



## Biomass survey and stock assessment of pipi (*Paphies australis*) on Mair and Marsden Bank, Whangarei Harbour, 2010

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## EXECUTIVE SUMMARY

**Pawley, M.D.M.; Hannaford, O.; Morgan, K. (2013). Biomass survey and stock assessment of pipi (*Paphies australis*) on Mair and Marsden Bank, Whangarei Harbour, 2010.**

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This New Zealand Fisheries Assessment Report produced for pipi (*Paphies australis*) summarizes fishery research for pipi on Mair and Marsden Bank at the mouth of Whangarei Harbour.

### *Mair Bank*

The report provides a description of the recent full biomass survey of pipi on Mair Bank and presents new site-specific estimates of growth parameters generated from tag-recapture experiments and multiple length-frequency analysis. These results were incorporated in an equilibrium model to estimate: Current Annual Yield (CAY), Maximum Constant Yield (MCY) and yield per recruit for the 2010/2011 fishing year.

Following Williams et al (2007), the 2010 Mair Bank survey had a sample extent that extended subtidally to a depth of 1.8 m. Within this area, we estimate the absolute biomass of pipi to be 4 452 t (c.v. 15%) – less than half of the 2005 estimated biomass. We estimate the recruited biomass for pipi larger than 50 mm and 60 mm was 3890 t (c.v. 17%) and 3145 t (c.v. 17 %) respectively. However, the shape of the length distribution suggests that the differences in estimated biomass may be due to a combination of successful reproductive pulses and older fish exiting the population (due to either fishing or natural mortality).

Growth was initially estimated using both modal progression analyses and the results of a tag-recapture experiment. Results from the latter were considered to be more reliable, so the von Bertalanffy parameter estimates based on this were used. The tag-recapture results estimated  $L_{\infty} = 79.5$  and  $K = 0.19$ . The estimate of  $L_{\infty}$  was higher, but our predicted growth rate was lower than the growth estimates used in the previous Mair Bank yield per recruit calculation (Williams et al 2007). Our estimates are likely to be an underestimate of growth of the harvested population as the tagged individuals were in the intertidal and the harvested individuals are from the subtidal zone.

Over a range of assumed values of (i) natural mortality rate ( $M = 0.3\text{--}0.5$ ) and (ii) fishery recruitment size (50–60 mm), the estimates of MCY (447–1322 t) and CAY (1253 – 1552 t) were always higher than the current total allowable commercial catch (TACC) (200 t) and recent reported landings (which have all been less than 150 t).

### *Marsden Bank*

Marsden Bank was surveyed to a depth of 0.5 m above Chart Datum. Within this sample extent extremely high numbers of pipi were found distributed in a highly patchy manner (some areas had densities exceeding 20 000 pipi per square meter). Nearly all pipi on the bank were small (less than 20 mm long). We estimated that there were between 260 million and 579 million pipi on Marsden Bank, equating to an estimated absolute biomass of between 497 and 1448 t.

## 1. INTRODUCTION

### 1.1 Overview

This report summarises fishery and research information for pipi (*Paphies australis*) on Mair Bank, Whangarei Harbour. The report provides a description of the recent full biomass survey of pipi on Mair Bank and presents new site-specific estimates of growth parameters generated from tag-recapture experiments and multiple length-frequency analysis. It also presents yield estimates for the 2010/2011 fishing year.

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#### 1.1.1 Overall objectives

1. To carry out a stock assessment of pipi (*Paphies australis*) on Mair Bank, Whangarei Harbour, including estimating absolute biomass and sustainable yields.
2. To assess the population of pipi (*Paphies australis*) on Marsden Bank, Whangarei Harbour, including estimating absolute biomass.

#### 1.1.2 Specific Objectives

1. To estimate the size structure and absolute biomass of pipi on Mair Bank during March – April 2010. The target coefficient of variation (c.v.) of the estimate of absolute recruited biomass is 20%.
2. To complete the stock assessment and estimate yields for pipi on Mair Bank for the 2010/2011 fishing year.
3. To determine the growth rate of pipi on Mair Bank.
4. To determine the population size of pipi at Marsden Bank.
5. To estimate the size structure and absolute biomass of pipi on Marsden Bank during March – April 2010. The target coefficient of variation (c.v.) of the estimate of population total is 20%.

## 1.2 Literature Review

### Mair and Marsden Banks

Mair Bank is an intertidal sand and shell ebb-tidal delta located at the southern side of the entrance to the Whangarei Harbour, north-eastern New Zealand. Marsden bank is a sand-bank on the shoreward side of Mair bank attached to the headland and accessible on foot from the shore at low tide. This is a relatively small feature compared to Mair Bank (Figure 1) and no literature about it could be found. Mair bank extends offshore from Marsden Point, a large prograded Holocene sandspit, and is separated from the Bream Bay coast by a narrow channel that expands eastward into the harbour. Mair Bank is fully submerged at high tide, but at low tide has a subaerial component of tightly-packed shell that extends approximately 1.1 km along its southern edge (Haddon 1989). The subtidal margins of Mair bank comprise sandy drifts of quartz and feldspar (Schofield 1970). The platform position of Mair Bank has been seen to remain relatively stable at decadal timescales, however, extensive changes in surface morphology are common in response to local energy conditions (Morgan 2008). Currents at the harbour entrance reach  $1.1 - 1.3 \text{ ms}^{-1}$  during spring tides (Black et al. 1989) and deliver clean oceanic water from Bream Bay, as well as enriched waters from the Whangarei Harbour, allowing for prolific growth of shellfish populations (of up to  $1000 \text{ m}^2$ ) within the harbour sand bodies (Whangarei Harbour Water Quality Management Programme 1989). Shell material supplied

by the dense aggregations of pipi on Mair Bank has created a distinct shell cap that is linked to the overall stability of the bank by armouring underlying sandy sediments.

## Pipi

Pipi (*Paphies australis*) are common burrowing infaunal bivalves. Pipi belong to the family Mesodesmatidae of which three main species occur in New Zealand: tuatua (*Paphies subtriangulata*) inhabit sandy beaches on exposed coastlines, toheroa (*Paphies ventricosa*) are found on fine-sand West Coast beaches of the North Island, and pipi which are typical of protected shores and moderate wave action environments (Powell 1979). Pipi have a wide distribution throughout New Zealand. They occur along the coastlines of both the North and South Islands of New Zealand, as well as on Stewart Island, the Chatham Islands, and Auckland Islands (Powell 1979). Usually restricted to sandbanks and harbour entrances, pipi inhabit the top few centimetres of coarse sandy sediments and are found stacked in the substrate with their posterior end protruding slightly (Dickie 1986). Pipi are moderately large (up to 90 mm in shell length) suspension feeders with short siphons that have a thick, solid, white shell covered with a periostracum. In some larger individuals, the middle of the ventral margin often becomes compressed so that it is concave. Pipi can tolerate moderate wave energy and commonly inhabit areas of sand and shell around harbour entrances, where tidal currents are sufficient to remove fine silt material. Pipi can occur in dense aggregations (up to 1000 m<sup>-2</sup>) over a broad tidal range, from intertidal to subtidal areas to a depth of at least 7 m (Dickie 1986, Hooker 1995).

Pipi in New Zealand have remained surprisingly understudied, despite being a common intertidal bivalve species with a wide distribution and recreational and customary popularity (Hooker 1995). Much existing knowledge has been derived from anecdotal sources and bio-environmental monitoring exercises conducted by local governmental authorities (Boyd 1983, Venus 1984, Dickie 1986). These early investigations focused on the intertidal aspect of population dynamics as subtidal populations were seen as temporary, isolated phenomena. Extensive subtidal populations have since been documented and the realisation has occurred that only a small subset of pipi populations have been studied in any detail (Hooker 1995). Hooker (1995) has provided the most comprehensive information on the ecology and life history of pipi in the Whangateau Harbour. However, the findings were set within an ecological framework and were not targeted as fisheries based research. The research provided a significant contribution to the understanding of pipi biology, yet it did not address specific biological parameters needed for fisheries stock assessment.

Pipi are gonochoristic and reproduce sexually by free-spawning, releasing sperm and eggs into the surrounding seawater for external fertilisation (Williams et al. 2007) becoming sexually reproductive when they reach a shell length of approximately 40 mm (Hooker & Creese 1995). Greatest spawning activity occurs during spring and summer months with spawning generally occurring synchronously, even amongst different sites within the same inlet (Hooker & Creese 1995). Spawning synchronicity and gametogenesis is strongly linked to local environmental conditions in bivalves (e.g. water temperature) and therefore small scale spatial patterns may not occur at larger scales (Hooker 1995). After fertilisation, eggs develop into planktotrophic larvae that settle and metamorphose after three weeks (Hooker 1995). Once settled, juvenile and adult pipi are thought to be sedentary. However, pipi have been observed using tidal currents to move within an inlet (Hooker 1995). The reason for the migration and the effect this has on population dynamics is unknown.

There is a paucity of information on the growth rate of pipi. Currently, there are no growth data available for pipi specific to Mair Bank, despite the largest commercial harvesting industry for pipi in New Zealand operating at this site. Past studies have outlined the difficulties in interpreting growth rings, particularly when distinguishing spawning and disturbance lines from annual patterns (Lutz 1976). Hooker (1995) documented the absence of external and internal growth bands in pipi. Therefore, other methods such as tag-recapture and the analysis of multiple length-frequency datasets must be used to generate estimates, both of which have been successfully used in a number of clam species (Hooker 1995; Cranfield & Michael 2001). Williams et al. (2007) attempted a tag-recapture

exercise of 1800 pipi on Mair Bank, but were unsuccessful in relocating any of the individuals due to significant shifts in the bank's morphology. Hooker (1995) provided growth rate estimates on tag-recapture data and the analysis of multiple length-frequency datasets at different sites within the Whangateau Harbour. He showed pipi took a period of three to four years to reach 55 – 60 mm shell length. Juveniles exhibited faster growth, reaching 30 mm in just over one year (16 – 17 months), and 50 mm in three years, whereas individuals over 50 mm grew much slower. Growth rates were seasonally variable with high rates of growth occurring in spring and summer, and much slower growth observed in autumn and winter. Due to the ecological context of Hooker's PhD thesis (1995), there were no official estimates of growth rate parameters made. However, Williams et al. (2007) used growth data collected by Hooker (1995) to produce von Bertalanffy growth curves (VB) for the Whangateau Harbour. Growth parameters were estimated for tagged pipi within the inlet ( $L_{\infty} = 57.3$  mm and  $K = 0.46$ ) and length-frequency data at the harbour entrance ( $K = 0.57$  and  $L_{\infty} = 63.9$ ). The latter was incorporated into their 2005 Mair Bank yield estimations as it was considered the most suitable for Mair Bank because of the faster growth and larger size of  $L_{\infty}$ . Estimates of the VB growth rate parameters  $K$  and  $L_{\infty}$  have also been made for pipi on sheltered Auckland beaches (Morrison & Browne 1999, Morrison et al. 1999). Growth parameters were estimated for pipi at Mill Bay, Manukau Harbour in 1997–98 ( $K = 0.15$  and  $L_{\infty} = 58.9$ ) and 1998–99 ( $K = 0.094$  and  $L_{\infty} = 84.6$ ), and at Cheltenham Beach, North Shore in 1997–98 ( $K = 0.48$  and  $L_{\infty} = 41.1$ ). However, growth characteristics of pipi on Mair Bank are likely to differ because of the variation in local environmental conditions compared with previously investigated sites.

The natural mortality and longevity of pipi are poorly understood. The lack of internal or external growth rings makes estimating longevity difficult. Experimental procedures have aimed to determine growth and longevity of the tuatua (*Paphies subtrigangulata*) and pipi by analysing the distribution of strontium and fluorine markings in shell cross-sections, but such methods are still being refined (see Coote & Trompetter 1993, 1995). In the absence of any data Haddon assumed maximum ages of 10, 15 and 20 years to estimate maximum constant yield in his assessment of Mair Bank pipi in 1989. He suggested pipi are unlikely to live past a maximum age of 10 years (Haddon 1989).

