The role of non-indigenous benthic macrofauna in the diet of snapper (*Pagrus auratus*)

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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.

Signed Date

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Abstract

Snapper, *Pagrus auratus* is a valuable coastal fish species in New Zealand and forms an important commercial and recreational fishing industry in the north-east of New Zealand. Previous studies revealed evidence that this carnivorous, primarily benthic feeder consumes a non-indigenous macrobenthic species. Many non-indigenous macrobenthic species have now become established in New Zealand waters. For example, in Rangitoto Channel, Hauraki Gulf, non-indigenous macrobenthic species are prolific, with three bivalve species in particular having thriving populations: *Limaria orientalis*, *Musculista senhousia*, and *Theora lubrica*. The role of these species in the diet of snapper, however, is unknown.

To assess the availability of indigenous and non-indigenous prey species to snapper, benthic macrofaunal assemblages throughout Rangitoto Channel were surveyed. To do so, sediment samples were collected at 84 sites. At 24 of these sites sediment was also collected for grain size analysis and at 40 of these sites the seafloor was surveyed with video. To investigate the diet of snapper, fish were collected from four monitoring sites within the channel. Bimonthly monitoring of the diet of snapper as well as the benthic macrofauna was completed at these monitoring sites and trends in the abundance of three prey species, two of which were non-indigenous species, within the sediment and the diet of snapper were compared from June to December 2008.

A detailed description of the benthic macrofaunal assemblages throughout Rangitoto Channel confirmed that three non-indigenous species are established throughout this area. The analyses revealed that the diet of snapper has shifted compared to previous studies. Snapper now consume large quantities of two non-indigenous species, *M. senhousia* and *L. orientalis*. Consumption of the former species apparently results from its dominance and biomass within the sediment. It is therefore not surprising that snapper consumed large amounts of this species. In contrast, *L. orientalis* occurred disproportionately in the diet of snapper compared to its abundance within the sediment. I suggest that the establishment of some non-indigenous species benefits snapper.

Introduction

The snapper fishing industry

Snapper, *Pagrus auratus* (Bloch & Schneider, 1801) is a fish that inhabits the coastal waters of New Zealand, Australia and Japan and has formed important commercial and recreational fishing industries within all three countries (Willis *et al*. 2003). Once described as two species it was only in 1990 that the Japanese species *Pagrus major*, and the Australian and New Zealand species *Chrysophrys auratus* were recognised as one (Paulin 1990).

In New Zealand the snapper fishery is the largest and most valuable commercial and recreational coastal fishery (Ministry of Fisheries 2008). The earliest coastal fishing in New Zealand was undertaken by Maori in the pre 1800's (Gibbs 2008). The bones of snapper have been found during archaeological excavations of middens (Leach & Davidson 2000). The methods used to catch fish by Maori during these times were thought to be sustainable, as Maori took into account of their availability and seasonality (Sharp 1997). Snapper are still a valued resource for Maori, however, the present customary annual catch is unknown (Ministry of Fisheries 2008).

When Europeans settled in New Zealand they soon developed a commercial coastal fishing industry, which targeted snapper in particular, during the 1800's (Gibbs 2008). The earliest recorded decline in the stocks of snapper was reported in 1915 (New Zealand Marine Department 1915). It was not until 1926, when another significant decline in the snapper stocks from Hauraki Gulf was noticed, that measures were put in place to prevent overfishing (New Zealand Marine Department 1927). The introduction of fishing equipment such as trawl and Danish seine expanded New Zealand's commercial fishing industry during the 1970's and increased the catch rates of snapper during this time (Paul 1974). By the mid 1980's, the snapper stocks were estimated to be half of what they were during the 1970's (Hauser *et al*. 2002). In 1982, concern over the ecological and biological effects of overfishing led to a 40% reduction in the allowable catch of snapper (Sharp 1997). The Quota Management System (QMS) was introduced in New Zealand in 1986 (Dewees 1998). Thirty species were included in the QMS at this

time. New Zealand waters were divided into ten management areas (Annala 1996). Within each of these areas a total allowable catch was quantified for each species. The total allowable catch indicates the tonnage of a species that can be extracted without affecting the sustainability of that stock, referred to as the maximum sustainable yield (MSY). Commercial fishing resulted in the landing of 6,328 tons of snapper during 2006–07 over all of the managed areas, which is the lowest reported commercial landing of this species since records were first documented in 1983 (Ministry of Fisheries 2008). Although generally the QMS is thought to be successful in terms of conserving stocks and maximising economic gain, it is not problem free (Annala 1996) and some snapper stocks are still thought to be over exploited (Gilbert *et al*. 2000). Hauser *et al*. (2002) found that snapper in New Zealand have experienced a significant decline in genetic diversity during the time it has been commercially fished, and considered that this could pose threats to the persistence and productivity of its population (Hauser *et al*. 2002).

Biology and ecology of snapper

Being one of New Zealand's best known and highly sought after fish species (Willis *et al*. 2003) snapper has been relatively well studied. New Zealand snapper belongs to the family Sparidae and is actually not a true snapper (Family Lutjanidae). In New Zealand this demersal species occurs along the entire coast of the North Island and the northwest coast of the South Island (Smith *et al*. 1978) although some individuals have been found further south. Snapper are commonly found in shallow water up to 50 m depth (Kendrick & Francis 2002) and inhabit a wide variety of habitats from estuarine environments (Hartill *et al*. 2003, Morrison & Carbines 2006) to rocky reef (Kingett & Choat 1981, Russel 1983, Jones 1988). They are most abundant in the north of New Zealand (Kendrick & Francis 2002) within the north-eastern fishery management area, SNA1 (from North Cape to Cape Runaway out to 200 nautical miles), consistently yielding the greatest reported commercial landings (Ministry of Fisheries 2008). Within SNA1, Hauraki Gulf has been and continues to be a significant fishing area for snapper (Kendrick & Francis 2002). A 34-year trawl survey of Hauraki Gulf revealed that snapper were present in nearly all of the tows and clearly dominated the weight of catches (Kendrick & Francis 2002). In Inner Hauraki Gulf both juvenile and adult snapper have

been recorded to be most abundant within areas where the seafloor consisted of mud (Francis 1995, Kendrick & Francis 2002).

The Hauraki Gulf has long been recognised as a significant spawning ground for snapper (Cassie 1956a). Snapper are serial spawners, releasing multiple batches of gametes between October and January (Crossland 1977). Spawning occurs when seawater temperature reaches 18°C as it is at this temperature that the eggs are able to hatch (Cassie 1956b). Snapper aggregate for spawning (Powell 1937) and rise into the mid-water to spawn (Cassie 1956a). The eggs of snapper only remain for a short period at the water surface (48 hours) before they hatch (Cassie 1956b). Francis & Pankhurst (1988) recorded that some juvenile snapper exhibit sex inversion. They found that juvenile snapper started life as females. At the age of between two and four years old snapper had gonads that were either ovary, ovo-testis or testis, whereas older fish were either male or female (Francis & Pankhurst 1988).

Snapper are highly mobile fish tagging studies have shown that the movements of individuals can vary (Paul 1967, Egli & Babcock 2004). In the study of Paul (1967) most snapper were recaptured close to where they were tagged while others were recorded to travel up to 260 miles. Paul (1976) reported sexually mature snapper moving off-shore in winter. Small juvenile snapper were found to inhabit shallow bays and harbours, whereas, larger juveniles inhabit progressively deeper waters (Paul 1976). He also found that the growth rates of snapper were closely correlated with changes in sea water temperature (Paul 1976). During spring and autumn snapper grow fastest whereas they grow slowest during winter (Francis 1994). Francis (1995) found no evidence of seasonal migration of juvenile snapper between shallow and deep water. Hartill *et al*. (2003) reported that most snapper in estuarine environments occupy relatively small (hundreds of metres) areas of seafloor and make predictable daily movements.

The rings that are formed on both the scales and otoliths are used to estimate the age of snapper. Paul & Tarring (1980) reported 40 year-old snapper and as Paul (1976) suggested they may live even longer.

Godfriaux (1970a) reported that snapper in Hauraki Gulf occurs in association with the following species: trevally *Caranx lutescens*, red gurnard *Chelidonichthys kumu*,

horse mackerel *Trachurus novaezelandiae*, eagle ray *Holorhinus tenuicaudatus* and John Dory *Zeus japonicus*. All five species consume benthic fauna (Godfriaux 1970a); however, there is little feeding overlap between the six species (Godfriaux 1970b). Snapper had the most varied diet, containing 99 prey species/categories. This species also had the smallest percentage of shared prey items with other fish species. Because of this Godfriaux (1970b) suggested that there was the least amount of inter-specific competition between snapper and the other five fish species. The author concluded that the high abundance of snapper in Hauraki Gulf was caused by its ability to consume a highly diverse diet. This would likely provide snapper with a greater flexibility to maintain the amount of food this species would need to consume over other predatory demersal fish species in the area.

The diet of snapper

The earliest reports of the diet of snapper were from compiled observations by New Zealand lighthouse keepers dating back to 1884 (Thomson 1892). Thomson (1892) reported that snapper commonly consumed "shellfish" however, Crustacea were found to be the most numerous prey items (Thomson 1892). Later Phillipps (1926) reported that snapper consumed molluscs including Octopus during the autumn months in Palliser Bay and Cook Strait. Graham (1939) found that snapper from Otago Harbour consumed molluscs, one species of crab, other crustaceans and pilchards. These very general observations led to more detailed study of the diet of snapper by Powell (1937), Godfriaux (1969, 1970 and 1974) and Colman (1972).

Godfriaux (1969), Colman (1972) and Godfriaux (1974) found that male and female snapper prefer similar prey items. For other fish species Kasumyan & Doving (2003) found that there was also little variation in diet between male and females as the taste preference of males and females was recorded to be similar. Furthermore, Colman (1972) showed there was a variation in the diet of differently sized snapper. Smaller snapper consumed polychaetes and small crustaceans whereas larger snapper consumed echiurids, crabs, molluscs and fish. Powell (1937) reported that during the spawning period snapper preferred pelagic prey items, such as salps and small fish however, Colman (1972) found no evidence for seasonal change in diet of snapper.

Powell (1937) recorded the diet of snapper from Hauraki Gulf. He examined 3,515 stomachs of snapper caught by the Fishery Department and found that a large proportion of the diet comprised of benthic macrofauna and that Crustacea, Mollusca and echinoderms were the most important prey items. Powell (1937) also described the benthic communities of Waitemata Harbour and recorded six distinct macrofaunal assemblages (formations) within Rangitoto Channel. He suggested that two of these assemblages contributed significantly to the diet of snapper; these were the *Echinocardium* formation and the *Tawera* and *Glycymeris* formation.

The introduction and establishment of non-indigenous marine fauna poses a threat to native fauna and has the possibility to alter the functioning of a marine ecosystem. Marine systems are one of the most heavily invaded ecosystems (Grosholz 2002). There are many human aided mechanisms for the introduction of marine species such as hull fouling, ballast water, sea chests, the aquarium trade, aquaculture, and even canals (Ruiz *et al*. 1997, Coutts & Taylor 2005, Padilla & Williams 2004, Semmens *et al*. 2004, Klein *et al*. 2005, Minchin 2007). Many thousands of species may survive the journey from one area to another, however, very few are able to become established, that is adapt to the new conditions of an environment, and even fewer are able to form viable populations (Kolar & Lodge 2001). Bivalves are often easily introduced into new marine ecosystems as their larval forms are readily picked up during the intake of ballast water and distributed when ballast water is discharged (Creese *et al*. 1997).

Non-indigenous marine species can affect the structure of assemblages of native species within a community. One effect is that they can compete with native species for food and physical resources (Bax *et al*. 2003). They can also have negative economic effects such as those seen in San Francisco Bay, where mass occurrences of the Asian clam *Potamocorbula amurensis* (>10,000 ind. m^{-2}) caused the collapse of local fisheries (Bax *et al*. 2003). Crooks (2002) suggested that introduced marine benthic species that directly modify the environment have a greater effect on communities than species that do not modify the environment as they can drastically alter the habitat of native species. For example, the Asian mussel *Musculista senhousia* forms dense mats using byssal threads (Willan 1987). The mats trap fine sediment and reduce the oxygen content of the sediment below them (Creese *et al*. 1997). Because anoxic sediment supports a different

set of species such mats can alter the natural species assemblages (Creese *et al*. 1997).

Many non-indigenous marine species have become established in and around the coastal waters of New Zealand. Cranfield *et al*. (1998) have identified at least 148 of these. In Waitemata Harbour alone, there have been 39 non-indigenous species identified that now have established populations (Hayward 1997). Some non-indigenous marine species can become food for native species (Rodriguez 2006). The earliest record of non-indigenous species in the diet of snapper was published by Dromgoole and Foster (1983). They found the non-indigenous bivalve *Limaria orientalis* in the diet of snapper from 50% of fish from four age classes sampled, *L. orientalis* appeared to be an important food source, particularly so for larger snapper.

New Zealand's busiest international port is the Port of Auckland. Many non-indigenous marine benthic species have established populations in the marine area surrounding this port. The introduction of these species is likely caused by the international shipping activity (Hayward 1997). Hayward *et al*. (1997) conducted a resurvey of the area studied earlier by Powell (1937) and found that dominant species that once depicted the assemblages of the benthic macrofauna as described by Powell, had changed or even disappeared. Hayward *et al*. (1997) recorded a reduction or disappearance of 14 mollusc species and a reduced range and abundance of the once highly abundant gastropod *Maoricolpus roseus*. The authors identified seven assemblages within Rangitoto Channel and found three non-indigenous marine species, the bivalves *Limaria orientalis*, *Musculista senhousia* and *Theora lubrica*. Rangitoto Channel is the main shipping lane into and out of the port of Auckland and will be used as my study site.

At present the role of non-indigenous benthic macrofauna in the diet of one of New Zealand's most popular commercial and recreational coastal fishes is unknown. The aims of this research are to describe the diet of snapper and ascertain the importance of non-indigenous species within the diet. I also want to assess if snapper display any preference for particular prey species both non-indigenous and native. The invasion of non-indigenous marine species to New Zealand waters is a common occurrence and to assess the role of these species in the diet of snapper, knowledge of the benthic macrofauna communities within the study area is required. To achieve this, detailed benthic sampling throughout the study area using a variety of methods will be employed.

Bimonthly monitoring of the diet of snapper as well the benthic communities at four monitoring sites within the study area will be undertaken. To assess if snapper feed in an opportunistic manner or display some degree of selectivity feeding trials will be conducted. Snapper has been studied extensively because it is a highly important coastal fish species to New Zealand. We know that snapper can consume non-indigenous benthic macrofaunal species, however, the importance and extent of the consumption of non-indigenous species is unknown.

Materials and methods

Sample collection

Spatial survey

Survey design

This study was conducted within Rangitoto Channel, Hauraki Gulf (Figure 1). A grid was used to distribute sampling sites throughout the study area. Longitudinal lines placed every 0.30 decimal degrees were laid over the bathymetric map of the study area (NZ 5322). Upon each of the 14 longitudinal lines, 78 sampling sites were randomly distributed in an area of 1–15 m water depth. Three water depth categories were identified from the chart NZ 5322, 1–5, 6–9 and 10–15 m. The number of sites allocated to each depth category was proportional to the size of the area covered by the depth category. On the eastern side of the channel, 13 sampling sites were established within 1–5 m and 12 sampling sites within 6–9 m water depth. On the western side of the channel, 14 sampling sites were selected within 1–5 m and 15 sites within 6–9 m water depth. Throughout the centre of the channel, 24 sampling sites were selected within 10–15 m water depth. In addition to the above 78 sites, six deeper sites (20–25 m) within the south-western region of the channel were established. No sites were allocated in areas containing underwater cable or areas with anchoring restrictions.

Sediment collection

To analyse the benthic macrofauna, sediment was collected with a Van-Veen grab sampler (KC Denmark, bite aperture of 0.0336 m^2) on 29th and 30th of January and the 19th and 20th of February 2008. One sediment sample was obtained from each of the 78 sites in 1–15 m water depth and three replicate sediment samples were obtained from each of the six deep-water sampling sites (Figure 2a). Due to the differing substrate type, the volume of sediment obtained by the grab sampler varied. Only grab samples that were over 50% full were considered. A GPS coordinate was recorded for every sample collected with a Garmin eTrex handheld GPS. Samples were bagged, labelled and preserved in 5% buffered (sodium bicarbonate) formalin and then left for at least 48

hours prior to sorting to allow for tissue fixation to occur.

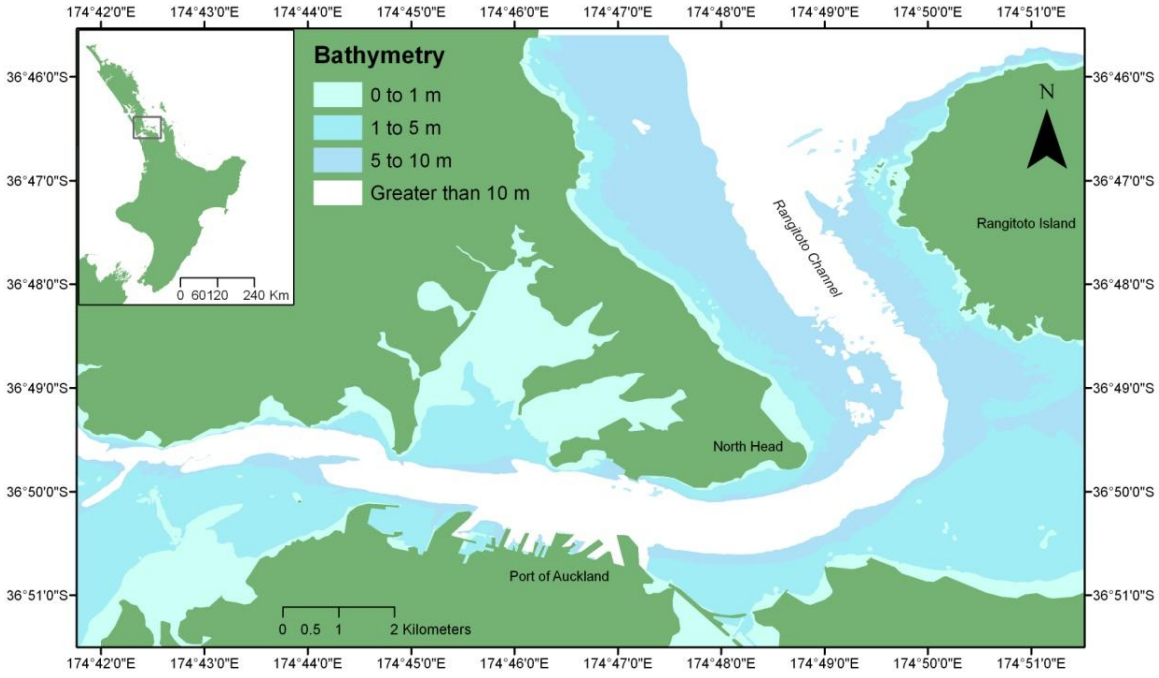

Figure 1. The study site, Rangitoto Channel, Hauraki Gulf, New Zealand. The channel is bound by the co-ordinates 36º46.10–50.00'S 174º46.30–51.40'E. Insert is a map of North Island, New Zealand; the box outlines the location of Rangitoto Channel.

To analyse the sediment grain size composition, sediment was collected from 26 of the 84 sites used for the analysis of benthic macrofauna (Figure 2b). Ten sites were located on the eastern side of the channel; seven sites within 1–5 m water depth and three sites within 6–9 m water depth. Six sites were located in the centre of the channel in 10–15 m water depth. Ten sites were located on the western side of the channel; three sites in 1–5 m water depth and seven sites were located in 6–9 m water depth. Originally 32 sites were selected for the collection of sediment; however, some sites could not be sampled due to weather and current conditions. These included two sites in 10–15 m water depth in the centre of the channel, one site in 6–9 m water depth at the eastern side of the channel, and one site in 1–5 m water depth at the western side of the channel. Two samples were collected from the western side of the channel, however, these samples were not analysed as the substratum for each was rocky reef. Samples were

collected in the same manner as the benthic macrofaunal samples and then bagged, labelled and frozen until the time of analysis.

Seafloor video

The seafloor was observed with video at 40 of the 84 spatial-survey sites (Figure 2c). At each site, an underwater video camera (RV-Marine, Waeco) was deployed. The camera was facing the sediment surface to give a vertical view of the sediment. At 0.5 m below the camera a 50 × 50 mm white plastic marker with a weight attached to it, was positioned as reference. Once a clear view of the sediment surface was available, recording commenced for two minutes while the boat drifted with the current. A GPS coordinate was recorded at the beginning and end of the recording as described above. Time and seawater depth was also recorded at each site.

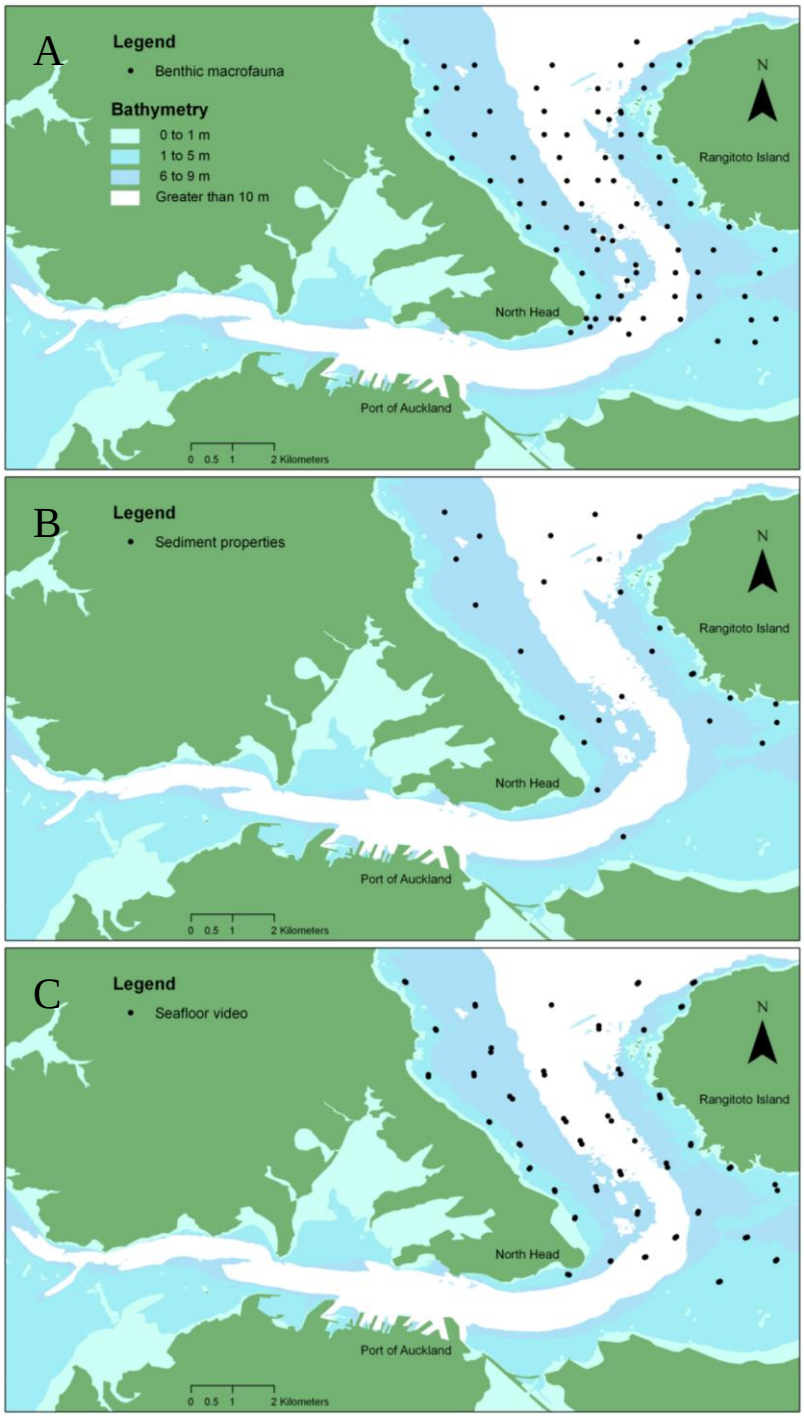

Figure 2. The locations at which samples were collected for the spatial survey of benthic macrofaunal assemblages in Rangitoto Channel. (A) A total of 84 locations were sampled in January and February 2008 to analyse the benthic macrofauna. (B) Sediment grain size analyses were conducted on samples from 26sites. (C) The seafloor was surveyed with video at 40 sites. Circles mark the start and finish of each underwater video deployment.

