The effects of green shelled mussel mariculture on benthic communities in Hauraki Gulf

A thesis submitted through the

Earth and Oceanic Science Research Institute,

School of Applied Science,

Auckland University of Technology

In partial fulfilment of the degree of the

Master of Applied Science.

Master of Applied Science

Ka Lai Clara Wong

March 2009

Cover Page: mussel farm, eastern Waiheke Island, May 2008, C. Wong.

Abstract

Sea-bed benthic-invertebrate assemblages of species within and proximal to an existing mussel farm off Taniwhanui Point, eastern Waiheke Island, are reported. Substratum type, whether predominantly muds, gravels or an admixture of the two, mud/gravels, is shown to influence infaunal species assemblage composition; the bivalve *Theora lubrica*, ostracods, amphipods and polychaetes characterise muddy substrata; polychaetes, particularly spionids and syllids, ostracods, amphipods, bivalves and ophiuroids characterise mud/gravel substrata; and diverse assemblages of polychaetes, bivalves, pagurid crabs, gastropods, ostracods, ophiuroids and nemertean worms characterise gravel substrata.

Significant differences in sea-bed assemblages are reported along one transect inside and outside the farm over the three seasons during which surveys were conducted, summer, autumn, winter of 2008. Along the northern side of the mussel farm those sediments beneath the farm are characterised by greater abundances of polychaetes and crustaceans (Malacostraca), whereas sediments outside the farm are characterised by greater abundances of bivalves and ostracods. Sediments both inside and outside the northeastern border of the farm during summer are characterised by similar abundances of polychaetes, bivalves and ostracods. Similarly, those sediments within and outside the farm along its southern border during summer are characterised by abundances of polychaetes, bivalves, crustaceans (Malacostraca) and gastropods.

Measures of relative abundance, rarity and species richness are applied to sea-bed assemblages off eastern Waiheke Island to enable an appraisal of the spatial distribution of each within and outside the farm, and throughout the eastern Waiheke Island region. One of these measures, relative abundance, is then compared with other, albeit limited abundance data from previous soft-sediment surveys conducted throughout Hauraki Gulf. The most species rich and abundant sites off eastern Waiheke Island occur in gravelly substrata between Waiheke Island and Pakatoa Island, and

between Rotoroa and Ponui Islands, in addition to beneath the southern portion of the existing mussel farm. Gravel-based substrata are recognised to be the most species rich and densely populated with invertebrates for this sediment type in Hauraki Gulf. Similarly, the muddy substrata off eastern Waiheke Island region appear to host more individuals and species than any other reported muddy substratum in Hauraki Gulf.

The existing mussel farm is shown to significantly affect sea-bed communities, but in a manner that has not been previously reported in New Zealand. Species richness and abundance are greater beneath the farm, as are the proportions of *very rare* and *uncommon* taxa to more *common* and *ubiquitous* taxa. Sediments beneath the farm are not characterised by elevated abundances and richness of opportunistic species; and no obvious difference in sediment grain size is apparent along a transect extending from 20 m inside the farm to at least 110 m outside it. The biological footprint of the farm is limited, appearing to extend no further than 20 metres from the northern physical boundary of the farm; the gross sedimentary characteristics (grain size) do not differ significantly within and outside the farm.

Within and immediately outside the farm species richness and abundance tend to increase during colder seasons; beneath the farm, species richness (d), abundance (N), Shannon index (H') and Simpson index (1-λ') were higher during May (autumn) and August (winter) than during February (summer); diversity values outside the farm were similar during summer and autumn, but species richness (d), evenness (J'), Shannon index (H') and Simpson index (1-λ') were all greater during winter.

No opportunistic taxa are considered to be appropriate indicators of organically enriched environments, at least enrichment that can be intuitively linked to any direct effect of the existing mussel farm. One species, the heart urchin *Echinocardium cordatum*, only rarely occurs inside the physical farm boundary, so its relative abundance renders it an appropriate indicator species of mussel-farm impacts.

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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:

Ka Lai Clara Wong

Acknowledgments

Firstly, a big thank to my primary supervisor Dr Steve O'Shea, who had to put up with me asking a million questions every day, when I was supposedly allowed one, and for all his encouragement and guidance over this last year.

I also wish to thank my secondary supervisor Dr Kay Vopel for showing me the PRIMER techniques, and Dr Barbara Breen for her assistance with GIS (all AUT).

I wish to acknowledge all staff and students in the Earth and Oceanic Sciences Research Institute, and School of Applied Sciences at Auckland University of Technology, who assisted in data collection, especially Emma Beatson for driving the boat, and Sue Dodd for field-assistance with sample collection.

Acknowledgement is due also to the Department of Conservation (DoC), especially Dr Dan Breen, for assistance with collection of side-scan data.

Finally, a special thanks to my parents, for falling in love and 'producing' me. And of course without their financial and mental support, I would not be able to finish this Masters degree. Thank you mum and dad big time!

Introduction

The aquaculture industry was worth $350 million to the New Zealand economy in 2008, a contribution forecast to reach a billion dollars by 2050 (MFish 2008a), with most of this contributed by three species: Greenshell™ mussel (*Perna canaliculus*), king salmon (*Oncorhynchus tschawytscha*) and Pacific oyster (*Crassostrea gigas*). Greenshell™ mussel is the largest by value and tonnage of all, with 2006−07 sales amounting to $223 million, $43 million contributed by the domestic market, $180 million by the international market (Aquaculture 2008).

Aquaculture is a form of aquatic farming that can take place both within the sea or in land-based, man-made enclosures (MFish 2008b). Mariculture, a specialized branch of aquaculture, refers to the cultivation of marine organisms in their natural environment. Mussel farming is a classic example of a mariculture activity, as mussels are grown on suspended lines in coastal waters, with the backbone longline of the structure buoyed at the surface, with each end anchored to the sea floor. Pacific oysters are another example of a mariculture activity, being usually farmed on wooden racks in the lower intertidal region. King salmon, to the contrary, can be farmed either in marine or freshwater environments, in sea-cages or unnatural freshwater raceways. Because these three species are farmed in completely different ways, their potential impacts on the receiving environment could be quite different.

Mussel farms are distributed throughout New Zealand, although the major centres occur in the Malborough Sounds (South Island), and Firth of Thames (North Island). Typically mussel farms are established in sheltered to semi-sheltered areas where there is sufficient water at low tide to keep the longline droppers off the bottom. By 2006, there were 898 mussel farms, covering 6,535 ha of coastal environment (MFish 2008b), producing 99,500 tonnes of mussels annually (MFA 2008).

The Auckland region extends from Wellsford in the north to Pukekohe in the south, and covers approximately 500,000 ha of land and coastal water, and 1,600 km coastline (ARC 2008a). Throughout this region mussel farms are situated in the southern Kaipara, eastern Firth of Thames (the western Firth of Thames falls within the Waikato region) and off eastern Waiheke Island. Additional expansion is envisaged, and the Auckland Regional Council is currently evaluating applications for new ventures in the southern Kaipara (approximately 228 ha being identified for potential mussel farm development), and a 10-ha extension to an existing mussel farm off eastern Waiheke Island; a decision on either has yet to be made, although in April 2008, 76 ha of Kaipara coast was approved for Pacific oyster, *Crassostrea gigas*, farming (ARC 2002, 2008b). Approval of the application to extend the existing mussel farm off eastern Waiheke Island by 10 ha is conditional upon an assessment of the effects such an expansion would have upon the receiving environment.

Despite the current and forecast value of mussel mariculture activities to the New Zealand economy, few published studies have reported the effects of this activity on the local marine environment, with even less whose focus has been on describing the effects of such activities on sea-bed communities. The primary objective of this thesis therefore is one of describing the effects on sea-bed communities beneath and proximal to an existing mussel farm, by describing the patterns of distribution and abundance of benthic-invertebrate and floral taxa within and outside it.

Effects of mariculture on sea-bed communities

Many international studies have reported the effects of shellfish aquaculture on the marine environment (e.g. Baudinet *et al*. 1990, Hatcher *et al*. 1994, Grant *et al*. 1995, Stenton-Dozey *et al*. 1999, Mirto *et al*. 2000, Crawford *et al*. 2003, Danovaro *et al*. 2004, Ljungqvist 2005, Callier *et al*. 2006, da Costa & Nalesso 2006), but only seven published accounts can be found reporting the effects of mussel-farming activities on the New Zealand marine environment (Kaspar *et. al*. 1985; Christensen *et al*. 2003; Giles & Pilditch 2004, 2006; Hartstein & Rowden 2004, Hartstein & Stevens 2005, Giles *et*

al. 2006), with three of these reports (Giles & Pilditch 2004, 2006; Giles *et al*. 2006) based on data from a single mussel farm in the Firth of Thames, Hauraki Gulf; and two of these reports (Hartstein & Rowden 2004, Hartstein & Stevens 2005) based on data from three mussel farms in Marlborough Sounds. Most research has been undertaken by students, the results of which have been detailed in unpublished university theses (de Jong 1994, Hartstein 2003, Plew 2005, Giles 2006) for the two main mussel-farming centres of Marlborough Sounds and Firth of Thames. Additional unpublished research not referred to herein has been undertaken for the Ministry of Fisheries, in series of Frisheries Research Impact Assessments (FRIAs).

Reported effects of shellfish aquaculture on sea-bed communities beneath shellfish farms are variable, ranging from those that describe significant negative effects, such as sea-bed organic enrichment and modification of benthic macrofaunal assemblages (Mattsson & Linden 1983, Stenton-Dozey *et al*. 1999, Mirto *et al*. 2000, Ljungqvist 2005, Callier *et al.* 2006), to those that describe little or no change in sediment composition or macrofaunal communities beneath farms (Baudinet *et al*. 1990, Hatcher *et al.* 1994, Grant *et al*. 1995, Crawford *et al*. 2003, Danovaro *et al*. 2004, da Costa & Nalesso 2006).

All published New Zealand studies on the effects of mussel mariculture on the receiving environment (Kaspar *et. al*. 1985; Christensen *et al*. 2003; Giles & Pilditch 2004, 2006; Hartstein & Rowden 2004; Hartstein & Stevens 2005; Giles *et al*. 2006) have reported an alteration of sea-bed sediments as a direct consequence of this activity. Four of these studies reported biological effects, a decrease in benthic invertebrate biomass (Kaspar *et. al*. 1985) and richness (Christensen *et al*. 2003, Hartstein & Rowden 2004), whereas macrofaunal abundance and biomass have only been reported to be higher beneath a farm on one occasion (Giles *et al*. 2006), although in this latter case the differences may not have been due to the influence of the farm as species diversity and abundance were low both within and outside the farm.

As only four studies have reported the biological effects of mussel mariculture on the receiving environment, despite there being 898 established farms in New Zealand waters, studies conducted overseas offer valuable insights into the potential effects such farming practices could have on New Zealand sea-bed communities. Grant *et al*. (1995) reported higher species richness but lower biomass beneath a mussel farm in Nova Scotia, with a polychaete (*Neptys neotena*) being dominant at control sites, whereas those sites beneath the mussel farm were dominated by two molluscs, the gastropod *Ilyanassa* spp. and nut-shell *Nucula temrisulcata*. Crawford *et al*. (2003) and da Costa & Nalesso (2006) report no significant difference between sites within and outside a mussel farm in Tasmania and southeastern Brazil respectively, with the farm having no negative effects on sea-bed assemblages. To the contrary, Mattsson & Linden (1983) recorded a replacement of taxa after 6–15 months of mussel culturing, with the bivalve *Nucula nitidosa*, heart urchin *Echinocardium cordatum* and brittle star *Ophiura* spp. being replaced in sediments beneath a farm by the polychaetes *Capitella capitata*, *Scolelepis fuliginosa* and *Microphthalmus sczelkowii*. This latter finding is similar to that of Ragnarsson & Raffaelli (1999), who undertook mussel transplant experiments and recorded a significantly lower number of individuals beneath transplanted plots than at control plots, with the transplanted plot eventually being colonised by the polychaete *Capitella* spp. In a survey of two mussel farm sites of different age, Callier *et al*. (2007) reported the lowest diversity and biomass beneath the more established of the two, with sea-bed communities similarly dominated by *Capitella capitata*, and sediments beneath the more recent (less than one year old) mussel farm site having greater species richness and biomass. Stenton-Dozey *et al*. (1999) recorded seven of nine sampled mussel sites had modified macrofaunal communities dominated by polychaetes (e.g. *Nephtys capensis*, *Prionospio sexoculata*) and scavenging gastropods (*Nassarius speciosa* and *N. vintus*), whereas sites outside farms were dominated by what they attributed to suspension feeders (chaetognaths, holothurians and brachyuran crabs).

National studies have focussed research on the two main centres of mussel mariculture activity in New Zealand, within the Firth of Thames and

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Marlborough Sounds. Of these, Kaspar *et al*. (1985) reported differences within and outside of mussel farms, citing higher benthic infaunal biomass outside of farms than within; more diverse benthic communities also were recognised outside mussel farm sites, characterised by ophiuroids, bivalves, crustaceans and polychaetes, whereas polychaetes characterised sediments beneath the mussel farm. Kaspar *et al*. (1985) reported total sediment organic matter to best explain macrofaunal assemblage composition.

Christensen *et al*. 2003 reported lower macro-invertebrate species richness and microphyto-benthic biomass beneath two farm sites compared with their control site. Species that were absent or reduced in abundance beneath the farm included polychaete worms *Heteromastus filiformis*, and those in the families Cirratulidae, Cossuridae, Lumbrineridae and Maldanidae, bivalves *Leptomya retiaria* and *Limaria orentalis*, a burrowing cumacean, and the ophiuroid *Amphiura rosea*; those taxa present at greater abundances beneath the farm included the polychaetes *Dorvillea incerta*, *Prionospio pinnata* and *Capitella capitata*. Christensen *et al*. 2003 suggested that enhanced mineralization due to impeded benthic photosynthesis and denitrification likely explained low within-farm species richness.

Research reported by Hartstein & Rowden (2004), based on Hartstein's PhD (Hartstein 2003) recognised lower species richness and macro-benthic invertebrate assemblages to occur beneath two of three surveyed mussel farms when compared with control sites. One taxon occurring at greater abundance beneath these two farms was the polychaete *Schistomeringos loveni*; the ophiuroids *Amphiura annulifera*, *A. alba*, and *A. aster* were all more abundant outside the farm. At a third site, a slightly greater species richness was recognised beneath a farm than at an adjacent control site, although macro-benthic invertebrate assemblages were not significantly different beneath and outside this farm.

Giles *et al*. (2006) recorded six main taxonomic groups in their survey and a higher macrofauna abundance and biomass beneath a farm in the Firth of Thames, but they also considered that differences in assemblages beneath

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the farm may not be due to the influence of the farm given generally low diversity and abundance both inside and outside the farm.

Until now, de Jong (1994) (unpublished MSc thesis) was the most comprehensive biological study evaluating the effects of mussel farming activities on sea-bed communities in New Zealand. de Jong (*loc. cit.*) measured species richness, biomass and abundance of the ten most abundant macro-benthic invertebrate species each quarter for one year. He reported no obvious difference in species richness beneath and outside the farm; highest species richness to occur in September, and lowest in December; no significant differences in biomass within and outside the farm, although biomass did tend to be higher within the farm; polychaete taxa *Onuphis aucklandensis*, *Lumbrinereis* sp. and *Aglaophamus macroura* to be less abundant within the farm, and an alpheid shrimp (*Alpheus* sp.) to be more abundant within the farm; and a biological footprint of the farm that tended to extend to a maximum of 10 m from the physical farm boundary.

Each of these studies that has assessed the footprint of a farm has focussed on quantifying the abundance, richness and diversity of invertebrates that occur beneath them, and comparing these with values collected outside of the farm within control sites. Effects need not necessarily be biological alone; they could equally be of a hydrographic nature, or relate to sediment chemistry and composition.

Benthic invertebrates are often used to appraise the environmental impact of an activity, as they are more persistant than, for instance, water or plankton samples (Pearson and Rosenberg 1978). Indicator species generally are classified as one of opportunistic or sensitive; opportunistic taxa are those that are more abundant at impacted sites, because they are more tolerant of environmental variation, and/or rapid colonisers of otherwise defaunated sediments; and sensitive taxa are less abundant or absent from impacted sites, because they are less tolerant of environmental variation, or less adept at recolonisation following disturbance.

Some of the most frequently cited opportunistic taxa are polychaete worms, with one in particular, *Capitella capitata* (Family Capitellidae), regularly used as an indicator of disturbance and/or organic enrichment or pollution in sediments (e.g. Pearson & Rosenberg 1978, Méndez *et al*. 1997, Surugiu 2005). Elevated abundances of this taxon have been reported in previous studies on the effects on mussel farming (Mattsson & Linden 1983, Ragnarsson & Raffaelli 1999, Christensen *et al*. 2003, Callier *et al*. 2007), and fish farming (Heilskov & Holmer 2001, Tomassetti & Porrello 2005). To the contrary, and of particular importance for this current study given the proximity of the two sample sites, Roberts *et al*. (1998) report polychaetes of the family Capitellidae to be more abundant at control sites than at dredge-spoil impacted sites in Rangitoto Channel, Hauraki Gulf. Thus, capitellid polychaetes, and particularly *Capitella 'capitata'* cannot be considered universally appropriate as indicators of anthropogenic disturbance.

Taxa recorded to be more abundant in spoil-disposal impacted sites by Roberts *et al*. (1998) for Hauraki Gulf included the bivalves *Dosinia lambata*, *Theora lubrica* and *Tellinota edgari,* and the heart urchin *Echinocardium cordatum*. Polychaete taxa identified as opportunistic appropriate as indicators of eutrophication and organic enrichment include those of the families Capitellidae, Dorvilleidae and Spionidae (Pearson & Rosenberg 1978, Surugiu 2005). Taxa considered sensitive to spoil disposal in Hauraki Gulf proposed by Roberts *et al*. (1998) included the ophiuroid *Amphipholis squamata*, an isopod (Anthuridae sp. 1), and polychaetes of the family Syllidae; sensitive taxa recorded by Surugiu (2005) included polychaetes in the families Nephtyidae, Glyceridae and Syllidae.

Effects of mariculture on sea-bed sediments

A body of research assessing mussel-farm impacts on the sea bed has examined the effects on sediment and water chemistry, and then related these effects to alteration of macrofauna. Pearson & Rosenberg (1978) suggest that benthic macrofauna respond quickly to organic enrichment and pollution, therefore bio-indicators are appropriate and therefore often used to determine environmental effects, as discussed previously.

Sedimentation from mussel farming activities can lead to accumulation of finer-grained sediments beneath farms, and organic enrichment of these sediments, sourced to chloroplastic pigment, protein and lipid accumulation beneath farms from mussel faecal (inclusive pseudo-faecal) deposits (Mattsson & Lindén 1983, Mirto *et al*. 2000); elevated levels of ammonium ions have also been found in the anoxic sediments beneath farms relative to reference, non-effected sites (Ljungqvist 2005).

Increased organic enrichment of sediments beneath mussel farms, from mussel faecal and pseudofaecal deposition has also been reported in New Zealand (Giles & Pilditch 2006), with increased deposition rates of faecal material occurring during the austral spring (Giles *et al*. 2006). The high levels of sedimentation and biodeposit decomposition usually result in organic enrichment of sediments beneath a farm, although adverse effects caused by biodeposits usually do not extend further than 50 m from the boundary of mussel farms studied in New Zealand (Hartstein & Stevens 2005). Elevated levels of ammonium ions, and both nitrogen and oxygen have been reported from beneath mussel farms, relative to levels at control sites (Kaspar *et al*. 1985, Christensen *et al*. 2003).

Similar to Mattsson & Lindén (1983), de Jong (1994) also recorded differences in the characteristics of sediments within and outside a mussel farm; silt was the major component of sediments outside the farm, whereas clays followed by silts characterised sediments beneath the farm.

Hartstein & Stevens (2005), based upon Hartstein (2003) (PhD thesis), recorded significantly higher sediment flux rates within farm sites than control sites, particularly during the austral spring. Mean sediment grain size differed within and outside the farm at each of three survey locations; two areas (one attributed to low and one to high hydrodynamic energy) had lower mean sediment grain size (coarser sediments) within farms than at control sites, and a third area (attributed to low hydrodynamic energy) had a higher mean sediment grain size (finer sediments) beneath the farm than at the control site. However, these differences were not statistically compared

in his report, grain-size analysis was undertaken in an inappropriate manner (it was not wet sieved, which is necessary for marine sediments), and they only commented that the fine sediment components beneath and outside the farm were almost identical, characterising the two low energy areas as predominantly muddy, and the high energy area as predominantly sandy. Side-scan sonar was also used by Hartstein, and more backscatter (indicative of mussel shell debris) was encountered within the farm than outside the farm, particularly in the two lower energy areas. Giles *et al*. (2006) and Giles (2006) report similar results to those of Hartstein (2003), with flux rate greater within a mussel farm, particularly during the austral spring, and with sediments beneath and outside this farm being dominated by silts, with a significantly greater shell material component in sediments beneath the farm.

Hydrodynamics

Chamberlain *et al*. 2001 recorded the biological effects of mussel aquaculture on macrobenthic communities varied in different areas, and suggested that such variation may be due to hydrographic regimes. This is supported by New Zealand research on sea-bed communities associated with three farms located in different hydrodynamic regimes (Hartstein & Rowden 2004); significant differences in macrofaunal assemblages were found inside and outside two mussel farms situated in a relatively low-energy environments, whereas no significant difference in these assemblages was recognised for one farm in a relatively high-energy environment. However, the hydrodynamics of one region differ from those of another, and therefore the biological effects of mariculture activities cannot be extrapolated to those of all sites. As studies of the effects of aquaculture in New Zealand have focused on Marlborough Sounds and Firth of Thames, the effect of this activity off eastern Waiheke Island cannot be presumed to be the same.

Benthic surveys throughout Hauraki Gulf and Waitemata Harbour

With the exception of the work on sea-bed communities throughout the Waitemata Harbour and inner Hauraki Gulf undertaken and reported by

Powell (1937), the sea-bed communities off eastern Waiheke Island have not been earlier reported. On the basis of nine dredge stations in this region, Powell attributed most of the sea bed off eastern Waiheke Island to an urchin (*Echinocardium*) formation/association (with a formation characterised by the presence of a characteristic taxon, and an association characterised by the absence of that taxon, but presence of subdominant taxa), and a second formation, that of a *Tawera* + *Venericardia* (now *Purpurocardia*) between Rotoroa Island and Ponui Island, and the eastern side of Ponui Island (Figure 6). The reality is that too few sites were sampled by Powell for him to have generalised sea-bed communities throughout this region.

Seabed communities in Waitemata Harbour have been comprehensively surveyed on one other occasion only (Hayward *et al* 1997), but this report did not extend to the sea-bed environment off eastern Waiheke Island. Additional, limited accounts of sea-bed fauna throughout the Waitemata Harbour and Hauraki Gulf are provided by Roberts (1990) and Roberts *et al*. (1998), both for Rangitoto Channel; Dewas (2008) for sea-bed communities off eastern Motutapu Island and Otata Island, part of the Noises complex of Islands in Hauraki Gulf; and Gowing *et al*. (1997) for the sea-bed off the Noises complex of islands, pre- and post spoil disposal.

The few published New Zealand studies report variable, but generally negative effects on sea-bed communities and sediments beneath mussel farms, partly consistent with international literature. Given so few studies have been undertaken in New Zealand, despite the importance of this industry to the New Zealand economy, additional research on these effects is warranted in different environments. Herein the sea-bed macrofaunal communities off eastern Waiheke Island are described, as are the patterns in distribution, abundance and diversity of species and their assemblages throughout the region, in addition to those beneath and at progressively increasing distances from an existing mussel farm at a hitherto unstudied location.

Methods

To meet the objectives of this research programme, a three-phase methodology was followed, although many aspects of this research were undertaken concurrently:

1. Characterisation of benthic invertebrate assemblages off eastern Waiheke Island.
2. Determination of spatial and temporal variation in the biological footprint of the existing mussel farm.
3. Determination of the physical footprint of the mussel farm (sediment grain-size analysis) along a single transect, and overall throughout the farm using side-scan sonar and drop cameras.

Sample collection

All samples, whether collected for biological purposes or for sediment grain-size analysis, were taken by Van Veen grab (KC Denmark, 12.110). This equipment has a bite aperture of 0.0336 m^2, but the depth to which it samples depends upon grain size and degree of substratum compaction; accordingly the volume of any sample can vary. Any grab was discarded in the event the sample was not at least ~50% full.

Upon collection each sample was labelled with a sample identifier relating it to GPS coordinate, date and depth (Appendix 1, Table A1). Biological samples were immediately fixed in a 5% buffered (sodium bicarbonate) formalin-seawater solution, double bagged, and left for a minimum of two days to fix prior to sorting. Samples for sedimentary analysis were chilled aboard the vessel and frozen when returned to AUT laboratory (within five hours of collection), until analysis was undertaken.

Biological sample processing

Following fixation, all samples were sieved over a 500 µm Endicott mesh, to remove fine-sediment fractions. Fractions retained in the sieve were sorted by eye in a tray filled with freshwater — a process usually taking 0.5–4

hours per sample — with all specimens within being removed and placed into plastic pottles containing 40% isopropyl alcohol for subsequent identification.

Where appropriate (with the obvious exception of large-bodied fauna), all invertebrate taxa have been identified using a combination of stereo and compound light microscopy.

In instances where fauna fragmented, only anterior or posterior/head or tail regions were counted, and the greater number (but not both) determined to estimate density of any given taxon. This is particularly important for polychaete taxa that are subject to damage during sample collection, fixation and subsequent sorting. In instances where neither head nor tails of polychaete taxa were included within or sorted from any sample, details of parapodial and setal structure were determined by light (compound) microscopy, and compared against vouchers taken from anterior, central and posterior body regions of intact specimens to identify species; in instances where fragments only were included, unless it was obvious that more than one individual was represented in any given sample (based on relative size, sex, colour, or other obvious anatomical condition of any fragments), counts are arbitrarily assumed to be one. Only individual colonies of colonial species have been enumerated.

In instances where some female (polychaetes and crustaceans) had been obviously brooding, the abundances of certain species sometimes are elevated given brood disassociation from parents during sample collection, fixation or subsequent sorting. Obvious cases of such disassociation were not counted in samples.

Given a general dearth of systematic monographs for Polychaeta and many Arthropoda, many taxa cannot be identified to species, and in many instances genera or even phylum. In such instances, taxa have been identified to the lowest common denominator, of species or species-specific enumerated unknown, and enumerated. Exceptions to this are all Bryozoa, Nemertea, Oligochaeta, Nematoda, Platyhelminthes, Pycnogonida, Porifera

and compound Ascidiacea, each being treated as a single taxonomic unit. One taxonomic unit, WTF is an abbreviation for an unknown taxon.

A voucher set of all identified taxa, and those attributed a species-specific enumerated unknown, have been accessioned into the biological collections at AUT.

Characterisation of benthic communities off eastern Waiheke Island

The macrobenthic communities off eastern Waiheke Island, between Cowes Bay and Kauri Point (36°46.52–49.85'S, 175°09.47–12.21'E), 4–30 m, were determined from species contained within 228 grab samples (including 102 samples collected along three transects extending from within the mussel farm to approximately 80 metres beyond its physical boundary) between February and March 2008 (Figure 1).

Sites were selected in the field, being distributed throughout the greater eastern Waiheke region within and proximal to the mussel farm, focussing on the northern and northeastern area, including all depth ranges. Survey effort constraints were imposed by sea and subsequent sorting time limitations.

Subtidal substratum characterisation, eastern Waiheke Island

Each of the 228 grab samples collected for characterisation of the benthic communities throughout eastern Waiheke Island was visually characterised into one of three substratum types: muds, mud/gravels or gravels. Characterisation was based on a visual appraisal of the proportion of shell gravel and granule to mud (silt) within any sample; this was undertaken in the laboratory during sample processing to remove benthic flora and fauna. Characterisation of sea-bed type into these three categories excluded obvious dead *Perna* (mussel) shell drop in samples from beneath the farm.
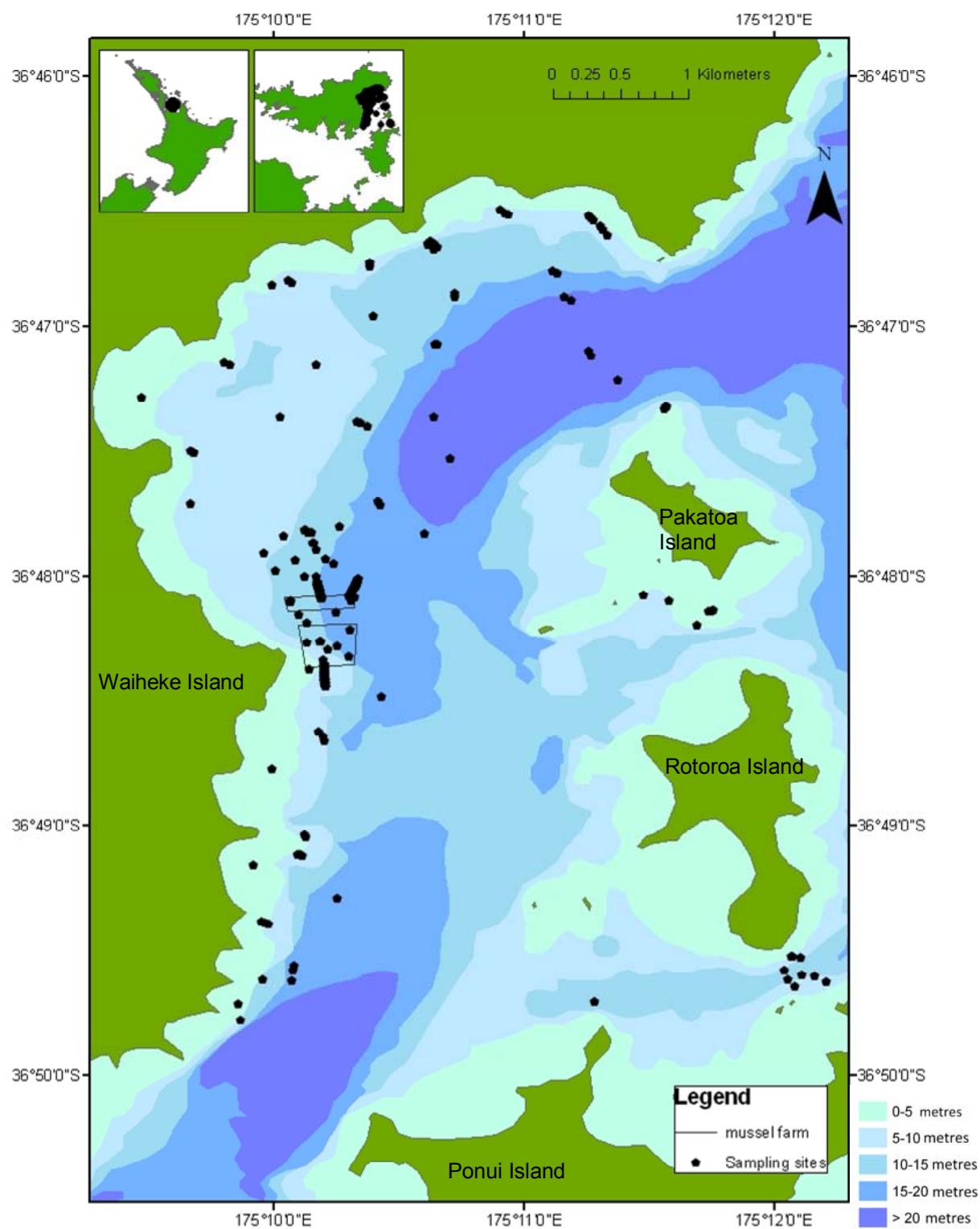
Figure 1: Sampling sites, eastern Waiheke Island, February and March 2008. Insets: North Island, New Zealand; and Waiheke Island, Hauraki Gulf. (Mussel farm depicted by rectangles.)

Following sample processing, and mapping of the distribution of the coarsely assessed three sedimentary types throughout eastern Waiheke region, nine additional samples (three from within each substratum type), were collected to more accurately determine sediment grain-size composition within what had been visually characterized as muds, mud/gravels and gravels, distributed in accordance with Figure 3. Within 5 hours of collection, samples were frozen and later defrosted for wet-sieving analysis.

Grain-size composition was measured based on the fractionated sieving of sediment through a stack of sieves. Water spray from the uppermost sieve left the sieve stack (available mesh sizes: 3,350, 1,180, 1,000, 600, 500, 300, 150, 63μm) together with the last fraction through the outlet in the collector. Rinsing and manual sample agitation was continued until the liquid leaving the sieve stack outlet was no longer turbid. Water contained in the collector was further filtered through 11μm filter paper, with the settled sediment fraction being collected after 48 hours. On completion of the rinsing and sample agitation process, the fractionated sediment residues in each mesh size, and settled sediment residue that passed through the 11μm filter paper were oven dried to constant weight at 90°C.

To assess the sedimentary characteristics of each sample, the sediment weights were calculated into cumulative percentage and plotted as a cumulative frequency curve, starting with the coarsest fraction and ending with the most fine (Appendix 2). Grain-size intervals used to produce the plots and in the rest of this document are presented in phi scale (φ): $\varphi = -\log_2$ of mesh size in mm (Table 1). The grain-size composition of each sample then was characterised by five granulometric indices: the median particle diameter (φ50), the first (φ25) and third (φ75) quartiles, sorting coefficient: (φ75 - φ25)/2, and φ-Quartile skewness: (φ75 + φ25)/2 - φ50; each φ-value was read directly from the plot (example as in Figure 2). The φ-values indicate the average grain size and spread of grain-size fractions within any given sample, enabling statistical evaluation of the relationship between sedimentary characteristics and the fauna associated with any substratum type in a universally accepted manner. The sorting coefficient expresses the number of phi units lying between upper and lower quartile diameters;

sediments with a small spread between the quartiles are classified as 'well sorted' (Table 2). The quartile skewness indicates the prevailing grain size fraction relative to the median grain-size diameter; a positive skewness indicates this to be greater than the median diameter, whereas a negative skewness indicate this to be less than the median diameter.

Table 1: Conversation of grain size from original (principal) size (µm) to phi-scale.

Principal size (µm)	Phi Scale Equivalent (φ)	Size Class
3,350	-1.74	Very coarse sand/ Gravel
1,180	-0.24	
1000	0	Coarse sand
600	0.737	Medium sand
500	1	
300	1.74	Fine sand
150	2.74	Very fine sand
63	4	Silt
11	6.5	

Table 2: Sediment sorting classes from Gray 1981.

Sorting coefficient class	Classification of sediment
<0.35	Very well sorted
0.35–0.50	Well sorted
0.50–0.71	Moderately well sorted
0.71–1.00	Moderately sorted
1.00–2.00	Poorly sorted
2.00–4.00	Very poorly sorted
>4.00	Extremely poorly sorted
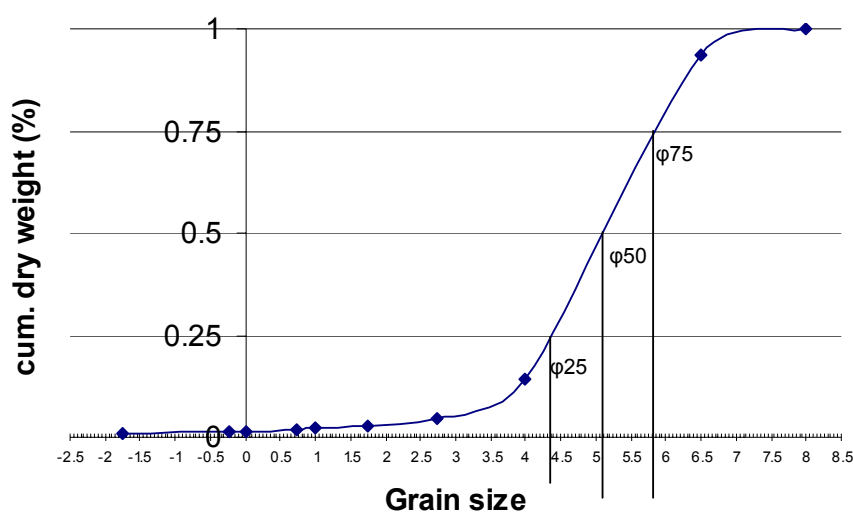
Figure 2: Example of cumulative percentage plot of sediment grain size, phi-scale.

Biological footprint of mussel farm

Without *a priori* knowledge of sea-bed type or community composition throughout this region, three transects were identified for preliminary surveying during February 2008: Transect 1 (north), 2 (northeast), and 3 (south) of the farm (Figure 4).

Given limitations in GPS accuracy (± 5m), to ensure accurate spacing of sampling sites, surface buoyed transects anchored at both ends, with floats tied at 10-metre intervals were established, starting 20 metres within the mussel farm and extending to 80 m (February), 70 m (May) and 110 m (August) outside the farm. At each 10 m interval three Van Veen grab replicate samples were collected from within a 2 m radius of the surface buoy.

Transect 1 was surveyed on each of three occasions (February, May, August 2008), whereas the sea bed along Transects 2 and 3 was sampled during the first survey (February 2008) only. Transect 1 was selected for longer-term monitoring for reasons to be detailed in the results and discussion; it is also in this general direction that a proposal exists to extend the mussel farm a further 10 ha.

An additional 17 Van Veen grab samples were collected within the mussel farm at 17 randomly pre-selected sites. Surveying of these 17 sites (± 5 m GPS accuracy) was undertaken on each of three occasions: February, May and August 2008; samples were collected from these same 17 sites during each survey; only a single (non-replicated) sample was taken at each site.

A synopsis of sampling effort within the farm, and along each of these transects is presented in Table 3.

Table 3: Van Veen grab samples collected by month.

	Transect 1	Transect 2	Transect 3	Within farm (random sites)	Totals
	# samples	# samples	# samples	# samples	# samples
February 2008	33	33	36	17	119
May 2008	30	0	0	17	47
August 2008	42	0	0	17	59

Biodiversity data analyses

Raw data were used to calculate DIVERSE indices in PRIMER: total individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H'), and Simpson index ($1-\lambda'$). Each index provides different information on aspects of species diversity, abundance and distribution (Table 4). DIVERSE indices of different environmental factors were tested by ANOVA in SPSS 15.0 to determine whether significant differences existed; null-hypotheses were rejected when p-values were less than 0.05.

Multivariate analysis followed methods of Clarke and Warwick (1994). Species abundances were square root-transformed to down-weight the effect of very abundant species; and similarity matrices were calculated with the Bray-Curtis similarity index. Data then were presented graphically using multi-dimensional scaling (MDS) ordinations.

One way and Two-way crossed pairwise comparisons (ANOSIM, Clarke & Green 1988) have been used to analyse species assemblage similarity by different factors (e.g. substratum type, spatial effects (whether inside or outside the physical boundary of the mussel farm), and temporal effects (month of sampling)); the null-hypothesis (that assemblages were similar) was rejected when significance levels were less than 0.5%.

Individual species contributions (up to about 90%) to average similarity and dissimilarity within each identified species assemblage were examined by the SIMPER (similarity percentage) procedure (Clarke & Warwick 1994) using a Bray-Curtis dissimilarity on square-root-transformed abundance data. Species were listed in decreasing order of their contribution to species assemblage similarity and dissimilarity (Clarke & Gorley 2001).
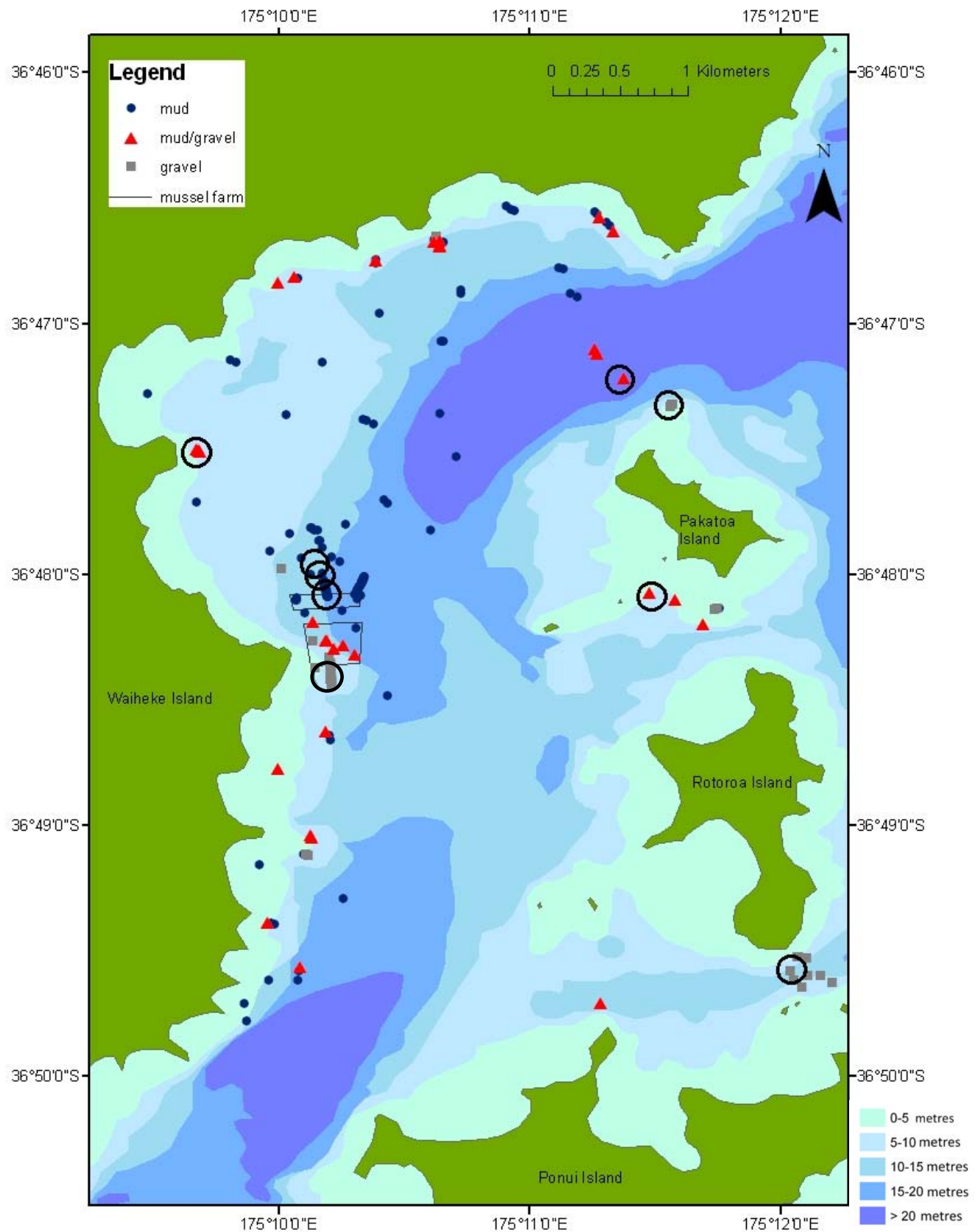
Figure 3: Location of nine sampling sites for grain-size analysis (hollow black circle), three replicates in each of muds (blue circle), mud/gravels (red triangle) and gravels (grey square).
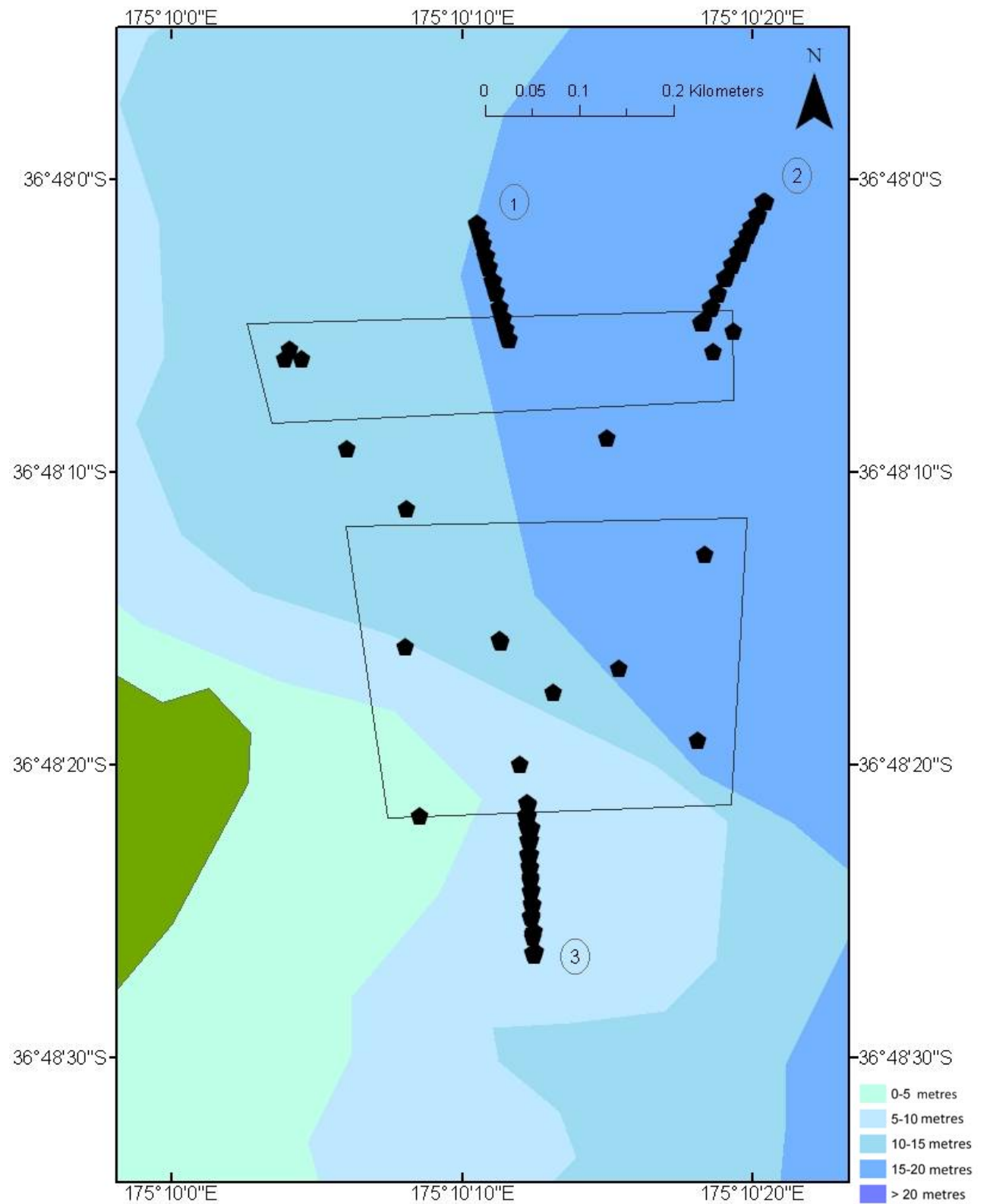
Figure 4: Mussel farm monitoring Transects (1–3), February 2008.