## 1.2 Description of the fishery

### Commercial fisheries

Over 99% of the total commercial landings of pipi in New Zealand are harvested from Mair Bank. Prior to the introduction of pipi to the Quota Management System (QMS) in 2004, the commercial fishery area formed a geographically discrete area that was defined in regulation as that area within 1.5 nautical miles of the coastline from Home Point (the northern extent of the Whangarei Harbour entrance), to Mangawhai Heads, south of the harbour. The defined area also encompassed Snake Bank within the Whangarei Harbour. Since all commercial harvesting must be conducted by hand, the thick shell cover over the central areas of Mair Bank is avoided and harvesting effort is largely concentrated on the southern edge of the Mair Bank where shell cover is less dense. There is no minimum legal size (MLS) for pipi, but larger individuals are generally targeted over smaller individuals. Commercial pipi harvesting occurs year-around and because of this there is no seasonality in harvesting pressure.

Licensed Fish Receiver Returns (LFRRs) have reported total commercial landings of pipi harvested in Whangarei Harbour from 1986–87 to the present, averaging 175.8 t greenweight (Table 1), although take since 2005–6 has been lower than the average (not exceeding 142 t). Total commercial landings have ranged between 131 t (1986–87 and 2008–09) and 326 t (1991–92), generally operating well below total allowable commercial catch (TACC). There have been no seasonal trends established in the level of effort or catch per unit effort (CPUE) in the fishery. Previous to the introduction of pipi into the QMS on 1 October 2004, regulations restricted daily catch limits to 200 kg per fisheries permit holder, of which there were nine for the Whangarei Harbour. Therefore, the collective TACC for all nine permit holders was 657 t of pipi per year. Since being introduced to the QMS, the 200 kg daily limit no longer applies for pipi in the Whangarei Harbour (PPI 1A), and existing permits have

been replaced with individual transferable quotas. At this same time, a total allowable catch (TAC) of 250 t was set, which comprised a TACC of 200 t, a customary allowance of 25 t, and a recreational allowance of 25 t.

**Table 1: Reported commercial landings (from Licensed Fish Receiver Returns: LFRR) of pipi (t greenweight) in Whangarei Harbour since 1986-87.**

Year	Reported landings (t)	Limit (t)	Year	Reported landings (t)	Limit (t)
1986–87	131	657	1998–99	130	657
1987–88	133	657	1999–00	143	657
1988–89	134	657	2000–01	184	657
1989–90	222	657	2001–02	191	657
1990–91	285	657	2002–03	191	657
1991–92	326	657	2003–04	266	657
1992–93	184	657	2004–05	206	200
1993–94	258	657	2005–06	137	200
1994–95	172	657	2006–07	135	200
1995–96	135	657	2007–08	142	200
1996–97	146	657	2008–09	131	200
1997–98	122	657	2009–10	136	200

### **Recreational and Maori customary fisheries**

Pipi on Mair Bank have for a long time been a resource of cultural and recreational significance to local residents and iwi. Recreational limits for pipi in this area are 150 per person per day. Customary fishing permits may be granted to Maori to exceed this daily limit for customary purposes. The channel that runs adjacent to Marsden Point restricts access to the bank by boat. Boat users as they enter and exit the harbour are the main recreational fishers. The intertidal nature of Mair Bank means that the greatest recreational harvest occurs on the eastern sandy flanks of the bank. Compared to commercial fisheries, recreational harvest is thought to be minimal. However, no formal quantitative estimate of recreational harvest has been estimated. A national marine recreational fishing (telephone and diary) survey in 1996 (Bell & Associates 1996), 1999–00 (Boyd & Reilly 2002) and 2000–01 (Boyd et al. 2004) estimated the number of pipi harvested in FMA 1 to be 2.2, 6.8, and 7.2 million, respectively. The Marine Recreational Fisheries Technical Working Group (RFTWG) has reviewed harvest estimates from the national surveys and concluded that the 1996 estimates are unreliable due to a methodological error. Estimates from the 1999–00 and 2000–01 surveys for some fishstocks were unbelievably high. There were no estimates of recreational or customary mean harvest weights, or harvest estimates specific to Mair Bank.

### **Geomorphic impact of the fishery on Mair Bank**

During the 1980s speculation began that the morphology of Mair Bank had changed (decreased in elevation and extent) due to commercial shellfish harvesting in the area. The dense stacking of live pipi in the substrate appears to increase the shear resistance of sediments to tidal currents and reduces sediment transport. Pipi harvesting removes potential detrital shell material, which is important to local geomorphology as it armours underlying finer-grained sediments reducing actual sediment transport rates well below the potential rates of transport (Black 1983).

Mair Bank is effective at reducing wave energy and mitigating erosion on the landward shoreline. A significant shift in morphology is likely to adversely impact Marsden Point and its infrastructure. In the past, significant declines in pipi have been documented to increase the ‘erodibility’ of Mair Bank under storm conditions (Whangarei Harbour Water Quality Management Programme 1989). Morgan (2008) showed that over the medium-term pipi harvesting has not impacted the gross delta morphology due to the small proportion of harvested individuals relative to total biomass and the

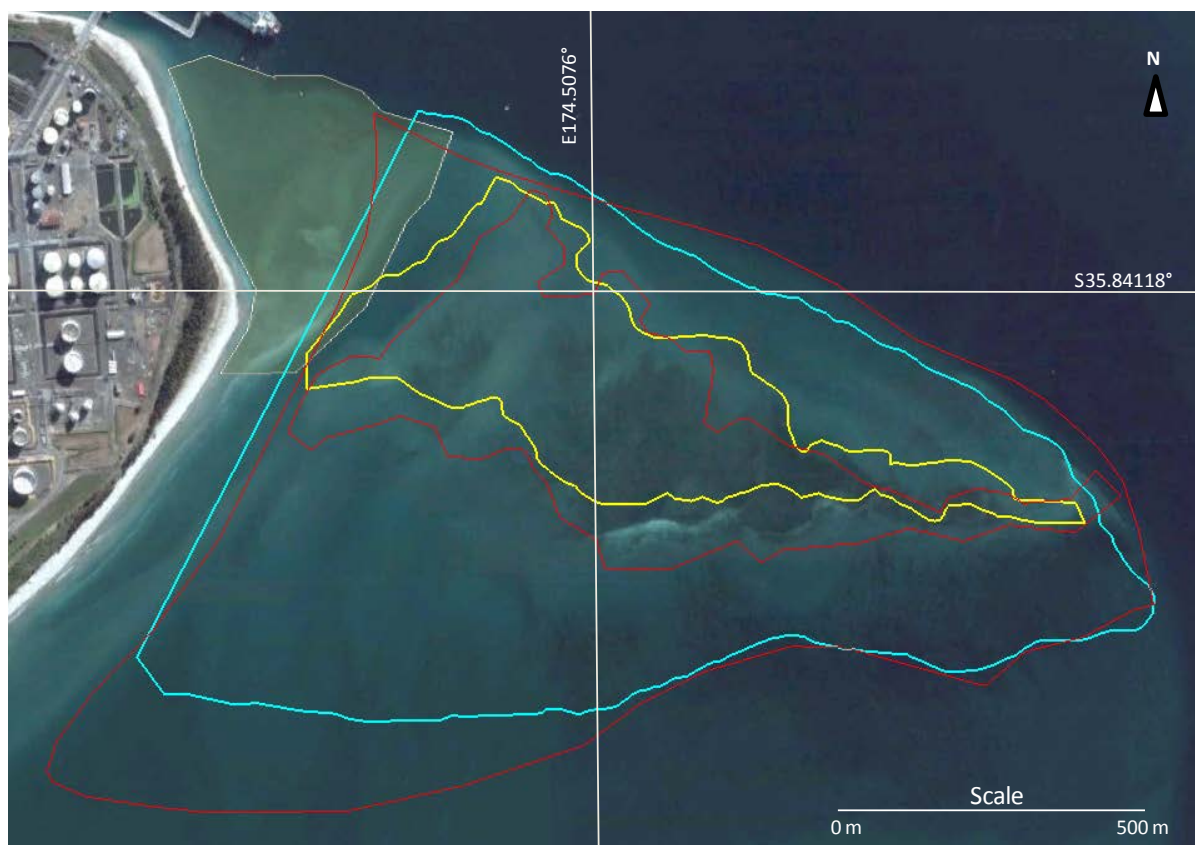
relatively non-invasive harvesting methods used. Furthermore, current landings over the past decade have ranged between 131 t and 266 t per year (Table 1), consistently operating below TACC. Based on assumptions of the density of shell, the TACC quantity represents approximately 96 m<sup>3</sup> of shell being removed per annum, which is less than 1% of the inter-annual variation in sediment volume observed on Mair Bank (Morgan 2008). However, it is unclear whether such rates of commercial harvest are sustainable to maintain current bank morphology in the long-term, particularly if annual catch rates increase to the TACC level.

## 2. METHODS

### 2.1 Sampling methods

#### 2.1.1 Population abundance - Mair Bank

The sample extent for Mair Bank was based on the area defined by Williams et al. (2007), i.e. pipi were sampled within the area defined by 1.8 m below chart datum (CD) contours. The sample extent was split into an intertidal area (defined by 0.5 m above CD) and subtidal area (the remaining area) (see Figure 1). Contour lines were delineated using a high-resolution RTK-GPS system that mapped the bathymetry of the bank (the full bathymetric map is shown in Appendix 1).



**Figure 1:** The 2010 Mair Bank survey split the bank into intertidal and subtidal strata (shown by the yellow and blue contours respectively). Red lines show the intertidal and sample extent from the 2005 survey (Williams et al. 2007). The pale yellow filled polygon indicates the sample extent for Marsden Bank.

### 2.1.2 Population abundance - Marsden Bank

The seaward Marsden Bank sample extent limits were defined as the contour 0.5 m above CD. The southern and northern limits were defined by GPS and are shown in Figure 1.

### 2.1.3 A pilot survey assessing the pipi population below 1.8 m depth

During the course of research for his Masters thesis, Morgan (2008) collected information about the pipi population. Although not published in the thesis, Morgan found pipi at depths greater than 2 m when diving on the South-eastern side of Mair Bank. We investigated whether there was a significant pipi population living at depths greater than 1.8 m, since the presence of a commercially unharvested area would mean that the stock assessment would be more conservative. The pilot study data was not used in the stock assessment calculations.

Nine transects were surveyed around Mair bank starting at depths greater than 1.8 m below CD.<sup>1</sup>

### 2.1.4 Sampling methods

The intertidal and subtidal samples were collected by taking a sample unit consisting of two adjacent, circular cores (with a 15 cm diameter) pushed into the substrate to a depth of 15 cm. The contents from the two cores were aggregated (so each sample unit covered a cross sectional area of 0.0353 m<sup>2</sup>) and passed through a 5 mm aperture sieve. All individuals of the target species retained on the sieve were identified, counted and measured across their widest axis to the nearest millimetre.

We sampled each of the defined sample extents (intertidal and subtidal) using a two-phase random start systematic design.

The mean abundance and biomass was calculated as the average of the site estimates for each stratum. The absolute biomass was then calculated using the weighted average of the strata estimates, with weights proportional to the relative area of each stratum.

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

where  $\bar{x}$  is the estimated average biomass,

$W_i$  is the area (m<sup>2</sup>), and

$\bar{x}_i$  is the mean biomass in stratum  $i$ .

The variance for the estimated mean biomass was then estimated as:

$$\text{var}(\bar{x}) = \sum_{i=1} \frac{W_i^2 s_i^2}{n_i} \quad [2]$$

where  $s_i^2$  is the sampling variance of the site biomass estimates in stratum  $i$ ,

and  $n_i$  is the number of samples within stratum  $i$  (Snedecor & Cochran 1989).

