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J. R. Williams
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J. R. Williams[1]
M. D. Smith[1]
G. Mackay[2]

[1]NIWA
PO Box 109695
Newmarket
Auckland

[2]NIWA
Bream Bay Aquaculture Park
PO Box 147
Ruakaka

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EXECUTIVE SUMMARY

Williams, J.R.; Smith, M.D.; Mackay, G. (2006). Biomass survey and stock assessment of cockles (*Austrovenus stutchburyi*) on Snake Bank, Whangarei Harbour, 2006.
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A stratified random survey of cockles (*Austrovenus stutchburyi*) on Snake Bank, Whangarei Harbour (COC 1A) in March 2006 produced an estimate of recruited biomass (30 mm or greater shell length, SL) of 792 t with a c.v. of 13.1%. This estimate is lower than the 2003 and 2005 estimates (1030 and 967 t with c.v.s of 12 and 20%, respectively) but higher than the estimates in 2000, 2001, 2002, and 2004 (435–570 t with c.v.s of 14–25%). Current recruited biomass is about 34% of its virgin level. Incorporating information from this latest survey leads to yield estimates of MCY = 171 t and CAY (for 2006) = 232 t. These yield estimates are lower than the current TACC of 346 t. Biomass and yield estimates 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 1194 t, about 48% of virgin biomass (2504 t, cockles 28 mm SL or larger). Yield at an assumed size at recruitment of 28 mm SL was estimated as MCY = 254 t and CAY (for 2006) = 329 t. Only at an assumed size at recruitment of 25 mm (roughly the size of the very smallest cockle in commercial landings) was the estimated CAY greater than 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. However, the 2006 length frequency distribution suggests that recent recruitment has been above average, and recent reported landings (151 t in 2004–05) are less than both the TACC and the estimates of MCY and CAY. These observations suggest that fishing at the level of recent landings is likely to be sustainable 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 2006) is described, an analysis of seasonal growth from tagging data is presented, and yield estimates for 2006 are derived using methods after Sullivan et al. (2005). The overall objective was to carry out a stock assessment of cockles on Snake Bank, including estimating absolute biomass and sustainable yields. Specific objectives were to:

1) estimate the size structure and absolute biomass of cockles on Snake Bank during March–April 2006. The target coefficient of variation (c.v.) of the estimate of absolute recruited biomass was 20%.
2) complete the cockle stock assessment and estimate yields for cockles on Snake Bank for the 2006–07 fishing year
3) estimate growth of cockles in COC 1A.

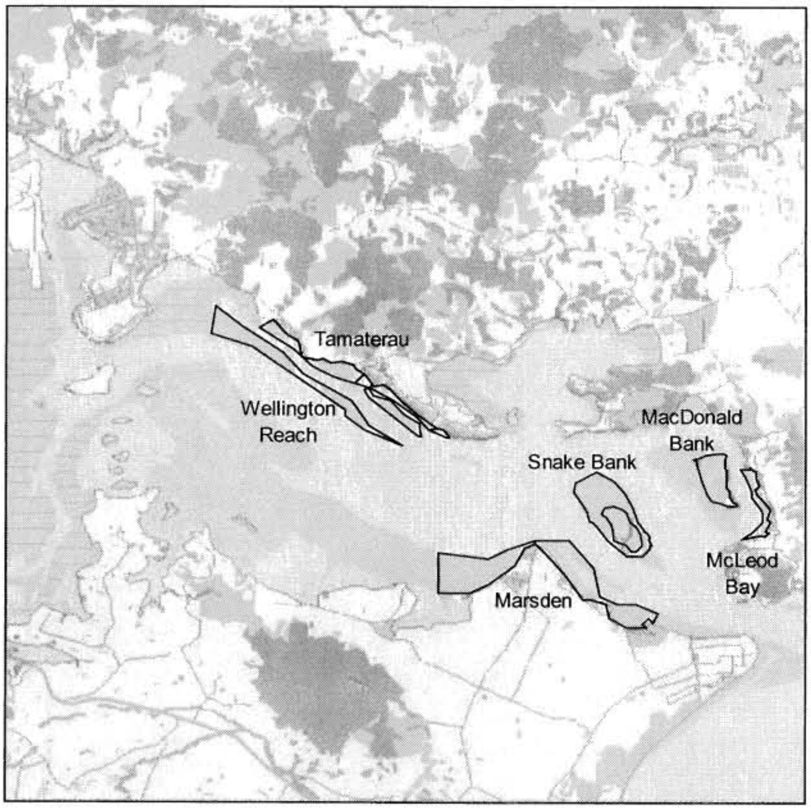

Figure 1: Beaches and banks within Whangarei Harbour that support appreciable numbers of cockles (as at July 2002, Cryer et al. (2002b)). Sampling strata are delineated by solid lines. The boundary of Snake Bank has subsequently moved (see Figure 5).

1.2 Description of the fishery

Commercial picking in Whangarei Harbour (COC 1A) 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. There is no minimum legal size for cockles.

1.3 Literature review

General reviews of the fishery and cockle biology were given by Cryer (1997) and the Ministry of Fisheries Science Group (2006). Biomass estimates have been generated for Snake Bank by Cryer (1997), Morrison & Cryer (1999), Morrison (2000), Morrison & Parkinson (2001), Cryer & Parkinson (2001), Cryer et al. (2002a, 2004), Watson et al. (2005), and Williams et al. (2006). 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, *Haliotis iris* (Breen et al. 2000), was developed for cockles by P. Breen (2000, unpublished results), and refined by McKenzie et al. (2003) and Watson et al. (2005), although the fit to the observed data was poor at all 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 (greenweight) 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 and catch limits (t greenweight) of cockles from Snake Bank since 1986–87 (from Quota Management Report records, after the Ministry of Fisheries Science Group (2006)). A TACC of 346 t was established in October 2002 when COC 1A entered the QMS. Before this, the fishery was restricted by daily catch limits which summed to 584 t in a 365 day year, but there was no explicit annual restriction. * The figure of 566 t for 1993–94 may be unreliable.

