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

[1]NIWA
P O Box 109695
Newmarket
Auckland

[2]NIWA
Bream Bay Aquaculture Park
P O Box 147
Ruakaka

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EXECUTIVE SUMMARY

Williams, J.R.; Smith, M.D.; Mackay, G. (2008). Biomass survey and stock assessment of cockles (*Austrovenus stutchburyi*) on Snake Bank, Whangarei Harbour, 2008.

New Zealand Fisheries Assessment Report 2008/43. 22 p.

A stratified random survey of cockles (*Austrovenus stutchburyi*) on Snake Bank, Whangarei Harbour (COC 1A), on 10 March 2008 produced an estimate of recruited biomass (30 mm or greater shell length, SL) of 1290 t with a c.v. of 13%. This was similar to the recruited biomass estimated from the last survey in 2007 (1411 t with a c.v. of 15%), which, together, represent the highest levels since 1999. Current recruited biomass (2008) was about 55% of its virgin level, and was about 43% above the average recruited biomass ($B_{av(1991-2008)}$ = 902 t). However, the 2008 length frequency distribution suggested that recent recruitment of juveniles (under 20 mm SL) had been poor compared with recent years (2005 and 2006), and this could lead to reduced levels of recruitment to the fishable biomass over the next year or two. Incorporating information from this latest survey led to yield estimates of MCY = 185 t and CAY (for 2008) = 379 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 1989 t, about 79% 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 = 293 t and CAY (for 2008) = 584 t. Only at an assumed large size at recruitment (35 mm SL) was the estimated CAY lower than the current TACC (346 t), but MCY was always lower unless a small size at recruitment (25 mm SL) was assumed. Recent reported landings (111 t in 2006–07) were less than both the TACC and the estimates of MCY and CAY (for cockles 30 mm or greater SL). These observations and the simple CAY estimates suggest that fishing at the level of the current TACC is likely to be sustainable in the short term. However, given the large fluctuations in cockle biomass observed over the last two decades, it is not known if fishing at the level of the TACC is likely to be sustainable in the long 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 2008) is presented, an ongoing tagging study to estimate cockle growth is described, and yield estimates for 2008 are derived using methods after the Ministry of Fisheries Science Group (2006). 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 2008. 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 2008–09 fishing year
3) estimate the age and growth of cockles.

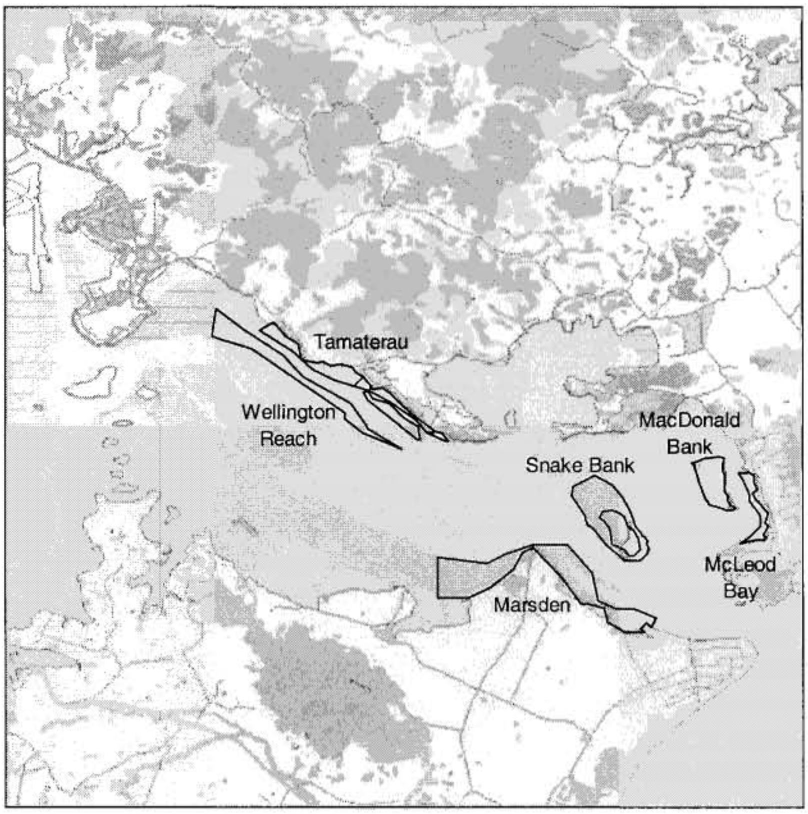

Figure 1: Beaches and banks within Whangarei Harbour that support appreciable numbers of cockles (as at July 2002, Cryer et al. (2003)). Sampling strata are delineated by solid lines.