Monitoring

Four monitoring sites were selected in areas where fishing and sediment collection were logistically convenient (Figure 3). Three sites were located on the eastern side of the channel and one on the western side. Ten sediment samples were collected bimonthly at each of the four monitoring sites. These samples were collected and treated in the same manner as those for the spatial survey of the benthic macrofauna.

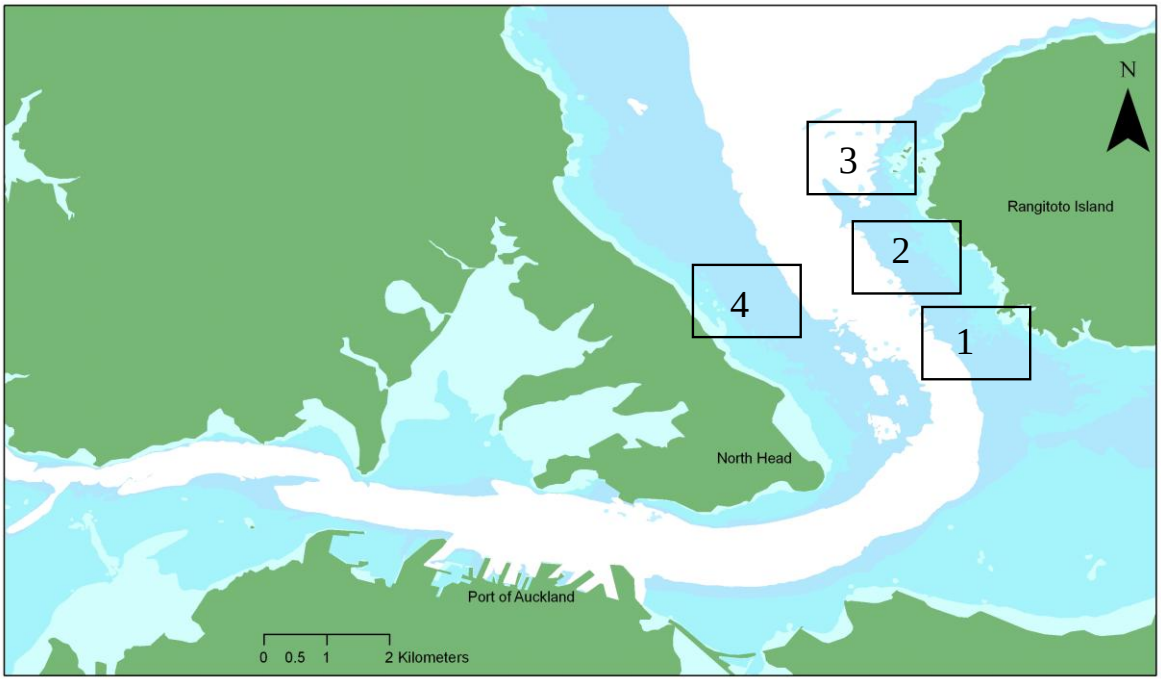

Figure 3. The locations of the four bi-monthly monitoring sites at which benthic samples were collected and fishing was undertaken from June to December 2008. Numbering relates to the site number.

All fish were caught in accordance with the AUT Special Permit (#405) and Ministry of Fisheries were notified before each fishing day. Fishing was undertaken over three or four days, following each collection of sediment samples at each of the four monitoring sites. Snapper were captured by long lines set along the seafloor. The horizontal orientation of the long line depended on the current and wind conditions on the day. Long lines were usually set twice, at each of the four sites, for one hour, on each sampling day. During winter months (June and August), long lines were set for

1.5–2 hours due to low numbers of snapper being caught.

Figure 4. A photograph showing a long line set in Rangitoto Channel with Rangitoto Island in the background. Two red buoys (arrows) mark each end of the long line at the water surface at Site 3.

The long lines consisted of a 100 m main line with stoppers every two meters. Each end of the main line was anchored to the seafloor with grapple anchors to which buoys were attached (Figure 4). One hook was placed on every other stopper. Squid was used as bait for most of the sampling period; however, in the winter monitoring period (June) hooks alternated pilchard and squid to increase the catch rate. Bait was cut into pieces of about 20 × 30 mm. The long-line approach was supplemented with rod and reel fishing when time allowed.

All snapper caught were euthanized using an iki spike and placed into labelled plastic bags. The bags were stored in an insulated box and transported to the AUT laboratory for processing.

Sample processing

Benthic macrofauna

Following fixation, sediment samples were washed with fresh water over a 0.5 mm sieve to remove fine sediment particles. The content remaining in the sieve was placed into a tray filled with freshwater. All fauna >5 mm were removed from the tray by hand, preserved in 40% isopropyl alcohol, and then identified using compound light microscopy. Identification was done to species or genus level wherever possible. Taxa that could not be identified to either of these levels were identified to the lowest common denominator. In some cases, individuals could be identified as different species, but those species names were unknown. These individuals belonged to taxa such as Ostracoda, Syllidae and *Eunice* and were allocated a number that relates to the species collection at AUT. When fragmented individuals were present, only the anterior or posterior were counted. The macrofauna within each sample were grouped into native and non-indigenous species. These two groups were blot dried and wet weighed. The non-indigenous species were then grouped into separate species and weighed.

Sediment properties

Grain size analysis was conducted with a wet sieve shaking machine (ACM-42308-U, Weiber). A stack of seven sieves (mesh sizes: 2000, 1180, 1000, 500, 300, 150 and 63 µm) was used. Fresh water was added to the reservoir in which the stack was placed. The wet sieve shaker was turned on for one hour after which the water in the reservoir and the contents of the sieves were removed and stored. The finer sieves often became blocked, which forced smaller particles out of the stack of sieves through the joins between the sieves. Because of this, the remaining water within the reservoir was sieved a further one to two times depending on the amount of finer particulate matter within a sample.

The content of each sieve was oven-dried at 100°C until its dry weight remained constant (10–24 hours). The water used for sieving was filtered through Whatman 1 Qualitative filter paper (pore size 11 µm) and then left for 48 hours to settle finer particulate matter. This matter was then dried at 100°C until its dry weight remained constant (8–12 hours).

Seafloor video

The video was viewed in slow motion to identify and count large epibenthic fauna. This fauna included; the horse mussel *Atrina zelandica*, the sea star *Coscinasterias muricata*, the sea urchin *Evechinus chloroticus*, the cushion star *Patiriella regularia* and the scallop *Pecten novaezelandica*. Most of these species were not detected in grab samples.

Snapper

The weight, fork length and the sex of each individual snapper were determined. Gonads were removed and then weighed and preserved in 5% buffered (sodium bicarbonate) formalin seawater solution. Otoliths were collected, washed, dried and stored for future aging.

Snapper diet

The alimentary tracts were removed from the body cavities of each snapper and were fixed in 5% buffered (sodium bicarbonate) formalin seawater solution and left for at least 48 hours to allow for tissue fixation. They then were divided into two sections, the stomach and the intestine. The contents of the two were carefully removed and weighed. They were then placed into 40% isopropyl alcohol until identification could take place.

The contents of the stomach and the intestine were identified separately. Identification of species was conducted using compound light microscopy. The level to which species could be identified differed due to the various degrees of digestion. Often soft bodied prey items could not be identified. When fragmented individuals were present, voucher specimens were used to aid the identification. Tissue attached to the shells of bivalves indicated that the organism was live at the time the fish consumed it and the shell was not simply incidental. In these instances, individuals were identified and counted using the presence of hinges, two hinges equating to one individual. Contents in either the stomach or the intestine which were clearly bait or non-prey items (e.g., shells which were degraded and had no tissue attached) were recorded as non-prey items. In cases where there was a large amount of unidentifiable matter, it was recorded as ‘unidentifiable’.

Snapper feeding trials

Preferences for prey species were observed during two sets of feeding trials using a total of seven snapper. Approval from Auckland University Animal Ethics Committee was obtained before studies commenced (AEC Number R721).

Collection of snapper and prey

Four similarly sized snapper were caught for the first set of feeding trials. Another three snapper were caught for the second set of feeding trials. Snapper were caught by long line as described above but wire fixings upon barbless hooks were used to minimise fishing related injuries to the snapper and long lines were set for only 30 minutes at a time. The snapper were placed in a seawater tank using wet cotton gloves to minimise infections. This tank was transported to the quarantine area of Kelly Tarlton's Aquarium, Orakei, Auckland. At Kelly Tarlton's Aquarium, snapper were placed into separate enclosures (~750 L) within one cylindrical polyethylene tank filled with ~3000 L seawater (Figure 5). Seawater was obtained from the nearby Orakei Bay and pumped through sand filters before it entered the tank. The seawater in the tank was aerated with air stones. It was not re-circulated but flowed directly to waste. The temperature of the seawater was the same as that of the seawater in Orakei Bay and was monitored throughout the day.

Seven invertebrate species, which were previously recorded in the diet of snapper, were collected using SCUBA, grab sampling and intertidal collection. Species included two non-indigenous bivalve species, *Limaria orientalis* and *Musculista senhousia*, and five native species including the crabs *Paguristes pilosus* and *Pilumnopeus serratifrons*, the gastropod *Maoricolpus roseus*, the shrimp *Alpheus* sp. and the polychaete *Flabelligeria* sp. The filter feeding species (*M. roseus*, *L. orientalis* and *M. senhousia*) and the crab species were placed in Orakei Bay in small wire mesh cages (320 mm length, 120 mm diameter) to allow them to feed until they were needed for the experiments. The crab species were fed small pieces of squid. The species *Flabelligera* sp. and *Alpheus* sp. were placed into a small tank at Kelly Tarlton's Aquarium. The polychaete *Flabelligera* sp. was fed a small amount of organic debris; the shrimp *Alpheus* sp. was fed a small amount of herring.

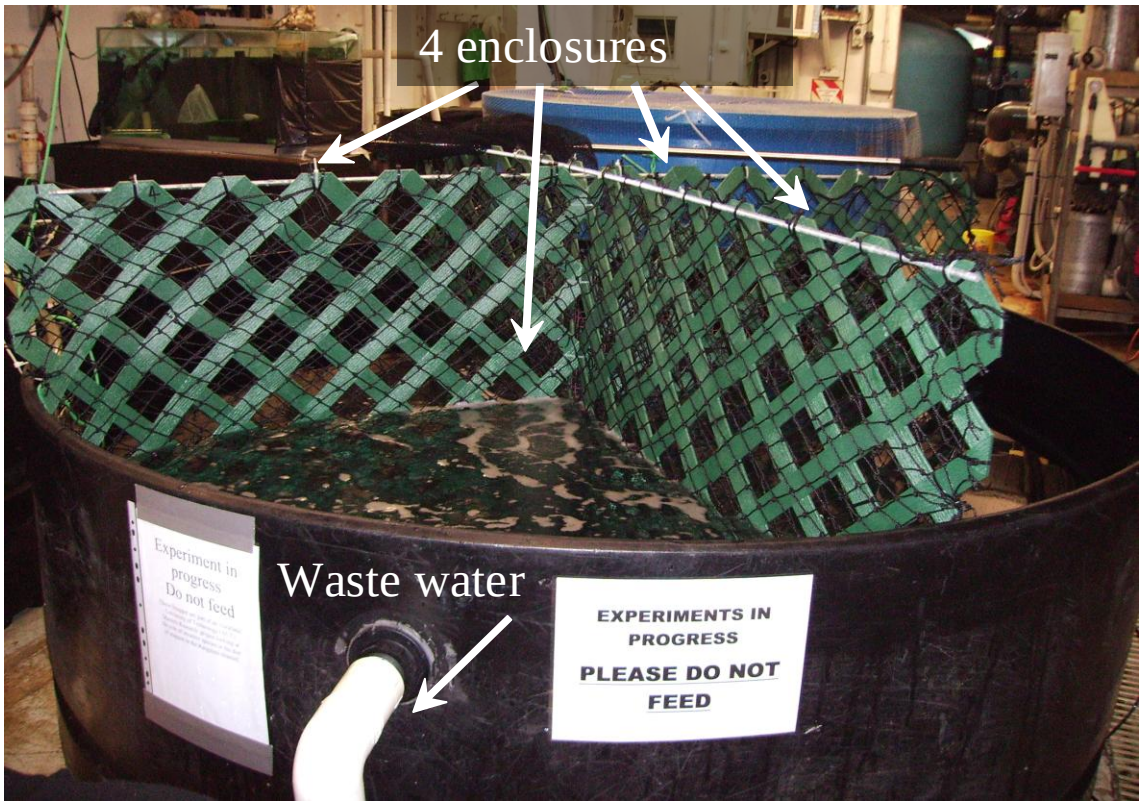

Figure 5. The tank in which the four ~750 L enclosures housed the snapper for feeding trails, Kelly Tarlton's quarantine area.

Trial procedure

The four snapper used during the first set of feeding trials were held for one week. During this time snapper were offered a variety of food, ranging from pilchard and squid to crabs, all naturally available to them in the wild. Following this acclimatisation period, they were not fed for 12 hours. A selection of live native and non-indigenous prey was then offered to each fish. The prey species were placed into a shallow black feeding container (350 mm diameter by 110 mm deep) with a wire mesh lid. One container of prey was offered to each fish during each feeding trial. The containers contained a mixture of the seven prey species. The seven different prey species were different sizes and weights; because of this the biomass and number of individuals of each species that was offered to each fish differed (Figure 6). Each fish was given approximately the same weight of each prey species during each feeding trial.

To assess if any and to what extent, feeding had occurred, the biomass and number of individuals offered to each fish in each experiment was recorded before and after each feeding trial. Prey containers were placed into the snapper enclosures. After a 10-minute acclimatisation period for the prey, the lid was removed for 30 minutes exposing the prey to the snapper. Once the lid was removed, the behaviour of snapper was recorded on video augmented with visual observation. The order of consumption (determined from the video observations), numbers of individuals of each species consumed and biomass consumed was recorded for each fish in each experiment.

Figure 6. An example of the amounts of each prey item offered to snapper during each feeding trial. Top left *Maoricolpus roseus*, below *Pagurid* sp., bottom *Limaria orientalis*, top centre *Musculista senhousia*, top right *Alpheus* sp., bottom right *Flabelligeria* sp., and centre *Pilumnopeus serratifrons*. The number 4 was used as a reference to the biomass and counts of that particular selection of prey items and refers to which fish it was offered to.

The feeding trials of the first set were carried out every other day for 30 minutes. After the third trial, video observations ceased and the period in which prey was available to snapper was prolonged to intervals of two, three, and 17 hours and from then on, 24

hours (Table 1). After each trial, prey was counted, fresh prey was put into the feeding containers and experiments were resumed immediately so that prey was constantly available to snapper. Following experimentation, the snapper were released into the wild close to the area in which they were caught.

Table 1. Summary of the feeding trials that were conducted during May to June 2008. Trial 1 was conducted using the first four snapper. Trial 2 was conducted using the second batch of three snapper. The length of the trial was the time in which prey was exposed to snapper.

Trial	Date	Water temp. (°C)	Trial length (h)	Video
1	20 May	16.2	0.5	Yes
	22 May	15.7	0.5	Yes
	24 May	15.4	0.5	Yes
	25 May	15.2	2	No
	25 May	15.2	3	No
	25–26 May	15.1	17	No
	26–27 May	15.0	24	No
	27–28 May	15.0	24	No
2	4–5 June	14.0	24	No
	5–6 June	13.9	24	No
	6–7 June	13.6	24	No
	7–8 June	13.7	24	No

During the second set of feeding trials, empty feeding containers were presented to the fish as soon as the fish were placed into the enclosures. Fish were kept for 24 hours without food. After 24 hours, prey was placed into the feeding containers and was offered during three feeding trials for 24 hours each trial. Feeding was not observed with video or visual observations. At the end of each trial, prey items were counted and any missing items were recorded (enclosures were extensively searched to locate any prey items that may have escaped the feeding containers). Thereafter, the snapper were released into the wild.

Data analysis

Spatial survey

Benthic macrofauna

Species counts of the six deep-water samples, at which three samples were collected, were averaged to obtain one data point at each of these six sites. All abundances were converted into individuals or biomass m^{-2}. To compensate for any variation in the volume of sediment collected by the grab sampler, species counts were standardised by the total number of individuals per sample. The standardised counts were square-root transformed to reduce the influence of highly abundant species on the results of the statistical analyses. Bray-Curtis similarities were used to create a similarity matrix using PRIMER version 6 (PRIMER-E Ltd, Plymouth Marine Laboratory, UK). To test for statistically significant structuring within the macrofaunal assemblages at the 84 sites the SIMPROF procedure was performed and a dendrogram was used to present groupings of sites with similar macrofaunal species assemblages.

Sediment properties

To determine the sediment property of each sample, the dry weight of the sediment within each sieve (calculated in percent of total sample) was transformed into a cumulative frequency series. The phi scale (φ): $\varphi = -\log^2$ (grain size, mm) (Table 2) was used to represent grain size. The percentage weight of the larger fraction (>-0.239 φ) of the total dry weight of the sediment was determined and analysis of the remaining finer fraction of the sediment (<-0.239 φ) was conducted whilst excluding the larger fraction. The exclusion of the larger fraction was to allow the comparison of the sediment found between the gaps of the large pieces of shell. A cumulative frequency curve was created for the finer fraction of the sediment for each sample to calculate the median particle diameter, $Md = (\varphi\ 16 + \varphi\ 50 + \varphi\ 84) / 3$, the lower (φ 25) and upper (φ 75) quartiles, the inclusive Sorting Coefficient, $QD_1 = (\varphi\ 84 - \varphi\ 16) / 4 + (\varphi\ 95 - \varphi\ 5) / 6.6$, and the inclusive Graphic Skewness, $Sk_I = (\varphi\ 16 + \varphi\ 84 - 2\ \varphi\ 50) / 2(\varphi\ 84 - \varphi\ 16)$.

Table 2. Conversion of particle size (μm) to phi scale equivalent (φ) and the corresponding particle size class (Higgins & Thiel 1988).

Mesh size (μm)	Phi scale equivalent (φ)	Size class (Wentworth Scale)
2000	>−1	Granule
1180	−0.239	Coarse sand
1000	0	Coarse sand
500	1	Medium sand
300	1.737	Medium sand
150	2.737	Fine sand
63	3.989	Very fine sand
11	6.506	Silt
<11	<6.506	Silt

Linking environmental factors and faunal assemblages

To investigate if multivariate patterns in the structure of the benthic macrofaunal assemblage could be explained by environmental factors a sub-set of 14 sites at which environmental variables and benthic macrofauna had been analysed was used to link environmental factors. Environmental variables included water depth, the percentage of the shell content (>−0.239 φ) of the total dry weight of the sediment, median particle size, lower quartile, upper quartile, inclusive sorting coefficient, inclusive graphic skewness of the finer fraction of the sediment (<−0.239 φ). Species counts were standardised and square-root transformed. The environmental data set was normalised before similarity matrices were calculated using Euclidean distance index. Similarity matrices were created for both the biotic and the environmental data-sets. The BIO-ENV procedure in PRIMER was used to determine the combination of environmental variables that groups the sites best, in a manner that is consistent with the faunal patterns.

The analysis of the sediment properties at 26 sites revealed that there were two sediment types present. Using Arc GIS 9 (ArcMap^{TM} Version 9.3) these sediment types were then projected throughout the channel. Multivariate analysis of the macrofaunal assemblages was then performed for each sediment type to test if there were any differences in the macrofaunal assemblages between the two. Similarity matrices were calculated using the Bray-Curtis similarity index on standardised, square-root

transformed species counts from each of the sediment types and one-way ANOSIM tests were used to determine if observed patterns were significant. To identify the highly contributing species to the similarity and dissimilarity of the faunal assemblages of each of the sediment types, the SIMPER procedure was used.

Bimonthly monitoring

Benthic macrofauna

To describe the species composition at each site the total number of individuals (N), species richness (S), Margalef' index (d), Pielou's evenness index (J'), Shannon-Wiener index (H'loge) and Simpson index were computed using the DIVERSE dialog in PRIMER. Average indices were calculated and standard deviations (SD) were determined for each site during each monitoring period. ANOVA (analysis of variance) was conducted using MINITAB VERSION 15 on the species diversity and the number of species for each month as both were normally distributed (Anderson-Darling) and had equal variances (Bartlett's test). A Tukey simultaneous test was undertaken to analyse pair-wise comparisons. Species evenness for the four monitoring periods did not meet the assumptions of ANOVA (normal distribution, equal variances), and was analysed using Kruskal-Wallis test. Multivariate analysis was performed in the same manner as above.

Snapper

To assess the size distribution of snapper caught throughout the four monitoring periods, the fork length of all snapper were placed into size classes and the frequency of individuals within each size class was then depicted using a frequency distribution graph. A gonad somatic index (GSI) was calculated using the ratio of the total weight of the gonads and the weight of the fish. The mean GSI for both male and female snapper was projected upon a graph and the standard error (SE) was calculated. The time at which spawning took place was indicated by an increase in the mean GSI.

Snapper diet

Only snapper that had prey in their stomach and/or their intestine were used for analysis. To asses if the prey species assemblages within the stomach were different from the assemblages within the intestine the prey species counts from both the stomach and the

intestines were standardised, square root transformed and normalised. Similarity matrices were calculated using the Bray-Curtis similarity index and an MDS ordination was created. A one-way ANOSIM test was performed for each monitoring period using the stomach and the intestinal contents as factors. From then on, the stomach and the intestinal contents for each fish were combined.

Univariate analysis of the prey species counts from the combined stomach and intestinal contents of snapper collected during the four monitoring periods was conducted in the same manner as that used on the spatial survey samples. This datum did not meet the assumptions of ANOVA, and was analysed using the Kruskal-Wallis test.

The prey assemblages of different sexed, different sized snapper and snapper caught at different times of the year were assessed to determine if there where any differences in the prey assemblages for these different classes. An MDS ordination was created in the same manner as above using the prey species counts of all the fish from all the monitoring sites. The sex and size class of the snapper as well as the monitoring period in which it was caught were used as factors. Analysis was conducted (ANOSIM) to determine if there were significant differences between the prey items present in the diet of snapper for each factor. For those factors that did show a significant difference in prey item assemblage, analysis of the species that contributed most to the prey species assemblages was conducted with the SIMPER routine in PRIMER.

Prey availability

The mean abundances (ind. per m^{-2}) of three important prey species within the sediment at each of the four monitoring sites were calculated. The mean abundances of these same three species within the diet of snapper were also calculated. Standard error (SE) was calculated for all three species both within the diet and the sediment and all were graphically represented. The temporal trends of the abundances of the three species within the sediment were compared to the trends of these same species within the diet of snapper (ind. per fish). Again this datum did not meet the assumptions of ANOVA so was analysed using the Kruskal-Wallis test. *Upogebia* sp., although an important prey species, could not be used for this analysis as it was not recorded in its adult form (and vary rarely in its juvenile form) within the sediment samples.

Snapper feeding trials

Feeding trials did not provide adequate data. Therefore, no data analysis was conducted.

Results

Spatial survey

Benthic macrofauna

In total 6,395 individuals were identified belonging to 158 taxa (Table 3). The dominant taxa were Bivalvia with 4,123 individuals, Polychaeta with 711, Malacostraca with 660 and Gastropoda with 251 individuals. The average macrofaunal abundance was 2,047 individuals m^{-2} (119 to 32,321 ind. m^{-2}).

Table 3. List of all taxa recorded within Rangitoto Channel in 2008. (S) spatial survey, (V) video survey, (B) bi-monthly monitoring of four sites and (D) species recorded in the diet of snapper collected from June to December 2008.

