Enhancing New Zealand surf clam fisheries

Glenn Farrington

0835812

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning

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This thesis is dedicated to my mum, Carol Mary Cattermole who passed away while I was undertaking it, she always believed in me and was proud of what I was doing.

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Abstract

With world population increasing the need for sustainable food resources grows with it. Therefore growing the seafood industry for both the domestic market as well as exports, in New Zealand is important both as a source of food, but also for economic gain. In New Zealand, there are 436 species of bivalves, including pipis, cockles, mussels, oysters and scallops (Wassilieff, 2014), this study examines one subset species commonly known as surf clams, a species with export potential. While there has been some limited fishing of these species, the main industry player has identified several impediments to growth. These are, a) the quite low Total Allowable Commercial Catch (TACC) which has limited the ability to create a sustainable business and b) high mortality of live clams that are shipped overseas. This study addresses each of these impediments.

First the biomass of commercially caught species was determined along a 26 km stretch of coast in Fishing Management Area 8 (FMA8, Foxton Beach), to ascertain the biomass of the seven commercially caught species of surf clam, with a view to ascertain how appropriate the current catch limits are, with a view to increase this limit to help drive a growing export business. Only four of the seven species were found with a total of 5.7t of surf clams landed in ten days of fishing. One dominant species, *Spisula aequilatera* (SAE) consisted of 43% of total catch, followed by *Dosinia anus* (DAN) 21.9%, *Mactra murchisoni* (MMI) 21.5% and *Paphies donacina* (PDO) 13.5%. Upon entry into the quota management system, these four species within FMA8 was set at 67t, from the results found in this study, it has seen an increase to 2816t for the same four species.

Secondly was a biomass survey conducted within Fishing Management Area 7 (FMA7, Golden Bay) with the same view of ensuring the current catch limits are set correctly to ensure sustainability of the species. Only one species (*Paphies donacina*) was found, and in ten explorative tows, only eight of these tows produced any catch. The total combined weight of these tows was 13.62kg. Due to the tough fishing conditions, lack of species and low catch numbers, the decision was made not to conduct any further investigation of this area.

Finally, experiments were undertaken on the oxygen consumption, and mortality tests. These tests were to replicate the transportation of live clams to ascertain the high mortality rates the industry partner was finding, when live product was shipped overseas. The results for the leakage test of the chilly bins, used to export the clams showed that when filled with 100% oxygen, after 30 hours this had leaked to an average of 24.9%, suggesting that the cause for the high mortality is not due to oxygen depletion. Clams of various sizes, when placed into an air tight chamber used varying

degrees of available oxygen, however after 30 hours oxygen consumption was less then available confirming the previous test that it is not due to lack of oxygen for the high mortality. The test to replicate transportation conditions was inconclusive; we were unable to replicate the high mortality rate seen by the industry partner. Using the same methods and duration the control test produced 0% mortality rate for the complete 72hr period, test one had a 0% mortality rate for the first 24hrs, then after 48hrs mortality had raised to .36% and after 72hrs it was .72%. Test two had a 0% mortality rate at re-swim after 24hrs it was .34%, then after 48hrs mortality had risen to 1.71% and stayed at this for the remaining time. Further investigation would need to be carried out to find the root cause of the high mortality seen by the industry partner; two such tests could be measuring temperature inside random chilly bins, as well as some shock device to see if they are being roughly treated and dyeing from shock.

Chapter One – General Introduction

Seafood is an important commodity, not only providing people with important nutrients but also in terms of its economic value (Teh & Sumaila, 2013), with ever growing importance for developing countries in the form of food, employment and economic independence (Food and Agriculture Organization, 2012). Globally bivalves form an important fishery (Gaspar et al., 2012) with at least one species harvested either recreationally or commercially on each continent (McLachlan et al., 1996). The percentage of commercial bivalve fisheries is small (less than 1% of total world capture of marine organisms in 2009) but the value is high compared to other marine organisms (Gaspar et al., 2012). In New Zealand, there are 436 species of bivalves, including pipis, cockles, mussels, oysters and scallops (Wassilieff, 2014). Clams are a subset of bivalves, which can be broadly described as animals that burrow into the sediment (infaunal), as opposed to mussels or oysters that that attach to a hard substrate (epifaunal) (MacKenzie et al., 2001) This study will focus on the group of clams commonly known as surf clams. Surf clam is the collective term for different species of clams all found within or immediately behind the surf zone on sandy beaches (Cranfield et al., 1994).

This introductory chapter will start by describing surf clams, it will then outline fishing as a global industry, and how this is regulated in some countries to ensure fishing is carried out in a sustainable manner. Then the chapter will focus on New Zealand fisheries management.

1.1 Surf Clams

Clams are bivalves within the Phylum Mollsuca, one of the largest phyla in the animal kingdom with over 50,000 described species (Gonzalez, 2012). The class Bivalvia has 9,200 species, 1,260 genera and 106 families making this class the second largest in this phylum (Gaspar et al., 2012). This includes 8,000 marine bivalves, with 1,100 genera and 99 families (Gaspar et al., 2012). Veneridae is the largest order of marine bivalves (>680), which inhabit the deep sea, estuaries, mangroves, coastal lagoons, bays and surf zones (Gaspar et al., 2012). Veneridae range in size from 4mm to over 10cm in shell length, most are edible and many are commercially fished for human consumption and as bait for fishing (Gaspar et al., 2012). In New Zealand “surf clams” is the collective term for different species of clams all found within or immediately behind the surf zone (Cranfield et al., 1994). However, more generally, the term is also used for different species found much further off shore (Gaspar et al., 2012; Gonzalez, 2012). The surf zone is a high impact area that few species have been able to occupy, yet it is rich in nutrients and diatoms. Surf clams are burrowers (McLachlan et al., 1996), found within sandy bottom open stretches of coast (Cranfield et al., 1994). While shape and colour change depends on the species and location (Cranfield et al., 1994), the general anatomy is the same. The clam is made up of two separate shells held together and controlled by the two adductor muscles. Surf clams are suspension feeders, with siphons for feeding and oxygen consumption (McLachlan et al., 1996) Water is sucked in via the inhalant siphon, and along with it the nutrients and diatoms found within this column of water (Cranfield et al., 1994). This in turn is passed over the gills where the food is trapped and passed along the gill pleats into the mouth. Waste products are passed back out into the water column via the exhalant siphon.

Surf clam larvae spend around 12 days as plankton, after which there is a metamorphosis and the sedentary phase begins (Donrung et al., 2011) . Surf clams in temperate locations tend to have higher growth rates and are larger and longer lived than any other beach bivalve (McLachlan et al., 1996). They can have life spans of up to five years, and reach high biomass values (McLachlan et al., 1996). Globally, clams form an important fishery, including the venerid clam *Chamelea gallina* in Italy (Repetto, 2001), the mactrid *Spisula solidissima* in the United States (Walden et al., 2012), *Spisula sachalinensis* in Japan (Nashimoto et al., 1986) and several species in Portugal (Gaspar et al., 1999). Surf clams are found in great numbers in the surf zone on sandy beaches throughout New Zealand (Cranfield and Michael 2001) and thus there is considerable interest in the exploitation of this resource in New Zealand. As with other fisheries, management is required for this resource to be sustainably fished.

1.1.1. Harvesting and Fishing

Where clams are found within intertidal flats and shallow water, common harvesting methods are hand picking, digging using simple tools such as spoons, knives and shovels, and raking (Gaspar et al., 2012); divers also collect clams (Gaspar et al., 2012; Ortega et al., 2012). Clams that are buried deeper in the sediment can be collected by a clam gun, hand dredge, ball rake or (in Italy) a hydraulic rake (Gaspar et al., 2012). To exploit deeper clam beds hand dredges, bull rakes and clam tongs can be operated from boats (Gaspar et al., 2012). Fishers also use the vessel’s propeller back wash to dislodge clams (Gaspar et al., 2012). When dredging, gear is towed by the vessel: in the UK pump scoop dredges (with water jets attached to the front of the scoop, to clean off the sediment) are used; in the US hydraulic escalator dredges (which pump jet streams of water to liquefy the sediment) are used, while in Portugal and Morocco dredges are hand winched (Gaspar et al., 2012). In coastal areas, mechanical dredges (dragging a metal toothed frame along the ocean floor) and hydraulic dredges (using sea water to liquefy the sediment before the blade cuts into the sediment) are used (Gaspar et al., 2012). These harvesting methods have different impacts on the environment, with dredges being associated with the greatest amount of disturbance to the environment (Gaspar et al., 2012). The extent of the impact depends on factors such as frequency of fishing, speed of tow, type of gear, time of year and local environment (Gaspar et al., 2012). For example the disturbance is greater in mangroves, reefs and kelp meadows than compared to shallow water where turbidity is common (Gaspar et al., 2012). Also the size of the gear, cutting depth and pressure of the jets will create furrows of different depths and longevity (Gaspar et al., 2012). The impact on target and non target species also varies; for example wastage varies depending on the species' ability to rebury into the sediment (Gaspar et al., 2012). Finally a significant impact of overfishing is creating a bottle neck in genetic diversity (Gaspar et al., 2012) leading to collapse of biomass as has occurred in Thailand (Donrung et al., 2011). In New Zealand, currently there is only one fisher harvesting Surf Clams, Cloudy Bay Clams Ltd. (CBC) from Blenheim in the South Island. Currently fishing for five species, Deepwater tuatua, *Paphies donacina*, Large trough shell, *Mactra murchisoni* (MMI), Ringed dosina, *Dosina anus* (DAN), Triangle shell, *Spisula aequilatera* (SAE) and Frilled Venus *Bassina yatei* (BYA). CBC use a modified hydraulic dredge similar to that tested in New Zealand, the rabbit dredge (Michael et al., 1990). Michael et al. (1990) found that of the two hydraulic dredges tested, one from Japan, the rabbit dredge, and one developed here in New Zealand, the Olsen dredge, while each performed better in different circumstances, overall the rabbit dredge was better for New Zealand surf clam fishing (Michael et al., 1990).

1.1.2. Fishing - a global industry

In the last five decades, both wild fishing and aquaculture has grown faster than global population growth (Food and Agriculture Organization, 2012). Today fish is an important source of nutrition and animal protein for much of the world's population (Teh & Sumaila, 2013), with an ever growing importance for developing countries not only as a valuable source of nourishment but also as economic income (Food and Agriculture Organization, 2012). In 2010 capture and aquaculture produced 148 million tons of fish, at an estimated $217.5 billion dollars (US) value (Food and Agriculture Organization, 2011). Worldwide capture and aquaculture provide employment for 54.8 million people, 26% (14 million people) of which are in China (Food and Agriculture Organization, 2011). In 2010 worldwide fish landings were recorded at 77.4 million tons: the Northwest Pacific accounting for the highest landings with 20.9 million tons, followed by the Western Central Pacific with 11.7 million tons (Food and Agriculture Organization, 2012). The Northeast Atlantic harvested 8.7 million tons and the Southeast Pacific had a total catch of 7.8 million tons (Food and Agriculture Organization, 2012). As human population is growing the demand for fish products increases; this puts an ever increasing strain on fish stocks (Food and Agriculture Organization, 2012). Since early primitive fishing there has been much advancement in fishing technology, which has enabled large quantities of fish to be captured (Bollmann et al., 2010). In addition the number of fishing vessels has increased, so that by 2010 it is believed there are 4.36 million fishing vessels worldwide (Food and Agriculture Organization, 2012). The Fishing and Agriculture Organisation state in a 2011 data report that since 1970 some fish stocks have been 10% overexploited, which had risen to 26% by 1974 (Food and Agriculture Organization, 2012). After 1990 the percentage of overexploitation was still increasing but at a much slower rate (Food and Agriculture Organization, 2011). The collapse of some commercially caught fish species, such as the Atlantic cod (*Gadus morhua*), and high-profile species such as northern bluefin tuna (*Thunnus thynnus*) (Repetto, 2001), has led some countries to introduce programs to ensure sustainable fishing practices that enable maximum economic profits, while ensuring the future of the species being targeted (Chu, 2009). Total Allowable Catch (TAC) or Individual Transferable Quotas (ITQ), specify numbers of individuals of a given species to be caught within Exclusive Economic Zones (EEZ) (Chu, 2009). These quotas have been implemented in different ways, and have been supported by a range of additional regulatory measures, with different degrees of success (Yandle & Dewees, 2008).

1.1.3. Total Allowable Catch and Individual Transferable Quotas

The Total Allowable Catch (TAC) is the upper limit set by the governing body for any given species for a given fishing management area (FMA) within a fishing season for both commercial and recreational fishers (Chu, 2009). A portion of this is then set aside for Total Allowable Commercial Catch (TACC). Individual quotas (IQ) are allocation of rights to commercially catch specified amounts of quota within the TACC to individuals or enterprises (Batstone & Sharp, 2003). In some programs they also may have the right to transfer or lease that quota to another individual or enterprise; this is then called an Individual Transferable Quota (ITQ) (Yandle & Dewees, 2008). The purpose of these ITQ programs is to prevent overfishing and overcapitalization (McCay et al., 1995). The move to programs such as an ITQ is growing worldwide and many of these countries are looking towards the program set out in New Zealand (Yandle & Dewees, 2008).

1.1.4. TAC in the European Union

With the formation of the new European Union (EU) in 1993; a Common Fisheries Policy (CFP) was created (Marchal et al., 2009). The CFP was created to conserve fish stocks. Every year the European Commission makes recommendations, based on scientific data for the Maximum Sustainable Yield (MSY), on numbers for the TAC, yet every year fish numbers are declining (Karagiannakos, 1996). This is due to the local Council of Ministers ignoring these figures, basing their decision on current employment and economic benefits, as opposed to sustainable fishing (Villasante et al., 2011). Instead they have set limits 48% higher than the recommended TAC, meaning some 88% of fish stocks are being fished beyond the MSY (Marchal et al., 2009). With both fish stock and economic value declining, in 2005 both the European Commission and the Council of Ministers put additional restrictions on commercial fisheries into place (Villasante et al., 2011). These included mesh size decrease, lowering the number of vessels, engine size limitations and the right to close any fishing area deemed to be overfished (Bollmann et al., 2010). For example, regulations have been introduced to conserve stocks of *Donax trunculs* and other bivalves, for example a minimum size, and a limited season in Andalusia, Spain (McLachlan et al., 1996). In this way, governments often impose further sanctions alongside the TAC to ensure juveniles have the opportunity to reproduce and therefore ensure the sustainability of fishing.

1.1.5. ITQ in Iceland

While in the EU they were struggling to introduce a system, both Iceland and the USA were having success (Thórarinsdóttir & Einarsson, 2009), at least for a short period. Iceland was one of the first countries to introduce a fishing management system (Arnason, 2005). However there has been more than one system introduced (Arnason, 1996). These systems include overall catch quotas, fishery access licenses, fishing effort restrictions, investment controls and vessel buy-back programs (Arnason, 2005). However the number of fish stocks, especially herring, Iceland's main fishing species (Haraldsson, 2008), continued to decline. 1990 saw the introduction of the current ITQ, covering some 19 species, and 30 sub-species, the new system was introduced in two stages, first the pelagic, then the demersal fisheries (Haraldsson, 2008). In the early 1990s a vast majority of the species included started to increase in numbers (McCay et al., 1995) however by 2002, numbers started to decline again (Bollmann et al., 2010). This led to the Marine Research Institute (MRI) to put forward a quota management agreement to government in 2003 (Arnason, 2005), imposing harder quota recommendations. To stop the declining stocks, the MRI proposed steps to ensure all vessels were included, as well as some other limitations including fewer fishing days and a maximum and minimum mesh size (Arnason, 2005). As well as these measures, the number of no fish zones between 0m and 8m in depth increased to include areas advised by MRI to be spawning areas for any of the species covered in the quota management agreement (Yandle & Dewees, 2008). Iceland is an example of a country that has a Quota Management System (QMS) that is set out by sound science and followed by fisheries (Thórarinsdóttir & Einarsson, 2009). This has meant that that the industry has grown in economic value, but done in such a manner that is sustainable.

1.1.6. ITQ in the United States of America (USA)

In the USA, since 1990 there have been currently three fisheries and five species covered by an ITQ (Walden et al., 2012), the surf clam and ocean quahog in Mid-Atlantic and New England waters; wreckfish along the South Atlantic coast; and halibut and sablefish off Alaska (Walden et al., 2012). It was the surf clam and ocean quahog ITQ that was first put in place by the Mid-Atlantic and New England Fishery Management Councils (Walden et al., 2012), and implemented by the National Marine Fisheries Service (NMFS) in October 1990 (Walden et al., 2012). The two governing bodies decided in the case of surf clams, to give the quota per vessel based on the catch record for the period 1986 to 1989, and for the ocean quahog for periods 1979 to 1987 (Walden et al., 2012). Pre ITQ there was some 135 vessels fishing for surf clams and 69 vessels fishing ocean quahogs (Food and Agriculture Organization, 2012). Four years after the ITQ was introduced this number had fallen to 48 vessels landing surf clams, with 36 vessels landing ocean quahogs (Buck, 1995). It is unclear whether the fleet has reduced in size due the transferability of the quota or simply due to there being too many vessels for the amount of quota - and thus not enough quota to go around. Both the landings and biomass have been declining for the period 1986 – 2005 (see table 1), however this species is deemed not to be overfished (Bollmann et al., 2010).

Table 1. Quotas, landing data and estimates of biomass and fishing mortality for ocean quahogs in US waters (thousand metric tons). Table sourced from World Ocean Review 2010

Category	1996	1997	1998	1999	2001	2002	2003	2004	2005
Quota	20.2	19.6	18.1	20.4	20.4	20.4	20.4	22.7	24.2
Landings	20.1	19.6	17.9	17.4	14.7	17.1	18.8	17.6	13.6
Biomass	3,435	3,401	3,367	3,335	3,303	3,272	3,324	3,214	3,159

1.1.7. TAC measures in New Zealand

No other country has introduced a QMS to the same extent as New Zealand (Annala, 1996), however the current system, like that of Iceland, has undergone several changes. Many believe that it was the 1986 QMS that was first in New Zealand (Marchal et al., 2009); however since 1982 there has been a system in place for the deep-sea fin fish. This management system was introduced at the same time New Zealand expanded its EEZ out to 200 nautical miles (Chu, 2009). This gave New Zealand a sea area EEZ 15 times that of its land mass, some 4 million square kilometres – the fourth largest in the world (Yandle & Dewees, 2008). The EEZ was expanded to exclude fishing boats from Japan and Korea fishing in an unsustainable manner. On the 1st October 1986 the new ITQ program went live (Chu, 2009). At its inception 32 species were covered, this included 21 inshore and eight deepwater species (Clark et al., 1989). As the years continued, more and more species were included and by the end of 2005, 68 species were covered (Lock & Leslie, 2007). In the QMS the country was divided into nine Fishing Management Areas (FMA) or Quota Management Areas (QMA) (see Figure 1) (Ministry for Primary Industries, 2014), and the minister on the recommendation from the science community, makes recommendations for fish quotas for each of the nine areas for each species covered in the agreement (Marchal et al., 2009). When setting the TAC the minister must also take into account of recreational fisheries, hence the minister will set a Total Allowable Commercial Catch (TACC) with the limits of the TAC (Lock & Leslie, 2007).

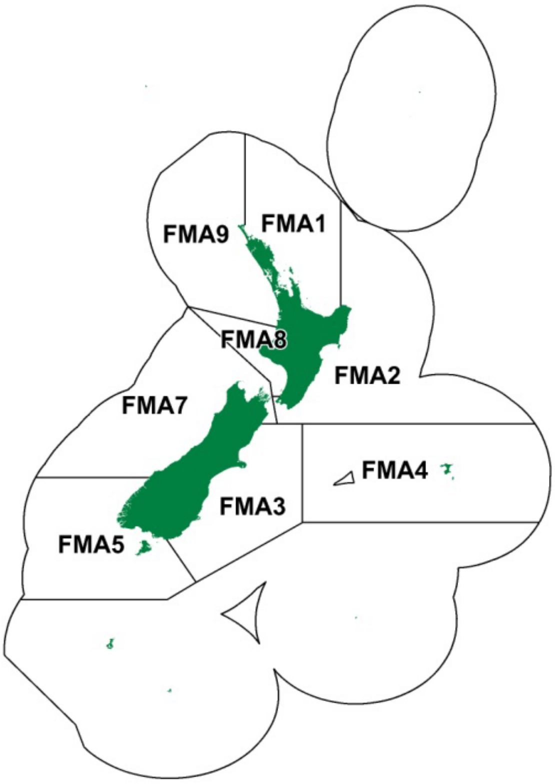

Figure 1. Fishing Management Areas (FMA) for New Zealand. Image sourced from Ministry of Fisheies website (http://www.mpi.govt.nz/fisheries/commercial) on 09/04/2014

When the ITQ was first developed the Governor-General could change the quota within a QMA, but could not alter QMA boundaries (Lock & Leslie, 2007). This was addressed in the revision of the QMS in 1996 fisheries act, but required a public notice as well as at least 75% of quota holders' agreement (Booth & Cox, 2003). Of course, if the quota holders felt this would change the profitability of the catch they would not sign, leaving the Governor-General unable to make the change and threatening the species' MSY, and making the process of the QMS a pointless task if fisherman could have an option to opt out. In 1996 a bylaw was passed to rectify this issue (Lock & Leslie, 2007), granting the governor-general the right to change any aspect of the QMS. When a change request is submitted, normally by a research institute, a public notice is sent out via the Ministry of Primary Industries (MPI) (Ministry for Primary Industries, 2014). This notice is then open for comment by industry partners and public, with a recommendation from MPI. After council the Governor-General will decide what form of action to take from the comments, but his say is final. An appeal process can be held, however this is rare (Ministry for Primary Industries, 2014).

1.2 International Surf Clam Fisheries

1.2.1 United States of America

In the United States of America (USA), clams have been eaten throughout indigenous Indian and European inhabitation (McLachlan et al., 1996), but it was not till the 1880s that commercial fisheries started to accommodate growing market demand (MacKenzie et al., 2001). The Pismo clam *Tivelo stultorum* was heavily fished between 1916 and 1947, but declined despite management attempts, including bag, size limits, area closures and transplanted stock (McLachlan et al., 1996). This decline may have been affected due to an increase in the number of the Sea Otter population, and El Nino storms (McLachlan et al., 1996). The Pacific Razor clam *Siliqua patula*, which have high retail value, is commercially harvested in Alaska and in Washington DC. In Washington stock of this species is now in decline, while in Alaska the resource is greater than utilised because of travel distances to reach markets, and toxin concerns (McLachlan et al., 1996). Currently the two main species that are fished are the ocean quahog, *Arctica islandica* and the Atlantic surf clam *Spisula solidissima* (McCay et al., 1995). In the early years primitive methods such as rakes and hands were used (MacKenzie et al., 2001), but in 1945 hydraulic dredges were introduced and harvesting increased from 20,000t in the 1960s to 25,000t during the 1970s (Cranfield et al., 1994). However since 1980 the reported number of landings has been slowly declining. In 2010 landings were down to 11,000t for both species (FishstatJ). One possible reason for this decline is due to overexploitation of near shore stocks, requiring fishing vessels to travel into deeper water, thus taking longer travel time and negotiating more difficult conditions associated with deeper waters (National Shellfisheries Association, 1995).