Year	Landings (t)	Limit (t)	Year	Landings (t)	Limit (t)
1986–87	114	584	1996–97	457	584
1987–88	128	584	1997–98	439	584
1988–89	255	584	1998–99	472	584
1989–90	426	584	1999–00	505	584
1990–91	396	584	2000–01	423	584
1991–92	537	584	2001–02	405	584
1992–93	316	584	2002–03	237	346
1993–94	*566	584	2003–04	218	346
1994–95	501	584	2004–05	151	346
1995–96	495	584			

Until 30 September 2002, there were eight permit holders, each allowed a maximum of 200 kg per day. If all permit holders took their limit every day a maximum of 584 t could be taken in one 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) after an extended closure for biotoxin contamination, but landings the following year (1993–94) were the highest on record (566 t). This figure may be unreliable; it is difficult to believe such high landings can have been achieved without some breaking of the 200 kg daily limit. The fishery averaged 400–500 t between 1994–95 and 2001–02. On 1 October 2002, this fishery was introduced to the Quota Management System (QMS) with a Total Allowable Commercial Catch (TACC) of 346 t. Landings have declined steadily since then, and landings in 2004–05 (151 t) were the lowest recorded since 1987–88. 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 on other sandbanks, notably MacDonald Bank (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 recreational fishers; cockles of about 30 mm or larger SL are acceptable (see Hartill & Cryer (2000) for estimates of recreational selectivity at four Auckland beaches). A regional telephone and diary survey in 1993/94 (Teirney et al. 1997), and national recreational diary surveys in 1996 (Bradford 1998), 1999/2000 (Boyd & Reilly 2004), and 2000/01 (Boyd et al. 2004) estimated the numbers of cockles harvested in QMA 1 to be 0.57–2.4 million (Table 2). It is not clear to what extent these estimates include customary take. No mean harvest weight for cockles was available, but an assumed mean weight of 25 g (as for cockles 30 mm SL or more from the 1992 Snake Bank survey) leads to a QMA 1 recreational harvest of 14–59 t (Table 2). In 2004, the Marine Recreational Fisheries Technical Working Group reviewed the harvest estimates of these surveys and concluded that the 1993/94 and 1996 estimates were unreliable due to a methodological error. While the same error did not apply to the 1999/2000 and 2000/01 surveys, it was considered the estimates may still be very inaccurate. No recreational harvest estimates specific to the Snake Bank fishery are available.

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 from national recreational diary surveys in 1996, 1999/2000, and 2000/01.

Year	QMA 1 harvest (number of cockles)	c.v. (%)	QMA 1 harvest (t)
1993/94	2 140 000	18	55
1996	569 000	18	14
1999/2000	2 357 000	24	59
2000/01	2 327 000	27	58

2.4 Other sources of fishing mortality

There have been sporadic suggestions of illegal fishing or over-catching of daily limits, but none have 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 1983–85 (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. Between 1982 and 1996, seven biomass surveys were conducted using orthogonal grid sampling (Cryer 1997). These early surveys were based on a permanent grid with 50 m intersection spacings and had typically 150–200 sites. In 1998, a stratified random sampling approach was adopted which used historical data from previous grid-based surveys to divide Snake Bank into appropriate density strata (Morrison & Cryer 1999). 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). Stratification was revised in 2001, 2003, 2004, and 2005 because the northern part of the high density area (and, probably, the whole bank) appeared to have moved slowly east between about 1999 and 2004 (see Figure 5).

Table 3: Estimates of biomass (t) of cockles on Snake Bank for surveys (*n*, number of sites) between 1982 and 2006. Biomass estimates marked with an asterisk (*) were made using length frequency distributions and length-weight regressions, others by direct weighing of samples sorted into three size classes. Two 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	2 597	0.11	1 567	0.15	1 030	0.12	121	0.14
2004	65	1 910	0.15	1 364	0.17	546	0.14	59	0.22
2005	57	2 592	0.18	1 625	0.18	967	0.20	111	0.20
2006	57	2 412	0.13	1 620	0.15	792	0.13	103	0.20

3.2.2 2006 Snake Bank survey methods

The 2006 survey of Snake Bank cockles was conducted using stratified random sampling (Figure 2). Snake Bank was divided into two survey strata: 1) the high density stratum, the main intertidal part of the bank exposed at a reasonably low tide (0.5 m chart datum); and 2) the low density stratum, the peripheral area exposed only on an extreme low tide (0.0 m chart datum). The location of the high density stratum was estimated on 27 February 2006 (three days before sampling started) by walking the perimeter of the bank at low tide (0.5 m chart datum) and periodically recording positions using a high-precision (but non-differential) hand-held Global Positioning System (GPS). The boundary of the low density stratum was determined in 1998 (Morrison & Cryer 1999), and is likely to be inaccurate because it has not been measured recently.

