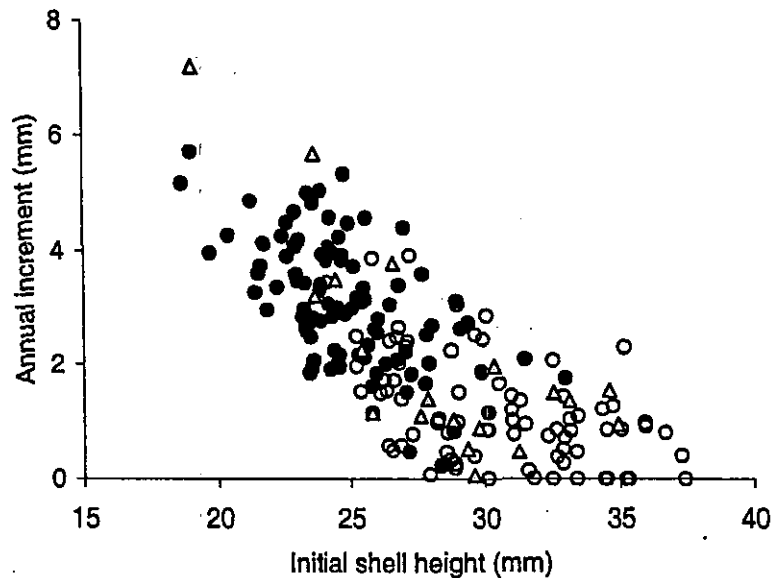


Figure 8: Marginal increments from a notch tagging study conducted on Snake Bank in April 2001–September 2002. The different symbols represent release sites with different densities of cockles (solid circles, high density; open circles, medium density; triangles, low density). It is not possible to measure negative growth using notch tags.

Notch tagging cannot be used to measure shrinkage (because the notch will extend to the margin of the shell whether the cockle has shrunk or simply not grown). However, even if all seven cockles with zero increments had in fact shrunk, they would be a small fraction of the total sample and would probably not affect the result very much. The MULTIFAN analysis could, however, have been adversely affected by highly size-dependent fishing mortality, causing this approach to underestimate L_{∞} and, consequently, overestimate K . The seasonal length frequency distributions, upon which the MULTIFAN estimates are based, are already fitted in the length-based model for cockles (McKenzie

et al. 2003), and the new notch tag results are fitted this year. A further large sample of notch tagged cockles was released in 2003 and recaptured in 2004 (Figure 9). From this plot it appears that there is little variation between years, although the 2001 data set had more large cockles than the 2003 set.

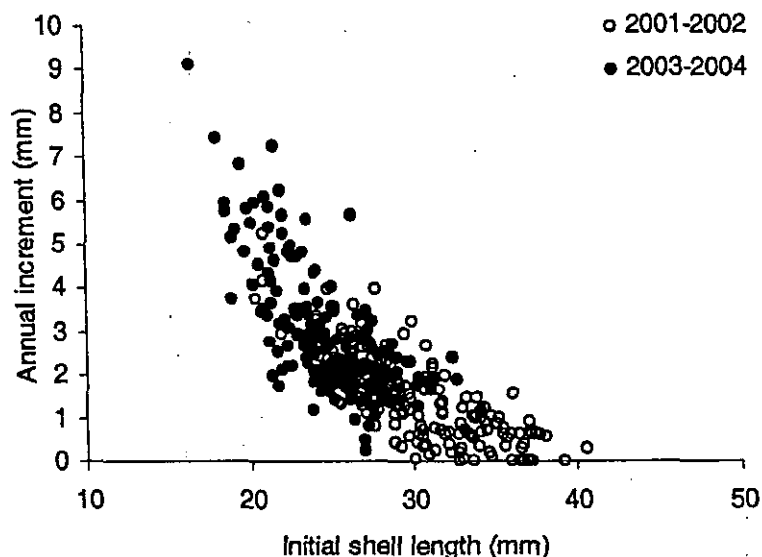


Figure 9: Marginal increments from a notch tagging study conducted on Snake Bank in 2003-04 (N=178) compared with the 2001-02 sample (N=191, all treatments combined). The 2001-02 experiment ran for 18 months and the observed increments have been scaled to reflect expected annual growth (assuming no seasonality).

3.4 Biomass estimates

Virgin recruited biomass of cockles on Snake Bank is assumed to be 2340 t, equal to the biomass of cockles of 30 mm or more SL in the first survey in 1982. Current (2004) recruited biomass was estimated by quadrat survey to be 546 t with a c.v. of 14%. Average recruited biomass was estimated from the eleven quadrat surveys between 1991 and 2004 (the fishery was assumed to have been "fully developed by about 1990) as 811 t with a c.v. of 12%. All estimates of reference and current biomass are sensitive to the assumed size at recruitment to the fishery.

3.5 Yield estimates

Yield was estimated using results from quadrat surveys and assumed values for size at recruitment. Better estimates of yield may eventually become available from modelling, but results so far have not been encouraging.

3.5.1 Estimation of Maximum Constant Yield (MCY)

MCY was estimated using method 2 (Annala *et al.* 2003):

$$MCY = 0.5 F_{0.1} B_{av} \quad (3)$$

where $F_{0.1}$ is a reference rate of fishing mortality and B_{av} is the average recruited biomass between 1991 and 2004 (811 t). Estimates of $M = 0.30$ and $F_{0.1} = 0.41$ were used (Cryer 1997).

$$MCY = 0.5 * 0.41 * 811 \text{ t} = 166 \text{ t} \quad (4)$$

This estimate would have a c.v. at least as large as that associated with the estimate of average recruited biomass between 1991 and 2004 (12%). The estimate of MCY is sensitive to the assumed size at recruitment to the fishery (Table 6).

Table 6: Sensitivity of MCY, estimated using method 2, to the assumed size at recruitment to the fishery. B_{av} was estimated for each size at recruitment using all surveys between 1991 and 2004, M is assumed, and estimates of $F_{0.1}$ were taken from Cryer 1997.

Size at recruitment (mm SL)	B_{av} (1991-04)	M	$F_{0.1}$	MCY
25	1 719	0.3	0.34	292
28	1 413	0.3	0.38	268
30	811	0.3	0.41	166
35	136	0.3	1.00	68

3.5.2 Estimation of Current Annual Yield (CAY)

Current Annual Yield (CAY) was estimated using method 1 and the full version of the Baranov Catch Equation (Annala *et al.* 2003).

$$CAY = \frac{F_{ref}}{F_{ref} + M} \left(1 - e^{-(F_{ref} + M)} \right) B_{beg} \quad (5)$$

where F_{ref} is a reference rate of fishing mortality, M is natural mortality, and B_{beg} is the start of season recruited biomass. Estimates of $M = 0.30$ and $F_{0.1} = 0.41$ were used (Cryer 1997).

$$CAY = 0.578 \times 0.508 \times 546 \text{ t} = 160 \text{ t} \quad (6)$$

This estimate would have a c.v. at least as large as that associated with the estimate of recruited biomass in March 2004 (14%). The estimate of CAY is sensitive to the assumed size at recruitment to the fishery (Table 7).

Table 7: Sensitivity of CAY, estimated using the full version of the Baranov Catch Equation, to the assumed size at recruitment to the fishery. B_{curr} was estimated for each size at recruitment, M is assumed and estimates of $F_{0.1}$ were taken from Cryer 1997.

Size at recruitment (mm SL)	$B_{curr}(04)$	M	$F_{0.1}$	CAY
25	1 500	0.3	0.34	377
28	1 009	0.3	0.38	278
30	516	0.3	0.41	160
35	59	0.3	1.00	31

3.6 Models

3.6.1 Structure of a length-based model of cockles on Snake Bank

A length based model was used by Cryer et al. (2004) to assess the snake bank cockle population. This model was adapted from a model developed by McKenzie et al. (2003), which itself was based on a model developed by Breen et al. (2000) to assess paua (*Haliotis iris*) in PAU 5B and 5D. The model is a stochastic, dynamic, length-based, observation-error time series model. It is stochastic because annual variations in recruitment can be estimated as a vector of free parameters. It is dynamic because no equilibrium, other than in the initial length structure, is assumed. Cockles are represented in the model as numbers-at-length rather than numbers-at-age. The error is assumed to be observation error rather than process error.

As at October 2003, all models developed for Snake Bank cockles had problems rationalising the observed biomass, the various length frequency distributions, and the growth increment (tagging) data. In general, fits were obtained to one series at the expense of the fit to the other(s). There seems to be a fundamental conflict in the observed data, and this may point to the existence of an "unseen" or unaccounted mortality factor impacting upon the cockle population, or high variability of growth or mortality between years. Additionally, one or more influential processes may not have been included in the model. By adding likelihood weightings into their model, Cryer et al. (2004) hoped to minimise this conflict by allowing the model to "select" the best combination of data, but this did not lead to any great improvement. In this study further development of the model has been undertaken and is outlined below.

