Ministry for Primary Industries
Manatū Ahu Matua

Ngā Tipa o Te Whaka ā Te Wera Mātaitai

Stratified survey of the Paterson Inlet customary scallop *(Pecten novaezelandiae)* fishery, 2013

New Zealand Fisheries Assessment Report 2014/16

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ISSN 1179-5352 (online)
ISBN 978-0-478-42392-1 (online)

April 2014

New Zealand Government

Growing and Protecting New Zealand

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Russell, P.; Hepburn, C.D.; Rayment, W.J.; Twist, B.A.; Kearney, E.J.F. (2014). Ngā Tipa o Te Whaka ā Te Wera Mātaitai-Stratified survey of the Paterson Inlet customary scallop (*Pecten novaezealandiae*) fishery, 2013.

***New Zealand Fisheries Assessment Report 2014/16.* 40 p.**

Te Whaka ā Te Wera Mātaitai was established in 2004 and encompasses all the internal waters of Paterson Inlet, Stewart Island, excluding the Ulva Island/Te Wharawhara Marine Reserve and Big Glory Bay. There had been no take of scallops (*Pecten novaezelandiae*) since 2001, prior to the establishment of the Mātaitai, due to concern about the decline in scallop numbers.

The overall goal of this research project was to provide information on current status of the scallop fishery within and surrounding the Te Whaka ā Te Wera Mātaitai to allow for local management of the fishery by the Te Whaka ā Te Wera Mātaitai Committee (Mātaitai Committee). The specific objective was to provide information on size-frequency and density of scallops, stratified using local knowledge and previous research to allow for assessments of fisheries' status and management plans.

Interviews were conducted with members of the Mātaitai Committee to gain information about the scallop fishery in the past, to help focus diving surveys to areas of the Mātaitai that once supported important scallop fisheries, and to provide a forum where aspirations of the local community for the fishery in the future could be discussed. Scallops were collected and measured at comparable sites inside the Mātaitai, in Te Wharawhara Marine Reserve (permanently closed) and in Big Glory Bay (open to scallop fishing, managed under the Southland Fishing Management Area). The use of an area open to fishing and a permanently closed reserve allowed the development of a MBACI (Multiple Before After Control Impact) design for future surveys of the Mātaitai, to allow managers to detect and respond to changes in the scallop fishery and also assess the success or otherwise of management initiatives. Preliminary investigations to determine whether any benthic variables were associated with the presence of scallops and if there was any relationship between benthic predators and scallops were also conducted.

A total of 20 sites were surveyed using SCUBA (14 in the Mātaitai, 3 in Te Wharawhara Marine Reserve, and 3 in Big Glory Bay) from 10th –17th June 2013. A total of 383 live scallops were sampled over a total surveyed area of 15 600 m^2. Within each site, nine 100 m^2 transects (50 m long by 2 m wide) were randomly selected from a grid of potential start points laid over an area identified by interviewees as having been important for scallop fishing in the past. Density and size-frequency information for *Pecten novaezelandiae* was determined over 100 m^2. More intensive surveys of five replicate 1 m^2 quadrats were used to estimate the proportion of cryptic individuals missed within the 100 m^2 transect and to determine the density of large mobile invertebrates. Habitat characteristics (e.g. algal cover) were determined using five 0.25 m^2 photoquadrats per transect. Over the entire survey, 99% of scallops were visually detected when surveying the 100 m^2 transect. Most sites showed very low density, however higher mean densities of scallops were observed in the Mātaitai (0.038 per m^2) compared to the Marine Reserve (0.0063 per m^2) and the open fishery at Big Glory Bay (0.0056 per m^2). Densities within the Mātaitai were much lower than that reported for other fisheries for *P. novaezelandiae.* The vast majority (72%) of scallops within the Mātaitai were found at two sites. Only one site surveyed had density similar to other recreational scallop fisheries.

One site (M2 – North Arm) showed an 8-fold recovery from the 2003 survey reported in Carbines & Michael (2007). However, our calculations suggest that densities at this site are still 50% lower than those reported for this location in the 1990 survey of Michael & Cranfield (1992). There was limited recovery in another site (M3 - Prices Inlet), increasing to 0.024 per m^2 from very low densities.

Uneven distribution of scallop size frequency suggests inconsistent recruitment. The size frequency distribution shows the presence of large scallops in the Mātaitai in comparison to the Coromandel recreational fishery; reflective of their growth to larger sizes and possibly the closure protecting larger individuals. The results of this survey will provide a baseline for future monitoring based on a MBACI design which will allow the Mātaitai management committee to manage the fishery with the ultimate goal of re-opening and maintaining a sustainable scallop fishery within Te Whaka ā Te Wera Mātaitai.

1. INTRODUCTION

1.1 Te Whaka ā Te Wera Mātaitai, Te Wharawhara Marine Reserve and Big Glory Bay

Te Whaka ā Te Wera Mātaitai was established in 2004 when Rakiura Māori, with the support of the Stewart Island community, successfully sought and secured legislative protection for an important customary fishery for Tāngata Whenua. Prior to this, Paterson Inlet had been closed to commercial fishing since 1994. Te Whaka ā Te Wera Mātaitai Reserve area encompasses all the internal waters of Paterson Inlet, Stewart Island, excluding the Ulva Island/Te Wharawhara Marine Reserve and Big Glory Bay. With a maximum depth of 45 m, the Inlet's combination of rocky reef, sand and soft mud floor bottom is an important habitat for a prolific and diverse range of marine life, including at least 56 different species of fish (MFish 2011). The Mātaitai committee has set limits on methods and bag limits for the take of finfish and shellfish, closed the fishery for scallops (*Pecten novaezelandiae*), and instituted a closure to fishing for pāua (*Haliotis iris*) in the Bravo Island group.

Te Wharawhara Marine Reserve was established in 2004. It consists of 1075 hectares adjoining the Ulva Island Open Sanctuary. The marine reserve is divided into three separate fragments; south of Native Island to the eastern end of Ulva Island, the Sydney Cove area, and southwest Ulva Island to the southwestern shore of Paterson Inlet (Wing 2006). Nothing within the reserve's boundaries can be removed or harmed. The Department of Conservation is the managing body for the reserve.

Big Glory Bay is located in the southeast part of Paterson Inlet, outside Te Whaka ā Te Wera Mātaitai, but within the Southland Fishery Management Area (SFMA). The open season for scallops is 1 October to 15 March inclusive; the maximum daily limit per fisher is 10, and the minimum size is 100 mm measured across the greatest diameter of the shell. Divers on a vessel may take an additional quota of scallops for up to two persons acting in a dive safety capacity.

1.2 Te Whaka ā Te Wera Mātaitai Management Committee

Te Whaka ā Te Wera Mātaitai Management Committee (Mātaitai Committee) comprises representatives from local Iwi, commercial fishing and recreational fishing. Members have a long standing connection to the fishery dating back more than 70 years. Committee members have a range of professional backgrounds, the dominant ones being commercial fishing and aquaculture. The committee's collective knowledge of the scallop and wider fishery surrounding the Island is significant.

1.3 Biology of *Pecten novaezelandiae*

P. novaezelandiae is one of several species of bivalve molluscs found in New Zealand waters, in a variety of coastal habitats, particularly in semi-enclosed areas where circulating currents are thought to retain larvae. Scallops inhabit waters to about 60 m depth but are more common in depths of 10 to 45 m on substrates of shell, gravel, sand or, in some cases, silt (Cryer 2001). Scallops are functional hermaphrodites and become sexually mature at a size of about 70 mm shell length. *P. novaezelandiae* breeds in early summer and scallops mature by the end of their first year, but contribute little to the spawning pool until the end of their second year. Scallop larvae spend about three weeks in the plankton and then attach to filamentous material (Bull 1976). When the spat reach about 5 mm they detach and take up the free-living habit of adults, usually lying in depressions on the seabed and often covered by a layer of silt (Cryer 2001). Although adult scallops can swim, they appear to move very little. The relatively high fecundity, and likely variability in the mortality of larvae and pre-recruits, could lead to high variability in natural annual recruitment. This variability is a characteristic of scallop populations worldwide, (Ministry for Primary Industries 2013).

1.4 Significant events relating to *P. novaezelandiae*

The issue of apparent depletion of scallops in Paterson Inlet came to the attention of MAF Fisheries in February 1990 during a series of consultative meetings and was reinforced by results from a MAF Fisheries recreational fishing survey (McKinnon 1992). In response to these concerns, a reduction in bag limit from 20 to 10 scallops per fisher per day was brought about in 1991, and a prohibition of dredging in 1993. The evidence for a decline of the scallop fishery in Paterson Inlet came from a recreational fishing diary scheme where fishers recorded scallops and paua as the principal target species and noted catch and effort (Carbines 1998). The total number of scallops caught over six years was low (n=186) and divers with local knowledge were unable to find scallops where they had been common in the past. In response to this decline, the Minister of Fisheries prohibited the take of scallops for two years from October 2001, then from 1 October 2003 until 30 September 2007. During this prohibition period Te Whaka ā Te Wera Mātaitai and the Ulva Island/Te Wharawhara Marine Reserve were established in 2004. Currently a ban on the take of scallops is still in place in the Mātaitai.

1.5 Potential benefits of protection for *P. novaezelandiae*

Scallop populations are ideal candidates for closed area management (Beukers-Stewart et al. 2005). Adult *P. novaezelandiae* are relatively sedentary (Morrison 1999), hence a single closed area can protect the entire post-settlement life cycle of individuals. Scallops rely on external fertilisation for reproduction and therefore increased densities of adults leads to greater fertilisation success (Marelli et al. 1999; Beukers-Stewart et al. 2005). Furthermore, the absence of disturbance due to mobile fishing gear may improve the habitat for larval settlement (Beukers-Stewart et al. 2005). The benefits of area-based protection have been demonstrated for the great scallop, *P. maximus*. Density and biomass of scallops increased in a closed area compared to an adjacent fished area over a 14 year period (Beukers-Stewart et al. 2005), and abundance of juvenile scallops increased following designation of a marine reserve due to the consequent increase in habitat complexity (Howarth et al. 2011). Adjacent scallop fisheries may also benefit from marine protection as the duration of the planktonic larval phase means that larval export from closed areas is likely (Grantham et al. 2003; Beukers-Stewart et al. 2005).

1.6 Past surveys in Te Whaka ā Te Wera

The first surveys of *P. novaezelandiae* in Paterson Inlet were conducted by the Department of Conservation Scallop Monitoring Programme initiated in 1988; results are reported in McKinnon (1992). The programme involved sampling three areas (Figure 1): Sawdust Bay, Dynamite Point and east of Manawahei Nugget off Ulva Island, before and after each annual scallop fishing season during the period February 1988 – February 1990. At each site, 10 replicate samples were taken by placing a 10 m transect along the seabed and collecting all scallops within 1 m to the left of the transect line. Scallops were brought to the surface and measured for length and width. Over the two-year period of the study, a significant decrease in scallop density occurred at the Ulva Island site. The other two sites had no overall changes in density, but there was fluctuation in numbers from year to year. There was a significant decrease in scallop size in Sawdust Bay (119 mm to 111 mm) and Dynamite Pt (108 mm to 81 mm). However there was also high variability among sites, with an increase at Dynamite Pt (54 mm to 81 mm) for 1989–1990 and at Ulva (110 mm to 123 mm) during the 1988 closed season, followed by a decrease (123 mm to 78 mm) during the 1988–1989 season. It was concluded that known scallop beds were fished regularly, with the Ulva site popular due to its proximity to the entrance of the inlet, and Sawdust Bay was popular with local fishers. Dynamite Point was less well known and remained relatively untouched (McKinnon 1992).

In 1990, a survey was conducted at seven locations (Figure 1) to estimate the density and length frequency of scallops from timed swim samples, results are reported in Michael & Cranfield (1992). No estimates of population size could be made as the extent of the size of the beds could not be determined. However, relative densities were calculated and recorded as scallops per diver hour. The mean relative densities (legal scallops over 100 mm per diver hour) of the three general areas of the seven locations surveyed were: North Arm (278.1); The Neck (209.0); and Prices Inlet (66.0); (Michael & Cranfield 1992, cited in Carbines & Michael 2007).

In 1991, MAF Fisheries tagged 1849 scallops for tag-recapture growth determinations at three sites: North Arm, Pipi Rocks and Tarpaulin Beach (Figure 1). In addition, another 150 scallops, less than 100 mm in length, were tagged around the Bravo Island group (Olsen 1994, cited in Carbines & Michael 2007). Scallops were tagged with small plastic tags cemented to the upper valve. In total, 110 scallops were recaptured and 89 had length data at release and recapture. There were no data on dates of release and recapture, but the numbers of days at liberty were recorded. Recaptured scallops were at liberty for between 22 and 730 days, however about 60% were at liberty for less than a year. It was concluded that scallops reached 100 mm in 1.5 years and grew to a maximum of 175 mm in 8–10 years (Olsen 1994, cited in Carbines & Michael 2007).

A recreational diary scheme where fishers recorded the catch per unit effort (CPUE) for scallops and paua was run from 1993 to 1998. The purpose of this scheme was to monitor changes in CPUE in response to management change. Over the six years of the scheme, scallops were recorded on 180 trips. Initially the CPUE climbed from 15.5 scallops/hour to 45.5 scallops/hour over the period 1993–1996, perhaps in response to the ban on dredging in 1993. However CPUE fell to 16.7 scallops/hour by 1998 (Carbines 1998).

A survey using both drift video and divers was conducted in November 2003, covering 7135 m^2, estimating scallop density and size structure in three areas (Figure 1) of relatively high historical density, results are reported in (Carbines & Michael 2007). Sampled areas were the same locations as the 1990 survey of Michael & Cranfield (1992). Using an 8 m radius circular search, divers collected live scallops, cluckers (dead intact shells) and clocks (separated shells), to estimate the density of live animals, length frequency distribution, and natural mortality. The relative densities (legal scallops per diver hour) were: North Arm (16.4), The Neck (33.4) and Prices Inlet (0.0). The mean densities per m^2 for all live scallops were: North Arm (0.026), The Neck (0.093) and Prices Inlet (0.003). The 2003 survey found that the relative density of legal sized scallops per diver hour declined to 16% of the value recorded in 1990 by Michael & Cranfield (1992). While the areas surveyed were the same in both surveys, differences in the sample size and number of areas sampled make comparing the size structures difficult. However, length frequency distributions of the 1990 and 2003 surveys were similar.

The Carbines & Michael (2007) study included a re-analysis of the tag-recapture work of Olsen (1994) using both regression of annualised increments against length at tagging and a modelling program GROTAG (Francis 1988). This program was modified to fit incremental growth data for shellfish (Cranfield et al. 1996). Based on this modified GROTAG model, Carbines & Michael (2007) concluded that scallops in Paterson Inlet could grow to legal size (100 mm) in 1.5 years, and while they appear to be longer lived than scallops in other areas, their growth is relatively fast and not likely to limit productivity.

Carbines & Michael (2007) mentioned a volunteer dive club survey from 1–2 March 2003 that recorded low densities of scallops within Paterson Inlet. A total of 17 sites were sampled using a 5 m circular search (78.5 m^2) and found only 43 scallops in total, with 11 above the minimum legal size. Carbines & Michael (2007) also mentioned previous reports of diseased scallops, recognised by gaping, suggesting heightened mortality. The index of mortality generated from this study (10–17%) is considered in the normal range for *P. novaezelandiae*. No diseased scallops were found to confirm that disease is responsible for decline in stocks. No microscopic examination of scallops for disease was required in the survey of Carbines & Michael (2007), but MFish proposed that scallop population health could be assessed from the numbers of live scallops and cluckers.

1.7 Goals of research

The overall goal of this research project was to provide information on current status of the scallop fishery within and surrounding Te Whaka ā Te Wera Mātaitai to allow for local management of the fishery by Te Whaka ā Te Wera Mātaitai Management Committee.

The specific objective was to provide size-frequency and density information for scallops using surveys stratified by site based local knowledge and previous research, to allow for assessments of fisheries' status and management plans. Preliminary investigations to determine whether any benthic variables were associated with the presence of scallops and if there was any relationship between benthic predators and scallops were also conducted.