Class	Species name	S	V	B	D
NA	Porifera	p	a	p	a
Anthozoa	*Edwardsia tricolor* (Farquhar, 1898)	p	a	p	a
	Actiniaria	a	a	p	a
	Hydroida sp.	a	a	p	p
NA	Platyhelminthes	p	a	p	a
NA	Nemertea	p	a	p	a
NA	Nematoda	p	a	p	a
NA	Sipuncula	a	a	p	a
Bivalvia	*Thracia vitrea* (Hutton, 1873)	p	a	a	a
	Ruditapes largillierti (Philippi, 1849)	p	a	a	a
	Corbula zelandica Quoy & Gaimard, 1835	p	a	p	a
	Hiatella arctica (Linnaeus, 1767)	p	a	p	a
	Modiolarca impacta (Hermann, 1982)	a	a	p	a
	Nucula hartvigiana Pfeiffer, 1864	p	a	a	a
	Nucula nitidula A. Adams, 1856	p	a	p	a
	Ostrea sp.	p	a	a	a
	Talochlamys zelandiae (Gray,1843)	a	a	p	a
	Myadora boltoni Smith, 1880	a	a	p	a
	Anomia trigonopsis Hutton, 1877	p	a	a	a
	Pecten novaezelandiae Reeve, 1853	p	p	a	a
	Atrina pectinata zelandica (Gray, 1835)	a	p	a	a
	Limaria orientalis (A. Adams & Reeve, 1850)	p	a	p	p
	Trichomusculus barbatus (Reeve, 1858)	p	a	a	a

Class	Species name	S	V	B	D
Bivalvia	*Musculista senhousia* Benson, 1842	p	a	p	p
	Solemya (*Solemyarina*) *parkinsoni* E. A. Smith, 1874	a	a	p	a
	Pleuromeris zelandica (Deshayes, 1854)	p	a	a	a
	Purpurocardia purpurata (Dashayes, 1854)	p	a	p	a
	Arthritica bifurca (Webster, 1908)	p	a	a	a
	Scintillona zelandica (Odhner, 1924)	p	a	p	p
	Scalpomactra scalpellum (Reeve, 1854)	p	a	p	a
	Zenatia acinaces (Quoy & Gaimard, 1835)	p	a	p	a
	Gari stangeri (Gray, 1843)	p	a	p	a
	Leptomya retiaria (Hutton, 1885)	p	a	p	a
	Felaniella zelandica (Gray, 1835)	p	a	p	a
	Dosina crebra (Hutton, 1873)	a	a	p	a
	Dosina zelandica (Gray, 1835)	p	a	p	a
	Dosinia lambata (Gould, 1850)	p	a	p	a
	Dosinia subrosea (Gray, 1835)	p	a	a	a
	Irus (*Notirus*) *reflexus* (Gray, 1843)	p	a	p	a
	Tawera spissa (Deshayes, 1835)	p	a	p	a
	Theora lubrica Gould, 1861	p	a	p	a
Gastropoda	*Lamellaria ophione* Gray, 1850	p	a	a	a
	Philine sp.	p	a	p	a
	Taron dubius (Hutton, 1878)	p	a	p	a
	Neoguraleus murdochi (Finlay, 1924)	p	a	a	a
	Sigapatella novaezelandiae (Lesson, 1830)	p	a	p	p
	Sigapatella tenuis (Gray, 1867)	p	a	p	a
	Eatoniella limbata (Hutton, 1883)	a	a	a	p
	Eatoniella sp.	p	a	a	a
	Dendrodoris gemmacea (Alder & Hancock, 1864)	p	a	a	a
	Dendrodoris sp.	a	a	p	a
	Pleurobranchaea maculata (Quoy & Gaimard, 1832)	a	a	p	a
	Philinopsis taronga Allan, 1933	a	a	p	a
	Cylichna thetidis Hedley, 1903	p	a	a	a
	Buccinulidae spp.	a	a	a	p
	Buccinulum lineum (Martyn, 1784)	a	a	p	a
	Buccinulum vittatum (Quoy & Gaimard, 1833)	p	a	a	a
	Cominella adspersa (Bruguière, 1789)	p	a	p	a
	Cominella quoyana A. Adams, 1854	p	a	p	a
	Maoricrypta costata (G. B. Sowerby I, 1824)	p	a	a	a
	Maoricypta monoxyla (Lesson, 1830)	p	a	a	a
	Trichosirius inornatus (Hutton, 1873)	p	a	a	a
	Amalda australis (Sowerby, 1830)	p	a	p	a
	Amalda novaezelandiae (Sowerby, 2859)	p	a	a	a
	Estea sp.	p	a	a	a
	Tomopleura albula (Hutton, 1873)	p	a	a	a
	Maoricolpus roseus (Quoy & Gaimard, 1834)	p	a	p	p

Class	Species name	S	V	B	D
Polyplacophora	*Acanthochitona zelandica* (Quoy & Gaimard, 1835)	p	a	a	a
	Acanthochitona sp.	a	a	p	a
	Acanthochitona (*Notoplax*) *violacea* (Quoy & Gaimard,1835)	p	a	a	a
	Craspedochiton rubiginosus (Swainson MS, Hutton, 1872)	a	a	p	a
	Craspedochiton sp.	a	a	a	p
	Leptochiton inquinatus (Reeve, 1847)	p	a	p	p
	Pseudotonicia cuneata (Suter,1908)	p	a	a	a
	Rhyssoplax stangeri (Reeve, 1847)	p	a	p	a
	Ischnochiton maorianus Iredale, 1914	p	a	p	a
Clitellata	Oligochaeta	a	a	p	a
Echiura	Echiura	a	a	p	a
Polychaeta	*Glycera Americana* Leidy, 1855	p	a	p	a
	Glycera tesselata Grube, 1840	p	a	p	a
	Hemipodus sp.	p	a	p	a
	Glycinde sp.	p	a	p	a
	Goniada sp.	p	a	p	a
	Ophiodromus angustifrons (Grube, 1879)	p	a	p	a
	Diopatra sp.	p	a	p	a
	Syllidae spp.	p	a	p	a
	Syllidae sp. 2	a	a	p	a
	Syllidae sp. 4	a	a	p	a
	Syllidae sp. 10	a	a	p	a
	Ampharetidae sp.	p	a	a	a
	Amphicteis sp.	p	a	p	a
	Amphicteis philippinarum Grube, 1878	a	a	p	a
	Chaetopteris sp.	p	a	p	a
	Cirratulidae	p	a	p	a
	Sabellidae sp. 1	p	a	p	a
	Sabellidae sp. 2	a	a	p	a
	Sabellidae sp. 3	a	a	p	a
	Sabellidae	p	a	a	a
	Aonides sp.	a	a	p	a
	Prionospio sp.	p	a	p	a
	Spionidae	p	a	p	a
	Spiorbidae	p	a	a	a
	Capitella capitata (Fabricius, 1780)	a	a	p	a
	Capitellidae	p	a	a	a
	Heteromastus filiformis (Claperède, 1864)	p	a	p	a
	Notomastus zeylanidcus	p	a	a	a
	Asychis theodori Augener, 1926	a	a	p	a
	Macroclymenella stewartensis Augener, 1926	p	a	p	a
	Maldanidae	p	a	p	a
	Cossura consimilis Read, 2000	a	a	p	a
	Dorvillea australiensis (McIntosh, 1885)	p	a	a	a
	Dorvillea sp.	a	a	p	a

Class	Species name	S	V	B	D
Polychaeta	*Eunice* sp. 1	p	a	p	a
	Eunice sp. 3	p	a	a	a
	Marphysa depressa Schmarda, 1861	p	a	p	a
	Lumbrineris sphaerocephala (Schmarda, 1861)	p	a	p	a
	Arabella sp.	p	a	p	a
	Flabelligera affinis M. Sars, 1829	a	a	p	p
	Pherusa parmata (Grube, 1877)	p	a	p	a
	Armandia maculata (Webster, 1884)	p	a	p	a
	Ophelia sp.	a	a	p	a
	Paraonis sp.	a	a	p	a
	Aricidea sp.	a	a	p	a
	Haploscoloplos cylindrifer (Ehlers, 1905)	a	a	p	a
	Orbinia papillosa (Ehlers, 1897)	p	a	p	p
	Owenia fusiformis Delle Chiaje, 1844	p	a	p	a
	Aphrodita telpa Quatrefages, 1866	p	a	p	p
	Pisione sp.	a	a	p	a
	Euphione squamosa (Delle Chiaje, 1827)	a	a	p	a
	Lepidasthenia sp.	p	a	p	a
	Lepidonotus polychromus Schmarda, 1861	p	a	p	p
	Lepidonotus purpureus Potts, 1910	p	a	a	a
	Lepidonotus sp. 1	a	a	p	a
	Lepidonotus sp. 2	a	a	p	a
	Hemipodus sp.	p	a	p	a
	Aglaophamus macroura (Schmarda, 1861)	p	a	p	a
	Neanthes cricognatha Ehlers, 1904	p	a	p	a
	Perinereis nuntia (Savigny in Lamarck, 1818)	p	a	p	a
	Sthenelais sp.	p	a	p	a
	Psammolyce antipoda (Schmarda, 1861)	a	a	p	a
	Phyllodocidae	p	a	p	a
	Phyllodocidae sp.8	a	a	p	a
	Sphaerosyllis sp.	a	a	p	a
	Galeolaria hystrix Mörch, 1863	a	a	p	a
	Hydroides norvegicus Gunnerus, 1768	p	a	p	a
	Scalibregmatidae	a	a	p	a
	Pectinaria australis (Ehlers, 1905)	p	a	p	a
	Terebellidae	p	a	p	a
	Terebellides stroemi Sars, 1835	p	a	p	a
	Thelepus sp.	p	a	p	a
	Trichobranchus glacialis Malmgren, 1866	p	a	a	a
	Trichobranchus sp.	p	a	p	a
	Polychaeta sp.1	a	a	a	p
	Polychaeta sp.2	a	a	a	p
	Polychaeta sp.3	a	a	a	p
	Polychaeta sp.4	a	a	p	a
	Polychaeta spp.	p	a	a	p

Class	Species name	S	V	B	D
Insecta	*Chironomus* sp.	a	a	p	a
Malacostraca	Ampeliscidae	p	a	a	a
	Caprellidae	p	a	a	a
	Caprella sp.	a	a	p	a
	Corophiidae	p	a	a	a
	Haustoriidae	p	a	a	a
	Lyssianassidae	p	a	p	a
	Phoxocephalidae	p	a	a	a
	Heterophoxus sp.	a	a	p	a
	Paraphoxus sp. 1	a	a	p	a
	Paraphoxus sp. 2	a	a	p	a
	Amphipoda spp.	p	a	p	p
	Cyclaspis thomsoni Calman, 1907	p	a	p	a
	Hemileucon comes Calman, 1907	a	a	p	a
	Cumacean sp.	p	a	p	a
	Alpheus sp.	p	a	a	p
	Alpheus richardsoni Yaldwyni, 1971	a	a	p	p
	Callianassa filholi (Milne-Edward, 1878)	a	a	p	a
	Pilumnus novaezelandiae Filhol, 1886	p	a	a	a
	Pontophilus sp.	p	a	p	a
	Petrocheles spinosus Miers, 1876	p	a	a	a
	Paguristes sp.	a	a	p	p
	Paguristes pilosus (H. Milne Edwards, 1836)	p	a	a	p
	Paguristes setosus (H. Milne Edward, 1848)	a	a	p	p
	Paguristes barbatus (Heller, 1862)	a	a	a	p
	Halicarcinus sp.	p	a	a	p
	Halicarcinus cookie Filhol, 1885	p	a	p	p
	Halicarcinus innominatus Richardson, 1949	p	a	p	a
	Macrophthalmus hirtipes (Heller, 1862)	p	a	p	p
	Notomithrax minor (Filhol, 1885)	p	a	p	p
	Pyromaia tuberculata (Lockington, 1877)	p	a	p	a
	Lophopagurus cristatus (H. Milne Edwards, 1836)	p	a	p	a
	Lophopagurus kirki (Filhol, 1883)	p	a	a	p
	Paguridae	p	a	a	a
	Pagurus novaezelandiae Dana, 1852	a	a	p	a
	Periclimenes yaldwyni Holthuis, 1959	p	a	p	p
	Periclimenes sp.	a	a	a	p
	Petrolisthes novaezelandiae Filhol, 1885	p	a	p	a
	Liocarcinus corrugatus (Pennant, 1777)	a	a	p	p
	Decapoda spp.	a	a	a	p
	Upogebia sp.	a	a	a	p
	Astacilla sp.	a	a	p	a
	Anthuridae	p	a	a	a
	Anthuridae sp. 1	a	a	p	a
	Cirolanidae	p	a	a	a

Class	Species name	S	V	B	D
Malacostraca	*Eurylana arcuata* (Hale, 1925)	a	a	p	p
	Cirolana sp.	a	a	a	p
	Eurylana arcuata (Hale, 1925)	a	a	p	a
	Flabellifera spp.	a	a	p	a
	Sphaeromatidae	p	a	p	p
	Asellota spp.	a	a	p	a
	Paranthuridae spp.	a	a	p	a
	Isopoda spp	a	a	a	p
	Nebalia sp.	p	a	p	a
	Mysid	p	a	p	a
	Tanaidae sp.	a	a	p	a
Maxillopoda	*Balanus trigonus* Darwin, 1854	p	a	p	p
	Ascidiacea indet.	p	a	a	a
	Asterocarpa humilis (Heller, 1878)	p	a	p	a
	Copepoda spp.	a	a	p	a
Ostracoda	Ostracod sp. 1	p	a	p	a
	Ostracod sp. 2	p	a	p	p
	Ostracod sp. 6	a	a	p	a
	Ostracod sp. 7	a	a	p	a
	Ostracod sp. 8	a	a	p	a
	Ostracod sp. 9	a	a	p	a
	Ostracod sp. 11	a	a	p	a
	Ostracod sp. 18	a	a	p	a
	Ostracod sp. 20	a	a	p	a
	Ostracod sp. 27	a	a	p	a
Pycnogonida	Pycnogonidae spp.	a	a	p	a
NA	Phoronid sp. 1	a	a	p	a
Asteroidea	*Coscinasterias calamaria* (Gray, 1840)	a	p	p	a
	Coscinasterias muricata Verrill, 1870	p	a	a	a
	Patiriella regularis (Verrill, 1867)	p	p	p	a
Echinoidea	*Evechinus chloroticus* Valenciennes, 1846	a	p	a	a
	Echinocardium australe Gray 1855	a	a	p	a
	Echinocardium cordatum (Pennant, 1777)	p	a	a	a
Holothuroidea	*Trochodota dendyi* Mortensen, 1925	p	a	p	a
	Kolostineura novaezelandiae (Dendy & Hindle, 1907)	a	a	p	a
	Stichopus mollis (Hutton, 1872)	a	a	p	a
	Ocnus brevidentis (Hutton, 1872)	p	a	a	a
	Heterothyone alba (Hutton, 1872)	p	a	a	a
Ophiuroidea	*Amphipholis squamata* (Delle Chiaje, 1828)	p	a	p	a
	Amphiura aster Farquhar, 1901	p	a	p	p
	Amphiura correcta Koehler, 1907	p	a	p	a
	Ophionereis fasciata Hutton, 1872	p	a	a	a
	Ophiurida spp.	a	a	a	p
	Ophiactis resiliens Lyman, 1879	a	a	p	a
	Ophiuroid indet.	p	a	a	a

Class	Species name	S	V	B	D
Ascidiacea	*Aplidium* sp.	p	a	a	a
	Corella eumyota Traustedt, 1882	p	a	p	a
	Styella clarva Monniot C., Monniot F. & Millar, 1976	p	a	p	a
	Asterocarpa coerulea (Quoy & Gaimard, 1834)	a	a	p	a
	Styela plicata (Lesueur, 1823)	a	a	p	a
	Pyura sp.	a	a	p	a
	Alcyonium sp.	p	a	a	a
Enteropneusta	*Saccoglossus* sp. ?	p	a	p	a
	Saccoglossus sp. 2	a	a	p	a

Seven non-indigenous macrobenthic species occurred in Rangitoto Channel: the barnacle *Balanus trigonus*, the polychaete *Chaetopteris* sp., the bivalves *Limaria orientalis*, *Musculista senhousia* and *Theora lubrica*, the sea squirt *Styella clarva* and the ascidian *Corella eumyota*. These species contributed 21.1 ± 30.7% (mean ± SD) of the total macrofaunal biomass. This equated to an average of 69 ± 331 g m^{-2} whereas the total average biomass was 221 ± 370 g m^{-2} (mean ± SD, n = 80, Appendix 1).

The Asian mussel *M. senhousia*, the semelid bivalve *T. lubrica* and the native hermit crab *Paguristes pilosus* were the most frequently occurring (in terms of presence) and most abundant species throughout the survey area. The bivalve *M. senhousia* was mainly found in water depths of 1–5 m to the sides of the channel (Figure 7a). Here, its abundance averaged 3,890 individuals m^{-2} (30–30,982 ind. m^{-2}), which equated to a biomass of 213 g m^{-2} (0.1–2,409 g m^{-2}). The bivalve *T. lubrica* was mainly found in the south-eastern region of the channel in water depths of 1–10 m (Figure 7b). Here, its average abundance was 318 individuals m^{-2} (ranging from 30–923 ind. m^{-2}), which equates to a very small average biomass of 2 g m^{-2} (0.1–5.4 g m^{-2}).

The remaining five non-indigenous species were less abundant. The file shell *L. orientalis* was mainly found within the centre of the channel in water depths greater than 5 m (Figure 7c) with an average abundance of 63 individuals m^{-2} (30–238 ind. m^{-2}). Its average biomass was 8 g m^{-2} (0.6–22.9 g m^{-2}). The barnacle *B. trigonus* was widely spread throughout the channel and occurred in average abundances of five individuals m^{-2}. At one site this species reached an abundance of 75 individuals m^{-2}. The parchment worm *Chaetopteris* sp., the sea squirt *S. clarva* and the ascidian *C. eumyota* occurred in very low abundances (one individual m^{-2}) throughout the entire channel.

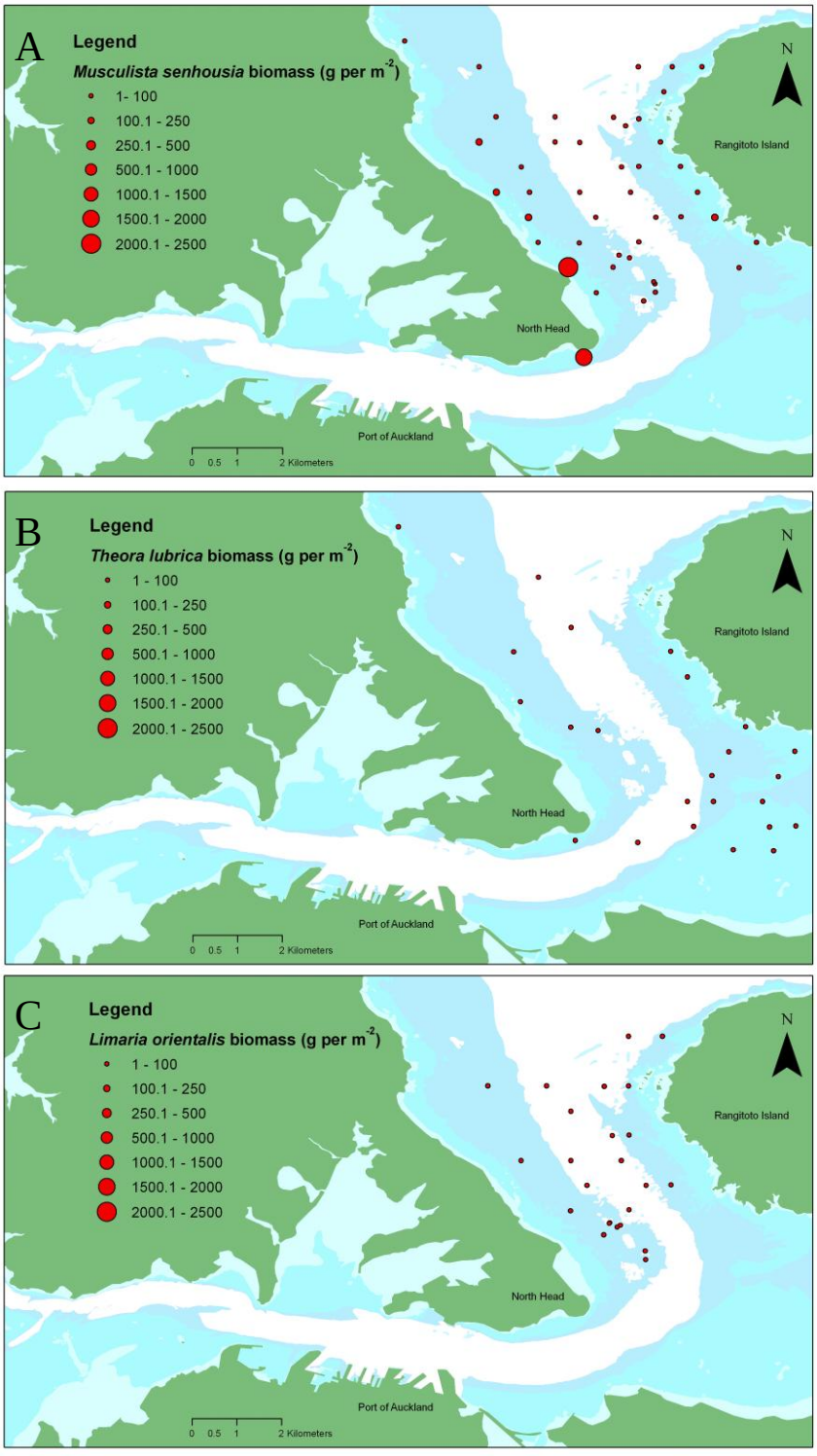

Figure 7. The distribution and biomass (g per m^{-2}) of the three main non-indigenous species within Rangitoto Channel, 2008. (A) *Musculista senhousia*, (B) *Theora lubrica* (C) and *Limaria orientalis*.

Multivariate pattern in the structure of the macrofauna assemblage

To search for regional differences in the structure of the macrofaunal assemblage, a SIMPROF analysis was conducted. SIMPROF detects statistically significant clustering of a priori unstructured samples. Inspection of the dendrogram in Figure 8a revealed seven main groups of sites that had similar macrofaunal assemblages. These groups had similarities ranging from 16 to 38%. Projecting these groups throughout the study area revealed that they defined discrete areas of the channel (Figure 8b). Group 1 is found in an area which is located in the southern region of the channel below Rangitoto Island whereas Group 3 is located in the areas to either side of the channel. Both groups are within water depths ranging from 1–10 m. Group 5 covers a large area in the centre of the channel in deeper water ranging from 5 to greater than 10 m water depth.

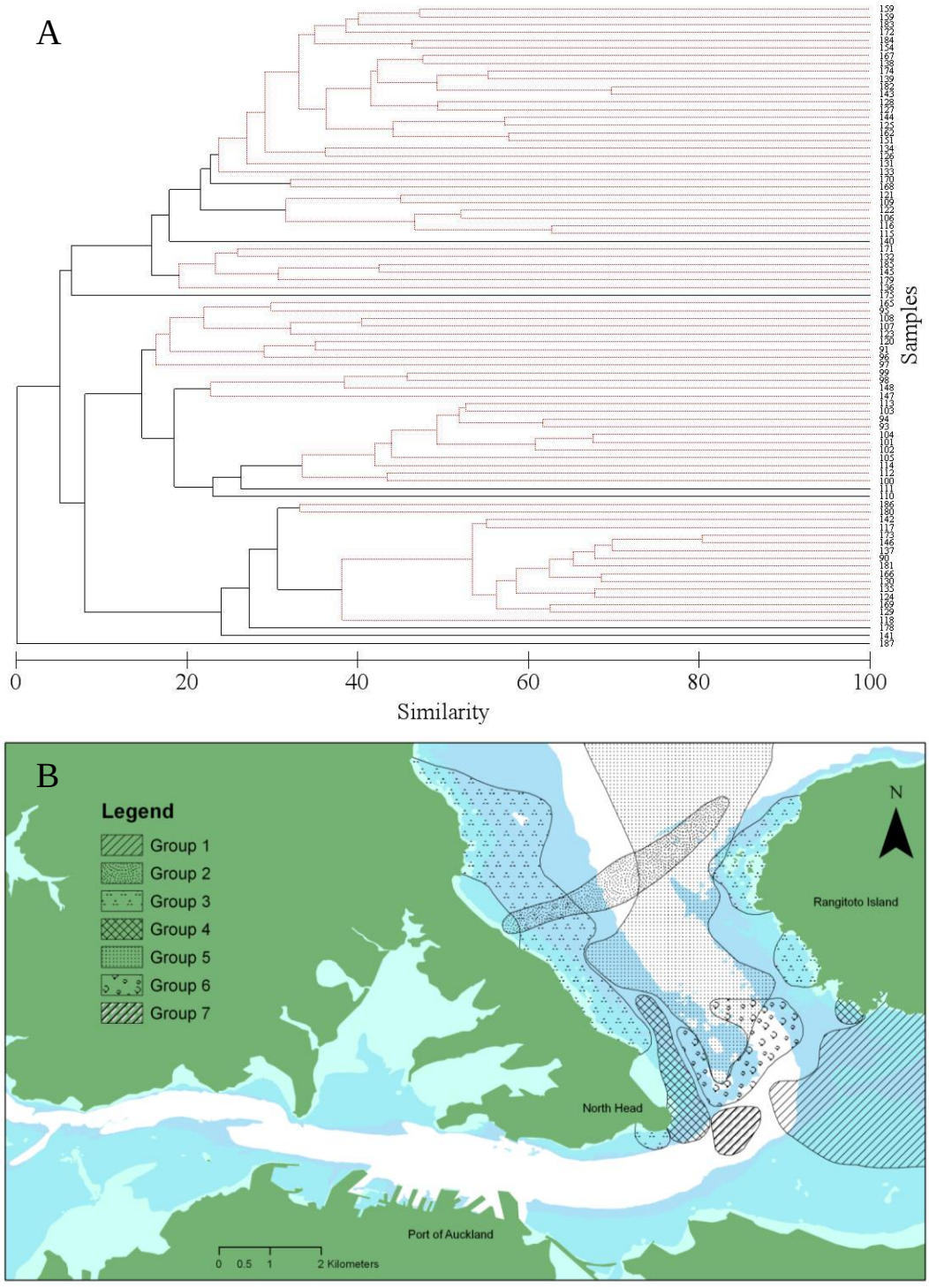

Figure 8. Assemblages of benthic macrofauna in Rangitoto Channel. (A) Dendrogram for hierarchical clustering (using group-average linking) of 84 sites from Rangitoto Channel based on the Bray-Curtis similarity matrix, (B) groups of sites in A projected onto a map of Rangitoto channel.