1.2.2 Japan

Japan has had hydraulic and beam trawl fisheries since 1976. The main species targeted is *Spisula sachalinensis* (Cranfield et al., 1994). Approximately 5000t per year are caught, however this is thought to be an unstable fishery due to the wide fluctuation in recruitment (Sasaki, 1986).

1.2.3 Portugal

Like New Zealand, Portugal has a relativity new surf clam industry, set up by the Spanish in 1969 (Leitão et al., 2009). Small vessels were used to tow a bag-like dredge across the ocean floor, targeting two species, *Ensis siliqua* and *Venus striatula (Palma et al., 2003).* However as no restrictions were in place to manage the fisheries, stocks soon showed signs of depletion (Gaspar et al., 1999). Presently attention has shifted towards different species: these are the donax clam (*Donax trunculus*), the striped venus (*Chamelea gallina*), the white clam (*Spisula solida*), and the razor clam (*Pharus legumen*) (Palma et al., 2003). In order to ensure that overexploitation does not occur limitations have been imposed since 2000 (Chu, 2009): limitations in the dredge size, and the size and engine power of vessels. Hydraulic dredging was forbidden, and controls set limits on the minimum catch size; in addition a quota per vessel was imposed (Chu, 2009).

1.2.4 Thailand

Thailand has had an off shore surf clam *(Paphia undulate)* fishery since 1970 (Donrung et al., 2011; Lethochavalit et al., 2004). The fishery grew from production of 13,806 t in 1974 to 131,230 t in 1987, since 1990 production has been declining with production at 31,495 t in 2002 (Donrung et al., 2011). This is likely due to over exploitation, degradation of habitat and low genetic diversity (Donrung et al., 2011). The Thai Department of Fisheries attempted a restocking program, by releasing 10^6 artificially breed larvae, however this was unsuccessful (Donrung et al., 2011). Evaluation of genetic diversity and population structuring is required to improve restocking programs (Donrung et al., 2011).The Department of Fisheries also places restrictions on quota each year based on the previous year’s landings in an attempt to the salvage Thailand’s largest fishery (Lethochavalit et al., 2004). As well as these measures there are now marine protected areas where fishing is prohibited (Donrung et al., 2011).

1.2.5 South America

Clams are important sources of food and income, and sometimes export income, in fishing communities, yet many of the resources are overfished (Ortega et al., 2012). In Chile and Peru, *M. donacium* is harvested from the Pacific coast, while in Brazil, Uruguay and Argentina *M.*

mactroides is fished from the Atlantic ocean (Ortega et al., 2012). Clams are harvested manually during low tides, and by divers from small boats in the surf zone (Ortega et al., 2012). Population of both these species of surf clam have had mass mortalities during the last 30 years possibly due to changes in sea temperatures, algal blooms, parasites and landings due to storms (Ortega et al., 2012). These mass mortalities make management strategies for these species difficult (Ortega et al., 2012). For example in Peru, landings increased from 200 t in 1970 to 4000 t in 1982, but following an El Nino event no live surf clams were found south of Lima and the fishery was closed (Ortega et al., 2012). The Argentinean stock of *M. macdroides* is also thought to be declining due to illegal fishing (McLachlan et al., 1996).

1.2.6 Caribbean

Three species of clam are commercially fished, *Tivelo mactroides, Donax denticulatus* and *Donax striatus* (McLachlan et al., 1996*).* Figures show an increase in the number of landings for all three species, but there is insufficient data to see if this is stable fishery thus assessment is needed to determine what fishing management is required (McLachlan et al., 1996).

1.2.7 Europe

The only species of clam that is widely harvested on sandy beaches is *Donax trunculus* which is distributed along the Atlantic coast, from France to Senegal and within the Mediterranean and Black Seas (McLachlan et al., 1996). It is harvested by a small dredge pulled by hand or animal power - hydraulic dredges were used in Italy, but are now prohibited (McLachlan et al., 1996).

1.2.8 New Zealand

In New Zealand, there are seven species of bivalve clams, found within the surf zone or immediately after it (0-10m depth) (Cranfield et al., 1994): Deepwater tuatua, *Paphies donacina* (PDO), Fine (silky) dosinia, *Dosinia subrosea* (DSU), Frilled venus shell, *Bassina yatei*, Large trough shell, *Mactra murchisoni*, Ringed dosina, *Dosina anus*, Triangle shell, *Spisula aequilatera*, and Trough shell, *Mactra discors* are all commercially caught (Cranfield et al., 1994). PDO is found mainly along the North Island’s west coast, the South Island’s east coast and Stewart Island, on beaches and sheltered locations including Harbour mouths (McLachlan et al., 1996). While the intertidal clams of New Zealand, such as tua tua, cockle and toheroa are quite well known and have been taken historically as a food source from pre-European times (McLachlan et al., 1996), surf clams are not so well known. This is due to surf clams living within the sand (up to 150mm deep) in the surf zone of sandy beaches and so they cannot therefore be harvested with surface dredges (Spence, 1980). The introduction of hydraulic dredges to New Zealand as a research tool in the 1980s allowed for the first time the scientific study of these animals and led to the discovery that they were both wide spread and abundant (Spence, 1980). The TACs for surf clam fishing are based on historical landings. These are very conservative numbers due to the fact that many areas have yet to have a surf clam fishery. However several studies have been conducted to estimate biomass in a more scientific manner to validate or increase the limit (Cranfield et al., 1994; Haddon et al., 1996; Triantafillos, 2008a, 2008b). Currently only one company is fishing surf clams in New Zealand, and within two fishing management areas (Ministry for Primary Industries, 2014). Prior to surf clams inclusion into the quota management system in 2004, special permits were required to commercially harvest surf clams (Ministry for Primary Industries, 2013). For the 2002–03 season no special permits were issued because of uncertainty about how best to manage these fisheries (Ministry for Primary Industries, 2013). Figures 2 to 5 shows landings for four of the main commercially caught species, from the 1992/93 season to the 2011/12 season. For the periods between 1996 to 2002, it seems that either nobody was fishing surf clams, or no reports of landings was made, there was no explanation for the absence of these in the report (Ministry for Primary Industries, 2013).

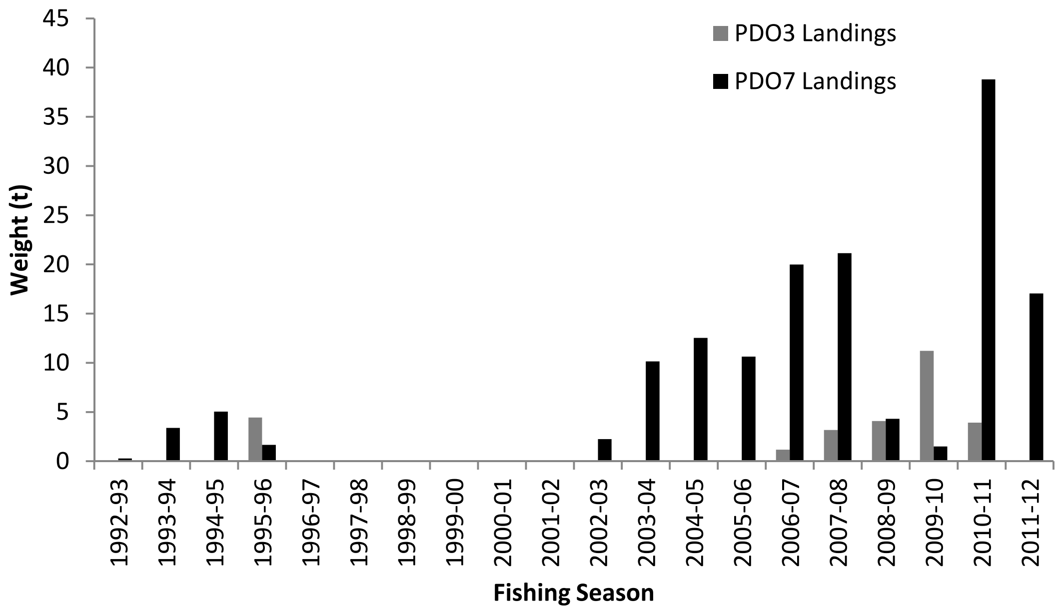

Figure 2. Reported landings for Deepwater Tuatua (*Paphies donacina)* for FMA 3 and 7. (data sourced from Ministry for Primary Industries, 2013).

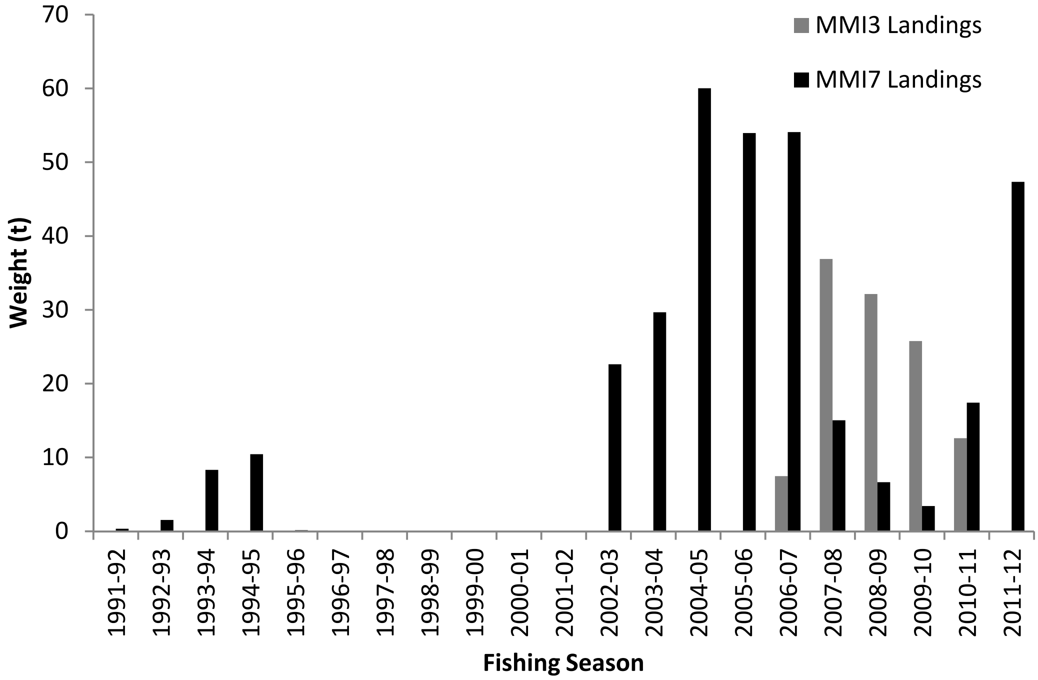

Figure 3. Reported landings for Large trough shell (*Mactra murchisoni)* for FMA 3 and 7. (data sourced from Ministry for Primary Industries, 2013).

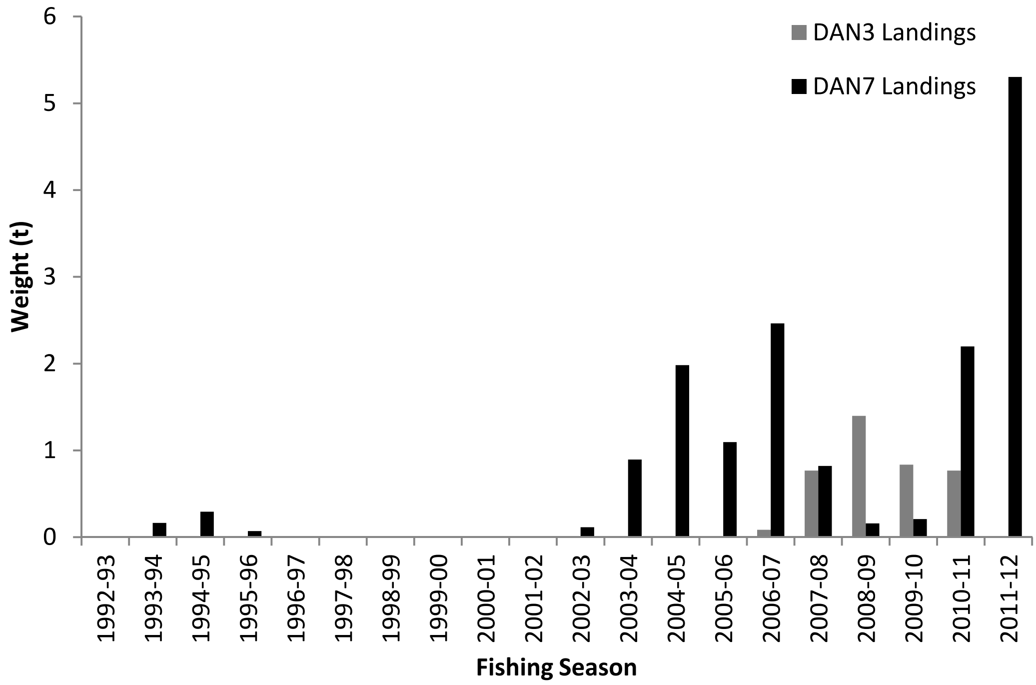

Figure 4. Reported landings for Ringed dosina (*Dosina anus)* for FMA 3 and 7. (data sourced from Ministry for Primary Industries, 2013).

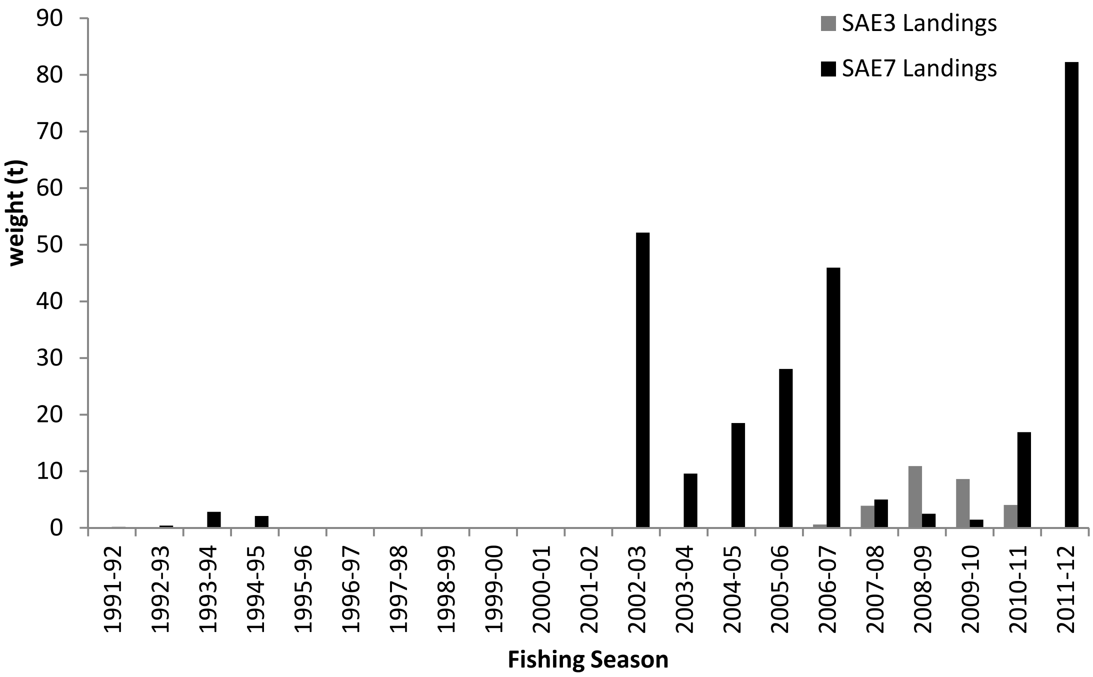

Figure 5. Reported landings for Triangle shell (*Spisula aequilatera)* for FMA 3 and 7. (data sourced fromMinistry for Primary Industries, 2013).

1.3 Surf Clams and Total Allowable Catch in New Zealand

Biomass estimates of surf clams have been carried out in a number of regions around New Zealand. Cranfield et al.'s (1994) report to Ministry of Agriculture and Fisheries (MAF) summarised both the habitat and distribution of the seven species of surf clam and determined a latitude gradient distribution in New Zealand waters. The paper also reported a clear depth zonation between species. *Pahpies donacina (PDO)* were most abundant between 2 and 3 m; *Spisula aequilatera* (SAE) between 3 and 7 m; *Mactra murchisoni* (MMI) between 4 and 8 m; *Mactra discors* (MDI) between 3 and 7 m; *Dosinia anus* (DAN) between 4 and 10 m; *Bassina yatei* (BYA) between 6 and 9 m; and *Dosinia subrosea* (DSU) between 6 and 10 m (Cranfield et al., 1994). Triantafillos (2008a,b) sampled regions in each of the QMAs 2, 3, 7 and 8, with three regions sampled per QMA, apart from QMA 3 and 7 where one and two regions respectively, were sampled. In QMA 3, a total of 13,437,173m^2 was covered in 18 vessel days, finding 3,189.6t of surf clams comprised of four main species. Triantafillos (2008a) concluded that the four main species found would be able to be targeted and maintain a biomass high enough to sustainably support a fishery within this QMA (Triantafillos, 2008). Triantafillos (2010) then conducted a biomass survey in QMA 2, just south of Napier. The survey found 7,581t for the five sample areas across the 250km stretch of coast sampled. All seven species of surf clams were collected; however the study found that the distribution of surf clams was patchy. Cranfield et al (1994) surveyed 450m trancets along 16 different locations around New Zealand to better understand their distribution. They found that while all species were present at all locations, there was a latitudinal difference in species dominance. MMI, MDI and SAE were most dominated on central and southern beaches around New Zealand while PDO, DSU and BYA on northern beaches. While the depth each species was found at changed depending on location, the pattern of distribution remained the same (Cranfield et al., 1994). Another study has been conducted in the same location as this study. Haddon (1996) dredged along a 27.5km stretch, south of the Manuatu River, from the low mean tide mark out to 8m in depth, and found five of the seven main species. Using a 6m vessel powered by water jet engines and a 1.3m rabbit dredge, a total of 127 50m tows were done. Numbers were low (D anus 12.76g m^{-2}, P donacina 4.44 g m^{-2}, M murchisoni 3.77 g m^{-2} and S aequilatera 0.77 g m^{-2}). Cloudy Bay Clams are the only company to harvest surf clams in New Zealand, currently fishing in two locations, within Cloudy Bay, Blenheim (FMA7), and Pegasus Bay, Christchurch (FMA3), South Island, New Zealand.

Table 2. Current total allowable catch (TAC) and total allowable Commercial Catch (TACC) for the four main species harvested in New Zealand, in each of the Quota Management Areas (QMA)

QMA	PDO TAC(t)	PDO TACC(t)	MMI TAC(t)	MMI TACC(t)	DAN TAC(t)	DAN TACC(t)	SAE TAC(t)	SAE TACC(t)
1	1	1	2	2	7	7	9	9
2	509	466	3	3	64	61	132	125
3	150	108	65	62	55	52	483	459
4	3	1	1	1	1	1	1	1
5	3	1	1	1	1	1	3	3
7	52	50	61	61	15	15	112	112
8	296	262	631	589	236	214	1821	1720
9	53	1	25	25	33	33	8	8
Total	1067	890	789	744	412	384	2569	2437

Two studies have seen an increase in biomass in FMA2 and FMA8 for PDO, introduced into the QMS in 2004 with a total of 164 t for all FMA’s (Ministry for Primary Industries, 2013). Triantafillos (2008b) biomass survey increased PDO from 5 t to 466 t in FMA2 (Triantafillos, 2008b), White et al. (2012) biomass survey increased PDO from 19 t to 296 t in FMA8 (White et al., 2012). When MMI was entered into the QMS the quota was 162 t for all FMA’s, the same two studies also increased MMI in FMA2 from 2 t to 62 t (Triantafillos, 2008b) and from 8 t to 631 t in FMA8 (White et al., 2012), bringing the total TAC up to 789 t for all FMA’s (Ministry for Primary Industries, 2013), a increase of 387%. DAN has seen three FMA’s have an increase, FMA2 has been increased from 18 t to 61 t (Triantafillos, 2008b), FMA3 was increased from 4 t to 52 t (Triantafillos, 2008a) and FMA8 has been increased from 33 t to 263 t (White et al., 2012). This brings the total TAC from 112 t (Ministry for Primary Industries, 2013) upon introduction into the QMS to 412 t, an increase of 267%. SAE has also seen an increase in three areas since its inclusion, original TAC was set at 406 t for all FMA's, FMA2 was increased from 1 t to 132 t (Triantafillos, 2008b), FMA3 from 264 t to 483 t (Triantafillos, 2008a) and FMA8 8 t to 1821 t (White et al., 2012). This took the total TAC from 406 t to 2437 t for all FMA's (Ministry for Primary Industries, 2013) a 500% increase across all FMA's.

1.4 Surf Clams as Export

Bivalve species like oysters, mussels, manila and hard shell clams are commercially caught and sold alive worldwide (Food and Agriculture Organization, 2012). However unlike some developing countries, where they are caught and sold at markets set up at the fishing port (Food and Agriculture Organization, 2012), in developed countries they travel huge distances to reach their place of sale(Barrento et al., 2013). Mussels caught within the United Kingdom (UK) shores are often transported to destinations within Europe, often taking 24-48 hours to reach the place of sale (Hauton et al., 2007). In the UK and Scotland there are various methods of transportation (Barrento et al., 2013). Some use small 1kg bags while others use larger 800kg bags of live mussels, but of the sixteen companies surveyed by the Mussels Alive program (Barrento et al., 2013), all shipped mussels in bags with ice in trucks where temperature was regulated at 4^{0}C. Another important factor was that if the bags were too tightly packed or over filled they would have a higher mortality rate (Barrento et al., 2013). Bivalves, when exposed to air, can be seen gaping and is believed that this gaping is used to exchange oxygen while out of the water (Lent, 1968). It has been shown in Blue Mussels that a higher mortality occurs when mussels are restricted from gaping as opposed to those that freely gape, and when temperature is reduced some can last as long as seven days out of water (Guderley et al., 1994). In *Mytilus Edulis* it has been shown that they can reduce their heart rate by some 40%, thus reducing the need to feed, at the same time by gaping they can retain oxygen levels in the water found in the mantle cavity at around 30-40%, while those that are forced shut use the oxygen up within 12 hours (Coleman, 1973). This oxygen level can be increased if the level of oxygen in the atmosphere is increased (Coleman, 1976).

1.5 Outline of the thesis

This thesis describes two studies of the biomass distribution of surf clams in two different FMAs in New Zealand. Chapter two reports on the study of surf clams, in FMA 8 at Foxton Beach, while chapter three reports the results of a similar study in FMA 7 at Golden Bay. Chapter four describes an investigation into the oxygen take-up of surf clams during lab tests which simulate the transportation of surf clams for export. Finally Chapter five discusses the findings and implications for the surf clam industry in New Zealand.

