Biomass survey and stock assessment of cockles (*Austrovenus stutchburyi*) in area COC 7A: Tapu Bay, Ferry Point, and Pakawau

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EXECUTIVE SUMMARY

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Two-phase stratified random surveys were conducted at three sites of present and past commercial fishing in QMA area COC 7A encompassing the top of the South Island. The three areas were Pakawau Beach and Ferry Point Beach in Golden Bay and Tapu Bay at the mouth of the Riwaka River in Tasman Bay. Recruited biomass on Pakawau, Tapu Bay, and Ferry Point beaches was 8285 ± 1599 tonnes, 939 ± 178 tonnes, and 470 ± 83 tonnes respectively. Not all this biomass is available to commercial harvesters as some occurs within mud and *Zostera* beds.

Over 4500 cockles were marked (by painting or notching) and released into experimental plots during 2007 and 2009 in a 2x2 experimental design with two shore levels (high and low) and two locations on the beach, Pakawau and Puponga (northern send of the beach). Of the treatments compared, tidal height had the greatest effect, with growth being significantly slower on the high shore. Painted cockles also grew slightly, but significantly, more slowly than notched cockles and cockles at Puponga slightly but significantly faster than those at Pakawau. Present growth estimates were slower than in a previous study in 1984. A modified von Bertalanffy growth model provided estimates of measurement error and seasonality of growth from recapture data after a variable number of days at liberty (quarterly samples). The standard von Bertalanffy growth model does not describe cockle growth very well in that the growth rate does not remain a constant proportion of size but rather declines with increasing size. A quadratic polynomial was fitted to predict annual growth increment from size. Size at age was estimated from an assumed starting point of 23 mm at age 2 and fitted with a logarithmic equation. A previous Yield Per Recruit (YPR) model was revised with the new growth model to give revised $F_{0.1}$ estimates.

Maximum Constant Yield (MCY) is calculated using $F_{0.1}$ estimates and average biomass levels available to the fishery calculated for 8 surveys in the past 16 years at Pakawau, 3 surveys over 17 years at Tapu Bay, and 3 surveys over 12 years at Ferry Point. Current Annual Yield (CAY) is calculated based on the recruited biomass available to the fishery (in substrate suitable for harvesters).

Fishing activity at Tapu Bay and Ferry Point has reportedly been dormant since the last survey in 2004. Biomass estimates in these two areas show a decline since the earliest estimates in 1991 at Tapu Bay and 1996 at Ferry Point, but changes since 2004 are only slight. Both areas show high levels of natural recruitment into smaller size classes.

At Pakawau, recruited biomass is high compared to estimates since 1992. Abundance of smaller size classes is within the range observed previously. The exceptionally strong pulse of recruitment first observed in 2001 is still evident in the population. There has been a decline in biomass in the area nearest the factory since the last survey in 2004, but not to levels low in a historical context.

Landings have declined over the past eight years and the TACC has not been reached since it was increased in 1997. There is no evidence that this decline is related to stock availability: it is more likely due to economic and market factors. There is no evidence of fishing pressure on the stock. Compared to the TAC of 1390 tonnes, present biomass levels indicate a CAY of about 1632 tonnes with a range from 1031 to 2257 tonnes, assuming M=0.3 and given uncertainty in the level of M. The biomass that will support the maximum sustainable yield (BMSY) is not known for any of the areas fished in COC 7A. Because of the uncertainty over the relationship between Bcurrent and BMSY, it is not known if recent catches and current catch limits will allow the COC 7A stock to move towards a size that will support the MSY.

1. INTRODUCTION

1.1 Overview

This report presents research and fisheries information for cockles, *Austrovenus stutchburyi*, in Tasman and Golden Bays (Fisheries Management Area 7A). The three fishing areas are Pakawau, Ferry Point, and Tapu Bay (Figure 1&2). The most recent biomass surveys for these three areas are described and yield estimates for 2008 derived using methods in Annala et al. (2002). A YPR model is updated with new information on annual growth rates from mark recapture experiments run during 2007–10. This work was funded by the Ministry of Fisheries under contract COC2007-03.

Overall objective

1. To carry out a stock assessment of cockles (*Austrovenus stutchburyi*) in Tapu Bay, Ferry Point and Pakawau (COC 7A) during the summer 2007/08, including estimating absolute abundance and sustainable yields.

Specific objectives

1. To estimate the size structure and absolute biomass of cockles at Tapu Bay, Ferry Point and Pakawau Beach during the 2007/2008 fishing year.

2. To estimate sustainable yields of cockles at the three locations in Objective 1.

3. To describe changes in the size structure and absolute abundance of cockles at Tapu Bay, Ferry Point and Pakawau Beach by comparing the results from this work with those from previous surveys.

4. To estimate growth of cockles in COC 7A.

1.2 Description of fishery

The cockle fishery in Quota Management Area COC 7 extends from Golden Bay to the Clarence River on the east coast of the South Island (Figure 1). Cockles are abundant in many of the estuarine and shallow coastal waters within this area, but are currently commercially fished at only three beaches, Pakawau and Ferry Point in Golden Bay and Tapu Bay in Tasman Bay (Figure 2). Commercial harvesting at Pakawau Beach in Golden Bay began in 1984 and has been continuous since then. Commercial harvesting has been periodic from Tapu Bay since 1992–93, and Ferry Point since 1998–99 and little if any has occurred since these beaches were last surveyed in 2004. All commercial landings have been taken by mechanical harvester. The harvesters grade cockles and return undersized ones to the beach (as determined by the size of the grading grill). There is currently no minimum legal size stipulated. Further grading happens after landing and again small sizes are often transplanted back to the beach. All cockles removed from the beach are reported as landed and the fate of those graded out and returned to the beach is unknown. The proportion of ‘discards’ from landings can be quite high and it is probable that at least some survive when returned to the beach so fishing mortality may be less than reported. This is discussed further below. There is some recreational and customary interest in cockles.

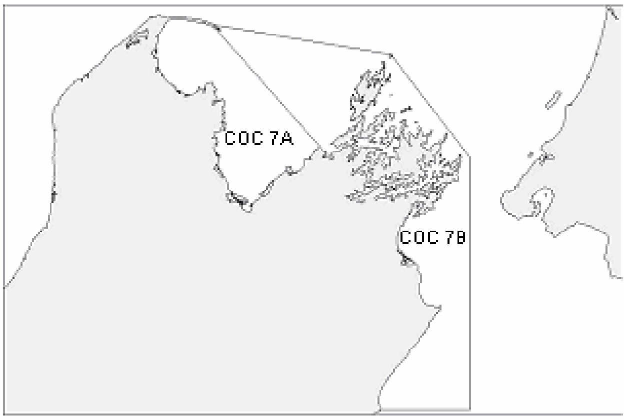


Figure 1: Extent of quota management area COC 7.

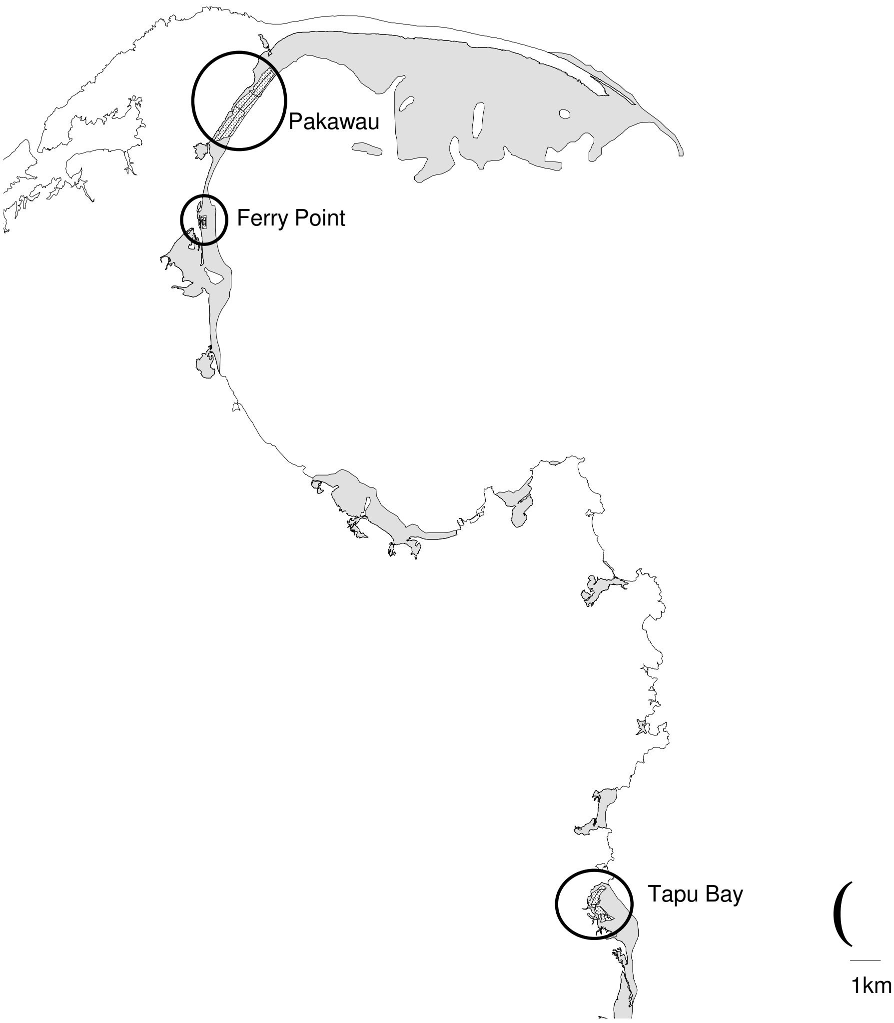


Figure 2: Location of the three commercial fisheries in Tasman and Golden Bays. The extent of the rest of the intertidal zone is the shaded area.

1.3 Literature review

Past studies on the Pakawau fishery include age and growth investigations and the effects of mechanical harvesting conducted by MAF staff in 1983 and 1984 (Bull 1984). Unpublished biomass surveys were conducted in 1982 and 1983 by MAF staff and in 1988 by DSIR personnel as part of an environmental impact assessment (Bull 1984, Wilson et al. 1988). In 1992 a stratified random survey estimated biomass and productivity of the fishery (Osborne 1992). The same survey design was used annually from 1997 to 2001 and 2004 and the present report details the eighth survey, conducted in January 2008. Both Tapu Bay and Ferry Point fisheries have been surveyed twice before (Stark & Asher 1991, Forrest & Asher 1997, Osborne 2004) and stock assessments undertaken to estimate sustainable yields (Breen 1997, Osborne 2004).

2. REVIEW OF THE FISHERY

At Pakawau Beach, the fishery operated up to October 1988 under a special permit constraining annual landings to 225 t. From 1988–89 to 1997–98, the fishery operated under a commercial permit allowing an annual catch of 300 t. In 1997–98, the fishery was re-assessed and a catch limit of 913 t was set based on a CAY harvest strategy. This level of harvest was varied to 760 t from the 1998–99 fishing year, and then 764 t for the 2000–01 fishing year. The harvest is taken from an area of about 500 ha. Only one fishing company currently takes cockles form Pakawau and they moderate their annual harvest quantities to maintain high catch rates of the sizes of cockles that they prefer to market.

The Ferry Point fishery, initiated in 1998–99, has an annual allowable catch of 334 t based on an MCY harvest strategy using F_{max} as the reference rate of fishing mortality. The harvested area is about 40 ha. The Tapu Bay fishery, which was developed in 1990–91, has operated under a commercial permit limiting catches to 36 t annually. This fishery has been only lightly harvested owing largely to water quality issues, and the area from which catches have been taken is probably less than 100 ha.

COC 7A was introduced to the Quota Management System in October 2002 with a TAC of 1510 t, comprising a customary allowance of 25 t, a recreational allowance of 85 t, an allowance for other fishing related mortality of 10 t, and a TACC of 1390 t.