## 2.2 Biomass estimation

### 2.2.1 Length-Weight relationship

The relationship between length and weight is required to calculate biomass estimates. To assess this relationship a sample of pipi ( $n = 300$ ) were collected from seven different intertidal locations on Mair

<sup>1</sup> Finger dredging was used to sample the substrate (see James & Fairweather 1995), so no estimates of abundance were made.

Bank during May 2010. A range of pipi sizes were selected and measured to the nearest 0.1 mm with vernier callipers and weighed to the nearest 0.1 g using electronic scales.

## **2.3 Growth rate estimation**

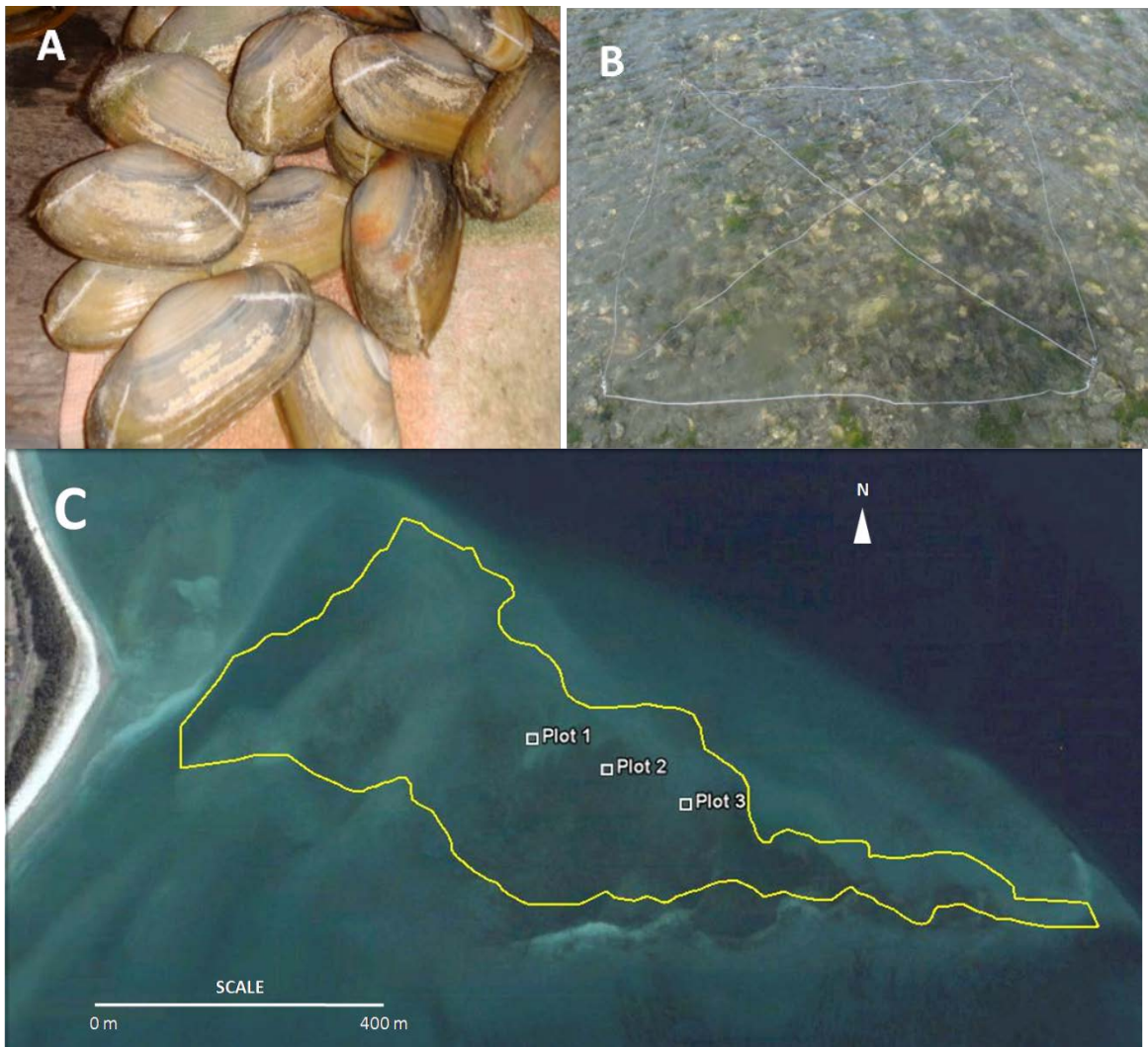
Growth rate is one of the basic parameters used to describe population dynamics and determine the sustainable yield which can be exploited from a stock. Prior to this survey, the only available growth data for pipi was by Hooker (1995) for the Whangateau Estuary in north-eastern New Zealand. Growth rate of pipi on Mair Bank is likely to differ from the Whangateau because of the higher energy oceanographic conditions, increased dynamism of the sedimentary unit and the differences in biological stock structure. Similar to Hooker (1995), we used (i) tag-recapture experiments to determine a growth estimate for Mair Bank pipi and (ii) multiple length-frequency analysis.

### **2.3.1 Tag and recapture**

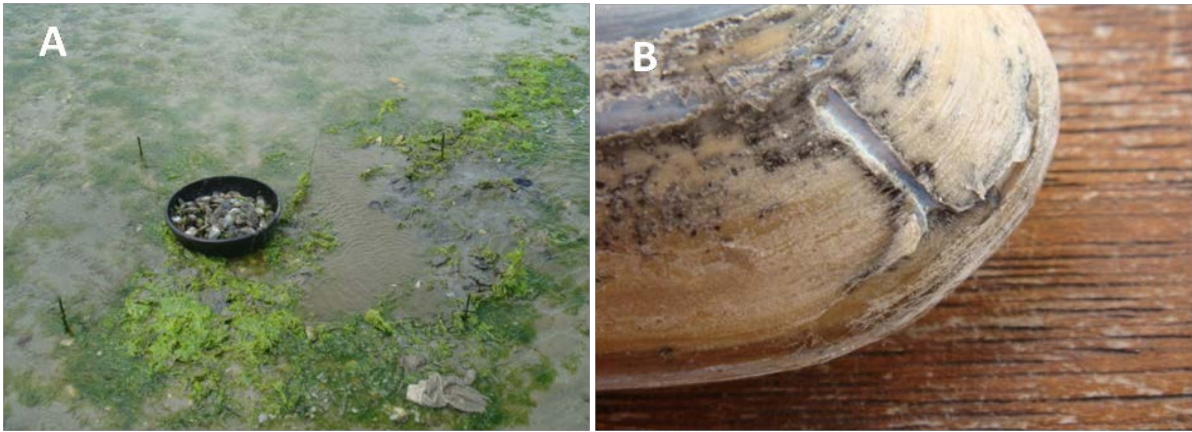
Pipi to be marked were collected by hand from four locations on Mair Bank in October 2009. Approximately 1500 pipi were notch tagged using a handheld engraver to cut a shallow groove from the anterior and posterior shell margin up onto the valve surface of each pipi (Figure 2A). Notches provide a permanent reference point of organism size at the time of marking. Crenfield et al (1996) found no evidence of differences in growth rates between notched and tagged surf clams. However, previous studies have found evidence that repeated handling and measuring of clams may reduce their growth rate (Kraus et al 1992), and this may have occurred in this study.

Marked pipi were reburied in 1 × 1 metre plots at three locations (500 per plot) across the length of Mair Bank (Figure 2B). Plot locations were all intertidal and selected based on evidence of long-term geomorphic stability (Morgan 2008) and the presence of live pipi in the substrate (Figure 2C). Notably, the sites of main commercial harvest are in the subtidal, therefore growth measured here is likely to underestimate the growth of the harvested population. Plots were established using small steel rods to denote the plot boundaries and the GPS position was recorded to aid recapture. Each plot was relocated after a 24 hour period to determine whether marked pipi had been retained and to assess if any disturbance or scour of sediment had occurred.

Plots were relocated after one year (November 2010) and marked pipi were harvested by hand (Figure 3A). The shell length of recaptured pipi was measured to the nearest 0.1 mm using digital vernier callipers. Organism length at the time of marking was determined by measuring the margins of the infilled anterior and posterior notches in the shell (Figure 3B) (Cranfield & Michael 2001).



**Figure 2: (A) Pipi after notch-tagging with a diamond tip engraver. Notches provide a permanent reference of organism size at the time of marking. (B) 1 × 1 metre plot where 500 marked pipi were replanted for a one year period. The surficial sediments regained natural character 24 hours after replanting. (C) Location of the three tag-recapture plots within the intertidal area on Mair Bank. The yellow line denotes the intertidal margin of Mair Bank at a 0.5 m tide above Chart Datum.**



**Figure 3: (A) Removal of marked pipi from Plot 3 for measurement of growth increments after one year. (B) Growth increment of a notch-tagged pipi on Mair Bank after one year. Notches allow for a direct estimate of organism growth when recaptured.**

Von Bertalanffy (VB) equation growth parameters were estimated on the notch-tag data using three methods:

1. A Ford-Walford plot.  
The growth increment form of the VB model is:

$$\begin{aligned} L_{t+1} &= L_t + (L_{\infty} - L_t) [1 - \exp(-K)] \\ &= \exp(-K) L_t + L_{\infty} [1 - \exp(-K)] \end{aligned}$$

Where  $L_t$  is the shell height at time  $t$  and  $L_{\infty}$  and  $K$  are the VB growth parameters. (Fabens 1965).

Therefore, one can estimate  $K$  and  $L_{\infty}$  by a linear regression of  $L_{t+1}$  vs  $L_t$  (assuming no individual variability in these parameters) using:

$$K = -\ln m \text{ and } L_{\infty} = b/(1 - m)$$

Where  $m$  and  $b$  are respectively the slope and intercept of the regression.

2. A Linear-Mixed Effect model (LME) following Hart & Chute (2009) that also accounts for individual variability in growth.

In brief,  $\alpha = (m_i - m)$  and  $\beta_i = (b_i - b)$ , are defined as deviations from the mean slope and intercept by the  $i^{\text{th}}$  individual. The shell length of the  $i^{\text{th}}$  individual at time  $t+1$ ,  $L_{t+1}$  depends on the random effects ( $\alpha_i$  and  $\beta_i$ ) as well as the mean slope and intercept. This method also allows plots to be considered as a random factor (i.e. samples from a population of plots within Mair Bank).

3. Francis' (1988) maximum likelihood method using the GROTAG program designed for the Microsoft Excel solver function (Simpfendorfer 2000). This method reparameterizes the Fabens (1965) growth model,  $K$  and  $L_{\infty}$  are initially replaced by two alternative parameters  $g_{\alpha}$  and  $g_{\beta}$  which represent mean annual growth increments (mm / yr) of chosen reference lengths  $\alpha$  and  $\beta$  (Francis 1988). Reference lengths of 52 and 71 mm were chosen because the majority of lengths fell within these limits.

The expected length increment,  $\Delta L$ , for a pipi tagged at length  $L_i$  at liberty for time  $\Delta T$  is given (assuming no measurement error) by:

$$\Delta L = \left\{ \frac{\beta g_\alpha - \alpha g_\beta}{g_\alpha - g_\beta} - L_i \right\} \left\{ 1 - \left[ 1 + \frac{g_\alpha - g_\beta}{\alpha - \beta} \right]^{\Delta T} \right\}$$

And fit using the likelihood function:

$$\lambda = \sum_i \log[(1 - p) \lambda_i + p / R]$$

where

$$\lambda_i = \log \left[ \exp \frac{-1/2(\Delta L_i - \mu_i)^2 / (\sigma_i^2)}{\sqrt{2\pi\sigma_i^2}} \right]$$

and  $\mu_i$  and  $\sigma_i^2$  are the expected value and standard deviation of the growth increment for the  $i^{th}$  pair. To describe growth variability,  $\sigma$  was modelled as being related to  $\mu$  (i.e.  $\sigma_i = v\mu_i$ ) since growth variability increased with growth increments.

