Addendum to: Williams et al. 2007 Biomass survey and stock assessment…

at (22nd February 2011).

A modelling error was discovered after the publishing of this report which means that the results in Table 6 and the graphics in Figure 14 of this pdf were incorrect. The corrected Table 6 and Figure 14 are given below. The originals have been crossed out in the subsequent document.

Two paragraphs of text starting on page 13 and ending on page 14 were affected by this error. These have been rectified and are given below. The originals have been crossed out in the subsequent document.

Revised text, table and figure below…

The yield per recruit analysis demonstrated that at higher assumed levels of natural mortality, more pipi annual productivity is lost, resulting in less biomass available for exploitation in subsequent years; yield per recruit, therefore, decreased substantially with increasing M (Table 6, Figure 14). The age at first recruitment to the fishery that maximised yield per recruit was affected only slightly under different levels of M, dropping from 3y (52 mm shell length) if M = 0.3 to 2.5 y (49mm) if M = 0.5 (Table 6, Figure 14). The level of F that maximised yield per recruit increased with increasing M (e.g., $F_{0.1}$ = 0.44 to 0.65 for the 'no restriction' strategy; Table 6). Assuming that M = 0.3, yield per recruit was maximised at a fishing mortality ($F_{0.1}$) of 0.44, leaving 44% of the unexploited spawning stock biomass per recruit remaining (Table 6). At higher levels of M, the percentage of the unexploited spawning stock biomass per recruit remaining increased slightly. For example, under the 'no restriction' strategy and assuming M = 0.5, fishing at an $F_{0.1}$ of 0.65 maximised yield per recruit and left 45% of the unexploited spawning stock biomass per recruit (Table 6).

The selectivity characteristics of a fishery can have a strong effect on yield per recruit. The yield per recruit model used here assumed uniform selectivity, but the available catch sampling data (see Figure 9) suggest that fishers typically select pipi 60 mm and over in shell length. Setting size at recruitment to 60 mm resulted in lower than 'optimum' levels of yield per recruit, but markedly increased the percentage of the unexploited spawning stock biomass per recruit. For example, assuming M = 0.3, yield per recruit was maximised at a fishing mortality ($F_{0.1}$) of 0.56, leaving 62% of the unexploited spawning stock biomass per recruit (Table 6).

Table 6: Revised estimates of the reference rate of fishing mortality $F_{0.1}$ that maximise yield per recruit (YPR) at three different assumed rates of natural mortality (*M*) for two harvest strategies ('no restriction' and 'current'). The corresponding spawning stock biomass per recruit (SSBPR) values are also shown. Values were calculated for 0.01 y increments in age (as opposed to the 0.25 y increments used in the original YPR modelling by Williams et al. (2007)).

'No restriction' strategy (maximise YPR without restricting the minimum age of recruitment)

M	Optimal age at recruitment (y)	SL (mm)	$F_{0.1}$	YPR (g)	SSBPR (%)
0.3	3	52	0.437	4.93	44
0.4	2.75	51	0.550	3.50	45
0.5	2.5	49	0.648	2.58	45

Current strategy (harvest pipi 60 mm and over)

M	Age at recruitment (y)	SL (mm)	$F_{0.1}$	YPR (g)	SSBPR (%)
0.3	5	60	0.564	3.98	62
0.4	5	60	0.755	2.41	70
0.5	5	60	0.949	1.47	76

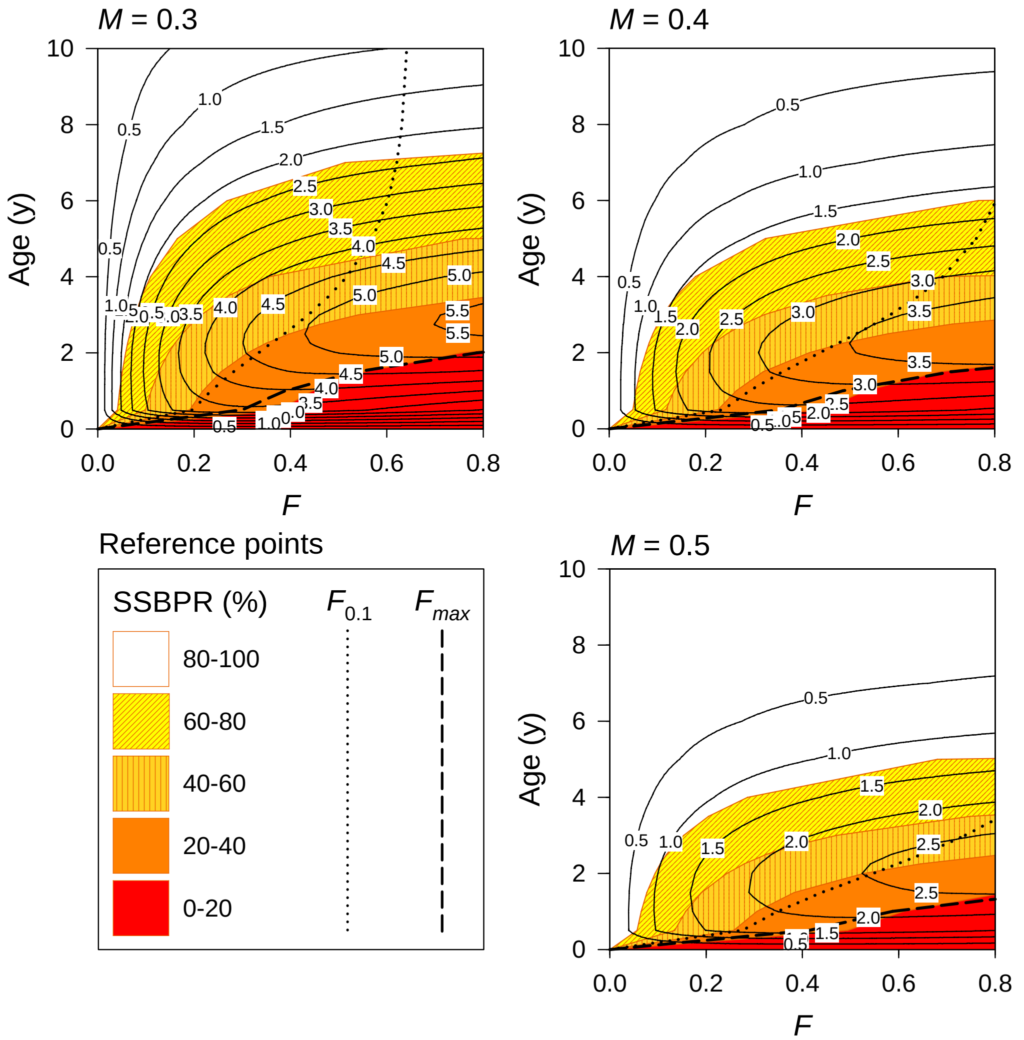

Figure 14: Revised yield per recruit (g) isopleths for pipi (*Paphies australis*) with respect to the instantaneous rate of fishing mortality (*F*) and age at recruitment to the fishery, for three different assumed instantaneous rates of natural mortality (*M* = 0.3, 0.4, 0.5). The reference rates of fishing mortality $F_{0.1}$ (dotted line) and F_{max} (dashed line) are also shown. Shaded areas represent the percentage of spawning stock biomass per recruit (SSBPR). Values were calculated for 0.01 y increments in age (as opposed to the 0.25 y increments used in the original YPR modelling by Williams et al. (2007)).

New Zealand Fisheries
Assessment Report
2007/3
February 2007
ISSN 1175-1584

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Biomass survey and stock assessment of pipi (*Paphies australis*) on Mair Bank, Whangarei Harbour, 2005

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New Zealand Fisheries Assessment Report 2007/3
February 2007

Published by Ministry of Fisheries
Wellington
2007

ISSN 1175-1584

Citation:
Williams, J.R.; Cryer, M.; Hooker, S.H.; Smith, M.D.; Watson, T.G.;
Mackay, G.; Tasker, R. (2007).
Biomass survey and stock assessment of pipi (*Paphies australis*)
on Mair Bank, Whangarei Harbour, 2005.
New Zealand Fisheries Assessment Report 2007/3. 29 p.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

Williams, J.R.; Cryer, M.; Hooker, S.H.; Smith, M.D.; Watson, T.G.; Mackay, G.; Tasker, R. (2007) Biomass survey and stock assessment of pipi (*Paphies australis*) on Mair Bank, Whangerei Harbour, 2005.

***New Zealand Fisheries Assessment Report 2007/3*. 29 p.**

This is the first New Zealand Fisheries Assessment Report produced for pipi (*Paphies australis*). It summarises research and fishery information for pipi on Mair Bank, Whangarei Harbour, and presents five main sources of new information: 1) an analysis of the pipi fishery; 2) a survey biomass estimate for 2005; 3) new growth estimates for pipi from tagging and multiple length frequency data; 4) results of yield per recruit modelling; and 5) yield estimates for 2005–06. A stratified random survey of pipi on Mair Bank in March–June 2005 produced an estimate of recruited biomass (50 mm and over shell length) of 8975 t with a c.v. of 14.0%. At an assumed size at recruitment of 60 mm shell length (which may be realistic given the size of pipi in the commercial catch), recruited biomass was estimated to be 3017 t with a c.v. of 25.4%. This was the first time that both the intertidal and subtidal areas of Mair Bank were surveyed, thus, the 2005 survey represents the first full biomass survey of Mair Bank. The only previous biomass survey was conducted in 1989, and covered the intertidal area of Mair Bank only. Although not strictly comparable, the 2005 biomass estimate for the intertidal area of Mair Bank appeared to be higher than the 1989 estimate.

Growth data for pipi at Whangateau Harbour were considered the best available to use to generate estimates of pipi growth. A GROTAG analysis of tag-recapture data for pipi at a site inside the harbour generated growth estimates of $L_\infty = 57.3$ mm and $K = 0.46$, whereas a MULTIFAN analysis of multiple length frequency data for pipi at the harbour entrance generated growth estimates of $L_\infty = 63.9$ and $K = 0.57$. The latter growth estimates were thought to be the closest available estimates to those expected at Mair Bank. A new equilibrium yield per recruit model was constructed that included these new estimates of pipi growth to generate estimates of reference rates of fishing mortality. Although this was an approximate approach, it was probably the best possible given the current paucity of biological data on pipi specific to Mair Bank. Because there is no stock assessment model for Mair Bank pipi, yield estimates were generated by applying these reference rates of fishing mortality to estimates of recruited biomass in 2005.

Depending on the assumed size at recruitment to the fishery and the assumed rate of natural mortality ($M = 0.3$–0.5), current estimates of MCY (241–1660 t) and CAY (720–2218 t) were always higher than the TACC (200 t). Reported landings have averaged about 187 t annually in New Zealand since 1986–87, which is less than all of the yield estimates. There appears to have been an increase in CPUE in recent years that could be associated with the apparent increase in biomass. Overall, the 2005 survey results and simple yield estimates suggest that fishing at the level of recent average landings is likely to be sustainable in the short term. However, these yield estimates are based on estimates of biological parameters for pipi elsewhere in northeastern New Zealand, and potential differences in the biology of Mair Bank pipi could significantly affect these yield estimates. More information on the growth and mortality of pipi specific to Mair Bank is required. It is, therefore, unknown whether fishing at the level of the current TACC is likely to be sustainable in the long term.

