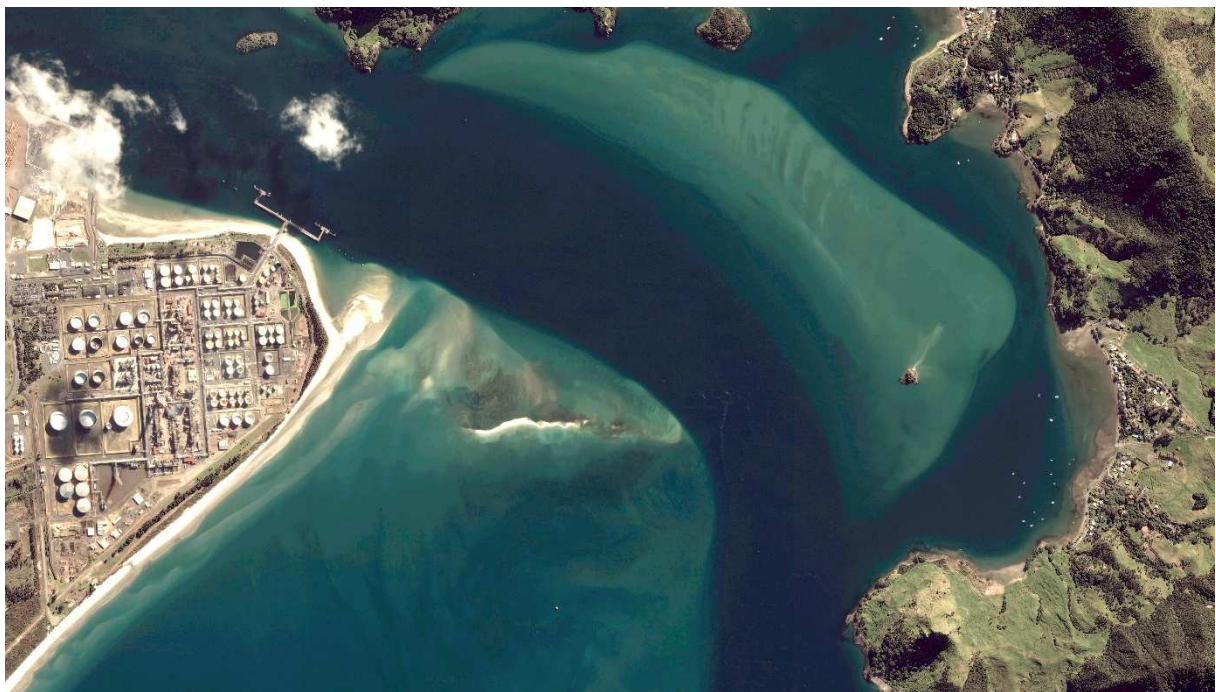


Investigation into the decline of pipi at Mair Bank, Whangarei Harbour

Prepared for Northland Regional Council

June 2014



Authors/Contributors:

Williams, J.R.; Hume, T.M.

For any information regarding this report please contact:

Dr James Williams
Fisheries Scientist
Group Manager - Fisheries and Marine Ecology
+64-9-375 2062
james.williams@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
41 Market Place
Auckland Central 1010
Private Bag 99940
Newmarket
Auckland 1149

Phone +64-9-375-2050
Fax +64-9-375-2051

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Cover image: Mair Bank at the entrance to Whangarei Harbour. Source: Google Earth.

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Reviewed by



.....
Dr Drew Lohrer

Approved for release by



.....
Ken Becker

Formatting checked by



.....
Beverley Wilson

Executive summary

NIWA conducted a desktop project for Northland Regional Council (NRC) to investigate a recent decline in the population of pipi (*Paphies australis*) at Mair Bank, Whangarei Harbour. Pipi are a common species of infaunal bivalve shellfish characteristic of beaches and sandbanks near the mouths of estuaries and harbours around the New Zealand coastline. Mair Bank, a prominent sandbank situated in the tidal inlet and entrance to Whangarei Harbour, supports an important pipi fishery and forms natural protection for the oil refinery and deepwater port development located at Marsden Point. The investigation involved reviewing relevant datasets provided by NRC and providing expert opinion on topics relevant to the decline. This report covers information on pipi biology and ecology, pipi population dynamics, the morphology of Mair Bank, its sediment characteristics, levels of contaminants in shellfish and sediments, and disease testing. Surveys and observations at Mair Bank and the adjacent Marsden Bank at the entrance to Whangarei Harbour show that the decline occurred from about 2009–10 to 2014, and that the pipi distribution on Mair Bank retracted during this period. Potential causes of the pipi decline are high natural mortality of an ageing pipi population and low recruitment, both of which may be related to observed changes in the morphology of Mair Bank. There was no evidence of disease in the population, and the decline did not appear to be associated with potential anthropogenic sources of mortality (e.g., sedimentation, contaminants, harvesting). It is possible that substances not measured in shellfish, sediment, or water quality monitoring work may have influenced the pipi decline. Consideration of what these substances could be, their levels in the environment, and their potential effects on bivalve biology could be worthwhile.

1 Introduction

1.1 Background

Pipi are a common species of New Zealand clam (bivalve shellfish), and the population of pipi at Mair Bank supports highly valued commercial, recreational, and customary harvesting (Ministry for Primary Industries 2013). Mair Bank is a prominent sandbank situated in the tidal inlet and entrance to Whangarei Harbour (Figure 1-1), and, as well as supporting the important pipi fishery, the bank forms natural protection for the oil refinery and deepwater port development located at Marsden Point. The stability of Mair Bank has been linked to the distinct cap of shell material in the central area and southern elevated edge produced by the pipi population, which is thought to maintain stability by armouring the underlying sandy sediments from erosion by waves and tidal currents.

A substantial decline in the pipi population at Mair Bank has been observed over recent years. The decline was first noted in 2009–2010 on the adjacent Marsden Bank (at Marsden Point), which consequently was placed under a rahui by local iwi Patuharakeke to try and allow the population to recover from suspected overharvesting. In 2011, the Ministry of Fisheries put in place a two year temporary closure to the take of pipi from Marsden Bank under section 186A of the Fisheries Act 1996, which later was extended another two years, and will expire in February 2015. The pipi decline was later noted at Mair Bank in 2012 and did not appear to be related to overharvesting (Bingham 2013). This is not the first decline observed in the pipi population at Mair Bank, but it appears to be the largest on record.

Multiple stakeholders are concerned about the pipi decline, including Northland Regional Council (NRC), Ministry for Primary Industries (MPI), iwi and others from the local community, and industry (fishing, port operations, oil refinery).

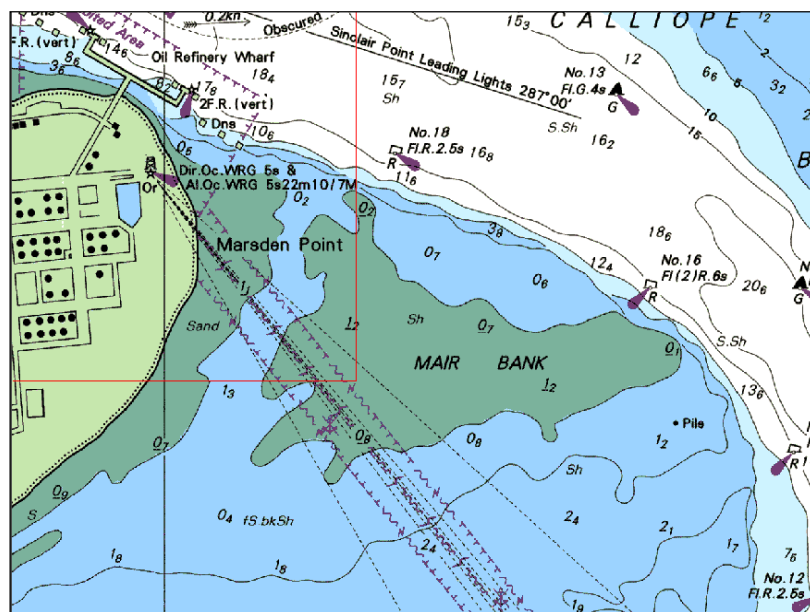


Figure 1-1: Location of Mair Bank at the entrance to Whangarei Harbour. Marsden Bank is the green coloured area adjacent to Marsden Point, separated from Mair Bank by a small channel.
Source: Land Information New Zealand.

In February 2014, NRC contacted NIWA about conducting a brief investigation into the decline of pipi at Mair Bank. At that time, a group of stakeholders were planning to contribute to a survey of pipi on Mair Bank in March 2014, to provide information on the current distribution, abundance and size of pipi on the bank. In addition to the survey, it was considered that a desktop review project should be carried out to explore reasons for the pipi decline.

NRC provided NIWA with relevant datasets and information for review, including:

- bathymetry data from recent annual surveys at Whangarei Harbour
- results of the 2014 pipi survey at Mair Bank, including sediment characteristics data for a subset of the sites sampled
- data on contaminants in shellfish and sediment samples from refinery consent monitoring
- results of long-term State of the Environment water quality monitoring and associated map of sampling sites
- email from MPI incursion lab following an anecdotal 'sudden die-off' in 2013, additional to the longer term pipi decline the bank has been experiencing
- additional relevant reports.

This client report documents the findings of NIWA's investigation into the decline of pipi at Mair Bank. The report covers information on pipi biology and ecology, pipi population dynamics, the morphology of Mair Bank, its sediment characteristics, levels of contaminants in shellfish and sediments, and disease testing.

1.2 Objectives

NIWA were contracted by NRC to conduct a brief desktop investigation into the decline of pipi at Mair Bank at the entrance to Whangarei Harbour, by:

1. reviewing relevant datasets provided by NRC (including any necessary analysis required i.e. Arcmap analysis of bathymetric data)
2. providing expert opinion on:
 - any potential causes as identified by the data provided
 - any data gaps or further investigation that may be useful
 - any potential non-anthropogenic causes, such as natural cycle
 - additional sampling to undertake at time of the 2014 Mair Bank pipi biomass survey
 - whether other harbours in northern NZ are currently experiencing similar shellfish decline, or historical examples, and any known reasons for these declines.

2 Pipi biology and ecology

Knowledge of pipi biology and ecology is required to consider possible reasons for the Mair Bank pipi decline. This section summarises relevant aspects of pipi biology and ecology.

Williams et al. (2007) briefly reviewed the literature on pipi biology and ecology, and a summary relevant to pipi fisheries is provided in the Fisheries Assessment Plenary (Ministry for Primary Industries 2013). Early work by Morton & Miller (1968) and Powell (1979) covered general aspects of pipi biology and ecology, and a PhD thesis (Hooker 1995a) and subsequent publications (Hooker 1995b, Hooker & Creese 1995a, b, Hooker 1997, Grant et al. 1998) provided detailed information on the ecology of pipi at Whangateau Harbour near Leigh (south of Whangarei Harbour). Little information is available on the biology/ecology of specific to pipi at Mair Bank.

2.1 Form and function

The pipi (*Paphies australis*) is a common marine infaunal bivalve mollusc with an oval-shaped shell that can grow to a size of about 85 mm in length. The shell protects the soft body of the animal inside. Pipi have a muscular foot for burrowing to maintain their position buried just below the surface of the sediment, and two short siphons that extend to the sediment-seawater interface for feeding and respiration. Pipi obtain their food and oxygen from the seawater by pumping seawater into the shell through the inhalant siphon, across the gills, and out through the exhalant siphon; food particles suspended in the seawater are filtered out by the gills. Their primary food source is phytoplankton, but other particulate matter (benthic microalgae, detritus, bacteria) when suspended in the seawater may also be important.

2.2 Distribution and abundance

Pipi are characteristically found on semi-sheltered beaches and sandbanks near the mouths of estuaries and harbours around the New Zealand coastline. They live in the mid intertidal to shallow subtidal zone, down to depths of about 7 m. Pipi prefer sandy rather than muddy sediments, and commonly inhabit coarse shell sand in areas with moderate to high current flow. They are intolerant of suspended fine sediments which can reduce rates of feeding and respiration. Pipi are patchily distributed in high densities (up to about 1000 m⁻²) known as 'beds' separated by areas with low densities or no pipi. Such dense aggregations are common in bivalves, and probably result from a combination of patchiness in habitat suitability, gregarious settlement, and to enhance the chances of successful broadcast spawning (see below).

2.3 Reproduction

Pipi reproduce by 'broadcasting' or releasing their eggs and sperm into the seawater for external fertilisation. On a local scale (cm to m), spawning must be synchronous among closely spaced individuals to achieve high levels of fertilisation. Pipi attain reproductive maturity at about 40 mm shell length, when they are about two years old. Spawning can occur multiple times during the pipi breeding season of late winter to late summer, with most spawning in spring and summer. Fertilised eggs develop into planktonic larvae, which live and further develop in the water column for about a three week period, before they settle to the seabed and change to a benthic form, a transition known as settlement and metamorphosis. Recently settled bivalves are known as 'spat'.

2.4 Movement

Dispersal of pipi mainly occurs during the larval phase, but pipi spat may also actively move some distance from the site of initial settlement via byssus and/or mucus thread drifting in the water column. In this way, pipi spat may initially settle in sheltered areas such as the high intertidal and, as they grow and their ability to maintain their position in the substrate increases, can later move downshore to inhabit the lower intertidal and subtidal habitats which are more exposed to higher tidal flows and wave action. As the pipi grow larger and heavier, dispersal using byssus or mucus drifting is not possible. Adult pipi are sedentary and movement is limited.