Table 4: Definition of DIVERSE indices.

Total number of individuals (*N*)

Number of individuals present in each sample.

Margalef's index (*d*)

d= (S-1)/log *N*

Species richness incorporates the total of individuals (*N*); A measurement of the number of species for a given number of individuals. *S* = total species richness.

Shannon diversity index (*H'*)

$H' = -\sum_i p_i \log (p_i)$, where p_i is the proportion of a species to the total number of individuals.

Commonly used diversity measurement, takes the total number of species (*S*) and the evenness of species into account. The index can be increased either by having rare species or high species evenness.

Pielou's evenness index (*J'*)

$J' = H'/H'_{max} = H'/\log S$

H'_{max} is the maximum possible value of Shannon diversity (namely log *S*). It represents the equitability of species distribution. In most cases, increase in environmental stress may decrease evenness by increasing dominance.

Simpson index (1-*λ'*)

$1-\lambda' = 1-\{\sum_i N_i(N-1)\}/\{N(N-1)\}$

λ' is a dominance index with a high value corresponding to assemblages dominated by one or very few species. In contrast, 1-*λ'* is a evenness/diversity index. This index (1-*λ'*) has a natural interpretation as the probability that any two individuals randomly chosen from a sample belong to the same species.

Species accumulation curves

To provide an indication of the thoroughness of sampling effort off Waiheke Island, species accumulation curves are prepared for all substrata combined, then separately for each substratum type and Transect. To eliminate the possibility of *Perna* shell drop, and/or live *Perna* within some grab samples elevating species richness and abundance within an otherwise relatively homogeneous muddy substratum, species accumulation curves are further determined for each transect, including and excluding those sites at which *Perna* occurred. Curves are prepared using the 'Species-Area plot' in PRIMER.

Occurrence of indicator taxa

Indicator taxa (both opportunistic and sensitive) of organic enrichment, dredge spoil, and mussel farm impacts (Table 5) are evaluated separately. The spatial and temporal distribution and abundance of each is analysed statistically to determine whether any one or assemblage of taxa is

appropriate for rapid assessment of the effects of mussel farming off eastern Waiheke Island.

Table 5: Indicator taxa evaluated in this study.

Perspective	Indicator taxa
Organic enrichment opportunistic taxa	*Capitella capitata*
	Heteromastus filiformis
	Dorvilleidae
	Spionidae
Organic enrichment sensitive taxa	Glyceridae
	Goniadidae
Organic enrichment and mariculture sensitive taxa (*sensu* de Jong 1994)	Nephtyidae
Organic enrichment and spoil sensitive taxa	Syllidae
Spoil sensitive taxa	Anthuridae
	Amphiuridae
Spoil opportunistic taxa	*Dosinia lambata*
	Theora lubrica
	Echinocardium cordatum
Mariculture opportunistic taxa (*sensu* de Jong 1994)	Alpheidae
Mariculture sensitive taxa (*sensu* de Jong 1994)	*Lumbrineris sphaerocephala*
	Onuphis aucklandensis

Relative Rarity

Earlier analyses have used full species and abundance data, and are informative for evaluating relationships between species and assemblages at various spatial scales (e.g., within and outside the farm, by bathymetry, and by substratum type). However, to appraise the relative rarity of species throughout the region these abundance data have been transformed into presence/absence format, and based on the frequency of occurrence of any taxon within samples (rather than its absolute numeric abundance), it is referred to one of *very rare* to *ubiquitous* in distribution, in accordance with that schema detailed in Table 6. This simple transformation (*sensu* Palacio 2008) provides an indication of the relative rarity of taxa throughout the survey region; it is possible for a single species to occur in more than one substratum type or depth range, and be classified differently within them.

By way of example, should one species occur at three of 228 surveyed sites (February) throughout eastern Waiheke Island, then it would be classed as a *very rare* species throughout the surveyed region (3 being ~1% of 228).

This, however, is not that meaningful, given unequal surveying intensity in different substratum types, and *a priori* knowledge that species assemblages do differ in different substrata. Accordingly, this schema is refined throughout this thesis, and in some instances is applied to a subset of data only, such as those sites occurring within muds, or even finer scale, those occurring within a bathymetric range within a particular substratum type.

Table 6: 7-point ordination of species rarity (from Palacio 2008).

Occurrence (%)	Rarity score
<5	Very rare
5–10	Rare
11–25	Uncommon
26–50	Frequent
51–75	Common
76–95	Very common
>95	Ubiquitous

Relative Species Richness

This scale ranks species richness at a given site relative to the maximum and minimum numbers of species encountered at any site during all survey dates for the eastern Waiheke region (Table 7); thus, if 40 taxa occurred within a given sample, and the maximum number of taxa recorded from any sample was 43, then this site would be classified as *high species richness* (40 being ~93% of 43).

Table 7: Ordination of Species Richness using a 7-point scale for all subtidal substratum types, eastern Waiheke Island.

Species richness (%)	Richness score
<5	Very low
5–10	Low
11–25	Fairly low
26–50	Medium
51–75	Fairly high
76–95	High
96–100	Very high

Relative Abundance

One final ordination is applied to biodiversity data collected during this research, to evaluate the spatial distribution of relative abundance of individuals throughout the surveyed region. For instance, should a sample from any site have 21 individuals in it, and the range in abundance of individuals throughout the survey region for any given sample was 2 to 1572, then this site would be categorised as *very low* in abundance (21 being ~0.1% of 1,572), in accordance with Table 8. Of course this schema, as previously, also can be broken down by substratum type, depth, and by season. This schema is referred to one of abundance of individuals, rather than density, so as not to confuse biomass, which was not determined in this research.

Table 8: Ordination of Relative Abundance (standardised per m^{-2}) using a 7-point scale for all subtidal substratum types, all surveys, eastern Waiheke Island.

Abundance (%) of 46,786 m^{-2} (maximum Abundance value)	Abundance score
<5	Very low
5–10	Low
11–25	Fairly low
26–50	Medium
51–75	Fairly high
76–95	High
96–100	Very high

Physical footprint of mussel farm

The physical footprint of the mussel farm was determined by way of a 2-phase approach: 1) sedimentary by sediment grain size analysis, and 2) structural by side-scan sonar, verified by drop camera.

Sediment grain-size analysis

During May 2008, 14 sediment samples were collected by Van Veen grab along Transect 1 at 10-metre intervals, starting 20 m within the farm and extending to 110 m outside the farm. As for biological sampling, sediment samples were collected along a surface buoyed line anchored at both ends, with floats tied off at 10 m intervals. All samples were frozen at -20°C until wet sieving was undertaken.

Structural (Side-scan sonar)

Side-scan sonar imagery was used to identify the sea-bed surface structure throughout the mussel farm. The underwater transducer (SportScan) was deployed into the water column, connected via a cable to the recording device, and towed at 4 knots from the AUT vessel in May 2008. Each scan commenced in the south and proceeded north along the mussel farm, with the transect stopped when no changes were apparent in sea-bed structure; each transect extended a minimum of 100 m from the northern and southern farm boundaries. Recorded sonar images were georarified to GIS recognized files through Sonar Wiz. Map. Side-scan imagery was verified by drop video deployments throughout the survey region.

GIS analysis

Coordinates of sample sites were recorded by GPS. Way point, species diversity and environmental factors were imported into Arc Map to create Attribute Tables, using the coordinate system WGS 1985.

Results

Sea-bed communities throughout eastern Waiheke Island

Based upon examination of grab samples in the laboratory, the substratum at each site was visually characterised as being primarily mud, gravel, or an admixture of the two, mud/gravel. Data from wet-sieving grain-size analysis of three replicate sediment samples collected from three representative sites of each (Figure 3) are presented in Table 9 and Figure 5; visual characterization resulted in 139 samples being classified as primarily mud, 32 as mud/gravel, and 57 as gravel; these are distributed throughout the survey area as depicted in Figure 6.

A drop-camera also was deployed throughout eastern Waiheke in January 2009, in areas deemed representative of each of the three main substratum types throughout this region. Stills from these deployments are presented in Figure 7.

Table 9: Sediment grain size of each substratum.

Substrata	Mud			Mud/gravel			Gravel		
	# of samples	Mean	SD	# of samples	Mean	SD	# of samples	Mean	SD
phi 25	3	4.13	0.38	3	0.1	0.61	2	-1.15	0.49
phi 50	3	4.97	0.15	3	1.9	0.98	3	-0.1	0.95
phi 75	3	5.93	0.45	3	4.63	0.4	3	2.07	0.67
Sorting coefficient	Moderately to Moderately well sorted			Very poorly sorted			Poorly sorted		

In total, 326 taxa were recorded, 168 taxa within the mussel farm and 307 taxa outside the mussel farm (Table 10) (Appendix 4, Table A9), from within 228 sea-bed samples collected off eastern Waiheke Island.

Table 10: Taxa recorded within, outside the farm, Transect 1, 2 and 3, February 2008

Phylum	Class	Order	Family	species	inside	outside	Transect 1		Transect 2		Transect 3	
							inside	ouside	inside	ouside	inside	ouside
Annelida	Clitellata	NA	NA	Oligochaeta	p	p	p	p	p	a	p	p
	Polychaeta	Aciculata	Aphroditidae	*Aphrodita talpa*	a	p	a	a	a	a	a	a
				cf. *Aphrodita talpa*	a	a	a	a	a	a	p	a
			Dorvilleidae	*Dorvillea antarctica*	p	p	p	a	a	a	p	p
				Dorvilleidae sp. 1	a	a	a	p	p	a	p	a
			Eunicidae	*Eunice* sp. 1	p	p	a	a	a	a	p	p
				Eunice sp. 2	a	a	a	a	a	a	p	p
				Eunice sp. 3	a	p	a	a	a	a	a	a
				Marphysa depressa	a	a	a	a	a	a	a	p
			Glyceridae	*Glycera americana*	p	p	a	a	a	a	p	p
				Glycera tesselata	p	p	a	a	p	a	p	p
				Hemipodus sp.	p	p	a	a	a	a	p	p
			Goniadidae	*Glycinde* sp.	a	p	a	a	a	a	p	p
				Glycinde sp.2	a	p	a	a	a	a	a	a
				Goniada sp.	a	p	a	a	a	p	a	p
			Hesionidae	*Ophiodromus* sp. 2	a	p	a	a	a	a	a	a
				Ophiodromus angustifrons	p	p	p	p	p	p	p	p
			Lumbrineridae	*Lumbrineris sphaerocephala*	p	p	p	p	a	p	a	p
			Nephtyidae	*Nephtys macroura*	p	p	p	p	a	p	a	p
			Nereidae	*Nereis cricognatha*	a	p	a	a	a	a	a	p
				Perinereis nuntia	a	p	a	p	p	a	p	p
				Nereidae	a	p	a	a	a	a	p	a
			Oenonidae	*Arabella* sp.	p	p	p	p	p	p	p	p
			Onuphidae	*Onuphis aucklandensis*	p	p	p	p	p	p	a	a
				Onuphis sp. 2	a	p	a	a	a	a	a	a
			Phyllodocidae	Phyllodocidae sp. 1	a	p	a	a	a	a	p	a
				Phyllodocidae sp. 2	a	p	a	a	a	a	a	p
				Phyllodocidae sp. 3	a	p	a	a	a	a	p	p
				Phyllodocidae sp. 4	a	p	a	a	a	a	p	a
			Pisionidae	*Pisione* sp.	a	p	a	a	a	a	a	p
			Polynoidae	*Lepidasthenia* sp.	p	p	a	a	a	a	a	a
				Lepidonotus sp. 1	a	p	a	p	p	a	a	p
				Lepidonotus sp. 2	p	p	a	p	a	p	a	p
			Sigalionidae	*Psammolyce antipoda*	p	p	a	a	a	a	p	p
				Sthenelais sp.	p	p	p	p	p	p	a	p
			Sphaerodoridae	*Sphaerodoridium* sp.	a	p	a	a	a	a	a	a
			Syllidae	*Sphaerosyllis* sp.	a	p	a	a	a	a	p	p
				Syllid sp. 4	a	p	a	p	a	a	p	p
				Syllid sp. 5	a	p	a	p	a	a	p	p
				Syllid sp. 6	a	p	a	a	p	a	a	p
				Syllid sp. 8	a	p	a	a	a	a	a	p
				Syllid sp. 10	p	p	a	a	a	a	p	p
				Syllid sp. 22	p	p	a	a	a	a	a	a

Phylum	Class	Order	Family	species	within	outside	Transect 1		Transect 2		Transect 3	
							within	ouside	within	ouside	within	ouside
Annelida	Polychaeta	Aciculata	Syllidae	Syllid sp. 23	a	p	a	a	a	a	a	a
				Syllid sp. 24	a	p	a	a	a	a	p	p
				Syllid sp. 25	a	a	a	a	a	a	a	p
				Syllid sp. 26	a	p	a	a	a	a	a	a
				Syllid sp. 27	a	p	a	a	a	a	a	a
				Syllid sp. 28	a	p	a	a	a	a	a	a
				Syllid sp. 29	a	p	a	a	a	a	a	a
				Syllid sp. 30	a	p	a	a	a	a	a	a
				Syllid sp. 31	a	p	a	a	a	a	a	a
		Canalipalpata	Ampharetidae	Ampharetidae sp.	p	p	a	a	a	a	p	p
			Chaetopteridae	*Chaetopterus* sp.	a	p	a	a	a	a	a	a
			Cirratulidae	Cirratulid sp. 1	p	p	a	a	p	p	p	p
				Cirratulid sp. 2	a	p	a	a	a	a	a	p
				Cirratulid sp. 3	a	p	a	a	a	a	a	p
				Cirratulid sp. 4	a	p	a	a	a	a	p	p
				Cirratulid sp. 5	a	p	a	a	a	a	a	a
				Cirratulid sp. 6	a	p	a	a	a	a	a	a
			Flabelligeridae	*Brada villosa*	p	p	a	a	a	a	a	p
				Diplocirrus sp. 1	p	p	a	a	a	a	p	p
				Flabelligera affinis	p	p	a	p	a	a	a	p
				Pherusa parmatus	a	p	a	a	a	a	a	a
			Oweniidae	*Owenia fusiformis*	a	p	a	a	a	a	a	a
			Pectinariidae	*Pectinaria australis*	p	p	a	p	p	p	p	p
			Sabellariidae	*Sabellaria* sp.	a	p	a	a	a	a	a	a
				Sabellariidae sp.	a	a	a	a	a	a	a	p
			Sabellidae	*Branchiomma* sp. 2	a	p	a	a	a	a	a	a
				Sabellid sp. 1	p	p	a	a	a	a	p	p
				Sabellid sp. 2	p	a	a	a	a	a	a	a
				Sabellid sp. 4	a	p	a	a	a	a	a	a
				Sabellid sp. 5	a	p	a	a	a	a	a	a
				Sabellid sp. 6	a	p	a	a	a	a	a	a
			Serpulidae	*Galeolaria hystrix*	a	p	a	a	a	a	a	a
				Hydroides norvegicus	p	p	a	p	p	a	p	p
				Pomatoceros terranovae	a	p	a	a	a	a	a	a
			Spionidae	*Aonides* sp.	p	p	p	p	p	p	p	p
				Prionospio sp.	p	p	p	p	p	p	p	p
				Scolecolepides benhami	a	p	a	a	a	a	a	a
				Spionid sp. 1	p	p	a	a	a	a	p	p
				Spionid sp. 3	a	a	a	a	a	a	p	p
				Spionid sp. 4	a	a	a	a	a	a	p	a
				Spionid sp. 5	a	a	a	a	a	a	p	p
				Spionid sp. 6	a	a	a	a	a	a	a	p

Phylum	Class	Order	Family	species	within	outside	Transect 1		Transect 2		Transect 3	
							within	ouside	within	ouside	within	ouside
Annelida	Polychaeta	Canalipalpata	Spionidae	Spionid sp. 7	a	p	a	a	a	a	a	a
				Spionid sp. 9	a	p	a	a	a	a	a	a
			Spirorbidae	*Protolaeospira* sp.	p	p	a	a	a	a	a	a
			Terebellidae	*Thelepus* sp.	p	a	a	a	a	a	a	p
				Terebellid sp. 1	a	p	a	p	a	a	p	p
				Terebellid sp. 2	p	a	a	a	a	a	p	a
				Terebellid sp. 3	a	a	a	a	a	a	p	p
				Terebellid sp. 4	a	p	a	a	a	a	p	a
				Terebellid sp. 5	a	p	a	a	a	a	a	a
				Terebellid sp. 6	a	p	a	a	a	a	a	a
			Trichobranchidae	*Terebellides stroemi*	p	p	a	a	a	a	p	p
				Trichobranchus sp.	p	p	p	p	p	p	p	p
		Capitellida	Capitellidae	*Capitella capitata*	p	p	p	a	a	a	p	p
				Heteromastus filiformis	p	p	p	p	a	a	p	p
			Maldanidae	*Macroclymenella stewartensis*	p	p	a	a	p	a	p	p
				Maldanidae sp. 1	p	p	a	a	a	a	a	a
				Maldanidae sp. 2	a	p	a	a	a	a	a	p
		Cossurida	Cossuridae	*Cossura consimilis*	p	p	p	p	p	p	a	p
		Opheliida	Opheliidae	*Armandia maculata*	p	p	a	a	p	a	p	p
				Ophelia sp.	a	p	p	a	a	a	p	p
			Scalibregmatidae	Scalibregmatidae sp.	a	a	a	a	a	a	p	a
		Orbiniida	Orbiniinae	*Orbinia papillosa*	p	p	a	a	a	a	p	p
			Paraonidae	*Aricidea* sp.	p	p	a	a	a	a	a	a
				Paraonis sp.	a	p	a	a	a	a	a	a
				Paraonidae sp.	a	p	a	a	a	a	a	a
Annelida	Polychaeta	NA	NA	unID polychaete	a	p	a	a	a	a	a	a
		NA	NA	WTF 1	p	a	a	a	a	a	a	a
		NA	NA	WTF 2	p	a	a	a	a	a	a	a
		NA	NA	WTF 3	a	p	a	a	a	a	p	p
		NA	NA	WTF 4	a	p	a	a	a	a	a	a
		NA	NA	WTF 7	a	p	a	a	a	a	a	a
		NA	NA	WTF 8	a	a	a	a	p	a	a	a
		NA	NA	WTF 9	a	p	a	a	a	a	a	a
		NA	NA	WTF 10	a	p	a	a	a	a	a	a
		NA	NA	WTF 11	a	p	a	a	a	a	a	a
		NA	NA	WTF 12	a	p	a	a	a	a	a	a
Arthropoda	Malacostraca	Amphipoda	Ampeliscidae	*Ampelisca* sp.	a	p	a	a	a	a	a	p
			Caprellidae	Caprellid sp. 1	a	a	a	p	a	a	a	a
				Caprellid sp. 2	a	a	a	a	p	a	a	p
			Corophiidae	*Corophium* cf. *acutum*	a	p	a	a	a	a	a	a
			Lysianassidae	Lysianassidae sp. 1	p	a	a	a	a	a	a	a
				Lysianassidae sp. 2	a	p	a	a	a	a	a	a
				Lysianassidae sp. 3	a	a	a	a	p	a	a	a

Phylum	Class	Order	Family	species	within	outside	Transect 1		Transect 2		Transect 3	
							within	ouside	within	ouside	within	ouside
Arthropoda	Malacostraca	Amphipoda	Phoxocephalidae	*Heterophoxus* sp.	a	p	a	a	a	a	a	a
			Corophiidae	*Paracorophium* sp.	a	p	a	p	p	a	a	p
			Phoxocephalidae	*Paraphoxus* sp. 1	p	p	p	p	p	p	p	p
			Phoxocephalidae	*Paraphoxus* sp. 2	a	p	p	p	p	p	p	p
			Podoceridae	*Podocerus* sp.	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 2	p	p	p	p	p	p	p	p
			NA	Amphipod sp. 3	p	p	a	a	a	a	a	p
			NA	Amphipod sp. 4	a	p	a	a	a	a	p	a
			NA	Amphipod sp. 5	a	p	a	p	a	a	p	p
			NA	Amphipod sp. 6	a	p	a	a	a	p	a	a
			NA	Amphipod sp. 7	p	p	a	p	a	p	p	p
			NA	Amphipod sp. 8	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 9	a	a	a	p	a	a	a	a
			NA	Amphipod sp. 10	a	p	p	p	a	a	a	a
			NA	Amphipod sp. 11	a	a	a	p	a	a	a	a
			NA	Amphipod sp. 12	a	p	a	a	p	a	a	a
			NA	Amphipod sp. 13	a	p	a	a	p	a	a	p
			NA	Amphipod sp. 14	a	p	a	a	a	a	a	p
			NA	Amphipod sp. 15	a	a	a	a	a	p	a	a
			NA	Amphipod sp. 16	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 17	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 18	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 19	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 20	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 21	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 22	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 23	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 24	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 25	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 26	a	p	a	a	a	a	a	a
			NA	Amphipod sp. 27	a	p	a	a	a	a	a	a
			NA	unID amphipod	a	a	p	p	a	p	a	p
		Cumacea	Bodotriidae	*Cyclaspis* cf. *coelebs*	a	p	a	a	a	a	a	a
				Cyclaspis thomsoni	a	p	a	a	a	a	a	a
			Diastylidae	*Diastylis insularum*	a	p	a	a	a	p	a	a
				Diastylis neozelanica	a	p	a	a	p	a	a	a
				Diastylopsis thileniusi	p	a	a	a	a	a	a	a
			Gynodiastylidae	*Gynodiastylis carinata*	a	p	a	a	a	a	a	a
			Leuconidae	*Hemileucon* sp.	p	a	a	a	a	a	a	a
				Leucon heterostylis	a	a	a	p	a	a	a	a
				Leucon latispina	a	a	p	a	a	a	a	a
		Decapoda	Alpheidae	*Alpheus richardsoni*	a	p	p	a	a	a	a	a

Phylum	Class	Order	Family	species	within	outside	Transect 1		Transect 2		Transect 3	
							within	ouside	within	ouside	within	ouside
Arthropoda	Malacostraca	Decapoda	Alpheidae	*Alpheus* sp. 1	p	p	a	a	a	a	a	a
			Diogenidae	*Paguristes barbatus*	a	p	a	a	a	a	a	p
				Paguristes setosus	a	p	a	a	a	a	p	p
				Paguristes sp.	p	p	a	a	a	a	a	a
				Paguristes subpilosus	a	p	a	a	a	a	a	a
			Hymenosomatidae	*Halicarcinus cookii*	a	p	a	p	p	a	p	p
				Halicarcinus innominatus	p	a	a	p	a	a	a	a
				Halicarcinus ovatus	a	p	a	a	a	a	a	a
				Halicarcinus varius	a	a	a	a	a	a	p	p
			Majidae	*Notomithrax minor*	p	p	a	p	p	a	p	p
				Pyromaia tuberculata	a	p	a	a	a	a	a	a
				Majidae sp.	a	p	a	a	a	a	a	a
			Ocypodidae	*Macrophthalmus hirtipes*	p	p	a	a	a	a	a	p
			Paguridae	*Lophopagurus cristatus*	a	p	a	a	a	a	p	p
				Lophopagurus kirki	a	p	a	a	a	a	a	a
				Lophopagurus lacertosus	a	p	a	a	a	a	a	a
				Lophopagurus pumilus	a	p	a	a	a	a	a	a
				Pagurus traversi	a	p	a	a	a	a	a	a
				un ID hermit	a	a	a	a	a	a	a	p
			Palaemonidae	*Periclimenes yaldwyni*	p	p	p	p	p	p	a	a
			Pinnotheridae	*Pinnotheres novaezelandiae*	a	a	a	p	p	p	a	a
			Porcellanidae	*Petrocheles spinosus*	a	a	a	p	p	a	a	a
				Petrolisthes novaezelandiae	p	p	a	a	p	p	a	a
			Portunidae	*Liocarcinus corrugatus*	a	p	a	a	a	a	a	a
			Upogebiidae	*Upogebia* sp.	a	p	a	a	a	a	a	a
		Isopoda	Anthuridae	Anthurid sp. 1	p	p	a	a	a	a	a	a
				Anthurid sp. 2	a	p	a	a	a	a	p	p
				Astacilla sp.	a	a	a	a	a	a	a	p
			Cirolanidae	*Cirolana arcuata*	a	a	a	a	a	a	a	p
			Gnathiidae	Gnathiid sp. 1	p	p	p	a	p	a	a	p
			Sphaerodoridae	*Cymodoce hodgsoni*	a	p	a	a	a	a	a	a
			NA	Isopod sp. 1	a	p	a	a	a	a	a	a
		Leptostraca	Nebaliidae	*Nebalia* sp.1	p	p	a	a	a	a	a	p
				Nebalia sp.2	a	p	a	a	a	a	a	a
		Tanaidacea	NA	Tanaid sp. 2	p	p	a	a	p	a	a	a
			NA	Tanaid sp. 3	a	a	a	a	a	a	a	p
			NA	Tanaid sp. 4	a	a	a	a	a	a	a	p
			NA	Tanaid sp. 5	a	p	a	a	a	a	a	a
			NA	Tanaid sp. 6	a	p	a	a	a	a	a	a
		NA	NA	Mysid sp.	a	p	p	p	a	p	a	a
	Maxillopoda	Harpacticoida	NA	Copepod sp.	a	p	a	a	a	p	a	a
		Sessilia	Balanidae	*Balanus trigonus*	p	p	a	p	p	p	a	p

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Phylum	Class	Order	Family	species	within	outside	Transect 1		Transect 2		Transect 3	
							within	ouside	within	ouside	within	ouside
Arthropoda	Ostracoda	NA	NA	Ostracod sp. 1	p	p	p	p	p	p	p	p
		NA	NA	Ostracod sp. 2	p	p	p	p	p	p	p	p
		NA	NA	Ostracod sp. 3	p	p	a	p	a	p	a	a
		NA	NA	Ostracod sp. 4	a	p	a	p	a	p	p	a
		NA	NA	Ostracod sp. 5	a	p	a	a	a	a	a	a
		NA	NA	Ostracod sp. 6	a	p	a	p	p	p	p	p
		NA	NA	Ostracod sp. 7	a	a	a	p	p	p	a	a
		NA	NA	Ostracod sp. 8	a	p	a	a	p	p	a	a
		NA	NA	Ostracod sp. 10	a	a	a	p	a	p	a	a
		NA	NA	Ostracod sp. 11	a	p	p	p	p	a	a	a
		NA	NA	Ostracod sp. 12	a	p	a	a	a	a	a	a
		NA	NA	Ostracod sp. 13	a	a	a	a	a	a	p	a
		NA	NA	Ostracod sp. 14	a	a	a	a	a	a	p	a
		NA	NA	Ostracod sp. 15	a	p	a	a	a	a	a	a
	Pycnogonida	Pantopoda	NA	Pycnogonida sp.	a	p	a	a	p	a	p	p
Brachiopoda	Rhynchonellata	Terebratulida	Terebratellidae	*Terebratella incomspicua*	a	p	a	a	a	a	a	a
Bryozoa	NA	NA	NA	Bryozoa	p	a	a	p	a	p	a	a
Chordata	Ascidiacea	Pleurogona	Styelidae	*Asterocarpa caerea*	a	p	a	a	a	a	a	a
				Cnemidocarpa bicornuta	a	p	a	a	a	a	a	p
				Styella clava	a	p	a	a	a	a	a	p
		Studidobranchidata	Pyuridae	*Microcosmos australis*	a	p	a	a	a	a	a	a
		NA	NA	Ascidiacea	a	p	a	a	p	a	p	a
Cnidaria	Anthozoa	Actinaria	Edwardsiidae	*Edwardsia tricolor*	a	p	a	a	a	a	p	p
		Alcyonacea	Alcyoniidae	*Alcyonium aurantium*	p	p	a	p	p	a	a	p
			Clavulariidae	? *Clavularia* sp.	a	a	a	p	a	a	a	a
				?*Telesto*	a	p	a	a	a	a	a	a
		Scleractinia	Flabellidae	*Monomyces rubrum*	a	p	a	a	a	a	a	a
			NA	Scleractinia	a	p	a	a	a	a	a	a
Echinodermata	Asteroidea	Forcipulatida	Asteriidae	*Coscinasterias calamaria*	a	a	a	p	a	a	a	a
		Spinulosida	Asterinidae	*Patiriella regularis*	a	p	a	a	a	a	a	a
	Echinoidea	Spatangoida	Loveniidae	*Echinocardium cordatum*	a	p	a	p	a	p	a	p
	Holothuroidea	Apodida	Chiridotidae	*Chiridota* sp.	a	a	a	a	a	a	a	p
				Kolostoneura novaezelandiae	a	a	a	a	a	a	p	a
			Synaptidae	*Trochodota dendyi*	p	p	a	a	a	a	p	p
		Dendrochirotida	Cucumariidae	*Neocucumella bicolumnata*	a	p	a	a	a	a	a	p
				Ocnus brevidentis	p	p	a	a	a	a	p	p
	Ophiuroidea	Ophiurida	Amphiuridae	*Amphipholis squamata*	a	p	a	a	a	a	p	p
				Amphiura aster	p	p	a	a	a	a	p	p
				Amphiura rosea	a	p	p	p	a	p	p	p
			Ophiactidae	*Ophiactis resiliens*	a	p	a	a	a	a	a	a
			Ophionereididae	*Ophionereis fasciata*	p	a	a	a	a	a	p	p
			NA	Ophiuroid sp.	a	a	a	a	a	a	a	p

Phylum	Class	Order	Family	species	within	outside	Transect 1		Transect 2		Transect 3	
							within	ouside	within	ouside	within	ouside
Hemichordata	Enteropneusta	NA	Harrimaniidae	*Saccoglossus australiensis*	a	p	a	a	a	a	p	p
Mollusca	Bivalvia	Arcoida	Glycymerididae	*Tucetona laticostata*	a	p	a	a	a	a	a	a
		Limoida	Limidae	*Limaria orientalis*	p	p	a	a	p	a	p	P
		Myoida	Corbulidae	*Notocorbula zelandica*	p	p	a	a	a	a	p	p
		Mytiloida	Mytilidae	*Modiolarca impacta*	a	a	a	a	a	a	a	p
				Perna canaliculus	p	a	a	p	p	p	a	a
		Ostreoida	Anomiidae	*Anomia trigonopsis*	p	p	a	a	p	a	p	p
		Nuculoida	Malletiidae	*Neilo australis*	a	p	a	a	a	a	a	a
			Nuculidae	*Nucula aff. hartvigina*	a	p	a	a	a	a	a	a
				Nucula castanea	a	p	a	a	a	a	a	a
		Nuculoida	Nuculidae	*Nucula nitidula*	a	p	a	p	p	p	p	p
		Pterioida	Pectinidae	*Pecten novaezelandiae*	a	p	a	a	a	a	a	a
			Pinnidae	*Atrina zelandica*	p	a	a	a	a	a	a	a
		Solemyoida	Solemyidae	*Solemya parkinsonia*	p	a	p	p	a	a	p	p
		Veneroida	Carditidae	*Pleuromeris zelandica*	a	p	a	a	a	a	p	p
				Purpurocardia purpurata	p	p	a	a	a	a	p	p
			Galeommatidae	*Scintillona zelandica*	a	a	a	a	a	a	p	p
			Lassaeidae	*Arthritica bifurca*	p	a	a	p	a	p	a	a
			Mactridae	*Resania lanceolata*	a	a	a	a	a	p	a	a
				Zenatia acinaces	a	p	a	a	a	a	a	a
			Montacutidae	*Montacuta semiradiata neozelanica*	a	p	a	p	a	p	a	a
			Psammobidae	*Gari hodgei*	a	p	a	a	a	a	a	a
			Semelidae	*Leptomya retiaria*	p	p	a	a	a	a	p	a
				Theora lubrica	p	p	p	p	p	p	a	p
			Ungulindae	*Diplodonta globus*	a	p	a	a	a	a	a	a
				Felaniella zelandica	p	p	a	a	a	a	a	p
			Veneridae	*Dosina zelandica*	a	a	a	a	a	a	a	p
				Dosinia greyi	a	p	a	a	a	a	a	a
				Dosinia lambata	p	p	a	p	a	a	a	p
				Tawera spissa	p	p	a	a	a	a	p	p
				Pahirus largillierti	a	p	a	a	a	a	a	a
	Gastropoda	Archarogastropoda	Trochidae	*Trochus tiaratus*	a	p	a	a	a	a	a	a
		Cephalaspidae	Philinidae	*Philine angasi*	a	p	a	a	a	a	a	a
		Neogastropoda	Buccinidae	*Taron dubius*	a	p	a	a	a	a	a	a
			Conidae	*Neoguraleus murdochi*	p	p	a	a	a	a	p	p
			Muricidae	*Muricopsis octagonus*	a	p	a	a	a	a	a	a
		Neotaenioglossa	Calyptraeidae	*Sigapatella novaezelandiae*	p	p	a	a	p	a	a	p
				Zegalerus tenuis	p	p	a	a	a	a	a	p
			Eatoniellidae	*Eatoniella* sp.	a	p	a	a	a	a	a	a
			Naticidae	*Proxiuber australe*	a	p	a	a	a	a	a	a
			Velutinidae	*Lamellaria cerebroides*	a	p	a	a	p	a	a	a
		Opisthobranchia	Aglajidae	*Aglaja cylindrica*	p	p	a	p	a	a	a	a
				Chelidonura aureopunctata	a	p	a	a	a	a	a	a

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Phylum	Class	Order	Family	species	within	outside	Transect 1		Transect 2		Transect 3	
							within	ouside	within	ouside	within	ouside
Mollusca	Gastropoda	Opisthobranchia	Tritoniidae	*Tritonia flemingi*	a	p	a	a	p	a	a	a
		Sorbeoconcha	Buccinidae	*Buccinulum lineum*	a	p	a	a	a	a	a	a
			Buccinidae	*Cominella adspersa*	a	p	a	a	a	a	p	p
				Cominella quoyana	a	p	a	a	a	a	p	p
			Calyptraeidae	*Crepidula costata*	a	a	a	a	p	a	a	a
			Drilliidae	*Tomopleura albula*	a	p	a	a	a	a	a	a
			Mitridae	*Austromitra rubiginosa*	a	a	a	a	a	a	a	p
			Muricidae	*Xymene gouldi*	a	p	a	a	a	a	a	a
				Xymene plebius	a	a	a	p	a	a	a	a
			Olicidae	*Amalda mucronata*	a	p	a	a	a	a	p	p
				Amalda novaezelandiae	a	p	a	a	a	a	p	p
			Rissoidae	*Estea* sp. 1	a	p	a	a	a	a	a	a
				Estea sp. 2	a	p	a	a	a	a	a	a
			Turritellidae	*Maoricolpus roseus*	a	p	a	a	a	a	p	p
		Vetigastropoda	Fissurellidae	*Emarginula striatula*	a	p	a	a	a	a	a	a
	Polyplacophora	Acanthochitonina	Acanthochitonidae	*Craspedochiton rubiginosus*	a	p	a	a	a	a	a	a
		Chitonida	Chitonidae	*Rhyssoplax stangeri*	a	p	a	a	a	a	a	a
		Lepidopleurina	Leptochitonidae	*Leptochiton inquinatus*	p	p	a	a	a	a	p	p
	Scaphopoda	Dentaliida	Dentaliidae	*Dentalium nanum*	a	p	a	a	a	a	a	a
Nematoda	NA	NA	NA	Nematoda	p	p	a	a	a	a	p	p
Nemertea	NA	NA	NA	Nemertea	p	p	a	p	p	p	p	p
Phoronida	NA	NA	NA	Phoronida	a	p	a	a	a	a	p	p
Platyhelminthes	NA	NA	NA	Platyhelminthes	a	a	a	a	p	a	a	a
Porifera	Demospongiae	Haplosclerida	Callispongiidae	*Callispongia ramosa*	a	p	a	a	a	a	a	a
	NA	NA	NA	Porifera	a	a	a	p	p	a	a	p
Priapulida	NA	NA	NA	Priapulida	a	p	a	a	p	p	a	a
Rhodophyta	Florideophyceae	Corallinales	Corallinaceae	*Lithophyllum* spp.	a	p	a	a	a	a	a	a
Sipuncula	Sipunculidea	NA	NA	Sipunculid sp. 1	a	p	a	a	a	a	a	p
		NA	NA	Sipunculid sp.2	a	p	a	a	a	a	a	a
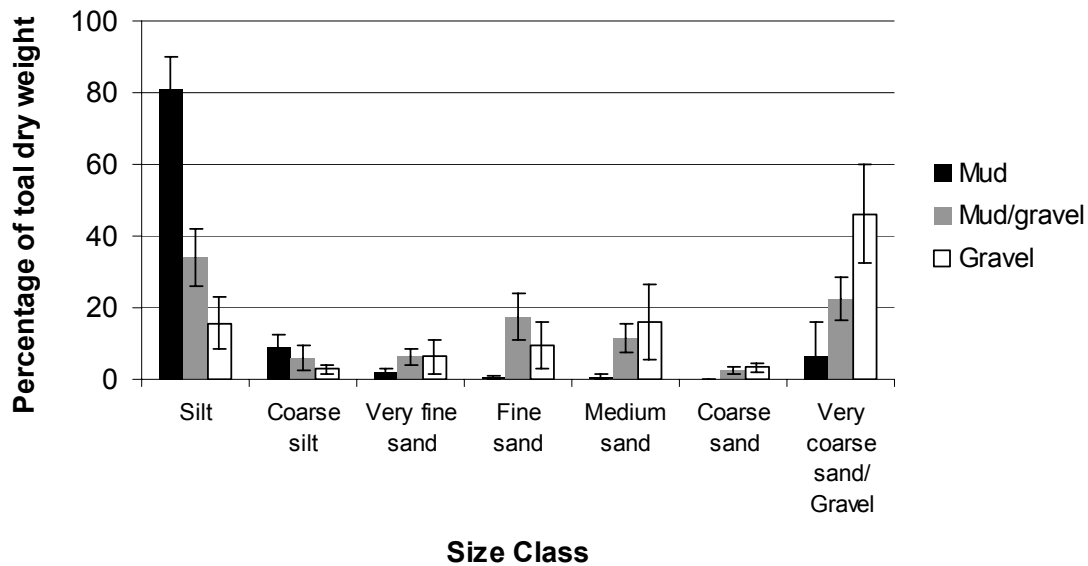
Figure 5: Dry weight composition of sediment grain size class each of the three substrata (mud, mud/gravel and gravel).

Table 11: Number of individuals and taxa in three substratum types, February 2008.

