“Potential benefits of transplanting kūtai to restore the mauri of Ōkahu Bay: developing baseline measures of subtidal macrobenthos, sediment environment and larval dispersal”

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Ngā mihi nui kia koutou katoa.

Background

This project fulfils part of the Ngā Pae o te Māramatanga summer studentship project that looks at the elements of ecological and mauri restoration at Ōkahu Bay. This Bay is connected to the hapū Ngāti Whātua Ōrākei as mana whenua. This project was three pronged in its approach, i.e. video analysis of the benthos and sediment sampling within the bay, larval dispersal models under the prevailing winds of Auckland city, and talking to Kaumatua about the state of the bay in past and present years and their thoughts on the direction of the bay.

Ōkahu Bay lies adjacent to Te Whenua Rangatira, occupying a dominant headland near the mouth of the Waitemata Harbour, collectively the ancestral home of Ngāti Whātua Ōrākei. The spiritual significance of the land was recognised by Ngāti Whātua Ōrākei ancestors who sought to safeguard Te Whenua Rangatira as a place which links water, land, forest and sky (Tangaroa, Papatūānuku, Tānemahuta and Ranginui) maintaining a strong link with surrounding cultural landmarks within the isthmus and beyond. Ngāti Whātua Ōrākei consulted widely amongst their people and asked them to describe how they would know when their relationship with Ōkahu Bay had been restored. This resulted in the following vision:

Waters fit to swim in at all times, with thriving marine eco-systems that provide sustainable kaimoana resources to a Ngāti Whātua Ōrākei community who have strong daily presence in and on the bay as users and kaitiaki

To realise that vision Ngāti Whātua Ōrākei developed and have implemented the Ōkahu Catchment Ecological Restoration Plan. This project aligns with Ngāti Whātua Ōrākei's vision statement to restore the mauri to Ōkahu Bay. A specific component of that vision is to restore water quality to that where the waters are safe to swim in and kaimoana can be safely gathered and eaten. Currently, Ōkahu Bay is suffering from an excess of nutrient, storm water pollution and sediment inputs which restrict what activities can be safely undertaken and negatively impact the mauri. Thus, efforts are being made to restore Ōkahu Bay to its former pristine condition. The efficacy of such restoration efforts can be assessed using the Mauri Model, a decision making tool that incorporates social, economic, cultural and environmental wellbeing into sustainability assessments using indicators identified in the iwi vision statement and measured by Ngāti Whātua Ōrākei tangata. The mātauranga of Ngāti Whātua Ōrākei will be complemented by science and cutting-edge technologies.

Ngāti Whātua Ōrākei are deeply committed to realising the dreams and aspirations of their people to enhance Te Whenua Rangatira, including Ōkahu Bay and its surrounding catchment. This project contributes to the wider goal of improving overall outcomes for their people by strengthening links to their natural and cultural heritage, will be part of a suite of projects underway this summer (2 Masters projects, 2 summer interns), and builds on former NPM internship projects.

Abstract

The Waitemata harbour is a drowned valley system at the door of New Zealand's largest urban centre, Auckland City which is now home to 1.4 million people and growing. The Waitemata Harbour is used both commercially and for recreation and acts as a sink for the city's urban storm water and associated contaminants. Efforts are being made by Ngāti Whātua Ōrākei to restore the mauri (life-force) to Ōkahu bay as it is their duty to as Kaitiaki and mana whenua over the area. As a result of this projects based on both in terrestrial and marine environments are being conducted to restore the mauri of Ōkahu bay. One such project is the transplantation of kūtai (a.k.a. green lipped mussels) *Perna canaliculus* into the bay to form reefs and initiate efforts at bioremediation. However, little is known of the current subtidal environment within the bay both now and in the past. To rectify this my project had the following aims 1) to investigate the current state of the benthos within Ōkahu bay, 2) Kaumatua interview to gather his knowledge of the bay over the past and present and his thoughts on the future and 3) conduct models of larval dispersal from a transplanted mussel bed under the predominant winds Auckland experiences. The study created a novel benthic sampling system ideal for use in urbanised areas characterised by heavy boat traffic. Using this system I found that the benthos showed signs of macrofauna at each site, while no populations of mussels were found we know there are intermittent wild populations of both Blue (*Mytilus edulis*) and Green lipped *Perna canaliculus* mussels within Ōkahu bay. Furthermore, Ōkahu bay is heavily dominated by silt <250 µm, whereas according to Tamaiti Tamaariki the bay used to be sandy. The larval dispersal models showed that after 20 days the larvae were settling in various areas of Tikapa Moana depending upon prevailing wind conditions.

Keywords

Bivalve Bioremediation, *Perna canaliculus*, Nutrient Removal, Heavy Metal, Waitemata Harbour, Ngāti Whātua, Kaitiaki, Kaitiakitanga, mana whenua, Mātauranga, Maori

Introduction

The Waitemata harbour

The Waitemata harbour is a large tidal estuary at the door of New Zealand's largest urban centre, Auckland City (Kainamu, 2012). Since pre-colonial times, Tamaki Makaurau was always a destination sought after. With the arrival of Europeans to the shores of Aotearoa the Waitemata harbour provided shelter to what would soon become the nation's largest port and in the years to follow the largest city in New Zealand. Auckland is now home to in excess of 1.4 million people (Statistics New Zealand 2011), the landscape has changed from lowland forest and scrub to bustling highways and extensive suburban neighbourhoods. The urbanisation of land is a result of the population growth and urbanisation drives change in the Hauraki Gulf's environment (Willis, 2008). The Waitemata Harbour is used both commercially and for recreation. And the Harbours act as sinks for the citys urban storm water and associated contaminants (NIWA, 2012a).