1. INTRODUCTION

1.1 Overview

This is the first New Zealand Fisheries Assessment Report produced for pipi (*Paphies australis*). It summarises research and fishery information for pipi on Mair Bank, Whangarei Harbour, and includes a description of the 2005 biomass survey of pipi on Mair Bank, the first such survey in 16 years. In addition, existing data on pipi growth were analysed to generate new estimates of growth parameters. A new equilibrium yield per recruit model was constructed and used to generate reference rates of fishing mortality, and the latter were used to estimate yields for 2005–06 using methods after Sullivan et al. (2005).

This work was funded by the Ministry of Fisheries under project PPI2004/01: Stock assessment of Mair Bank pipi. The overall objective was to carry out a stock assessment of pipi on Mair Bank, Whangarei Harbour, including estimating absolute biomass and sustainable yields. Specific objectives were: 1) to estimate the size structure and absolute biomass of pipi on Mair Bank during March–April 2005. The target coefficient of variation (c.v.) of the estimate of absolute recruited biomass was 20%; and 2) to complete the stock assessment and estimate yields for pipi on Mair Bank for the 2005–06 fishing year.

1.2 Description of the fishery

Mair Bank is an intertidal sand, shingle, and shell bank located at the southern side of the entrance to Whangerei Harbour, northeastern New Zealand (Figure 1). The bank can be considered an extension of the Marsden Point sand spit, but it is separated by a shallow channel and extends east towards the main shipping channel. Mair Bank is the most topographically complex of the shell banks in Whangarei Harbour (Dickie 1986b). At low tide an area of approximately 1.1 km long by 400 m wide is exposed (Haddon 1989), although the bank is considered a fluid mobile shoal, stationary in position but changing in shape and form continually (Venus 1984). Close proximity to clean, clear oceanic currents from Bream Bay, together with enrichment from Whangarei Harbour, allow Mair Bank and surrounding banks within the harbour to support shellfish populations of relatively high density.

Mair Bank produces virtually all the commercially harvested pipi in New Zealand. Before the introduction of pipi in Whangerei Harbour (PPI 1A) and FMA PPI 1 to the Quota Management System (QMS) in 2004, the commercial fishery area was defined in regulation as that area within 1.5 nautical miles of the coastline from Home Point, at the northern extent of the Whangarei Harbour entrance, to Mangawhai Heads, south of the harbour. The defined area included Snake Bank within the harbour. Commercial fishers tend to gather pipi from the seaward edge of Mair Bank, particularly the southern end, and avoid the centre of the bank itself where there is a lot of shell debris. Regulations require that all gathering be done by hand, and fishers typically use a mask and snorkel. There is no minimum legal size (MLS) for pipi, although all fishers probably favour larger pipi over smaller ones. Pipi are available for harvest year-round, so there is no apparent seasonality in the fishery.

1.3 Literature review

The pipi (*Paphies australis*) is a common burrowing bivalve mollusc of the family Mesodesmatidae. Related species are *Paphies subtriangulata* (tuatua), *P. ventriculosa* (toheroa), and *P. donacina* (deep water tuatua). Pipi are distributed around the New Zealand coastline, including the Chatham and Auckland Islands (Powell 1979), and are characteristic of protected beaches, bays, and estuaries (Morton & Miller 1968). They are moderately large (up to about 90 mm in shell length) suspension-feeders with short siphons, and are usually found wedged just below the surface of the sand with their posterior end protruding slightly. Pipi are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents (Morton & Miller 1968). They have a broad tidal range, occurring intertidally and subtidally in high-current harbour channels to water depths of at least 7 m (Dickie 1986a, Hooker 1995a), and are locally abundant, with densities greater than 1000 m^{-2} in certain areas (Grace 1972).

Hooker's (1995a) PhD thesis on the ecology of pipi in the Whangateau Harbour, northeastern New Zealand provides the most comprehensive information to date on pipi biology. Although some of the demographic information overlaps with fisheries type information, the thesis was a pure ecology research study that was not targeted at fisheries research. Consequently, no formal estimates were made of specific biological parameters required for fisheries stock assessment, such as instantaneous rates of growth or natural mortality.

Pipi are gonochoristic and reproduce sexually by free-spawning, releasing their sperm and eggs into the surrounding seawater for external fertilisation. Most individuals are sexually mature at about 40 mm shell length (Hooker & Creese 1995a). In general, gametogenesis begins in autumn, and by late winter many pipi have mature, ready-to-spawn gonads (Hooker & Creese 1995a). Pipi have an extended breeding period from late winter to late summer, with greatest spawning activity occurring in spring and early summer. Within a population, spawning appears to occur as a series of partial spawning events over time (Hooker & Creese 1995a). Hooker and Creese (1995b) described small-scale spatial patterns of the reproductive cycle in the Whangateau Harbour and found that reproduction was synchronous among sites within the same harbour. Given that bivalve reproduction is often strongly influenced by local environmental conditions, such reproductive synchrony may not occur over larger spatial scales. Fertilised eggs develop into planktotrophic larvae, and settlement and metamorphosis occur about three weeks after spawning (Hooker 1997). In general, pipi have been considered sedentary when settled, although Hooker (1995b) found that pipi may use water currents to disperse actively within a harbour. The trigger for movement is unknown, but this ability to migrate may have important implications for their population dynamics.

Limited information is available on the growth of pipi. Growth appears to be fairly rapid, at least in dynamic, high-current environments such as harbour channels. Hooker (1995a) conducted tag-recapture experiments and length frequency studies on pipi at Whangateau Harbour, northeastern New Zealand as part of his PhD thesis. He showed that pipi took about three or four years to reach 55–60 mm shell length. Juveniles were observed to grow to about 30 mm in just over one year (16–17 months), and reached 50 mm after about three years. Pipi over 50 mm grew very slowly. There was a strong seasonal component to growth, with rapid growth occurring in spring and summer, and little growth in autumn and winter. However, Hooker (1995a) did not formally estimate growth rate parameters. Estimates of the von Bertalanffy growth rate parameters K and L_∞ are available for pipi on sheltered Auckland beaches (Morrison & Browne 1999, Morrison et al. 1999), although the type of growth occurring in these habitats is likely to be very different to that of pipi at exposed locations such as Mair Bank, Whangerei Harbour. Growth parameters were estimated for pipi at Mill Bay (Manukau Harbour) in 1997–98 (K = 0.15 and L_∞ = 58.9) and 1998–99 (K = 0.094 and L_∞ = 84.6), and at Cheltenham Beach (North Shore) in 1997–98 (K = 0.48 and L_∞ = 41.1).

Little is known about the natural mortality or longevity of pipi. Haddon (1989) suggested pipi are unlikely to live much more than 10 years, and used assumed maximum ages of 10, 15, and 20 years old to estimate maximum constant yield for Mair Bank pipi in 1989. The estimation of the rate of instantaneous natural mortality (M) is difficult for pipi owing to the immigration and emigration of individuals from different areas. As the timing and frequency of these movements are largely unknown, the separation of mortality from movement effects is likely to be problematic.

Access to the fishery has, however, been restricted through other regulations since the mid 1980s, and more formally since 1988. Under previous non-QMS management arrangements, there was a daily catch limit of 200 kg per permit holder, meaning that, collectively, the nine permit holders could, theoretically, take 657 t of pipi per year. That upper limit is within the range of the 1989 maximum constant yield (MCY) estimate of 517 to 1033 t y^{-1} (Haddon 1989). The permit holders have indicated that annual harvest quantities have been considerably less than the potential maximum because of the relatively low market demand for commercial product rather than the availability of the resource.

On 1 October 2004, pipi in Whangerei Harbour (PPI 1A) were introduced into the QMS, and the nine existing permits were replaced with individual transferable quotas. The 200 kg daily catch limit no longer applies. A total allowable catch (TAC) of 250 t was set, comprising a total allowable commercial catch (TACC) of 200 t, a customary allowance of 25 t, and a recreational allowance of 25 t. The sustainability of these allocations is uncertain, suggesting that some means of assessing the resource needs to be developed. To date, there is little information relating to pipi resource sustainability on Mair Bank. Venus (1984) noted concern for the stability of the bank and ensuing erosion of the Marsden Point oil refinery structures from sustained over-harvesting, though this has proved unfounded. The only attempt at a biomass estimation on Mair Bank was conducted in March 1989 (Haddon 1989), again dictated from bank stability concern. A conservative absolute biomass of 2245 t plus or minus 10% was estimated. With an assumed maximum age of 20 years, the Maximum Constant Yield (MCY) at the estimated biomass was calculated as 516 t, increasing to 1033 t if maximum age of 10 years was assumed. Haddon (1989) indicated the maximum age is unknown for the Whangarei area, but is unlikely to exceed 10 years. Current harvest rates are well below the conservative 1989 MCY estimate, although the biomass estimate is now 16 years old and may be unreliable. Until 2005, there have been no recent determinations of biomass or yield, nor consideration of any MLS-type benefits. A regular survey programme for PPI 1A is envisaged so managers can assess the suitability of catch limits on an ongoing basis.

2.2 Recreational and Maori customary fisheries

Local people have gathered shellfish, particularly pipi, from Mair Bank for many years (Haddon 1989). Pipi attract intense recreational interest and are very important to Maori as a traditional food source. The recreational daily bag limit is 150 pipi per person per day, although customary fishing permits can be issued to allow Maori to exceed this limit for customary purposes. Mair Bank is a popular place to collect pipi within the Whangarei area, and is well known to local people as an important pipi resource. Access to the bank generally requires a boat, but the sheltered nature of Whangerei Harbour means that access is restricted only in very poor weather. Compared with commercial landings, the non-commercial take of pipi is likely to be small. National marine recreational fishing (telephone and diary) surveys in 1996 (Bradford 1998), 1999–2000 (Boyd & Reilly 2002), and 2000–01 (Boyd et al. 2004) estimated the number of pipi harvested in FMA1 to be 2.2, 6.8, and 7.2 million, respectively. No mean harvest weight was available. However, the Marine Recreational Fisheries Technical Working Group reviewed these surveys and concluded the estimates were unreliable. No recreational harvest estimates are available from the Mair Bank fishery.

3. RESEARCH

3.1 Stock structure

Little is known of the stock structure of pipi. The commercial fishery based on Mair Bank (PPI 1A) forms a geographically discrete area and it is assumed for management purposes that Mair Bank is a separate stock from pipi elsewhere in the region. There have been no biological studies directly relevant to the identification of separate stocks of pipi around New Zealand. Following spawning and fertilisation, pipi have an extended planktonic larval phase (about three weeks) (Hooker 1997) before settlement and metamorphosis, so pipi "stocks" are likely to be linked by larval dispersal.

3.2 Resource surveys

3.2.1 Historical information for Mair Bank

Surveys of Mair Bank pipi were conducted in 1974, 1977, 1982, 1983, 1986, and 1989 (see Haddon 1989). These early grid surveys recorded pipi densities and average sizes, with the exception of the 1989 survey (Haddon 1989), which also included the first and only previous biomass and yield estimates of pipi on Mair Bank. For the 1989 survey, 263 stations were sampled on a grid of 20 transects distributed east to west along the bank (Haddon 1989). No attempt was made to sample the surrounding subtidal region, despite acknowledging the existence of pipi there. Haddon (1989) estimated the recruited biomass (over 49 mm shell length) of pipi on Mair Bank in 1989 to be 2245 t (± 10%), but this can be considered a conservative estimate because only the intertidal portion of the bank was surveyed, and a large number of pipi are known to exist subtidally.

