# Kaimoana on beaches from Hōkio to Ōtaki, Horowhenua

Manaaki Taha Moana

MTM Report No. 22
June 2014

# KAIMOANA ON BEACHES FROM HŌKIO TO ŌTAKI, HOROWHENUA

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ISSN 2230-3332 (Print)
ISSN 2230-3340 (Online)
ISBN 978-0-9876638-1-8

Published by the Manaaki Taha Moana Research Team
Funded by the Ministry for Science and Innovation
MAUX 0907 Contract Holder: Massey University
www.mtm.ac.nz

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ISSUE DATE: 18 August 2014

RECOMMENDED CITATION: Newcombe E, Poutama M, Allen C, Smith H, Clark D, Atalah J, Spinks A, Ellis J, Sinner J 2014. Kaimoana on beaches from Hōkio to Ōtaki, Horowhenua. Manaaki Taha Moana Research Report No. 22. Cawthron Report No. 2564. 40 p. plus appendices.

# MIHIMIHI[1]

Tuia i runga, tuia i raro, tuia i waho, tuia i roto, tuia te here tangata, ka rongo te pō, ka rongo te ao.

Ka tuku te ia o whakaaro kia rere makuru roimata atu ki te kāhui ngū kua hoki atu ki te waro huanga roa o te wairua, rātou kei tua o te ārai, takoto, okioki, e moe.

Tātou ngā waihotanga o te reka ki a tātou, ā, e mihi kau atu ana mātou ki a kōutou i kotahi ai te whakaaro i raro i te korowai whakamarumaru o tēnei taonga, Manaaki Taha Moana (MTM).

Tihei Mauri Ora, ki a tātou katoa.

Ki ngā taniwhā hikurauroa i putaputa mai ai i ngā rua kōniwhaniwha, ngā whare maire, ngā whare wānanga me ngā whare whakahuruhuru manu ā pūtea nei o te motu, tēnā koutou.

Ki ngā manu tioriori e karangaranga ana te taha wairua ki te taha tangata i runga i ngā marae mahamaha o Rongomaraeroa, whātoro atu ana ki ngā unaunahi nunui e pīataata mai rā i te nuku o te ika, te mata o te whē,

Tēnā hoki koutou, oti rā, tēnā tātou katoa.

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[1] Composed by Tipene Hoskins

Published by the Manaaki Taha Moana Research Team
MAUX 0907 Contract Holder:
Massey University
Palmerston North
New Zealand

# EXECUTIVE SUMMARY

Ānō he karoro e topa ana i runga i ngā kaimoana
*Like a black-backed gull soaring above seafood*

Tangata whenua are concerned about the decline of toheroa (*Paphies ventricosa*) and other kaimoana species along the Horowhenua coastline. Toheroa are still found on beaches in the study area, but populations are reduced to the point that it is no longer possible to effectively study them. Currently tuatua / pipi are the only common intertidal shellfish. Most tuatua / pipi are the species *Paphies subtriangulata*, but *P. donacina* is also present. Tuatua / pipi[2] were historically an important food source for hapū and iwi in the Horowhenua and have become increasingly popular with non-Māori. While tuatua / pipi are still harvested by tangata whenua, they are found at much lower densities than in the past.

Local hapū have aspirations to rebuild toheroa populations, possibly by reseeding. Accordingly this study assessed the status of current shellfish populations and key environmental factors likely to influence their survival and abundance. Survey design was a collaboration between scientists and local Māori researchers to ensure relevance to both groups, and data collection involved 44 hapū volunteers. We surveyed 13 sites for shellfish populations and environmental variables including land use, grain size, organic matter, and salinity.

Changes to freshwater input to beaches, brought about by changes in land cover, are among numerous factors that possibly affect toheroa populations in New Zealand. We characterised the current land use and the change in key landscape features (primarily wetlands) from historical information and looked for relationships between land cover and current shellfish populations. Since the 1940s, dunes have been stabilised by planting pine forest, marram grass and lupin; although the total present day coverage of pine forest within the broader coastal margin is relatively low (13%). Wetland extent in the 1940s appears to be similar to that of the present day (2%), which is much reduced from the pre-European cover (28%). Pasture dominates present day land cover.

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[2] The shellfish referred to collectively as tuatua / pipi are two very similar species: *Paphies subtriangulata* and *P. donacina*. Throughout New Zealand these species are most commonly referred to as tuatua, though *P. donacina* is sometimes called southern tuatua. Apparently no distinction is generally made between the two species by shellfish harvesters. In the study area there were a range of views on the naming of *P. subtriangulata* and *P. donacina.* Some people used the term ‘pipi’, others used ‘tuatua’, and some felt that the smaller shellfish of these species are termed ‘pipi’ while the larger ones are ‘tuatua’. Because of the differing usage locally and throughout New Zealand, choosing a single name would cause confusion. Referring to both scientific names is unwieldy; therefore in this document we refer to *Paphies subtriangulata* and *P. donacina* as ‘tuatua / pipi’.
Similarly, some kaumatua and resource gatherers speak of ‘tohemanga’ and ‘toheroa’ interchangeably. Some see them as two distinct species, namely toheroa (*Paphies ventricosa*) and tohemanga (*Oxyperas elongata*), while others speak of tohemanga as being a local dialectical name for toheroa.
The estuarine species *P. australis* is commonly referred to as pipi in many parts of New Zealand. In the Kuku area the estuarine species (probably *P. australis*) is referred to as ‘kokata’ (pers comm. H. Smith)

The number of toheroa encountered in the survey was too low to assess the impact of local land cover or other aspects of the beach environment on toheroa populations. The distribution of tuatua / pipi varied along the beach, and a weak pattern was observed where tuatua / pipi were more abundant with greater distance from access points. This shows that human impacts are capable of depressing these species. Harvesting is a likely cause of this relationship, and it is possible that crushing or other disturbance by vehicles also reduces the survival of shellfish, particularly of juveniles.

The beaches from Hōkio to Ōtaki displayed little variability in grain size, nitrogen and organic content, but there was some variability in the salinity of the interstitial water in sands at the high- and mid-shore levels. Sites with greater freshwater influence had fewer tuatua / pipi than sites with higher salinity, this relationship was particularly apparent in the high shore.

Ghost shrimp (*Biffarius filholi*) modify habitat and possibly predate on tuatua / pipi. Attempts to quantify ghost shrimp numbers were unsuccessful. However, using burrow counts as an indicator of abundance, there was no evidence of a relationship between ghost shrimp and the sediment structure of the beach, or with tuatua / pipi populations.

An associated study assessing *Escherichia coli* (a bacteria that indicates faecal contamination) clearly indicated that shellfish are regularly contaminated with faecal material to the point that they are considered marginally suitable or unsuitable for human consumption. The land cover data showed a dominance of particular land covers, *e.g.* high intensity farming, which can contribute to this contamination.

This project brought together a range of people and types of information, all relevant to the future of toheroa and other shellfish on beaches from Hōkio to Ōtaki. Cooperation between hapū and scientists was a positive and productive experience and provided an excellent foundation for future collaboration.

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# 1. INTRODUCTION

This research was undertaken as part of the Manaaki Taha Moana (MTM) programme (see Box 1).

## 1.1. Cultural connections to shellfish populations

Tangata whenua are concerned about the decline of toheroa (*Paphies ventricosa*) and other kaimoana species along the Horowhenua coastline. A Ngāti Raukawa-based environmental consultancy[3] recently commented on the severe decline in shellfish populations in the region of interest, particularly “the total absence of Tohemanga … (in areas) … once revered as a place of abundance for the large delicacy. It is now devoid of Tohemanga which is an alarming finding” (Moore & Royal 2012). Tuatua / pipi[4] were historically an important food source for hapū and iwi in the Horowhenua and have become increasingly popular with non-Māori. While tuatua / pipi persist, they are found at much lower densities than in the past (Moore & Royal 2013).

Local hapū have aspirations to rebuild toheroa populations, possibly via reseeding, and our project aims to inform that process. Accordingly we undertook a study to assess the status of current shellfish populations and key environmental factors likely to influence the survival of toheroa.

## 1.2. Toheroa decline

Intense harvesting of toheroa populations occurred throughout New Zealand (Redfern 1974, Williams *et al.* 2013a). Anecdotal evidence suggests that gathering without customary permit occurs today, but other factors potentially contribute to the decline of this taonga[5] species. Factors identified as possibly contributing to the decline of toheroa include land cover change and associated changes to the freshwater flows coming onto the beaches, food availability, climate and weather, sand

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[3] The Taiao Raukawa Environmental Resource Unit led the survey presented in this report through the MTM research project, the Moore and Royal report was produced by Hapai Whenua Consultants Limited.

[4] The shellfish referred to collectively as tuatua / pipi are two very similar species, *Paphies subtriangulata* and *P. donacina*. Throughout New Zealand these species are most commonly referred to as ‘tuatua’, and *P. donacina* can also be called Southern tuatua. Apparently no distinction is generally made between the two species by shellfish harvesters. In the study area there were a range of views on the naming of *P. subtriangulata* and *P. donacina.* Some people used the term ‘pipi’, others used ‘tuatua’, and some felt that the smaller shellfish of these species are termed ‘pipi’ while the larger ones are ‘tuatua’. Because of the different usage locally and throughout New Zealand, choosing a single name would cause confusion. Referring to both scientific names is unwieldy; therefore it seems to be the best approach in this document to refer to *Paphies subtriangulata* and *P. donacina* as ‘tuatua/pipi’.
Similarly, some kaumatua and resource gatherers speak of ‘tohemanga’ and ‘toheroa’ interchangeably. Others see them as two distinct species; namely toheroa (*Paphies ventricosa*) and tohemanga (*Oxyperas elongata*), while others speak of tohemanga as being a local dialectical name for toheroa.
The estuarine species *P. australis* is commonly referred to as pipi in many parts of New Zealand. In the Kuku area the estuarine species (probably *P. australis*) is referred to as kokata (pers. comm. H. Smith).

[5] Treasure, anything prized — applied to anything considered to be of value.

smothering / sediment instability, damage caused by vehicle traffic, predation, harvesting, toxic algal blooms and disease (Heasman *et al.* 2012; Williams *et al.* 2013a). Moreover, ghost shrimp (*Biffarius filholi*) may be predating or otherwise displacing toheroa and other shellfish, or may be correlated with other changes that are causing shellfish decline (Heasman *et al.* 2012; Moore & Royal 2012).

**Box 1. Manaaki Taha Moana**

Manaaki Taha Moana (MTM) is a six-year programme, which runs from 1 October 2009 to 30 September 2015. Research is being conducted primarily in two areas:

1. Tauranga moana region
2. Horowhenua coastline between Hōkio Stream, south of Foxton Beach, and Waitohu Stream, just north of Ōtaki Beach.

This programme of research activities has built upon previous research with Ngāti Raukawa ki te Tonga in the lower North Island through the programme, Ecosystem Services Benefits in Terrestrial Ecosystems for Iwi and Hapū (MAUX0502).

Professor Murray Patterson (School of People, Environment and Planning, Massey University) is the Science Leader for the MTM programme.

A number of different organisations are contracted to deliver the research. Caine Taiapa of the Manaaki Te Awanui Trust is Research Leader Māori for the Tauranga Moana case study and Dr Huhana Smith is Research Leader Māori in the Horowhenua coastal case study through Te Reo a Taiao Raukawa, the Ngāti Raukawa Environmental Resource Unit (Taiao Raukawa). Freshwater and marine expertise comes from Cawthron Institute (Nelson), information technology expertise from WakaDigital Ltd (Tauranga), and project management and ecological economics expertise comes from the School of People, Environment and Planning, Massey University (Palmerston North).

Taiao Raukawa (on behalf of hapū of Ngāti Raukawa ki te Tonga and affiliates) is linked with other iwi and groups, particularly Muaūpoko hapū and whanau who have tangata whenua status in the northern Waiwiri to Hōkio case study area. The research team tries to engage extensively with all iwi and hapū, kaitiaki (environmental guardians) and other end-user groups, who have been set up in each case study region.

Manaaki Taha Moana is a collaborative, action and kaupapa Māori research project that uses and bolsters mātauranga Māori or Māori knowledge systems within whenua (lands), awa (waterways), repo (wetlands) and moana (sea and harbours).

The Horowhenua MTM research activity centres on an area of interrelated hapū (collective of multiple whanau groups), within a south-west coastal rohe (region). This areas once had extensive coastal forest, with streams, rivers, estuaries, a series of lakes, lagoons and dune wetlands that teemed with freshwater food and fibre resources and kaimoana (tidal and marine resources). The coastal, cultural landscape is bounded by the Tasman Sea and extends from the Hōkio Stream in the north to the dynamic Waitohu Stream, wetland and estuary at Ōtaki Beach in the south. The case study includes awa and awa iti (rivers and streams), repo (wetlands), roto (dune lakes) and moana (seas and estuaries) within the coastal region (Smith *et.al* 2014).

## 1.3. Land cover and freshwater

Toheroa appear to be associated with freshwater seepage and beds are often located close to freshwater streams, near seepage from brackish lagoons behind adjacent sand dunes or where the water table lies close to the surface (Williams *et al*. 2013a, Heasman *et al*. 2012).

Changes to local sub-surface hydrology brought about by changes in land cover are among numerous possible factors that may influence toheroa populations in New Zealand (Heasman *et al.* 2012; Williams *et al.* 2013b).

The flow of shallow groundwater into the beach may be important as it provides protection from desiccation, specific temperature and salinity conditions, and a supply of nutrients that promote the growth of phytoplankton, mainly diatoms, which are a significant food source for toheroa (Morton & Miller 1973; Heasman *et al.* 2012; Williams *et al.* 2013a). In addition, a lowering of the water table has the potential to affect erosion of beach sediments and alter temperature and salinity regimes that might affect shellfish recruitment or survival (Heasman *et al*. 2012).

A local reduction in shallow unconfined groundwater flows could therefore reduce both the availability of food and the extent of habitable space for toheroa; the latter making them more susceptible to desiccation. This was highlighted as a possible factor in the decline of major populations of toheroa in Northland, where back-dune land cover changed from large areas of open sand dune to plantation forest (*Pinus radiata*) (Williams *et al.* 2013a). As a consequence of the extensive pine afforestation, it is thought that soil moisture and groundwater levels were greatly reduced, resulting in less freshwater seepage on the adjacent beach.

Drainage of coastal wetlands may also be affecting flows and levels of shallow unconfined groundwater (and hence freshwater seepage along the inter-tidal beach). The conversion of wetlands to pastoral land cover has been happening in New Zealand for more than 100 years. It has been estimated that wetland loss since 1900 is in the vicinity of 90% nationally (Stevenson *et al.* 1983) and 97% for the Manawatu / Wairarapa region (Ausseil *et al.* 2008).

## 1.4. Shellfish populations

Past surveys on Horowhenua beaches have been insufficiently frequent to present a clear picture of the decline in shellfish numbers on Horowhenua beaches (see toheroa data summary, Appendix 1. Heasman *et al.* 2012a). Toheroa, and beach macrofauna with planktonic larvae generally, are subject to high levels of natural variation in their distribution over time (Defeo & McLachlan 2005; Williams *et al.* 2013b). In 1974, Redfearn stated that there had not been a successful spatfall of toheroa on Wellington west coast beaches (*i.e.* Horowhenua) since 1964. The general impression from locals is that there has been a steady decline since this time, but in recent years toheroa have become scarce enough to be completely absent on many occasions when they have been sought (as food or for research purposes). Some limited recruitment must still be taking place however, as reports of toheroa sightings or collection are not uncommon. Since this species is relatively short-lived (Redfearn 1974), the individuals observed recently have very likely settled within the last five years.

Due to the expected low toheroa numbers, we planned to record all kaimoana species encountered, and expected that the most common shellfish would be tuatua / pipi. Because of their differing biology and ecology, the distribution or survival of tuatua / pipi cannot be used to indicate habitat suitability or likely survival of toheroa. For example, unlike toheroa, tuatua are not commonly found in association with fresh water seepage. In addition, while toheroa is generally considered to be a predominantly intertidal species, tuatua / pipi (particularly the species *Paphies donacina*) can have substantial sub-tidal populations. Accordingly their populations are presumably more resilient to factors that impact on survival in the intertidal zone.

## 1.5. Ghost shrimp

A ‘mega-worm bed’, which is likely a ghost shrimp (*Biffarius filholi*) colony, has been described on these beaches (Moore & Royal 2012). Ghost shrimp modify the habitat by changing sediment quality through burrowing and irrigation activities. Ghost shrimp may exclude shellfish by modifying the habitat, or the decline in shellfish may have allowed ghost shrimp to colonise new areas. In addition, although there is very limited direct evidence, anecdotal reports suggest that ghost shrimp predate upon toheroa. Ghost shrimp density and distribution increased dramatically (Williamson 1967–1970 in O'Shea 1986) in the same period that a decline in toheroa density and distribution along Wellington west coast beaches was reported. Moreover, on Orepuki Beach in Southland, the highest levels of toheroa recruitment occurred where ghost shrimp were absent or present at a very low density (O'Shea 1986).

## 1.6. Faecal contamination

Kaitiaki, customary fisheries representatives and kaumātua have also expressed concern about the safety of eating shellfish harvested along the Horowhenua coastline because of poor water quality and faecal contamination. Evidence of this was presented in a recent report on water quality in Waiwiri Stream (Allen *et al.* 2012), so we also investigated faecal contamination in shellfish along the

Horowhenua coast. This is presented in a companion report to this one (Newcombe *et al.* 2014).

## 1.7. Objectives

This study aimed to:

- characterise (map and classify) the land use immediately behind the beach, along the coast from Hōkio to Ōtaki.
- describe current and historical land cover along the coastal margin and discuss how these may have affected groundwater hydrology.
- document the current state of toheroa and tuatua / pipi populations on the study beaches.
- examine relationships between landscape, beach characteristics, ghost shrimp, and tuatua / pipi populations.
- contribute to a baseline body of information from which to assess future change in coastal land cover, beach characteristics, and shellfish populations.
- constitute the first step towards an assessment of requirements and recommendations for reseeding of toheroa.

# 2. METHODS

The study area was the coastal zone between the Hōkio Stream and Ōtaki. Thirteen sites were identified (by M. Poutama and A. Spinks) to represent a range of land covers and landscape types, and to include mahinga matāitai[6] where kaitiaki gathered seafood for the marae. Coming from a whanau of kaimoana gatherers and as a lead ringawera[7] for the purposes of manaakitanga[8], Moira Poutama had particular insight into the use of different areas of the coast by those who gathered for the kitchen.

Figure 1. The study area, stars indicate sites at which the shellfish survey was undertaken, and red dots indicate vehicle access points.

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[6] Seafood-gathering place(s)
[7] Cook
[8] Caring for visitors at marae

## 2.1. Landscape

The assessment of land cover in this study had two main components. We first characterised current land cover within a broad coastal margin between Ōtaki River and Hōkio Stream. Current and historical wetland extent in this area was also mapped to explore changes in local sub-surface hydrology. Secondly, we mapped current and (estimated) historic land cover in six sub-catchments inside the broader coastal boundary.

### *2.1.1. The broader coastal margin*

An inland coastal boundary was defined to capture the extent of land covers which are most likely to influence shallow groundwater emerging on the beach. The area between this boundary and the sea, which we refer to as the broad coastal margin, encompasses the fore-dune and back-dune systems as well as the trough in between, which sometimes develops into inter-dunal wetlands (Figure 2).

Being gravity-fed, shallow groundwater generally flows in a seaward direction from local high points located in the back-dunes. Therefore the inland boundary for this investigation was drawn across the high points of the back-dune system that runs parallel to the coast approximately 1.5 to 5 km inland. Boundaries formed by small catchments (*i.e.* orders 1 or 2 from the River Environments Classification layer [REC]) found seaward of the back-dune system (≤ 20 m above sea level) were used to define the inland coastal boundary where possible. Medium to large catchments (*i.e*. order 3 or higher) were omitted from the study area in an attempt to capture local land cover more accurately. Hōkio Stream and Ōtaki River formed the northern and southern boundaries of the study area, respectively.

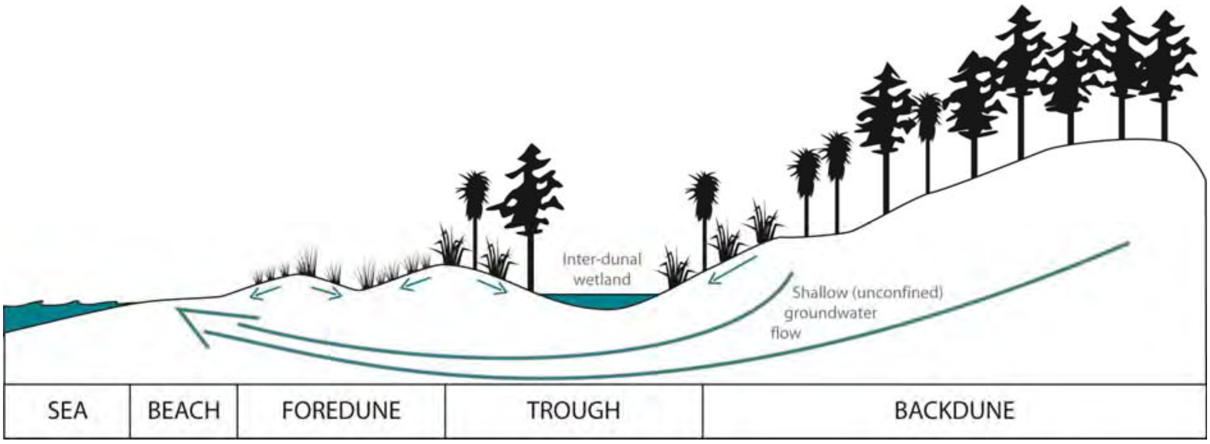

Figure 2. A typical hummocky dune landscape with seaward shallow groundwater flow and wetland areas between dune systems[9].

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[9] Original diagram reference unavailable.

Current land cover was mapped within the study area using the New Zealand Land Cover Database (LCDB) version 3.3, which provides an estimate of land cover derived from satellite imagery captured in 2008 and 2009. Land cover was quantified using four main categories: percentage cover of pasture (high and low producing exotic grassland), exotic forest, urban areas, and sand dunes / beach.
While land cover maps provide a useful qualitative comparison, assessing the specific impacts of certain land covers is considerably more difficult and is outside the scope of this investigation. For example, the extent of pastoral farming can be estimated by land cover, but the impact of pastoral farming on water quality will depend on the type of farming (*e.g.* dairy *vs* beef and sheep), intensity (*e.g.* stocking rate) and farming practices (*e.g.* riparian management).

The exchange of water between wetlands and groundwater depends largely on wetland type, though other factors such as season and vegetation cover are also important (Mitsch & Gosselink 2007). The majority of the existing and historical wetlands in the study area are swamps (Leathwick *et al.* 2010). While swamp hydrology (the relative exchange of water between overland flow, groundwater, and wetland water level) is difficult to define without long term monitoring, several studies have attempted to characterise the hydrology of similar wetlands in Kapiti / Horowhenua coastal dune-lands. These studies found that the wetlands are either entirely or partially dependant on input from shallow groundwater, and that water is lost from wetlands via evapotranspiration, outflow into drains / streams, and outflow into groundwater (Allen, 2010; Phreatos, 2006; Thompson, 2012). Therefore it follows that changes in local surface water hydrology (*i.e.* wetlands) will have an effect on sub-surface hydrology. The broad-scale drainage of inter-dunal wetlands along this coast is likely to cause a localised reduction in groundwater level of unknown extent.

To quantify this, the change in wetland extent since pre-European times was mapped using the Freshwater Environments of New Zealand (FENZ) geodatabase (Leathwick *et al.* 2010).

### *2.1.2. Sub-catchments*

The 13 sites studied in the shellfish survey are each associated with one of six sub-catchments (*i.e.* multiple survey sites occurred within most of the six sub-catchments). Land cover in each sub-catchment was assessed as described below.