This model has been previously used to analyse mark-recapture data in several clam species (Hooker 1995, Cranfield et al. 1996, Cranfield & Michael 2001).

### 2.3.2 Length-frequency analysis (modal progression analysis)

Population samples for length-frequency analysis were collected at 14 locations on Mair Bank approximately every three months between November 2009 and August 2010. Sampling sites were stratified into seven intertidal and seven subtidal regions of Mair Bank (Figure 4). Intertidal sites were classified as locations that become exposed during a tide that is 0.3 m above Chart Datum (generally occupying the central bank), whereas subtidal sites remained submerged under the same tidal conditions (concentrated on the bank margins). Site locations were recorded using a differential GPS unit.

At each sampling site a quadrat (0.5 m<sup>2</sup>) was placed on the sediment surface and all material beneath it was excavated to the anaerobic layer. Pipi were separated from the sediment by sieving the material through a 5 mm mesh sieve. The length of all pipi (anterior-posterior axis) in the sample were measured to the nearest 1 mm using vernier callipers then returned to the excavation site and covered with sediment. Repeat sampling of each site was conducted every three months using a handheld GPS unit to relocate sample sites.

Length-frequencies were aggregated at the subtidal and intertidal level. Three sites (intertidal site one, two and subtidal site five) did not contain sufficient individuals to construct a sufficient size population curve and were therefore excluded from the analysis.

The multiple length-frequency data from all surveys were analysed using:

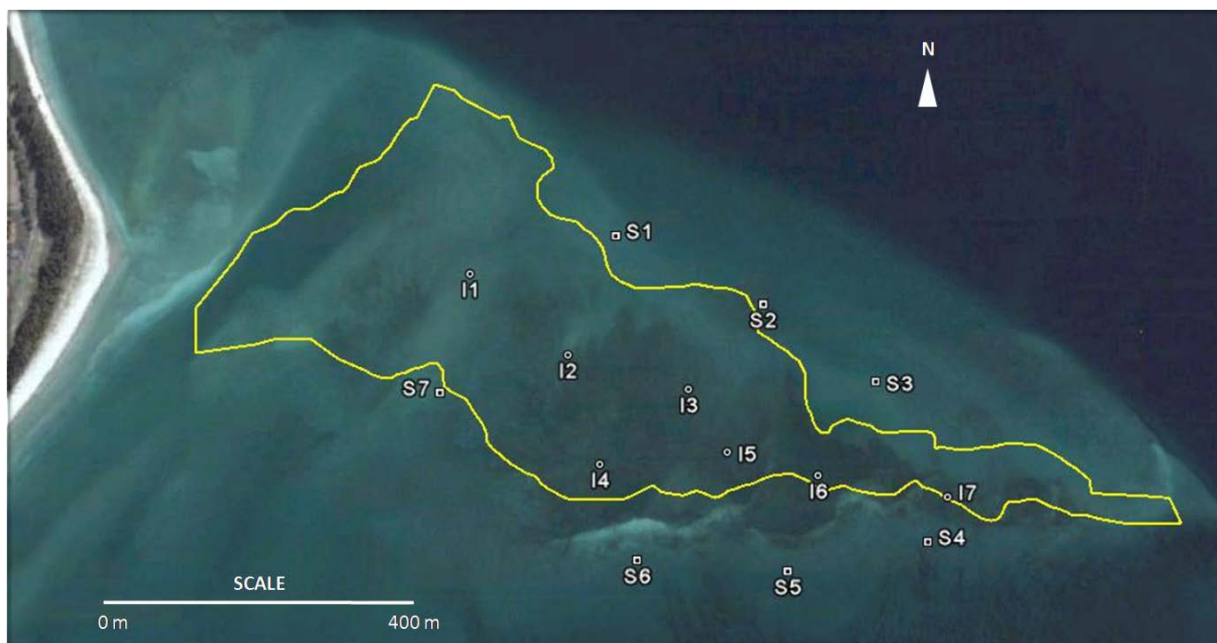
1. The ELEFAN 1 method (using the computer program FiSAT II (FAO-ICLARM Fish stock assessment tools).

Using the ELEFAN 1 method, the length frequency distributions (LFD) were reconstructed to generate 'peaks' (cohort modes) and 'troughs' from a moving average. A curve that fit the data well would pass through the all the 'peaks'.

2. The computer program MULTIFAN (Fournier et al. 1990).

MULTIFAN provides a method of analysing multiple sets of length-frequency data using statistical theory to estimate the proportion of pipi in each age class, their size distribution and the von Bertalanffy growth parameters (Cranfield & Michael 2001). This model has been used in

several studies to estimate growth rate of clams based on multiple length-frequency datasets (Hooker 1995, Cranfield 1996, Cranfield & Michael 2001).



**Figure 4: Sampling locations of length-frequency surveys on Mair Bank. The yellow line denotes the intertidal margin of Mair Bank at a 0.5 m tide above Chart Datum. I1-I7 represent sampling sites located within the intertidal strata. S1-S7 show the location of sampling sites classified as subtidal.**

### Caging experiment

In February 2007, 1000 pipi were individually double tagged using unique number plastic mollusc tags and measured to the nearest millimetre using calipers (shell length, shell width and shell height) as part of a tag-recapture growth study of pipi on Mair Bank (Morgan 2008). These pipi were equally divided into 10 mesh bags (as above) and fixed to permanent structures around Mair Bank (as shown in Figure 2). Several bags were recovered<sup>2</sup>, but no live pipi were found.

In the present study, 1000 pipi of varying sizes were notch tagged and divided (100 per bag) into ten 50 × 50 cm plastic mesh bags (35 mm mesh size). Bags containing notched pipi were buried in the top layer of substrate at 10 different intertidal locations across Mair Bank with the intention of being an alternate source of incremental growth data if the mark-recapture plots had been significantly disturbed. Localised scour, excessive fouling of the mesh and predation meant that no live pipi were recovered from the bags for analysis.

## 2.4 Stock assessment

### 2.4.1 Yield-per-recruit modelling

As there is currently no empirical information available on recruitment variation, fishing mortality rates or natural mortality rates for the Mair Bank pipi, yield estimates were generated by applying reference rates of fishing mortality to a new equilibrium yield per recruit model (Ricker 1975, Gabriel et al. 1989) across a range of natural mortality rates. Although equilibrium yield per recruit models are approximate and based on a number of strong assumptions which may not be met, they are the best approach given the paucity of the data available.

<sup>2</sup> With the aim of using any pipi within to provide multi-annual growth information on Mair Bank.

Estimates of the biological parameters in the model were derived from the growth model from the 2010 notch tagging experiment, the length-weight relationship from the 2010 survey data, and information of size at reproductive maturity (Hooker & Creese 1995). The assumed rates of natural mortality used were those considered plausible by the previous study (Williams et al. 2007).

### Maximum Constant Yield

Maximum Constant Yield (*MCY*) was estimated using method 2, as outlined in Ministry of Fisheries (2011).

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

Where  $F_{0.1}$  is the reference fishing mortality rate and  $B_{av}$  is the historical recruited biomass.

### Current Annual Yield

Current Annual Yield (*CAY*) was estimated using method 1 (Ministry of Fisheries 2011), at an assumed natural mortality rate of  $M = 0.3$ .

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

Where  $F_{ref}$  is the reference rate of fishing mortality,  $M$  is the assumed rate of natural mortality and  $B_{beg}$  is the start-of-season recruited biomass.

### 3. RESULTS

#### 3.1 Length Frequency Distributions

##### 3.1.1 Mair Bank

Length frequency distributions (weighted by strata size) are shown for the Mair Bank intertidal, subtidal and total population (Figure 5).

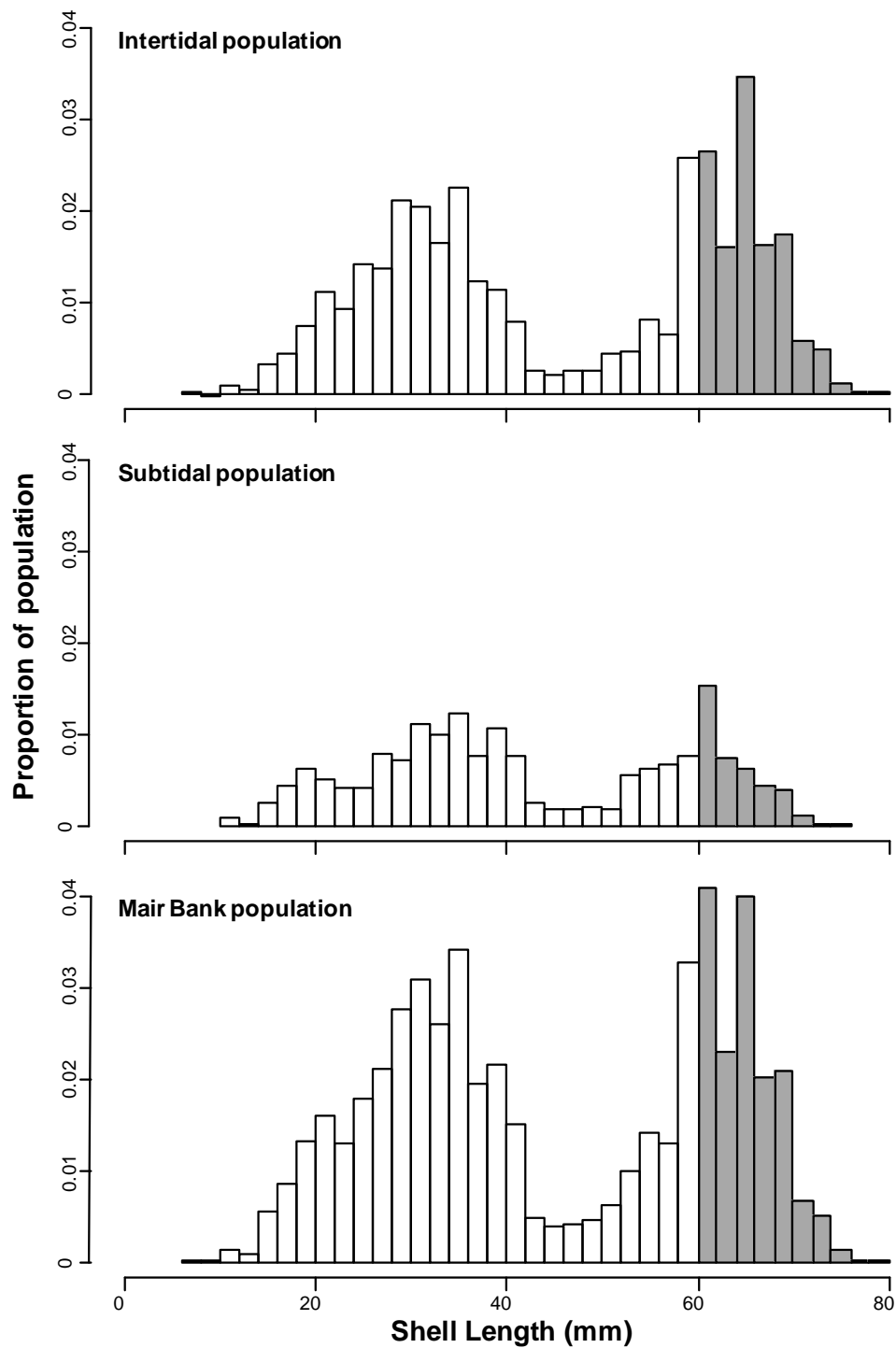
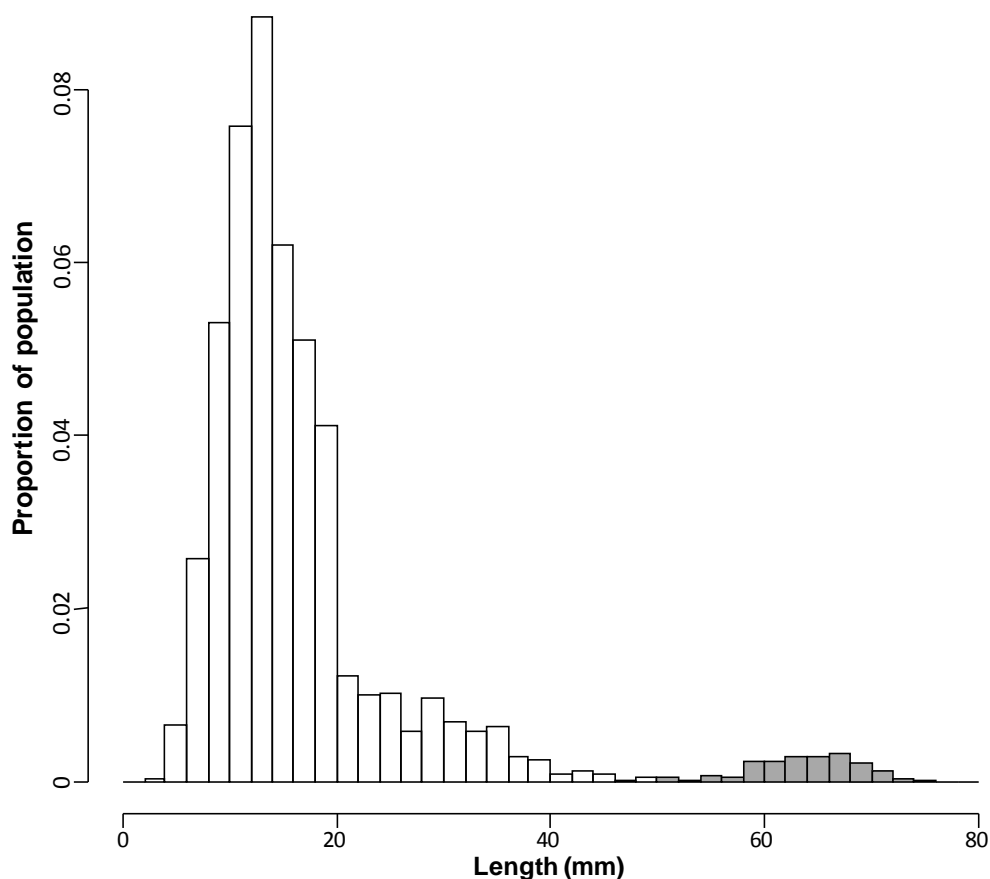