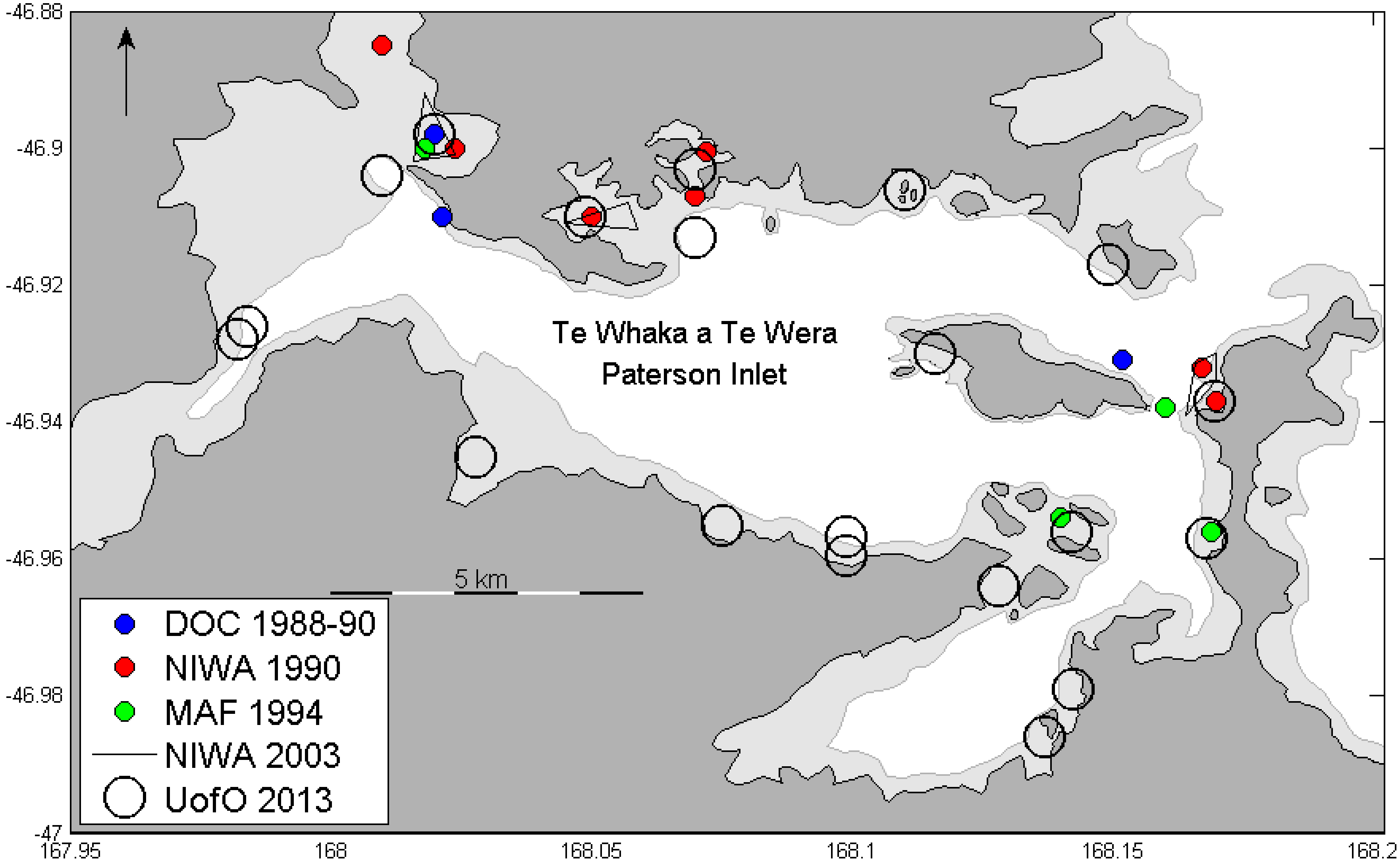

Figure 1: Location of surveys of *P. novaezelandiae* in Te Whaka ā Te Wera/Paterson Inlet, Stewart Island. The surveys are detailed in the following publications: DOC 1988–1990 – (McKinnon 1992); NIWA 1990 – (Michael & Cranfield 1992); MAF 1994 - (Olsen 1994); NIWA 2003 - (Carbines & Michael 2007); UofO 2013 – (this work).

2. METHODS

2.1 Interviews with members of the Te Whaka ā Te Wera Mātaitai committee

We received Category B ethical approval to conduct interviews from the University of Otago Ethics Committee (Reference number - D13/137).

We conducted nine 30 – 60 minute interviews with members of the Mātaitai Committee and other Island residents between April and June 2013. This group of people has a personal long-standing connection to the Mātaitai and surrounding area stretching back as far as 70 years. Aside from building the relationship between the researchers and members of the Mātaitai Committee, the purpose of the interviews was to:

- Gather location information of key scallop beds to focus the dive survey.
- Provide anecdotal evidence on past changes in the fishery and perceptions of why change occurred.
- Determine typical methods for harvesting scallops in Paterson Inlet and how these have changed with time.
- Gain information on current problems facing the scallop fishery.
- Catalogue ideas for future management of the scallop fishery, particularly surrounding a re-opening strategy.
- Provide an opportunity to record the aspirations of members of Mātaitai Committee for the scallop fishery.

In total, seven out of eight members of the Mātaitai Committee and two other permanent Stewart Island residents were interviewed using a semi-structured style, with interviewees being asked a set range of questions. Discussions were allowed to run their natural course if other topics were raised. Interviewees were provided with a map to mark the historical location and extent of key scallop beds in the Mātaitai, Marine Reserve and the open fishery within Big Glory Bay. All interviewees were fully briefed as to the purpose of the interviews, gave their written consent and were informed that they did not have to answer questions if they were uncomfortable. Everyone approached agreed to be interviewed and the discussion was frank. Interviews were transcribed into semi-quantitative software platform NVivo and returned to interviewees for verification of accuracy. This allowed interviewees to confirm the accuracy of what they said and allowed an opportunity to withdraw statements they did not want to appear in the final archived transcript. No interviewees have withdrawn any statements.

2.2 Survey stratification

Survey sites were mostly limited to depths within the range of reasonably proficient breath hold divers (i.e. depths less than 5 m) after interviewees expressed a clear desire that scallops within the Mātaitai must be accessible to people without the need for SCUBA.

The locations and extent of scallop beds in Paterson Inlet indicated by interviewees were digitised in a GIS (ArcMap 10.1). A separate layer of the GIS was created for each interviewee. Candidate sites for survey were identified based on concurrence of at least two interviewees (example provided in Figure 2). In this way, ten sites were selected within the Mātaitai, three within the Te Wharawhara Marine Reserve and three within Big Glory Bay. The boundaries of the sites were defined by the overlap between the areas identified by the interviewees in water shallower than 5 m depth (based on the charted isobaths from nautical chart NZ 6825 digitised in ArcMap 10.1). Within these boundaries, a set of potential sampling locations was generated by overlaying a 50 m^2 grid on each site and exporting the co-ordinates of the centre of each grid square. Field sampling locations were chosen at random from the set of potential locations and navigated to using the dive tender's onboard GPS. In instances where the selected sampling location was inappropriate due to actual water depth being less

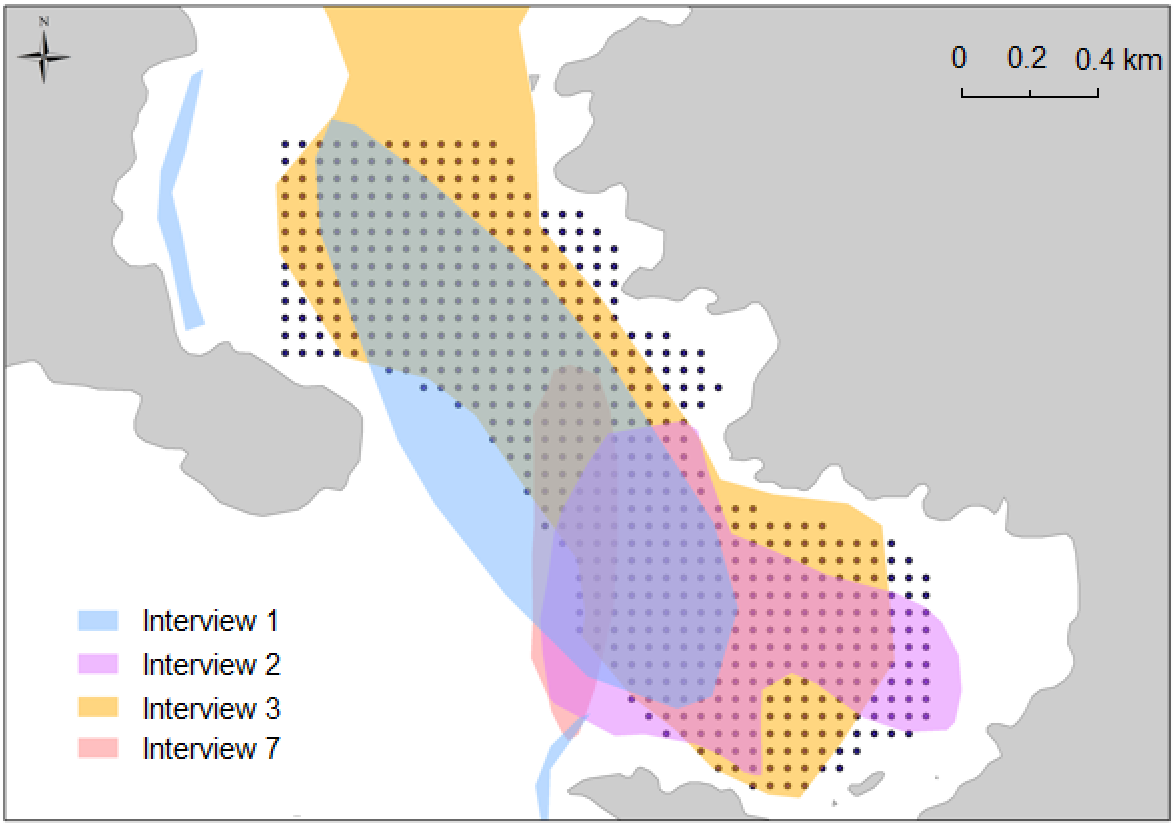

Figure 2: Example of stratification of dive survey location from four interviews. The dots indicate potential start locations for dive transects.

than 2 m or greater than 6 m (due to difference between actual and charted depths), the location was discarded and another was chosen at random.

An additional four sites were selected in deeper water adjacent to sites M1, M2, M4 and M5, (Figure 3). The site adjacent to M1 was not surveyed due to poor visibility. Three transects were completed at each "deep" site approximately following the 20 m isobath. These sites were surveyed to determine whether deeper areas adjacent to important scallop beds possessed scallop populations. Interviews suggested that after reopening, the Mātaitai might only allow shallow water harvest methods (e.g. snorkelling, a scoop on a pole), so that deeper habitats would provide a refuge from overfishing. The aim was to determine if sections of the inlet deeper than 8 m that were adjacent to important sites for scallop fishing contained scallops.

2.3 Dive surveys

In total 20 sites were surveyed using SCUBA, (14 in the Mātaitai, 3 in Te Wharawhara Marine Reserve, and 3 in Big Glory Bay) between 10 and 17 June 2013. A total of 383 live scallops were sampled over a total surveyed area of 15 600 m^2. From the 14 sites in the Mātaitai, 4 were sites deeper than 8 m. Each dive site was categorised by treatment (management area); Mātaitai (M1 – M10), Mātaitai Deep (D1–D4), Marine Reserve (MR1–MR3) and Big Glory Bay (BGB1 – BGB3), (Figure 3). One site, D2, was not surveyed due to poor visibility and the benthos being covered in black silt. Any scallops collected from within each transect were counted and measured aboard the dive tender after the completion of each transect. Scallops were then returned to the water near the location of each transect. A more intensive search was conducted along the transect using a 1 m^2 quadrat placed at five random locations in order to estimate the proportion of cryptic individuals missed within the 100 m^2 transect.

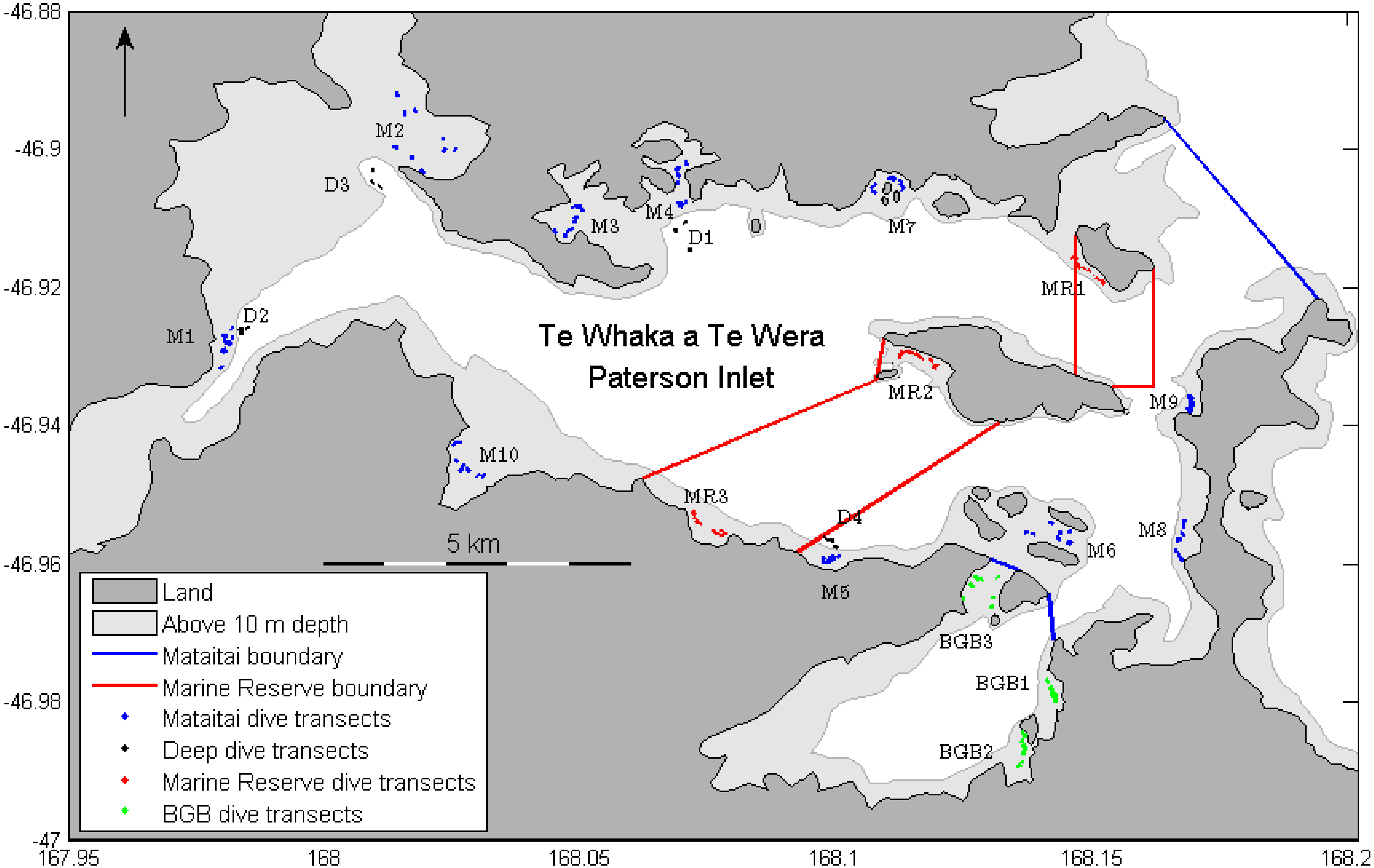

Figure 3: Location of University of Otago 2013 dive survey sites within Te Whaka ā Te Wera. Each dive site is categorised by treatment: Mātaitai less than 8 m (M1 – M10), Mātaitai Deep greater than 8 m (D1–D4), Marine Reserve (MR1–MR3) and Big Glory Bay (BGB1 – BGB3).