For each sub-catchment, polygons were drawn to encompass first and second order REC catchments within the landward area defined above. Historical land cover was then estimated and mapped within each sub-catchment using geo-rectified aerial photos from 1942 / 1948[10]. These were selected because they were the oldest images available, taken at a time when large populations of toheroa are known to

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[10] Aerial photos from 1942 were available for areas north of Waitohu Stream (encompassing most of the study area), while the earliest photos from southern areas were taken in 1948.

have existed along the coast (Heasman *et al.* 2012). While the moderate quality of the photos made this task somewhat subjective, it was possible to distinguish areas of land covered by pasture, exotic forest, and sand dunes / beach.

## 2.2. Shellfish survey

Sampling for the shellfish survey was planned to coincide with moderately large tides during daylight hours, but a forecast storm meant that the survey was moved to 3–6 April 2014. Tides were moderate but decreasing in height over the survey period.

### *2.2.1. Survey designs*

Toheroa surveys are generally undertaken with a stratified random design (where sampling effort reflects the expected density of toheroa in different long-shore zones) where a series of quadrats (0.5 $m^2$ or 0.25 $m^2$) are taken at 5 m or 10 m intervals along transects run across the intertidal beach (*e.g.* Carbines & Breen 1999; Williams *et al.* 2013b). Tuatua surveys have been undertaken in a range of ways in different parts of New Zealand. Some have used specialised equipment, boats and scuba divers to survey the shallow subtidal (Brighton Beach, Cranfield & Michael, 2002), though most have relied on land-based survey methods. On Brighton Beach, Canterbury, tuatua were too scarce to be surveyed effectively in randomly placed quadrats, so sampling instead focussed on areas where hydroids (indicating the presence of tuatua) were visible on the beach (Marsden 2000). In Northland, however, intertidal tuatua densities were sufficiently high to be well-sampled with the same methodology as used for toheroa (Williams *et al.* 2013b).

To undertake a survey that was comparable to other scientific surveys, a general methodology based on other toheroa surveys was developed (Clark *et al.* 2013). Further discussion emphasised that an intertidal-only survey lacked relevance to iwi since it did not include the shallow subtidal areas where tuatua / pipi are normally collected. Adaptation to incorporate subtidal sampling in quadrats allowed for extension of data into the zone normally used when harvesting tuatua / pipi, and inclusion of a ‘freestyle’ unrestricted search (resulting in a ‘catch-per-unit effort’, or CPUE) measured the shellfish populations in a way that is relevant to the normal use of the resource.

### *2.2.2. Shellfish data*

At each site, three stakes were placed at least 20 m apart on the high tide mark (identified by minor debris line, not the high-shore storm-wash line) and transects were run directly down-shore. Initially it was intended that quadrats (1 m × 0.5 m) be placed every 10 m along transects, however on the first day (where team leaders were working together to sample the first site), it became apparent that on wide sections of the beach there would be insufficient time to process so many quadrats. Accordingly, on all three transects, quadrats were marked every 20 m at most sites, and every 10 m at a sub-set of sites. For each site, the distance to the nearest public access point was measured in Arc GIS. Public vehicle access points are marked in Figure 1.

On one transect at each site, each quadrat was photographed. On all transects the number of burrow holes in each quadrat were counted, then quadrats were excavated to 0.3 m, and the sand placed on a tarpaulin. The sand was searched and all shellfish were identified and measured to the nearest centimetre, except for those below 3 cm which were grouped as juveniles. Prior to undertaking the study, it was thought that shellfish smaller than 4 cm would not be well-surveyed by hand-sorting of sand dug from quadrats. It became apparent, however, that this method was effectively capturing even quite small (~ 2 cm) individuals, and the 3 cm and < 3 cm size classes were therefore recorded in quadrat data. It is likely, however, that smaller size classes were not well-surveyed in the ‘in-water’ quadrats. Water movement in the shallow surf was often quite strong, and it is likely that smaller individuals were washed away, particularly in areas where shellfish were dense.

Up to three in-water quadrats at the end of each transect were searched at low tide. A 1 × 0.5 m metal frame was haphazardly placed in the shallow water (less than knee deep) quadrats were searched by hand, and all shellfish encountered in the frame were collected. Shellfish were measured and recorded as for the ‘exposed-shore’ quadrats.

Also at low tide, one or more searchers undertook a freestyle search for five minutes. The search was undertaken in the general vicinity of the transects. Searchers could use whatever technique they chose to select areas to dig and worked by hand and unassisted (*e.g.* no assistance from a second person holding the bucket). All shellfish collected this way were measured as for the other collections. Searches that were more or less than 5 minutes duration were standardised to a 5-minute effort. Both abundance and size of these shellfish were compared with shellfish data from in-water quadrats.

In an effort to capture juvenile density, a series of cores 15 cm diameter and 30 cm deep were taken and sieved through a 3.75 mm mesh. Three cores were taken at each of three beach levels (high-, mid-, and low-shore). The core size was apparently too small to capture juvenile distribution, with no individuals found in the vast majority of cores. These results will therefore not be considered further in this report.

### Species distribution

There are two species of tuatua / pipi on Horowhenua beaches; the grey-shelled northern tuatua (*Paphies subtriangulata)* and the cream-coloured southern tuatua (*Paphies donacina*). The two species are not always readily distinguishable, so were not sorted in the field by volunteers. Instead the samples of 20–50 individuals, which were collected from each site for faecal indicator bacteria analysis (Newcombe *et al.* 2014), were used to record relative abundances of the two species. Species were assigned on the basis of shell and adductor muscle colour (Richardson *et al.* 1982).

### 2.2.3. Environmental data

**Salinity**

Salinity was measured at four shore heights at most sites (at two sites, no high-shore water samples were collected). Water was collected from dug quadrats on the exposed beach at high- mid- and low-shore, and a fourth water sample was collected from the sea at low tide. Samples were transported back to the survey base, where salinity was measured with a YSI Model 85 handheld meter.

**Sand characteristics**

Sediment samples were collected from three points at each of high-, mid-, and low-shore. Three 10 cm deep cores were combined into a single sample at each shore level. Samples were placed on ice and shipped to RJ Hill Laboratories (Hamilton, New Zealand) for analyses of total nitrogen, grain size, and organic content. Methods are summarised in Table 1.

Table 1. Summary of sediment analytical methods[11].

| Test | Method description |
|---|---|
| Environmental solids sample preparation | Air dried at 35°C and sieved, < 2 mm fraction<br>Used for sample preparation<br>May contain a residual moisture content of 2%–5% |
| Ash | Ignition in muffle furnace 550°C, 6hr, gravimetric. APHA 2540 G 22nd ed. 2012. |
| Organic matter | Calculation: 100 - Ash (dry wt). |
| Total nitrogen | Catalytic combustion (900°C, O2), separation, thermal conductivity detector [elementar analyser]. |
| Seven grain sizes profile | Dry matter drying for 16 hours at 103°C, gravimetry (free water removed before analysis). Wet sieved, gravimetry (calculation by difference) into size classes: silt (< 63 µm), very fine sand (63–125 µm), fine sand (125–250 µm), medium sand (250–500 µm), coarse sand (0.5–1 mm), very coarse sand (1–2 mm) and very fine gravel (> 2 mm) |

**Landscape features and local knowledge**

Teams were asked to write down any observations and knowledge they wanted to contribute about their site, and were prompted with a list of questions. The observations are reported in Appendix 3.

Photographs were also taken of each site in all four directions from the stake at the top of Transect 1, and from the top of the beach / dunes, of the land behind the beach and dune vegetation. Land-ward images are shown in Appendix 3.

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[11] Analyses carried out by R J Hill Laboratories Limited, Hamilton, New Zealand. www.hill-labs.co.nz

# 3. RESULTS AND DISCUSSION

## 3.1. Land cover

### *3.1.1. The broader coastal margin: current and historical land cover*

Much of the coastal margin in 1942 was relatively undeveloped. Large drifts of active (unstable) dunes covered broad areas up to 2 km inland, particularly in the north (Figure 3). Drifting dunes had been an issue for landowners along the coast since the 1880s, being attributed partly due to overgrazing and burning of the original (stable) vegetation, and partly to increased accumulation of sand along the beaches due to wide spread land clearance (Cowie 1962). Today, these drifting dunes have stabilised following the planting of marram grass, lupin and exotic forest (Figure 4). It has been estimated that dune stabilisation efforts since 1950 have reduced the area of active dunes in the Manawatu region by 81%, which is the highest rate in New Zealand (Hilton *et al.* 2000). While dune-land extent will vary over time, the estimated area of New Zealand's active dune-land in the early 1900s was very similar to that estimated by Hilton for the 1940s / 1950s (Cockayne [1911] via Hilton *et al.* [2000]).

Current land cover within the broader coastal margin (Figure 5) is dominated by pasture (61%), which is made up of both 'high producing' (50%) and 'low producing' (11%) exotic grassland. Other noteworthy land covers include exotic forest (13%), urban areas (10%), and sand (7%).

The FENZ database[12] indicates that the pre-European wetlands covered nearly one third (28%) of the land area between the beach and the inland back-dunes (Figure 6). Wetland coverage in aerial images from 1942 / 1948 (Figure 3) appears to be considerably less than this, resembling a wetland landscape more similar to the present day, suggesting that wetlands were drained prior to the 1942 / 1948 images. The FENZ database estimates that wetlands currently cover about 2% of the total land area, which is a reduction of 93%.

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[12] The FENZ historical wetland layer was put together using the FSL ('Fundamental Soil Layer') of the New Zealand Land Resource Inventory (NZLRI). This was augmented by additional information about land units dominated by other limiting factors such as nutrients, climate and erosion, but which also contained poorly drained/wetland areas. The FENZ current wetland layer was made by combining several existing databases, including satellite descriptions of land-cover (LCDB2), topographic maps, existing survey data (from regional councils and others), QEII covenant maps, DOC surveys, and a 15 m digital elevation model. Candidate polygons were checked against recent Landsat imagery.

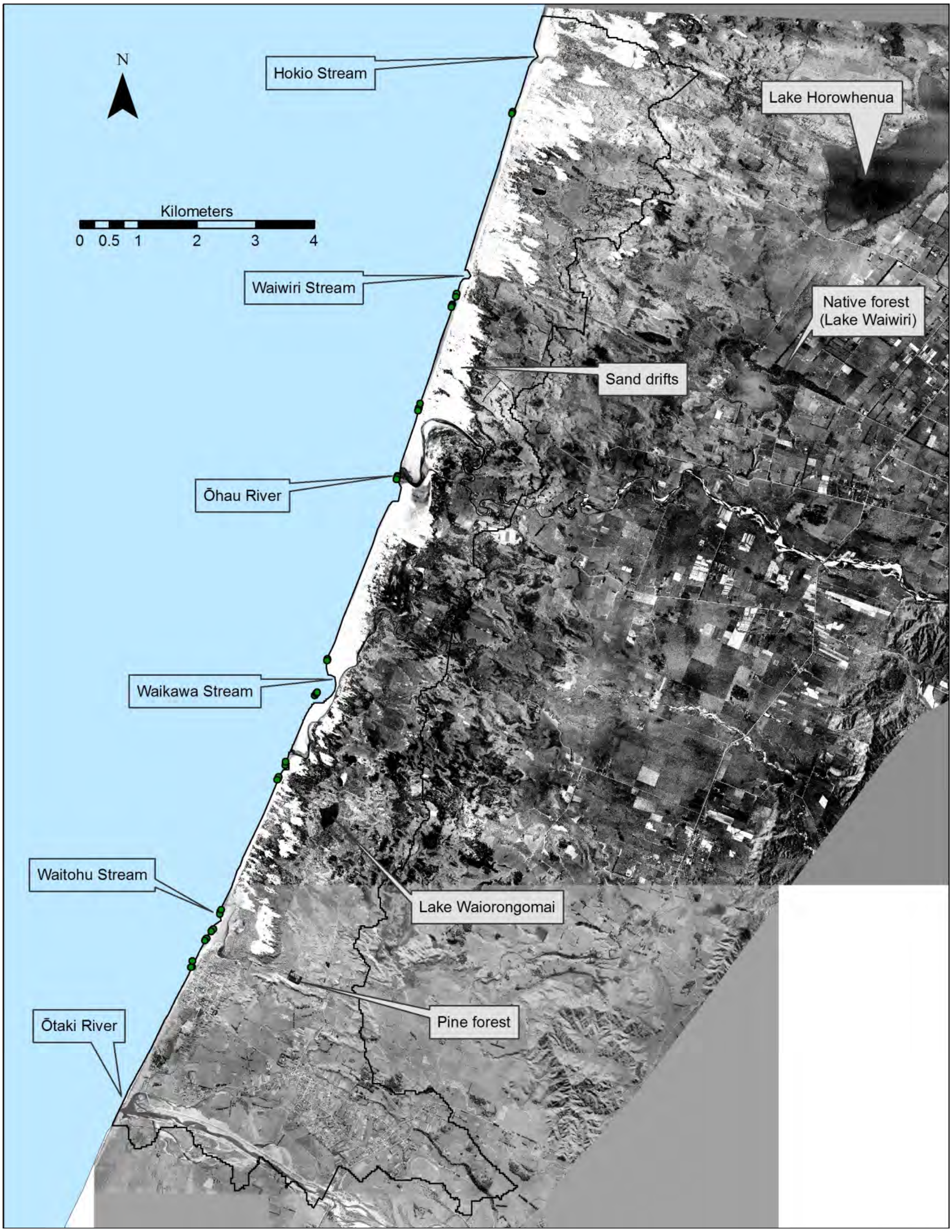
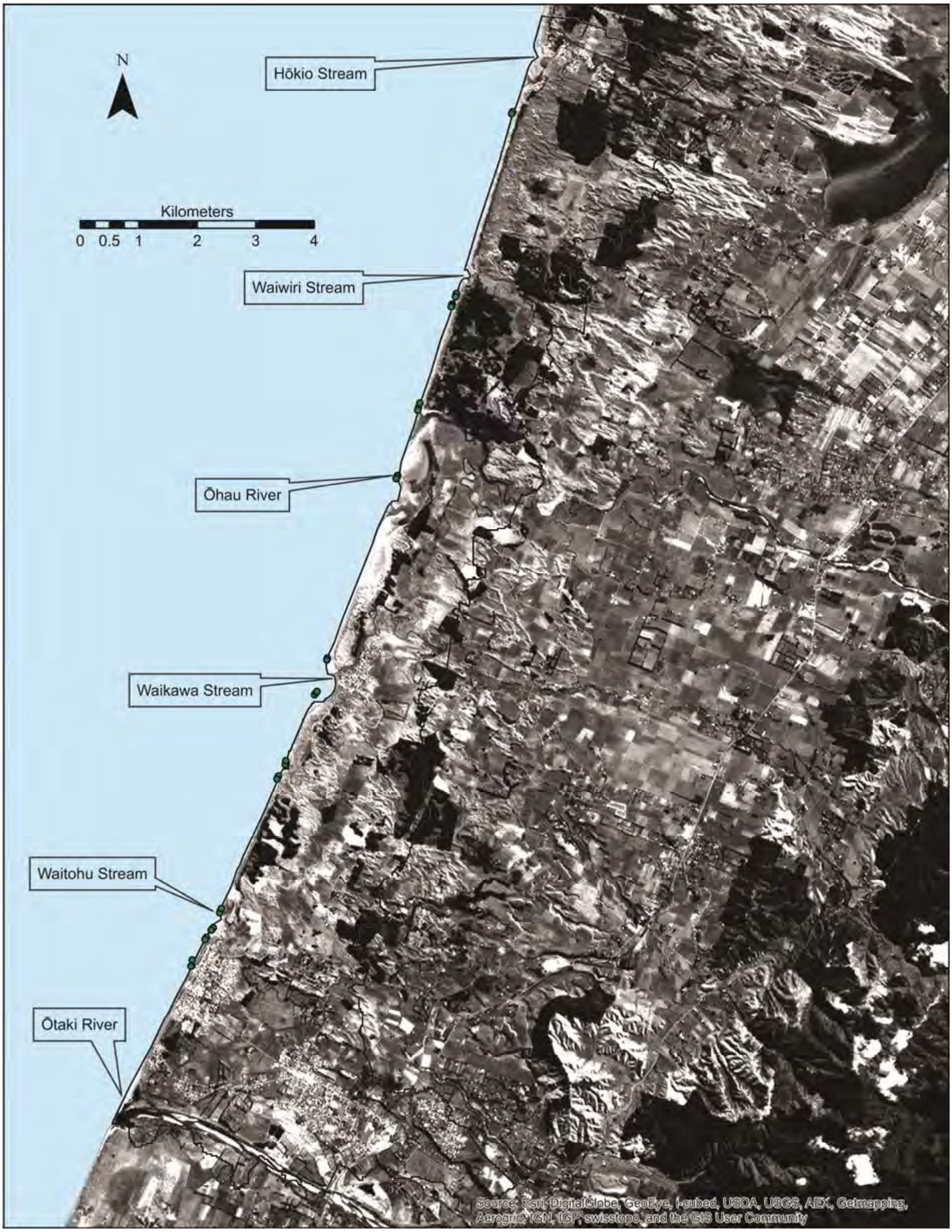


Figure 3. Historical aerial photo of the broader coastal margin. Most of the aerial images north of Waitohu Stream are from 1942, with others being taken in 1948.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 4. Current aerial photo of the broader coastal margin (presented here in black and white in an attempt to improve comparison with the historical photo, a colour version is presented in Appendix 2).

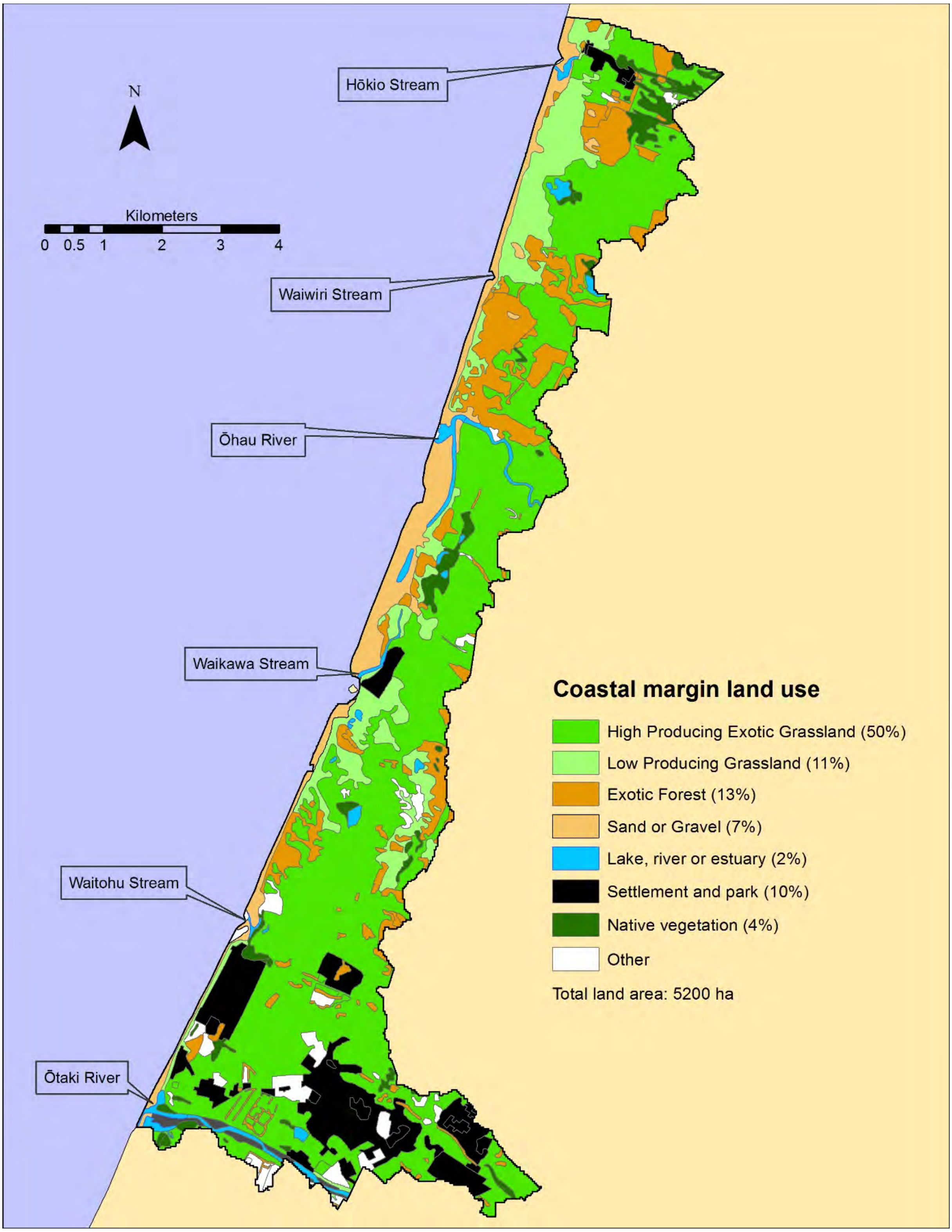


Figure 5. Current land cover in the broader coastal margin (Source: Land Cover Database v3.3).

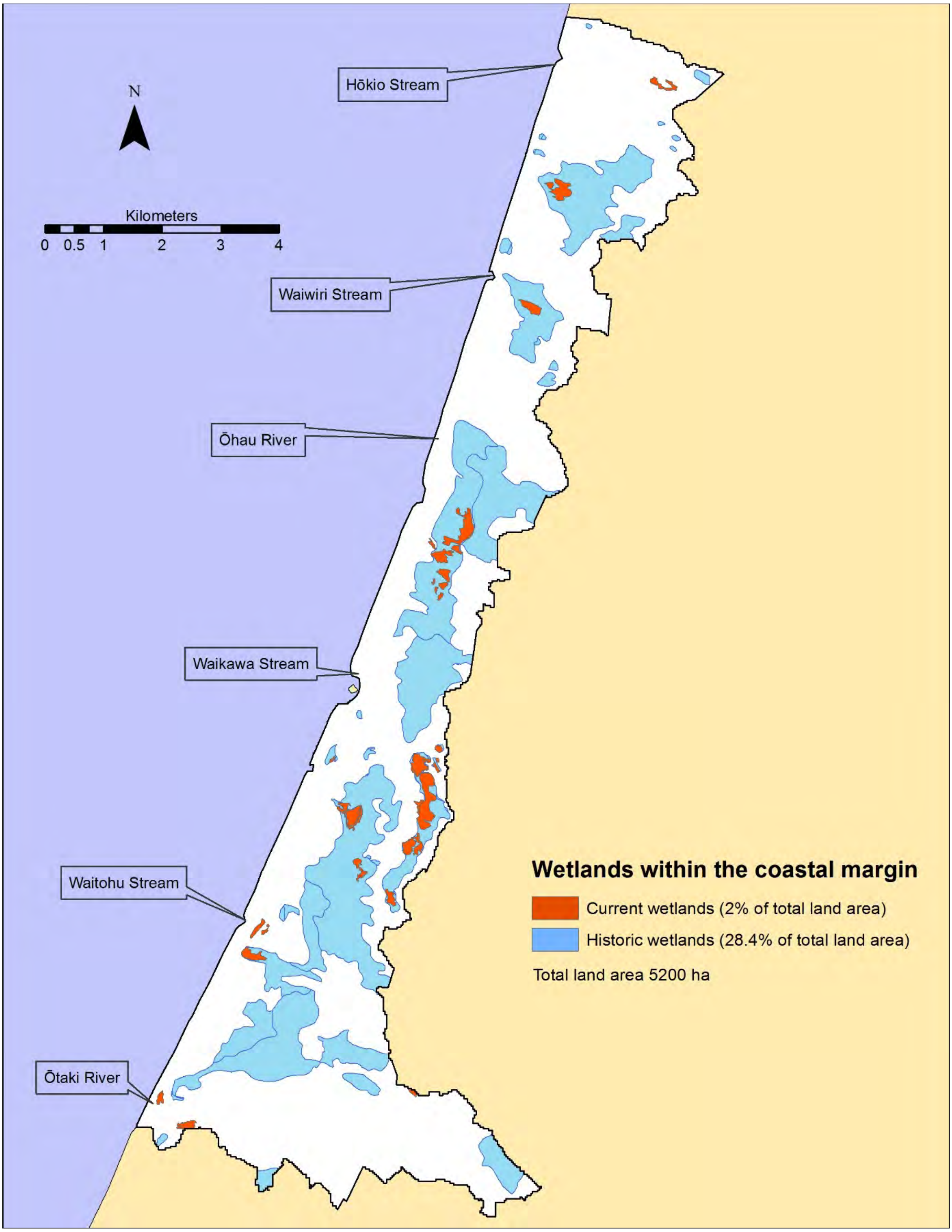


Figure 6. Current and historical (pre-European) wetland area along the broader coastal margin (Source: FENZ 2010).