2.5 Growth, mortality and recruitment

Growth rates for pipi are mainly based on studies at Whangateau Harbour, where pipi were observed to grow to about 30 mm in just over one year, reached 50 mm after about three years, and grew very slowly after that. Growth occurs mainly in spring and summer, and is faster in high-current environments such as harbour channels than in low-current areas such as sandflats. Pipi at Mair Bank possibly have faster average growth than pipi at Whangateau.

Little is known about pipi natural mortality (death from natural causes). Fishery yields for Mair Bank pipi have been calculated by assuming the instantaneous rate of natural mortality (M) is in the range 0.3–0.5, which equates to an annual natural mortality of 26 to 39% of the population per year. The longevity of pipi is unknown, but has been suggested to be about 10 years or more. Sources of natural mortality include predation (e.g., by gastropods, starfish, crabs, octopus, fish, birds), disease, unsuitable environmental conditions (e.g., burial during storms, toxic algae, high temperature, low salinity), and old age. Sources of anthropogenic mortality include harvesting (commercial, recreational and customary fishing), environmental contaminants (e.g., trace metals and organic hydrocarbons), suspended sediments (e.g., from land-based sources and marine dredging activities), and damage by vehicles driving on beaches.

Recruitment, the addition of new individuals to a population, is typically variable in bivalves. Recruitment may be higher in years preceded by favourable environmental conditions that promoted successful reproduction, growth and survivorship, or lower when one or more of these processes were suboptimal. The appearance and progression of size modes of individuals in survey length frequency data are a useful indicator of recruitment. A well-defined size mode may be interpreted as a cohort (a group of individuals born in the same year within a population). In broadcast spawning bivalves such as pipi, recruitment can result from larvae produced by the local spawning population and retained within the local area ('self-recruitment'), or from larvae produced by distant spawning populations dispersing into the local area.

3 Population dynamics

Changes in population abundance can occur from migration (usually only relevant to small pipi), recruitment (the addition of new individuals to the population), and mortality (death from natural and other causes). Changes in population biomass occur from these same processes, but biomass can also increase from the growth of individuals already in the population.

This section briefly reviews information from surveys of pipi at Mair Bank to characterise changes in the distribution, abundance, and size structure of the pipi population and give some insight on possible mechanisms of the pipi population decline.

3.1 Mair Bank pipi surveys

Early surveys of pipi at Mair Bank were conducted in 1974, 1977 and 1982 by MAFFish, in 1983 as part of the Whangarei Harbour Study, and in 1986 by the Northern Regional Council (Haddon 1989). The aim of these surveys was to discover the densities and average size of shellfish on the bank, and sampling was mainly focused on the seaward side of the bank where pipi densities were highest (Haddon 1989). The whereabouts of the data from these early surveys is unknown and they were not available for this review of the pipi decline.

The first biomass survey of pipi at Mair Bank was carried out in 1989 and covered the intertidal portion of the bank only (Haddon 1989). Subsequent biomass surveys of the intertidal and subtidal portions of Mair Bank were conducted in 2005 (Williams et al. 2007), 2010 (Pawley et al. 2013), and 2014 (Pawley 2014).

3.1.1 Distribution

In 1989 (Haddon 1989) most of the intertidal pipi biomass was found on the seaward (southern) edge of Mair Bank. Although the subtidal portion of the bank was not surveyed in 1989, informal inspection during the survey revealed that the pipi beds did extend into the subtidal.

In 2005 (Williams et al. 2007) there was a substantial biomass of pipi across most of the intertidal bank except for the northwestern part of the bank. Sampling of the subtidal habitat down to about 2 m depth showed that there was a substantial biomass of pipi on the seaward (south-eastern) portion of the subtidal area, while other subtidal areas to the southwest, northwest, and north of the bank were virtually devoid of pipi.

In 2010 (Pawley et al. 2013), the distribution of pipi on the bank was not presented in the survey report.

In 2014 (Pawley 2014), the few pipi found were patchily distributed across the intertidal bank interspersed with areas where no pipi were found. Few pipi were found subtidally, and there were no pipi found in the subtidal samples taken on the seaward (southern) side of the bank that held extensive pipi beds in 2005.

Data from these pipi surveys suggest the distribution of pipi on Mair Bank has retracted during the decline: historically, pipi were most abundant on the seaward (southern) portion of the bank, in both the intertidal and subtidal areas, but in 2014 the pipi distribution was patchy in the intertidal and no pipi were found in the subtidal area on the seaward side of the bank.

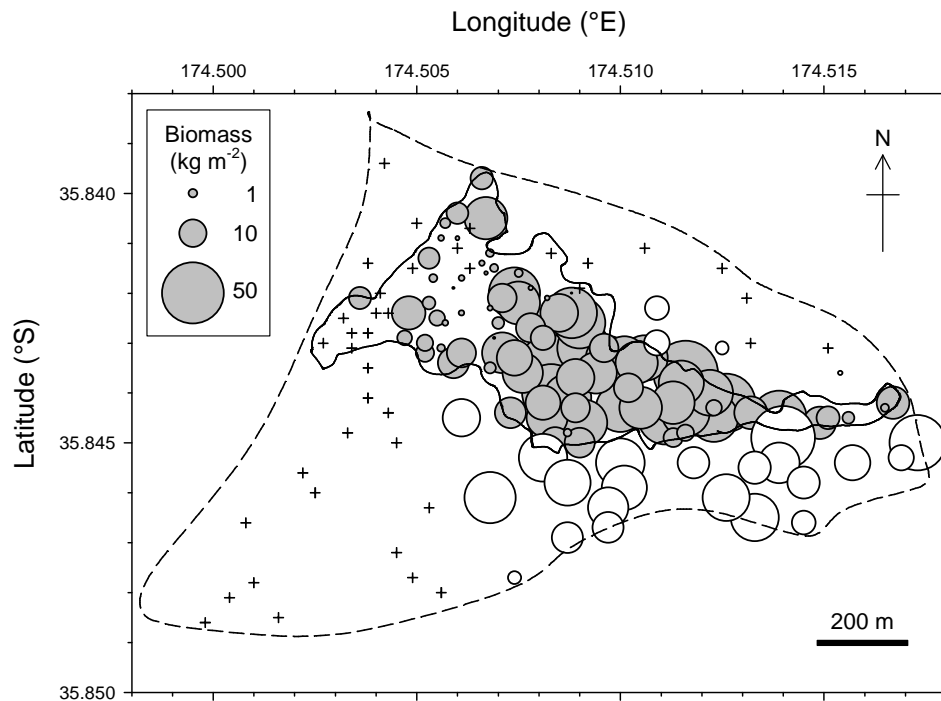


Figure 3-1: Distribution of pipi biomass at Mair Bank, 2005. From Williams et al. (2007). Circle area is proportional to the estimated absolute biomass (kg.m^{-2}) of pipi at each site. Filled circles show intertidal sites, open circles show subtidal sites, and crosses show sites sampled with zero pipi.

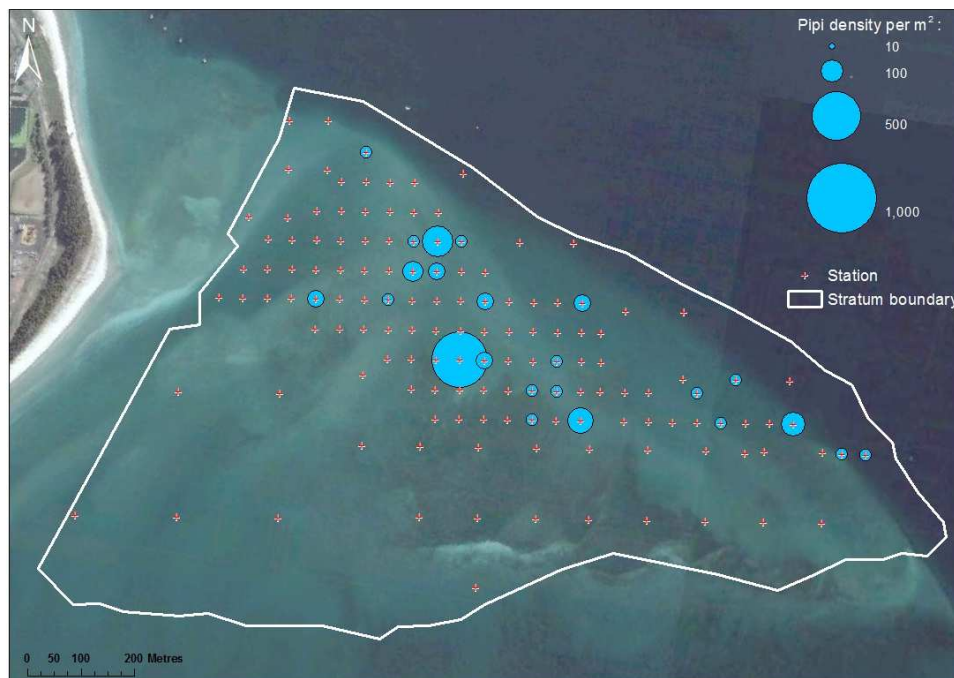


Figure 3-2: Distribution of pipi density at Mair Bank, 2014. Source: NRC, plotted from data collected by Pawley (2014).

3.1.2 Abundance (biomass)

Estimates of pipi abundance at Mair Bank since 1989, reported in terms of biomass greenweight (wet weight of live animal in shell) (Figure 3-3 and Table 3-1), show that there had been a clear biomass decline since the 2005 survey. The initial decline, which occurred sometime between 2005 and 2010, was larger in the subtidal than the intertidal pipi, with the loss of about two thirds of the estimated 2005 subtidal biomass. The biomass in both the intertidal and subtidal areas showed a similar magnitude of decline between 2010 and 2014. The biomass of pipi in 2014 was the lowest on record.

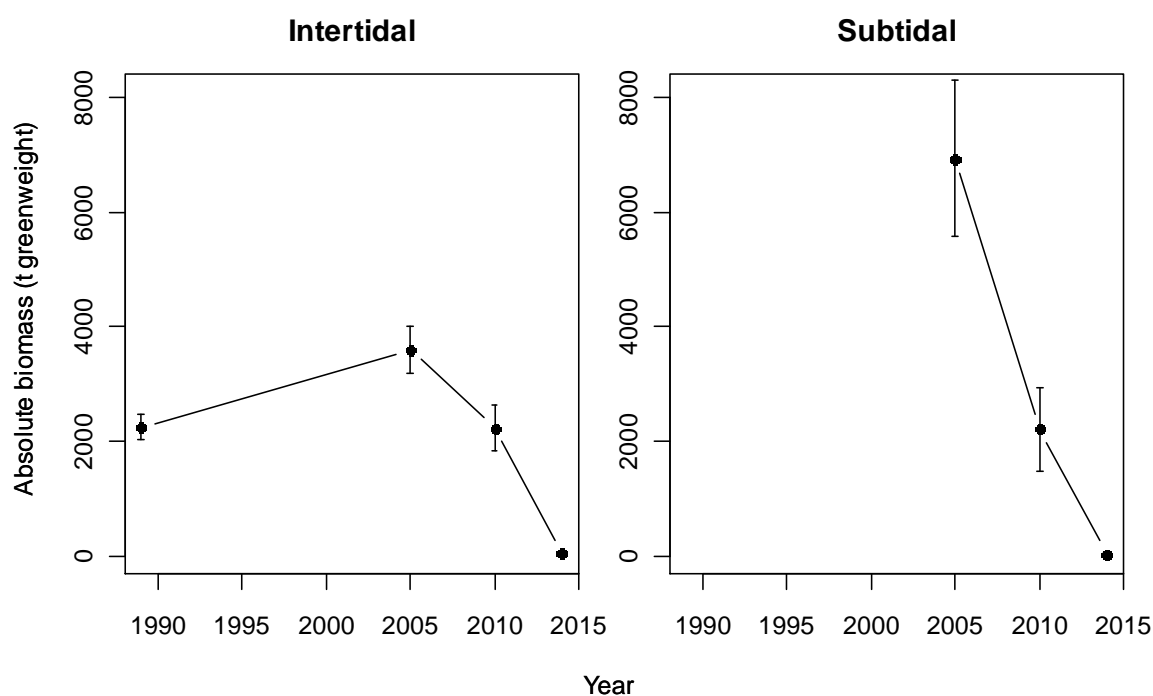


Figure 3-3: Trends in pipi absolute biomass at Mair Bank, 1989 to 2013. Estimates (in t greenweight) for the intertidal and subtidal areas of the bank surveyed are plotted separately. Error bars show the co-efficient of variation (CV) of the estimated mean. Estimates sourced from Haddon (1989), Williams et al. (2007), Pawley et al. (2013), and Pawley (2014). The subtidal portion of Mair Bank was not surveyed in 1989.

Table 3-1: Estimates of pipi absolute biomass at Mair Bank, 1989 to 2013. Estimates in t greenweight. The subtidal portion of Mair Bank was not surveyed in 1989.

Bank	Year	Month	Intertidal	Subtidal	Total	Reference
Mair	1989	Mar	2245	–	–	Haddon (1989)
	2005	Mar / Jun	3602	6940	10542	Williams et al. (2007)
	2010	Mar / Apr	2233	2218	4452	Pawley et al. (2013)
	2014	Feb / Mar	139	27	167	Pawley (2014)

3.1.3 Size structure

Length frequency distributions from individuals measured during surveys represent the approximate size structure of the population sampled, and comparing distributions can provide insights on recruitment, growth, and mortality occurring in the population. Plots showing the length frequency distribution of pipi in the intertidal and subtidal areas at Mair Bank in 1989 (intertidal only) and 2005 (Figure 3-4), 2010 (Figure 3-5), and 2014 (Figure 3-6) indicate that the population size structure has changed markedly through time.