3.2.2 2005 Mair Bank survey methods

Field survey methods

The 2005 survey of Mair Bank pipi was conducted using stratified random sampling (Figure 4). Mair Bank was divided into two survey strata: 1) the intertidal stratum, the main intertidal part of the bank exposed at low tide (0.5 m chart datum); and 2) the subtidal stratum, the area constrained by water depth at low tide. The location of the intertidal stratum was estimated on 9 February 2005 (about one month before sampling) by walking the perimeter of the bank at low tide (0.5 m chart datum) and periodically recording positions using a high-precision (but non-differential) hand-held Global Positioning System (GPS). The boundary of the subtidal stratum roughly followed the 1.8 m chart datum depth contour, and was estimated from a large-scale marine chart (see Figure 1).

During March 2005 (10–31 March), 100 randomly located sites in the intertidal stratum were sampled in turn, using hand-held GPS sets to determine site positions. Sites with access constrained by water depth (the remaining 50 deeper water sites in the subtidal stratum) were sampled by scuba divers from 8 to 10 June 2005. At each site, a square quadrat of 0.5 × 0.5 m (0.25 m^2) was thrown haphazardly onto the bank. All sediment beneath the quadrat was excavated to the anaerobic layer (generally to a depth of about 100 mm, but sometimes considerably deeper) by hand, including in the sample any pipi directly under the south- and west-facing sides to account for any "edge effect". Pipi were extracted from the sediment using a metal sieve of 5 mm square aperture agitated in water. Except for those sites where more than about 200 pipi were taken, all pipi were measured (shell length) to the next whole millimetre rounded down, and the aggregate weight of pipi determined by direct weighing. Where more than about 200 pipi were taken, a subsample of about 200 pipi was randomly taken and their shell lengths were measured. The remaining unmeasured pipi were counted, and the aggregate weight of all pipi in the sample was determined by direct weighing.

Length-weight relationship

To determine a length-weight relationship, a sample of pipi (n = 203) was collected during March 2005 from 16 sites selected at random within the intertidal stratum, with 8–18 individuals collected from each site. All pipi were measured to the nearest 0.1 mm and weighed to the nearest 0.1 g. A length-weight relationship was estimated for these individuals using a log-log regression (thereby assuming lognormal distribution of error).

Length frequency estimation and scaling

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

Biomass estimation

Standard methods were used to estimate pipi biomass from the single-phase stratified random sampling design of the 2005 Mair Bank survey (Snedecor & Cochran 1989). At each site, biomass was estimated by applying the 2005 length-weight relationship to the length frequency distribution for that site and summing the weight across the appropriate length classes (e.g., all length classes for absolute site biomass). For each stratum, mean biomass was calculated as the average of the site biomass estimates for that stratum. The overall biomass of pipi was calculated using the weighted average of the two stratum estimates of mean biomass, weights being proportional to the relative area of each stratum:

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

where $\bar{x}$ is the estimated biomass (t), W_i is the area (m^2), and $\bar{x}_i$ is the mean biomass (t) in stratum i. The variance for this mean was estimated using:

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

where s^2 is the variance of the estimated biomass, s_i^2 is the sampling variance of the site biomass estimates in stratum i, and n_i is the number of sites within stratum i (Snedecor & Cochran 1989). No finite correction term was applied because the sampling fraction was negligible (less than 0.01% of the total area).

3.2.3 2005 Mair Bank survey results

Length-weight relationship

Length-weight regressions are required to assess the sensitivity of biomass estimates to the assumed size at recruitment to the fishery. To date, two regressions have been derived for pipi in the intertidal area of Mair Bank (Table 2; Figure 5).

Table 2: Length-weight regressions ($W = aL^b$) for pipi on Mair Bank (length in mm, weight in g).

Year	Location	a	b	n	r^2	p	Reference
1989	intertidal	4.5×10^{-5}	3.27943	526	0.9947	< 0.001	Haddon (1989)
2005	intertidal	3.114×10^{-6}	3.87010	203	0.9430	< 0.001	This report

Length frequency distribution

The estimated stratum and population length frequency distributions in 2005 illustrated a dominant modal size of about 52 mm in shell length, with a smaller mode at about 71 mm (Figure 6). Few pipi smaller than 30 mm were observed, and the largest size observed was 83 mm. Small pipi (under 30 mm) were observed only in the intertidal stratum, and the largest pipi were found in the subtidal stratum. There were marked differences in the percentage length frequency distribution of pipi in the intertidal area of Mair Bank between 1989 and 2005. The modal size was much larger in 1989 (about

70 mm) (Haddon 1989) than in 2005 (Figure 7). This difference was difficult to interpret, however, and could have arisen if there were many more large (or far fewer medium-sized) pipi in 1989, or, alternatively might be owing to differences (i.e., in selectivity) in survey methods between years.

Biomass

The 2005 survey of Mair Bank produced an absolute (1 mm or more shell length) biomass of pipi of 10 542 t with a c.v. of 13.4% for the entire Mair Bank population. Most of the biomass was distributed on the seaward (southeastern) portion of the bank, and a substantial portion of this was found subtidally (Figure 8). The southwestern subtidal area of the bank was virtually devoid of pipi (Figure 8). Future surveys might benefit from further stratification of the bank to allow this southwestern subtidal area of the bank to be surveyed as a separate low-density stratum.

Estimates of recruited biomass are sensitive to the assumed size at recruitment to the fishery. Haddon (1989) used a size at recruitment to the fishery of greater than 49 mm shell length when estimating the 1989 biomass of pipi on Mair Bank. To compare the 2005 biomass estimate with the 1989 estimate, size at recruitment in the present study was assumed to be 50 mm. Therefore, the overall recruited (50 mm and over shell length) biomass in 2005 was 8975 t with a c.v. of 14.0% (Table 3). Estimated recruited biomass of pipi in the subtidal stratum was 5989 t with a c.v. of 20.1%, and recruited biomass in the intertidal stratum was estimated to be 2986 t with a c.v. of 11.3%. This 2005 estimate for the intertidal stratum is higher than the 1989 biomass of 2245 t estimated by Haddon (1989), representing an increase in biomass of about 33 %.

Given there is no minimum legal size for pipi, size at recruitment was also estimated after analysing the length frequency distribution of pipi harvested by a commercial fisher (Figure 9). On 30 November 2005, a random sample of a commercial fisher's pipi catch from Mair Bank was measured. Most pipi in the catch were over 60 mm in shell length, and the modal size was about 75 mm. The smallest pipi in the sample was 57 mm. Recruited biomass in 2005 was estimated for five different assumed sizes at recruitment to the fishery, ranging from 40 to 60 mm shell length (Table 3).

Table 3: Estimated recruited biomass (*B*) of pipi on Mair Bank in 2005 for different assumed sizes at recruitment to the fishery.

Assumed shell length at recruitment (mm)	Intertidal stratum		Subtidal stratum		Mair Bank Total	
	B (t)	c.v. (%)	*B* (t)	c.v. (%)	*B* (t)	c.v. (%)
1 (absolute biomass)	3 602	11.4	6 940	19.5	10 542	13.4
40	3 569	11.4	6 922	19.5	10 490	13.4
45	3 434	11.4	6 791	19.6	10 226	13.6
50	2 986	11.3	5 989	20.1	8 975	14.0
55	2 022	11.1	3 855	23.8	5 877	16.0
60	1 004	13.1	2 013	37.5	3 017	25.4

3.3 Other studies

To carry out the stock assessment and estimate yields of pipi on Mair Bank for the 2005–06 fishing year, it was necessary to conduct new analyses of growth, mortality, and yield per recruit. These analyses used the best available information on pipi, most of which was sourced from the PhD study of Hooker (1995a).

2. REVIEW OF THE FISHERY

2.1 TACCs, catch, landings, and effort data

Over 99% of the total commercial landings of pipi have been from statistical area 003 and PPI1. In the most recent years, where a distinction has been made, virtually all the landings have been from PPI1A (Whangerei Harbour). Total commercial landings of pipi reported by Licensed Fish Receiver Returns have remained reasonably stable through time, averaging 187 t greenweight annually in New Zealand since 1986–87 (Table 1). The highest recorded landings were in 1991–92 (326 t). There is generally good agreement between the reported landings and the catch estimated by fishers (Table 1). A breakdown of pipi landings by main target fishery showed that, with the exception of the 1989–90 fishing year, pipi landings from the targeted fishery have always exceeded pipi bycatch in the cockle fishery (Figure 2). Cockle fishery bycatch approached the landings of the targeted fishery in 2000–01, but have declined since. There is no evidence of any consistent seasonal pattern in either the level of effort or catch per unit effort (CPUE) in the pipi fishery. Annual CPUE in the pipi targeted fishery increased in the early stages of the series (1989–90 to 1992–93), then appears to have remained relatively stable, showing an increase in the most recent years (Figure 3).

Table 1: Estimated commercial catch (estimated by fishers on Catch Effort and Landings Returns; CELRs) and reported landings (from Licensed Fish Receiver Returns; LFRR) of pipi (t greenweight) in New Zealand since 1986–87. Before the introduction of PPI 1A to the QMS on 1 October 2004, the fishery was limited by daily limits which summed to 657 t greenweight in a 365 day year, but there was no explicit annual restriction. A TACC of 200 t was set for PPI 1A on 1 October 2004. The large discrepancy observed between estimated catch and reported landings in 1989–90 could be related to the introduction of CELR forms at that time. Similarly, the discrepancy in 2004–05 could be owing to the introduction of PPI 1 to the QMS.

Fishing year	Estimated catch (t)	Reported landings (t)	Limit (t)
1986–87	–	131	657
1987–88	–	133	657
1988–89	–	134	657
1989–90	121	222	657
1990–91	276	285	657
1991–92	303	326	657
1992–93	188	184	657
1993–94	244	258	657
1994–95	175	172	657
1995–96	138	135	657
1996–97	146	146	657
1997–98	120	122	657
1998–99	126	130	657
1999–00	153	143	657
2000–01	187	184	657
2001–02	193	191	657
2002–03	188	191	657
2003–04	262	266	657
2004–05	145	206	200

Before the introduction of PPI 1A to the QMS there were nine permit holders for Whangerei Harbour (PPI 1A). No new entrants have entered the fishery since 1992 when commercial access to the fishery was constrained by the general moratorium on granting new fishing permits for non-QMS fisheries.

3.3.1 Growth estimates

Growth parameters for pipi in relatively exposed locations such as Mair Bank have not been estimated previously, and little information is available on pipi growth specific to Mair Bank. The best available data on pipi growth can be found in Hooker (1995a) for pipi in Whangateau Harbour, northeastern New Zealand, so these data were analysed to produce estimates of pipi growth to estimate yields for the Mair Bank fishery. Given the larger maximum observed size of Mair Bank pipi and the dynamic nature of the bank, it is likely that Mair Bank pipi grow faster than those at Whangateau Harbour. The following growth estimates are, therefore, probably conservative for use in estimating Mair Bank yields. Two approaches were used to produce estimates of pipi growth using existing data from Hooker (1995a): 1) analysis of tagging data (GROTAG); and 2) multiple length frequency analysis (MULTIFAN).

GROTAG analysis

Hooker (1995a) conducted a tag-recapture experiment in Whangateau Harbour to investigate pipi growth rate. This experiment was carried out at a site in the inner part of the estuary ("site 3", South Channel, Whangateau Harbour). A total of 698 pipi of a wide range of sizes were tagged and replanted *in situ* in late November 1992. The animals were recovered, remeasured, and replanted in January, April, and December 1993. Consequently, incremental growth data were available for a total of 381 recovered pipi. Initial shell length ranged from 29 to 65 mm, and time at liberty ranged from 62 to 388 days. These incremental growth data were analysed in the present study using the growth model GROTAG (Francis 1988) to estimate pipi growth parameters (Figure 10). The addition of seasonal variation parameters significantly improved the GROTAG model fit ((likelihood ratio probability $p > \chi^2 = <0.0001$). The seasonal model generated the following estimates of the von Bertalanffy growth rate parameters: L_∞ = 57.3 mm shell length (c.v. = 1.7%) and K = 0.46 (c.v. = 5.5%) (Table 4). Although these estimates appear to adequately describe the growth of pipi at this relatively sheltered site, they were considered inappropriate to use as descriptors of pipi growth at Mair Bank.