Figure 5: Length frequency distribution of pipi at Mair Bank. Grey bars indicate pipi larger than 60 mm.

The Mair Bank distribution of pipi length in 2010 was bimodal in both intertidal and subtidal areas - with modes around 30 mm and 62 mm. Compared to the 2005 population (Williams 2007), the 2010 population had a larger proportions of pipi longer than 60 mm.

### 3.1.2 Marsden Bank

The length frequency distribution for Marsden Bank is shown in Figure 6. Marsden Bank had large numbers of juvenile pipi approximately 14 mm long. There was also a small mode of large pipi (around 65 mm).



**Figure 6: Length frequency distribution of pipi at Marsden Bank. Grey bars indicate pipi of 'harvestable' size (i.e., greater than 50 mm).**

## 3.2 Population and biomass estimates

### 3.2.1 Mair Bank

#### *Pilot study*

The only subtidal transect in the pilot study that found pipi was located in the middle of the northern bank. The maximum depth examined for that transect was approximately 10 m below CD, and pipi were still found in moderate abundance at that depth. The bank profile in this area was very steep, so even high density of pipi are unlikely to greatly affect the population and biomass estimates unless pipi were resident at depths greater than 20 m. All pipi sampled in the transect were larger than 50 mm in length.

#### *Main study*

We estimate, with 95% confidence that the 2010 absolute biomass of pipi in the entire Mair Bank sample extent is between 4400 and 4500 t. Biomass estimates are sensitive to the fishery recruitment size –we estimated recruited biomass at 50 mm and 60 mm (Table 2).

**Table 2: Biomass estimates of pipi on Mair Bank in 2010.**

	<u>Intertidal stratum</u>		<u>Subtidal stratum</u>		<u>Mair Bank Total</u>	
Recruited shell length (mm)	Biomass (t)	c.v. (%)	Biomass (t)	c.v. (%)	Biomass (t)	c.v. (%)
1 mm (absolute biomass)	2 233	17.4	2 218	33.0	4 452	15.2
50 mm	2 001	18.1	1 889	36	3 890	16.6
60 mm	1 751	18.3	1 393	33.7	3 145	17.4

The 2010 absolute biomass estimate and 50 mm recruited biomass were less than half the respective 2005 estimates (2005 estimates [absolute biomass]:10 542 t, [50 mm recruited biomass]: 8975 t). However the 60 mm recruited biomass was similar to the 2005 estimate (3017 t). Pipi were, on average, less dense in 2010 (compared to 2005); however a higher proportion of the population was larger than 60 mm in the 2010 survey. This is reflected in the length frequency distribution (see §3.1.1). In the 2010 survey 2028 pipi were counted, and approximately 1 150 individuals were randomly sub-sampled and measured.

### 3.2.2 Marsden Bank

From this survey extent, we estimate, with 95% confidence, that there are between 260 million and 579 million pipi on Marsden Bank. This equates to an estimate of absolute biomass of between 497 t and 1 448 t.

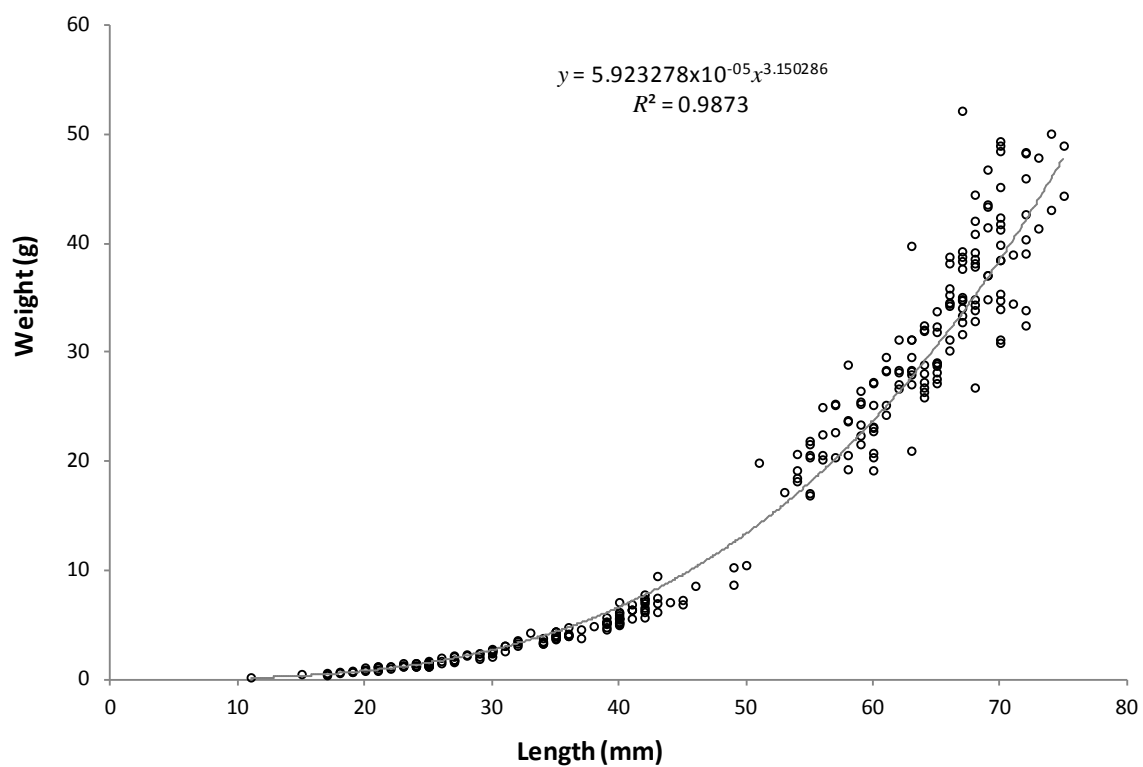
The vast majority of the Marsden Bank population (approximately 98.5%) consisted of pipi on the bank itself, with a small number of pipi found in the surrounding channel. On the bank itself, there was an average density of approximately 3600 pipi per square meter (standard error 700). We estimate that only approximately 4% are individuals larger than 50 mm (the size considered typically of interest to harvesters in the MFish intertidal shellfish survey project AKI/01, although this size is estimated to be around 60 mm at neighbouring Mair Bank).

Pipi density was extremely patchy at Marsden - we found 700 individuals in one sample (equivalent to a density of 20 000 pipi per m<sup>2</sup>), and nothing in a neighbouring sample. A consequence of the

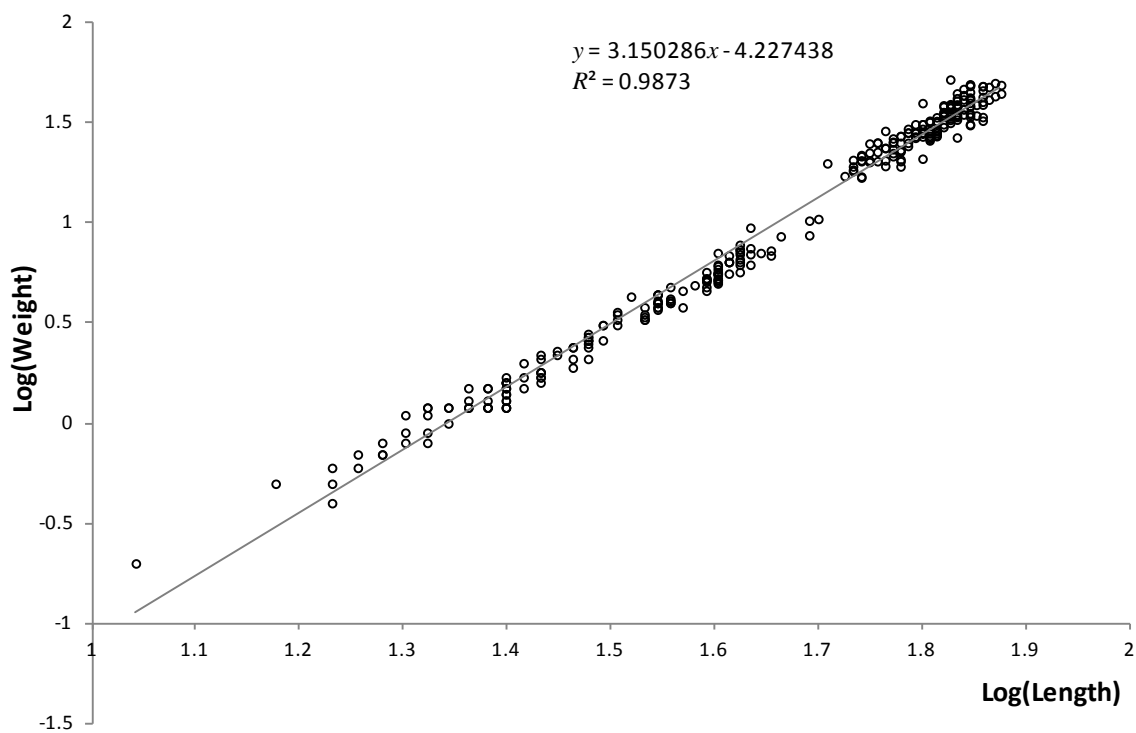
highly over-dispersed nature of the population was an imprecision in the biomass and population estimates (the c.v. was approximately 20%). At Marsden Bank 7619 pipi were counted, and approximately 1000 individuals were randomly sub-sampled and measured.