In 1989, the pipi population in the intertidal portion of Mair Bank was dominated by large, presumably old, adult pipi of about 60 to 85 mm shell length (mode of about 70 mm) although smaller pipi from a wide range in length (5 to 60 mm) were also present in low proportions, indicating there had been some recruitment in the years prior. The subtidal portion of the bank was not surveyed.

In 2005, the size structure was very different, with the intertidal and subtidal beds dominated by medium sized presumably young, adult pipi of about 40 to 60 mm (mode of about 52 mm). There was also a much smaller secondary mode at about 72 mm (which was more defined in the subtidal), but it is obvious that proportionally there were far fewer large pipi (>60 mm) in 2005 than in 1989. The overall length range (20 to 80 mm) in 2005 was similar but slightly narrower to that in 1989, and there were few pipi smaller than 30 mm in 2005 indicating possible low recruitment in the year prior.

In 2010, there was a clear bimodal length distribution with a juvenile mode at about 30 mm, indicative of recruitment in the previous year, and an adult mode at 65 mm, although pipi from a wide range of lengths (about 6 to 80 mm) were also present.

In 2014, there were so few pipi found that the length frequency was not well defined; the length range was 13–72 mm, suggesting that there had at least been some minimal recruitment in the years prior. In 2014, only large pipi were found subtidally.

It is possible that the dominant 52 mm mode of young adult pipi in 2005 survived and grew to produce the 65 mm mode in 2010, but then potentially underwent high natural mortality.

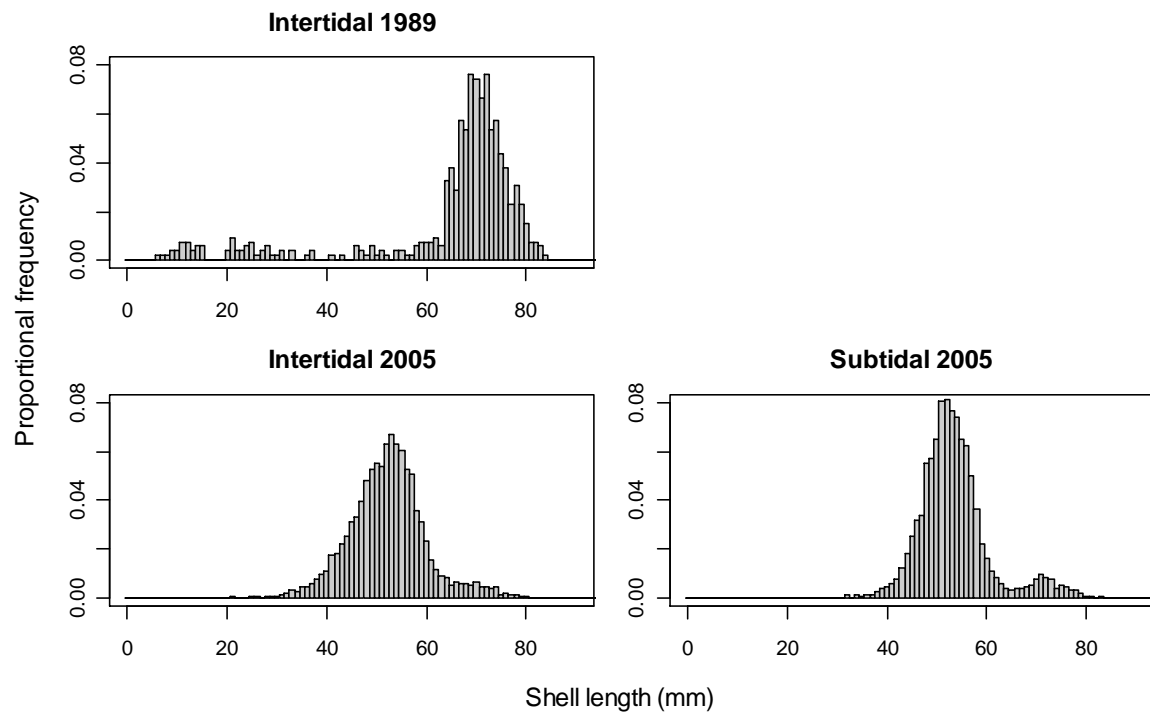


Figure 3-4: Length frequency of pipi at Mair Bank, 1989 and 2005. Plotted using data from Haddon (1989) and Williams et al. (2007).

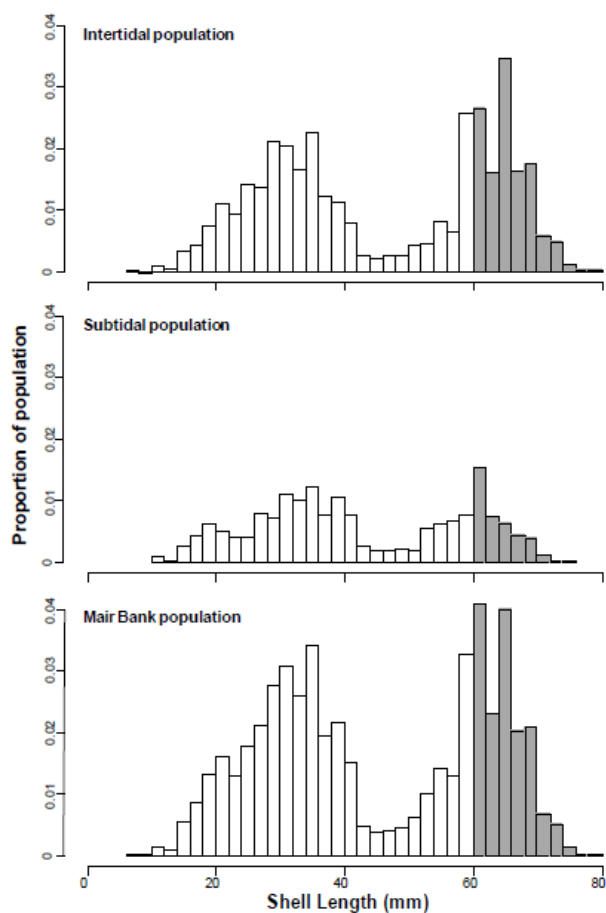


Figure 3-5: Length frequency of pipi at Mair Bank, 2010. Source: From Pawley et al. (2013). Grey bars indicate large pipi in the size range of interest to commercial harvesting.

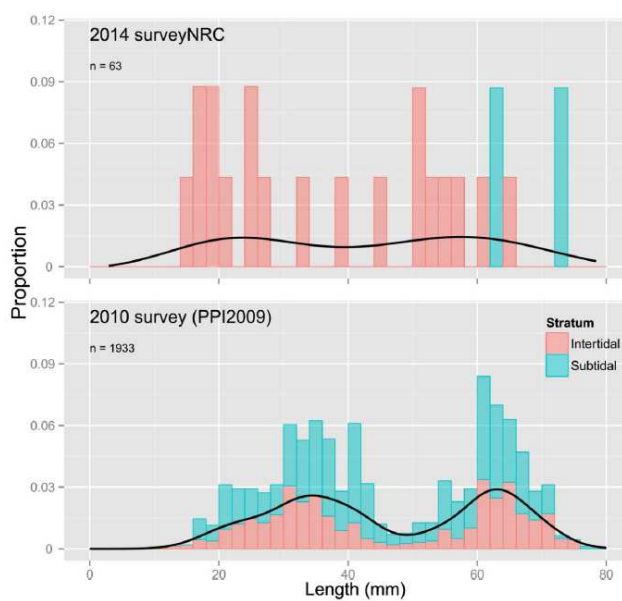


Figure 3-6: Length frequency of pipi at Mair Bank, 2014. The 2010 length frequency is also shown. Source: From Pawley (2014).

3.2 Marsden Bank pipi surveys

Marsden Bank was surveyed for pipi in 2010 (Pawley et al. 2013), March 2012 (MPI), 4 May 2012 (Williams et al. 2012) and 2 February 2014 (survey by Dragonfly for MPI, results unpublished).

In 2010 (Pawley et al. 2013), high numbers of pipi were patchily distributed across Marsden bank interspersed with areas of few or no pipi. The pipi were predominantly juveniles (up to 40 mm, modal length of about 14 mm), although a very small proportion of the sampled population were about 60–70 mm in length.

Data from the March 2012 (MPI) survey were not available for this investigation.

In May 2012 (Williams et al. 2012), the few pipi that were found were restricted to the northern end of Marsden Bank. The pipi were all juveniles up to about 40 mm in length, mostly in the 10–30 mm range (mode of about 20 mm); the largest pipi found was 43 mm.

Preliminary results of a 2014 survey of Marsden Bank were as follows (R. Ford, MPI, pers. comm.):

‘The preliminary (indicative and non-reviewed) estimates from the MPI survey completed on Marsden Bank in February were as follows: An average density of 26 pipi per square metre (compared with 950 pipi per square meter in 2012, and 1815 pipi per square metre in 2010). These findings are based on 129 samples and a total of 91 pipi across the bank and the beach immediately to the south. From these samples, the provisional estimate is 3.2 +/- 1.7 million pipi on Marsden Bank, compared with around 60 +/- 12 million pipi in 2012. Owing to the very low numbers, the surveyors could not achieve a c.v. of 50%. While at Marsden Bank, [the surveyor] noticed a considerable number of clean shells (not worn down yet), suggesting that there may have been recent mortality.’

The above results suggest that there was some recruitment of juveniles at Marsden Bank in 2010, 2012, and 2014, but there is no evidence of their survival and growth into the adult population.

4 Morphology of Mair Bank

Mair Bank provides the physical benthic habitat for the pipi population, and it is possible that changes in the morphology (surface shape) of Mair Bank may have occurred and influenced the status of the pipi population. Here, we review changes in the morphology of Mair Bank using information from:

- an MSc thesis by Morgan (2008) describing changes in biogenic sediment controls on ebb-tidal delta stability
- bathymetry data from the 2000 to 2013 annual surveys of Whangarei Harbour for port and refinery requirements provided by NRC as ArcGIS shapefiles and JPEG images showing changes in bathymetry between successive years (Coordinate system GD2000, New Zealand Transverse Mercator. Vertical datum Marsden Point Chart Datum)
- an understanding of tidal inlet morphodynamics.

4.1 Mair Bank and ebb tidal delta morphodynamics

Mair Bank forms the shallow and eastern part of the ebb tidal delta which is a large body of sand situated in the tidal inlet and entrance to Whangarei Harbour (Figure 4-1). Mair Bank is submerged at high tide but there is a subaerial component at low tide in the central area. Marsden Bank is the shallow western part of the ebb delta attached to Marsden Point and separated from Mair Bank by a shallow subtidal channel (see Figure 1-1).

Surface sediment on Mair Bank is comprised of a mix of gravels and coarse sand made up of high proportions of shell material. The shell material is characterised by pockets of sandy sediments on the outer margins and lobes of shell material across the centre of the bank, which includes a prominent shell ridge running east-west along the southern margin of the bank (Figure 4-1). The stability of Mair Bank has been linked to the distinct cap of shell material in the central area and southern elevated edge produced by the pipi population, which is thought to maintain stability by armouring the underlying sandy sediments from erosion by waves and tidal currents.



Figure 4-1: Mair Bank at the entrance to Whangarei Harbour. Source: Google Earth.

The primary controls on sand storage in the ebb shoals of New Zealand's tidal inlets have been shown to be wave and tidal energy and shoreline configuration (Hicks & Hume 1996). On embayed coasts such as Northland's, bedrock headlands have a major influence on these controls and the shape and size of the space in which the sand body can accumulate and therefore on the overall shape of the delta. Hicks & Hume (1996) identified four basic delta forms. Mair Bank falls into the category of the "high-angle half-delta" (Hume 2003) which are typically shore normal L-shaped (or elongate-triangular) sand bodies that occur on the barrier (Marsden Point) side of the inlet channel and bordered by the ebb jet flow which is pinned against the rocky overlapping headland (Bream Head). In New Zealand tidal inlets, sand bodies associated with headlands tend to be positionally stable (i.e., stay in the same place) and do not migrate up and down the coast (Hume & Herdendorf 1992). The total amount of sand stored in the Mair Bank ebb tidal shoal (168 M m^3) is also relatively fixed as it depends on the size of the tidal prism (the amount of water flowing in and out on the tide), the wave energy and the angle of the ebb jet (Hicks & Hume 1996). However, the planform shape and the distribution of smaller scale sand banks and channels on the surface delta will change continually at a local scale as forced by waves and tides.

4.2 Bank morphodynamics at long-term to short-term time scales

Morgan (2008) provides an excellent summary of morphodynamics of Mair Bank at long term (decadal), medium term (inter-annual) and short term (daily) time scales.

At decadal time scales (1950 to 2006) the main harbour channel and the northern edge of Mair Bank have been the most stable features. The main shell ridge on Mair Bank has been the most dynamic, oscillating back and forth at its eastern end and the central and west part of the ridge migrating some 580 m north. The shell ridge decreased significantly in length between 1950 and 2006. The tip of the Marsden Point sand spit shoreline has been observed to oscillate between a rounded shape to more triangular at the tip, with the position of the tip oscillating in and out some 50 m during this cyclic process. The southern side of the Marsden Point shoreline has remained stable.