### *3.1.2. Sub-catchments: current and historical (both pre-European and 1942) land cover*

Wetlands were a dominant feature in the pre-European landscape, making up more than 30% of the total land area in five of the six groundwater sub-catchments (Table 2, Appendix 2). With wetland loss ranging from 85%–100%, shallow groundwater level is likely to be lower than in pre-European times.

Since 1942, changes in land cover within the six sub-catchments are clearly visible (Appendix 2 Figures A2.1–A2.6), illustrating a transition from a broad, dynamic coastal margin dominated by dunes and wetlands to a predominance of pastoral farming and exotic forestry. Drifts of active (unstable) dunes and dune scrub covered as much as 88% (Hōkio) of the sub-catchment land areas at that time (Table 3). By 2008, however, the highest coverage was 14% (Ōhau), and the average coverage of pasture across all sites was 63%, up marginally from 56% in 1942. The biggest increase in land cover was exotic forest which, virtually non-existent in this area in 1942, covered up to 43% (Waiwiri) of the sub-catchment land areas in 2008.

The majority of wetland drainage appears to have been carried out prior to 1942. Current wetland area (Table 2) is similar to those of 1942 (Table 3). However, at least some of the pasture visible in the historical aerial photos appears to have been recently converted from wetland. Table A2.1 (Appendix 2) provides greater detail of current land cover percentages.

Table 2. Change in wetland area since pre-European settlement in the six shellfish study areas. Source: FENZ (2010).

| Sub-catchment | Total area (ha) | Pre-European extent (ha) | Pre-European extent (% of catchmt) | Current extent (ha) | Current extent (% of catchmt) | % loss |
|---|---|---|---|---|---|---|
| Hōkio | 240 | 2 | 1 | 0 | 0 | 100 |
| Ohau | 586 | 218 | 37 | 12 | 2 | 95 |
| Ōtaki / Waitohu | 1,071 | 326 | 30 | 9 | 1 | 97 |
| Waikawa | 358 | 108 | 30 | 13 | 4 | 88 |
| Waiorongomai | 521 | 247 | 47 | 37 | 7 | 85 |
| Waiwiri | 254 | 82 | 32 | 5 | 2 | 94 |
| **Total** | 3,030 | 983 | - | 75 | - | 92 |

Table 3. Estimated land cover in 1942 / 1948 and 2008 for the six shellfish study areas (% of total sub-catchment area) (Source for 2008 land cover: LCDB 3.3)

| Sub-catchment | Total area (ha) | Sand dune & scrub (%) | | Exotic forest (%) | | Pasture (%) | | Wetland (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1942 | 2008 | 1942 | 2008 | 1942 | 2008 | 1942 | 2008 |
| Hōkio | 240 | 88 | 8 | 0 | 27 | 29 | 52 | 0 | 0 |
| Ohau | 586 | 56 | 14 | 0 | 18 | 33 | 60 | 11 | 2 |
| Ōtaki / Waitohu | 1,071 | 18 | 2 | 0 | 4 | 75 | 62 | 6 | 1 |
| Waikawa | 358 | 37 | 10 | 0 | 10 | 59 | 70 | 17 | 4 |
| Waiorongomai | 521 | 21 | 2 | 0 | 11 | 70 | 80 | 9 | 7 |
| Waiwiri | 254 | 32 | 6 | 0 | 43 | 68 | 51 | 0 | 2 |

## 3.2. Shellfish survey

### *3.2.1. Survey success and data quality*

The use of community groups to undertake sampling was very successful. Each team had approximately seven members of the local hapū and one of the co-authors of this report.

A number of different sample types were collected. Although there was limited time available for training team leaders, and no training time for team members, the data collected was largely of a high standard. Some errors occurred with respect to pooling of samples or reduced replication. Some extra data was also collected, as teams made the effort where time was available to more intensively sample some transects (placing quadrats every 10 m).

### *3.2.2. Species distribution*

*Paphies subtriangulata* (northern tuatua) were the dominant species of tuatua / pipi on all beaches, with *P. donacina* (southern tuatua or deep-water tuatua) never making up more than 23% of the individuals sampled (Figure 7).

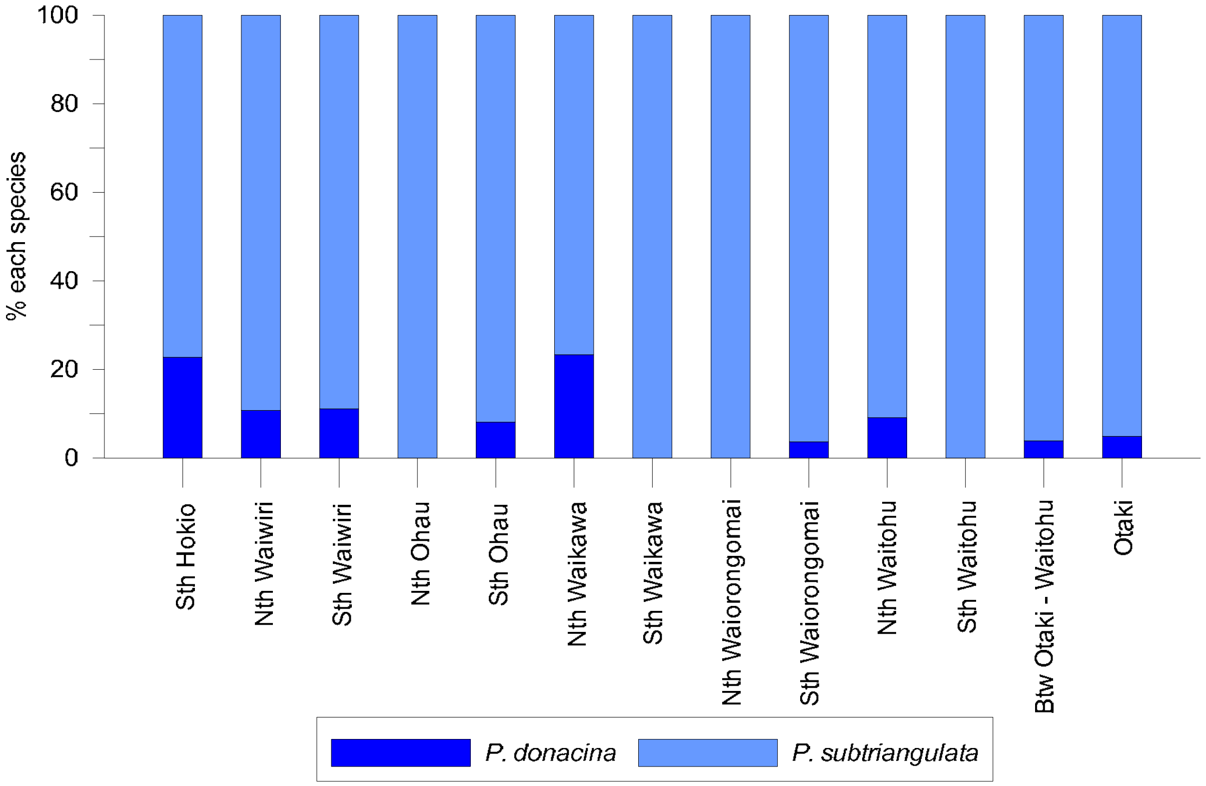


Figure 7. Relative abundance of two species of tuatua / pipi — *P. subtriangulata* (northern tuatua) and *P. donacina* (southern or deep-water tuatua) on beaches from Hōkio to Ōtaki (n = 9–55)

The species distribution found in the study area was consistent with that found nearby in 1978, where 13% of tuatua / pipi collected at Peka Peka and 3% of those collected at Waikanae were identified as *P. donacina* (Richardson *et al.* 1982).

### *3.2.3. Shellfish abundance and distribution*

Only two toheroa were observed during the survey. One was a 7 cm individual found in a high-shore quadrat north of Waiwiri, the other was found during an informal search of the mid- to low-shore north of the Waikawa Stream. The latter was not measured as it escaped capture by rapidly burrowing. Toheroa siphons were also visible south of the Waiwiri Stream (Appendix 3).

No more than two individuals of species other than tuatua / pipi were found at any site. Those that were found were either trough shells (*Crassula aequilatera*) or *Dosinia* sp.

Tuatua / pipi were found at all sites (Figure 9). Averaging across all sites, there were more tuatua / pipi in the subtidal (in-water) quadrats than on the exposed beach. Small tuatua / pipi did not follow this pattern, with more found at high-shore and in the subtidal than mid- and low-shore. Numbers of small shellfish are less reliable than medium and large, as some may have been missed when sorting sand or searching in-water quadrats.

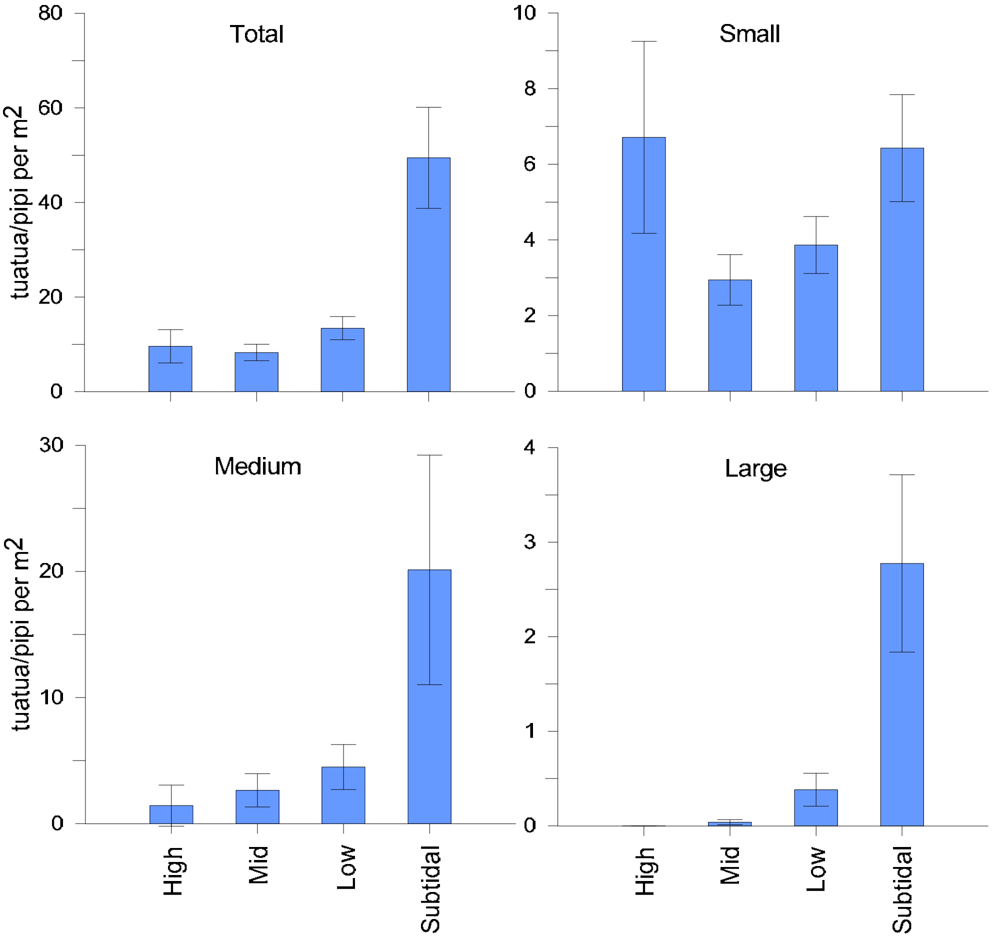


Figure 8. Mean tuatua / pipi density (individuals/m$^2$) at each shore height for total, small (≤ 3 cm), medium (4 cm–6 cm) and large (≥ 7 cm) individuals. Error bars are ± 1 SE. Note the differences in scale on the y-axes.

When size distribution from high-shore to the subtidal zone is viewed by site, it is apparent that tuatua / pipi varied in both abundance and population size structure along the beach (Figure 9).

Large tuatua / pipi were generally rare. Where they did occur they were almost always found at low-shore or in the water, while smaller individuals showed variable distribution.

The site south of the Ōhau River showed the most marked difference from the general pattern of increasing abundance towards the lower-shore. At the Ōhau-south site, small and medium tuatua / pipi were progressively less abundant lower on the shore and least abundant in the sea. This was also one of the few sites at which large tuatua / pipi were found at mid shore. An experienced shellfish gatherer commented that she expected to see this higher-shore distribution at that site.

From north of Waitohu to Ōtaki, the vast majority of shellfish were collected from the in-water quadrats. The most abundant populations were found in the sea either side of the Waitohu Stream, where medium-sized tuatua / pipi dominated the populations. Substantial numbers of large individuals were also found at these sites (note the different axes for these two sites in Figure 9).

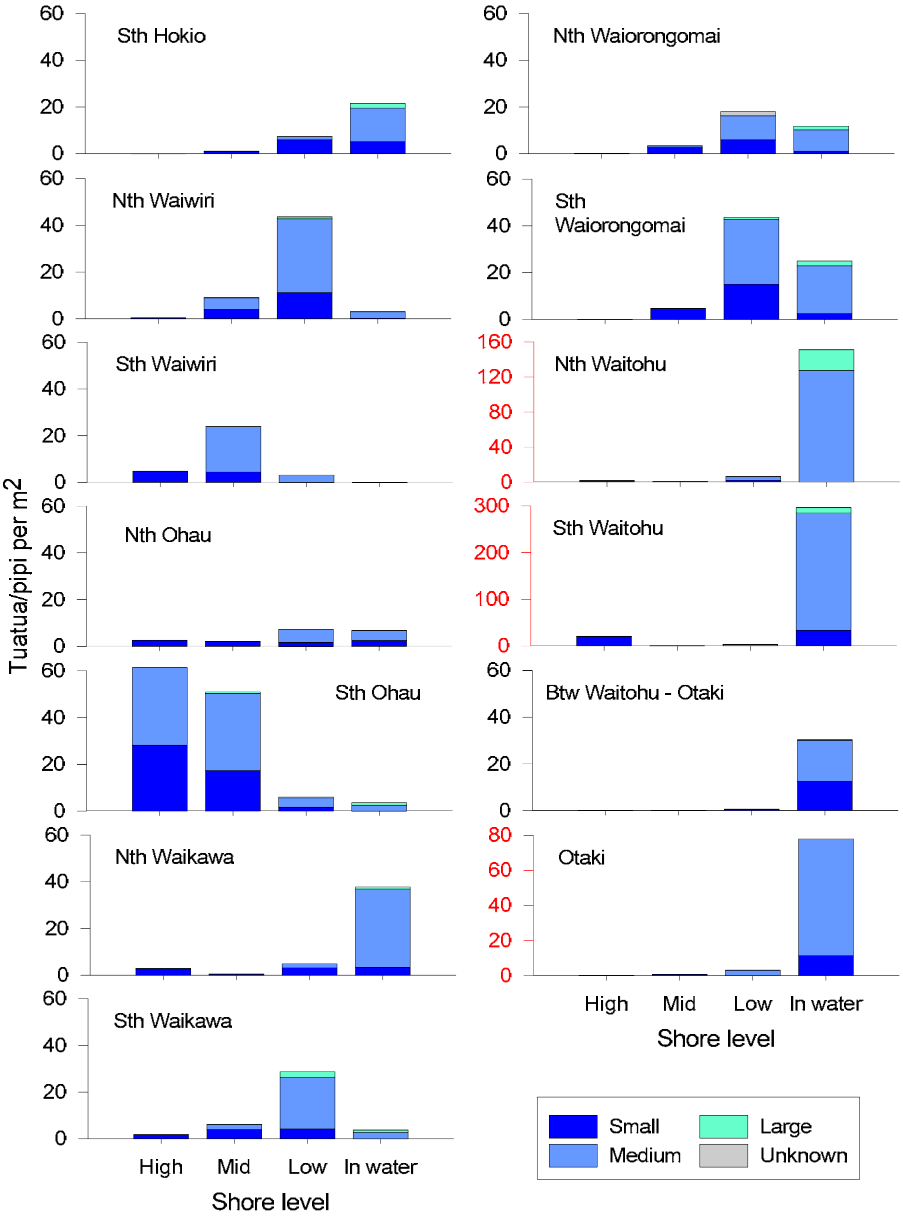


Figure 9. Tuatua / pipi distribution across 13 sites from Hōkio to Ōtaki. Size classes are small (dark blue, ≤ 3 cm), medium (light blue 4cm–6 cm) and large (blue-green ≥ 7 cm). Tuatua / pipi for which no size was recorded are represented in grey. Figures are average number per m$^2$ at quadrats dug out from exposed high-, mid-, and low-shore, and from quadrats searched by hand in shallow water at low tide. Y-axes with maxima other than 60 are highlighted in red.

No correlation was found (linear regression, $R^2 = 0.04$) when freestyle searches and in-water quadrat counts results were compared. At eight sites the number found during a 5-minute search was greater than the average for a 0.5 $m^2$ in-water quadrat. On five occasions there were more shellfish found in the quadrats than during the freestyle search. There was similarly no pattern in the proportion of large tuatua / pipi in the freestyle searches compared to the in-water quadrats.

During the tuatua surveys undertaken in January of 2013 by Royal *et al*, in-water searches (on a day with only moderate tidal range) south of Hōkio located more tuatua than at the other sites surveyed (north of Waiwiri, north of Ōhau, south of Waikawa). However, the Hōkio populations were not sufficient to provide ‘a feed’ and Ōtaki was determined to be a better site for collection, due to both abundance and size of shellfish. This is generally consistent with our results for in-water populations at these sites, although we did not record many large tuatua / pipi at Ōtaki.

When viewed in 1 cm size classes, the size structure of the population collected from beach and in-water quadrats at all sites was fairly similar ≥ 3 cm (Figure 10). At all sites the most common size class ≥ 3 cm was either 4 cm or 5 cm. At all sites there was a steep drop in abundance between the 5 cm and 6 cm size classes.

The largest individual was 9 cm long, found in an in-water quadrat south of Waiorongomai. Eight centimetre individuals were found at six sites, usually in the water, but occasionally in the intertidal. It is not known whether these large individuals were *Paphies subtriangulata* or *P. donacina*. *P. subtriangulata* is considered to have a maximum length of 80 mm. *Paphies doncina* is larger, with a maximum length of 110 cm (Cook & Archer 2010), making it more likely that they were the latter.

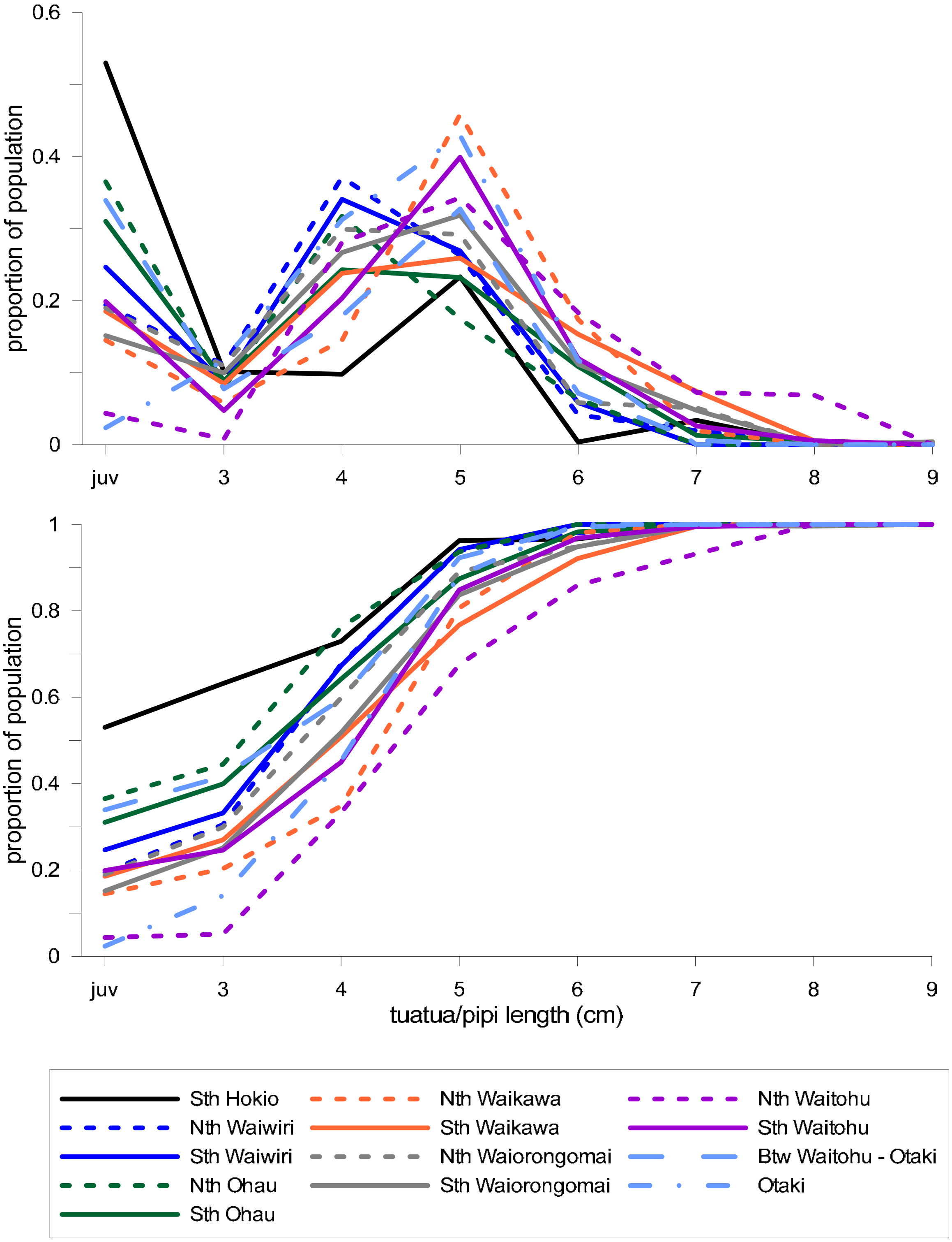


Figure 10. Discrete (top) and cumulative (bottom) proportion of the tuatua / pipi population (from quadrat samples) by size class at 13 sites from Hōkio to Ōtaki.

In some shellfish populations, separate year classes are visible when the size structure is examined (*e.g*. Redfern 1974, Williams *et al.* 2013b). This was not seen in the tuatua / pipi data from our survey. The low number of 3 cm individuals relative to larger sizes may suggest that there had been a recent year of low recruitment, or this size might fall between two recent cohorts. Alternatively, it could be an artefact of sampling, indicating that 3 cm individuals were not as well-sampled with the methods used as we initially thought. At larger size classes it may be that patterns have been missed due to the broad size categories that were used in our survey, as older adults may grow less than 1 cm per year[13].

The peak abundance reported at 4 and 5 cm for *P. subtriangulata* is widely observed (Cook & Archer 2010), but the steep decline between the 5 and 6 cm size classes may be exacerbated by harvesting. This is consistent with statements from locals who state that tuatua / pipi at about 6 cm are considered a good size for collecting. Smaller tuatua / pipi were, however, observed in the baskets of harvesters collecting near the survey areas.

Growth of shellfish such as toheroa and tuatua is highly variable, and may change with depth (Cranfield & Michael 2001) and presumably with shore height in the intertidal. A study on the growth of *P. donacina* in Cloudy Bay (north-eastern South Island)*,* suggests that those in subtidal area, would grow to 2.5 cm–3 cm in the first year, reaching 6 cm in the third or fourth year[13] (Cranfield & Michael 2001). However these estimates are variable, not necessarily exact or transferrable to *P. subtriangulatum*.