The model is length-based, with 47 length 'bins', each of 1 mm shell length. The lower limit of the first bin is 4 mm; the largest bin is a plus-group representing cockles larger than 50 mm (which have always been very rare in the field). Sexes are not distinguished. The time step is one season (3 months). The model is implemented in AD Model Builder™ (Otter Research Ltd., <http://otter-sch.com/admodel.htm>). AD Model Builder™ incorporates a Markov chain Monte Carlo procedure for the calculation of Bayesian posterior distributions.

The model population is initialised and then driven by reported catches. The model is fitted, using maximum likelihood methods, to vectors of absolute abundance estimates from surveys, survey length frequency samples, and commercial length frequency samples. Outputs are the past, present, and (potentially) projected states of the stock, estimated using Bayesian methods. Parameters estimated in the model are:

$\ln(R_0)$	log of base recruitment R_0
I^R	mean size of new recruits to population
$(\sigma^R)^2$	variance of the size distribution of newly recruited animals
M	instantaneous annual natural mortality rate
$g_{10,y}$	mean growth increment at 10 mm for a given year
$g_{30,y}$	mean growth increment at 30 mm for a given year
α	c.v. of the expected growth increment
σ_{MIN}	minimum standard deviation of expected growth increment
ν^{lr}	shape parameter for the left-hand limb of research survey selectivity
ν^{ls}	shape parameter for the left-hand limb for commercial catch
ϕ^{diff}	The average shift in length of ϕ_1^s from period to period (3 months)
$\tilde{\sigma}$	common component of observation error
ϵ_t	vector of recruitment deviations

w_{like_x}	Likelihood weightings
w_{C_x}	Commercial catch weightings
K_{mul}	Density dependant growth scalar

Related parameters that are fixed in the model (see also Appendix 1) are:

ϕ^r	size of maximum selectivity for research surveys fixed at 11.1 mm
ν^{2r}	shape parameter for the right-hand limb of research survey selectivity fixed at 10^8
ϕ_1^s	size of maximum selectivity for commercial catch; fixed in period 1 at 32 mm
ν^{2s}	shape parameter for the right-hand limb for commercial catch fixed at 200
w_{CLF_x}	Commercial length frequency weightings

3.6.2 Summary of previous models and current additions

Over time, several additions and enhancements have been made to the original model developed by P. Breen (2000, unpublished results). We provide a brief summary of developments including (what we term) the first iteration, developed by McKenzie et al. (2003), the second iteration, developed by Cryer et al. (2004), and the third and current iteration (i.e. this report).

In the original model (and subsequent models) there was a substantial conflict between the observed biomass and the length frequency data. This resulted in poor model fits of the estimated parameters to the data. In particular, the model had great difficulty in estimating mortality, growth, and recruitment. Subsequent models have investigated possible causes of this conflict.

The first iteration investigated a variety of enhancements to the original model. Several growth models were explored as the original growth model tended to favour solutions that allowed it to shrink large proportions of the population by allowing negative growth. It was believed that this was because the model couldn't "kill off" cockles sufficiently quickly at times of low productivity and shrinking them was a reasonable (if biologically implausible) alternative. After trying a wide variety of approaches (including exponential as well as linear declines in the expected length increments) a linear growth model was chosen as the most appropriate and implemented in the model. Negative growth was not allowed. This remains the basis of the current model. Also within the first iteration, inter-annual variation in growth, and density-dependant growth, were investigated. Although successfully implemented, these options did not allow the model to produce good fits to all the data, and neither has been included in subsequent models (although both could be reinstated in future model iterations).

The second iteration of the model investigated possible misreported catch by the use of an annual scalar that represented the magnitude of over- or under-reporting of actual catches. Experience of the fishery led us to believe that both are plausible (and, indeed, quite likely at different times). The model results favoured extended periods (several years at a time) of alternating under-reporting and over-reporting at levels that are so gross (more than a factor of two) as to be implausible. We inferred from this that, although mis-reporting was possible, high variability in productivity between years (some combination of growth, recruitment, and mortality) seemed to be a much more likely explanation for most of the conflict within the model. In this iteration, the model was also modified to allow the likelihood weightings, w_{like_x} , to be freely fitted by the model. This option has been retained in the current model, although we apply identical weightings when comparing fits between iterations.

In the third and current iteration of the model we have made the following additions:

The model was updated to include all recent available data, specifically:

- 2004 total biomass estimate (see Table 3),
- 2004 population length frequency distribution (see Figures 5 and 6),
- 2004 commercial landings (assumed equal to the TACC),
- 2003–04 growth increment data from a tagging experiment (see Figure 9)

The first iteration set a semi-informative prior for M (mean 0.3, c.v. 0.8), but it was found that the model explored a wide range of values, many of which we thought to be biologically implausible. We have, therefore, implemented a tight, informative prior (mean 0.35, c.v. 0.10, Appendix 2) based on the upper limit of our biological expectations. Additionally, we have constrained the average shift in length of commercial selectivity from the previous range of 0–1.0 to 0–0.1 (cm.y^{-1}). We think this more realistic as it results in a maximum shift of about 9 cm over 20 years.

In this model we have modified growth such that separate growth models can be estimated for each year. A likelihood is calculated for each year in which growth increment data are available. For years in which no data exists, we use the combination of all the growth data as one data set (we call this global growth and the resultant global growth transition matrix). Additionally, years in which growth is fitted to the global growth can, optionally, be removed from the final growth likelihood. Thus, the model will fit the annual growth independent of the other likelihoods.

For projections of biomass estimates in the future, the choice of unknown parameters is, to some extent, arbitrary and based on assumptions of what we think is likely to occur in the near future. Here we assume the average level of future recruitment to be the same as the average over the most recent three years, with a sigma of 1.0 (indicating wide variation and uncertainty in possible future recruitment). Future growth is assumed to be the same as that estimated for “global growth” across all years in the model. Future commercial catch was set at the level of the current TACC (346 t), and all other parameters were set to the value estimated in the last period of observed data (see Appendix 3).

3.6.3 Initial conditions

The initial population is assumed to be in equilibrium with zero fishing mortality and the base recruitment. The model is run for 60 periods (15 years) with no fishing to obtain near equilibrium in numbers-at-length. To start, recruitment is evenly divided among the bins (it is added to any animals remaining there after growth from the previous quarter) in proportions determined from:

$$\beta_k^R = \exp\left(-\left(\frac{l_k - l^R}{\sigma^R}\right)^2\right) \quad (7)$$

where l_k is the midpoint length of the k th length class, l^R and σ^R are the mean and the standard deviation of the distribution of recruited cockle’s length. The last bin acts as a “plus group”. The recruitment happens annually in a chosen season (spring) for the burn-in and project periods, and in any period with $\tau_t^R = 1$ for periods with data, hence the number of recruits in period t is:

$$R_{k,t} = \tau_t^R \beta_k^R R_0 \quad (8)$$

where the τ_t^R is a switch based on whether the recruitment happens in period t ($\tau_t^R = 1$) or not ($\tau_t^R = 0$).

3.6.4 Growth transition matrix

During initialisation, the vector N_t of numbers-at-length is determined from numbers in the previous year, survival, the global growth transition matrix (G), and the vector of recruitment:

$$N_t' = N_{t-1}' \bullet G \exp(-M/4) + R_t \quad (9)$$

where the prime (') denotes vector transposition and the dot (\bullet) denotes matrix multiplication.

A growth transition matrix is calculated inside the model from the estimated growth parameters and assumed to be linear. The expected annual growth increment for the k th length class is

$$\Delta l_k = \left(\frac{\beta g_\alpha - \alpha g_\beta}{g_\alpha - g_\beta} - l_k \right) \left[1 - \left(1 + \frac{g_\alpha - g_\beta}{\alpha - \beta} \right) \right] \quad (\text{after Francis 1988}) \quad (10)$$

The model uses the ADMBTM function *posfun*, with a dummy penalty only, to ensure a positive expected increment at all lengths, using a smooth differentiable function. The *posfun* function is also

used to prevent the quantity $\left(1 + \frac{g_\alpha - g_\beta}{\alpha - \beta} \right)$ from becoming negative. The standard deviation of Δl_k

is assumed to be proportional to Δl_k with minimum σ_{\min} :

$$\sigma^{\Delta l_k} = (\Delta l_k \phi - \sigma_{\min}) \left(\frac{1}{\pi} \tan^{-1} (10^6 (\Delta l_k \phi - \sigma_{\min})) + 0.5 \right) + \sigma_{\min} \quad (11)$$

From the expected increment and standard deviation for each length class, the probability distribution of growth increments for a cockle of length l_k is calculated from the normal distribution, and translated into the vector of probabilities of transition from the k th length bin to other length bins to form the growth transition matrix G . Again, a *posfun* is implemented on l_k to ensure that negative growth does not occur.