Substrata	# of samples	# of individuals	Average individuals/ sample	# of taxa	Taxa range/ sample
mud	139	6,805	49.0	142	2–41
mud/gravel	32	2,531	79.1	166	11–53
gravel	57	10,559	185.2	255	18–69

Benthic-invertebrate assemblages off eastern Waiheke Island were attributed one of two formations by Powell (1937): a *Venericardia* (now *Purpurocardia*) formation between Rotoroa Island and Ponui Island, and the eastern side of Ponui Island (Figure 6); and an *Echinocardium* formation throughout most of the rest of the survey region. Too few samples were collected at sites falling within Powell's *Purpurocardia* (as *Venericardia*) formation in this current study to compare/contrast with Powell's earlier formations. However, homogeneous 'formations' (assemblages, communities) were not distributed throughout the survey, as these assemblages varied according to substratum type, and the composition of this varied considerably throughout the survey region.
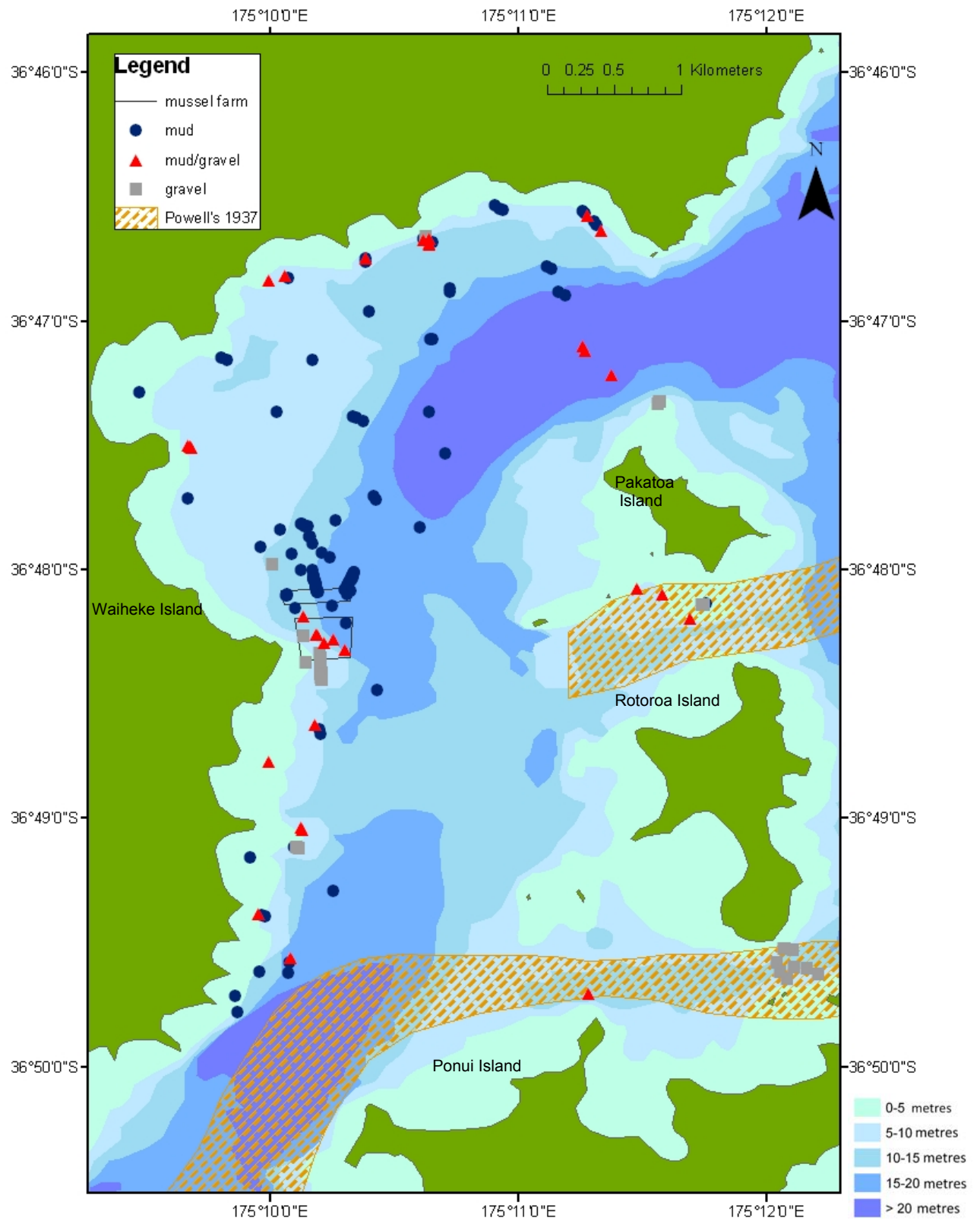
Figure 6: Site distribution and associated substratum type (hatched area depicts *Tawera + Purpurocardia* Formation of Powell (1937)).
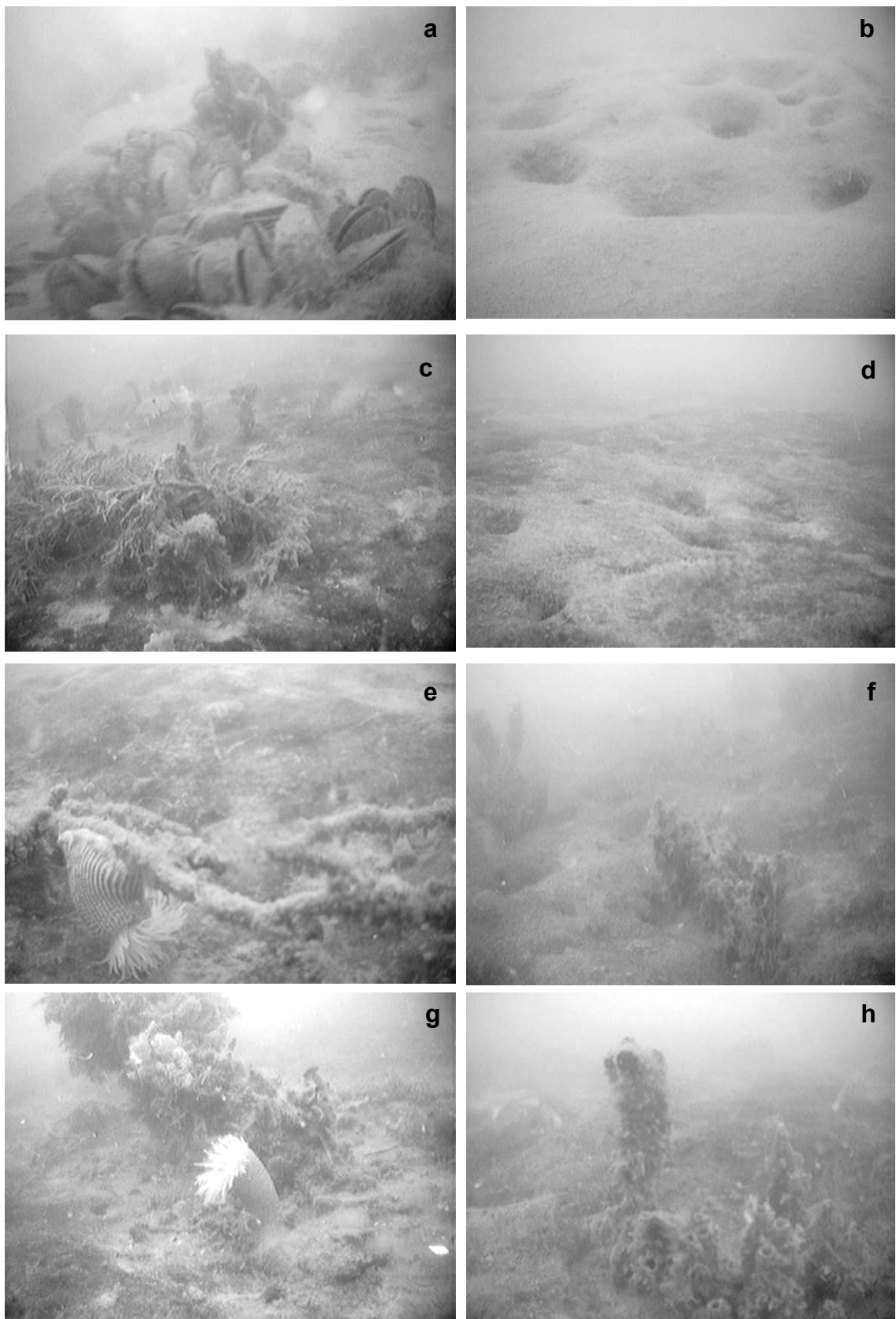
Figure 7: Drop-video stills of sea-bed types (a: beneath the northern side of the farm; b, d: outside the northern side of the farm; c, e–h, backscatter zone, *Perna*, *Styela clava*, *Atrina zelandica*, anemones, mussel farm anchoring lines, within 30 m of the northern and northwestern boundary of the farm).

In general, samples with increasing amounts of coarse sediments had increasing number of individuals and taxa (Table 11). In 139 mud samples, 6,805 individuals were attributed to 142 taxa; the number of taxa per grab sample ranged from 2–41. From within 32 mud/gravel samples, 2,531 individuals were collected, referred to 166 taxa, with the number of taxa ranging from 11–53 per sample (0.0336 m^{-2}). From 57 gravel samples, a total of 10,559 individuals were referred to 255 taxa, ranging from 18–69 taxa per sample.

No asymptote is reached on the species accumulation curve combining all substrata (Figure 8), those for specific substratum types (Figure 9–11), or when these are plotted on the same axes (Figure 12).
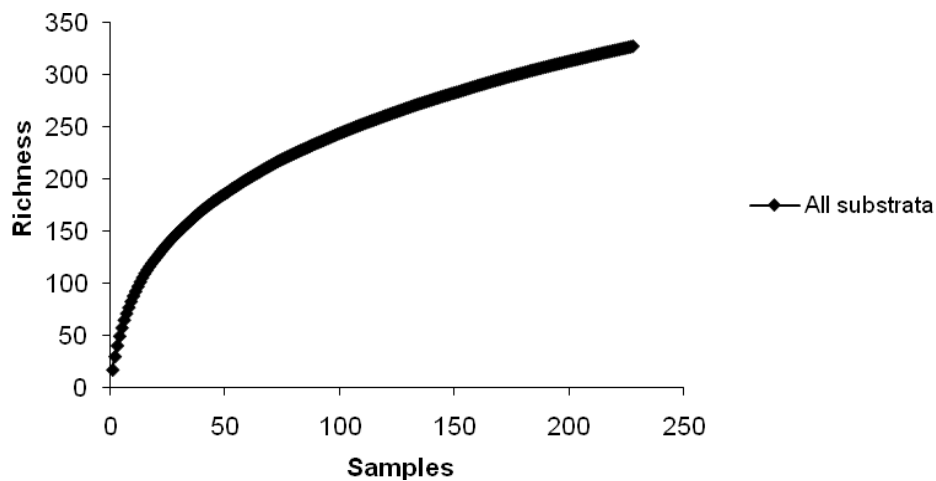
Figure 8: Species accumulation curve, all substrata.
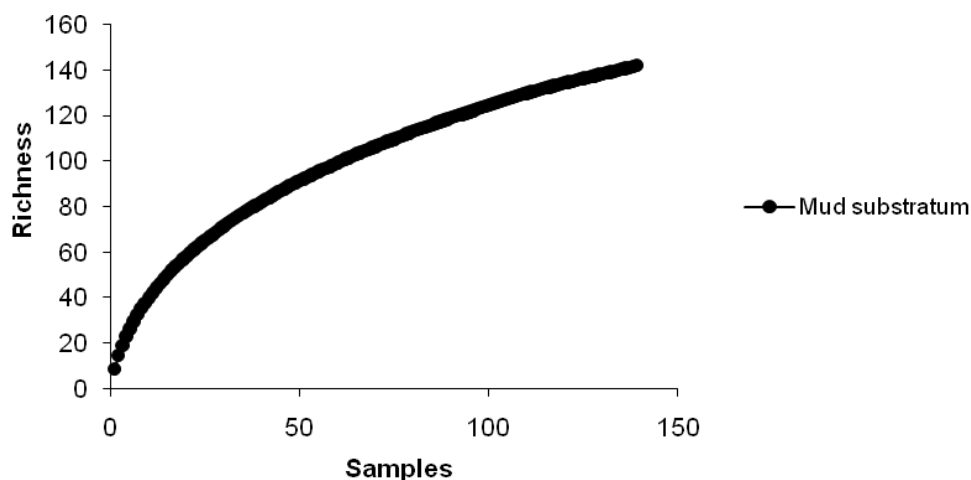
Figure 9: Species accumulation curve, muds.
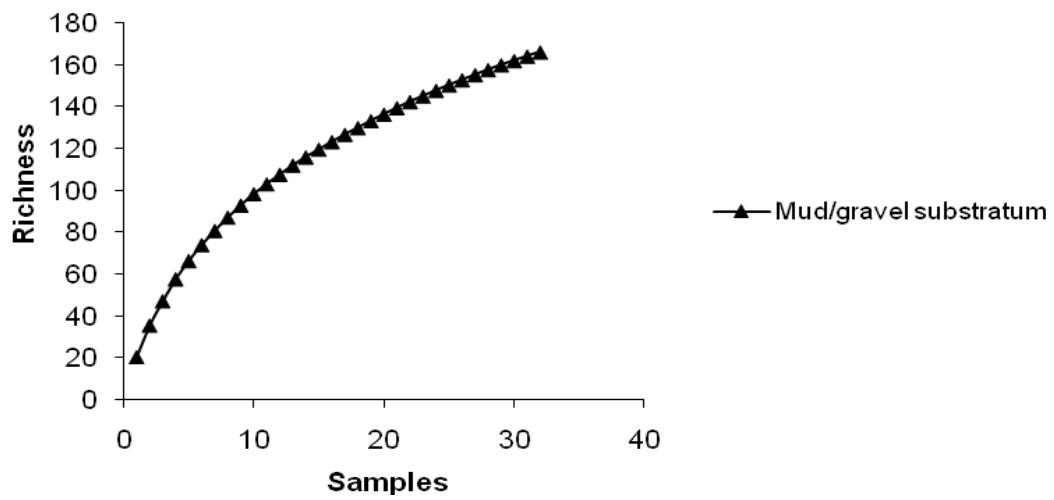
Figure 10: Species accumulation curve, mud/gravels.
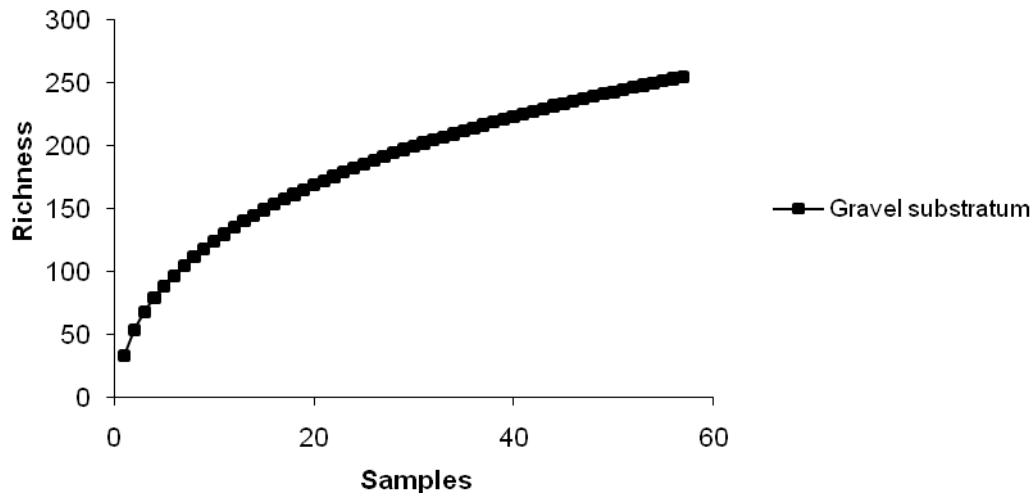
Figure 11: Species accumulation curve, gravels.
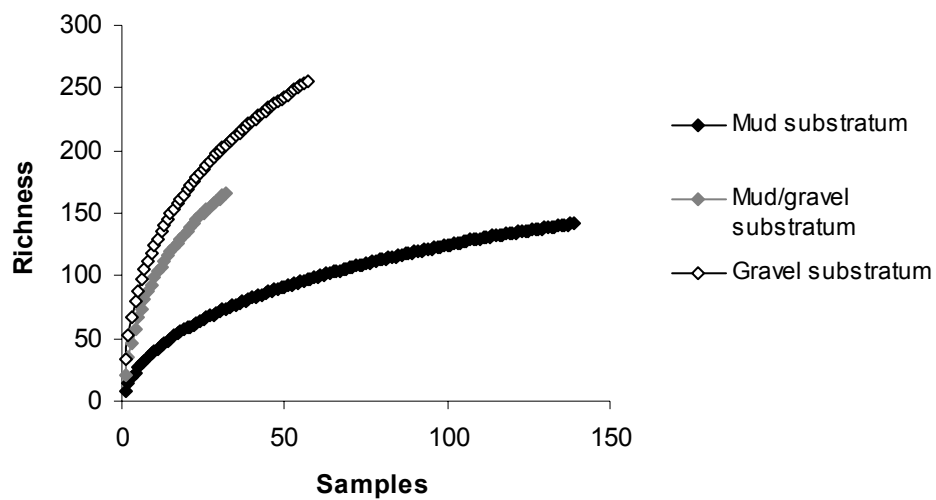
Figure 12: Species accumulation curves, all three substrata.

DIVERSE indices and community structure both significantly differ among substrata (ANOVA test with p-value less than 0.05 (Appendix 6, Table A11)). Gravel samples, followed by mud/gravel samples, had the highest total 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'); mud substrata had the lowest value for each DIVERSE index (Table 12). Community structure was also significantly different (p=0.001) among substratum types (Appendix 7, Table A24), with mud/gravel sites having species assemblages intermediate between mud and gravel sites (Figure 13).

Table 12: DIVERSE indices for the three substratum types, February 2008 (SD, standard deviation; DIVERSE symbols as in Table 4).

Substratum	# of samples	Abundance (min, max)		N	d	J'	H'	1-λ'
Mud	139	4, 586	Mean	48.96	2.08	0.64	1.32	0.60
			SD	55.85	0.95	0.16	0.47	0.18
Mud/gravel	32	8, 232	Mean	79.09	4.49	0.72	2.07	0.75
			SD	57.29	1.78	0.21	0.67	0.22
Gravel	57	45, 1572	Mean	185.25	6.32	0.73	2.54	0.84
			SD	197.15	1.58	0.11	0.42	0.11
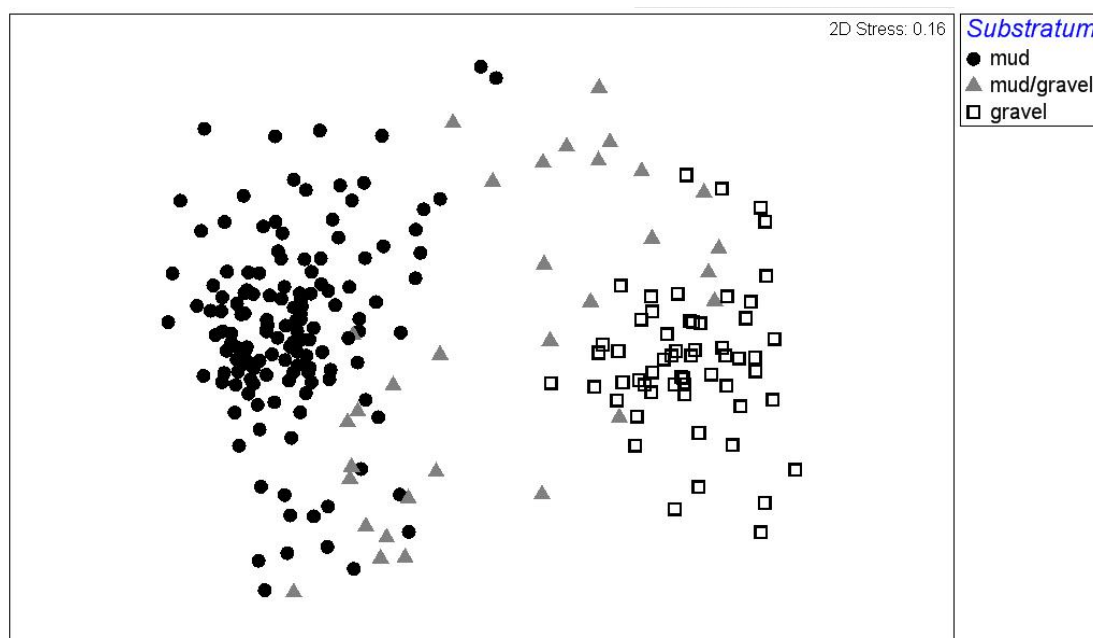
Figure 13: MDS plot of species assemblages within three substrata.

SIMPER reveals bivalves to characterise muds, while polychaetes characterise mud/gravels and gravels (Table 13). The invasive bivalve *Theora lubrica* was the main contributor to species assemblages (over 50%) in muds. Together

with an ostracod (Ostracod sp. 2) and Nemertea, three polychaete species (*Prionospio* sp., *Heteromastus filiformis* and *Sthenelais* sp.) were the main contributors (over 50%) to species assemblages in mud/gravels. Almost 40% of the taxa characterising gravels were polychaetes (*Heteromastus filiformis*, *Prionospio* sp., Spionid sp. 1 and *Macroclymenella stewartensis*), and a bivalve, *Notocorbula zelandica* (Table 14–16).

Table 13: Breakdown of average similarity by substratum type, February 2008, to Class (including the Phylum Nemertea).

SIMPER	Muds	Mud/gravels	Gravels
Similarity class (Cummulative %)	58.26	50.37	66.40
	Bivalvia (41.85%)	Polychaeta (41.69%)	Polychaeta (42.74%)
	Ostracoda (64.79%)	Ostracoda (60.07%)	Bivalvia (62.09%)
	Polychaeta (86.58%)	Malacostraca (72.88%)	Malacostraca (74.00%)
	Malacostraca (96.44%)	Bivalvia (83.80%)	Gastropoda (81.61%)
		Ophiuroidea (90.23%)	Ostracoda (85.89%)
			Nemertea (89.18%)
			Ophiuroidea (92.31%)

Table 14: SIMPER results for muds, eastern Waiheke Island (Average similarity: 39.09).
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Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Theora lubrica	4.05	19.59	1.57	50.12	50.12
Ostracod sp. 2	2.55	9.68	1.16	24.77	74.88
Prionospio sp.	0.84	1.85	0.56	4.73	79.62
Sthenelais sp.	0.51	1.28	0.47	3.28	82.90
Paraphoxus sp. 1	0.73	1.18	0.35	3.03	85.93
Cossura consimilis	0.51	1.12	0.42	2.86	88.79
Echinocardium cordatum	0.41	0.75	0.32	1.92	90.71

Mud and mud/gravel sites fall into three arbitrarily selected depth ranges: those more shallow than 10 m, those from 10–15 m, and those at depths greater than 15 m. Gravel sites, however, were encountered within only two of these depth ranges, those more shallow than 10 m, and those between 10 and 15 m.

ANOSIM reveals assemblages of species from muddy sites differed significantly between depth ranges ($p < 0.005$) (Figure 14) (Appendix 7, Table A25); although no significant difference was revealed in any DIVERSE index. ANOSIM reveals assemblages of species from mud/gravel sites also differed significantly by depth, more shallow than 10 m and deeper than 15 m ($p < 0.005$) (Figure 15) (Appendix 7, Table A26), but again DIVERSE indices identified no

significant difference in assemblages between these depth ranges. To the contrary, ANOSIM reveals assemblages of species from gravel sites did not differ significantly between depths (Figure 16) (Appendix 7, Table A27), but DIVERSE indices did, in terms of species richness (S) and Margalef's index of species richness (d), both of which were significantly higher between 10 m and 15m.

Table 15: SIMPER results for mud/gravels, eastern Waiheke Island (Average similarity: 22.09).

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Ostracod sp. 2	3.30	4.80	0.63	21.72	21.72
Prionospio sp.	1.54	3.38	1.12	15.30	37.02
Heteromastus filiformis	2.14	2.07	0.59	9.38	46.40
Nemertea	0.77	1.07	0.62	4.83	51.23
Sthenelais sp.	0.52	0.93	0.50	4.23	55.46
Paraphoxus sp. 1	0.70	0.88	0.47	4.00	59.46
Amphiura rosea	0.65	0.76	0.41	3.42	62.88
Echinocardium cordatum	0.40	0.58	0.38	2.63	65.51
Theora lubrica	0.64	0.57	0.32	2.56	68.07
Aonides sp.	0.40	0.51	0.37	2.30	70.37
Trichobranchus sp.	0.39	0.41	0.33	1.86	72.22
Cirratulid sp. 1	0.36	0.34	0.30	1.52	73.75
Arabella sp.	0.36	0.32	0.31	1.47	75.21
Glycera tesselata	0.45	0.31	0.33	1.42	76.64
Macroclymenella stewartensis	0.42	0.29	0.26	1.32	77.96
Ostracod sp. 1	0.33	0.27	0.25	1.24	79.19
Onuphis aucklandensis	0.32	0.24	0.23	1.11	80.30
Sphaerosyllis sp.	0.34	0.24	0.30	1.07	81.37
Spionid sp. 1	0.60	0.23	0.26	1.05	82.42
Leptochiton inquinatus	0.37	0.19	0.24	0.87	83.30
Cossura consimilis	0.26	0.18	0.21	0.83	84.12
Syllid sp. 4	0.33	0.18	0.27	0.82	84.94
WTF 3	0.52	0.17	0.18	0.76	85.71
Ampharetidae sp.	0.37	0.16	0.23	0.73	86.43
Armandia maculata	0.46	0.16	0.24	0.72	87.16
Phoronida	0.32	0.15	0.23	0.67	87.83
Terebellides stroemi	0.31	0.14	0.20	0.62	88.45
Nematoda	0.28	0.13	0.23	0.60	89.05
Notocorbula zelandica	0.27	0.13	0.20	0.59	89.64
Paraphoxus sp. 2	0.27	0.13	0.20	0.59	90.22

Table 16: SIMPER results for gravels, eastern Waiheke Island (Average similarity: 38.16).

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Heteromastus filiformis	5.03	6.52	1.77	17.08	17.08
Notocorbula zelandica	4.45	5.50	1.85	14.43	31.51
Prionospio sp.	2.24	2.83	1.55	7.41	38.91
Spionid sp. 1	2.87	2.36	1.31	6.20	45.11
Macroclymenella stewartensis	1.45	1.51	1.18	3.97	49.08
WTF 3	1.75	1.24	0.56	3.25	52.33
Terebellides stroemi	1.28	1.21	0.84	3.18	55.51
Nemertea	1.09	1.08	0.91	2.83	58.34
Sabellid sp. 1	1.60	1.05	0.69	2.74	61.08
Paguristes setosus	1.83	0.94	0.51	2.47	63.54
Sphaerosyllis sp.	1.01	0.73	0.65	1.92	65.46
Ampharetidae sp.	0.93	0.73	0.66	1.91	67.37
Trochodota dendyi	0.95	0.73	0.71	1.90	69.27
Ostracod sp. 2	0.97	0.71	0.57	1.85	71.12
Ophiodromus angustifrons	0.81	0.65	0.71	1.70	72.82
Aonides sp.	0.82	0.59	0.54	1.56	74.38
Hydroides norvegicus	1.14	0.59	0.49	1.54	75.92
Ostracod sp. 1	0.67	0.53	0.55	1.39	77.31
Anomia trigonopsis	0.76	0.52	0.59	1.37	78.67
Armandia maculata	0.74	0.52	0.54	1.35	80.03
Leptochiton inquinatus	0.73	0.51	0.59	1.33	81.35
Glycera tesselata	0.62	0.46	0.54	1.21	82.56
Nematoda	0.63	0.44	0.56	1.15	83.71
Syllid sp. 10	0.68	0.43	0.51	1.14	84.85
Anthurid sp. 2	0.62	0.38	0.45	0.98	85.84
Maoricolpus roseus	0.67	0.35	0.42	0.92	86.76
Paraphoxus sp. 1	0.52	0.33	0.43	0.87	87.63
Glycinde sp.	0.64	0.33	0.41	0.86	88.48
Trichobranchus sp.	0.49	0.30	0.42	0.79	89.28
Amphiura aster	0.55	0.28	0.40	0.72	90.00
Syllid sp. 4	0.52	0.24	0.35	0.62	90.62
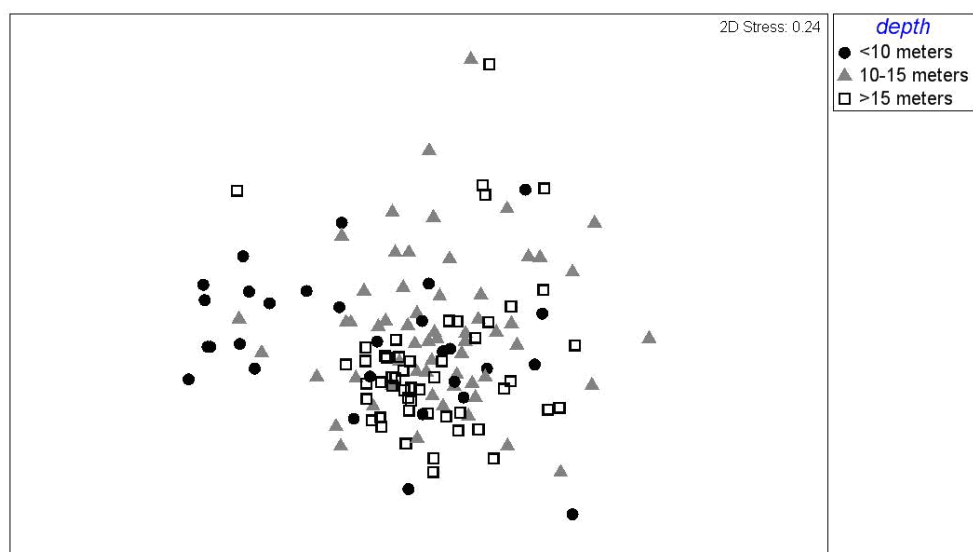
Figure 14: MDS plot of species assemblages within muds, grouped by depth (<10, 10–15, >15 m).
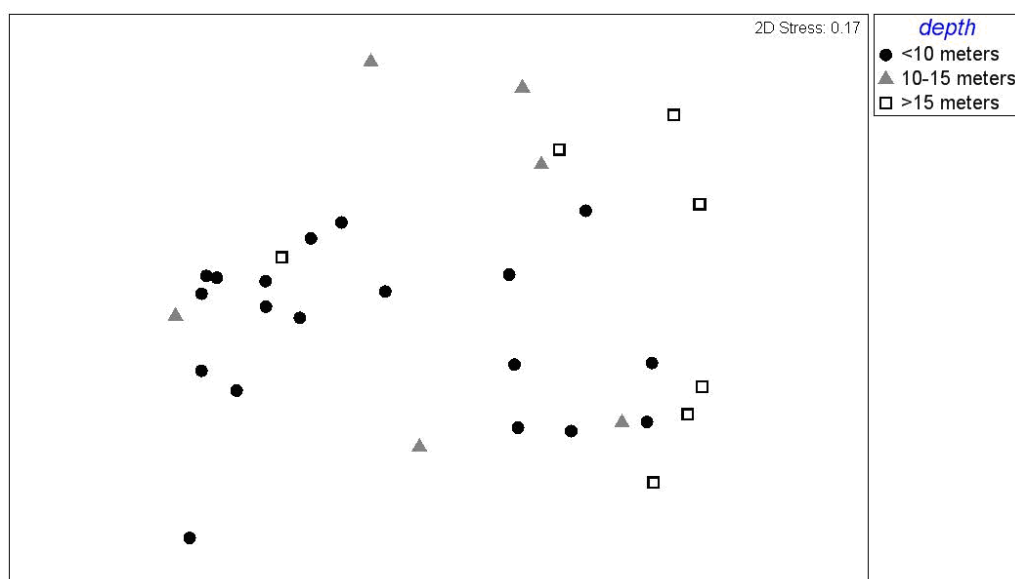
Figure 15: MDS plot of species assemblages within mud/gravels, grouped by depth (<10, 10–15, >15 m).
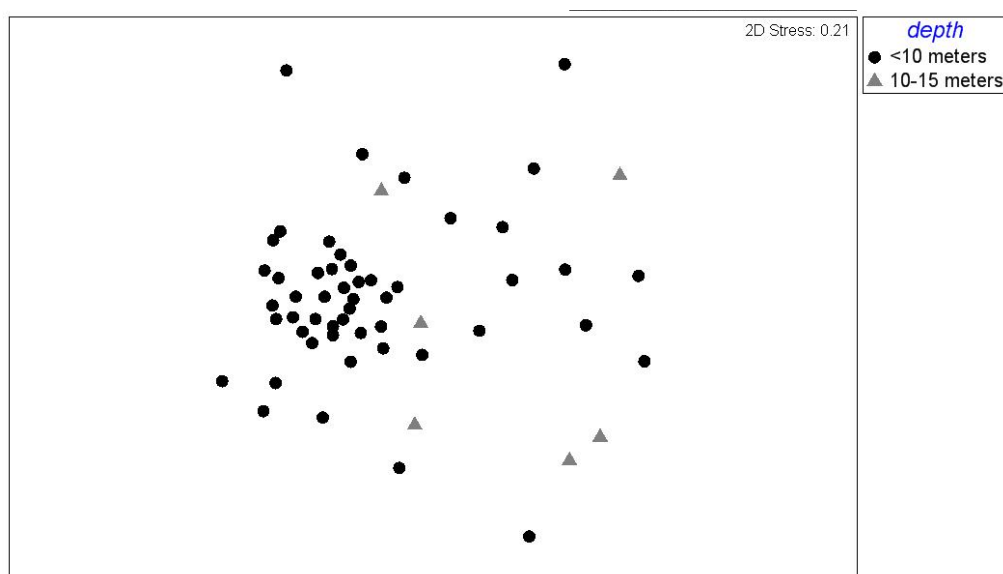
Figure 16: MDS plot of species assemblages within gravels, grouped by depth (<10, 10–15 m).

Spatial distribution of species richness and abundance

<u>Relative Richness</u>

Combining species richness data for each survey period, February to August 2008, the total number of taxa recorded was 359, of which 232 occurred within and 329 occurred outside the physical boundary of the mussel farm; the maximum number of taxa recorded from any one sample was 69 (Table 17).

Table 17: Richness maxima and minima per survey, all substrata, eastern Waiheke Island, 2008.

Survey date (2008)	# of samples	Min. richness/sample (all samples, all substrata)	Max. richness/ sample (all samples, all substrata)	Mean ± SD
February	228	2	69	16.3 ± 12.4
May	47	3	43	16.5 ± 10.8
August	59	2	47	16.4 ±10.3

When combining species richness data for this same survey period, but limiting analysis to samples collected within muds only, the total number of species recorded from any one sample was reduced to 43 (Table 18).

Table 18: Richness maxima and minima per survey, muds, eastern Waiheke Island, 2008.

Survey date (2008)	# of samples	Min. richness/sample (muds)	Max. richness/ sample (mud)	Mean ± SD
February	139	2	41	8.7 ± 4.7
May	38	3	43	13.2 ± 9.2
August	50	2	41	13.5 ± 7.4

Using these data, the ranges in species richness used to characterise all sites throughout eastern Waiheke Island in accordance with their relative species richness are presented in Table 19, and those unique to muds throughout this region in Table 20.

Table 19: Species richness ranges, all substrata, eastern Waiheke Island, 2008.

Species richness (%)	Richness range (all samples)	Relative Richness score
<5	0–3	Very low
5–10	4–7	Low
11–25	8–17	Fairly low
26–50	18–35	Medium
51–75	36–52	Fairly high
76–95	53–66	High
96–100	67–69	Very high

Table 20: Species richness ranges, muds, eastern Waiheke Island, 2008.

Species richness (%)	Richness range (mud samples)	Relative Richness score
<5	0–2	Very low
5–10	3 or 4	Low
11–25	5–11	Fairly low
26–50	12–22	Medium
51–75	23–32	Fairly high
76–95	33–41	High
96–100	42 or 43	Very high

Relative Abundance

Combining species abundance data for each survey period, February to August 2008, the total number of individuals of all taxa recorded from any one sample ranged from 2 to 1,572 per 0.0336 m^2 (Table 21). Therefore, characterisation of any site throughout the survey region, eastern Waiheke Island, as being any of *very low* through to *very high* abundance follows the ranges presented in Table 22.

Table 21: Abundance maxima and minima per survey, all substrata, eastern Waiheke Island, 2008.

Survey date (2008)	# of samples	Min. abundance/sample (all substrata)	Max. abundance/ sample (all substrata)	Mean ± SD
February	228	4	1,572	87.3 ± 123.5
May	47	6	222	63.4 ± 49.3
August	59	2	353	64.1 ± 68.5

Table 22: Range values for characterising relative abundance of taxa within samples (m^{-2}), all substrata, eastern Waiheke Island, 2008.

Abundance (%) of 46,786 m^{-2} (maximum Abundance value)	Abundance range (m^{-2})	Relative Abundance score
<5	0–2,339	Very low
5–10	2,340–4,679	Low
11–25	4,680–11,697	Fairly low
26–50	11,698–23,393	Medium
51–75	23,394–35,090	Fairly high
76–95	35,091–44,447	High
96–100	44,448–46,786	Very high

Combining species abundance data for each survey period, February to August 2008, the total number of individuals of all taxa recorded from any single muddy substratum sample ranged from 2 to 586 per 0.0336 m^2 (Table 23). Therefore, characterisation of any site throughout the survey region, eastern Waiheke Island, as having any of *very low* through to *very high* abundances of individuals in muddy substrata follows ranges presented in Table 24.

Table 23: Abundance maxima and minima per survey, muds, eastern Waiheke Island, 2008.

Survey date (2008)	# of samples	Min. abundance/sample (muddy substrata)	Max. abundance/ sample (muddy substrata)	Mean ± SD
February	139	4	586	49.0 ± 41.8
May	38	6	184	51.4 ± 7.1
August	50	2	210	44.7 ± 42.7

Table 24: Range values for characterising relative abundance of taxa within mud samples (m^{-2}).

Abundance (%) of 17,440 m^{-2} (maximum Abundance value)	Abundance range (m^{-2})	Relative Abundance score
<5	0–872	Very low
5–10	873–1744	Low
11–25	1745–4360	Fairly low
26–50	4361–8720	Medium
51–75	8721–13,080	Fairly high
76–95	13,081–16,568	High
96–100	16,569–17,440	Very high

When plotted on maps of eastern Waiheke Island (Figure 17, 18), the most species-rich sites (relative to all sites throughout the survey region) proved to be those beneath and in the immediate vicinity of the existing mussel farm, in the deeper channels between Waiheke Island and Pakatoa Island, and between Rotoroa and Ponui Islands (Figure 17). When limiting analysis to relative species richness within muds (Table 20), the most species-rich sites are rather evenly distributed throughout the eastern Waiheke Island region, but are elevated within and in the immediate vicinity of the northern side of the existing mussel farm (Figure 18).