2.1 TACCs, catch, landings, and catch and effort data

No attempt has been made to analyse CPUE data held by the Ministry. Westhaven’s company statistics are believed to be reliable and the sole landings from Pakawau. Landings from the other two beaches make up the balance between Pakawau and total landings given in Table 1 and have been erratic. The TACC set for Pakawau Beach is 764 tonnes and has never been reached.

Table 1: Reported landings (t) of cockles from all commercially harvested areas in COC 7. Total landings from 1983–84 to 1991–92 and all Pakawau landings are based on company records. The difference between total and Pakawau landings is assumed to come from Ferry Point and Tapu Bay.

Fishing Year	Total Landings	Pakawau Landings	combined TACC
1983–84	2	2	225
1984–85	38	38	225
1985–86	174	174	225
1986–87	230	230	225
1987–88	224	224	225
1988–89	265	265	300
1989–90	368	368	300
1990–91	513	513	300
1991–92	298	298	300
1992–93	300	300	336
1993–94	440	300	336
1994–95	326	300	336
1995–96	329	296	336
1996–97	325	325	336
1997–98	513	480	949
1998–99	552	515	1130
1999–2000	752	641	1130
2000–01	731	678	1134
2001–02	556	516	1134
2002–03	569	509	1390
2003–04	553	626	1390
2004–05	428	428	1390
2005–06	460	450	1390
2006–07	337	391	1390

2.2 Other information

The areas developed as commercial cockle fisheries are not the only areas where high density of cockles occurs. The extent of the vast intertidal areas of Golden Bay is shown in Figure 2. The main area of significant cockle density is in the Farewell Spit wildlife reserve and a few smaller patches on Golden Bay beaches close to residential areas.

2.3 Recreational and Maori customary fisheries

Cockles are taken by recreational fishers, generally by hand digging. The catch limit is currently 150 cockles per person per day. Relatively large cockles (i.e., shell length over 40 mm) are generally preferred.

Estimates of the amateur cockle harvest from QMA 7 are available (Table 2) from a telephone and diary survey in 1992–93 (Teirney et al. 1997) and from national diary surveys in 1996 (Bradford 1998) and 2000 (Boyd & Reilly 2005). Harvest weights were estimated assuming a mean weight of 25 g per cockle. The 1992–93 and 1996 estimates are very uncertain and probably underestimate actual recreational catch. The 2000 survey is considered to be a more reliable estimate of recreational harvest.

Table 2: Estimated numbers of cockles harvested by recreational fishers in QMA 7, and the corresponding harvest tonnage. Data from both surveys were not sufficiently reliable to allow estimates of CVs.

Year	QMA 7 harvest	
	number	t
1992–93	166 000	4
1996	325 000	8
2000	499 000	12.5

Cockles are an important Maori traditional food, but no quantitative information on the level of customary take in COC 7A/7B is available. However, Kaitiaki are now in place in many areas and estimates of customary harvest can be expected in the near future.

2.4 Other sources of fish mortality

In the summer of 1999–2000 an unusually severe natural mortality event was observed on the Pakawau Beach and reported from the Ferry Point fishery. There were anecdotal reports of similar mortality in other cockle populations around New Zealand in the same summer. The present survey shows that this event was followed by an equally unusual recruitment pulse of a magnitude not seen in the fishery before – suggesting the interesting possibility of a natural population regulation mechanism.

Mortality of unrecruited cockles during the mechanical harvesting process has been reported to be very low (Bull 1984), and disturbance and mortality of other invertebrates in the harvested areas are slight (Wilson et al. 1988). Cockles (particularly those smaller than 25 mm, which are not taken by the mechanical harvester) are vulnerable to predation by birds and may be important in the diet of some species (Wilson et al. 1988).

3. RESEARCH

3.1 Stock structure

Little is known of the stock boundaries of cockles. Cockles are relatively sedentary and although individuals are capable of wandering and possibly at times migrating across Pakawau Beach, significant movement of cockles to and from the fishery are unlikely. The planktonic larval phase of this shellfish lasts about 3 weeks, so dispersal of larvae to and from a particular site could be considerable. Cockles are known to be abundant and widely distributed throughout Golden and Tasman Bays, and although nothing is known about larval dispersion patterns, cockles in these areas are likely to comprise a single stock. However, in the absence of any detailed information on stocks, the three currently fished sites in COC 7A are all managed separately.

3.2 Resource surveys

3.2.1 Historical information

Biomass surveys have been conducted periodically at Pakawau Beach since 1992. The total biomass estimated in all previous surveys is given in Table 3. The recruited biomass this year was the highest ever recorded on the beach. The difference in biomass between these nine surveys is an indication of the degree of variability in recruitment in this fishery.

The difference between the biomass per unit area in 1988 and 1984 is likely to be mostly due to the larger area of coverage of the 1988 survey. The cockle stock had only been very lightly fished in the years between the first two surveys and it is unlikely that much of the apparent drop in biomass per unit area was attributable to commercial harvesting. The biomass per unit area in 1988 was very similar to the results of the 1992 survey. Since then the average density of cockles on the beach has generally increased. The extra area added to the survey between 1992 and 1997 is Stratum 12, which is not a high density area and is not the cause of the increase in average density between these two years.

Table 3: Estimates of biomass (t) with 95% confidence intervals (CI) where available, and mean density (kg/m^2) for cockles on Pakawau Beach. Values are given for the total and recruited (≥ 35 mm prior to 1999 and ≥ 30 mm since) biomass. Available biomass is recruited biomass not occurring in areas of *Zostera*. n = number of samples in the survey.

Date	Area	n	Total biomass			Recruited biomass			Available biomass	
	(ha)		t	CI	kg/m^2	t	CI	kg/m^2	t	CI
1984	326	–	4604	1562	1.41	–	–	–	–	–
1988	510	–	5640	–	1.11	–	–	–	–	–
Nov 1992	588	313	6784	929	1.15	5521	852	0.94	3407	–
May 1997	642	264	9279	1741	1.45	7796	1628	1.21	4203	1389
Jun 1998	642	272	8269	1360	1.29	6915	1224	1.08	3604	842
Apr 1999	642	269	8666	1425	1.35	7905	1376	1.12	3645	869
Mar 2000	642	256	7878	1302	1.23	7128	1237	1.11	2849	707
Mar 2001	642	231	10252	1629	1.60	9117	1519	1.42	3613	764
Feb 2004	642	312	10185	1238	1.59	9421	1195	1.47	6191	945

Source: original data from 1997–2001 surveys have been checked for consistency of definitions and calculations of recruited and available biomass.

3.2.2 2008 biomass survey methods

Pakawau

In the past, up to 12 strata have been surveyed on this beach covering all the intertidal space regardless of habitat type. The extent of natural variability of habitat spatial distribution and associated cockle distribution has been observed over seven seasons. In 2008 the area surveyed was reduced by removing strata that are consistently not suitable habitat for either the fishing method or inhabitance by cockles of fishable size and density.

The remaining strata are the same as those used in all the past 7 surveys, except stratum 8 was reduced in size to remove a persistent area of *Zostera*. Strata for the 2008 survey are shown in Figure 3. Standardised biomass estimates were calculated for all past surveys to compare with the area of the 2008 survey. Additionally, each year the course of the Pakawau River varies slightly. Sample stations falling within the river are sampled if possible or, if too deep, are excluded from the survey. In this case, the area of the strata is not adjusted to take account of changing access and habitat caused by movement of the river.

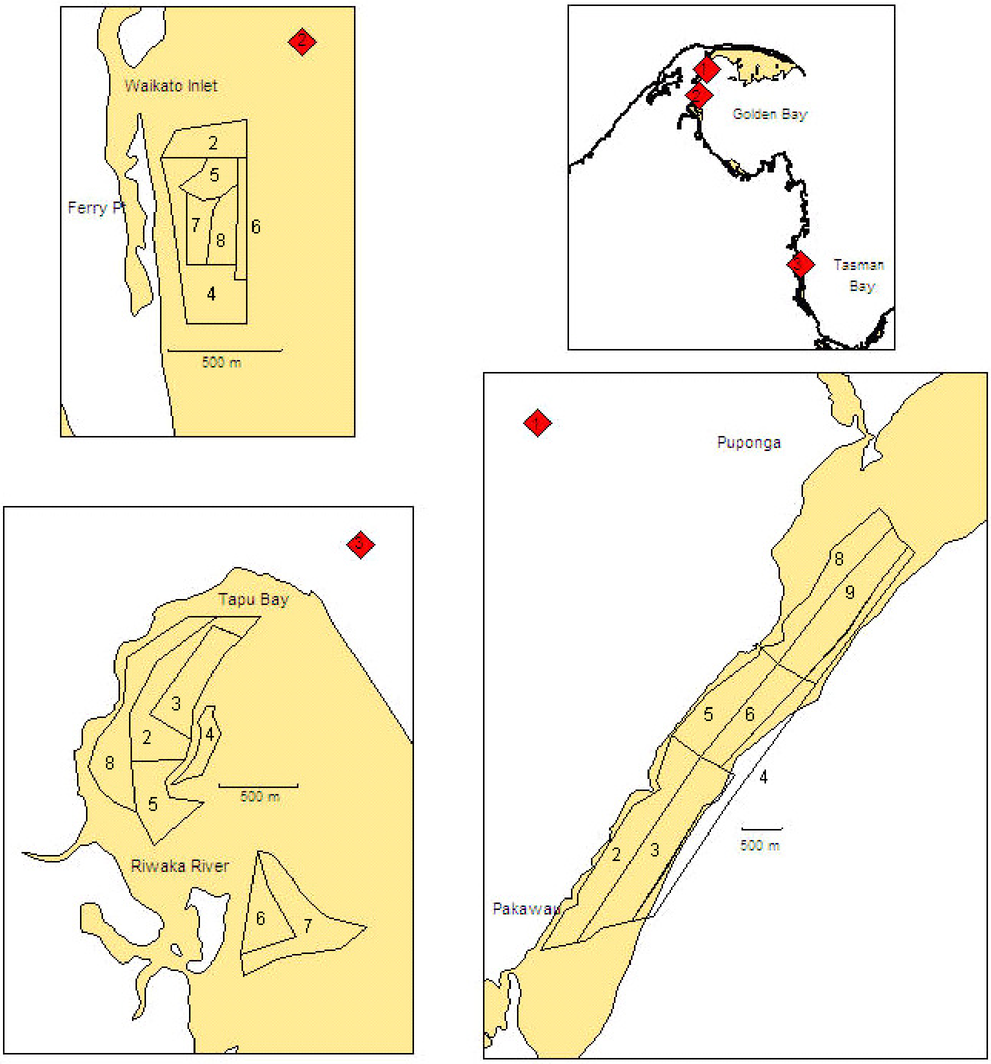


Figure 3: Location of cockle beds and survey strata.

Based on observations of cockle numbers taken from sample sites within rivers from time to time, it is assumed that the stations not sampled due to river movement do not cause bias.

The number of stations allocated to each stratum was determined from the variability of the biomass estimates for each stratum in the previous surveys. Random stations were generated by computer programme. From 10–14 January 2008, 180 stations were sampled using GPS to locate the station and a 0.1 m^2 quadrat tossed over the shoulder. The substrate was dug to the depth of the anoxic layer (at least 5 cm) and sampled material washed on a screen of 2 mm square mesh. On this occasion there was no need for any second phase stations as the desired level of accuracy was achieved at the end of phase 1 sampling.

All cockles retained on the sieve in each sample were measured to the nearest 1 mm of shell length (maximum anterior-posterior axis). The combined weight (to the nearest 0.1 g) and number of cockles in each of three size groups were recorded (over 35, 30–34, under 30).