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 recreational 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. (2003, 2004), Watson et al. (2005), and Williams et al. (2006a, 2006b, 2008). Estimates for cockles in other parts of the harbour were made by Morrison & Parkinson (2001) (MacDonald Bank) and Cryer et al. (2003) (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)	Year	Landings (t)	Limit (t)
1986–87	114	584	1993–94	*566	584	2000–01	423	584
1987–88	128	584	1994–95	501	584	2001–02	405	584
1988–89	255	584	1995–96	495	584	2002–03	237	346
1989–90	426	584	1996–97	457	584	2003–04	218	346
1990–91	396	584	1997–98	439	584	2004–05	151	346
1991–92	537	584	1998–99	472	584	2005–06	137	346
1992–93	316	584	1999–00	505	584	2006–07	111	346

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 2006–07 (111 t) were the lowest ever recorded. 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. 2003). 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 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, and 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 2002) , 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 (no. of cockles)	c.v. (%)	QMA 1 harvest (t)	Source
1993–94	2 140 000	18	55	Teirney et al. (1997)
1996	569 000	18	14	Bradford (1998)
1999–2000	2 357 000	24	59	Boyd & Reilly (2002)
2000–01	2 327 000	27	58	Boyd et al. (2004)

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 (Table 3). 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 stations. 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). Annual surveys since 1998 have had 50–73 stations in various single phase stratified random designs constrained to keep stations at least 50 m apart. 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 stations) since 1982. 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
2007	73	2 893	0.13	1 423	0.18	1 411	0.15	321	0.41

3.2.2 2008 Snake Bank survey methods

The 2008 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 (0.6 m chart datum); and 2) the "medium" stratum, the area exposed between 0.3 and 0.6 m c.d. These high-density and medium strata were the same as those used in the 2007 biomass survey of Snake Bank (see Williams et al. 2008). To check that the location of the high-density stratum had not moved considerably since 2006, the boundary of the high-density part of the bank was estimated on 21 February 2008 by walking the perimeter of the bank at low tide (0.6 m chart datum) and periodically recording positions using a high-precision (but non-differential) hand-held Global Positioning System (GPS). The "low" stratum used in the 2007 survey (Williams et al. 2008), the peripheral area of shallow water that is rarely exposed (0.0 to 0.3 m c.d.), was not sampled in 2008 because surveys in recent years demonstrated an absence of cockles in this lower tidal portion of the bank (see Williams et al. 2008).

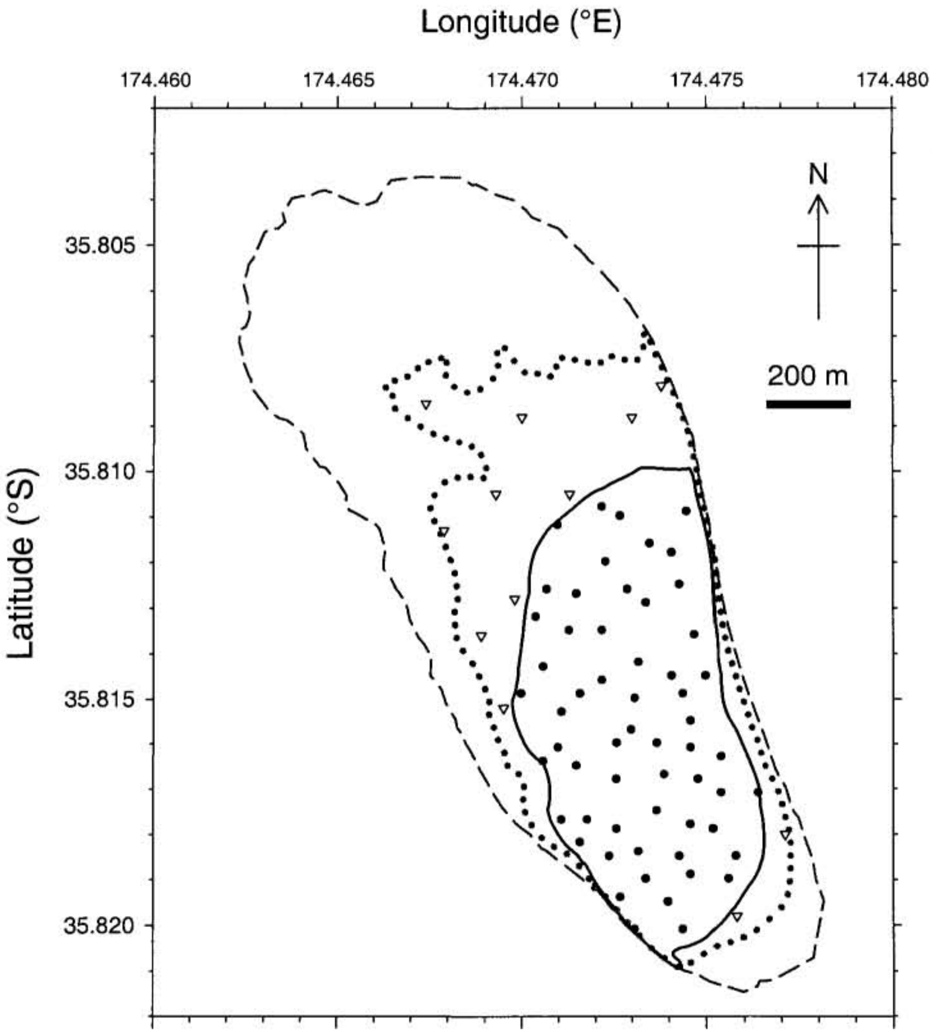

Figure 2: Design of the March 2008 cockle survey on Snake Bank, Whangarei Harbour. Filled circles indicate station positions (n = 58) in the high density stratum (solid inner line) and open triangles denote stations (n = 12) in the medium stratum (dotted line). The low stratum (dashed line) was not sampled in 2008 because surveys in recent years have demonstrated an absence of cockles in this lower tidal portion of the bank. Latitude and longitude are in decimal degrees.