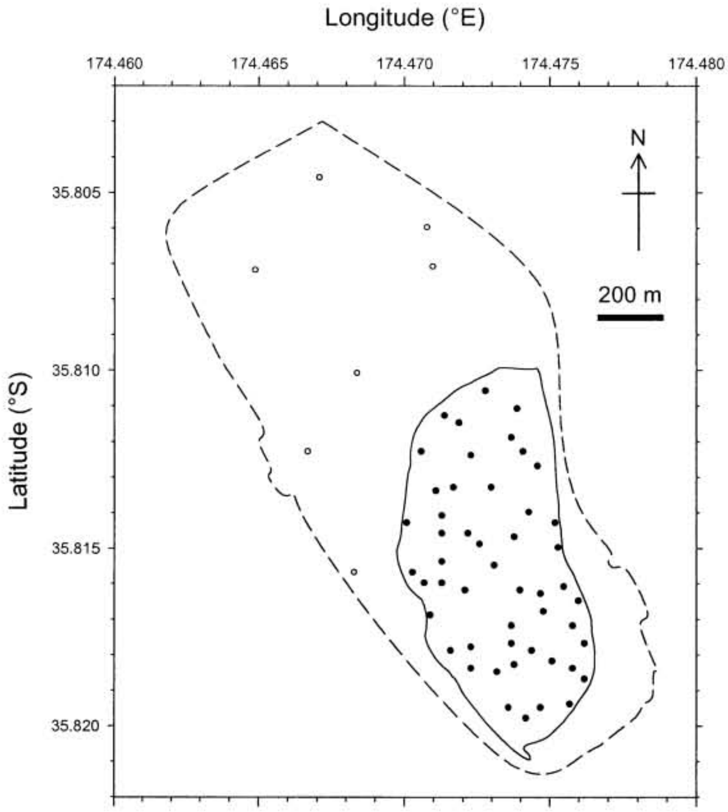

Figure 2: Design of the March 2006 cockle survey on Snake Bank, Whangarei Harbour. Filled circles indicate site positions (n = 50) in the high density stratum (solid line) and open circles denote sites (n = 7) in the low density stratum (dashed line). The boundary of the high density stratum was estimated by walking the perimeter of the bank at a reasonably low tide (0.5 m chart datum) and periodically recording positions using GPS. The low density stratum boundary was determined in 1998 by Morrison & Cryer (1999), and is likely to be inaccurate because it has not been measured recently. Latitude and longitude are in decimal degrees.

On 2 March 2006, 57 randomly located sites (50 in the high density stratum and 7 in the low density stratum; Figure 2) were visited in turn, using GPS. At each site, a square quadrat of 0.5 × 0.5 m (0.25 m^2) 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 (under 30 mm, 30–34 mm, 35 mm and over 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.

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

$$\bar{x} = \sum_{i=1} W_i \bar{x}_i$$

where $\bar{x}$ is the estimated biomass (t), W_i is the area (m^2), and $\bar{x}_i$ is the mean biomass (t) in stratum i.

The variance for this mean was estimated using:

$$s^2 = \sum_{i=1} W_i^2 s_i^2 / n_i$$

where s^2 is the variance of the estimated biomass, s_i^2 is the sampling variance of the site biomass estimates in stratum i, and n_i is the number of sites within 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 2006 Snake Bank survey results

The March 2006 survey produced an estimated recruited biomass (30 mm or more SL) of 792 t with a c.v. of 13.1% (Table 3). Restricting the estimate of recruited biomass to cockles 35 mm or more SL produced a biomass estimate of 103 t with a c.v. of 20.2%. These estimates are higher than those recorded in 2000, 2001, 2002, and 2004 (which were the lowest on record) but lower than those in 2003 and 2005 (Figure 3). Total biomass was estimated to be 2412 t with a c.v. of 12.6%. The biomass of cockles under 30 mm SL was estimated to be 1620 t with a c.v. of 15.1%, considerably higher than in the 1980s, and about one-quarter higher than the average since 1990 (1294 t with a c.v. of 9.1%).

Cockles 30 mm SL or more were distributed throughout the high density stratum in 2006, but we found no cockles in the low density stratum (Figure 4). The location of the top of the bank (and, we assume, the high density area for cockles in 2006, Figure 5) suggests that the bank has not continued the move eastward observed between 2001 and 2004 (Cryer et al. 2002a, 2004; Watson et al. 2005). Movement of the bank caused poor survey precision and equivocal results in the first of two surveys in (April) 2001 and requires careful monitoring if survey accuracy precision is not to be jeopardised.

The estimated population length frequency distribution in 2006 had two modes at 14 and 28 mm SL (Figure 6) and continued the recent pattern of domination by cockles just under 30 mm SL. The large number of small cockles (20 mm SL or less) compared with most recent years (Figure 6) suggests relatively good recruitment to the fishable biomass for the near future.