### **3.3 The relationship between length and weight for pipi**

The modelled relationship between length and weight is shown in Figure 7. Although the model fits individuals above 25 mm well (i.e., individuals greater than  $\log(1.4)$ ), it appears to consistently underestimate smaller individuals. This is the third estimate relating length and weight for pipi at Mair Bank –parameters for all estimates are shown in Table 3.



A



B

**Figure 7: Relationship between pipi weight and length. Results are shown on the linear (A) and log-log scale (B).**

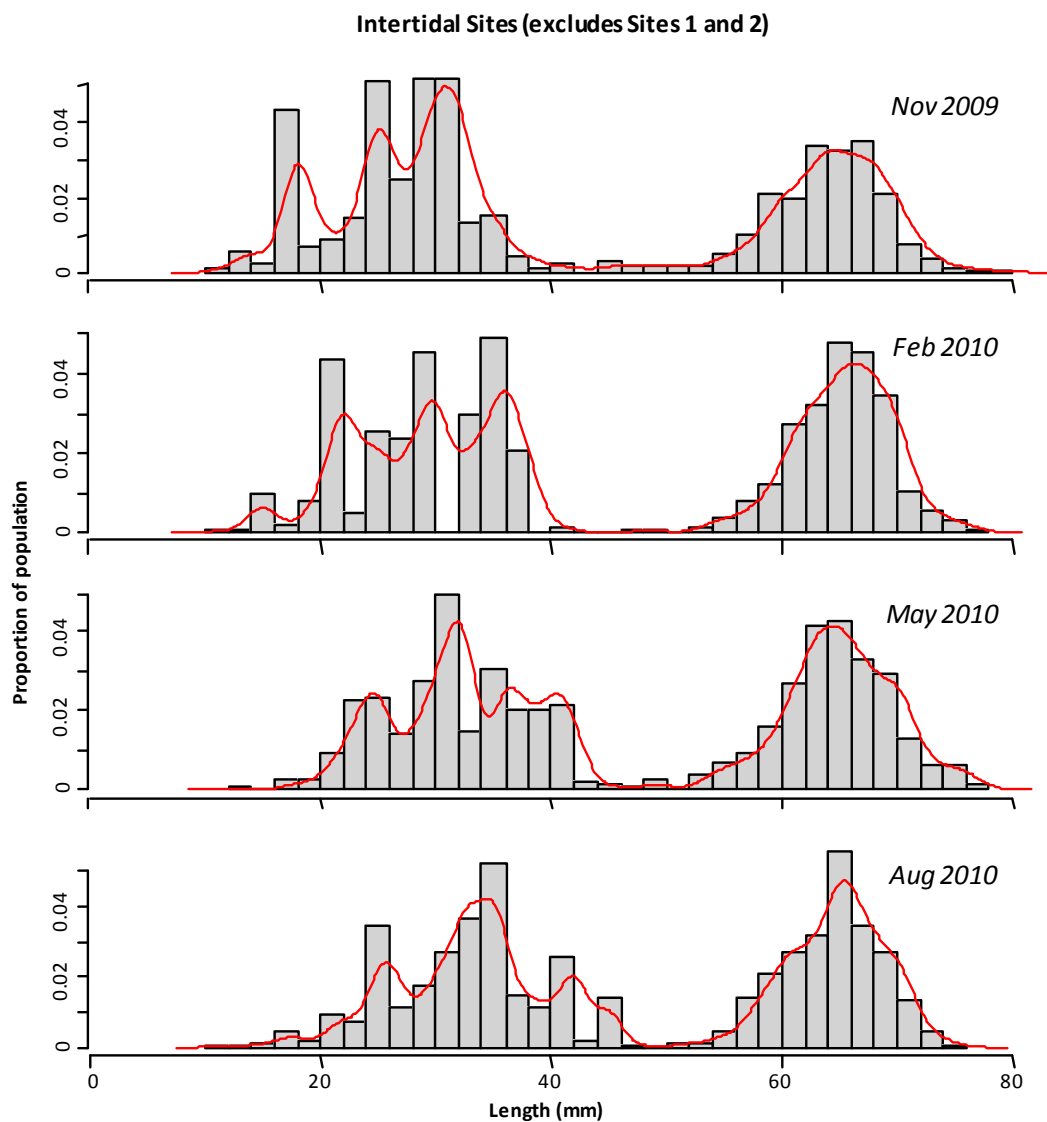
**Table 3: Pigi length-weight relationship estimates.**

Year	A	b	n	R <sup>2</sup>	Reference
1989	$4.5 \times 10^{-5}$	3.2794	526	0.995	Haddon (1989)
2005	$3.114 \times 10^{-6}$	3.8701	200	0.943	Williams et al. (2007)
2010	$5.923 \times 10^{-5}$	3.1523	300	0.987	(this study)

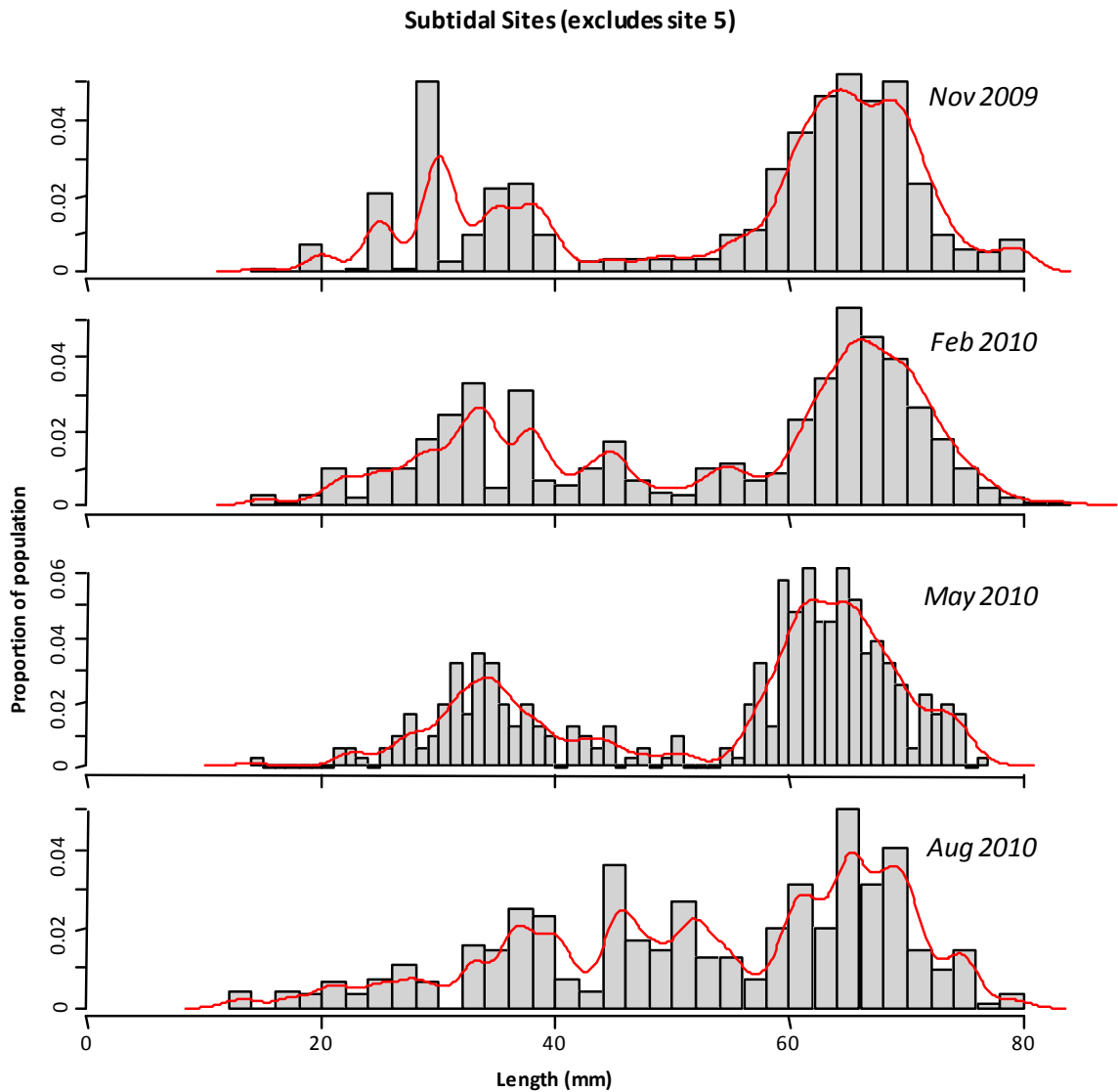
### 3.4 Growth estimates – Mair Bank pigi

#### 3.4.1 Length Frequency Distribution analysis

Data from all the subtidal and intertidal sites were aggregated to give two length frequency distribution time series shown in Figure 8 and Figure 9.



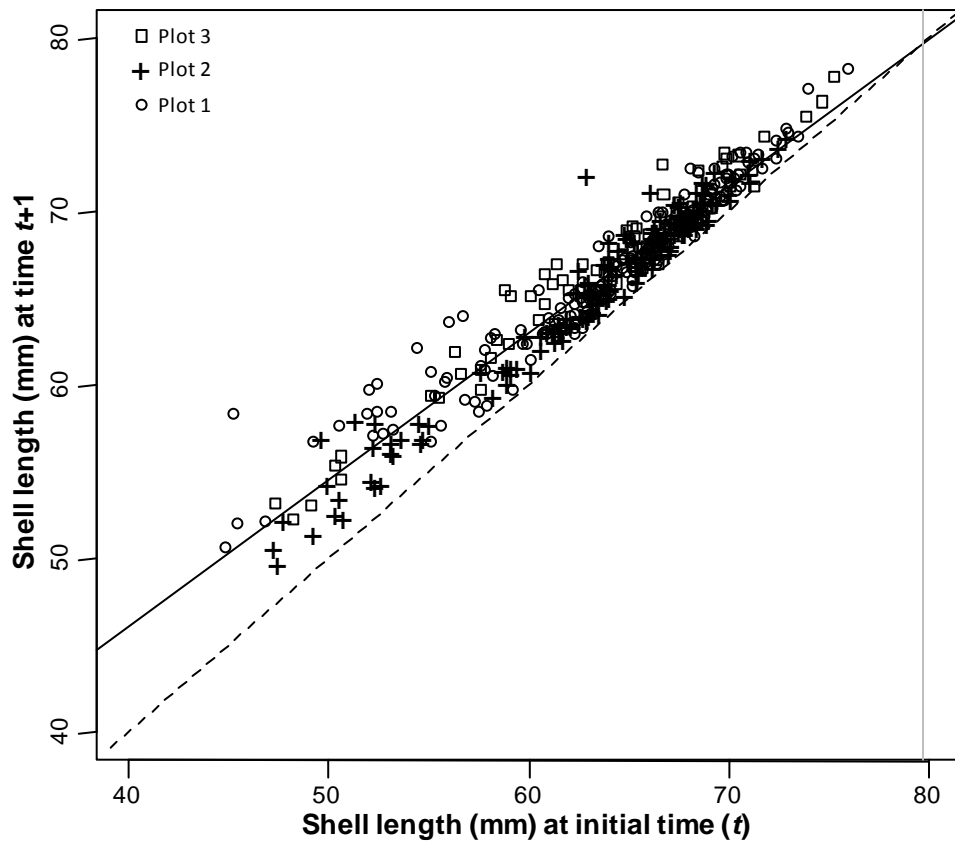
**Figure 8: Length frequency density for pigi at intertidal sites (data from sites one and two were excluded due to low numbers). The line shows the estimated density using a kernel smoother.**