### *3.2.4. Ghost shrimp burrows / worm holes*

Burrow holes (referred to as ‘worm holes’ by locals) possibly indicating ghost shrimp presence were recorded at all sites and at all shore levels (Figure 11). No consistent relationship with shore height was detected. The highest densities were recorded at the mid-shore level south of the Ōhau River, but it was most common for the average low-shore density to be higher than the mid-shore density. The presence of ghost shrimp / worm holes was most variable in the high-shore.

Burrow holes / worm holes could indicate the presence of ghost shrimp or possibly a range of other species. In the cores taken at the high-shore, worms and isopods were commonly found; ghost shrimp were absent. However, lower down the shore ghost shrimp were the most common animal found in cores.

A number of factors other than the presence of different species could affect the relationship between the number of ghost shrimp holes and the actual number of ghost shrimp. For example, the holes were more difficult to see in wet sand, so tidal level and tidal state are likely to influence the number of visible holes.

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[13] Von Bertalanffy parameter estimates from Table 5 and 6, Cranfield & Michael, 2001.

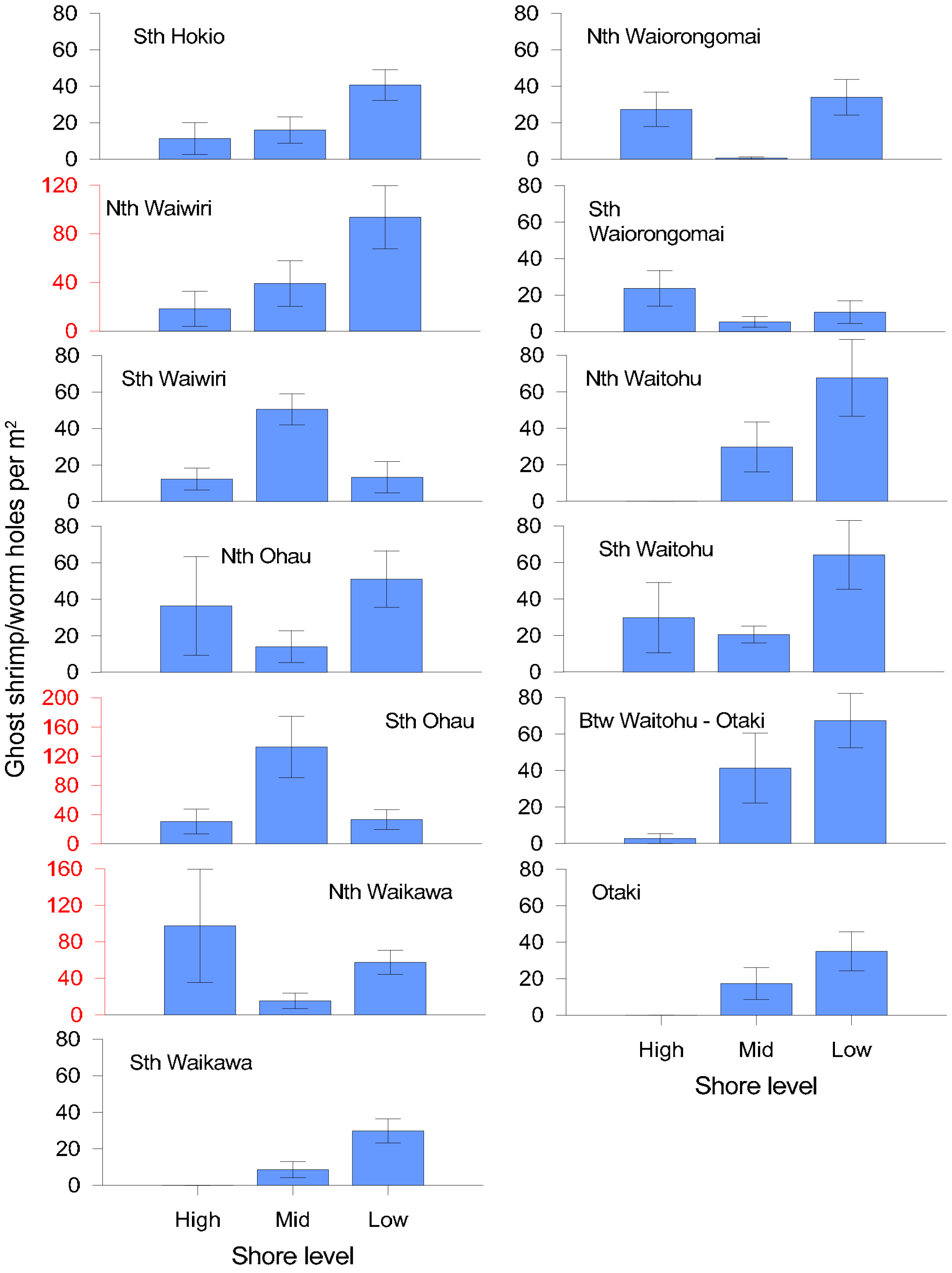

Figure 11. Ghost shrimp burrow / worm hole distribution across 13 sites from Hōkio to Ōtaki. Figures are average number counted per m$^2$ at quadrats prior to digging for shellfish high-, mid-, and low-shore, and from quadrats searched by hand in shallow water at low tide. Y-axes with maxima other than 80 are highlighted in red.

Attempts (with dedicated core-sampling) to establish a relationship between the number of ghost shrimp holes and the number of ghost shrimp were unsuccessful.

The ghost shrimp are small and burrow extremely quickly, so that they largely avoided being collected in the sand that was excavated and searched for shellfish. The cores used in our attempts to calibrate ghost shrimp holes to actual numbers of ghost shrimps were small enough to allow one person to excavate and sieve a sample, but the sampling area was probably too small to produce a reliable relationship between holes and number of animals. More importantly, the depth of the core (30 cm) was apparently too shallow to prevent shrimp burrowing out the bottom of the core. Accordingly, cores that were excavated quickly were found to have more ghost shrimp than cores that were dug out more slowly.

To more effectively count ghost shrimp a larger and deeper sampling unit would be required. This would also necessitate a means of transporting samples up and down the beach for washing through the sieve. The core would ideally be at least 30 cm in diameter, and 60 cm deep. It is uncertain whether the shrimp would still be able to burrow below the sampled 60 cm depth, but we suspect that they would, particularly as the core would need to be gradually dug out from the inside, rather than removed intact.

### *3.2.5. Sand characteristics*

The grain size, nitrogen content, and organic content of sand were measured in samples from the high-, mid-, and low-shore.

Nitrogen content was below the detection limit of 0.02 g/100 g dry weight for most samples (at one site the reading was at the detection limit of 0.02), so data were not graphed or analysed. Sediments from some Wellington beaches (Petone Beach, Lowry Bay, and Fitzroy Bay) were similarly low in nitrogen when tested in 2004 (Stevens *et al.* 2004).

Grain size distribution was relatively uniform across sites, and was dominated by fine sand (125–250 µm grain size, Figure 12). Only the site at the Ōtaki surf club had a noticeably higher proportion of larger grain sizes in the sediment profile. At this site a layer of fine sand sits over a distinct layer of larger grain size.

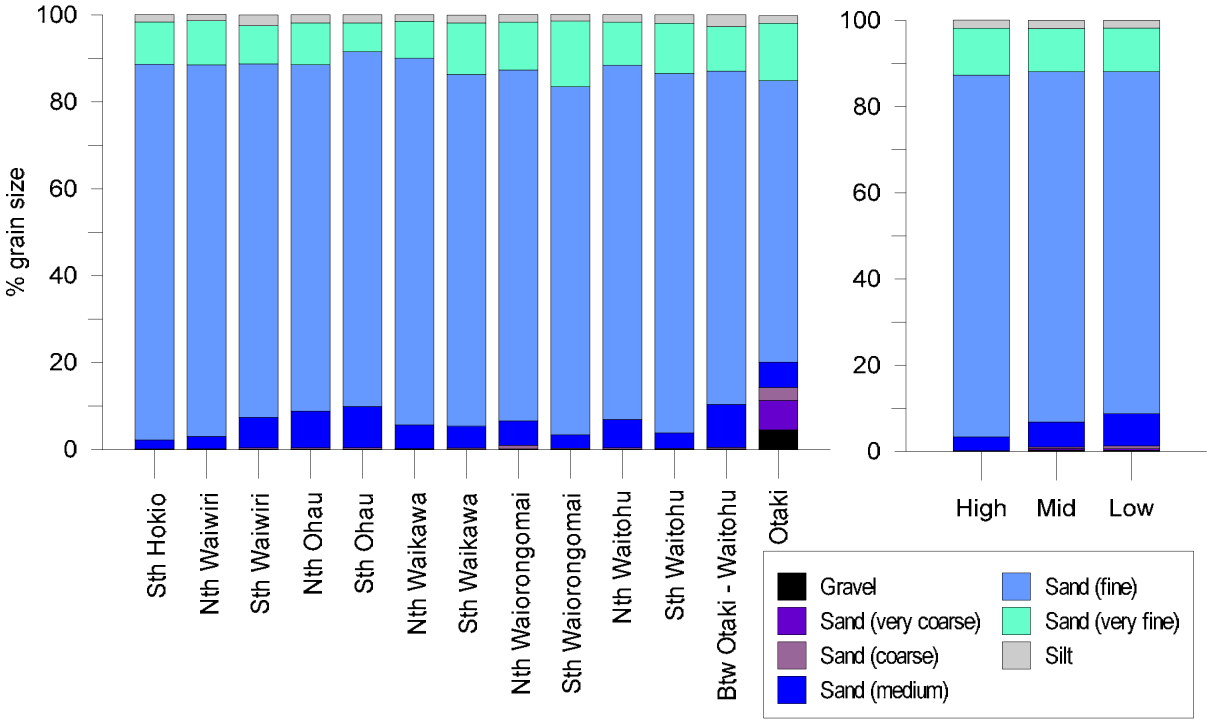

Figure 12. Average sediment grain size composition at each a) site and b) shore height. Sediments are categorised as: silt (< 63 µm), very fine sand (63 µm–125 µm), fine sand (125 µm–250 µm), medium sand (250–500 µm), coarse sand (0.5 mm–1 mm), very coarse sand (1 mm–2 mm) and gravel (> 2 mm)

Organic content in the beach sand was low (between ~0.8% and 1.6%), and showed no pattern with shore height. Sandy beaches naturally have much lower organic matter in sediments than more muddy estuarine environments, and levels seen in our study were similar to those found on some Wellington beaches (Petone Beach, Lowry Bay, and Fitzroy Bay), where organic content ranged from 1.0% to 1.8 %.

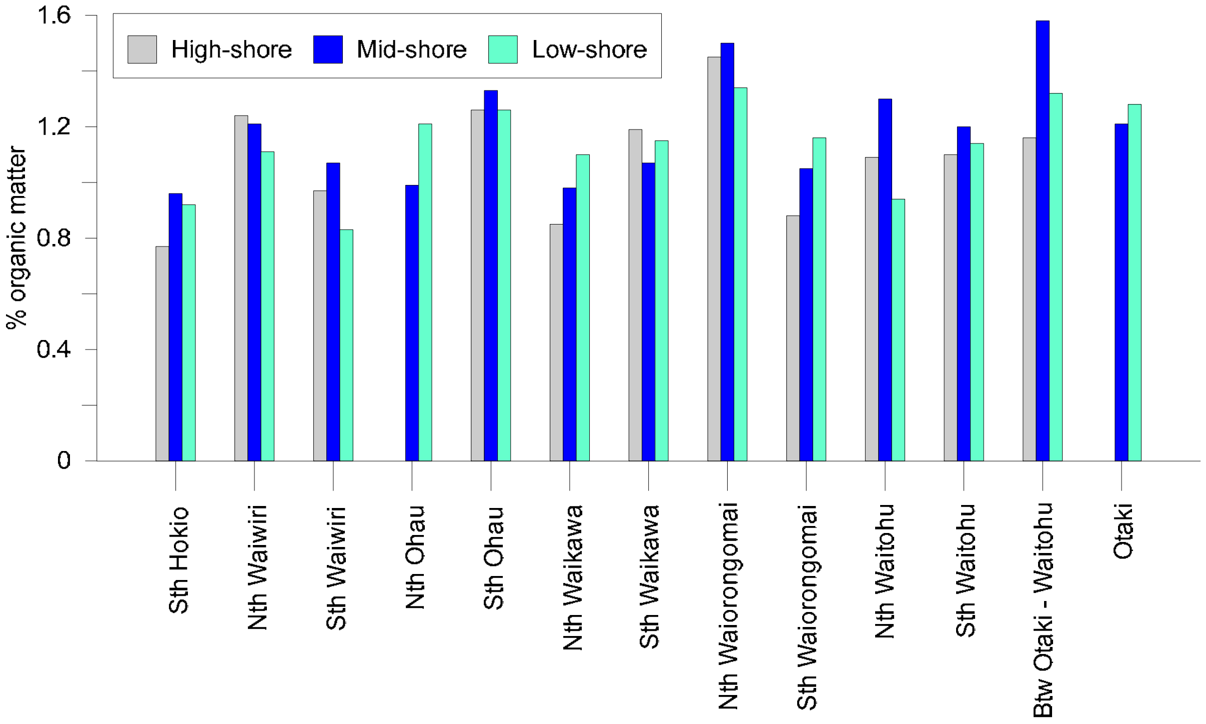

Figure 13. Percentage of organic matter in sand across 13 sites from Hōkio to Ōtaki.

### *3.2.6. Salinity*

Measurements from single samples taken at each of the high-, mid-, low-shore, and directly from the sea, indicated substantial variation in salinity. The normal salinity of the ocean is about 35 psu (practical salinity units), and samples taken from the sea were generally close to this. The most notable exceptions were the two sites either side of the Waikawa Stream, where the lower salinity reading suggests that freshwater input here was substantial. Further up the beach at this site, salinity was higher, suggesting that the stream, rather than groundwater input, is the source of the low salinity water just off the beach. At other sites salinity was lower (indicating greater freshwater input) further up the shore, which suggests that freshwater is flowing toward the sea through (rather than over) the land. This was most strongly seen at high- or mid-shore sites either side of the Waiwiri and either side of the Waiorongomai. South of Hōkio salinity was moderately but consistently low across the whole beach, and at Ōtaki the salinity was lower than normal at the low-shore sites. The salinities greater than 35 psu measured on the high-shore at some sites presumably result from evaporation of seawater concentrating the salts in the remaining water.

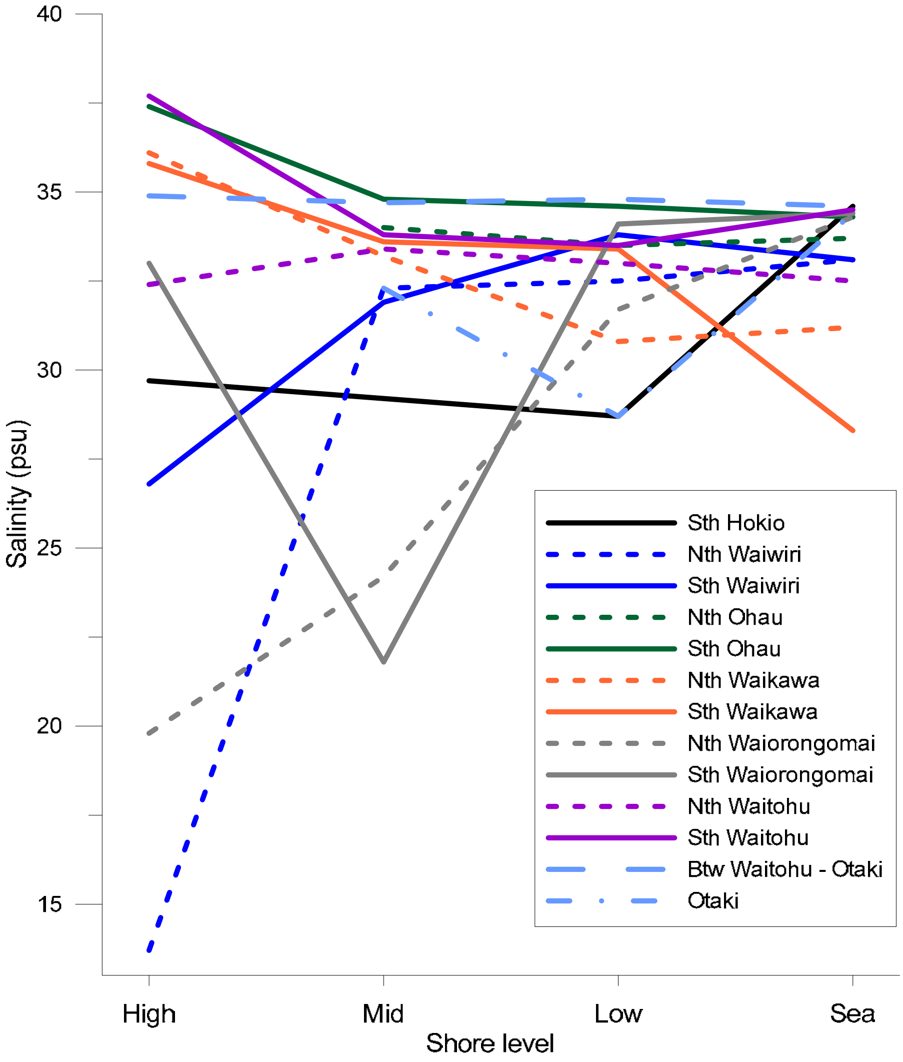

Figure 14. Salinity across 13 sites from Hōkio to Ōtaki. high-, mid-, and low-shore samples were collected by digging into the sand until water was encountered, and the fourth sample was collected directly from shallow water in the sea. High-shore samples were not collected north of Ōhau, or at Ōtaki.

While these data clearly identify some freshwater input, there may have been substantial variation in the way samples were collected, for example, how deep the holes were dug, and at which tidal state the sample was taken. Also, because only one sample was collected at each beach level for each site, variation within the sites is not captured by this data. It is well-established that toheroa are often associated with freshwater on beaches, so a better understanding of this aspect of the environment would be important to inform a toheroa reseeding programme.

One way this could be easily undertaken is by setting up an array of water sampling tubes. A series of these (perhaps three per standardised shore level per site) can be hammered into the sand to a known depth and the salinity of the collected water measured *in situ*. This could be undertaken at all sites studied so far, or at sub-set of sites that have been identified as potential reseeding areas.

## 3.3. Can we statistically identify relationships between all these aspects of the environment?

A series of statistical analyses were undertaken to test for relationships between tuatua / pipi populations, ghost shrimp populations (as indicated by ghost shrimp / worm holes) and characteristics of the environment. The full methods and results of these analyses are presented in Appendix 1, but we provide a summary here.

The statistical tests included assessments of relationships between:

- tuatua / pipi and shore height, salinity, organic matter, grain size, ghost shrimp holes, distance from nearest public access point, land cover
- ghost shrimp and grain size
- salinity and land cover.

As expected, there was a strong statistical relationship between tuatua / pipi density and shore height. Tuatua / pipi were least abundant at the high-shore line and progressively more abundant down-shore.

Both small and medium tuatua / pipi were less common where lower salinity was measured in the high-shore and in the subtidal, but this relationship was not apparent in the mid-and low-shore (there were insufficient large tuatua / pipi found to include them specifically in the statistical analysis).

Distance from public vehicle access points had a weak but significant relationship with the density of total and medium-sized tuatua / pipi. This could be due to higher harvesting pressure or more vehicle traffic closer to access points.

Some other statistical relationships were expected but not observed. For example, there was no relationship between the number of ghost shrimp holes and the grain size distribution of the sand. There was also no relationship between any measures of land cover and either shellfish distribution, salinity, or organic content of sand.

It is important to recognise that this statistical testing only identifies factors that vary together; it is not able to identify the cause of this variation. For example, we saw a positive relationship between tuatua / pipi density and salinity (*i.e.* places with higher salinity had higher numbers of tuatua / pipi), but this could be due to some other factor that we did not measure. In this case, we expect that the tuatua / pipi move away from areas with freshwater input, but we are not able to say whether this is related to the salinity itself, or temperature differences, contaminant input, or any other factor that might be related to freshwater input.

Similarly, the lack of an identified relationship does not prove that no relationship exists, only that the type and number of samples collected in this study do not demonstrate a relationship.

Because the beaches in the survey area are similar in many attributes (all have tuatua / pipi, similar beach type and land cover, *etc*.) it can be difficult to find statistically significant relationships. A study over a larger and more diverse area would have a better chance of identifying relationships between the factors tested here. Land cover impacts in particular were potentially obscured by the fact that two or more survey sites occurred within most sub-catchments. This effectively reduces the sample size of the study, which limits the ability of the statistical analysis to identify relationships.

Biological and physical factors such as shellfish populations and freshwater input can change markedly over time. For this reason, it is preferable to repeat surveys to understand temporal variability in the factors being measured.

# 4. CONCLUSIONS AND RECOMMENDATIONS

This project brought together a range of people and types of information, all relevant to the future of toheroa and other shellfish on beaches from Hōkio to Ōtaki. Cooperation between hapū and scientists was a positive and productive experience and provided an excellent foundation for future collaboration.

Land cover changes in the region have been substantial since before the 1940s. Toheroa numbers were still quite high at this point (see summary data in Heasman *et al*. 2012), and harvest was ongoing. However, Cassie (1955) stated that populations in the 1930s at Waikanae were likely to have been much more substantial than in the 1950s. Harvesting has not been permitted since 1970 (Redfern 1974) excepting cultural harvest. Toheroa are still found on beaches in the study area, but densities are so low that standard scientific methodology is insufficient to survey them. Local knowledge is the best available information on the current status of toheroa. The paucity of remaining toheroa means that we are unable to directly assess the impact of local land cover on toheroa populations; however it is clear that land cover change has occurred on a scale that was more than sufficient to have played a part in toheroa decline.

Tuatua / pipi are the dominant shellfish in the intertidal and shallow subtidal (on moderate tides). These are largely the species *Paphies subtriangulata*, but *P. donacina* is also present. Any future study on tuatua / pipi should separate the two species if possible. *P. donacina* is more abundant in the subtidal off Wellington beaches, and *P subtriangulatum* is dominant in the intertidal (Cranfield & Michael 1989). Failure to separate the two in ongoing studies could result in one species masking important changes in the dynamics of the other.

Of the environmental factors studied, distance from public vehicle access points is one of the few factors associated with reduced densities. This shows that human impacts are capable of depressing these species. Harvest is a likely cause, but it is possible that crushing or other disturbance by vehicles reduces the survival of shellfish (Brunton 1978, Redfearn 1974, Stevenson 1999).

The beaches from Hōkio to Ōtaki displayed little variability in grain size, nitrogen and organic content, but there was some variability in the salinity of the interstitial water in sands at the high- and mid-shore levels.

Tuatua / pipi and toheroa have different environmental requirements and distribution across the shore, and accordingly tuatua / pipi do not function as a proxy for toheroa. In fact it is reported that they seldom exist together, and that abundant tuatua can even smother toheroa (Morton and Miller 1973). Our finding that tuatua / pipi are measurably lower in areas with greater freshwater input provides a means of mitigating any competitive relationship between tuatua / pipi and toheroa that could occur in any reseeding effort. Reseeding of toheroa would best occur in areas with freshwater input, where tuatua / pipi are naturally less abundant.

In our study, we surmise that the lack of a relationship between data collected in quadrats and using the freestyle method, was due to the number of different of people who undertook the searches, and hence variation in both technique and experience. It may have been more effective to have collected these data with a small team of experienced shellfish gatherers and transported them around sites so that similar gathering strategies were used at all sites. In this way the freestyle searches would have been replicated, allowing us to analyse variability in space and between searchers. A survey with these components would be easily undertaken, and would provide an insight into the way abundance as measured with standard population survey methodology relates to abundance relevant to human shellfish gatherers.

Theories of searching / foraging behavior in a patchily distributed resource may also be relevant to the different results achieved with the two different search methods. When fishers are not constrained in their choice of site, they will logically move to sites where the target species is still abundant. Using such a strategy in patchy populations, CPUE (catch-per-unit effort) can be maintained even when total population size has been dramatically reduced, until the last patches are harvested. However, in our study, the tuatua / pipi collectors had only limited choice of where to collect (within tens of metres of a set point). In this situation the relationship of CPUE to transect data might be expected to be more closely related.