When plotted on maps of eastern Waiheke Island (Figure 19, 20), those sites with the greatest abundance of individuals proved to be beneath and in the immediate vicinity of the existing mussel farm, again in the deeper channels between Waiheke Island and Pakatoa Island, and Rotoroa and Ponui Island, in addition to one site with relatively exceptional abundance north of Pakatoa Island (Figure 19). When limiting analysis to abundance within muds only (Table 24), those sites with the greatest abundance of individuals are rather evenly distributed throughout the eastern Waiheke Island region, but are elevated within and in the immediate vicinity of the northern side of the existing mussel farm (Figure 20), at depths exceeding 20 metres north and northeast of the mussel farm, and in the deeper parts of the channel between Waiheke and Pakatoa Islands.
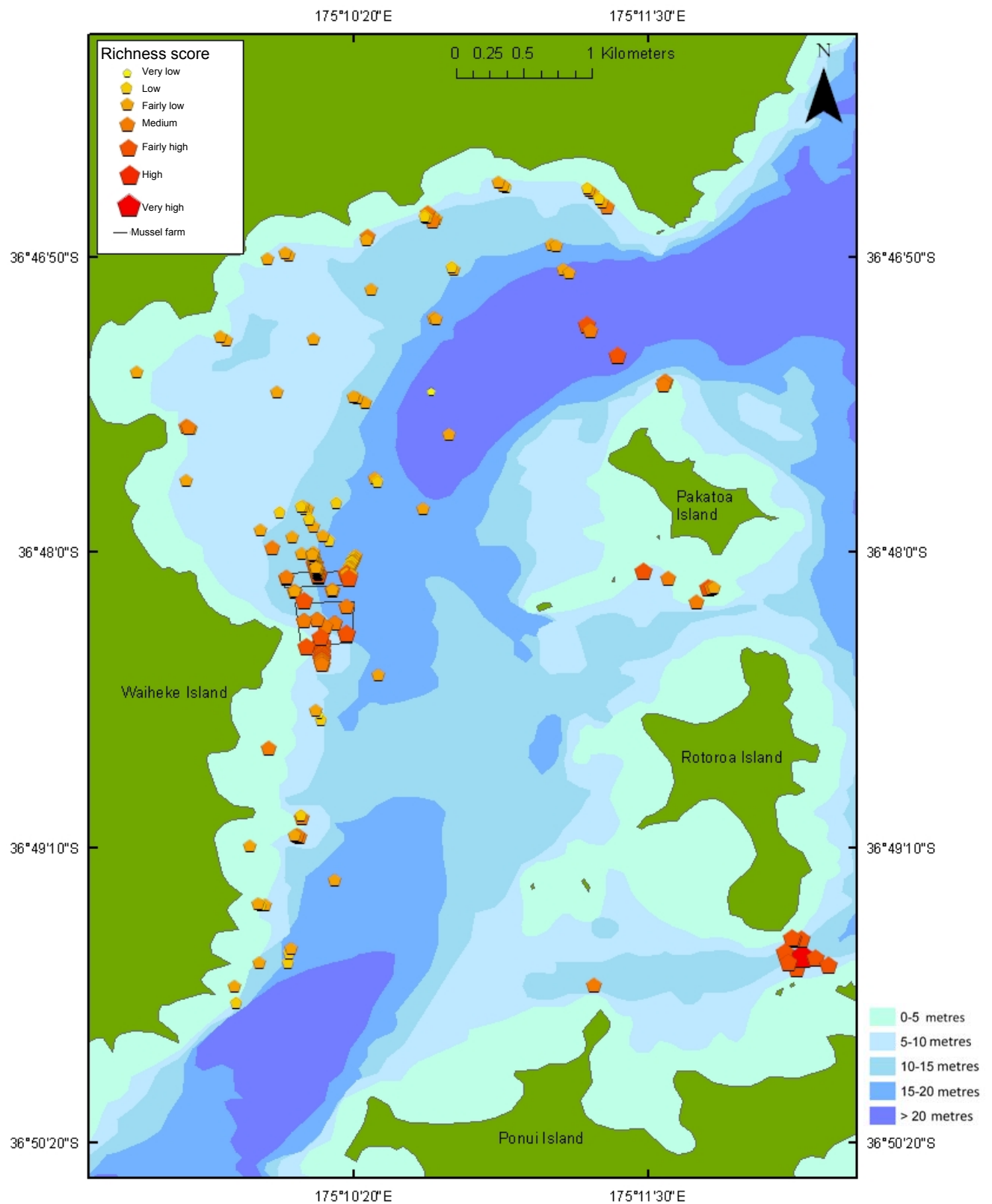
Figure 17: Spatial distribution of relative species richness, all sites, all substrata, February to August 2008.
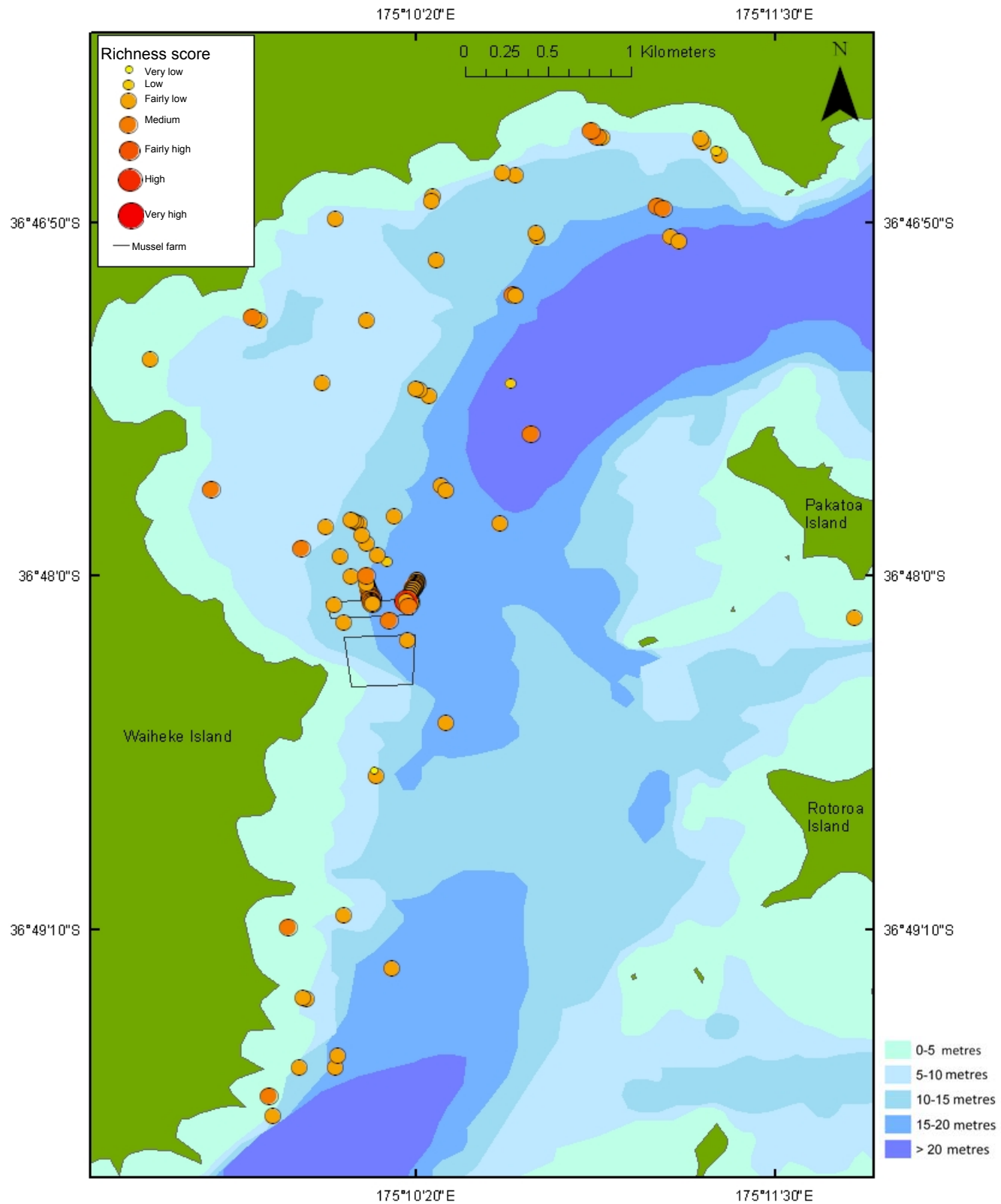
Figure 18: Spatial distribution of Relative Species Richness, muds, February 2008.
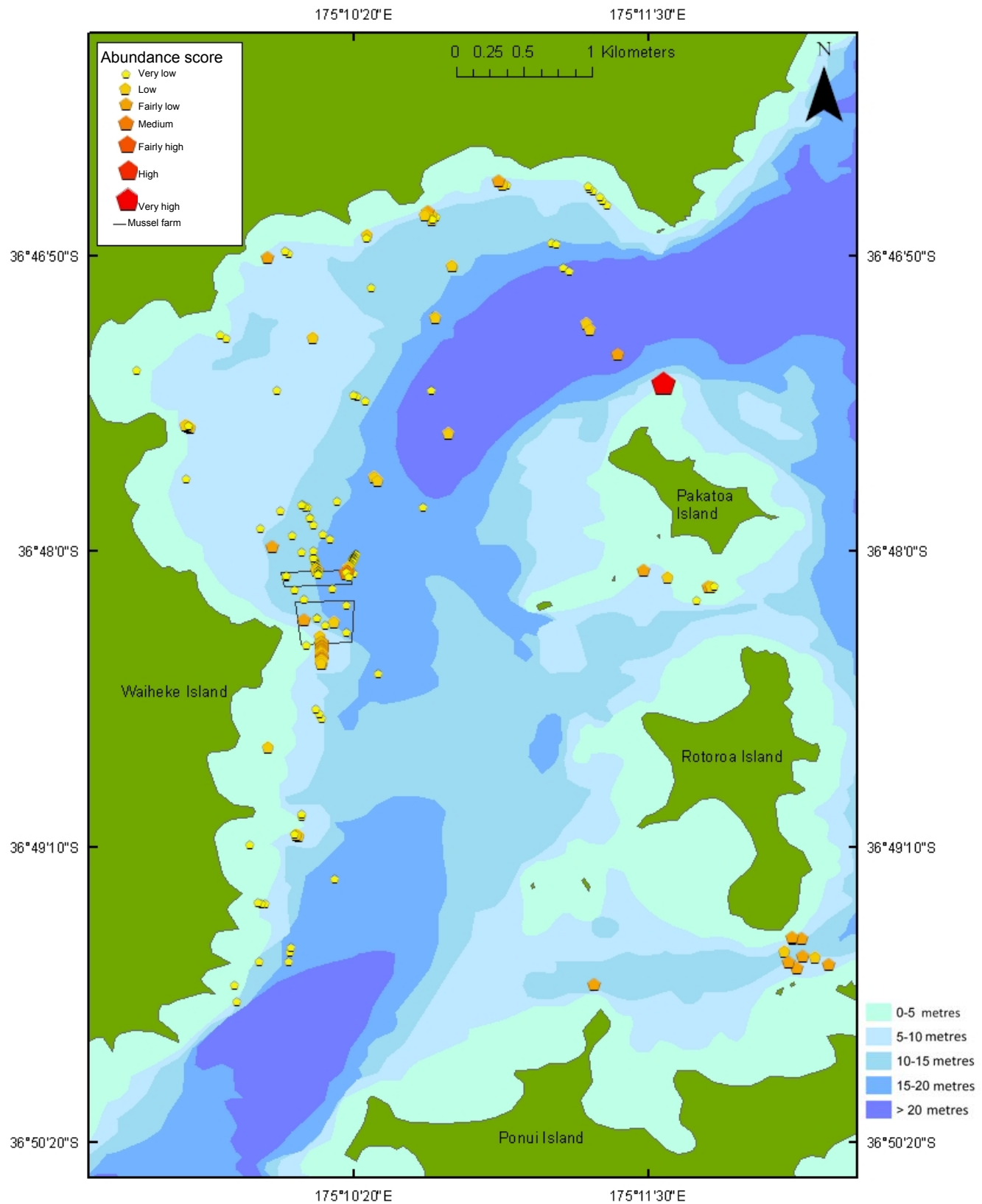
Figure 19: Spatial distribution of total species abundance, eastern Waiheke, all survey dates (February to August 2008).
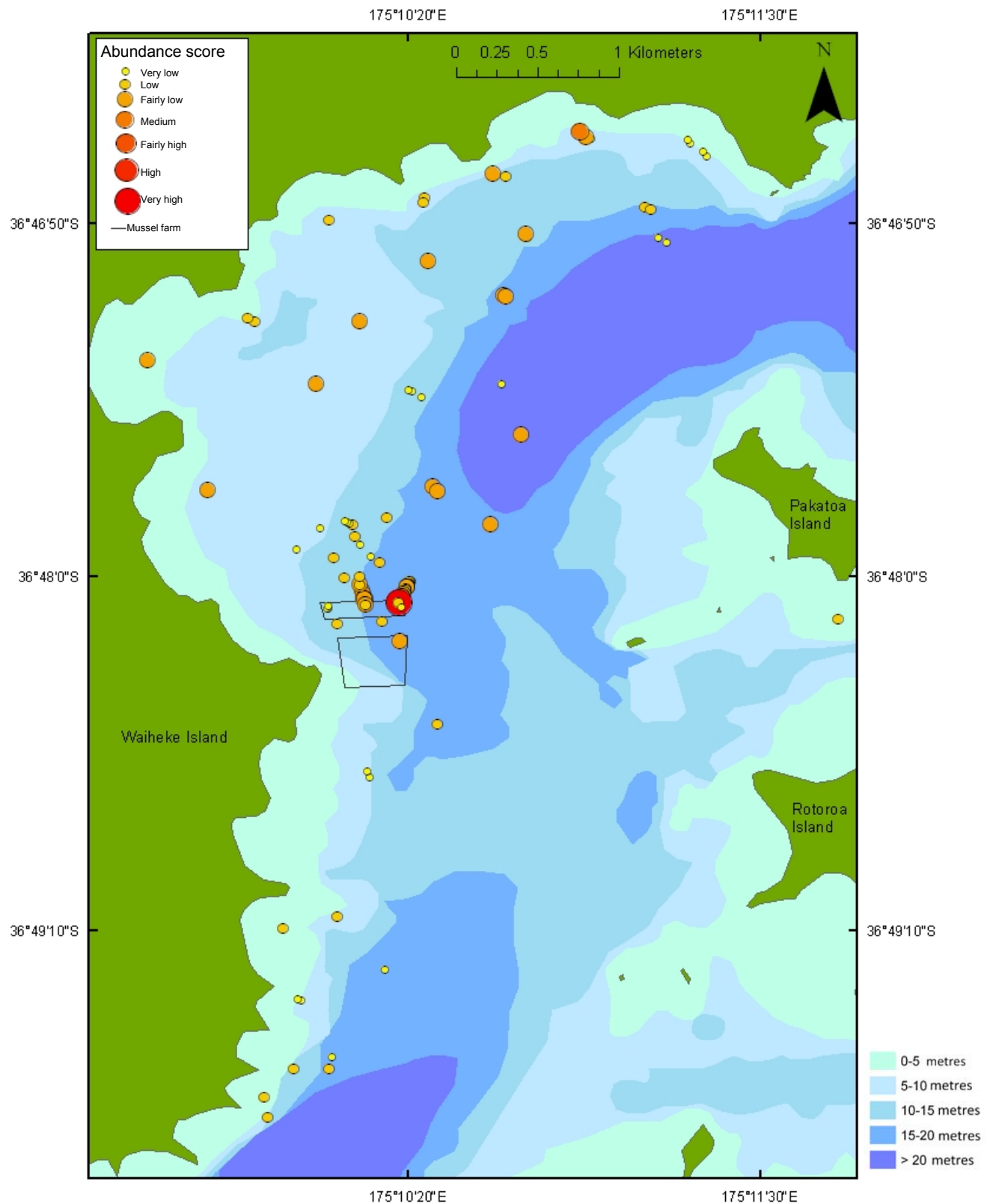
Figure 20: Spatial distribution of total species abundance, muds, eastern Waiheke, February 2008.

Biological footprint of mussel farm

Transect monitoring

Sampling along Transects 1, 2 and 3 was undertaken in February 2008, with subsequent monitoring (May and August 2008) undertaken along Transect 1 only (the time required to collect and process all samples, and to identify and enumerate all flora and fauna contained within them, in the event all transects were monitored, and a repeat survey throughout the eastern Waiheke region was undertaken, would have exceeded the time available to conduct this research programme).

February 2008

Flora and fauna were identified from samples collected along three Transects in February 2008: Transect 1 (11 sites, 33 samples), 2 (11 sites, 33 samples) and 3 (12 sites, 36 samples) (Table 3). When sites are grouped by their location relative to the physical boundary of the farm, whether within (-20, -10 and 0 m) the farm, or outside (+10 m to +80 m) the farm, ANOVA reveals no significant differences in DIVERSE indices, along Transects 1 and 2, with the exception of evenness (J') on Transect 1 (Figure 21–23), whereas significant differences are apparent in Margalef's index (d) and Shannon diversity index (H') along Transect 3 (Figure 25) (Appendix 6, Table A11).

As the presence of *Perna* at some sites within and outside the farm elevates species richness, a revised DIVERSE index excluding *Perna* sites was also applied to compare diversity within and outside the physical boundary of the farm. ANOVA reveals no significant difference in DIVERSE indices along Transect 1 or 2, with the exception of evenness (J') on Transect 1 (Figure 22, Figure 24); *Perna* was not recorded along Transect 3 (Appendix 6, Table A11).

ANOSIM reveals significant differences in the composition of species assemblages (p= 0.001) within (-20, -10 and 0 m) and outside (+10 m to +80 m) the farm along Transect 1 (Figure 26), whereas no significant difference was identified at the farm boundary along either Transects 2 or 3 (Appendix 7, Table A28–A30).

SIMPER tests (Table 25) (Appendix 7, Table A36−A38) reveal those taxa that best characterise species assemblages along the first 20 metres of the farm (sites -20, -10 and 0m) to be the invasive bivalve *Theora lubrica* (46.77%), polychaete *Prionospio* sp. (73.4%), amphipod *Paraphoxus* sp. 1 (89.9%) and oligochaetes (92.51%); those taxa characterising assemblages of species outside the farm (10−70m) are *Theora lubrica* (58.79%), Ostracod sp. 2 (81.04%), *Prionospio* sp. (85.15%), *Paraphoxus* sp. 1, and a second polychaete, *Onuphis aucklandensis* (90.77%). Although three of these species are common to the two assemblages, their relative and proportional abundances differ.

No asymptote was reached on either species accumulation curve for Transects 1 (Figure 27) or 2 (Figure 28), whether including or excluding those samples within which *Perna* occurred. Additional sampling in this region, within muds, is required to fully characterise the assemblages of species occurring within them. The species accumulation curve for Transect 3, gravels, most closely approximated an asymptote (Figure 29), although no *Perna* were recorded from any sample along it. When these curves are plotted on common axes (Figure 30) Transect 1 proves to have the lowest species richness, and sampling along it characterises species assemblages better than along any other Transect option.

Subsequent surveys to determine the biological footprint of this farm were limited to Transect 1. This Transect was selected for ongoing monitoring purposes because it is in this direction that a proposal exists to increase the size of the current mussel farm by 10 ha, and sampling along it repeating the earlier sampling methodology best described species assemblages, at least during February 2008.
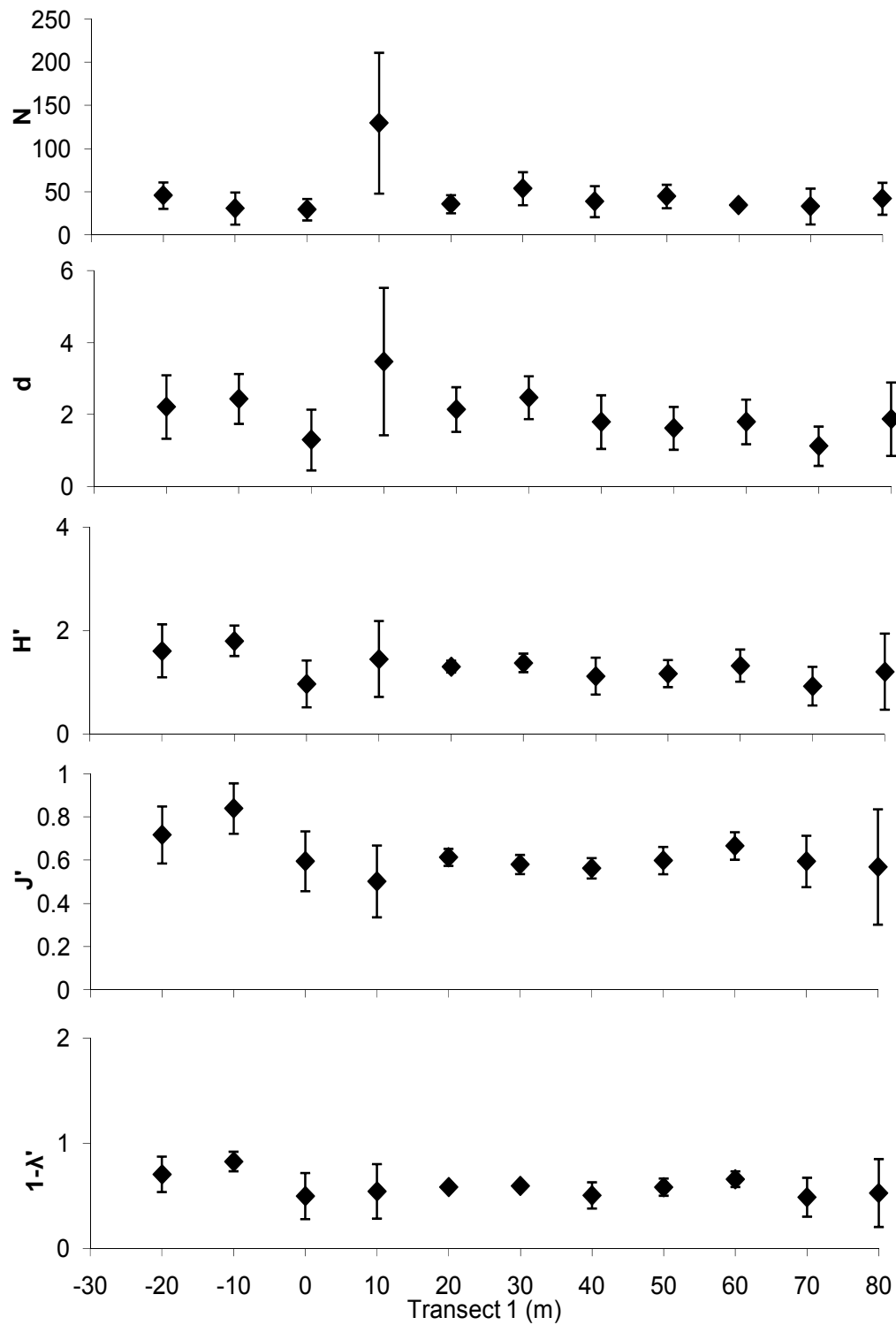
Figure 21: Mean (± SD) of total individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H'), and Simpson index (1-λ'), for three replicates at each site, at 10 m intervals along Transect 1, February 2008.
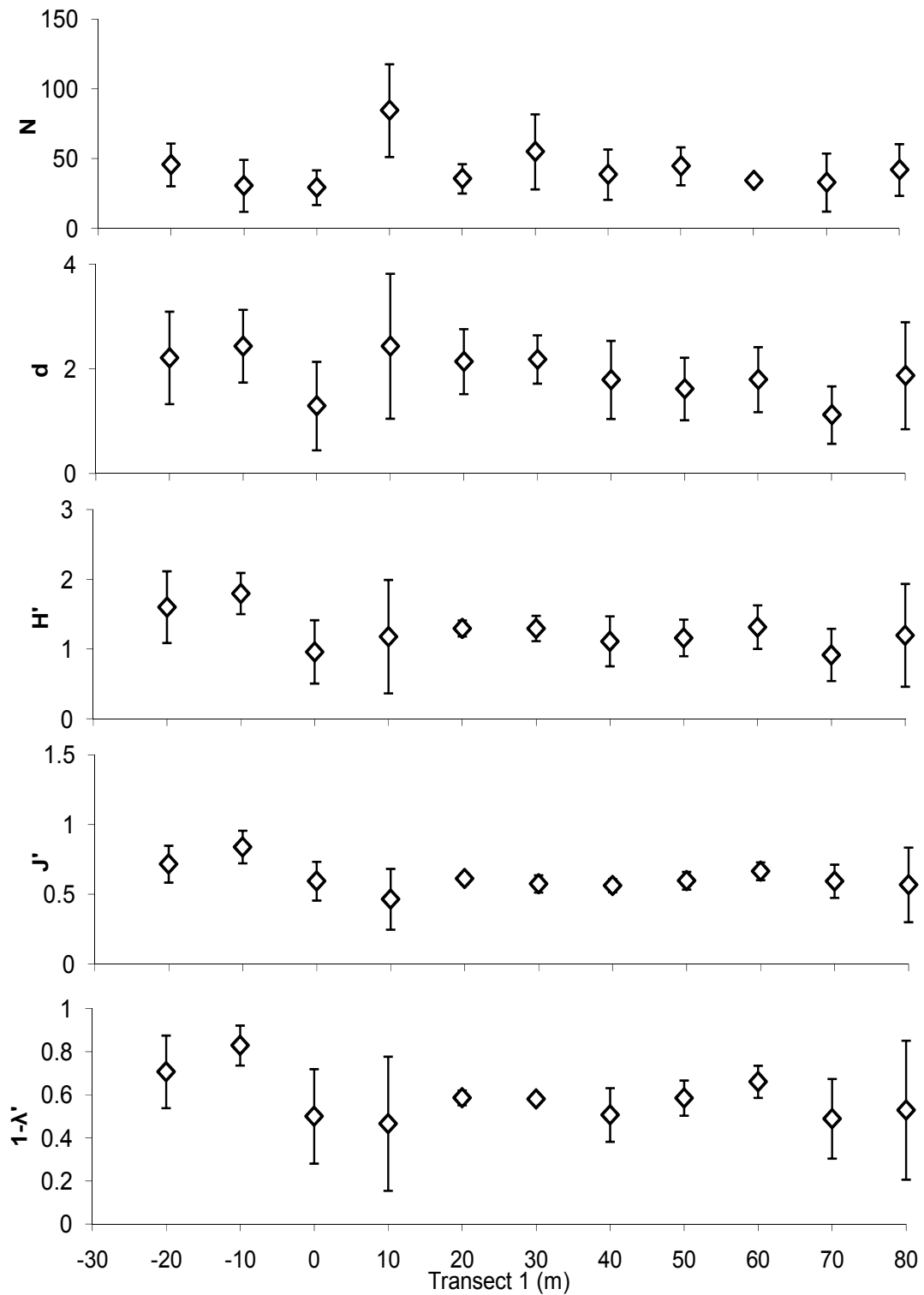
Figure 22: Mean (± SD) of total individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H'), and Simpson index (1-λ'), for three replicates at each site, at 10 m intervals along Transect 1, *Perna* sites excluded, February 2008.
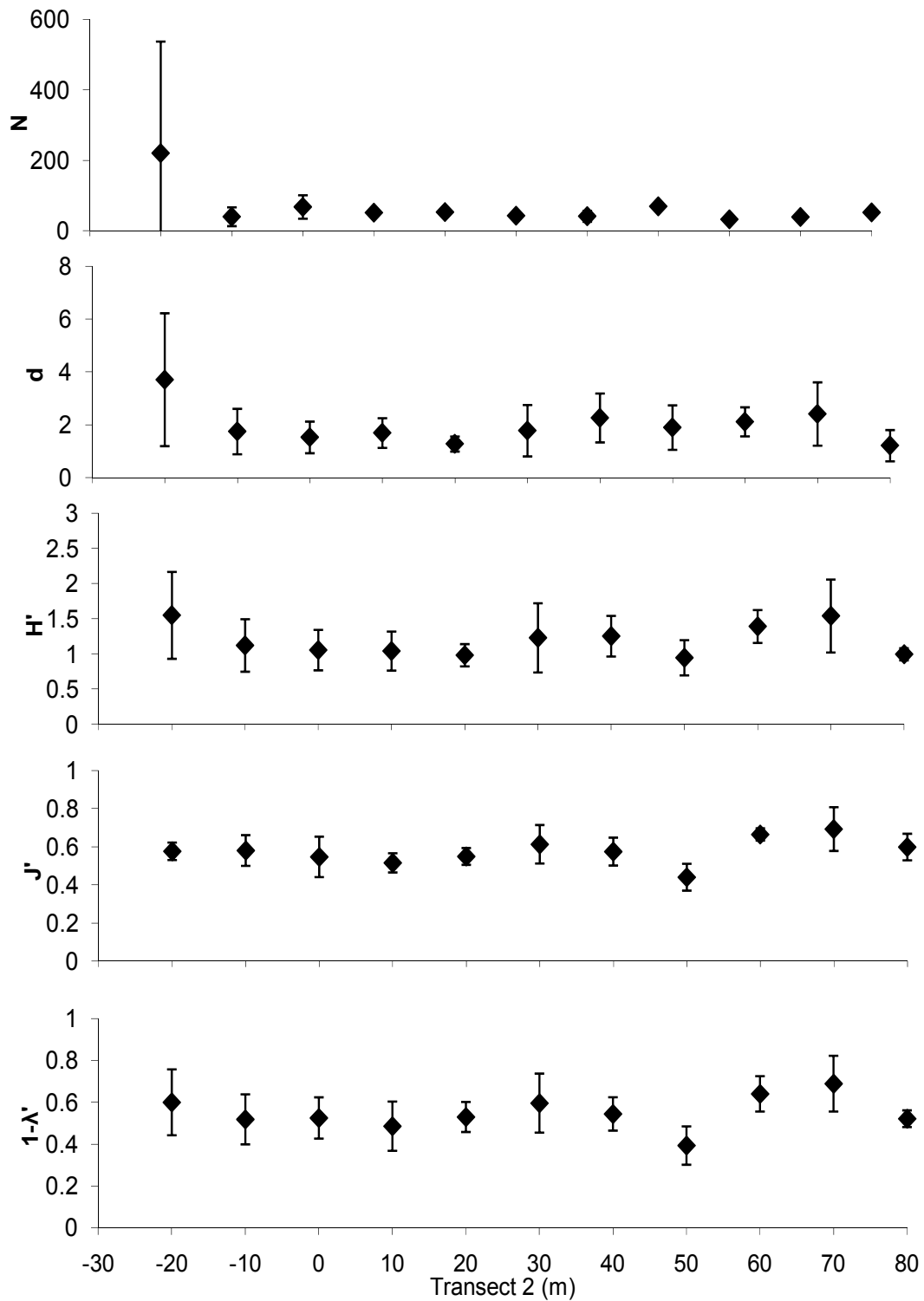
Figure 23: Mean (± SD) of total individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H'), and Simpson index (1-λ'), for three replicates at each site, at 10 m intervals along Transect 2, February 2008.

Figure 24: Mean (± SD) of total individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H'), and Simpson index (1-λ'), for three replicates at each site, at 10 m intervals along Transect 2, *Perna* sites excluded, February 2008.

Figure 25: Mean (± SD) of total individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H'), and Simpson index (1-λ'), for three replicates at each site, at 10 m intervals along Transect 3, February 2008.
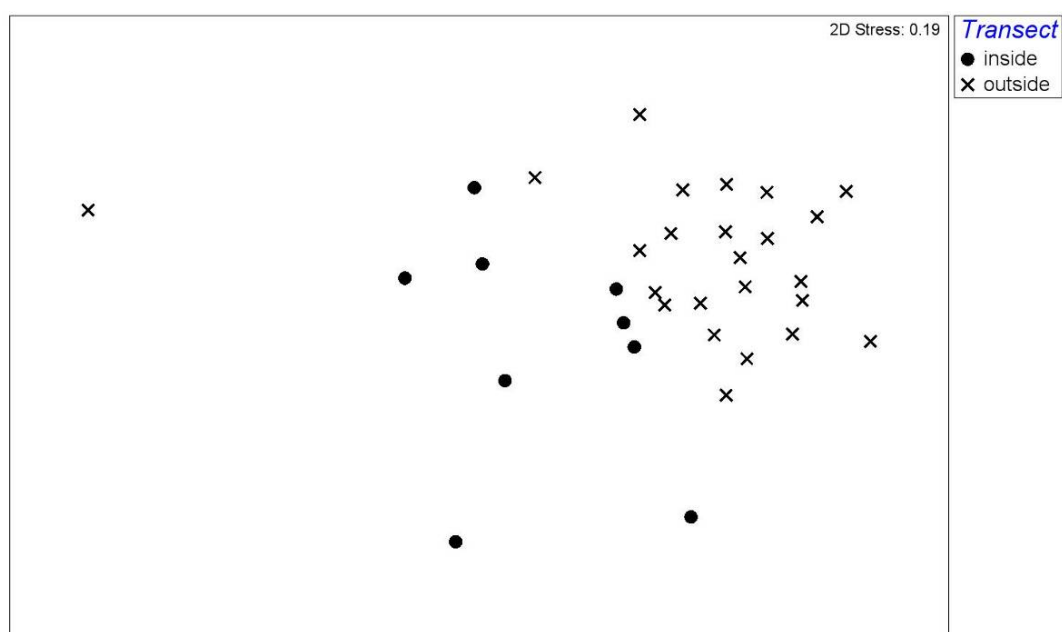
Figure 26: MDS plot of species assemblages, inside (-20–0 m) and outside the mussel farm (10–80 m), February 2008.

Table 25: Breakdown of average similarity (SIMPER) along Transect 1, February, by species.

SIMPER	-20m to 0m	10m to 70m
Similarity	45.10	49.31
Species (Cummulative %)	*Theora lubrica* (46.77%)	*Theora lubrica* (58.79%)
	Prionospio sp. (73.40%)	Ostracod sp. 2 (81.04%)
	Paraphoxus sp. 1 (89.80%)	*Prionospio* sp. (85.15%)
	Oligochaeta (92.51%)	*Paraphoxus* sp. 1 (88.44%)
		Onuphis aucklandensis (90.77%)
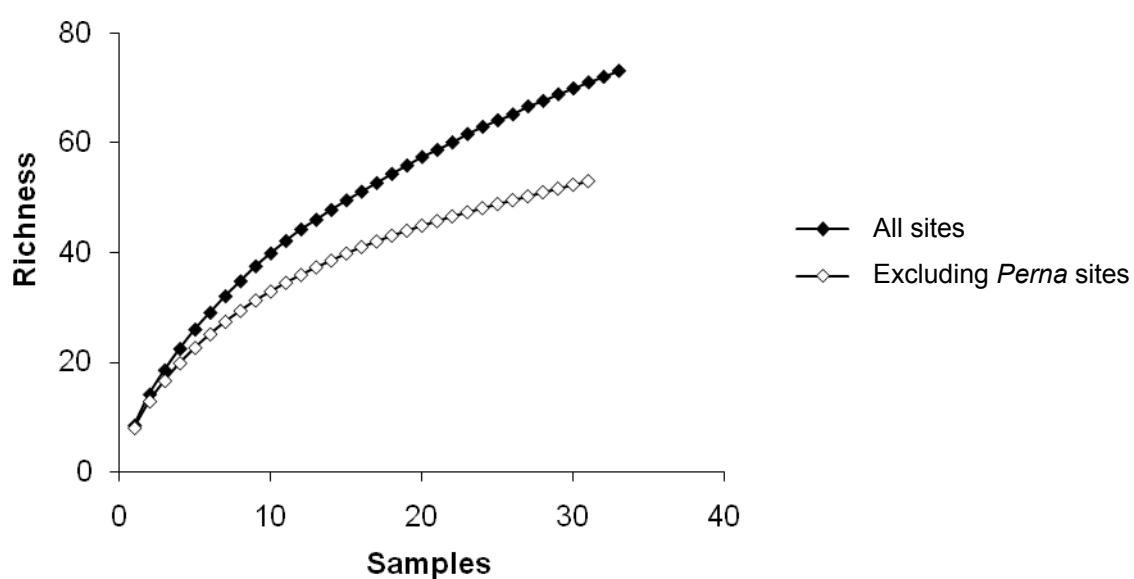
Figure 27: Species accumulation curves, Transect 1, February 2008.
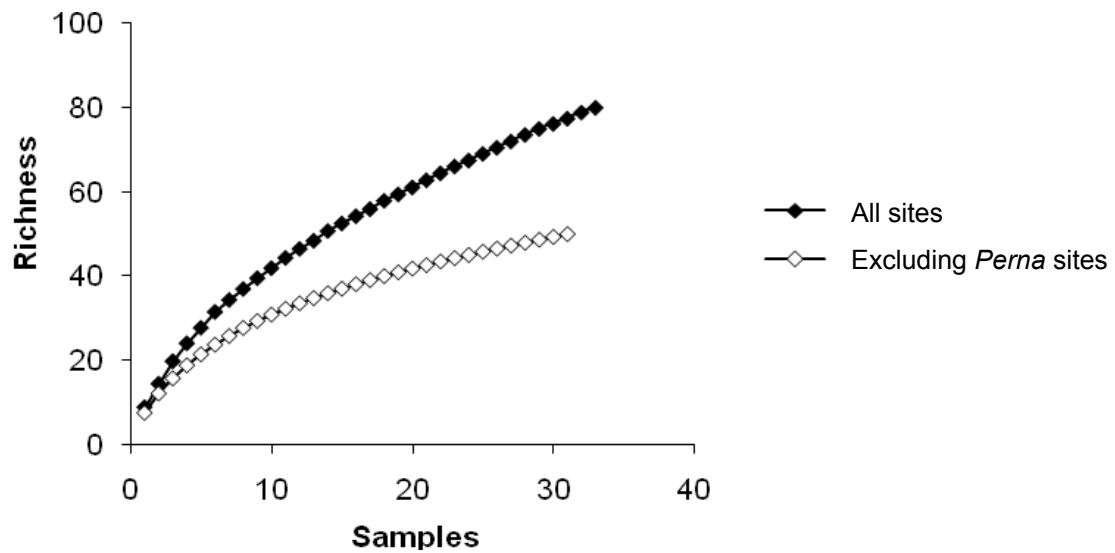
Figure 28: Species accumulation curves, Transect 2, February 2008.
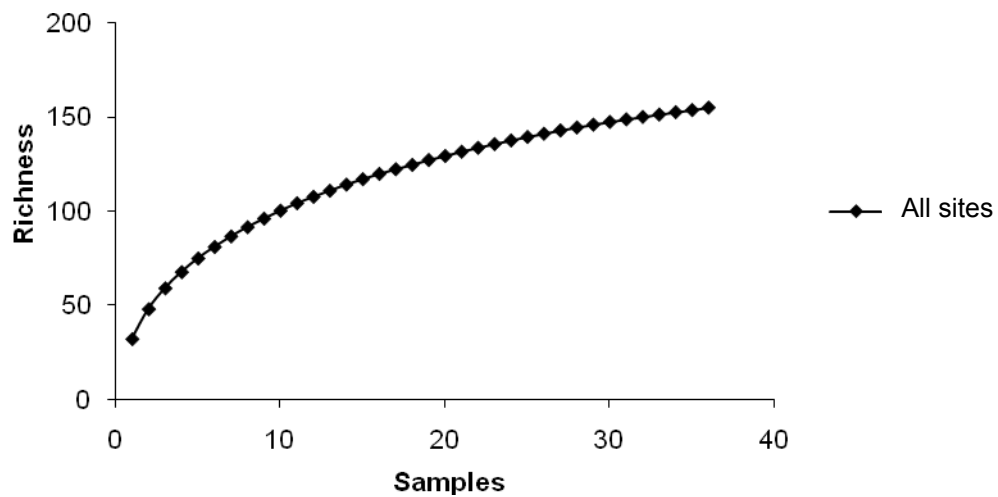
Figure 29: Species accumulation curves, Transect 3, February 2008.
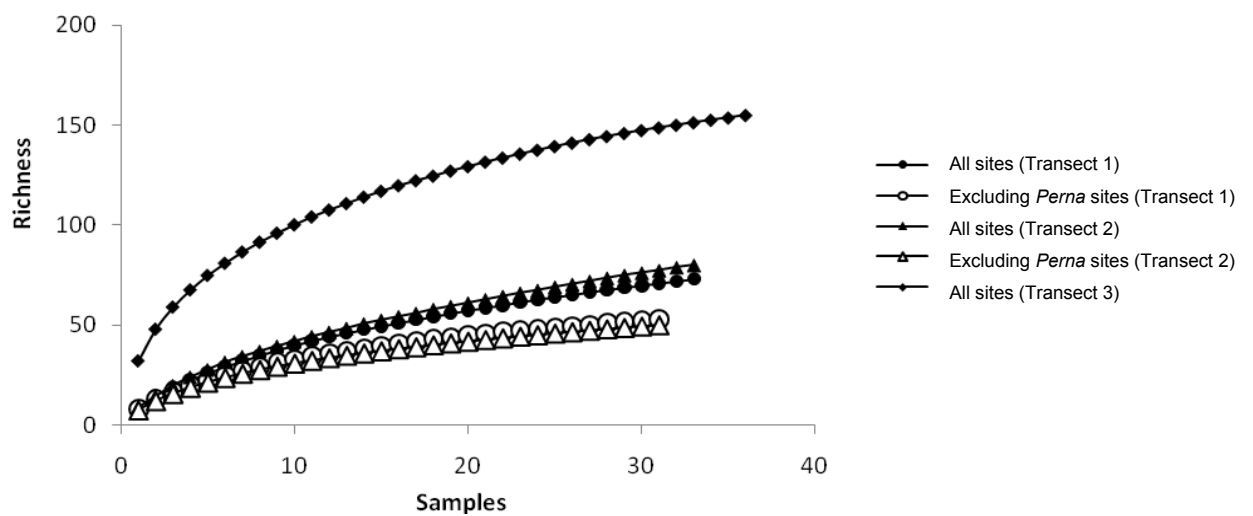
Figure 30: Species accumulation curves, Transects 1–3, February 2008.

During May Transect 1 extended 70 m beyond the physical boundary of the farm, and 20 metres within it. DIVERSE indices decreased from 10m to 40m outside the farm, then increased at 50 m before decreasing to a level comparable to those of the first 40 m from the farm (Figure 31). ANOVA revealed number of individuals (N), Margalef's index of species richness (d), Shannon index (H') and Simpson index (1-λ') all to be significantly different (p<0.05) for sites grouped within (-20–0 m) and outside the farm (10–70 m) along Transect 1, but not between any of those sites 10 and 70 m outside the farm (Appendix 6, Table A12). When *Perna* sites are excluded, ANOVA revealed only number of individuals (N), Shannon index (H'), and Simpson index (1-λ') to differ significantly between sites within and outside the farm (Figure 32) (Appendix 6, Table A12).

Species assemblages were significantly different between sites within (-20, -10 and 0 m) and outside (10 m to 70 m) the farm (ANOSIM, p=0.001) (Figure 33) (Appendix 7, Table A31). SIMPER tests (Table 26) (Appendix 7, Table A39–A41) reveal a more diverse (10 species) suite of taxa to characterise species assemblages along the first 20 metres within the farm (sites -20, -10 and 0m), with the five main contributors being *Theora lubrica* (25.2%), *Prionospio* sp. (45.1%), *Paraphoxus* sp. 1 (57.9%), a capitellid polychaete *Capitella 'capitata'* (~ 68.5%), and *Paraphoxus* sp. 2 (75.2%); the less diverse assemblage (five species) characterising assemblages outside the farm (10–70m) were *Theora lubrica* (52.7%), and two ostracod (Ostracod sp. 2, 11) and polychaete species (*Sthenelais* sp. and *Prionospio* sp.), with a cumulative contribution of 90.8%.