Chapter Two – Surveys in Fishing Management Area 8

2.1 Introduction

Foxton Beach is located on the west coast of the North Island, New Zealand, and falls within FMA8. The stretch of coast where this study was conducted was approximately 262km, of the total coastline of FMA8 of 540Kkm (Ministry for Primary Industries, 2014). The complete fishing management area covers some 53,000 km^2 (Ministry for Primary Industries, 2014). The range of FMA8 starts from the southern end of Nukuhakari Bay(38º 23.30s 174º 38.00E), out to sea in a westerly direction for 409km, then heads back inland in a south easterly direction to the northern end of Titahi Bay (41º 06.00S 174º 50.00E) and includes Mana Island (Ministry for Primary Industries). The current quota in FMA8 for surf clams was set in 2004 when the species entered into the QMS (Ministry for Primary Industries, 2014). It was set on historical landings, however this area is deemed un-fished or virgin ground so these estimates of surf clams were low (Ministry for Primary Industries, 2014) .

Table 3. Surf clam TAC quotas upon introduction into the QMS in 2004 (data sourced from Ministry for Primary Industries, 2012).

Stock	TAC (t)
PDO	168
SAE	406
MMI	162
DAN	112

A previous study has been conducted prior to this study, along the same stretch of coastline. Haddon (1996) dredged along a 27.5km stretch, south of the Manuatu River, from the low mean tide mark out to 8m in depth, and found five of the seven main species. Using a 6m vessel powered by water jet engines and a 1.3m rabbit dredge, a total of 127 50m tows were done. The length of the tow was determined by a line with a 3kg weight attached and thrown over board at the same time as the dredge lowered in to the water. Once the hose was at the optimum pressure the boat was put into drive and a lead line that was marked every 10 meters was let out to determine the 50m mark. Densities were low (D anus 12.76g m^{-2}, P donacina 4.44 g m^{-2}, M murchisoni 3.77 g m^{-2} and S aequilatera 0.77 g m^{-2}) compared to similar studies conducted elsewhere, where four times greater numbers were found (Cranfield et al., 1994).

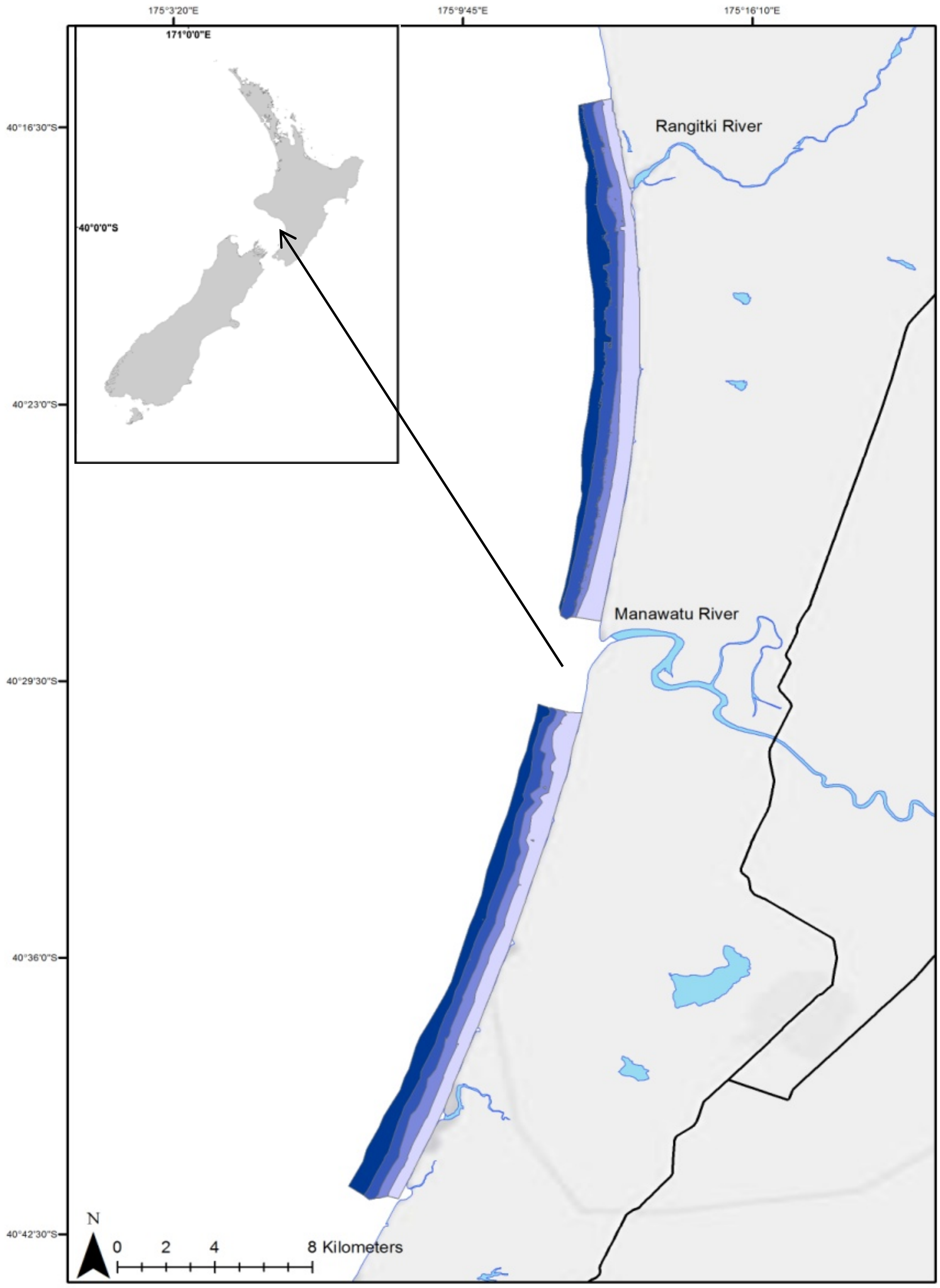

Figure 6. Complete 27 km study area, Foxton Beach, North Island, New Zealand.

2.2 Methods

2.2.1 Boat and Dredge Specifications

A commercial fishing vessel was chartered for this research that included an operational hydraulic dredge. The vessel was 10.9m by 3.1m wide, powered by two 380 hp engines through two Hamilton jets. The dredge was 1.6m wide, with water pumped through a 15cm lay flat hose at 500 l/m at ~65 psi, with the dredge digging at 190mm depth with a tow speed of approximately 0.6 knots. The mesh on the dredge basket was set at 10mm. The default tow direction was parallel to the shore. The direction of the tow was determined by the boat skipper to ensure that the dredge hose did not become fouled on the boat. Procedures were put in place should we encounter foul ground: if this were to occur we were to abandon the tow and use the next station. Surveying was to be abandoned when the sea became too rough to carry out surveys for any of the following reasons: scales would not calibrate, for the safety of boat or crew, or because the dredge would not stay on the bottom.

2.2.2 Study design

This study followed those of previous research (Haddon et al., 1996; Triantafillos, 2008a, 2008b), where the bathymetry of the study area was first determined to enable depth strata to be mapped. This was followed by an exploratory study to allow the setting of longitudinal strata boundaries and sampling effort to each stratum for the following 2-Phase biomass survey (Francis, 1984).

2.2.3 Sample handling

In the exploratory study and Phase 1 and 2 studies, all commercial species of subtidal surf clams caught in every tow were sorted by species, and the greenweight of each species recorded using M1100 Series motion compensating marine scales (Marel, Norway). The catch was released at the end of each subsequent tow, or if in a different depth stratum, was kept until the vessel had completed a tow in the stratum of collection. At least 500 individuals of each of the main species were randomly collected, landed and a) measured for shell length along the anterior-posterior axis to the nearest mm using Kincrome vernier calliper 2310, and b) weighed to the nearest 0.1g using MM MPB-300 digital scales. The weight of the main by-catch species was recorded as was dredge fullness.

2.3 GIS Bathymetry and Map Generation

Bathymetry

Latitude and longitude was collected over a three day period from depths 0 – 10 meters using a on board Raymarine W90 GPS device, recording depth, time and date to enable us to later correct depth for tide using the following formula provided by Australian Hydrographic Service, Royal Australian Navy:

> h = h1 + (h2 - h1)[(cosA + 1)/2] where A = □([(t - t1)/(t2 - t1)] + 1) radians
> Note 1: On falling tides (h2 - h1) will be negative.
> Note 2: t , t1 and t2 are in decimal hours.

The data was then imported into ArcGIS 10.1, and a class feature was created, using WGS1984 coordinate system. Once the points were displayed as a layer we used the Spatial Analyst Tools > Interpolation > Natural Neighbour function to create the contour lines, reclassifying the breaks at 2, 4, 6, 8 and 10 meter depths.

2.4 Results

This study was carried out as two separate components, first the exploratory phase then the biomass survey.

2.4.1 Explorative Phase

From the 26th to the 30th September 2012, a total of 105 stations were sampled for the exploratory phase, on average 21 stations were sampled per day. Six species were found, but four (PDO, SAE, MMI and DAN) made up 99% of the total catch for this phase. From this exploratory phase we used the information to break up the study area into depth strata. Table 4 shows the size of each new area. Figures 7 to 14 show the kg m^{-2} for both the northern and southern sites for the four main species found.

Table 4. Size (m^2) of each study area.

Distance	0-2m	2-4m	4-6m	6-8m	Totals
N1	1585001	1466532	1912699	1993676	6957908
N2	1401644	919836	1261221	1595089	5177789
N3	2355017	1614087	2169860	1958534	8097498
N4	1773057	1193205	1403080	1162064	5531407
N5	3189990	1459104	2171055	1684877	8505026
N subtotals	10304709	6652763	8917915	8394240	34269628
S1	2344623	1123452	1046092	962934	5477102
S2	1729646	876258	821521	906690	4334115
S3	1148797	693700	927370	802867	3572733
S4	2152219	1549301	1523536	1672717	6897774
S5	1453360	1306844	1203131	1263266	5226601
S6	2025579	2006263	1953717	2201003	8186561
S subtotals	10854224	7555818	7475367	7809476	33694886
Totals	21158934	14208581	16393282	16203716	67964513

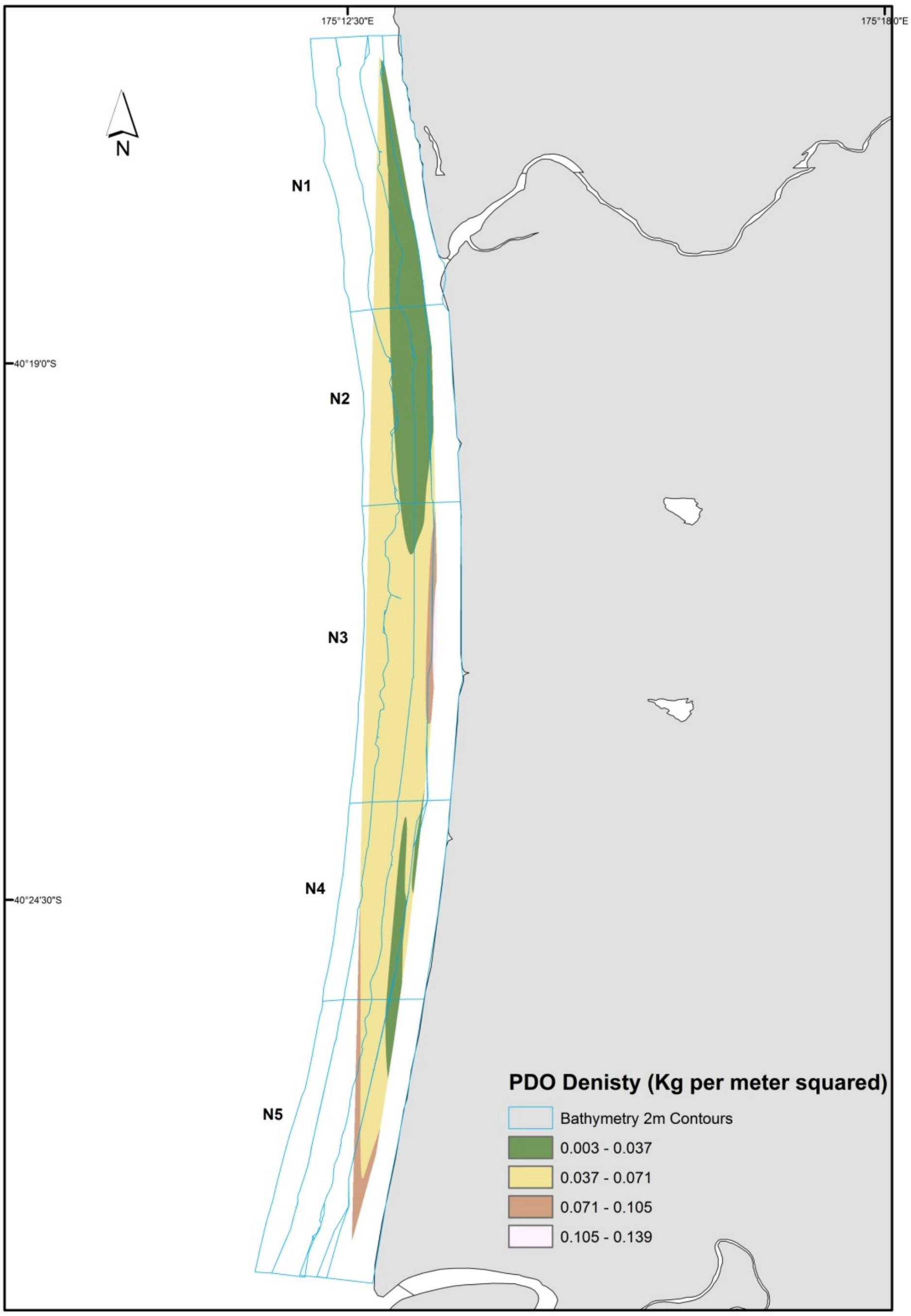

Figure 7. Explorative phase survey showing the kg m^{-2} for tuatua, *Paphies donacina* (PDO), for the north section of Foxton Beach.

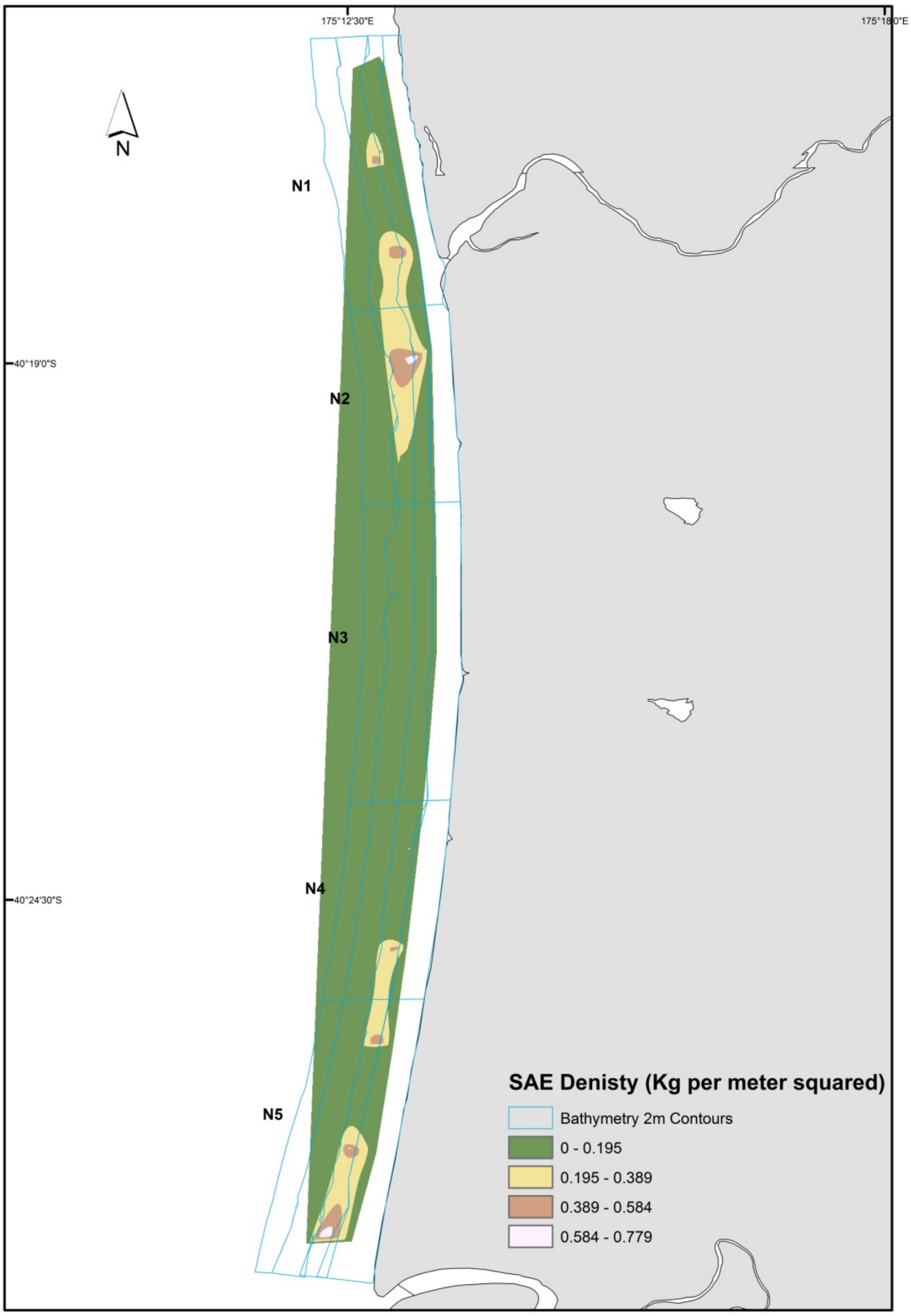

Figure 8. Explorative phase survey showing the kg m^{-2} for Triangle shell, *Spisula aequilatera* (SAE), for the north section of Foxton Beach.

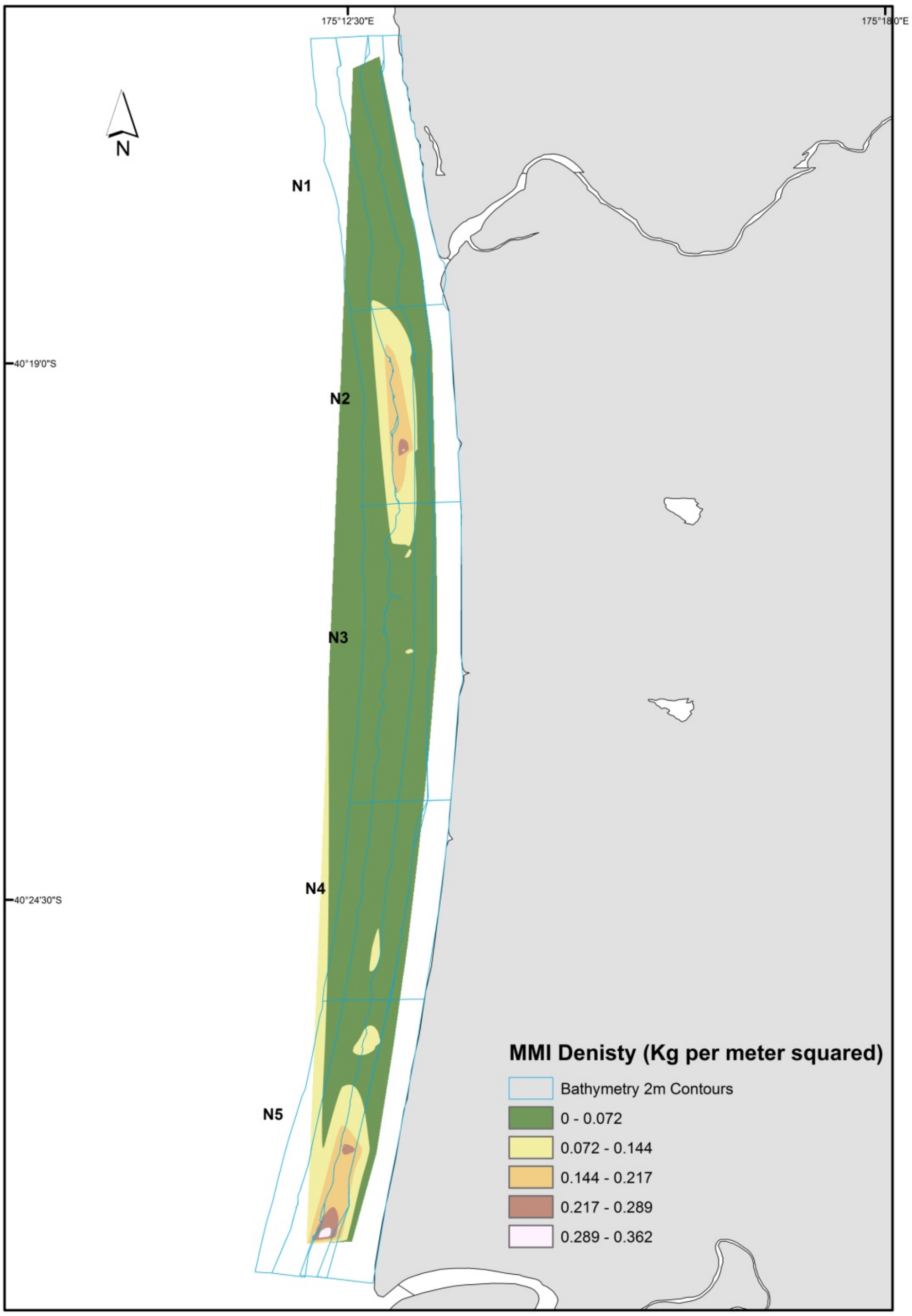

Figure 9. Explorative phase survey showing the kg m^{-2} for large trough shell, *Mactra murchisoni* (MMI), for the north section of Foxton Beach.