Ghost shrimp have been shown to be associated with changes in community structure in intertidal sandflats (Berkenbusch *et al.* 2000). The failure to find any relationship between ghost shrimp and either sediment properties or shellfish populations may be due to the very uniform nature of the beach and also the scale of sample collection; single composite sediment samples were taken to represent a beach level, while ghost shrimp densities varied on a smaller scale. It is also possible that ghost shrimp replace, rather than displace, toheroa, and that ghost shrimp do not cause environmental changes relevant to toheroa survival. The MPI-commissioned toheroa survey (TOH2013-01) “Distribution and abundance of toheroa in the South Island” may provide more information about the relationship between ghost shrimp and toheroa. Results are expected to be available late in 2014.

The associated study assessing *Escherichia coli* (a bacteria that indicates faecal contamination) found high levels of faecal contamination in tuatua / pipi at many study sites, even under conditions of low rainfall (Newcombe *et al.* 2014). That study clearly indicated that shellfish are regularly contaminated with faecal material to the point that they are considered marginally suitable or unsuitable for human consumption (MfE/MoH 2003). This is of considerable concern given the extensive collection of tuatua / pipi for consumption. In the longer term this would be an issue for use of re-established toheroa populations. The land cover data presented here shows a dominance of particular land covers, *e.g.* high intensity farming, which can contribute to this contamination (*e.g*. Ballantine & Davies-Colley, 2009).

## 4.1. Multiple stressors

No single factor can be identified as explaining the decline of toheroa or other kaimoana species along the Horowhenua coast. Management of shellfish should recognise the role of multiple stressors. This approach considers that a given activity or impact may not be detrimental to a healthy population or environment, but when combined with other stressors, or when persisting over long periods of time, the impact becomes unsustainable.

Harvest of stressed populations is a prime example. For example, a healthy population of a kaimoana species may be able to sustain quite high levels of exploitation because production and survival of juveniles are high and food supply is abundant, producing good growth rates and healthy individuals. When some of these factors change, however, the resilience of the population can be reduced. For example, if adjacent populations of adults are overfished, the supply of larvae, and therefore juveniles, to the local population may be reduced. Juvenile survival may also be reduced, for example, by increased disturbance, predation, or harsh environmental conditions such as temperature changes. Adult survival and growth may also be reduced by changes in food supply.

Each of these compound the stress on the population. Moreover, the cumulative impacts can be worse than we would predict by simply adding the effects of each individual stressor. Accordingly a population that was once able to persist in spite of quite high levels of exploitation can become incapable of sustaining itself in the presence of even very low levels of harvest.

All the factors given in the example above are likely to apply to Horowhenua toheroa populations. The changes in land cover are an example of this, in that toheroa apparently persisted beyond a time at which large-scale wetland drainage had occurred. This land cover change, may, however, have lowered the resilience of the population to other stressors, such as disturbance and harvest.

## 4.2. Summary of findings

### Land cover changes

- There has been a substantial reduction in the area of active (unstable) sand dunes since the 1940s. The 240 ha Hōkio sub-catchment for example, was 88% dune and associate scrub in 1942, compared to 8% today.
- Since the 1940s dunes were stabilised by planting pine forest, marram grass and lupin, although the total present day coverage of pine forest within the broader coastal margin is relatively low (13%).
- Wetland extent in the 1940s appears to be similar to that of the present day (2%), which is much reduced from the pre-European cover (28%).

- The average coverage of pasture across all sub-catchment sites was 63% (61% for the broader coastal margin), up marginally from 56% in 1942.

### Shellfish populations

- While many reports and observations of toheroa between Hōkio and Ōtaki still occur, populations are clearly vastly reduced to the point that it is no longer possible to effectively study them in the local environment.
- Tuatua / pipi were the only common intertidal shellfish.
- Most tuatua / pipi found were the species *Paphies subtriangulata,* but *P. donacina* was also present.
- In general, there were more tuatua / pipi in the subtidal than the intertidal zone, but this pattern was not apparent for the smallest size class, which had similar numbers in the high-shore and the subtidal zone at some sites. The sampling method may have missed some small individuals.
- The distribution of tuatua / pipi varied along the beach, *e.g*. they were much more abundant at some sites than at others and the position of shellfish beds relative to shore height also varied between sites.
- A weak pattern was observed where tuatua / pipi were more abundant with greater distance from access points.
- Tuatua / pipi populations decreased in abundance between the 5 and 6 cm size classes.

### Ghost shrimp

- Ghost shrimp burrows / worm holes were found at all sites, and varied both across and along shore.
- Attempts to establish a relationship between ghost shrimp burrows / worm holes and numbers of ghost shrimp were limited by the size of sampling units and the difficulty in excavating the animals.
- We did not identify any impact of ghost shrimp on shellfish populations or the sediment structure of the beach.

### Beach environment

- Sediment characteristics were mostly uniform across sites.
- Nitrogen levels and organic content in the sand were low, which is expected in this beach environment.
- Freshwater input to beaches varied, and initial measurements suggested higher freshwater inputs at Waiwiri and Waiorongomai.
- A negative relationship between freshwater and tuatua / pipi was apparent, particularly in the high-shore where salinity varied most strongly.

## 4.3. Future research

A series of possibilities are suggested to inform future reseeding efforts and toheroa ecology generally.

- Collection of complementary information in toheroa beds in other parts of the Horowhenua would be useful. This would allow us to assess differences in characteristics of sites with and without toheroa, and to record population structure of the toheroa to assess juvenile survival.
- The abundance of ghost shrimp may be better assessed with improved (larger area, deeper core) sampling units.
- Further investigation of freshwater input at sites would inform site selection for reseeding.
- Analysis of coastal oceanography and microbial source tracking could be used to identify the key sources of faecal contamination so that riparian planting and other land management measures can be targeted to most effectively reduce contamination of coastal waters.

A comparison of freestyle searches with abundance estimates using standard quadrats, and using the same team at multiple sites, would provide an insight into the relationship between these two methods for estimating abundance. While not directly relevant to shellfish management, this is an interesting question with respect to the integration of traditional search methods and standardized scientific methodologies.

To move towards reseeding a series of other aspects of biology, ecology, or management should be assessed. These include the current state of knowledge regarding reseeding in other parts of New Zealand; identification of the most appropriate sites and scale for reseeding; options for natural or cultured source populations and assessment of the life-stage at which reseeding would be most likely to succeed; and a programme of management and monitoring requirements that would promote both successful reseeding and maximum learning from the reseeding attempts.

# 5. ACKNOWLEDGEMENTS

Craig Allen undertook all the mapping and land cover work, and the statistical analysis was done by Javier Atalah.

Taiao Raukawa Environmental Resource Unit would like to thank Moira Poutama for leading the organisation of all kaitiaki with the April survey. Raukawa ki te Tonga Trust provided funding for kaitiaki engagement. All kaitiaki stepped forward to help our MTM team with this survey.

Kia ora to these kaimahi who undertook the field survey:

Pete Sciascia
Rena Sciascia
Maia Whiterod
Richard Anderson
Huhana Smith
Tash McMeekin
John Gardiner
Tiana Gardiner
Jade Gardiner
Ben Gardiner
Angeles Gardiner
Tristan Hegglun
Lindsay Peihopa
Kyle Taylor
Sean Bennett-Ogden
Kirsty Bennett-Ogden
Iritana Bennett
Reuben Bennett
Oneroa Macdonald
Te Wiata Raika
Ariana Raika
Heni Wirihana Te Rei
Ihapera Gotty
Keremihana Heke
Taya Te Mihinga Heke
Brieahn Heke
Yvonne Wehipeihana Wilson
Kane Aporo
Reina Taplin
Tiaria Ransfield
Hone Taiapa
Jennette Gregory
Tura Ransfield
Te Aowera Ransfield
Hemi Rangiuia
Puawai Rangiuia
David Seymour
Moko Morris
Kiana Morris
Mahaki Morris
Aria Dobson Waitere
Landros Lewis
Mana Poutama
Haley Poutama Wood
Ruby Poutama Wood
Cassius Poutama Wood
Apina Poutama Gregory
Villiamu Lauvi
Moira Poutama

Thanks also to Peter Sciasica, Landros Lewis and Huhana Smith for sampling shellfish for faecal contamination testing in May.

This project was aptly summed up by two local leaders:

Moko Morris of Ōtaki was “thrilled to have my children involved in this local hapū initiative, whose vision is to secure better outcomes for all who enjoy the moana[14]. We learnt and laughed alongside all those contributing to the future health of Tangaroa[15]. It was an honour to be engaged in active kaitiakitanga and to strengthen whanaungatanga[16] amongst us.”

Keremihana Heke, customary kaitiaki for Ngāti Tukorehe and Deputy Principal for Whakatupuranga Rua Mano Kura Kaupapa, Ōtaki was a key participant with his whanau in the shellfish survey. “Having our tamariki[17] involved and exposing them to the stories of their pakeke[18] about the numbers of shellfish gathered in past years, was invaluable. I was reminded of how important it is for my own mokopuna[19] that we continue to work with our environment for the betterment of the resource for future generations. Nā Rangi tāua, nā Tuānuku tāua - We are all descendants of the Sky and the Earth.”

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[14] Sea
[15] Entity of the sea
[16] Interrelationships
[17] Children
[18] Adult relatives
[19] Grandchildren

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# 7. APPENDIX 1: STATISTICS

## Data analyses

Tuatua count data was analysed using generalised linear mixed models (GLMM; McCullagh & Nelder 1989, Zuur *et al.* 2009). Data was analysed separately for total, small (≤ 3 cm) and medium (4 cm–6 cm) tuatua density (individuals $m^{-2}$). There were not enough data on density of large individuals (≥ 7 cm) to allow convergence of a GLMM model, thus these data are only presented graphically. As the data consisted of over-dispersed counts, GLMMs with negative binomial error and a log link were used. Negative binomial models are fit on a log scale, so resulting models are multiplicative on the scale of the original variables. Height of the shore ('Tide', 3 levels: low, mid and high) was incorporated as a fixed factor, whereas 'Site' (13 levels) and 'Transect' (3 levels, nested in site) were included as random variables.

Sediment environmental variables were not measured in the subtidal, so regression analyses were initially conducted with data from high, mid and low shore height. Collinearity among predictor variables was initially checked by calculating the variance inflation factor (VIF) of each covariate and sequentially dropping the covariate with the highest VIF until all were <3 (Zuur *et al.* 2010). Models were initially fitted with all non-collinear covariates (Table A1.1), following backwards elimination of non-significant terms ($P > 0.1$). Sediment was not included as a covariate in the final models, so models were re-run to include density data from the subtidal. The effect of ghost shrimp holes on sediment grain size composition was tested using a multivariate generalised liner models (mvabund, Wang *et al.* 2012). All models were selected using AIC criterion and validated by inspecting the deviance residuals. The computer program R was used for all analyses (R Development Core Team 2014).

## Results

### Covariate correlations

In total, 22 covariates were considered in the regression analyses to predict density of each size class of tuatua (Table A1.1). After VIF analyses identified collinearity among covariates only 12, 12, and 13 covariates were incorporated in the total, small and medium tuatua density regression analyses, respectively (Table A1.1). There was high correlation (> 0.7) among several sediment grain sizes (Figure A1.1). Similarly, several land use covariates were highly correlated (> 0.7, Figure A1.2), including distance from access with both forestry and urban. Salinity did not correlate with any of the other covariates considered in the models (Figure A1.2).

Table A1.1. Environmental variables (and abbreviations) used as covariates in the generalised mixed effect models. * denotes variables that were considered not collinear by the variance inflation factor (VIF < 3) and thus included in the analyses for size class

| **Group** | **Abbreviation** | **Description** | **Total** | **Small** | **Medium** |
|---|---|---|---|---|---|
| Biological | Shrimp | Number of ghost shrimps holes | * | * | * |
| | Toheroa | Presence / absence of toheroa | * | * | * |
| Water | Salinity | Salinity (PSU) | * | * | * |
| Organics | OM | organic matter | * | * | * |
| | TN | total nitrogen | | | |
| Grain size (GS) | GS7 | > 2 mm | * | | |
| | GS6 | 1 mm–2 mm | | | |
| | GS5 | 0.5 mm–1 mm | * | | * |
| | GS4 | 250 µm–500 µm | * | * | * |
| | GS3 | 125 µm–250 µm | | * | |
| | GS2 | 63 µm–125 µm | * | * | * |
| | GS1 | < 63 µm | * | * | * |
| Land use | Forestry | Percentage cover of exotic forestry | | | |
| | High pasture | Percentage cover of high producing exotic grassland | * | * | * |
| | Low pasture | Percentage cover of low producing grassland | | * | * |
| | Dune | Percentage cover of sand dune | * | * | * |
| | Urban | Percentage cover of built up areas (settlement) | | | |
| | Native | Percentage cover of native forest, scrub or wetland vegetation | | | |
| | Other | Percentage cover of others (*e.g.* gorse / broom) | | | |
| | Wetland_2012 | Percentage cover of wetland in 2012 | * | * | * |
| | Wetland_loss | Percentage loss of wetland between 1900 and 2012 | | | |
| Distance | Distance to access | Distance to the nearest access point | * | * | * |

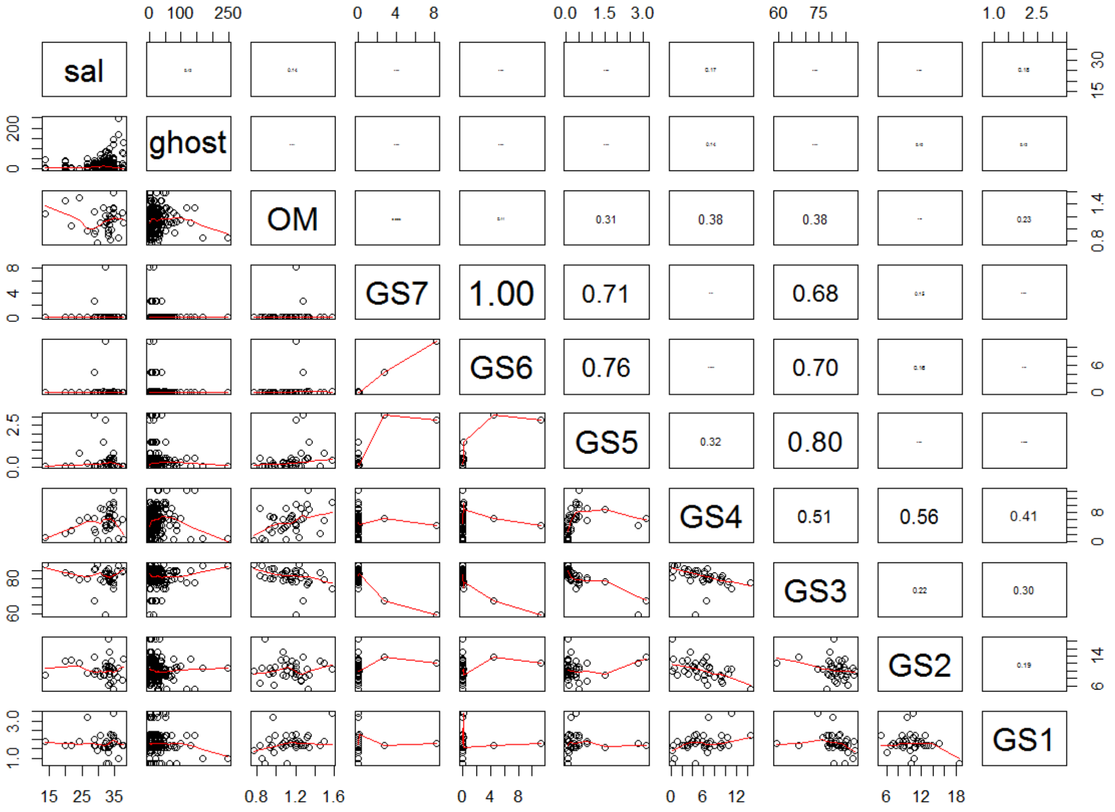


Figure A1.1. Plots of salinity, ghost shrimp and sediment covariates. Lower panels show scatter plots with a loess smooth line to aid visualisation. Upper panels indicate correlations with size proportional to the value. See Table A1.1 for covariate abbreviations and description.

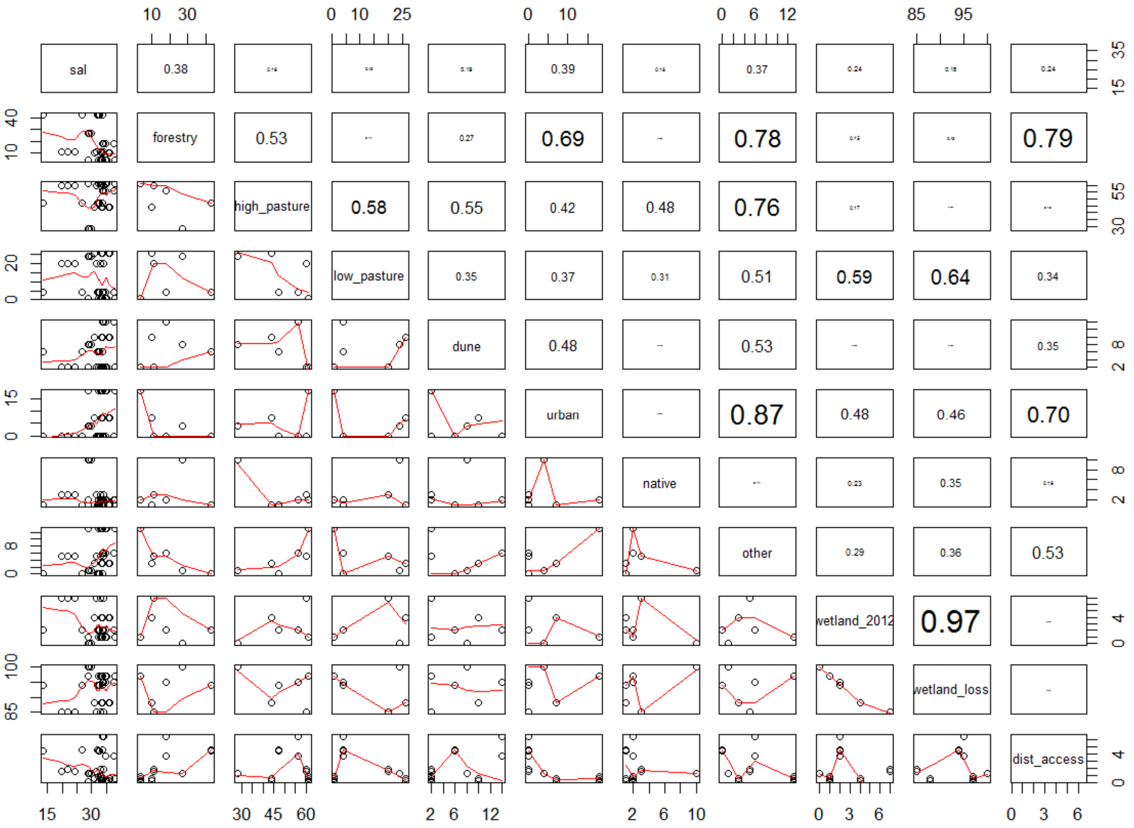


Figure A1.2. Plots of salinity and land use covariates. Lower panels show scatter plots with a loess smooth line to aid visualisation. Upper panels indicate correlations with size proportional to the value. See Table A1.1 for covariate abbreviations and description.

## Tuatua density regression models

There was a significant variation in the total density of tuatua in relation to the height of the shore (Figure A1.3a and Table A1.2). The highest average densities were recorded in subtidal sites (49.5 ind. $m^{-2}$ ± 10.7 SE), followed by low shore sites. Low shore sites had on average significantly higher densities (13.42± 2.4) compared to the mid and high shore sites (ave +- SE mid and high respectively) (Figure A1.3a). There was a significant interaction effect of salinity and shore height with respect to tuatua / pipi densities. A significant and positive relationship was detected in the high shore only (Figure A1.4a and Table A1.2Table A1.). Distance from the nearest access point was also positively correlated with total tuatua density (Table A1.2), however this relationship was weak.

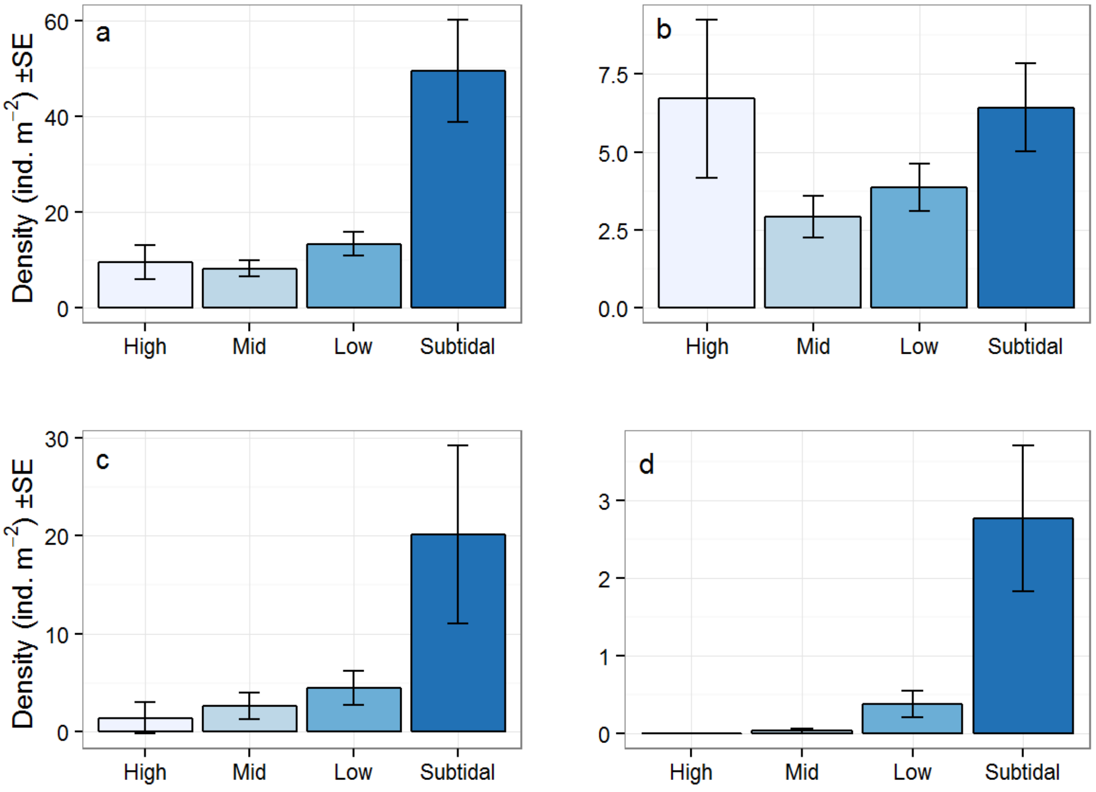


Figure A1.3. Mean tuatua density (individuals·m$^{-2}$) at each shore height for a) total, b) small (≤ 3 cm), c) medium (4 cm–6 cm) and large (≥ 7 cm) individuals. Note the difference in the *y*-axis scales.

Overall, a total of 922 small tuatua (≤ 3 cm) individuals were recorded. Density of small tuatua was on average 2.5 ind. m$^{-2}$ (± 0.41 SE) and did not significantly differ among shore heights (Figure A1.3b). Overall, the density of small tuatua was only significantly and positively related to salinity at high shore and subtidal sites (Table A1.2 and Figure A1.4b). Medium-sized tuatua were the most abundant, with a total of 2,315 individuals recorded across all sites. Medium-sized tuatua density was higher with decreasing shore height (Figure A1.3c and Table A1.2), with the highest densities recorded in subtidal sites (mean 20.1 ind. m$^{-2}$ ±9.1 SE). Similar to total density, the abundance of medium size tuatua was positively and significantly related to salinity, but again only in the high shore and subtidal. Additionally, medium size densities had a weak, but significant positive relationship with distance from the nearest access point (Table A1.2). Large tuatua (≥ 7 cm) was the least abundant of the three tuatua size classes, with only 121 tuatua recorded. Most large tuatua were recorded in the subtidal, while none were recorded in the high shore and very few in the mid shore (Figure A1.3d).