3.6.5 Dynamics

For each period t , the model calculates the biomass available to the fishery based on the selectivity $V_{k,t}^s$ and the average weight w_k :

$$B_t = \sum_k N_{k,t} V_{k,t}^s w_k \quad (12)$$

The selectivity of the commercial fishery is assumed to have changed over time, taking smaller cockles in later years. Hence, the selectivity, $V_{k,t}^s$ is calculated from:

$$V_{k,t}^s = \lambda_{k,t}^s \exp\left(\frac{(\ln 0.5)(l_k - \phi_t^s)^2}{(v_t^{1s})^2}\right) + (1 - \lambda_{k,t}^s) \exp\left(\frac{(\ln 0.5)(l_k - \phi_t^s)^2}{(v_t^{2s})^2}\right) \quad (13)$$

$$\text{where } \phi_t^s = \phi_1^s - (t-1)\phi^{\text{diff}} \quad (14)$$

$$\text{and } \lambda_{k,t}^s = \frac{1}{1 + \exp\left(-\frac{1}{(l_k - \phi_t^s)\delta}\right)} \quad (15)$$

where δ is a shape parameter for mixing selectivity curves (assumed to be 5).

The observed catch is then used to calculate exploitation rate, which was limited to a U^{\max} with the *posfun* function of AD Model Builder™. If the ratio of catch to biomass exceeds this, then exploitation rate is restricted to just over U^{\max} and a penalty is added to the total negative log-likelihood function. It should be noted that the observed catch (C_t) can be either set as given or estimated by the model as described in Section 3.6.2. Let A_{\min} be the survival rate at U^{\max} , i.e. $1 - U^{\max}$, and A_t be $1 - U_t$:

$$A_t = 1 - \frac{C_t w_{C_x}}{B_t} \quad \text{for } \frac{C_t w_{C_x}}{B_t} \leq U^{\max} \quad (16)$$

(15)

$$A_t = 0.5A_{\min} \left[1 + \left(1 + 3 - \frac{2 \left(1 - \frac{C_t w_{C_x}}{B_t} \right)}{A_{\min}} \right)^{-1} \right] \quad \text{for } \frac{C_t w_{C_x}}{B_t} > U^{\max} \quad (17)$$

The penalty invoked when exploitation rate is limited is:

$$1000000 \left(A_{\min} - \left(1 - \frac{C_t w_{C_x}}{B_t} \right) \right)^2 \quad (18)$$

Survival from fishing is calculated as:

$$SF_{k,t} = 1 - (1 - A_t)V_{k,t}^s \quad (19)$$

The vector of numbers-at-length in the following year is calculated from:

$$N_t' = (SF_{t-1} \otimes N_{t-1}') \bullet G \exp(-M/4) + R_t \quad (20)$$

where \otimes denotes a vector element product and recruitment is modified by the estimated deviations:

$$R_{k,t} = \tau_t^R \beta_k^R R_0 \exp(\varepsilon_t - 0.5\sigma_\varepsilon^2) \quad (21)$$

3.6.6 Predictions

The predicted survey index is calculated from model numbers in bins greater than 5 mm length, taking into account sampler selectivity-at-length:

$$\hat{J}_t = \sum_{k=2}^{47} N_{k,t} V_k^r \quad (22)$$

where V_k^r is calculated from:

$$V_k^r = \lambda_k^r \exp\left(\frac{(\ln 0.5)(l_k - \phi^r)^2}{(v^{1r})^2}\right) + (1 - \lambda_k^r) \exp\left(\frac{(\ln 0.5)(l_k - \phi^r)^2}{(v^{2r})^2}\right) \quad (23)$$

and

$$\lambda_k^r = \frac{1}{1 + \exp(- (l_k - \phi^r) \delta)} \quad (24)$$

where δ is again assumed to be 5.

The model predicts proportions-at-length for the research survey from numbers in each length class for lengths greater than 5 mm:

$$\hat{p}_{k,t}^r = \frac{N_{k,t} V_k^r}{\sum_{k=2}^{47} N_{k,t} V_k^r} \quad (25)$$

Predicted proportions-at-length for commercial catch sampling are similar starting at length 19 mm:

$$\hat{p}_{k,t}^s = \frac{N_{k,t} V_{k,t}^s}{\sum_{k=16}^{47} N_{k,t} V_{k,t}^s} \quad (26)$$

Proportions at length were converted to weight at length using a length-weight relation from Cryer (1997):

$$w_k = 1.60 \cdot 10^{-7} l_k^{3.29} \quad (27)$$

where l_k is the length in millimetres and w_k is the weight in kilograms.

In calculating spawning biomass, maturity-at-length, m_k , was assumed to be knife-edged at 19 mm. Spawning biomass is, therefore:

$$S_t = \sum_k N_{k,t} m_k \quad (28)$$

3.6.7 Fitting the model

The likelihood for the predicted survey index is:

$$L(\hat{J}_t | \theta) = \frac{\varpi^J}{\sigma_t^J \tilde{\sigma} \sqrt{2\pi}} \exp \left[\frac{-\left(\ln(J_t) - \ln(\hat{J}_t)\right)^2}{2 \left(\frac{\sigma_t^J \tilde{\sigma}}{\varpi^J}\right)^2} \right] \quad (29)$$

where θ is the parameter vector. The following likelihood is used to fit model predictions to observed proportions-at-length from surveys (after Breen et al. 2000).

$$L(\hat{p}_{k,t}^r | \theta) = \frac{\kappa_t^r \varpi^r \sqrt{(p_{k,t}^r + 0.1)}}{\tilde{\sigma} \sqrt{2\pi}} \exp \left[\frac{-(p_{k,t}^r + 0.1)(p_{k,t}^r - \hat{p}_{k,t}^r)^2}{2 \left(\frac{\tilde{\sigma}}{\kappa_t^r \varpi^r}\right)^2} \right] \quad (30)$$

where κ_t^r is the square root of numbers measured in period t . The negative log-likelihood is summed for all years with observations and for all length classes. The likelihood components for commercial catch sampling and the quarterly samples are analogous.

The optimum model fit to the data was deemed to be at the mode of the joint posterior distribution (MPD) i.e., the minimum negative log value of the combined likelihoods and priors. The MPD was estimated using the auto differentiation-based minimiser ADMB.9

Likelihood weighting

Changing the relative weightings on the likelihood terms was achieved by multiplying the common observational error term ($\tilde{\sigma}$) by an inverse scalar (w_{like_x}).

$$\tilde{\sigma}_{w_{like_x}} = \tilde{\sigma} \left(\frac{1}{w_{like_x}} \right) \quad (31)$$

This weighting parameter can be set or estimated by the model. An upper bound of 20 was set for estimated weighting parameters.

Priors, bounds, and assumptions

Bayesian priors were established for all parameters. With the exception of natural mortality, M , and recruitment, all were uninformative, incorporated simply as uniform distributions with upper and lower bounds set so wide as not to restrict the estimation unless highly implausible values were explored (Appendix 2)

The prior probability density for M was calculated from the normal distribution (Appendix 2):

$$L(M) = \frac{1}{\sigma_M^2 \sqrt{2\pi}} \exp\left(-\frac{M^2}{2\sigma_M^2}\right) \quad (32)$$

The prior probability density for the vector of estimated recruitment deviations vector, ε , was calculated from the normal distribution:

$$L(\varepsilon) = \frac{1}{\sigma_\varepsilon^2 \sqrt{2\pi}} \prod_i \exp\left(-\frac{\varepsilon_i^2}{2\sigma_\varepsilon^2}\right) \quad (33)$$

3.7 Model results

3.7.1 Model fits

The model was run under several scenarios although, as in previous stock assessments, no scenario produced a completely satisfactory fit across all the observed data. All model results and parameter estimates can be found in Appendix 3. We summarise the main models below.

Under “uniform” weighting across all likelihoods (Model 1) the model achieved an excellent fit to the biomass estimates and the commercial catch-at-length distributions. However, the estimated value of M (0.57) was considered to be extreme and the fits to the survey and seasonal length frequency distributions were poor, with the model “missing” most of the observed peaks. The fit to the tag growth data was good for the 2003 data and poor for the 2001 data. The global estimates of g_{10} and g_{30} were 6.16 and 0.32 cm, respectively. This seems slightly low, although not unrealistically far from the observed annual growth for 2001 and 2003.

It should be noted that any model weightings are arbitrary and don't necessarily represent the implicit weightings used within the likelihood calculations. The implicit weightings are based on the number of data points and the error associated with each data point and the model fit. An equal weighting of 1:1:1:1 therefore does not mean all the data sets are accorded the same weight within the fitting procedure, rather, it implies a relative weighting.

When likelihood weightings were estimated rather than set, the model provided very similar weightings to the previous 2003 fitted likelihood weightings. This is not surprising as the data sets are almost identical. The optimal weightings were estimated as 1 for the biomass estimates, 5 for the commercial length frequency estimates, 13 for the survey length frequency distributions, 20 for the seasonal length frequency distributions, and 2 for the growth increment (tagging) data. For comparative purposes, we therefore decided to fix the likelihood weights at the previous values and called this the base model. This model includes fitted growth model for years in which tag return data are available, and uses the global growth model for other years.