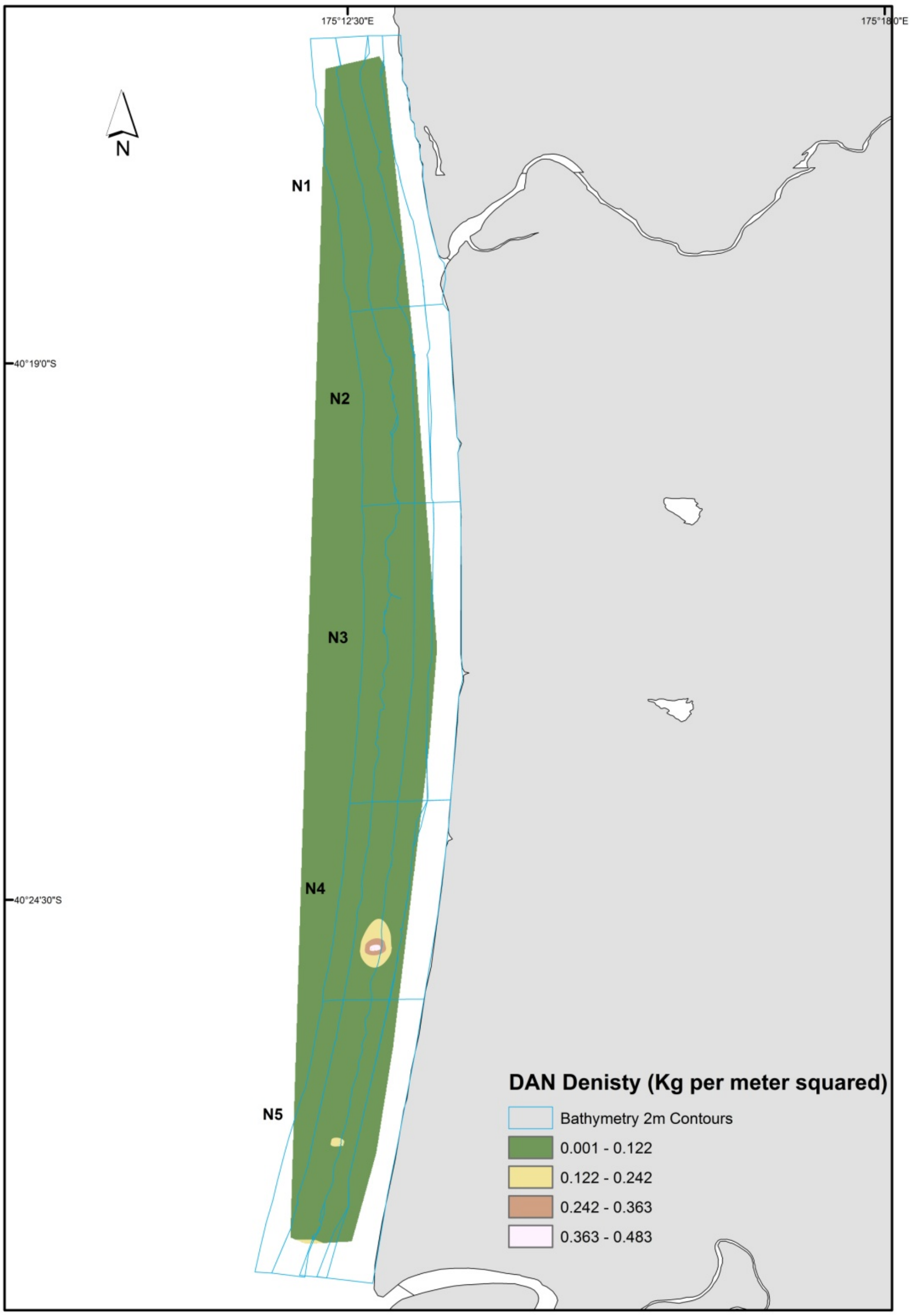

Figure 10. Explorative phase survey showing the kg m^{-2} for Ringed dosina, *Dosina anus* (DAN), for the north section of Foxton Beach.

Figure 11. Explorative phase survey showing the kg m^{-2} for tuatua, *Paphies donacina* (PDO), for the south section of Foxton Beach.

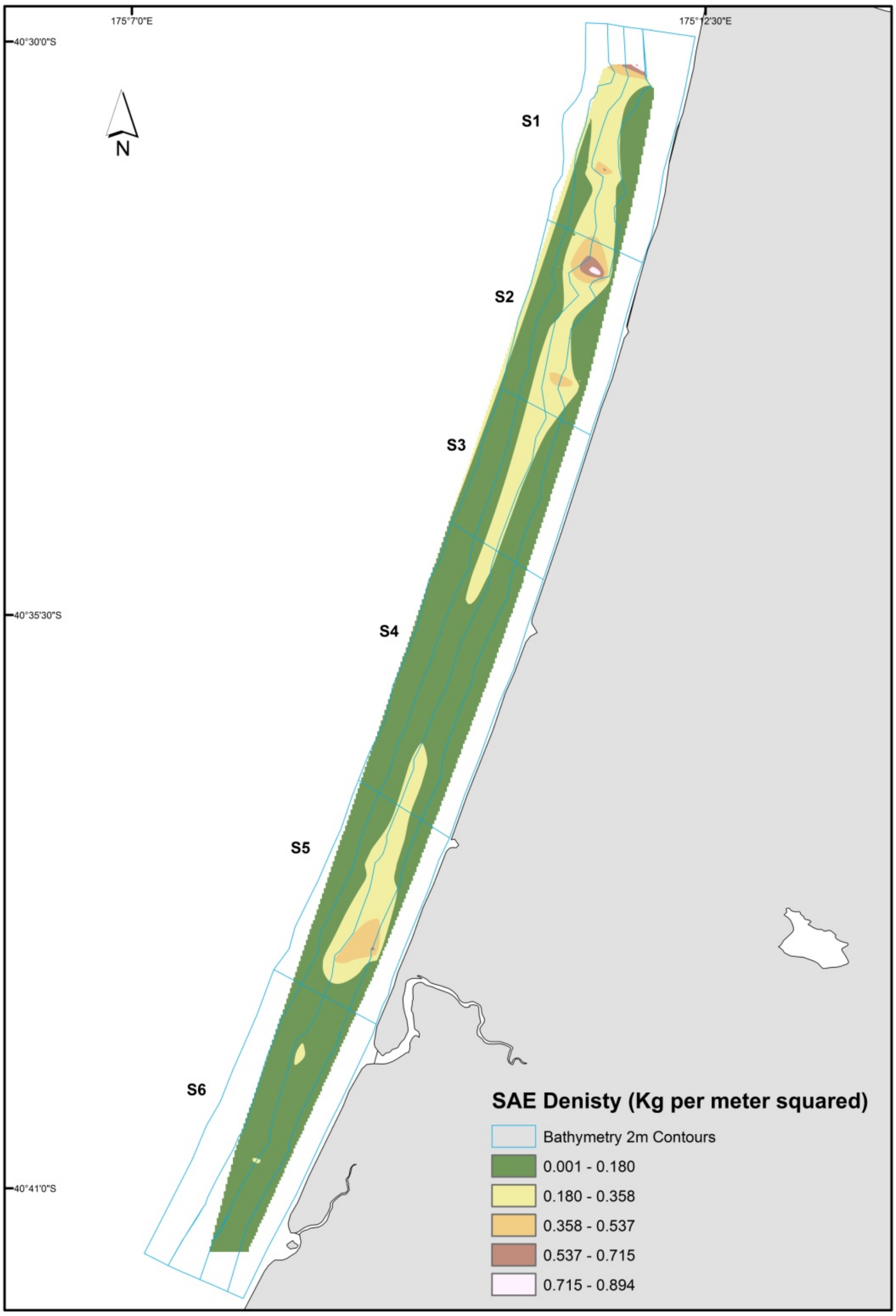

Figure 12. Explorative phase survey showing the kg m^{-2} for Triangle shell, *Spisula aequilatera* (SAE), for the south section of Foxton Beach.

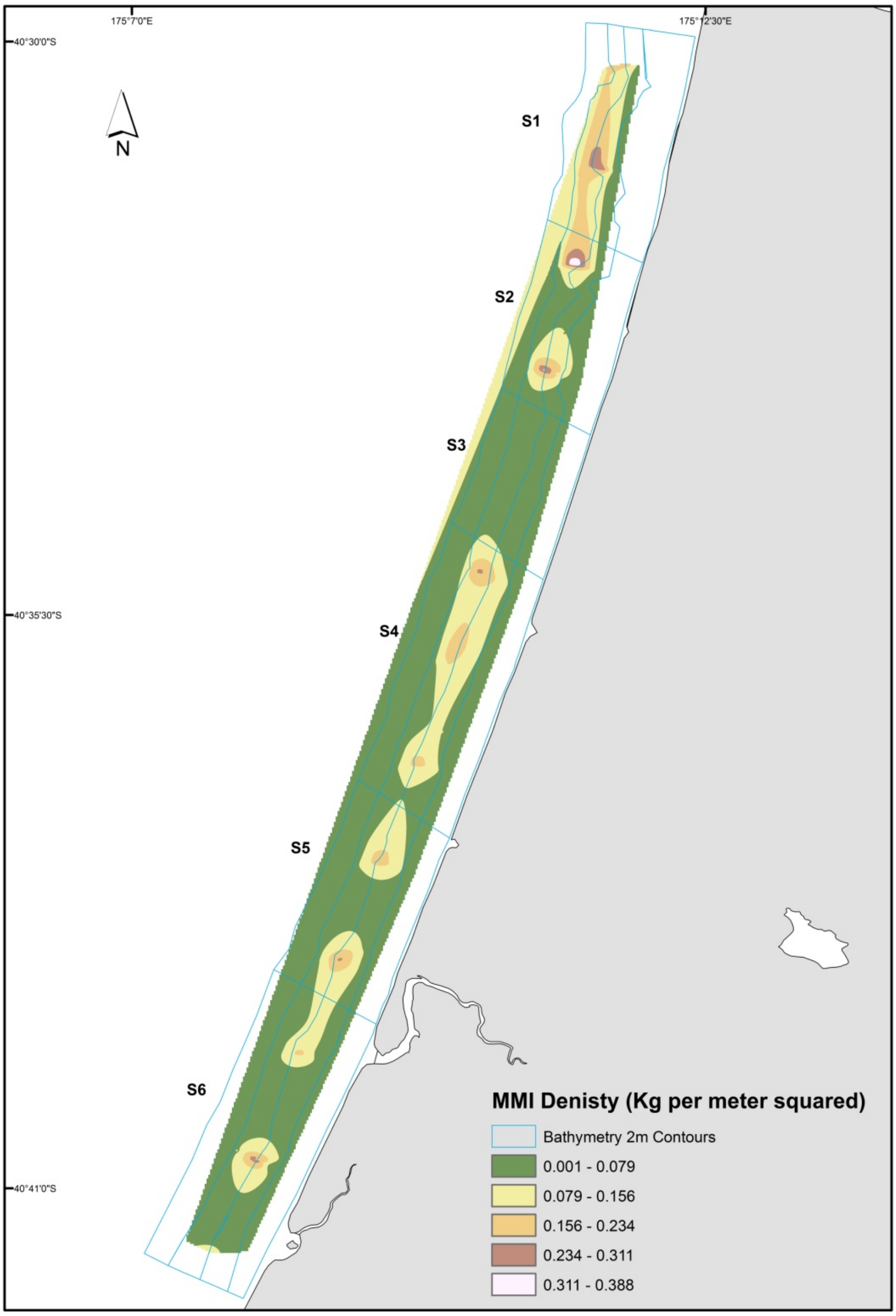

Figure 13. Explorative phase survey showing the kg m^{-2} for Large trough shell, *Mactra murchisoni* (MMI), for the south section of Foxton Beach.

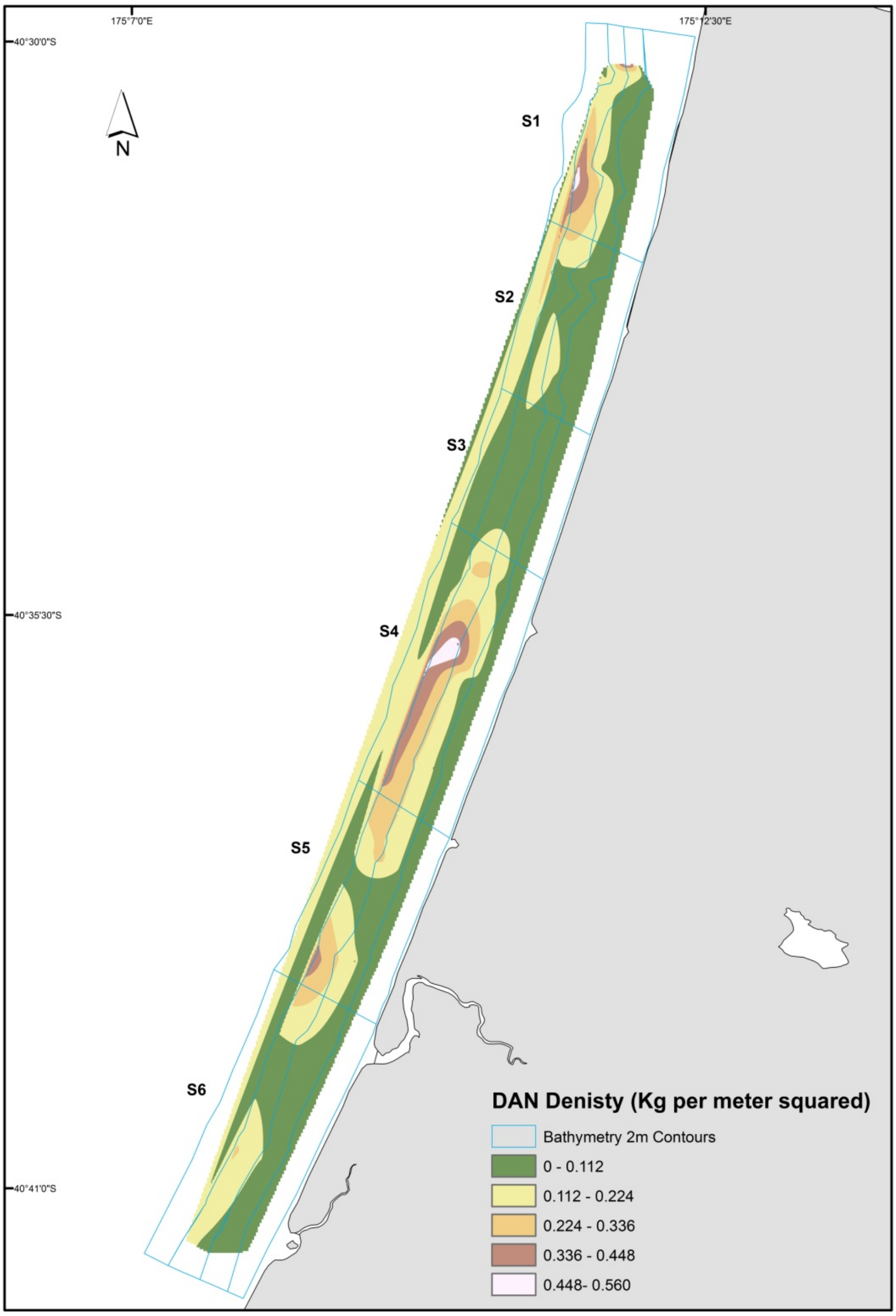

Figure 14. Explorative phase survey showing the kg m^{-2} for Ringed dosina, *Dosina anus* (DAN), for the south section of Foxton Beach.

To apportion sampling effort to each strata, the procedure outlined above was applied to each of the four main species separately; resulting in four sets of allocated samples sizes. The final allocation was obtained using a weighted sum of these individual allocations, with the relative weighting given by the relative abundance of each of the four species from the exploratory survey. This resulted in 125 sites being allocated north of the Manawatu River, and 163 to the south, reflecting the generally higher densities of clams caught by the exploratory tows to the south (Table 5).

Table 5. Number of stations allocated to 1st phase sampling.

Distance	**0-2m**	**2-4m**	**4-6m**	**6-8m**	**Totals**
N1	5	5	9	6	25
N2	5	5	8	5	23
N3	8	5	7	6	26
N4	6	4	6	4	20
N5	10	8	8	5	31
S1	8	9	11	6	34
S2	9	5	7	4	25
S3	3	3	3	3	12
S4	7	5	12	7	31
S5	7	8	10	6	31
S6	7	6	10	7	30
Totals	75	63	91	59	288

2.4.2 Biomass Survey

Due to bad weather and time constraints on the fishing vessel hired to conduct this study, we were only able to complete the survey in the more productive south sites. The survey started on the 8th of October and ran till the 8th November, however due to constant high winds only 10 sample days were possible. During the 10 days we averaged 16 stations a day, meaning a total of 163 stations were completed (Table 6).

Table 6. Number of tows and dates completed.

Date	No. of Tows
8/10/12	18
23/10/12	22
24/10/12	13
26/10/12	7
28/10/12	11
29/10/12	30
30/10/12	23
1/11/12	13
7/11/12	11
8/11/12	15
Grand Total	163

Consistent with the exploratory stage, the same four species made up 99% of the total 5.7t of surf clams caught; the most dominate was SAE accounting for 43% ((2.4t)Table 7).

Table 7. Total weight (and their percentages) of the main species of surf clams caught during the biomass survey.

Species	Weight (kg)	% Weight
Paphies donacina (PDO)	782.2	13.5
Spisula aequilatera (SAE)	2489.0	43.0
Mactra murchisoni (MMI)	1242.4	21.5
Dosinia anus (DAN)	1267.6	21.9

Paphies donacina (PDO)

The majority of PDO was found within depths of 0-2m (Figure 15), but some was also seen in the 2-4m depths, with the majority being found down the southern end, of the test area, furthest away from the river mouth (Figure 16). Table 8 shows the estimated biomass (kg) of *Paphies donacina* (PDO) per stratum.

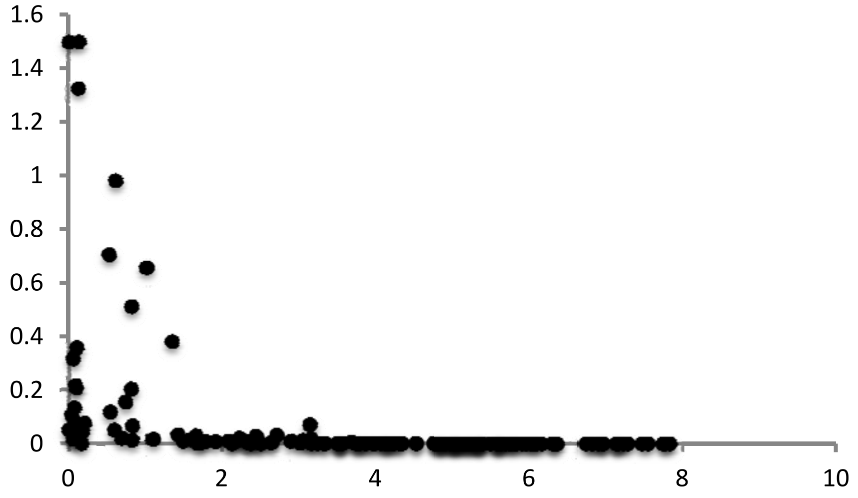

Figure 15. Depth distribution of *Paphies donacina* (PDO).

Table 8. Estimated biomass (kg) of *Paphies donacina* (PDO) per stratum.

Strata ID	Density ($kg.m^{-2}$)	CV	Est. Biomass (kg)
S1A	0.0392	0.65	91902
S1B	0.0102	0.42	11431
S1C	0		0
S1D	0		0
S2A	0.0619	0.35	107150
S2B	0.0026	1.00	2293
S2C	0		0
S2D	0		0
S3A	0.0509	0.17	58511
S3B	0.0107	0.57	7437
S3C	0		0
S3D	0		0
S4A	0.1337	0.41	287763
S4B	0.0036	0.55	5545
S4C	0		0
S4D	0		0
S5A	0.6663	0.41	968417
S5B	0.0106	0.80	13821
S5C	0		0
S5D	0		0
S6A	0.4899	0.25	992295
S6B	0.0040	0.37	8091
S6C	0		0
S6D	0		0

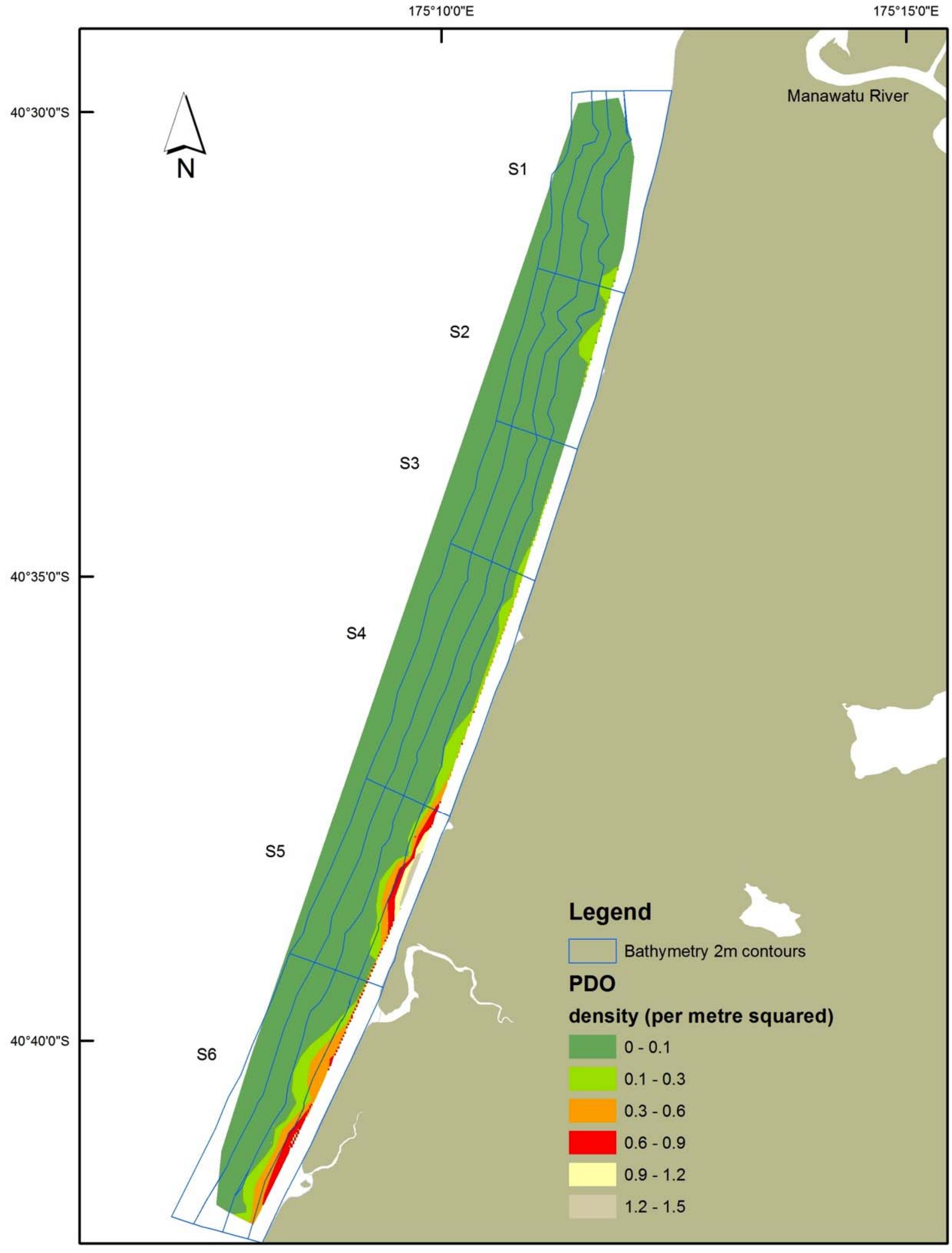

Figure 16. Density (per m^2) for *Paphies donacina* (PDO) at the southern end of Foxton Beach.