No asymptote was reached in the species accumulation curve along Transect 1, including or excluding those sites at which *Perna* occurred (Figure 34).
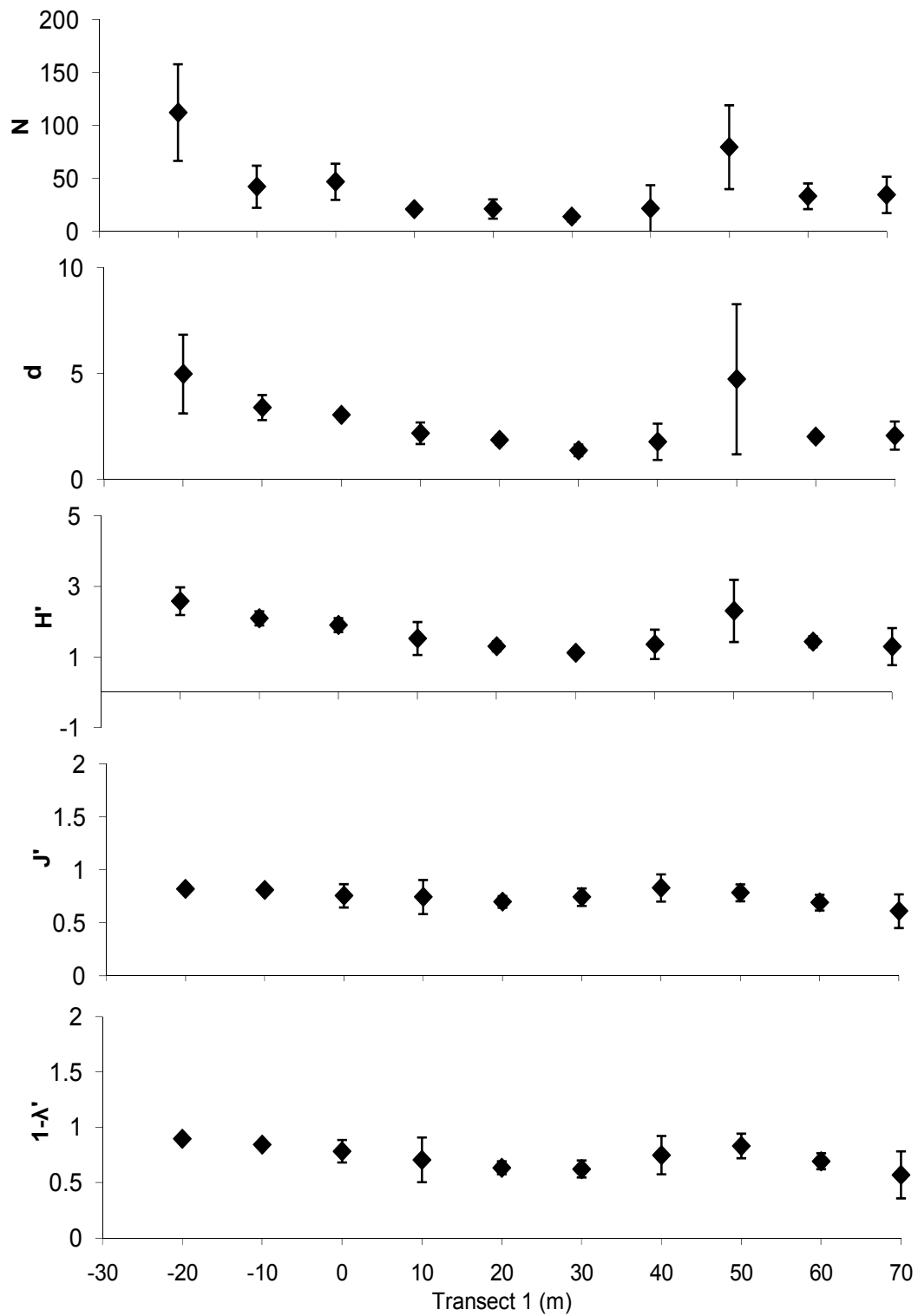
Figure 31: Mean (± SD) of total individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H'), and Simpson index (1-λ'), three replicates, at 10 m intervals along Transect 1, May 2008.
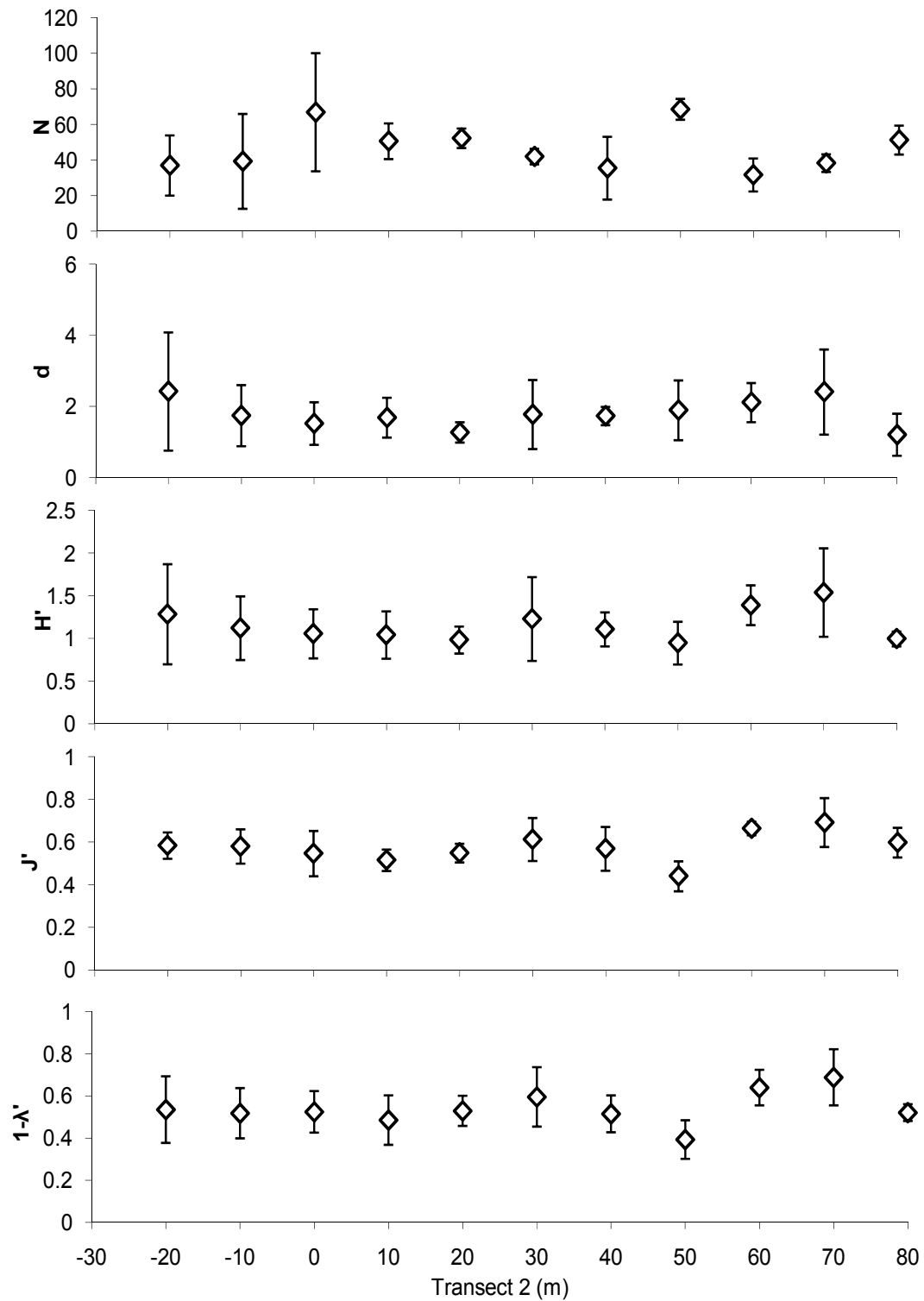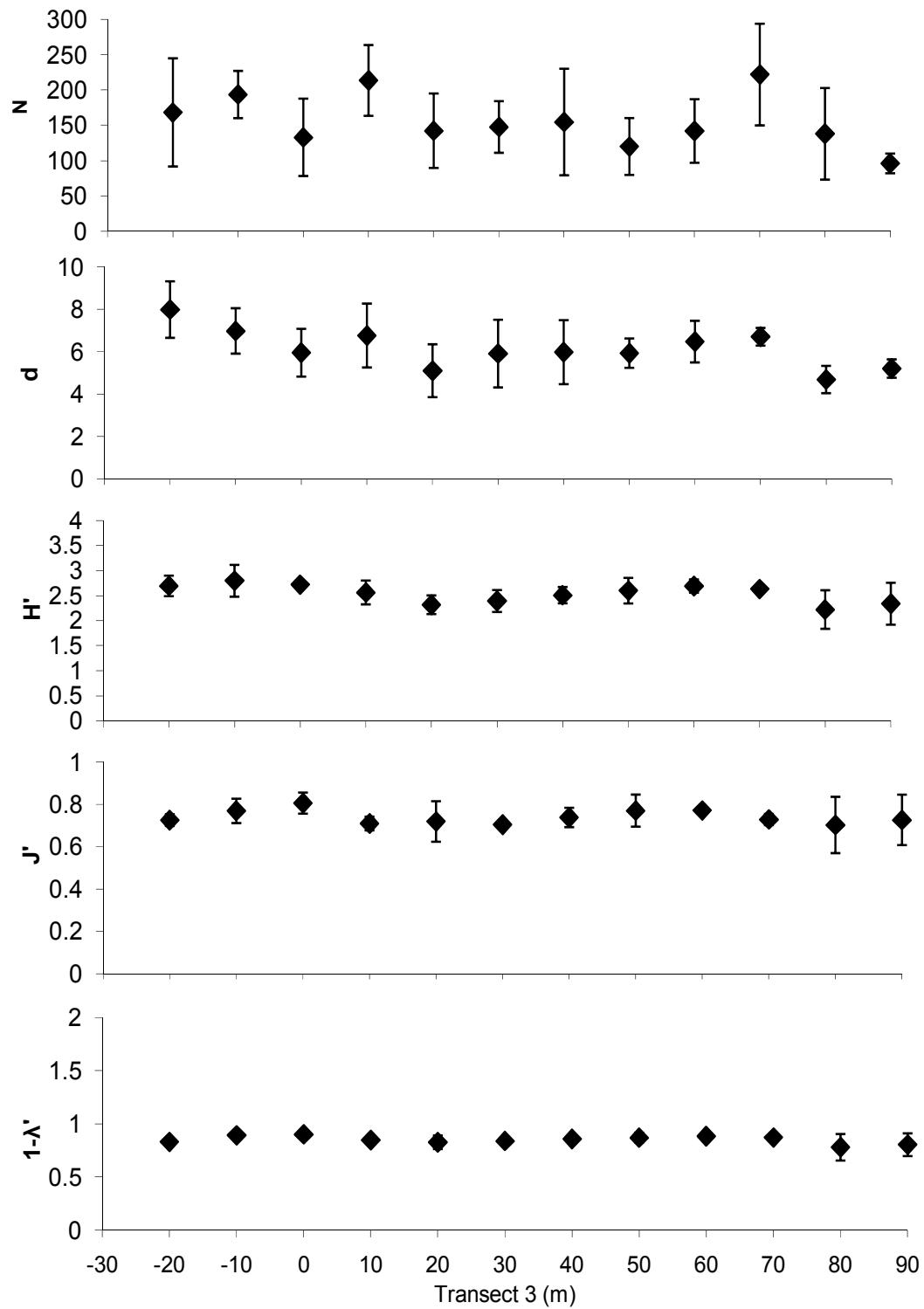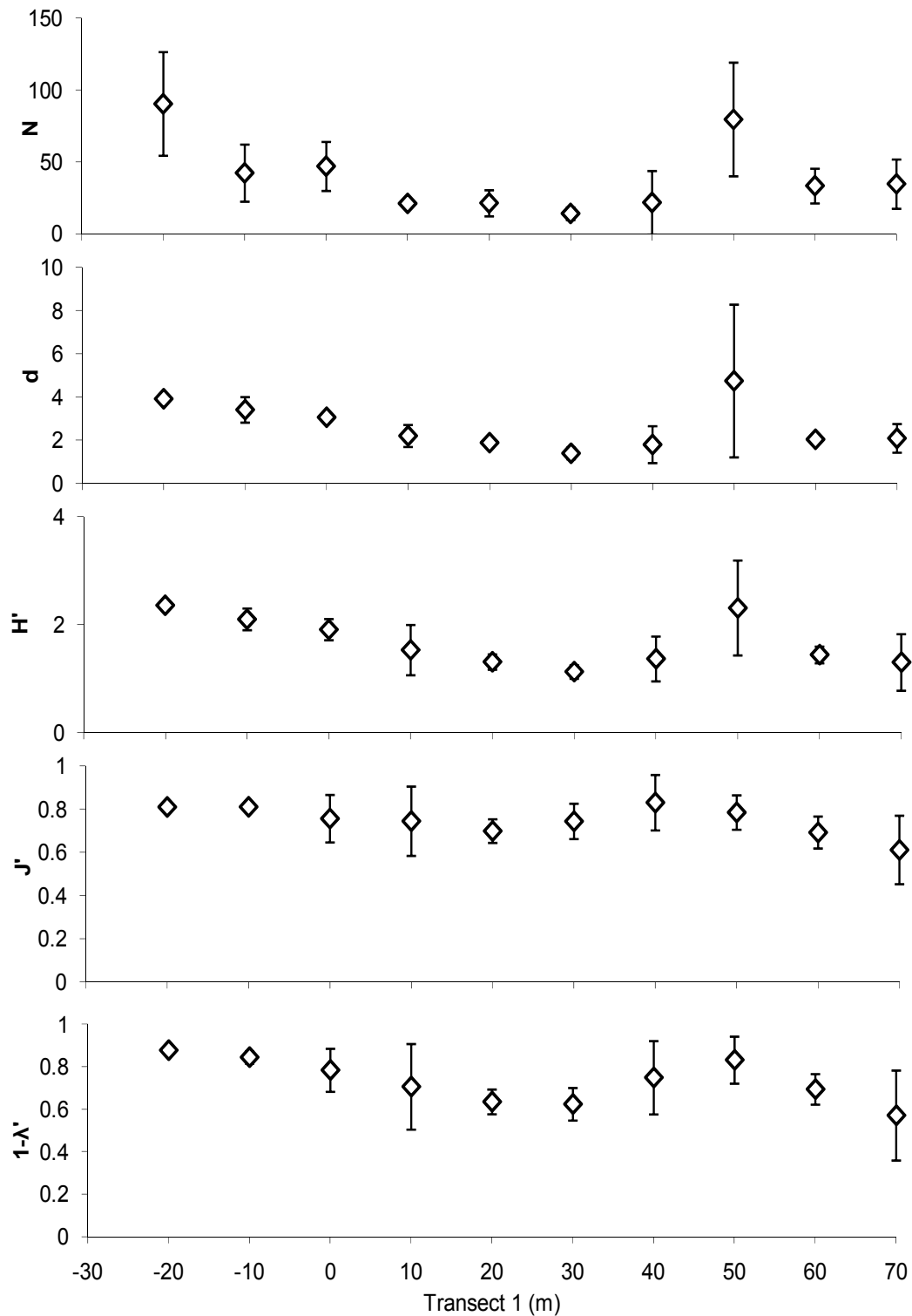
Figure 32: Mean (± SD) of total individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H'), and Simpson index (1-λ'), for three replicates, *Perna* sites excluded, Transect 1, May 2008.
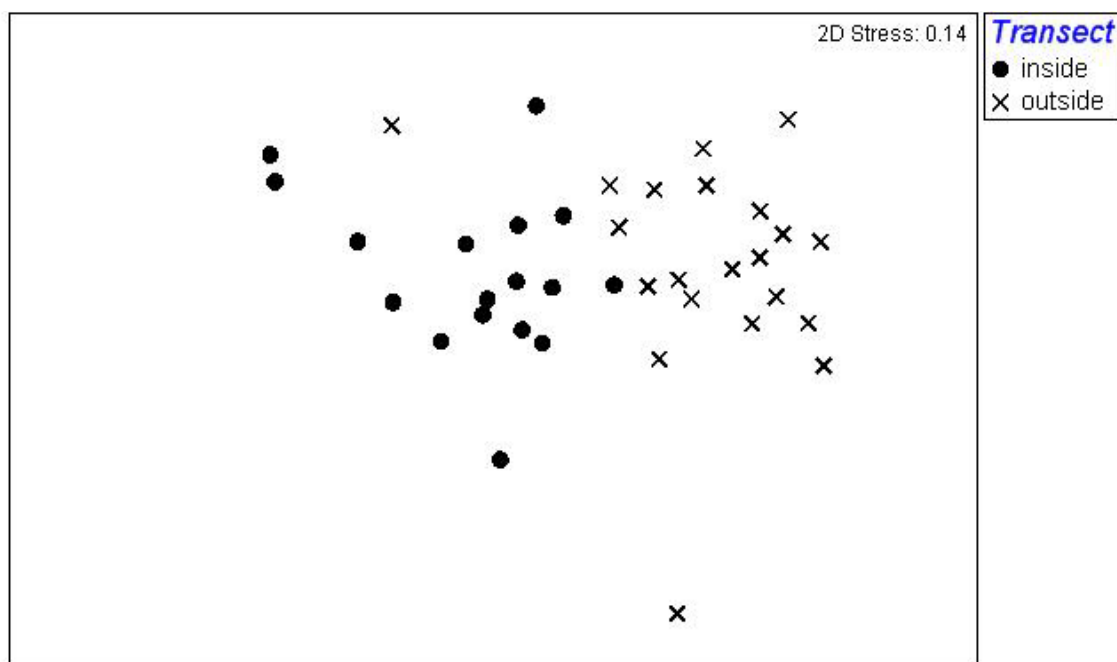
Figure 33: MDS plot of species assemblages, inside (-20−0 m) and outside the farm (10−70 m), May 2008.

Table 26: Breakdown of average similarity (SIMPER) by species along Transect 1, May.

SIMPER	**-20m to 0m**	**10m to 70m**
Similarity	42.53	41.81
Species (Cummulative %)	*Theora lubrica* (25.19%)	*Theora lubrica* (54.17%)
	Prionospio sp. (45.12%)	Ostracod sp. 2 (69.59%)
	Paraphoxus sp. 1 (57.93%)	*Sthenelais* sp. (80.93%)
	Capitella 'capitata' (68.45%)	Ostracod sp. 11 (86.63%)
	Paraphoxus sp. 2 (75.23%)	*Prionospio* sp. (90.84%)
	Pectinaria australis (79.35%)	
	Armandia maculata (82.58%)	
	Hydroides norvegicus (85.76%)	
	Heteromastus filiformis (88.25%)	
	Cossura consimilis (90.02%)	
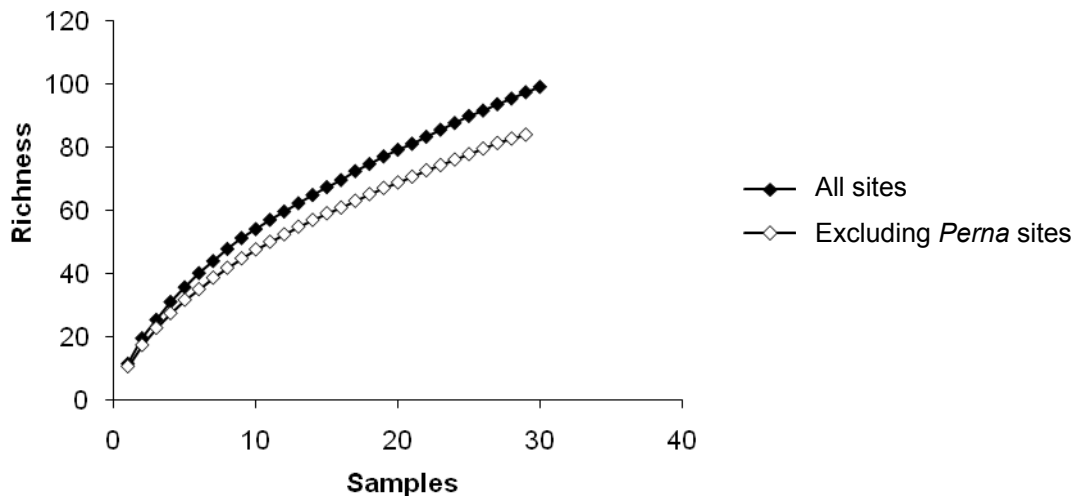
Figure 34: Species accumulation curve, Transect 1, May 2008.

<u>August 2008</u>

In August Transect 1 extended from 20 m within to 110 m beyond the physical boundary of the farm. ANOVA revealed all DIVERSE indices, with the exception of evenness (J') and Simpson index (1-λ'), to be significantly different ($p<0.05$) for -20 m to 20 m, and 30 m to 110 m (Figure 35) (Appendix 6, Table A13); there were no significant differences in any DIVERSE index between 30–50 m and 60–110 m. Species composition was significantly different ($p=0.001$) inside (-20–0m) and outside (10–110m) the farm, but no significant difference was observed between sites 10–110 m outside the farm (Figure 36) (Appendix 7, Table A32). Of nine samples collected within the farm, eight contained *Perna*; accordingly DIVERSE indices were not calculated within and outside the farm excluding these sites for August.

SIMPER tests (Table 27) (Appendix 7, Table A42–A44) identify 11 taxa both within and outside the farm to contribute ~90% to the similarity in species assemblages characterising each. The top five of these species in assemblages within the farm (sites -20, -10 and 0m) in August were dominated by *Paraphoxus* sp. 1 (17.6%), and polychaetes *Prionospio* sp. (34.2%) and *Capitella 'capitata'* (48.8%), and bivalves, the mussel itself, *Perna* (58.4%), and *Theora lubrica* (67.2%); the most dominant species outside the farm (10–110m)

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were *Theora lubrica* (29.2%), Ostracod sp. 2 (55.1%), and polychaetes *Prionospio* sp. (64.73%) and *Sthenelais* sp. (72.4%).

No asymptote was reached in the species accumulation curve for Transect 1, whether including or excluding those sites at which *Perna* occurred (Figure 37).

Table 27: Breakdown of average similarity (SIMPER) along Transect 1 in August, by species.

SIMPER	-20m to 0m	10m to 110m
Similarity	36.79	33.70
Species (Cummulative %)	*Paraphoxus* sp. 1 (17.56%)	*Theora lubrica* (29.15%)
	Prionospio sp. (34.15%)	Ostracod sp. 2 (55.12%)
	Capitella 'capitata' (48.83%)	*Prionospio* sp. (64.73%)
	Perna canaliculus (58.40%)	*Sthenelais* sp. (72.37%)
	Theora lubrica (67.17%)	*Cossura consimilis* (78.27%)
	Armandia maculata (74.51%)	*Paraphoxus* sp. 1 (82.97%)
	Paraphoxus sp. 2 (78.46%)	Ostracod sp. 11 (85.29%)
	Sthenelais sp. (81.76%)	*Echinocardium cordatum* (86.91%)
	Halicarcinus cookii (84.28%)	*Nephtys macroura* (88.45%)
	Platyhelminthes (86.76%)	*Paraphoxus* sp. 2 (89.96%)
	Periclimenes yaldwyni (90.68%)	*Diastylis insularum* (90.94%)
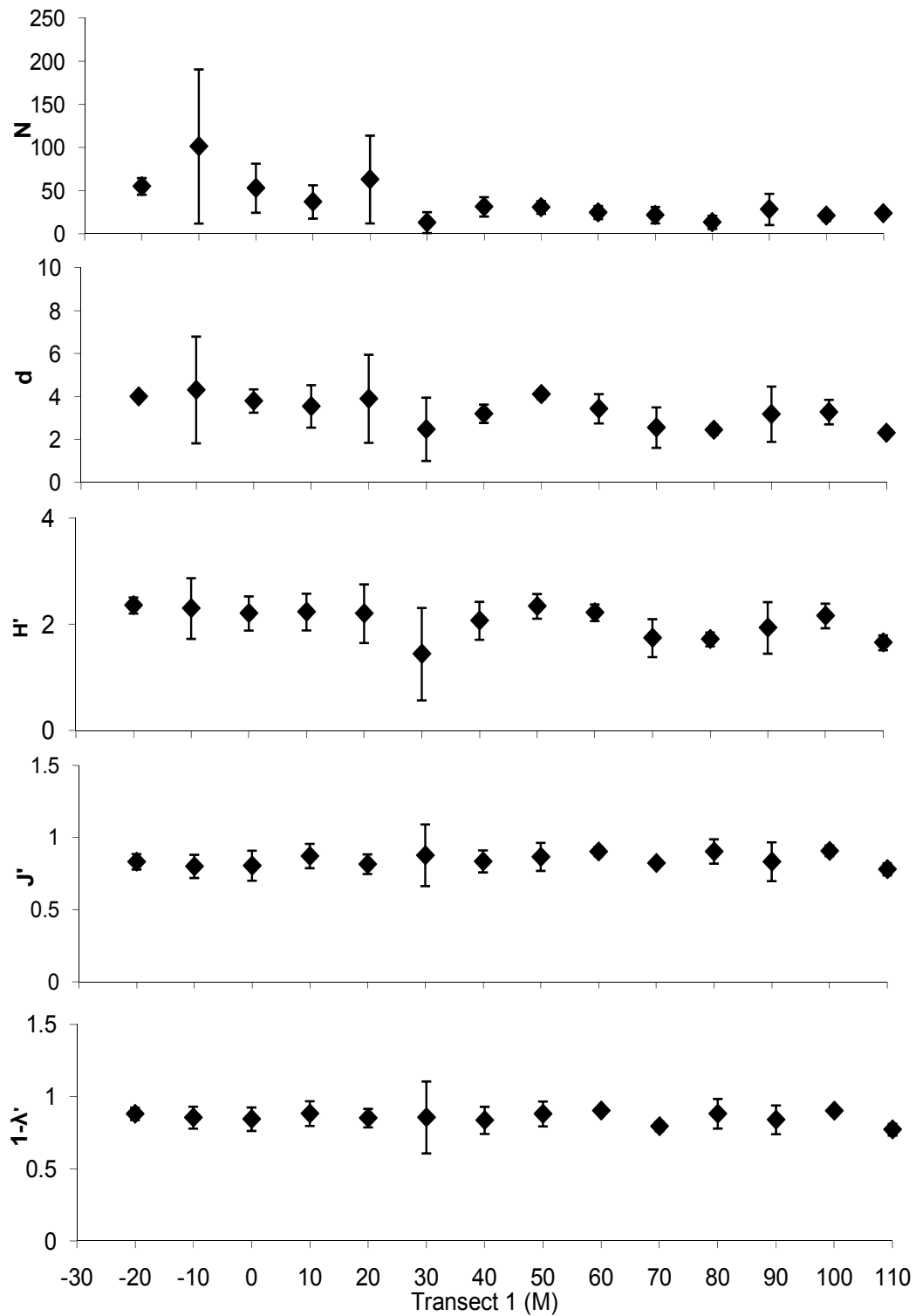
Figure 35: Mean (± SD) of total individuals (N), Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H'), and Simpson index (1-λ'), for three replicates at each site, at 10 m intervals along Transect 1, August 2008.
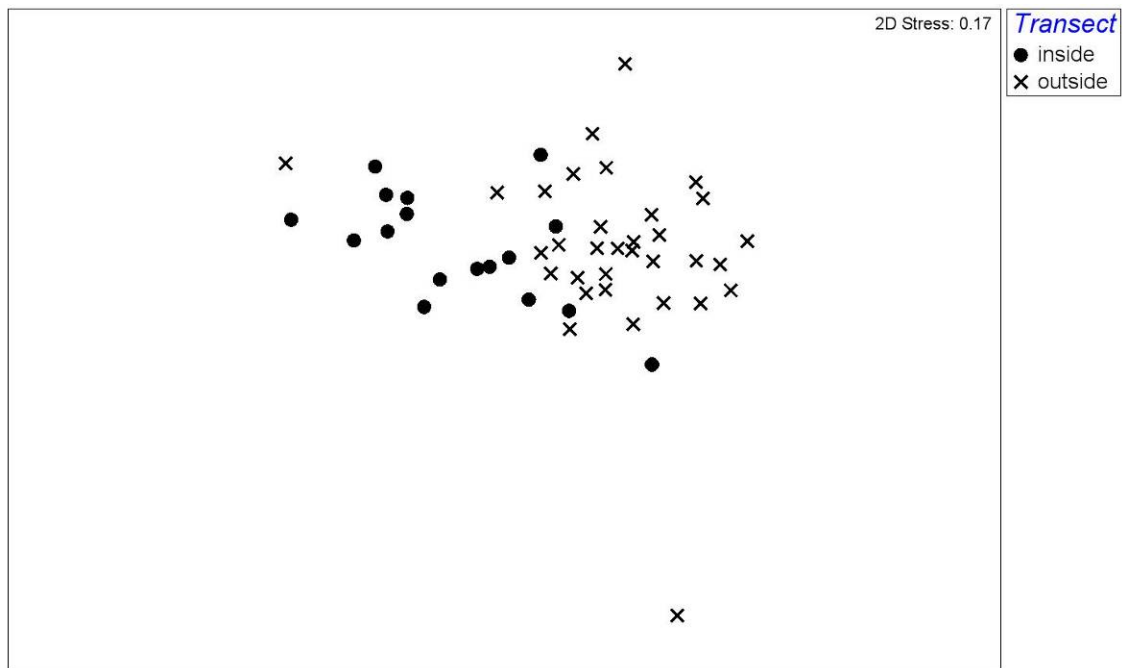
Figure 36: MDS plot of species assemblages inside (-20–0 m) and outside (10–110 m) the farm, August 2008.
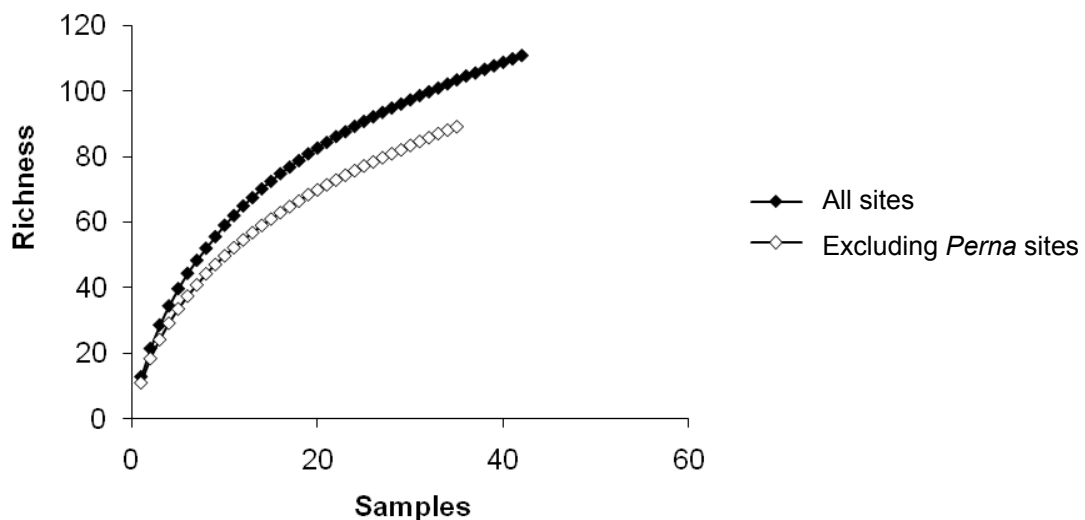
Figure 37: Species accumulation curves, Transect 1, August 2008.

Temporal variation along Transect 1

Margalef's index of species richness (d), Pielou's evenness index (J'), Shannon-Wiener diversity index (H') and Simpson index (1-λ') all were significantly different between seasons, and all were greater during August, followed by May, then February (Appendix 6, Table A14). There was no

significant difference in the number of individuals (N) between the three sampling occasions (Table 28).

Table 28: DIVERSE indices on three survey occasions, February, May and August 2008 (SD = standard deviation, DIVERSE symbols as defined in Table 4).

Month		N	d	J'	H'	1-λ'
February 2008	Mean	47.03	2.02	0.62	1.29	0.59
	SD	36.44	0.99	0.14	0.44	0.17
May 2008	Mean	42.73	2.76	0.75	1.70	0.73
	SD	35.46	1.65	0.11	0.59	0.15
August 2008	Mean	36.93	3.33	0.85	2.04	0.86
	SD	34.23	1.13	0.09	0.44	0.09

Within Farm monitoring

During each survey, February, May and August, 17 samples were collected within the mussel farm: eight from sites characterised as mud, six as mud/gravel, and three as gravel.

Two-way ANOSIM reveals species composition to differ significantly ($p < 0.005$) within the farm in each substratum type, between months (Figure 38) (Appendix 7, Table A33).
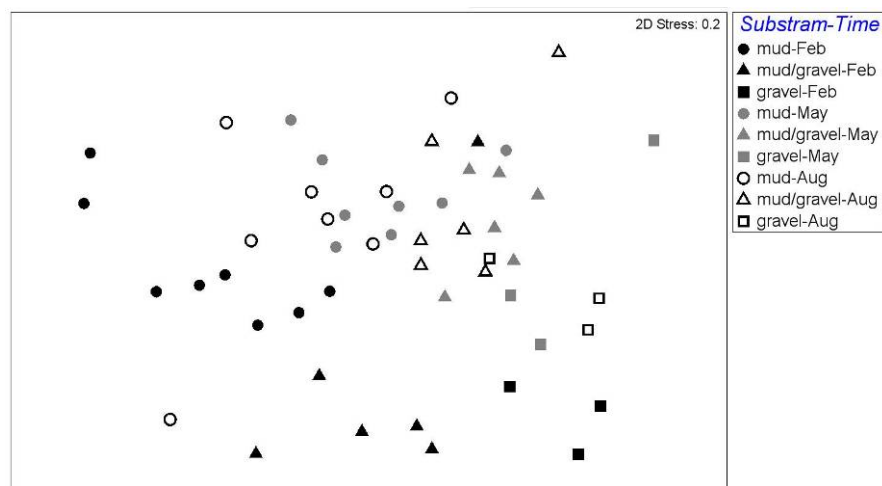
Figure 38: MDS plot of species assemblages, by months and substratum type.

To determine whether any difference existed in the assemblages of species occurring within and outside the mussel farm in muds, all samples collected from muds within the farm (those along Transect 1 and eight sites from the 17 randomly distributed sites within the farm), and those outside the farm along Transect 1 were compared (Table 29).

Table 29: Sampling effort in muddy substrata within and outside the farm, all survey dates.

	Transect 1 (within farm) # mud samples	Within farm (random sites) # mud samples	Transect 1 (outside farm) # mud samples	Totals # mud samples
February 2008	9 (3 sites)	8	24 (8 sites)	41
May 2008	9 (3 sites)	8	21 (7 sites)	38
August 2008	9 (3 sites)	8	33 (11 sites)	50

With the exception of Pielou's evenness index (J'), all DIVERSE indices within the farm for the month of February differ significantly from those of May and August, although no significant difference is apparent in these indices between May and August (Table 30) (Appendix 6, Table A15). With the exception of Pielou's evenness index (J') and Simpson index (1-λ'), no significant difference is apparent in species assemblages outside the farm between February and May; all DIVERSE indices were significantly different between August and February; and all DIVERSE indices, except total number of individuals (N), were significantly different between August and May (Table 31) (Appendix 6, Table A16).

Two-way ANOSIM reveals species assemblages differed significantly within and outside the physical boundary of the farm (p<0.005), and this difference was significant for each of the survey months, February, May and August (Figure 39) (Appendix 7, Table A34).

No asymptote was reached on any species accumulation curve along, within, or outside the farm for any sampling month (February, May and August), including or excluding those sites at which *Perna* occurred (Figure 40–45). However,

species richness always was higher within the farm than it was outside the farm, except during the month of February (including *Perna* sites).

Table 30: DIVERSE indices within the farm, on three survey occasions (SD = standard deviation, DIVERSE symbols as defined in Table 4).

Month		N	d	J'	H'	1-λ'
February 2008	Mean	33.18	2.14	0.75	1.51	0.70
	SD	17.68	0.95	0.13	0.52	0.17
May 2008	Mean	75.29	4.02	0.80	2.26	0.85
	SD	45.36	1.24	0.07	0.33	0.06
August 2008	Mean	77.29	3.94	0.77	2.16	0.82
	SD	55.17	1.42	0.11	0.45	0.11

Table 31: DIVERSE indices outside the physical boundary of the farm, on three survey occasions (SD = standard deviation, DIVERSE symbols as defined in Table 4).

Month		N	d	J'	H'	1-λ'
February 2008	Mean	51.46	2.04	0.59	1.23	0.56
	SD	41.07	1.05	0.11	0.40	0.15
May 2008	Mean	32.14	2.29	0.72	1.47	0.68
	SD	26.57	1.60	0.12	0.55	0.16
August 2008	Mean	27.97	3.14	0.86	1.97	0.85
	SD	20.45	1.02	0.09	0.44	0.09
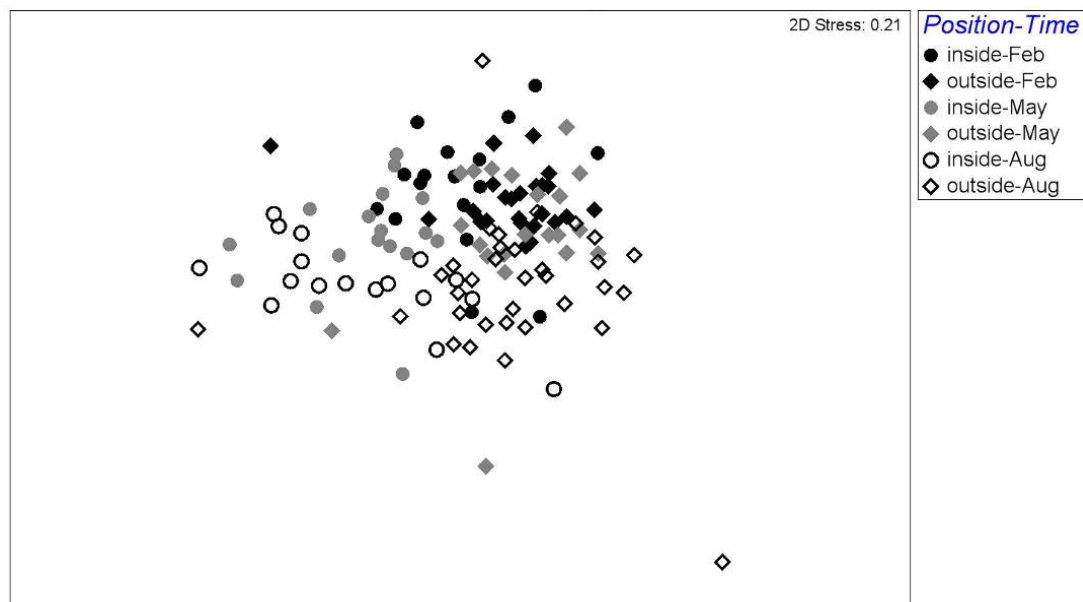
Figure 39: MDS plot of species assemblages, within and outside the physical boundary of the farm, by survey month.
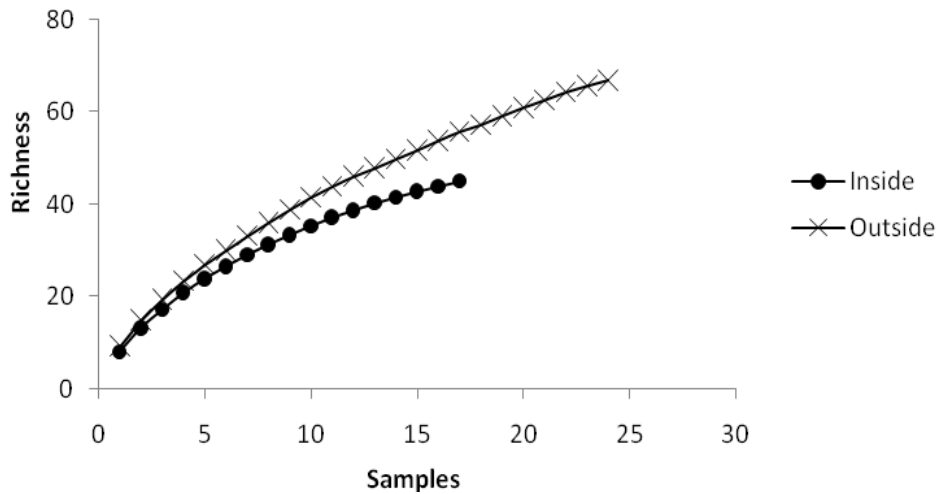
Figure 40: Species accumulation curves, within and outside the farm, all sites, February 2008.
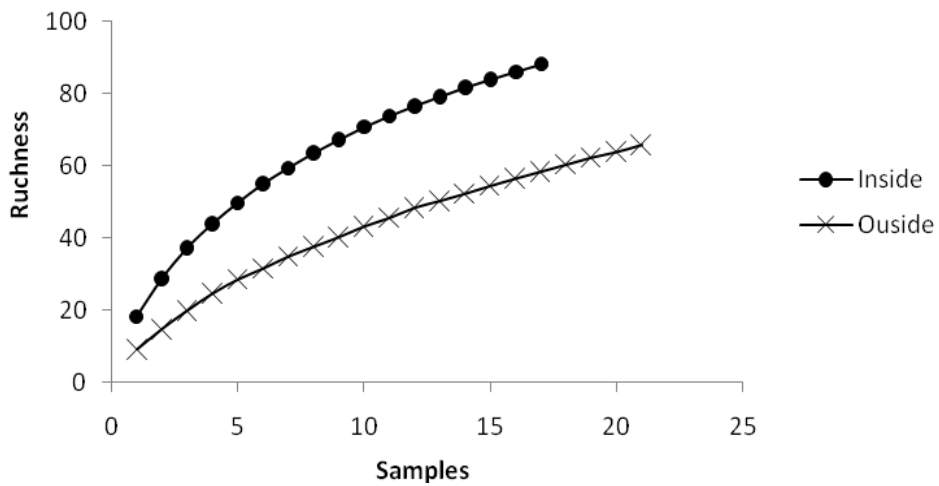
Figure 41: Species accumulation curves, within and outside the farm, all sites, May 2008.
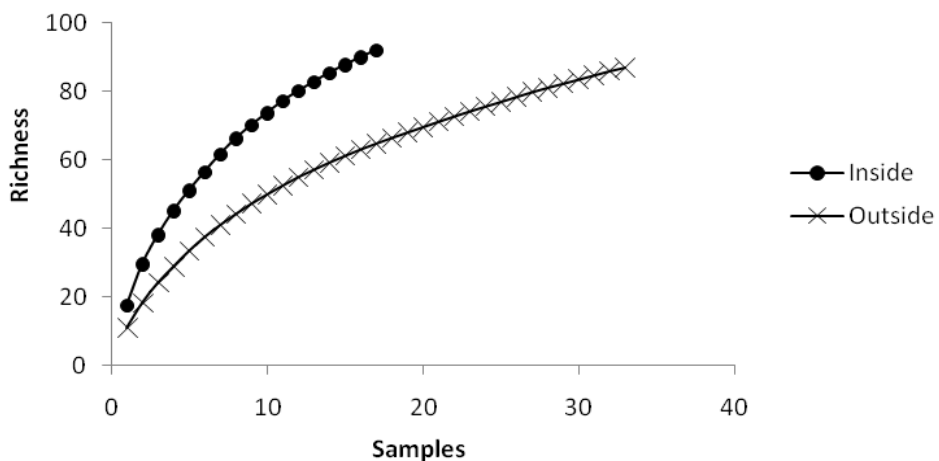
Figure 42: Species accumulation curves, within and outside the farm, all sites, August 2008.
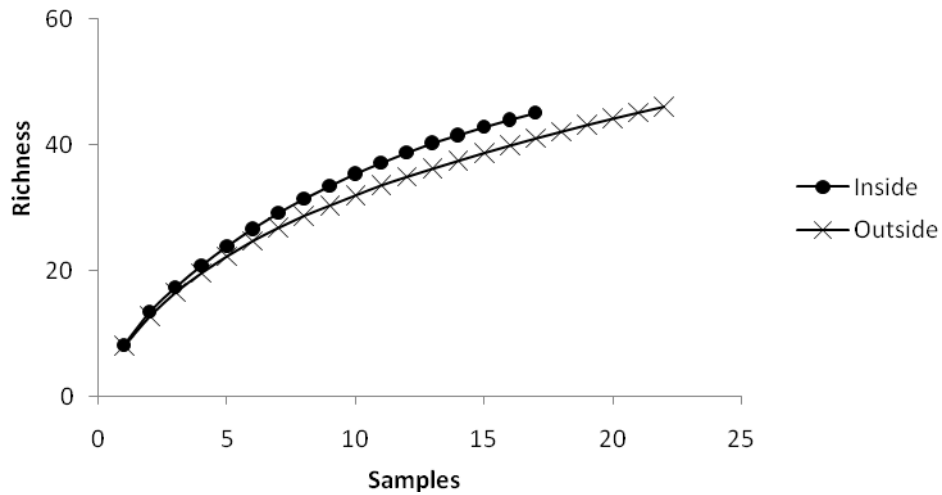
Figure 43: Species accumulation curves, within and outside the farm, *Perna* sites excluded, February 2008.
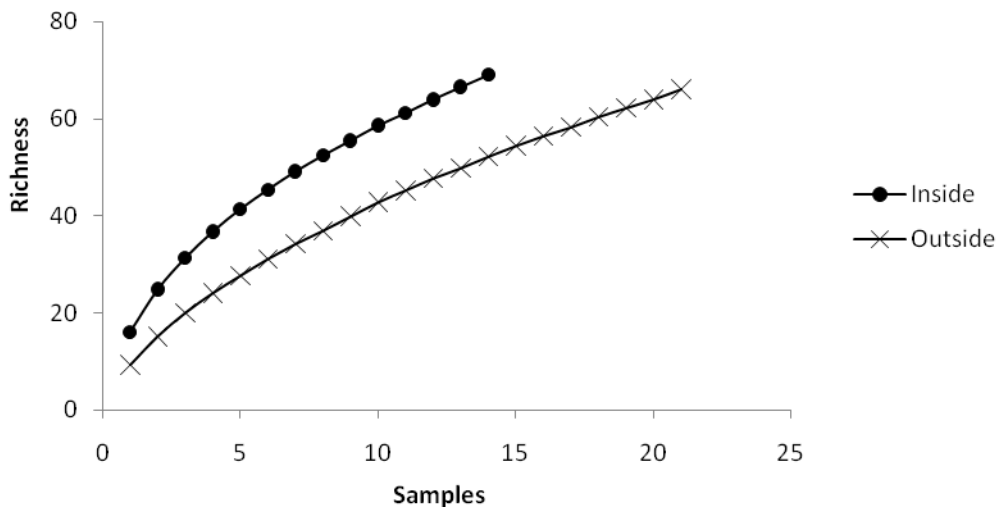
Figure 44: Species accumulation curves, within and outside the farm, *Perna* sites excluded, May 2008.
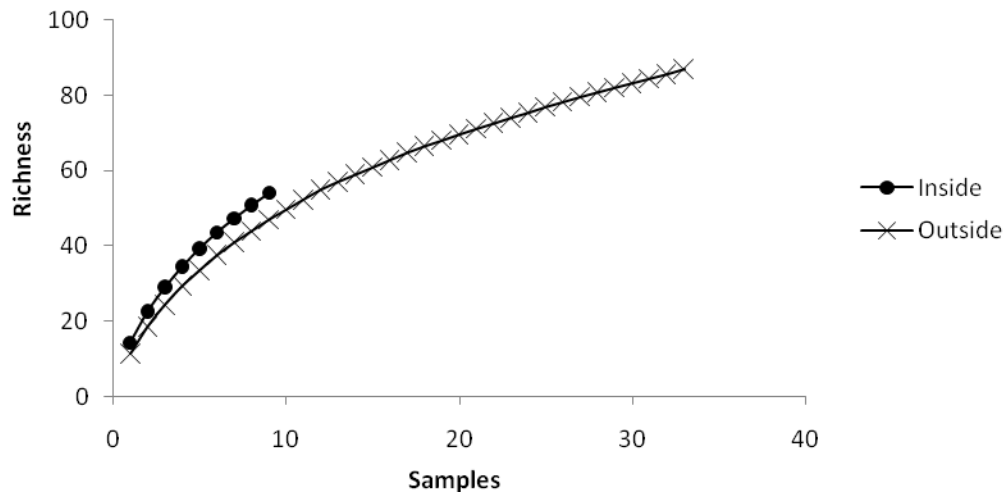
Figure 45: Species accumulation curves, within and outside the farm, *Perna* sites excluded, August 2008.

Dominant taxa within and outside the farm

To determine the dominant classes of taxa contributing to species assemblages within and outside the mussel farm, all samples collected outside the physical boundary of the farm along transects, those collected within the farm along each transect, and those occurring in the same substratum type within the farm (of 17 randomly selected sites) were compared.

Transect 1 was surveyed on three occasions (Table 29). Transects 2 and 3 were surveyed once only. The number of samples within the farm compared to outside the farm for muds characterising Transect 2 was 17 and 24 respectively (8 muddy samples within the farm, and 9 samples from the three sites with three replicates at each within the farm boundary; and eight sites each with three replicates along this Transect outside the farm boundary). The number of gravel samples within the farm compared to outside the farm along Transect 3 was 12 and 27 respectively (three gravel samples within the farm nine samples from the three replicated sites within the farm boundary, and 27 samples from 9 replicated sites outside the farm boundary).

On the northern side of the farm (Transect 1), SIMPER reveals similar taxa to occur in muds within and outside the farm, although at different average abundances, especially polychaetes in May and August. During each survey dominant taxa within the farm were polychaetes, bivalves and crustaceans (Malacostraca), whereas outside the farm bivalves, polychaetes and ostracods prevailed; polychaetes were the main contributors within the farm in all three occasions, in addition to one occasion outside the farm in August, whereas bivalves were the main contributor outside the farm during February and May (Table 32).

On the northeastern (Transect 2) and southern (Transect 3) sides of the farm, similar taxa dominated sediments within and outside the farm, at similar average abundances; bivalves, polychaetes and ostracods were the major taxa on the northeastern side of the farm, and polychaetes, bivalves, crustaceans

(Malacostraca) and gastropods were the dominant taxa on the southern side of the farm (Table 33).

Table 32: Breakdown of average similarity by Class within and outside the mussel farm on its northern border, muds.

SIMPER	Inside February	May	August	Outside February	May	August
Siimilarity (Average abundance)	Polychaeta (4.57) Bivalvia (3.12) Malacostraca (3.71)	Polychaeta (16.1) Malacostraca (6.27) Bivalvia (3.77)	Polychaeta (13.72) Malacostraca (8.04) Bivalvia (3.26)	Bivalvia (5.39) Ostracoda (3.23) Polychaeta (4.02)	Bivalvia (3.7) Polychaeta (4.88) Ostracoda (2.97)	Polychaeta (5.38) Ostracoda (3.34) Bivalvia (2.58) Malacostraca (3.16)

Table 33: Breakdown of average similarity by Class within and outside the northeastern (muds) and southern (gravels) substrata, February 2008.