Sediment properties

The sediment in the deeper region of the channel contained more shell than that of the shallower regions. The average contribution of the large-shell fraction (>1.18 mm) to the total dry weight of the sediment in the deeper region of the channel was 49.3% (n = 11, SD 9.7%). In the shallower region of the channel, the contribution of the large-shell fraction to the total dry weight of the sediment was 10.0% (n = 14, SD 8.9%). The finer fraction of the sediment (<1.18 mm) throughout the channel was poorly sorted medium to fine sand.

Linking environmental factors and faunal assemblages

To investigate if multivariate patterns in the structure of the benthic macrofaunal assemblage could be explained by environmental factors, a sub-set of sites at which environmental factors and species counts had been determined was analysed. Environmental factors included seawater depth, contribution of larger shells (>1.18 mm) to the dry weight of the sediment, and the median particle size, lower quartile, upper quartile, inclusive sorting coefficient and inclusive graphic skewness of the finer sediment fraction (<1.18 mm). The BIO-ENV procedure revealed that the combination of environmental variables that best groups sampling sites in a manner that is consistent with the grouping based on species counts was "seawater depth" and "contribution of larger shells (>1.18 mm) to the dry weight of the sediment" (hereafter referred to as "larger shells") (Table 4).

Table 4. Combinations of seven environmental variables taken k at a time, yielding the best matches of biotic and abiotic similarity matrices for each k, as weighted by Spearman rank correlation. Parentheses contain the ranking for the combinations of variables, ***** indicates overall optimum.

k	Best variable combinations (Spearman rank correlation)
2	depth, % of large shells (0.51)*****
3	depth, % of large shells, Inclusive sorting coefficient of fine fraction (0.505)
4	depth, % of large shells, Inclusive sorting coefficient of fine fraction, Upper Quartile of fine fraction (0.505)

When the sites were grouped using the variables "seawater depth" and "larger shells" and projected onto a map of the channel, the locations of the groups of sites were similar despite which of the two variables was used. Therefore, the sites were then grouped based on only one of these environmental factors, "larger shells" and two sediment types were identified within the channel. These were "mud" and "shell-mud", depending on the contribution of larger shells (Table 5). When the larger shell fraction contributed less than 30% to the total dry weight of the sediment, the sediment was classified as "mud". The large shells in "mud" were embedded in poorly sorted coarse silt to fine sand (82–287 μm). When the larger shell fraction contributed more than 30% to the total sediment dry weight, the sediment was classified as "shell-mud". The large shells in "shell-mud" were embedded in poorly sorted fine to very fine sand (871 to >2000 μm).

Inspection of Figure 9 revealed that "shell-mud" was found throughout the centre of the channel whereas "mud" was found in shallower areas to the sides of the channel. "Mud" and "shell-mud" contained different macrofaunal assemblages. In shell-mud, *Paguristes pilosus* was the most dominant species; it occurred at over half of the "shell-mud" sites (Table 6). The species *Maoricolpus roseus*, Amphipoda indet., *Corbula zelandica* and *Nucula hartvigiana* were common (occurring in over 50% of the sites). The two species *M. roseus* and *C. zelandica* were also dominant species. The species *Limaria orientalis* did not dominate but occurred at over half of the "shell-mud" sites. In contrast the non-indigenous species *Musculista senhousia* and *Theora lubrica* were the most dominant and common species occurring in just under half of the "mud" sites (Table 7). The following species were common but not dominant in mud: the polychaetes *Prionospio* sp. and *Heteromastus filiformus*, species of the polychaete families Cirratulidae and Spionidae, the amphipod *Heterophoxus* sp. and some unidentified amphipods.

Table 5. Properties of the sediment using 26 samples collected within Rangitoto Channel, 2008. The percentage of the larger shell fraction (>1180 µm) of the dry weight of the sediment of each of the sediment types and the median (Md), lower (Q_1) and upper quartiles (Q_3), inclusive Sorting Coefficient (QD_1), classification and inclusive Graphic Skewness (Sk_I) of the finer fraction (<1180 µm) of the sediment. The classification *M. senhousia* refers to one sample that contained a large mat of this species and was therefore considered to be an anomaly.

		Exclusive of >1180 µm					
Classification	**% > 1180 µm**	**Md**	**Q1**	**Q3**	**QD1**	**Classification of sediment**	**Sk1**
Mud	0.36	2.50	2.10	2.85	0.563	Moderately well sorted	0.136
Mud	0.44	2.85	2.30	3.60	1.045	Poorly sorted	0.125
Mud	1.93	3.73	2.85	4.40	1.385	Poorly sorted	0.184
Mud	4.00	3.94	3.05	4.70	1.317	Poorly sorted	0.185
Mud	4.34	3.33	2.98	3.70	0.766	Moderately sorted	0.045
Mud	4.78	3.36	2.55	4.15	1.285	Poorly sorted	0.186
Mud	6.55	2.86	2.20	3.40	1.159	Poorly sorted	0.132
Mud	7.38	2.76	1.95	3.55	1.360	Poorly sorted	−0.140
Mud	7.92	3.09	2.00	4.00	1.601	Poorly sorted	0.115
Mud	15.32	3.16	2.00	4.15	1.683	Poorly sorted	0.035
Mud	17.07	2.42	2.00	2.75	1.901	Poorly sorted	0.140
Mud	19.19	2.78	2.12	3.30	1.996	Poorly sorted	0.167
Mud	24.25	2.34	1.42	3.80	1.683	Poorly sorted	6.800
Mud	26.91	3.88	2.90	5.07	1.797	Poorly sorted	0.103
Shell-mud	35.61	3.07	2.05	3.85	1.470	Poorly sorted	0.156
Shell-mud	38.68	3.06	2.08	3.87	1.523	Poorly sorted	0.245
Shell-mud	40.36	3.30	2.10	4.50	1.731	Poorly sorted	0.043
Shell-mud	42.24	3.17	2.45	3.75	1.164	Poorly sorted	0.054
Shell-mud	46.79	2.91	2.10	3.58	2.969	Very poorly sorted	−0.017
Shell-mud	49.77	1.83	1.25	3.05	1.584	Poorly sorted	0.026
Shell-mud	52.24	2.47	1.90	3.10	1.033	Poorly sorted	0.055
Shell-mud	52.53	2.51	2.23	3.55	1.264	Poorly sorted	−0.174
Shell-mud	55.42	3.22	2.87	3.60	0.908	Moderately sorted	0.028
Shell-mud	63.58	2.73	1.08	3.95	1.933	Poorly sorted	−0.081
Shell-mud	65.07	3.08	2.74	3.68	1.293	Poorly sorted	−0.090
M. senhousia	83.42	0.58	0.00	1.95	1.264	Poorly sorted	0.154

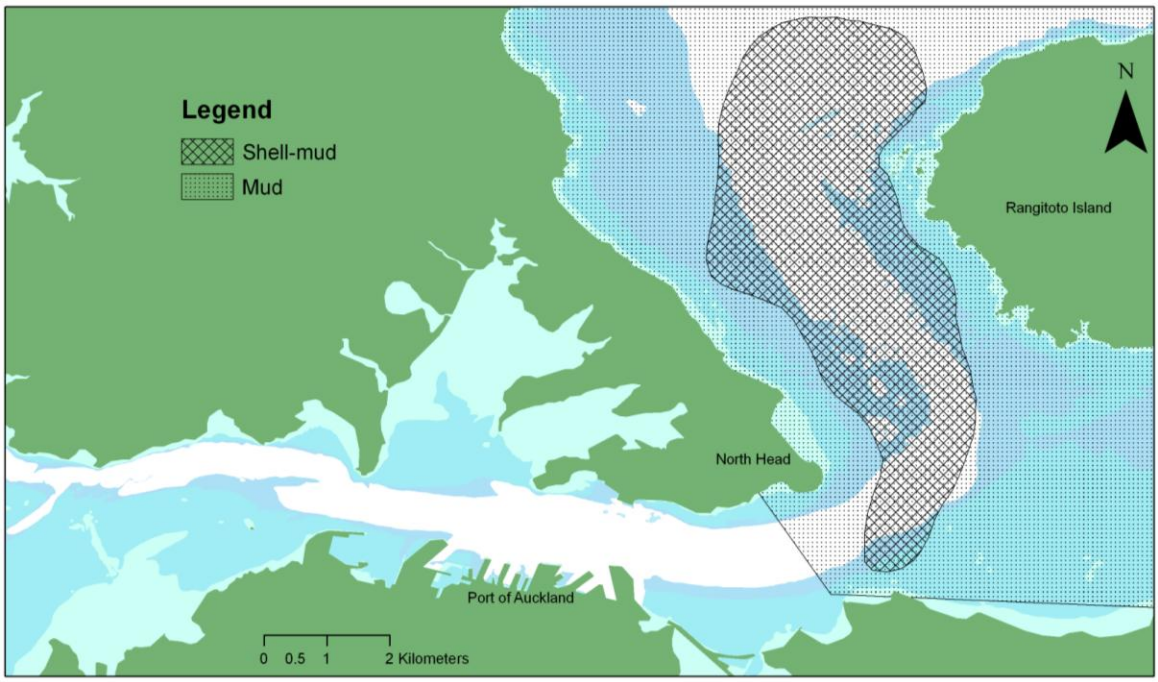

Figure 9. Sediment types within Rangitoto Channel. The sediment in the centre of the channel consists mainly of sediment (shell-mud) containing 31–70% larger shell fraction (>1.18 mm) of the dry weight of the sediment. The sediment at the sides of the channel mainly consists of finer sediment (mud) containing less than 30% of larger shell fraction (>1.18 mm) of the dry weight of the sediment.

Table 6. Dominance and presence (%) (mean ± SD) of benthic macrofaunal species within shell-mud sediments (part only given, lower limit 8% abundance). n = 35.

Shell-mud Species	**Dominance (%)**	**Presence (%)**
Paguristes pilosus	11.61 ± 17.75	51.43
Maoricolpus roseus	10.97 ± 15.17	65.71
Corbula zelandica	7.07 ± 13.04	54.29
Amphipoda indet.	6.75 ± 8.21	62.86
Leptochiton inquinatus	4.03 ± 7.42	45.71
Nucula hartvigiana	4.03 ± 5.89	51.43
Musculista senhousia	3.56 ± 14.4	14.29
Limaria orientalis	3.55 ± 4.89	54.29
Ampharetidae	3.39 ± 5.56	48.57
Owenia fusiformis	1.86 ± 3.24	28.57
Amphiura correcta	1.62 ± 5.15	17.14
Lophopagurus cristatus	1.62 ± 3.33	25.71
Nebalia sp.	1.59 ± 7.44	11.43
Sabellidae sp.1	1.53 ± 3.27	22.86
Theora lubrica	1.45 ± 4.32	14.29
Balanus trigonus	1.39 ± 4.12	14.29
Felaniella zelandica	1.25 ± 2.55	25.71
Sigapatella novaezelandiae	1.20 ± 5.67	11.43
Leptomya retiaria	1.16 ± 2.14	25.71
Ruditapes largillierti	1.15 ± 2.56	25.71
Amphiura aster	1.11 ± 2.38	28.57
Ophionereis fasciata	0.93 ± 4.51	11.43
Tawera spissa	0.81 ± 1.50	28.57
Trochodota dendyi	0.78 ± 2.19	14.29
Heteromastus filiformis	0.75 ± 2.04	17.14

Table 7. Dominance and presence (%) (mean ± SD) of benthic macrofaunal species within mud sediments (part only given, lower limit 8% abundance). n = 48.

Mud **Species**	**Dominance (%)**	**Presence (%)**
Musculista senhousia	26.49 ± 38.65	45.83
Theora lubrica	14.42 ± 24.37	41.67
Heteromastus filiformis	3.17 ± 6.60	43.75
Amphipoda indet.	2.93 ± 7.65	37.50
Cirratulidae	2.70 ± 6.08	27.08
Paguristes pilosus	2.38 ± 9.64	8.33
Prionospio sp.	2.09 ± 4.93	31.25
Aglaophamus macroura	1.88 ± 4.32	27.08
Heterophoxus sp.	1.83 ± 4.76	25.00
Urothidae	1.62 ± 7.41	6.25
Spionidae	1.52 ± 4.18	27.08
Balanus trigonus	1.49 ± 8.29	8.33
Paraonis sp.	1.29 ± 3.94	20.83
Cossura consimilis	1.17 ± 3.17	16.67
Macroclymenella stewartensis	1.10 ± 3.01	20.83
Hydroides norvegicus	1.06 ± 5.19	6.25
Amphipoda sp. 10	0.99 ± 5.40	4.17
Nucula hartvigiana	0.95 ± 3.27	20.83
Paracorphium sp.	0.93 ± 2.67	14.58
Ostracoda sp. 2	0.91 ± 6.30	2.08
Trochodota dendyi	0.59 ± 1.60	18.75
Sigapatella novaezelandiae	0.57 ± 3.39	6.25
Ostrea sp.	0.08 ± 0.55	2.08

An MDS ordination and subsequent ANOSIM analysis using Bray-Curtis similarities revealed a significant difference in the structure of the macrofaunal assemblages inhabiting “mud” and “shell-mud” sites (R = 0.356, p = 0.1%) (Figure 10). The SIMPER analysis revealed that the gastropod *Maoricolpus roseus*, the hermit crab *Paguristes pilosus* and the bivalve *Thracia australica* contributed most to the dissimilarity of the two groups of sites (Appendix 2). The same species contributed most

to the similarities within either of the two groups of sites. The species *T. australica* and *Heteromastus filiformus* contributed most to the similarities within the group of "mud" sites whereas *M. roseus* and *P. pilosus* contributed most to the similarities within "shell-mud" sites.

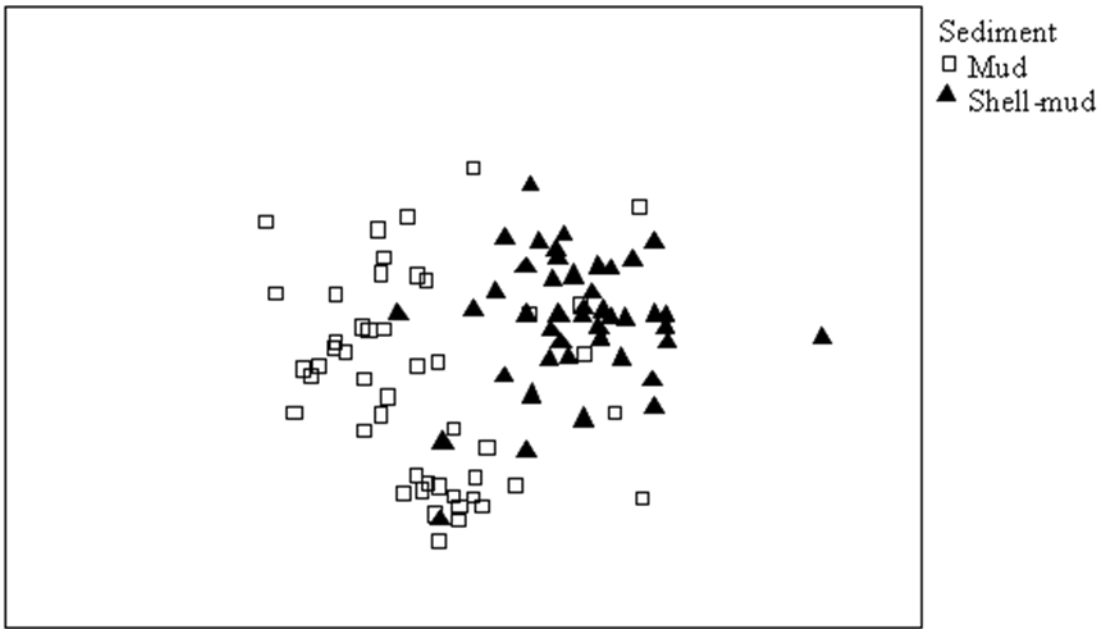

Figure 10. An MDS ordination representing the benthic macrofaunal assemblages within mud and shell-mud sediment types. Bray-Curtis similarity index on standardised, square-root transformed species counts from spatial survey data. Mud sediment containing less than 30% of larger shell fraction (>1.18 mm) of the dry weight of the sediment, Shell-mud sediment containing 31–70% larger shell fraction (>1.18 mm) of the dry weight of the sediment. Stress: 0.1.

Bimonthly monitoring

Benthic macrofauna

The following indices increased from June to December at the four sampling sites (Table 8): number of species (S), the number of individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H') and Simpson index (1-λ'). The increases in the number of species and the Margalef' index of species richness (four combined sites) from June to December and from August to December were statistically significant (Table 9). Species evenness in June, August, October and December did not differ significantly (Kruskal-Wallis; $H_{3,\ 143} = 1.76$; $P = 0.625$).

Table 8. The species richness (S) (ind. m^{-2}), total number of individuals (N) (ind. m^{-2}), Margalef's index (d), Pielou's evenness index (J'), Shannon-Wiener index (H'(log)) and Simpson index (1-Lambda') for the bimonthly monitoring of the benthic macrofauna at all four monitoring sites (mean ± SD).

	June n = 33	**August n = 37**	**October n = 40**	**December n = 40**
S	7.30 ± 4.60	22.35 ± 6.14	22.38 ± 8.70	28.20 ± 8.88
N	2,339 ± 2,677	2,860 ± 1,428	4,723 ± 4,965	4,223 ± 3,012
d	0.94 ± 0.70	2.71 ± 0.71	2.63 ± 0.92	3.29 ± 0.88
J'	0.57 ± 0.36	0.76 ± 0.14	0.75 ± 0.15	0.76 ± 0.11
H'(loge)	1.14 ± 0.94	2.34 ± 0.50	2.26 ± 0.54	2.50 ± 0.38
1-Lambda'	0.46 ± 0.37	0.82 ± 0.14	0.80 ± 0.14	0.84 ± 0.10

Table 9. A table displaying the ANOVA results comparing the number of species (S) and species diversity (d) between sediments collected during the four monitoring periods (Tukey; $T_{3,\ 145}$).

	Comparison of monitoring periods	Tukey	P
S	June and December	11.95	0.00
	August and October	0.05	1.00
	August and December	3.46	0.00
d	June and December	12.20	0.00
	August and October	0.08	0.00
	August and December	12.20	0.00

Some non-indigenous species were present throughout the monitoring period while others were not. For example; *S. clarva*, *B. trigonus*, *Cheatopteris* sp., and *C. eumyota* were not always recorded within the sediment whereas *L. orientalis* and *T. lubrica* were always present within the channel.

Some species reached high abundances during some monitoring periods whereas others maintained constant abundances throughout all monitoring periods. For example, the bivalve *M. senhousia* reached a maximum abundance of 17,411 individuals m^{-2} during October whereas during December the maximum abundance was only recorded to be 1,027 individuals m^{-2}.

Multivariate patterns in the structure of macrofaunal assemblages

The structures of the macrofaunal assemblages at the four monitoring sites changed over time (Figure 11). An ANOSIM test revealed significant differences between faunal assemblages of sediments sampled during the four monitoring periods ($R_{\text{site one}} = 0.638$, $R_{\text{site two}} = 0.872$, $R_{\text{site three}} = 0.679$, $R_{\text{site four}} = 0.461$, significance level of 0.1).

To find out which species contributed most to the difference in the faunal assemblages over the monitoring periods, a SIMPER analysis was performed. This analysis revealed that the species *Musculista senhousia* and *Heteromastus filiformus* contributed most to the dissimilarity between the macrofaunal assemblages found in June and August, and October and December. The species *M. senhousia* was very abundant during June but not during the other three monitoring periods (Appendix 3). In contrast,

the polychaete *H. filiformus* was abundant during August, October and December and less abundant during June. The bivalve *L. orientalis* did not contribute highly to similarity or dissimilarity of the faunal patterns during any of the monitoring periods.

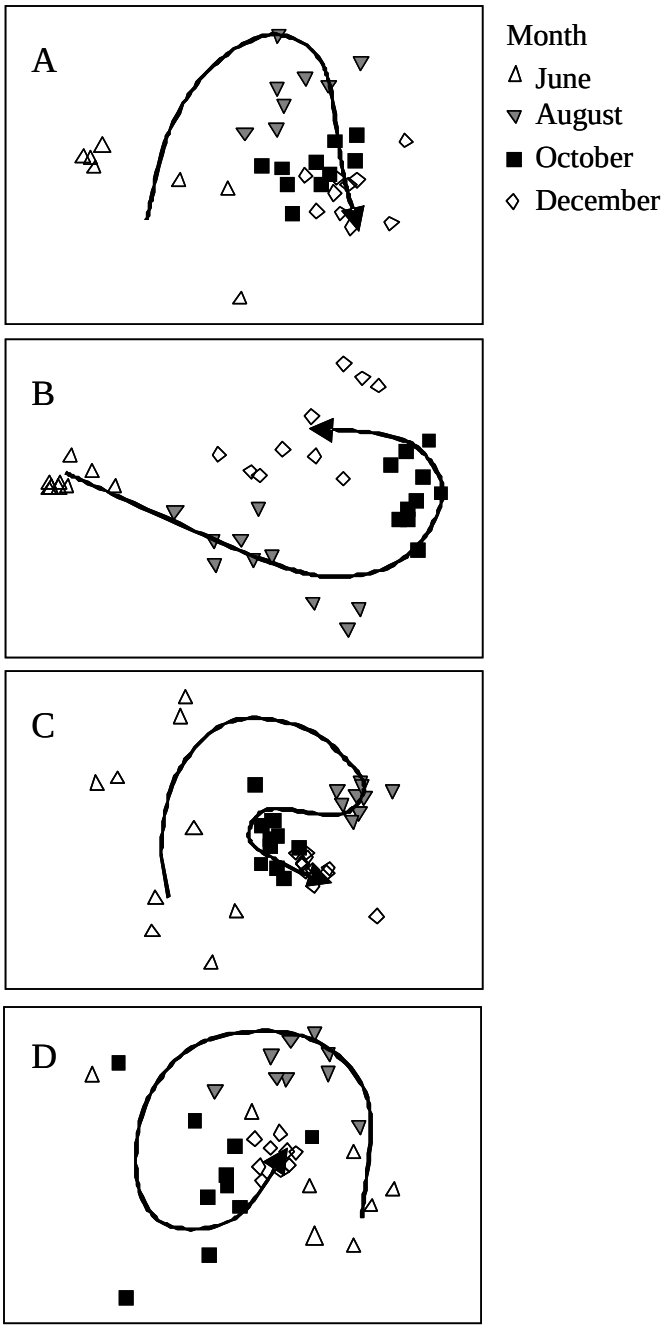

Figure 11. MDS ordinations representing the temporal trends in the benthic macrofaunal assemblages within each monitoring period at each of the four monitoring sites. Bray-Curtis similarity index on standardised, square-root transformed species counts from benthic macrofaunal monitoring data. (A**)** Site 1, stress: 0.14, (B) Site 2, stress: 0.11, (C) Site 3, stress: 0.17 and (**D**) Site 4, stress: 0.2. Arrows represent the time of which samples were collected from June to December 2008.