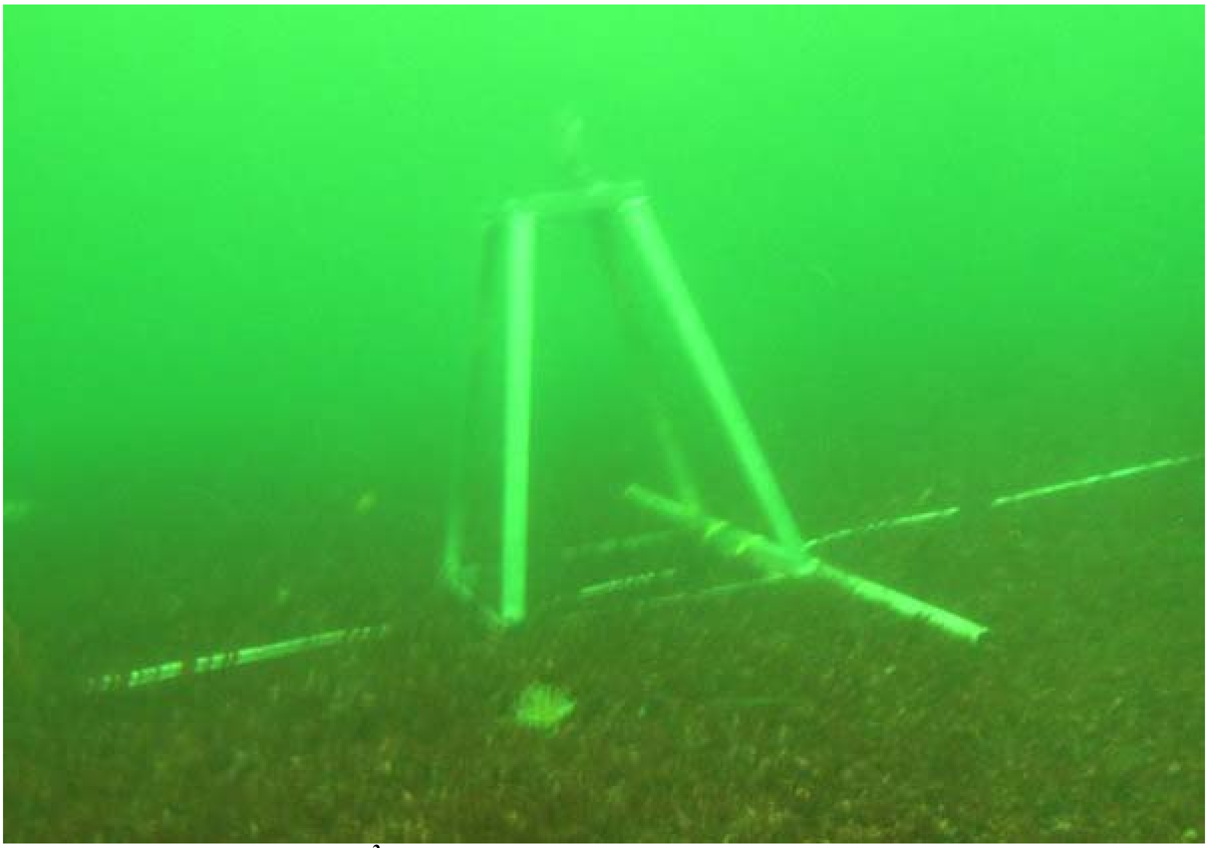

Figure 4: Photo-quadrat (0.25 m^2) camera and frame with 2 m pole on transect line. All scallops within the 2 m pole length were collected and measured.

Within each site, nine 100 m^2 (50 m long by 2 m wide) transects were randomly selected from the grid of potential start points using a random number generator. For the deep sites, only three transects were randomly selected because of limitations on time available due to diver decompression limits. A further nine substitute transects were selected for each site in the event that a selected transect was unsuitable for the survey (e.g. too deep or shallow). If a transect was unsuitable, the next available transect was surveyed. The 50 m × 2 m long transect dimension was selected because it was manageable in a single dive and allowed divers a reasonable chance of locating scallops visually.

At the start of each transect, a weight with a float attached was dropped into the water and at this point a GPS mark was taken. The vessel then steamed parallel to the shore while the transect line (a graduated, vinyl, heavy duty surveyors tape) was kept taut and fed out into the water. At the end of the rope the weight was dropped into the water and a transect end point GPS mark recorded. Two divers worked on each transect line. The first diver swam along the transect collecting all visible scallops within each transect and taking digital images at five random points (selected using a random number generator) of the benthos within a 0.25 m^2 quadrat, to provide information on sediment characteristics, algal cover etc. The photo-quadrat frame had a 2 m pole attached along its bottom rail (Figure 4), allowing the diver to measure 1 meter either side of the transect line and collect any scallops within. The second diver also checked the transect for any scallops missed by the first diver as they swam down the transect. The second diver also placed a 1 m^2 quadrat at five random points along the transect and counted all mobile invertebrates (e.g. starfish, crabs, urchins), as well as carefully searching the quadrat (visually and by touch beneath any algae or mud) for any cryptic scallops (Figure 5).

2.4 Metrics related to fishers perceptions and "gatherability"

In order to provide a more understandable view of the numbers in each site for managers of the Mātaitai – who relate to the status of the scallop fishery as gatherers, rather than as scientists – metrics related to the ability to gather scallops were designed. An estimated field of view of a person

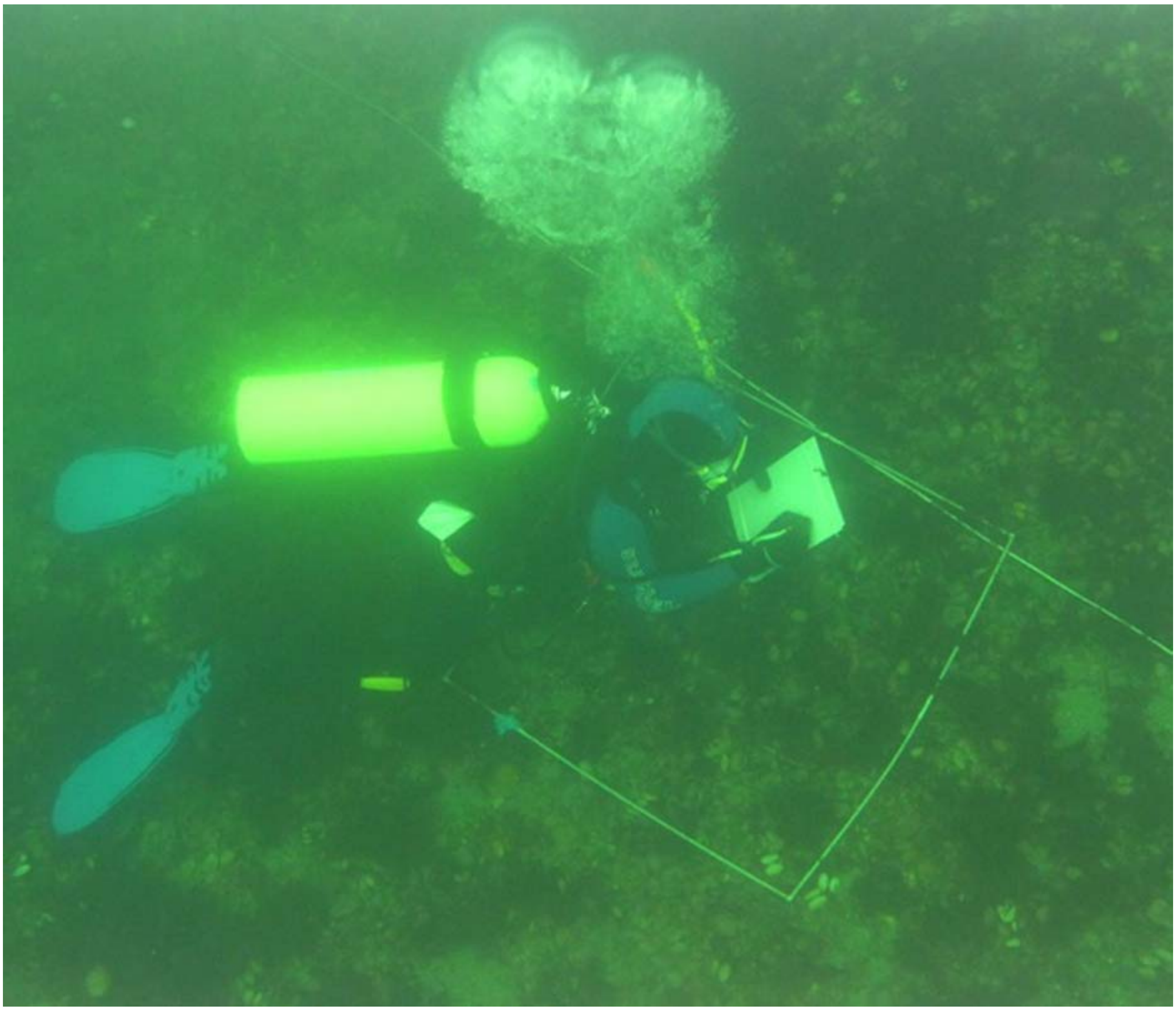

Figure 5: Diver recording data from one of the five random 1 m^2 quadrats placed on a transect line.

swimming at the surface 4 m above the seabed is a good measure of how healthy a fishery is from the gatherer's perspective. We believe a person could think back and remember what they may have seen from the surface in the past and perhaps also how many scallops they might have caught on one lung full of air (also related to the number of scallops that can be seen from the surface). From the surface at a typical snorkelling depth (4 m), we suggest a 16 m^2 field of view of the benthos is likely in the clear waters of the Mātaitai. Along with the field of view density, the distance required for a person to snorkel to catch a bag limit of 10 SFMA legal scallops (over 100 mm) with a 16 m^2 field of view, is another reasonable estimate of effort that can be related to the managers of the Mātaitai.

2.5 Benthic habitat associations

Five 0.25 m^2 photo-quadrats, randomly placed along each transect, were used to determine whether any benthic variables (e.g. sediment characteristics, presence of algal films) were associated with the presence of scallops. Photo-quadrats were analysed using the program Coral Point Count. Points on the image were randomly selected and the type of substratum or algae at each point was recorded. A total of 25 points was chosen as this number is appropriate to provide the precision required to provide reasonable estimates of percentage cover (Drummond & Connell 2005). The five photos from each transect were then pooled and the percentage cover of different algae and substrate determined. Other conspicuous organisms present within the quadrat (e.g. small starfish, bivalves) were also identified and counted. The density (number per m^2) of common species for each transect was calculated. The presence or absence of microalgal mats (microphytobenthos) on the substrate surface was also recorded for each transect. These photo-quadrat data and geographical information about the site were used in the construction of variables for use in the analysis (Appendix B, Table B-1).

2.6 Predator associations

The density of the large predatory sea stars, *Coscinasterias muricata* and *Astrostole scabra,* per transect was determined using counts from the 1 m^2 quadrats (n = 5 per transect). These sea stars were the only benthic predators observed in the quadrats during the survey although octopus (*Pinnoctopus cordiformis)* were also commonly observed elsewhere. The density of the large predatory sea stars was analysed by relating it to scallop density information on a transect by transect basis.

2.7 Statistical analyses

A nested ANOVA was conducted on the density of scallops, with sites nested within management area. All data were examined for homoscedasticity and normality. The data failed a Ryan Joiner normality test due to the number of null transects and a few null sites. However, ANOVA is robust to non-normality, particularly with large sample sizes (Khan 2003).

Logistic regression was carried out on presence/absence data of scallops for all sites within Paterson Inlet (Model A) and for sites within the Mātaitai only (Model B). Subsequently, a linear regression was carried out for the sites that contained scallops, for both models A and B. AICc values, which correct for small sample size, were used to compare models because the number of parameters used was greater than n/40 (where n is the sample size; Johnson & Omland 2004). Model averaging was performed on models within two AICc points of the best model (Burnham & Anderson 2002). This technique allows for averaging of parameter estimates and calculation of unconditional standard errors, not conditional on any model (Burnham & Anderson 2002). The uncertainty both in the model and the estimates of the parameters are therefore reduced; thus, model averaging allowed better evaluation of the important variables in determining which factors control scallop distributions. The importance of each variable in explaining scallop distributions was determined by the relative importance and the significance level of the variable. Relative importance (RI) was estimated as the sum of the Akaike weights (ωi) for all the models that variable appears in.

The influence of predator abundance on scallop abundance was explored using XY scatter graphs and Pearson product moment correlation analyses that assume linear relationships and normal bivariate distributions with both variables measured at either the interval or ratio level. Predator densities and scallop densities were compared at the transect level.

3. RESULTS

3.1 Summary of interviews

In addition to location information, the interviews provided information on observations, perceptions and aspirations of the fishery. These can be divided into observations/perceptions about declining scallop numbers, general observations/perceptions and aspirations/management initiatives for the fishery.

Observations/perceptions about declining scallop numbers:

- A major disease event occurred circa 1999–2000 wiping out the scallops.
- Scallop recruitment is poor in the Inlet and inconsistent at best.
- Tank diving, better boats from the mainland and the invention of the freezer all contributed to a decline in scallop numbers.
- Behaviours of greed and self-entitlement are the main cause of declining scallop numbers. Examples of three such behaviours are:
  - i) Fishers consume scallops while on the Island, and still leave with their accumulated daily take.
  - ii) Visitors to the Island try to recover the expense of their trip with take of scallops or fish.
  - iii) Some boats from the mainland travel direct to the inlet, gather in excess of their daily limit and send person(s) back on the ferry with the excess to avoid fisheries inspection at the boat ramp on return to the mainland.
- Some hunters armed with generators, portable freezers and dinghies spend more time gathering than hunting.
- There is evidence of poaching, such as discarded shells around campsites and jetties.
- Natural predation has an impact on scallop numbers.

General observations:

- Scallops are recovering in some places.
- Scallops migrate between deeper and shallower locations.

Aspirations/management initiatives for the fishery:

- A healthy fishery where fishers can catch a feed in the shallows.
- No SCUBA diving for scallops; there is a perception that scallops are connected via movement (either by adults or larvae) between deeper and adjacent shallower areas. If deeper areas are protected it is believed that scallops will move into and replenish shallower areas open to fishing.
- No accumulated take; it is a perception that this gives fishers flexibility to exceed their daily take by consuming scallops on the water and still retaining this accumulated take.
- A voucher system for scallop take either balloted or seasonal, this would allow for closer monitoring and greater control of the take.
- Limited trial opening in selected beds, e.g. one month. This would enable the committee to observe the impact on the fishery in a more controlled way.
- No collecting for dive safety persons on board vessels, it is a perception that this gives fishers flexibility to exceed their daily take and conceal it within this clause.

3.2 Density, size and numbers

Tables relating to size, density and numbers are found in Appendix A. In 2013, a total of 383 live scallops were sampled over a total surveyed area of 15 600 m^2. Scallops were found in significantly higher densities in the Mātaitai compared to the Marine Reserve and Big Glory Bay (Figure 6, Nested ANOVA $F_{2,143} = 9.563$, $P < 0.0001$). Scallop density was extremely variable within and among sites (Figures 7 and 8) and two sites contained the majority of scallops. Within the Mātaitai, 56% of scallops were found in one site (M2) and 72% in the top two sites surveyed (M2 and M9; see Figure 3 for locations). The M2 site is a very important site as it exhibits the highest density (0.2 scallops per m^2) and also potentially covers the greatest area (Figure 3). We found significant differences among sites within management area ($F_{15,143}$ = 14.182, P <0.0001), but only site M2 was significantly different from the other sites (Tukey HSD). The sites in the north-west part of the inlet (M2, M3 and M4) accounted for 70% of all scallops within the Mātaitai.

A similar trend was seen for scallops larger than 100 mm. We found significant differences between the management areas ($F_{2,143}$ = 9.986, P <0.0001), with significantly higher densities in the Mātaitai compared to the other two management areas (Tukey HSD). We also detected a significant difference among sites within management areas ($F_{15,143}$ = 16.598, P <0.0001). Site M2 was significantly different from all other sites, and M9 was significantly different from sites M6, M7, M8, M10, MR1, MR2, BGB1 and BGB3 (Figures 6 and 8).

Scallop size showed some variation among beds in the Mātaitai (Figures 9 and 10). Scallops found at site M9 were on average 14% larger than the average size in the Mātaitai, and 85% were larger than 120 mm. One site, M6, only had juvenile scallops, all smaller than 40 mm. Mean scallop size was large in Big Glory Bay; possibly because no juvenile scallops were observed in that area (all 15 of the scallops measured in Big Glory Bay were greater than 100 mm; Figure 11). The mean size of scallops in the Mātaitai and Marine Reserve were similar, with 65% of scallops in the Mātaitai and 75% of scallops in the Marine Reserve greater than 100 mm.