Total biomass of cockles and its 95% confidence limits were calculated from the following equations:

$$\text{Biomass} = \sum_i (M_i A_i)$$

$$95\% \text{ confidence limits} = \pm 1.96 \sqrt{\sum_i (S^2_i A^2_i / n_i)}$$

where A_i is the area of stratum i (m^2), M_i and S^2_i are the mean and variance of catch per m^2 in strata i and n_i is the number of stations in strata i.

The spatial coverage of the fishery is estimated by classifying the substrate at each sample location as one of three classes: 1. sandy substrate suitable for harvester; 2. partial *Zostera* or fine sediment unlikely to be suitable for harvester; 3. *Zostera* or mud. Most of the class 3 sites occur within the thick *Zostera* patches that occupy parts of the beach. The class two sites are areas where *Zostera* is a thin covering. A map surface was created by the inverse distance weighted method in ARCINFO from a composite of sample locations from eight annual surveys. Minimum size at recruitment to the fishery was reconfirmed by measuring a sample of cockles landed. The sample was made up of a simple random sample taken from the discard pile at a convenient time during the grading of a day's landings, plus a selection of 15 of the smallest cockles selected by the grader. Larger graded cockles were not of interest. The grading grill on the harvester can be changed and different grill sizes have been used in the past to selectively harvest desired size classes. The smallest grill was sampled to give an indication of the minimum size harvested.

Ferry Point

The sampling methods for Ferry Point were the same as described above for Pakawau. The 2008 strata were slightly modified on the basis of the 2004 survey and are shown in Figure 3. The survey was conducted during spring low tides in the period 25–27 January and 12 March 2008. Of a total of 75 samples eventually taken, 6 were allocated in phase II to improve precision of the estimate in stratum 2.

Tapu Bay

The sampling methods for Tapu Bay were the same as described above for Pakawau. The strata were redesigned based on the results of the pervious survey and are shown in Figure 3. The survey was conducted during spring low tides in the period 8–11 March 2008. Of a total of 82 samples eventually taken, 10 were allocated in phase II to improve precision of the estimate in stratum 2.

3.2.3 2008 biomass survey results

Pakawau

There is no minimum legal size under which cockles are not permitted to be harvested. The minimum size of recruitment into the fishery varies between different cockle fisheries. Minimum size of harvesting is generally based on market price, size availability and shell shape retained by a grader. Grading typically selects by minimum shell dimension and this translates to a range of shell widths, so the minimum shell width at recruitment to the fishery is not a precise threshold. At Pakawau the fishery is based on cockles mostly larger than 35 mm but includes some cockles down to sizes of about 30 mm shell width (Figure 4). Discards are returned to the beach and the mortality rate of them is unknown. Therefore in assessments of the fishery on Pakawau Beach, mortality of discards is assumed to be 100% and the minimum size of recruitment to the fishery is assumed to be 30 mm shell width.

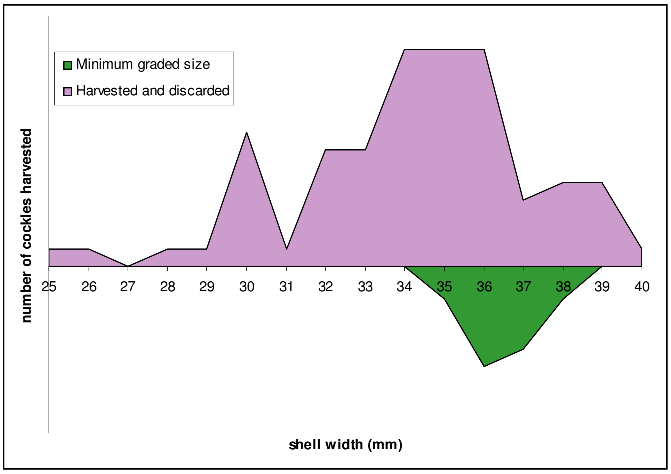


Figure 4: The minimum shell width range of landed cockles kept for selling (lower graph) and the sizes of those harvested but graded out and discarded (upper graph). Grading acts on shell depths which translates to a range of shell widths giving an imprecise threshold for minimum recruitment to the fishery.

Estimated biomass and 95% confidence limits of recruited and undersized cockles in each stratum are given in Table 4. The c.v. for recruited stock biomass for the whole area was 9.8% and no more than 20% for the main two strata.

As in previous years the greatest recruited biomass was found in strata 3 and 9. The position of the strata, stations, and relative biomass of cockles at each station sized over 30 mm is shown in Figure 5.

The coverage of *Zostera* varies from year to year and this affects the amount of cockle stock accessible for harvesting as the harvesters don't operate in areas of *Zostera* (both for physical and regulatory reasons). Over the surveyed years the amount of beach covered by *Zostera* has varied from about 22% up to 37%. In 2008 the coverage of *Zostera* was 27%. The spatial coverage of *Zostera* shown in Figure 5 is a composite of the eight surveys. The dark green shaded area signifies areas that are generally unavailable for harvesting. The pale green shade denotes areas where *Zostera* coverage is partial or transient and may be available to the cockle harvester at times.

Table 4: Survey statistics for each strata and the total population of cockles on Pakawau Beach in 2008.

			Recruits (>=30mm)				Pre-recruits (<30mm)			
Stratum	Area (ha)	n	Tonnes	c.v. %	95% CI	Kg m^{-2}	Tonnes	c.v. %	95% CI	no m^{-2}
2	85	47	977	22.2	424	1.1	166	14.1	46	85.5
3	92	48	1652	16.6	537	1.8	151	23.1	68	49.4
5	53	15	806	37.2	587	1.5	118	26.9	62	60.0
6	41	15	1223	33.1	793	3.0	46	49.0	45	24.7
8	54	15	1225	31.2	750	2.3	107	24.9	52	75.3
9	81	40	2403	15.8	743	3.0	95	27.9	52	34.0
TOTAL	407	180	8285	9.8	1599	2.0	683	10.0	134	56.2

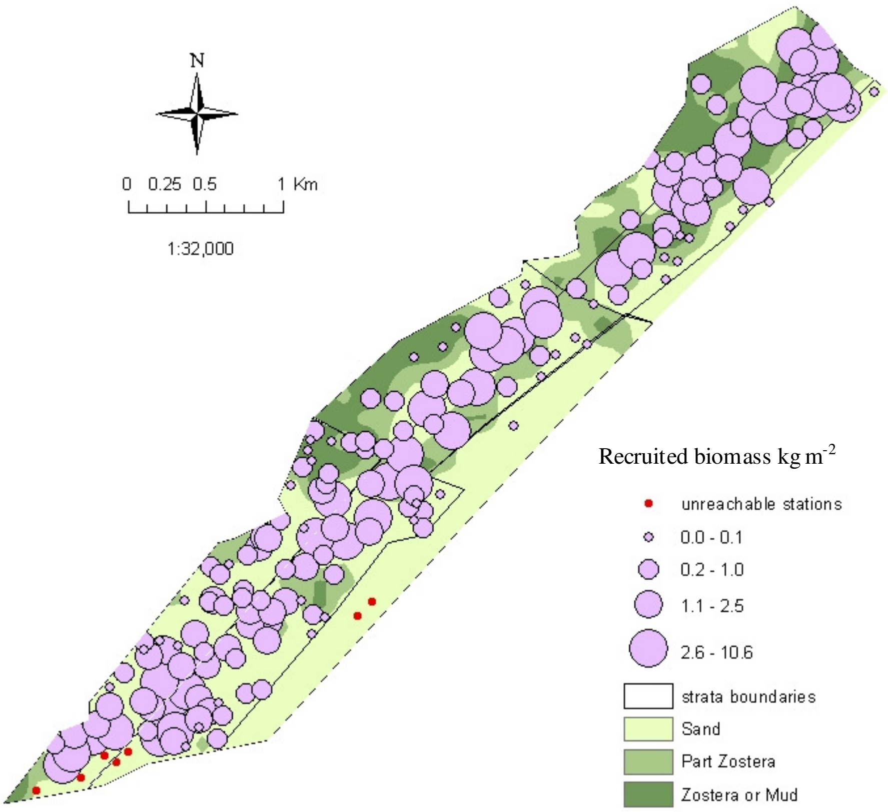


Figure 5: Map of sample sites in 2008 survey. Graduated symbols are the density of recruited cockles (>30 mm shell length) in the samples (kg/m^2). Shade areas show estimated distribution of substrate types.

Table 5: Cockle biomass available to the fishery on Pakawau beach in 2008.

		recruits fishable			
Stratum	Area (ha)	Tonnes	c.v. %	95% CI	Kg m^{-2}
2	62	642	25.4	320	1.04
3	81	1117	14.4	315	1.39
5	29	650	40.0	510	2.28
6	33	434	39.4	335	1.31
8	29	309	41.0	248	1.07
9	67	1802	18.2	644	2.71
TOTAL	299	4954	10.6	1025	1.66

The biomass of cockles in the fishery (above minimum size at recruitment and in areas in suitable substrate for the harvester) is given in Table 5. The precision of biomass estimates in Table 5 is lower with the sample size reduced but is still acceptable with the c.v. for recruited stock biomass for the whole area at 10.6% and no more than 20% for the main two strata. The fishable area of the beach is about 299 ha, 47% of the entire intertidal area lying between the Pakawau and Puponga rivers.

The total biomass of small cockles across the whole beach was 683 tonnes and the distribution and density of small cockles is shown in Figure 6. The distribution is similar to that of larger cockles. The relative densities of small cockles (spat) are quite low on this beach compared to the other two beaches surveyed (see Figures 9 and 12). This can also be seen in the size frequency distribution in Figure 7 which shows the comparative abundance and size structure of cockles on Pakawau Beach for all survey years. The average size of cockles is large compared to many other cockle populations in New Zealand for which there is size information. The very strong recruitment to the beach in 2001 is still evident in the large numbers of cockles in the 35–45 mm sizes compared to the years before 2001.

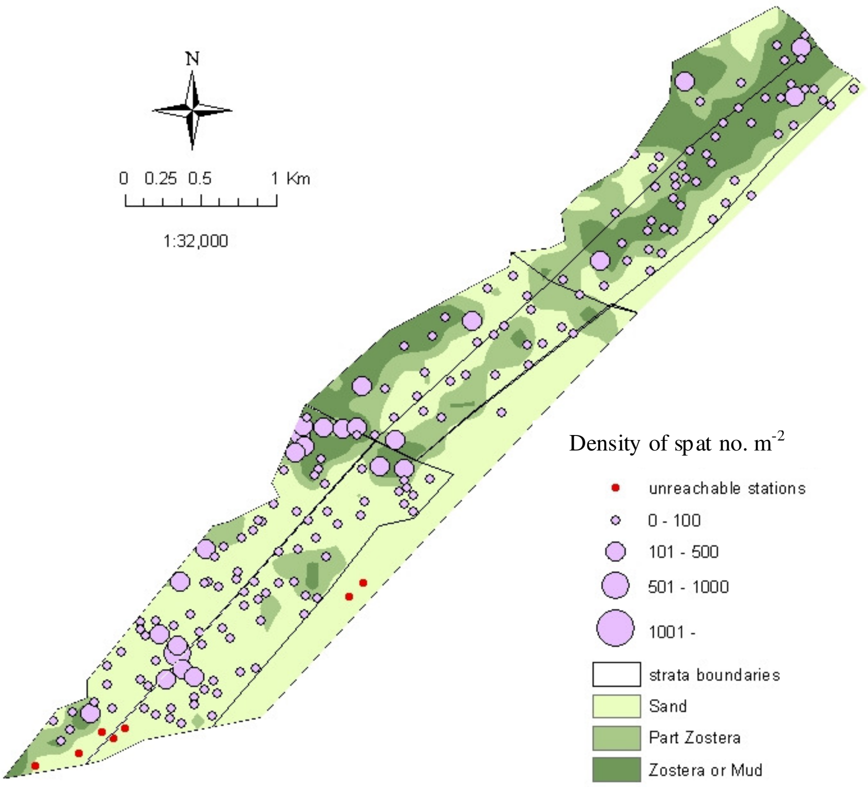


Figure 6: Map of sample sites in 2008 survey. Graduated symbols are the density of small cockles less than 30mm shell length in the samples shown at the same scale as in Figures 9 and 12 (cockles/m^2). Shade areas show estimated distribution of substrate types.