On 10 March 2008, 70 randomly located stations (58 in the high density stratum and 12 in the medium tidal stratum; Figure 2) were visited in turn, using GPS. At each station, 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. At each station, up to about 200 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) was determined by direct weighing. At stations where large numbers of cockles (over 200) were present, a random subsample of about 200 cockles was taken, shell lengths were measured, and the aggregate weights of cockles in each of the three size classes determined by weighing. The remaining (unmeasured) cockles in the sample were counted, and their aggregate weight was determined by weighing. 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 station biomass estimates in stratum i, and n_i is the number of stations 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).

Station length frequency distributions were estimated by scaling the recorded length frequency distributions by the inverse of the sampled fraction (number of cockles measured divided by the total number of cockles) at each station and to a square metre of sediment. Stratum length frequency distributions were estimated as the average station 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 2008 Snake Bank survey results

The March 2008 survey produced an estimated recruited biomass (30 mm or more SL) of 1290 t with a c.v. of 12.9% (Table 3). Restricting the estimate of recruited biomass to cockles 35 mm or more SL produced a biomass estimate of 209 t with a c.v. of 48.5%. These estimates were lower than those in 2007 but were still reasonably high by historical estimates, being the second highest recorded since 1999 (Figure 3). Total biomass was estimated to be 2818 t with a c.v. of 12.2%. The biomass of cockles under 30 mm SL was estimated to be 1527 t with a c.v. of 16.0%, considerably higher than in the 1980s and early 1990s, and about 26% higher than the average since 1991 (1209 t, c.v. = 8.0%).

Cockles 30 mm or more SL were distributed throughout the high density stratum in 2008, but we found only two cockles in the medium stratum (Figure 4). Both were from the same station, located in the northwest corner of the medium stratum, on a small sandbank that was at a higher tidal elevation than the surrounding area. These were the first cockles found in this medium stratum during the annual Snake Bank biomass surveys. The boundary of the high density stratum mapped by GPS in 2008 suggested the location of the bank was fairly stable and had not continued the apparent move eastward observed between 1999 and 2003 (Figure 5) (Cryer et al. 2003, 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 is not to be jeopardised.

The estimated population length frequency distribution in 2008 had a single mode at 28 mm SL (Figure 6) and, therefore, continued the recent pattern of domination by cockles just under 30 mm SL. The small number of juvenile cockles (20 mm SL or less) compared with 2005 and 2006 (Figure 6) could suggest relatively poor recruitment to the fishable biomass for the near future.