Table 4: Parameter estimates for the GROTAG model (Francis 1988) fitted to Hooker's (1995a) growth increment data for tagged pipi at Whangateau Harbour, 1992–93. Corresponding estimates of the von Bertalanffy growth function parameters L_∞ and K are also shown.

Parameter	Symbol (unit)	Standard model	Seasonal model
Mean growth rates	g_{40} (mm y^{-1})	5.62	6.41
	g_{50} (mm y^{-1})	1.36	2.70
Growth variability	v	0.16	0.20
Outlier contamination	p	0.031	0.034
von Bertalanffy	L_∞ (mm)	53.2	57.3
	K	0.56	0.46

MULTIFAN analysis

In addition to the tag-recapture experiment, Hooker (1995a) also conducted multiple length frequency studies on pipi at a more exposed site at the entrance to Whangateau Harbour. In the present study, MULTIFAN software (Fournier et al. 1990, Otter Research 1992) was used to derive growth rate parameters for pipi at this more exposed site (Figure 11). MULTIFAN is a likelihood-based analysis of several sets of size frequency data simultaneously. Analysis of roughly monthly length frequency distributions for pipi at the entrance to Whangateau Harbour from 1992 to 1993 (Figure 11) using MULTIFAN generated the following estimates of the von Bertalanffy (1938) growth parameters: K = 0.57 and L_∞ = 63.9. The MULTIFAN analysis could, however, have been adversely affected by highly size-dependent fishing mortality, causing this approach to underestimate L_∞ and, consequently, overestimate K. The MULTIFAN model fitted the length frequency data time series well and estimated 10 significant year classes in the dataset. These estimates, and their associated von Bertalanffy growth curves (Figure 12), suggest the growth characteristics of pipi at the entrance to Whangateau Harbour (faster growth, larger size of L_∞) were closer to what might be expected on Mair Bank than the estimates generated by the GROTAG analysis of data for pipi from the inner Whangateau Harbour (slower growth, smaller size). Furthermore, cumulative length frequency curves were plotted for pipi inside (GROTAG analysis) and at the entrance (MULTIFAN analysis) to Whangateau Harbour in March 1993 (data from Hooker 1995a), and for pipi at Mair Bank at the entrance to Whangerei Harbour during March–June 2005 (present study). These plots showed that the length frequency distribution of pipi at the entrance to Whangateau Harbour was more similar to that of pipi at Mair Bank compared with the inner Whangateau site (Figure 13). Although not ideal, the estimates of growth parameters generated by the MULTIFAN analysis of data for pipi at the entrance to Whangateau harbour were, therefore, considered the most suitable for use in Mair Bank yield estimations.

Pipi notch tagging experiment

To provide data for future estimates of pipi growth specific to Mair Bank, over 1800 pipi of a range of sizes were "notch tagged" (marked with distinct, shallow grooves from the shell margin up onto the valve surface) in March 2005 and returned to a known location in the intertidal stratum for future recoveries. Notch tagging provides a permanent reference for length at release and is faster and more efficient than conventional tagging (Cranfield et al. 1993). Tagged animals can be recovered after an appropriate time at liberty and measured to determine incremental growth. Unfortunately, despite extensive searching, no tagged pipi have been found subsequently. The morphology of this part of the bank appears to have changed substantially following an easterly storm event from 13 to 18 June 2005.

3.3.2 Mortality estimates

The instantaneous rate of natural mortality (*M*) is one of the most difficult biological parameters to estimate (Vetter 1988). In the absence of natural mortality estimates, a general indication of *M* can be generated based on longevity (Hoenig 1983, Hewitt & Hoenig 2005). Haddon (1989) estimated *M* using Hoenig's (1983) method:

$$M = \mathrm{Ln}(100)/\mathrm{max.age}$$

Assuming maximum ages of 10, 15, and 20 years, Haddon (1989) estimated *M* to be 0.46, 0.31, and 0.23, respectively. He noted that because shellfish, such as pipi, are relatively fast growing and highly productive, the maximum age was unlikely to be more than 10 years. The MULTIFAN analysis described above for pipi at the entrance to Whangateau Harbour suggested there were 10 significant year classes in the dataset. The MULTIFAN analysis also generated an estimate of the instantaneous rate of total mortality (*Z*) of 0.72, but the assumption that the rate of mortality is constant over all age classes is probably unreasonable, because bivalves such as pipi are likely to experience high rates of mortality early in life, with mortality rate decreasing with age. Cranfield et al. (1993) generated an estimate of $M = 0.26$–0.32 for the closely related surf clam *Paphies donacina*. A range of $M = 0.3$–0.5 was considered plausible for Mair Bank pipi, and was used in the following yield per recruit analysis.

3.3.3 Yield per recruit modelling

Because there is no stock assessment model for Mair Bank pipi, yield estimates were generated by applying reference rates of fishing mortality to estimates of recruited biomass in 2005. The reference rates were obtained from a new equilibrium yield per recruit model (Ricker 1975) that was constructed using data from Hooker (1995a) for pipi in Whangateau Harbour, northeastern New Zealand. Although this is an approximate approach, it is probably the best possible given the current paucity of data.

Estimates of biological parameters used in the equilibrium yield per recruit model were derived following the analysis of existing data on growth (Hooker 1995a), information on size at reproductive maturity (Hooker & Creese 1995a), length-weight relationship (2005 survey of Mair Bank), and using assumed values of natural mortality (Table 5). The reference rates of fishing mortality used in the equilibrium yield per recruit model were $F_{0.1}$ and F_{max}.

Table 5: Parameters used to derive pipi yield-per-recruit isopleths, the reference rates of fishing mortality $F_{0.1}$ and F_{max}, and the percentage of spawning stock biomass per recruit remaining after fishing.

Mortality		Growth			Length-weight ($W = aL^b$)		Size at maturity (SL in mm)
M	F	K	L_∞	t_0	a	b	$L_{maturity}$
0.3, 0.4, 0.5	0–0.8	0.574	63.9	0.0	3.114×10^{-6}	3.87010	40

Yield per recruit and spawning stock biomass per recruit analyses were conducted over a range of fishing mortalities (F = 0–0.8) and ages at first recruitment to the fishery (0.5–10 y) for three different assumed rates of natural mortality (M = 0.3, 0.4, and 0.5). All analyses assumed knife-edged recruitment to the fishery and uniform selectivity over all exploitable age classes. Estimates of the fishing mortality reference points $F_{0.1}$ and F_{max} were calculated for two harvest strategies that aimed to maximise yield per recruit: 1) the 'no restriction' strategy, which maximised yield per recruit without restricting size at recruitment; and 2) the 'current' strategy, which maximised yield per recruit at a size at recruitment to the fishery of 60 mm shell length. Corresponding levels of spawning stock biomass per recruit, the total biomass of mature fish per recruit summed over all years the cohort is in the population, were also calculated, and expressed as a percentage of the unexploited spawning stock biomass per recruit.

~~[illegible]ield per recruit analysis demonstrated that at higher assumed levels of natural mortality [illegible] pipi a[illegible] productivity is lost, resulting in less biomass available for exploitation in subse[illegible] years; yield per re[illegible] therefore, decreased substantially with increasing M (Table 6, Figur[illegible]). The age at first recruitment [illegible]e fishery that maximised yield per recruit was affect[illegible]ly slightly under different levels of M, d[illegible] [illegible].0 y (44 mm) if M = 0.5 (Table 6, Figure 16). The le[illegible] eased with increasing M, although the range in F over[illegible] tively narrow (e.g., $F_{0.1}$ = 0.26 to 0.33 for the 'no restr[illegible] 0.3, yield per recruit was maximised at a fishing mo[illegible] xploited spawning stock biomass per recruit remaini[illegible] F, the percentage of the unexploited spawning stock [illegible] high. For example, under the 'no restriction' strategy, [illegible] ecruit and left 36% of the unexploited spawning stock [illegible]~~

A modelling error was discovered after the publishing of this report which means that the results in Table 6 and the graphics in Figure 14 of this pdf were incorrect. The corrected Table 6 and Figure 14, and the text that relate to them are given in the Addendum at the beginning of the document

~~The selectivity ch[illegible]eristics of a fishery can have a strong effect on yield pe[illegible]uit. The yield per recruit mod[illegible]sed here assumed uniform selectivity, but the available catch sam[illegible]g data (see Figur[illegible] suggest that fishers typically select pipi 60 mm and over in shell length. Sett[illegible]ize at [illegible]itment to to 60 mm resulted in lower than 'optimum' levels of yield per recruit, but mar[illegible]~~

increased the percentage of the unexploited spawning stock biomass recruit. For example, assuming M = 0.3 yield per recruit was maximised at a fishing mortality ($F_{0.1}$) of 0.32, leaving 69% of the unexploited spawning stock biomass per recruit (Table 6).

Table 6: Estimates of fishing mortality rates for the reference points $F_{0.1}$ and F_{max} that maximise yield per recruit (YPR) at three different assumed rates of natural mortality (M) for two harvest strategies ('no restriction' and 'current'). The corresponding spawning stock biomass per recruit values are also shown. Values were calculated for [illegible] fishery.

A modelling error was discovered after the publishing of this report which means that the results in Table 6 and the graphics in Figure 14 of this pdf were incorrect. The corrected Table 6 and Figure 14, and the text that relate to them are given in the Addendum at the beginning of the document

'No restriction' strategy (no r[illegible]

M	Age (y)	SL (mm)	$F_{0.1}$	YPR (g)	SSBPR (%)	F_{max}	YPR (g)	SSBPR (%)
0.3	2.5	49	[illegible]	[illegible]	[illegible]	[illegible]	3.35	36
0.4	2.5	49	[illegible]	[illegible]	[illegible]	[illegible]	2.16	40
0.5	2.0	44	[illegible]	[illegible]	[illegible]	[illegible]	1.46	37

'Current' strategy (select pipi 60mm and over)

M	Age (y)	SL (mm)	$F_{0.1}$	YPR (g)	SSBPR (%)	F_{max}	YPR (g)	SSBPR (%)
0.3	[illegible]	60	0.32	2.30	69	0.56	2.47	[illegible]
0.4	5.0	60	0.39	1.22	76	0.64	1.3	71
0.5	5.0	60	0.45	0.66	82	0.71	0.70	78

3.4 Biomass estimates

There have been only two estimates of biomass for Mair Bank pipi to date, in 1989 and 2005. However, the 1989 estimate was conservative because only the intertidal portion of the bank was surveyed, and considerable numbers of pipi are known to occur in the subtidal portion of the bed that was not surveyed. The 2005 estimate was, therefore, the first and only full estimate for the entire bank (both intertidal and subtidal portions). Recruited (60 mm and over shell length) biomass in 2005 was estimated by quadrat survey to be 3017 t with a c.v. of 25.4%. This estimate is sensitive to the assumed size at recruitment to the fishery (see Table 3).

3.5 Yield estimates

Yield was estimated using results from the 2005 quadrat survey of Mair Bank and assumed values for size at recruitment. The yield per recruit model (and subsequent yield estimates) could be improved in future years using site-specific growth and mortality information for pipi on Mair Bank.