3.3 Factors explaining distribution of scallops

All tables relating to this analysis are found in Appendix B. Scallops were present in 66 of the 153 transects surveyed. The best model for within the Mātaitai included location, north-south location, algal cover (green, red and film), sand cover and depth (Model B, Table B-2) as factors. Fifteen models were within two AICc points of the top model for all sites within Paterson Inlet (Model A), while four models were within two AICc for sites only in the Mātaitai (Model B). The model averaged coefficients with the unconditional standard error, the significance levels and relative importance (RI) of each predictor variable are shown in Table B-3.

There was a higher chance of scallops being present within the Mātaitai compared with the marine reserve and Big Glory Bay. The locations with less than 15% gravel and greater than 50% red algal turf (dominated by *Adamsiella chauvinii*) also had a higher chance of scallops being present. Locations with microalgal mats on the substrate were negatively correlated with the presence of scallops and locations with sand levels over 50% positively correlated with the presence of scallops within both models (Models A and B). Within the Mātaitai area (Model B) the location of the site was important in explaining the presence of scallops. The inner sites had a greater chance of scallops being present compared to the mid and outer sites. Sites on the northern side of the inlet also had a greater chance of scallops being present than the southern sites. Depth was also important with the chance of scallops being present greater in shallow sites (less than 10 m), although more shallow sites (n=10) were surveyed than deep sites (n=3). Locations with green algae (primarily *Ulva* spp.) were positively correlated with the presence of scallops within the Mātaitai (Model B), although all but two transects contained less than 10% algae cover. Green algae was, however, not an important variable in the whole of Paterson Inlet (Model A).

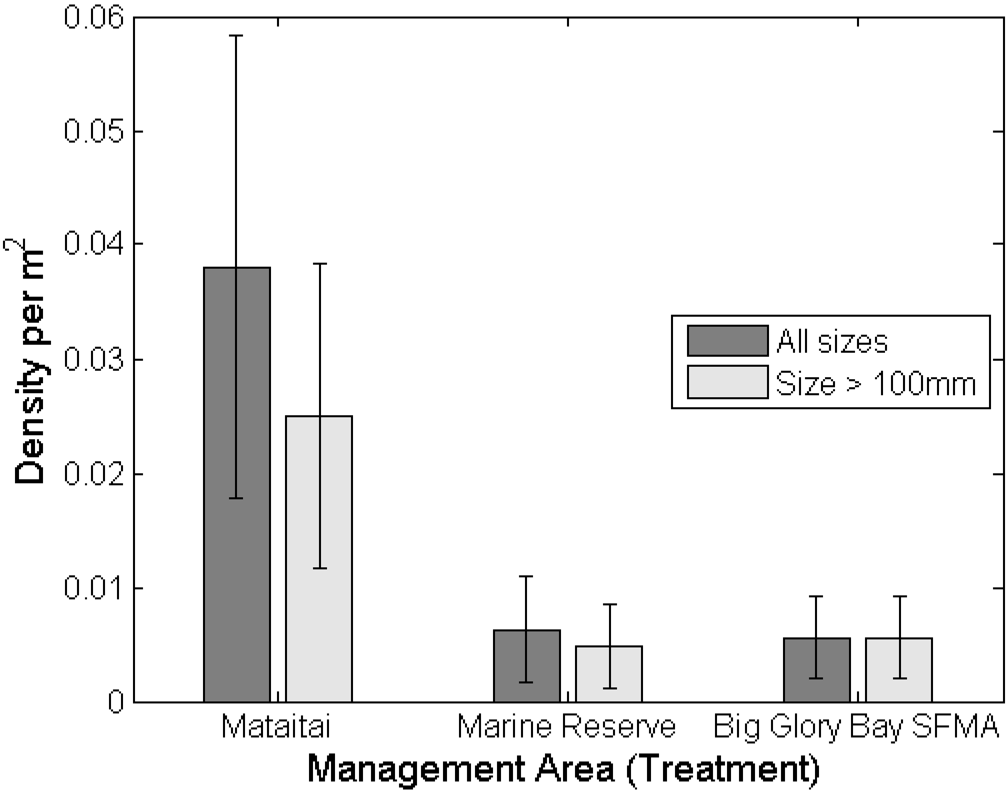

Figure 6: Density of *P. novaezelandiae* within Te Whaka ā Te Wera Mātaitai (n=10), Te Wharawhara Marine Reserve (n=3) and Big Glory Bay SFMA (n=3). Bars indicate means ± 1 S.E.

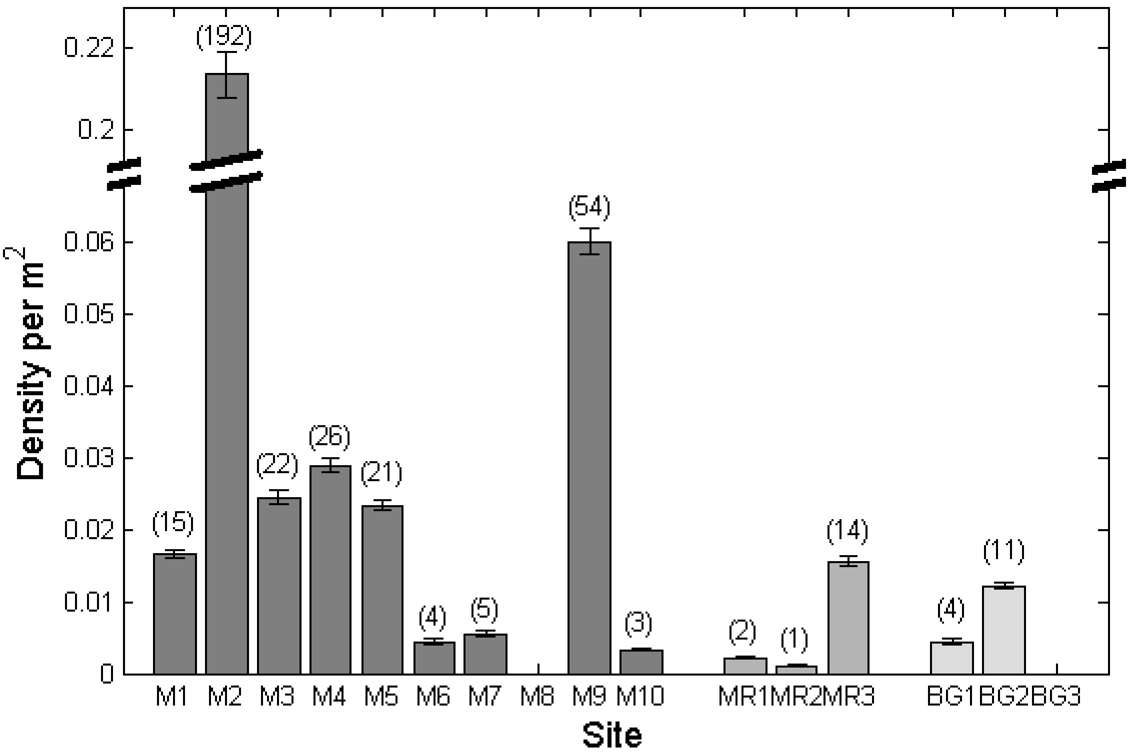

Figure 7: Density of *P. novaezelandiae* for ten beds within Te Whaka ā Te Wera Mātaitai (M1–10), three within Te Wharawhara Marine Reserve (MR1–3) and three in Big Glory Bay SFMA (BG1–3). Bars indicate means ± 1 S.E. (n=9 transects per site). Numbers of scallops found at each bed are in brackets.

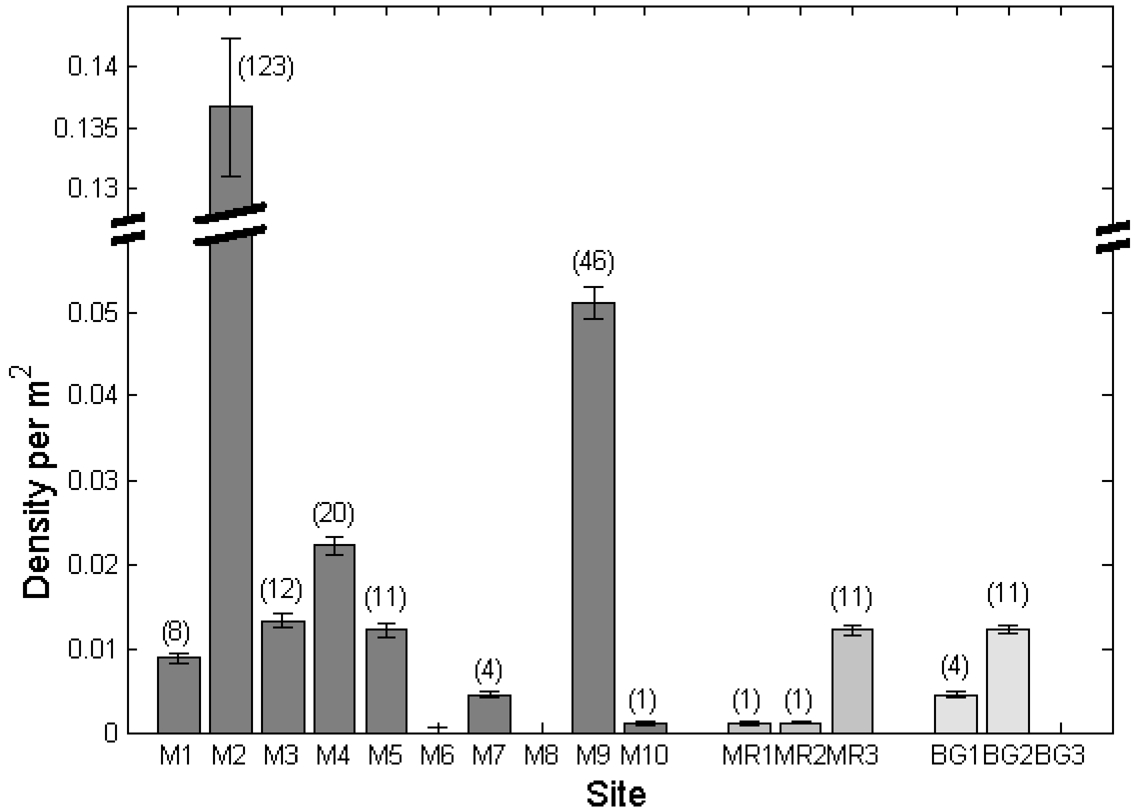

Figure 8: Density of *P. novaezelandiae* with size greater than 100 mm for ten beds within Te Whaka ā Te Wera Mātaitai (M1–10), three within Te Wharawhara Marine Reserve (MR1–3) and three in Big Glory Bay SFMA (BG1–3). Bars indicate means ± 1 S.E. (n=9 transects per site). Numbers of scallops larger than 100 mm are in brackets.

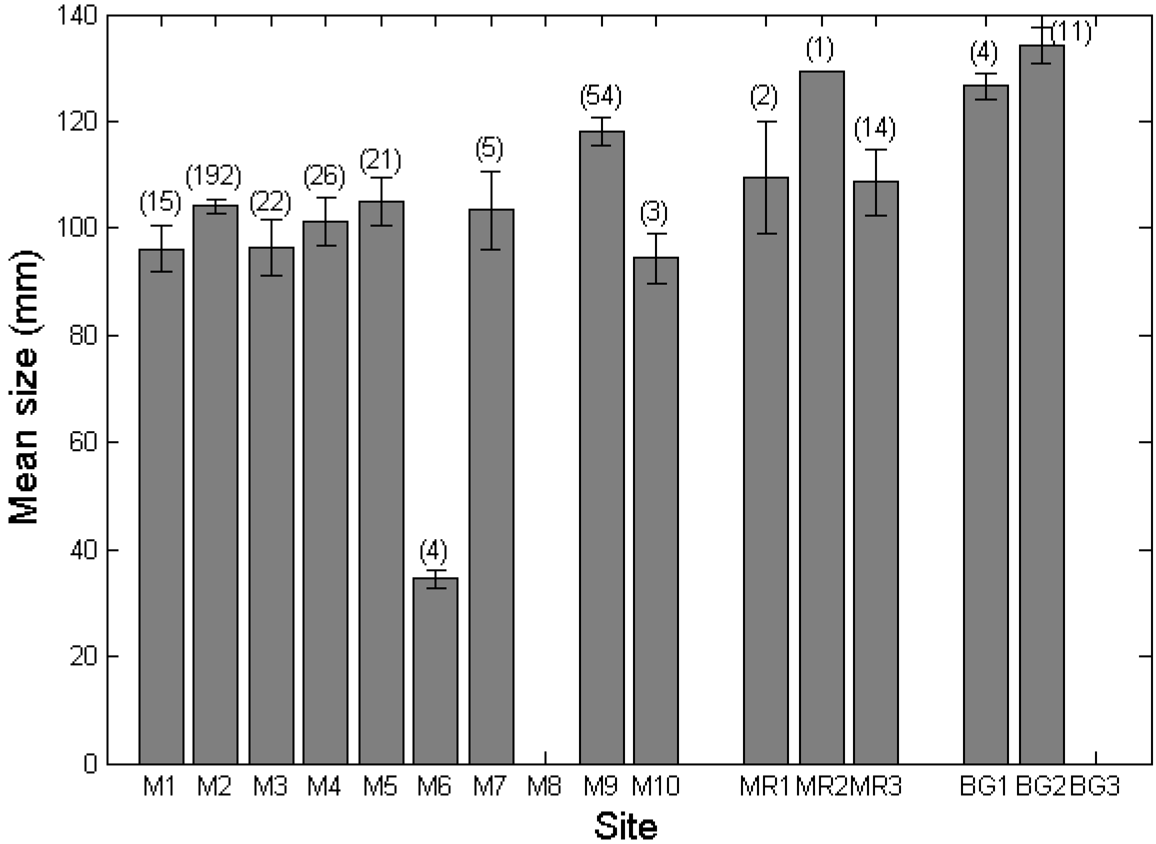

Figure 9: Mean size of *P. novaezelandiae* for ten beds within Te Whaka ā Te Wera Mātaitai (M1–10), three within Te Wharawhara Marine Reserve (MR1–3) and three in Big Glory Bay SFMA (BG1–3). Bars indicate means ± 1 S.E. Numbers of scallops measured are in brackets.

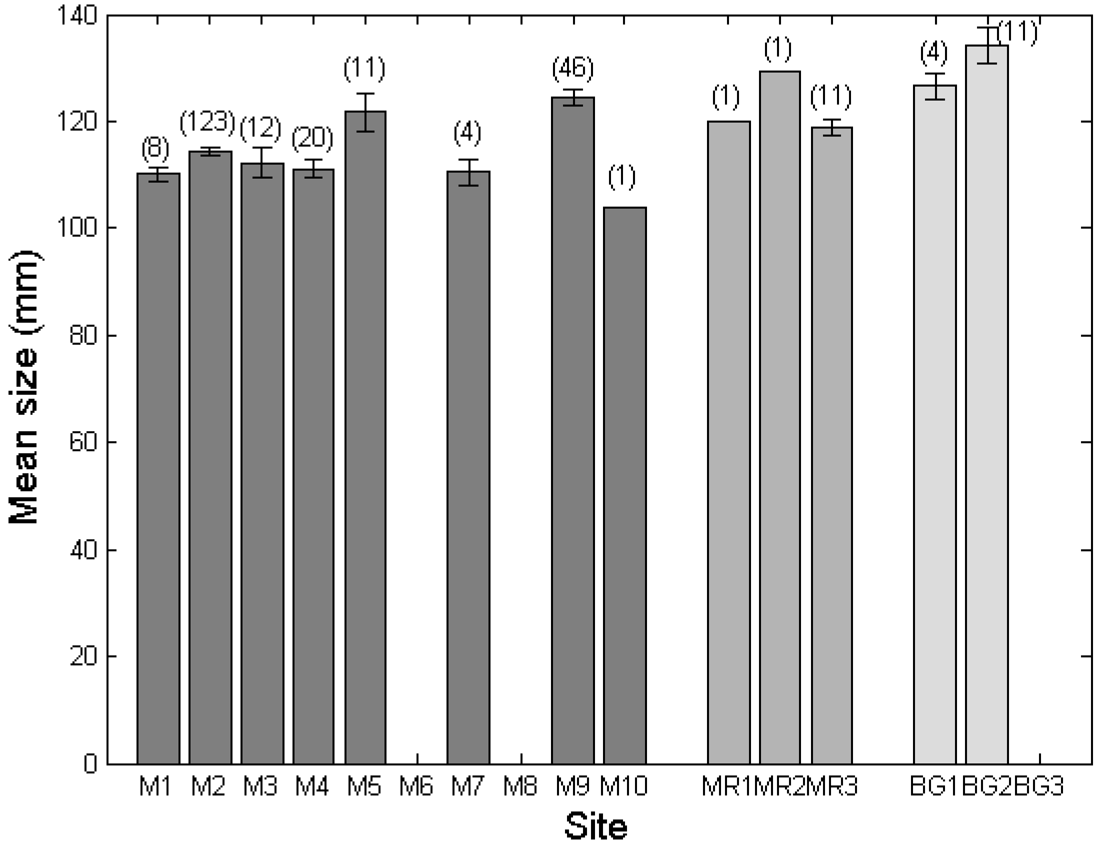

Figure 10: Mean size of *P. novaezelandiae* with size greater than 100 mm for ten beds within Te Whaka ā Te Wera Mātaitai (M1–10), three within Te Wharawhara Marine Reserve (MR1–3) and three in Big Glory Bay SFMA (BG1–3). Bars indicate means ± 1 S.E. Numbers of scallops larger than 100 mm are in brackets.