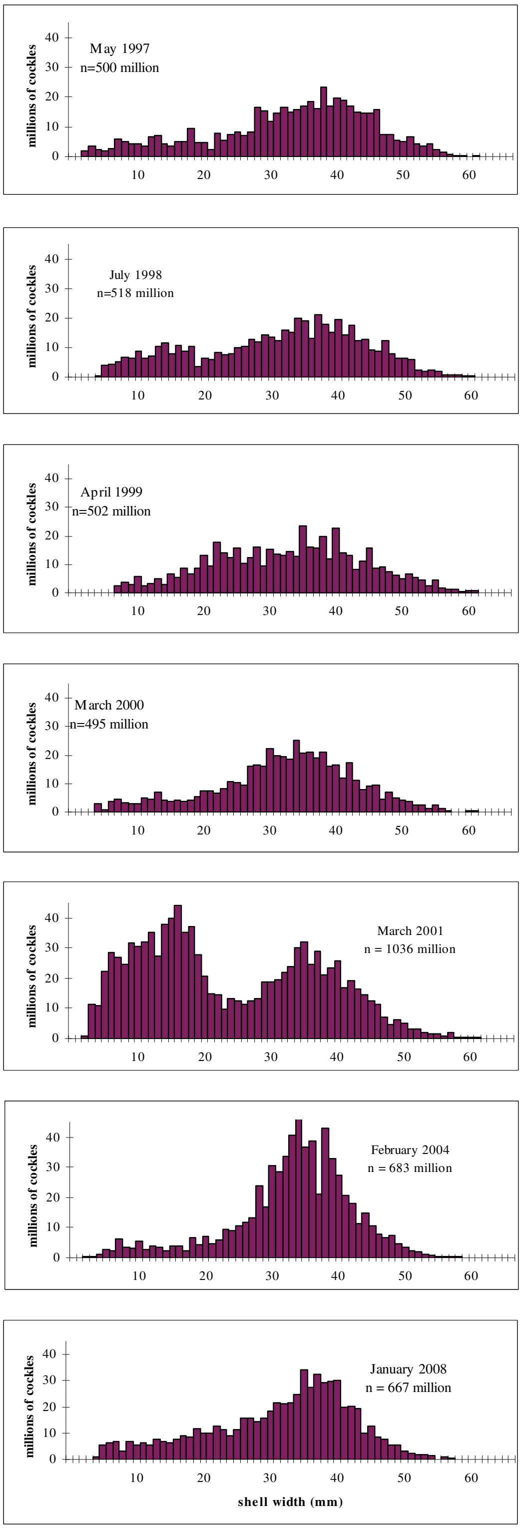


Figure 7: Estimated population size frequency distribution of cockles on Pakawau Beach from 1997 to 2008 (n= estimated total number of cockles in the surveyed area).

Ferry Point

Estimated biomass and 95% confidence limits of recruited and undersized cockles in each stratum are given in Table 6. The c.v. for recruited stock biomass for the whole area was 9.0% and no more than 20% for the three strata with the greatest biomass. As in 2004, the greatest recruited biomass in 2008 was found in stratum 4 and high densities were found in stratum 7. The range of average densities of recruited cockles in strata at Ferry Point was similar to those recorded at Pakawau (about 1–3 kg/m^2).

Table 6: Survey statistics for each strata and the total population of cockles on Ferry Point Beach in 2008.

			Recruits (>=30mm)				Pre-recruits (<30mm)			
Stratum	Area (ha)	n	Tonnes	c.v. %	95% CI	Kg m^{-2}	Tonnes	c.v. %	95% CI	no m^{-2}
2	4.8	15	104	17.7	36	2.2	27	32.6	17	220
4	10.9	27	150	20.0	59	1.4	66	13.4	17	204
5	3.2	10	57	22.2	25	1.8	16	57.9	18	132
6	2.5	5	18	59.5	21	0.7	29	57.6	33	340
7	3.2	10	90	15.0	26	2.8	10	23.3	5	88
8	3.5	8	51	21.0	21	1.4	43	58.9	50	579
TOTAL	28.2	75	470	9.0	83	1.7	192	17.9	67	245

The position of the strata, stations, and relative biomass of cockles sized over 30 mm at each station is shown in Figure 8. The total area of this fishery is small and in future years most of the strata could be combined. The area of the northernmost stratum was reduced in the 2008 survey compared to 2004 in order to follow the course of the river. The northernmost stratum was also an area where biomass of cockles had increased since 2004. Otherwise densities and distribution were similar between the 2004 and 2008 surveys with a total recruited biomass in 2008 of 470 tonnes compared to 377 tonnes in a similar area in 2004.

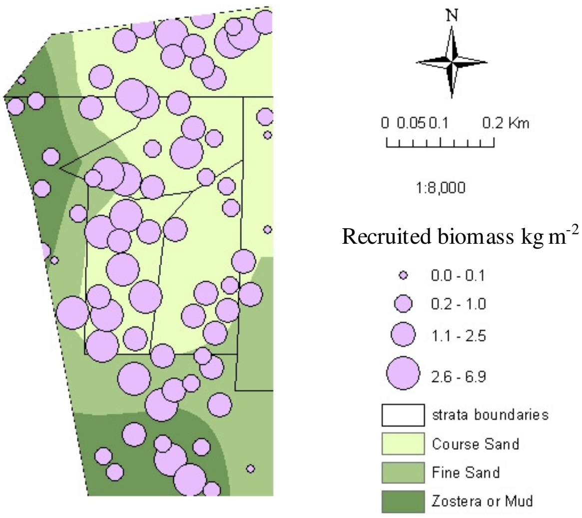


Figure 8: Map of sample sites in 2008 survey. Graduated symbols are the density of recruited cockles (>30 mm shell length) in the samples (kg m^{-2}). Shade areas show estimated distribution of substrate types.

Biomass of small cockles was 192 tonnes in 2008 compared to 170 tonnes in a similar area in 2004 and about 175 tonnes in 1996. The distribution of small cockles in the 2008 survey is shown in Figure 9. The average densities of small cockles in strata at Ferry Point were 4–5 times higher than at Pakawau. This can also be seen in the size frequency distribution in Figure 10 compared to that in Figure 7. Mean adult size has been declining in the period spanning the three biomass surveys on this beach.

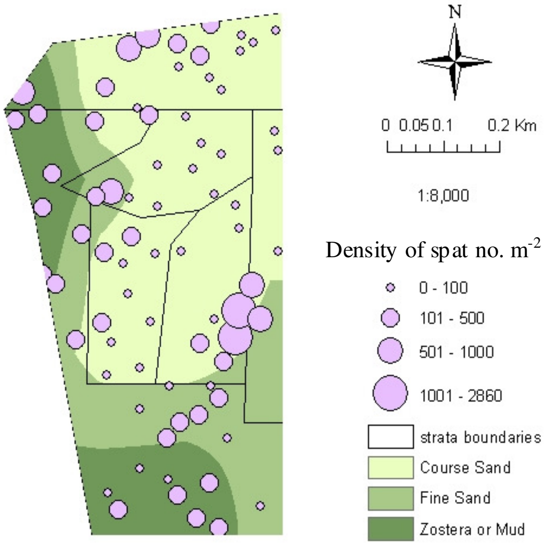


Figure 9: Map of sample sites in 2008 survey. Graduated symbols are the density of small cockles less than 30 mm shell length in the samples (cockles/m^2). Shade areas show estimated distribution of substrate types.

The decline in mean size between 1996 and 2004 coincided with the beginning of commercial fishing, but this may not have been the only or even a major cause of the observed decline. Fishery statistics show that tonnages landed in cockle area 7A outside of Pakawau Beach have been relatively small (less than 100 tonnes) and only over 4–5 years at the most (see Figure 14). A large natural mortality event affected this beach and the Pakawau beach in the summer of 1999–2000 (personal communication with fishers at both beaches). Furthermore, the reported density of cockles at Ferry Point during the 1996 survey was very high compared to that observed at Pakawau and three other beaches surveyed in Golden Bay (unpublished data) and may have been unusual.

The present biomass of cockles in the fishery (above minimum size at recruitment and in areas with suitable substrate for the harvester) is given in Table 7. The fishable area of the beach is about 20 ha compared to 300 ha at Pakawau Beach.

Table 7: Cockle biomass available to the fishery on Ferry Point beach in 2008.

		Recruits fishable			
Stratum	Area (ha)	Tonnes	c.v.%	95% CI	Kg m^{-2}
2	4.5	104	16.2	33	2.3
4	4.0	86	26.5	44	2.1
5	2.8	56	21.0	23	2.0
6	2.0	7	79.6	11	0.3
7	3.2	90	15.0	26	2.8
8	3.1	42	24.8	21	1.4
TOTAL	19.7	385	9.2	69	2.0

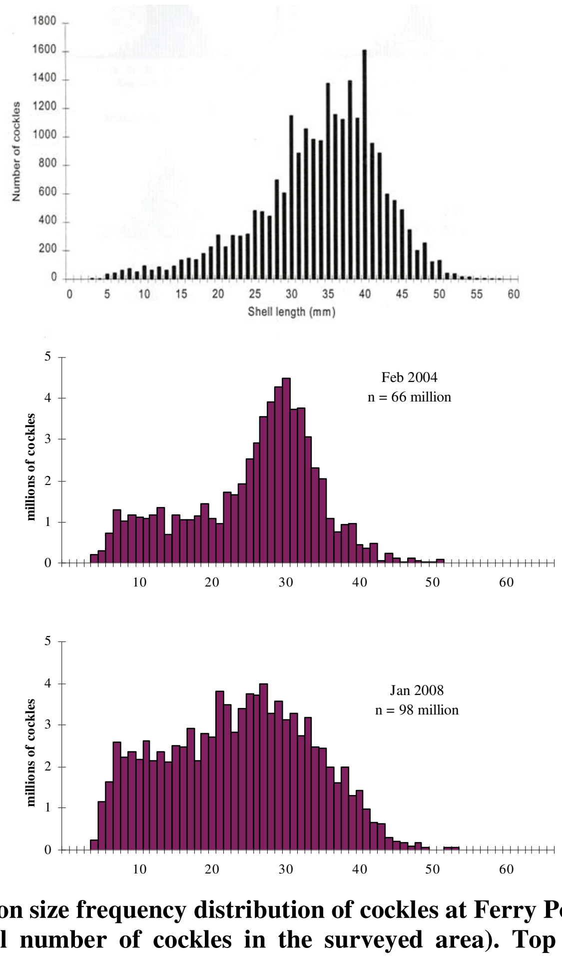


Figure 10: Estimated population size frequency distribution of cockles at Ferry Point from 1996 to 2008 (n= estimated total number of cockles in the surveyed area). Top graph is reproduced from Forrest & Asher (1997).

Tapu Bay

Estimated biomass and 95% confidence limits of recruited and undersized cockles in each stratum in the Tapu Bay biomass survey are given in Table 8. The CV for recruited stock biomass for the whole area was 9.6% and less than 20% for the two strata with the greatest biomass.

Table 8: Survey statistics for each strata and the total population of cockles at Tapu Bay in 2004.