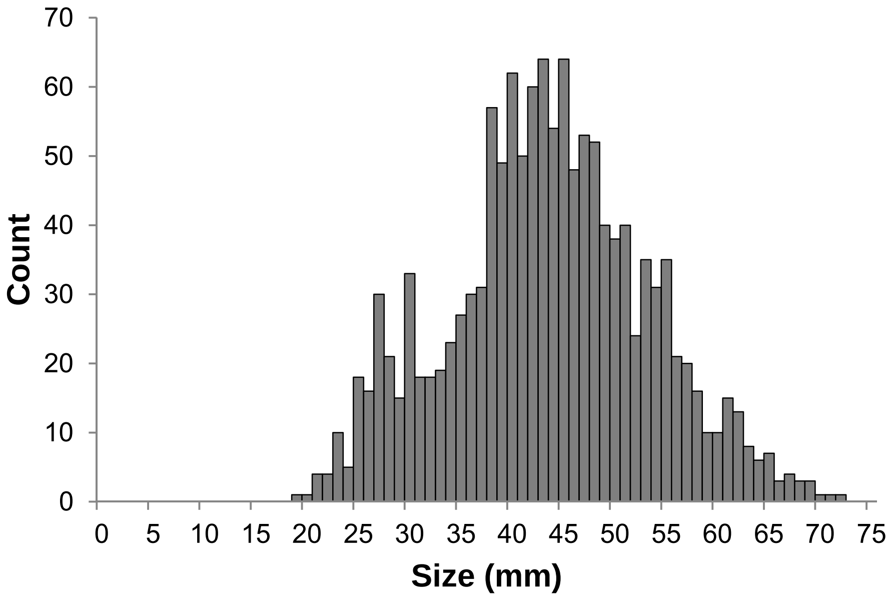

Figure 17. Size-frequency distribution of *Paphies donacina* (PDO) from the Manawatu coast. n = 1322.

Spisula aequilatera (SAE)

SAE was found between the depths of 2-6m peaking in weight at 4m (Figure 18), having a much clearer zonation, when compared to PDO. While SAE was found throughout the whole study site, the denser patches were found in the northern end of the study area (Figure 19). Table 9 shows the estimated biomass (kg) of *Spisula aequilatera* (SAE)per stratum

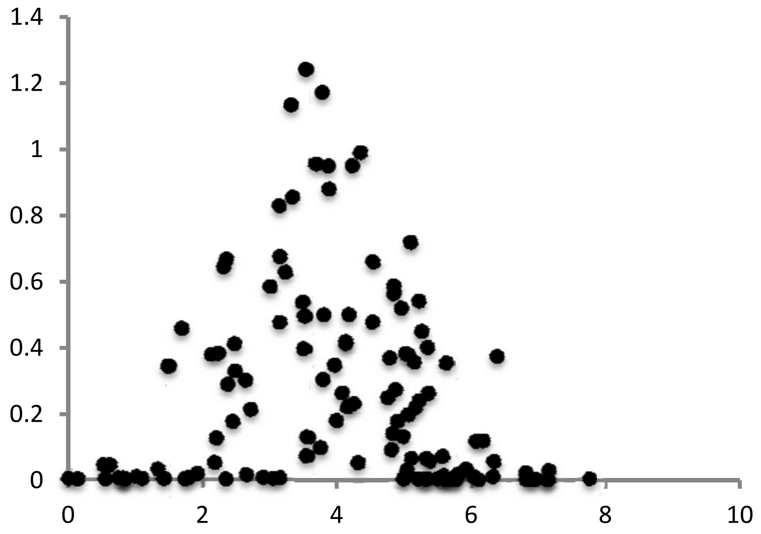

Figure 18. Depth distribution of *Spisula aequilatera* (SAE).

Table 9. Estimated biomass (kg) of *Spisula aequilatera* (SAE) per stratum.

Strata ID	Density (kg.m^{-2})	CV	Est. Biomass (kg)
S1A	0.0008	0.43	1808
S1B	0.5363	0.24	602463
S1C	0.4330	0.23	453010
S1D	0.0646	0.95	62246
S2A	0.0038	0.61	6607
S2B	0.8155	0.22	714585
S2C	0.3786	0.27	311006
S2D	0.0125	0.59	11315
S3A	0.0003	1.00	386
S3B	0.1708	0.65	118464
S3C	0.3339	0.41	309653
S3D	0.0024	0.67	1904
S4A	0		0
S4B	0.1074	0.86	166328
S4C	0.1984	0.23	302223
S4D	0.0007	0.53	1118
S5A	0.0007	0.54	978
S5B	0.4939	0.19	645436
S5C	0.2168	0.37	260800
S5D	0.0009	0.38	1170
S6A	0.0195	0.37	39511
S6B	0.4491	0.13	900921
S6C	0.2065	0.22	403507
S6D	0.0026	0.48	5616

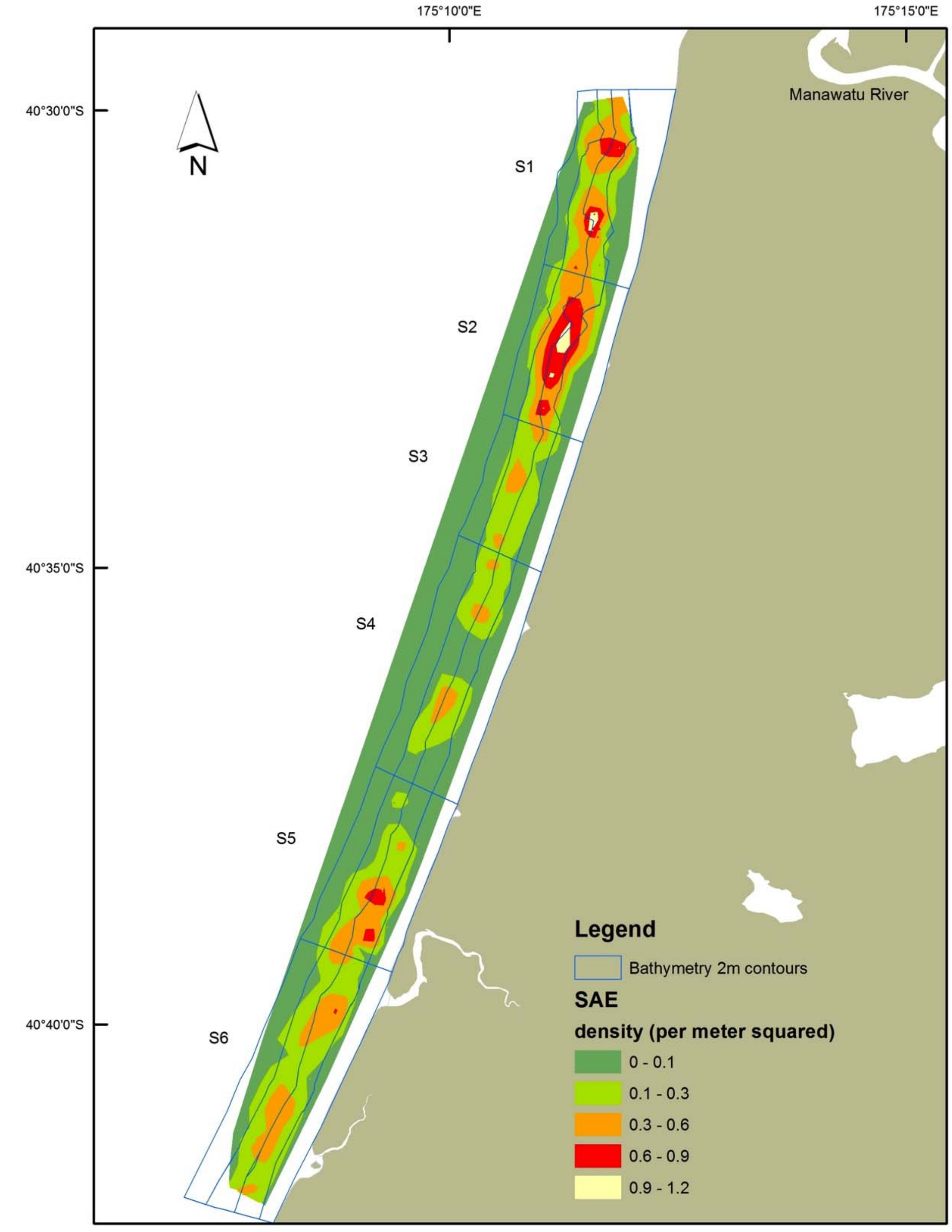

Figure 19. Density (per m^2) for *Spisula aequilatera* (SAE) at the south end of Foxton Beach.

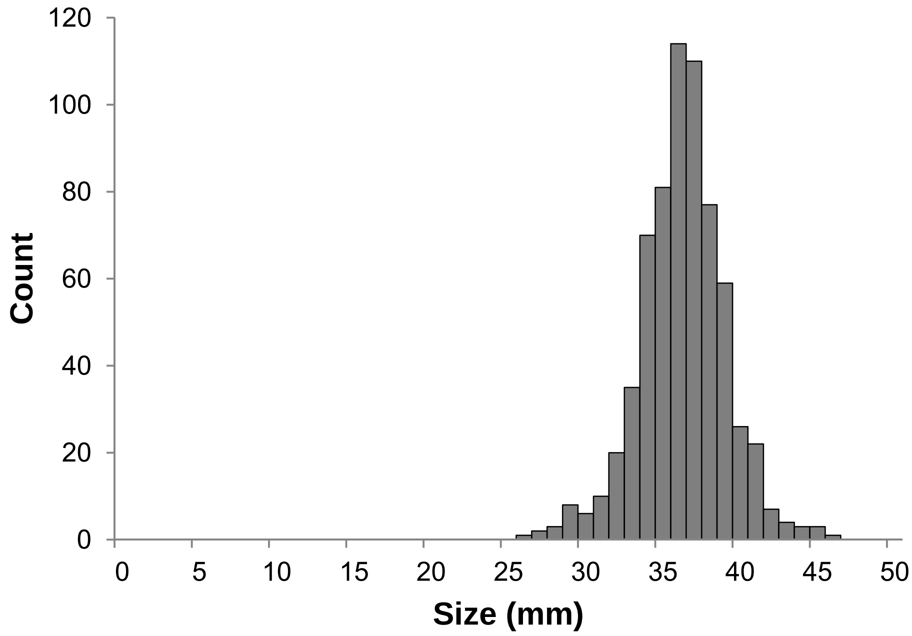

Figure 20. Size-frequency distribution of *Spisula aequilatera* (SAE) from the Manawatu coast. n = 662.

Mactra murchisoni (MMI)

MMI was found mainly in depths between 2-6m, however some was also found as deep as 8m (Figure 21). While found in the whole of the study area, the larger amounts were found in the end of the northern and southern tip (Figure 22).

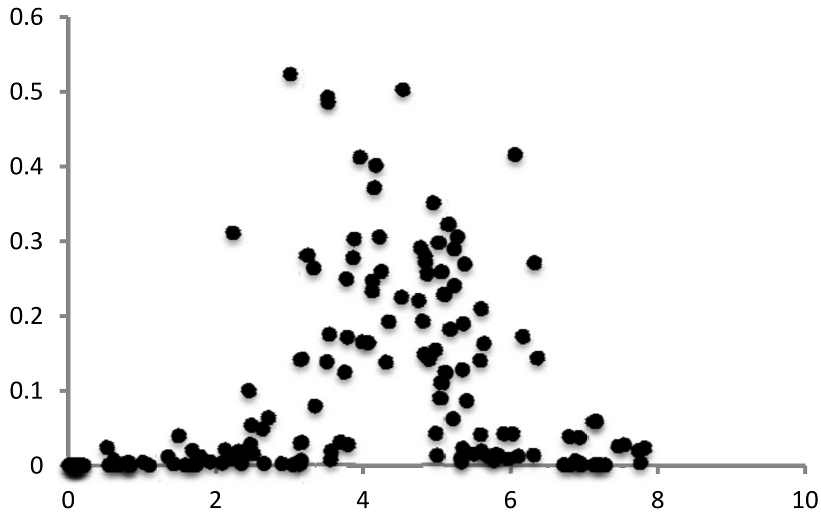

Figure 21. Depth distribution of *Mactra murchisoni* (MMI).

Table 10. Estimated biomass (kg) of *Mactra murchisoni* (MMI) per stratum.

Strata ID	Density (kg.m^{-2})	CV	Est. Biomass (kg)
S1A	0.0009	0.46	2095
S1B	0.1230	0.37	138196
S1C	0.2815	0.11	294469
S1D	0.0500	0.40	48167
S2A	0.0007	0.71	1273
S2B	0.2143	0.26	187792
S2C	0.2545	0.07	209081
S2D	0.0402	0.17	36448
S3A	0		0
S3B	0.1098	0.92	76202
S3C	0.2358	0.28	218698
S3D	0.0086	0.37	6940
S4A	0		0
S4B	0.0359	0.74	55553
S4C	0.1446	0.10	220282
S4D	0.0075	0.39	12611
S5A	0		0
S5B	0.0220	0.39	28765
S5C	0.1325	0.24	159453
S5D	0.0076	0.47	9559
S6A	0.0074	0.42	14993
S6B	0.1947	0.50	390671
S6C	0.2538	0.18	495914
S6D	0.0073	0.32	16025

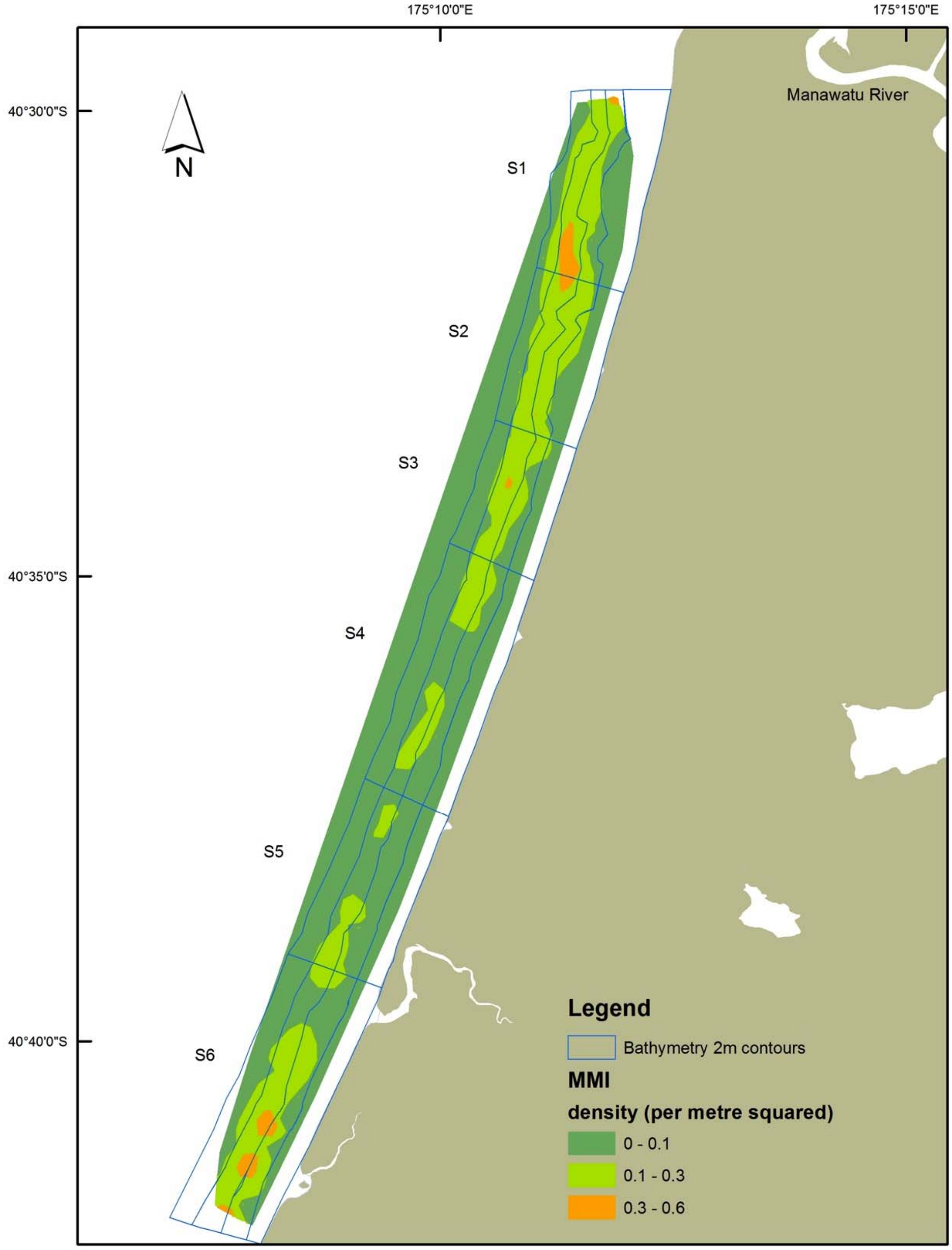

Figure 22. Density (per m^2) for *Mactra murchisoni* (MMI) at the south end of Foxton Beach.

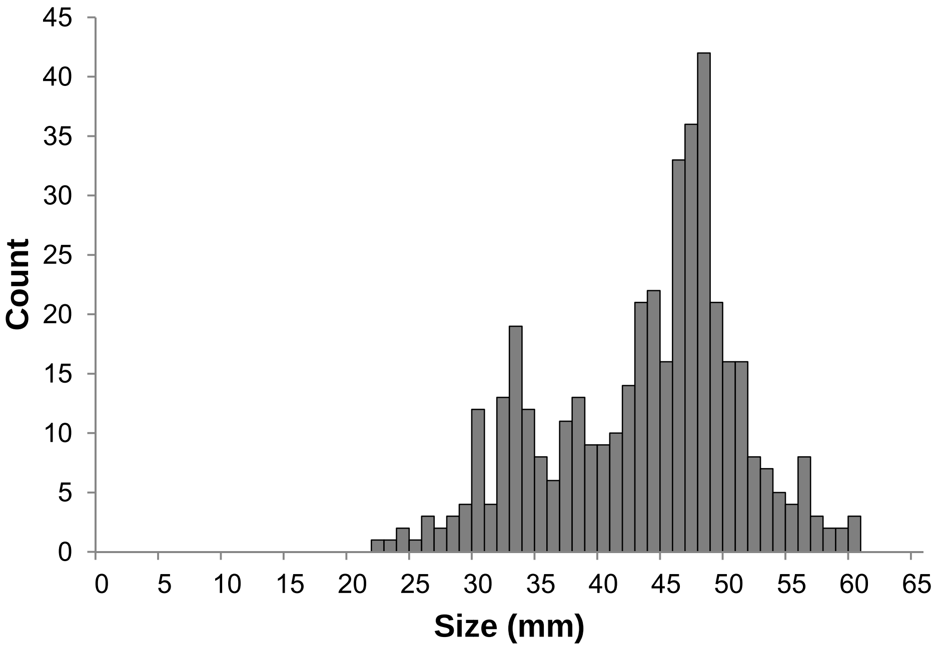

Figure 23. Size-frequency distribution of *Mactra murchisoni* (MMI) from the Manawatu coast. n = 422.

Dosinia anus (DAN)

The biomass of DAN is concentrated in the 4-8m strata (Figure 24) and is found throughout this zone, with some higher density patches in the mid and lower sections (Figure 25).

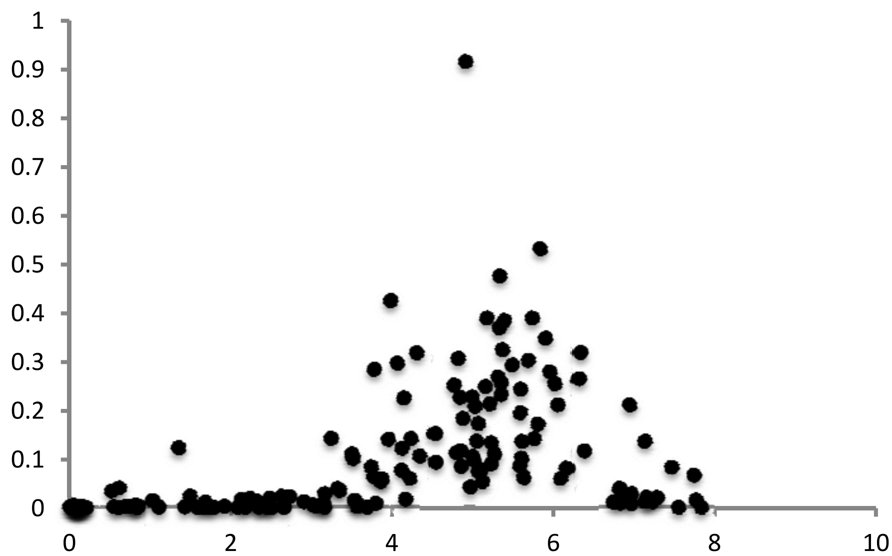

Figure 24. Depth distribution of *Dosinia anus* (DAN).

Table 11. Estimated biomass (kg) of *Dosinia anus* (DAN) per stratum.

Strata ID	Density (kg.m^{-2})	CV	Est. Biomass (kg)
S1A	0.0002	0.55	577
S1B	0.0159	0.56	17839
S1C	0.1535	0.19	160547
S1D	0.1600	0.25	154105
S2A	0.0003	0.86	498
S2B	0.0535	0.31	46908
S2C	0.1660	0.23	136332
S2D	0.0655	0.75	59398
S3A	0.0017	1.00	1928
S3B	0.0075	0.73	5236
S3C	0.0719	0.35	66679
S3D	0.0549	0.48	44054
S4A	0.0011	0.67	2431
S4B	0.0090	0.58	13945
S4C	0.2448	0.28	372964
S4D	0.1182	0.37	197741
S5A	0.0012	0.36	1790
S5B	0.0107	0.36	13968
S5C	0.2345	0.16	282142
S5D	0.1571	0.47	198406
S6A	0.0319	0.51	64581
S6B	0.0164	0.18	32863
S6C	0.2262	0.15	442023
S6D	0.1644	0.47	361760

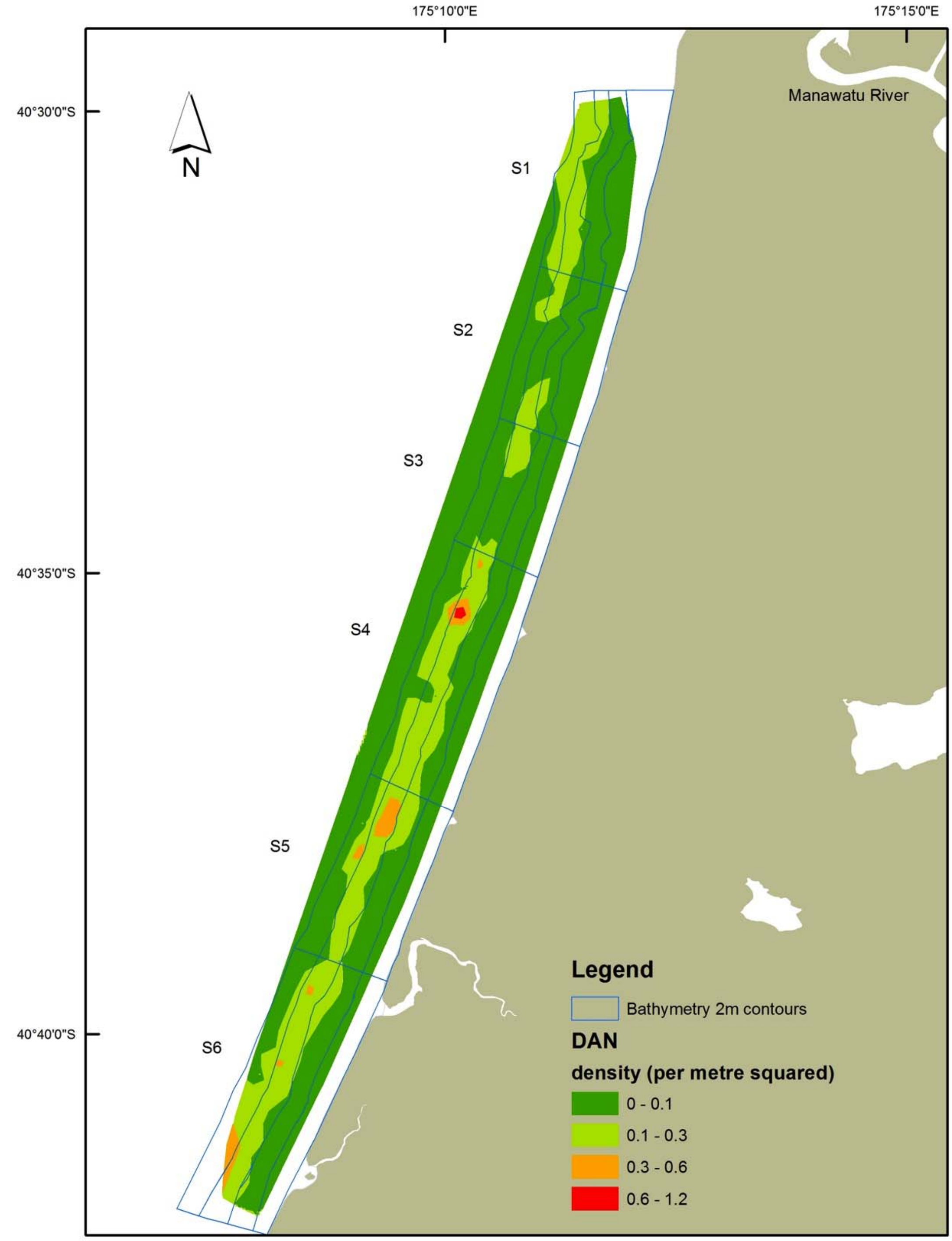

Figure 25. Density (per m^2) for *Dosinia anus* (DAN) at the south end of Foxton Beach.