**Figure 9: Length frequency distribution for pipi at subtidal sites (data from site five was excluded due to low numbers). The red line shows the estimated density using a kernel smoother**

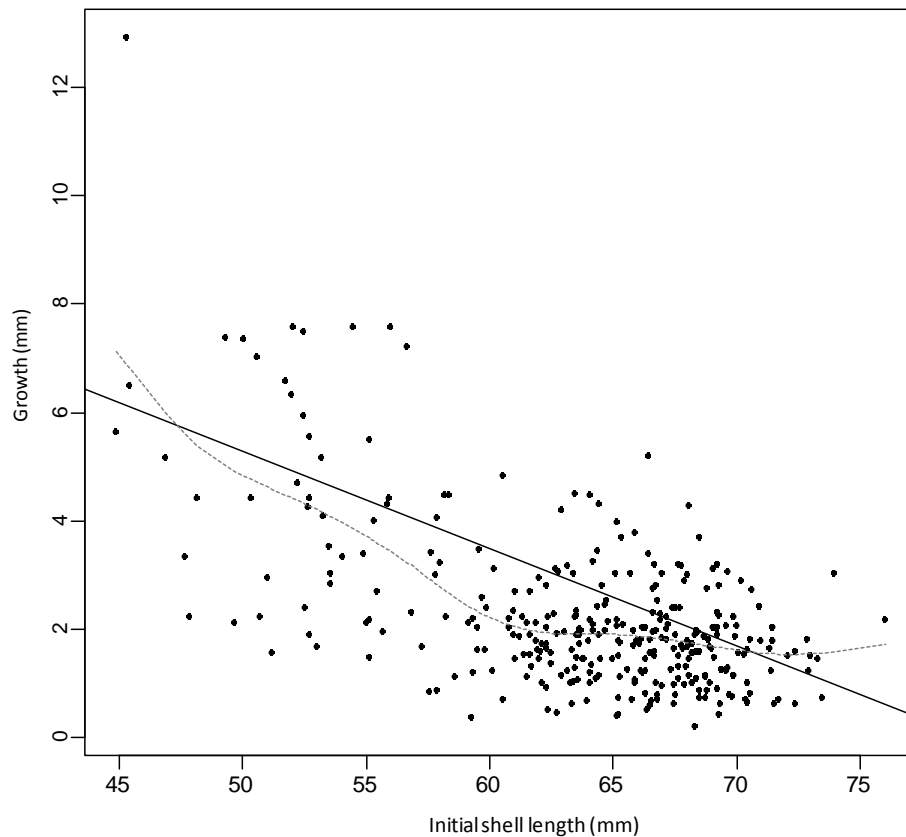
### 3.4.2 Notch tagging experiment

The Ford-Walford plot used to estimate the  $L_{\infty}$  and  $K$  parameters of the von Bertalanffy model from the notch-tagging data is shown in Figure 10.



**Figure 10: Ford-Walford plot showing the results of the notch tagging experiment. The solid black line is the regression line combining all plot areas (see Figure 2C). The dashed line shows a 1:1 relationship and the vertical line (at  $x = 79.7$ ) marks the shell length intersection point with the solid black regression line (i.e. the estimate of  $L_{\infty}$ ).**

Figure 11 shows the observed change in shell length with respect to the initial measurement. The VB model assumes a linear change (decline) in growth ( $\Delta L$ ) as length increases (the model based on the GROTAG parameter estimate are shown in red). A smoothing-spline was fit to the data, suggesting that  $\Delta L$  may not change in the linear manner that is assumed by the VB equation.



**Figure 11: Change in pipi growth with respect to initial shell length. The red line shows the von Bertalanffy estimate based on the GROTAG parameter estimate. The grey line shows a smoothing-spline fit to the data.**

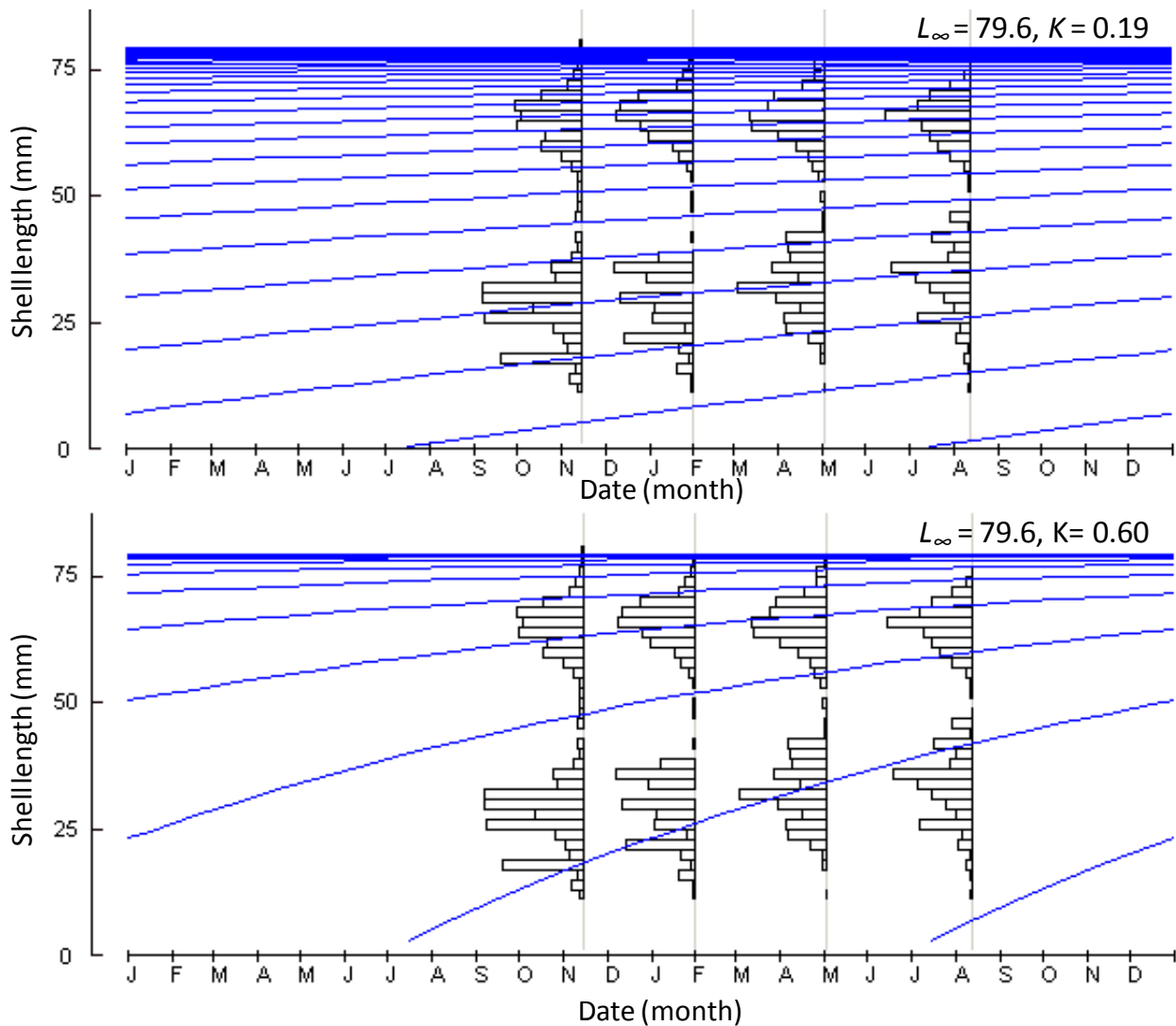
### 3.4.3 Von Bertalanffy parameter estimates

Parameters for the *VB* growth model for pipi at Mair Bank from: (i) the notch tagging experiment and (ii) the LFD model progression analyses are shown in Table 4 below.

**Table 4: Parameter estimates of a von Bertalanffy model for pipi at Mair Bank. The GROTAG estimate of the von Bertalanffy growth parameters (in bold) were used to model yield per recruit.**

Data type	Area	Method	K	$L_{\infty}$
Notch-tag	Intertidal	Ford-Walford	0.16	79.7
Notch-tag	Intertidal	LME	0.16	80.9
<b>Notch-tag</b>	<b>Intertidal</b>	<b>GROTAG</b>	<b>0.19</b>	<b>79.5</b>
Modal progression	Intertidal	ELEFAN	0.66	79.9
Modal progression	Intertidal	MULTIFAN	0.61	66.9
Modal progression	Subtidal	ELEFAN	0.6	79.0
Modal progression	Subtidal	MULTIFAN	0.55	76.2

Estimates of  $L_{\infty}$  were relatively consistent across all methods, but the estimate of  $K$  was much lower for the notch-tag data compared to the modal progression results. Modal progression analyses have been frequently criticized but are widely applied in small, short-lived invertebrate studies (Pauly & David 1981). The techniques rely on the ability of an algorithm to accurately separate and track cohorts (modes) from the LFD.



**Figure 12: Growth curves (blue lines) using  $L_{\infty} = 79.6$  and  $K = 0.19$  (top) and  $0.60$  (bottom) fit to the intertidal length frequency data.**

Figure 12 compares growth curves indicative of the notch-tagging and modal-progression analyses for the intertidal results. We used growth parameters derived from direct measurements (specifically the GROTAG parameter estimates) as the basis for our fisheries model parameters (see Table 5 in §3.3).

### 3.3 Yield per recruit modelling

**Table 5: Parameters used to estimate yield per recruit isopleths,  $F_{0.1}$ ,  $F_{max}$ , and  $SSBPR$ .**

Mortality		Growth			Length-Weight		
$M$	$F$	$K$	$L_{\infty}$	$t_0$	$a$	$b$	$L_{maturity}(mm)$
0.3, 0.4, 0.5	0 - 1.0	0.19	79.5	0.0	$5.92 \times 10^{-5}$	3.15	40

Our results indicate a later optimal age of recruitment to the fishery and higher optimal fishing mortalities than previous studies. This is a result of the substantially lower estimate of the growth rate parameter,  $K$ . The optimal age of recruitment varied depending on the assumed rate of natural

mortality, but was always lower than the minimum age believed to be targeted by fishers, 7.5 years, which corresponds to a shell length of approximately 60 mm. The optimal  $F_{0.1}$  fishing rate varied depending on the assumed natural mortality, with higher natural mortality leading to higher optimal fishing mortality.

The estimated yield per recruit depended strongly on the assumed rate of natural mortality, with yield decreasing as natural mortality increased (Table 6, Figure 13). Estimated yield was lower than previous studies, as slower growth implies a greater portion of the population lost to natural mortality.

For the estimation of the ‘current’ strategy, the minimum size at recruitment was set to 60 mm. This strategy resulted in a decrease in yield per recruit, but a substantial increase in percentage spawning stock biomass per recruit (%SPR), especially under the high natural mortality scenario ( $M = 0.5$ ).