			Recruits (>=30mm)				Pre-recruits (<30mm)			
Stratum	Area (ha)	n	Tonnes	c.v.%	95% CI	Kg m^{-2}	Tonnes	c.v.%	95% CI	no.m^{-2}
2	19.8	15	153	31.7	95	0.8	126	30.7	76	268.0
3	14.2	24	368	14.7	106	2.6	171	17.9	60	439.6
4	4.9	5	34	61.6	41	0.7	12	80.0	20	10.0
5	12.8	4	15	72.3	21	0.1	31	59.4	36	127.5
6	10.1	4	25	76.1	37	0.2	33	62.3	40	205.0
7	19.3	26	345	13.1	88	1.8	124	22.3	54	200.4
8	21.6	4	0				38	51.7	38	97.5
TOTAL	102.6	82	939	9.6	178	0.9	535	12.5	131	207.2

The range of average densities of recruited cockles in strata at Tapu Bay was similar to those recorded at both Ferry Point and Pakawau (about1–3 kgm^{-2}). The position of the strata, stations, and relative biomass of cockles at each station sized over 30 mm is shown in Figure 11. The distribution of cockles on the beach was generally similar to that reported in 2004. The biomass of cockles in 2008 was 939 tonnes compared to about 943 tonnes in a similar area in 2004.

The distribution of small cockles in the 2008 survey is shown in Figure 12. The average densities of small cockles in strata at Tapu Bay were about 4 times higher than at Pakawau and slightly less than at Ferry Point. Biomass of small cockles was 535 tonnes in 2008 compared to 260 tonnes in a similar area in 2004. This increase can also be seen in the size frequency distributions in Figure 13.

The biomass of cockles in the fishery (above minimum size at recruitment and in areas with suitable substrate for the harvester) is given in Table 9. The fishable area of the beach is about 84 ha compared to 20 ha at Ferry Point and 300 ha at Pakawau Beach. The fishable biomass in 2008 in Tapu Bay is estimated as 713 tonnes compared to 385 tonnes at Ferry Point and 4954 tonnes at Pakawau.

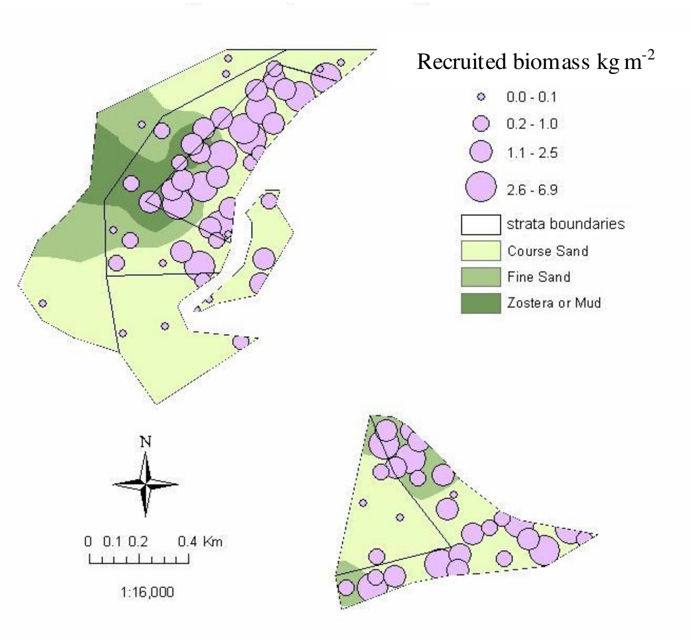


Figure 11: Map of sample sites in 2008 survey. Graduated symbols are the density of recruited cockles (>30 mm shell length) in the samples (kg m^{-2}). Shade areas show estimated distribution of substrate types.

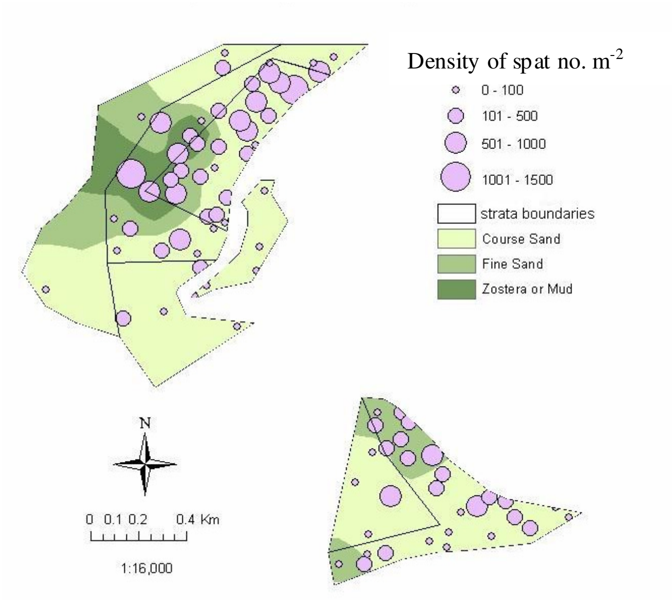


Figure 12: Map of sample sites in 2008 survey. Graduated symbols are the density of small cockles less than 30mm shell length in the samples (cockles m^{-2}). Shade areas show estimated distribution of substrate types.

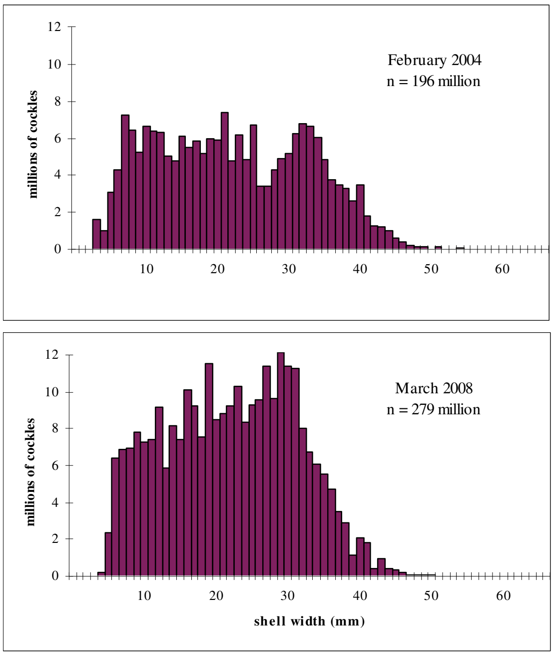


Figure 13: Estimated population size frequency distribution of cockles at Tapu Bay in 2004 and 2008 (n= estimated total number of cockles in the surveyed area).

Table 9: Cockle biomass available to the fishery at Tapu Bay in 2008.

		Recruits fishable			
Stratum	Area (ha)	Tonnes	c.v.%	95% CI	Kgm^{-2}
2	15.8	127	37.5	93	0.80
3	11.2	306	17.1	102	2.72
4	4.9	34	61.6	41	0.69
5	12.8	15	72.3	21	0.12
6	10.1	25	76.1	37	0.25
7	12.6	207	18.4	75	1.64
8	16.2	0		0	0.00
TOTAL	83.6	713	12.0	168	0.85

3.2.4 Biomass time series evaluation

The cockle fishery in area COC 7A is predominantly based on the Pakawau Beach population. Landings from Pakawau Beach and total landings are shown in Figure 14. There are a few minor discrepancies between company records and the Ministry's landing statistics, presumably due to data handling errors. It is believed that fishing has taken place at only low levels at Ferry Point and not at all in the last 4 years. Tapu Bay has never had water quality classification for export and any landings from this area would have been for domestic sale only. The difference in total landings and Pakawau company landings records suggest that landings outside Pakawau have been less than 100 tonne annually and only over a few years from 1998 to 2003. The declining trend for cockle biomass on each of these two beaches (Figure 15) may be more related to natural environmental changes than fishing pressure. In the period 1999–2000 unusually high natural mortality was observed by fishers at Pakawau and Ferry Point.

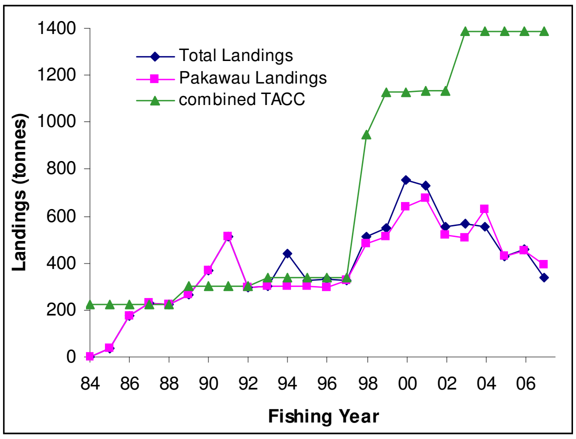
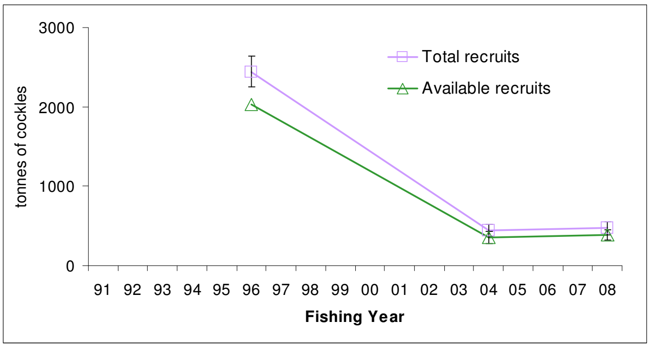


Figure 14: Landings from Ministry records for the total COC7A area and company records for Pakawau beach alone compared to the TAC.



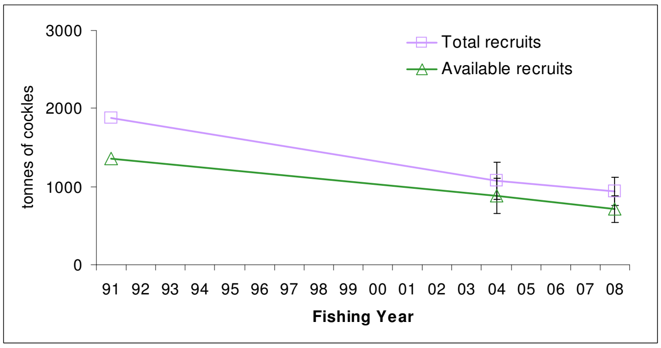


Figure 15: Time series of biomass estimates from cockle surveys at Ferry Point (top) and Tapu Bay (bottom). Plots are total recruits in the survey area and recruits available to the fishery which are those in suitable substrate for commercial harvesting.

In contrast, abundance of cockles in the fishery at Pakawau is higher in recent years than at the beginning of the fishery (Figure 16). Observed variability in annual recruitment and natural mortality could explain the pattern of abundance and over a longer time period this may be cyclic. The fishing company may also affect natural mortality by thinning and redistributing cockle densities. It should be noted that reported landings in the fishery include the weight of shell rubbish and undersized cockles that is graded out and returned to the beach (or dumped on land if it is mostly rubbish shell). Westhaven's company records show that 10–70% of reported landed weight can be returned to the beach in any month (average for 2001–2007 fishing years is 38%). Much of this returned weight is live cockles that are spread back onto the beach and their fate is unknown. The conclusion is that fishing intensity of cockles on Pakawau Beach is quite light.

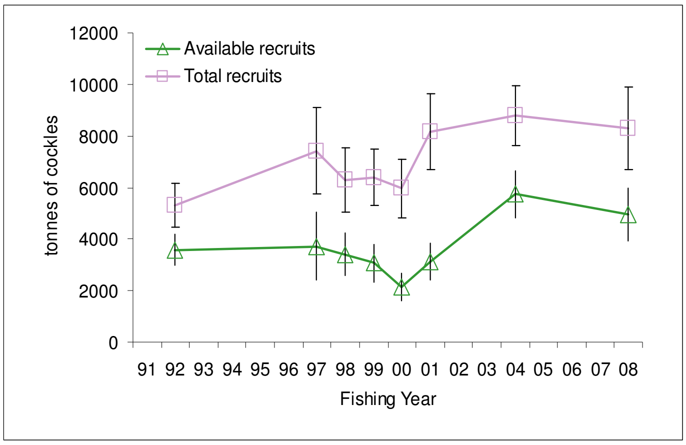


Figure 16: A standardised time series of mean recruited biomass calculated for the same six strata in surveys of Pakawau beach (bars are 95% confidence interval). Plots are total recruits in the survey area and recruits available to the fishery which are those in suitable substrate for commercial harvesting.