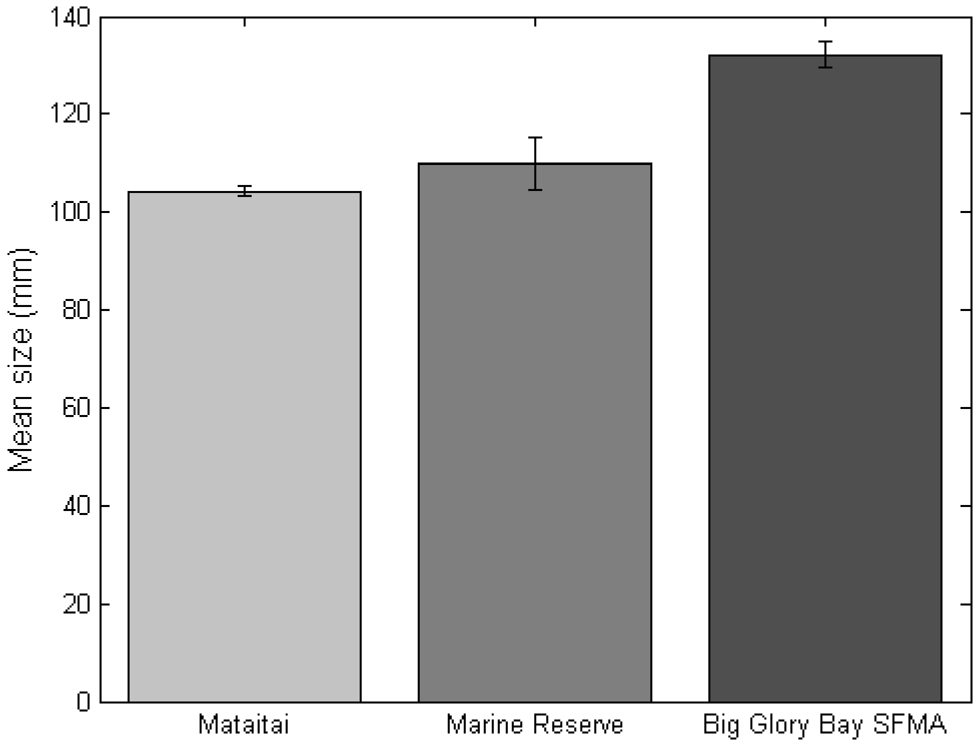

Figure 11: Mean size of *P. novaezelandiae* within Te Whaka ā Te Wera Mātaitai, Te Wharawhara Marine Reserve and Big Glory Bay SFMA. Bars indicate means ± 1 S.E. Numbers of scallops measured are in brackets.

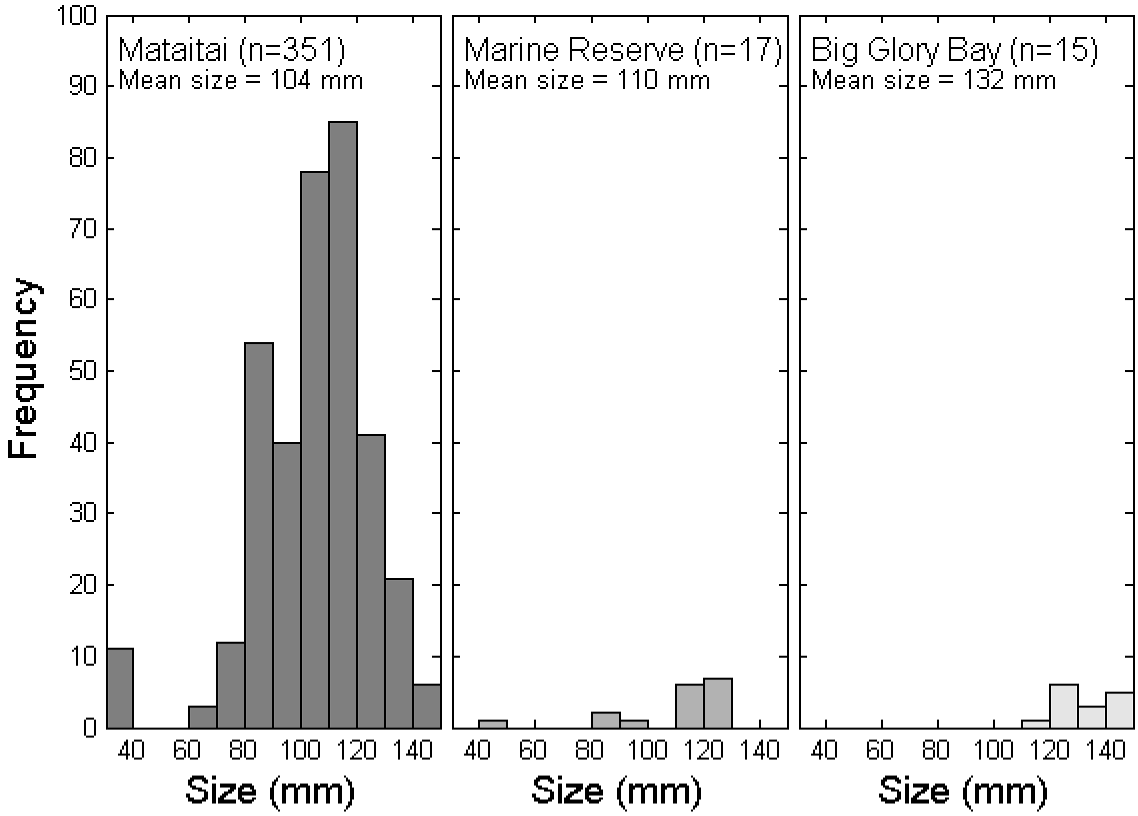

Figure 12: Size frequency distribution of P. novaezelandiae within Te Whaka ā Te Wera Mātaitai, Te Wharawhara Marine Reserve and Big Glory Bay (SFMA).

3.4 Size frequency distribution

Figure 12 shows the size frequency distribution for the three different management areas in size bands of 10 mm. More than 90% of scallops measured were found within the Mātaitai. This is primarily a result of high densities of scallops in two sites (M2 and M9) and greater sampling effort within the Mātaitai (9900 m^2 covered within compared to 5700 m^2 outside). Figure 13 shows size frequency distribution for the Mātaitai in 1 mm bands. Very few smaller scallops in the size class (under 60 mm) were found, despite a sampling design that included more intensive searching of smaller 1 m^2 areas along transects. A bimodal pattern is evident in the size frequency distribution.

3.5 Metrics related to fishers' perceptions

Figure 14 and Table 1 provide a measure of scallop abundance that relates to what fishers might see or the effort needed to be put in to catch a reasonable number of scallops in the field. We estimated that on a reasonably clear day a 16 m^2 area of the seabed may be seen by a snorkel diver. In the Mātaitai you would see on average half a legal scallop in this area; outside the Mātaitai this measure is five times lower (Figure 14). Obviously this is strongly related to site; in one bed in the Mātaitai it would be possible to see two scallops within a diver's field of view from the surface (Table 1). The distance required to swim to catch a bag limit of scallops (i.e. 10 scallops larger than 100 mm) ranges between 18 m and 2250 m in different sites in the Mātaitai (Table 1). Outside the Mātaitai this distance tends to be longer.

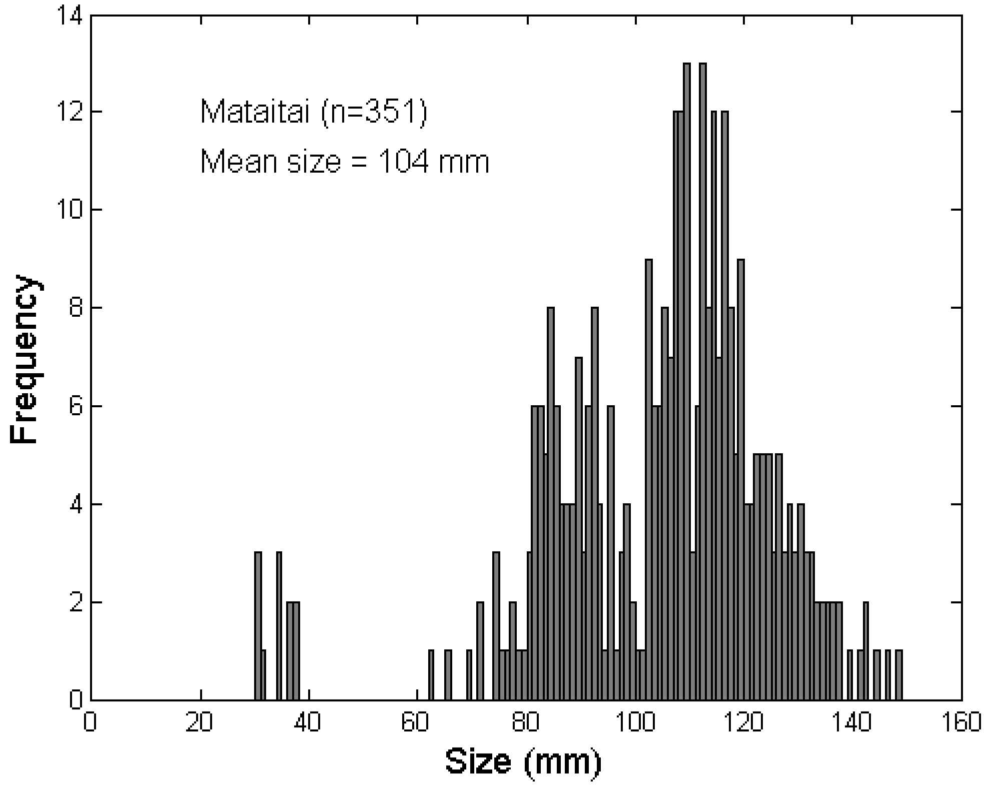

Figure 13: Size frequency distribution of *P. novaezelandiae* within Te Whaka ā Te Wera Mātaitai using 1 mm size bands.

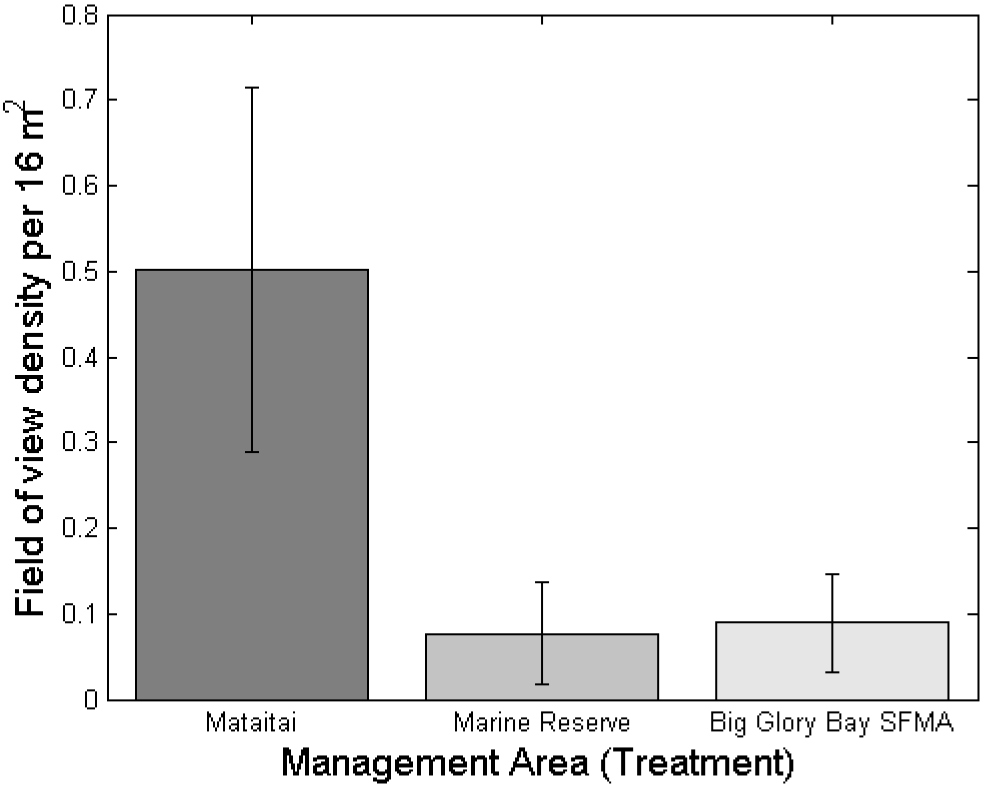

Figure 14: Field of view density of *P. novaezealandiae* within Te Whaka ā Te Wera Mātaitai, Te Wharawhara Marine Reserve and Big Glory Bay SFMA). Bars indicate means ± 1 S.E for n=10 sites in the Mātaitai and n=3 sites in the Marine Reserve and Big Glory Bay.

Table 1: Field of view (FOV) information showing number of scallops in the field of view from 4 m above the seabed and how far one would have to swim to catch 10 SFMA legal scallops for each site surveyed (n=9 transects per site).

Site	FOV Density (per 16 m^2) > 100 mm	Catch swim distance (m)
M1	0.14	281
M2	2.19	18
M3	0.21	188
M4	0.36	113
M5	0.20	205
M6	0.00	∞
M7	0.07	563
M8	0.00	∞
M9	0.82	49
M10	0.02	2250
MR1	0.02	2250
MR2	0.02	2250
MR3	0.20	205
BGB1	0.07	563
BGB2	0.20	205
BGB3	0.00	∞

3.6 Deep scallop beds

An additional three sites were selected in deeper water adjacent to sites M2, M4 and M5. Three transects were completed at each “deep” site approximately following the 20 m isobath. These sites were surveyed to determine whether deeper areas adjacent to important scallop beds possessed scallop populations. Scallops were not found or only at low densities in deep sites (more than 8 metres) that were adjacent to shallow scallop beds that have traditionally supported productive fisheries (Figure 15).

3.7 Predator associations

The epibenthic scallop predator *Coscinasterias muricata* (11 arm starfish) was absent from four sample sites (Figure 16); one of these sites, M9, had a relatively high density of scallops, where M8 had no scallops. There were only two specimens of the epibenthic scallop predator *Astrostole scabra* (7 arm starfish) found during the entire survey, insufficient to permit analysis. The highest concentrations of *C. muricata* occurred within sites M1, M2 and M6 (all over 0.2 individuals per m^2; Figure 16). No meaningful relationship between *C. muricata* and scallop density was found from correlation analysis and data visualisation using XY scatter plots (Figure 16).