3.5.1 Estimation of Maximum Constant Yield

Maximum Constant Yield (MCY) was estimated using methods 1 and 2 (Sullivan et al. 2005):

Method 1 $$MCY = 0.25F_{0.1}B_0$$

Method 2 $$MCY = 0.5F_{0.1}B_{av}$$

where $F_{0.1}$ is a reference rate of fishing mortality, B_0 is the virgin recruited biomass, and B_{av} is the historical average recruited biomass. Because estimates of B_0 and B_{av} for Mair Bank are unavailable, the 2005 recruited (60 mm and over shell length) biomass estimate of 3017 t was used to calculate MCY. Estimates of $M = 0.3$ and $F_{0.1} = 0.32$ were used.

Method 1 $\qquad \text{MCY} = 0.25 \times 0.32 \times 3017 = 241\ \text{t}$

Method 2 $\qquad \text{MCY} = 0.5 \times 0.32 \times 3017 = 483\ \text{t}$

These estimates of MCY would have a c.v. at least as large as that associated with the 2005 recruited (60 mm and over shell length) biomass (25.4%). Estimates of MCY are sensitive to the assumed size at recruitment to the fishery (Table 7), 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 as follows using method 1 and the full version of the Baranov catch equation (Sullivan et al. 2005):

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

where F_{ref} is a reference rate of fishing mortality, M is the instantaneous rate of natural mortality, and B_{beg} is the start of season recruited biomass. The current estimate of recruited biomass (B_{curr}) derived from the 2005 survey of Mair Bank was substituted for B_{beg} to calculate CAY. Estimates of $M = 0.3$, $F_{0.1} = 0.32$, and B_{beg} (60 mm and over shell length) = 3017 t were used.

$$\text{CAY} = \frac{0.32}{0.32 + 0.3} \times \left(1 - e^{-(0.32+0.3)}\right) \times 3017 = 720\ \text{t}$$

This estimate would have a c.v. at least as large as that associated with the estimate of the start of season recruited biomass in 2005 (25.4%). Estimates of CAY are sensitive to the assumed size at recruitment to the fishery (Table 7), and to uncertainty in $F_{0.1}$ (arising from the considerable uncertainty in both growth parameters and M).

Table 7: Sensitivity of maximum constant yield (MCY) and current annual yield (CAY) to the assumed size at recruitment to the fishery. Biomass was estimated for two sizes (50 and 60 mm) at recruitment to the fishery using the 2005 survey data only, values of M were assumed, and estimates of $F_{0.1}$ were generated using equilibrium yield per recruit modelling.

Size at recruitment (mm shell length)	Biomass (2005)	M	$F_{0.1}$	MCY method 1 (t)	MCY method 2 (t)	CAY (t)
50	8975	0.3	0.26	583	1 167	1 787
		0.4	0.32	718	1 436	2 047
		0.5	0.37	830	1 660	2 218
60	3017	0.3	0.32	241	483	720
		0.4	0.39	294	588	814
		0.5	0.45	339	679	877

4. MANAGEMENT IMPLICATIONS

The 2005 survey of Mair Bank represents the first full estimate of pipi biomass on Mair Bank. Depending on the assumed size at recruitment to the fishery and the assumed rate of M, current estimates of MCY (241–1660 t) and CAY (720–2218 t) are higher than the TACC (200 t). Reported landings have averaged about 187 t annually in New Zealand since 1986–87, which is less than all of the yield estimates. There appears to have been an increase in CPUE in recent years that could be associated with the apparent increase in biomass. Overall, the 2005 survey results and simple yield estimates suggest that fishing at the level of recent average landings is likely to be sustainable in the short term. However, these yield estimates are based on estimates of biological parameters for pipi elsewhere in northeastern New Zealand, and potential differences in the biology of Mair Bank pipi could significantly affect yield estimates. Information on the growth and mortality of pipi specific to Mair Bank are required. It is, therefore, unknown whether fishing at the level of the current TACC is likely to be sustainable in the long term.

5. ACKNOWLEDGMENTS

This work was funded by the Ministry of Fisheries under project PPI2004/01: Stock assessment of Mair Bank pipi. Many thanks to the scuba divers for sampling the subtidal sites. Thanks to Jeremy McKenzie and Nick Davies for help with growth and yield per recruit modelling; Ian Tuck for analysing catch, effort, and landings data; and Bruce Hartill and Dave Allen for their useful comments on the pipi fishery. We are grateful to the Shellfish Fishery Assessment Working Group and Marc Griffiths for reviewing an earlier version of this manuscript, and Mike Beardsell for editorial work.

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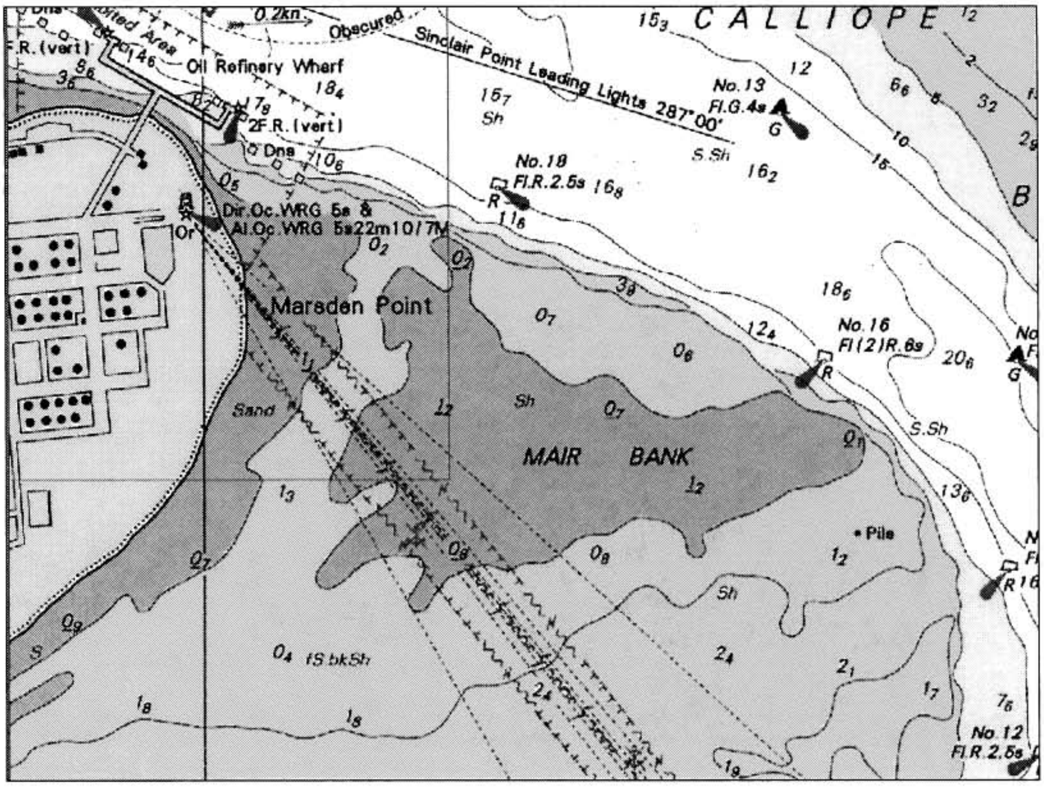


Figure 1: Location of Mair Bank at the entrance to Whangerei Harbour, showing the drying heights above sea level and surrounding 1.8 m chart datum depth contour. (Source: Land Information New Zealand.)

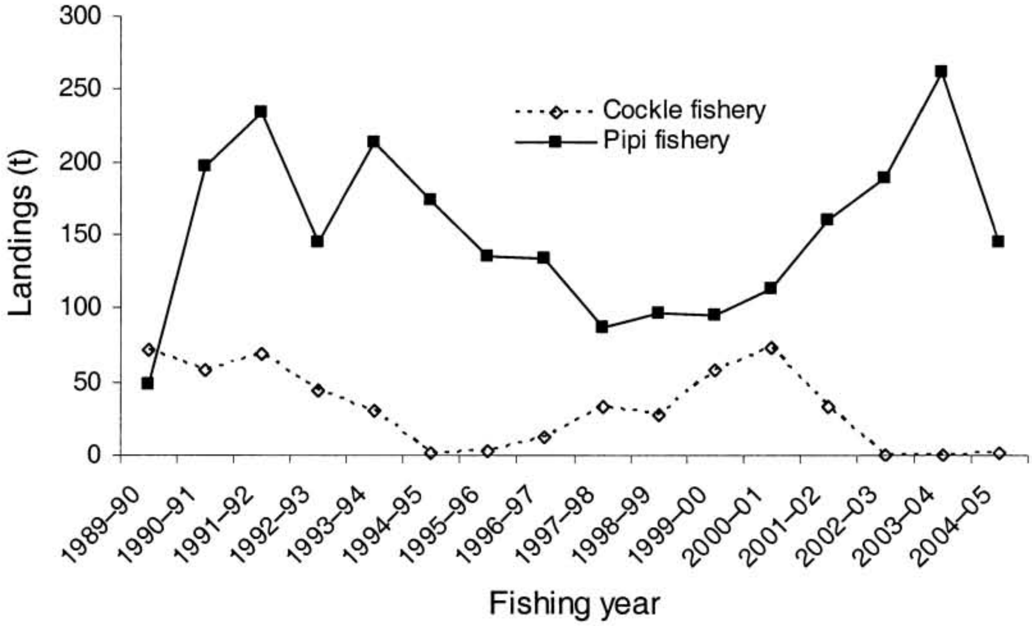


Figure 2: Total commercial landings of pipi (*Paphies australis*) by target fishery from 1989–90 to 2004–05.

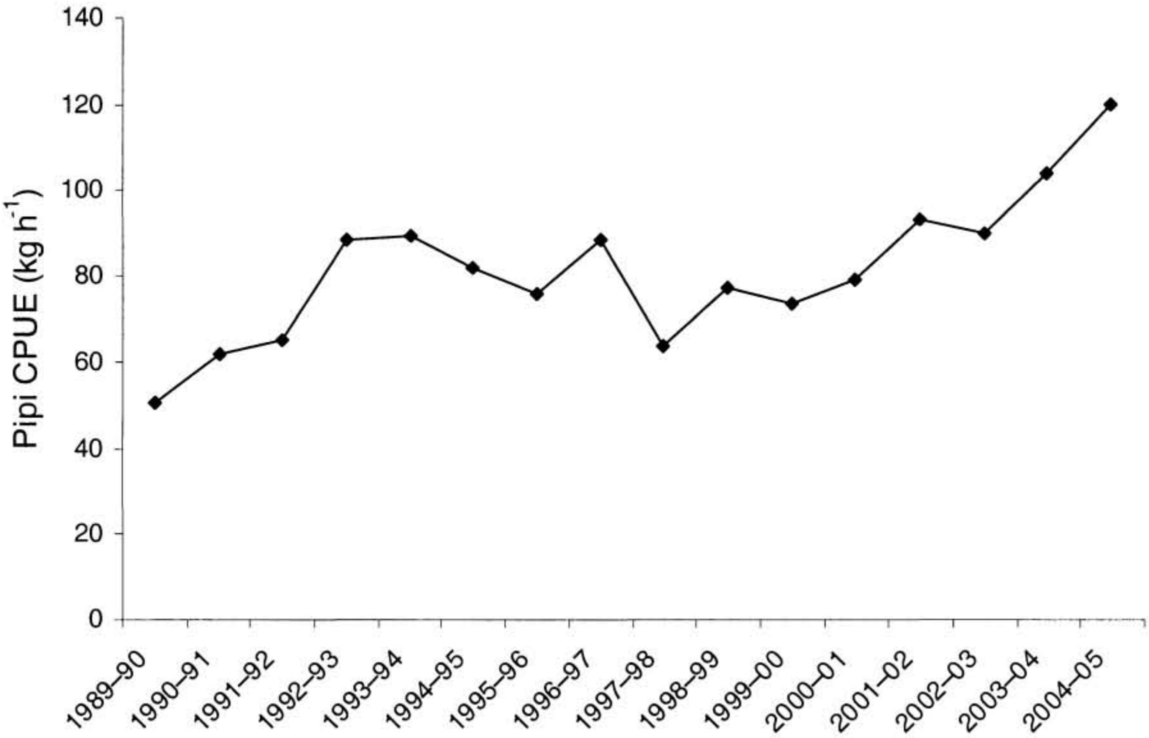


Figure 3: Annual catch per unit effort (CPUE) in the pipi (*Paphies australis*) fishery from 1989–90 to 2004–05.