Interpolated contours of cockle biomass from the combined sampling points of 8 survey years are shown in Figure 17. Much of the biomass typically occurs in the northern part of the beach where *Zostera* beds have wide coverage. Some of this biomass is accessible as the *Zostera* is patchy. To date harvesting has been predominantly concentrated in the southern part of the beach closest to the factory. The TACC has never been reached. Business costs and market factors have reportedly restrained fishing (Westhaven owner, pers. comm.). A time series of estimates of available recruited cockles in the southern area of the beach where the fishery is mostly concentrated (strata 2 and 3) is shown in Figure 18. The biomass varies with the observed patterns of recruitment. The drop in commercial landings since 2004 seen in Figure 14 may be related to the drop in recruited biomass between 2004 and 2008, but biomass in other areas of the beach is still high as seen in Figure 16.

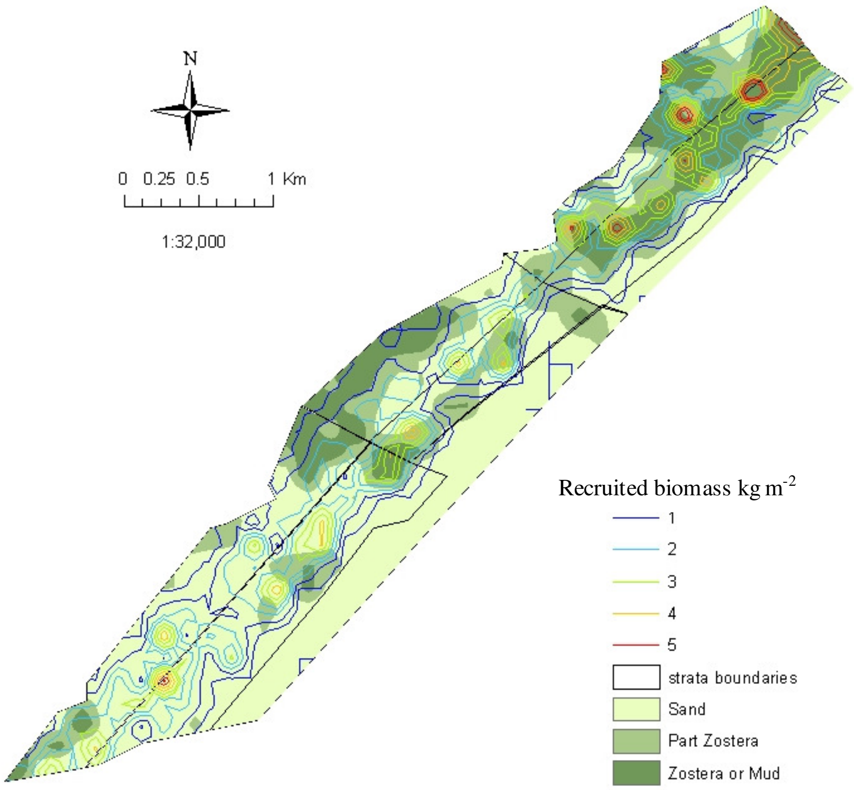


Figure 17: Distribution of cockles on Pakawau Beach averaged from eight annual surveys between 1992 and 2008. Contours show densities of recruited cockles >30 mm shell length (kg/m^2). Shade areas show estimated distribution of substrate types

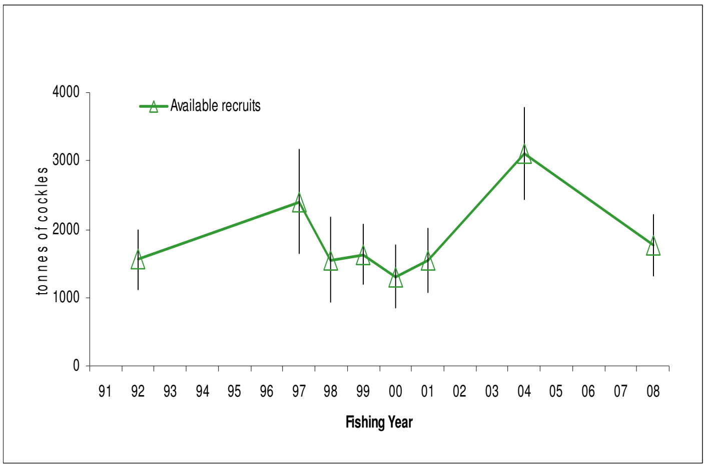


Figure 18: A standardised time series of mean recruited biomass available to the fishery calculated for the same two southern most strata in surveys of Pakawau beach (bars are 95% confidence intervals).

3.3 Other studies

3.3.1 Previous estimates of biological parameters

Estimates of growth and mortality have been made for cockles from Pakawau Beach (Osborne 1992, 1999), and are summarised in Table 10. The 1992 study estimated von Bertalanffy growth parameters with available tag recapture data from Bull (1984), and growth increments of translocated cockles from Westhaven Shellfish company records. Analysis of the scaled length-frequency distribution from the 1992 survey using the MIX software[1] enabled calculation of the proportional reduction of the 4+ and 5+ age classes to produce estimates of instantaneous natural mortality, M (after removal of estimated fishing mortality, F).

The 1999 study used a MIX analysis of length-frequency data from two strata in comparable surveys in 1997, 1998, and 1999 to estimate mean lengths (and proportion in the population) of the first 8 year classes (Osborne 1999). Mean natural mortality rates were estimated (for age classes 4–7) between 1997 and 1998, and 1998 and 1999 and are given in Table 10.

Table 10: Estimates of biological parameters.

Population & years		Parameter estimates		Source
1. Natural mortality (M)				
Pakawau Beach (1992)			0.45 for 4+; 0.30 for 5+	Osborne (1992, 1999)
Pakawau Beach (1998)			0.40	Osborne (1999)
Pakawau Beach (1999)			0.52	Osborne (1999)
2. Weight = a (shell length)^b (weight in g, shell length in mm)				
Pakawau Beach (1992)	a = 0.000017		b = 3.78	Osborne (1992)
Ferry Point (1996)	a = 0.000205		b = 3.153	Forrest & Asher (1997)
Tapu Bay-Riwaka (1991)	a = 0.000150		b = 3.249	Stark & Asher (1991)
3. von Bertalanffy growth parameters				
	K	t_0	L_∞	
Pakawau Beach (1984–92)	0.36	0.30	49.0	Osborne (1992)
Pakawau Beach (1997)	0.38	0.68	48.3	Osborne (1999)
Pakawau Beach (1998)	0.40	0.68	47.4	Osborne (1999)
Pakawau Beach (1999)	0.41	0.66	47.0	Osborne (1999)

3.3.2 The 2007–2010 growth study

A mark recapture experiment was undertaken to test previous growth estimates used for a YPR model which in turn was used to estimate F0.1 reference fishing mortality rate for the cockle fishery on Pakawau Beach. There are no immediate plans to develop stochastic models of this fish stock so the main aim of the growth study was to review the previous deterministic estimates of F0.1 and von Bertalanffy growth parameters. Nevertheless, the opportunity was taken to gain information on the seasonality and variability of growth rates within the fished beds both in relation to tidal height and distance from Pakawau River.

[1] Developed by P. D. M Macdonald, McMaster University, 1988 and available from http://www.math.mcmaster.ca/peter/mix/mix.html

Methods

In July 2007, about 1200 cockles were marked and released at each of three marked plots on Pakawau Beach (Figure 19). The sites were chosen to test for differences in growth rate between the Pakawau and Puponga ends of the beach and between high shore and low shore at the Pakawau location. The Puponga and low shore Pakawau sites were of similar tidal height and were selected to be generally within the areas usually fished, so that the cockles were of commercial density. The Pakawau high tide site was selected to be towards the highest tidal level where commercial densities of recruited cockles occurred.

At each site a strip of dry beach was fished with the mechanical harvester and then a plot 3 x 3 m within the area fished was marked with stakes. About 1200 cockles of a range of sizes were selected from both the harvest and the material discarded from the harvester (in order to collect smaller sizes) and the rest returned to roughly where they were taken from. The cockles were marked during the intervening high tide and replanted into the staked area upon the next low tide, giving a maximum time between harvest and release of 12 hours. The cockles were kept out of water and in the shade during this time. Replanting was done by sprinkling the cockles evenly into shallow trenches and lightly covering with sand to hide the cockles from view. Cockles were marked with a small notch on the growing margin of both valves. The notches were highlighted with a groove cut on the surface of each valve to aid recovery. Samples of about 100 marked cockles were recovered from each plot at quarterly intervals for the next 12 months.

In January 2009, a further 1000 or more cockles were harvested, marked, and released at the Pakawau site (site B in Figure 19). This time the cockles were marked with brightly coloured spray paint, allowed 1 hour to dry, and then reburied within the marked plots. Time between harvest and reburial was a maximum of 2 hours and was timed so that the plots were being submerged by the incoming tide within 30 minutes of replanting. This second experiment differed from the first in three main variables: the type of shell marking used, the time between mark and release, and the season of mark and release.

Results

Mean annual growth at size

The effect of marking method, tidal height, and river proximity on annual growth increments as a function of size were determined by multiple regression analysis on all growth increments measured after 12 months at liberty (12 months defined as 343 to 387 days giving a sample size n=469). Previous mark recapture data of Bull (1984) were added to the multiple regression for comparison (n=190). A quadratic polynomial fit to the curvilinear relationship between annual growth increment and size gave reasonably well behaved residuals (Figure 20). All the regression coefficients were significant (Table 11) and stepwise regression using AIC criteria retained all the predictors in the best model (Table 12). Of the three treatments, tide level has the greatest effect, with growth being significantly slower on the high shore. Painted cockles also grew slightly, but significantly, more slowly than notched cockles, cockles at Puponga slightly but significantly faster than those at Pakawau. Growth of cockles marked and released by Bull in 1984 was faster than at any sites monitored in 2007–2010. Polynomial regressions fitted to each of the sites individually are shown in Figure 21.