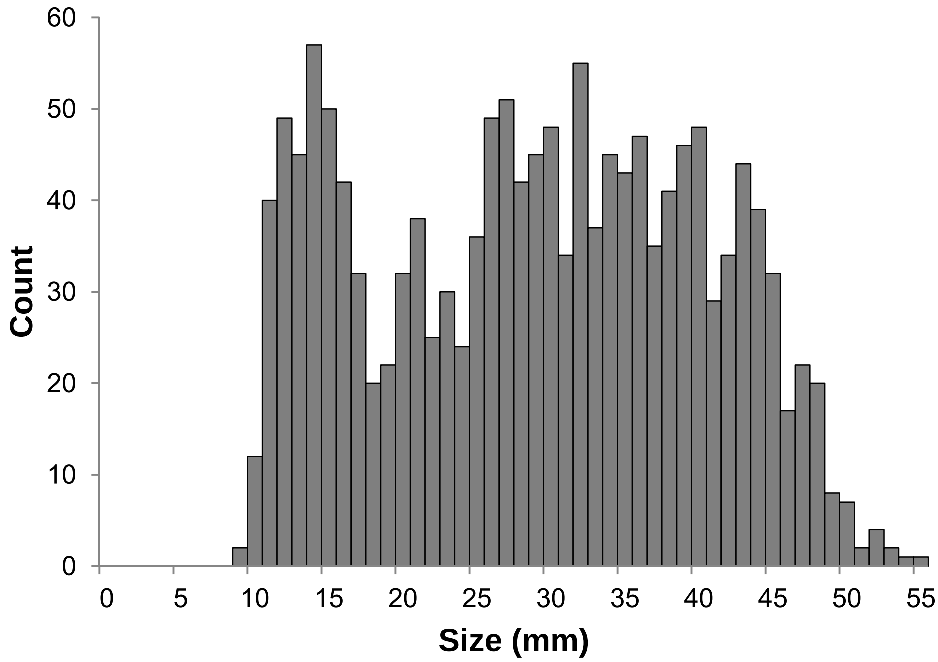

Figure 26. Size-frequency distribution of *Dosinia anus* (DAN) from the Manawatu coast. n = 1447.

Length-Weight relationships

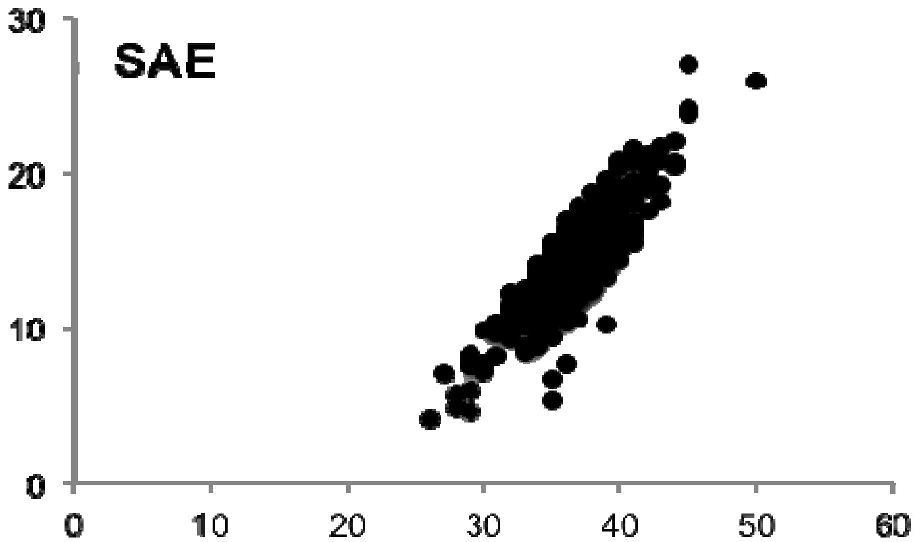

Figure 27 Length-weight relationship of *Spisula aequilatera* caught off the Manawatu coast (n = 506).

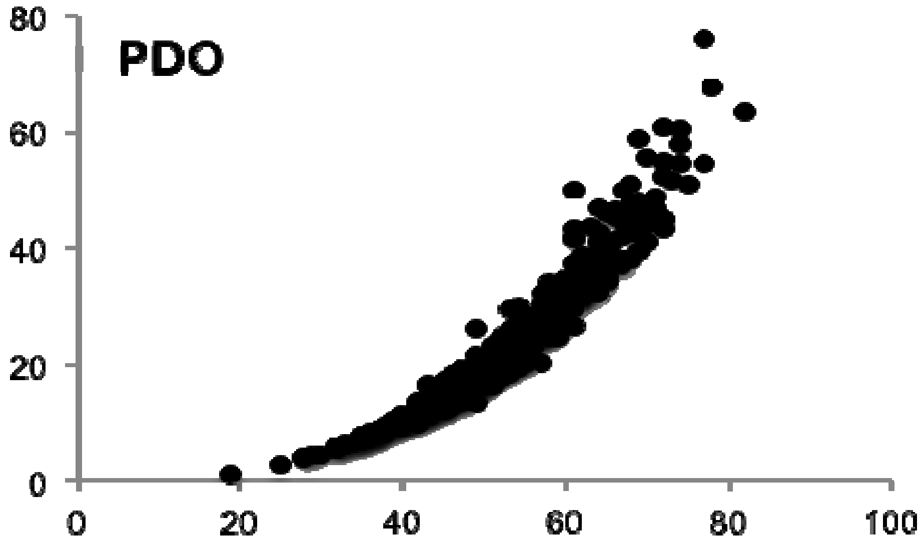

Figure 28 Length-weight relationship of *Paphies donacina* caught off the Manawatu coast (n = 561)

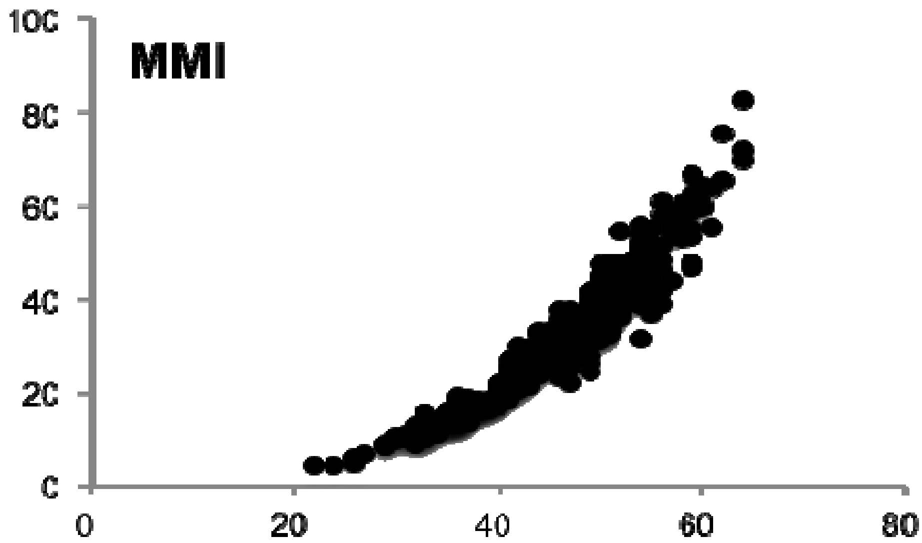

Figure 29 Length-weight relationship of *Mactra murchisoni* caught off the Manawatu coast (n = 422).

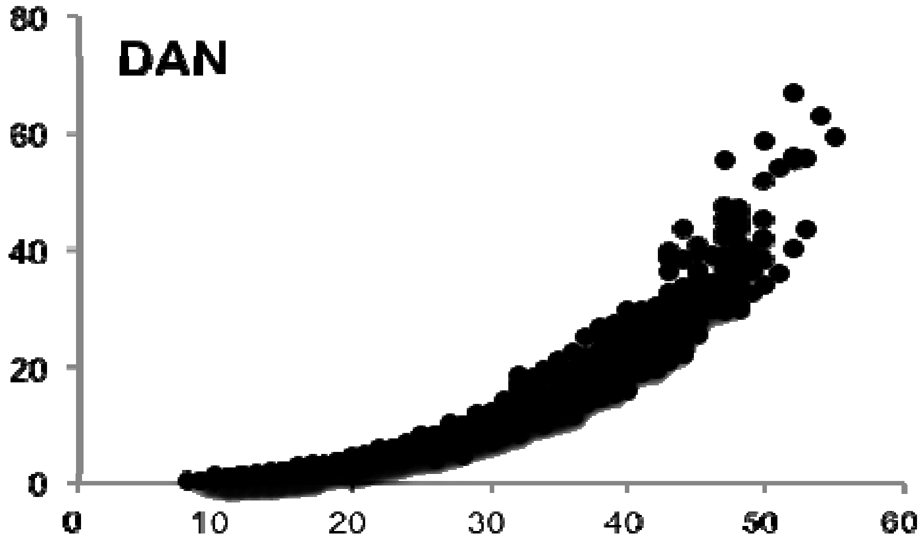

Figure 30 Length-weight relationship of *Dosinia anus* caught off the Manawatu coast (n = 1447).

By Catch

The only by-catch of any significance was the sand dollar *Fellaster zealandiae*. The sand dollar made up a total of 20% of total dredge weight, at 1470kg. It was found mainly in the deeper water and none being found shallower then 2m in depth.

2.5 Discussion

To date this study has found higher biomass of Surf Clams than any other. Haddon (1996) studied the same area with similar study area, but found far less. SAE made up 43% of the four species in this study, and found 157 g m^{-2} compared to Haddon's 0.77 g m^{-2} , some 200 times greater biomass. An increase was also true of the reaming species, for PDO we found 75.8 g m^{-2} where Haddon found 4.44 g m^{-2}, this study found 77.85 g m^{-2} of MMI while Haddon found 3.77 g m^{-2} and 79.48 g m^{-2} of DAN while Haddon found 12.76 g m^{-2} (Table 12). While this study had far greater biomass then Haddon (1996), it had higher but similar results to Triantafillos (2008a and b). In Triantafillos' (2008a; 2008b) studies greater numbers were found compared to Haddon, but still less then this study. Triantafillos (2008a) was conducted on the east coast on the South Island, and 2008b was on the east coast of the North Island. The first (2008a) study caught a total combined weight of 1.5 t (four times less than this study) while the second (2008b) study caught a total combined weight of 897.28Kg of the seven species of commercial surf clams (six times less than this study). However this study only found four of the seven commercial species; the combined weight was 5.7 t.

Table 12. Estimated biomass (g m^{-2}) in three studies.

Species	This Study	Triantafillos 2008a	Haddon et al. 1996
PDO g m^{-2}	75.80	23.81	4.44
SAE g m^{-2}	157.92	116.62	0.77
MMI g m^{-2}	77.85	33.04	3.77
DAN g m^{-2}	79.48	62.81	12.76

Triantafillos (2008a) stated that, of the 20 studies carried out on the North Island previously, their study was the first to have a biomass where SAE and DAN made up the majority of the catch. While this study also found SAE to be a dominant species on the west coast of the North Island we found similar amounts of DAN, MMI and PDO. One possible reason for the difference in PDO was Triantafillos (2008a) had bad weather limiting the number of the days they were not able to get into the shallow areas, whereas in this study we were able to spend more time in the shallows. Another reason for the higher biomass of species is the improvement in dredge technology; all studies to date have used the same hydraulic dredge (the Japanese rabbit dredge) where the Piper dredge used in this study has vast improvements in both capture and impact on the ocean floor. The Japanese rabbit dredge used by Triantafillos (2008a and b) was the same type as tested by Michael et al. (1990): comparing the Japanese rabbit dredge to that of New Zealand Olsen Dredge, it was found that the rabbit dredge was best but only had a catch efficiency of 65.1% (Michael et al., 1990). However Triantafillos and Haddon applied a dredge efficiency of 100%, this reason could also explain to so some degree the difference in biomass, as the Piper dredge actually had efficiency near or at 100%. Cranfield (1994) was one of the first to conduct a depth zonation report; he found that each species of surf clam had a distinct zone that they were found most abundant in, this he found true for both the North and the South Islands. Table 13 shows the depth zonation for the main studies conducted in New Zealand, while Cranfield (1994) found a depth of 3 to 4 meters for PDO, all the other studies found them in shallower water. DAN was always found deeper than four meters across all the studies, being found as deep as ten meters in Cranfield's (1994) study. It was both MMI and SAE that all the studies found in all different areas, both species could be found between zero and eight meters, making targeting a single species troublesome.

Table 13. Comparison of depth distribution of four studies in New Zealand.* shows the depth distribution of MDI instead of MMI as no MMI was found.

Species	Cranfeild (1994)	Haddon (1996)	Triantafillos (2008A)	Triantafillos (2008B)	This Study (2012)
PDO	3 to 4	2 to 3	0 to 2	2 to 6	0 to 2
MMI	4 to 8	3 to 6	2 to 8	4 to 8*	2 to 8
SAE	3 to 7	2 to 4	0 to 6	3 to 6	1 to 6
DAN	4 to 10	4 to 7	4 to 8	5 to 8	4 to 8

Table 13 shows the depth distribution of the four main New Zealand studies, Triantafillos (2008b) found no or very low biomass of MMI and has reported MDI instead. Whereas our study found no MDI to report, however the two species are the same colour, shape (see Figure 31) and in both the colour can change of the shell depending on the coarseness of the substrate, so this cannot be used as identification.

Figure 31. showing MMI (left) and MDI (right). Image used with permission from https://www.flickr.com/photos/cataylor/375493468

There are several ways to distinguish between the two species, such as the colour of the periostracum, the shape of the pallial sinus, and the sculpture of the lateral teeth (Conroy et al., 1993). But the clams need to be opened to view these structures which is impractical in both commercial and biomass surveys. Both species can be found within the same depths, therefore I feel it possible that this species could be reported incorrectly, and therefore the biomass estimates be incorrect for either species. Foxton beach currently has no commercial surf clam fishery, therefore the size and weight of the biomass would give us some insight into a virgin population of surf clams. The size was comparable to those found at other study sites (Triantafillos, 2008a, 2008b), PDO ranged from 19 to 73mm with several potential modes. One was centred around 25-30mm with the main one centred around 40-45mm. Only one of the five sites in Triantafillos 2008a showed more the one mode, while in 2008b also only showed the one mode. SAE ranged from 26 to 47mm with only one main mode apparent, centred around 37mm. MMI ranged from 23 to 61mm with several potential modes. The most obvious ones centred on 34 and 44mm. DAN ranged from 9 to 56mm with many potential modes, each one spanning around 7mm. This suggests that a virgin population can consist of more than one breeding season. One issue that could pose issues fishing at Foxton Beach is the large population of *Fellaster zealandiae*, as mentioned they made up some 20% of total dredge weight, and would need to be sorted from the surf clams caught. This would increase workload and slow down the harvesting process. However this is an un-fished area and perhaps if fished regularly the population of *Fellaster zealandiae* may thin out. Further investigation would have to be conducted to see if this is accurate. The main findings from this study was that prior to this study, the biomass of surf clams was at the entry quota level of just 67 t (Ministry for Primary Industries, 2013) for TACC, and it was increased to 2816 t for the four species in FMA8, making it possible to grow this industry to meet market demand.

Chapter Three – Surveys in Fishing Management Area 7

3.1 Introduction

Golden Bay is found at the very Northern tip of the South Island, New Zealand. Protected by New Zealand's largest sand spit, Farewell Spit. The spit reaches some 26km in an easterly direction. On the northern side of the spit there is a 26km long sandy bottom stretch of coast, an ideal environment for surf clams (Cranfield et al., 1994). However the northern side is very exposed and has large rolling waves; this could cause issues with harvesting. The Southern side of farewell spit already has a few commercial fisheries, both a geoduck and a cockle industry (Ministry for Primary Industries). Farewell spit falls within Fishing Management Area 7, and starts at the Northern tip of Big Bay on the west coast of the South Island (44º 10.00s 173º 56.50e) and encompasses approximately two thirds of the west coast of the south island, the northern tip of the South Island, and a portion of the east coast, till the outlet of the Clarence River (42º 10.00s 173º 56.50e) (Ministry for Primary Industries, 2014). With a total coastline of 3,390km and a total area of 334,000km^2 (Ministry for Primary Industries, 2014). FMA7 already has a commercial aquaculture fishery in the form of Green Lipped Mussel (*Perna canaliculus*), an important and valuable export for New Zealand, with export earnings of over $150 million dollars (US) (Chandurvelan et al., 2012). As well as the Green Lipped Mussel, Surf Clams are also harvested from FMA7, Cloudy Bay Clams fish out of Cloudy Bay (Cranfield et al., 1994). The current TAC for FMA7 is 50 t for PDO, 61 t for MMI, 112 t for SAE and 15 t for DAN (Ministry for Primary Industries, 2013). That is a total of 238 t for the four species in FMA7, the study conducted at FMA8 produced over 1000% more biomass for the same four species (White et al., 2012).

3.2 Methods

The methods used for this portion of the study was the same as was used for the Foxton study, please refer to chapter 2.2

3.3 Results

3.3.1 Bathymetry

As Figure 32 shows the bathymetry at Farewell Spit has clear boundaries, but also has some shallow areas within deeper zones. To the west side of the spit there is no distinguishable shallows (0-2m); instead depth seems to stay at 2 meters for some distance from the shoreline. On the eastern side there is a channel breaking the deeper depths, with pockets of shallower and deeper areas with each depth strata. A total of 1534 waypoints were taken to produce the bathymetry data, however I feel we would have to take considerably more to truly get a clearer mapping of the bottom. However due to Cloudy Bay Clams deciding to stop exploration of this area we did not have time to gain any further data.

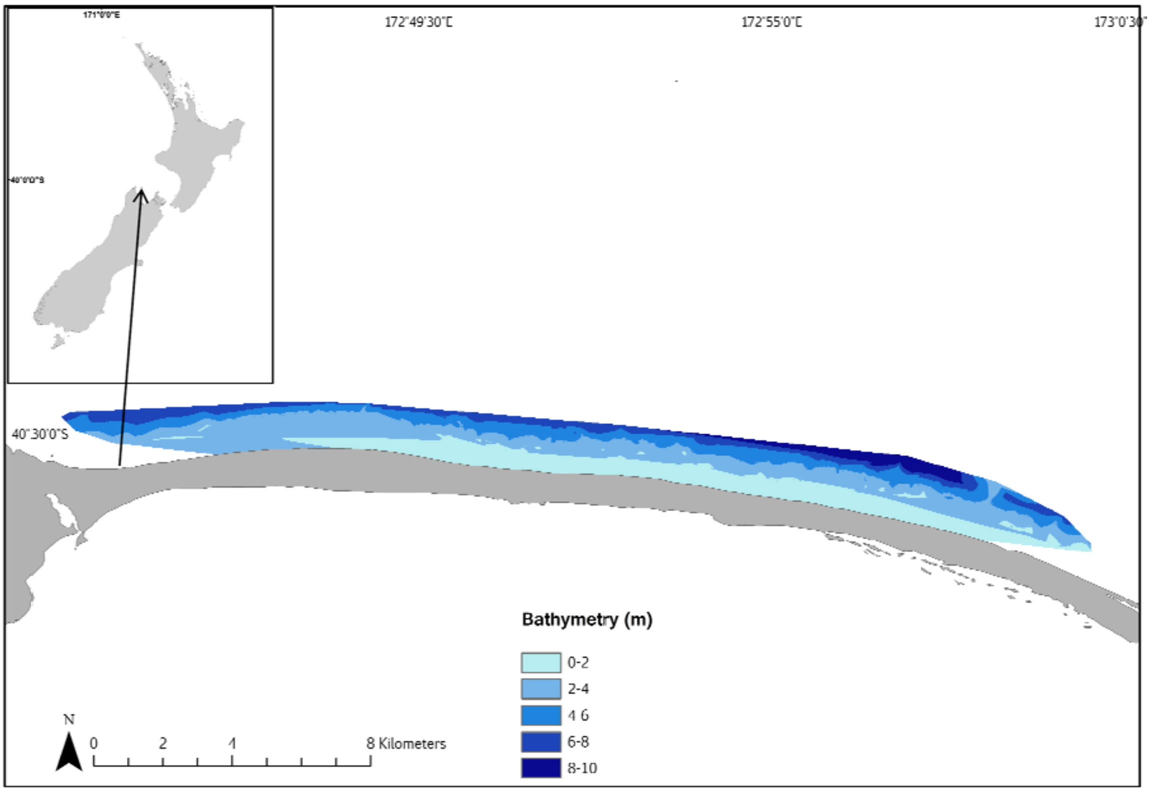

Figure 32. Depth contours of the 26 km stretch of coastline at Farewell Spit.

3.3.2 Survey Stations

Figure 33 shows the explorative tows taken on one day at Farewell Spit, a total of ten tows were taken but only eight produced any catch, and all was PDO. The biggest weight was 5.66Kg, and the smallest 100g (table 14).