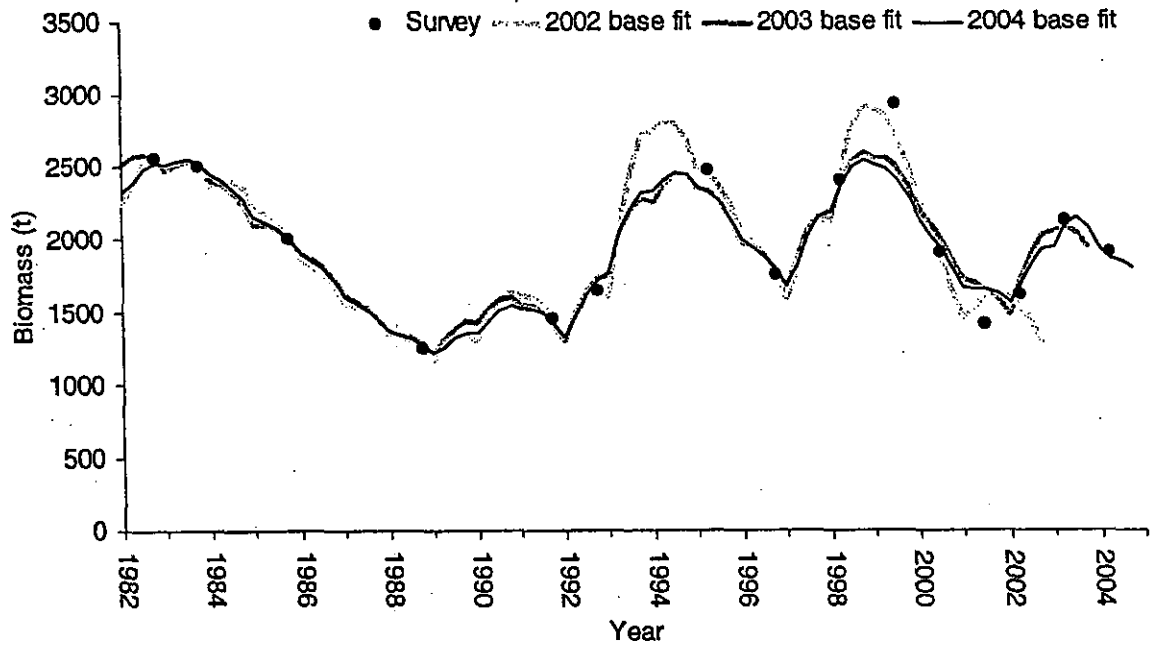


Figure 10: Model fits to survey biomass estimates under base model fit compared with the previous study base case.

The base model provided reasonable fits to the survey length frequency data (this is where most of the observed data exists), except for the peaks in 2001 and 2002, which were not reproduced (refer to Appendix 4). The biomass estimates can be seen in Figure 10. Mortality was estimated to be 0.46, which we consider high (although more plausible than previous estimates).

Fits to the annual growth parameters improved for both the observed years, although the model seems to underestimate g_{10} in 2001 (see Figure 11). It can also be seen that the fit to the global growth model suggests that average annual growth since the start of the fishery has been lower than observed in recent years.

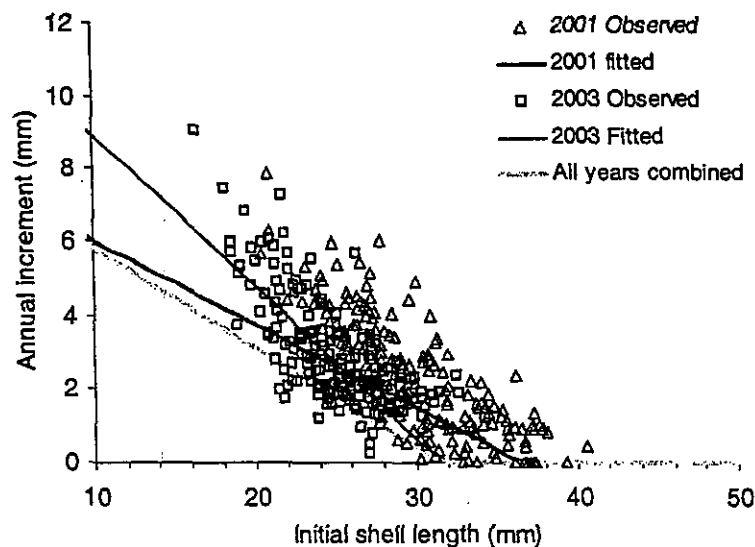


Figure 11: Model fits to the growth increment data from the 2001-2002 and 2003-04 notch-tag experiments. The 2001-2002 experiment lasted for 18 months. The grey line represents the global growth model for years without tag data.

The fitted annual recruitment residuals for the base fits of the previous models are shown in Figure 12. It is difficult to extract anything tangible from this plot, although it does appear that some autocorrelation exists, especially in the earlier years. Annual recruitment appears to oscillate between periods of high and low recruitment (positive and negative residuals). The period from 1983 to 1998 displays a period of low recruitment, (see Figure 10) corresponding to a period of steady (and unexpected) decline in biomass. The period from 1992 to 1998 shows a period of generally high recruitment, corresponding to a gradual (and surprising) increase in biomass. However, since 2001, recruitment appears to have been more random.

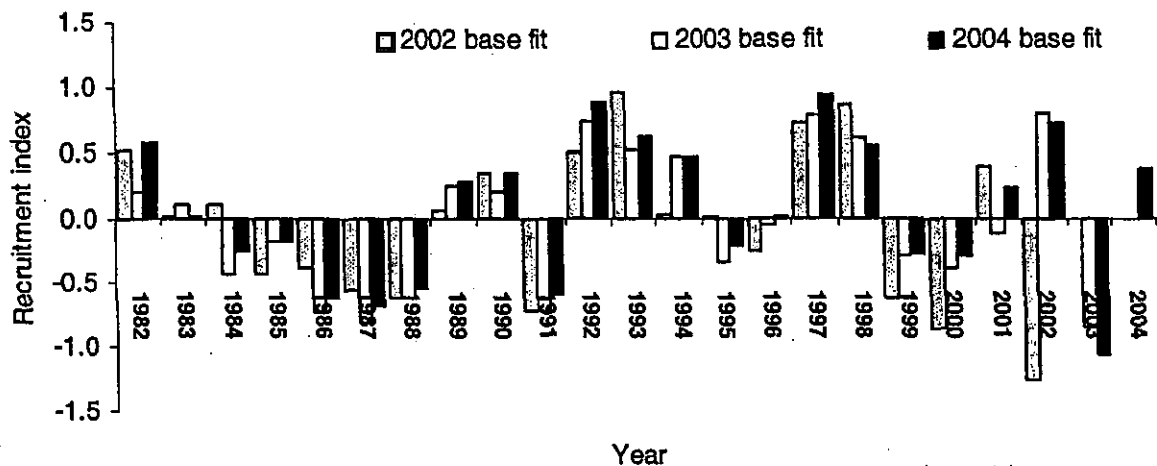


Figure 12: A comparison of annual population recruitment indices estimated from the 2002, 2003, and 2004 (current) base models.

Parameter values and correlation statistics, as output from ADMB™, for the base model are given in Appendix 5. Mean recruitment, mean recruitment variance, and survey selectivity parameters have very high c.v.s, as do most of the recruitment deviations (Eps), particularly for recent years. M is highly correlated Rcoeff, suggesting that the model has great difficulty estimating these parameters independently.

The base model was used to project the biomass three years into the future (Figure 13). It can be seen from the 90% credibility intervals that the model has very little predictive power for future biomass. It seems most likely that total biomass will decline slightly, but a rapid increase to the highest ever recorded biomass or a rapid decrease to the lowest ever recorded biomass are also possible (given the model's structure and our assumptions about future recruitment, growth, and catch).