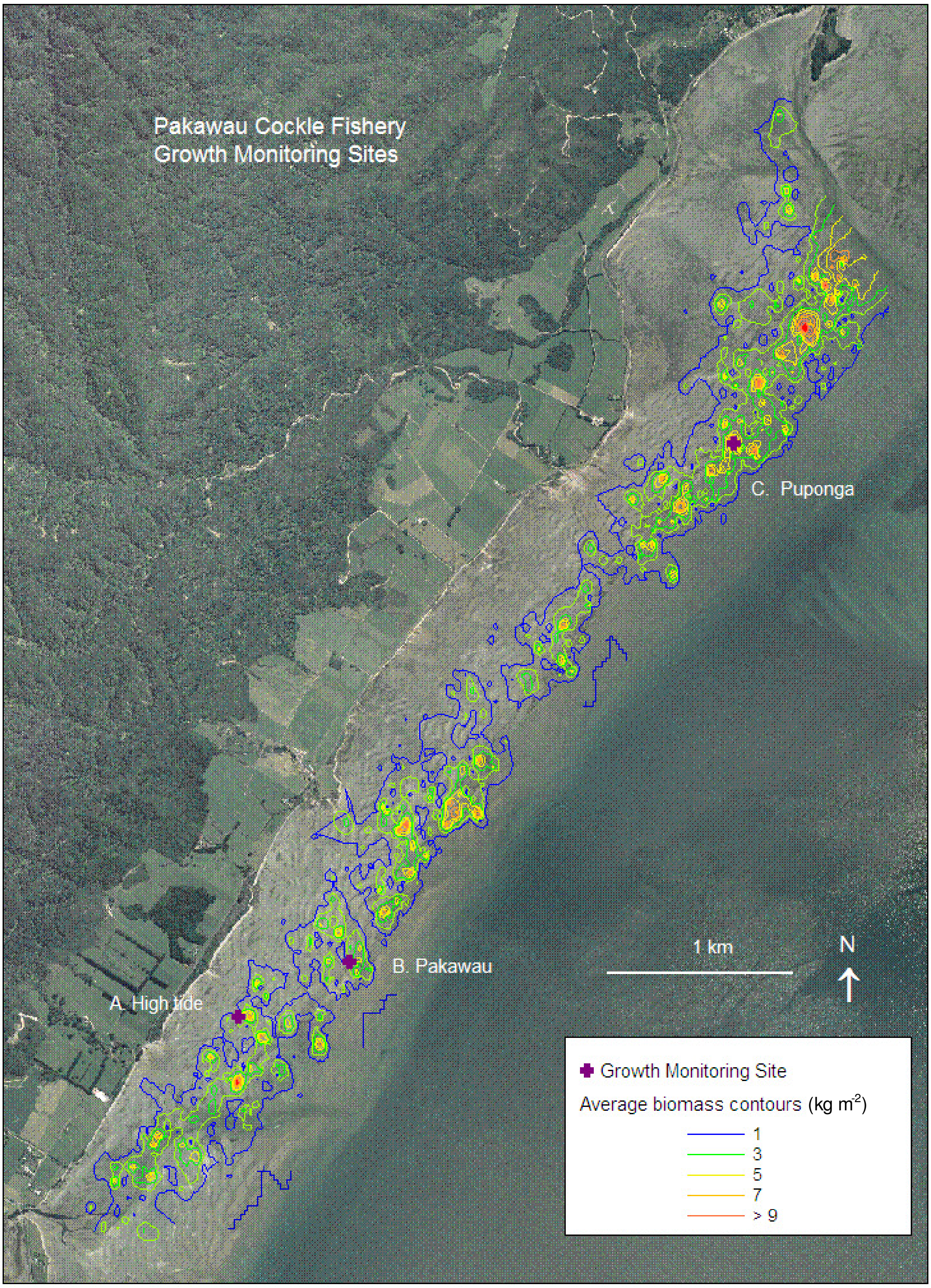


Figure 19: Location of three growth monitoring sites in relation to average cockle biomass contours in the Pakawau cockle fishery

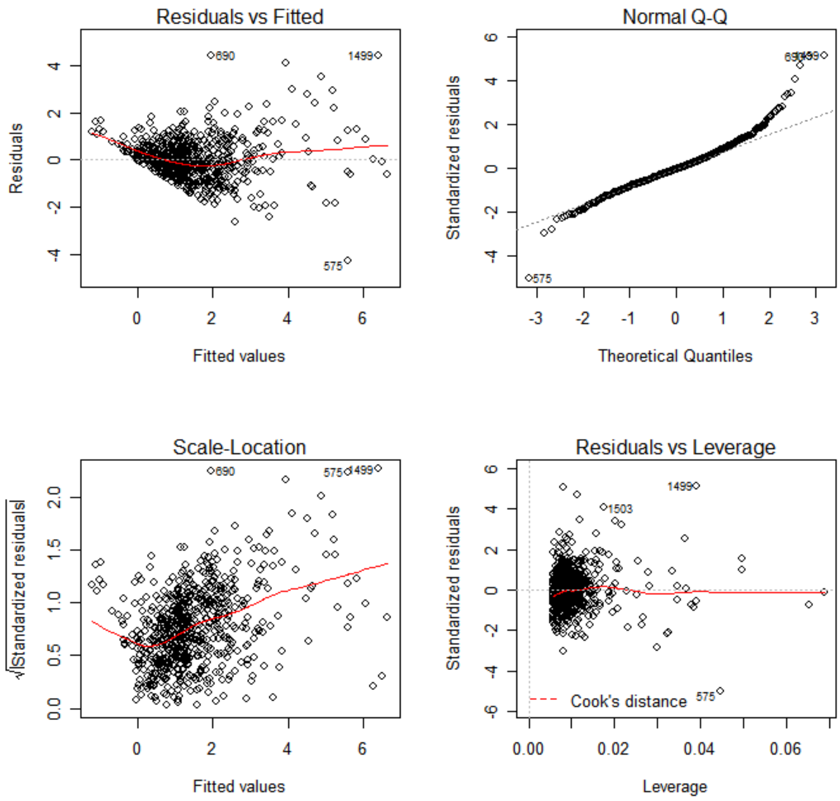


Figure 20: Analysis of residuals from a quadratic regression of growth increment on size at mark and release with additional categorical predictors, tidal height (high or low), position along the beach (Pakawau or Puponga), marking method (notched or painted) and year of experiment (1984 (Bull) or 2007). Residuals are reasonably normally distributed around a mean of zero with no influential outliers but do not have constant variance (heteroskedastic).

Table 11: Parameters for coefficients in a linear regression of annual growth increment on multiple predictors, and t-test values for H_0: $\mu=0$. All predictors have a significant positive or negative relationship with increment i.e., increment declines as size increases; Puponga and Bull predictors explain higher than average increments; high tide level and painted predictors explain smaller than average increments. (H_0 acceptance region at $\alpha=0.05$ is $-1.96 < t < 1.96$). Predictors detailed in caption of Figure 20.

Predictors	Mean	Std. Error	t value
Intercept	21.005	1.180	17.806
Size	-0.820	0.061	-13.465
$Size^2$	0.008	0.001	10.413
Tide level	-1.635	0.124	-13.155
Painted	-0.341	0.106	-3.219
Puponga	0.325	0.118	2.755
Bull	0.705	0.104	6.766

Table 12: The order of predictors removed in backward stepwise regression and the contribution of each to total variance in the regression (sum of square error explained by each predictor). Residual error declines as each additional explanatory variable is added to the model and the AIC score indicates the full model is best, i.e., all the treatments had significant effects on growth rate.

Predictor removed	Df	Sum of Squares	Residual Sum of Squares	AIC
None			499.53	-168.58
Puponga	1	5.82	505.34	-162.96
Painted	1	7.94	507.46	-160.19
Bull	1	35.07	534.60	-125.87
Size^2	1	83.07	582.59	-69.21
Tide level	1	132.57	632.10	-15.46
Size	1	138.90	638.42	-8.90

It is not surprising that growth rate varies with tidal height as cockles lower on the shore have longer periods of feeding. Observed differences in growth rates may partly explain the observed differences in length frequencies at the three sites on the beach. The Puponga end of the beach exhibited higher growth rates and more large cockles than the low shore site at Pakawau. The high shore site at Pakawau exhibited slower growth rates than the low shore sites and smaller size distribution of cockles by comparison. The precise location of Bull's marked cockles is unknown. It is possible that areas on the beach closer to the rivers may have even faster growth rates than the three sites monitored in the present study. The extent of interannual variation in growth is also unknown. Therefore the reason for growth rates apparently being slower in 2007–2010 than in 1984 cannot be determined. Ongoing monitoring of annual growth rates may be worthwhile in this fishery to give information on interannual variation and address the question of whether size selective harvesting affects growth.

Estimating natural growth from that observed in marked cockles assumes the act of marking and the mark itself does not alter growth. The close similarity of mean annual growth between the two different methods of marking gives some confidence that this assumption is valid, but is not a rigorous test. Notching required the cockles to be removed from the beach and kept out of water through one high tide. It also involved removal of some shell material and the risk of damaging some soft tissue in the process. Painting was quicker: the cockles never left the beach and were not out of water any longer than normal during a tidal cycle. The paint was assumed to be non-toxic to the animal and not affect its normal behaviour (the possible bias introduced by altering vulnerability to predation of cockles nearest the food supply is an interesting point not addressed in the present study). If handling the cockles for marking or if the mark itself disturbed normal growth then notching might be expected to have a greater retarding effect than painting. In fact, notched cockles grew slightly faster than painted cockles. Slower growth of painted cockles might be explained by the time of year of marking: winter for notching and summer for painting. Marking may have a temporary effect on normal metabolism which can be detected during the growing season but not during the winter (further discussion of seasonal growth below). The present study gives an indication of the range of natural variation in growth rates across the beach and in different years. Any effect of marking appears to be minor in comparison to this natural variation.

The standard von Bertalanffy growth model assumes growth rate is linearly proportional to size and is not a good fit to the observed nonlinear relationship between growth rate and size in cockles. Cockle growth rate declines with increasing shell size. Modified von Bertalanffy growth equations were used to examine measurement error and seasonality of growth from growth increment data after a variable number of days at liberty (samples taken at 3 month intervals). Due to the curvilinear relationship between increment and size, the standard von Bertalanffy growth model was modified following Francis (1995) to incorporate an additional parameter that influences the shape of the relationship between size and growth increment (b).

The equations were fitted separately to data from each experiment (using an Excel spreadsheet supplied by Malcolm Haddon (CSIRO Hobart) for the model of Francis (1988) and modified to include the shape parameter 'b' after Francis (1995)). The model used was submodel 5.3 from Francis (1995) for which expected growth is decelerating and always positive (for this submodel, $\Delta Y \rightarrow 0$ as $Y \rightarrow +\infty$):

$$\Delta Y = -Y_m + [Y_m^{\ b} + (\lambda_1^{\ b} - y_1^{\ b})\ \Delta t]^{\ 1/b}$$

where ΔY is size increment; Y_m is size at marking; Δt is time at liberty; y_1 is an arbitrary fish size whose value is specified by the user (usually be chosen to be near the lower end of the range of values of Y in the data set to be modelled); $\lambda_1 = y_1 + g_1$; and g_1, is the mean annual growth (size increment) for fishes of size y_1.

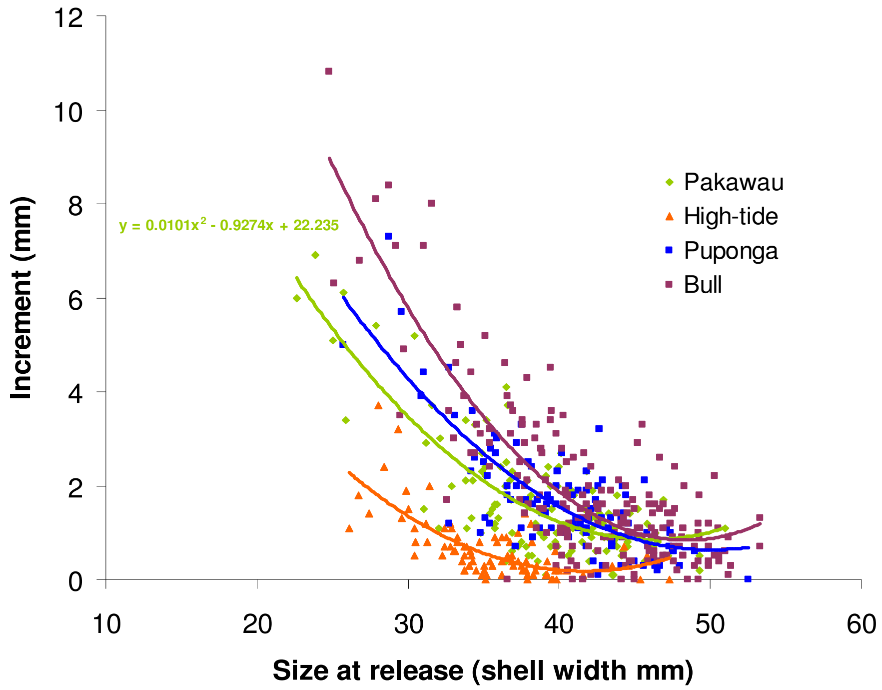


Figure 21: Measured growth increments of cockles at liberty for 12 months from three sites in the Pakawau fishery during 2007-2008 and from an unknown site in the same fishery in 1984 (Bull's data). The curves are fitted to each site individually so the coefficients differ from those from the multiple regression given in Table 11. The equation of the curve fitted to the Pakawau data is given.