Previous Benthic Studies of the Waitemata Harbour

While there is little published material on the benthic environment of the Waitemata harbour, a habitat survey was conducted by Auckland regional council in 2002. The findings of this showed that the intertidal and sub-tidal benthic communities and habitats were generally in good condition but are fragile and must be considered when developing in local catchments. The harbour has a diverse range of invertebrates however populations are smaller in size and individuals are smaller in comparison to other invertebrates found in areas with less development. The diversity of invertebrates within the harbour is supported by the introduction of species on the hulls of shipping containers or in the ballast waters of boats visiting the ports of Auckland. Within the harbour the predominant substrate is composed of predominantly mud (i.e., silt + clay), or a blend of mud and fine to medium sand (ARC, 2002).

Ōkahu Catchment

Although New Zealand has been inhabited by humans for a relatively short period of time, the environmental impacts have been significant (Hauraki Gulf Forum 2011). The Auckland area in densely populated with a population in excess of 1 million. With this high population, development and urbanisation has played a major role in shaping the city's landscape. These changing landscapes have had a significant effect on the ecology and environment of the Hauraki Gulf and Waitemata Harbour.

With the rapid growth of Auckland over time, urban development has had serious impacts on Ōkahu Bay. Raw sewage was discharged from the head of the bay from 1914 until 1960 (when it was diverted to Mangere wastewater treatment plant). The development of Tamaki drive and residential dwellings in Ōkahu Bay altered the catchment and increased the input of urban pollutants and excess nutrients.

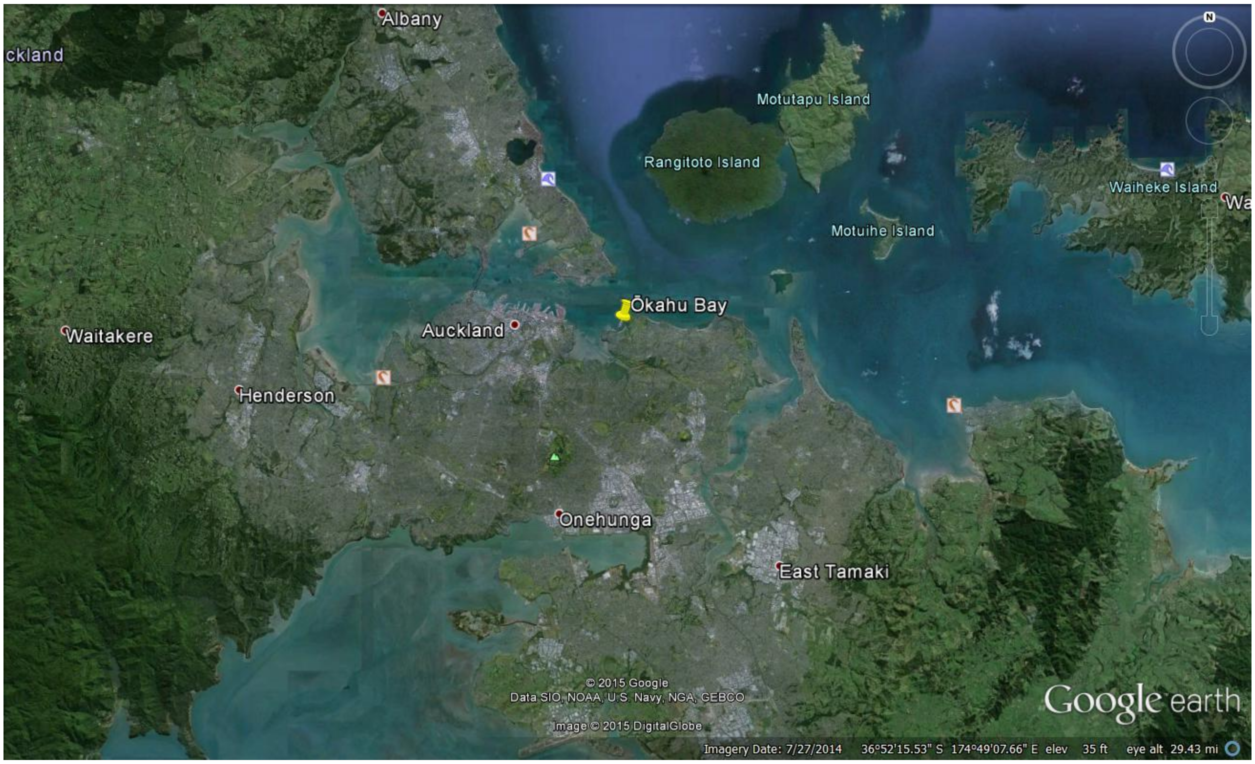


Figure 1: Map of Auckland with the position of Ōkahu bay

Figure 2: Map of the Ōkahu bay and the surrounding Judges Bay, Hobson Bay and Mission Bay.