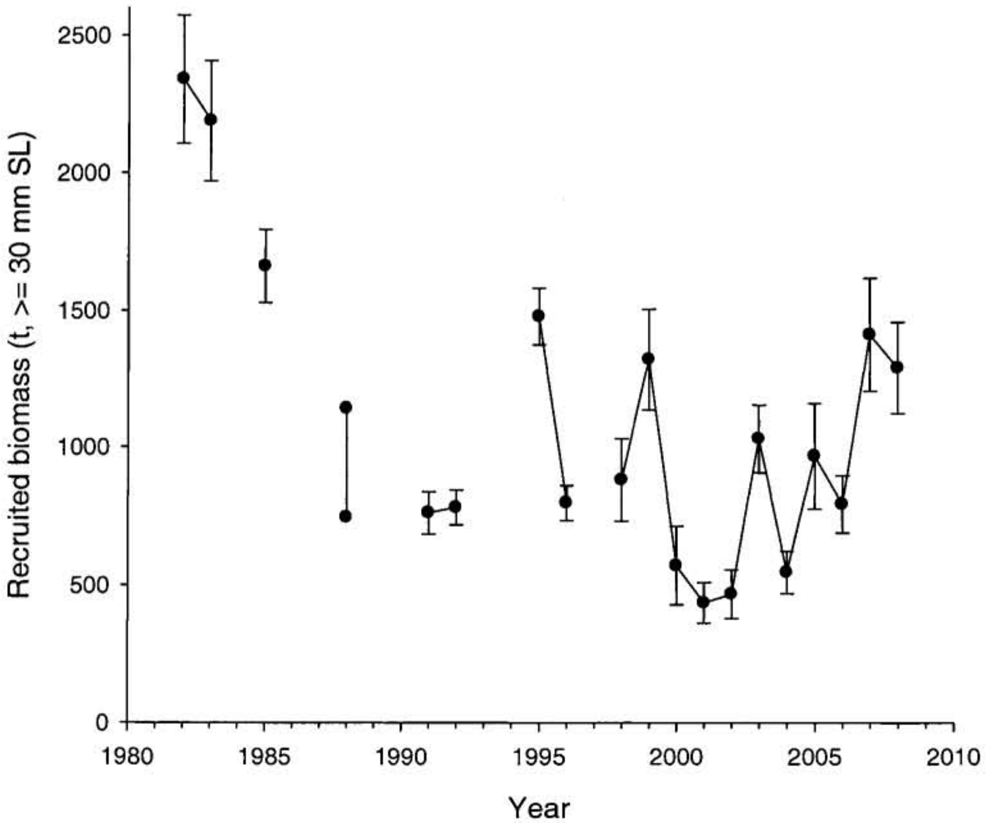

Figure 3: Estimated recruited biomass of cockles (30 mm or more SL, ± one standard error) on Snake Bank from surveys between 1982 and 2008. The 1988 grid survey was abandoned part-way through and its analysis is complicated; two alternative analytical approaches are plotted as dots. The 2001 result comes from the second of two surveys, the first (in April) having produced unacceptably imprecise results.

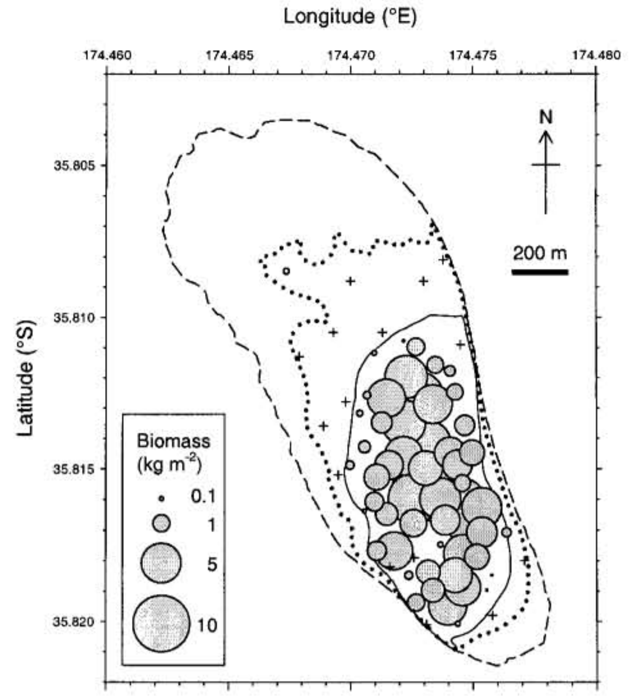

Figure 4: Distribution of recruited biomass of cockles on Snake Bank, Whangarei Harbour, 2008. Filled circles indicate stations sampled in the high density (solid line) or medium (dotted line) strata where cockles 30 mm or more SL were present; circle area is proportional to the estimated biomass (kg m^{-2}) of cockles at each station. Crosses denote those stations sampled with zero cockles. The low tidal stratum (dashed line) was not surveyed in 2008 because recent surveys demonstrated cockles were absent from this lower tidal area of the bank. Latitude and longitude are in decimal degrees.