Table A1.2. Results of generalised linear mixed models (estimates ± SE) examining treatment effects on the density of total, small (≤ 3 cm) and medium size (4 cm–6 cm) tuatua. Shore height effect is in reference to the high shore. *P < 0.05, **P < 0.01 and ***P < 0.001

| | **Total** | **Small** | **Medium** |
|---|---|---|---|
| Intercept | -2.00 (± 1.37) | -4.26 (± 1.45)** | -18.44 (± 4.2)*** |
| Mid | 4.97 (± 1.88)** | 4.0 (± 3.34) | 14.83 (± 4.98)** |
| Low | 5.76 (± 2.53)* | 4.99 (± 7.15) | 16.53 (± 6.88)* |
| Subtidal | 3.05 (± 2.34) | -13.16 (± 6.26) | 7.79 (± 7.06) |
| Distance to access | 0.08 (± 0.04)* | | 0.4 (± 0.17)* |
| High × Salinity | 0.09 (± 0.04)* | 0.16 (± 0.04)*** | 0.46 (± 0.12)*** |
| Mid × Salinity | -0.04 (± 0.04) | 0.02 (± 0.09) | 0.07 (± 0.1) |
| Low × Salinity | -0.05 (± 0.06) | 0.0 (± 0.20) | 0.08 (± 0.17) |
| Subtidal × Salinity | 0.06 (± 0.06) | 0.55 (± 0.17)** | 0.41 (± 0.17)* |
| Site SD | 9.77E-05 | 0.1371 | 1.039 |
| Transect SD | 6.38E-05 | 4.54E-05 | 4.59E-05 |

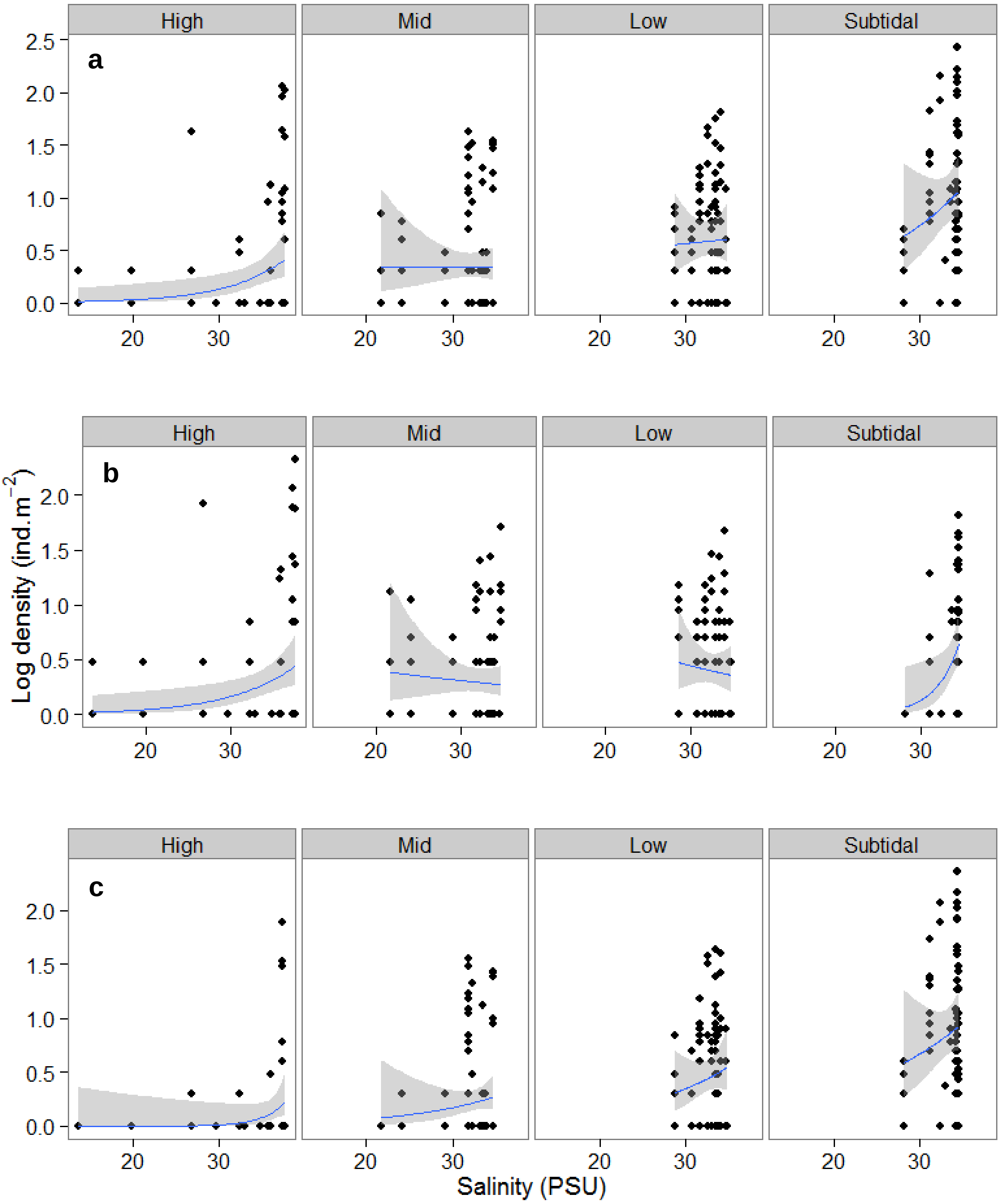


Figure A1.4. Total tuatua density (individuals·m$^{-2}$) in relation to salinity for each shore height: High, Mid, Low and Subtidal as predicted by the negative binomial regression model for: a) total, b) small and c) medium tuatua density. Grey bands around the regression line indicate 95% confidence intervals.

### Sediment properties

The dominant sediment fraction was fine sand (125 µm–250 µm), with an average of 81%, followed by very fine sand and medium sand (10.3% and 5.5%, respectively) (Figure A1.5). Site 12 had a relatively higher proportion of larger grain sizes (coarse sand, very coarse sand and very fine gravel) compared to the other sites (Figure A1.5). The sediment grain size composition was similar among shore heights, with the exception of the proportion of medium sand which increased with decreasing shore height. Levels of organic matter were similar across sites and shore heights (Figure A1.6; mean 1.13% AFDW ± 0.1 SE). Levels of total nitrogen were at or below detection limits at all sites (0.02 mg.100 g). The multivariate analysis showed no significant effect of number of shrimp holes on sediment grain composition (mvabund, W = 3.4, *P* = 0.9), and number of ghost shrimp holes did not correlate with any other variables.

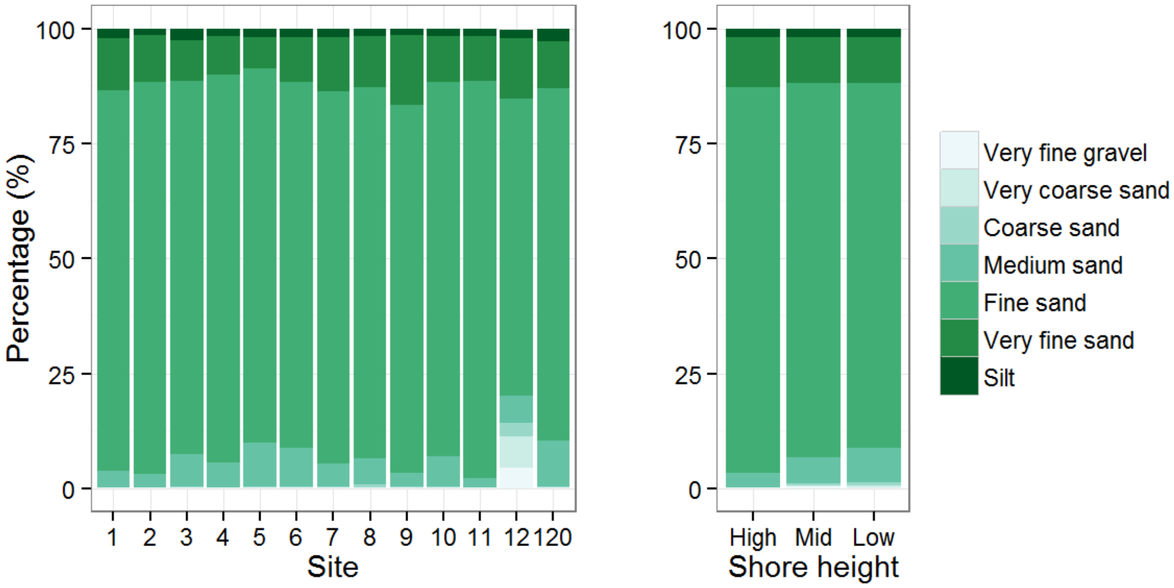


Figure A1.5. Average sediment grain size composition at each a) site and b) shore height. Silt (< 63 µm), very fine sand (63 µm–125 µm), fine sand (125 µm–250 µm), medium sand (250 µm–500 µm), coarse sand (0.5 mm–1 mm), very coarse sand (1 mm–2 mm) and very fine gravel (> 2 mm).

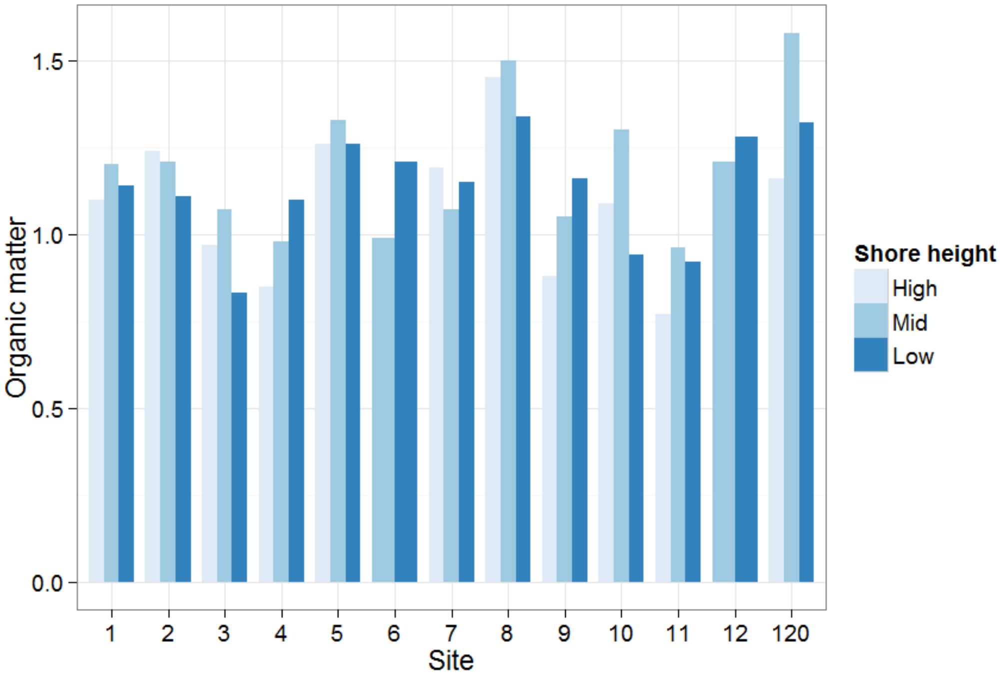


Figure A1.6. Sediment organic content (% ash-free dry weight, AFDW) for each site and shore height.

## References

McCullagh, P, Nelder JA. 1989. Generalized Linear Models. Chapman and Hall, London.

R Development Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Wang Y, Naumann U, Wright ST, Warton DI 2012. mvabund- an R package for model-based analysis of multivariate abundance data. Methods in Ecology and Evolution **3**:471-474.

Zuur AF, Ieno EN, Elphick CS 2010. A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution **1**:3-14.

Zuur AF, Ieno EN, Walker NJ, Saveliev AA, Smith GM 2009. Mixed Effects Models and Extensions in Ecology with R. Springer.

# 8. APPENDIX 2: LAND COVER

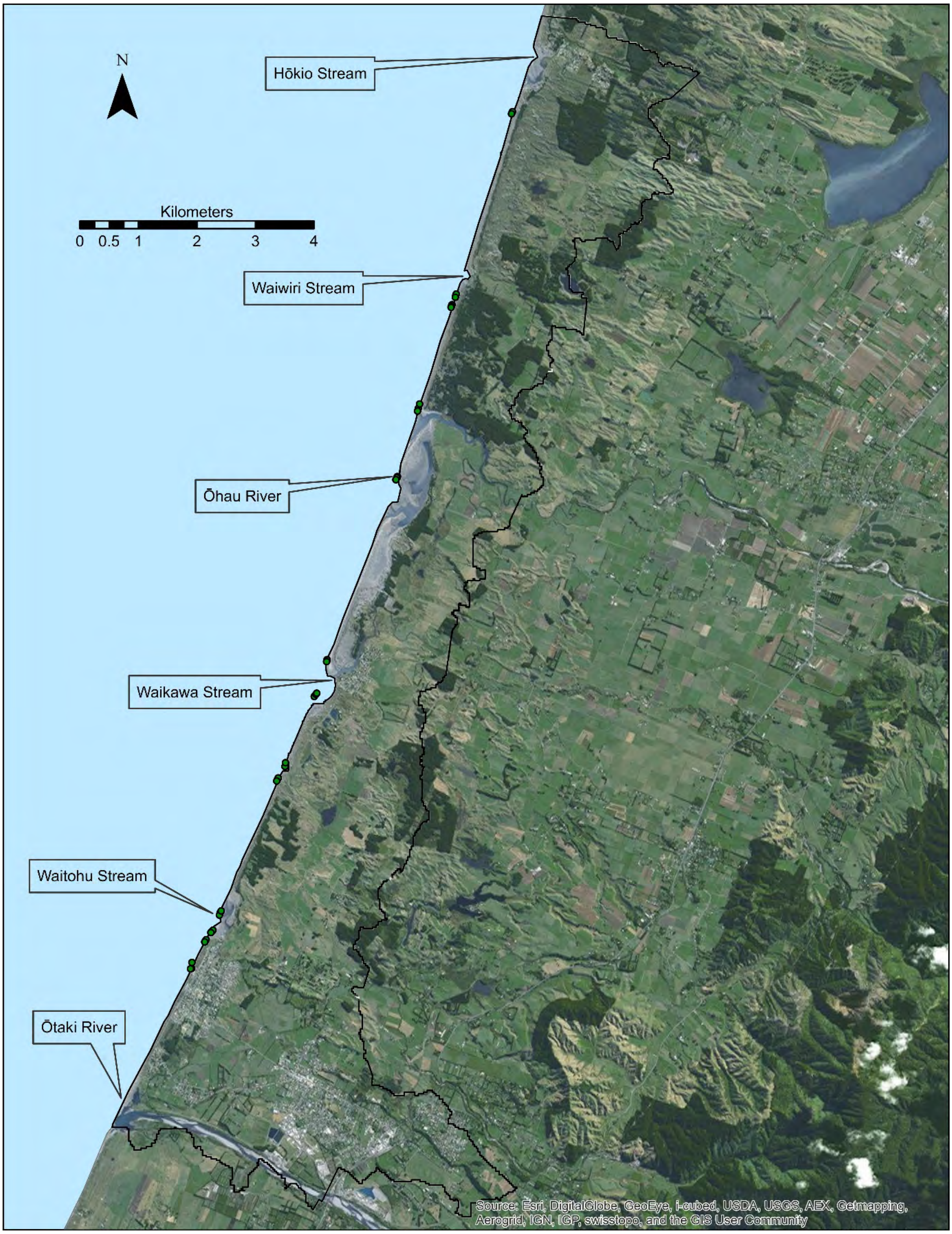


Figure A2.1. Current aerial photo of the broader coastal margin (a black and white version is presented in the body of the report as Figure 4).

Table A2.1. Current land cover in the six shellfish study areas (as % for the area).

| | Total area (ha) | Exotic forest (%) | High producing exotic grassland (%) | Low producing exotic grassland (%) | Sand dune (%) | Urban (%) | Native (%) | Other (%) |
|---|---|---|---|---|---|---|---|---|
| **Hokio** | 240 | 27 | 17 | 24 | 8 | 4 | 10 | 1 |
| **Ohau** | 586 | 18 | 56 | 4 | 14 | 0 | 2 | 6 |
| **Ōtaki / Waitohu** | 1071 | 4 | 61 | 1 | 2 | 18 | 2 | 13 |
| **Waikawa** | 358 | 10 | 44 | 26 | 10 | 7 | 1 | 3 |
| **Waiorongomai** | 521 | 11 | 60 | 20 | 2 | 0 | 3 | 5 |
| **Waiwiri** | 254 | 43 | 47 | 4 | 6 | 0 | 1 | 0 |

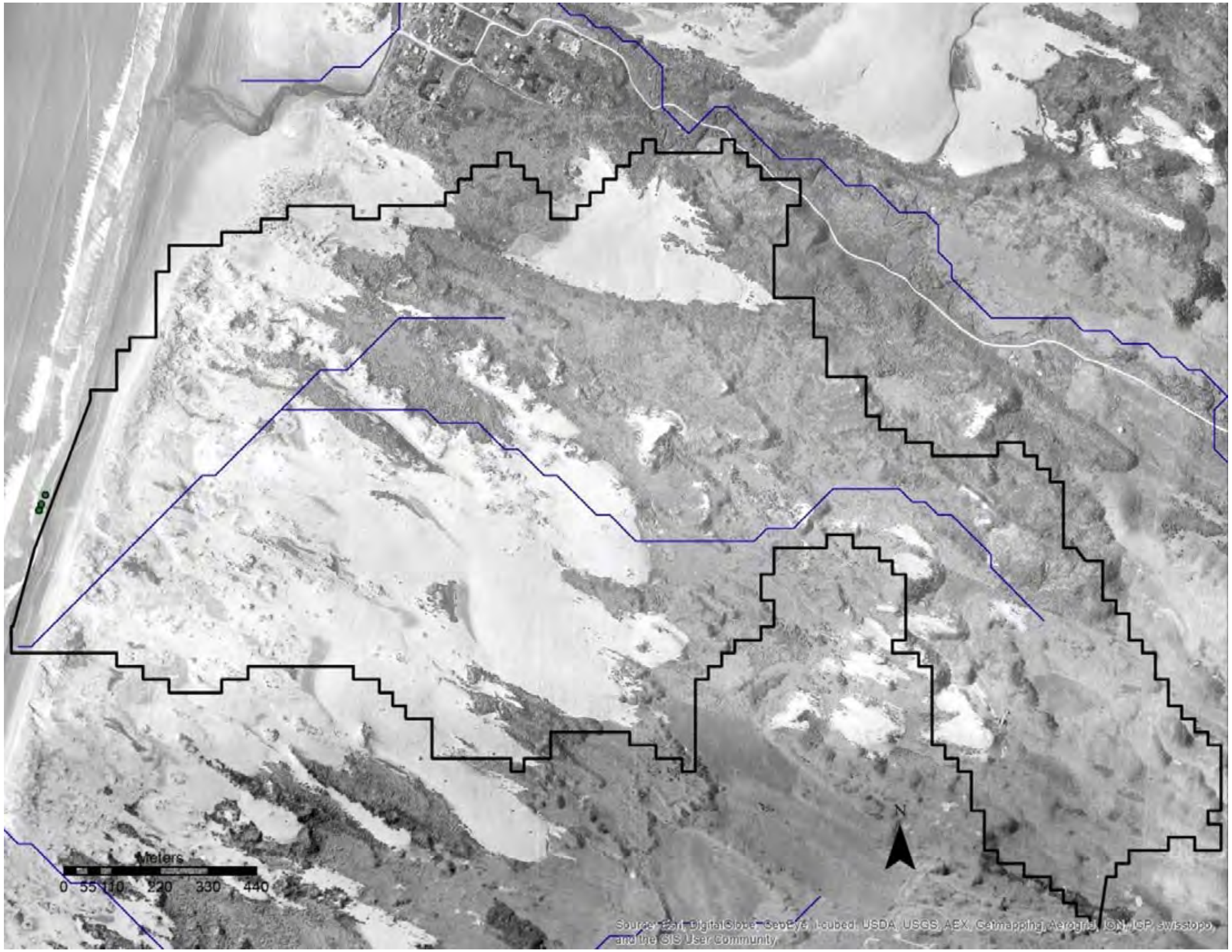


Figure A2.1a. 1942: Approximate sub-catchment feeding shallow groundwater at the Hokio tuatua sampling points (site: south of Hōkio).

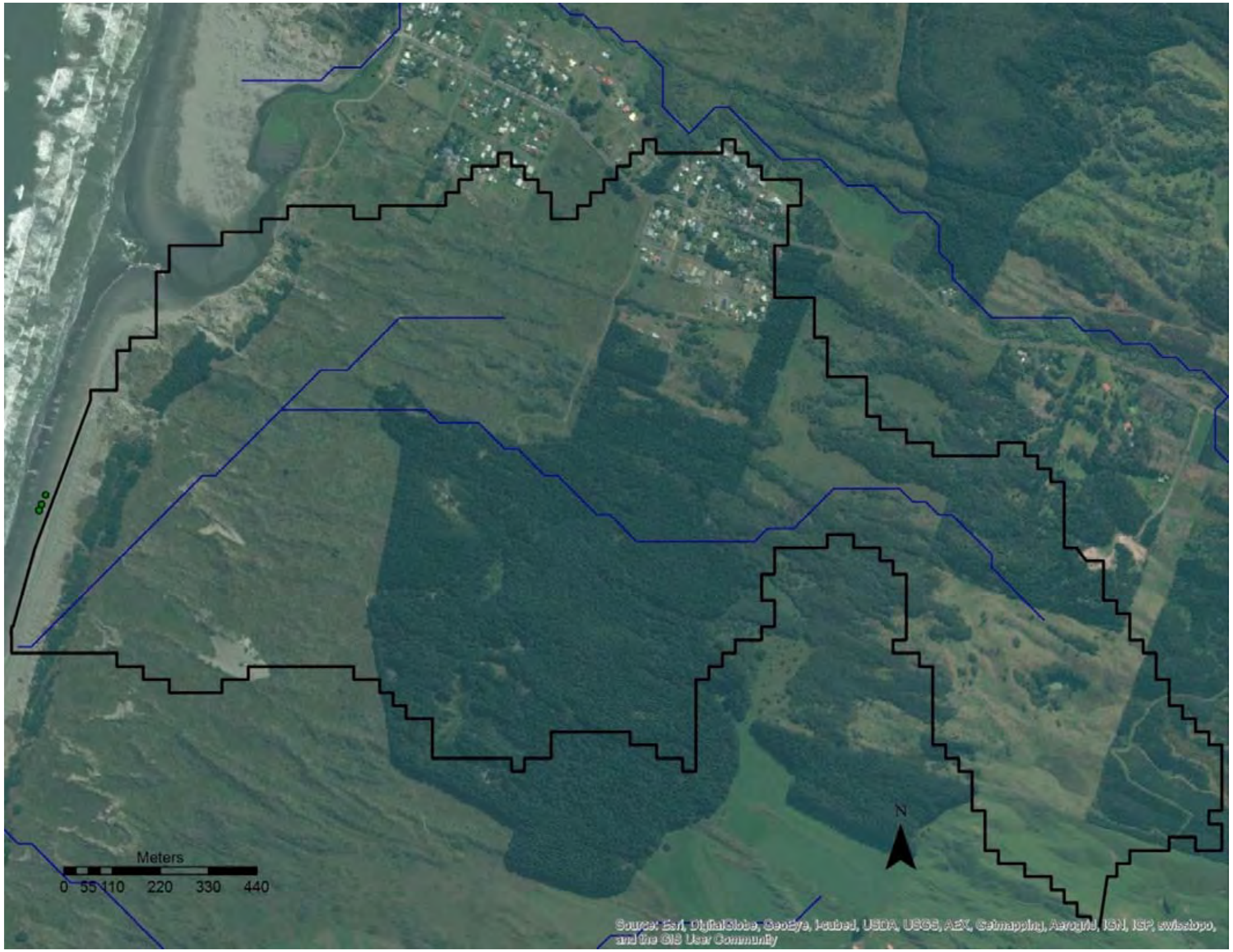


Figure A2.1b. 2008: Approximate sub-catchment feeding shallow groundwater at the Hokio tuatua sampling points (site: south of Hōkio).