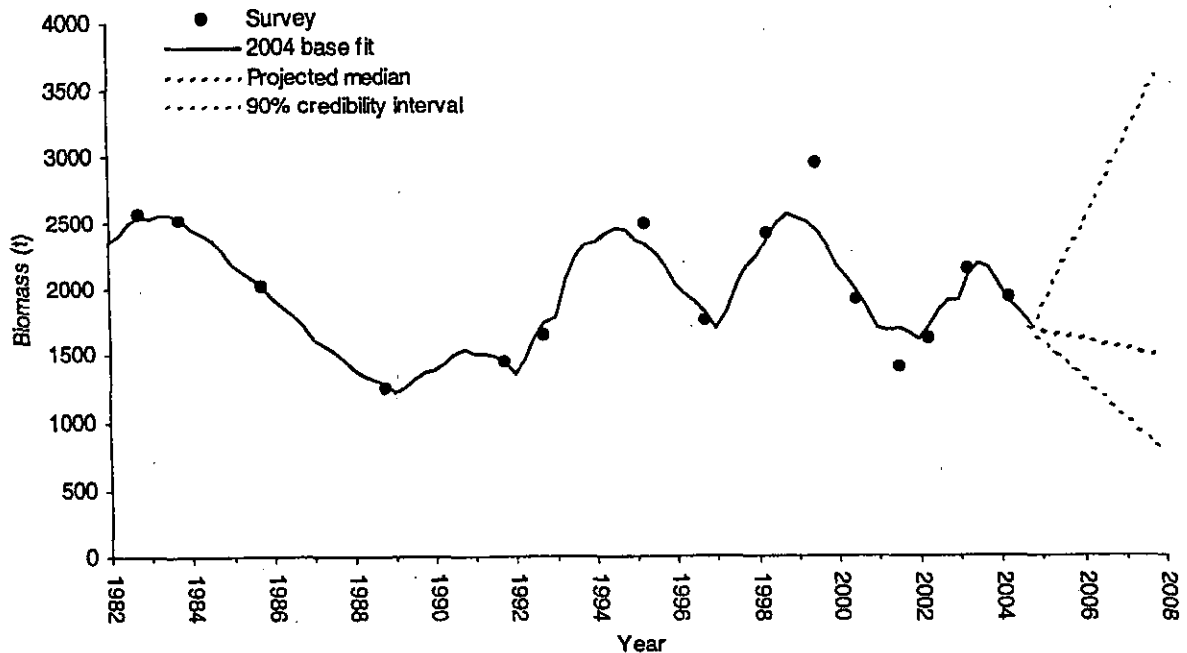


Figure 13: Projected biomass estimates using current TACC (346 t), variable recruitment, and the final period estimated parameters of the base model (see section 3.6.2 for further detail relating to parameter values).

3.7.2 Discussion of model results

Our base model suggests that the current total recruited biomass of cockles on Snake Bank is about 93% of virgin biomass (comprising mostly small cockles compared with the original population). However, all our models (Appendix 3) had problems rationalising the observed biomass, the various length frequency distributions, and the growth increment (tagging) data. In general, as found by previous studies (McKenzie et al. (2003) and Cryer et al. (2004)), fits were obtained to one observational series at the expense of the fit to the other(s). There seems to be a fundamental conflict in the observed data or the model formulation. The high c.v.'s of the mean size and variance of size at recruitment indicate that the model does not fit these parameters well. Additionally, mortality (M) has a high positive correlation with base recruitment (R_{coeff}). Both indicate that the model has great difficulty in rationalising recruitment of new individuals into the population and their subsequent mortality.

One fundamental assumption of the model is that several parameters, including mortality, length of recruitment, and global growth, are constant over the entire observed time period. This may be an unrealistic restriction in the model because some (or all) may be highly variable between years. The most obvious example of this is growth (where substantially different growth models are generated using the tag return data or the length frequency distributions), but the model population tends to favour high natural mortality so it can "shed" excess biomass rapidly at some times. We recommend that further growth increment data be collected over several years, preferably with recovery several times each year to assess seasonal variability as well as inter-annual variability in growth. Variability in recruitment probably exceeds variability in other "productivity parameters". Although this is recognised through the inclusion of annual recruitment deviations in the model, we believe that this variability also suggests that the population is responding to environmental conditions that can vary substantially between years. This variability may affect growth and mortality as well as recruitment, but such complexity is not presently captured by the model.

We believe that using the model to make future projections is questionable; the variability and unpredictability in mortality, growth, and recruitment, render any future projections extremely sensitive to the assumed parameters. Without having any idea about the likely value these parameters will be in the future any projections have to be based on past values. Selection of different past values creates an extremely wide range of possible future values as the 90% confidence intervals convey.

There are several possibilities for further model development, the most obvious of which is to allow more inter-annual variability in the model. Parameters could be made annual instead of fixed across the whole time period. However, this approach would rely on the availability of substantially more data on growth variability, mortality experiments, and detailed recruitment measurements. It is doubtful that another years' data would make much difference to the current results. We therefore suggest that no further development of the model should be undertaken for 3–5 years, and that resources be concentrated more on data collection, particular for growth and recruitment variability. Further collection of growth data should include a seasonal component, to gain an understanding of any seasonal variability. Recruitment data could be obtained by conducting surveys with much finer sieve sizes, thereby collecting the smaller recruiting cockles at key times of year. Although we do not recommend much model development for the near future, it would be worthwhile including any new data into the current model to examine the effect. This would entail only a modest amount of work.

Another potentially important use of the model is for risk analysis and management. Current projections are made using the average recruitment over the past three years. However, this may seriously overestimate likely recruitment in the future. For example, consecutive years of poor recruitment would probably lead to some or all of rapidly declining biomass, permanent recruitment failure, and inability to take the TACC. Risk analysis could be done independent of model development and would not necessarily require and additional data.

4. MANAGEMENT IMPLICATIONS

There has been a decline in the biomass of cockles of 30 mm or greater SL on Snake Bank since 2003, although the biomass remains higher than in 2001 and 2002. Current estimates of yield (as CAY and MCY) are lower than recent average landings if the size at recruitment to the fishery is assumed to be 30 mm SL. Yield estimates are sensitive to the assumed size at recruitment but CAY is less than the TACC and recent average landings for all assumed sizes at recruitment except 25 mm SL, and MCY is always less than the TACC and recent average landings.

Better estimates of yield may eventually become available as the length-based model is developed and refined, but models based on different growth models, a variety of weighting scenarios, and explorations of density dependent growth, inter-annual variability of growth, and mis-reporting have not fitted the data well. There appear to be fundamental conflicts in the data suggesting that growth and/or mortality (as well as recruitment) may be highly variable among years, or that there are substantial errors in the reported landings. There are sufficient inconsistencies and conflicts in all versions of the model for us to conclude that, despite its long development, it still cannot provide a reasonable description of the observed data. We are, therefore, not confident that estimates of productivity, biomass, and yield made using the length based model are reliable, and we suggest that the simpler estimates based on observed biomass and reference rates of fishing mortality are likely to be more reliable in the short to medium term.

5. ACKNOWLEDGMENTS

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6. REFERENCES

- Annala, J.H., Sullivan, K.J. (Comps.) 1996: Report from the Fishery Assessment Plenary, May 1996: stock assessments and yield estimates. 308 p. (Unpublished report held in NIWA library, Wellington.)
- Annala, J.H., Sullivan, K.J., O'Brien, C.J.; Smith, N.W.McL., and S.M. Grayling. (Comps.) 2003: Report from the Fishery Assessment Plenary, May 2003: stock assessments and yield estimates. 616 p. (Unpublished report held in NIWA library, Wellington.)
- Bradford, E. (1998). Harvest estimates from the 1996 national recreational fishing surveys. New Zealand Fisheries Assessment Research Document 98/16. 27 p. (Draft report held in NIWA library, Wellington).
- Breen, P.A.; Andrew, N.L.; Kendrick, T.H. (2000). The 2000 stock assessment of paua (*Haliotis iris*) in PAU 5B using an improved Bayesian length-based model. *New Zealand Fisheries Assessment Report 2000/48*. 36 p.
- Cryer, M. (1997). Assessment of cockles on Snake Bank, Whangarei Harbour, for 1996. N.Z. Fisheries Assessment Research Document 97/2. 29 p. (Draft report held in NIWA library, Wellington).
- Cryer, M.; Holdsworth, J. (1993). Productivity estimates for Snake Bank cockles, August 1992 to August 1993. MAF Fisheries Northern Fisheries Region Internal Report, Auckland. (Draft report held at NIWA, Auckland).
- Cryer, M.; Watson, T.G.; Smith, M.D.; MacKay, G.; Tasker, R. (2004). Biomass survey and stock assessment of cockles on Snake Bank, Whangarei Harbour, 2003. Draft New Zealand Fisheries Assessment Report submitted in fulfilment of project COC200201. 39 p.
- Cryer, M.; Parkinson, D.M. (2001). Biomass surveys and preliminary stock assessment of cockles, Snake Bank, Whangarei Harbour, 2001. Final Research Report for Ministry of Fisheries Research Project COC2000/01, Objectives 1 & 3. (Unpublished report available from Ministry of Fisheries, Wellington).
- Cryer, M.; McKenzie, J.R.; Breen, P.A.; Kim, S.; Parkinson, D.M.; Smith, M.D.; MacKay, G.; Tasker, R. (2003). Biomass surveys and stock assessment of cockles in Whangarei Harbour, including Snake Bank, 2002. *New Zealand Fisheries Assessment Report 2003/xx*. 40 p.
- Cryer, M.; Smith, M.; Mackay, G.; Tasker, R. (2002a). Biomass survey and preliminary stock assessment of cockles, Snake Bank, Whangarei Harbour, 2002 Final Research Report for Ministry of Fisheries Research Project COC2001/01, Objectives 1 & 2. (Unpublished report available from Ministry of Fisheries, Wellington.)
- Cryer, M.; Smith, M.D.; Parkinson, D.M.; MacKay, G.; Tasker, R. (2002b). Biomass surveys of cockles in Whangarei Harbour, 2002. Final Research Report for Ministry of Fisheries Research Project COC2001/01, Objectives 3. (Unpublished report available from Ministry of Fisheries, Wellington.)
- Franics, R.I.C.C. (1988). Maximum likelihood estimation of growth and growth variability from tagging data. *New Zealand Journal of Marine and Freshwater Research* 22: 43-51.
- Hartill, B.; Cryer, M. (2000). Shellfish harvesting in the Auckland metropolitan area. *NIWA Technical Report No. 96*. 51 p.
- Larcombe, M.F. (1971). The ecology, population dynamics, and energetics of some soft shore molluscs, Unpublished PhD thesis, University of Auckland, N.Z.
- McKenzie, J.R.; Cryer, M.; Breen, P.A.; Kim, S. (2003). A length-based model for cockles on Snake Bank, Whangarei Harbour, 2002. Final Research Report for Ministry of Fisheries Research Project COC2001/01, Objective 2. (Unpublished report available from Ministry of Fisheries, Wellington).
- Martin, N.D. (1984). *Chione stutchburyi* population responses to exploitation. Unpublished MSc thesis, University of Auckland, N.Z.
- Morrison, M. (2000). Stock assessment of cockles on Snake Bank, Whangarei Harbour, 1999. *New Zealand Fisheries Assessment Report 2000/26*. 20 p.