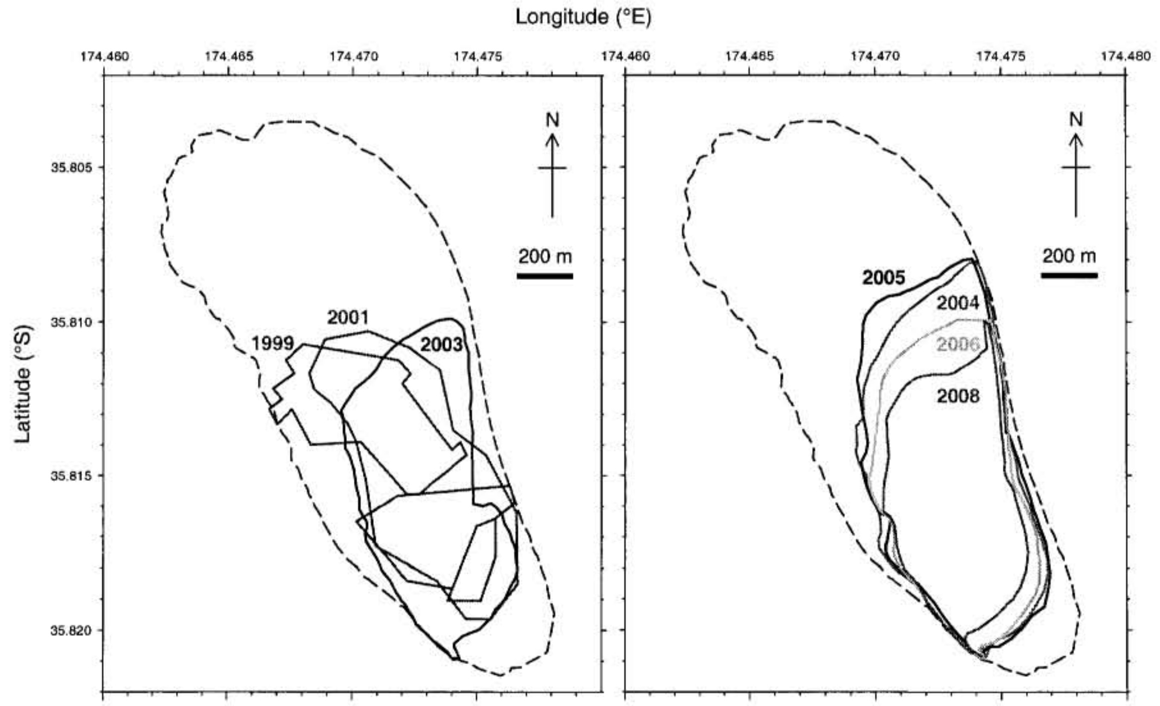

Figure 5: Location of the high density sampling strata on Snake Bank between 1999 and 2008, showing the apparent movement to the east, at least for the northern part of the stratum, observed between 1999 and 2003 (left plot). The position of the bank since then appears to have been fairly stable (right plot). 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 tidal stratum boundary (0.0 m c.d.), estimated using GPS in 2007. Latitude and longitude are in decimal degrees.

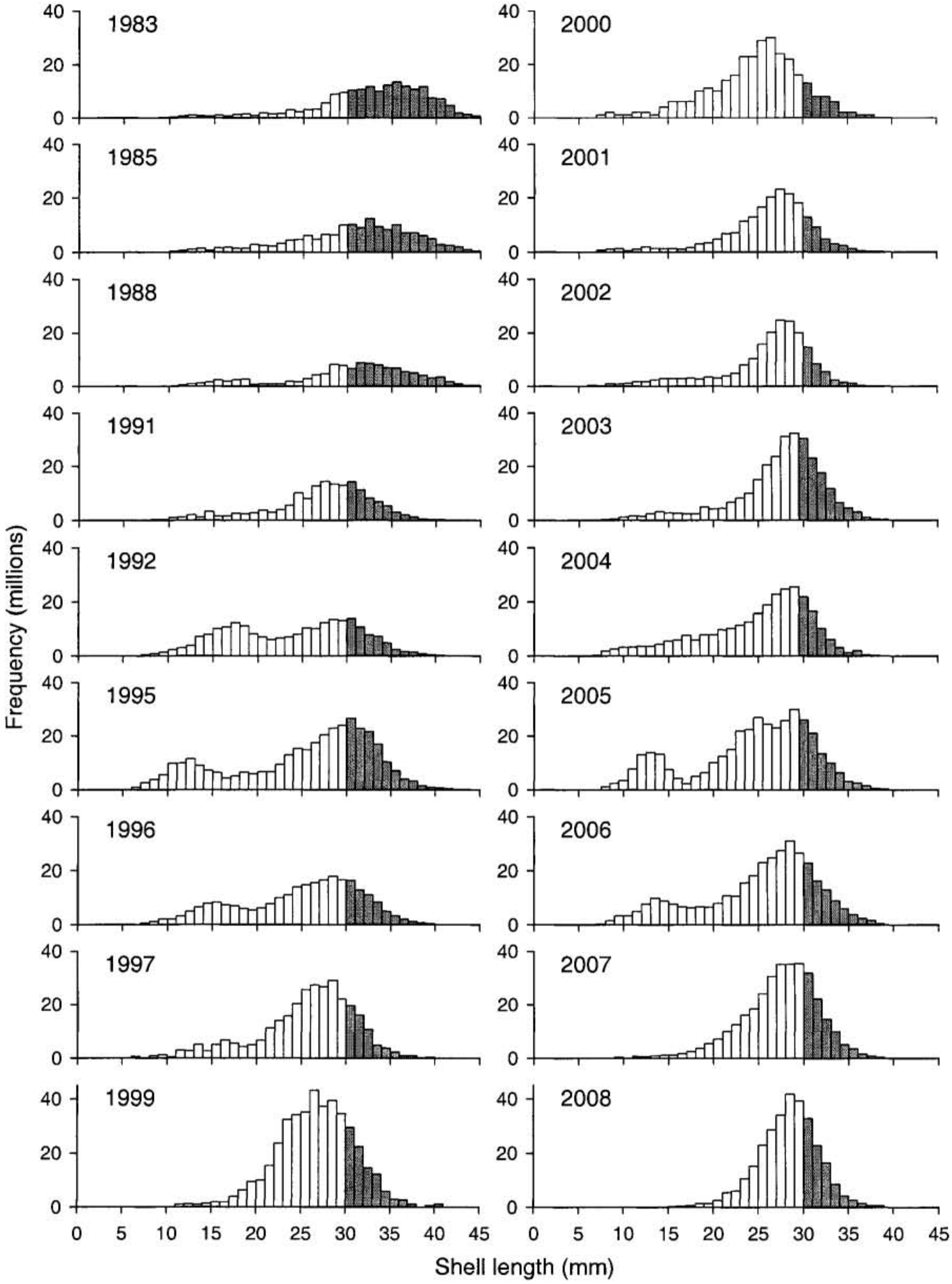

Figure 6: Estimated population length frequency distribution of cockles on Snake Bank, 1983–2008. Shaded bars represent cockles of 30 mm SL or more, the assumed size at recruitment to the fishery.