In 2005, the Ōrākei marina was constructed which altered the sedimentation rates within Ōkahu Bay. Before the Ōrākei marina, sedimentation rates were 0.135 mm of sediment collecting per year. However, after construction of the marina sedimentation had risen to 0.156 mm $year^{-1}$. With this increased sediment it is likely that more contaminants being deposited within Ōkahu Bay. With the addition of Ōrākei marina, it has likely altered the hydrology of Ōkahu Bay. Speeding up and slowing currents under various conditions. Within Ōkahu Bay, the overall current pattern has not been significantly altered, however hydrodynamic modelling by the University of Auckland's Faculty of Engineering indicates that the presence of the marina will have had some impact on the currents in Ōkahu Bay, particularly at the western end. Man-made structures such as bridges, causeways, culverts, floodgates, fords and weirs, are known to have the potential to reduce tidal flows (Williams and Watford, 1997). This obstruction to tidal flushing can cause environmental issues like a build-up of sediment, nutrients and reductions in salinity.

Nutrient build up can lead to an influx of cyanobacterial growth, which can change the aquatic ecosystem dynamics (ANZECC, 2000; EPA, 2001). Excessive nutrients enrich the water and sediment with organic matter, causing a flux in oxygen from aerobic marine microbes which may lead to anoxic conditions or hydrogen sulphide production (ANZECC, 2000). These conditions could prove detrimental to sessile organisms within the bay with potentially fatal consequences for many organisms.

Studies have reported that sediment transport processes are altered at coastal ports and marinas through reflection of waves of port structures and hydrographical modifications caused by dredging. Permanent loss of habitat and biological productivity occurs where structures occupy the foreshore and seabed, or where major dredging works are performed to establish harbours and shipping channels (Coleman et al., 1999).

The Green Lipped mussel*, Perna canaliculus*

The kūtai, or green-lipped mussel (*Perna canaliculus*), is the largest of the 12 species of Mytilid mussels present within New Zealand growing up to 240 mm in shell length (anterior-posterior axis). *P. canaliculus* is found in both the north and south island, however it is more common in the warmer northern regions (Powell 1979; Alfaro et al., 2011; McLeod, 2009; Jenkins 1985; Gibbs, 2004). *P. canaliculus* is found in depths from the mid-littoral to waters over 50 m (Alfaro et al. 2011). Distribution is governed by environmental parameters such as temperature and salinity (Alfaro et al. 2011). While it has a temperature range from 5.3 °C in the south, to 27 °C in the north (Alfaro et al. 2011, MacDonald 1963, Hickman 1991) *P. canaliculus* is far more successful in the warmer waters of estuaries and bays in the northern coastal areas. This species is highly tolerant to a wide range of salinities, however the optimum range is from 30 to 35 PSU (Alfaro et al. 2011; Flaws 1975) and feeds by filtering phytoplankton and other particulate matter from the water column.

P. canaliculus is a dioecious (male and female sexes) broadcast spawner, essentially both males and females release their gametes (eggs and sperm) in to the water column to reproduce (Alfaro et al. 2011; Jenkins 1985). Generally *P. canaliculus* have mass spawning events, these spawning events happen from June through to December in the Ninety Mile beach area (Ministry of Fisheries, 2010), while populations in the Marlborough Sounds have spawning periods in early summer, autumn and spring. It is also widely acknowledged that larvae can be present all year round (McLeod 2009; Alfaro et al. 2001).

Individuals are sexually mature after its first year, generally when the shell has reached 40-50 mm, with females showing the ability to produce up to 100 million eggs per season. During post larval stages *P. canaliculus* is able to re-settle numerous times on to different substrates (McLeod 2009; Buchanan and Babcock 1997; Alfaro and Jeffs 2002; Alfaro et al. 2004; Alfaro 2005).

Transplantation of kūtai as a bioremediation effort

Bioremediation is concerned with the biodegradation of organic compounds to nontoxic forms in order to improve and restore the environmental quality of a selected site (Baker and Herson 1994). Excessive nutrient loading is a large pollution issue for the marine environment worldwide (Cloern, 2001; Petersen et al, 2014). Previous efforts to combat excessive nutrient loading have all been land based and are either aimed at the point source or non-point source reduction on nutrient (Petersen et al. 2014). With the increased awareness of heavy metal and excess nutrient content in the marine environments, the use of bivalves as a natural solution to remove these contaminants have been investigated, particles such as copper, lead and zinc (Dunphy et al. 2011) as well as the remediating nitrogen loads to coastal waters (Carmichael et al. 2012; Petersen et al. 2014).

Mauri restorative efforts at Ōkahu bay.

The University of Auckland (Dr. Brendon Dunphy and Alyx Pivac) in collaboration with Ngāti Whātua Ōrākei have a project underway which aims to use Kutai as a form bioremediation to restore and increase the mauri to Ōkahu bay and as an extension the surrounding areas. Whilst surveys of the intertidal have been carried out annually, subtidal surveys have been neglected. If the transplantation efforts are to be increased we need to have a better understanding of the subtidal environment within Ōkahu Bay. Furthermore, an understanding of past conditions and subsequent change due to urbanisation is vital, this information however is absent from scientific literature for Ōkahu bay. To supplement this loss in scientific literature we are able to utilize Mātauranga Māori from residents within the community who have witnessed the changes. By seeking their input we can obtain valuable insights of changes over the long term thus enhancing any effort at restoration. Lastly, if transplantation efforts are to become self-sustaining an understanding of larval dispersal and supply is needed. In this regards hydrodynamic models can offer insights into potential larval trajectories.