At inter-annual time scales (2001 to 2006), the relative overall position of Mair Bank has remained fairly stable. However there were significant shifts of sand over Mair Bank. There were changes to the marginal ebb channel to the west of the bank along the Marsden Point shoreline in the form of a constriction of the channel and a welding of bars to the shore. A large area of erosion (c. 0.25 – 0.5 m) was identified on the southwest part of Mair Bank. The main shell ridge along the southern margin of the Mair Bank has become more extensive over time and increasing in elevation and size until 2006. The ridge has been eroded (c. 0.6 m) along the southern edge and with deposition (c. 0.6 m) occurring to the north, indicating a migration to the north. Analysis of volumetric changes over the 5 years showed the winter volumes to be relatively lower than estimates generated for the summer months. Generally there was an increase in sediment storage over time. The least variation in sediment volume was for the sediment above chart datum, compared to other depth bands (>4 m and >8 m). Overall the volume of sediment above chart datum increased. Analysis of the cut and fill data for 2001 to 2006 showed two main areas of sediment loss/gain. The main seaward shell ridge was the area of predominate net loss, along with the southern seaward flank of Mair Bank. The centre of the bank and the back-barrier of the main ridge both accreted over the period. Infilling of the northern entrance to the marginal ebb-channel also occurred.

4.3 Bathymetry changes 2000 to 2013

Bathymetry data from the 2000 to 2013 annual surveys of Whangarei Harbour for port and refinery requirements provided by NRC document changes in the morphology of Mair Bank (Figure A-1). The surveys show a continuation of the interannual-scale patterns of change reported by Morgan (2008). Over the 13 years the northern flank of the delta bounded by the main harbour channel has been fairly stable. In the nearshore off the Marsden Refinery to the northeast where the base of the delta attaches to the tip of Marsden Point there has been substantial cut and fill (+1 m) in the marginal channels as swash bars migrate on and off the shore in response to waves and tidal flows. There has been a substantial retreat to the north of the southern flank of Mair Bank and shell ridge of about 300 m over the 13 years and associated bed level changes of the order of +1 m, which is similar to the tide range (mean range = 1.7 m). The rate of retreat (23 m.y⁻¹) is double that of the 10.4 m.y⁻¹ retreat reported by Morgan (2008) for the 1950 to 2006 period. In comparison the distal eastern tip of Mair Bank appears to be more stable over the 13 years. Overall between 2000 and 2013 the bathymetry surveys show:

- substantial erosion along the southern part of Mair Bank
- accretion on Marsden Bank and on the northwest of Mair Bank.

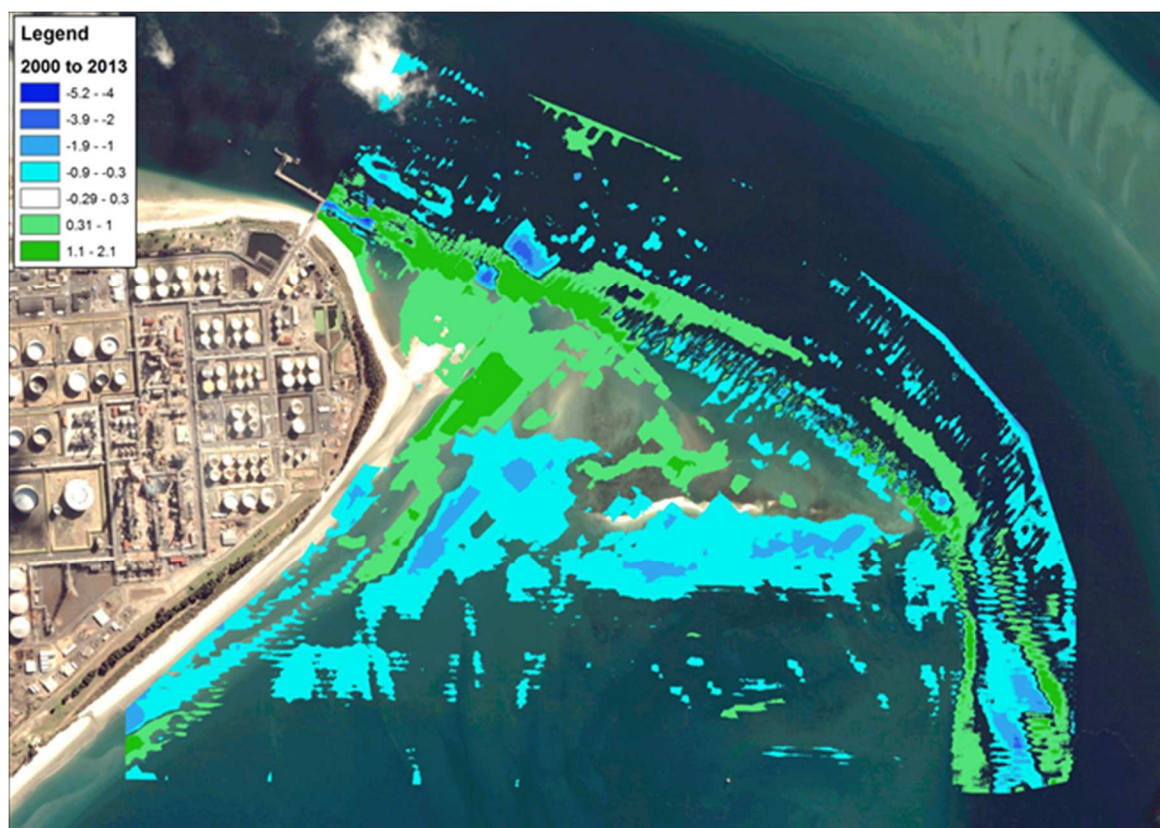


Figure 4-2: Differences Mair Bank bathymetry between the years 2000 and 2013. Green colour = increase in elevation, blue colour = decrease in elevation. Only changes of more than ± 0.3 m are shown to reduce noise in the data.

A survey in 2010 (Pawley et al. 2013) indicated a substantial decline in the pipi population compared to the 2005 survey when pipi were very abundant (Williams et al. 2007).

Comparing the bathymetry data from the 2005 and 2010 soundings surveys (Figure 4-3, centre plot) shows the net changes in the 5 years to be characterised by:

- erosion in the nearshore along the southern refinery shore of Marsden Point
- accretion on Marsden Bank and growth into the main channel (0.3 – 2 m)
- erosion in the channel separating Marsden Bank and Mair Bank
- accretion on around the margins of the shallower central part of Mair Bank (0.3 – 1 m)
- little change in the central of Mair Bank and at its eastern distal end and northern margin
- erosion along the southern seaward margin of Mair Bank and a migration northwards of the shell ridge of some 150 m.

While there were substantial changes in bathymetry the 2005–10 period, they are of a similar scale and variability to changes in the 2000–05 period (Figure 4-3, top plot) leading up to a time when pipi were very abundant.

Between 2010 and 2013 (Figure 4-3, bottom plot) the pattern of change is similar to that in the 2005–10 period except for:

- substantial accretion in the area of the channel separating Marsden Bank and Mair Bank
- less accretion on Marsden Bank.

Overall there has been substantial changes in the surface topography of Mair Bank (of the order of +1 to -1 m elevation, with +2 to -2 m elevation locally) as banks and channels on the surface shift about in response to storm events and currents. This is normal on a tidal delta on the open coast. There were substantial changes in topography in the 2000 to 2005 period and leading up to the time when pipi were very abundant in 2005, and also in the 2005 to 2010 period leading up to the time of decline in pipi numbers. Over the 2000 to 2013 period there has been substantial and continual retreat of the southern flank and shell ridge on Mair Bank.

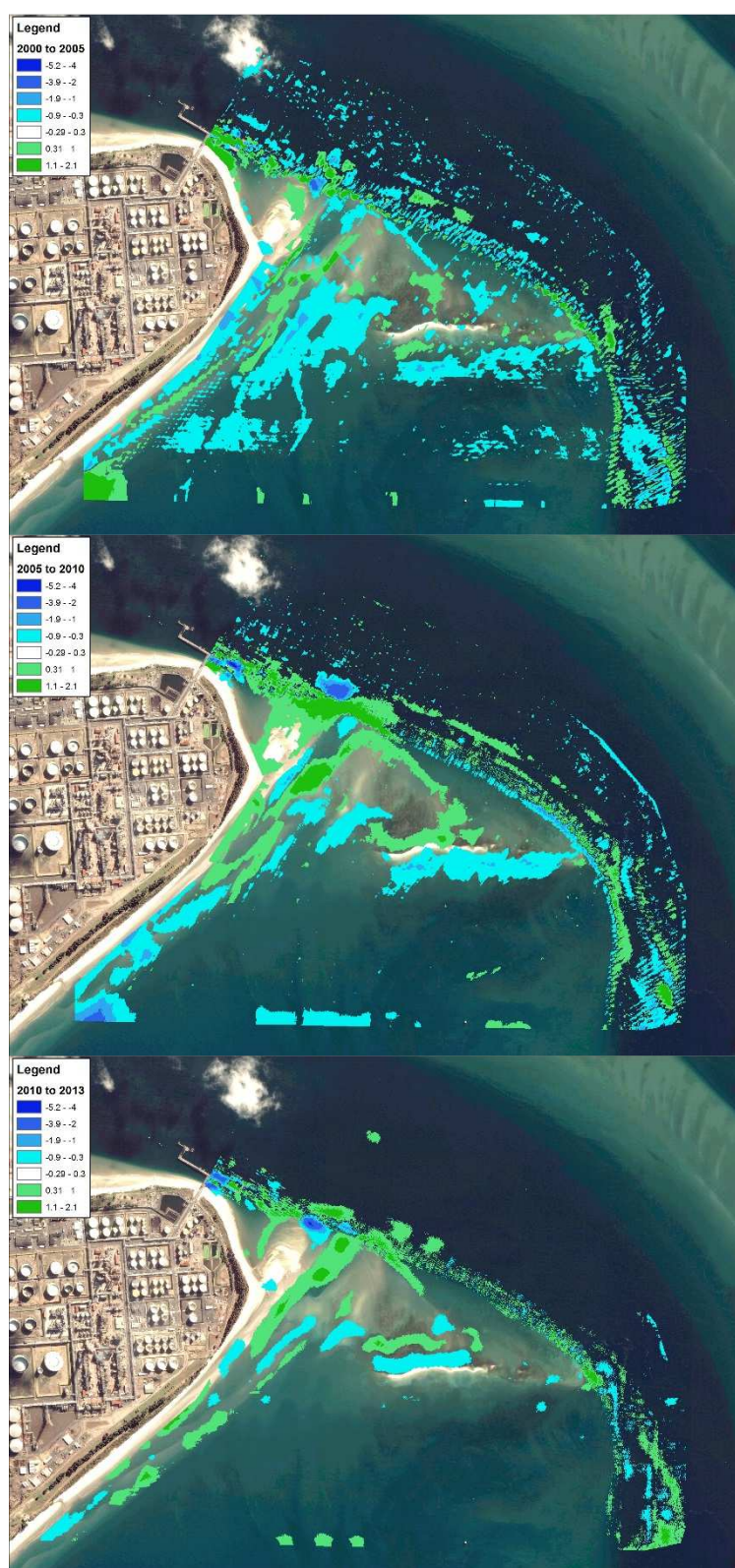


Figure 4-3: Differences in Mair Bank bathymetry in three periods between 2000 and 2013. The plots show the difference in bathymetry between the years 2000 and 2005 (top), 2005 and 2010 (centre), and 2010 and 2013 (bottom). Green colour = increase in elevation, blue colour = decrease in elevation. Only changes of more than ± 0.3 m are shown to reduce noise in the data.

4.4 Possible effects of port development works

An assessment was made of the potential effects of forestry port development at Marsden Point on tidal current and wave regime on Mair Bank. New development and erosion mitigation works at Marsden Bay in the last two decades were summarised by Liefing & Ivamy (2010), and include a 30 hectare reclamation as part of NorthPort Ltd expansion constructed from 2000 to 2002. Before the development occurred, Barnett (2009) used a calibrated numerical model to investigate the possible effects of construction works and capital dredging associated with three-berth and four-berth developments. Predicted changes in ebb flows around the new berths proposed showed marked changes in the current velocity in the immediate vicinity of the developments but these were restricted to the area to the west of the mooring dolphin. Outside this area, and including the area of Mair Bank, the changes in ebb current would be expected to be far less than 0.05 m.s^{-1} for most of the ebb flow which was the smallest velocity contour plotted in the report. Flood tide current velocities on Mair Bank will be unaffected by forestry port development downstream. The wave climate on Mair Bank will be unaffected by forestry port development to the west.

In summary, the construction works and dredging associated with three-berth and four-berth developments forestry port development are not expected to have any significant effects on the tidal current and wave regime on Mair Bank. Note that to date only construction of Berth 3 has been completed.