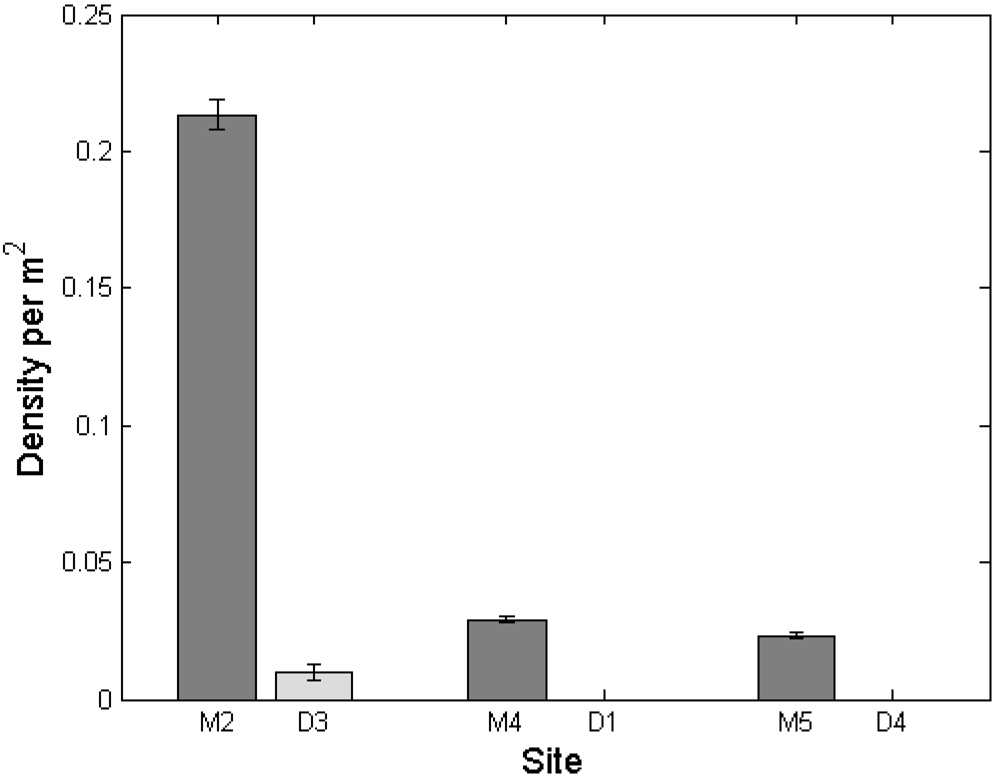

Figure 15: Shallow (M) and Deep (D) densities of *P. novaezelandiae* within Te Whaka ā Te Wera Mātaitai. Deep is greater than 8 m. The deep sites were adjacent to the shallow sites. Bars indicate means ± 1 S.E (n=9 for shallow and n=3 for deep).

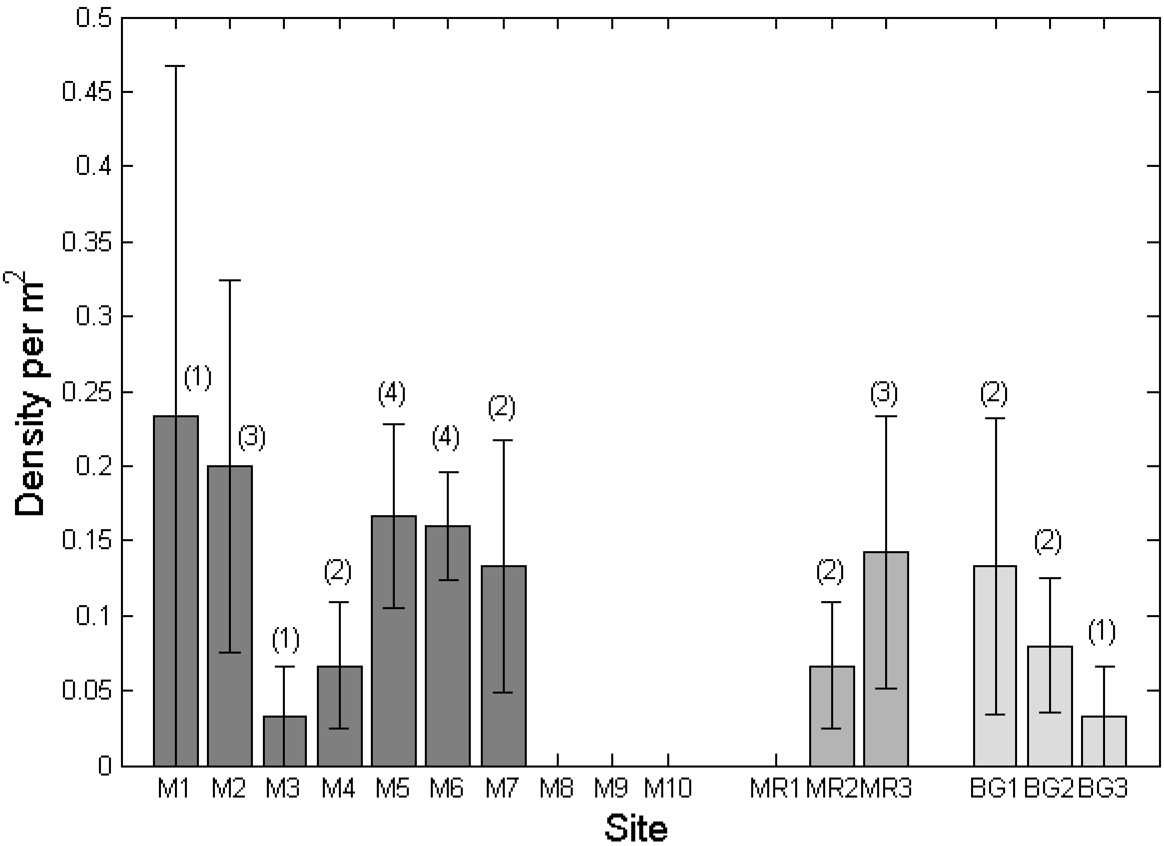

Figure 16: Density of epibenthic scallop predator *C. muricata*. The number in brackets is the specimens found at each site. Bars indicate means ± 1 S.E (n=9).

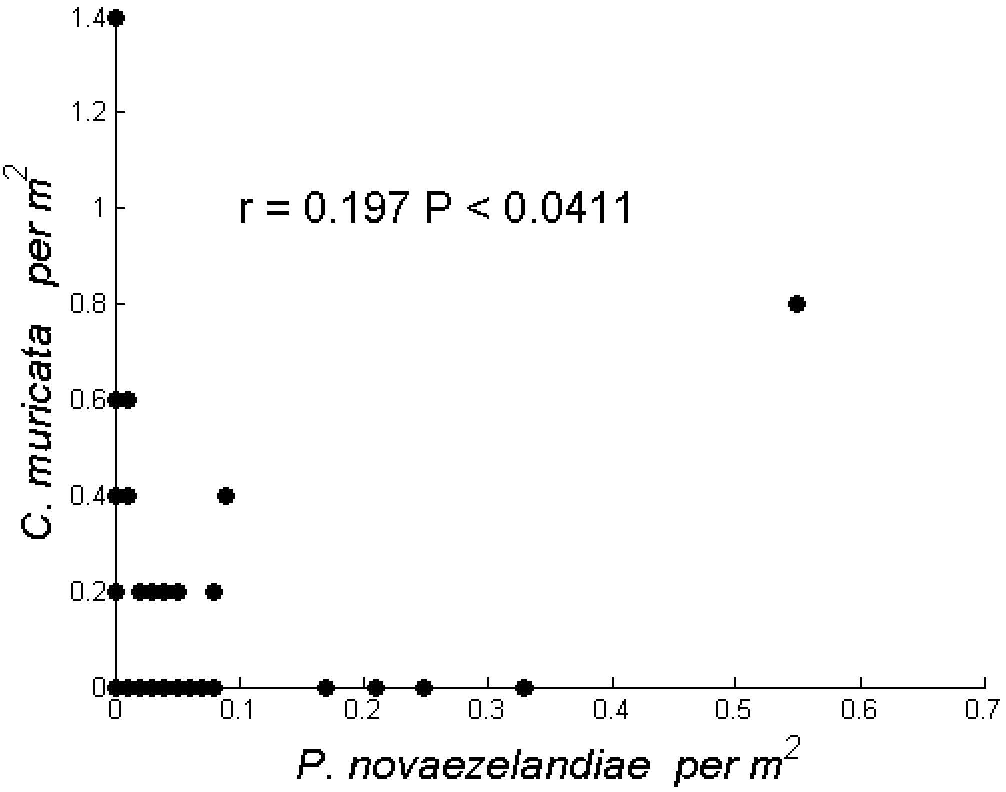

Figure 17: Correlation of density of epibenthic scallop predator *C. muricata* with density of *P. novaezelandiae* within Te Whaka ā Te Wera Mātaitai n=98 (transects).

4. DISCUSSION

4.1 General

Overall, scallop densities were higher in the Mātaitai than in the Marine Reserve or Big Glory Bay (Figure 6). This could be due to a number of factors, possibly interacting with each other, including variable recruitment, habitat differences and the influence of differing management regimes. It is possible that low densities observed in the Marine Reserve during this survey could be due to the reserve not having suitable habitat to support significant scallop populations. The rationale behind this is that during the establishment consultation for the reserve, allowing high density scallop beds popular with fishers to be covered by the reserve, would have been strongly opposed. The low numbers of juvenile scallops in the Mātaitai was attributed to the time of year the survey was conducted, (i.e. the recruits from spring/summer may have already grown beyond the 60 mm size when the survey was conducted). A high degree of temporal variability evident in the uneven distribution of scallop size frequency suggests inconsistent recruitment. This is typical of *P. novaezelandiae* populations as high fecundity and variability in the mortality of larvae and pre-recruits leads to great variability in annual recruitment. This, combined with variable mortality and growth of adults, leads to scallop populations exhibiting high temporal variability (Ministry for Primary Industries 2013). Site M2 (North Arm) dominates the data, which not only has the highest density (0.27 per m2) but this bed potentially covers the greatest area. All surveys over time suggest that North Arm is a relatively good habitat for scallops.

4.2 Comparison with past surveys in Te Whaka ā Te Wera

It is possible to compare data from different surveys over time despite different ways of presenting the data. What is evident from all surveys is a large decline over time and then a small recovery (at some sites) in more recent times (Table 2 and Figure 18). It is also possible to compare some of the density and size data from this survey with that of 2003 reported in Carbines & Michael (2007). The sites M2, M3 and M9 are North Arm, Prices Inlet and The Neck respectively in the 2003 survey. The survey of 1990 reported in Michael & Cranfield (1992) did not record density per m^2 but gave relative density as legal scallops per diver hour. Carbines & Michael (2007) also recorded relative density in the 2003 survey and made the general observation that scallops had declined to 16% of 1990 levels.

Table 2: Comparison of density information for *P. novaezelandiae* from 1990, 2003 and 2013 surveys. 1990 and 2003 data from Carbines & Michael (2007).

Year	1990	2003			2013	
Site	Relative Density (Legal scallops per diver hour)	Relative Density (Legal scallops per diver hour)	Mean Density (All scallops per m^2)	SE	Mean Density (All scallops per m^2)	SE
North Arm (M2)	278.1	16.4	0.026	0.006	0.213	0.006
The Neck (M3)	209	33.4	0.093	0.021	0.06	0.002
Prices Inlet (M9)	66	0	0.003	0.001	0.024	0.001

By reviewing the data in Table 2, we can see that in North Arm, the decline from 1990–2003 was from 278.1 to 16.4 legal scallops per diver hour, or 6% of 1990 levels. If we use the density information from 2003 and 2013 (density of all scallops), the recovery is from 0.026 to 0.21 per m^{2,}, an eight fold recovery which would bring the relative density back to 134 legal scallops per diver hour or about 50% of 1990 levels. This means that in 1990 in North Arm one should have been able to see 4 legal scallops in a 16 m^2 field of view and swim a distance of about 10 m to catch a bag limit of 10. This indicates how healthy the fishery once was in this location. By reviewing the relative density data (Table 2) at The Neck, the decline from 1990–2003 was from 209 to 33.4 legal scallops per diver hour, or 16% of 1990 levels. A further decline was evident from 2003 to 2013, of 0.093 to 0.06 per m^2, a decline to 65% of 2003 levels. This would bring the relative density to 22 legal scallops per diver hour or 10% of 1990 levels. In Prices Inlet no legal scallops were found in 2003.

There is an indication of a 30% decline in scallop densities at the Neck (site M9) since 2003. In the 2003 survey the majority of live scallops were found in this location (77%). However in 2003, a much wider area was surveyed to greater depths, whereas in 2013 the site (M9) was limited to the confines of Papatiki Bay shallower than 5 m. Therefore comparisons over time at this site should be interpreted with caution.

By digitising the 2003 size frequency data from Carbines & Michael (2007) it is possible to calculate the mean size at the three locations and compare this with the 2013 data (Figure 19). The mean size has declined in North Arm, but increased at The Neck. From the 1988–1990 survey significant changes in scallop size were observed from one sample period to the next but it was unclear what caused these changes (McKinnon 1992).

The size frequency distribution for the 2003 and 2013 surveys in the Mātaitai show a bimodal distribution (Figure 20). This could be due to inconsistent recruitment from one year to the next. For example, if scallops in Paterson Inlet reach legal size in 1.5 years (Carbines & Michael 2007), then bad recruitment in the previous season would show up in the size frequency distribution (Figure 19). Inconsistent recruitment could also explain the changes in scallop size observed in McKinnon (1992) and between the 2003 and 2013 surveys (Figure 19). It is also possible that the area surveyed for smaller, more cryptic size classes (5 m^2 per transect), was not large enough to reasonably estimate the abundance of scallops within this group.

4.3 Comparison with Coromandel recreational fishing locations

Diver surveys of scallops were conducted in 2009 and 2010 at two recreational fishing locations within the Coromandel scallop stock (SCA CS; Appendix C, Table C-1). In 2009 a dive area of 9783 m^2 of seabed was swept and a total of 5713 scallops were collected and measured. In 2010 a dive area of 10 077 m^2 of seabed was swept and a total of 8749 scallops were collected and measured. In 2009 the average density was 0.14 per m^2 for scallops above 100 mm and in 2010 the average density was 0.12 per m^2 for scallops above 100 mm. In comparison, the best area in the Mātaitai, site M2, had a density of 0.13 per m^2 for scallops above 100 mm. The average across all sites in the Mātaitai is 0.03 per m^2, which is low in comparison to the Coromandel recreational harvest survey results (Table 3).

Table 3: Comparison of number and density of *P. novaezelandiae* found in surveys in the Te Whaka ā Te Wera Mātaitai (2013) and the Coromandel recreational fishery (2009 and 2010).

Location/Year	Number of scallops	Density range (per m^2) of scallops size > 100 mm	Mean density (per m^2) of scallops size > 100 mm
Mātaitai 2013	351	0.004–0.13	0.03
Coromandel 2009	5713	0.01–0.3	0.14
Coromandel 2010	8749	0.03–0.2	0.12

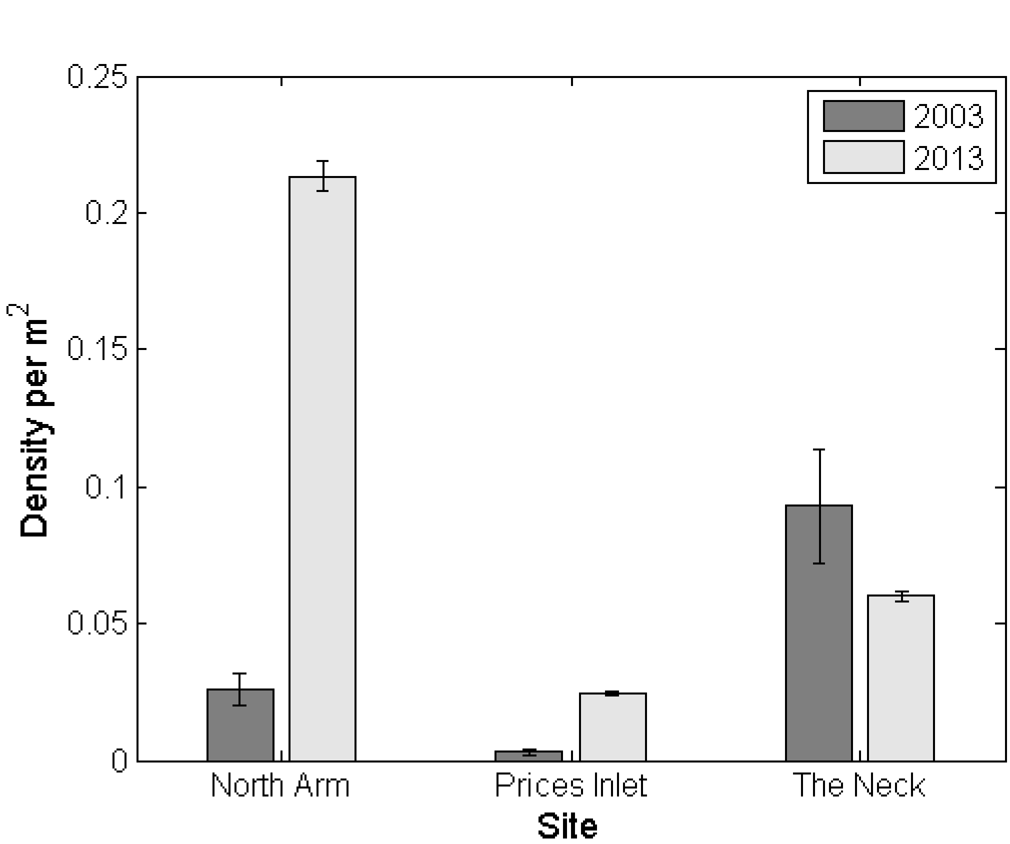

Figure 18: Comparison of density of *P. novaezelandiae* within Te Whaka ā Te Wera Mātaitai between surveys conducted in 2003 (Carbines & Michael 2007) and 2013 (current study). Bars indicate means ± 1 S.E.