Snapper

In total eight juvenile, 53 female and 49 male snapper were caught during bimonthly collections from June to December (Appendix 4). The smallest fish caught was 158 mm and the largest was 445 mm, larger fish were caught during August and smaller fish were caught during December (Figure 12).

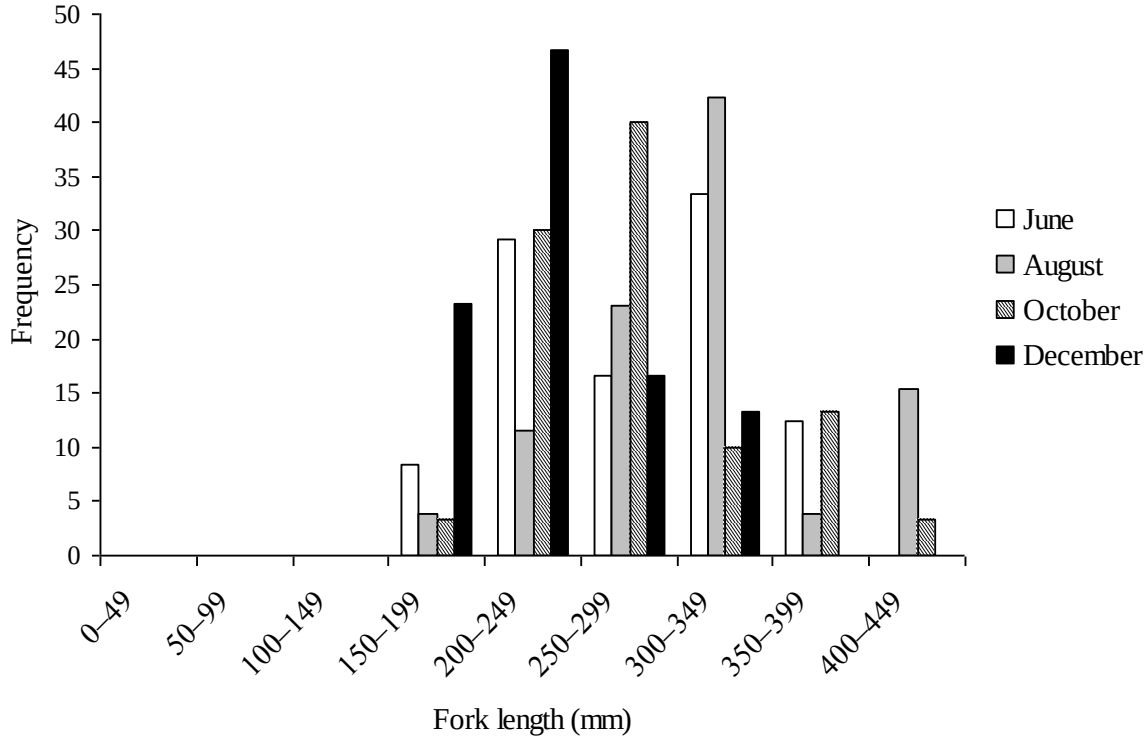

Figure 12. The size of snapper (fork length, mm), caught during the four monitoring periods June n = 25. August n = 26, October n = 30 and December n = 30.

The success of the fishing trips varied for each monitoring period (Appendix 5). In June 0.7 snapper were caught per long line set whereas the 1.6 snapper were caught per long line set during August. In October and December 1.2 and 1.5 snapper were caught per long line set.

The weight of the gonad in relation to the weight of the fish indicates the reproductive phase of the fish. The gonad somatic index (GSI) for both male and female snapper increased during December and was significantly different in male snapper during December compared to the other three monitoring periods (Figure 13).

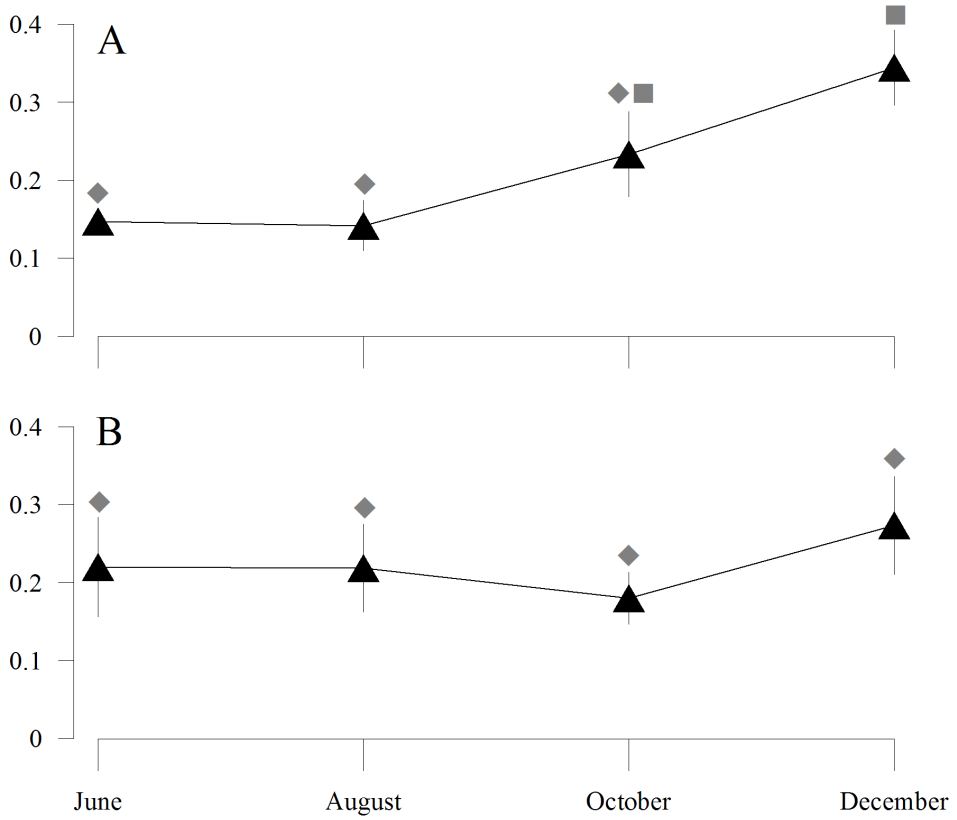

Figure 13. The mean gonad somatic index for snapper, (A) adult male (n = 35) and (B) adult female (n = 52). Grey symbols represent significant differences between months using a Kruskal-Wallis test. Snapper were caught throughout Rangitoto Channel from June to December 2008. Vertical bars; standard error.

Snapper diet

In total there were 52 different prey items recorded from the diet of snapper (Table 3). The three most dominant prey items from the combined four monitoring periods were the non-indigenous bivalve *L. orientalis*, the native hermit crab *Paguristes* sp., and the non-indigenous bivalve *M. senhousia*, in order of decreasing dominance. The species *Paguristes* sp., *L. orientalis* and *Upogebia* sp. were the most commonly occurring species in the diet of snapper. The bivalve *L. orientalis* and the hermit crab *Paguristes* sp. were the most dominate prey species in the diet (Table 10).

Table 10. The presence and dominance (mean ± SD) of prey species within the stomach and intestinal content of snapper over all of the monitoring periods. n = 109.

Species	Presence (%)	Dominance (%)
Paguristes sp.	42.20	15.05 ± 25.32
Limaria orientalis	32.11	15.13 ± 29.64
Upogebia danae	25.69	7.86 ± 19.11
Decapoda spp.	22.94	3.88 ± 9.64
Unidentifiable	22.94	11.10 ± 27.32
Musculista senhousia	18.35	8.05 ± 21.45
Alpheus sp.	15.60	4.15 ± 14.20
Periclymenes yaldwyni	15.60	3.54 ± 12.87
Polychaeta spp.	14.68	3.76 ± 12.79
Halicarcinus cookii	10.09	3.24 ± 11.63
Polychaeta sp.1	9.17	1.29 ± 5.37
Macrophthalmus hirtipes	8.26	3.25 ± 13.48
Liocarcinus corrugatus	7.34	1.77 ± 7.57
Flabelligira affinis	6.42	1.51 ± 6.49
Halicarcinus sp.	5.50	1.19 ± 5.88
Notomithrax minor	4.59	2.37 ± 12.15
Alpheus richardsoni	4.59	0.75 ± 3.88
Maoricolpus roseus	4.59	1.06 ± 5.86
Polychaeta sp.3	4.59	0.82 ± 4.40
Trochodota dendyi	3.67	0.89 ± 5.43
Amphipoda	2.75	1.55 ± 9.67
Amphiura aster	0.92	0.24 ± 2.52

To determine if the prey species assemblages of the stomach contents differed from those of the intestinal contents, analysis using Bray-Curtis similarities between the prey item counts from the stomach and the intestines of all snapper, (from the four combined monitoring sites), for each of the four monitoring periods, was conducted. This revealed that the assemblages of prey items in the stomach and in the intestine of snapper were not significantly different during any of the four monitoring periods (Table 11). This allowed me to combine the stomach and intestinal contents for the remaining analysis.

Table 11. One-way ANOSIM analysis comparing the stomach and intestinal content of snapper for each monitoring period.

Monitoring period	R value	Significance level (%)
June	0.002	38.60
August	-0.015	66.80
October	0.034	22.50
December	0.104	1.40

A Kruskal-Wallis test was conducted on the univariate indices calculated for the diet of snapper from each of the monitoring periods. This revealed that there were no significant differences between the prey-species assemblages throughout the monitoring periods. The diet did not differ significantly with respect to the number of species ($H_{3,\ 107}$ = 2.08; P = 0.555), number of individuals ($H_{3,\ 107}$ = 3.38; P = 0.337), or the prey species diversity ($H_{3,\ 107}$ = 2.06; P = 0.56), between the four monitoring periods (Table 12). The indices relating to the four monitoring sites are presented in Appendix 6.

Table 12. Indices relating to the temporal consumption of prey species by snapper from June to December. Species richness (S) (ind. m^{-2}), total number of individuals (N) (ind. m^{-2}), Margalef's index (d), Pielou's evenness index (J'), Shannon-Wiener index (H'(log)) and Simpson index (1-Lambda') of the total contents based on standardised totals per fish (mean ± SD). June n = 24, August n = 26, October n = 29 and December n = 30.

	June	August	October	December
S	3.21 ± 1.87	3.04 ± 1.51	3.17 ± 1.93	3.80 ± 2.02
N	16.04 ± 4.94	15.50 ± 4.23	16.21 ± 4.65	17.93 ± 4.99
d	0.75 ± 0.59	0.71 ± 0.48	0.73 ± 0.62	0.93 ± 0.61
J'	0.92 ± 0.12	0.88 ± 0.12	0.96 ± 0.06	0.95 ± 0.06
H'(loge)	0.91 ± 0.62	0.88 ± 0.54	0.94 ± 0.63	1.14 ± 0.58
1-Lambda'	0.52 ± 0.31	0.52 ± 0.28	0.53 ± 0.33	0.64 ± 0.26

To test if different sized snapper as well as male, female or juvenile snapper consumed different prey species assemblages I combined the diets of all fish caught within the entire monitoring period. Analysis using ANOSIM revealed that the prey species assemblages of juvenile, adult male and adult female snapper did not differ significantly (R = 0.015, p = 18.8%). The prey species assemblages of six different size

classes of snapper also did not differ significantly (R = 0.048, p = 1%). That is snapper, regardless of size or sex, ate similar assemblages of prey species.

To test if there was a temporal change in the diet of snapper over the monitoring period, an ANOSIM test was conducted on the prey species counts from snapper caught during each of the four monitoring periods. The assemblages of prey items within the diet of snapper were significantly different for each of the monitoring periods (R = 0.19, significance level = 0.1%). Different species dominated the diet of snapper during different monitoring periods. The non-indigenous bivalves *L. orientalis* and *M. senhousia* were dominant prey species during June and August (Table 13). The file shell *L. orientalis* was present within the diet more often than *M. senhousia* during both monitoring periods, occurring in over 65% of snapper during August whereas, *M. senhousia* was present in the diet of over 30% of snapper. The hermit crab *Paguristes* sp. was present in the diet of 50% or more snapper during August and October; however, *L. orientalis* and *Upogebia* sp. were more dominant prey items during August and October respectively. During December, crab species dominated the diet of snapper. The three crab species *Paguristes* sp., *Halicarcinus cookii* and *Macrophthalmus hirtipes* were all common and occurred in the diet of 43%, 30% and 16% of snapper, respectively.

A SIMPER analysis revealed that the species *L. orientalis*, *Upogebia* sp. and *Paguristes* sp. contributed highly to the dissimilarity between the prey species assemblages of snapper over the monitoring periods. The contribution to the dissimilarity between the monitoring periods was related to the abundances of each of the three species and differed accordingly (Appendix 7). For example, the differences in the structure of the prey item assemblages of snapper during October and December were caused by a high abundance of the mud shrimp *Upogebia* sp. in the diet during October. The differences in the prey species structure during June and August compared to October and December were caused by the increased abundance of *L. orientalis* during June and August. The dissimilarity between the prey species assemblages during June and December was caused by increased abundances of *Paguristes* sp. during December.

Table 13. Dominance (mean ± SD) and presence (%) (per fish), of prey species within the diet of snapper during the four monitoring periods (part only given, lower limit of 1% dominance). June n = 24, August n = 26, October n = 29 and December n = 30.

June **Prey species**	**Dominance %**	**Presence %**
Limaria orientalis	19.3 ± 34.1	41.7
Musculista senhousia	14.8 ± 31.1	20.8
Unidentifiable	13.0 ± 29.4	33.3
Flabelligira affinis	6.4 ± 12.7	25
Notomithrax minor	5.2 ± 20.8	8.3
Periclymenes yaldwyni	4.8 ± 14.7	16.7
Upogebia danae	4.4 ± 9.2	20.8
Paguristes sp.	4.3 ± 10.8	20.8
Craspedochiton	4.2 ± 20.4	4.2
Trochodota dendyi	4.0 ± 11.2	16.7
Liocarcinus corrugatus	2.1 ± 7.0	12.5
Cirolana sp.	2.1 ± 10.2	4.2
Lepidonotus polychroma	1.3 ± 5.2	8.3
Amphiura aster	1.1 ± 5.4	4.2
Cirolana arcuata	1.0 ± 5.1	4.2
Alpheus richardsoni	1.0 ± 3.7	8.3

August **Prey species**	**Dominance %**	**Presence %**
Limaria orientalis	35.6 ± 37.8	65.4
Paguristes sp.	18.9 ± 31.3	50
Musculista senhousia	11.7 ± 22.0	34.6
Unidentifiable	8.9 ± 27.3	15.4
Decapoda spp.	3.4 ± 8.4	23.1
Macrophthalmus hirtipes	3.4 ± 17.4	3.8
Polychaeta spp.	3.2 ± 7.9	19.2
Upogebia danae	2.6 ± 8.1	11.5
Alpheus richardsoni	2.2 ± 7.0	11.5
Alpheus sp.	1.7 ± 7.3	7.7
Polychaeta sp.1	1.7 ± 6.7	11.5
Periclymenes yaldwyni	1.3 ± 4.2	11.5
Ophiurida spp.	1.0 ± 4.9	3.8

October **Prey species**	**Dominance %**	**Presence %**
Upogebia danae	21.0 ± 31.5	51.7
Paguristes sp.	20.3 ± 28.2	51.7
Alpheus sp.	8.4 ± 24.8	13.8
Polychaeta spp.	7.5 ± 20.8	20.7
Periclymenes yaldwyni	6.2 ± 19.6	20.7
Notomithrax minor	4.6 ± 13.8	10.3
Decapoda spp.	4.4 ± 8.7	31
Amphipoda	4.2 ± 16.5	6.9
Limaria orientalis	4.1 ± 15.5	10.3
Unidentifiable	3.9 ± 18.7	6.9
Isopoda spp.	2.0 ± 6.3	10.3
Musculista senhousia	1.7 ± 5.8	10.3
Halicarcinus sp.	1.4 ± 5.3	6.9
Halicarcinus cookii	1.4 ± 5.3	6.9
Polychaeta sp.2	1.4 ± 5.3	6.9
Macrophthalmus hirtipes	1.4 ± 5.2	6.9
Liocarcinus corrugatus	1.2 ± 4.9	6.9
Maoricolpus roseus	1.0 ± 5.6	3.4

December **Prey species**	**Dominance %**	**Presence %**
Unidentifiable	16.9 ± 31.2	36.7
Paguristes sp.	15.2 ± 23.4	43.3
Halicarcinus cookii	10.5 ± 20.0	30
Macrophthalmus hirtipes	7.1 ± 18.9	16.7
Decapoda spp.	6.9 ± 13.8	33.3
Musculista senhousia	5.6 ± 20.0	10
Alpheus sp.	5.4 ± 8.4	36.7
Limaria orientalis	4.7 ± 16.2	16.7
Polychaeta spp.	3.6 ± 10.5	16.7
Liocarcinus corrugatus	3.5 ± 12.0	10
Polychaeta sp.1	3.0 ± 7.9	16.7
Polychaeta sp.3	2.5 ± 7.8	13.3
Upogebia danae	2.4 ± 6.2	16.7
Halicarcinus sp.	2.2 ± 9.5	6.7
Periclymenes yaldwyni	1.9 ± 6.5	13.3
Amphipoda	1.6 ± 8.6	3.3
Maoricolpus roseus	1.2 ± 3.7	10
Ophiurida spp.	1.1 ± 6.1	3.3
Leptochiton inquinatus	1.0 ± 3.0	10

Prey availability

To asses if changes in the abundances within the sediment, of important prey species of snapper, correlate with the changes in the diet of snapper, the average abundance of three prey species at the four monitoring sites during the four monitoring periods was calculated. This revealed changes in the abundance of *L. orientalis* and *M. senhousia*, from June to December (Figure 14). There was a large variation in the abundances of the three species between the four sites. The hermit crab *Paguristes* sp. was abundant only at Site Three where its abundances remained relatively constant throughout the monitoring period (Figure 14a). The abundances of *L. orientalis* were also high at Site Three, however, the abundance of *L. orientalis* did increase during October and December at Site One and Three. At Sites Two and Four the abundances of both species were low, however, they did increase at Site Four during December whereas abundances remained low at Site Two throughout the monitoring period (Figure 14b). The abundances of *M. senhousia* decreased during August at Site One and Site Two but increased again at Site One, Three and Four during October (Figure 14c). Site Three appeared to support large abundances of both *Paguristes* sp. and *L. orientalis* whereas Site Two and Site Four supported high abundances of *M. senhousia* during different monitoring periods.

To assess if the trends in the abundance of the three prey species within the sediment were represented within the diet of snapper, the trends of these three species in the diet were also calculated (Figure 15). Snapper consumed more *L. orientalis* and *Paguristes* sp. during August than any other monitoring period (Figure 15 a, b) however, this trend does not correlate with the trends observed for both of these species within the sediment (Figure 14 a, b). Although *Paguristes* sp. remained relatively abundant (at one of the four monitoring sites) snapper only consumed large amounts of this species during August. The file shell however was more abundant within the sediment during October and December but snapper again only consumed high numbers of it during August. The amounts of *M. senhousia* consumed by snapper decreased from June to December (Figure 15c). This reflects the trend in the abundance of *M. senhousia* within the sediment (Figure 14c).

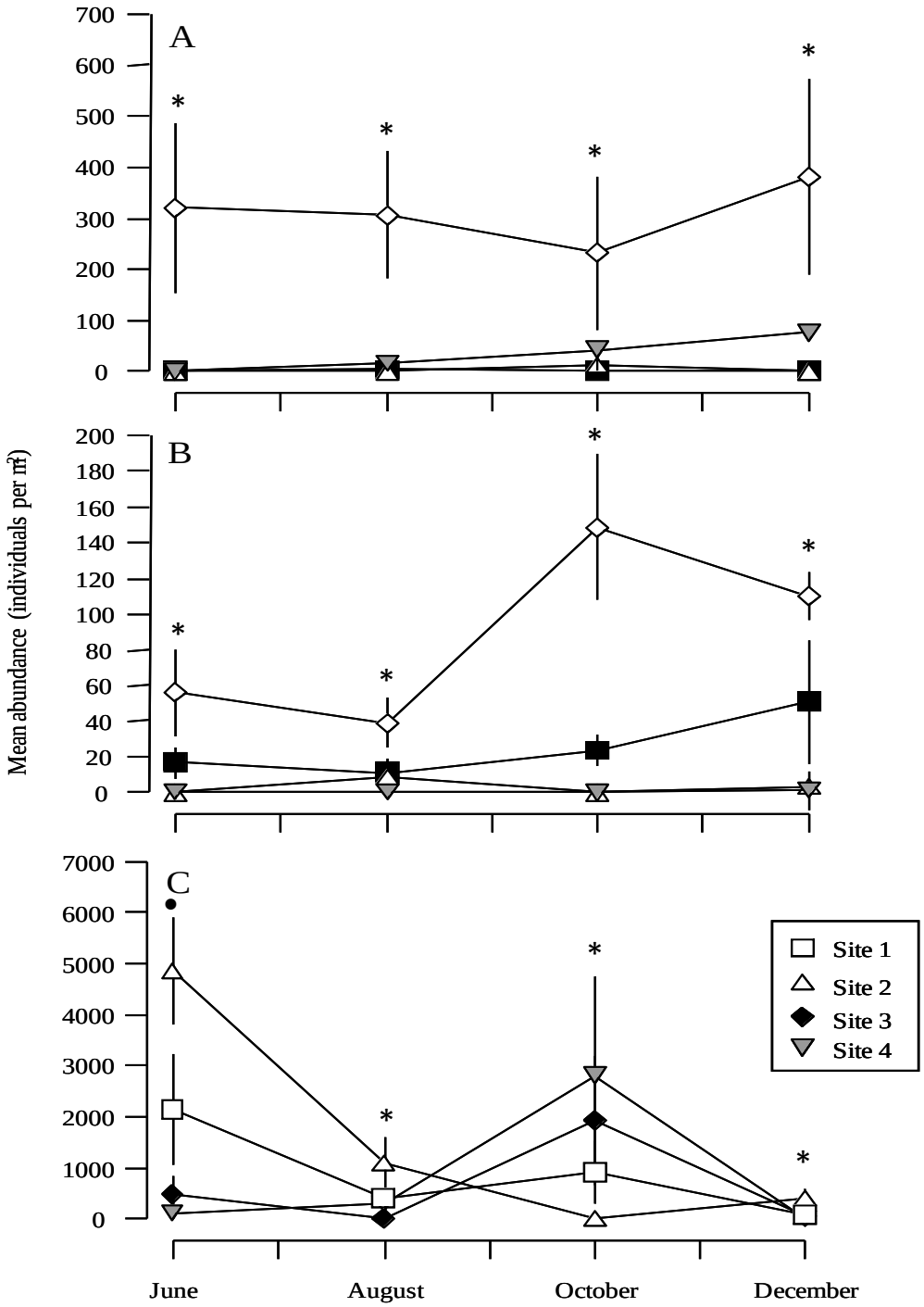

Figure 14. The mean abundance (ind. m^{-2}) of three prey species of snapper within the sediment, at four monitoring sites throughout four monitoring periods, (A) *Paguristes* sp., (B) *Limaria orientalis* and (C) *Musculista senhousia.* Vertical bar; standard error. (see Appendix 8 for n). Symbols above vertical bas refer to significant differences between months using a Kruskal-Wallis test.