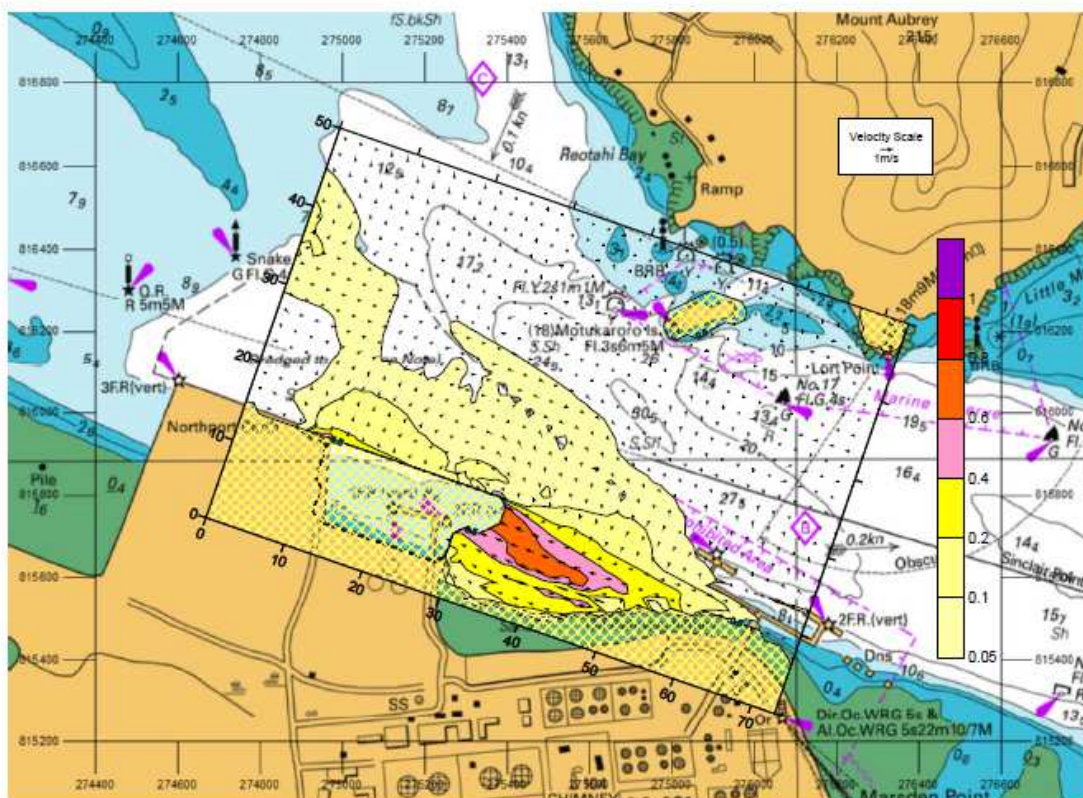


Figure 4-4: Ebb tide velocity differences between the Four-Berth and Initial Stage Layout and how the significant increases in currents lie west of the mooring dolphin. The highest velocity increases are $0.6\text{--}0.8 \text{ m.s}^{-1}$ (red) and the lowest plotted are $0.05\text{--}0.1 \text{ m.s}^{-1}$ (pale yellow). Source: Figure 3.2 from Barnett (2009).

5 Sediment characteristics

At a stakeholder meeting held on 11 February 2014, in relation to planning the March 2014 survey of pipi at Mair Bank, it was asked what else should we be sampling/testing for to help answer the question 'why is the decline happening?'. NIWA advised that collecting sediment samples during the survey would be useful to characterise the sediment properties of the bank and assess the relationship between pipi density distribution and sediment characteristics. Such sediment data were collected during NIWA's small survey of Marsden Bank in 2012, but had not been collected before during previous pipi surveys at Mair Bank. The collection of pipi samples to store frozen was also advised to enable tissue analysis to be carried out later if required.

This section describes the sediment sampling conducted during the March 2014 survey of pipi at Mair Bank, and how a selection of these was chosen by NRC for analysis by NIWA to determine the sediment characteristics of grain size, organic content and chlorophyll *a*.

5.1 Sediment methods

During the survey, at each site, two small sediment cores (2 cm deep, 2 cm diameter) were collected: one to determine grain size and organic content and the other for chlorophyll *a* analysis. Cores were kept frozen in the dark prior to analysis.

After the survey, NRC selected the cores from 25 of the stations in the intertidal portion of Mair Bank, to give a spatial spread of stations across the bank and including some stations where pipi were present and some stations where pipi were absent. Cores from the 25 selected stations were sent to the NIWA Hamilton laboratory for analysis as described below.

Grain size: The samples were homogenised and a subsample of approximately 5 g of sediment taken, which was then placed in ~ 9% hydrogen peroxide until frothing ceased, indicating that all organic matter present had been digested. The sample was then wet sieved through nested 2000 µm, 500 µm, 250 µm and 63 µm mesh sieves. Pipette analysis was used to separate the <63 µm fraction into >3.9 µm and <3.9 µm. All fractions were then dried at 60°C until a constant weight was achieved (fractions were weighed at ~ 40 h and then again at 48 h). The results of the analysis are presented as percentage weight of gravel/shell hash (>2000 µm), coarse sand (500 – 2000 µm), medium sand (250 – 500 µm), fine sand (62.5 – 250 µm), silt (3.9 – 62.5 µm) and clay (<3.9 µm). Mud content is calculated as the sum of the silt and clay content.

Chlorophyll *a*: Within one month of sampling, the full sample was freeze dried, weighed, then homogenised and a subsample (~0.5 g) taken for analysis. Chlorophyll *a* was extracted by boiling the sediment in 90% ethanol, and the extract measured using a spectrophotometer. An acidification step was used to separate degradation products (phaeophytin) from chlorophyll *a*. The results of the analysis are presented as weight of pigment per gram of sediment.

Organic content: Approximately 5 g of sediment was placed in a dry, pre-weighed tray. The sample was then dried at 60°C until a constant weight was achieved (the sample was weighed after ~ 40 h and then again after 48 h). The sample was then ashed for 5.5 h at 400°C (Mook & Hoskin 1982) and then reweighed. The results of the analysis are presented as a percentage weight of organic content.

5.2 Sediment results

Overall, most of the sediment was sand (mean = 79% and range = 63–100% for fine, medium, and coarse sand categories combined), comprising predominantly fine sand (mean = 50%) and medium sand (mean = 22%) with a small amount of coarse sand (mean = 7%). There was a substantial amount of gravel/shell hash (mean = 21%, range = 0.3–37%), and a very low level of mud (mean = 0.1% and range = 0–0.4% for silt and clay categories combined). Chlorophyll *a* content of the sediment was low (mean = 4.7 $\mu\text{g.g}^{-1}$ sediment, range = 2.3–8.3 $\mu\text{g.g}^{-1}$), and phaeophytin content was very low (mean = 0.6 $\mu\text{g.g}^{-1}$ sediment, range = 0.1–2.0 $\mu\text{g.g}^{-1}$). Sediment organic content was low (mean = 1.0%, range = 0.7–1.6%).

There were no obviously strong patterns in the spatial distribution of sediment characteristics across the intertidal portion of the bank sampled for sediments, with patchiness observed in most characteristics, but there were some indications of weak patterns (Figure 5-1). In general, gravel/shell hash was highest in the central part of the bank running northwest to southeast and lowest along the harbour channel flank of the bank to the northeast. Mud content, although very low in all samples, appeared to be slightly higher in the centre of the bank, and lowest in the southeast. Pigment content was variable across the bank, but the highest levels of both chlorophyll *a* and phaeophytin were in the centre of the bank, and the lowest levels of phaeophytin were in the southeast. Organic content, although generally very low, was highest at sites in the northwest. In comparison with these sediment characteristics, pipi were patchily distributed across the bank, with highest densities observed in the centre of the bank running east to west along the bank.

The characteristics of the surface sediments of Mair Bank sampled during the 2014 pipi survey appear to be consistent with those of habitats suitable for pipi, being predominantly sand with high levels of gravel/shell hash and very low levels of mud (silt and clay, which can cause problems for pipi respiration and feeding).

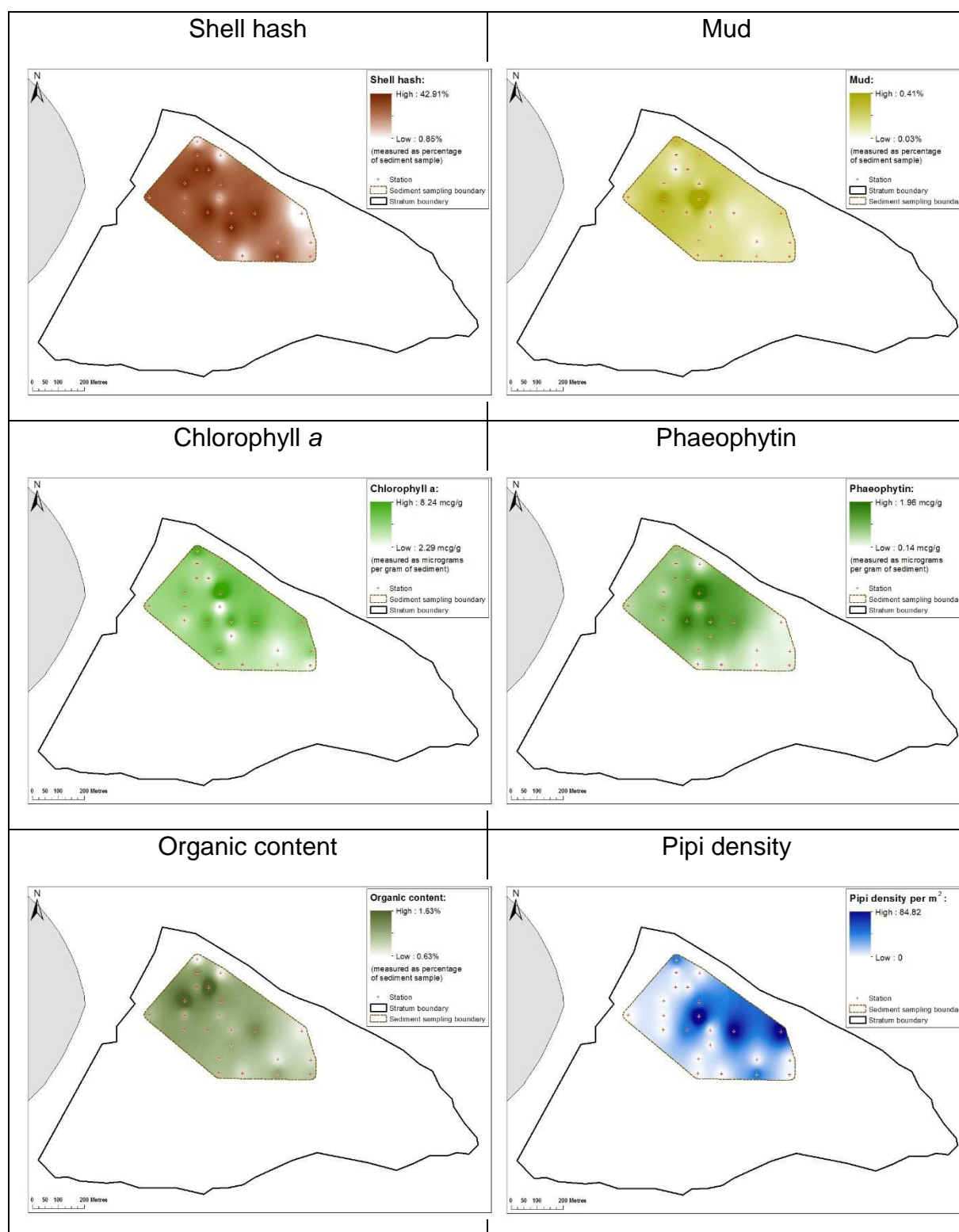


Figure 5-1: Intertidal sediment characteristics of Mair Bank, March 2014. Pipi density (m²) at the same sites analysed for sediment characteristics is also shown (bottom right). Plots use inverse distance weighted (IDW) analysis with maximum-minimum stretched colour ramps.

6 Contaminants

This section briefly examines data on the concentration of various chemical contaminants (trace metals and hydrocarbons) measured in shellfish and sediments collected from various sites in the outer Whangarei Harbour from 2002 to 2012 as part of the oil refinery consent monitoring. These data were provided by NRC as two separate datasets: 'refinery shellfish' and refinery sediment'. A subset of these data was analysed, using data only from sites in the vicinity of Mair Bank where pipi and sediment samples were collected and tested for contaminants. Data on sediment and biota from a harbour-wide study undertaken in 2012 in Whangarei Harbour were also available, but none of the study sites were in the vicinity of Mair Bank so those data were not examined here.

Trace metals and hydrocarbons as contaminants are discussed in relevant report on the levels of contaminants in the marine environment adjacent to the Marsden Point Deepwater Port Development, Whangarei Harbour (Tricklebank 2003).

6.1 'Refinery shellfish' data

The 'refinery shellfish' dataset has the following attributes: 17 sites across Whangarei Harbour, 6 types of shellfish (pipi, cockle, tuatua, mussel, feral shellfish, and unknown; for the latter two, the actual species was not recorded), and 27 contaminant variables. For all contaminants, the test conducted measured the 'total recoverable' concentration. Some of the values were recorded as '<' (i.e. less than a particular value) presumably because the values measured by the test were lower than the detection limits of the test equipment. In this analysis, the '<' values specified were divided by two to enable values to be plotted. Data were available from seven sites where pipi had been collected and tested for contaminants, but only four of these sites were in the vicinity of Mair Bank (Figure 6-1):

- 100190: Mair Bank outer marker pile
- 103247: Mair Bank seaward side
- 100191: Marsden Point – Mair Bank channel
- 110624: Marsden Bank.



Figure 6-1: Locations of sites near Mair Bank from the refinery consent monitoring data on shellfish and sediment contaminants. The oil refinery is on the top left of the image. Pipi and sediments were collected from all sites shown except for 100191 (pipi only), 100268 (sediment only), and 100266 (neither collected).