Study Aims

Therefore, the aims of this study were to

1) investigate the current state of the benthos within Ōkahu bay,
2) Conduct interviews with Kaumatua to gather knowledge of Ōkahu Bay over the past and present and his thoughts on the future.
3) Generate hypothetical models of larval dispersal from future transplanted mussels from Ōkahu bay under the prevalent winds Auckland experiences,.

Methods

Study Sites

Study sites were established along three transect lines in the subtidal zone of Ōkahu Bay (see Figure 3). Transects ran from West to East and were set up in line with the Ōrākei marina, inside the break water and outside the breakwater. GPS Coordinates are provided in Appendix 3.

Figure 3: Map of Ōkahu bay with sample sites highlighted.

Sediment collection and analysis

Samples were collected from each site using a towing dredge (90mm x 90mm x 300mm long) for 30 seconds at a boat speed of 1.5 - 2 knots.

These samples were then dried for 72 hours in an oven at a constant temperature of 40 °C. Once dry each sample was broken down using a pestle and mortar. Samples once broken down were run through a set of vibrating sieves for 10 minutes to sort the sample by grain size. The sieves used sorted grain sizes of >2 mm, 1 mm, 500 µm, 250 µm, 125 µm, 63 µm and < 63 µm. The cumulative weight of the sample was taken as well as the weight of each sieved amount. These proportions were then used to figure out percentage (sieved amount of sediment/total amount of sediment per sample).

Still imagery collection and analysis

Images were captured from each site using an innovative low cost GoPro bucket mount and later an novel GoPro transect mount was used to take images. The initial bucket mount took images of the sediment in 200 mm x 250 mm rectangles. The GoPro transect mount took images within a quadrat of 0.5 m^2. Four images were taken from each site, mounts were lowered from the bow and stern on both port and starboard sides of the boat. The mount was left to video for 30 seconds once on the bottom. These videos were then played back and still images were used.

Larval dispersal model- RMA-10 hydrodynamic simulator

The RMA-10 hydrodynamic simulator encompasses a two-fold approach to modelling the dispersal of mussel larvae. First, a hydrodynamic model (§ 2) is constructed to simulate the currents and tides in the area of interest. Second, the simulated currents and tides are fed into a particle tracking model (§ 3), which simulates the movement of larvae spawned in Ōkahu Bay. Both biotic and abiotic variables can then be added to the model to represent different environmental and biological scenarios. In this case we looked at the settlement of larvae after 20 days under these three scenarios: No wind, constant north/north easterly and constant westerly. Larvae were released from the study site: 36°50’49 S; 174°48’59 E, with a buoyancy velocity set to -0.25 mm/sec.

Historical interview

An informal interview was conducted with Tamaiti Tamaariki, a Kaumatua who grew up in Ōkahu Bay and had seen the changes that had happened within Ōkahu Bay over time. The purpose of this interview was to incorporate Mātauranga Ōrākei and provide understanding of Ōkahu Bay in terms of past habitats, and species presence and abundance. While this interview was informal the Mātauranga Ōrākei gathered gives a background that scientific data cannot provide. While interviews with Kaumatua and Kuia have been documented before I don’t believe their findings have been published before. This paper will refer to dialogue from this interview however a transcript will not be made available. These questions where first written to ask however the interview went off cuff due to time constraints.

1. What are your thoughts on the current state of the bays ora/health?
2. How would you describe a healthy bay?
3. What did the bay used to be like when it was healthy?
4. What kaimoana was collected, from where and in what quantities?
5. What was in the bay that isn’t anymore?
6. What would your idea of a healthy bay be? How would you measure this?
7. How do you want to achieve this?
8. What are your thoughts on seeding Kutai(mussel) in the bay as a method of restoring mauri

Results

In total 15 sites were sampled within Ōkahu Bay and the results are provided in Table 1 Great abundances of surface macrobenthos were not evident. Every site except 3 showed the presences of burrow. Site 1 had one Cushion star *Patiriella regularis*. Site 3 had *Ecklonia radiata* present. At Site 4 a juvenile horse mussel *Atrina Zelandica* was present. Site 12 had another algae present. Every site sampled had a predominantly silt substrate, whereas Site 3 showed the presence of rock surface also. Sites 7 and 13 both had sand present while site 7 had relatively high shell presence.

Table 1: Organisms and substrate found at each sample site within Ōkahu Bay.

Site	Present	Substrate
1	Burrows, Cushion Star *Patiriella regularis*	Silt
2	Burrows	Silt
3	Ecklonia	Rock/Silt
4	Burrows, Juvenille Horse Mussel *Atrina zelandica*	Silt
5	Burrows	Silt
6	Burrows	Silt
7	Burrows	Silt/Sand/Shell
8	Burrows	Silt
9	Burrows	Silt
10	Burrows	Silt
11	Burrows	Silt
12	Burrows, Macro Algae	Silt
13	Burrows	Silt/Sand
14	Burrows	Silt
15	Burrows	Silt

Figure 4 shows the breakdown of grain size percentages per site. The grain size for each site is predominantly made up of particles of 125 µm or smaller. Only Sites 7 and 10 had an average site composition of equal to or over 125 µm in size. For all sites except site 14, 125 µm is the representative grain size. Site 14 has a representative grain size of 63 µm. Site 13 has a significant amount of particles which are 250 µm. Sites 7 and 10 have a large amount of particles which are larger than 2 mm.