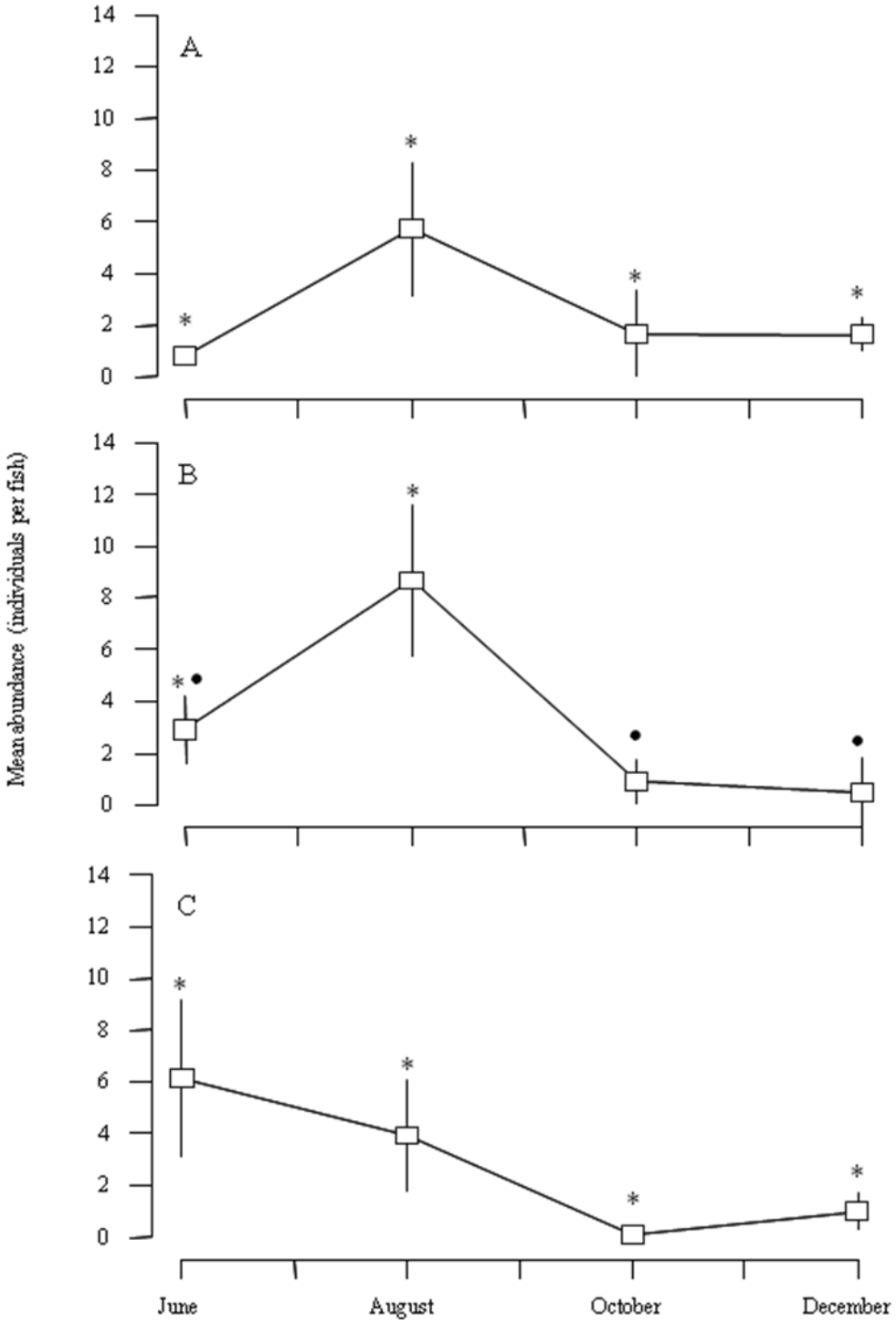

Figure 15. The mean abundance (per fish), of three popular prey species of snapper, (**A**) *Paguristes* sp., (**B**) *Limaria orientalis* and (**C**) *Musculista senhousia*. Vertical bar: standard error. June n = 24, August n = 26, October n = 29 and December n = 30.

Symbols above vertical bars refer to significant difference between months using a Kruskal-Wallis test.

Snapper feeding trials

During the feeding trials none of the fish fed from the prey items that were offered to them. The snapper did not appear to be “afraid” of the feeding containers as they were observed resting inside them. They appeared distracted by each other as they could see one another through the coarse plastic grid that separated the enclosures within the tank. Snapper were often observed resting in the corners of the enclosures as close to the other snapper as they could get. Individuals of the selected prey were thrown into the tanks after all of the feeding trials were completed, however, the fish still did not feed on the prey items. The snapper fed on pilchard that was thrown into the tanks after the selected prey items were offered to them.

Discussion

Non-indigenous species in the diet of snapper

This study showed that two non-indigenous bivalves, the file shell *Limaria orientalis* and the Asian mussel *Musculista senhousia*, significantly contributed to the diet of snapper. Prior to 1983, non-indigenous species had not been reported in snapper diet at all; Dromgoole & Foster (1983) then found that snapper consumed large amounts of *L. orientalis*. Many more non-indigenous species have become established in Hauraki Gulf (Hayward *et al*. 1997) in the meantime, and their role in the diet of snapper has not been assessed until now.

Seven non-indigenous benthic macrofaunal species have now been observed in Rangitoto Channel. Five of these were not important prey species or did not occur at all in the diet of snapper, perhaps due to palatability or availability. Non-indigenous species that modify the environment are thought to have the largest impact on species assemblages, as they can have cascading effects on resident species (Crooks 2002). One such species, *M. senhousia*, modifies the environment through the creation of dense mats (Hayward 1997). The mats support high densities of mussels and trap fine sediment particles, reducing the oxygen content of the sediment below the mats. Creese *et al*. (1997) recorded a reduction in the abundance of invertebrate species in areas where *M. senhousia* mats were formed. The mats themselves have been found to increase the species diversity of some taxa such as polychaetes, amphipods and small gastropods (Crooks 1998) due to the extra habitat available for species to inhabit (Crooks & Khim 1999). The effects of *M. senhousia* on benthic fauna are believed to be localised and brief, this is because this mussel is a short-lived species and it is uncommon for new individuals to recruit into existing mats (Creese *et al*. 1997). As this mussel occurs in large densities this may either increase or decrease its chances of being consumed by a predator. A predator would have to expend less energy per unit biomass when feeding on a dense patch of *M. senhousia*, but the byssal threads used to construct the mats may be unpalatable and therefore the consumption of this species may not be favourable.

The abundance of a particular prey species is not the only factor that may affect to

what extent it is consumed by a predator. Serrano *et al*. (2003) studied the abundance of macrobenthic crustaceans in the diet of 18 fish species in the Bay of Biscay and looked at the abundance of these prey species in the diet in relation to their abundance within the environment. They suggested that benthic feeding fish do not necessarily consume prey species proportionally to their availability in the sediment, rather that they exhibit a degree of selectivity. A prey species' characteristic, feeding mode, living position within the sediment and degree of mobility can also affect its likelihood of being consumed. Other factors influence the availability and subsequent consumption of prey species by snapper, such as depth of sediment accessible to the predator, or the extent to which a prey species is camouflaged. It is difficult to directly compare the benthic assemblages recorded within sediment samples obtained using a grab sampler with the prey species assemblages within the diet of snapper. This is because snapper use a very different strategy of "sampling" the sediment compared to the grab sampler. Although sampling the same sediment, the grab sampler and the fish may obtain different assemblages as the depth each is able to "sample" to, as well as the sample size differs. For this reason the compositions of the faunal assemblages found in the sediment and in the diet of snapper were not directly compared but instead temporal trends in the abundance of particular prey species in the sediment were compared with the relative contribution of these species in the diet.

Both *L. orientalis* and *M. senhousia* live on the surface of the sediment. Therefore, both species are likely to be captured or accessible by both the grab sampler and snapper. The former species moves small distances and builds a protective nest with shells (both behaviours were observed during my study). This nest may camouflage *L. orientalis* and thus protect it from being seen by a predator.

The contribution of the Asian mussel *M. senhousia* to the prey assemblage did reflect the abundance of this species within the sediment. The abundance of *M. senhousia* in the sediment peaked in June and October when this species was also abundant in the diet of snapper (Figure 15). Subsequently, when *M. senhousia* became less abundant in the sediment it became less important in the diet. Although *M. senhousia* dominated the macrofaunal communities in June, it was not the only species highly contributing to the diet of snapper during that time. Other less abundant species within the sediment also

featured in the diet of snapper. This suggests that *M. senhousia* was not a favoured prey item of snapper, but rather was consumed simply because it occurred in large densities.

The file shell, *L. orientalis*, was not very abundant in the channel; however, it dominated the prey species assemblages in the diet of snapper in June and August. If snapper were feeding in an entirely opportunistic manner then one would expect that the relative abundance of a prey species within the sediment would therefore be reflected in the diet of snapper. The abundance of *L. orientalis* within the sediment, however, was lowest in June and August and increased in October and December (Figure 14). That is, the seasonal changes in the abundance of *L. orientalis* in the diet of snapper were not paralleled by the temporal changes in the abundance of this species in the sediment. One possible explanation for this may be that snapper are selectively feeding upon this species during particular times of the year. Selection of this species may be due to their visual attractiveness or obviousness as they have bright orange tentacles. Furthermore *L. orientalis* have a relatively thin shell, equating to a greater proportion of flesh available to snapper compared to thicker-shelled bivalves.

To investigate whether snapper feed selectively, feeding trials were conducted; however, snapper did not accept any prey offered to them during these trials. Snapper are highly sensitive to stress (Cleary & Pankhurst 2000). The conditions during the feeding trials may have been too stressful for snapper to feed on the selected prey items. The quarantine area at Kelly Tarlton's is a busy working environment and the placement of the tank meant that people often looked into or knocked it as they walked past. The area is also quite noisy, which is possibly an additional stressor. Because only one tank was available to accommodate four snapper we divided this tank into four separate enclosures, one for each fish. To allow flow of oxygenated seawater through these enclosures, a coarse plastic grid was used to subdivide the tank, meaning that the snapper could see each other (Figure 5). Individuals were often observed resting in the corners of their enclosures as close to the others as possible and appeared distracted by other individuals' behaviour. Successful feeding trials have been reported for different fish species including blue fish, *Pomatomus saltatrix* (Juanes *et al*. 2001) and I do believe these trials could have been successful and valuable in a different set-up, within a more

controlled environment. Further trials, however, could not be undertaken within the time frame of this study.

Macrobenthic communities within Rangitoto Channel

Seven distinct macrobenthic assemblages were identified in specific areas within the channel during this study. One assemblage occurs within the deeper, centre region of the channel. Past studies of the macrobenthic assemblages in the channel (Powell 1937, Hayward *et al*. 1997) also found separate assemblages within the centre of the channel (Figure 16) even though different methods were used to determine assemblages within our study as well as the other two studies. The occurrence of a distinct species assemblage in the central region of the channel is most likely related to the physical properties of a channel environment, since seawater current, depth and sediment type all influence which species are able to inhabit a particular area. Larger shell was found in the centre of the channel than at the sides. This is consistent with the findings of Powell (1937), Jillet (1971) and Hayward *et al*. (1997). Direction and speed of the current and seafloor topography of the channel would all influence the spatial distribution of larger sediment particles, such as shell, within a channel environment.

The structures of the benthic macrofaunal species assemblages within the channel appear to be closely correlated with water depth and the amount of shell within the sediment. To investigate the species composition throughout the channel I classified the sediment into two types based on the amount of larger shells present within the sediment and found two distinct macrofaunal assemblages that were characterised by different species with different traits. For example, the filter feeding *Maoricolpus roseus* was found in coarser sediment, in the centre of the channel, apparently because it prefers areas with moderate to strong water currents (Allmon *et al*. 1994). The deposit feeder *Theora lubrica* was found mainly to the sides of the channel as it feeds on detritus deposited on the surface of muddy sediment.

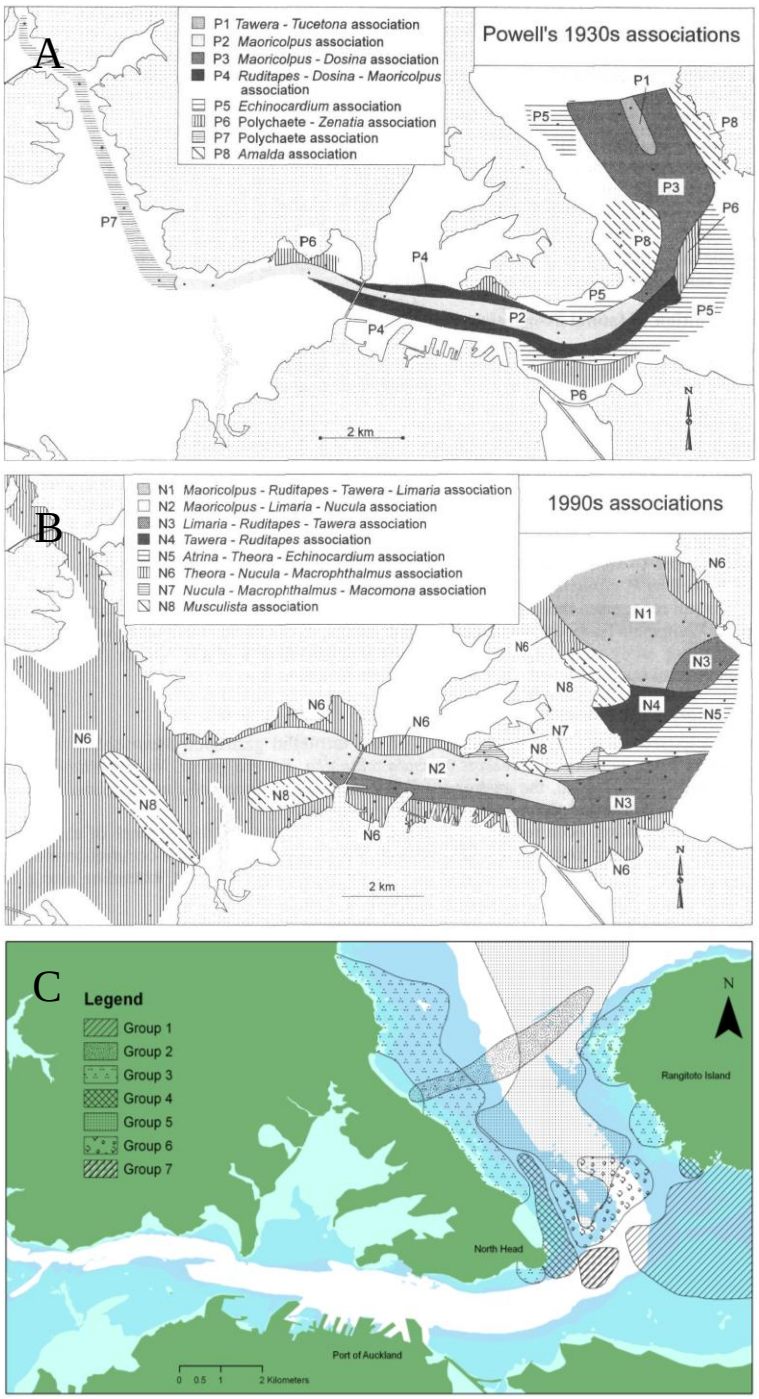

Figure 16. Three maps showing the distribution benthic macrofaunal communities as identified by three studies within Rangitoto Channel. (A) Powell (1937) described five communities within Rangitoto Channel. (B) Hayward *et al*. described six communities within the channel (1997). (C) The present study describes seven groups of similar macrofaunal assemblages. Maps A and B were obtained from Hayward *et al*. 1997.

Physical sediment properties can also influence the distribution of faunal species by limiting the depth to and ease with which an organism can burrow (de la Hue *et al*. 2002). The capitellid polychaete *Heteromastus filiformis* was present within finer sediment; this is consistent with the findings of Aller & Yingst (1985) as they found that this species was a deep deposit-feeder, ingesting anoxic mud 10–30 cm below the surface. The distribution of species observed within Rangitoto Channel in this study is consistent with those found in Manukau Harbour, Auckland, by Grange (1977) who also found that suspension feeders such as the bivalves *Chione stutchburyi* and *Paphies australe*, typically inhabited coarser sediments whereas deposit feeders such as *Macomona liliana* and *Nucula hartvigiana* favoured finer sediments. Carnivores and scavengers were mainly located in intermediate grades of sediment.

Benthic macrofaunal assemblages are constantly changing over time in response to environmental changes. Our study offers only a snap-shot of the assemblages present within the channel at the time of sampling. Such changes will affect the diets of benthic-feeding fish species such as snapper. For example, the heart urchin *Echinocardium* sp. was formerly an important part of the diet of snapper from Hauraki Gulf (Powell 1937), but was not found in the diet during the present study. Powell described the macrobenthic communities of the south-eastern region below Rangitoto Island as the "*Echinocardium* formation". This formation was dominated by the heart urchin *E. cordatum*, the Venus shell *Dosinia lambata*, and the brittle star *Amphiura corectum*. These three species were present, but did not dominate the presently observed macrofauna. The current dominant species within this region of the channel include the olive shell *Amalda novaezelandiae*, and the holothurian *Trochodota dendyi*. Although both species (described by Powell as *Amalda australis* and *Trochodota* sp.) were recorded by Powell, they were listed as subdominant or secondary species within the formation. The decline of *Echinocardium* sp. since the 1930's may be due to anthropogenic disturbances such as dredging; Rangitoto Channel has a long history of dredging and the heart urchin *Echinocardium* sp. is particularly vulnerable to damage from the passage of trawls and dredges (Bergman & Santbrink 2000).

Lohrer *et al*. (2008) suggested that the decline of *Echinocardium* sp. in the area may have allowed the invasion of *T. lubrica*, since the latter has a higher invasion success

rate in areas with low bioturbation. It has been reported that in soft-sediment marine environments the *Echinocardium* sp. is a dominant bioturbator (Lohrer *et al*. 2005). None of the four present monitoring sites were specifically located within this area and *T. lubrica* was not observed in the diet of snapper. Being relatively small, this species may not be a targeted prey species, and contributes only a very small proportion to the overall biomass of available prey within the channel. The four monitoring sites were not located within the area where *T. lubrica* were most abundant. This may have been a contributing factor as to why this species was not recorded in the diet of the snapper during this study. The area of greatest *T. lubrica* abundance may also not be a snapper "feeding ground", as diversity of potential prey species may have been lower in this area compared to other areas.

The diet of snapper

In this study I investigated the diet of 110 snapper from Rangitoto Channel and found a total of 52 different prey taxa. Godfriaux (1969) examined a considerable number more snapper (1,194) from a much larger area, the inner and outer Hauraki Gulf and as far as north-west Bay of Plenty, and reported 99 different prey taxa. The differing results from these two studies may not only be related to differences in the number of samples and the size of the study area but also reflect the ability of each researcher to identify digested matter.

The three species that occurred in the diets of most snapper individuals were the native hermit crab *Paguristes* sp., the burrowing mud shrimp *Upogebia* sp. and the non-indigenous bivalve *L. orientalis*. Interestingly, adult individuals of *Upogebia* sp. were not recorded in the sediment of the channel, yet only adults were found in the diet of snapper. The absence of the adult stage of this species in the sediment samples is probably due to the technique used to collect these samples. The grab sampler penetrates the sediment to a depth of only about 20 cm depending on the type of sediment. Deep-burrowing species could therefore be missed using this method. Thalassinideans are known to be proficient diggers, and the difficulty of catching *Upogebia* sp. using a grab sampler has been reported in other studies (Zuschin & Stachowitsch 2009). Some species of *Upogebia* have been recorded to burrow as far as two meters into the sediment (Coelho *et al*. 2000).

If the *Upogebia* individuals encountered in this study exhibit deep-burrowing behaviour, it is unlikely that snapper prey upon this species while it inhabits the burrow. One possible explanation for *Upogebia* sp. being present in the diet of snapper but not observed in the sediment is that mud shrimp may migrate to the sediment surface during certain times of a day, night or crepuscular periods, becoming accessible to snapper. If this is the case, species exhibiting such behaviour will be misrepresented within this study as the sediment sampling was carried out during daylight hours. Another explanation may simply be that snapper fed on *Upogebia* sp. outside the study area before moving into the channel, or snapper may feed in different areas within the channel at different times of the year.

The dominance and presence of the hermit crab *Paguristes* sp. in the diet of snapper peaked in August, October and December (Table 12). *Paguristes* sp. occurred in the sediment throughout June to December; however, it was abundant at only one of the four monitoring sites (Figure 14 a). No significant increases or decreases in the abundance of this species at any single site were observed during this time. A correlation between trends in a species' abundances within the sediment and within the diet of snapper over time would be expected if snapper were feeding in an "unselective" manner. The decreased consumption of *Paguristes* sp. by snapper in June (Figure 15 a) therefore appears to not be related to its actual abundance; given that the abundance of this species was stable from June to December, snapper appear to be selectively feeding on this species during particular times. It should also be noted that *Paguristes* sp. individuals commonly use the shells of the gastropod *Maoricolpus roseus*. Live *M. roseus* were present within the channel yet *M. roseus* rarely occurred in the diet of snapper. The consumption of *Paguristes* sp. but not *M. roseus* may be related to the behaviour of *Paguristes* sp. (which is more mobile than *M. roseus*) making it more visible and therefore attractive to snapper.

Temporal variations in the diet of snapper

The composition of the diet of snapper changed from June to December. The dominance and presence of different taxa was observed in the groups of prey (e.g., bivalves, crustaceans) consumed by snapper at different times of the year. For example, in June

and August the species *L. orientalis* and *M. senhousia* were dominant species in the diet, whereas in October *Upogebia* sp. and *Paguristes* sp. dominated, and in December *Paguristes* sp. was most common and dominant species. This temporal change in diet may result from factors such as prey availability, the seasonal nutritional requirements of snapper, or the behaviour of prey species. Steimle & Terranova (1985) reported that crabs as prey had higher energy content than bivalves on the continental shelf of the temperate Northwest Atlantic. If this applies in Rangitoto Channel, snapper may be preferentially selecting crab species for their higher energy content. Snapper may select prey species with higher energy content during the summer months when they are more active (Egli & Babcock 2004) and/or during spawning.

Spawning in snapper occurs once the seawater temperature reaches 18°C (Cassie 1956b). Being serial spawners (Cassie 1956b) snapper release multiple batches of eggs during the spawning season. Crossland (1977) found that snapper spawn within the Hauraki Gulf from October to January, and in this study, the gonad somatic index (GSI) of both male and female snapper caught during December increased accordingly. Crossland (1977) found the gonad somatic index of snapper during the spawning season to be higher than that reported in this study; these differences may be influenced by the area in which snapper were collected during each study. It is unlikely that snapper spawn in Rangitoto Channel, given that Cassie (1955b) found very few eggs in the waters of Rangitoto Channel and none from the enclosed waters south of Rangitoto and Waiheke Islands during planktonic sampling throughout the spawning period. Snapper may therefore move out of the channel to spawn, which may explain why the snapper captured within the channel had a lower GSI during this time. The snapper used in Crossland's (1977) study were also captured using a trawl, allowing fish to be caught that would perhaps not be caught using bait. Moreover, spawning snapper may not be interested in bait, making the fish we caught during our study pre- or post spawning; therefore the GSI of benthic-feeding snapper caught during the spawning period may not represent that of the whole population.

Powell (1937) found a marked increase in the amount of pelagic fish and salps in the stomachs of spawning snapper. No such increase was found in the present study however, monitoring of the diet of snapper did not occur throughout the entire

spawning season.

Snapper are thought to be less affected by inter-specific competition than other predatory fish species (Godfriaux 1970b). Godfriaux (1970b) reported that mud shrimp species, *Upogebia* spp., are not only consumed by snapper, but also by trevally, *Pseudocaranx dentex* (Bloch & Schneider 1801), and eagle rays, *Myliobatis tenuicaudatus* Hector 1877. *Upogebia* spp. was reported to be a more important prey species to these two predators than to snapper. The predation pressure of a prey species from fish other than snapper may change seasonally and so affect the diet of snapper. The diet of predatory fish species other than snapper was not examined during this study but such future investigations could aid the understanding of why snapper consume different prey items at different times of the year.

General observations regarding the diet of snapper

No significant difference between the prey species assemblages of male, female and juvenile snapper was found in this study, which supports findings from previous studies (Godfriaux 1969, Colman 1972, Godfriaux 1974). Furthermore, the size of snapper does not appear to have influenced the composition of the prey species assemblages of snapper during this study. This finding contrasts with the findings of Colman (1972), who reported that smaller snapper tended to prey on polychaete worms and small crustaceans and larger fish tended to prey on larger organisms such as echiurids, crabs, hermit crabs, molluscs and fish. Similar ontogenetic diet shifts have been observed in many other fish species (Labropulou *et al*. 1997, Scharf *et al*. 2000, Lukoschek & McCormide 2001).

In this study I investigated the content of the stomach and the intestine separately to determine if there were any variations in the contents of each. Inspection of the contents revealed that the prey species assemblages of the stomach and the intestines did not differ significantly. This indicates that, since the stomach contents are presumably more recently consumed than the intestinal contents, snapper feed on a similar assemblage of prey items at least over the gut retention time. Godfriaux (1974) reported a gut retention time (the time over which a food item remains within the body cavity before it is passed out as waste) for snapper of 24 hours. Three possible explanations for there being no significant difference between the stomach and intestinal content are: (1) the

items observed in the stomach and the intestine were consumed during one feeding period, (2) the items observed in the stomach and the intestine were consumed from a relatively small area during several feeding periods, and (3) snapper are selectively feeding upon the same prey items across the span of gut retention time.