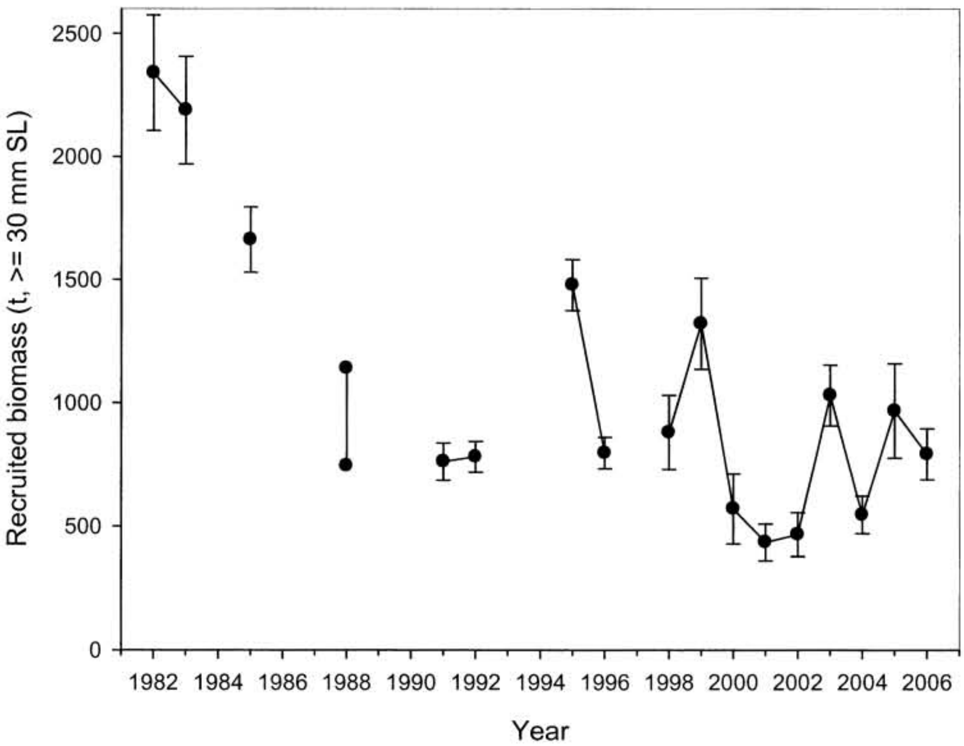

Figure 3: Estimated recruited biomass of cockles (30 mm or more SL, ± one standard error) on Snake Bank from surveys between 1982 and 2006. The 1988 grid survey was abandoned part-way through and its analysis is complicated; two alternative analytical approaches are plotted as dots. The 2001 result comes from the second of two surveys, the first (in April) having produced unacceptably imprecise results.

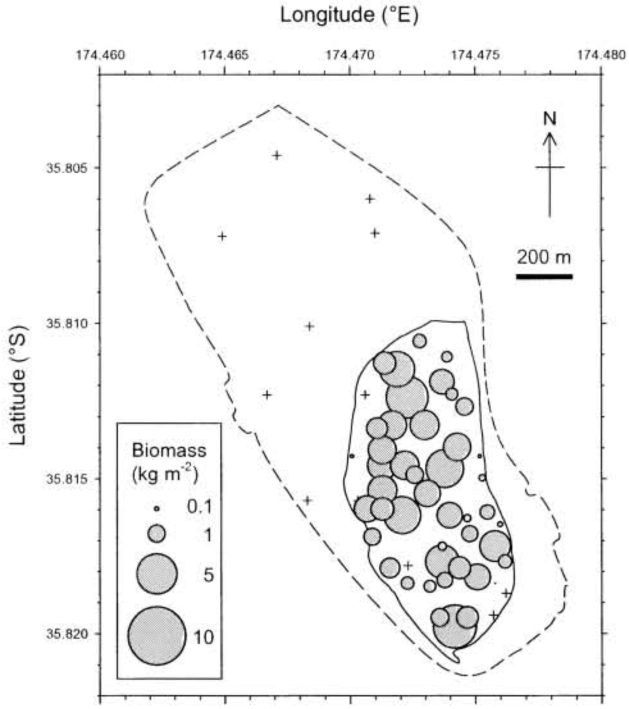

Figure 4: Distribution of cockle biomass on Snake Bank, Whangerei Harbour, 2006. Filled circles indicate sites sampled in the high density stratum (solid line) where cockles were present; circle area is proportional to the estimated biomass (kg m^{-2}) of cockles at each site. Crosses denote those sites sampled with zero cockles. Zero cockles were found in the seven sites sampled in the low density stratum (dashed line). Latitude and longitude are in decimal degrees.

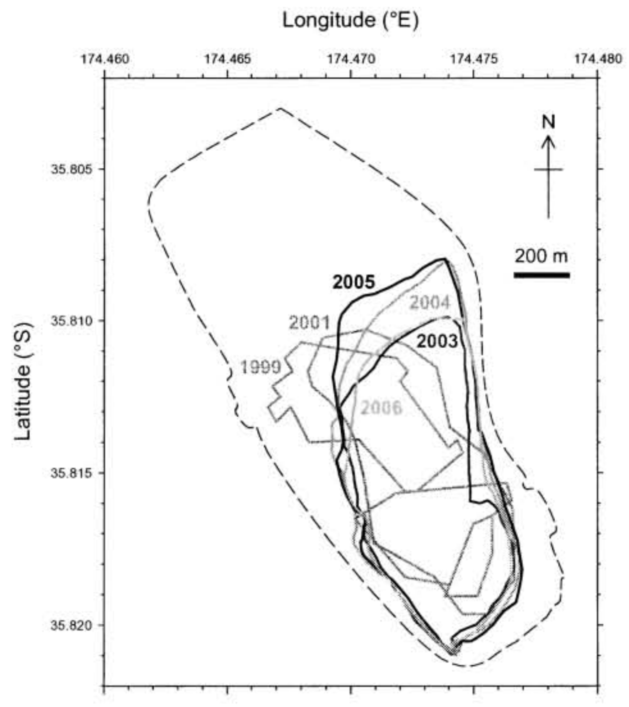

Figure 5: Location of the high density sampling strata on Snake Bank between 1999 and 2006 showing movement to the east, at least for the northern part of the stratum. The 1999 stratification was a modified version of the 1998 stratification which, in turn, was based on the average distribution of cockles 1985–96. Dashed line indicates the low density stratum boundary. Latitude and longitude are in decimal degrees.