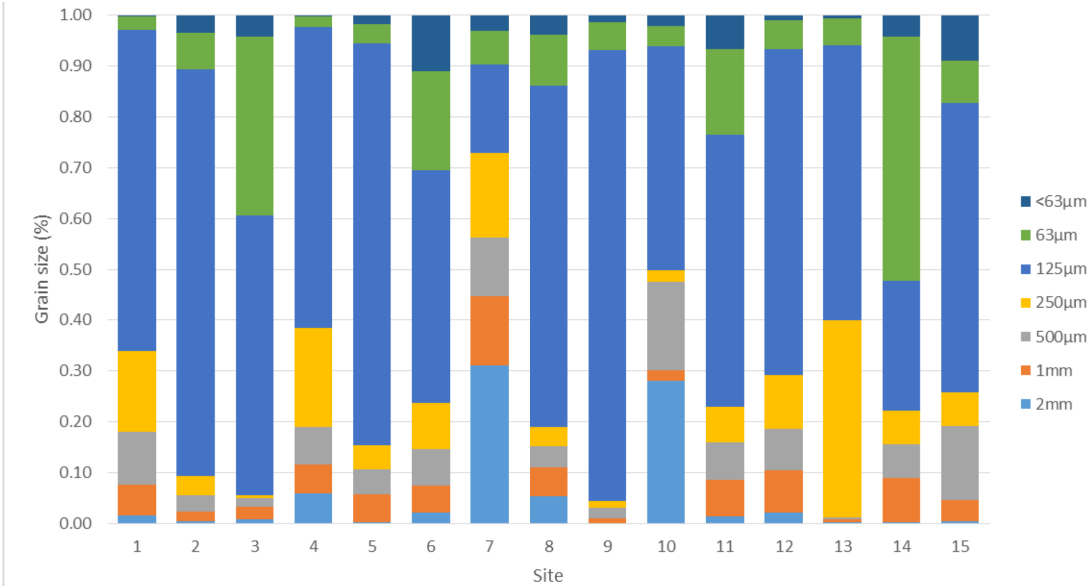


Figure 4: Grain size as a percentage for sites sampled at Ōkahu Bay

<u>Larval dispersal models</u>

Modelling of 500 particles released from Ōkahu Bay revealed that under "No wind" after 20 days the larvae settles within the mid harbour and extends out towards the northern bays, Tamaki River and Rangitoto (Figure 5.).

Figure 5: Hypothetical settlement of mussel larvae from Ōkahu Bay under "No wind"

Whereas, under a northerly wind after 20 days the larvae settles within the mid harbour and extends out towards the northern bays, Tamaki River and Rangitoto. And extends out to the north of Rangitoto and Motutapu(Figure 6.).

Figure 6: Hypothetical settlement of mussel larvae from Ōkahu Bay under a "Northerly wind".

Under a westerly wind after 20 days the larvae settles within the Tamaki River in small fragments continuing on along the coast to the firth of Thames where the majority of larvae settles (Figure 7.).

Figure 7: Hypothetical settlement of mussel larvae from Ōkahu Bay under a "Westerly wind".

Interview with Tamaiti Tamaariki

Interesting points taken from the meeting

- The bay was traditionally composed of sand
- Since the development of Tamaki drive and the Ōrākei marina it has become silt
- The bays mauri has been subject to many events which have degraded the bay
- While the addition of the Ōrākei marina and moorings the bay has also had an increase in mussels fixing to hard structures like breakwaters and boats.
- The water in the bay used to be "red with Snapper"

Discussion

The findings of the benthic survey are consistent with what we expected to see. Due to the relatively small area able to be videoed it was hard to find biological organisms in the footage. However the presence of burrows at all silt sites suggest the presence of many interstitial macrofauna. The Waitemata harbour's silt bottom floors provide ideal habitats for the likes of snapping shrimp *Alpheidae*, and burrowing crabs *Helice crassa* and *Hemiplax hiritipes*. The presence of the cushion star *Patiriella regularis* and a juvenile horse mussel are the only fauna identified in our video analysis. Due to the relatively sessile or slow moving states of both these organisms they were the only ones able to be caught on film. Faster moving fauna like the crabs or snapping shrimp would most likely have fled into their burrows once the camera mount was visible to them. This is an issue with such passive methods of data collecting. The presence of two different types of algae and at two different sites was also of interest. *Ecklonia radiata* was found on what appeared to be rocky reef at site 3, this area according to models run by The University of Auckland Department of Engineering Science show a high amount of current running through the site. Site 12 which is out past the break water also had the presence of macro algae. From previous studies conducted in the intertidal by Kainamu (2012) we know that sea grass (*Zostera marina*), Cockles (*Austrovenus stutchburyi*), pipis (*Paphies australis*), are present as well as greenlipped mussels (*Perna canaliculus*) and scallops (*Pecten novaezelandiae*) in small pockets.