- Morrison, M.; Cryer, M. (1999). Stock assessment of cockles on Snake and MacDonald Banks, Whangarei Harbour, 1998. New Zealand Fisheries Assessment Research Document 99/07. 9 p. (Unpublished report held in NIWA Library, Wellington).
- Morrison, M.; Parkinson, D.M. (2001). Stock assessment of cockles on Snake and MacDonald Banks, Whangarei Harbour, 2000. *New Zealand Fisheries Assessment Report 2001/19*. 16 p.
- Ricker, W.E. 1975: Computation and interpretation of biological statistics of fish populations. *Bulletin 191, Department of the Environment, Fisheries and Marine Service, Ottawa, Canada*. 382 p.
- Snedecor, G.W.; Cochran, W.C. (1989). *Statistical methods*. 8th ed. Iowa State University Press, Ames, Iowa, USA.
- Teirney, L.D.; Kilner, A.R.; Millar, R.E.; Bradford, E.; Bell, J.D. (1997). Estimation of recreational catch from 1991-92 to 1993-94, New Zealand Fisheries Assessment Research Document 97/15. 43 p. (Unpublished report held in NIWA Library, Wellington).

Appendix 1

Non estimable model parameters

Parameter	Description
RO	base number of annual recruits ($= \exp(\ln(RO))$)
β_k^R	proportion of recruits that enter the k th length class
τ_i^R	a switch based on whether animal is recruited in period t ($\tau_i^R = 1$) or not ($\tau_i^R = 0$)
σ_ε	assumed standard deviation of recruitment deviations in logarithmic space
$N_{k,t}$	number of cockles in the k th length class in period t
$R_{k,t}$	recruits to the model in the k th length class in period t
Δl_k	expected seasonal growth increment for cockle in the k th length class
$\sigma^{\Delta l_k}$	standard deviation of the growth increment for cockle in the k th length class
G	growth transition matrix
B_t	biomass of cockles available to the fishery in period t
l_k	length of a cockle at the midpoint of the k th length class
w_k	average weight of a cockle at l_k
m_k	proportion of mature cockles at l_k
S_t	biomass of mature cockle in period t
C_t	total observed catch in period t
U_t	exploitation rate in period t
U^{max}	maximum permitted exploitation rate
$SF_{k,t}$	finite rate of survival from fishing for cockles in the k th length class in period t
\hat{J}_t	predicted research diver survey index
J_t	observed research diver survey index
V_k^r	relative selectivity of research divers for cockles in the k th length class
λ_k^r	proportion of mixing the two normal curve for the research survey selectivity
$V_{k,t}^s$	relative selectivity of the commercial fishery for cockles in the k th length class, in period t
$\lambda_{k,t}^s$	proportion of mixing two normal curve for the commercial fishery selectivity
ϕ_t^s	size of maximum selectivity for catch sampling selectivity function in period t
σ_t^J	the standard error of the estimate of research survey index in period t
ω^J	relative weight assigned to the research diver survey index data set
κ_t^s	a relative weight for length frequency data from commercial catch sampling in period t
$\hat{P}_{k,t}^s$	predicted proportion-at-length in the k th length class in period t in commercial catch sampling
$P_{k,t}^s$	observed proportion-at-length in the k th length class in period t in commercial catch sampling
ω^s	relative weight assigned to the commercial catch sampling length frequency data
κ_t^r	a relative weight for length frequency data from research surveys in period t
$\hat{P}_{k,t}^r$	predicted proportion-at-length in the k th length class in period t in research surveys
$P_{k,t}^r$	observed proportion-at-length in the k th length class in period t in research surveys
ω^r	relative weight assigned to the research survey length frequency data
L	likelihood
μ_M	mean of the prior distribution for M
σ_M	standard deviation of the prior distribution for M

Appendix 2 Prior specifications and parameter bounds

Parameter	Prior	Mean	c.v.	Lower bound	Upper bound
$\ln(R0)$	Uniform	-	-	1.000	50.000
t^R	Uniform	-	-	2.000	10.000
$(\sigma^R)^2$	Uniform	-	-	0.200	25.000
M	Normal	0.35	0.10	0.050	0.800
L_{∞}	Uniform	-	-	20.000	50.000
$g10$	Uniform	-	-	1.000	20.000
K	Uniform	-	-	0.010	2.000
$g30$	Uniform	-	-	0.000	2.000
α	Uniform	-	-	0.001	1.000
σ_{min}	Uniform	-	-	0.001	5.000
ν^r	Uniform	-	-	2.000	5.000
ν^s	Uniform	-	-	0.001	50.000
ϕ^{diff}	Uniform	-	-	0.000	0.100
σ	Uniform	-	-	0.010	100.000
ε_t	Normal	0.00	0.40	-2.300	2.300

Appendix 3: Parameter estimates from Maximum Probability Density (MPD) fits to observational data under various weighting scenarios (weighting ratios biomass : commercial LF : seasonal LF: survey LF: tag data)