SIMPER	Northeastern (Transect 2) Inside	Outside	Southern (Transect 3) Inside	Outside
Similarity (Average abundance)	Bivalvia (4.35) Polychaeta (5.6) Ostracoda (2.82) Malacostraca (4.16)	Bivalvia (5.64) Ostracoda (3.57) Polychaeta (3.69)	Polychaeta (36.62) Bivalvia (5.6) Malacostraca (4.49) Ostracoda (3.08) Gastropoda (2.25)	Polychaeta (30.94) Bivalvia (6.63) Malacostraca (5.14) Gastropoda (2.9)

Application of Relative Richness and Abundance scores

Based on relative taxon richness for muds (Table 20), richness within and outside the farm generally falls into *medium* and *fairly high* categories (Figure 46). Exceptions to this are *high* and *very high* levels of species richness 20 m within the farm on Transect 2 in February 2008, 50 m outside of the farm on Transect 1 in May 2008, and one site within the farm on its northeastern boundary in August 2008.

Based on relative abundance scores for muds (Table 24), abundance within and outside the farm in February 2008 generally falls into *very low* to *fairly low* categories, with the exception being *very high* abundance within the farm during February, again in its northeastern section. In May and August 2008, most of the sites outside the farm are categorised as *very low* abundance, while abundance at sites within the farm was generally *fairly low* to *medium* (Figure 47).
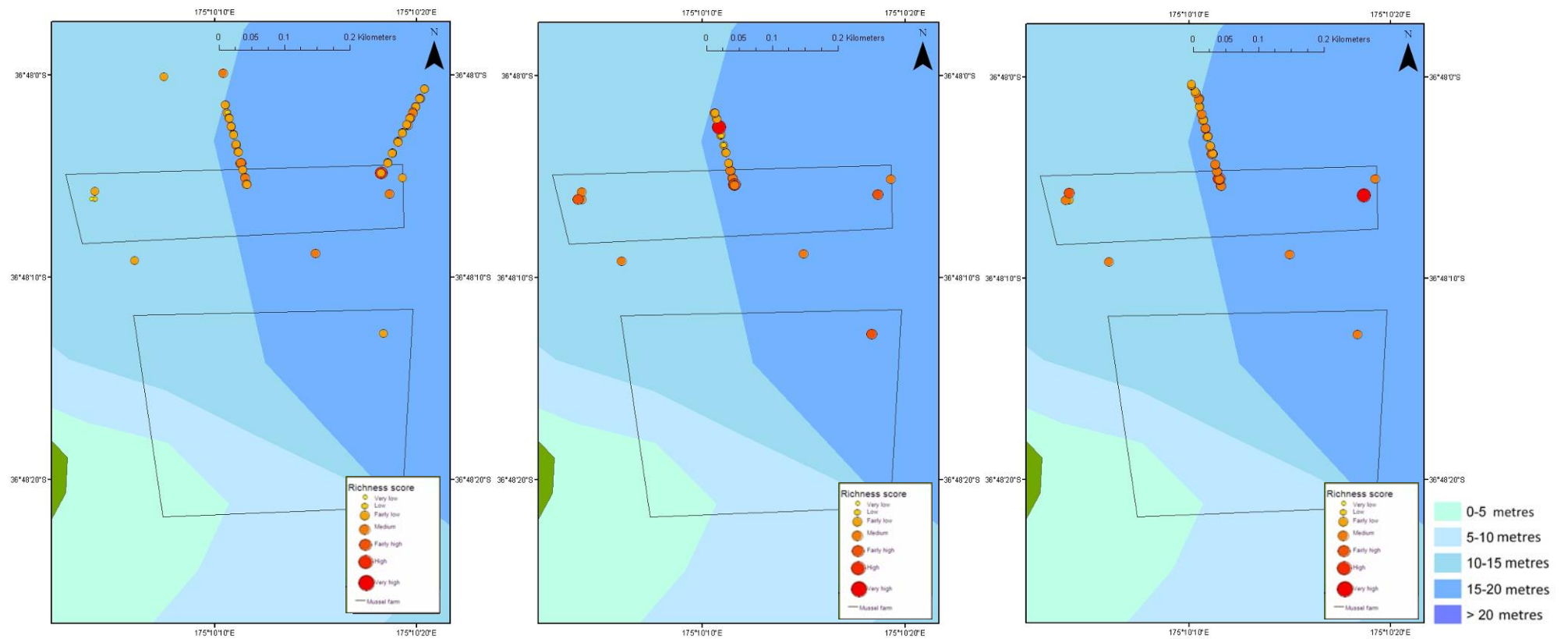
Figure 46: Spatial distribution of Species Richness, muds, within and proximal to mussel farm along Transects 1 & 2, and those muddy sites within farm from the 17 randomly selected stations: February (left), May (middle) and August (right).
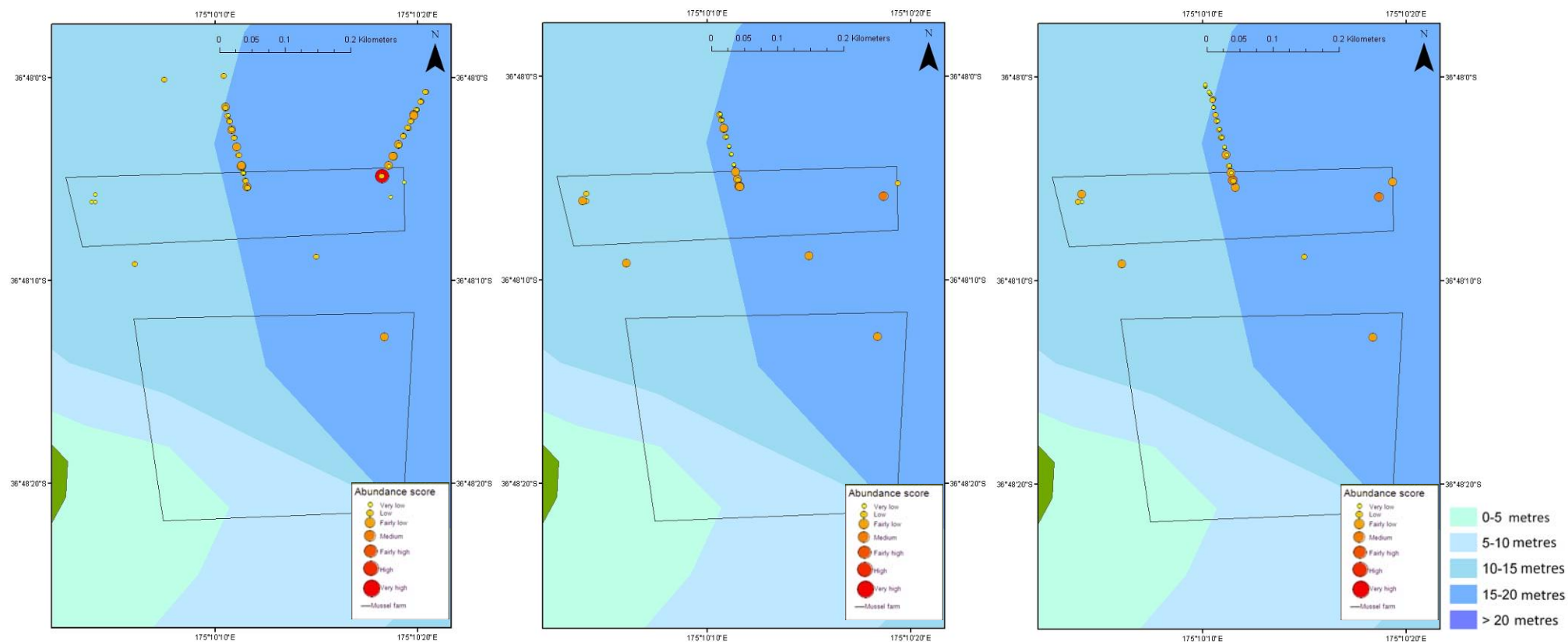
Figure 47: Spatial distribution of Species Abundance, muds, within and proximal to mussel farm along Transects 1 & 2, and those muddy sites within farm from the 17 randomly selected stations: February (left), May (middle) and August (right).

Relative Rarity scores

In total, 142 taxa were identified from 139 mud samples throughout the entire region during February, with species richness ranging from 2 to 41 taxa per sample. No *ubiquitous* species were recorded from any muddy sites (Appendix 3, Table A4). A general trend was apparent, with a greater proportion of *very rare* taxa occurring at sites with greater species richness (Figure 48).

From within 32 mud/gravel samples, 166 taxa were recorded throughout the entire region during February, with species richness ranging from 11 to 53 taxa per sample. Again, no *ubiquitous* species were recorded (Figure 49) (Appendix 3, Table A5). A similar trend was apparent, with the proportion of *very rare* to *uncommon* species increasing with an increase in species richness.

From within 57 gravel samples, 255 taxa were recorded throughout the entire region during February, with species richness ranging from 18 to 69 taxa per sample. Only one *ubiquitous* species, *Notocorbula zelandica*, was identified (Figure 50) (Appendix 3, Table A6). A trend similar to that observed in mud/gravels also was apparent, with the proportion of *very rare* to *uncommon* species increasing as species richness within any given sample increased.
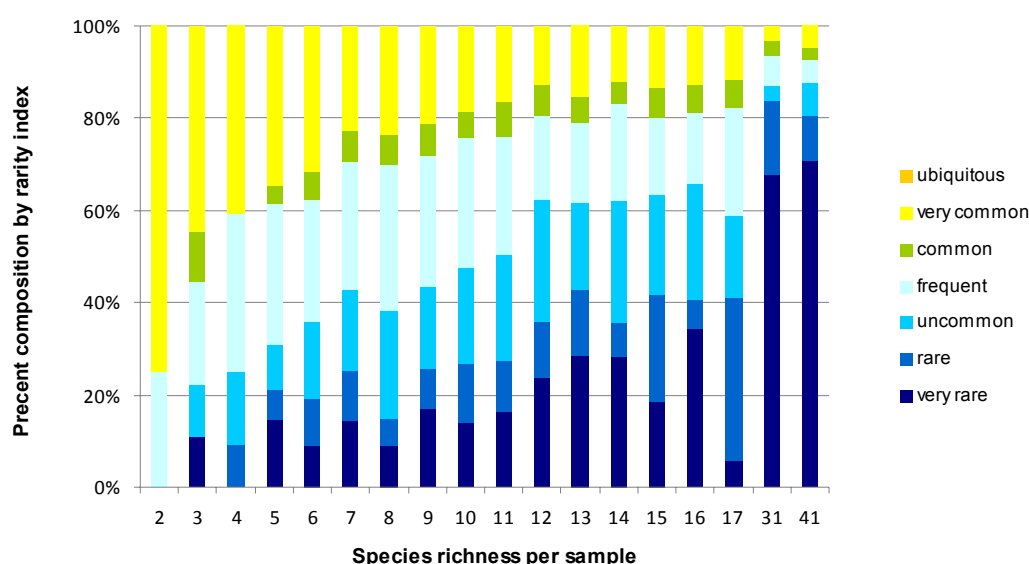
Figure 48: Relative rarity of species (y axis) at all sites by increasing species richness (x axis), mud substratum.
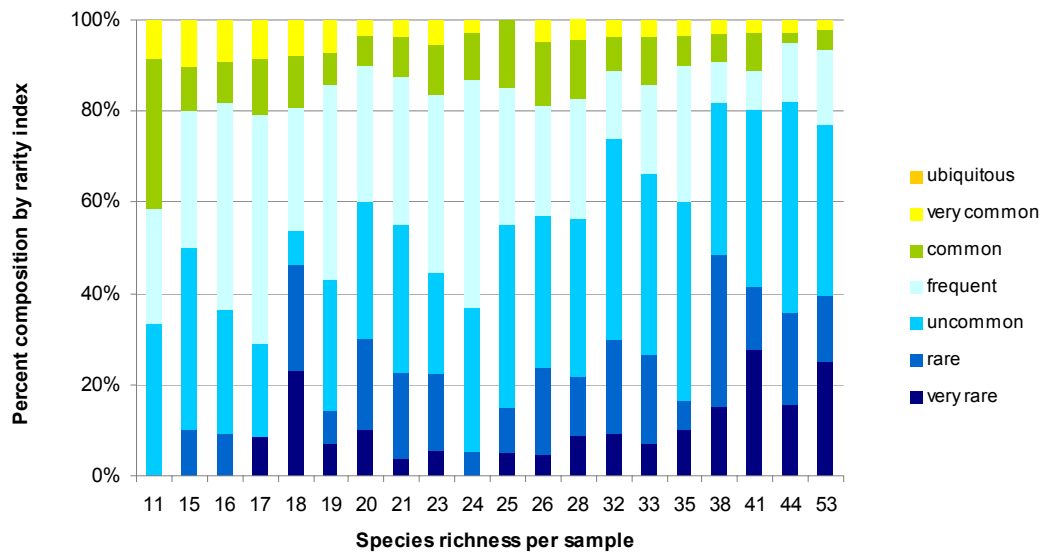
Figure 49: Relative rarity of species (y axis) at all sites by increasing species richness (x axis), mud/gravels.
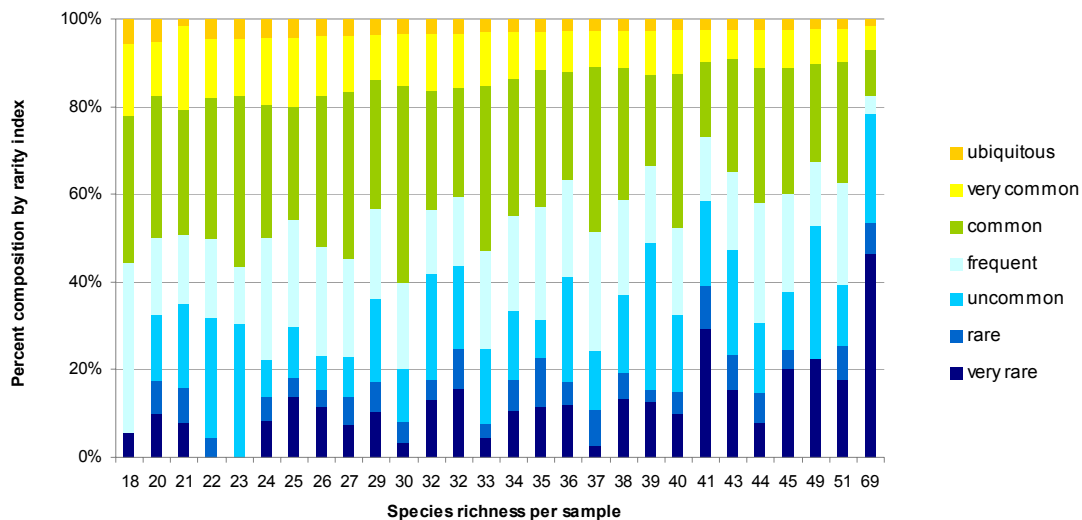
Figure 50: Relative rarity of species (y axis) at all sites by increasing species richness (x axis), gravels.

As the incidence of *Perna canaliculus* in samples elevated species richness through provision of structure upon and within which myriad other species associated, rarity scores were recalculated to exclude those sites within which *Perna* occurred (4 of 139 samples). Even having excluded these samples the same general trend was apparent, that the proportion of *very rare* to *uncommon* species increased as species richness increased (Figure 51).

Species assemblages within and outside the farm have been shown to vary spatially, bathymetrically and temporaly (between seasons). However, the

effect the mussel farm has had on the relative rarity of taxa has yet to be considered.
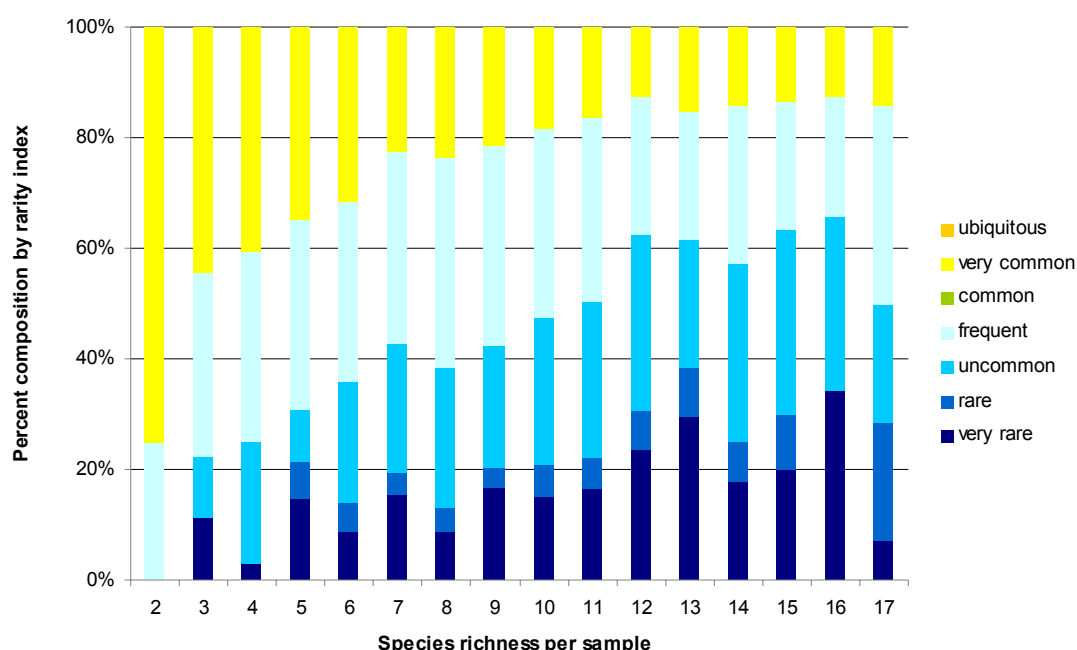
Figure 51: Relative rarity of species (y axis) at sites by increasing species richness (x axis), muds (*Perna* sites excluded).

Although earlier analysis has revealed significant differences in species assemblages occurring in muds more shallow than 10 m, from 10–15 m, and deeper than 15 m (Figure 14), based on the occurrence of species (presence/absence data), ANOSIM reveals assemblages of species from muddy sites only differ significantly between those more shallow than 10 m and 10–15 m, and between those more shallow than 10 m and those deeper than 15 (p<0.005), but not between those occurring between 10 and 15 m and those deeper than 15 m (Figure 52).

Transect 1 varied from 10–15 m depth. Accordingly, a revised rarity schema is calculated to remove those sites and taxa occurring more shallow than 10 m, to determine whether any particular rare species typical of the depth range of Transect 1 are affected by the mussel farm (Appendix 3, Table A7).

To determine the proportional contribution of *very rare* to *ubiquitous* taxa along Transect 1, the rarity schema was applied to sites along it. To eliminate the

effects of live and dead *Perna* shell (and associated species) from influencing rarity categories for these sites, a revised schema that excluded all *Perna* sites was also applied to these data (Appendix 3, Table A8). Regardless of whether *Perna* was or was not included in the overall rarity characterisation, *very rare* to *uncommon* taxa were distributed along the length of Transect 1 (Figure 53, Figure 54), within and outside the physical boundary of the mussel farm.
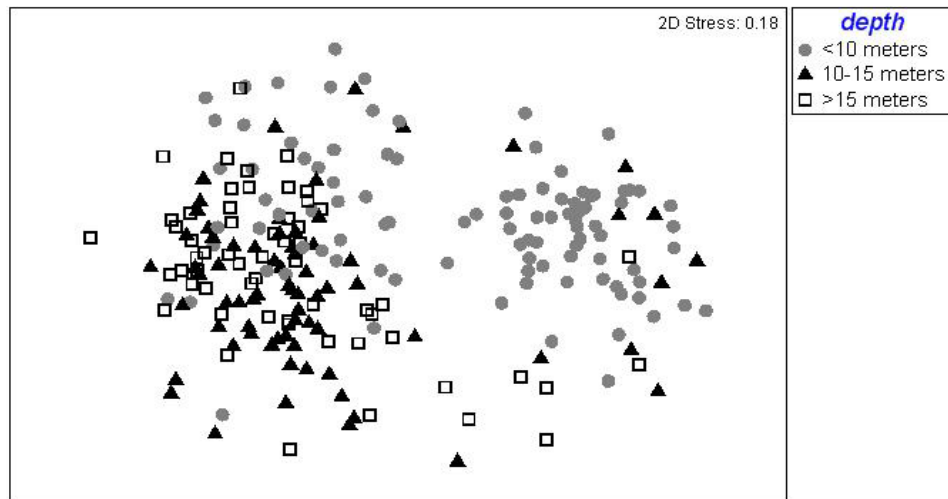
Figure 52: MDS plot of species assemblages (present/absent) within muds.
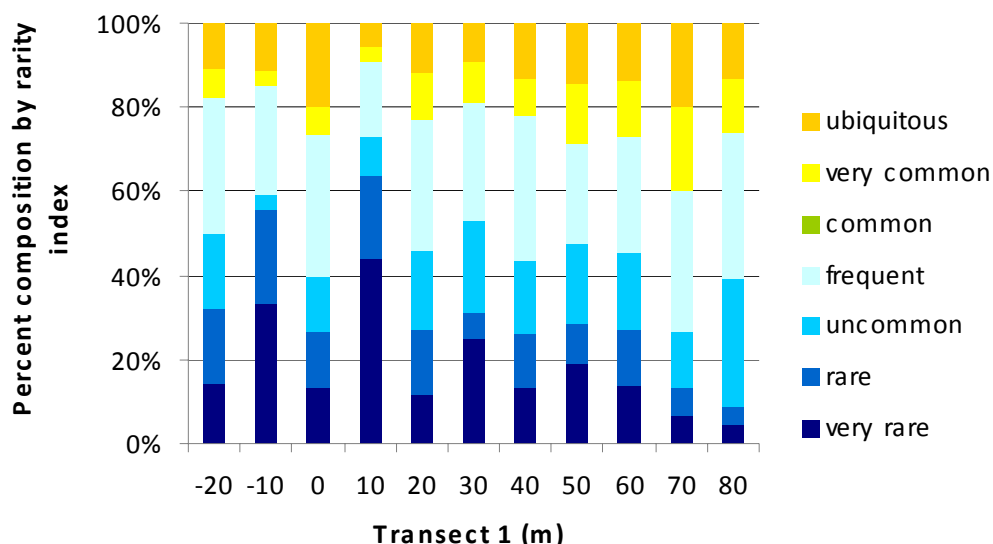
Figure 53: Relative rarity of species (y axis) at 10 m intervals along Transect 1 (x axis), muds, all sites deeper than 10 m, February 2008.
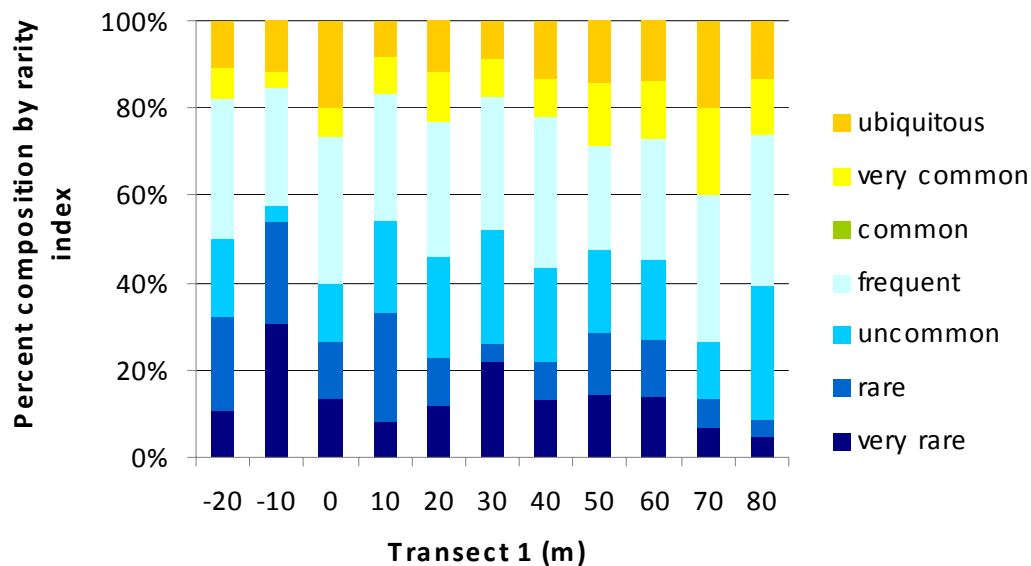
Figure 54: Relative rarity of species (y axis) at 10 m intervals along Transect 1 (x axis), muds > 10 m, excluding *Perna* sites, February 2008.

Indicator taxa

Those opportunistic polychaete taxa characterising organically enriched sediments (Capitellidae, Dorvilleidae and Spionidae), but particularly spionids (Table 34, 35), were always more abundant in muds beneath the farm than outside it. These opportunists were widely distributed throughout the survey region, and also proved to be extremely abundant at one site due north of Pakatoa Island. During each survey (February, May, August) these opportunistic taxa were also relatively more abundant on the south-eastern side of the mussel farm, particularly within gravel substrata, and were extremely abundant at one site south-east of the farm in August (Figure 55). Of the two capitellids recorded in this region, *Capitella 'capitella'* were most abundant in August, especially on the northern side of the mussel farm in muds (Figure 61), whereas *Heteromastus filiformis* were more abundant beneath the farm on all three occasions, but also along Transect 3 and between Rotoroa and Ponui Island during February (Figure 62).

Those polychaete taxa cited as sensitive to organic enrichment (Glyceridae, Goniadidae, Nephtyidae and Syllidae) (Surugiu 2005) were significantly more abundant outside the farm in mud/gravels during February, but they also were

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significantly more abundant within the farm in muds along Transect 1 during May (Table 34). Two of these sensitive taxa, Glyceridae and Syllidae, were significantly more abundant within the farm in different assemblages (Table 35). These sensitive taxa occurred within and outside the mussel farm, and at times were abundant in both, particularly on the southern side the farm, and they also occurred throughout the survey region, being particularly abundant in channel environments between Waiheke Island and Rotoroa Island, and Pakatoa and Ponui Island. These taxa were not always present outside the farm along Transect 1, and were relatively more abundant within the farm during August (Figure 56).

Taxa considered to be opportunists in dredge-spoil affected areas in Rangitoto Channel (*Dosinia lambata*, *Theora lubrica* and *Echinocardium cordatum*), particularly *E. cordatum* (Table 34, 35), were significantly more abundant outside the farm in muddy substrata than they were within it (along Transect 1) in February. These so-called opportunists occurred throughout the survey region, and were relatively more abundant in muds outside the farm during all three surveys, and throughout the eastern Waiheke Island region region during February (Figure 57).

Those taxa considered sensitive to dredge spoil (Syllidae, Anthuridae, Amphiuridae) were significantly more abundant along Transect 1 within the farm than they were outside the farm during February (Table 34). These spoil-sensitive taxa occurred primarily in gravels throughout the eastern Waiheke Island region, but they occurred at greater abundances within the farm and only occurred at a few sites outside the farm during May and August (Figure 58).

The one taxon considered to be an opportunist in mariculture-affected environments, *Alpheus* spp., was always significantly more abundant in muddy substrata (10−15 m depth) within the farm than it was outside the farm (Table 34); species attributed to this genus were recorded at very few sites within and outside the farm, and throughout the eastern Waiheke region (Figure 59).

Those polychaete taxa considered to be sensitive to mariculture-affected environments (*Nephtys macroura, Lumbrineris sphaerocephala* and *Onuphis aucklandensis*) were only significantly more abundant outside the farm in muddy substrata at depths exceeding 15 m (Table 34). These sensitive taxa were distributed throughout the survey region, and were particularly abundant within the channel between Waiheke and Pakatoa Island. During each survey event (February, May, August), these sensitive taxa were seldom recorded from within the farm, but always occurred outside it (Figure 60).

Table 34: Relationship between substratum type and abundance (sums) of indicator taxa inside and outside the mussel farm (NSD, no significant difference) (Appendix 6, Table A17−A23).

	Substratum by depth (m)				Monitoring (Transect 1 + muds within the farm)		
Indicator taxa	Gravel	Mud/gravel (>10)	Mud (10−15)	Mud (>15)	February	May	August
Opportunistic taxa to organic enrichment	NSD	NSD	inside > outside	inside > outside	inside > outside	inside > outside	inside > outside
Sensitive taxa to organic encrihment	NSD	inside < outside	NSD	NSD	NSD	inside > outside	NSD
Opportunistic taxa in dredge spoil	NSD	NSD	NSD	NSD	inside < outside	NSD	NSD
Sensitive taxa to dredge spoil	NSD	NSD	NSD	NSD	NSD	NSD	inside > outside
Opportunistic taxa *fide* de Jong (1994)	NSD	NSD	inside > outside	NSD	NSD	NSD	NSD
Sensitive taxa *fide* de Jong (1994)	NSD	NSD	NSD	inside < outside	NSD	NSD	NSD

Table 35: Significant difference of indicator by family and species (NSD, no significant difference; DNO, does not occur) (Appendix 6, Table A17−A23).