When looking at the still imagery of each site it was clear that all sites besides sites 3, 7 and 13 clearly had a substrate composed of silt. Site 3 has what appeared to be rocky reef, and sites 7 and 13 had a combination of shell and sand. All of these sites are areas of high current flow according to previous models run in The University of Auckland Department of Engineering Science. The high current running through these areas are most likely what plays a part in the composition of the substrate. In areas of fast current it will be harder for silt to settle and most likely what silt does get deposited is flushed out with the currents over time (van der Ham, 1999*)* Due to the dangerous conditions Ōkahu Bay presents with its urbanised environment and high boat traffic it was unsafe for divers to conduct surveys. To counter this we decided to make an underwater camera mount which overlooked a built in quadrat. This innovative system was both small and mobile while providing us with high resolution imagery at a relatively low cost.

The grain size distribution throughout the bay is relatively uniform with the majority of each site being made up of particles smaller than 250 um. The only exception to this is site 7. The grain size percentages for site 7 show that over 70 % of the sample is larger than 250 um, 30 % of that is over 2 mm in size. It is evident both visually and after doing sieve analysis. The sample is made up of a lot of shell material and sand. Whilst some of the shell was destroyed during the pestle and mortar stage of dry sieving. This unusual finding could be due to numerous factors, most likely due to the position it is subject to strong currents. One disadvantage of only doing the dry sieve analysis is that we don't know the material make up of each site. This sort of information would be valuable as we would be able to ascertain the origin of the material at each site, this would provide us with an idea of the true effects of urbanization on Ōkahu Bay over time. What is being deposited? Where is it coming from? Is the contaminant dangerous? What volumes of heavy metals are being added to Ōkahu Bay?

In essence what we witness when looking at the state of the benthic environment of Ōkahu Bay, is what is to be expected, extensive mud flats with many macrofauna. Though the addition of the Ōrākei marina has been shown to have increased the sedimentation rate within the bay the true effects of that will only be noticed over a large period of time. Also the altered currents have affected stretches of Ōkahu Bay in different ways. Increased currents directly in front of the marina and decreased currents inside the bay cause the bending and refraction off the marinas breakwater.

The larval dispersal models generated show three very different scenarios. Under the "No wind" scenario we see the majority of the larvae settle within the middle harbour and northern bays and Tamaki River. If these models were correct the placement of these reefs would be ideal, uptake of contaminants through filter feeding would be removing them close to the introduction source. The habitat building structures that mussels provide would also look to increase the biomass within areas which are currently just mudflats. Under a "Northerly wind" we see the larvae settle around the northern bays and carry further out to sea eventually settling around the noises (Otata Island, Motuhoropapa Island). Under a "Westerly wind" we see the larvae settling along the Tamaki River, Auckland's eastern bays down in t the western coastline of the firth of Thames (somewhere in between Orere point and Miranada). Under this scenario we would most likely be getting an aggregation of spat from farmed mussels at the back of Waiheke and within the Firth of Thames also. One caveat with these models is that require steady wind conditions for 20 days – an unlikely situation within Aotearoa. We must also consider that the current model we have for the Waitemata is only two dimensional while the environment is actually three dimensional to enhance the accuracy of these models using a 3D dataset would be a necessity. Nonetheless, they provide an understanding the dispersal envelops for mussels from site and amply demonstrate the spillover effects of transplanting mussels.

Limitations

Due to the relatively short timeframe and challenges the urban environment presented, we were very limited to the depth of data we were able to collect. Limited funding meant that the models which were run weren't as accurate as we would have liked, it would be ideal to get 3D mapping of the Waitemata Harbour done to see how this changes the larval dispersal models we ran. Also given the collaborative effort put in to this project it was hard to meet with all contributors. Boat availability and suitable weather conditions provided and issue to ensure work could be carried out. Ideally if we had a larger time frame and were better resourced we could provide more in-depth information. It would be of interest to see if these results change through seasonality.

Conclusion

In conclusion we found that the benthos is consistent with what we would expect of an inner harbour bay. The potential spillover effects of larvae from the bay covers a relatively local area which is good for adding wild stock to the Waitemata harbour. The data gathered provides key baseline information for any future studies of the subtidal within Ōkahu Bay. We can now see what role the transplant reefs will play in restoring not only the health but the mauri of Ōkahu Bay.

References

Alfaro, A.C., Jeffs, A.G., Gardner, J.P.A., Bollard Breen, B.A., Wilkin, J. (2011) Green Lipped Mussels in GLM 9. New Zealand Fisheries Assessment Report 2011/48. Ministry of Fisheries, Wellington. pp 1-77.

Alfaro, A. C., Jeffs, A.G., Hooker, S.H. (2001). Reproductive behaviour of the greenlipped mussel, *Perna canaliculus*, in northern New Zealand. Bulletin of Marine Science 69(3): 1095-1108.

Alfaro, A. C. (2006). Population dynamics of the green-lipped mussel, *Perna canaliculus*, at various spatial and temporal scales in northern New Zealand. Journal of Experimental Marine Biology and Ecology 334(2): 294-315.

ARC, Auckland Regional Council (2002). Upper Waitemata Harbour Benthic Habitat Survey, Technical Publication No. 219, 1-58.

ANZECC, Australia and New Zealand Conservation Council, (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy, Australia and New Zealand Environment and Conservation Council. CoA, Canberra.