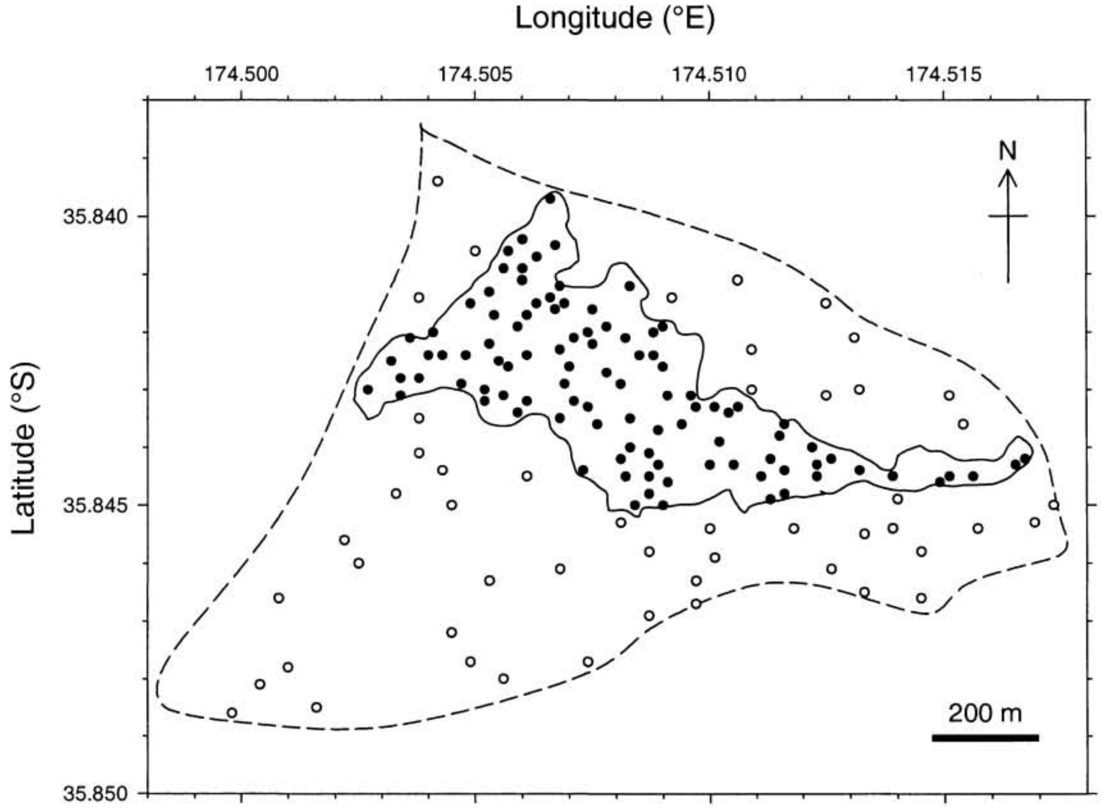
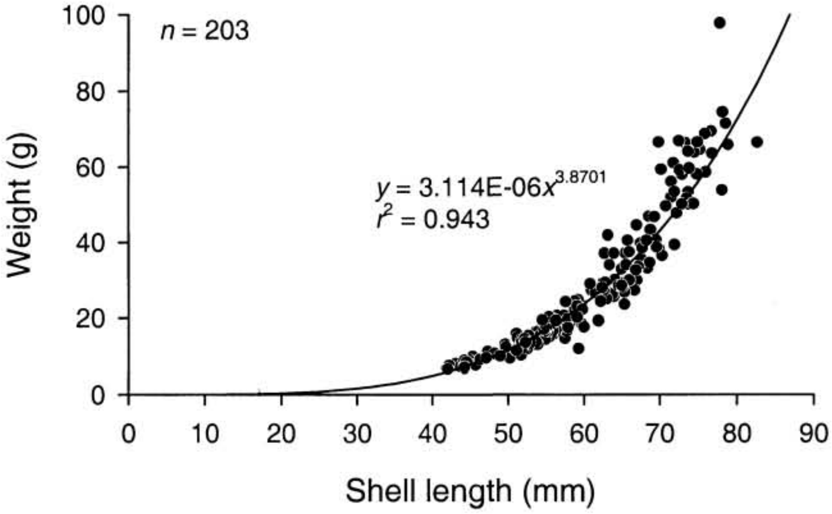


Figure 4: Design of the 2005 pipi (*Paphies australis*) survey on Mair Bank, Whangerei Harbour. Filled circles indicate site positions in the intertidal stratum (solid line) and open circles denote sites in the subtidal stratum (dashed line). The boundary of the intertidal stratum was estimated by walking the perimeter of the bank at low tide (0.5 m chart datum) and periodically recording positions using GPS. The subtidal stratum boundary roughly followed the 1.8 m chart datum depth contour estimated from a large-scale marine chart. Latitude and longitude are in decimal degrees.



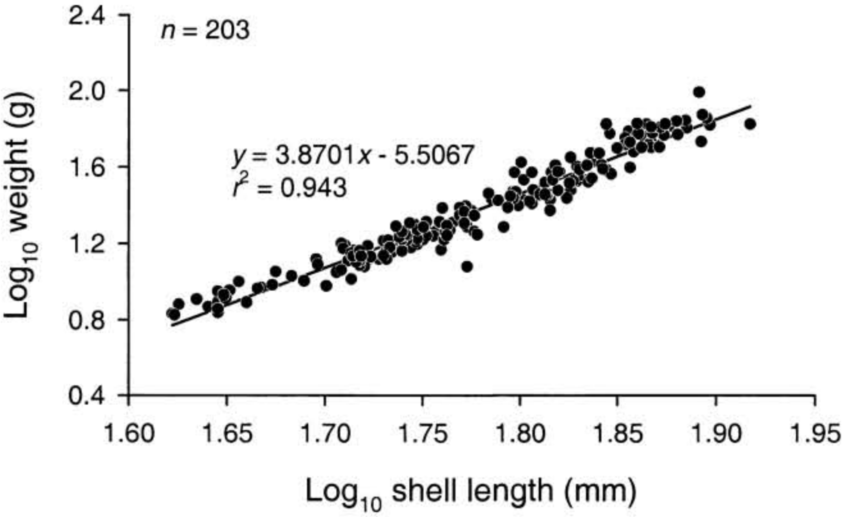


Figure 5: Length-weight relationship for pipi (*Paphies australis*) in the intertidal stratum on Mair Bank, Whangerei Harbour, March 2005.

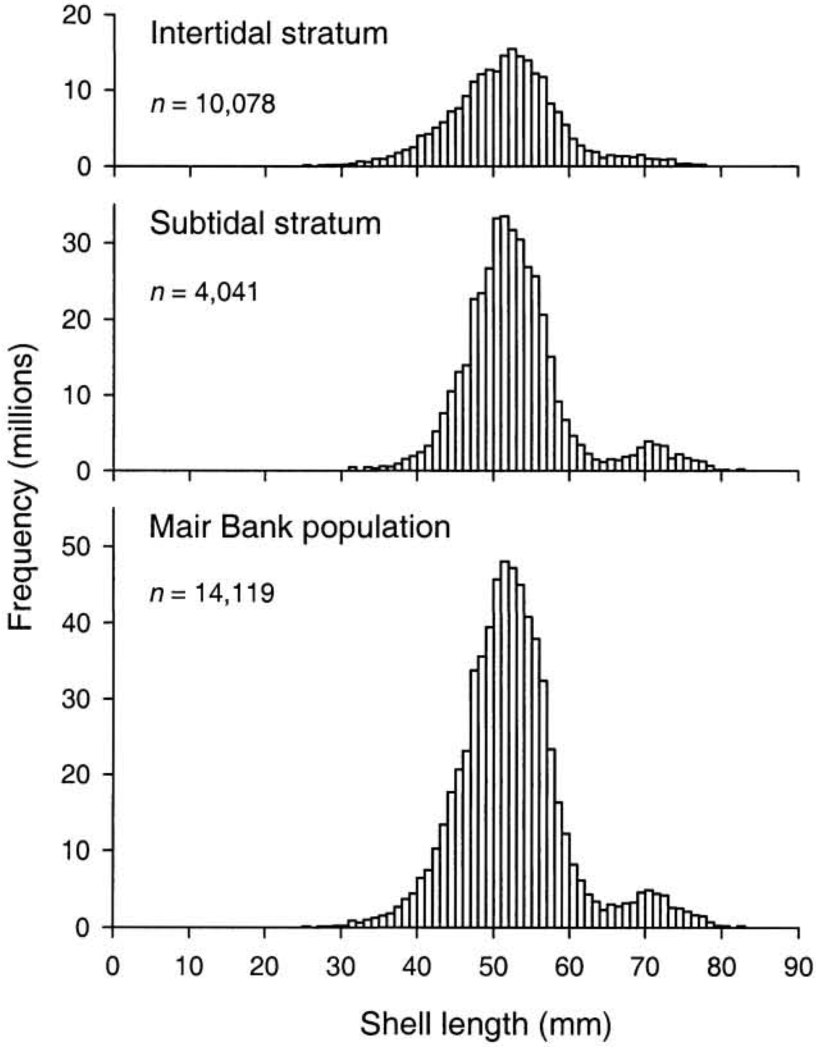


Figure 6: Estimated length frequency distribution of pipi (*Paphies australis*) on Mair Bank, Whangerei Harbour, 2005. The intertidal stratum was sampled in March 2005 and the subtidal stratum was sampled in June 2005.