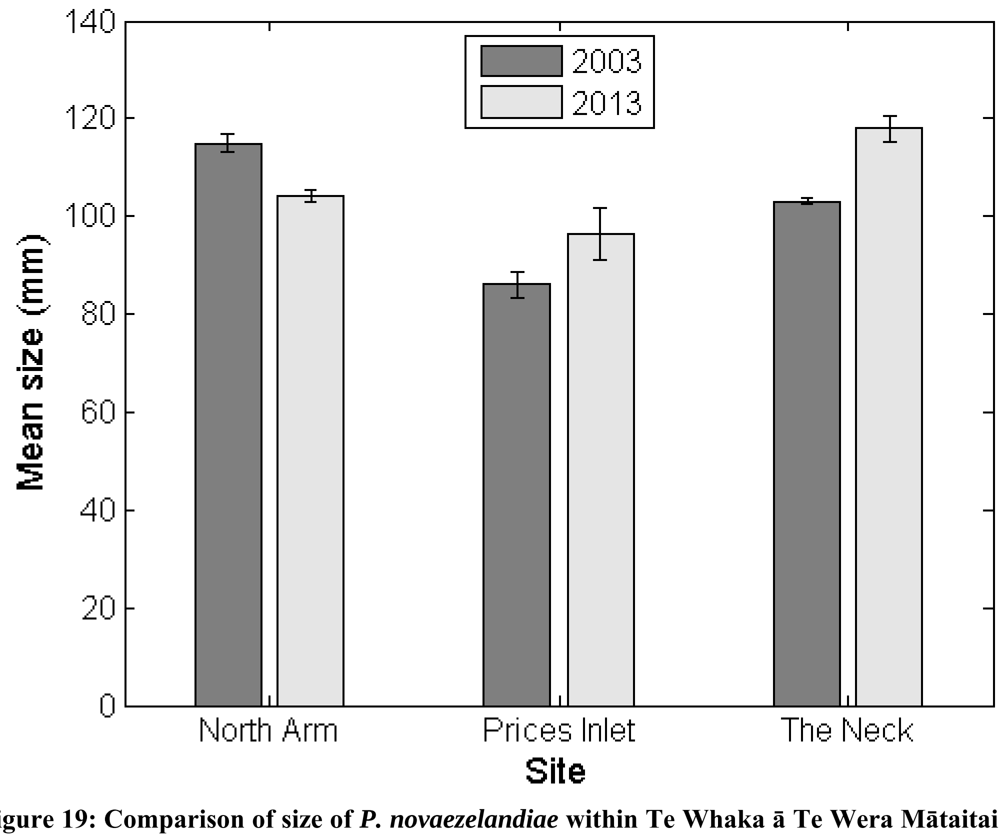

Figure 19: Comparison of size of *P. novaezelandiae* within Te Whaka ā Te Wera Mātaitai between surveys conducted in 2003 (Carbines & Michael 2007) and 2013 (current study). Bars indicate means ± 1 S.E.

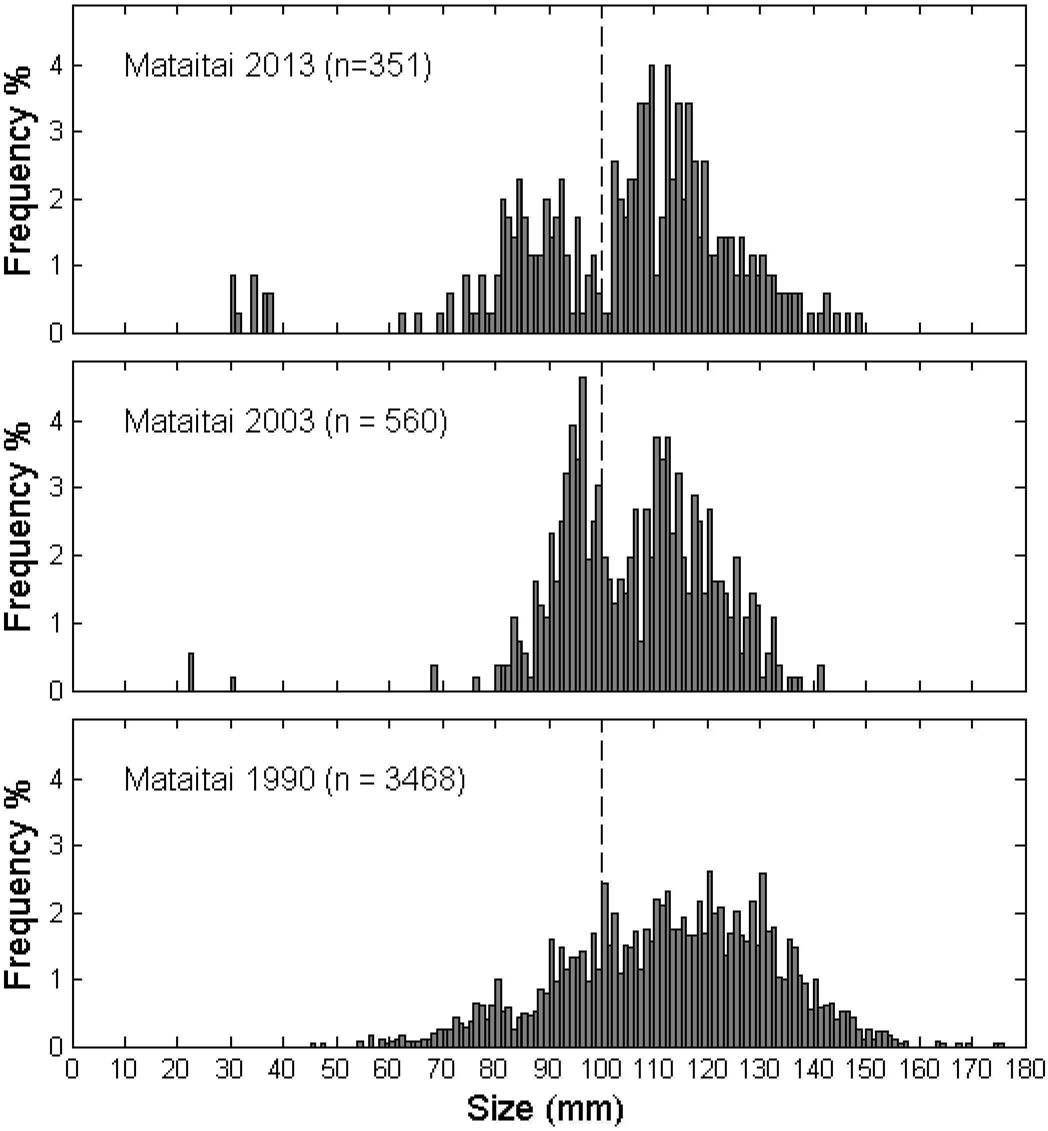

Figure 20: Comparison of size frequency distribution of *P. novaezelandiae* within Te Whaka ā Te Wera Mātaitai between surveys conducted in 1990 (Michael & Cranfield 1992), 2003 (Carbines & Michael 2007) and 2013 (current study). The dashed line marks the SFMA legal size and n = number of scallops sampled. 1990 and 2003 data digitised from Carbines & Michael (2007).

The Mātaitai site showed relatively fewer juveniles and more large scallops than were seen in the Coromandel. It is possible that the lack of juveniles in the Mātaitai in the current survey could be due to inconsistent recruitment of scallops or that low densities of scallops in smaller size classes were missed as a result of the smaller area surveyed for these cohorts. Williams (2012) describes the 30–60 mm cohort in the 2010 size frequency distribution for the Coromandel recreational fishery (Figure 21, bottom), as likely to be the result of successful larval settlement during the 2009–2010 summer.

The 2009 Coromandel size frequency distribution (Figure 21, middle), shows a solid 70–100 mm cohort which could be the result of successful larval settlement in the 2008–2009 summer, which has grown and survived leading to good recruitment in the fishable biomass. This distribution also shows scallops in all size ranges. In comparison, the 2003 and 2013 size frequency distribution of the Mātaitai (Figure 20, middle and top) show very few small scallops (under 70 mm), and the distribution is bimodal so at best we can say the recruitment is inconsistent. What is starkly evident is the presence of significant numbers of large scallops in the Mātaitai compared to the Coromandel recreational fishing areas (Williams 2012). This is reflective of their growth to larger sizes but could also be reflective that the closure is working as large scallops were also observed in the open fishery in Big Glory Bay but in much lower densities.

There are recreational fisheries in other parts of the country, for example Nelson, where an estimate has been made of the recreational take based on interviews with fishers at access points (Cole et al. 2006). However there is very little published work based on dive surveys of a transect search nature, which give density results in scallops per m^2. Therefore the comparisons have been restricted to those few works which contain sufficient density information.

4.4 Factors explaining distribution of scallops

The location within the Mataitai appeared to be important in describing where scallops were present. The northern, shallow and inner inlet had greatest densities of scallops, site (M2). This could indicate that hydrodynamics are important in controlling larval supply to these inner northern sites, but without a detailed hydrodynamic picture within Paterson Inlet no firm conclusions can be drawn. Benthic substrate was another factor identified as being important in controlling distribution, with scallops typically found on sandy habitats. Early benthic surveys of Paterson Inlet revealed that scallops are primarily found on sandy and muddy bottoms, with occasional individuals found on gravel substratum (Willan 1981). Scallops in sandy areas were found more frequently in areas with less than 50% red turfing macroalgae. Although macroalgae may be important for juvenile scallop settlement (Arsenault & Himmelman 1996), after initial settlement scallops are thought to be relatively sedentary and undergo very little movement (Hartnoll 1967; Dadswell & Weihs 1990). Some studies have, however, documented cases of scallops moving to better quality habitats or moving to shallower water to spawn (Winter & Hamilton 1985; Stokesbury & Himmelman 1996).There is also some potential that this pattern was a result of scallops being missed by divers in areas with high levels of algal cover. However, this was not reflected in more intensive surveys of 1 m^2 quadrats designed to detect cryptic individuals.

The presence of green algae (*Ulva* spp.) in small amounts was positively related to the presence of scallops, perhaps indicating that small amounts of filamentous structures could be important for juvenile settlement. Locations containing benthic microlgal mats were less likely to contain scallops. A possible explanation of this pattern is that the microalgal mats could produce unfavourable conditions for scallops, such as toxic, low oxygen conditions, or prevent settlement of scallop larvae (Österling & Pihl 2001).

4.5 Deep scallop beds

While there was a perception that there is some deep-shallow connectivity between scallop beds where scallops migrate between the two, there is no evidence to support this. Scallops were only found adjacent to site M2, in the high flow area at the entrance to North Arm. Other deep sites were characterised by soft mud and dominated by lamp shells (*Terebratella sanguinea*). Other deep areas of high flow were referred to in the interviews as productive with large "clean" scallops. There is literature to support the association of larger sizes and faster growth rates with relatively strong currents (Marshall 1960). The Neck area surveyed in 2003 recorded high numbers of live scallops (77% of all collected; Carbines & Michael 2007) but significant directional movement of *P. novaezelandiae* from deeper to shallower water has yet to be demonstrated. Studies have shown movements of scallops up or down slopes into deeper or shallow water (Wolf & White 1997; Arsenault et al. 2000). A study by Stokesbury & Himmelman (1996), however, showed no directional movement of scallops on any substrate type.

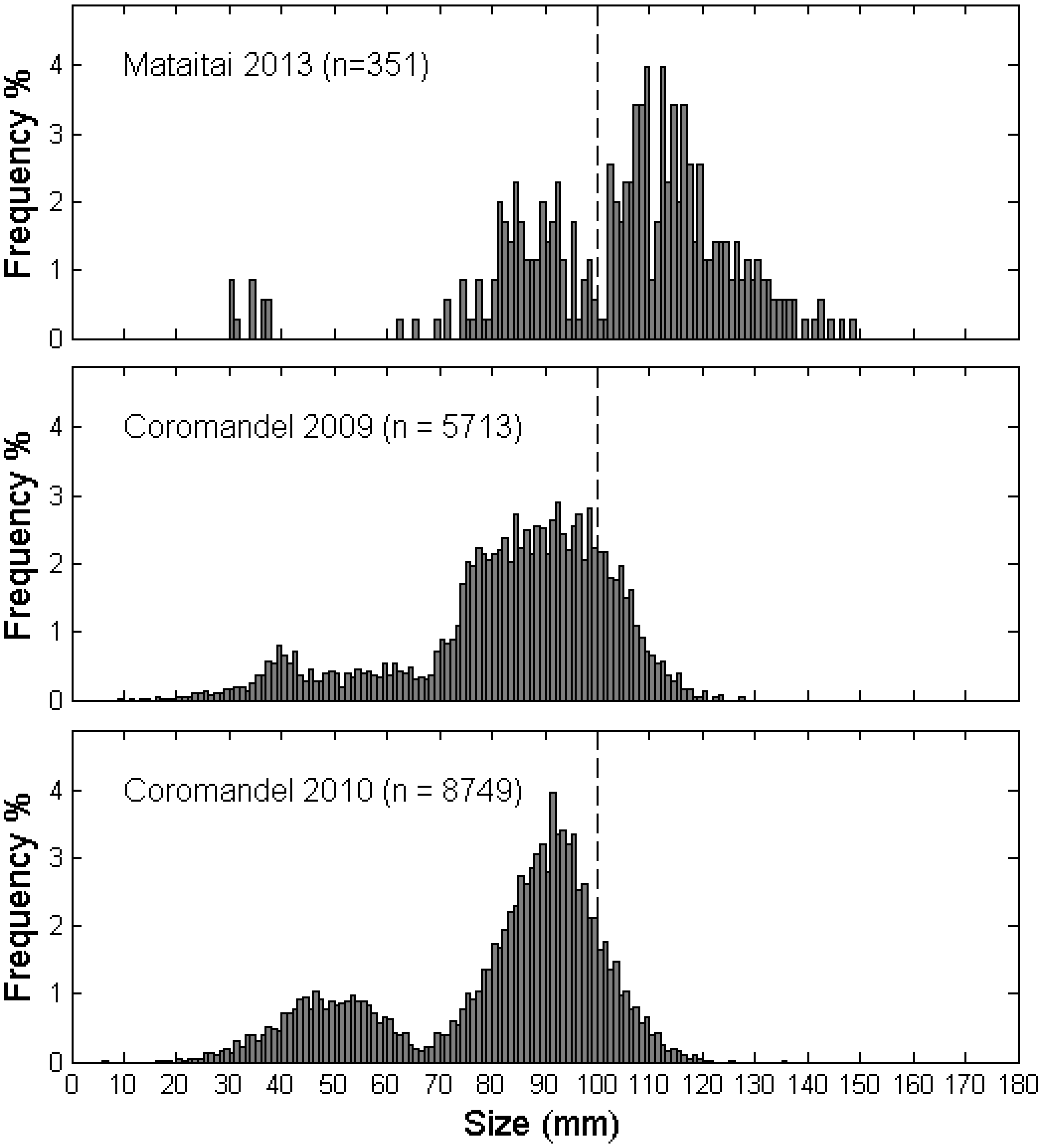

Figure 21: Size frequency distribution for the total area surveyed during the 2009 surveys of *P. novaezelandiae* in Coromandel recreational fishing areas. The dashed line marks the SFMA legal size and n = number of scallops sampled. Coromandel 2009 & 2010 data digitised from Williams (2012).