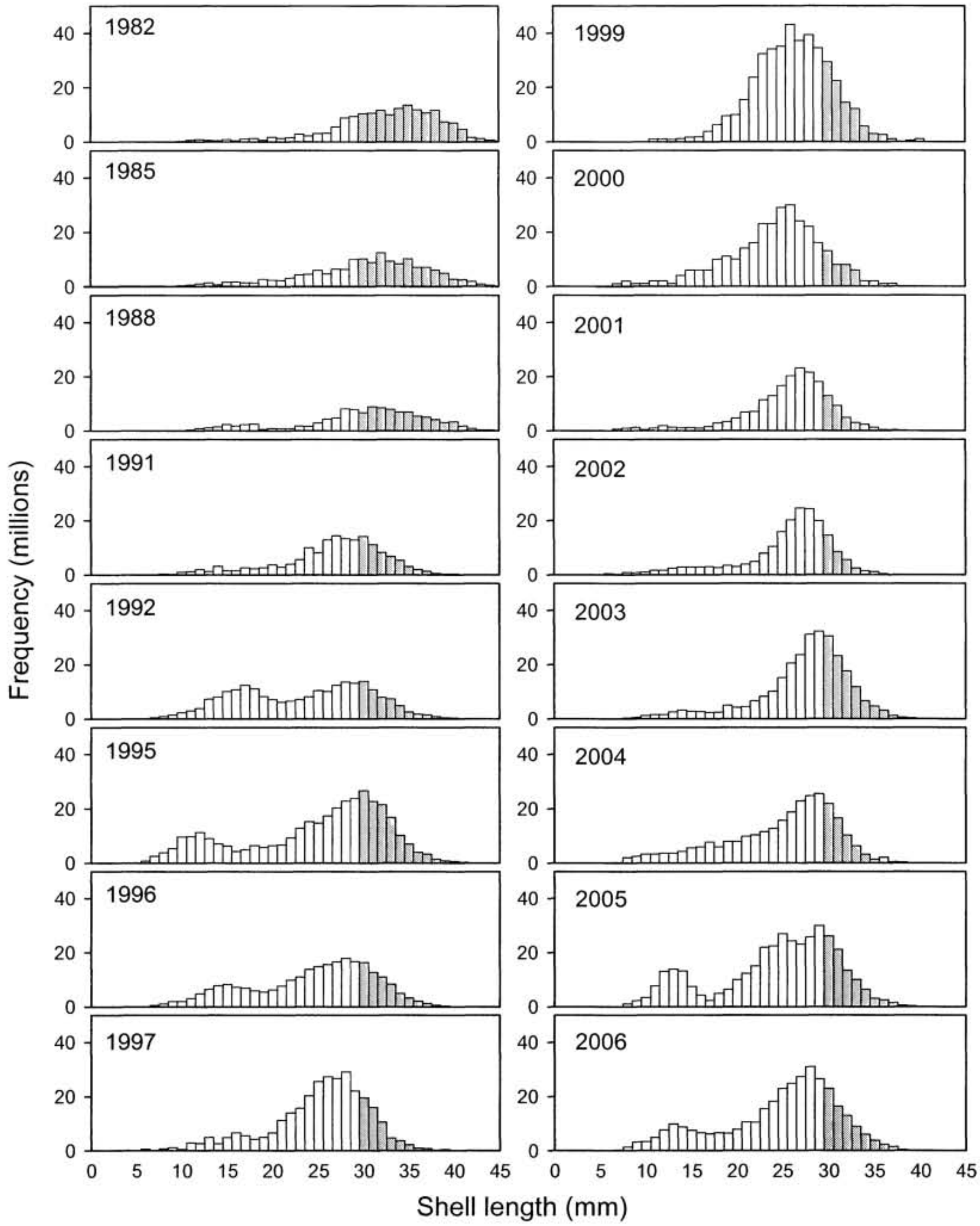

Figure 6: Estimated population length frequency distribution of cockles on Snake Bank, 1983–2006. Shaded bars represent cockles of 30 mm SL or more, the assumed size at recruitment to the fishery.

3.2.4 Sensitivity of biomass estimates to the assumed size at recruitment

Actual (aggregate) weights were measured for size classes under 30, 30–34, and 35 mm and over 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 2006 was, therefore, estimated for assumed sizes at recruitment of 28, 25, and 20 mm SL using the estimated 2006 population length frequency distribution and a length-weight regression (scaling these estimates to account for the minor discrepancy between 2006 estimates derived by direct weighing and length frequency analysis).

The estimated recruited biomass in 2006 at an assumed size of recruitment to the fishery of 28 mm SL was 1194 t (Table 4). At assumed sizes of recruitment to the fishery of 25 and 20 mm SL, the estimated recruited biomass was 1584 t and 1779 t, respectively. We have not formally estimated c.v.s for these estimates, but all would probably be similar to that on the estimate at 30 mm SL.

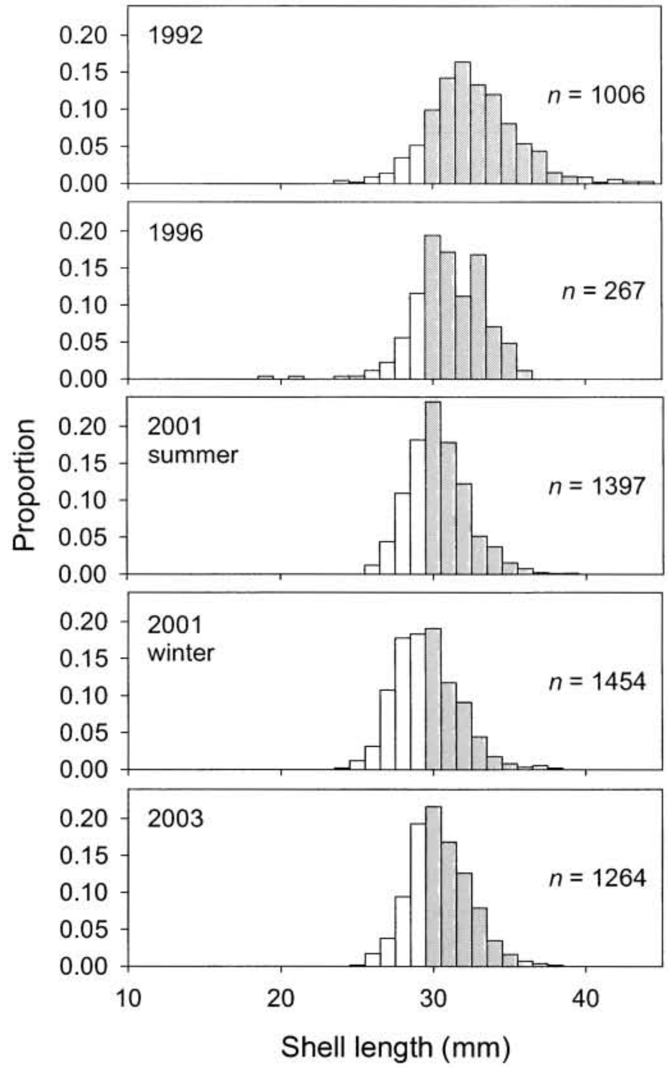

Figure 7: Estimated length frequency distribution of cockles in the commercial harvest from Snake Bank in 1992 (Cryer 1997), 1996 (Cryer 1997), 2001 (Cryer & Parkinson 2001) and 2003 (Cryer et al. 2004). The shaded part of each histogram contains cockles 30 mm SL and larger (the nominal size at recruitment to the fishery).