Parameters	2002 Base	2003 Base 1:5:13:20:2	2004 Variants			
			Model 1 1:1:1:1:1	Model 2 1:6:14:20:2 (fitted wghts)	Model 3 1:5:13:20:2 (with global tags)	Model 4 1:5:13:20:2 (no global tags)
<i>ln(F0)</i>	19.04	18.51	18.84	18.5916	18.5498	18.5054
<i>i</i> [*]	3.12	2.60	2.88	2.91537	2.79273	2.8317
<i>M</i>	0.66	0.45	0.57	0.463215	0.462225	0.431311
<i>g30</i>	0.54	0.39	0.32	0.523165	0.547334	0.477771
<i>g10</i>	5.91	6.75	6.16	5.71042	5.93596	5.55824
<i>g30 - 2002</i>	-	-	1.60	1.6052	1.59221	1.60518
<i>g10 - 2002</i>	-	-	6.02	5.98689	6.1226	5.98664
<i>g30 - 2003</i>	-	-	0.32	0.523165	0.547334	0.477771
<i>g10 - 2003</i>	-	-	7.62	8.43515	9.15726	9.05669
<i>v</i> ^{1'}	1.57	2.00	0.02	0.00958277	0.00388792	0.00384478
<i>v</i> ^{1*}	0.24	0.10	1.69	1.58969	1.45226	1.51908
<i>v</i> ^{2*}	0.05	0.04	0.02	0.0228664	0.0227419	0.0218058
<i>ε</i> 1982	0.51	0.20	0.63	0.580221	0.572952	0.597132
<i>ε</i> 1983	0.01	0.11	-0.02	-0.0102503	0.00834768	-0.0621064
<i>ε</i> 1984	0.10	-0.43	-0.06	-0.269367	-0.266473	-0.286845
<i>ε</i> 1985	-0.43	-0.17	-0.12	-0.18758	-0.178352	-0.226518
<i>ε</i> 1986	-0.39	-0.72	-0.47	-0.625936	-0.628052	-0.66716
<i>ε</i> 1987	-0.56	-0.81	-0.62	-0.681765	-0.683922	-0.720807
<i>ε</i> 1988	-0.62	-0.62	-0.56	-0.53992	-0.545583	-0.542392
<i>ε</i> 1989	0.06	0.24	0.47	0.300033	0.269929	0.358397
<i>ε</i> 1990	0.33	0.19	0.11	0.297059	0.330741	0.29173
<i>ε</i> 1991	-0.72	-0.71	-0.55	-0.51254	-0.582023	-0.46636
<i>ε</i> 1992	0.50	0.73	0.60	0.885606	0.874937	0.929471
<i>ε</i> 1993	0.95	0.51	0.84	0.619393	0.619421	0.624867
<i>ε</i> 1994	0.03	0.46	0.47	0.417908	0.458492	0.442803
<i>ε</i> 1995	0.01	-0.34	-0.28	-0.172128	-0.21434	-0.237911
<i>ε</i> 1996	-0.26	-0.06	-0.11	0.00512483	0.0102133	-6.28E-03
<i>ε</i> 1997	0.72	0.77	0.68	0.946201	0.933693	1.02662
<i>ε</i> 1998	0.86	0.61	1.15	0.464352	0.548313	0.492172
<i>ε</i> 1999	-0.61	-0.29	-1.21	-0.259098	-0.281495	-0.360109
<i>ε</i> 2000	-0.85	-0.38	-2.27	-0.257244	-0.296982	-0.294565
<i>ε</i> 2001	0.38	-0.12	0.36	0.319102	0.221945	0.313808
<i>ε</i> 2002	-1.26	0.80	0.71	0.583733	0.714231	0.652337
<i>ε</i> 2003	-	-0.85	-1.31	-0.794552	-1.06635	-1.06991
<i>ε</i> 2004	-	-	0.39	0.133629	0.375732	0.155823
<i>Likelihoods</i>						
Like Blo	5.39	16.17	-64.03	26.4232	21.5377	26.3449
Like Com LF	-106.14	-290.79	-273.50	-332.4	-310.023	-3.19E+02
Like Seas LF	-	-1137.46	-981.91	-1132.79	-1148.41	-1131.73
Like Survey LF	-2293.78	-1508.85	-1593.92	-1665.72	-1645	-1660.12
Like Tag LF	-	390.90	515.81	1202.07	1195.29	527.423
Mprior	3.27	9.56	76.59	17.8003	17.4357	7.66754
RecruitPrior	22.73	19.17	44.27	18.004	20.9828	21.6129
Total like	-2368.52	-2501.31	-2276.69	-1866.61	-1848.19	-2527.9
<i>Indicators</i>						
B0	2,328,270	2,593,240	2,263,400	2,374,770	2,372,330	2,391,080
B0rec	1,104,360	1,325,750	1,327,410	1,532,760	1,552,740	1,543,410
B2002rec	929,631	-	-	-	-	-
B2003rec	-	1,510,090	-	-	-	-
B2004rec	-	-	1,396,790	1,424,240	1,449,220	1,435,170
B2002rec/B0rec	84%	-	-	-	-	-
B2003rec/B0rec	-	114%	-	-	-	-
B2004rec/B0rec	-	-	105%	93%	93%	93%

Appendix 4 Model fits under base model weighting.

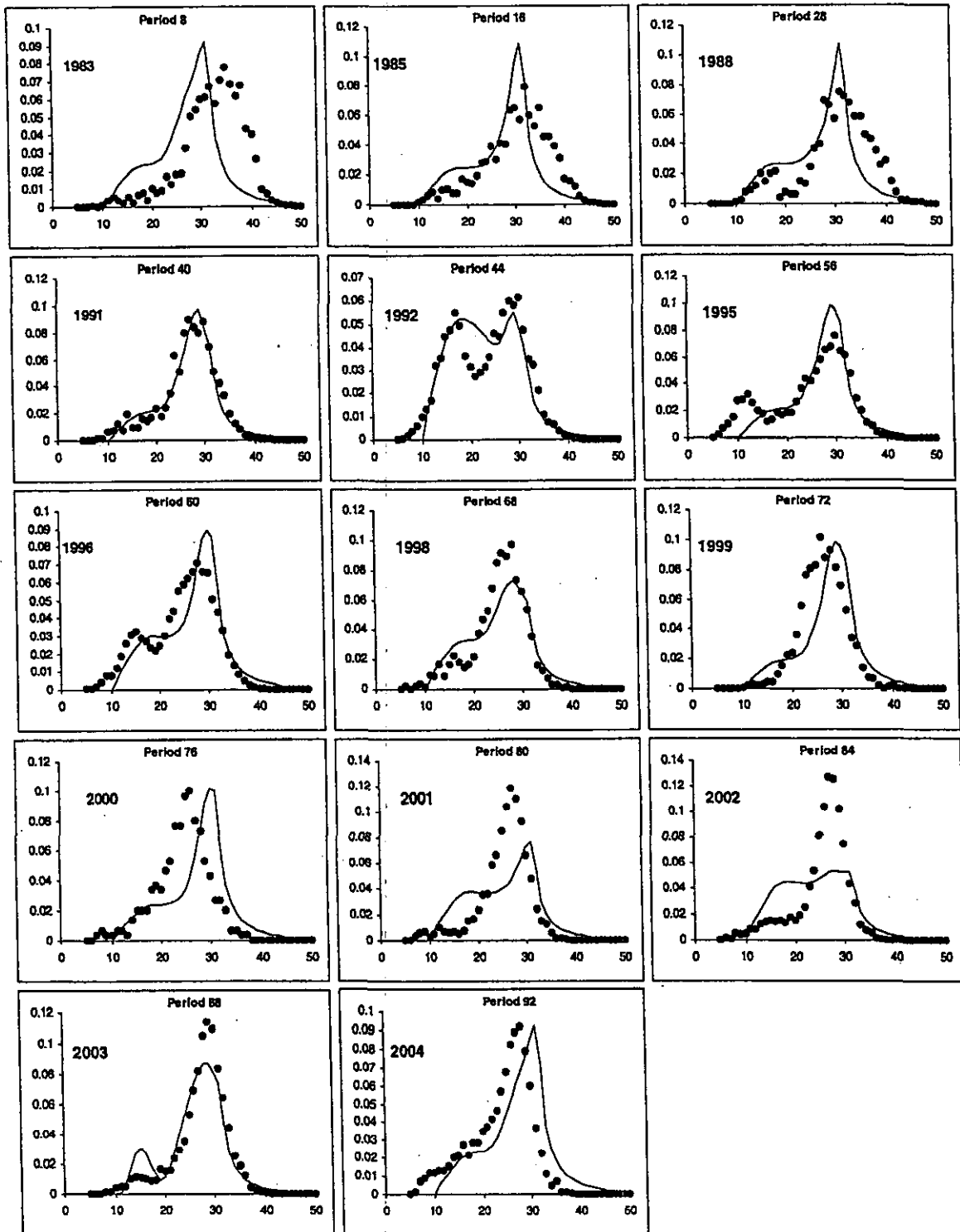


Figure 14: Model fits to the survey length frequency data under base model weighting.

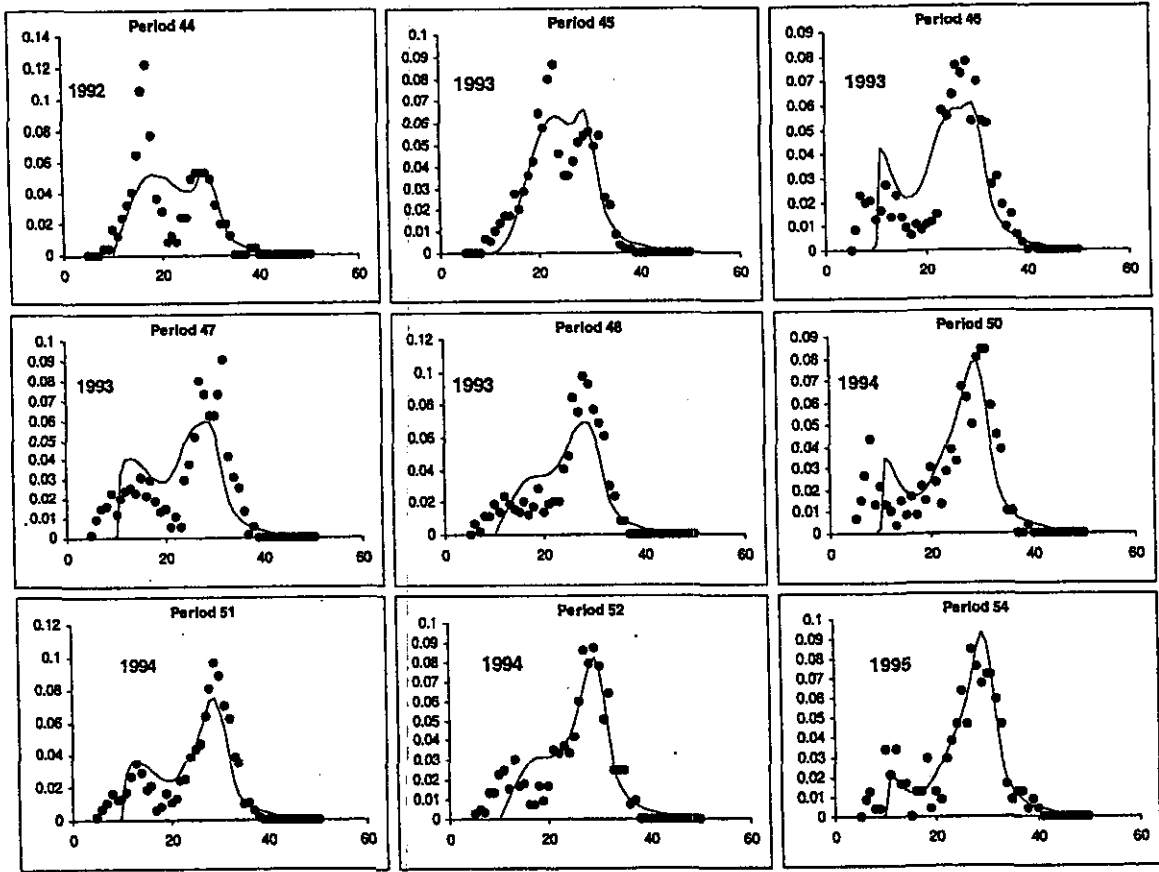


Figure 15: Model fits to the seasonal length frequency data under base model weighting.