For the four pipi sites in the vicinity of Mair Bank, there were four dates when pipi had been collected and tested for contaminants, but only site 100190 at Mair Bank had been sampled more than once (three different collections, on 10 December 2008, 23 November 2009 and 11 December 2012); one-off collections of pipi have occurred at the other sites. The number of chemicals measured in pipi at each of the four sites has increased over time; in 2003, pipi were tested only for heavy metals, but since 2008 hydrocarbons were also measured (Table 6-1). Note that the tests have been carried out by different laboratories over time: the 2003 samples were analysed at the 'Hills' laboratory, the 2008–12 samples were analysed at the 'Watercare' laboratory.

Table 6-1: Number of contaminants measured in pipi from sites near Mair Bank. Contaminant variables shown by site and sampling date.

Date	Mair Bank site 100190	Mair Seaward Site 103247	Marsden-Mair site 100191	Marsden Bank site 110624
29/04/2003	0	0	5	0
10/12/2008	24	0	0	0
23/11/2009	24	0	0	0
11/12/2012	25	25	0	25

The concentrations of the various metals and hydrocarbons in pipi at Mair Bank from 2003 to 2012 were plotted to assess whether there had been any substantial changes that may be associated with the pipi population decline (Figure 6-2).

There were no obvious trends in the concentration of the six metals (arsenic, chromium, copper, lead, mercury, and zinc) tested for in pipi (Figure 6-2). Levels of arsenic, copper and mercury remained similar throughout, levels of chromium were slightly more variable, and levels of lead and zinc were slightly higher in 2012 than previously recorded. These levels were relatively low compared with those measured in shellfish at other sites in Whangarei Harbour recorded in the 'refinery shellfish' dataset.

Concentrations of the 21 hydrocarbon contaminants that were tested for in pipi showed no obvious trends (Figure 6-2). The plots suggest apparent increases in some of these hydrocarbons at Mair Bank site 100190 between 2008 and 2012, but this appears to be an artefact of the minimum detection level recorded by the test laboratory increasing over time. For example, the concentration (mg.kg^{-1}) of naphthalene in pipi at Mair Bank site 100190 was recorded in the dataset as '<0.001' in 2008, '<0.005' in 2009, and '<0.019' in 2012.

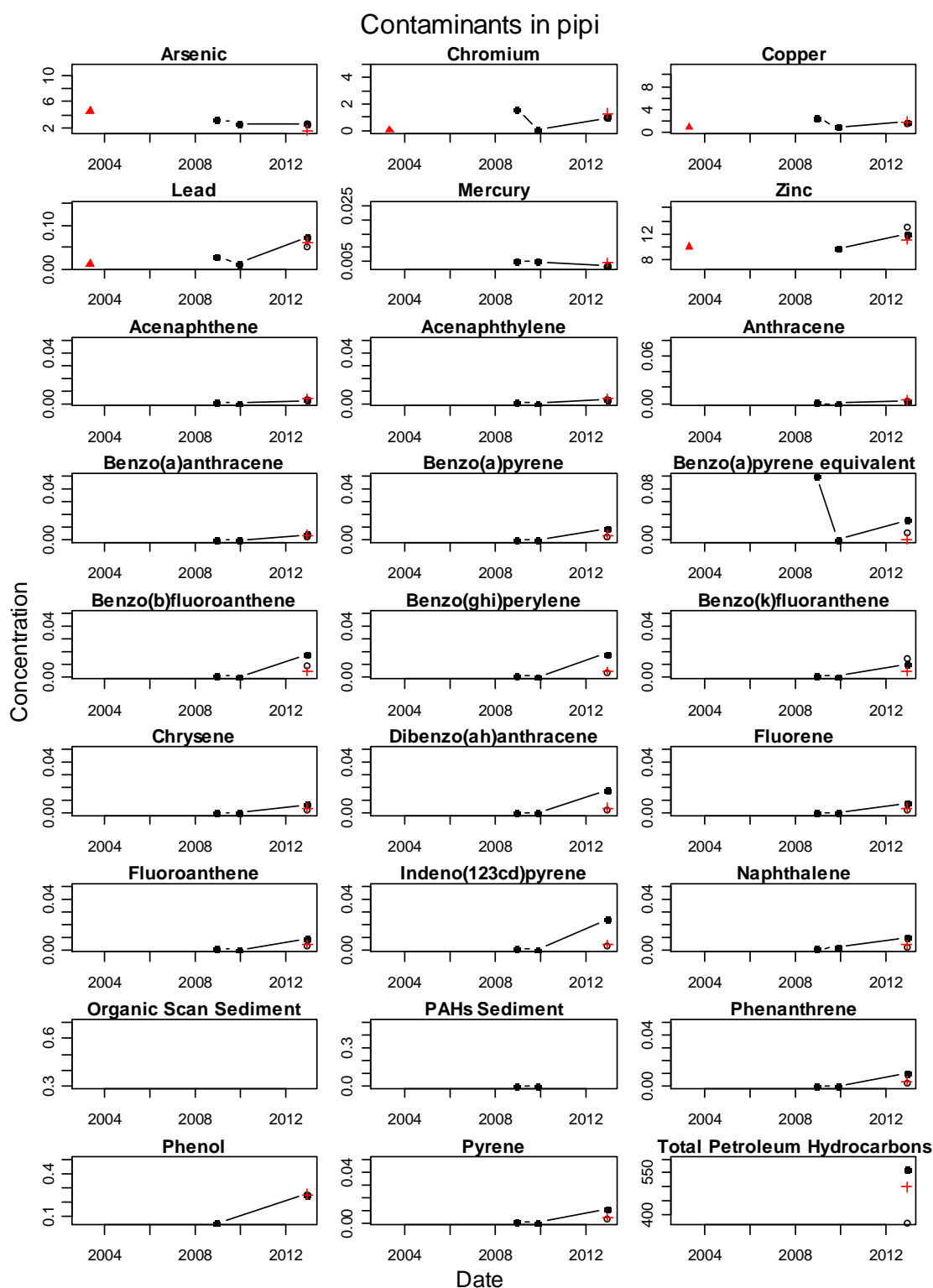


Figure 6-2: Concentration of contaminants in pipi at Mair Bank, 2003–12. Concentration units are mg.kg^{-1} . Mair Bank site 100190 (filled circles joined by lines) and the following sites of interest are shown: 103247 Mair Seaward (open circles), 100191 Marsden-Mair (filled triangles), and 110624 Marsden Bank (crosses). No data for 'Organic Scan Sediment' (which refers to the 'Acid herbicides, GC-MS' test). Note that there is some doubt about the reliability of the phenol data (R. Eyre, NRC, pers. comm.).

The concentration of contaminants measured in pipi at sites in the vicinity of Mair Bank were compared with guideline values from the following food safety guidelines documentation provided by NRC:

- **Standard 1.4.1: Contaminants and Natural Toxicants.** This Standard sets out the maximum levels (MLs) of specified metal and non-metal contaminants and natural toxicants in nominated foods (this Standard was made by the Australia New Zealand Food Authority on 20 December 2000).
- **NZFSA: Animal Products (Contaminant Specifications) Notice 2008.** This notice is administered by the New Zealand Food Safety Authority (NZFSA), and was issued under section 167(1)(h) of the Animal Products Act 1999 (date of notification in Gazette: 26 June 2008).
- **GELs: Generally Expected Levels (GELs) for Metal Contaminants.** These are additional guidelines to the maximum levels (MLs) in Standard 1.4.1 – Contaminants and Natural Toxicants. July 2001.

These guidelines provide values for most of the trace metals measured in pipi but not for the hydrocarbon contaminants measured.

Specifically, at site 100190 Mair Bank, the mean concentration (mg.kg^{-1}) of each metal measured in pipi during 2008–2012 was as follows: arsenic (2.96), chromium (0.88), copper (1.83), lead (0.04), mercury (<0.01) and zinc (10.80). These measured concentrations were lower than the recommended food safety guidelines (Table 6-2). Note that although the (total) arsenic measured was three-fold higher than the arsenic guideline, the guideline refers to inorganic arsenic which is about 10% or less of total arsenic (Phillips & Depledge 1986). Also note that Zinc was lower than the GEL guideline for oysters, and higher than the median GEL but lower than the 90th percentile GEL guideline for fish.

Table 6-2: Guideline concentrations of trace metals in nominated foods. Data sourced from Standard 1.4.1 values are maximum levels of contaminants in nominated foods, NZFSA are X levels, and GELs values are the median and 90th percentile of the proposed GEL. Chromium did not feature in these guidelines.

Contaminant	Food	Concentration (mg.kg^{-1})	Guideline
Arsenic (inorganic)	Shellfish; Molluscs	1	NZFSA; Standard 1.4.1
Cadmium	Molluscs	2	Standard 1.4.1
Chromium	NA	NA	NA
Copper	Molluscs	5	GELs, median value
Lead	Shellfish; Molluscs	2	NZFSA; Standard 1.4.1
Mercury	Shellfish; Molluscs	0.5	NZFSA; Standard 1.4.1
Zinc	Fish	5–15	GELs
Zinc	Oysters	130–290	GELs

6.2 'Refinery sediment' data

A similar procedure was used to inspect the 'refinery sediment' dataset, selecting only data for sites in the vicinity of Mair Bank (100190, 103247, 110624, and 100268; see Figure 6-1), and plotting the concentration of contaminants in the sediments from 2002 to 2012 (Figure 6-3). The concentration of contaminants measured in sediments were then compared with guideline levels in the following documentation provided by NRC:

- Australian and New Zealand Guidelines for fresh and marine water quality documented by ANZECC (2000).

The concentrations of the seven metals (arsenic, cadmium, chromium, copper, lead, mercury, and zinc) measured in sediments in the vicinity of Mair Bank were all consistently low and showed no trends during the period of interest (Figure 6-2). As with the contaminant levels tested for in pipi, these levels tested for in the sediments were all low compared with those measured in sediments at other sites in Whangarei Harbour recorded in the 'refinery sediment' dataset.

The maximum concentrations of all of the metals measured in the sediments were all considerably lower than the recommended sediment quality guideline levels (Table 6-3). Specifically, at site 100190 Mair Bank (sampled once only in 2012), the concentrations (mg.kg^{-1}) of metals measured in the $<500\ \mu\text{m}$ fraction of the sediment were as follows: arsenic (1.5), cadmium (<0.01), chromium (2.9), copper (0.13), lead (0.46), mercury (<0.005) and zinc (3.8); these measured concentrations were all substantially lower than the guidelines.

Concentrations of the hydrocarbons measured in the sediments were generally lower than the detection limits of the test equipment; although the plots show some apparently higher levels of some hydrocarbons in 2005 and 2007 (Figure 6-2), this is an artefact of the detection limits of the test equipment changing over time. For example, the detection limits for benzo(a)pyrene were <0.008 and <0.009 in 2002, changed to a higher level of <0.03 in 2005 and 2007, and changed to a much lower level of <0.001 in 2012.

Comparison of the hydrocarbons measured in sediments compared with the recommended sediment quality guidelines was difficult because the measured concentrations were lower than the detection limits of the test equipment.

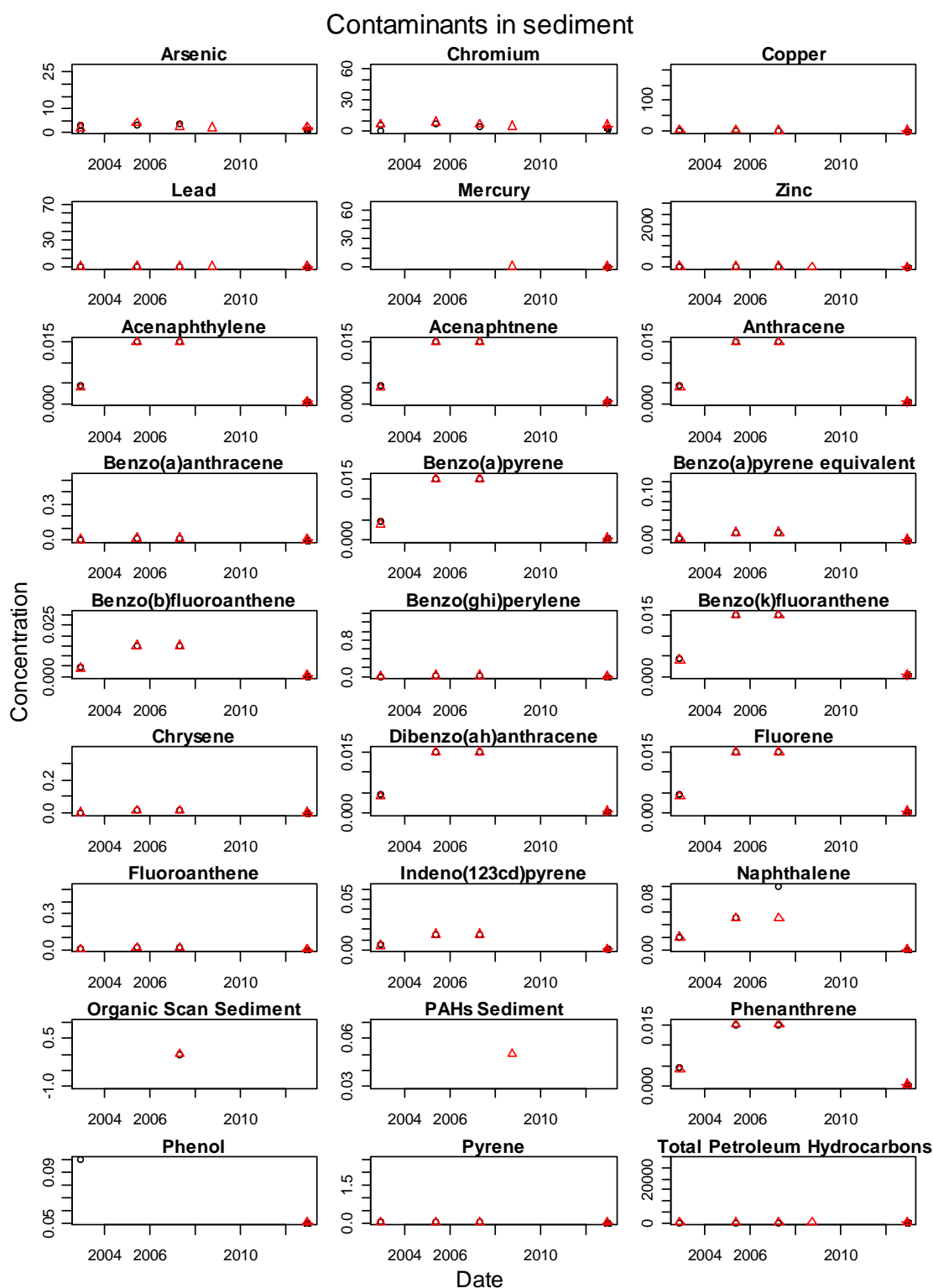


Figure 6-3: Concentration of contaminants in sediments at Mair Bank, 2003–12. Concentration units are mg.kg^{-1} . Mair Bank site 100190 (filled circles) and the following sites of interest are shown: 103247 Mair Seaward (open circles), 110624 Marsden Bank (crosses), and 100268 Marsden South (open triangles). No data for site 100191 Marsden-Mair. No data for PAHs Sediment. Data for cadmium not plotted (4 records, all less than the highest detection limit of 0.091 mg.kg^{-1}).