Table 4: Estimated recruited biomass (*B*) of cockles on Snake Bank in 2003–06 for different assumed shell lengths at recruitment to the fishery (L_{recr}).

L_{recr} (mm)	Rationale	2003 *B* (t)	2003 c.v.	2004 *B* (t)	2004 c.v.	2005 *B* (t)	2005 c.v.	2006 *B* (t)	2006 c.v.
30	Historical assumption	1 030	0.12	546	0.14	967	0.20	792	13.1
28	Recent selectivity	1 489	–	1 009	–	1 410	–	1 194	–
25	Smallest in catch	1 815	–	1 500	–	1 842	–	1 584	–
20	Reproductive maturity	1 929	–	1 768	–	2 127	–	1 779	–

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 larger 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 historically accepted recruited biomass (30 mm SL or larger), 33% of the biologically mature cockles (20 mm SL or larger), and 31% of the total (sampled) cockle biomass in Whangarei Harbour.

3.3 Other studies

3.3.1 Length-weight relationships

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) and there has been considerable variation among them. It is not known whether this variation is random, or a result of variation among locations, years, or tidal height.

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)
2005	Random	0.00012	3.385	208	Williams et al. (2006)
2006	Random	0.00009	3.440	200	Present study

3.3.2 Mortality and yield-per-recruit

Experimental work on Snake Bank led to estimates of absolute natural mortality of 17–30% per annum, or 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 over 35 mm SL and, as these are uncommon, $M = 0.30$ (range 0.20–0.40) is usually assumed for yield-per-recruit modelling and yield calculations (Cryer 1997).

3.3.3 Previous growth estimates

Analysis of roughly quarterly length frequency distributions between 1992 and 1996 on Snake Bank using MULTIFAN software generated von Bertalanffy (1938) growth parameter estimates of L_∞ = 31.0 mm, $K = 1.02$ y^{-1}, and $t_0 = 0.00$ y (Cryer 1997). These estimates suggested rapid growth (about 2 y) to the size of interest to fishers (Cryer & Holdsworth 1993, Cryer 1997). This was much faster growth than estimated in previous tagging studies by Martin (1984), who suggested cockles could take up to 4 or 5 years to attain 30 mm SL. 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.

Since 2001, three tag-recapture experiments have been conducted on Snake Bank to investigate cockle growth rate (Table 6). In each experiment, up to 2000 cockles of a wide range of sizes were "notch tagged" (marked with distinct, shallow grooves from the shell margin up onto the valve surface) and replanted within the main fishery area. Notch tagging provides a permanent reference for length at release and is faster and more efficient than conventional tagging (Cranfield et al. 1993). Marked cockles were recovered after 1–2 y at liberty (Table 6) and measured to determine incremental growth, the difference between length at release (i.e. length to notch) and recapture (total SL).

Table 6: Cockle notch-tagging experiments on Snake Bank, 2001–2005. *n* = number of cockles recovered.

Experiment	Tagging date	Recapture date	Time at liberty (days)	*n*
2001–02	7 June 2001	9 September 2002	459	191
2003–04	17 April 2003	18 May 2004	397	178
2003–05	17 April 2003	8 April 2005	722	96

Cryer et al. (2004) analysed the results of the 2001–02 experiment 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, a much shallower growth curve than suggested by the MULTIFAN length frequency analysis, and similar to the earlier estimates of Martin (1984). Watson et al. (2005) examined the 2003–04 data and showed there was little variation in growth from the 2001–02 experiment.

Williams et al. (2006) recovered a further sample of cockles tagged in 2003, after almost two years at liberty. Incremental growth data from all three tag-recapture experiments (2001–02, 2003–04 and 2003–05) were pooled and analysed by Williams et al. (2006) using the growth model GROTAG (Francis 1988) (Figure 8). The model fitted to the pooled dataset produced estimates of $L_\infty = 35.0$ mm SL (c.v. = 2.9%) and $K = 0.26$ (c.v. = 5.3%) (Table 7). The addition of seasonal variation parameters did not significantly improve the model fit (likelihood ratio probability $p > \chi^2 = 0.34$). Thus, although these tag-recapture data did not provide evidence of seasonal variation in growth rates, it was possible they were not collected at sufficiently fine temporal scales to detect seasonality.

Williams et al. (2006) also assessed interannual variation in growth using the three sets of notch-tag data (2001–02, 2003–04 and 2003–05). The standardised residuals from the GROTAG model fitted to the pooled data were allocated to their respective experiments and compared using the non-parametric Kruskal-Wallis test (Kruskal & Wallis 1952). There were no differences in standardised residuals among experiments ($\chi^2 = 2.78$; d.f. = 2; $p = 0.25$), suggesting there was little interannual variation in growth, although the treatment of these experiments as separate "years" was not ideal given their varied durations (see Table 6). Furthermore, from plots of standardised residuals against initial shell length at release it appeared that most residuals for the smallest and largest cockles were positive (Figure 8). This suggested that the simple linear two-parameter (g_{20}, g_{30}) model may be inadequate, especially for cockles greater than about 30 mm. Williams et al. (2006) suggested future analyses might benefit from using alternative growth models that allow the predicted growth of larger animals to decline asymptotically to zero and never be negative (e.g., Cranfield et al 1996). Also, it is likely that several years of annual growth data would be needed before definitive conclusions on interannual growth variability could be made.