Baker, K.H., Herson, D.S (1994). Bioremediation. McGraw-Hill, University of Minnesota.

Buchanan, S. and R. Babcock (1997). Primary and secondary settlement by the greenshell mussel, *Perna canaliculus*. Journal of Shellfish Research 16(1): 71-76.

Carmichael, R.H., Walkton, W., Clark, H. (2012) Bivalve-enhanced nitrogen removal from coastal estuaries. Canadian Journal of Fisheries and Aquatic Science.69: 1131-1149.

Cloern, J.E., 2001. Our evolving conceptual model of the coastal eutrophication problem. Mar. Ecol.-Prog. Ser. 210, 223–253.

Dunphy, B.J., Millet, M.A., Jeffs, A.G. (2011) Elemental signatures in the shells of early juvenile green-lipped mussels (*Perna canaliculus*) and their potential use for larval tracking. Aquaculture. 311. 187-192

EPA, Environment Protection Authority (2001). Water quality objectives for marine and estuarine waters – ecosystem protection. Draft State Environment Protection Policy (Waters of Victoria). Publication No 794. Environment Protection Authority, Victoria.

Gibbs, M. T. (2004). Interactions between bivalve shellfish farms and fishery resources. Aquaculture 240(1-4): 267-296.

Hauraki Gulf Forum, (2011). State of our Gulf. State of the Environment Report 2011.Hauraki Gulf Marine Park.

Hickman, R.W. (1991). *Perna canaliculus* (Gmelin 1791) in New Zealand. Estuarine and marine bivalve mollusk culture. CRC Press, Boca Raton, Florida.pp 325– 334.

Jackson, J. B. C. (2001). What was natural in the coastal oceans? Proceedings of the National Academy of Sciences of the United States of America 98(10): 5411-5418.

Jenkins, R. L. (1985). Mussel cultivation in the Marlbrough Sounds (New Zealand) N.Z. Fishing Industry Board, Wellington, New Zealand.

Kainamu, A., Hikuroa, D. (2012). Ōkahu Bay restoration, Ngā Pae o te Māramatanga. The University of Auckland. Web. 20/11/2014

Lloyd, B.D. (2003). Potential effects of mussel farming on New Zealand marine mammals and seabirds: a discussion paper. Department of Conservation, Wellington, New Zealand.

MacDonald, I.H. (1963). Studies in the biology of *Mytilus edulis aoteanus* (Powell, 1958) and *Perna canaliculus* Gmelin (1791) , two intertidal molluscs of the rocky shore. Unpublished MSc. thesis, Canterbury University Christchurch, New Zealand

McLeod, I.M (2011). Green-Lipped mussels, *Perna canaliculus*, in soft sediment systems in northeastern New Zealand (Thesis). The University of Auckland.

NIWA, National Institute of Water and Atmospheric Research (2012a) online document as of 20/02/15 http://www.niwa.co.nz/our-science/coasts/research-projects/predictinglong-term-contaminant-accumulation).

Morrison, M.A., Lowe, M.L., Parsons, D.M., Usmar, N.R., McLeod, I.M. (2009) A review of land-based effects on coastal fisheries and supporting biodiversity in New Zealand. New Zealand Aquatic Environment and Biodiversity Report 37, Ministry of Fisheries, Wellington

Petersen, J.K., Hasler, B., Timmermann, K., Nielsen, P., Torring, D.B., Larsen, M.M., Holmer, M (2014). Mussels as a tool for mitigation of nutrients in the marine environment. Marine Pollution Bulletin. 82:137-143

Powell, A.W.B. (1979). New Zealand Mollusca: Marine land and freshwater shells. Collins, Auckland. 500 p.

Statistics New Zealand, (2014). New Zealand in Profile 2014. New Zealand Foreign Affairs and Trade. New Zealand Government

Van der Ham, R. (1999). Turbulent exchange of fine sediments in tidal flow. Communications on Hydraulic and Geotechnical Engineering. 99(1):1-167