Table 6-3: Recommended sediment quality guidelines. Source: ANZECC (2000).

Table 3.5.1 Recommended sediment quality guidelines^a

Contaminant	ISQG-Low (Trigger value)	ISQG-High
METALS (mg/kg dry wt)		
Antimony	2	25
Cadmium	1.5	10
Chromium	80	370
Copper	65	270
Lead	50	220
Mercury	0.15	1
Nickel	21	52
Silver	1	3.7
Zinc	200	410
METALLOIDS (mg/kg dry wt)		
Arsenic	20	70
ORGANOMETALLICS		
Tributyltin ($\mu\text{g Sn/kg dry wt.}$)	5	70
ORGANICS ($\mu\text{g/kg dry wt}$)^b		
Acenaphthene	16	500
Acenaphthalene	44	640
Anthracene	85	1100
Fluorene	19	540
Naphthalene	160	2100
Phenanthrene	240	1500
Low Molecular Weight PAHs ^c	552	3160
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Dibenzo(a,h)anthracene	63	260
Chrysene	384	2800
Fluoranthene	600	5100
Pyrene	665	2600
High Molecular Weight PAHs ^c	1700	9600
Total PAHs	4000	45000
Total DDT	1.6	46
p,p'-DDE	2.2	27
o,p'- + p,p'-DDD	2	20
Chlordane	0.5	6
Dieldrin	0.02	8
Endrin	0.02	8
Lindane	0.32	1
Total PCBs	23	–

^a Primarily adapted from Long et al. (1995);

^b Normalised to 1% organic carbon;

^c Low molecular weight PAHs are the sum of concentrations of acenaphthene, acenaphthalene, anthracene, fluorene, 2-methylnaphthalene, naphthalene and phenanthrene; high molecular weight PAHs are the sum of concentrations of benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene.

7 Disease

Disease is a potential cause of shellfish mortality, and shellfish are sometimes collected during observed mortality events and examined in the laboratory for signs of disease. This section summarises investigations into mortality events that have occurred in Mair Bank pipi and in other shellfish species at other locations in Northland in recent years.

7.1 Mair Bank pipi

Following an anecdotal observation in 2013 of a ‘sudden die-off’ of pipi at Mair Bank, additional to the longer term decline the population had been experiencing, a sample of pipi was collected from Mair Bank in April 2013 and submitted to MPI’s Animal Health Laboratory for examination. Histopathology (microscopic examination of tissue for signs of disease) and molecular testing (polymerase chain reaction, PCR) did not reveal any significant pathogens, and no diagnosis could be reached. If there had been some sort of historical disease event in the population, there was no evidence of it in the pipi tested (Bingham 2013). Specifically, the laboratory reported that the pipi tested were in spawning or spent reproductive condition, and showed a haemocyte response consistent with the pipi spawning. In several of the pipi there were some parasites (possibly digeneans), in two pipi there were rickettsia-like bodies, one pipi was noted as possibly infected with bacteria and one may have had *Perkinsus* sp. present, but otherwise there were no significant pathogens. A subset of the pipi were tested for *Perkinsus* by PCR, and returned negative results. Overall the pipi tested appeared quite healthy.

7.2 Other shellfish mortalities

Cockles at Whangarei Harbour

In 2013, at the same time as the ‘sudden die-off of pipi was noted at Mair Bank, NRC also received reports of a mortality occurring in cockles (*Austrovenus stutchburyi*) in Whangarei Harbour. Samples were collected from McLeod Beach and Snake Bank in May 2013 and submitted to MPI’s Animal Health Laboratory for examination. Bingham (2013) reported: ‘As with the pipi, histopathology found that all specimens were spawning or had recently spawned, but did not reveal any significant pathogens. A subset of samples tested negative by PCR for *Perkinsus*. A marked haemocyte reaction was noted in both the pipi and the cockle samples. While this is associated with recently spawned shellfish, it may also mask a bacterial infection. It was recommended that, should further mortalities occur, swabs should be taken in the field for bacteriological investigation. Spawning itself is a stressful period for shellfish and in theory acute mortality could occur after a spawning event, but this does not explain the reported overall decline in the pipi population over the past four years.’

Cockles at Whangateau Harbour

An investigation into a large mortality of cockles at Whangateau Harbour in 2009 was summarised by Bingham (2009) although a detailed study (Tricklebank et al., in prep) of the mortality event and its impact on the cockle population in the harbour is planned for publication (K. Tricklebank, Leigh, pers. comm.). Sample testing by MPI concluded that endemic bacteria/parasites appeared to be the cause of the mortality, probably combined with environmental conditions (prolonged hot, dry weather and the coincident extraordinarily low tides). Given the timing of when the samples were taken (April 2009), however, it is

suspected that the bacteria/parasites may have been a secondary cause of mortality (K. Tricklebank, Leigh, pers. comm.). A more recent mortality of cockles in Whangateau Harbour was observed in March 2014, and appears to have occurred at other harbours in the area as well (Sandspit, Orewa). Samples of cockles have been collected and sent for disease testing.

Pacific oysters

There was an exceptional mortality event that occurred in farmed pacific oysters (*Crassostrea gigas*) in northeastern New Zealand between March and May in 2010 (T. Hollings, Secretary, NZ Oyster Industry Association Inc., pers. comm.). The mortality predominantly affected small (juvenile) oysters (in many cases at 75% or more of stocks), but mortality of medium and large oysters also occurred. First incidence was noted in Coromandel Harbour around mid-March, was noted later in Hauraki Gulf and then in other areas. Mortality was more evident, in more areas than Coromandel Harbour, from around late March and during April. In some cases the die-off occurred suddenly (e.g., during one tide) but in others it was more gradual. It occurred during an 'Indian summer' (hot, dry weather in autumn), but at the time of the event the cause of the mortality was unknown. The March to May 2010 pacific oyster mortality is now considered to be due to the oyster herpes microvariant strain of virus that was diagnosed in November 2010 and has caused recurrent high mortality of pacific oysters since then. Mortality has not been observed in other species such as green-lipped mussels (*Perna canaliculus*) and native oysters (*Saccostrea glomerata*) in affected-farms and adjacent areas.

Toheroa

Williams et al. (2013) provided a detailed review of factors affecting the abundance of toheroa (*Paphies ventricosa*), focusing specifically on sources of mortality and factors affecting recruitment. The main factors identified that potentially affect toheroa abundance were food availability, climate and weather, sand smothering/sediment instability, toxic algal blooms, predation, harvesting, vehicle impacts, and land use change. Mass mortalities of toheroa have been linked to adverse weather conditions, such as prolonged or extreme hot or cold conditions, and an association was found between mass mortality events and easterly zonal flow, which corroborates anecdotal observations that these events often coincide with easterly winds. No specific diseases or parasites are known to affect toheroa, but this could be because of a lack of knowledge, rather than a lack of diseases. Small DNA-negative virus-like particles were found to be associated with moribund toheroa but it is not known whether they were the cause of mortality. Land use has the potential to change the quantity and quality of surface water reaching toheroa beach habitats, and the influence of exotic forestry on water quality is of particular interest in investigating the mortality of toheroa. Phytochemicals such as terpenes are naturally produced by the exotic pine *Pinus radiata*, and when released into the environment can potentially influence water and sediment chemistry and organism biology. However, the potential toxicity of terpenes on toheroa (or closely related species such as pipi) is unknown.

8 General discussion

Surveys and observations at Mair and Marsden Banks at the entrance to Whangarei Harbour show that there has been a large decline in the pipi population. The decline was first noted anecdotally around 2009–10 at Marsden Bank, and was confirmed at Mair Bank by the 2010 survey findings, and the Mair Bank population reached its lowest recorded level in 2014. The distribution of pipi at Mair Bank has retracted during the period 2005 to 2014. It appears the large subtidal bed of pipi has disappeared, and the few pipi found in 2014 were restricted to limited patches within the intertidal portion of the bank.

8.1 Potential causes identified by the data examined

It is difficult to confirm the cause(s) of the pipi decline, because of the multiple factors that can affect pipi population dynamics, and the limited data available on these factors. From the data examined in this investigation, however, potential causes of the pipi decline are natural mortality of an ageing pipi population and low recruitment to the adult population, both of which may be related to observed changes in the morphology of Mair Bank.

In 2005, when there was a large biomass of pipi at Mair Bank, the population was dominated by medium sized adult pipi, possibly the result of a large successful cohort originating from about 2002. Assuming average growth between 2005 and 2010, we would expect the modal length to increase from 52 mm in 2005 to 65 mm in 2010, which is consistent with the survey data. While the longevity of pipi is unknown, it has been suggested to be about 10 years or more. It is possible that pipi in this putative ageing cohort were about eight years of age in 2010 and thus approaching the end of their natural lifespan. Natural mortality of these pipi would be expected between 2010 and 2014, when the major decline occurred.

Recruitment of juvenile pipi to the adult population at Mair Bank appears to have been low in recent years. In 2005 there were proportionally few juveniles. In 2010 there was a clear mode of juvenile pipi (mode = 30 mm), but this has apparently failed to survive and grow to recruit into the adult population by 2014. The 2014 survey and recent surveys at Marsden Bank showed that juvenile pipi were present but only in low numbers. Recruitment could be low because of low reproductive success and/or low habitat suitability (e.g., high intra-specific competition for space and food, unstable substrate due to erosion).

Changes in the physical surface habitat of Mair Bank could be related to the decline of pipi. While there has been little change in the overall form of Mair Bank as a whole, there have been substantial changes in the morphology of the bank locally at annual time scales during the last 13 years. The most notable change is the retreat to the north of the southern flank of the central part of the bank. The changing patterns of scour and accretion are associated with changes in bed level of the order of +1 m to -1 m (and +2 m to -2 m locally). Possible implications of the observed changes in bank morphology for pipi were considered. In areas where there is scour and accretion taking place, changes in the tidal velocity regime are expected which may affect pipi distribution, and the sediment is very mobile and unconsolidated potentially making it less suitable substrate for pipi to inhabit in the long term. Changes in mean depth are also expected in these areas, and if pipi distribution is affected with respect to the tide level, then this cut and fill may affect their distribution on the bank. Over time, the central shallow intertidal area of Mair Bank may have become smaller in area overall meaning there is less available habitat for pipi than before. A decline in bank area could explain the shrinkage of the total population estimate, but not necessarily the density.

8.2 Other potential effects examined

There was no evidence of disease in the Mair Bank pipi tested, although the tests were undertaken on pipi collected in 2013, which is quite some time after the initial decline had been noted around 2010. Some parasites were present in the pipi but these are often observed in shellfish. A marked haemocyte reaction was noted which is associated with spawned shellfish, and may also mask a bacterial infection, but this was not tested for.

From the brief examination of the data provided by NRC, there was no evidence that anthropogenic sources of mortality have potentially caused the pipi decline.

There were no obvious signs in the sediment characteristics of Mair Bank at the time of the 2014 survey to suggest degradation of sediment suitability for pipi. The sediment was mainly sand/gravel with very low levels of mud, and contaminant values are typically low in such sandy sediments. It is unknown whether the 2014 characteristics are typical for Mair Bank or whether they may have changed over time. Local observations of the bank by fishers would be informative to help describe any changes in the sediment characteristics in relation to the pipi decline.

Levels of trace metal and hydrocarbon contaminants measured in pipi and sediments at sites in the vicinity of Mair Bank were low, and where comparison with safe guideline levels was possible, the measured contaminants were lower than the guidelines. Most of the hydrocarbon levels measured were less than the detection limits of the test equipment. However, the available 'refinery consent' data for these sites around Mair Bank were limited. Mortimer (2010) reviewed the data between 2005 and 2009 to determine trends over time and likely sources of any metal contamination. Throughout this period the sampling was conducted haphazardly and is not very conducive to trends analysis. In 2012, NRC conducted a review to rationalise the sampling and create a monitoring program that should improve the utility of the data in future work.