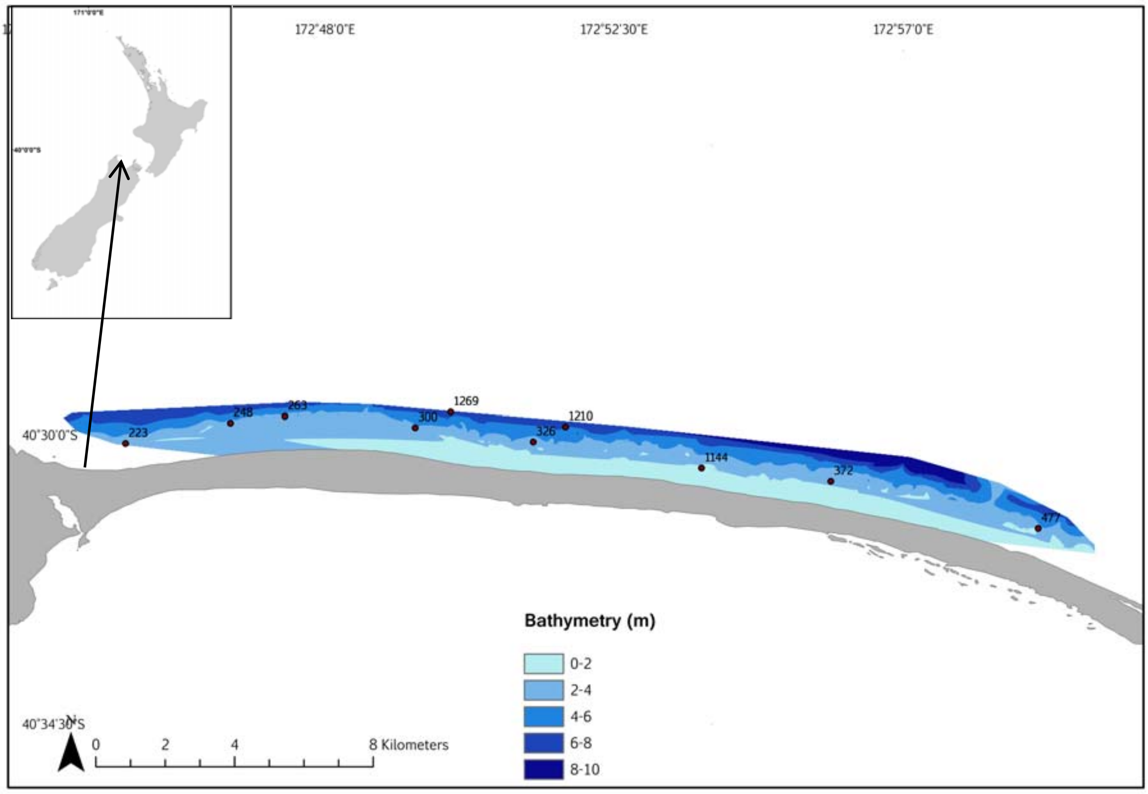

Figure 33. Ten exploration tows and the depth they were taken at.

Table 14. Depth, weight and species for explorative phase at Farewell Spit.

Tow	Species	Depth	Weight (kg)
1	PDO	2.7	0.44
2	-	2.4	0
3	PDO	3.8	0.12
4	PDO	4	1.23
5	PDO	6.4	5.19
6	-	2.2	0
7	PDO	6.7	0.88
8	PDO	1.4	5.66
9	-	2.9	0
10	PDO	3.2	0.1
Total			13.62

3.4 Discussion

Commercial fishing on the northern side of Farewell Spit would be hazardous and more weather dependant due to the shallow sections all along the coast line, as seen in Figure 32. The depth contours rapidly change with distance from the shore line, so that waves were breaking on both sides of the vessel along the complete 26km stretch of coast. In the ten explorative shots that were done, only eight produced any catch of surf clams, with the total combined catch consisting of only

PDO, and only weighing a total of 13.62 Kg. It is surprising that only PDO was found, and in depths up to 6.7m. No other study to date has only found just a single species, and finding PDO so deep is also rare but not unheard of (Cranfield, 1994). Due to the difficult conditions and the low catch rate, Cloudy Bay Clams decided to go no further with this study. More investigation would have to be conducted to explain the absence of the other species of surf clams. This could be because the surf zone is just too strong and PDO is the most hardy species able to survive these conditions.

Chapter Four – Oxygen uptake and survivability

4.1 Introduction

Cloudy Bay Clams (CBC) is a major stakeholder and fisher of New Zealand surf clams, exporting internationally, as well as supplying a domestic market. The clams are caught using a similar dredge as described in chapter one, placed into one ton blue tubs where fresh sea water is passed over them, continually being replaced. Then the clams are off loaded onto a trailer for delivery to the wet store, where they are re-swam. The re-swimming process is to remove sand and reduce stress before the live calms are shipped to Hong Kong, where they are re-swam in smaller tanks before being sold to the Hong Kong market. From being caught the only time they are out of the water for more than one hour is during transport from the wet store in New Zealand to the wet store in Hong Kong, normally taking between 12-15 hours. However the mortality rate during this transportation is high, especially during the summer months when it can be as high as 35% of stock. This study will replicate some of the conditions the clams will undergo during transport, specifically temperature and oxygen levels, to monitor survivability rates, and determine the best conditions for transportation. The chilly bin leakage test was to ascertain if the clams being shipped were being sufocatiated during transportation, while the oxygen chamber tests were to see how much oxygen clams would use if available. Finally the survivability tests were to mimic shipping methods while manipulating temperature and varying degrees of oxygen.

4.2 Methods

4.2.1 Chilly Bin Leakage Tests

Using a standard 20L polystyrene bin, a Apogee M200 Oxygen meter was placed inside and taped up to prevent any oxygen from leaking out between the lid and main body. Using a glass probe a hole was made in opposite ends of the bin, and 100% oxygen was pumped into the box until the probe reported 100% oxygen inside the bin. Both holes were then taped up and the probe was set to record every 30 minutes for a 24hr period. This test was carried outa total of four times, with four different bins to ensure consistency of leakage if any.

4.2.2 Survivability Tests

The aim of this study was to ascertain the best conditions during transportation to ensure successful re-swimming and survivability of clams by manipulating both oxygen content and temperatures within the chilly bins.

Test One 15kg of clams were taken out of the swimming area and packed into a chilly bin. The clams were then re-swam immediately, and after 1, 24, 48 and 72 hours the mortality rate was recorded.

Test Two 15kg of clams were taken out of the swimming area and packed into a chilly bin. They were then left in the chilly bin for a period of 30 hours with the lid removed, in a controlled temperature environment. The clams were then re-swam and after 1, 24, 48 and 72 hours the mortality rate was recorded.

Test Three 15kg of clams were taken out of the swimming area and packed into a chilly bin. They were then left in the chilly bin for a period of 30 hours, in a controlled temperature environment, with the lid in place and taped as if they were being shipped. A temperature logger was also placed in the chilly bin to log the data for the full 30 hour period. The clams were then re-swam and after 1, 24, 48 and 72 hours the mortality rate was recorded.

Test Four 15kg of clams were taken out of the swimming area and packed into a chilly bin. They were then left in the chilly bin for a period of 30 hours, in a controlled temperature environment, with the lid in place and taped as if they were being shipped. 100% oxygen was placed into chilly bin at the start and 15 hours into the test. The clams were then re-swam and after 1, 24, 48 and 72 hours the mortality rate was recorded. One replicate of each of the four tests will be conducted on the same day to ensure the environmental conditions remain the same. A total of 3 replicates for each test will be conducted. To investigate effect of temperature, a total of three treatments were also carried out. In the first replicate no ice was placed into the chilly bins, in the second two ice blocks were placed into the chilly bins, and in the third four ice blocks were placed into each of chilly bins to see what effect if any temperature plays.

Materials used:

- 12 Chilly Bins
- At least 15kg of both Diamond and Storm clams per test per replicate. All surviving clams will be returned but will not be reused in any further tests
- Two rolls of tape used for shipping
- Nine temperature loggers
- Small canister of 100% oxygen

Schedule:

Day One

- Prepare tests 2, 3 and 4 a total of three replicates each per species
- Perform test one a total of three times for each species to be tested

- After 8 hours inject oxygen into test 4

Day Two

- Prepare tests 2, 3 and 4 a total of three replicates each per species
- Perform test one a total of three times for each species to be tested
- After 8 hours inject oxygen into test 4
- After 30 hours of the previous days tests, re-swim clams, after one hour count and record mortality rate

Day Three

- Prepare tests 2, 3 and 4 a total of three replicates each per species
- Perform test one a total of three times for each species to be tested
- After 8 hours inject oxygen into test 4
- After 30 hours of the previous days tests, re-swim clams, after one hour count and record mortality rate

Day Four

- Perform test one a total of three times for each species to be tested

After 30 hours of the previous days tests, re-swim clams, after one hour count and record mortality rate

4.2.3 Oxygen Consumption

Surf Clams of various sizes and weight's (table 15) were placed into a custom made air tight chamber (figure 34), with an Apogee M200 Oxygen meter in the top. The Oxygen meter was set to record every 30 minutes for a 30 hour period.

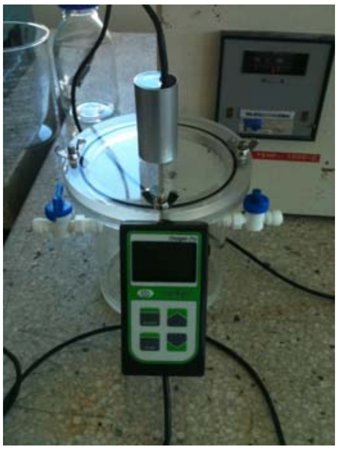

Figure 34. The custom made chamber for the Oxygen consumption tests, with the Apogge M200 Oxygen sensor screwed into the top to record Oxygen levels.

4.3 Results

4.3.1 Chilly Bin Leakage

Figure 35 shows the leakage test with a standard 20L chilly Bin, when filled with 100% oxygen. After 30 hours with nothing inside using the oxygen, the oxygen leaks to an average of 24.6%, just slightly higher than ambient oxygen in the atmosphere (20.9%).

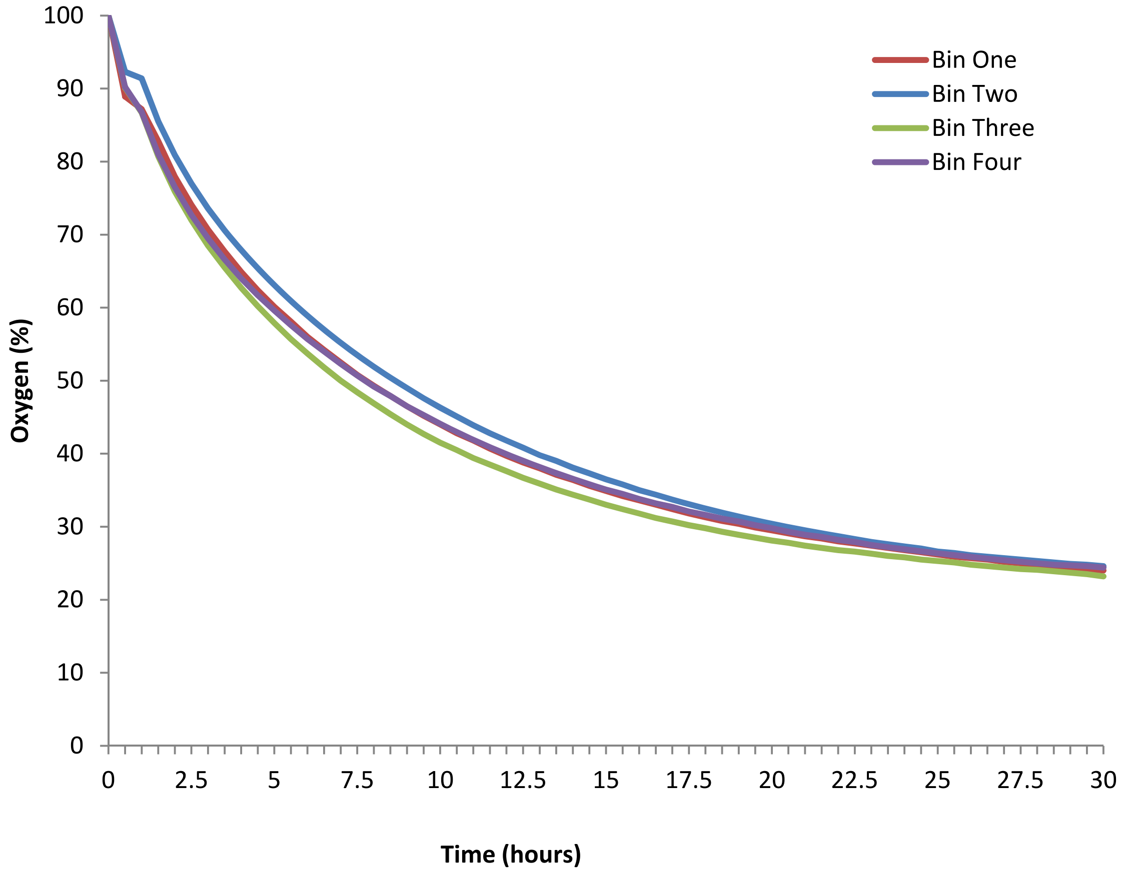

Figure 35. Oxygen leakage of a standard 20l chilly bin when filled with 100% oxygen for all four bins tested.

4.3.2 Survivability Tests

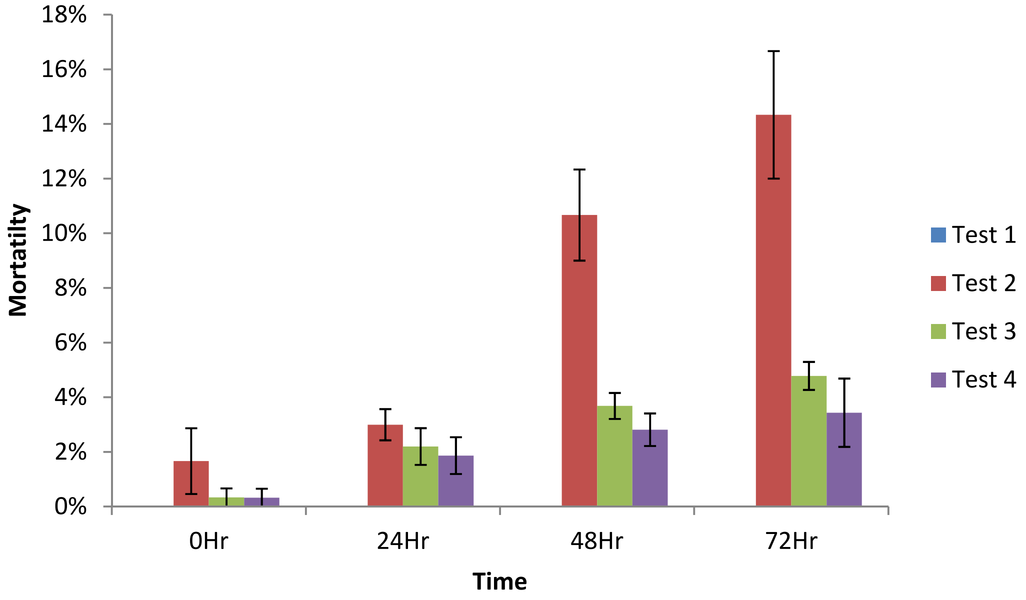

Figure 36. Survivability test results for all four treatments, with no ice.

Figure 36 shows the survivability test for all four treatments, with no ice. Test one had a 0% mortality rate for the complete 72hr test period. Test two at re-swim had a mortality of 1.66%, after 24hr it was 3%, 48hrs was 10.67% and after 72hrs mortality was at 14.33%. Test three at re-swim had a mortality of .33%, at 24hrs it was 2.2%, after 48hrs it was 3.68% and after 72hrs mortality was at 4.78%. Test four at re-swim had a mortality of .33%, at 24hrs it was 1.87%, after 48hrs it was 2.81% and after 72hrs mortality was at 3.44%.

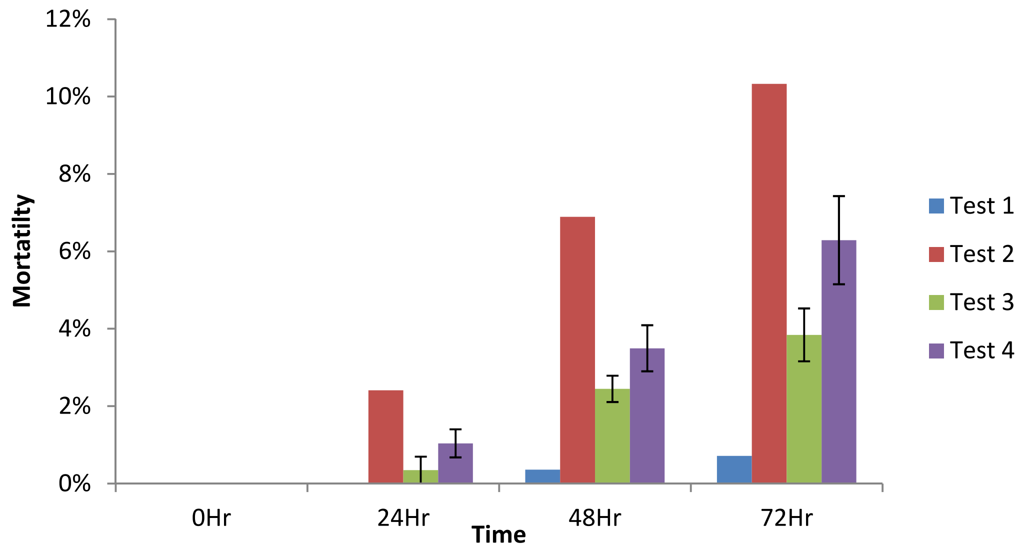

Figure 37. Survivability test results for all four treatments, with two ice blocks.

Figure 37 shows the survivability test for all four treatments, with two ice blocks. Test one had a 0% mortality rate for the first 24hrs, then after 48hrs mortality had raised to .36% and after 72hrs it was .72%. Test two at re-swim had a mortality of 0%, after 24hr it was 2.41%, 48hrs was 6.89% and after 72hrs mortality was at 10.33%. Test three at re-swim had a mortality of 0%, at 24hrs it was .35%, after 48hrs it was 2.45% and after 72hrs mortality was at 3.84%. Test four at re-swim had a mortality of 0%, at 24hrs it was 1.04%, after 48hrs it was 3.49% and after 72hrs mortality was at 6.29%.

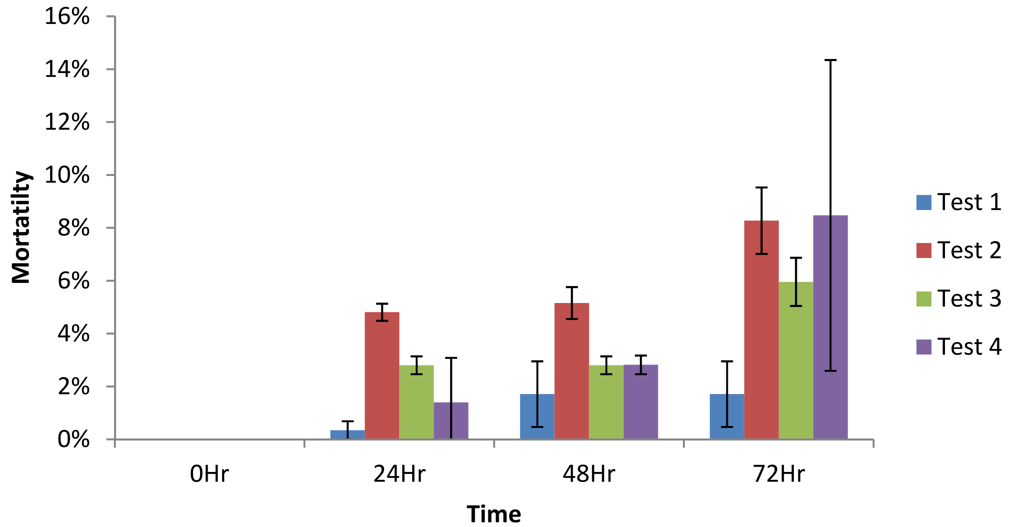

Figure 38. Survivability test results for all four treatments, with four ice blocks.

Figure 38 shows the survivability test for all four treatments, with four ice blocks. Test one had a 0% mortality rate at re-swim after 24hrs it was .34%, then after 48hrs mortality had risen to 1.71% and stayed at this for the remaining time. Test two at re-swim had a mortality of 0%, after 24hr it was 4.81%, 48hrs was 5.16% and after 72hrs mortality was at 8.27%. Test three at re-swim had a mortality of 0%, at 24hrs it was 2.80%, and stayed this way till 72hrs where mortality was at 5.96%. Test four at re-swim had a mortality of 0%, at 24hrs it was 1.40%, after 48hrs it was 2.82% and after 72hrs mortality was at 8.47%.

4.4 Oxygen Consumption

Table 15 shows the length from posteria to anterior and umbo to outer edge. Weights ranged from 32.82 g to 41.59 g for SAE and 111.2 g to 144.4 g for MMI. All clams were randomly chosen and sent up by Cloudy Bay Clams from the wet store after a period of reswimming to remove grit and dirt.

Table 15. Length and weight of the clams used for the Oxygen consumption tests.

Clam #	Pos/Ant (mm)	Umbo/Outer (mm)	Weight (g)	Species
1	85	72	128.7	MMI
2	78	68	111.2	MMI
3	79	68	127.4	MMI
4	78	69	118.3	MMI
5	83	74	141.3	MMI
6	82	68	144.1	MMI
7	83	72	144.4	MMI
8	53.13	43.4	37.32	SAE
9	51.18	42.5	33.37	SAE
10	51.84	42.42	35.67	SAE
11	89.09	75.12	180.5	MMI
12	87.92	75	177.2	MMI
13	55.77	43.74	41.59	SAE
14	52.87	42.1	37.95	SAE
15	51.65	41.41	32.82	SAE

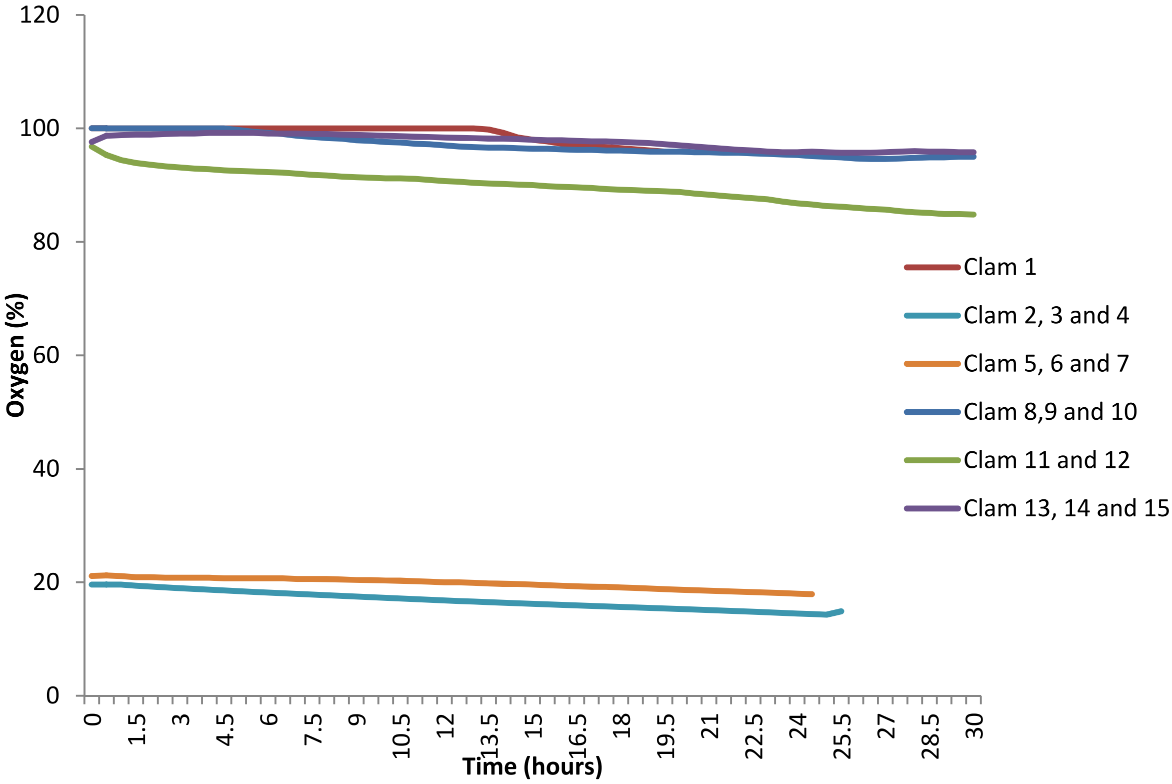

Figure 39. Oxygen consumed by test clams in the sealed oxygen chamber.