Indicator taxa		substratum assemblages by depth (m)				Monitoring (Transect 1 + mud within the farm)		
		gravel	mud/gravel (>10)	mud (10−15)	mud (>15)	February	May	August
Opportunistic taxa to organic enrichment	*Capitella capitata*	NSD	NSD	NSD	DNO	NSD	farm > outside	farm > outside
	Heteromastus filiformis	NSD	NSD	NSD	inside > outside	inside > outside	inside > outside	inside > outside
	Dorvilleidae	inside > outside	inside > outside	NSD	NSD	NSD	NSD	NSD
	Spionidae	NSD	NSD	inside > outside	inside > outside	inside > outside	inside > outside	inside > outside
Sensitive of organic enrichment	Glyceridae	inside > outside	NSD	NSD	inside > outside	inside > outside	inside > outside	NSD
	Goniadidae	NSD	NSD	DNO	NSD	DNO	DNO	NSD
Taxa sensitive to organic encrihment and by de Jong	Nephtyidae	NSD	NSD	NSD	inside < outside	NSD	NSD	NSD
Taxa sensitive to organic encrichment and dredge spoil	Syllidae	NSD	NSD	NSD	NSD	NSD	NSD	inside > outside
Taxa sensitive to dredge spoil	Anthuridae	NSD	NSD	DNO	DNO	DNO	NSD	NSD
	Amphiuridae	NSD	NSD	DNO	DNO	DNO	NSD	NSD
Opportunistic taxa in dredge spoil	*Dosinia lambata*	NSD	NSD	NSD	DNO	NSD	NSD	NSD
	Theora lubrica	NSD	NSD	NSD	NSD	farm < outside	NSD	NSD
	Echinocardium cordatum	NSD	NSD	inside < outside	inside < outside	NSD	inside < outside	NSD
Opportunistic taxa de Jong (1994)	Alpheidae	NSD	NSD	inside > outside	DNO	NSD	NSD	NSD
Sensitive taxa de Jong (1994)	*Lumbrineris sphaerocephala*	NSD	NSD	NSD	NSD	NSD	NSD	NSD
	Onuphis aucklandensis	NSD	NSD	NSD	NSD	NSD	NSD	NSD
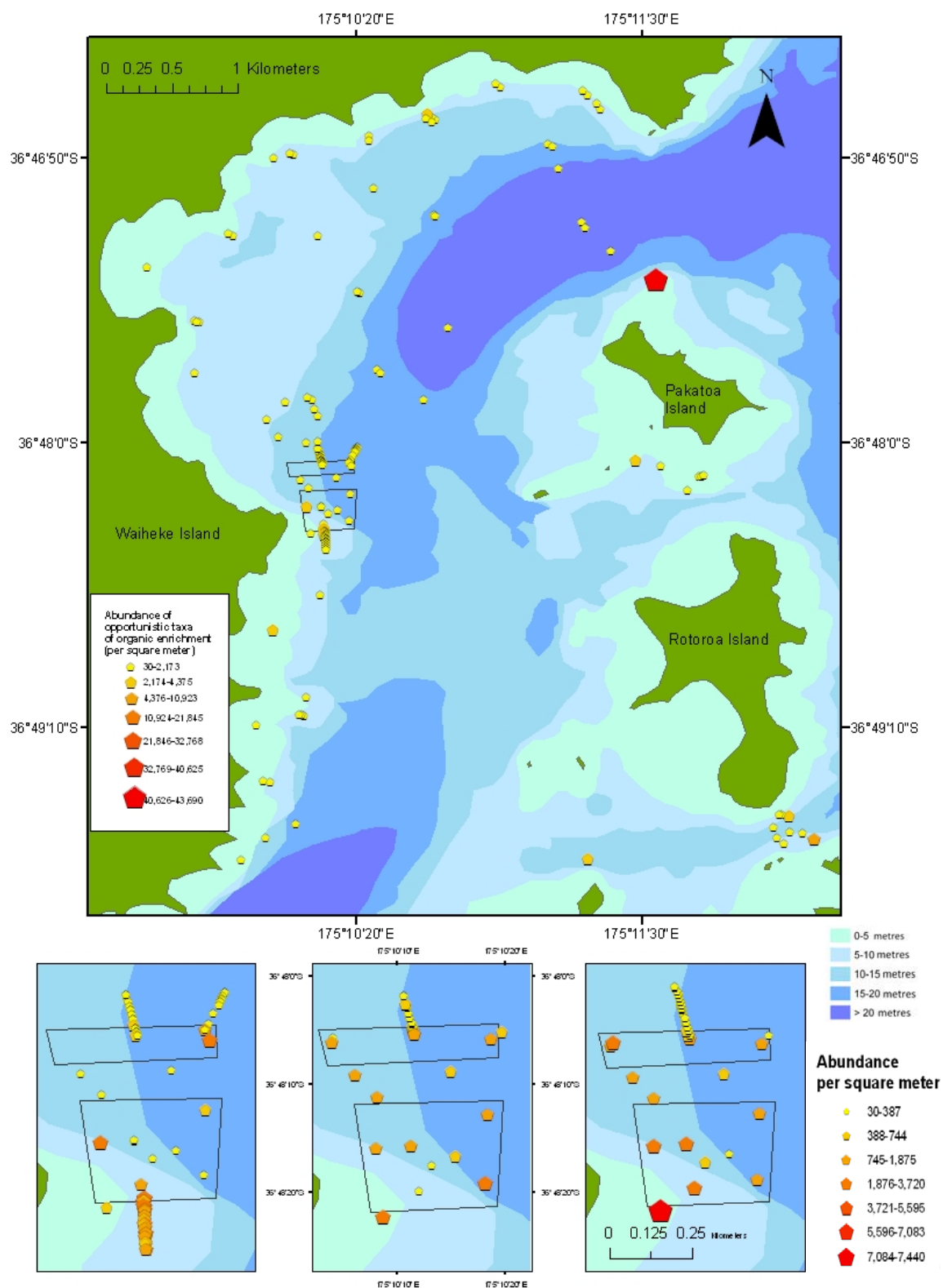
Figure 55: Spatial and temporal distribution of taxa considered opportunistic in organically enriched sediments; top: survey region, February; bottom left, middle, right: February, May, August, respectively.
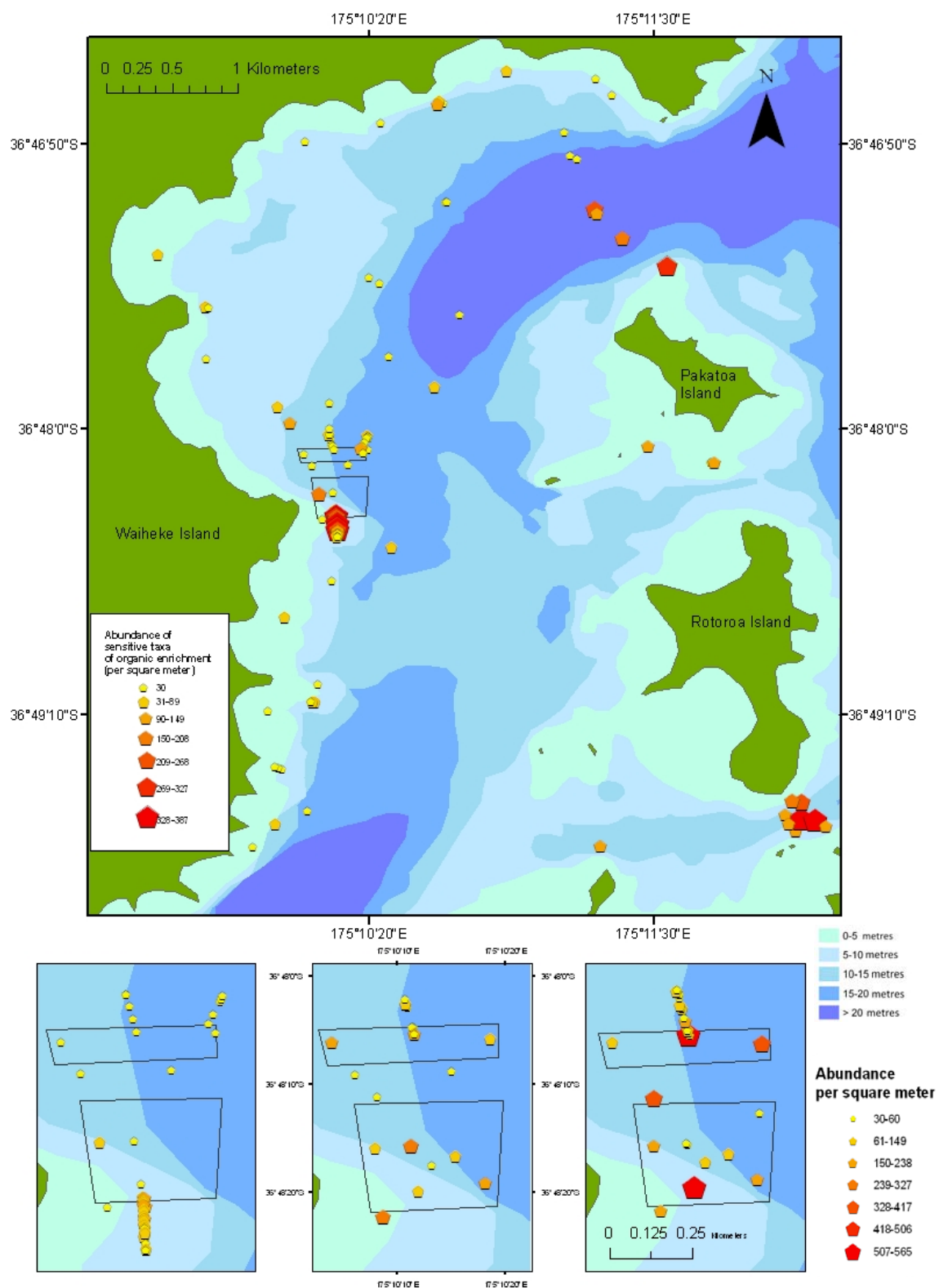
Figure 56: Spatial and temporal distribution of taxa sensitive to organic enrichment; top: survey region, February; bottom left, middle, right: February, May, August, respectively.
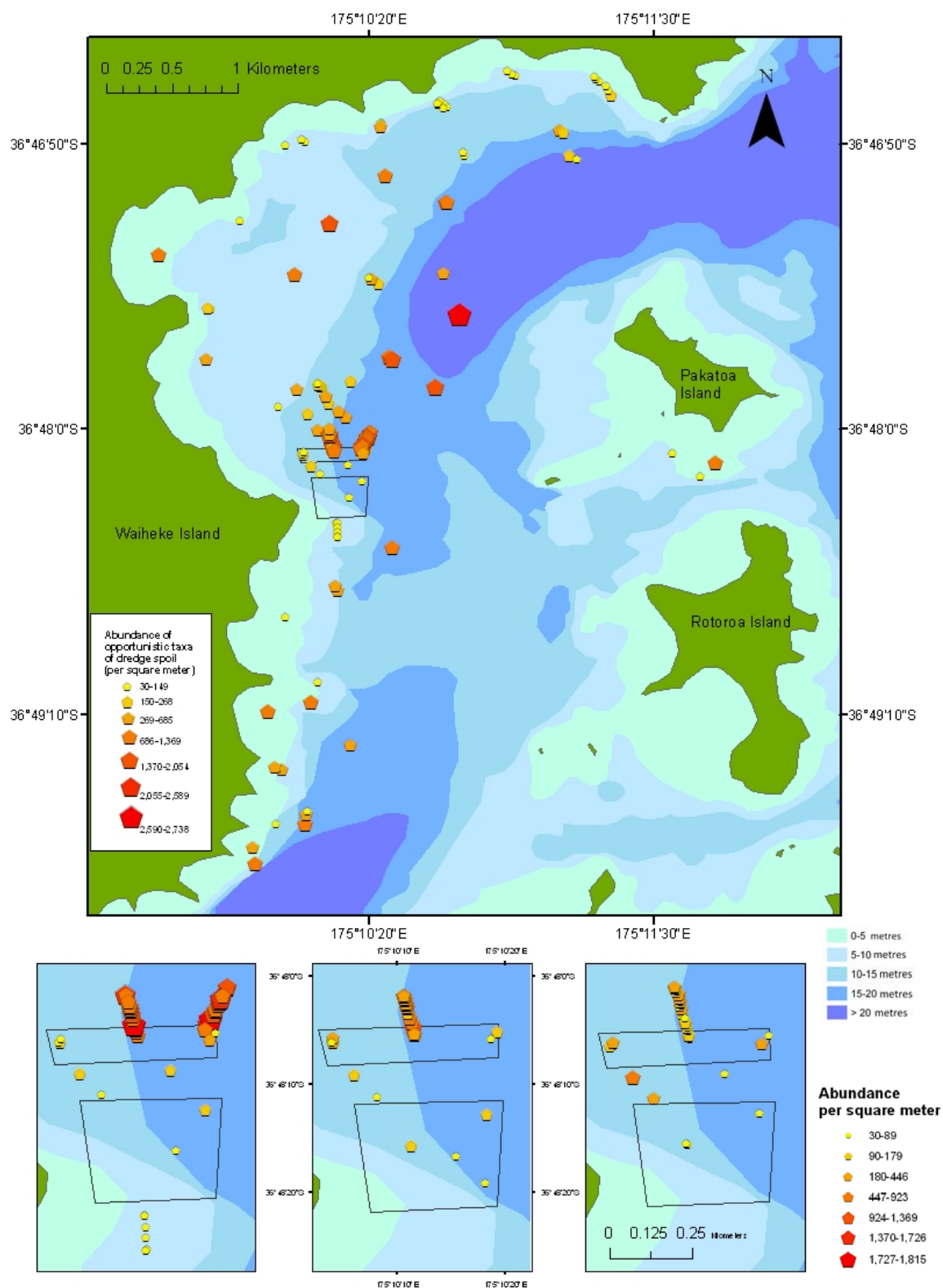
Figure 57: Spatial and temporal distribution of taxa considered opportunistic in dredge spoil; top: survey region, February; bottom left, middle, right: February, May, August, respectively.
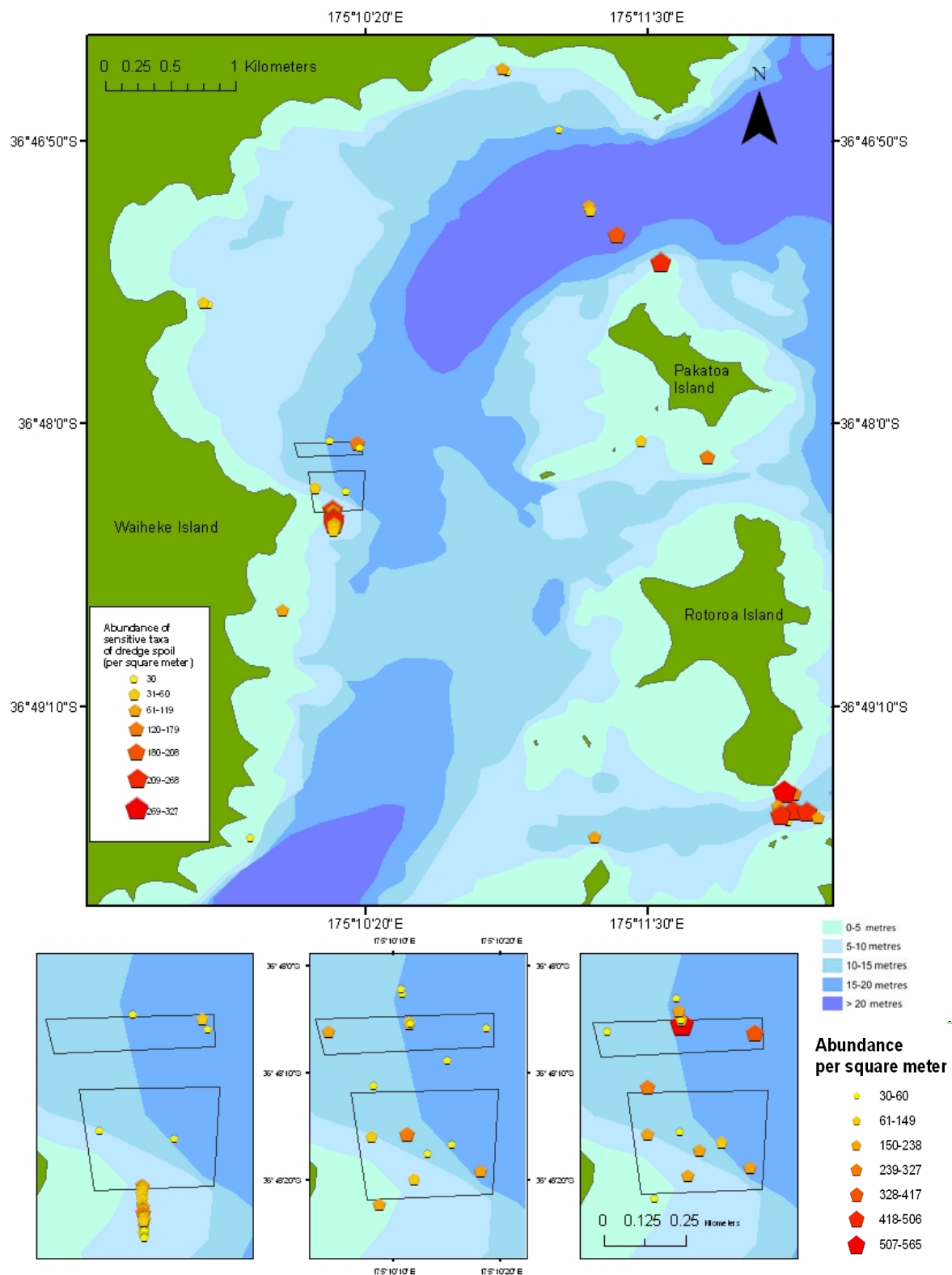
Figure 58: Spatial and temporal distribution of taxa sensitive taxa to dredge spoil; top: survey region, February; bottom left, middle, right: February, May, August, respectively.
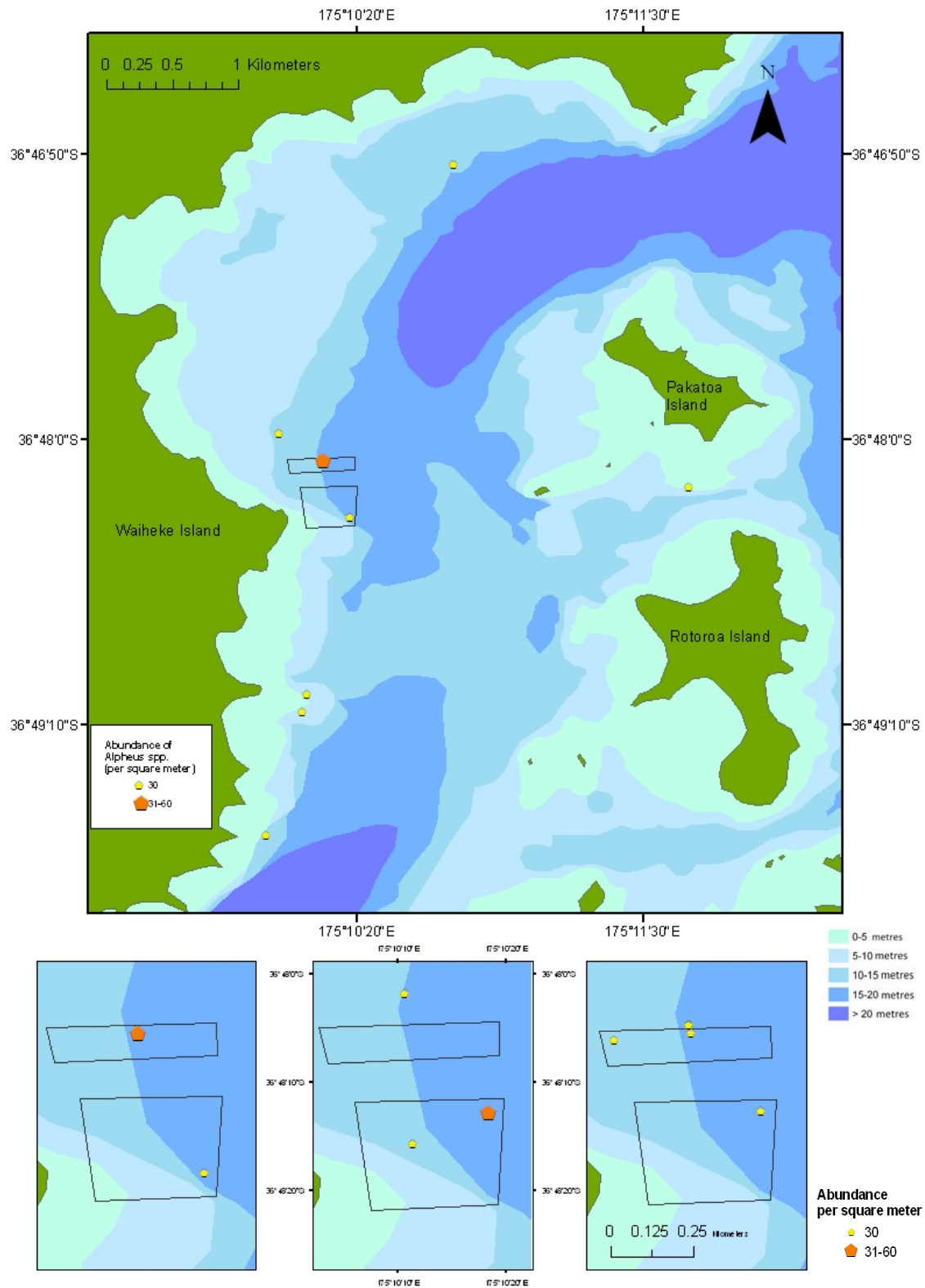
Figure 59: Spatial and temporal distribution of mariculture-opportunistic taxa *fide* de Jong (1994); top: survey region, February; bottom left, middle, right: February, May, August, respectively.
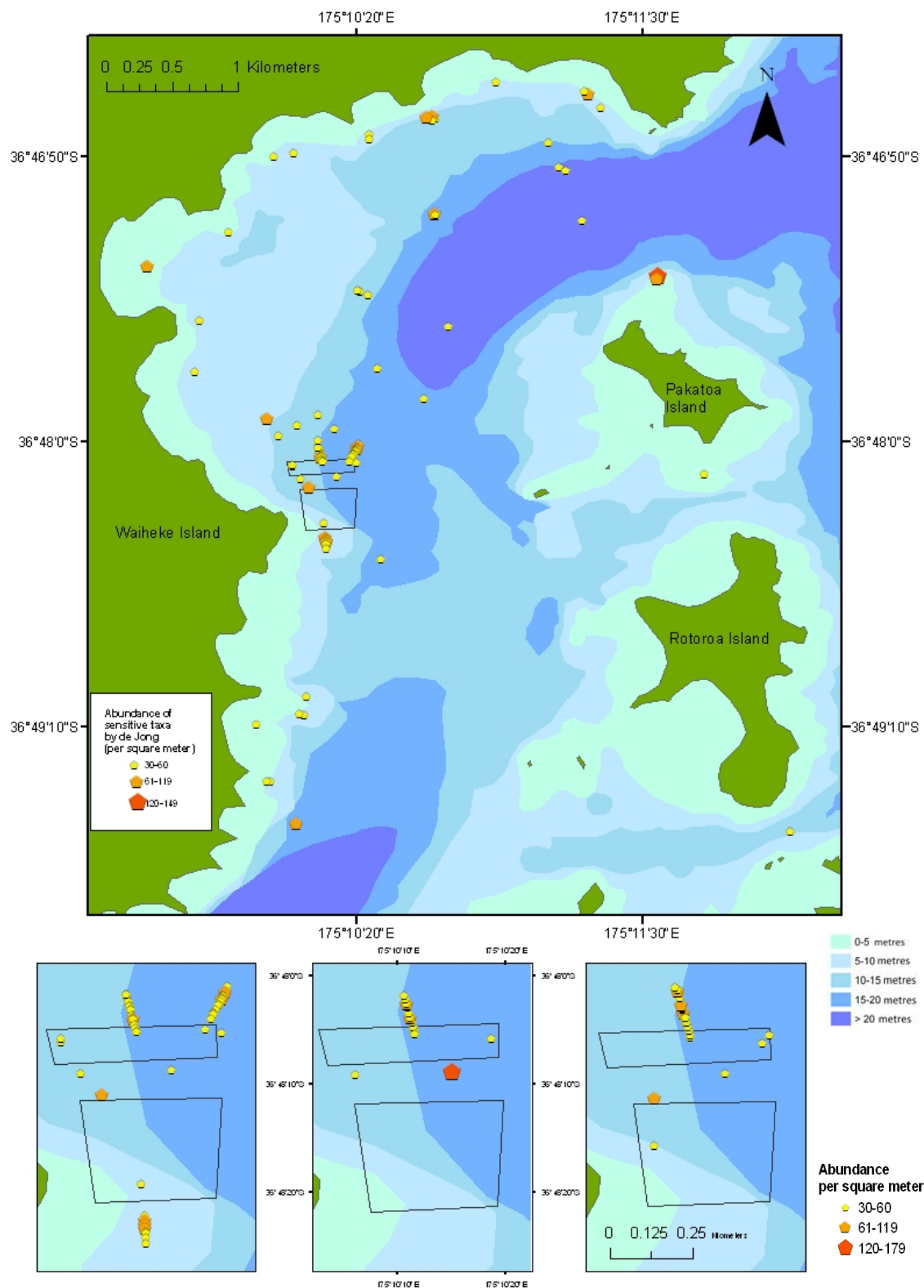
Figure 60: Spatial and temporal distribution of mariculture-sensitive taxa *fide* de Jong (1994); top: survey region, February; bottom left, middle, right: February, May, August, respectively.
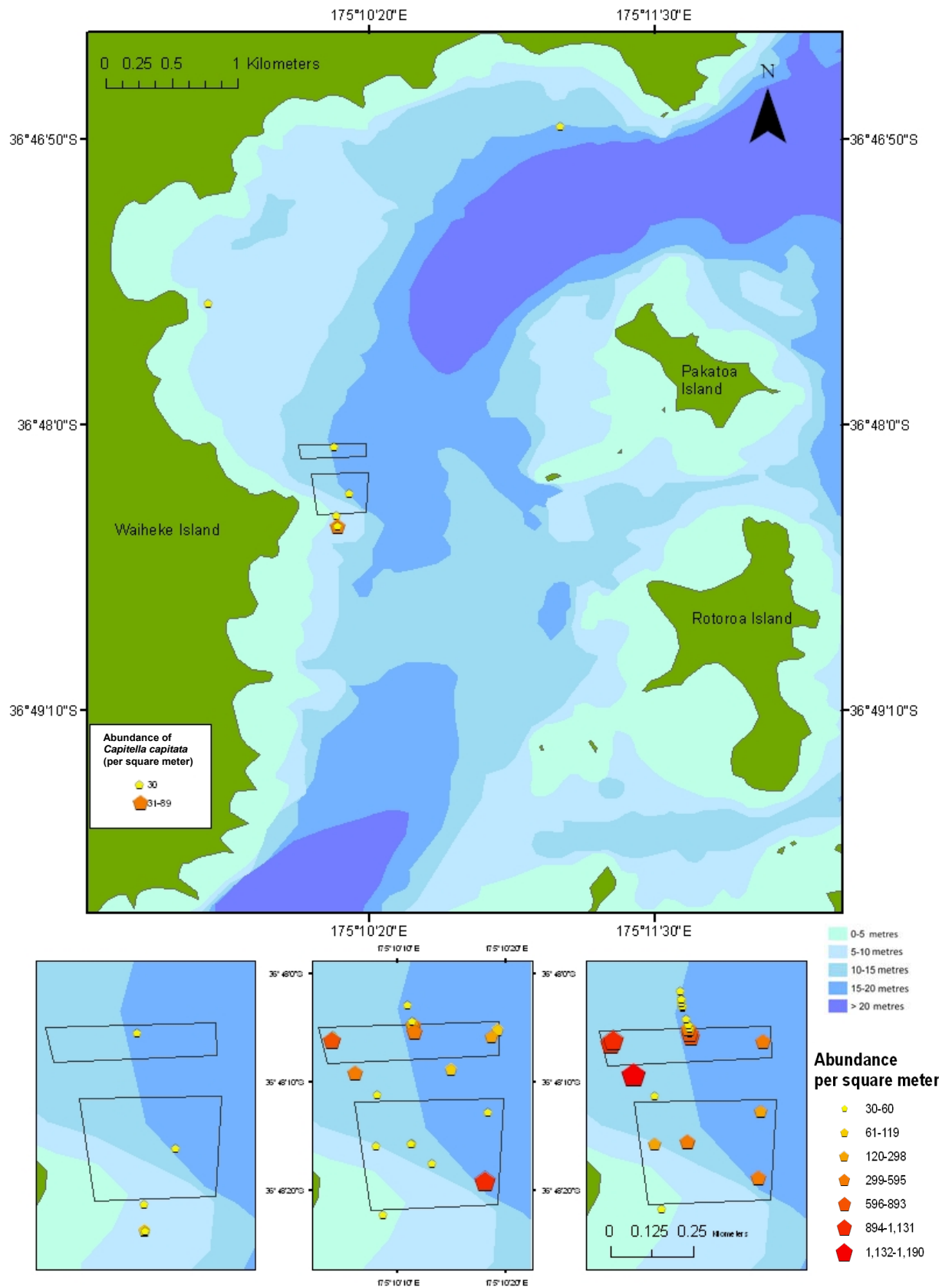
Figure 61: Spatial and temporal distribution of *Capitella 'capitata'*; top: survey region, February; bottom left, middle, right: February, May, August, respectively.
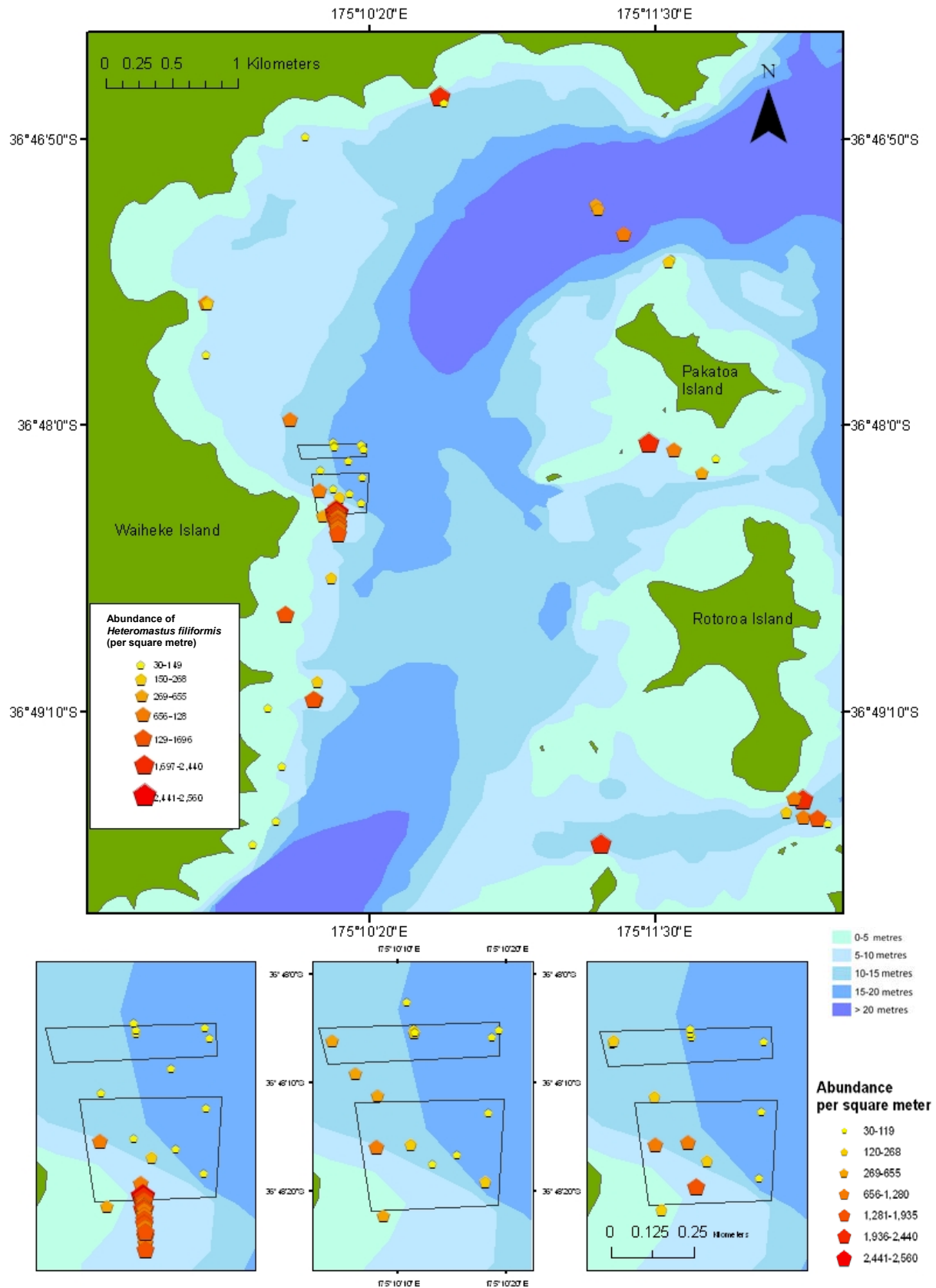
Figure 62: Spatial and temporal distribution of *Heteromastus filiformis*; top: survey region, February; bottom left, middle, right: February, May, August, respectively.

An alternative way to determine those species that contribute most to observed differences in community structure between sites within and outside of the farm, for the purposes of identifying likely opportunistic taxa, is by looking at a breakdown of average dissimilarity between sites (Table 36−38).

The greatest difference in the composition of species assemblages inside and outside the physical farm boundary of the farm is in the relative abundance of taxa, and shifts in their relative contribution to dissimilarity of these taxa between surveys.

Table 36: Breakdown of average dissimilarity (SIMPER), February 2008, Transect 1 and muddy stations within mussel farm (Average dissimilarity 63.44).

Species	Group inside Av.Abund	Group outside Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Theora lubrica	3.06	5.00	8.44	1.34	13.31	13.31
Ostracod sp. 2	0.87	2.28	6.65	1.24	10.48	23.79
Paraphoxus sp. 1	2.09	0.88	5.98	1.33	9.43	33.22
Prionospio sp.	1.81	0.87	5.10	1.27	8.04	41.26
Onuphis aucklandensis	0.35	0.45	1.90	0.88	2.99	44.25
Oligochaeta	0.54	0.19	1.86	0.69	2.93	47.18
Paraphoxus sp. 2	0.06	0.52	1.85	0.72	2.92	50.11
Sthenelais sp.	0.18	0.44	1.74	0.77	2.75	52.85
Amphipod sp. 2	0.53	0.16	1.71	0.76	2.70	55.55
Ostracod sp. 1	0.44	0.13	1.67	0.71	2.63	58.18
Cossura consimilis	0.12	0.35	1.42	0.72	2.24	60.42
Arabella sp.	0.20	0.25	1.29	0.69	2.03	62.45
Ostracod sp. 11	0.08	0.31	1.14	0.51	1.80	64.25
Heteromastus filiformis	0.35	0.04	1.14	0.62	1.79	66.04
Ophiodromus angustifrons	0.14	0.21	1.05	0.59	1.66	67.70
Nephtys macroura	0.12	0.18	0.99	0.53	1.56	69.27
Lumbrineris sphaerocephala	0.12	0.17	0.93	0.54	1.46	70.73
Aonides sp.	0.18	0.10	0.85	0.52	1.34	72.07
Trichobranchus sp.	0.12	0.17	0.81	0.55	1.28	73.35
Ophelia sp.	0.27	0.00	0.79	0.44	1.25	74.60
Balanus trigonus	0.06	0.44	0.77	0.26	1.21	75.81
Amphiura aster	0.24	0.00	0.73	0.42	1.16	76.97
Ostracod sp. 3	0.06	0.16	0.61	0.44	0.96	77.92
Ostracod sp. 4	0.00	0.17	0.60	0.43	0.94	78.86
Gnathiid sp. 1	0.17	0.00	0.59	0.34	0.92	79.79
Echinocardium cordatum	0.00	0.20	0.57	0.37	0.90	80.69
Mysid sp.	0.06	0.13	0.56	0.42	0.88	81.56
Lepidonotus sp. 2	0.14	0.04	0.54	0.40	0.85	82.41
unID amphipod	0.14	0.04	0.53	0.41	0.84	83.25
Amphiura rosea	0.12	0.08	0.51	0.46	0.81	84.06
Periclimenes yaldwyni	0.14	0.04	0.49	0.39	0.78	84.84
Amphipod sp. 7	0.06	0.08	0.46	0.37	0.73	85.57
Petrolisthes novaezelandiae	0.14	0.00	0.40	0.25	0.63	86.20
Ostracod sp. 7	0.00	0.11	0.39	0.29	0.61	86.81
Orbinia papillosa	0.12	0.00	0.39	0.35	0.61	87.42
Alpheus richardsoni	0.14	0.00	0.38	0.35	0.61	88.02
Amphipod sp. 5	0.00	0.10	0.38	0.29	0.60	88.62
Solemya parkinsonia	0.06	0.04	0.36	0.32	0.56	89.19
Aglaja cylindrica	0.06	0.04	0.34	0.32	0.54	89.73
Hydroides norvegicus	0.00	0.25	0.34	0.21	0.54	90.27

Table 37: Breakdown of average dissimilarity (SIMPER), May 2008, Transect 1 and muddy stations within mussel farm (Average dissimilarity 73.29).

Species	Group inside Av.Abund	Group outside Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Prionospio sp.	3.28	0.88	6.19	1.58	8.45	8.45
Capitella capitata	2.40	0.11	5.30	1.58	7.23	15.68
Paraphoxus sp. 1	1.74	0.56	3.60	1.32	4.91	20.59
Theora lubrica	2.74	3.46	3.54	1.20	4.83	25.41
Ostracod sp. 2	0.69	1.64	3.47	1.14	4.74	30.15
Paraphoxus sp. 2	1.37	0.47	3.11	1.22	4.24	34.39
Pectinaria australis	1.28	0.23	2.99	1.25	4.08	38.47
Armandia maculata	1.35	0.07	2.85	1.64	3.89	42.36
Heteromastus filiformis	1.24	0.05	2.59	1.06	3.53	45.89
Hydroides norvegicus	1.38	0.24	2.41	0.73	3.28	49.17
Ostracod sp. 1	0.98	0.23	2.18	0.95	2.97	52.14
Sthenelais sp.	0.38	0.99	1.93	1.20	2.64	54.78
Ostracod sp. 11	0.43	0.65	1.92	0.92	2.62	57.41
Onuphis aucklandensis	0.40	0.40	1.48	0.80	2.02	59.42
Cossura consimilis	0.44	0.26	1.33	0.84	1.82	61.24
Nemertea	0.45	0.11	1.05	0.69	1.43	62.68
Hemileucon comes	0.39	0.05	1.01	0.64	1.38	64.05
Balanus trigonus	0.59	0.07	1.00	0.54	1.36	65.41
Ophiodromus angustifrons	0.38	0.16	0.95	0.72	1.29	66.70
Amphipod sp. 2	0.30	0.14	0.94	0.59	1.28	67.98
Dorvillea antarctica	0.55	0.07	0.91	0.63	1.24	69.23
Glycera tesselata	0.35	0.00	0.84	0.66	1.15	70.37
Anomia trigonopsis	0.46	0.08	0.83	0.56	1.14	71.51
Arabella sp.	0.24	0.11	0.76	0.61	1.04	72.55
Paraonis sp.	0.20	0.16	0.74	0.56	1.01	73.57
Oligochaeta	0.24	0.05	0.72	0.46	0.98	74.55
Ostracod sp. 4	0.08	0.26	0.67	0.56	0.91	75.46
Perna canaliculus	0.39	0.00	0.61	0.44	0.83	76.30
Echinocardium cordatum	0.00	0.26	0.57	0.52	0.77	77.07
Paracorophium sp.	0.26	0.18	0.55	0.47	0.75	77.82
Ophelia sp.	0.24	0.00	0.53	0.51	0.72	78.54
Tanaid sp. 2	0.31	0.07	0.48	0.47	0.65	79.19
Limaria orientalis	0.26	0.00	0.47	0.52	0.64	79.83
Amphiura rosea	0.06	0.14	0.46	0.45	0.62	80.46
Leucon latispina	0.12	0.05	0.43	0.41	0.58	81.04
Sphaerosyllis sp.	0.24	0.00	0.42	0.43	0.57	81.61
Halicarcinus cookii	0.24	0.00	0.40	0.45	0.54	82.15
Spionid sp. 1	0.18	0.00	0.39	0.44	0.53	82.68
Ascidiacea	0.29	0.00	0.38	0.32	0.52	83.20
Nephtys macroura	0.12	0.14	0.37	0.51	0.50	83.70
Aonides sp.	0.18	0.00	0.36	0.43	0.49	84.19
Lumbrineris sphaerocephala	0.00	0.14	0.35	0.39	0.48	84.67
Syllid sp. 23	0.12	0.00	0.33	0.33	0.45	85.12
Lepidonotus sp. 2	0.06	0.10	0.32	0.37	0.43	85.55
Corophium cf. *acutum*	0.10	0.00	0.31	0.24	0.43	85.98
Mysid sp.	0.12	0.00	0.31	0.33	0.43	86.41
Copepod sp.	0.18	0.00	0.31	0.44	0.42	86.83
Amphiura aster	0.12	0.00	0.31	0.36	0.42	87.25
Lysianassidae sp. 1	0.12	0.15	0.30	0.33	0.41	87.66
Syllid sp. 4	0.16	0.07	0.28	0.42	0.39	88.05
Macrophthalmus hirtipes	0.12	0.00	0.27	0.36	0.37	88.41
Leucon heterostylis	0.14	0.00	0.27	0.25	0.36	88.78
WTF 3	0.12	0.00	0.25	0.36	0.34	89.12
Cominella adspersa	0.12	0.00	0.25	0.36	0.34	89.46
Alpheus richardsoni	0.08	0.05	0.24	0.33	0.33	89.80
Notomithrax minor	0.14	0.05	0.24	0.42	0.33	90.12

Table 38: Breakdown of average dissimilarity (SIMPER), August 2008, Transect 1 and muddy stations within mussel farm (Average dissimilarity 76.27).

Species	Group inside Av.Abund	Group outside Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Capitella capitata	2.87	0.25	6.33	1.24	8.30	8.30
Ostracod sp. 2	0.89	2.02	4.86	1.21	6.37	14.67
Prionospio sp.	2.71	1.04	4.47	1.14	5.85	20.52
Paraphoxus sp. 1	2.14	0.85	3.98	1.21	5.22	25.74
Perna canaliculus	1.38	0.00	2.63	0.81	3.45	29.19
Theora lubrica	1.58	1.92	2.59	1.18	3.40	32.60
Sthenelais sp.	1.14	0.79	2.11	1.11	2.77	35.37
Ostracod sp. 11	0.70	0.56	2.08	0.94	2.73	38.10
Paraphoxus sp. 2	0.76	0.40	1.82	1.00	2.38	40.48
Cossura consimilis	0.08	0.66	1.72	0.82	2.26	42.74
Hemileucon comes	0.68	0.09	1.72	0.78	2.25	44.99
Armandia maculata	0.79	0.06	1.70	0.83	2.22	47.21
Heteromastus filiformis	0.73	0.00	1.53	0.76	2.01	49.22
Amphipod sp. 10	0.76	0.24	1.41	0.68	1.85	51.07
Ostracod sp. 1	0.59	0.19	1.37	0.73	1.79	52.86
Platyhelminthes	0.65	0.12	1.33	0.76	1.74	54.60
Hydroides norvegicus	0.68	0.08	1.17	0.64	1.54	56.14
Halicarcinus cookii	0.58	0.05	1.06	0.69	1.40	57.53
Nephtys macroura	0.12	0.35	1.00	0.64	1.31	58.85
Balanus trigonus	0.44	0.14	0.93	0.48	1.22	60.07
Aonides sp.	0.20	0.25	0.90	0.61	1.19	61.25
Dorvillea antarctica	0.62	0.09	0.88	0.55	1.16	62.41
Ostracod sp. 4	0.20	0.27	0.87	0.64	1.14	63.55
Macrophthalmus hirtipes	0.35	0.09	0.85	0.73	1.12	64.66
Ophiodromus angustifrons	0.32	0.20	0.82	0.67	1.08	65.74
Echinocardium cordatum	0.06	0.32	0.81	0.65	1.06	66.80
Nemertea	0.24	0.21	0.80	0.65	1.05	67.84
Syllid sp. 27	0.47	0.07	0.79	0.54	1.04	68.88
Periclimenes yaldwyni	0.38	0.03	0.79	0.67	1.03	69.92
Onuphis aucklandensis	0.12	0.25	0.77	0.59	1.01	70.93
Diastylis insularum	0.06	0.29	0.76	0.56	1.00	71.93
Corophium cf. *acutum*	0.28	0.10	0.75	0.56	0.99	72.91
Paraonis sp.	0.22	0.15	0.71	0.56	0.93	73.84
Diastylis neozelanica	0.18	0.13	0.70	0.56	0.91	74.76
Syllid sp. 4	0.45	0.07	0.70	0.60	0.91	75.67
Lepidonotus sp. 2	0.24	0.09	0.65	0.60	0.85	76.52
Ampharetidae sp.	0.12	0.15	0.62	0.51	0.82	77.34
Pectinaria australis	0.23	0.03	0.62	0.48	0.81	78.14
Ostracod sp. 8	0.25	0.12	0.60	0.46	0.78	78.93
Cirratulid sp. 1	0.12	0.15	0.54	0.52	0.71	79.64
Montacuta semiradiata neozelanica	0.00	0.23	0.51	0.44	0.66	80.30
Alpheus richardsoni	0.18	0.06	0.50	0.49	0.65	80.95
Nucula nitidula	0.06	0.18	0.49	0.48	0.64	81.59
Petrolisthes novaezelandiae	0.24	0.00	0.45	0.38	0.59	82.18
Amphipod sp. 2	0.12	0.10	0.43	0.35	0.56	82.74
Tanaid sp. 3	0.32	0.00	0.42	0.35	0.55	83.29
Copepod sp.	0.24	0.00	0.41	0.46	0.54	83.83
Lumbrineris sphaerocephala	0.12	0.06	0.39	0.39	0.51	84.34
Actiniaria	0.12	0.03	0.38	0.39	0.50	84.85
Cyclaspis elegans	0.06	0.12	0.38	0.43	0.50	85.34
Oligochaeta	0.06	0.12	0.37	0.38	0.48	85.83
Arabella sp.	0.06	0.09	0.36	0.38	0.47	86.29
Pinnotheres novaezelandiae	0.20	0.03	0.35	0.42	0.46	86.75
Flabelligera affinis	0.18	0.00	0.35	0.43	0.45	87.20
Gnathiid sp. 1	0.00	0.14	0.33	0.22	0.43	87.64
Ostracod sp. 3	0.00	0.15	0.33	0.40	0.43	88.07
Amphipod sp. 28	0.14	0.03	0.31	0.37	0.40	88.47
Trichobranchus sp.	0.00	0.12	0.30	0.35	0.39	88.85
Petrocheles spinosus	0.23	0.03	0.29	0.40	0.38	89.23
Nebalia sp.	0.10	0.03	0.28	0.28	0.37	89.60
Perinereis nuntia	0.12	0.06	0.28	0.38	0.36	89.97
Ostracod sp. 6	0.08	0.03	0.27	0.29	0.35	90.32

Physical footprint of mussel farm

Grain size analysis along Transect 1

In May 2008, 14 samples were collected from along Transect 1 for sediment grain-size analysis, with a single sample collected at each 10 m interval, from 20 m within the farm to 110 m outside the farm. Granulometric indices for these sediments are presented in Table 39 and Appendix 2 (Table A2, Figure A1−A14).

The median (φ50) grain-size value for all sediments along this transect was greater than 4 φ, the equivalent of silt. At 20 m within the farm, the physical boundary (0 m) and 70 m and 80 m outside the farm, silts were coarser; those sediments at 40 m outside the farm were the finest along the length of the transect (Figure 63). Quartile skewness reveals the prevailing grain size at the relatively coarser sites, except 70 m outside the farm, to be finer than the median grain size (Figure 64). The sediment sorting coefficients were randomly distributed along Transect 1, but the sediments are effectively *moderately* to *moderately well* sorted (Figure 64).

Table 39: Granulometric indices for sediments along Transect 1, May 2008.

Transect 1 (m)	φ 25	φ 50	φ 75	Sorting Coefficient	Quartile Skewness
-20	3.7	4.8	5.5	0.9	-0.2
-10	4.3	5	5.7	0.7	0
0	3.9	4.9	5.7	0.9	-0.1
10	4.5	5.1	5.7	0.6	0
20	4.4	5.1	5.7	0.65	-0.05
30	4.4	5.1	5.9	0.75	0.05
40	4.3	5.4	6.4	1.05	-0.05
50	4.3	5	5.7	0.7	0
60	4.4	5.1	5.7	0.65	-0.05
70	4.1	4.9	5.7	0.8	0
80	4.1	4.9	5.6	0.75	-0.05
90	4.4	5.1	5.9	0.75	0.05
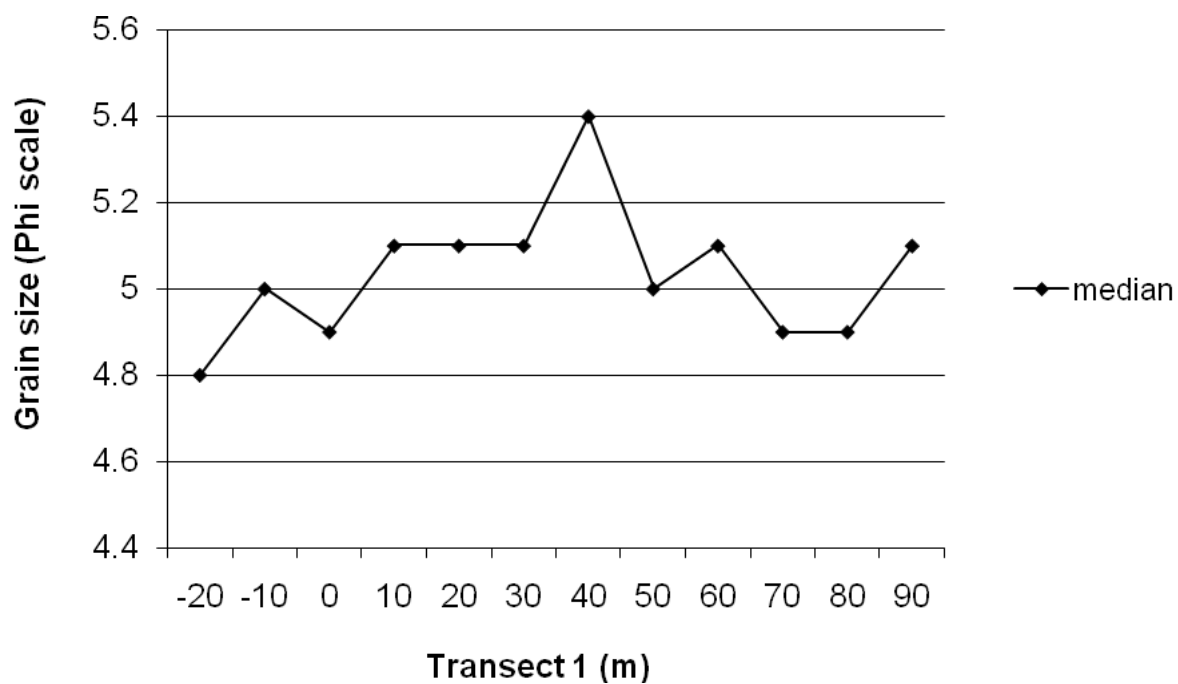
Figure 63: Median (φ50) sediment grain size, Transect 1, May 2008.
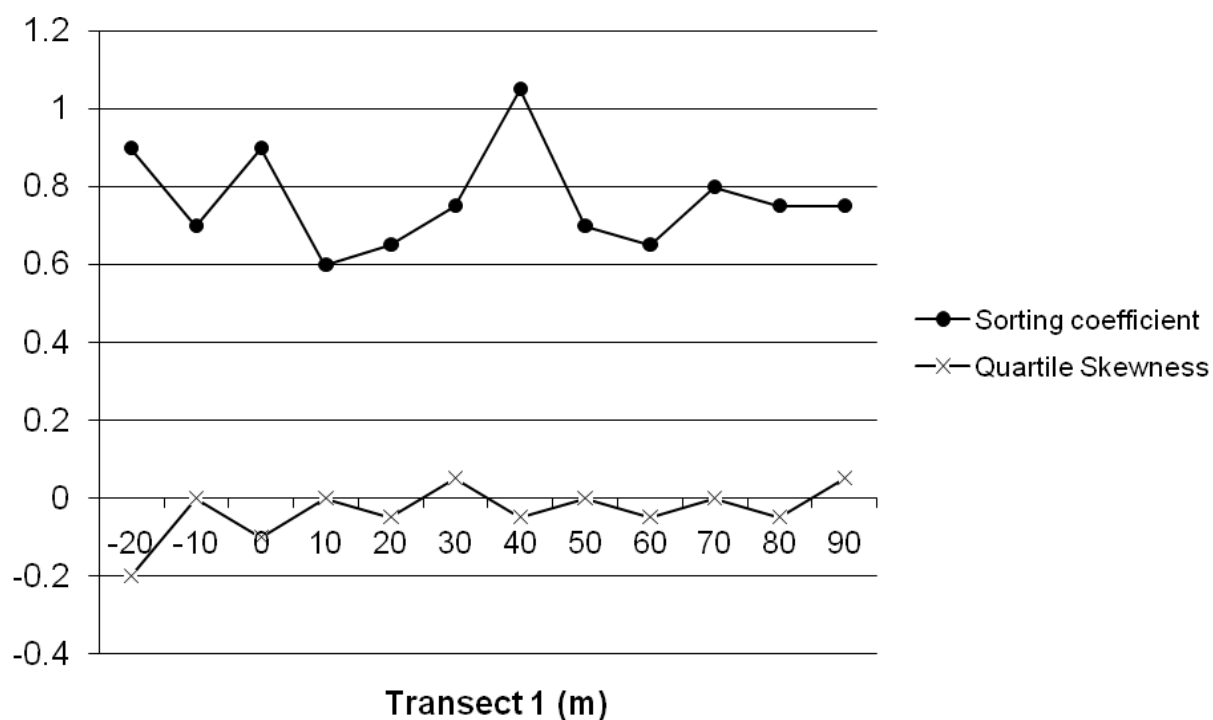
Figure 64: Sediment sorting coefficient and quartile skewness along Transect 1, May 2008.

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Sea-bed structure

Sea-bed side-scan imagery reveals surface topography to vary from within the farm to approximately 30 m outside its northern physical boundary, and secondarily between 30 m to 60–70 m (Figure 65). These discontinuities are not apparent in sediment grain size analysis. On the southern side of the farm, Transect 3, this difference extended 120–140 m from the physical boundary of the farm.
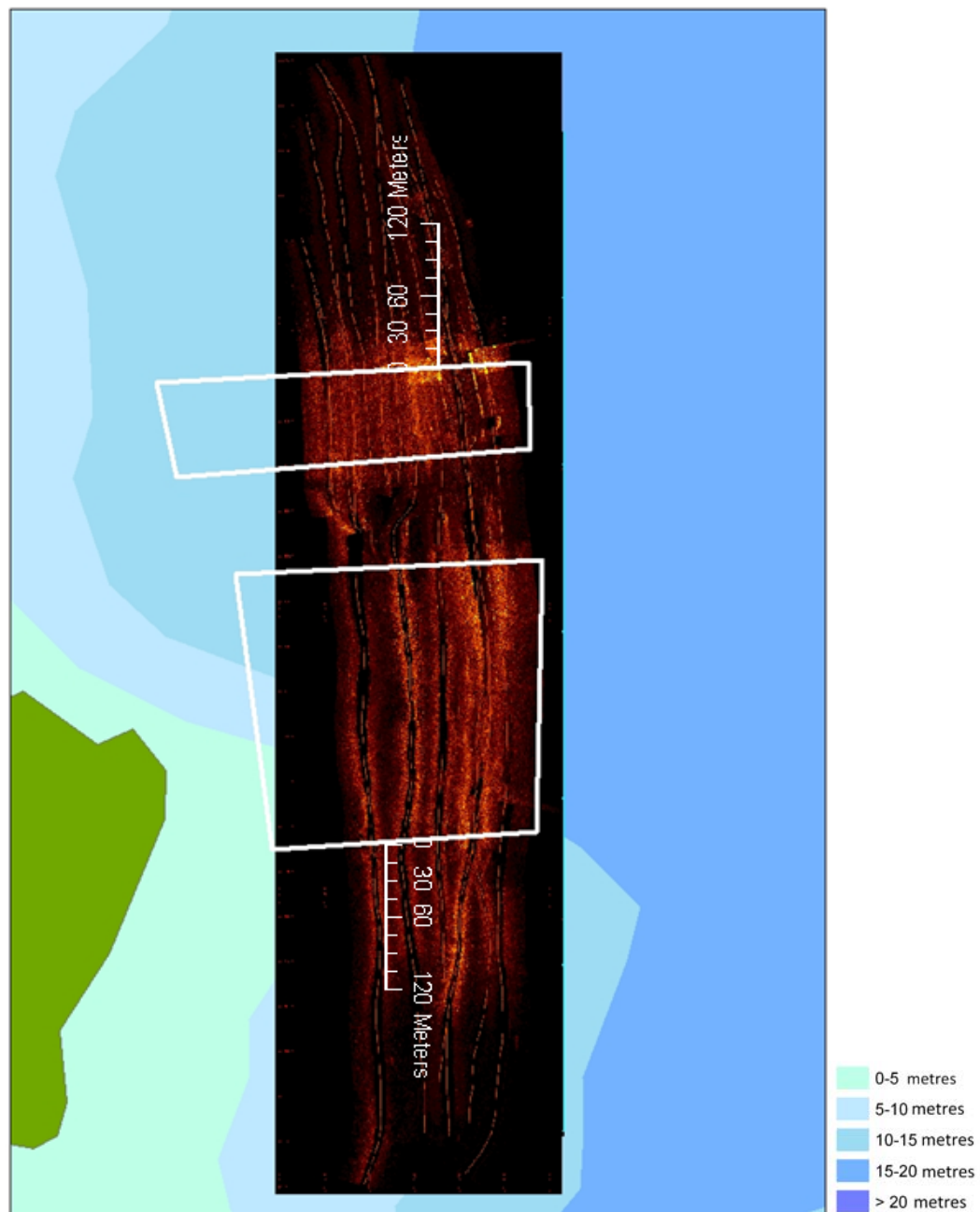
Figure 65: Side-scan sonar along the mussel farm.

Visual image

To determine what contributed to observed discontinuities in side-scan imagery at distances to 30 m, and to lesser extent 60–70 m from the physical boundary of the farm, a drop camera was deployed to examine the sea-bed type within and outside the physical boundary of the farm. Unfortunately the only window of opportunity to conduct these drop-camera deployments occurred when wind speeds approached 25 knots, so a more structured sampling design (transects perpendicular and throughout of the mussel farm) could not be achieved, given the small boat available drifted at the mercy of both current and wind.