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 allowed the 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.

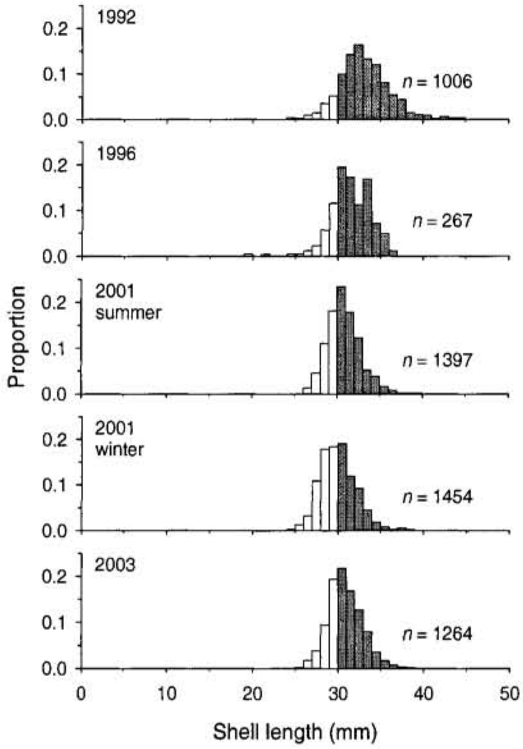

Figure 7: Estimated length frequency distribution of cockles in the commercial harvest from Snake Bank in 1992 (Cryer 1997), 1996 (Cryer 1997), 2001 (Cryer & Parkinson 2001), and 2003 (Cryer et al. 2004). Shaded bars represent cockles 30 mm SL or longer (the nominal size at recruitment to the fishery).

Recruited biomass in 2008, therefore, was estimated for a range of additional assumed sizes at recruitment (20, 25, and 28 mm SL) using the estimated 2008 population length frequency distribution and a length-weight regression (from Cryer 1997). These estimates were scaled to account for the minor discrepancy between 2008 estimates derived by direct weighing and length frequency analysis. At assumed sizes of recruitment to the fishery of 20, 25, and 28 mm SL, the estimated recruited biomass was 1989, 2619 t, and 2808 t, respectively (Table 4). We have not formally estimated c.v.s for these estimates, but all would probably be similar to that (12.9%) on the estimate at 30 mm SL.

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

L_{recr}	Rationale	$B_{curr(2008)}$		B_{2007}		$B_{av\,(1991–2008)}$		Ratio	
(mm)		(t)	c.v.	(t)	c.v.	(t)	c.v.	B_{curr}:B_{2007}	B_{curr}:B_{av}
1	Absolute biomass	2818	0.12	2834	0.13	2220	0.07	0.99	1.27
20	Reproductive maturity	2808	–	2801	–	2161	0.07	1.00	1.30
25	Smallest in catch	2619	–	2514	–	1912	0.07	1.04	1.37
28	Recent selectivity	1989	–	1867	–	1431	0.08	1.06	1.39
30	Historical assumption	1290	0.13	1411	0.18	902	0.10	0.91	1.43
35	Largest cockles	209	0.49	321	0.41	150	0.15	0.65	1.39

3.2.5 Biomass in other parts of Whangarei Harbour (2002)

Cryer et al. (2003) described surveys of cockle beds in parts of Whangarei Harbour other than Snake Bank. Their survey was conducted in July–August 2002 and is best compared with the survey of Snake Bank in late March 2002 (Cryer et al. 2003). 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 stations 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. 2003). 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*	r^2	Reference
1992	Random	0.001100	2.721	607		Cryer & Holdsworth (1993)
1995	Random	0.000150	3.285	226		Annala & Sullivan (1996)
1996	Mid-tide	0.000180	3.253	240		Cryer (1997)
1996	Lagoon	0.000370	3.060	204		Cryer (1997)
1998	Mid-tide	0.000180	3.275	103		Morrison & Cryer (1999)
1999	Lagoon	0.000090	3.450	114		Morrison (2000)
1999	Mid-tide	0.000100	3.445	122		Morrison (2000)
2001	Random	0.000170	3.246	193		Cryer et al. (2003)
2005	Random	0.000118	3.385	208	0.98	Williams et al. (2006a)
2006	Random	0.000092	3.440	200	0.98	Williams et al. (2006b)
2007	Random	0.000083	3.455	315	0.95	Williams et al. (2008)
2008	Random	0.000114	3.360	291	0.93	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 $M = 0.28$ (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 (Fournier et al. 1990, Otter Research 1992) generated von Bertalanffy (von Bertalanffy 1938) growth parameter estimates of $L_\infty = 31.0$ 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 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*.

In 2001 and 2003, tag-recapture experiments were set up 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, 2001–05. *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 (see 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. (2006a) 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. (2006a) 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.