Table 7: Parameter estimates for the GROTAG model (Francis 1988) fitted to growth increment data for notch tagged cockles on Snake Bank, 2001–05 (using data pooled from the 2001–02, 2003–04 and 2003–05 tag-recapture experiments). The GROTAG model parameters s and m for measurement error could not be estimated from these data, so both s and m were set to zero. Corresponding estimates of the von Bertalanffy growth function parameters L_∞ and K are also shown. After Williams et al. (2006).

Parameter	Symbol (unit)	Value
Mean growth rates	g_{20} (mm y^{-1})	3.44
	g_{30} (mm y^{-1})	1.15
Growth variability	v	0.31
Outlier contamination	p	3.02×10^{-8}
von Bertalanffy	L_∞ (mm)	35.03
	K	0.26

3.3.4 New seasonal tag-recapture experiment

A tag-recapture experiment was initiated in 2005 on Snake Bank to investigate seasonal variation in cockle growth rate. Williams et al. (2006) notch-tagged a large sample of cockles of a range of sizes and replanted them on Snake Bank on 31 March 2005. Four (roughly quarterly) recoveries of these tagged animals have been made subsequently (Table 8), and additional recoveries will be made over the next year. Preliminary results suggest there may be strong seasonal variability in growth, and this will be investigated further on completion of the experiment. Early indications are that most growth occurs in spring and summer, and average growth essentially ceases during winter. Another large sample of cockles (about 2000 individuals) was notch-tagged and replanted on Snake Bank on 3 March 2006. Future recoveries of these animals should provide more data on seasonal variation in cockle growth rates.

Table 8: Seasonal tag-recapture experiment on Snake Bank, 2005–06. n = number of cockles recovered.

Tagging date	Recapture date	Time at liberty (days)	n
31 March 2005	8 August 2005	130	286
31 March 2005	13 October 2005	196	215
31 March 2005	16 January 2006	291	207
31 March 2005	26 April 2006	391	170

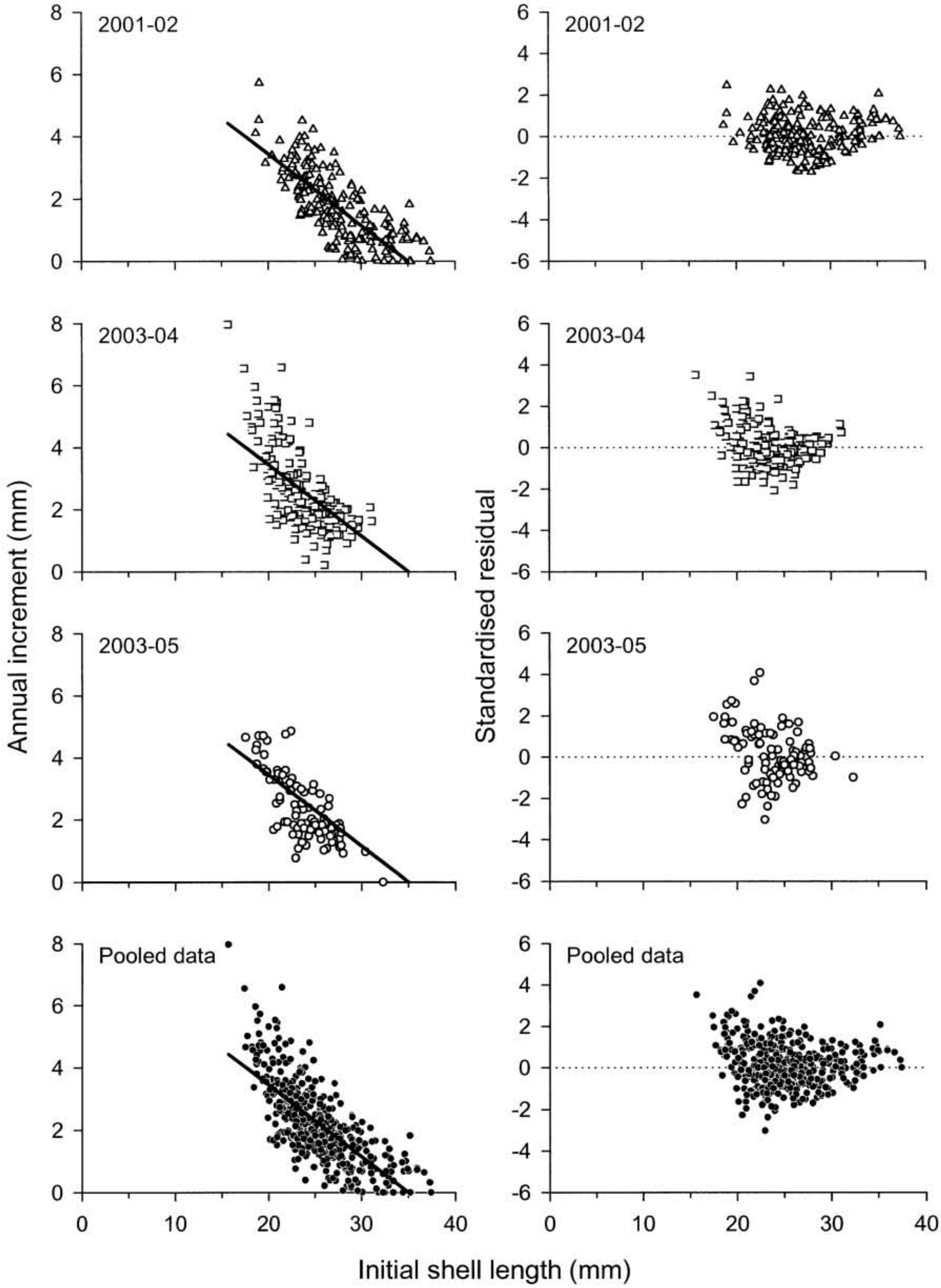

Figure 8: Incremental growth data and standardised residuals from the fitted GROTAG model (Francis 1988) for notch tagged cockles on Snake Bank, Whangerei Harbour, 2001–2005. The solid blank line represents the model fitted to the data pooled from the 2001–02 (n = 191), 2003–04 (n = 178) and 2003–05 (n = 96) tag-recapture experiments. The observed increments have been scaled to reflect expected annual growth. After Williams et al. (2006).