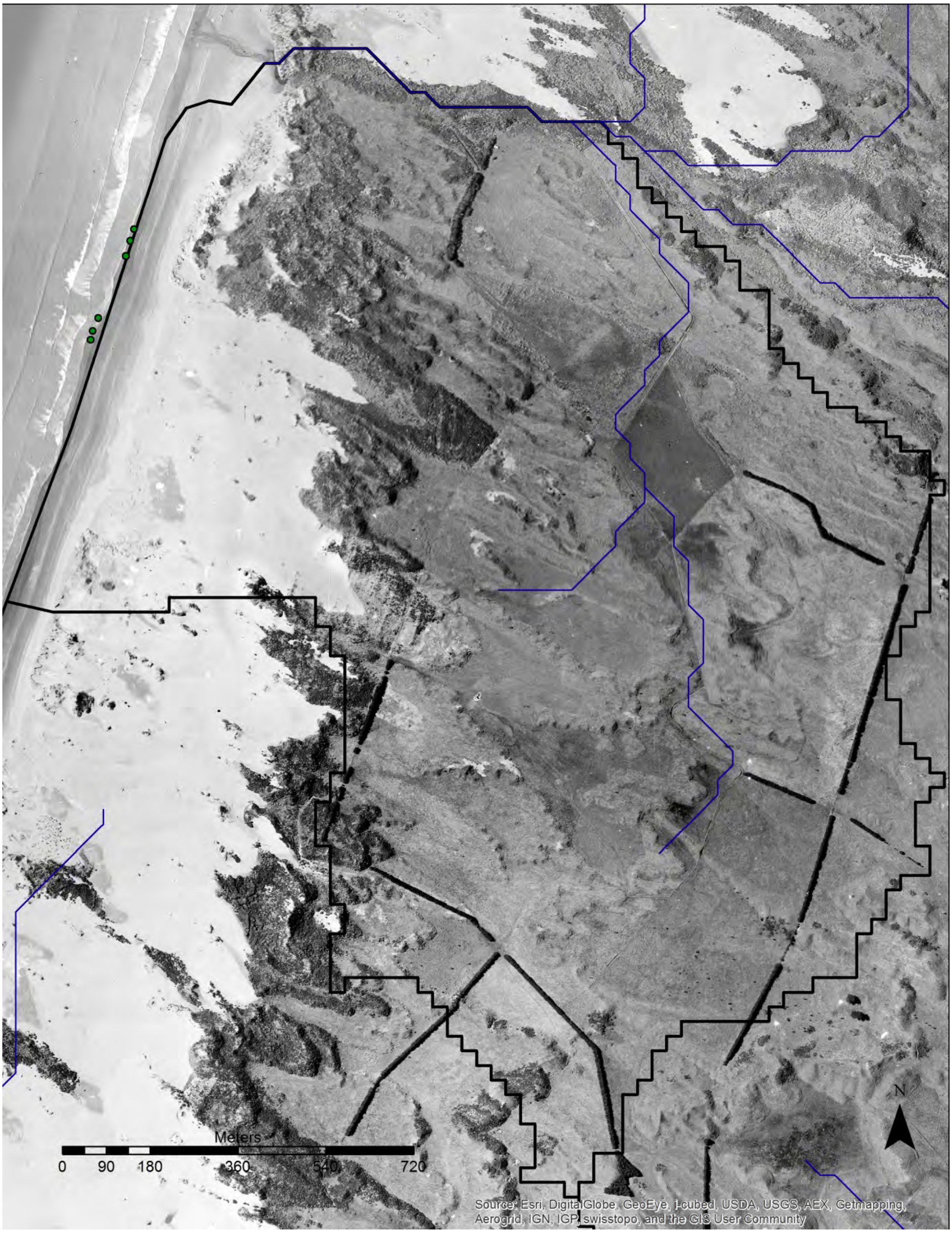


Figure A2.2a. 1942: Approximate sub-catchment feeding shallow groundwater at the Waiwiri tuatua sampling points (sites: north of Waiwiri, south of Waiwiri).

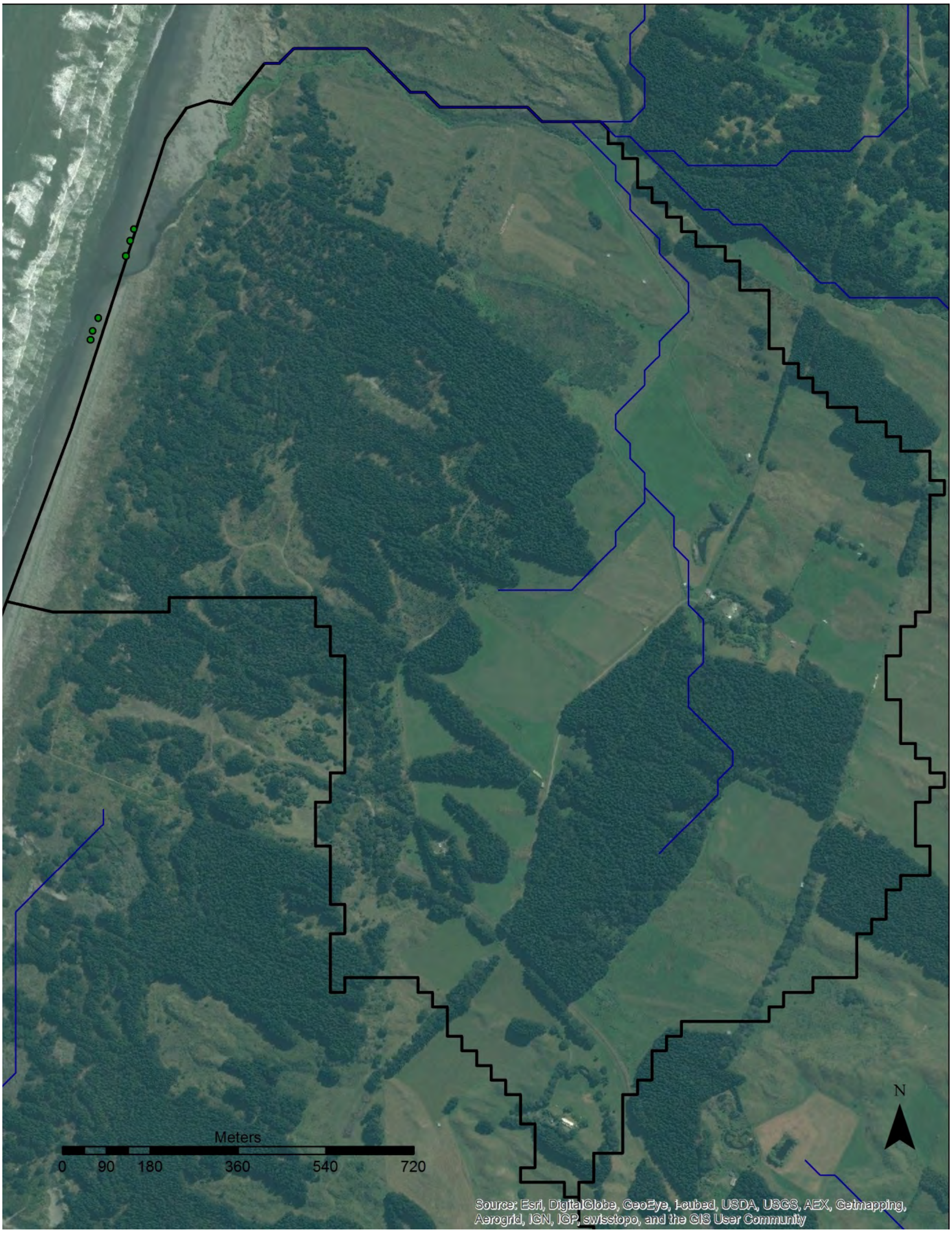
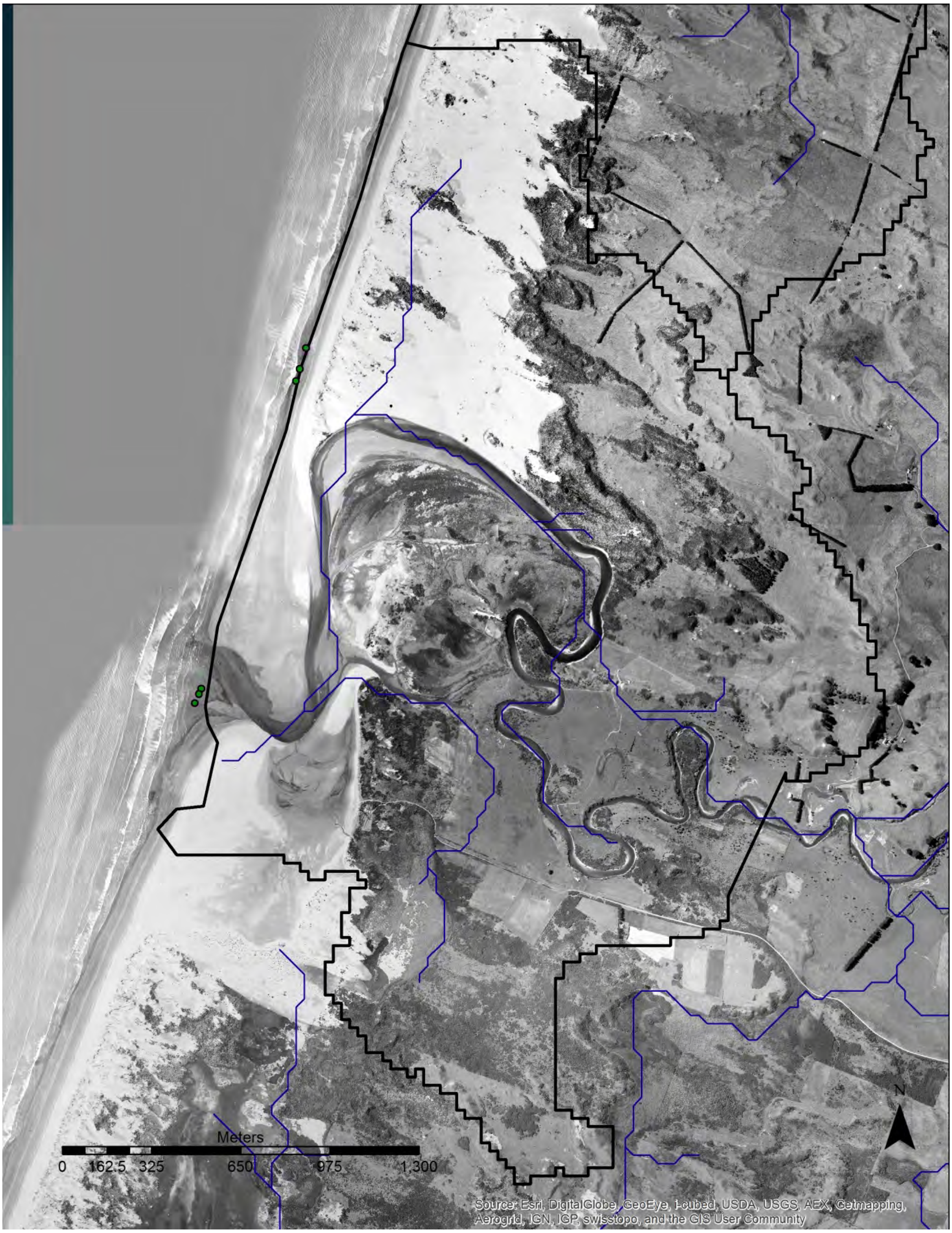


Figure A2.2b. 2008: Approximate sub-catchment feeding shallow groundwater at the Waiwiri tuatua sampling points (sites: north of Waiwiri, south of Waiwiri).



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure A2.3a. 1942: Approximate sub-catchment feeding shallow groundwater at the Ohau tuatua sampling points (sites: north of Ōhau, south of Ōhau).

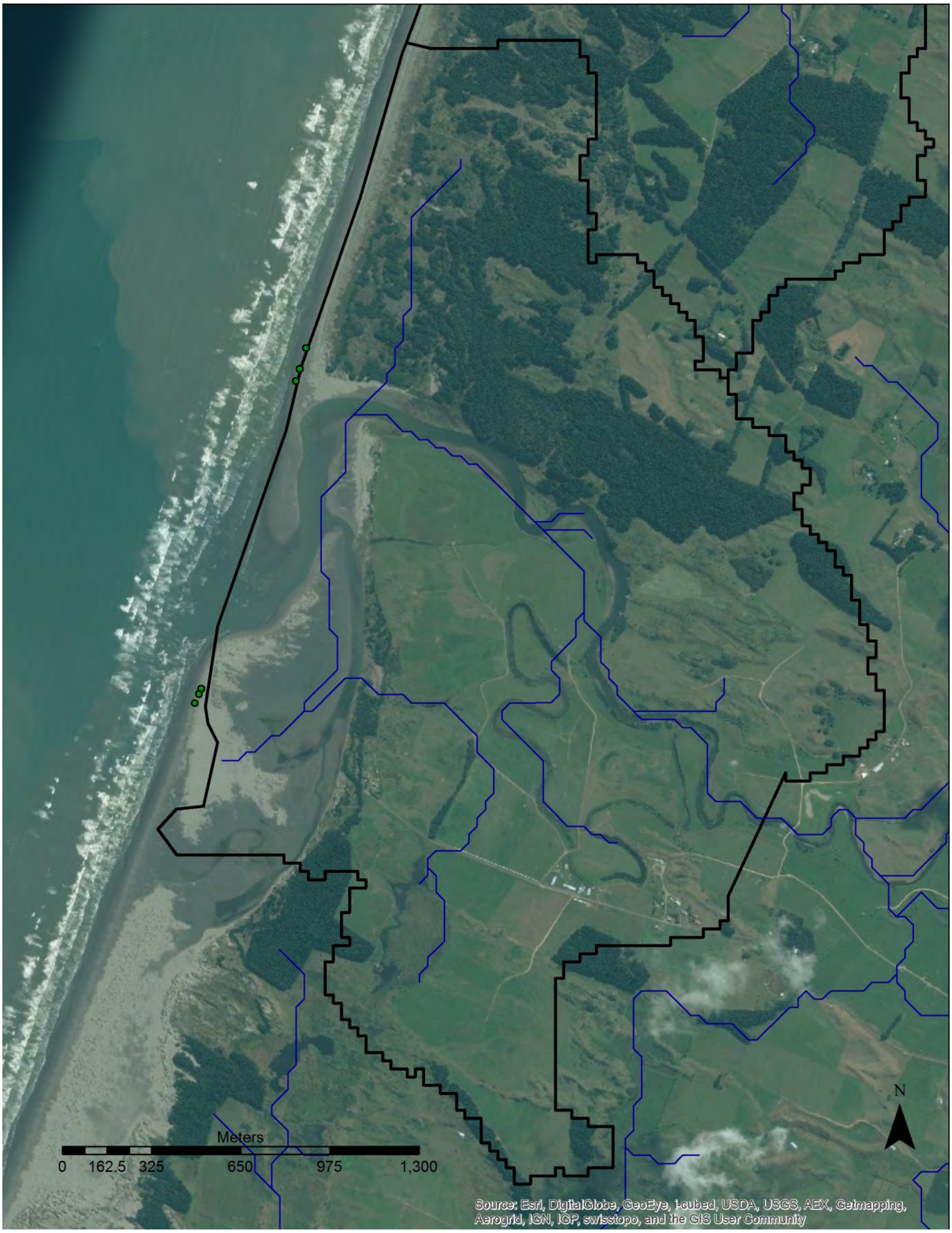


Figure A2.3b. 2008: Approximate sub-catchment feeding shallow groundwater at the Ohau tuatua sampling points (sites: north of Ōhau, south of Ōhau).

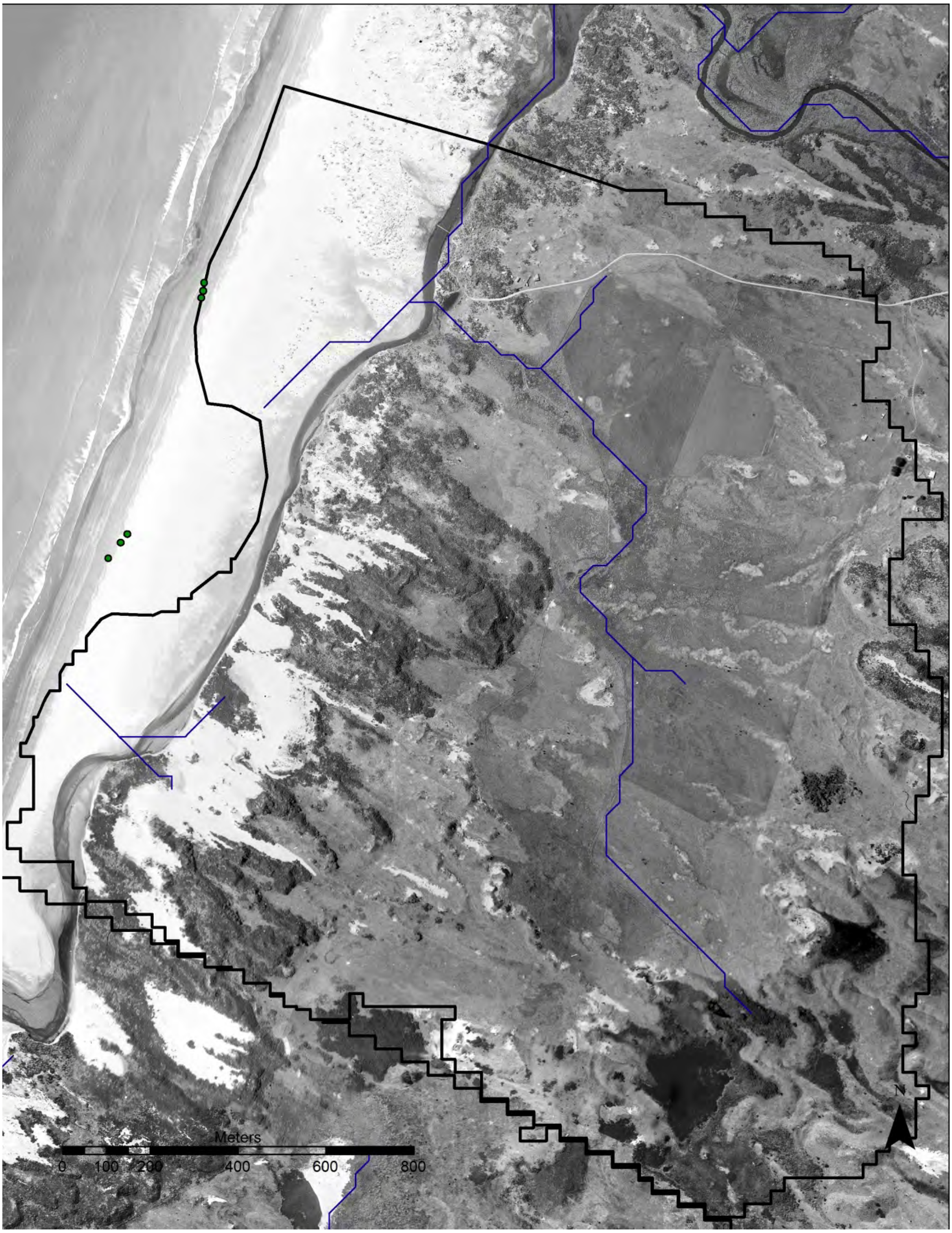
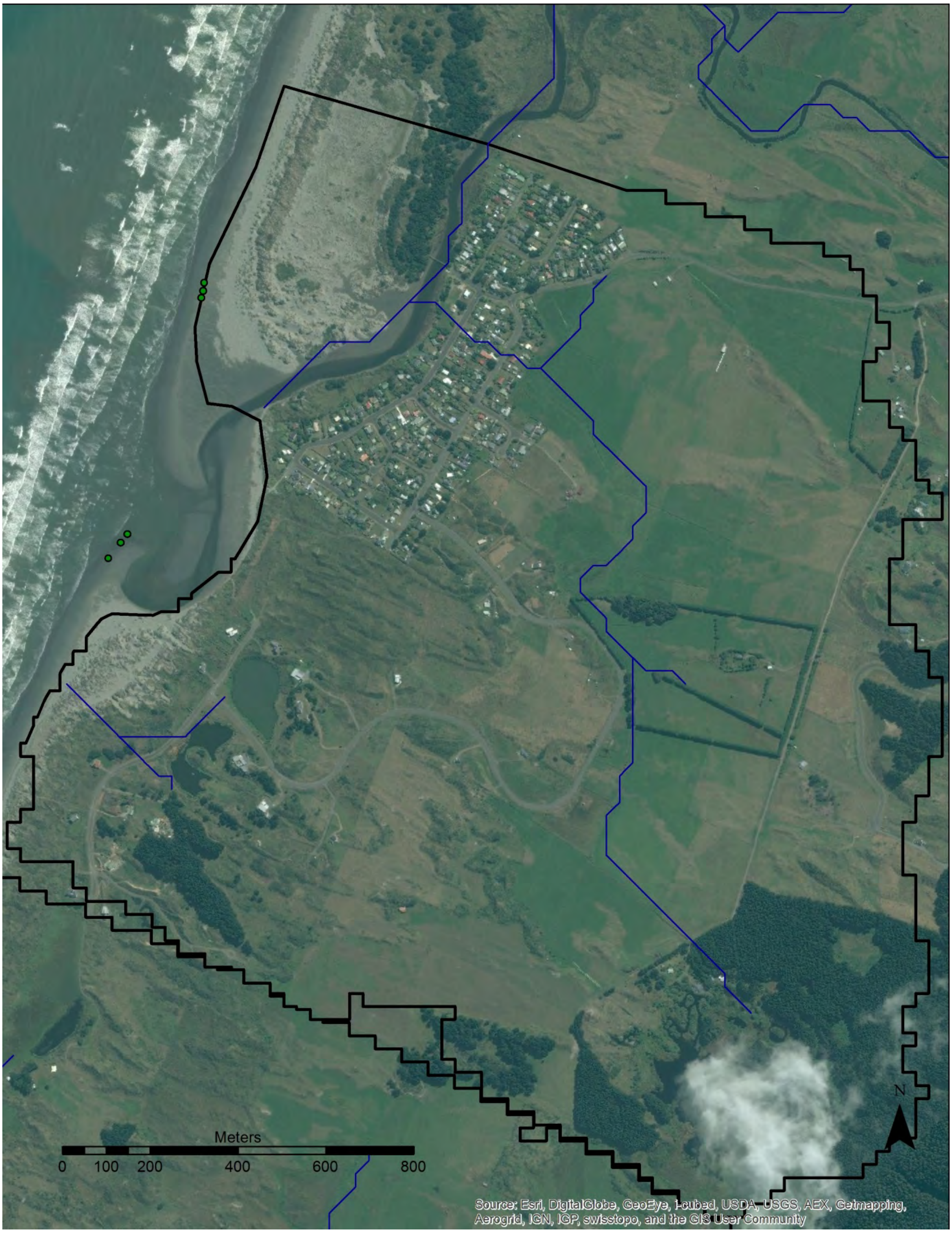
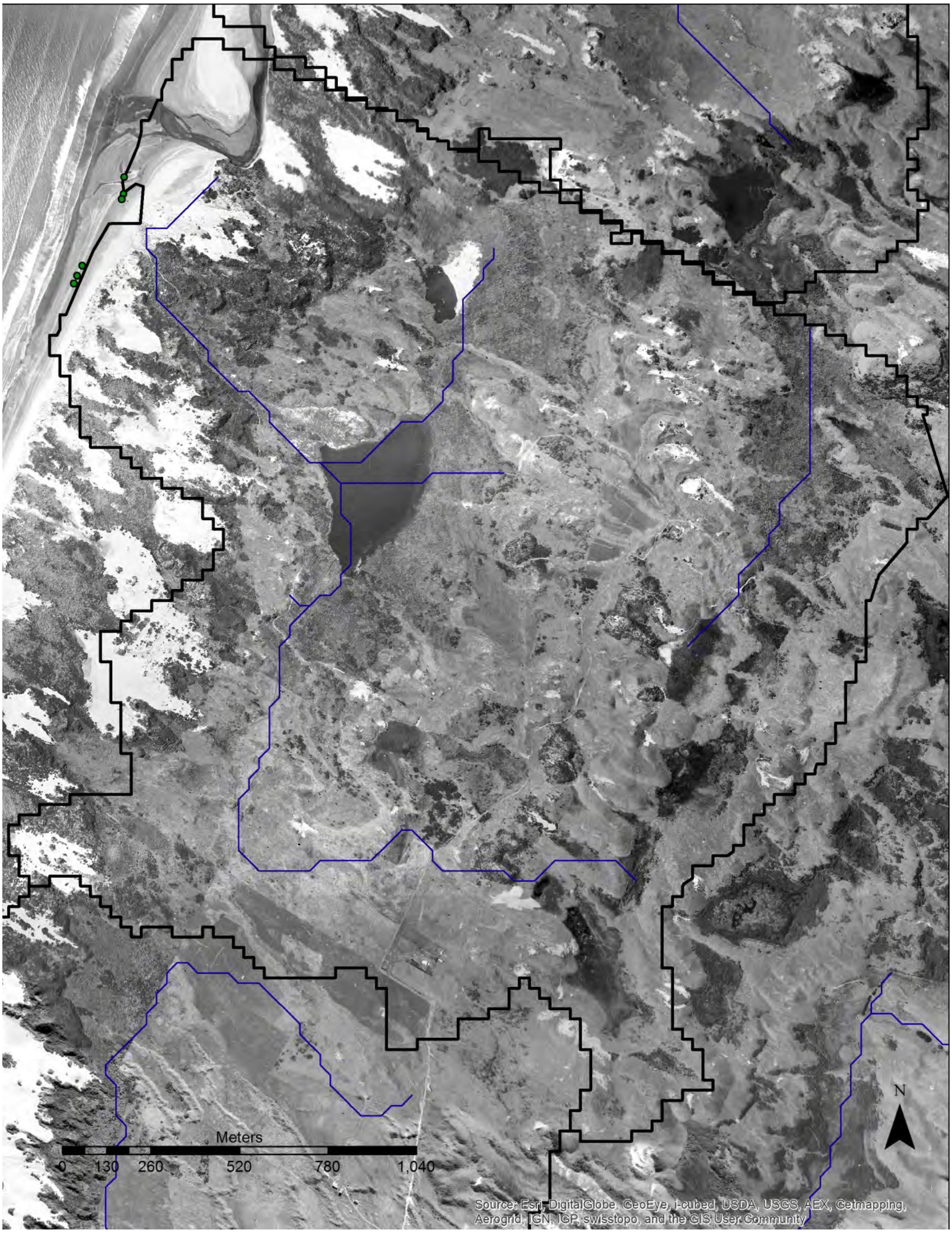


Figure A2.4a. 1942: Approximate sub-catchment feeding shallow groundwater at the Waikawa tuatua sampling points (sites: north of Waikawa, south of Waikawa).