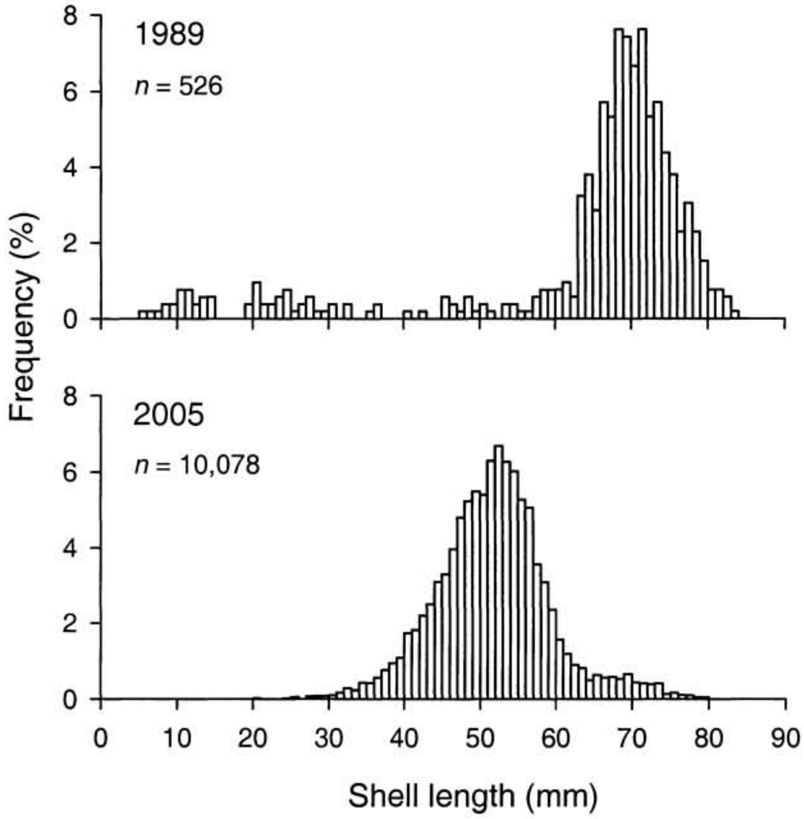


Figure 7: Percent length frequency distribution of pipi (*Paphies australis*) on the intertidal area of Mair Bank, Whangerei Harbour in March 1989 (after Haddon 1989) and March 2005 (intertidal stratum, present study).

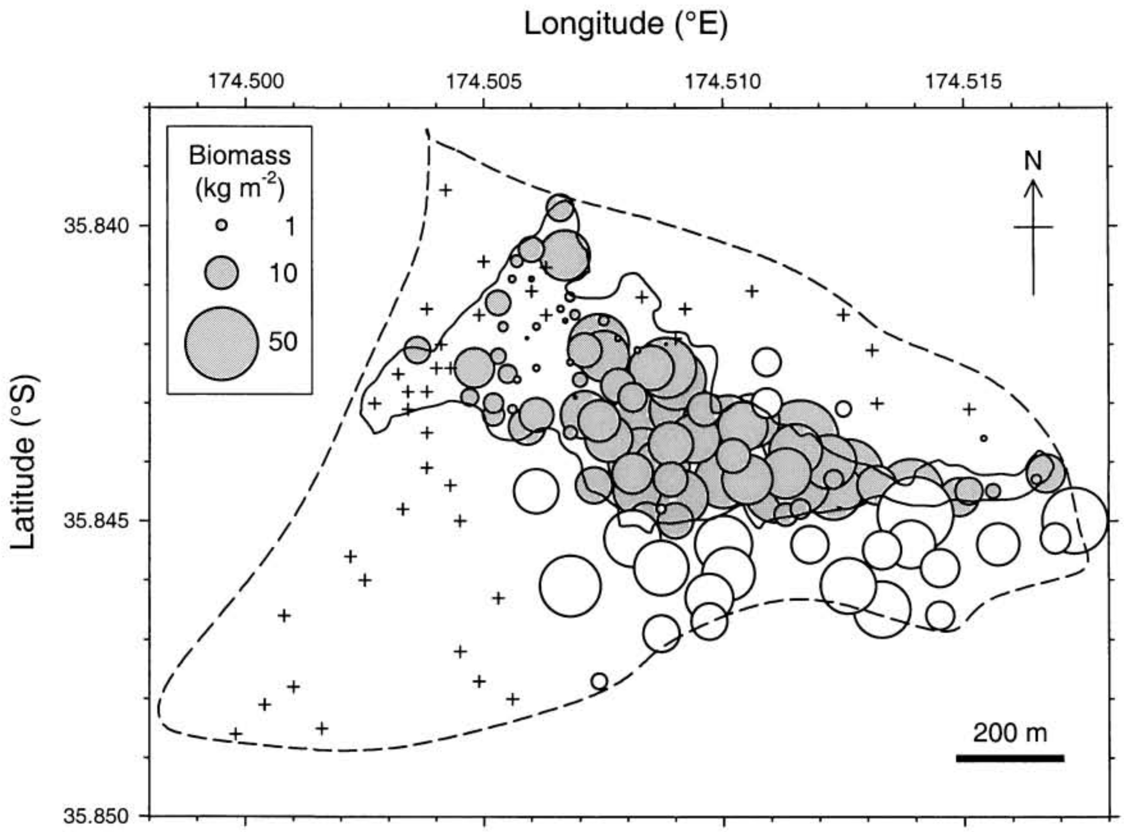


Figure 8: Distribution of pipi (*Paphies australis*) biomass on Mair Bank, Whangerei Harbour, 2005. Filled circles indicate sites sampled in the intertidal stratum (solid line) where pipi were present, and open circles denote sites sampled with pipi present in the subtidal stratum (dashed line). Circle area is proportional to the estimated absolute biomass (kg m^{-2}) of pipi at each site. Crosses denote sites sampled with zero pipi. Latitude and longitude are in decimal degrees.

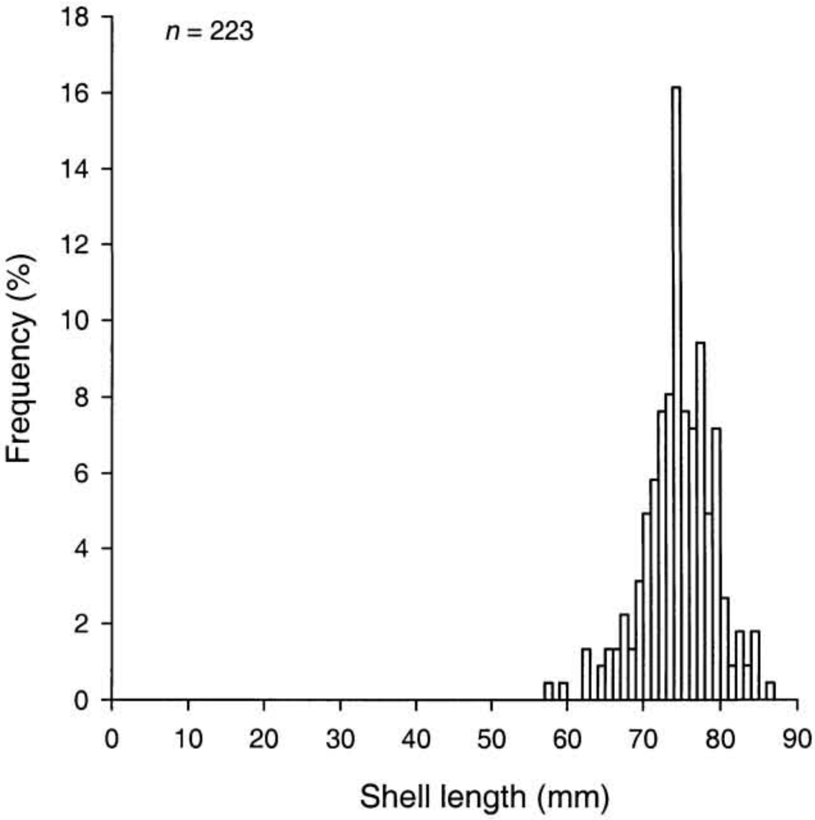


Figure 9: Percent length frequency distribution of pipi (*Paphies australis*) in a subsample taken from a commercial harvester's catch on 30 November 2005 at Mair Bank, Whangerei Harbour.

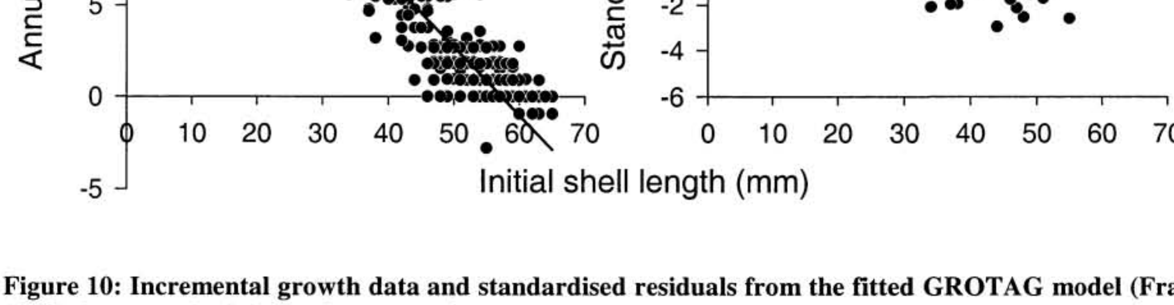


Figure 10: Incremental growth data and standardised residuals from the fitted GROTAG model (Francis 1988) for tagged pipi (*Paphies australis*) at the entrance to Whangateau Harbour, November 1992 to December 1993. The observed increments have been scaled to reflect expected annual growth. Tagging data from Hooker (1995a).

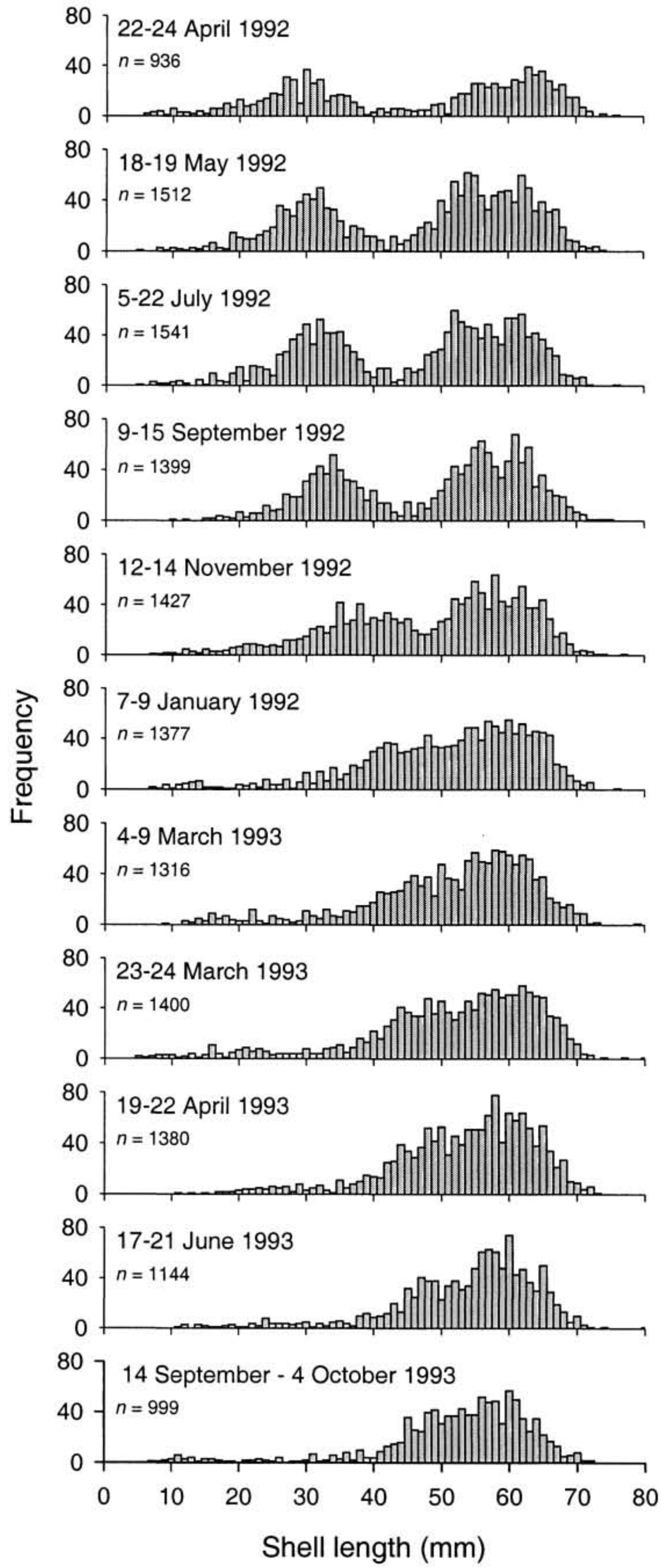


Figure 11: Length-frequency distributions of pipi (*Paphies australis*) at Site 1 in the entrance to Whangateau Harbour, April 1992 to October 1993. After Hooker (1995a).