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 (2006) recruited biomass was estimated by quadrat survey to be 792 t with a c.v. of 13.1%. Average recruited biomass was estimated from the 13 quadrat surveys between 1991 and 2006 (the fishery was assumed to have been "fully developed" by about 1990) as 832 t with a c.v. of 10.8%. 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

Maximum Constant Yield (MCY) was estimated using method 2 (Sullivan et al., 2005):

$$\mathrm{MCY} = 0.5F_{0.1}B_{av} \tag{1}$$

where $F_{0.1}$ is a reference rate of fishing mortality and B_{av} is the average recruited biomass between 1991 and 2006 (832 t). Estimates of $M = 0.30$ and $F_{0.1} = 0.41$ were used (Cryer 1997).

$$\mathrm{MCY} = 0.5 \times 0.41 \times 832 = 171\,\mathrm{t} \tag{2}$$

This estimate would have a c.v. at least as large as that associated with the estimate of average recruited biomass between 1991 and 2006 (10.8%). The estimate of MCY is sensitive to the assumed size at recruitment to the fishery (Table 9), and to uncertainty in $F_{0.1}$ (arising from the considerable uncertainty in both growth parameters and M).

3.5.2 Estimation of Current Annual Yield

Current Annual Yield (CAY) was estimated using method 1 and the full version of the Baranov catch equation (Sullivan et al., 2005).

$$\mathrm{CAY} = \frac{F_{ref}}{F_{ref} + M}\left(1 - e^{-(F_{ref}+M)}\right)B_{beg} \tag{3}$$

where F_{ref} is a reference rate of fishing mortality, M is natural mortality, and B_{beg} is the start of season recruited biomass. The current estimate of recruited biomass (B_{curr}) derived from the March 2006 survey of Snake Bank was substituted for B_{beg}. Estimates of $M = 0.30$ and $F_{0.1} = 0.41$ were used (Cryer 1997).

$$\mathrm{CAY} = 0.578 \times 0.508 \times 792 = 232\,\mathrm{t} \tag{4}$$

This estimate would have a c.v. at least as large as that associated with the current estimate of recruited biomass in March 2006 (13.1%). The estimate of CAY is sensitive to the assumed size at recruitment to the fishery (Table 9), and to uncertainty in $F_{0.1}$ (arising from the considerable uncertainty in both growth parameters and M).

Table 9: Sensitivity of Maximum Constant Yield (MCY) and Current Annual Yield (CAY) estimates to the assumed size at recruitment to the fishery. MCY was estimated using method 2 (Sullivan et al. 2005); B_{av} was estimated for each size at recruitment using data from the 13 surveys between 1991 and 2006. CAY was estimated using method 1 and the full version of the Baranov catch equation (Sullivan et al. 2005); the current estimate of recruited biomass (B_{curr}) was estimated for each size at recruitment and substituted for B_{beg} to calculate CAY. M was assumed, and estimates of $F_{0.1}$ were taken from Cryer (1997).

Size at recruitment (mm SL)	B_{av}(1991–2006) (t)	B_{curr} (2006) (t)	M	$F_{0.1}$	MCY (t)	CAY (t)
20	1 863	1 779	0.3	0.30	279	401
25	1 619	1 584	0.3	0.34	275	398
28	1 337	1 194	0.3	0.38	254	329
30	832	792	0.3	0.41	171	232
35	132	103	0.3	1.00	66	58

3.6 Models

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

A length-based model was used by Watson et al. (2005) to assess the Snake Bank cockle population. This model was adapted from a model developed by McKenzie et al. (2003) (see also Cryer et al. (2004), 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. All model iterations up to and including that developed by Watson et al. (2005) 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 affecting the cockle population, or high variability of growth or mortality among years. One assumption of the model is that mortality, length at recruitment, and growth are constant over the entire observed time period. This may be unrealistic and some (or all) may vary substantially among years in response to some environmental driver that varies among years. We believe that the current model does not capture the historical dynamics sufficiently well to give any confidence in future projections. Further, if mortality, growth, and recruitment are all allowed to vary among years, then all projections become extremely sensitive to the future behaviour of these parameters, and this can only be assumed. We are currently collecting more data on growth and its variability among seasons and years in an attempt to constrain the behaviour of growth parameters in models where they are allowed to vary.

4. MANAGEMENT IMPLICATIONS

There has been a decrease of about 18% in the biomass of cockles of 30 mm or more SL on Snake Bank since the last survey in 2005. Depending on the assumed size at recruitment to the fishery, current estimates of MCY (66–279 t) were always lower than the TACC (346 t), and CAY (58–401 t) was also lower than the TACC unless the size at recruitment was assumed to be 25 mm or less SL. Reported landings have declined steadily since introduction to the QMS, averaging 202 t (only 58% of the TACC), which is less than most of the yield estimates. Landings in 2004–05 (151 t) were the lowest recorded since 1987–88. The 2006 length frequency distribution suggests that recent recruitment of juveniles has been good, and this bodes well for recruitment to the fishery over the next year or two. Overall, therefore, the 2006 survey results and our simple yield estimates suggest that fishing at the level of recent average landings is likely to be sustainable in the short term. However, fishing at the level of the TACC is not likely to be sustainable in the long term.

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