Limitations of the study

Conclusions from this study are restricted by many factors. One major factor is that snapper are a highly mobile species meaning that they may have fed outside the studied area. The number of fish studied was relatively small, leading to some size classes of snapper being underrepresented. Analysis of the diet of differently sized snapper may have been affected by an underrepresentation of small and large snapper. Such underrepresentation of particular size classes of snapper may be caused by the type of gear used to catch the fish. Smaller fish would be unable to swallow the hooks used and larger fish would be more likely to escape the hook.

The spatial survey revealed that there are seven benthic faunal assemblages within the channel. If we were to repeat this study, the placement of the four monitoring sites would account for these faunal assemblages to achieve a more representative survey of the faunal assemblages within the channel. However, the locations of the four monitoring sites were selected based on logistical convenience as the sites needed to be suitable for both fishing and grab sampling.

Stomach and intestinal content analysis was limited in the sense that soft-bodied species (which would have been quickly digested) may not be identified correctly. The weight of each of the prey items was not recorded; this would have allowed assessment of the relative importance of prey items to snapper.

Recommendations for further study

Serrano *et al*. (2003) suggested that benthic-feeding fish can alter the structure of benthic faunal assemblages. If this is so, the consumption of non-indigenous benthic macrofaunal species by fish could affect the spread of non-indigenous species. Another interesting research question could be directed at investigating the nutritional content of these species, and whether there is any difference between the nutritional content of native and non-indigenous species. This information could provide valuable insight into the consumption of particular species, and whether the feeding strategy of snapper is purely opportunistic.

Additionally, the establishment of non-indigenous benthic species has altered the benthic communities within the channel. The introduction of some of these species provides a different variety of prey items that are now available to predatory benthic feeding fish. The three main non-indigenous species within Rangitoto Channel are all bivalve species, and snapper consumed large quantities of at least two of these. Bivalves are known to take up and store contaminants and toxins from the water column (Nielsen & Nathan 1975). If snapper are consuming large quantities of bivalves, rather than other, less contaminated species, this could potentially pose health problems further up the tropic level.

The role of non-indigenous prey items in the diets of other predatory fish species has not been investigated. A comprehensive temporal study of the diets and inter-specific competition of predatory demersal fish species, coupled with temporal monitoring of the benthic fauna, would increase our understanding of the current trophic interactions, habitat use and role of non-indigenous prey species of common predatory fish species in the area.

Summary

Non-indigenous species are widespread throughout Rangitoto Channel. Three non-indigenous bivalve species are particularly abundant, and two of these, *M. senhousia* and *L. orientalis*, are significant contributors to the diet of snapper. Due to the relative abundance and biomass of *M. senhousia*, it is not surprising that snapper often consumed large quantities of this species. By contrast, the file shell, *L. orientalis*, appeared in disproportionate abundance in the diet of snapper compared to its actual densities within the sediment. Snapper have been described as opportunistic feeders; however, snapper appear to be targeting this species, and further investigation should be undertaken to determine whether and to what extent snapper feed selectively.

This study has provided novel information on one of New Zealand's most popular recreational and commercial fish species. It seems that the successful establishment and subsequent abundance of some non-indigenous species may benefit native, predatory fish species.

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Appendices

Appendix 1. Biomass (g) per m^2 of macrofauna at 80 sites throughout Rangitoto Channel.

Way point	*L. orientalis*	*M. senhousia*	*T. lubrica*	Total native	Total non-indigenous
WP90	0.00	1756.55	0.60	2.68	1757.14
WP91	0.00	0.00	0.00	13.69	0.00
WP93	0.00	0.00	2.98	6.55	2.98
WP94	0.00	0.00	2.08	0.00	2.08
WP95	0.00	0.00	0.00	382.74	0.00
WP96	0.00	0.00	0.00	17.56	0.00
WP97	0.00	0.00	0.00	2.68	0.00
WP98	0.00	0.00	0.00	10.71	0.00
WP99	0.00	0.00	0.00	39.29	0.00
WP100	0.00	0.00	0.60	0.00	0.60
WP101	0.00	0.00	3.57	4.76	3.57
WP102	0.00	0.00	2.38	2.38	2.38
WP103	0.00	0.00	3.57	7.74	3.57
WP104	0.00	0.00	2.38	21.73	2.38
WP105	0.00	0.00	0.89	6.85	0.89
WP106	0.00	0.00	0.00	187.20	0.00
WP108	0.00	0.89	0.00	19.64	0.89
WP109	1.49	0.00	0.00	425.60	1.49
WP110	0.00	0.00	0.00	8.04	0.00
WP111	0.00	0.00	1.79	41.67	7.74
WP112	0.00	0.00	2.68	7.74	2.68
WP113	0.00	0.00	4.17	5.06	4.17
WP114	0.00	1.79	2.68	2.38	4.46
WP115	0.00	0.00	0.00	710.12	0.00
WP116	16.07	0.00	0.00	435.71	16.07
WP117	0.00	2408.93	0.00	0.00	2408.93
WP118	0.00	1.79	0.00	3.87	1.79
WP120	9.82	0.00	2.38	860.12	12.20
WP121	8.63	0.00	0.00	466.96	55.95
WP122	0.00	0.00	0.00	423.21	0.00
WP123	0.00	0.09	5.36	88.10	5.45
WP124	0.00	127.08	0.30	26.79	127.38

Way point	*L. orientalis*	*M. senhousia*	*T. lubrica*	Total native	Total non-indigenous
WP125	0.00	0.00	0.00	132.44	0.00
WP126	8.04	0.00	0.00	132.14	8.04
WP127	5.65	0.00	0.00	352.38	5.65
WP128	22.92	0.00	0.00	423.51	22.92
WP129	0.00	109.82	0.00	45.54	109.82
WP130	0.00	60.12	1.19	380.65	61.31
WP131	6.85	0.00	0.00	119.35	51.19
WP132	0.00	0.00	0.00	40.77	0.00
WP133	3.27	0.00	0.00	394.05	3.27
WP134	14.29	0.00	0.00	742.86	14.29
WP135	0.00	197.32	0.00	21.73	197.32
WP136	0.00	0.00	0.00	0.89	0.00
WP137	0.00	90.77	0.06	42.86	90.83
WP138	0.00	0.00	0.00	121.73	0.00
WP139	2.98	0.00	0.00	174.11	2.98
WP140	9.23	0.00	0.00	73.81	9.23
WP141	0.00	30.36	1.49	96.13	31.85
WP142	0.00	26.79	0.00	394.35	26.79
WP143	0.00	0.00	0.00	99.11	0.00
WP144	2.08	0.00	0.89	937.20	2.98
WP145	0.00	0.30	0.00	5.95	0.30
WP146	0.00	155.65	0.00	151.49	155.65
WP148	0.00	0.00	0.60	0.30	0.60
WP153	0.00	0.40	0.00	66.87	0.40
WP155	0.00	0.20	0.00	33.43	0.20
WP157	12.40	0.00	0.00	119.15	12.40
WP160	5.85	0.00	0.00	210.71	5.85
WP163	0.00	0.00	0.13	59.62	0.13
WP165	0.00	0.00	0.00	561.90	0.00
WP166	0.00	14.88	2.38	9.23	17.26
WP167	0.00	0.00	0.00	128.57	0.00
WP168	0.00	0.00	0.00	98.51	0.00
WP169	0.00	49.70	0.00	55.36	49.70
WP170	0.60	0.00	0.00	75.00	0.60
WP171	0.60	0.00	0.00	46.73	0.60
WP172	0.00	0.00	0.00	340.18	0.00
WP173	0.00	86.31	0.00	10.71	86.31
WP175	0.00	0.00	0.00	98.51	0.00

Way point	*L. orientalis*	*M. senhousia*	*T. lubrica*	Total native	Total non-indigenous
WP178	0.00	0.00	0.60	2.08	0.60
WP179	0.00	0.00	0.00	140.77	39.29
WP180	0.00	0.89	0.00	73.81	0.89
WP181	0.00	0.89	0.00	0.30	0.89
WP182	0.00	0.30	0.00	216.96	0.30
WP183	21.73	0.00	0.00	364.88	21.73
WP184	10.42	0.00	0.00	164.29	11.61
WP185	2.38	0.00	0.00	13.69	2.38
WP186	0.00	0.30	0.00	160.71	0.30
WP187	0.00	0.00	0.00	32.74	0.00

Appendix 2. Analysis of the highly contributing species to the similarity and dissimilarity of the faunal assemblages within mud and shell-mud sediment types, abundance (Av. Ab), similarity (Av. Sim), similarity/standard deviation (Sim./SD), percentage contribution (Cont. %), cumulative percentage (Cum. %), average dissimilarity between faunal assemblages (Av. Diss.) and dissimilarity/standard deviation (part only given).

Mud sediment **Average similarity: 9.95**					
Species	**Av. ab.**	**Av. Sim.**	**Sim./SD**	**Cont. %**	**Cum.%**
Thracia australica	2.16	2.68	0.36	26.88	26.88
Heteromastus filiformis	1.01	1.13	0.43	11.35	38.24
Amphipoda indet.	0.90	0.80	0.31	8.08	46.32
Psammolyce antipoda	0.72	0.53	0.29	5.32	51.64
Cirratulidae	0.78	0.53	0.25	5.31	56.95
Nephtys macroura	0.65	0.44	0.24	4.42	61.37
Heterophoxus sp.	0.62	0.39	0.24	3.96	65.33
Spiorbidae	0.56	0.32	0.24	3.17	68.50
Macroclymenella stewartensis	0.42	0.26	0.19	2.65	71.15
Paraphoxus sp. 1	0.46	0.23	0.19	2.26	73.41
Nucula hartvigiana	0.35	0.21	0.18	2.09	75.50
Amalda novaezelandiae	0.22	0.19	0.15	1.89	77.40
Cossura consimilis	0.43	0.16	0.15	1.58	78.98
Trochodota dendyi	0.30	0.14	0.17	1.40	80.38

Shell-mud sediment **Average similarity: 21.26**					
Maoricolpus roseus	2.79	5.05	0.72	23.75	23.75
Paguristes pilosus	2.61	4.18	0.61	19.65	43.40
Amphipoda indet.	1.72	2.44	0.60	11.46	54.86
Ampharetidae	1.42	1.79	0.46	8.44	63.30
Corbula zelandica	1.44	1.54	0.44	7.24	70.53
Nucula hartvigiana	1.17	1.24	0.44	5.86	76.39
Leptochiton inquinatus	1.01	0.93	0.35	4.38	80.78

Mud & Shell-mud
Average dissimilarity: 93.24

Species	Mud Av. Ab.	Shell-mud Av. Ab.	Av. Diss.	Diss./SD	Cont. %	Cum. %
Maoricolpus roseus	0.25	2.79	5.97	0.95	6.40	6.40
Paguristes pilosus	0.41	2.61	5.65	0.93	6.06	12.46
Thracia australica	2.16	0.44	4.72	0.74	5.07	17.53
Amphipoda indet.	0.90	1.72	3.80	0.95	4.08	21.61
Corbula zelandica	0.21	1.44	3.16	0.65	3.39	25.00
Ampharetidae	0.10	1.42	3.06	0.75	3.28	28.28
Nucula hartvigiana	0.35	1.17	2.52	0.86	2.70	30.99
Leptochiton inquinatus	0.13	1.01	2.19	0.59	2.35	33.33
Heteromastus filiformis	1.01	0.27	2.01	0.80	2.16	35.49
Owenia fusiformis	0.20	0.72	1.74	0.61	1.87	37.36

Appendix 3. Analysis of the highly contributing species to the similarity and dissimilarity of the faunal assemblages within mud and shell-mud sediment types, abundance (Av. Ab), similarity (Av. Sim), similarity/standard deviation (Sim./SD), percentage contribution (Cont. %) and cumulative percentage (Cum. %) (part only given). June n = 33, August n = 37, October n = 40 and December n = 40 (part only given).

June **Average similarity: 25.24** **Species**	**Av. Ab.**	**Av. Sim.**	**Sim./SD**	**Cont. %**	**Cum. %**
Musculista senhousia	5.26	19.07	0.63	75.56	75.56
Heteromastus filiformis	1.42	1.12	0.29	4.42	79.98
Amphipoda spp.	0.72	0.67	0.29	2.64	82.62
Limaria orientalis	0.83	0.55	0.28	2.19	84.81
Nemertea	0.78	0.51	0.26	2.02	86.83
Paguristes setosus	0.96	0.46	0.16	1.83	88.65
Sabellidae sp. 1	0.74	0.36	0.21	1.44	90.09
August **Average similarity: 37.83**					
Heteromastus filiformis	4.36	8.86	2.74	23.43	23.43
Amphipoda spp.	2.10	3.84	1.78	10.14	33.57
Prionospio sp.	2.40	3.74	1.29	9.88	43.45
Armandia maculata	1.41	2.12	0.97	5.61	49.06
Sabellidae sp. 1	1.68	1.99	0.76	5.26	54.32
Spionidae	1.49	1.87	0.80	4.94	59.26
Musculista senhousia	2.02	1.61	0.38	4.24	63.51
Nemertea	1.14	1.57	0.83	4.16	67.66
Ophiactis resiliens	0.98	1.29	0.88	3.42	71.08
Macroclymenella stewartensis	0.88	0.83	0.56	2.20	73.28
Terebellides stroemi	0.88	0.73	0.47	1.92	75.20
Sthenelais sp.	0.79	0.70	0.48	1.85	77.05
Ophiodromus angustifrons	0.54	0.48	0.50	1.27	78.32
Paranthuridae spp.	0.56	0.48	0.49	1.27	79.59
Lepidonotus polychromus	0.67	0.47	0.38	1.25	80.84
Eunice sp. 1	0.61	0.44	0.42	1.16	81.99
Cossura consimilis	0.67	0.43	0.37	1.14	83.13
Ostracoda sp. 1	0.52	0.41	0.41	1.09	84.23
Phoronida sp. 1	0.55	0.41	0.41	1.09	85.32
Macrophthalmus hirtipes	0.53	0.41	0.38	1.08	86.40

August **Average similarity: 37.83** **Species**	**Av. Ab.**	**Av. Sim.**	**Sim./SD**	**Cont. %**	**Cum. %**
Perinereis nuntia	0.44	0.39	0.43	1.02	87.42
Pectinaria australis	0.49	0.31	0.34	0.82	88.24
Paguristes sp.	0.76	0.30	0.26	0.81	89.04
Theora lubrica	0.48	0.29	0.32	0.77	89.81
Glycera tesselata	0.39	0.29	0.35	0.76	90.57

October **Average similarity: 31.41**					
Heteromastus filiformis	3.21	5.23	1.45	16.64	16.64
Amphipoda spp.	2.71	4.27	1.02	13.6	30.23
Armandia maculata	1.75	1.87	0.65	5.96	36.19
Spionidae	1.50	1.87	0.87	5.94	42.13
Prionospio sp.	1.28	1.37	0.67	4.38	46.51
Macroclymenella stewartensis	1.27	1.29	0.66	4.11	50.62
Goniada sp.	1.32	1.27	0.55	4.03	54.65
Macrophthalmus hirtipes	1.09	1.16	0.59	3.70	58.35
Perinereis nuntia	0.87	1.05	0.73	3.33	61.68
Musculista senhousia	1.62	1.03	0.26	3.29	64.97
Cossura consimilis	1.08	0.88	0.38	2.81	67.79
Cirratulidae	0.95	0.79	0.46	2.53	70.32
Sabellidae sp. 1	0.91	0.73	0.49	2.34	72.65
Ophiactis resiliens	0.78	0.70	0.53	2.24	74.89
Sthenelais sp.	0.80	0.65	0.44	2.06	76.95
Nemertea	0.73	0.60	0.45	1.91	78.86
Eunice sp. 1	0.69	0.58	0.48	1.84	80.70
Theora lubrica	0.84	0.47	0.28	1.50	82.20
Ostracod sp. 1	0.59	0.45	0.44	1.44	83.64
Terebellides stroemi	0.59	0.40	0.38	1.26	84.90
Paguristes sp.	0.67	0.37	0.32	1.18	86.08
Phoronida sp. 1	0.56	0.35	0.36	1.12	87.20
Limaria orientalis	0.50	0.33	0.38	1.05	88.25
Paranthuridae spp.	0.45	0.32	0.39	1.03	89.28
Arabella sp.	0.51	0.27	0.31	0.85	90.13

December **Average similarity: 40.97** **Species**	**Av. Ab.**	**Av. Sim.**	**Sim./SD**	**Cont. %**	**Cum. %**
Heteromastus filiformis	4.25	7.88	2.87	19.22	19.22
Amphipoda spp.	3.13	4.68	1.58	11.43	30.65
Prionospio sp.	2.08	3.83	2.47	9.34	39.99
Nemertea	1.91	3.01	1.64	7.34	47.33
Goniada sp.	1.31	1.96	1.28	4.78	52.11
Spionidae	1.19	1.59	0.96	3.87	55.98
Macroclymenella stewartensis	1.22	1.39	0.82	3.40	59.38
Terebellides stroemi	1.24	1.15	0.63	2.81	62.19
Armandia maculata	1.11	1.08	0.68	2.62	64.82
Ostracod sp. 1	1.04	1.07	0.70	2.60	67.42
Ophiactis resiliens	0.85	1.02	0.85	2.49	69.91
Sabellidae sp. 1	0.96	0.85	0.65	2.07	71.97
Perinereis nuntia	0.72	0.76	0.68	1.86	73.83
Anthuridae sp. 1	0.73	0.76	0.68	1.86	75.69
Lepidonotus sp. 1	0.67	0.64	0.58	1.56	77.25
Limaria orientalis	0.65	0.61	0.59	1.48	78.73
Phoronida sp. 1	0.70	0.50	0.47	1.22	79.95
Pagurus novaezelandiae	0.81	0.50	0.44	1.21	81.16
Eunice sp. 1	0.65	0.44	0.43	1.06	82.23
Musculista senhousia	1.00	0.41	0.21	1.00	83.22
Cirratulidae	0.51	0.35	0.42	0.86	84.08
Halicarcinus cookii	0.44	0.35	0.44	0.86	84.94
Ophiodromus angustifrons	0.44	0.35	0.48	0.86	85.80
Cumacean sp.	0.47	0.32	0.39	0.78	86.58
Unidentified poly. 3	0.58	0.32	0.30	0.78	87.36
Trochodota dendyi	0.48	0.32	0.39	0.77	88.13
Leptochiton inquinatus	0.50	0.29	0.36	0.71	88.84
Syllidae	0.45	0.29	0.37	0.70	89.55
Flabelligera affinis	0.52	0.28	0.36	0.69	90.23

June & August **Average dissimilarity = 83.32**	**June**	**August**				
Species	**Av. Ab.**	**Av. Ab.**	**Av. Diss.**	**Diss./SD**	**Cont.%**	**Cum.%**
Musculista senhousia	5.26	2.02	8.97	1.20	10.77	10.77
Heteromastus filiformis	1.42	4.36	6.31	1.45	7.57	18.33
Prionospio sp.	0.52	2.40	3.84	1.35	4.60	22.94
Amphipoda spp.	0.72	2.10	3.08	1.38	3.70	26.64
Sabellid sp. 1	0.74	1.68	2.91	1.13	3.49	30.13
Spionidae	0.28	1.49	2.51	1.09	3.02	33.14
Armandia maculata	0.20	1.41	2.30	1.34	2.76	35.91
Nemertea	0.78	1.14	2.23	1.22	2.67	38.58
Ophiactis resiliens	0.54	0.98	1.82	1.27	2.18	40.76
Macroclymenella stewartensis	0.50	0.88	1.64	1.03	1.96	42.72
Paguristes setosus	0.96	0.00	1.58	0.41	1.89	44.61
Limaria orientalis	0.83	0.39	1.55	0.74	1.86	46.48
Terebellides stroemi	0.07	0.88	1.44	0.81	1.73	48.21
Sthenelais sp.	0.03	0.79	1.37	0.77	1.65	49.86
Paguristes sp.	0.00	0.76	1.20	0.50	1.44	51.30

June & October **Average dissimilarity = 85.36**	**June**	**October**				
Musculista senhousia	5.26	1.62	9.40	1.14	11.02	11.02
Heteromastus filiformis	1.42	3.21	5.08	1.43	5.95	16.97
Amphipoda spp.	0.72	2.71	4.29	1.21	5.03	22.00
Armandia maculata	0.20	1.75	2.87	1.01	3.36	25.36
Spionidae	0.28	1.50	2.54	0.99	2.98	28.34
Goniada sp.	0.16	1.32	2.48	0.66	2.90	31.24
Prionospio sp.	0.52	1.28	2.36	0.97	2.76	34.00
Macroclymenella stewartensis	0.50	1.27	2.19	0.95	2.56	36.57
Sabellid sp. 1	0.74	0.91	2.09	0.85	2.44	39.01
Macrophthalmus hirtipes	0.14	1.09	1.99	0.76	2.34	41.35
Cossura consimilis	0.06	1.08	1.99	0.66	2.33	43.68
Nemertea	0.78	0.73	1.83	0.94	2.15	45.83
Limaria orientalis	0.83	0.50	1.68	0.80	1.97	47.79
Perinereis nuntia	0.40	0.87	1.66	1.11	1.94	49.73

August & October **Average dissimilarity = 67.58**	**August**	**December**				
Species	**Av. Ab.**	**Av. Ab.**	**Av. Diss.**	**Diss./SD**	**Cont.%**	**Cum.%**
Musculista senhousia	2.02	1.62	3.70	0.86	5.47	5.47
Heteromastus filiformis	4.36	3.21	3.16	1.19	4.68	10.15
Prionospio sp.	2.40	1.28	2.49	1.25	3.69	13.84
Amphipoda spp.	2.10	2.71	2.49	1.32	3.68	17.51
Armandia maculata	1.41	1.75	2.13	1.34	3.16	20.67
Sabellidae sp. 1	1.68	0.91	2.09	1.18	3.10	23.76
Spionidae	1.49	1.50	1.98	1.13	2.94	26.70
Goniada sp.	0.17	1.32	1.81	0.72	2.68	29.38
Cossura consimilis	0.67	1.08	1.74	0.89	2.58	31.96
Macroclymenella stewartensis	0.88	1.27	1.67	1.06	2.46	34.42
Macrophthalmus hirtipes	0.53	1.09	1.49	0.92	2.21	36.63
Paguristes sp.	0.76	0.67	1.46	0.73	2.16	38.79
Nemertea	1.14	0.73	1.43	1.22	2.11	40.90
Theora lubrica	0.48	0.84	1.38	0.81	2.04	42.94
Sthenelais sp.	0.79	0.80	1.37	1.03	2.03	44.97
Cirratulidae	0.44	0.95	1.33	0.95	1.97	46.94
Terebellides stroemi	0.88	0.59	1.31	1.01	1.94	48.88

June & December **Average dissimilarity = 85.43**	**June**	**December**				
Musculista senhousia	5.26	1.00	8.70	1.17	10.19	10.19
Heteromastus filiformis	1.42	4.25	5.61	1.70	6.57	16.75
Amphipoda spp.	0.72	3.13	4.26	1.29	4.99	21.74
Prionospio sp.	0.52	2.08	3.10	1.83	3.63	25.37
Nemertea	0.78	1.91	2.85	1.34	3.34	28.71
Terebellides stroemi	0.07	1.24	2.02	0.84	2.37	31.07
Goniada sp.	0.16	1.31	2.01	1.46	2.36	33.43
Macroclymenella stewartensis	0.50	1.22	1.94	1.13	2.27	35.70
Sabellidae sp. 1	0.74	0.96	1.90	0.97	2.23	37.93
Spionidae	0.28	1.19	1.90	1.30	2.22	40.15
Ostracod sp. 1	0.33	1.04	1.76	0.94	2.06	42.21
Armandia maculata	0.20	1.11	1.73	1.02	2.02	44.23
Limaria orientalis	0.83	0.65	1.64	0.94	1.92	46.15
Ophiactis resiliens	0.54	0.85	1.55	1.30	1.81	47.96
Paguristes setosus	0.96	0.00	1.47	0.41	1.72	49.69

August & December **Average dissimilarity = 64.29** **Species**	**August** **Av. Ab.**	**December** **Av. Ab.**	**Av. Diss.**	**Diss./SD**	**Cont.%**	**Cum.%**
Musculista senhousia	2.02	1.00	2.98	0.85	4.63	4.63
Amphipoda spp.	2.10	3.13	2.29	1.09	3.56	8.20
Heteromastus filiformis	4.36	4.25	2.19	1.19	3.41	11.61
Sabellid sp. 1	1.68	0.96	1.87	1.22	2.91	14.52
Prionospio sp.	2.40	2.08	1.79	1.31	2.79	17.31
Terebellides stroemi	0.88	1.24	1.66	1.03	2.58	19.89
Spionidae	1.49	1.19	1.57	1.27	2.45	22.33
Nemertea	1.14	1.91	1.57	1.07	2.44	24.77
Goniada sp.	0.17	1.31	1.51	1.48	2.35	27.12
Armandia maculata	1.41	1.11	1.48	1.30	2.30	29.42
Macroclymenella stewartensis	0.88	1.22	1.43	1.21	2.22	31.64
Ostracod sp. 1	0.52	1.04	1.25	1.00	1.94	33.58
Cossura consimilis	0.67	0.56	1.19	0.76	1.85	35.44
Sthenelais sp.	0.79	0.49	1.19	0.92	1.84	37.28
Phoronid sp. 1	0.55	0.70	1.03	0.94	1.60	38.88
Ophiactis resiliens	0.98	0.85	1.02	1.26	1.59	40.48
Eunice sp. 1	0.61	0.65	1.01	1.03	1.57	42.05
Pagurus novaezelandiae	0.00	0.81	0.96	0.63	1.49	43.54
Macrophthalmus hirtipes	0.53	0.39	0.90	0.84	1.41	44.95
Paguristes sp.	0.76	0.00	0.88	0.51	1.37	46.32
Anthuridae sp. 1	0.00	0.73	0.88	1.03	1.37	47.69
Limaria orientalis	0.39	0.65	0.88	1.08	1.37	49.05

October & December **Average dissimilarity = 66.94**	**October**	**December**				
Species	**Av. Ab.**	**Av. Ab.**	**Av. Diss.**	**Diss./SD**	**Cont.%**	**Cum.%**
Heteromastus filiformis	3.21	4.25	2.85	1.32	4.25	4.25
Musculista senhousia	1.62	1.00	2.80	0.72	4.18	8.43
Amphipoda spp.	2.71	3.13	2.73	1.20	4.08	12.52
Armandia maculata	1.75	1.11	2.07	1.24	3.09	15.60
Nemertea	0.73	1.91	1.89	1.18	2.82	18.43
Prionospio sp.	1.28	2.08	1.85	1.40	2.77	21.20
Goniada sp.	1.32	1.31	1.80	0.95	2.69	23.89
Macroclymenella stewartensis	1.27	1.22	1.67	1.13	2.50	26.38
Cossura consimilis	1.08	0.56	1.64	0.84	2.45	28.83
Spionidae	1.50	1.19	1.61	1.08	2.40	31.23
Terebellides stroemi	0.59	1.24	1.60	0.94	2.39	33.62
Macrophthalmus hirtipes	1.09	0.39	1.47	0.89	2.20	35.81
Sabellidae sp. 1	0.91	0.96	1.43	1.01	2.14	37.96
Ostracod sp. 1	0.59	1.04	1.31	1.00	1.96	39.92
Cirratulidae	0.95	0.51	1.27	1.01	1.90	41.82
Sthenelais sp.	0.80	0.49	1.19	0.92	1.78	43.60
Ophiactis resiliens	0.78	0.85	1.11	1.29	1.66	45.26
Theora lubrica	0.84	0.12	1.10	0.64	1.64	46.90
Phoronid sp. 1	0.56	0.70	1.10	0.91	1.64	48.54

Appendix 4. Length (fork length), weight (wet weight), sex and date of capture of all snapper caught during four monitoring periods from June to December 2008. F females, M males and Juv juvenile (sex could not be determined).