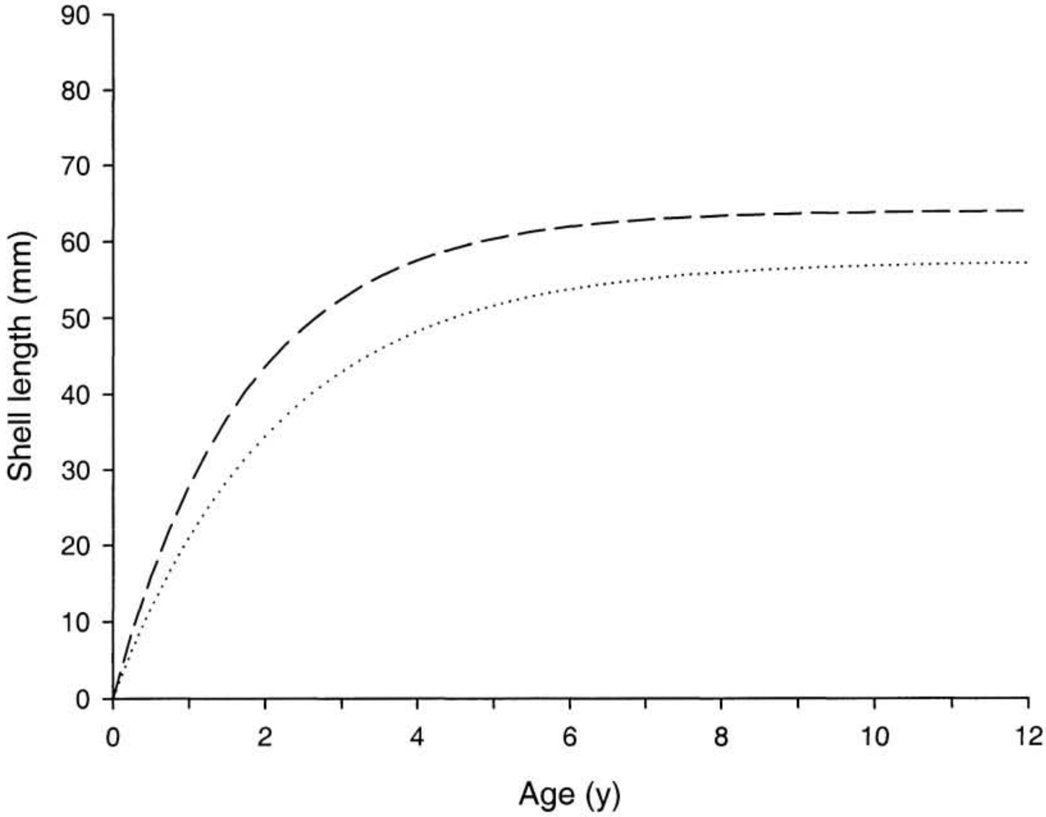


Figure 12: Von Bertalanffy growth curves for pipi (*Paphies australis*) in Whangateau Harbour, northeastern New Zealand. Incremental growth and length frequency data from Hooker (1995a) were analysed in the present study using GROTAG and MULTIFAN approaches, respectively, to produce the VB curves for pipi inside (dotted line) and at the entrance (dashed line) to Whangateau Harbour, respectively.

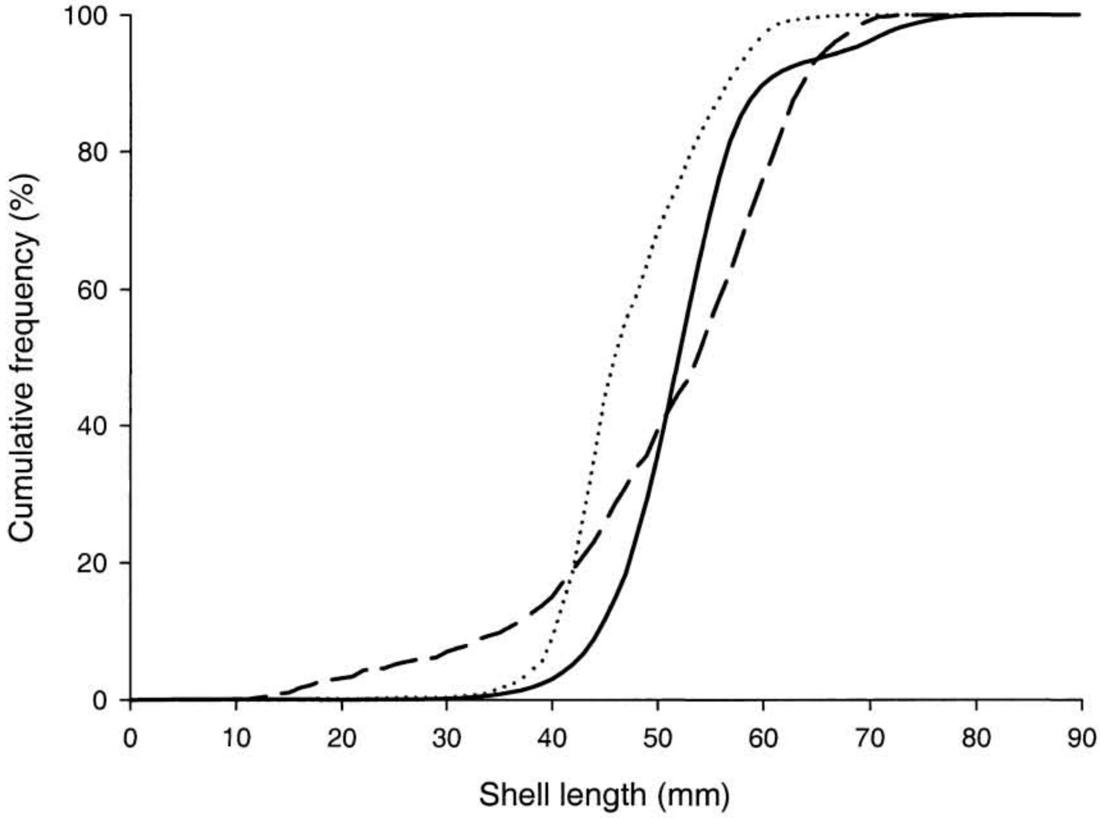
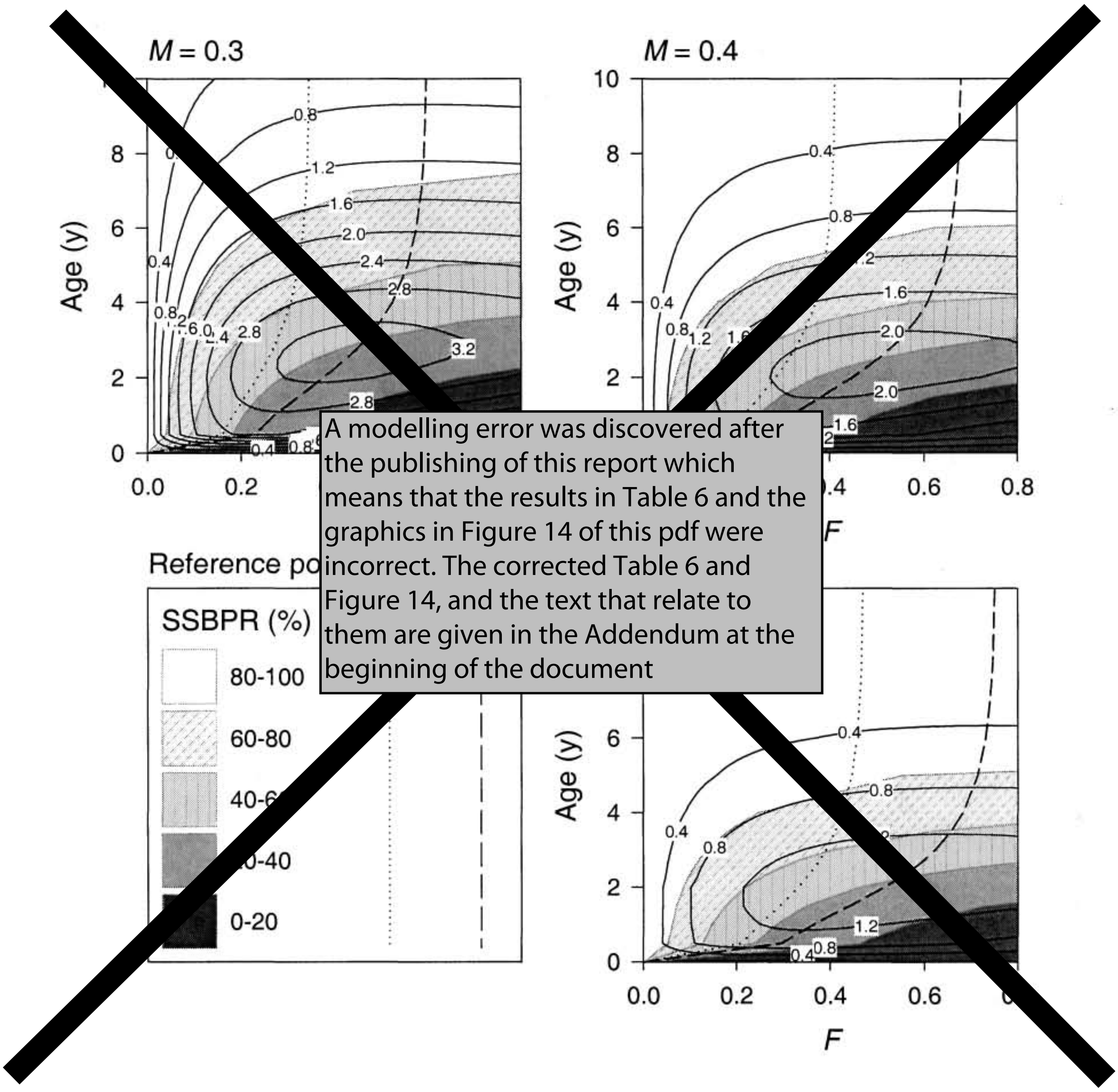


Figure 13: Cumulative length frequency curves for pipi (*Paphies australis*) at three different sites in northeastern New Zealand. Pipi were sampled inside (dotted line) and at the entrance (dashed line) to Whangateau Harbour in March 1993 (data from Hooker 1995a), and at Mair Bank (solid line) at the entrance to Whangerei Harbour during March/June 2005 (present study).



A modelling error was discovered after the publishing of this report which means that the results in Table 6 and the graphics in Figure 14 of this pdf were incorrect. The corrected Table 6 and Figure 14, and the text that relate to them are given in the Addendum at the beginning of the document

Figure 14: Yield per recruit (g) isopleths for pipi (*Paphies australis*) with respect to the instantaneous rate of fishing mortality (*F*) and age at recruitment to the fishery, for three different assumed instantaneous rates of natural mortality (M = 0.3, 0.4, 0.5). The reference rates of fishing mortality $F_{0.1}$ (dotted line) and F_{max} (dashed line) are also shown. Shaded areas represent the percentage of spawning stock biomass per recruit (SSBPR).