In the three sites the fitted growth model was significantly improved (using a likelihood ratio test) with the addition of both measurement error terms and seasonality terms (Table 13). A slight negative bias in measurement accuracy was suggested by the model. Summer growth was faster than winter growth in the two low shore sites, in fact growth over winter practically stopped. The model for high shore growth suggested growth was significantly slower in autumn which may be interesting to examine further but is beyond the scope of this project.

Table 13: Mean parameter values from submodel 5.3 in Francis (1995) for each site. Y1 was chosen as 25 mm, Y2 is not used in this model and is instead replaced by b. Otherwise - means the additional parameter did not significantly improve the model.

Parameter	Puponga notched	Pakawau notched	High tide notched
g25	6.17	4.35	2.26
g50	-	-	-
b	4.96	3.92	4.33
ν	0.50	0.52	0.63
u	0.67	2.10	-1.18
w	0.04	0.00	0.30
s	0.00	0.00	0.00
m	-0.13	-0.13	-0.17
p	0.03	-	-

Size at age

Previous estimates of size at age for cockles at Pakawau were obtained from length frequency analysis. They suggested the first four year class modes at about 11, 23, 31, and 36 mm in early autumn.

Repeatedly applying mean growth increments to cockles starting at age 2 for which the assumed mean size is 23 mm gives estimates of size at age for cockles. Resulting mean sizes at age for each site are shown in Figure 22. These are deterministic estimates and do not offer information on variation of size at age. Monte Carlo simulation of a population of cockles starting with a cohort of 2-year olds of assumed size distribution and applying growth at size with parameter distributions derived from the analyses above would give estimates of probability distributions for size at age which could then be compared with observed size frequency distributions in the fishery, but this is beyond the scope of the present study. The immediate need for parameters describing growth of cockles is to review and update estimates of $F_{0.1}$ obtained from a simple deterministic YPR model.

Osborne (1992) used the YPR method of Ricker (1975) implemented in Excel to estimate $F_{0.1}$ for various levels of M and using a von Bertalanffy growth equation to give size at age. This model was reviewed using the new information on growth from the present study. Each time step was 0.1 years and size at age was calculated from a logarithmic equation fitted to the Pakawau size at age estimates. The differences between the von Bertalanffy model and the new model are shown in Figure 22. The resulting differences in $F_{0.1}$ are given in Table 14.

Table 14: Values of $F_{0.1}$ derived from a YPR model using the original von Bertalanffy growth model of Osborne (1992) and the new model from this study, for different assumed levels of natural mortality (M).

	M=0.2	M=0.3	M=0.4
New growth model	0.27	0.37	0.46
Old growth model	0.24	0.34	0.46

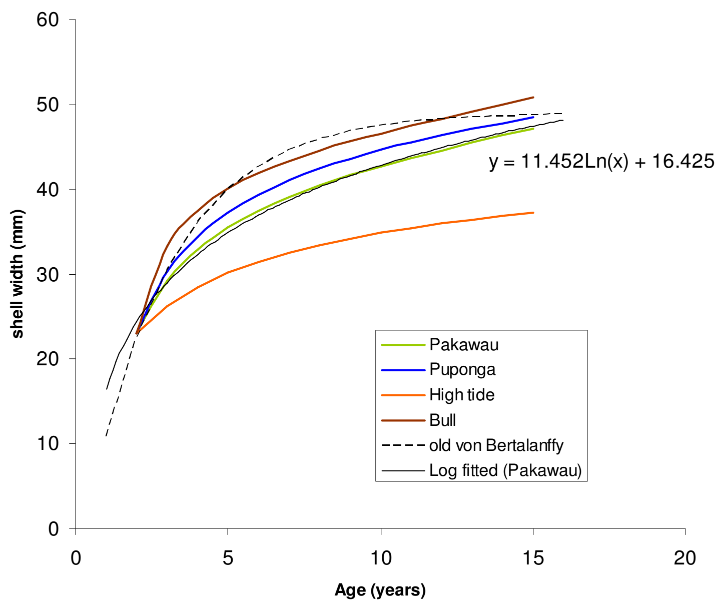


Figure 22: Size at age curves derived from mean growth at size estimates and a starting size of 23mm at age 2. The logarithmic curve and equation used to describe Pakawau growth in a YPR model are shown.

Table 15: Past and present biomass levels and estimated reference levels for the fisheries of COC 7A.

	Recruited biomass				Available biomass				Assessed reference levels		
	Area	tonnes	95% CI	c.v.	Area	tonnes	95% CI	c.v.	B_0	B_{av}	95% CI
Pakawau											
1984	326	4604	1562								
1988	510	5640									
1992	421	5299	836	8.1	361	3586	612	8.7	3586		
1997	421	7422	1665	11.0	275	3723	1331	18.2		3655	134
1998	421	6285	1252	9.8	317	3412	827	12.4		3574	176
1999	421	6388	1091	8.7	246	3058	727	12.1		3445	282
2000	421	5966	1140	9.7	266	2139	555	13.2		3184	556
2001	421	8160	1460	9.1	254	3111	712	11.7		3172	455
2004	421	8803	1164	6.7	307	5747	909	8.1		3539	817
2008	407	8285	1599	9.8	299	4954	1025	10.6		3716	788
Ferry Point											
96	45	2442	191			2031*			2031		
04	40	443	80	9.2	30.0	354	75	10.8			
08	28	470	83	9.0	19.7	385	69	9.2		923	1086
Tapu Bay											
91	306	1880	450		61.0	1358+			1358		
04	123	1076	235.6	11.2	110.7	883	222	12.8			
08	103	939	177.6	9.6	83.6	713	168	12.0		985	378

* harvestable biomass >30mm (Forrest & Asher 1997).
+ Size classes A and B in commercially available areas from Stark & Asher (1991).

3.4 Biomass estimates

Previously, yield assessments for commercial fishing of cockles in area COC 7A were made using estimates of biomass available to mechanical harvesters, i.e., biomass occurring outside *Zostera* beds and muddy substrates. Past and present estimates of reference and current biomass for the three fisheries are given in Table 15.

In 2008, B_{av} for Pakawau was calculated as the average recruited biomass for the eight surveys from 1992 onwards. B_{av} for Ferry Point was calculated as the average recruited biomass for the three surveys from 1996 onwards and for Tapu Bay for the three surveys from 1991 onwards.

3.5 Yield estimates

Estimation of MCY

MCY for all three beaches was estimated using method 2 of Annala et al. (2002):

$$MCY = 0.5 * F_{0.1} * B_{av}$$

Estimates of $F_{0.1}$ were calculated using the yield per recruit model based on a new growth model reported above (Table 14).

Estimation of CAY

CAY has been estimated using the Baranov catch equation (Method 1 in Annala et al. 2002). Fishing occurred evenly throughout the year so the full catch equation was used:

$$CAY = F_{0.1}/(F_{0.1} + M) * (1 - e^{-(F0.1 + M)}) * B_{beg}$$

CAY estimates were made using total recruited biomass available to harvesters (i.e. outside *Zostera* and soft mud patches) in January 2008 as "beginning of season" biomass (Bbeg). This makes the assumption that changes in the population from growth, mortality, and recruitment between the time of survey and the beginning of the fishing season (1 October 2008) are insignificant.

It has been the practice to calculate yields for a range of assumed natural mortality (M) values. Typically M = 0.2–0.3 has been acceptable for setting TACs. The most recent estimates of M in this fishery indicates M = 0.4 and can in some seasons be higher than M = 0.5. Accordingly CAY has also been calculated using M = 0.4.

The ranges of yield estimates for each of the three fisheries are given in Tables 16 and 17.

The TAC for COC 7A originally started at 300 tonnes for the Pakawau Beach area. This increased to 336 with 36 tonnes being allocated to Tapu Bay. Subsequently, the Pakawau TAC rose to 760 tonnes and a new allocation of 334 tonne was added for Ferry Point. Since then the three fisheries have been managed under a single TAC which now stands at 1390 tonnes. At this level the TAC falls at the high end of the range of MCY. CAY calculated with M = 0.3 and mean B_{beg} is 1632 tonnes which is greater than the present TAC.

Table 16: Yield estimates for the three fisheries that make up COC 7A (tonnes).

			Pakawau			Ferry Point			Tapu Bay		
			Mean	Low 95%	High 95%	Mean	Low 95%	High 95%	Mean	Low 95%	High 95%
	Bav		3716	2928	4504	923	0	2009	985	606	1363
	2008 Bbeg		4954	3929	5979	385	315	454	713	545	881
MCY	M	F0.1									
	0.2	0.27	502	395	608	125	0	271	133	82	184
	0.3	0.37	688	542	833	171	0	372	182	112	252
	0.4	0.46	855	673	1036	212	0	462	226	139	313
CAY	M	F0.1									
	0.2	0.27	1067	846	1288	83	68	98	154	117	190
	0.3	0.37	1336	1059	1612	104	85	122	192	147	238
	0.4	0.46	1528	1212	1845	119	97	140	220	168	272

Table 17: Summary of yield estimates for the three fisheries that make up COC 7A (tonnes)

	MCY	CAY	TAC
Pakawau	395-1036	846-1845	
Ferry Point	0-462	68-140	
Tapu Bay	82-313	117--272	
Total	477-1811	1031-2257	1390

4. MANAGEMENT IMPLICATIONS

As a sedentary species, the assumption that the whole recruited biomass is available to the fishery and that M and F will act evenly across the recruited stock does not hold. Some of the recruited biomass may not be fishable because the density is too low to make fishing attractive. Areas of high density may be susceptible to local depletion as fishing intensity increases and this will affect catch rates. The extent to which cockles move around in response to factors such as density is unknown, but there is evidence of a considerable amount of short distance wandering occurring on the beach. Therefore, there is scope for mixing of patches.

Protection of spawning stock biomass is not considered an issue in this fishery due to the large stocks of cockles not subject to fishing pressure both within *Zostera* patches and outside the fished areas. For this reason, a fishing strategy based on harvesting the maximum obtainable surplus production without being concerned about maintaining a minimum spawning stock biomass appears reasonable.

At Pakawau, recruited biomass is high in relation to the series of estimates available since 1992. Abundance of smaller size classes is within the range observed previously. The exceptionally strong pulse of recruitment first observed in 2001 is still evident in the population. There has been a decline in biomass in the area nearest the factory since the last survey in 2004, but not to levels low in a historical context.

Landings have declined over the past eight years and the TACC has not been reached since it was increased in 1997. There is no evidence that this decline is related to stock availability but is more likely due to economic and market factors. The fishery has been lightly fished to date with an estimated F = 0.1–0.2 fishing rate compared to an M of about 0.4–0.5 (Osborne 1999). The stock has yet to be tested with fishing intensity required to extract the full TACC. Maximising sustainable yield from this fishery is likely to reduce the size range of the product. The commercial company harvesting this beach prefers to keep the size range up at the cost of lower yields (Westhaven owner, pers. comm.). Compared to the TAC of 1390 tonnes, present biomass levels indicate a CAY of about 1632 tonnes assuming M = 0.3 and range from 1031 to 2257 given uncertainty in the level of M. The biomass that will support the maximum sustainable yield (BMSY) is not known for any of the areas fished in COC 7A. Because of the uncertainty over the relationship between Bcurrent and BMSY, it is not known if recent catches and current catch limits will allow the COC 7A stock to move towards a size that will support the MSY.

Fishing activity at Tapu Bay and Ferry Point has reportedly been dormant since the last survey in 2004. Biomass estimates in these two areas show a decline since the earliest estimates in 1991 at Tapu Bay and 1996 at Ferry Point. These declines may have been due to differences in survey methods and natural variability. The changes since 2004 are only slight. Both areas show high levels of natural recruitment into smaller size classes.

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