Although not specifically investigated in detail, a brief examination of pipi commercial catches at Mair Bank in relation to estimates of biomass in 2005 and 2010 suggests that the decline is not related to overfishing. Commercial harvesting of pipi at Mair Bank was conducted at a relatively low and fairly consistent level over time, until 2010 when landings started to decrease (Table C-1). For the fishing years (1 April to 31 March) 2005–06 to 2009–10, the mean landed catch was 136 tonnes, but the catch in 2010–11 was only 87 t and in 2011–12 was only 55 t. The biomass of recruited (harvestable size) pipi 60 mm or larger) in 2005 was 3017 t (CV = 0.25) and in 2010 was 3145 t (CV = 0.17). The commercial catch landed was 137 t in 2005–06 and 87 t in 2010–11, equating to an annual exploitation rate (catch divided by biomass) of 0.05 (5%) and 0.03 (3%) in those years, respectively. These low rates of exploitation are considered sustainable for productive shellfish species such as pipi.

8.3 Effects not examined

Data from State of the Environment water quality monitoring from 2008 to 2014 were also provided by NRC, and may be useful to check that the water quality at Mair Bank has remained suitable for pipi (i.e. low levels suspended sediment, high salinity), but these data could not be reviewed within the limited time of this project. Of course, a limited number of variables are measured during water quality monitoring, and substances that may be harmful to pipi may not have been measured. One possibility not examined is the potential for

phytochemicals such as terpenes released by exotic pine into surface water discharge from log storage areas; it is unknown whether this occurs or whether it would be harmful to pipi.

Outbreaks of predators (e.g., carnivorous whelks, starfish) could drive population declines in pipi, but there were no reports of large numbers of predators associated with the decline, other than anecdotal evidence that a number of years ago there was an abundance of octopus on Mair Bank, but further details about this were not available at the time of writing (R. Eyre, NRC, pers. comm).

Toxins accumulated through filter feeding is another possible cause of mortality not examined. Algal blooms have been observed in the Bream Bay region, but data on these phenomena are usually rare, and no such data were not available for this review.

Occasional mass mortalities are observed in various species of bivalve shellfish (e.g., scallops, toheroa), but reasons for the mortalities are usually unclear. Storms can cause mass mortalities. By comparing the density plots of pipi from a council survey carried out in 1985 with the 1989 survey, Haddon (1989) concluded that the number of pipi had reduced significantly between 1985 and 1989. That decline could have been associated with the impact of storms, such as cyclone Bola in March 1988 which altered the shape and elevation of the bank. The recent pipi decline has occurred over at least four years from about 2010 to 2014, and does not appear to be related to specific storms.

Mass-mortalities may also be density-dependent, where the resource requirements of the high-density population increase over time as the individuals grow and their energy demands increase, eventually exceeding the carrying capacity of the environment. Although pipi are suspension feeders that feed primarily on non-locally replenished supplies, food supply at times may still be limited, and could potentially be a problem in high-density pipi beds.

Low densities of pipi could restrict fertilisation success and larval production from the local population, but recruitment of pipi to Mair Bank may also come from non-local populations.

8.4 Further investigation

Detailed analysis of the available survey data was not conducted here due to limited time. It would be useful to look at changes in actual densities at length (scaled to the estimated population size), rather than the proportional length frequency plots presented in this report. This might give a better indication of the scale of the decline, and which size groups have been most affected.

In future, more regular (e.g., annual) surveys would provide more data to monitor the population and improve our understanding of pipi population dynamics. Additional collection of benthic community data could enable the investigation of trends in the abundance of other species (i.e. other bivalves, gastropods, crustaceans) to determine whether the mortality-inducing factor is specific only to pipi.

It is possible that substances not measured in shellfish, sediment, or water quality monitoring work may have influenced the pipi decline. Consideration of what these substances could be, their levels in the environment, and their potential effects on bivalve biology could be worthwhile. Cumulative effects of contaminants on shellfish are also worth considering.

Discussing the findings of this investigation with the multiple stakeholders concerned about the Mair Bank pipi decline could help to identify other relevant data and information for investigation, such as important anecdotal information gained through long-term observation of the pipi population and the nature of Mair Bank.

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Appendix A Changes in Mair Bank bathymetry, 2000–13

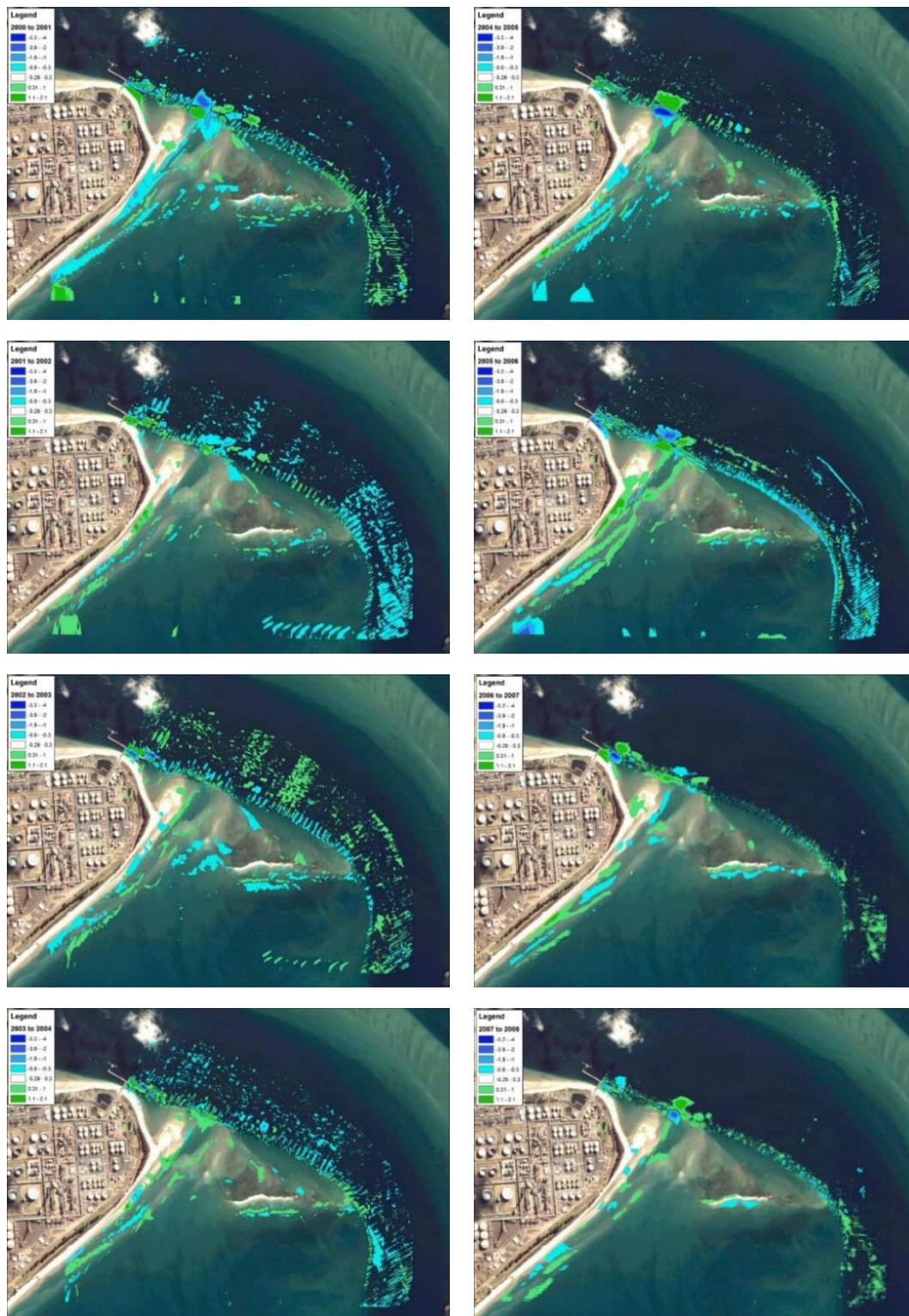


Figure A-1: Differences in Mair Bank bathymetry between successive years between 2000 and 2013. Years read top to bottom starting with 2000–01 (left column) and 2004–05 (right column), figure continued on next page. Green colour = increase in elevation, blue colour = decrease in elevation. Only changes of greater than +/- 0.3 m are shown to reduce noise in the data.

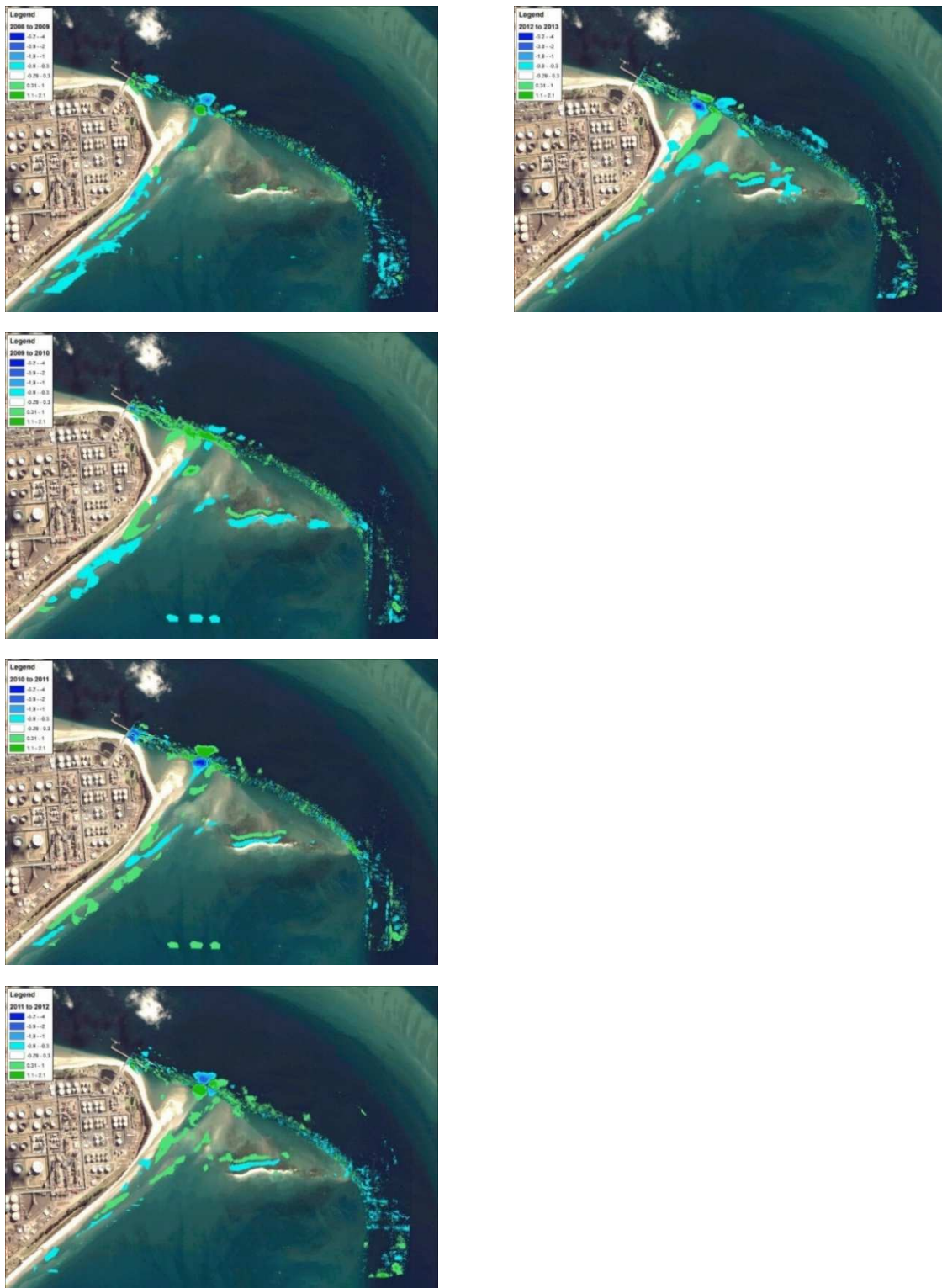


Figure A-1 continued from previous page. Years read top to bottom starting with 2008–09 (left column) and 2012–13 (right column).

Appendix B Mair Bank morphology in 2006 and 2014



Figure B-1: Images of Mair Bank morphology before and after the pipi decline. Top image taken on 17 May 2006, bottom image taken on 27 March 2014. Source: Google Earth.

Appendix C Commercial pipi landings

Table C-1: Reported commercial landings of pipi (t greenweight) since 1986–87. Source: Ministry for Primary Industries (2013). Data from Licensed Fish Receiver Returns. Prior to 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.

Fishing year	Landings (t)	Limit (t)	Fishing year	Landings (t)	Limit (t)
1986–87	131	657	1999–00	143	657
1987–88	133	657	2000–01	184	657
1988–89	134	657	2001–02	191	657
1989–90	222	657	2002–03	191	657
1990–91	285	657	2003–04	266	657
1991–92	326	657	2004–05	206	200
1992–93	184	657	2005–06	137	200
1993–94	258	657	2006–07	135	200
1994–95	172	657	2007–08	142	200
1995–96	135	657	2008–09	131	200
1996–97	146	657	2009–10	136	200
1997–98	122	657	2010–11	87	200
1998–99	130	657	2011–12	55	200