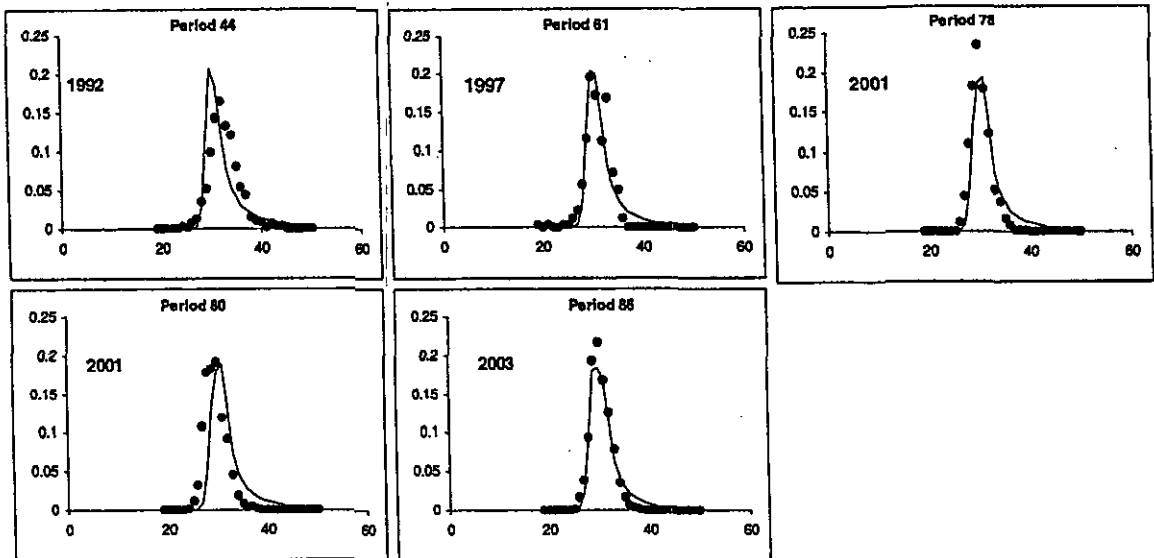


Figure 16: Model fits to the commercial length frequency data under base model weighting.

Appendix 5: Base model parameter values and correlations from auto-differentiation fitting process (shaded indicates high correlation).

index	name	value	sd	cv	Rcoeff	sigmaIide	M	g30	g30	g30	g10	g10	g10	SelectUS	SelectdLLF	SelectLLF	RecSizeMean	RecSizeVar	GrowthCV	GrowthCV	GrowthCV	GrowthStdevMin	GrowthStdevMin	GrowthStdevMin	Eps 1982	Eps 1983					
1	Rcoeff	18.55	0.05	0.3%	1.0																										
2	sigmaIide	0.18	0.00	2.1%	-0.1	1.0																									
3	M	0.46	0.01	2.8%	-0.7	-0.1	1.0																								
4	g30	1.59	0.05	3.2%	0.0	0.0	0.0	1.0																							
5	g30	0.84	0.09	10.6%	0.1	0.0	0.1	0.0	1.0																						
6	g30	0.55	0.02	3.7%	0.1	0.1	0.2	0.0	-0.3	1.0																					
7	g10	6.12	0.30	4.9%	0.0	0.0	0.0	0.2	0.0	0.0	1.0																				
8	g10	9.16	0.29	3.2%	-0.1	0.0	-0.1	0.0	-0.1	0.2	0.0	1.0																			
9	g10	5.94	0.10	1.7%	0.2	0.1	0.5	0.0	0.0	0.1	0.0	-0.1	1.0																		
10	SelectUS	0.00	12.91	332081.6%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0																	
11	SelectdLLF	0.02	0.00	8.0%	-0.1	0.0	0.0	0.0	0.3	0.0	0.0	-0.2	0.1	0.0	1.0																
12	SelectLLF	1.45	0.13	8.9%	0.0	0.0	0.0	0.0	-0.2	-0.1	0.0	0.1	-0.1	0.0	0.0	1.0															
13	RecSizeMean	2.79	772.13	27648.2%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0														
14	RecSizeVar	0.23	49.96	21823.9%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0													
15	GrowthCV	0.44	0.03	6.1%	0.0	0.0	0.0	-0.3	0.0	0.0	-0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0												
16	GrowthCV	0.12	225.34	186508.9%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0											
17	GrowthCV	0.88	0.03	3.8%	-0.1	-0.1	0.1	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0										
18	GrowthStdevMin	1.86	0.10	5.3%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0									
19	GrowthStdevMin	1.98	0.10	5.0%	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0							
20	GrowthStdevMin	3.02	0.11	3.5%	-0.3	-0.3	0.0	0.0	0.0	-0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0						
21	Eps 1982	0.57	0.13	22.4%	-0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.0					
22	Eps 1983	0.01	0.10	1167.4%	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0				
23	Eps 1984	-0.27	0.17	-65.1%	-0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	-0.4			
24	Eps 1985	-0.18	0.19	-106.7%	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	-0.1			
25	Eps 1986	-0.63	0.26	-41.1%	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0			
26	Eps 1987	-0.68	0.24	-35.1%	-0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-0.1		
27	Eps 1988	-0.55	0.24	-43.2%	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-0.1		
28	Eps 1989	0.27	0.23	85.6%	-0.1	0.0	-0.1	0.0	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-0.1		
29	Eps 1990	0.33	0.19	57.1%	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	-0.1		
30	Eps 1991	-0.58	0.19	-32.8%	0.2	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	-0.1		
31	Eps 1992	0.87	0.06	6.5%	-0.7	0.0	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.4		
32	Eps 1993	0.62	0.07	11.6%	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.5	-0.2	
33	Eps 1994	0.46	0.08	17.6%	-0.3	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	-0.2		
34	Eps 1995	-0.21	0.11	-60.0%	-0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	-0.2	
35	Eps 1996	0.01	0.09	890.6%	-0.4	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	-0.2	
36	Eps 1997	0.93	0.08	8.1%	-0.4	0.0	-0.2	0.0	0.0	-0.1	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	-0.3		
37	Eps 1998	0.55	0.11	20.4%	-0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	-0.1		
38	Eps 1999	-0.28	0.18	-62.8%	-0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	-0.1	
39	Eps 2000	-2.97E-01	1.54E-01	-52.0%	-0.2	0.0	0.0	0.0	-0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	-0.1
40	Eps 2001	2.22E-01	1.17E-01	52.9%	-0.3	0.0	-0.2	0.0	0.1	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	-0.2	
41	Eps 2002	7.14E-01	6.65E-02	9.3%	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	-0.2
42	Eps 2003	-1.07E+00	1.94E-01	-18.2%	-0.2	0.1	-0.1	0.0	-0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.1	0.0	0.0	0.2	-0.1		
43	Eps 2004	0.38	0.34	90.3%	0.1	-0.1	0.2	0.0	-0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
44	Rcoeffprof	18.55	0.05	0.3%	1.0	-0.1	-0.2	0.0	0.1	0.1	0.0	-0.1	0.2	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	-0.3	0.0	0.7	0.3			

index	name	value	sd	cv	Eps 1984	Eps 1985	Eps 1986	Eps 1987	Eps 1988	Eps 1989	Eps 1990	Eps 1991	Eps 1992	Eps 1993	Eps 1994	Eps 1995	Eps 1996	Eps 1997	Eps 1998	Eps 1999	Eps 2000	Eps 2001	Eps 2002	Eps 2003	Eps 2004	Rcoeffprof
23	Eps 1984	-0.27	0.17	-65.1%	1.0																					
24	Eps 1985	-0.18	0.19	-106.7%	-0.2	1.0																				
25	Eps 1986	-0.63	0.26	-41.1%	0.1	-0.1	1.0																			
26	Eps 1987	-0.68	0.24	-35.1%	0.1	-0.1	-0.5	1.0																		
27	Eps 1988	-0.55	0.24	-43.2%	0.1	0.0																				