Figure 39 shows the amount of oxygen consumed for each test run. Clam one used 8.67% of oxygen. Clams two, three, and four were in the same chamber and used a total of 23.98%, an average consumption of 7.99% per clam. Clams five, six and seven consumed 15.17% of oxygen, averaging 5.06 per clam. Clams eight, nine and ten used a total of 7.59% averaging just 2.53%. Clams eleven and twelve used 12.40% oxygen, an average of 6.2% per clam, and clams thirteen, fourteen and fifth teen used 1.82% of oxygen and average of just 0.61 per clam.

4.4 Discussion

Cloudy Bay Clams transport their clams as far afield as Hong Kong, often taking anywhere between 12 and 15 hours from the wet store to destination in Hong Kong, where they are re-swam before being sold live to local restaurants. The main issue is that on some occasions as much as 35% of product die upon re-swim or dead in the chilly bin upon arrival. Then more clams are required to be shipped to ensure the supply of surf clams meets local demand, losing profit every time.

Several theories could explain the cause of death, including lack of oxygen, shock or overheating. The leakage test was held to see if the chilly bin could contain the oxygen that it was filled with, to rule out starvation due to lack of oxygen. However after thirty hours the oxygen had leaked out to just above ambient oxygen found in the atmosphere. The material of the chilly bin is obviously permeable, as the chilly bin was sealed in all openings, meaning the only way leakage could happen is via the walls. This suggests that if pressure inside was less then outside, oxygen would also be drawn in as well. The test was conducted on four different chilly bins to ensure that they were not faulty in any way. All four chilly bins lost oxygen at similar rate, and after thirty hours had similar degrees of oxygen inside them.

We have seen in the oxygen tests, that bivalves can exchange oxygen via the water retained in the mantle cavity, so by placing them in the chamber we can get a good understanding of consumption. Clam one used 8.67% oxygen, however by 19.5 hours the clam had died. Clams two, three and four were MMI and were placed in the chamber together, and stored in a cooler temperature controlled area, and only ambient air pressure was inside the chamber. After thirty hours they had 23.98% oxygen (19.6% to 14.9%) with an average per clam of 7.99%. Clams five, six and seven were of similar size and were kept in the same conditions, but only used an average of 5.06%, the last group of MMI clams were eleven and twelve and used a total of 12.40%, an average of 6.2%. From the results for MMI there seems to be no link between bigger size and oxygen consumption, the highest clams to use oxygen were the smallest, and the lowest were the middle sized clams, meaning the largest were middle of the range.

For the SAE tests clams eight, nine and ten used on average of 2.53%, while thirteen, fourteen and fifth teen used only .61%, both with 100% oxygen starting point, in the same temperature. So with the chilly bin being permeable and knowing that if available the clams will exchange oxygen in the water in the mantle cavity, our final test was to see if the clams reacted differently when packed into chilly bins for a thirty hour period, with modified temperature within the chilly bins.

As would have been expected (with minimal time out of the water) the control tests performed the best, interestingly the best performer of the control test was with the treatment of no ice, with 100% surviving after the 72hrs, but they were closely followed by two ice blocks at 99% and four at 98% surviving. The other three treatments results are mixed, with all being in the 90% survivability rate, however the higher percentage of survivability all had larger ice packs in them. The lowest result of 86% surviving was that of test two with no ice.

The Mussel's Alive program (2013), and Guderley, Demers et al. (1994) study also found a decrease in temperature also increased the survivability of product. These tests fail to see why CBC are having such a high mortality rate, further test would have to be carried out to investigate the cause, for example, placing shock recorders within the chilly bins, to see if the chilly bins are being treated roughly causing stress to the clams, or temperature loggers to see if they are being exposed to high heat at some point during their journey.

Chapter 5 – General Discussion

At this time no other study has found as many commercially caught surf clams as this study. The quota prior to this study for FMA8 was set at 114 t with a TACC of 96 t. With the results we have found at Foxton Beach of an estimated biomass of 13,177 t for the four of the seven species the original quota is very conservative. On the basis of this study a proposal was put to the Ministry of Primary Industries for an increase for the study area within FMA8. Table 16 shows the current TAC and TACC along with the proposed changes, this has since gone out for public consultation and been accepted. Thus the study we conducted at Foxton Beach has directly led the greatest increase in the quota for commercially caught surf clams.

Table 16. Current and new TAC and TACC quotas for Foxton Beach.

Species	Current TAC	Current TACC	New TAC	New TACC
PDO	9	1	296	263
SAE	8	8	1821	1730
MMI	25	25	631	599
DAN	33	33	236	224

New Zealand has some long open stretches of coast yet to be surveyed for further increases for surf clams, and this needs to occur if New Zealand is grow this industry into a multimillion export industry. The results for Golden Bay were surprising: no clams of significance and certainly none to sustain a stable fishery, with all being *Paphies donacina*. The bathymetry is also very random, with pockets of shallows in deeper water and pockets of deeper sections in shallower section. This was on the northern side of Farewell Spit, the southern side is very tidal, however further south near Collingwood there is many kilometres of open coast to survey. This study was scheduled to include another three areas, the western end of Ohope Beach to approximately 1.8 nautical miles east of Opotiki , FMA1. FMA5, Oreti Beach and FMA9 the entrance of the Kaipara Harbour heading north. The test for the survivability was inconclusive with regards to explaining why Cloudy Bay Clams are at times losing 35% of shipped stock. This study fits with others that chilling and not over packing seems to be best with regards to the product reaching its destination alive. Further investigation would need to be done as to why the loss of stock is occurring. Tests such as determining water quality at destination, and measuring shock and temperature in the chilly bins during transportation would be very relevant/informative.

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Appendix 1 – Raw data from surveys in FMA 8

						Biomass (kg)					
Area	Depth Stratum	Station No.	Start Latitude	Start Longitude	Depth (m)	PDO	SAE	MMI	DAN	DSU	BYA
6	B	0	-40.682134	175.136292	3.54	0.10	49.30	44.20	0.40	0	0
6	B	1	-40.680921	175.138422	2.25	0.30	23.50	3.80	1.80	0	0
6	B	2	-40.685429	175.136131	2.25	0.20	25.80	4.20	1.50	0	0
6	B	3	-40.688836	175.132608	3.60	0	40.90	40.10	1.20	0	0
6	B	4	-40.696620	175.131220	1.96	0.75	28.00	3.20	1.90	0	0
6	B	5	-40.664287	175.146014	2.60	0.60	51.90	1.50	1.10	0	0
6	A	6	-40.659731	175.151068	-0.22	5.19	0.30	0	0.19	0	0
6	A	8	-40.669835	175.147237	0.43	54.31	0.66	0.33	1.18	0	0
6	A	9	-40.677689	175.142426	0.02	11.90	0.32	0.14	0.22	0	0
6	A	10	-40.675644	175.144743	0.06	37.01	0.27	0.29	0.35	0	0
6	A	11	-40.683647	175.140452	0.20	72.06	3.20	0.50	3.02	0	0
6	A	12	-40.695108	175.135234	0.20	50.77	3.15	1.74	2.54	0	0
6	A	13	-40.699739	175.132874	0.61	27.02	2.20	0.80	8.80	0	0
6	D	14	-40.673320	175.132497	6.70	0	0.11	0.10	1.69	0	0
6	D	15	-40.686683	175.127176	6.42	0	0	1.09	46.23	0	0
6	D	16	-40.682127	175.128563	6.36	0	0.79	1.10	21.76	0	0
6	D	17	-40.670350	175.132238	7.03	0	0.10	0	0.85	0	0.17
6	D	18	-40.668987	175.133009	7.13	0	0.17	0.29	1.37	0	0.45
6	D	19	-40.654150	175.141332	6.21	0	0.12	0.49	1.48	0	0
6	D	20	-40.685230	175.129217	5.55	0	0.22	1.25	24.54	0	0
6	C	21	-40.672238	175.136828	5.07	0	4.62	7.03	31.51	0	0.15
6	C	22	-40.669451	175.140231	4.26	0	31.82	25.11	9.71	0	0
6	C	23	-40.658577	175.142121	5.82	0	2.80	3.60	29.92	0	0
6	C	24	-40.695942	175.126258	5.00	0	7.50	15.90	25.40	0	0
6	C	25	-40.691890	175.127540	4.82	0	4.15	11.09	25.75	0	0
6	C	26	-40.687544	175.132410	4.21	0	24.75	29.40	9.98	0	0
6	C	27	-40.673437	175.137658	4.47	0	22.18	24.98	13.65	0	0
6	C	28	-40.676711	175.136055	4.63	0	21.30	19.98	14.32	0	0
6	C	29	-40.697258	175.128297	3.46	0	28.70	35.70	7.30	0	0
6	C	30	-40.696689	175.127097	4.34	0	17.40	29.30	17.76	0	0
1	B	31	-40.527700	175.193483	2.19	2.16	13.25	7.56	0	0	0
1	B	32	-40.506800	175.197750	3.20	0.44	77.86	2.42	0	0	0
1	B	33	-40.521583	175.194517	2.61	3.10	20.44	6.12	2.11	0	0
1	B	34	-40.497350	175.198367	4.69	0	40.93	32.90	1.36	0	0
1	B	35	-40.523783	175.193383	3.35	0	34.48	1.82	0.56	0	0
1	B	36	-40.519083	175.193250	2.92	0	92.64	13.02	0.91	0	0
1	B	37	-40.523098	175.195714	1.90	0.56	0.36	0.73	0	0	0
1	B	38	-40.517317	175.192333	4.90	0	46.37	22.32	6.92	0	0
1	B	39	-40.508183	175.197433	2.95	1.38	54.79	2.37	0	0	0
1	A	40	-40.524753	175.196375	2.24	0.34	0.10	0.04	0.04	0	0
1	A	41	-40.504159	175.200487	1.82	0.26	0.07	0.20	0.04	0	0

						Biomass (kg)					
	Depth	Station		Start	Depth						
Area	Stratum	No.	Start Latitude	Longitude	(m)	PDO	SAE	MMI	DAN	DSU	BYA
1	A	42	-40.524860	175.199279	0.02	1.70	0	0	0	0	0
1	A	43	-40.507709	175.201238	0.10	1.80	0	0	0	0	0
1	A	44	-40.531007	175.197266	0.05	17.30	0	0	0	0	0
1	A	45	-40.512887	175.198607	1.85	0.83	0	0.23	0	0	0
1	A	46	-40.518106	175.197572	0.44	1.30	0.20	0	0	0	0
1	A	47	-40.527878	175.196225	1.52	2.91	0.20	0.14	0.09	0	0
1	D	48	-40.498500	175.191133	5.79	0	0.20	0.94	24.00	0.11	0
1	D	49	-40.499600	175.192533	6.24	0	0.69	3.20	19.51	0.46	0
1	D	50	-40.519350	175.186800	7.45	0	0	2.06	6.71	0	0
1	D	51	-40.526333	175.184733	7.58	0	0	1.63	5.60	0	0
1	D	52	-40.507350	175.189350	7.27	0	0.33	4.96	11.60	0	0
1	D	53	-40.505233	175.191567	6.63	0	38.16	14.69	11.94	0	0
1	C	54	-40.505633	175.194950	4.90	0	46.03	14.59	4.97	0	0
1	C	55	-40.528483	175.189750	4.76	0	49.98	38.07	7.03	0	0
1	C	56	-40.521167	175.190917	4.53	0	27.70	18.88	5.39	0.08	0
1	C	57	-40.521583	175.192433	3.37	0	90.24	19.20	4.85	0	0
1	C	58	-40.508733	175.192883	5.69	0	42.29	22.60	7.00	0	0
1	C	59	-40.510433	175.192717	5.43	0	16.26	7.48	2.80	0	0
1	C	60	-40.526800	175.187467	6.49	0	3.87	18.59	21.84	0	0
1	C	61	-40.513483	175.189783	6.15	0	0.75	18.03	16.80	0.70	0
1	C	62	-40.523067	175.189000	5.93	0	8.37	29.44	15.01	0	0
1	C	63	-40.505733	175.193117	5.59	0	27.49	12.99	17.64	0	0
1	C	64	-40.520250	175.189733	5.32	0	28.94	26.18	20.23	0	0
2	B	65	-40.555745	175.186293	2.45	1.13	10.81	0.74	0.44	0	0
2	B	66	-40.548417	175.185267	4.60	0	74.88	14.48	7.98	0	0
2	B	67	-40.542317	175.187667	3.80	0	77.67	18.06	2.64	0	0
2	B	68	-40.554333	175.183833	4.59	0	62.76	20.17	3.94	0	0
2	B	69	-40.535850	175.189067	4.20	0	65.53	22.57	4.39	0	0
2	A	70	-40.557914	175.188958	0.05	8.70	0	0	0	0	0
2	A	71	-40.552340	175.188286	2.26	0.70	1.60	0.40	0.20	0	0
2	A	72	-40.558831	175.188373	0.02	6.60	0	0	0	0	0
2	A	73	-40.553990	175.190583	0.07	1.70	0	0	0	0	0
2	A	74	-40.555762	175.187836	1.29	1.40	0.21	0	0.03	0	0
2	A	75	-40.545197	175.192816	0.00	5.12	0	0	0	0	0
2	A	76	-40.535025	175.195935	0.18	6.59	0	0	0	0	0
2	A	77	-40.547910	175.189681	2.83	0.48	1.30	0.20	0	0	0
2	A	78	-40.544015	175.193485	0.05	18.70	0	0	0	0	0
2	D	79	-40.540383	175.181167	7.73	0	2.20	4.60	0.98	0	0
2	C	80	-40.552225	175.182075	5.27	0	20.11	20.65	24.95	0	0
2	D	81	-40.534933	175.183733	7.64	0	0	2.68	15.26	0	0
2	D	82	-40.533883	175.182933	6.84	0	1.90	3.30	3.40	0	0.23
2	C	83	-40.555730	175.181447	5.15	0	36.35	28.31	19.79	0	0
2	C	84	-40.531756	175.188049	4.71	0	38.57	26.21	9.42	0	0
2	D	85	-40.545267	175.180433	7.45	0	0	2.36	0	0	0

						Biomass (kg)					
	Depth	Station		Start	Depth						
Area	Stratum	No.	Start Latitude	Longitude	(m)	PDO	SAE	MMI	DAN	DSU	BYA
2	C	86	-40.550067	175.181733	6.60	0	8.85	12.78	5.98	0	0
2	C	87	-40.534550	175.186683	5.86	0	16.92	16.96	9.39	0.24	0
2	C	88	-40.539433	175.188433	3.53	0	62.69	18.31	3.51	0	0
3	B	89	-40.559317	175.183833	2.77	1.60	28.76	23.45	1.40	0	0
3	B	90	-40.581450	175.176827	2.63	0	9.74	1.36	0.12	0	0
3	B	91	-40.565451	175.183308	2.10	0.88	0.22	0.03	0.20	0	0
3	A	92	-40.574488	175.183724	0.05	3.30	0	0	0	0	0
3	A	93	-40.565436	175.186524	0.36	6.50	0.10	0	0.50	0	0
3	A	94	-40.563303	175.187215	0.01	5.30	0	0	0	0	0
3	D	95	-40.572344	175.172952	6.04	0	0.14	0.20	0.68	0	0
3	D	96	-40.556806	175.178448	5.92	0	0.01	0.93	4.63	0	0
3	D	97	-40.576307	175.172402	4.90	0	0.45	0.98	8.12	0	0
3	C	98	-40.578263	175.175434	3.80	0	36.15	20.12	10.52	0	0
3	C	99	-40.566833	175.178800	5.34	0	37.67	25.47	3.02	0	0
3	C	100	-40.577883	175.173267	5.67	0	4.64	8.92	3.78	0	0
4	B	101	-40.603183	175.169744	2.37	0.80	5.30	1.60	0	0	0
4	B	102	-40.597558	175.172142	2.22	0	0	1.20	0	0	0
4	B	103	-40.617942	175.164795	2.24	0.70	0.45	0.15	0.90	0	0
4	B	104	-40.591723	175.172222	4.47	0	34.99	10.41	2.05	0	0
4	B	105	-40.616965	175.166083	2.68	0.10	0.37	0.40	0.44	0	0
4	A	106	-40.588005	175.179677	0.00	29.40	0	0	0	0	0
4	A	107	-40.624296	175.164107	1.50	1.20	0	0	0	0	0
4	A	108	-40.586870	175.179419	0.04	3.60	0	0	0	0	0
4	A	109	-40.605687	175.172615	0.17	4.79	0	0	0	0	0
4	A	110	-40.590433	175.178128	0.05	12.10	0	0	0	0	0
4	A	111	-40.618836	175.168325	0.05	32.39	0	0	0.50	0	0
4	A	112	-40.597978	175.175137	1.16	1.60	0	0	0.25	0	0
4	D	113	-40.593318	175.166512	5.90	0	0.05	1.18	9.76	0	0.01
4	D	114	-40.596661	175.164774	5.85	0	0.16	0.68	20.47	0	0
4	D	115	-40.608020	175.161354	5.66	0	0	0.70	23.60	0	0
4	D	116	-40.615421	175.155448	7.42	0	0	0	1.80	0.21	0
4	D	117	-40.588926	175.165904	7.00	0	0	0.04	0.98	0	0
4	D	118	-40.604601	175.159181	7.37	0	0	0	0.90	0	0
4	D	119	-40.587897	175.167965	6.33	0	0.15	1.49	8.07	0.12	0
4	C	120	-40.604572	175.164563	4.47	0	7.17	9.16	6.16	0	0
4	C	121	-40.585671	175.170760	6.01	0	5.31	10.54	6.44	0	0
4	C	122	-40.611727	175.163108	3.88	0	25.33	14.25	23.71	0	0
4	C	123	-40.607351	175.162838	5.07	0	0.20	3.60	9.10	0	0
4	C	124	-40.590742	175.169435	4.72	0	12.54	9.99	64.96	0	0
4	C	125	-40.582681	175.174714	3.71	0	30.48	18.15	5.62	0	0
4	C	126	-40.607240	175.165608	3.97	0	42.50	10.90	8.70	0	0
4	C	127	-40.616218	175.160286	5.04	0	9.96	11.70	17.35	0	0
4	C	128	-40.601857	175.165145	5.52	0	2.09	6.63	10.17	0	0
4	C	129	-40.604155	175.165710	4.30	0	21.45	13.30	24.22	0	0

						Biomass (kg)					
Area	Depth Stratum	Station No.	Start Latitude	Start Longitude	Depth (m)	PDO	SAE	MMI	DAN	DSU	BYA
4	C	130	-40.587188	175.171082	4.65	0	10.59	11.13	17.08	0	0
4	C	131	-40.581917	175.172933	5.12	0	18.39	15.26	32.78	0	0
5	B	132	-40.641212	175.154751	2.50	0	29.34	1.58	1.23	0	0
5	B	133	-40.652875	175.150386	2.71	0	5.10	0.45	0.67	0	0
5	B	134	-40.644366	175.154759	2.30	0.47	47.75	0.61	0.12	0	0
5	B	135	-40.651102	175.152292	2.19	5.66	67.26	0.08	0.29	0	0
5	B	136	-40.646864	175.153213	1.96	0.09	35.40	1.52	0.85	0	0
5	B	137	-40.634130	175.158174	2.76	0.60	33.49	2.26	0.37	0	0
5	B	138	-40.635251	175.157288	2.61	0	22.63	1.12	0.38	0	0
5	B	139	-40.642782	175.153394	3.33	0	65.08	5.98	2.65	0	0
5	A	140	-40.633352	175.160769	0.75	2.30	0	0	0	0	0
5	A	141	-40.654942	175.153517	0.02	0	0	0	0.11	0	0
5	A	142	-40.651892	175.155012	0.35	9.15	0.09	0	0.16	0	0
5	A	143	-40.637420	175.161506	0.04	71.90	0	0	0.10	0	0
5	A	144	-40.642153	175.159669	0.05	123.77	0.10	0	0	0	0
5	A	145	-40.648161	175.155460	0.61	16.20	0.20	0	0.20	0	0
5	A	146	-40.635008	175.161954	-0.11	102.40	0	0	0	0	0
5	D	147	-40.637612	175.147108	7.11	0	0	0	2.09	0	0
5	D	148	-40.637861	175.150029	5.75	0	0.11	0.46	10.56	0	0
5	D	149	-40.634380	175.150441	5.90	0	0.12	0.33	27.84	0	0
5	D	150	-40.647599	175.142561	7.45	0	0.05	0	1.14	0	0.21
5	D	151	-40.628874	175.151319	7.20	0	0	1.75	0	0	0
5	D	152	-40.632989	175.151768	5.69	0	0.15	0.92	29.83	0	0
5	C	153	-40.623422	175.156516	4.79	0	0.98	3.32	19.82	0	0
5	C	154	-40.645288	175.149610	4.63	0	16.85	9.36	14.78	0	0
5	C	155	-40.651681	175.147756	4.31	0	39.32	18.47	12.52	0	0
5	C	156	-40.632155	175.152848	5.30	0	1.51	1.10	13.52	0	0
5	C	157	-40.653164	175.147330	4.30	0	44.84	21.40	8.90	0	0
5	C	158	-40.624932	175.157088	4.53	0	15.70	14.40	37.32	0	0
5	C	159	-40.635942	175.151740	5.16	0	0.15	4.55	15.65	0	0
5	C	160	-40.629473	175.155255	4.64	0	6.93	13.76	51.20	0	0
5	C	161	-40.643596	175.151451	3.94	0	48.11	21.52	10.89	0	0
5	C	162	-40.627136	175.154793	5.42	0	0.23	1.91	19.86	0	0
2	C	163	-40.562291	175.179266	4.76	0	20.61	18.25	20.92	0	0