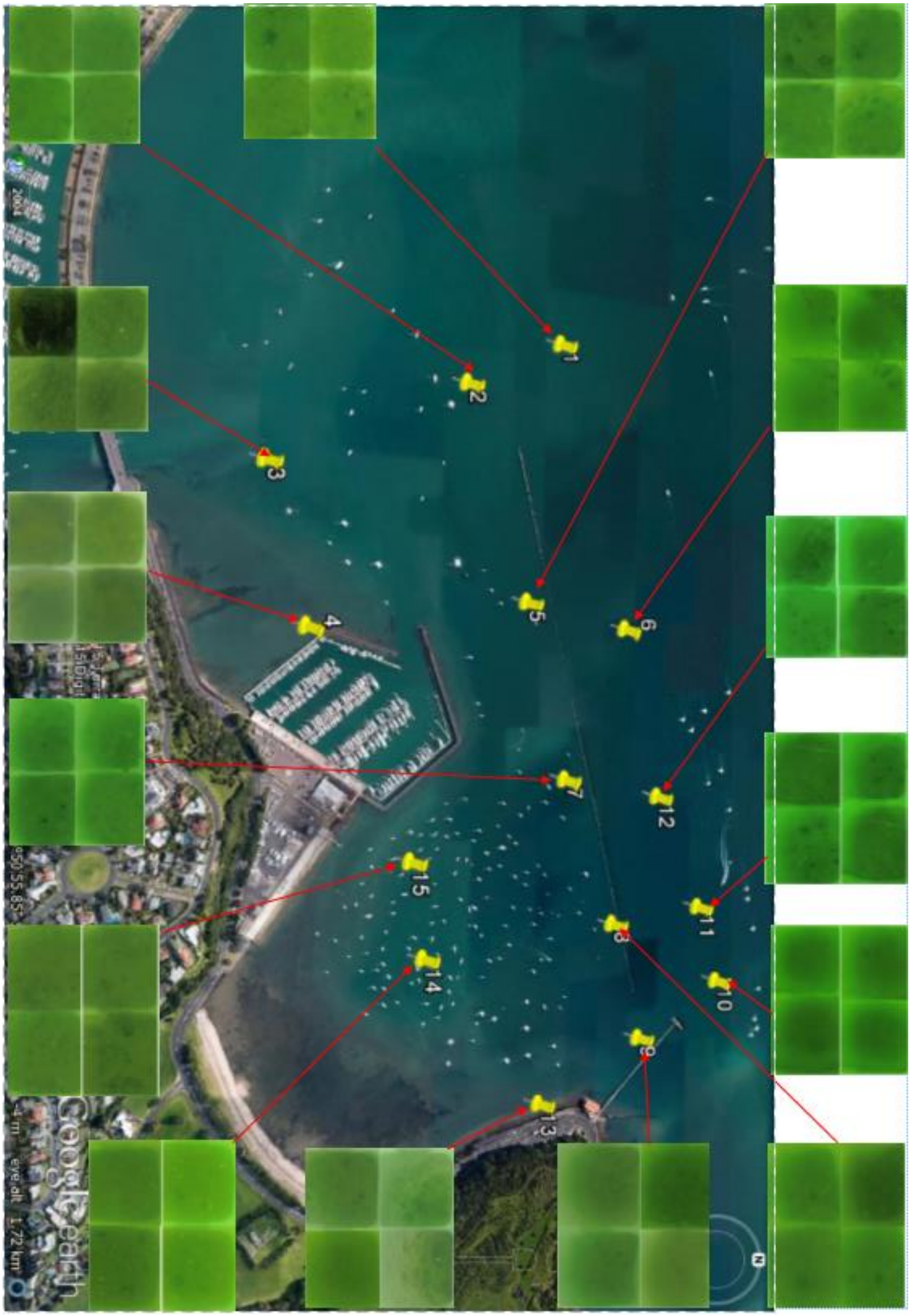
Willis, G (2008) Tikapa Moana, Hauraki Gulf, State of the Environment Report. March 2008.

Appendix

Udden-Wentworth scale

	Wentworth size class	Phi (Φ)	Millimetres (mm)	Micrometres (µm)
Gravel	Boulder	-12	4096	
		-11	2048	
		-10	1024	
		-9	512	
	Cobble	-8	256	
		-7	128	
	Pebble	-6	64	
		-5	32	
	Granule	-4	16	
		-3	8	
		-2	4	
Sand	V. coarse sand	-1	2.000	2000
		-0.75	1.682	1682
		-0.5	1.414	1414
		-0.25	1.189	1189
	Coarse sand	0	1.000	1000
		0.25	0.841	841
		0.5	0.707	707
		0.75	0.595	595
	Medium sand	1	0.500	500
		1.25	0.420	420
		1.5	0.354	354
		1.75	0.297	297
	Fine sand	2	0.250	250
		2.25	0.210	210
		2.5	0.177	177
		2.75	0.149	149
	V. fine sand	3	0.125	125
		3.25	0.105	105
		3.5	0.088	88
		3.75	0.074	74
Silt	Coarse silt	4	0.063	63
		4.25	0.053	53
		4.5	0.044	44
		4.75	0.037	37
	Medium silt	5	0.031	31
		5.25	0.026	26
		5.5	0.022	22
		5.75	0.019	19
	Fine silt	6	0.016	15.6
		6.25	0.013	13.1
		6.5	0.011	11.1
		6.75	0.009	9.3
	V. fine silt	7	0.008	7.8
		7.25	0.007	6.6
		7.5	0.006	5.5
		7.75	0.005	4.6
Mud	Clay	8	0.004	3.9
		9		1.95
		10		0.98
		11		0.49
		12		0.24
		13		0.12
		14		0.06

Appendix 1: Udden-Wentworth Scale, standardized form of grain size measurement.



Appendix 2: Sites sampled with still images collected on site at Ōkahu Bay

Site	Lat	Long
1	1,760,78.35	5,920,763.83
2	1,760,843.23	5,920,531.66
3	1,760,884.93	5,920,295.52
4	1,760,939.17	5,920,044.83
5	1,761,126.36	5,920,325.95
6	1,761,176.63	5,920,104.36
7	1,761,252.70	5,920,848.63
8	1,761,307.60	5,920,613.81
9	1,761,502.73	5,920,894.27
10	1,761,640.31	5,920,241.41
11	1,761,748.13	5,920,941.24
12	1,761,782.53	5,920,689.22
13	1,761,805.68	5,920,452.42
14	1,761,822.88	5,920,290.36
15	1,761,977.66	5,920,977.62

Appedix 3: GPS Coordinates for Sites within Ōkahu Bay.