**Table 6: Estimates of optimal fishing mortality rates and associated spawning stock biomass per recruit values for reference points  $F_{0.1}$  and  $F_{max}$  at three different natural mortality rates and two different harvest strategies.**

‘No restriction’ strategy (no minimum age of recruitment)								
M	Age	SL (mm)	$F_{0.1}$	YPR (g)	SSBPR(%)	$F_{max}$	YPR (g)	SSBPR (%)
0.3	5.0	48.75	0.42	2.39	0.49	1.60	2.73	0.27
0.4	4.0	42.32	0.43	1.38	0.41	1.64	1.60	0.16
0.5	3.5	38.62	0.49	0.87	0.35	1.95	1.02	0.08
‘Current’ strategy (minimum age 7.5 years / 60 mm at recruitment)								
M	Age	SL (mm)	$F_{0.1}$	YPR (g)	SSBPR(%)	$F_{max}$	YPR (g)	SSBPR (%)
0.3	7.5	60.38	0.66	2.01	0.72	3.58	2.37	0.59
0.4	7.5	60.38	0.75	0.89	0.78	4.66	1.09	0.67
0.5	7.5	60.38	0.84	0.40	0.83	5.00	0.51	0.75

### 3.3.1 Sensitivity Analysis

**Table 7: Estimates of optimal fishing mortality rates and associated spawning stock biomass per recruit.**

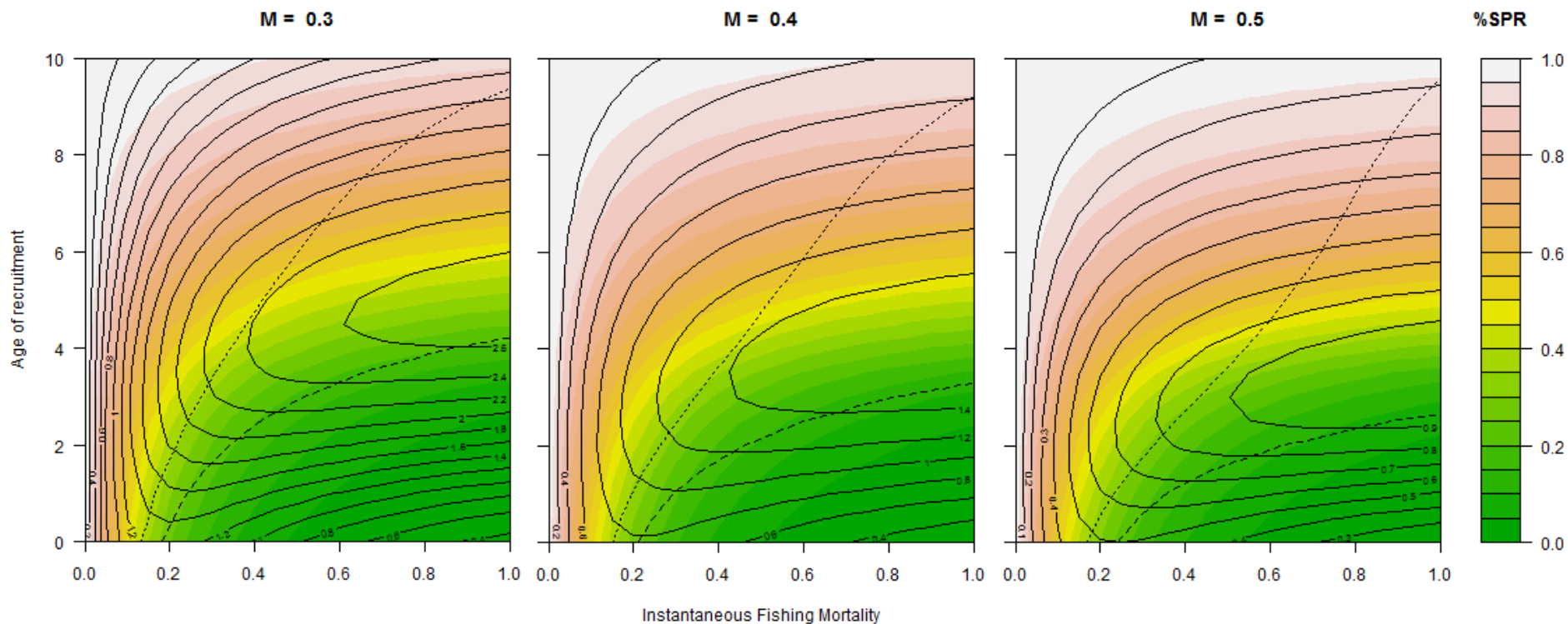
‘No restriction’ strategy (no minimum age of recruitment)								
$M$	Age	SL (mm)	$F_{0.1}$	YPR (g)	SSBPR(%)	$F_{max}$	YPR (g)	SSBPR (%)
0.3	2.5	48.76	0.42	5.20	0.41	1.82	6.16	0.19
0.4	2.5	48.76	0.56	3.80	0.44	3.60	4.61	0.20
0.5	2.0	43.71	0.61	2.89	0.39	2.50	3.39	0.16
‘Current’ strategy (minimum age 5.0yrs / 60mm at recruitment)								
$M$	Age	SL (mm)	$F_{0.1}$	YPR (g)	SSBPR(%)	$F_{max}$	YPR (g)	SSBPR (%)
0.3	5.0	60.31	0.58	3.82	0.65	>5	5.146	0.51
0.4	5.0	60.31	0.78	2.29	0.73	>5	3.06	0.63
0.5	5.0	60.31	0.97	1.37	0.79	>5	1.82	0.72

Estimates of optimal fishing mortality rates and associated spawning stock biomass per recruit values for reference points.  $F_{0.1}$  and  $F_{max}$  at three different natural mortality rates and two different harvest strategies are shown in Table 7. Estimated YPR using Von Bertalanffy growth parameters from Williams et al. 2007 used the following parameters:  $K = 0.576$ ,  $L_{\infty} = 63.9$ ,  $t_0 = 0$ .

The estimates of optimal fishing mortality rate ( $F_{0.1}$ ), yield-per-recruit and SSBPR were sensitive to the choice of parameters. The lower growth rate parameter ( $K$ ) used in this study implies a larger portion of the population lost to natural mortality, and consequently lower yield per recruit. Although these parameters produce generally higher estimated SSBPR, particularly for the ‘current’ strategy, this is because the slower growth rate also leads to a lower estimated unexploited biomass, and the given SSBPRs represent a smaller absolute estimate of spawning biomass, but a higher relative proportion of the unexploited biomass.

The slower growth rate parameter also resulted in large differences in the estimated optimal age of recruitment; however, the corresponding optimal lengths were quite similar. One suggestion of the shellfish working group was to change to a length-based modelling approach in future, which could potentially avoid ambiguities in estimates of age.

For the ‘current’ strategy, using the growth parameters from Williams et al. (2007), the yield per recruit curve increased asymptotically, leading to infinite values for  $F_{\max}$ . Although YPR and SSBPR are undefined in this case, values are given for a very high level of fishing mortality ( $F_{\max} = 5$ ) for the purposes of comparison.



**Figure 13: Pigi yield per recruit (g) isopleths with respect to the instantaneous rate of fishing mortality ( $F$ ) and age at recruitment (years) to the fishery for assumed rates of natural mortality ( $M = 0.3, 0.4$  and  $0.5$ ). The reference rates of fishing mortality,  $F_{0.1}$  and  $F_{max}$ , are shown as dotted and dashed lines respectively. Coloured areas represent the percentage of spawning stock biomass per recruit (%SPR).**

### 3.4 Maximum Constant Yield

Estimated maximum constant yield estimated using Method 2 (Ministry of Fisheries 2011), assuming  $M=0.3$ .

$$\text{This study} \quad MCY = 0.5 \times F_{0.1} \times B_{av} = 0.5 \times 0.66 \times \left( \frac{3145 + 3017}{2} \right) = 1017 t$$

$$\text{Williams et al. (2007)} \quad MCY = 0.5 \times F_{0.1} \times B_{av} = 0.5 \times 0.58 \times \left( \frac{3145 + 3017}{2} \right) = 893 t$$

As yield per recruit analyses treat a number of variable parameters as fixed and constant, a reliable estimate of the c.v. of  $MCY$  is not available - but it will be at least as large as the c.v. for recruited biomass in 2010 (approximately 17%). Sensitivity of  $MCY$  to changes to assumed size at recruitment and natural mortality rates are given in Table 8.

### 3.5 Current Annual Yield

An assumed rate of natural mortality of  $M = 0.3$ , reference fishing rate  $F_{0.1} = 0.42$  and biomass  $B_{curr} = 3145$  were used.

$$\text{This study} \quad CAY = \frac{0.66}{0.66 + 0.3} \times (1 - e^{-(0.66+0.3)}) \times 3145 = 1334 t$$

$$\text{Williams et al. (2007)} \quad CAY = \frac{0.58}{0.58 + 0.3} \times (1 - e^{-(0.58+0.3)}) \times 3145 = 1213 t$$

The c.v. for this estimate will be at least as large as the c.v. for recruited biomass (i.e. 7%). The sensitivity of this estimate to the assumed size of recruitment to the fishery is shown in Table 8.

**Table 8: Sensitivity of maximum constant yield (MCY) and current annual yield (CAY) to changes in assumed time of recruitment. For comparison with previous studies, results using MCY Method 1 (Ministry of Fisheries 2011) for developing fisheries have been included**

Size at recruitment (mm)	Biomass (2010)	M	$F_{0.1}$	MCY method 1 (t)	MCY method 2 (t)	CAY (t)
50	3 890	0.3	0.46	447	895	1 253
		0.4	0.57	554	1 109	1 419
		0.5	0.68	661	1 322	1 552
60	3 145	0.3	0.66	519	1 038	1 334
		0.4	0.75	590	1 180	1 401
		0.5	0.84	660	1 321	1 455

## 4. DISCUSSION

### Mair Bank

The 2010 survey of Mair Bank is only the second pipi biomass estimate that accounts for the subtidal population. Our estimate of absolute biomass, 4450 t, is less than half of the 2005 estimate (10 152 t) made by Williams et al. (2007). The current estimates of *MCY* (447–1322 t) and *CAY* (1253–1552 t) are higher than the TACC (200 t).

Two results from the length frequency data (Figure 5) suggest that the observed differences in estimated biomass between 2005 and 2010 are not the result of fishing pressure. Firstly, although the 2010 estimated biomass was lower than 2005 estimate, the proportion of pipi over 60 mm was similar; as fishers target pipi 60 mm or larger, we would expect any fishery-driven changes to be expressed in this length class first. Secondly, the strong bimodality of the 2010 length frequencies is suggestive of a new cohort of young pipi which have not yet recruited to the fishery. The length frequency data in Williams et al. (2007, Fig 6) was similarly bimodal, however, the primary mode was much larger, and centred around 50–55 mm. These shifting modes are likely to represent successful reproductive pulses, rather than fishery driven changes in an equilibrium population. In any future study, particular attention should be given to changes in the 60 mm plus group.

It should be noted that our yield estimates are dependent upon an estimate of pipi growth derived from the notch-tagging experiment. Although the von Bertalanffy model parameters fit the notch-tagged data moderately well, we note that we were unable to recover pipi smaller than 45 mm. Indeed, we were unable to notch small pipi (smaller than 25 mm) without destroying their shell. The lack of small pipi may have biased our growth estimate. If the experiment were to be replicated, we would suggest additionally using individual-marked tags for the small pipi. Our estimate of growth rate was lower than previous pipi growth estimates based at other sites (Hooker 1995). Our estimate is likely to be an underestimate of the growth of the harvested population, as the tagged shells were from the intertidal and the harvested shells come from the subtidal. The modal progression analysis experiment also suggested higher growth rates (a higher growth rate is likely to decrease the estimated *MCY* and *CAY*). However, reported landings since 2005 have been less than 150 t, an amount smaller than all yield estimates (almost an order or magnitude smaller than some estimates). Consequently, we believe that the results indicate that fishing at the level of recent landings is likely to be sustainable in the short term.

### Marsden Bank

Marsden Bank has extremely high numbers of pipi which were distributed in patches. Some areas had densities exceeding 20 000 pipi per square meter, with nothing in a neighbouring sample. As a consequence the population estimate was imprecise (the c.v. was approximately 20% of the mean).

Anecdotal reports from the *Patuharakeke Te Iwi* Trust Board state that adult pipi were numerous on Marsden Bank in previous decades and that Marsden Bank does not appear to have been under much fishing pressure in recent years. Our results lead to the question - why are there dense numbers of juveniles but few adult pipi on Marsden Bank in recent times? One may speculate that it is due to adult individual preference of hydrodynamics, geomorphology or nutrition; and that these aspects of Marsden Bank have changed over time.

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## APPENDICES

### 1. Bathymetric Map of Mair Bank – April 6, 2010.