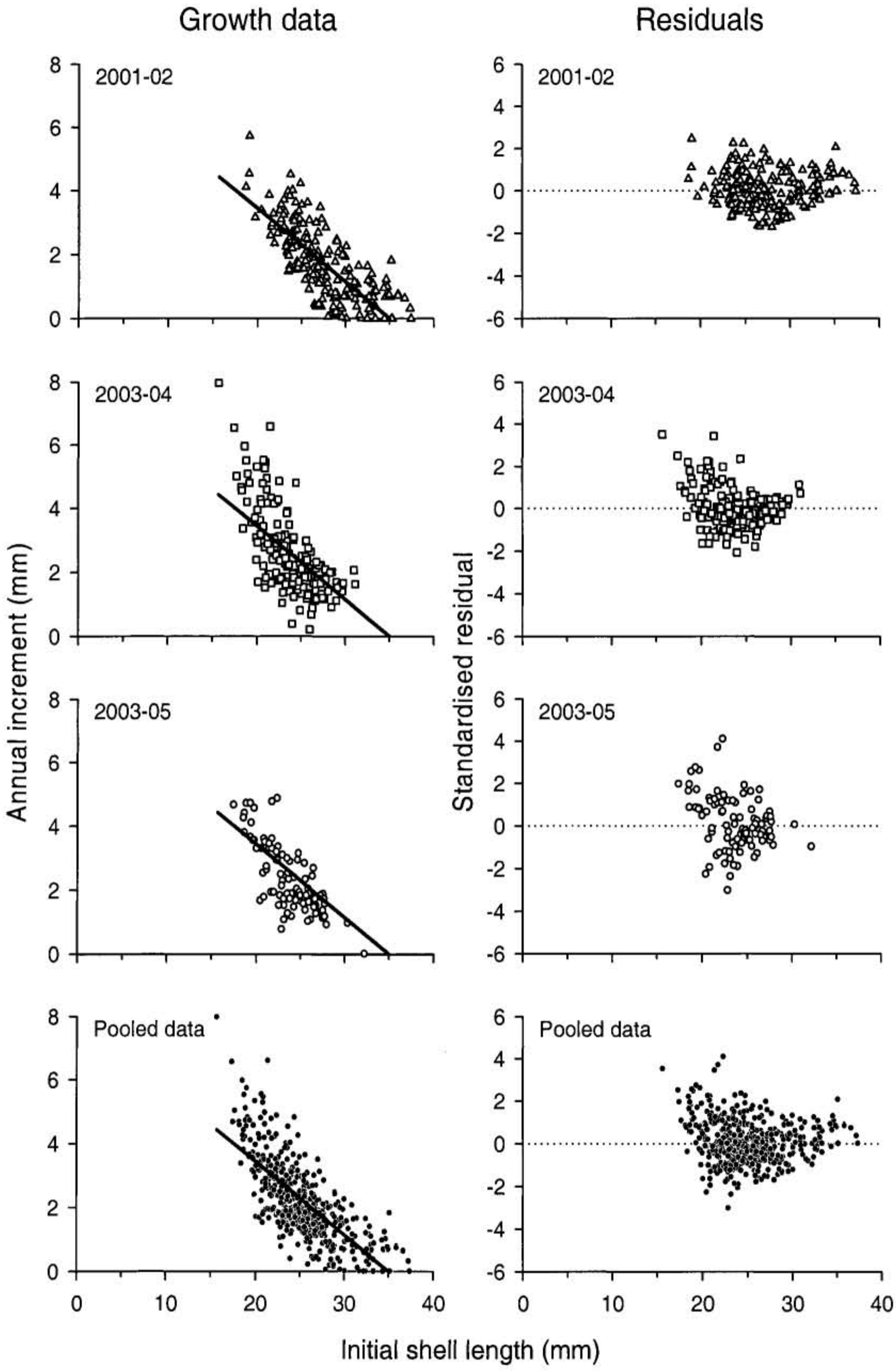

Figure 8: Incremental growth data and standardised residuals from the fitted GROTAG model (Francis 1988) for notch tagged cockles on Snake Bank, Whangarei Harbour, 2001–05. The solid black line represents the model fitted to the data pooled from the 2001–02 (n = 191), 2003–04 (n = 178) and 2003–05 (n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

Williams et al. (2006a) 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 longer than about 30 mm. Williams et al. (2006a) 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, Haddon et al. 2007). 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. (2006a).

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 Ongoing seasonal tag-recapture study

A long-term tag-recapture study was initiated in 2005 on Snake Bank to investigate seasonal variation in cockle growth rate. Williams et al. (2006a) notch-tagged a large sample of cockles (about 2000 individuals) of a range of sizes and replanted them on Snake Bank on 31 March 2005. Further large samples of cockles were notch-tagged and replanted on Snake Bank on 3 March 2006 (Williams et al. 2006b) and 22 March 2007 (Williams et al. 2008). For the latter (2007 sample), cockles were tagged using a combination of notch-tagging and individually identifiable plastic tags superglued to the shells. Future recoveries of these animals should provide more data on seasonal variation in cockle growth rates, and allow a comparison between the two tagging methods.