Monitoring period	Date	Sex	FL (mm)	Weight (g)
June	22/05	Juv	200	177.5
		M	375	863.2
		F	265	414.3
		F	345	895.5
		F	330	830.0
		F	285	485.0
		Juv	193	173.4
		F	350	936.8
		Juv	190	124.6
		F	340	880.6
		M	315	661.8
		M	263	427.9
		M	210	213.6
		M	215	217.0
	11/06	F	320	740.8
		F	211	201.7
		F	242	294.9
	12/06	F	395	1285.2
		M	270	473.8
		F	245	312.8
		F	344	905.2
		F	345	948.4
		M	340	885.0
	13/06	F	232	273.4
		M	364	1074.8

Monitoring period	Date	Sex	FL (mm)	Weight (g)
August	28/08	M	259	346.7
		F	302	668.4
		M	282	498.2
		M	390	1235.6
		M	327	792.2
		F	313	743.5
	4/09	F	309	632.6
		F	325	739.8
		M	280	486.3
		F	195	171.5
		F	308	710.6
		M	335	834.6
	5/09	M	445	1293.9
		M	348	996.2
		F	287	560.1
		F	268	459.8
		M	297	617.0
		F	310	727.6
		F	305	635.8
		M	424	1675.8
		F	211	806.3
		F	238	862.7
		F	238	867.2
		F	415	1508.3
		F	345	948.9
		M	400	1449.2

Monitoring period	Date	Sex	FL (mm)	Weight (g)
October	23/10	M	330	797.9
		M	350	594.8
		M	273	458.2
		F	405	1380.3
		M	269	438.9
		F	351	956.1
		M	232	269.9
		M	248	310.4
		M	285	506.9
		F	283	616.8
		F	275	474.8
	28/10	M	244	339.0
		M	245	306.0
		M	277	496.7
		F	195	175.2
		F	289	581.2
		F	333	856.2
		M	202	193.3
	31/10	F	268	450.1
		F	365	987.2
		F	306	637.2
		M	269	467.5
		M	209	211.8
		F	202	179.0
		M	211	217.1
		M	270	419.5
		M	371	1143.7
		M	286	600.2
		F	225	235.7
		M	262	396.4

Monitoring period	Date	Sex	FL (mm)	Weight (g)
December	11/12	Juv	199	169.2
		M	254	380.0
		F	266	395.0
		F	230	263.0
		F	265	418.2
		Juv	195	160.3
		F	188	161.3
		M	248	313.3
		Juv	158	90.3
		M	224	256.2
		M	214	231.6
		M	206	210.9
		M	208	204.8
		M	278	454.7
		F	310	597.3
		M	201	185.7
		M	200	196.6
		F	197	165.1
	18/12	M	306	579.6
		F	324	697.1
		Juv	186	143.0
		F	346	899.5
		F	236	318.5
		M	224	280.9
	19/12	M	213	209.3
		F	295	559.1
		M	223	252.4
		Juv	197	181.9
		F	215	216.7
		F	245	360.9

Appendix 5. Fishing trips undertaken during each monitoring period. Number of long line deployments and number of snapper caught. Total number of long line deployments, hooks used, total fish caught and total number of snapper caught during each monitoring period.

Monitoring period	Date	Time	Tide time	Tide height (m)	Moon phase	Long lines	Hooks	Fish	Snapper
June	16-May	09.30–15.30	0420 1033 1657 2256	3.0 0.9 2.9 0.9	Waxing gibbous	4	100	1	0
	22-May	09.35–14.40	0229 0847 1446 2116	0.9 2.9 0.7 3.1	Full	5	125	14	13
	11-Jun	09.50–15.05	0107 0718 1335 1934	3.1 0.8 2.9 0.9	First quarter	8	200	4	3
	12-Jun	09.45–14.45	0200 0812 1431 2032	3.0 0.8 2.9 1.0	Waxing gibbous	8	200	7	6
	13-Jun	09.25–12.35	0252 0905 1527 2129	3.0 0.9 2.8 1.0	Waxing gibbous	8	200	4	2
June Total						33	825	30	24

Monitoring period	Date	Time	Tide time	Tide height (m)	Moon phase	Long lines	Hooks	Fish	Snapper
August	11-Aug	09.45–13.00	0216 0828 1503 2103	2.7 1.0 2.7 1.1	Waxing gibbous	4	100	0	0
	28-Aug	11.55–15.20	0426 1035 1704 2310	2.9 0.7 3.1 0.7	Waning crescent	4	100	9	6
	4-Sep	15.00–17.00	0401 1023 1614 2239	0.5 3.1 0.6 3.1	Waxing crescent	4	100	6	6
	5-Sep	13.50–17.50	0441 1104 1656 2320	0.6 3.0 0.7 3.0	Waxing crescent	4	100	16	14
Aug Total						16	400	31	26
October	22-Oct	10.00–13.15	0149 0746 1420 2031	3.0 0.6 3.1 0.7	Third quarter	4	100	0	0
	23-Oct	10.10–15.45	0250 0851 1524 2135	2.9 0.7 3.0 0.8	Waning crescent	8	200	13	11
	28-Oct	10.15–15.20	0117 0742 1337 1954	0.6 3.0 0.7 3.0	Waning crescent	8	200	16	11
	31-Oct	10.10-15.20	0322 0949 1540 2200	0.5 3.1 0.7 3.0	Waxing crescent	8	200	16	12
Oct Total						28	700	45	34

Monitoring period	Date	Time	Tide time	Tide height (m)	Moon phase	Long lines	Hooks	Fish	Snapper
December	11-Dec	09.50–15.40	0629 1231 1848	3.0 0.7 3.1	Waxing gibbous	8	200	21	18
	18-Dec	10.00–15.55	0615 1245 1854	0.4 3.3 0.5	Waning gibbous	8	200	6	6
	19-Dec	10.20–12.30	0113 0708 1338 1948	3.1 0.6 3.2 0.6	Waning gibbous	4	100	6	6
Dec Total						20	500	33	30

Appendix 6. Indices relating to the temporal change in benthic species assemblages at four monitoring sites. The species richness (S) (ind. m^{-2}), total number of individuals (N) (indiv m^{-2}), Margalef's index (d), Pielou's evenness index (J'), Shannon-Wiener index (H'(log)) and Simpson index (1-Lambda') for the bimonthly monitoring of the benthic macrofauna at four monitoring sites (mean ± SD).

Site 1. June n = 7, August n = 8, October n = 10 and December n = 10.

	June	August	October	December
S	6.43 ± 4.08	26.88 ± 5.00	29.70 ± 9.52	27.30 ± 8.69
N	2377 ± 2725	3665 ± 1428	5732 ± 3834	4027 ± 1998
d	0.81 ± 0.65	3.17 ± 0.48	3.35 ± 0.95	3.18 ± 0.85
J'	0.52 ± 0.38	0.74 ± 0.11	0.74 ± 0.07	0.76 ± 0.08
H'(loge)	0.98 ± 0.97	2.41 ± 0.35	2.46 ± 0.31	2.48 ± 0.29
1-Lambda'	0.40 ± 0.39	0.81 ± 0.11	0.83 ± 0.05	0.84 ± 0.06

Site 2. June n = 9, August n = 10, October n = 10 and December n = 10

	June	August	October	December
S	3.67 ± 2.40	19.00 ± 3.27	17.90 ± 2.33	19.80 ± 4.39
N	4987 ± 3101	2679 ± 1731	1685 ± 881	1970 ± 636
d	0.33 ± 0.29	2.33 ± 0.42	2.30 ± 0.28	2.48 ± 0.50
J'	0.18 ± 0.17	0.76 ± 0.16	0.87 ± 0.10	0.81 ± 0.09
H'(loge)	0.21 ± 0.25	2.23 ± 0.48	2.49 ± 0.27	2.39 ± 0.25
1-Lambda'	0.09 ± 0.12	0.80 ± 0.15	0.88 ± 0.07	0.84 ± 0.06

Site 3. June n = 9, August n = 10, October n = 10 and December n = 10.

	June	August	October	December
S	8.78 ± 3.80	26.50 ± 4.20	26.20 ± 5.05	36.00 ± 8.49
N	1187 ± 1024	3051 ± 870	6012 ± 4078	7460 ± 3616
d	1.18 ± 0.57	3.20 ± 0.55	2.96 ± 0.57	3.96 ± 0.89
J'	0.69 ± 0.30	0.79 ± 0.08	0.67 ± 0.13	0.69 ± 0.14
H'(loge)	1.52 ± 0.80	2.58 ± 0.32	2.20 ± 0.48	2.44 ± 0.56
1-Lambda'	0.62 ± 0.30	0.87 ± 0.05	0.78 ± 0.15	0.80 ± 0.17

Site 4. June n = 8, August n = 9, October n = 10 and December n = 9.

Average	June	August	October	December
S	10.50 ± 5.21	17.44 ± 5.75	15.70 ± 7.65	29.00 ± 3.74
N	621 ± 345	2133 ± 1358	5461 ± 7802	2989 ± 650
d	1.48 ± 0.73	2.20 ± 0.73	1.90 ± 0.99	3.50 ± 0.42
J'	0.83 ± 0.21	0.76 ± 0.21	0.74 ± 0.20	0.81 ± 0.07
H'(loge)	1.90 ± 0.68	2.15 ± 0.70	1.89 ± 0.79	2.73 ± 0.26
1-Lambda'	0.76 ± 0.23	0.78 ± 0.20	0.73 ± 0.19	0.88 ± 0.04

Appendix 7. Analysis of the highly contributing species to the similarity and dissimilarity of the prey species patterns of snapper caught during four monitoring periods. Average abundance, similarity, similarity/standard deviation, percentage contribution and cumulative percentage (part only given).

June **Average similarity: 12.73** **Species**	**Av. Ab.**	**Av. Sim.**	**Sim./SD**	**Cont.%**	**Cum.%**
Limaria orientalis	2.53	4.44	0.33	34.88	34.88
Unidentifiable	1.99	3.01	0.26	23.62	58.50
Musculista senhousia	1.74	1.59	0.19	12.50	71.00
Flabelligira affinis	1.23	1.19	0.23	9.36	80.37
Upogebia danae	0.94	0.70	0.19	5.53	85.90
Paguristes setosus	0.88	0.54	0.18	4.25	90.15
August **Average similarity: 25.27**					
Limaria orientalis	4.49	14.57	0.67	57.65	57.65
Paguristes sp.	2.69	5.31	0.43	21.02	78.67
Musculista senhousia	1.91	2.91	0.34	11.51	90.18
October **Average similarity: 18.52**					
Upogebia danae	3.03	7.55	0.49	40.77	40.77
Paguristes sp.	3.03	6.51	0.51	35.15	75.93
Decapoda spp.	1.09	1.20	0.29	6.47	82.39
Polychaeta spp.	1.14	0.84	0.17	4.52	86.92
Periclymenes yaldwyni	0.98	0.66	0.17	3.56	90.48
December **Average similarity: 17.15**					
Paguristes sp.	2.43	4.13	0.43	24.08	24.08
Unidentifiable	2.30	4.11	0.32	23.95	48.04
Alpheus sp.	1.37	2.13	0.37	12.40	60.43
Halicarcinus cookii	1.69	1.91	0.28	11.11	71.54
Decapoda spp.	1.44	1.76	0.33	10.24	81.78
Macrophthalmus hirtipes	1.05	0.60	0.15	3.48	85.26
Limaria orientalis	0.80	0.40	0.15	2.34	87.60
Polychaeta spp.	0.73	0.38	0.15	2.19	89.80
Polychaeta sp.1	0.68	0.34	0.15	2.00	91.80

June & August
Average dissimilarity = 85.95

Species	June Av. Ab.	August Av. Ab.	Av. Diss.	Diss./SD	Cont.%	Cum.%
Limaria orientalis	2.53	4.49	14.76	1.11	17.17	17.17
Musculista senhousia	1.74	1.91	9.19	0.80	10.69	27.86
Unidentifiable	1.99	1.06	9.16	0.66	10.65	38.51
Paguristes sp.	0.00	2.69	8.75	0.72	10.18	48.70
Flabelligira affinis	1.23	0.13	3.86	0.57	4.49	53.18
Upogebia danae	0.94	0.54	3.81	0.60	4.44	57.62
Periclymenes yaldwyni	0.80	0.38	3.33	0.49	3.87	61.49
Paguristes setosus	0.88	0.00	2.47	0.47	2.88	64.37
Decapoda spp.	0.00	0.79	2.43	0.47	2.83	67.20
Trochodota dendyi	0.79	0.00	2.38	0.40	2.77	69.97
Notomithrax minor	0.63	0.00	2.27	0.27	2.64	72.61
Polychaeta spp.	0.00	0.76	2.10	0.45	2.45	75.06
Alpheus richardsoni	0.29	0.49	2.07	0.45	2.41	77.46
Craspedochiton sp.	0.42	0.00	1.67	0.21	1.95	79.41
Macrophthalmus hirtipes	0.16	0.36	1.66	0.25	1.93	81.34
Liocarcinus corrugatus	0.47	0.00	1.42	0.34	1.65	82.99
Polychaeta sp.1	0.00	0.40	1.16	0.31	1.35	84.34
Lepidonotus polychroma	0.30	0.12	1.05	0.34	1.22	85.56
Cirolana sp.	0.29	0.00	1.01	0.21	1.18	86.73
Maoricolpus roseus	0.29	0.00	1.01	0.21	1.18	87.91

June & October
Average dissimilarity = 93.92

Species	June Av. Ab.	October Av. Ab.	Av. Diss.	Diss./SD	Cont.%	Cum.%
Upogebia danae	0.94	3.03	10.39	0.85	11.06	11.06
Paguristes sp.	0.00	3.03	9.28	0.84	9.88	20.94
Limaria orientalis	2.53	0.61	9.10	0.70	9.69	30.64
Unidentifiable	1.99	0.48	7.90	0.60	8.41	39.05
Musculista senhousia	1.74	0.39	6.04	0.56	6.43	45.48
Periclymenes yaldwyni	0.80	0.98	5.00	0.53	5.32	50.80
Notomithrax minor	0.63	0.69	3.97	0.41	4.23	55.03
Polychaeta spp.	0.00	1.14	3.68	0.41	3.91	58.94
Alpheus sp.	0.00	1.02	3.63	0.36	3.86	62.80
Flabelligira affinis	1.23	0.00	3.56	0.53	3.80	66.60
Decapoda spp.	0.00	1.09	3.12	0.60	3.33	69.92
Paguristes setosus	0.88	0.00	2.44	0.47	2.60	72.52
Trochodota dendyi	0.79	0.00	2.35	0.40	2.50	75.03
Liocarcinus corrugatus	0.47	0.28	2.06	0.43	2.19	77.22
Craspedochiton sp.	0.42	0.00	1.64	0.20	1.75	78.97
Maoricolpus roseus	0.29	0.19	1.49	0.27	1.59	80.56
Amphipoda	0.00	0.53	1.41	0.26	1.50	82.06
Isopoda spp.	0.00	0.46	1.25	0.33	1.33	83.39
Macrophthalmus hirtipes	0.16	0.31	1.22	0.34	1.30	84.69

August & October
Average dissimilarity = 86.39

Species	August Av. Ab.	October Av. Ab.	Av. Diss.	Diss./SD	Cont.%	Cum.%
Limaria orientalis	4.49	0.61	14.66	1.07	16.97	16.97
Paguristes sp.	2.69	3.03	11.83	1.01	13.69	30.66
Upogebia danae	0.54	3.03	10.47	0.84	12.12	42.78
Musculista senhousia	1.91	0.39	6.43	0.69	7.44	50.23
Unidentifiable	1.06	0.48	5.13	0.42	5.94	56.17
Polychaeta spp.	0.76	1.14	5.07	0.56	5.87	62.04
Decapoda spp.	0.79	1.09	4.57	0.76	5.29	67.33
Alpheus sp.	0.35	1.02	4.34	0.42	5.02	72.34
Periclymenes yaldwyni	0.38	0.98	4.03	0.48	4.67	77.01
Macrophthalmus hirtipes	0.36	0.31	2.10	0.30	2.43	79.44
Notomithrax minor	0.00	0.69	2.08	0.33	2.41	81.85

June & December
Average dissimilarity = 92.25

Species	June Av. Ab.	December Av. Ab.	Av. Diss.	Diss./SD	Cont.%	Cum.%
Unidentifiable	1.99	2.30	10.52	0.82	11.41	11.41
Limaria orientalis	2.53	0.80	8.81	0.73	9.55	20.96
Paguristes sp.	0.00	2.43	7.10	0.75	7.70	28.66
Musculista senhousia	1.74	0.70	6.42	0.57	6.96	35.61
Halicarcinus cookii	0.00	1.69	4.90	0.59	5.31	40.92
Decapoda spp.	0.00	1.44	4.07	0.61	4.41	45.34
Alpheus sp.	0.00	1.37	3.96	0.71	4.30	49.63
Upogebia danae	0.94	0.62	3.57	0.65	3.87	53.51
Flabelligira affinis	1.23	0.00	3.39	0.54	3.67	57.18
Macrophthalmus hirtipes	0.16	1.05	3.34	0.43	3.62	60.80
Periclymenes yaldwyni	0.80	0.48	3.33	0.51	3.61	64.41
Liocarcinus corrugatus	0.47	0.58	2.79	0.45	3.02	67.43
Paguristes setosus	0.88	0.00	2.32	0.47	2.52	69.95
Trochodota dendyi	0.79	0.00	2.23	0.40	2.42	72.37
Polychaeta spp.	0.00	0.73	2.13	0.39	2.30	74.67
Notomithrax minor	0.63	0.00	2.09	0.27	2.27	76.94
Maoricolpus roseus	0.29	0.34	1.87	0.36	2.03	78.97
Polychaeta sp.1	0.00	0.68	1.85	0.41	2.00	80.97
Polychaeta sp.3	0.00	0.54	1.54	0.35	1.67	82.64
Craspedochiton sp.	0.42	0.00	1.54	0.21	1.66	84.31
Halicarcinus sp.	0.16	0.37	1.40	0.31	1.51	85.82
Cirolana sp.	0.29	0.00	0.94	0.21	1.02	86.84

August & December
Average dissimilarity = 85.85

Species	August Av. Ab.	December Av. Ab.	Av. Diss.	Diss./SD	Cont.%	Cum.%
Limaria orientalis	4.49	0.80	13.73	1.08	15.99	15.99
Paguristes sp.	2.69	2.43	10.44	0.98	12.16	28.15
Unidentifiable	1.06	2.30	9.57	0.71	11.15	39.30
Musculista senhousia	1.91	0.70	6.88	0.70	8.02	47.31
Decapoda spp.	0.79	1.44	5.22	0.76	6.08	53.39
Halicarcinus cookii	0.00	1.69	4.95	0.59	5.77	59.16
Alpheus sp.	0.35	1.37	4.42	0.76	5.15	64.30
Macrophthalmus hirtipes	0.36	1.05	4.07	0.44	4.74	69.04
Polychaeta spp.	0.76	0.73	3.62	0.59	4.21	73.26
Upogebia danae	0.54	0.62	2.94	0.55	3.42	76.68
Polychaeta sp.1	0.40	0.68	2.69	0.51	3.14	79.82
Periclymenes yaldwyni	0.38	0.48	2.25	0.49	2.62	82.44
Liocarcinus corrugatus	0.00	0.58	1.72	0.31	2.00	84.44

October & December
Average dissimilarity = 86.04

	October	December				
Paguristes sp.	3.03	2.43	10.34	1.02	12.01	12.01
Upogebia danae	3.03	0.62	9.65	0.84	11.21	23.23
Unidentifiable	0.48	2.30	8.58	0.65	9.98	33.20
Alpheus sp.	1.02	1.37	6.24	0.70	7.25	40.46
Decapoda spp.	1.09	1.44	5.43	0.81	6.31	46.76
Halicarcinus cookii	0.30	1.69	5.31	0.64	6.17	52.93
Polychaeta spp.	1.14	0.73	4.87	0.55	5.66	58.59
Periclymenes yaldwyni	0.98	0.48	3.95	0.49	4.59	63.18
Limaria orientalis	0.61	0.80	3.71	0.48	4.32	67.50
Macrophthalmus hirtipes	0.31	1.05	3.65	0.46	4.24	71.73
Musculista senhousia	0.39	0.70	2.96	0.40	3.44	75.17
Liocarcinus corrugatus	0.28	0.58	2.32	0.40	2.70	77.87
Polychaeta sp.1	0.12	0.68	2.07	0.46	2.40	80.27
Notomithrax minor	0.69	0.00	1.95	0.33	2.26	82.53
Amphipoda	0.53	0.23	1.85	0.32	2.15	84.69

Appendix 8. Number of sediment samples obtained at each of the monitoring sites during 2008.

	June	August	October	December
Site 1	7	8	10	10
Site 2	9	10	10	10
Site 3	9	10	10	10
Site 4	8	9	10	9