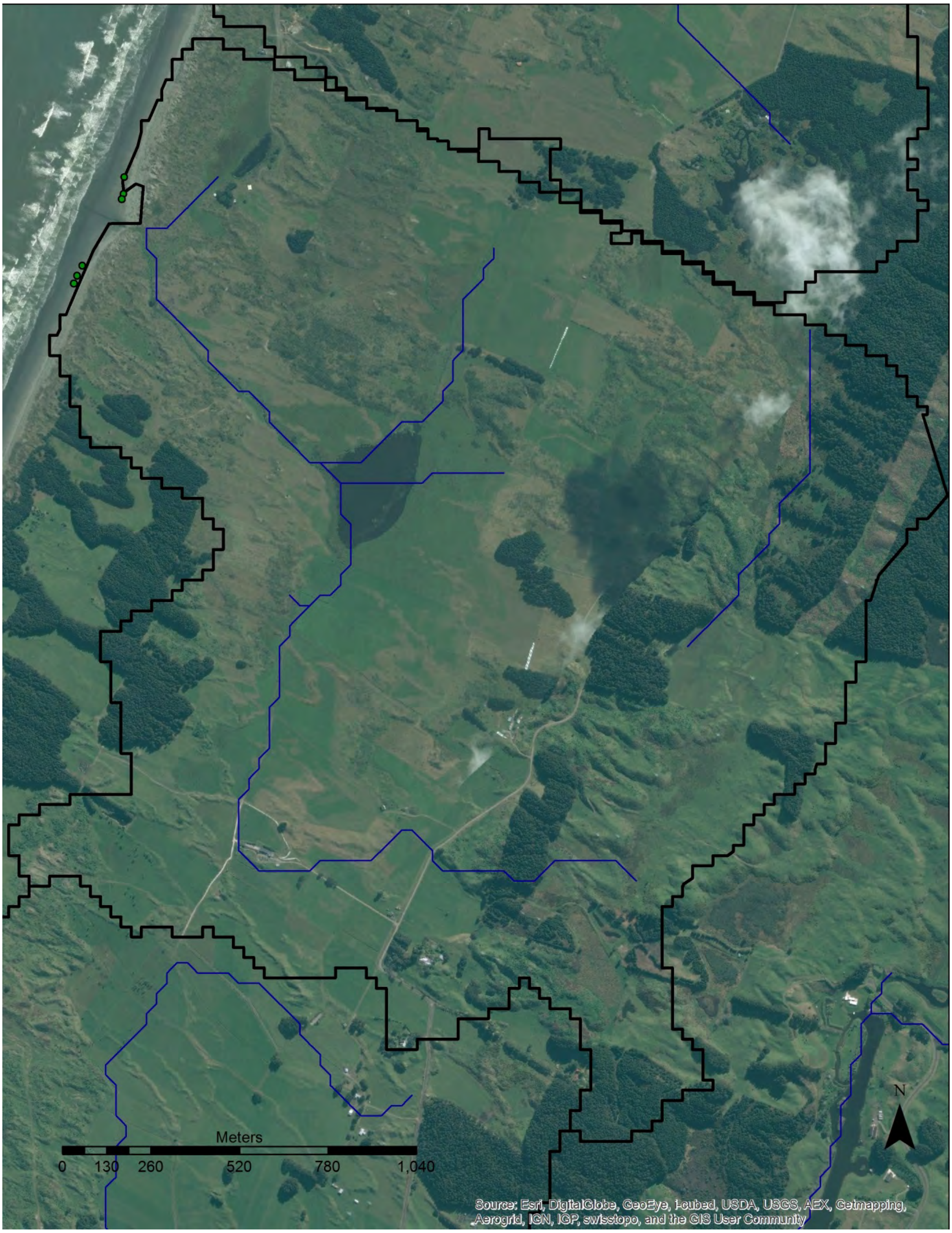
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure A2.4b. 2008: Approximate sub-catchment feeding shallow groundwater at the Waikawa tuatua sampling points (sites: north of Waikawa, south of Waikawa).



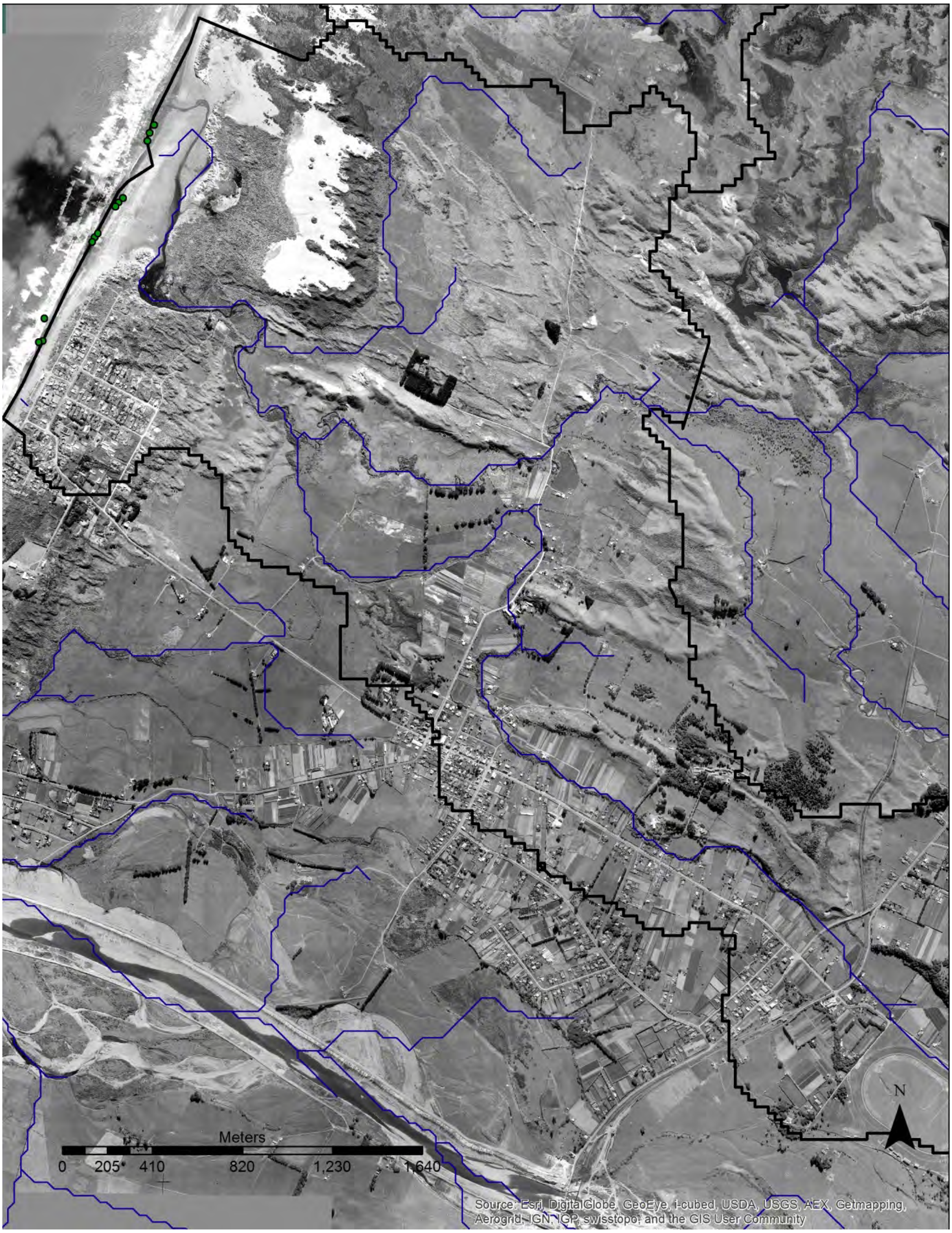
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure A2.5a. 1942: Approximate sub-catchment feeding shallow groundwater at the Waiorongomai tuatua sampling points (sites: north of Waiorongomai, south of Waiorongomai).



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure A2.5b. 2008: Approximate sub-catchment feeding shallow groundwater at the Waiorongomai tuatua sampling points (sites: north of Waiorongomai, south of Waiorongomai).



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure A2.6a. 1948: Approximate sub-catchment feeding shallow groundwater at the Ōtaki / Waitohu tuatua sampling points (sites: north of Waitohu, south of Waitohu, between Waitohu and Otaki, Otaki [surf club]).

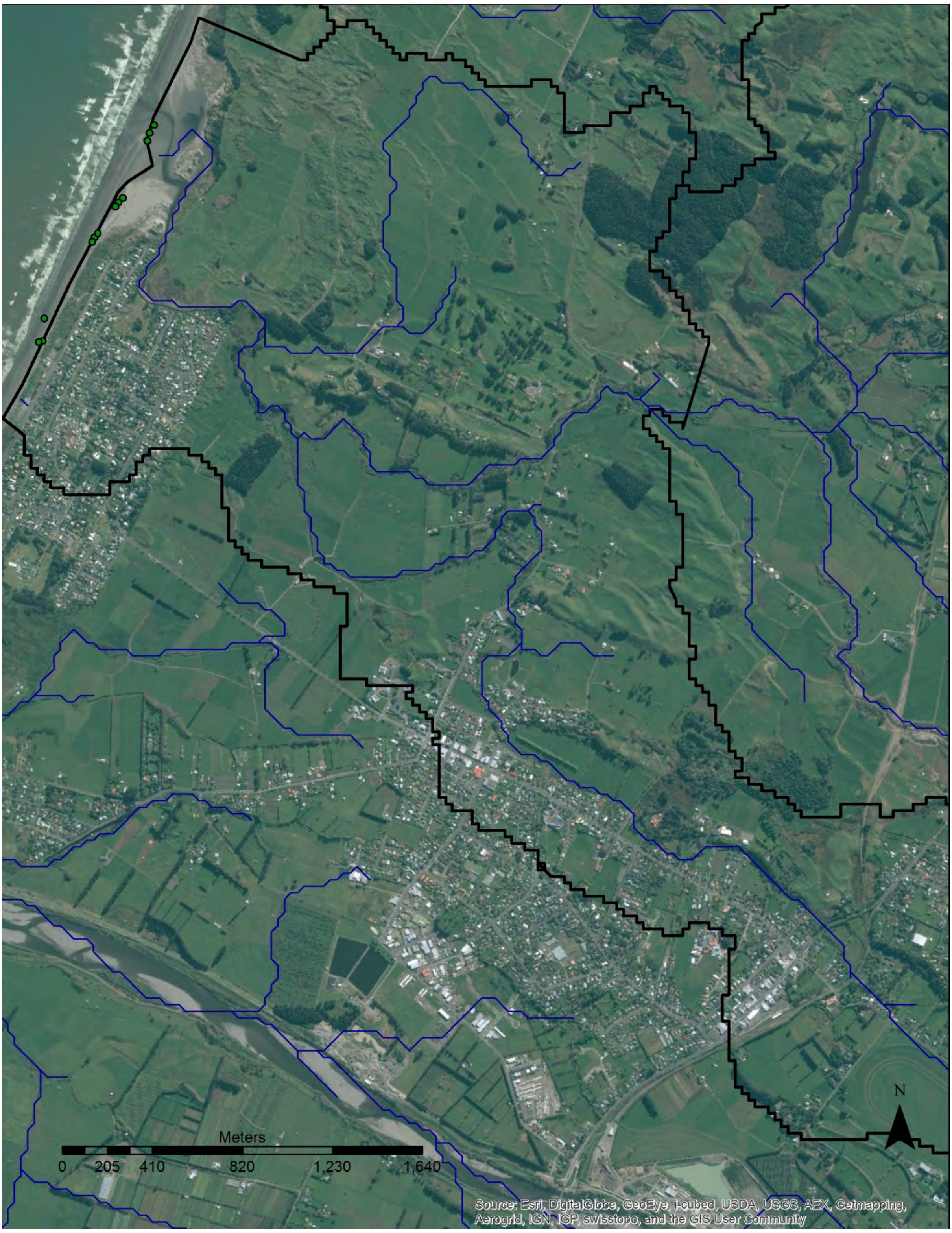


Figure A2.6b. 2008: Approximate sub-catchment feeding shallow groundwater at the Ōtaki / Waitohu tuatua sampling points (sites: north of Waitohu, south of Waitohu, between Waitohu and Otaki, Otaki [surf club]).

# 9. APPENDIX 3: SITE OBSERVATIONS OF SURVEY TEAMS

## Site observations by survey teams

**North of Waiwiri (Site 2)**

**South of Waiwiri (Site 3)**

**North of Ohau (Site 6)**

|  | **South of Hokio (Site 11)** | **North of Waiwiri (Site 2)** | **South of Waiwiri (Site 3)** | **North of Ohau (Site 6)** |
|---|---|---|---|---|
| What is the land like above the beach? (*e.g.* urban, forest, weeds, scrub) | Spinifex, dunes before pine trees, weeds behind dunes | Pine forest, marram grass on dunes | Shrubs, forestry | Scrub, high marram sand dunes |
| Do you know what it used to be? (If known, indicate any previous land covers and approximate year of change.) | Low level dunes covered in spinifex, dune plants including sand coprosma with back dune systems with wet foot plants including hard harakeke etc | Don't know |  |  |
| Traffic – Roughly how many vehicles (excepting ours) have driven on the beach while you were working? | 3 | 2 quad bikes, 2 Landrovers | 4-5 | 3 |
| What number of vehicles do you think would be typical on a summer day? |  |  |  |  |
| What kaimoana are usually found at this site? | tuatua, cockles, Dosinia | Mullet, kahawai, crabs, flounder gurnard, snapper, herrings, tuatua | - | Toheroa |
| What kaimoana used to be found at this site? | Famous for plentiful supplies of toheroa | Toheroa, tuatua, cockles |  |  |
| Is water seeping out of the sand? (yes/no) | yes, low tide, 100 m, 80 m, 50 m | No | 20 m–200 m | 40 m, low to mid tide |
| Are toheroa siphons visible on the beach? Where? | no | No (but 1 found in quadrat) | yes | shells, lots at high tide mark |
| Are ghost shrimp holes visible on the beach? Where? | yes (ref data sheets) | yes, in lower beach area | yes | yes, from water to low tide, few at medium |
| Any thoughts on the health of this area of beach? Is it healthy, have people seen changes? | Poor, while digging holes it smells. | Waiwiri, few pipi, wouldn't drink it, is paru[20]. Better as it comes thru sand but it is still paru[20], so happy to eat shellfish at bottom of beach | no | Very healthy beach |

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[20] (stative) be dirty, muddy, soiled. (noun) dirt, mud, earth. (noun) sewage. www.maoridictionary.co.nz

| | South of Hokio (Site 11) | North of Waiwiri (Site 2) | South of Waiwiri (Site 3) | North of Ohau (Site 6) |
|---|---|---|---|---|
| Anything else you think is important | Definitely lots of tuatua in the tide. | Beach looks ok, just the stream is paru. | lots of tuatua on top of sand | |

Note: There is no photograph of the South of Hokio (Site 11)

**South of Ohau (Site 5)**

**North of Waikawa (Site 4)**

**South of Waikawa (Site 7)**

**North of Waiorongomai (Site 8)**

| | **South of Ohau (Site 5)** | **North of Waikawa (Site 4)** | **South of Waikawa (Site 7)** | **North of Waiorongomai (Site 8)** |
|---|---|---|---|---|
| What is the land like above the beach? (*e.g.* urban, forest, weeds, scrub) | Dunes, backwash, forestry, farming | Forest, grasslands, dunes | Dunes and subdivision. Still some farming. Backwash, whole area covered at extreme high tide. | Dunes |
| Do you know what it used to be? (If known, indicate any previous land covers and approximate year of change.) | Backwash used to be close to the beach 15 years ago | Used to be sand dunes closer to shore around about 1979 | 10 years ago, no houses, was foresty (pine) was developed in 05/06 | don't know |
| Traffic – Roughly how many vehicles (excepting ours) have driven on the beach while you were working? | Vehicle access limited since new gate | 3 cars, 2 quad bikes | 1 | lots, depends on depth of Waitohu |
| What number of vehicles do you think would be typical on a summer day? | | | 12+ | |
| What kaimoana are usually found at this site? | Expect toheroa | Mullet, snapper, kahawai, flounder, tuatua | Maybe rare toheroa. Lemonfish, kahawai, mullet up river. flounder, whitebait, trout up Ohau, Jack salmon up Waikanae<br>(toheroa can be found at Pekapeka and Waikanae) | |

| | **South of Ohau (Site 5)** | **North of Waikawa (Site 4)** | **South of Waikawa (Site 7)** | **North of Waiorongomai (Site 8)** |
|---|---|---|---|---|
| What kaimoana used to be found at this site? | Was a prime toheroa site | Pipi | Toheroa was found at bottom of foothills 06 – 08 | |
| Is water seeping out of the sand? (yes/no) | | yes, 60m | no | not fw seeps @ 100m |
| Are toheroa siphons visible on the beach? Where? | no | no | yes | no |
| Are ghost shrimp holes visible on the beach? Where? | yes | yes | | lots in low shore |
| Any thoughts on the health of this area of beach? Is it healthy, have people seen changes? | | Vehicle traffic/use higher in this area than at Kuku Beach Rd entrance | Very negative about the subdivision | |
| Anything else you think is important | This site and Te Horo, no foot traffic, therefore good for finding toheroa. Older toheroa collector that visited 5 years ago commented that there weren't as many as there used to be. | | | |

**South of Waiorongomai (Site 9)**

**South of Waitohu (Site 1)**

**Between Otaki surfclub and Waitohu (Site 120)**

Note: There is no photograph of the South of Waioronomai (Site 9).

| | **South of Waiorongomai (Site 9)** | **North of Waitohu (Site 10)** | **South of Waitohu (Site 1)** | **Between Otaki surfclub and Waitohu (Site 120)** |
|---|---|---|---|---|
| What is the land like above the beach? (*e.g.* urban, forest, weeds, scrub, …) | Dunes | Marram dunes and some spinifex – high building dunes (scrubby pines N and E) overlooking Waitohu backwash | Thursday | Residential suburb of Ōtaki, behing ~100 m of dunes |
| Do you know what it used to be? (If known, indicate any previous land covers and approximate year of change.) | Swamp before people here, drained now for farming | Was harakeke resource site, was resource use rights for tangata whenua | | 160 yrs ago – settled Taumanuka Block. Swamps before then w/ kahikatea |
| Traffic – Roughly how many vehicles (excepting ours) have driven on the beach while you were working? | High traffic between here and Ohau | 6 x quad bikes<br>1 x van | 2 | 5 cars, 4 quad bikes, 1 horse |
| What number of vehicles do you think would be typical on a summer day? | 20 cars/day | 12 | | |
| What kaimoana are usually found at this site? | tuatua, pipi, turangi (cockle), tohemanga, kahawai, snapper, mullet, gurnard, dogfish, stingray, trevally, groper (further out), terakihi, icefish (phosfish), herrings | tuatua | | Herrings, mullet, kahawai, gurnard, frostfish, dogfish, snapper, tuatua, tuangi (trough shell?) |
| What kaimoana used to be found at this site? | same species but more abundant (used to be able to catch snapper off beach) | toheroa, pipi – all shellfish | | Tohemanga tuatua, tuangi, titoko (estuary) |
| Is water seeping out of the sand? (yes/no) | no | yes – med-low tide | | no |
| Are toheroa siphons visible on the beach? Where? | no | Waitohu improving health, medium health | No | no (despite searching) |
| Are ghost shrimp holes visible on the beach? Where? | yes – low to mid shore | | Yes | yes, more than surf club, but less than Kuku |
| Any thoughts on the health of this area of beach? Is it healthy, | cowpoo, colour of water more cowpoo colour | | | Beach is healthy for pipi. Issue is vehicle traffic, |

| | **South of Waiorongomai (Site 9)** | **North of Waitohu (Site 10)** | **South of Waitohu (Site 1)** | **Between Otaki surfclub and Waitohu (Site 120)** |
|---|---|---|---|---|
| have people seen changes? | (including Ohau) wouldn’t let kids swim in Ohau, & smell. | | | fish carcasses with sharp bones. |
| Anything else you think is important | Shared mahinga kai (not specific to Ohau)<br>Wairongomai had tuna run. Small lakes feed into Waiorongomai. When Papa Sean was a kid it looked like a proper lake. | | | Boaties getting fish and throwing it on beach. |

| | **Otaki surf club (Site 12)** |
|---|---|
| What is the land like above the beach? (*e.g.* urban, forest, weeds, scrub, …) | Urban |
| Do you know what it used to be? (If known, indicate any previous land covers and approximate year of change.) | Urban in living memory |
| Traffic – Roughly how many vehicles (excepting ours) have driven on the beach while you were working? | 4 |
| What number of vehicles do you think would be typical on a summer day? | |
| What kaimoana are usually found at this site? | tuatua, flounder |
| What kaimoana used to be found at this site? | tuatua, flounder |
| Is water seeping out of the sand? (yes/no) | 60 m from high tide |
| Are toheroa siphons visible on the beach? Where? | no |
| Are ghost shrimp holes visible on the beach? Where? | yes, from 10 m below high tide |
| Any thoughts on the health of this area of beach? Is it healthy, have people seen changes? | surprisingly healthy in regards to shellfish considering where it is |
| Anything else you think is important | |