Seasonal (roughly quarterly) recoveries of these tagged animals have been made subsequently (Table 8), and we hope to make additional recoveries over the next few years. Preliminary results suggest there may be strong seasonal variability in growth, and this will be investigated further on completion of the study. Early indications are that most growth occurs in spring and summer, and average growth essentially ceases during winter.

Another large sample of cockles (n = 1204) was tagged and replanted on 13 March 2008. Cockles were tagged using individually identifiable plastic tags superglued to the shells. Future recoveries of these animals should provide more data on seasonal variation in cockle growth rates, and allow the estimation of cockle mortality.

Table 8: Seasonal tag-recapture study on Snake Bank, 2005–08. *n*, number of cockles recovered.

Tagging date	Recapture date	Days at liberty	*n*
31 March 2005	8 August 2005	130	286
	13 October 2005	196	215
	16 January 2006	291	207
	26 April 2006	391	170
	18 September 2006	536	106
	6 December 2006	615	82
	21 March 2007	720	50
	3 July 2007	824	123
	25 September 2007	908	72
	17 December 2007	991	80
	10 March 2008	1075	46
3 March 2006	22 June 2006	111	214
	18 September 2006	199	198
	6 December 2006	278	210
	21 March 2007	383	180
	3 July 2007	487	159
	25 September 2007	571	109
	17 December 2007	654	135
	10 March 2008	738	105
22 March 2007	3 July 2007	103	165
	25 September 2007	187	205
	17 December 2007	270	115
	10 March 2008	354	84

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 shell length in the first survey in 1982. Current (2008) recruited biomass (30 mm or more SL) was estimated by quadrat survey to be 1290 t with a c.v. of 12.9%, which is about 55% of its virgin level. Average recruited biomass was estimated from the 15 quadrat surveys between 1991 and 2008 (the fishery was assumed to have been "fully developed" by about 1990) as 902 t with a c.v. of 9.8%. 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 (Ministry of Fisheries Science Group 2006):

$$\mathrm{MCY} = 0.5 F_{0.1} B_{av} \quad (1)$$

where $F_{0.1}$ is a reference rate of fishing mortality and B_{av} is the average recruited biomass between 1991 and 2008 (902 t). Estimates of $M = 0.30$ and $F_{0.1} = 0.41$ were used (Cryer 1997).

$$\text{MCY} = 0.5 \times 0.41 \times 902 = 185 \text{ t} \qquad (2)$$

This estimate would have a c.v. at least as large as that associated with the estimate of average recruited biomass between 1991 and 2008 (9.8%). 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 (Ministry of Fisheries Science Group 2006).

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

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 2008 survey of Snake Bank was substituted for B_{beg}. Estimates of $M = 0.30$ and $F_{0.1} = 0.41$ were used (Cryer 1997).

$$\text{CAY} = 0.578 \times 0.508 \times 1290 = 379 \text{ t} \quad (4)$$

This estimate would have a c.v. at least as large as that associated with the current estimate of recruited biomass in March 2008 (12.9%). 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 (L_{recr}) to the fishery. MCY was estimated using method 2 (Ministry of Fisheries Science Group 2006); B_{av} was estimated for each size at recruitment using data from the 15 surveys between 1991 and 2008. CAY was estimated using method 1 and the full version of the Baranov catch equation (Ministry of Fisheries Science Group 2006); 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).

L_{recr} (mm)	Rationale	B_{av} (1991–2008) (t)	B_{curr}(2008) (t)	M	$F_{0.1}$	MCY (t)	CAY (t)
25	Smallest in catch	1912	2619	0.3	0.34	392	769
28	Recent selectivity	1431	1989	0.3	0.38	293	584
30	Historical assumption	902	1290	0.3	0.41	185	379
35	Largest cockles	150	209	0.3	1.00	31	61

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 was 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 seemed 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

The biomass of cockles of 30 mm or more SL on Snake Bank in 2008 was similar to that estimated from the last survey in 2007, which represented the highest levels since 1999. Depending on the assumed size at recruitment to the fishery, current estimates of CAY (379–769 t) were always higher than the TACC (346 t) unless the size at recruitment was assumed to be 35 mm or longer SL (CAY = 61 t). However, current estimates of MCY (31–293 t) were always lower than the TACC unless the size at recruitment was assumed to be 25 mm or longer SL (MCY = 392 t). Despite the reasonable level of recruited biomass, the 2007 and 2008 length frequency distributions suggest that recruitment of juveniles (under 20 mm SL) has been poor compared with recent years (e.g., 2005 and 2006), and this could lead to reduced levels of recruitment to the fishable biomass over the next year or two.

Reported landings have declined steadily since the introduction of COC 1A to the QMS in 2002, averaging 171 t (49% of the TACC) between 2002–03 and 2006–07, which is less than most of the yield estimates. Landings in 2006–07 (111 t) were the lowest ever recorded, although this is more likely due to economic and market factors than stock availability.

Overall, the 2008 biomass survey results and our simple yield estimates suggest that fishing at the level of either recent average landings or the TACC is likely to be sustainable in the short term. However, given the large fluctuations in cockle biomass observed over the last two decades, it is not known if fishing at the level of the TACC is likely to be sustainable in the long term.

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