4.6 Predator scallop associations

Only a very weak relationship was detected between *C. muricata* and *P. novaezelandiae*, so no firm conclusions can be drawn concerning the effect on scallop densities. In future a survey that searches the entire transect for predators, equivalent to the scallops survey, would be best practice to maximise the opportunity to test the relationship. The site (M9) that contained scallops in a relatively higher density with no predators was in an area of higher flow, near the inlet entrance.

4.7 Conclusions

- Higher densities of scallops were observed in the Mātaitai than the Marine Reserve and Big Glory Bay (Figure 6).
- The vast majority of scallops within the Mātaitai are found in two beds (72%) (Figure 7).
- The sites in the north-west part of the inlet (M2, M3 and M4) accounted for 70% of all scallops within the Mātaitai (Figures 3 and 7).

- An increased density of scallops from 2003 was observed in North Arm (M2). Relative density estimates suggest that this bed may have recovered to 50% of the density observed in 1990 (Table 2).

- No change in density was observed on the Neck (M9), but this is most likely related to depth differences between surveys in 2003 compared to the current study (Table 2).

- Densities increased in Prices Inlet but remain very low (Table 2).

- Scallops in deeper sections appeared to be only found in areas with high levels of tidal flow (Figures 3 and 15).

- Many shallow beds are not connected with scallop beds in deeper water making post settlement movement of scallops up to shallower areas unlikely (Figures 3 and 15).

- Low numbers of juvenile scallops were observed in the Mātaitai (Figure 13).

- Uneven distribution of scallop size frequency suggests inconsistent recruitment (Figure 13).

4.8 Future research

The following research is currently being undertaken;

An MSc study in 2014 by Brenton Twist is investigating factors (e.g. food supply and growth rate) that potentially affect the distribution of *P. novaezelandiae* seen within Paterson Inlet, and to determine the magnitude of movement of the adult scallop populations. The food source utilised by scallops in different areas within the inlet will be determined by performing carbon isotope analyses on scallops and their potential food sources. Scallop growth rate will be determined by measuring the increase in length of tagged scallops over an 11 month period and then applying a growth model curve. The growth of scallops will then be linked to food utilisation and scallop density. Finally, a movement study of adult scallops will be conducted to determine the magnitude and direction of scallop movement on different slope and substrate types across Paterson Inlet. This study will therefore lead to a better understanding of what factors control scallop distribution within Paterson Inlet, to better implement future management plans for harvesting scallops within the Mātaitai in Paterson Inlet.

An MSc study in 2014 by Emma Kearney will investigate the abiotic (temperature, salinity, currents, sediments and topography) and biotic (predation) factors that affect the recruitment, distribution and population structure of scallops within Paterson Inlet during 2014/15. This research will involve benthic surveys similar to those undertaken within Paterson Inlet in 2013, employing an increased focus on the presence of predatory sea stars on the distribution and abundance of *P. novaezelandiae*. Research will also compare spatial and temporal variations in scallop spat distribution and investigate the relationship between spat settlement patterns and existing scallop beds.

5. MANAGEMENT IMPLICATIONS

Most sites showed very low scallop densities. Only one site in the Mātaitai showed scallop densities approaching that of the Coromandel recreational fishery. This site also potentially could cover the largest area; however without any information on the spatial extent of the bed it would be premature to make any decisions based on this assumption. Recruitment of scallops appears to be a problem in the Mātaitai. Without further knowledge about recruitment it would be unwise to make any decisions as regards to take. Particular areas of low current flow might be self-recruiting, which means any overfishing would result in stocks taking a very long time to recover.

This survey used areas open and closed to fishing, which will enable the development of MBACI (Multiple Before After Control Impact) designs to be used for any future surveys. This will give the Mātaitai committee the ability to detect changes, respond to these changes and assess any management initiatives. The Mātaitai committee ultimately have a goal to open and maintain a healthy fishery and acknowledged this work in providing information to enable them work towards that goal.

Figure 22: *P. novaezelandiae* in Te Whaka ā Te Wera Mātaitai.

6. ACKNOWLEDGMENTS

Ministry of Primary Industries Funding CUS2012-01 Stewart Island Scallop Survey. This work was completed under objective one of Ministry of Primary Industries project CUS2012-01 Stewart Island Scallop Survey by members of the Department of Marine Science, University of Otago.

The authors of this report would like to acknowledge and thank the members of the Te Whaka ā Te Wera Mātaitai Management Committee for their knowledge and support, and Nigel Scott (Toitū te Whenua, Te Rūnanga o Ngāi Tahu) for facilitating and supporting the relationship between our research team and the community on Rakiura.

The people of Rakiura who agreed to participate in the interviews.

Diver Tender Skipper: Steve King

Divers: Peri Subritzky, Gaya Gnanalingam, Emma Kearney, Brenton Twist, Chris Hepburn, Will Rayment, and Reuben Pooley.

A.J Woodhouse, Research and Enterprise Division, University of Otago.

Dr Sheri Johnson, Department of Zoology, University of Otago.

We thank Richard Ford (MPI) for his constructive comments that helped significantly improve this report.

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APPENDIX A NUMBERS, DENSITY AND SIZE

Table A-1: Number and density of *P. novaezelandiae* for ten beds within Te Whaka ā Te Wera Mātaitai (M1–10), three within Te Wharawhara Marine Reserve (MR1–3) and three in Big Glory Bay SFMA (BG1–3).

Site	Count	>100 mm	Density (per m^2)	SE	Density (per m^2) >100 mm	SE
M1	15	8	0.0167	0.0006	0.0089	0.0006
M2	192	123	0.2133	0.0057	0.1367	0.0057
M3	22	12	0.0244	0.0009	0.0133	0.0009
M4	26	20	0.0289	0.0011	0.0222	0.0011
M5	21	11	0.0233	0.0008	0.0122	0.0008
M6	4	0	0.0044	0.0005	0.0000	0.0005
M7	5	4	0.0056	0.0004	0.0044	0.0004
M8	0	0	0.0000	0.0000	0.0000	0.0000
M9	54	46	0.0600	0.0018	0.0511	0.0018
M10	3	1	0.0033	0.0002	0.0011	0.0002
MR1	2	1	0.0022	0.0002	0.0011	0.0002
MR2	1	1	0.0011	0.0001	0.0011	0.0001
MR3	14	11	0.0156	0.0006	0.0122	0.0006
D1	0	0	0.0000	0.0000	0.0000	0.0000
D3	9	5	0.0100	0.0029	0.0056	0.0029
D4	0	0	0.0000	0.0000	0.0000	0.0000
BGB1	4	4	0.0044	0.0004	0.0044	0.0004
BGB2	11	11	0.0122	0.0005	0.0122	0.0005
BGB3	0	0	0.0000	0.0000	0.0000	0.0000

Table A-2: Number and size of *P. novaezelandiae* for ten beds within Te Whaka ā Te Wera Mātaitai (M1–10), three within Te Wharawhara Marine Reserve (MR1–3) and three in Big Glory Bay SFMA (BG1–3).

Site	Count	>100 mm	Size (mm)	SE	Size>100 mm	SE
M1	15	8	96.13	4.40	110.06	1.32
M2	192	123	104.08	1.23	114.50	0.77
M3	22	12	96.43	5.33	112.29	2.78
M4	26	20	101.25	4.62	111.13	1.76
M5	21	11	104.88	4.49	121.82	3.58
M6	4	0	34.50	1.59	0.00	0.00
M7	5	4	103.40	7.34	110.50	2.40
M8	0	0	0.00	0.00	0.00	0.00
M9	54	46	118.02	2.66	124.37	1.55
M10	3	1	94.33	4.84	104.00	0.00
MR1	2	1	109.50	10.50	120.00	0.00
MR2	1	1	129.50	0.00	129.50	0.00
MR3	14	11	108.61	6.09	118.91	1.48
D1	0	0	0.00	0.00	0.00	0.00
D3	9	5	98.39	4.72	0.00	0.00
D4	0	0	0.00	0.00	0.00	0.00
BGB1	4	4	126.63	2.48	126.63	2.48
BGB2	11	11	134.05	3.38	134.05	3.38
BGB3	0	0	0.00	0.00	0.00	0.00

APPENDIX B PHOTO-QUADRAT ANALYSIS TABLES

Table B-1: Transect characteristic variables used for the models predicting *P. novaezelandiae* presence within Paterson Inlet, Stewart Island.

Abbrev-iation	Variable	Variable type	Description
Site characteristic properties			
D	Depth of site	Categorical (2 levels): Reference - Deep	The depth at which the surveys for the site were done. Shallow (<10m), deep (>10m)
Ft	Fishing Type	Categorical (3 levels): Reference -Mataitai	The type of fishing/harvesting pressure the scallops subject to. MR:Marine Reserve, Open
Loc	Location of site	Categorical (3 levels): Reference - Inner	The location of the site within Paterson Inlet. Upper, middle and Inner
NS	North-South side of inlet	Categorical (2 levels): Reference - North	If the site is situated on the north or south side of the Inlet
Organisms present (only meaningful organisms included)			
11arm	Eleven armed starfish (*Coscinasterias muricata)*	Continuous	The density (#/m^2) of the eleven arm starfish. Predator of scallops
Sediment and algal cover			
Snd	Sand cover	Categorical (2 Levels): Reference: 0–50%	The percentage of the transect covered in sand. 0–50%, 50–100%
Md	Mud cover	Categorical (2 Levels): Reference: 0–50%	The percentage of the transect covered in mud. 0–50%, 50–100%
Rck	Rock cover	Categorical (2 Levels): Reference: absent	The presence of rock within the transect
Grv	Gravel cover	Categorical (2 Levels): Reference: 0-15%	The percentage of gravel within the transect. 0–15%, 15–50%
Shl	Shell cover	Categorical (2 Levels): Reference: absent	The presence of shell within the transect
FlmA	Film algae cover	Categorical (2 Levels): Reference: absent	The presence or absence of micro algae mats over the substrate within the transect
RdA	Red algal cover	Categorical (2 Levels): Reference: 0-50%	The percentages cover of red algae. Less than 50% , greater than 50%
GrnA	Green algal cover	Categorical (2 Levels): Reference: absent	The presence or absence of green algae within the transect

Table B-2: Results of model based AICc Selection for *P. novaezelandiae* within a/ the whole of Paterson inlet and b/ within the Mataitai within Paterson inlet. The table also shows Maximized log – likelihood function (Log(L)), number of predictor variables (K), AICc differences (Δ□) and Akaike weights (ω□) . All models within 2 AICc points shown.

Rank	Model †	log(L)	K	AIC_c	Δ□	ω□
A/ Logistic Regression (Full model: all sites)						
Best	D + Ft + Grv + FlmA + Md + Snd + Shl	-84.36	8	187.99	0.00	0.11
2	D + Ft + Grv + FlmA + RdA + Snd	-85.60	7	188.22	0.22	0.10
3	Ft + Grv + FlmA + RdA + Snd	-86.81	6	188.41	0.41	0.09
4	D + Ft + Grv + FlmA + RdA + Snd +Shl	-84.60	8	188.47	0.48	0.09
5	D + Ft + Grv + FlmA + Md + RdA + Snd + Shl	-83.63	9	188.83	0.83	0.08
6	D + Ft + Grv + FlmA + RdA	-87.81	6	189.14	1.14	0.06
7	Ft + Grv + FlmA + RdA + Snd +Shl	-86.12	7	189.25	1.26	0.06
8	Ft + Grv + FlmA + Md + RdA + Snd +Shl	-85.04	8	189.36	1.37	0.06
9	Ft + FlmA + RdA + Snd	-88.41	5	189.39	1.40	0.06
10	D + Ft + Grv + GrnA + FlmA + Md + Snd +Shl	-83.96	9	189.49	1.50	0.05
11	D + Ft + FlmA + RdA + Snd	-87.39	6	189.57	1.57	0.05
12	Ft + Grv + FlmA + RdA	-88.59	5	189.77	1.78	0.05
13	D + Ft + Grv + FlmA + Md + RdA + Snd	-85.27	8	189.81	1.81	0.05
14	Ft + GrnA + FlmA + Md + RdA + Snd	-86.42	7	189.85	1.86	0.05
15	Ft + Mat + Md + RdA + Snd	-87.59	6	189.97	1.98	0.04
B/ Logistic Regression (Mataitai model)						
Best	D + GrnA + Loc + FlmA + NS + RdA + Snd	-39.47	8	99.00	0.00	0.37
2	D + GrnA + Loc + FlmA + NS + Snd	-40.85	7	99.34	0.34	0.31
3	D + GrnA + Loc + FlmA + Mud + NS + RdA + Snd	-39.01	9	100.59	1.59	0.17
4	D + Loc + FlmA + NS + RdA + Snd	-41.64	7	100.91	1.91	0.14

† See Table B-1 for model parameter definitions

Table B-3: Results from model averaging of the top models within 2 AICc points of the best model for *P. novaezelandiae* within a/ the whole of Paterson inlet and b/ within the Mataitai within Paterson inlet. The table shows averaged coefficients ± standard error for each variable in relation to the reference variable, the z-score and corresponding significance. The relative importance of each model averaged variable.

Variable †		Coefficient	Z Score	Sig level	Relative importance
			A/ Logistic Regression (Full model: all sites)		
Fishing **Ref: Mataitai**	MR	-1.64 ± 0.58	2.80	0.005**	**1.00**
	Open	-1.72 ± 0.57	3.01	0.003**	
Mat **Ref: Absence**	Presence	-1.30 ± 0.44	2.92	0.004**	**1.00**
Sand **Ref: 0-50%**	50–100%	1.21 ± 0.64	1.89	0.059	**0.89**
Red Algae **Ref: 0-50%**	50–100%	-1.66 ± 0.84	1.97	0.048*	**0.83**
Gravel **Ref: 0-15%**	15–50%	-1.54 ± 0.87	1.75	0.079	**0.80**
Depth **Ref: Deep**	Shallow	1.51 ± 0.95	1.58	0.114	0.60
Shell **Ref: Absence**	Presence	0.72 ± 0.44	1.62	0.106	0.45
Mud **Ref: 0-50%**	50–100%	1.15 ± 0.76	1.49	0.135	0.43
			B/ Logistic Regression (Mataitai model)		
Location **Ref: Upper**	Mid	-3.00 ± 1.09	2.74	0.006**	**1.00**
	Outer	-2.87 ± 1.10	2.58	0.010**	
North-South **Ref: North**	South	-2.10 ± 0.80	2.61	0.009**	**1.00**
Sand **Ref: 0-50%**	50–100%	2.71 ± 1.05	2.56	0.011*	**1.00**
Mat **Ref: Absence**	Presence	-2.41 ± 0.70	3.41	6e-4**	**1.00**
Depth **Ref: Deep**	Shallow	3.50± 1.64	2.10	0.036*	**1.00**
Green Algae **Ref: Absence**	Presence	1.94 ± 0.99	1.93	0.054	**0.86**
Red Algae **Ref: 0-50%**	50–100%	-1.75 ± 1.07	1.61	0.106	0.69

Notes: Those variables with a relative importance above 0.20 included. * indicate significant difference at $P < 0.05$, ** indicate significant difference at $P < 0.01$.

† See Table B-1 for model parameter definitions

APPENDIX C COROMANDEL RECREATIONAL DATA

Table C-1: Location and density data of survey of Coromandel recreational scallop fishery 2010, adapted from Williams (2012).

Location	Stations (Transects)	Density (per m^2)	Std. Error
>100 mm			
Bostaquet Bay	22	0.037	0.0156
Iris Shoal	17	0.1029	0.016
Mercury Cove	23	0.1926	0.0355
Opito Bay	26	0.0614	0.01
Kawau	39	0.0809	0.0119
Mercury	49	0.1387	0.0216
Total	88	0.1226	0.0159
>90 mm			
Bostaquet Bay	22	0.2338	0.0867
Iris Shoal	17	0.4459	0.0825
Mercury Cove	23	0.6621	0.1303
Opito Bay	26	0.1442	0.04
Kawau	39	0.3751	0.0621
Mercury	49	0.4492	0.0782
Total	88	0.4285	0.059
>1mm			
Bostaquet Bay	22	1.0666	0.1993
Iris Shoal	17	1.5439	0.3487
Mercury Cove	23	1.2694	0.2455
Opito Bay	26	0.5083	0.0991
Kawau	39	1.3847	0.2417
Mercury	49	0.9565	0.1502
Total	88	1.076	0.1276