The sea bed within and proximal to the northern physical boundary of the farm was populated with clumps of *Perna* and horse mussel (*Atrina zelandica*), and at greater distances by burrows attributed to species of *Alpheus*, *Macropthalmus*, *Echinocardium* or *Upogebia* (Figure 7).

Discussion

Substrata and communities throughout eastern Waiheke Island

Sediments

On the basis of sampling undertaken in February 2008, sea-bed substrata were visually characterised into three sediment types. Muds occurred throughout the region to 30 m, both inshore and offshore, within and proximal to channels. Gravels, typical of higher-energy environments, occurred only in narrow, relatively shallow channels (< 15 m) between islands, and off larger headlands in the region, like that near the southern end of the mussel farm. An admixture of the two sediment types, mud/gravels, occurred off many headlands, beneath the southern portion of the mussel farm, and also within channels between the Waiheke and Pakatoa Island, and between Pakatoa and Rotoroa Island. The distribution of these substrata throughout this region likely reflects local hydrodynamic regimes, with faster currents being associated with coarser sediment grades, and conversely, finer-graded sediments being associated with reduced current flow.

Muds along Transect 1, both within and outside the farm, prove to be *moderately* to *moderately well* sorted; mud/gravels throughout the region are *very poorly sorted*; and gravels are *poorly sorted*, at least in accordance with the schema of Gray (1981) (Table 9). The extent of sediment sorting does not correlate with the perceived impact of the mussel farm, as those areas with gravel-characterised substrata that intuitively are the most natural (least affected by the mussel farm by virtue of distance) between Rotoroa and Ponui Islands are classified as *poorly sorted*; those sediments beneath and proximal to the mussel farm along its northern face (Transect 1) are either *well*, or *moderately well sorted*; and the most poorly sorted sediments (*very poorly sorted*) are those mud/gravels in the vicinity of and beneath the southern portion of the existing farm.

Biology

With the exception of the work on sea-bed communities throughout the Waitemata Harbour and inner Hauraki Gulf undertaken by Powell (1927−1935), reported by Powell (1937), the sea-bed communities off eastern Waiheke Island had not been earlier described. On the basis of nine dredge stations in the eastern Waiheke Island region, Powell attributed most of the sea bed to an *Echinocardium* formation/association (with his formations characterised by the presence of a characteristic taxon, and his associations characterised by the absence of that taxon but presence of subdominant taxa), and a second formation, that of a *Tawera* + *Venericardia* (now *Purpurocardia*) between Rotoroa and Ponui Islands, and the eastern side of Ponui Island (Figure 6).

Only four of Powell's (*loc. cit.*) nine sea-bed stations off eastern Waiheke Island occur within the region surveyed in this thesis; for only two of Powell's stations did he provide species data (Powell's J3, J4); only one of these two stations has been resampled in this thesis (J4). A further two sites surveyed by Powell, for which no data were presented, were also resampled (Powell's J1, J6), both within his *Tawera* + *Purpurocardia* formation between Rotoroa and Ponui Islands. On the basis of recent sampling neither *Tawera* nor *Purpurocardia* prove to characterise species assemblages within gravels throughout the eastern Waiheke region, so unless there have been significant changes in benthic invertebrate community structure since the early 1930s neither would be appropriate to characterise this substratum type; a small, thick-shelled bivalve, *Notocorbula zelandica*, the only *ubiquitous* taxon recorded from gravels, would today be a far-more appropriate species to characterise these communities (Table 40).

During this current study too few samples were collected within areas characterised by Powell as *Tawera* + *Purpurocardia* formation to compare/contrast in any meaningful way with earlier reported species assemblages. However, excluding Powell's unidentified polychaetes, nine of the 28 taxa (Table 40) reported by him from two of four sea-bed stations within this formation for which he furnished a taxonomic inventory (Powell *loc. cit.*:

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370–384) were not re-identified during recent (2008) sampling. Two of those taxa reported by Powell were likely misidentified (*Petrolisthes elongatus* and *Nectocarcinus antarcticus*), and his 'small, pink holothurian' was probably one of *Ocnus brevidentis* or, more likely, *Trochodota dendyi*, both of which occurred throughout the region (*very rare* and *uncommon* in mud/gravels, and *uncommon* and *common* in gravels, respectively, according to the proposed rarity schema herein) (Appendix 3, Table A4–A6).

Table 40: Species names reported by Powell (1937) from eastern Waiheke Island, and their current names used in this thesis.

Powell (1937)	Current study
Tawera spissa	*Tawera spissa*
Venericardia purpurata	*Purpurocardia purpurata*
Cominella quoyana	*Cominella quoyana*
Cominella adspersa	*Cominella adspersa*
Nectocarcinus antarcticus	*Liocarcinus corrugatus* (possibly misidentified by Powell)
Trochus tiaratus	*Trochus tiaratus*
Zegalerus tenuis	*Zegalerus tenuis*
Petrolisthes elongatus	*Petrolisthes novaezelandiae*, or *Petrocheles spinosus*
Cirostrema zelebori	Not found
Proxiuber australis	*Proxiuber australe*
Rhyssoplax stangeri	*Rhyssoplax stangeri*
Zemysia zelandica	*Felaniella zelandica*
Epitonium jukesianum	Not found
Holothuria (small, pink)	Probably *Ocnus brevidentis* or *Trochodota dendyi*
Trachelochismus pinnulatus	Not found
Terenochiton inquinatus	*Leptochiton inquinatus*
Marginella pygmaea	Not found
Condylocardia concentrica	Not found
Condylocardia crassicosta	Not found
Notosetia micans	Not found
Estea minor	Rissoidae
Notoacmaea subtilis	Not found
Zemitrella choava	Not found
Echinocardium cordatum	*Echinocardium cordatum*
Dosinia lambata	*Dosinia lambata*
Amphiura rosea	*Amphiura rosea*
Neilo australis	*Neilo australis*
Polychaetes (not ident.)	Many taxa
Cadulus delicatulus	*Cadulus delicatulus*

On the basis of fauna recovered from 228 grab samples collected in February 2008 it is apparent that clearly, spatially defined species assemblages as depicted by Powell (1937) do not occur off eastern Waiheke Island. Species assemblages are shown to vary according to substratum type, which varies considerably throughout the survey region, and by depth, although the major difference in the latter case is in the relative abundance rather than composition of certain taxa within an assemblage. Accordingly, despite the relatively intensive nature of this recent survey to characterise sea-bed communities throughout this region, no schematic depiction of community distributions, as presented by Powell (1937), is attempted. The reality is that too few sites were sampled by Powell for him to have generalised sea-bed communities throughout this region, and the same applies in this current study.

Muds

The *well-sorted* mud-dwelling infaunal assemblage was characterised by bivalve, ostracod, polychaete and amphipod taxa. A single bivalve taxon, *Theora lubrica*, dominated these sediments, followed by a single species each of Ostracoda and Amphipoda; three polychaete species in three genera (*Prionospio*, *Sthenelais* and *Cossura*) largely completed the characteristic muddy substratum species assemblage.

Theora also characterises muddy sediments in Waitemata Harbour and Rangitoto Channel (Hayward *et al*. 1997), and now appears abundant throughout the Waitemata Harbour and inner Hauraki Gulf. Having been relatively recently recognised from New Zealand waters, first recorded in 1971 (Climo 1976), it has since established itself throughout Waitemata Harbour in muddy substrata (Hayward 1997); it was not a species recognised by Powell in his pioneering benthic ecological surveys 40 decades earlier, with Powell (1979: 451) making specific reference to this fact.

Muds + gravels

The *very poorly sorted* mud/gravel-dwelling in- and epifaunal species assemblage was characterised by polychaetes, ostracods, amphipods, bivalves

and ophiuroids. The polychaete fauna characterising this assemblage was diverse, and included representatives of at least 18 genera (two genera in each of the families Spionidae and Syllidae, one of Ampharetidae, and *Heteromastus*, *Sthenelais*, *Aonides*, *Trichobranchus*, Cirratulidae, *Arabella*, *Glycera*, *Macroclymenella*, *Onuphis*, *Cossura*, *Armandia*, and *Terebellides* and its commensal tube-dwelling polychaete referred to as WTF 3); two species of ostracod and amphipod also characterised this assemblage, as did one bivalve and one ophiuroid taxon, *Amphiura rosea* and *Notocorbula zelandica*, respectively.

Gravels

The *poorly sorted* gravel-dwelling in- and epifaunal species assemblage was characterised by polychaetes, bivalves, pagurid crabs, gastropods, ostracods, ophiuroids and nemertean worms. The polychaete fauna characterising this assemblage also was diverse, and included representatives of at least 18 species in 17 or 18 genera (likely three genera of Syllidae, two genera of Spionidae, and one species in each of the genera or families *Heteromastus*, *Macroclymenella*, *Terebellides* and its commensal WTF 3, Sabellidae, Ampharetidae, *Ophiodromus*, *Aonides*, *Hydroides*, *Armandia*, *Glycera*, *Glycinde*, and *Trichobranchus*); two species of bivalve (*Notocorbula zelandica* and *Anomia trigonopsis*); one hermit crab (*Paguristes setosus*); one amphipod (*Paraphoxus*); one isopod (Anthuridae); two ostracods; a single gastropod (*Maoricolpus roseus*); and the ophiuroid *Amphiura aster*, completed the assemblage of taxa characterising this substratum type.

Within the 228 samples collected in February 2008, 326 taxa were recorded (Figure 8): 142 taxa from 139 muddy sites, 166 taxa from 32 mud/gravel sites, and 255 taxa from 57 gravel sites. None of the species accumulation curves (Figure 9−11) prepared for individual substrata reaches an asymptote, so it is apparent that many additional taxa occur within each, and throughout this region. The most species rich sites prove to be those within gravels (Figure 12).

Regardless of whether the individual substrata are classified as *well sorted*, *moderately well*, *poorly* or *very poorly* sorted, when the incidence of gravel is used as a proxy for structural complexity, it is apparent that this structure results in elevated diversities and abundances of benthic invertebrate taxa (Table 13). These findings are consistent with those of Dewas (2008), for sea-bed communities off Otata Island, Hauraki Gulf, where the abundance and richness of benthic invertebrates in adjoining types of sea-bed, structurally complex valves of the bivalve *Tucetona laticostata*, and less structurally complex and extensively fragmented shell gravels, is greater in the former.

Because substratum type is shown to influence the composition of in- and surface-dwelling epifaunal species, subsequent appraisals of relative rarity, richness and abundance had to be prepared that were unique to each substratum type.

Bathymetry

The assemblage of species characterising muds varied by depth. Assemblages of species characterising mud/gravels differed significantly only between sites more shallow than 10 m and those deeper than 15 m. However, assemblages of species characterising gravels, encountered only at depths <10 m and between 10 and 15 m, did not differ significantly. To an extent these findings are inconsistent with those of Dewas (2008), wherein the abundance, richness and diversity of invertebrate taxa characterising shell gravels off Otata Island were shown to differ between depths separated by as little as two metres (between 5 and 7 metres water depth).

Because depth, in addition to substratum type, is shown to influence the composition of in- and surface-dwelling epifaunal species, these same appraisals of relative rarity, richness and abundance had to be prepared specifically for depth ranges within each substratum type.

Side-scan sonar

Side-scan sonar revealed differences in sea-bed topography along Transect 1, with the structural footprint of the farm extending to approximately 40 m from the physical farm boundary on the northern side. These data also revealed differences in sea-bed topography along Transect 3, where the apparent structural footprint of the farm extended approximately 120 m from the southern farm boundary, although this could equally be the distribution of gravels on the sea bed, rather than a consequence of the farm. Drop camera images from the northern side of the farm, within the structural footprint, reveal a sea bed populated with clumps of *Perna*, *Atrina*, *Styela*, and other sessile macrobenthos; beyond 40 m from the northern boundary of the farm *Perna* is sparsely distributed or no longer apparent, and the sea bed is extensively bioturbated (Figure 7).

Spatial distribution

Relative Rarity

The large data set built up to characterise sea-bed communities throughout this region, initially developed with the intention of identifying appropriate control sites in a survey design that had to be subsequently abandoned, was used to appraise the relative rarity of taxa throughout the region. This schema previously has been used to characterise the proportional contribution of *ubiquitous* to *very rare* species in assemblages of taxa occurring intertidally, based on their frequency of occurrence at 296 sites between Tauranga and Whangarei, East Coast North Island (Palacio 2008), but had not been previously applied to subtidal communities.

Significant differences were apparent in the composition of species assemblages in the three major substrata identified off eastern Waiheke Island, necessitating development of taxon rarity scores that were specific to each substratum type. Only gravels had any *ubiquitous* taxa, and only one species was so characterised — the bivalve *Notocorbula zelandica*. Otherwise species assemblages within each of muds and mud/gravels had variable proportional

contributions of *very rare* to *very common* species only, with the most pronounced trend being apparent in muds (where the relative contribution of *very rare* species increased demonstrably with a corresponding increase in species richness (Figure 48)), although this trend is less marked when the effects of *Perna* and associated species are excluded from the histogram (Figure 51). The proportional contribution of *very rare* to *uncommon* species trends upwards in mud/gravels as species richness in these sites increases (Figure 49), as does that, although to a lesser extent, for gravel-characterised substrata (Figure 50).

When this rarity schema is applied at a reduced scale (only for muds deeper than 10 m [removing those sites more shallow than 10 m]) along Transect 1, it is apparent that the proportional contribution of *very rare* to *uncommon* species trends downwards from 20 metres inside the mussel farm to 80 metres outside the mussel farm, with (Figure 53) or without (Figure 54) *Perna* sites included in calculations. Thus, a greater proportion of taxa occurring in muds beneath the farm are of *very rare* to *uncommon* occurrence within muds throughout the eastern Waiheke Island region. Had the opposite been the case, that mud beneath the farm had a greater proportion of (conjecturally more tolerant and widely distributed) *ubiquitous* taxa then it is likely this would be construed as a negative effect.

No previous New Zealand study that has appraised the effects of mussel farming on sea-bed communities has undertaken such an intensive biological survey of the sea-bed around a farm in order to identify appropriate control sites, or characterise sea-bed communities throughout a region. Given the sea-bed beneath the mussel farm proved to have three separate substrata, and the assemblages of species in each were determined to differ, the originally envisaged survey design involving monitoring of control sites within and outside the farm was abandoned as the time required to conduct an appropriately replicated monitoring exercise in each substratum exceeded that available to conduct this research. Generalised statements have been made regarding sea-bed communities at other surveyed sites throughout New Zealand, such as

'communities are typical of those throughout Marlborough Sounds' (Christensen *et al*. 2003, Hartstein & Rowden 2004), but this current research has shown that the sea bed and associated communities beneath and surrounding the existing mussel farm off eastern Waiheke Island are not typical of those occurring throughout the region.

Relative Richness

Based on the relative richness schema proposed in this thesis, specifically for this region, the most species-rich sites are those beneath and in the immediate vicinity of the mussel farm, in the deeper channel between Waiheke Island and Pakatoa Island, and that between Rotoroa and Ponui Island (Figure 17).

Previous studies appraising the effects of mussel farming activities on sea-bed communities in New Zealand have presented species richness data in varied formats (Table 41). However, total species richness depends upon sampling effort, and sorting and identification proficiency, and as has been shown for this current study (Figure 9–11), despite the intensity of sampling undertaken, no species accumulation curve for any substratum type, individually or collectively, or sampling event (season) reaches an asymptote.

de Jong (1994) recorded 48 taxa in total from beneath and adjacent to a mussel farm in the Firth of Thames; Christensen *et al*. (2003) cited taxa recorded within (two sites, 31 and 26 taxa) and outside a farm (one site, 41 taxa) in the Marlborough Sounds, but did not present total species richness for the three sites combined, or report how many taxa were common to the three; Hartstein & Rowden (2004) record 132 taxa in total for surveys sites within Marlborough Sounds, for three mussel farms (83, 63, 57 species), and three control sites (82, 78, 68 species), although data are not presented in a manner that enables determination of the proportion of taxa common to farm and control sites. Herein, 326 taxa were recorded during February 2008: 168 taxa within and 307 outside a farm, with 149 taxa common to the two; subsequent surveys (May and August 2008) increased the total number of taxa recorded from the region to 359, 232 of which occurred within and 329 taxa outside the

farm. A partially anonymised data set is presented in Appendix 4 (Table A9), with abundance data reduced to presence/absence format; full abundance data are entered into the AUT *Monalisa* Biodiversity database.

Table 41: Synopsis of previously reported mussel farming sampling designs and species richness in New Zealand.

Study	# of mussel farms surveyed	Sampling Period	# samples	Sieve size (mm)	Taxa within mussel farm	Taxa outside mussel farm	Taxa in common to two habitats	Total taxon richness
Kaspar *et al*. (1985)	1	Sep, 82 Oct, 82 Jan, 83 May, 83	?	?	?	?	?	?
de Jong (1994)	1	Dec, 93 April, 93 June, 93 Sep, 93	60 60 60 60	0.5	?	?	?	48
Christensen *et al*. (2003)	1	?	15	0.5	32 & 26 (2 sites)	41	?	?
Hartstein & Rowden (2004)	Site 1 (low energy)	Sep, 01 Jan, 02 May, 02	11 10 11	1	63	82	?	101
	Site 2 (low energy)	Sep, 01 Jan, 02 May, 02	9 11 10	1	57	78	?	93
	Site 3 (high energy)	Sep, 01 Jan, 02 May, 02	8 11 10	1	71	68	?	83
Giles H. (2006)	1	Oct, 03 Aug, 04		0.5	4 families	5 families (edge) 4 families (control)	?	6 families
Current study	1	Feb, 08 May, 08 Aug, 08 Overall	228 47 59 334	0.5	168 137 143 232	307 66 87 329	149 48 70 203	326 155 160 359

Relative Abundance

Although this new abundance schema has several limitations, most notably that it can be applied only to abundances (densities) of taxa in sea-bed assemblages off eastern Waiheke Island, and possibly for the month of February 2008 only, it still enables a snapshot comparison of relative taxon abundance beneath and at progressively increasing distances from the mussel farm for February 2008.

It is apparent that the greatest abundance of individuals (to 46,786 m^{-2}) off eastern Waiheke Island occurred in February in gravels beneath and in the immediate vicinity of the existing mussel farm, in the deeper channel between Waiheke Island and Pakatoa Island, and Rotoroa and Ponui Island, in addition to one site with an exceptional value north of Pakatoa Island. Muds and mud/gravels have maximum and minimum abundances of individuals of 119 m^{-2} and 17,440 m^{-2}, and 238 m^{-2} and 6,905 m^{-2} respectively (with mean abundances of 1,458 m^{-2} and 2,351.2 m^{-2}, respectively).

de Jong (1994) presented mean abundance data only for his grab samples collected within muds beneath and adjacent to a mussel farm in the Firth of Thames, 84 individuals m^{-2} (8.4 per 0.1 m^{-2} grab sample) within and 115.5 m^{-2} (11.5 per 0.1 m^{-2} grab sample) outside the farm. Although his results cannot be directly compared with those determined for off eastern Waiheke Island, given the comparable sample-processing methodologies used in these two studies it would appear that the sea bed in the Firth of Thames, beneath and adjacent to an existing mussel farm, has a *very low* number of species for muds relative to values determined for off eastern Waiheke Island; de Jong also reports a 92% sorting efficiency (1994: 130), identifying his abundance values to be relatively accurate.

As the sample-processing methodologies used herein are the same as those of Dewas (2008), these two data sets can be directly compared. It is apparent that the maximum abundances of taxa in shell gravels off Otata Island, Noises, 142,385 individuals m^{-2} (Dewas 2008), are considerably greater than these values for off eastern Waiheke Island in comparable substrata, 46,786 individuals m^{-2} (herein). Therefore, the abundance scale determined for off eastern Waiheke Island will vary by region, and by time.

Maximum abundances of species in Rangitoto Channel (Roberts 1990), collected by Van Veen grab, but from a range of substrata (potentially muds through to gravels) are also *low* (to 4,440 m^{-2}) relative to those values

determined for all substrata combined off eastern Waiheke Island (Table 21, 22).

Excluding commercial environmental consultant reports (for which species inventory data are less reliable (Palacio 2008)), quantitative accounts of temporal variation in subtidal soft-sediment community structure throughout Waitemata Harbour and Hauraki Gulf are rare, being limited largely to university theses (Roberts 1990, de Jong 1994, Dewas 2008, this present study), and the results of one commercial report assessing the effects of spoil disposal off the Noises group of Islands (Gowing *et al*. 1997). Identical sample processing and species identification and enumeration methodologies were followed by Dewas and in this current study, with both being relatively recent (2007 through 2008 sampling); both recognise significant temporal changes in abundance, richness and diversity of species occurring within a substratum type, although Dewas (2008) focussed her research on gravels, and muds were the primary focus in this current study. Both accounts report lowest values for each in late summer (January/February), and highest values in winter (June/August) (Dewas 2008: p 38; herein, Table 30, 31), although off eastern Waiheke Island species richness in May within the farm is similar to that for August.

The overall relative abundance values proposed herein were calculated from data collected in February 2008 only, and accordingly it is likely that considerably higher values would be determined for winter surveys; thus, caution must be used when applying this abundance ranking schema, limiting it to a clearly defined region, and at the very least to abundance data collected from comparable seasons.

The value of this abundance schema is that it enables a comparison of the relative abundances of species in areas throughout Hauraki Gulf, at least for those limited locations, dates and depths that have been surveyed in a quantitative manner. To date those areas with the greatest abundances of individuals, in decreasing order, occur off Otata Island in *Tucetona*-based shell gravels (142,385 m^{-2}, Dewas 2008); eastern Waiheke Island in shell gravels

(with limited *Tucetona*, 46,786 m^{-2}, herein); muds off eastern Waiheke Island (17,440 m^{-2}, herein); muddy gravels off eastern Waiheke Island (6,905 m^{-2}, herein); muds off eastern Motutapu Island (maximum abundances 5,832 individuals m^{-2}, Dewas 2008); undefined substrata (potentially all of muds, mud/gravels and gravels) in Rangitoto Channel (maximum abundance 4,440 m^{-2}, Roberts 1990); general muds off eastern Motutapu Island (mean abundance 1,797 m^{-2}, Dewas 2008); and muds proximal to the mussel farm in the Firth of Thames (mean abundance 115.5 m^{-2} outside and 84 m^{-2} inside a mussel farm, de Jong 1994). Data are too limited to further compare patterns of spatial or temporal variation in these abundance values.

In the event the same rigour was applied to processing, sorting, and counting individuals within samples in each of these surveys, those muds off eastern Waiheke Island host relatively high abundances of taxa for this substratum type throughout Hauraki Gulf. At an even finer scale, the abundances of taxa within muds throughout eastern Waiheke Island are highest beneath the mussel farm (Figure 20), and vary temporally, both within and outside the mussel farm over the three seasons for which data are available (Figure 46).

Previous New Zealand studies reporting the effects of mussel farming on sea-bed communities (e.g. Kaspar *et al*. 1985, Hartstein & Rowden 2004) do not present abundance data in a format enabling comparisons with abundance data reported herein.

Species richness and abundance in muddy substrata

When limiting analysis to species richness and abundance within muds, little spatial variation is apparent in species richness throughout the surveyed region, although considerable variation is apparent in the spatial distribution of species abundance, with those sites within and on the immediate boundary of the farm having the greatest abundances of individuals, and those to the north of the farm, and northeast and south of the farm in deeper waters having the least abundance values. Along Transect 1, species richness within and outside the farm are similar, although localised spikes in richness occur within and

outside the farm. Species abundance varies seasonally, being lowest during late summer (February), and greatest during autumn (May) and winter (August), but abundance values do not differ significantly within and outside the farm during any of these survey periods. Finally, the proportional contribution of *very rare* to *uncommon* species within a sample is greatest beneath the farm, tending to decrease along Transect 1 progressing away from the mussel farm boundary. The existing mussel farm does not appear to depress values of either species richness or abundance of individuals throughout the surveyed region.

Species composition

The combined recognised taxon richness in eastern Waiheke Island samples comprises 359 species or species-groups of collective unknowns (e.g., Nemertea, Nematoda and Platyhelminthes). Of these 359 taxa, only 45.1% could be reliably identified to species, and for some identification could not proceed past phylum (Table 42). The level to which species could be reliably identified reflects a number of factors: the general lack of monographic revisions of the New Zealand shallow-water invertebrate fauna (e.g., Annelida: Polychaeta and Oligochaeta; Nematoda; Arthropoda), and otherwise poor knowledge of these species taxonomy; and lack of systematic expertise to identify some of the lesser-known phyla amongst samples (e.g., Platyhelminthes, Sipunculida).

As some phyla could not be identified within the time available to conduct this study, or could not be identified given the lack of systematic reviews, a voucher set of all taxa identified in the course of this research programme has been accessioned into the biological collections of AUT. This will enable continuity in identification of species-specific enumerated unknown taxa between surveys off eastern Waiheke Island, and within soft-sediments throughout Hauraki Gulf, given personnel with varying degrees of systematic experience are likely to be involved.

Table 42: Taxonomic resolution (n = 359 taxa).

Phylum	Phylum	Class	Order	Family	Genus	Species
Annelida		11%		2.3%	62.5%	24.2 %
Arthropoda		14.1%	31.4%	4.1%	15.7%	34.7%
Chordata		16.7%				83.3%
Cnidaria			28.6%		28.6%	42.8%
Echinodermata					14.3%	85.7%
Hemichordata						100%
Mollusca			1.4%		4.3%	94.3%
Brachiopoda						100%
Porifera	50%					50%
Rhodophyta					100%	
Sipunculida		100%				
Bryozoa	100%					
Nematoda	100%					
Nemertea	100%					
Phoronida	100%					
Platyhelminthes	100%					
Priapulida	100%					
Total	2%	9.5%	11.4%	2.2%	29.8%	45.1%

Indicator taxa

Opportunistic species

Surugiu (2005) identified a suite of polychaete taxa appropriate for identification of eutrophication and/or organic enrichment in marine sediments. A number of these taxa occur in sediments beneath and in the vicinity of the mussel farm off eastern Waiheke Island (polychaetes of the families Capitellidae, Dorvilleidae and Spionidae, represented at eastern Waiheke sites by the capitellids *Capitella 'capitata'* and *Heteromastus filiformis*; dorvilleids *Dorvillea* sp. and Dorvilleidae sp. 1; and spionids *Aonides* sp., *Prionospio* sp., *Scolecolepides benhami* and Spionid spp. 1 and 3–9) (Appendix 5, Table A10). These apparent opportunistic taxa (*fide* Surugiu 2005) had differing distributions during the three sampling occasions (February, May and August). During February they were almost absent outside the farm boundary, and did not occur at all sampling sites within the farm; during May they extended a greater distance outside the farm along Transect 1, and occurred at all sites within the farm; during August they extended even further outside the farm along Transect 1.

Capitella sp. (often referred to *C. capitata* but possibly a species complex (Méndez (2006)) is one of the most frequently cited opportunistic species in

national (e.g. Christensen *et al*. 2003) and international (e.g., Pearson & Rosenberg 1978, Mattsson & Linden 1983, Surugiu 2005) studies. Off eastern Waiheke Island the distribution and abundance of one species attributed to *C. 'capitata'* varied over the three seasons for which sea-bed communities were studied (Figure 61). During February, this species occurred in seven of 228 sampling sites (3%), but in May it occurred in 24 of 47 sampling sites (51%), and in August in 25 of 59 sampling sites (42%), and during August also at higher abundance. Additionally, *C. 'capitata'* was classified as a *very rare* taxon in muds from the eastern Waiheke region during February 2008.

Méndez (2006) identified *Capitella* sp. as a species complex, with more than 50 variable life cycles and development/egg types known; the median longevity of one of the 'species' included in this complex was six months. Otherwise remarkably few studies have been undertaken on the life cycle and longevity of species in this complex attributed to *C. capitata* (Méndez 2006), despite its repeated use as an indicator species of organic enrichment, environmental degradation and pollution. Because of its relatively *very low* abundance, temporal variation in spatial distribution and abundance (Figure 61), and *very rare* nature, *C. 'capitata'* is not considered to be a good opportunistic indicator, or indicator of organic enrichment off eastern Waiheke Island, especially in the vicinity of the mussel farm, at least for the month of February (no large-scale sampling programme could be undertaken in any other month to determine the extent of changes in distribution and abundance of this species). *C. 'capitata'* also did not occur during two of four seasons of monitoring for the effects of fish farming in Canada (Tomassetti & Porrello 2005), so its ephemeral nature renders it potentially of limited value for assessing the effects of aquaculture activities on sea-bed species assemblages; off eastern Waiheke Island this species only had a significantly greater abundance in muds within the farm during May and August. Temporal changes in the spatial distribution and abundance of this species along Transect 1 are likely the result of recruitment (rather than immigration), given the relatively short life span of the one species in this complex for which life history information is available, and its likely

limited dispersal capability through sediments during its relatively brief life cycle.

A second capitellid species in this study, *Heteromastus filiformis*, occurred at significantly greater abundances within the farm than outside the farm in muds greater than 15 m depth during February, along Transect 1 during each survey month, and at depths greater than 15 m depth throughout the eastern Waiheke Island region (Table 33). However, this species was one of the most prevalent taxa in gravels throughout the region (Table 16), and in addition to being most abundant in the southern portion of the mussel farm, it was also abundant in channels between Rotoroa and Ponui Island a considerable distance from the existing mussel farm that are not subject to any other obvious anthropogenic disturbance (Figure 62). Accordingly, high abundances of this species cannot be solely attributed to the effects of a mussel farm, and elevated levels in areas not obviously subject to other anthropogenic disturbance render it an inappropriate taxon to use as an indicator of localised organic enrichment, at least that sourced to any local mariculture activity.

Dorvilleids were significantly more abundant within the farm than outside the farm in mud/gravels and gravels; spionids were significantly more abundant in muds within the farm than outside the farm, on each sampling occasion (Table 35, Figure 55).

Roberts *et al*. (1998) proposed a suite of macrofaunal taxa that could be used for rapid assessment of sea-bed communities in Waitemata Harbour, whether they were impacted by spoil, or whether they were relatively natural (at some distance from disposal sites). Taxa cited by Roberts *et al*. (*loc. cit*.) to occur in greater abundances in spoil-effected sites were the bivalves *Dosinia lambata*, *Theora lubrica* and *Tellinota edgari*, the latter not recorded off eastern Waiheke Island in this current study, and the urchin *Echinocardium cordatum*. *Echinocardium cordatum* proved to be significantly more abundant outside the mussel farm off eastern Waiheke Island, and almost absent beneath it. Thus, rather than being an opportunistic species, *E. cordatum* would more

appropriately be referred to as a sensitive species, at least for evaluating the effects of mariculture activities on sea-bed communities. The distribution and abundance of other opportunistic taxa cited by Roberts *et al*. (1998) was greater outside the existing mussel farm, so all would more appropriately be referred to as sensitive species, or indicators of naturalness, at least for the eastern Waiheke Island region.

As sediments were not analysed for organic content during this research, the relationship between organic content and taxon abundance and distribution cannot be evaluated. However, it appears that no taxa can be definitively identified as opportunistic, that is appropriate as indicator species of mussel-farm sourced organic enrichment. Those taxa previously proposed as appropriate indicator species for determining the effects of aquaculture activities on sea-bed communities (e.g., Christensen *et al*. 2003, Pearson & Rosenberg 1978, Mattsson & Linden 1983, Surugiu 2005) appear to be inappropriate for this purpose for sea-bed assemblages beneath and surrounding the mussel farm off eastern Waiheke Island.

Sensitive species

Sensitive taxa, those occurring at greater abundance outside impacted environments by Surugiu (2005), included polychaetes in the families Nephtyidae, Glyceridae and Syllidae, of which representatives of each also occurred off eastern Waiheke Island. Of these, glycerid polychaetes were significantly more abundant within the mussel farm in gravels and muds than they were outside the farm; glycerids are thus inappropriate indicators of natural environments in this region. Otherwise, those taxa categorised as sensitive according to Surugiu (2005) were distributed throughout the eastern Waiheke region, and occurred at greater abundances outside the farm, within and proximal to the southern portion of the farm, and in channels between Waiheke and Pakatoa, and Rotoroa and Ponui Islands.

During all three sampling events (February, May, August), sensitive taxa (*sensu* Surugiu 2005)) were distributed within and outside the farm, and some even

occurred at greater abundances beneath the farm (Glyceridae and Syllidae). During February, sensitive taxa were distributed within and outside the farm at similar abundances, in contrast to May and August when these taxa were more abundant outside the farm. Because of the widespread distribution of sensitive taxa, and temporal variation in their abundance, none is likely to be an appropriate indicator for assessing the spatial effects of mussel farming at all times in this region.

Echinocardium cordatum already has been identified as a more appropriate sensitive species for this environment, occurring at average abundances in muds outside the farm of 0.48 individuals (±0.8) between 10 and 15 m depth, and 0.63 individuals (± 0.9) at depths greater than 15 m. de Jong (1994) also reported this taxon to be more abundant outside a mussel farm in the Firth of Thames, although his differences in abundance for this species were not significant.

A tiny ostracod, Ostracod sp. 2, tentatively attributed to *Aglaiocypris* sp., characterised muds along Transect 1 outside the farm on all three sampling occasions (February, May and August). Were it not for the small size of this species (~ 1.5 mm maximum dimension, and therefore potential for being overlooked during sample sorting), it would be an appropriate taxon to refer to as a sensitive species, at least for this mussel farm off eastern Waiheke Island.

Those species proposed as sensitive in accordance with the schema proposed by Roberts *et al.* (1998) included the ophiuroid *Amphipholis squamata*, an anthurid isopod, and polychaetes of the family Syllidae. These so-called sensitive species had limited distributions off eastern Waiheke Island, occurring beneath and in the vicinity of the southern portion of the mussel farm, and in channels between Waiheke Island and Pakatoa Island, and between Rotoroa Island and Ponui Island. Neither *Amphipholis squamata* nor any anthurid amphipods were recorded from muds, and syllid polychaetes actually proved to be more abundant beneath the farm in August. None of those species proposed by Roberts *et al*. (1998) to be sensitive to spoil disposal are

particularly sensitive to mariculture-effected sea bed, and are therefore deemed to be inappropriate indicators of natural environment throughout the eastern Waiheke region.

Perhaps the most appropriate indicator to use to rapidly assess the biological footprint of the farm off eastern Waiheke Island is the mussel itself, *Perna*, as infaunal assemblages have changed well before the relatively narrow *Perna* footprint (< 30 metres) of the farm has ended (Figure 65).

Sampling effort (adequacy of effort)

The adequacy of sampling effort along each Transect, and throughout the survey region in each of the three substrata already has been discussed for February 2008 in the preceding review of overall community structure throughout the eastern Waiheke Island region.

Along Transect 1, 53 and 73 taxa were recorded from 31 and 33 samples, the former including and the latter excluding sites at which *Perna* occurred. Along Transect 2 (only sampled during February), 50 and 80 taxa were recorded from 31 and 33 samples also, the former with and the latter without sites at which *Perna* occurred. Along Transect 3 (also sampled only during February), 155 taxa were recorded from 33 samples (no samples with *Perna* occurred along this transect). None of the species accumulation curves for any of these Transects reaches an asymptote, however, when all are plotted on the same axes (Figure 12) it is apparent that Transect 1 most adequately describes (of the three options available) the richness of benthic-invertebrates and flora.

Due to the time required to process, sort and identify flora and fauna within mud/gravel and gravel-based substrata, Transect 1 was selected for ongoing monitoring purposes. This Transect option required the least effort to obtain the information necessary to appraise the effects of this farming activity on sea-bed communities in this region. This transect also was oriented in the direction of the proposed 10-ha mussel farm expansion.

During February, all muddy sites within the farm boundary, including those from Transect 1 and the randomly distributed sites throughout the farm, contained 45 taxa from 17 samples; outside the farm boundary, in muds, 67 and 46 taxa were recorded from 24 and 22 samples, the former including and the latter excluding sites at which *Perna* occurred. None of the species accumulation curves reaches an asymptote for the month of February, indicating that additional taxa would be recorded from this substratum type in the event additional sampling was undertaken.

Along Transect 1 in May, 89 and 84 taxa were recorded from 30 and 29 samples, the former including and the latter excluding sites at which *Perna* occurred. Those muddy substratum sites within the farm boundary, including those from Transect 1 and the randomly distributed sites throughout the farm, contained 88 and 69 taxa from 17 and 14 samples, the former including and the latter excluding sites at which *Perna* occurred; 66 taxa were recorded outside the farm from within 21 samples, none contained *Perna*. None of the species accumulation curves reaches an asymptote for the month of May, indicating that additional taxa also would be recorded from this substratum type with additional sampling.

Along Transect 1 during August, 111 and 89 taxa were recorded from 42 and 35 samples, the former including and the latter excluding sites at which *Perna* occurred. Those muddy sites within the farm boundary, including those from Transect 1 and the randomly distributed sites throughout the farm, contained 92 and 54 taxa from 17 and 9 samples, the former including and the latter excluding sites at which *Perna* occurred; 87 taxa were recorded outside the farm from within 33 samples, none contained *Perna*. None of the species accumulation curves reaches an asymptote for the month of August, indicating that additional taxa also would be recorded from this substratum type with additional sampling.

With the exception of sampling undertaken in May, including those sites at which *Perna* occurred, species accumulation curves were always higher within

the farm than they were outside the farm, whether samples with or without *Perna* were included (Figure 40–45), a finding similar to that of Hatcher *et al.* (1995) and da Costa & Nalesso (2006), where mussel farms were reported to enhance sea-bed species richness.

Despite intensive biological sampling effort compared to any previous undertaking (Table 42), species accumulation curves by substratum and survey date reveal benthic communities beneath and adjacent to the mussel farm, and those throughout the greater eastern Waiheke Island region, have not been fully characterised. Nevertheless, sampling effort was sufficient to recognise significant differences in the composition of species assemblages in muds within and outside the existing mussel farm, and between survey events, and between the three substratum types recognised in this region.

Monitoring

February 2008

During February sampling no DIVERSE index differed significantly between those stations within and outside the farm along Transect 1 or 2, however, Margalef's richness and Shannon's diversity indices were significantly greater within the farm than they were outside the farm along Transect 3. For this same month there was no significant difference in the composition of species assemblages within and outside the farm along either Transects 2 or 3, but there was a significant difference in these along Transect 1.

Based on the relative richness schema proposed herein, no obvious pattern in the distribution of species richness along Transect 1 was apparent during February; sites all were generally *fairly low* to *fairly high* in species richness. Based on the relative abundance schema proposed herein, abundance values along Transect 1 generally were *low* during February, and were the lowest values recorded for this Transect during any of the survey events.

Ubiquitous taxa appear at all sites along Transect 1, both within and outside the farm, however the proportional contribution of *very rare* taxa to the total species

assemblage at any site was greatest 10 m outside the farm boundary, and was only slightly lower 10 m within this boundary (Figure 53). However, when samples within which *Perna* occurred were excluded from analysis, the proportion of *very rare* taxa dropped on the 10 m mark outside the farm boundary, and was greatest 10 m within this boundary (Figure 54).

The distance at which any significant effect of the farm on sea-bed communities ceased to occur is difficult to identify, but during February it appeared to be somewhere within the first 10 metres of the physical boundary of the farm (Figure 26).

May 2008

During May sampling along Transect 1, species abundance, richness, Shannon's index and Simpson's index of diversity were significantly lower outside the physical boundary of the farm than within it, but this includes those samples within which *Perna* occurred. When *Perna* samples were removed from analysis, only species abundance, Shannon's index and Simpson's index of diversity were significantly lower outside of the farm. It is likely that the shells of live *Perna* provide structure that elevates overall abundance of many taxa, rather than elevate abundances of a few taxa only, given the high diversity of both indices (H') (1-λ') amongst samples with and without *Perna*. Species assemblages also differed within and outside the farm in May, with more taxa contributing to the top 90% of species characterising assemblages within the farm (Table 26, Figure 33).

Relative species richness outside the farm was generally *fairly low*, and within the farm it was *medium* to *fairly high*, when compared with those values throughout the eastern Waiheke region from muds deeper than 10 m, possibly because of the incidence of live *Perna* in several samples (Figure 46). Relative abundances of individuals outside the farm were generally *very low* to *low*, and somewhat higher within the farm, ranging from *fairly low* to *medium* (Figure 47).

The distance at which any significant effect of the farm on sea-bed communities ceased to occur is similarly difficult to identify, but during May it appeared to be somewhere within the first 10 m of the physical farm boundary.

August 2008

During August sampling along Transect 1, all of species richness, Margalef's index, abundance and Shannon's diversity index were higher within the farm than they were outside it, although this is likely attributable to the effects of *Perna* in eight of nine samples recovered along this Transect within the farm this month. *Perna* samples could not be removed from analysis, given only one sample within the farm would remain to compare with fauna recovered from that outside it. Although DIVERSE indices indicate a change in community structure this month occurs 20 m outside the farm boundary (Figure 35), species composition changes at the physical farm boundary (Figure 36).

Relative species richness outside the farm was generally *fairly low* to *medium*, but within the farm it was *medium* to *high* (Figure 46)*.* Relative species abundance appears to be *very low* to *fairly low* outside the farm, but within the farm it appears *fairly low* to *medium* (Figure 47). These differences within and outside the farm also are supported by DIVERSE indices (Figure 35).

The distance at which any significant effect of the farm on sea-bed communities ceased to occur is similarly difficult to determine, but during August it occured either at the physical farm boundary, or approximately 20 m from it.

<u>**Synopsis**</u>

Most earlier studies in New Zealand have concluded that the impact of mussel farming decreases species richness and abundance in sediments beneath farms, with the exception of de Jong (1994), who recorded no significant difference on richness among sites and higher abundance outside the farm, and Giles *et al.* 2006, who recorded greater richness and biomass beneath the farm, but had insufficient data to determine whether this relationship was significant. Beneath the mussel farm off eastern Waiheke Island species

richness and abundance can be either significantly higher beneath the farm compared to outside the farm (May, August), or not significantly different at all (February), depending on the season and Transect that is surveyed.

There are many accounts of fauna beneath farms differing from those outside of farms. Usually sediments beneath farms are characterised by elevated diversities and abundances of polychaetes (Ragnarsson & Raffaelli 1999, Christensen *et al*. 2003, Hartsein & Rowden 2004, Callier *et al*. 2007); polychaetes and crustaceans (Mattsson & Lindon 1983); and polychaetes and gastropods (Stenton-Dozey *et al*. 1999), whereas those sites outside of farms can be dominated by ophiuroids (Hartsein & Rowden 2004), chaetognaths, holothurians and crustaceans (Stenton-Dozey *et al*. 1999), polychaetes, bivalves, crustaceans (Cummacea) and ophiuroids (Christensen *et al*. 2003), or bivalves, echinoderms (ophiuroids and echinoids) and crustaceans (Kaspar *et al*. 1985, Mattsson & Lindon 1983). In this current study a trend is apparent also, but only for those taxa occurring along the northern side of the farm (Transect 1), within which sediments beneath the farm are characterised by greater abundances of polychaetes and crustaceans (Malacostraca), and sediments outside the farm are characterised by bivalves, ostracods and polychaetes (Table 32). Sediments inside and outside the farm along Transect 2 were characterised by polychaetes, bivalves and ostracods at similar abundances, and those along Transect 3 were characterised by polychaetes, bivalves, crustaceans (Malacostraca) and gastropods, again at similar abundances (Table 33).

Christensen *et al*. (2003) sampled three sites around one farm in Marlborough Sounds, two within a mussel farm in Beatrix Bay and one 250 m outside of it. They reported distinct macro-invertebrate communities within farm-affected stations compared to control sites. The dissimilarity was based on greater abundance of three polychaete taxa, all purported to be deposit feeders: *Dorvillea incerta*, *Capitella capitata* and *Prionospio* spp. However, of these only *C. capitata* is a true deposit feeder; *Prionospio* spp. likely catches food particles in suspension (Worsaae 2003), and polychaetes of the genus *Dorvillea* are

usually, if not always carnivores (Day 1967, Fauchald & Jumars 1979). In terms of diversity, Christensen *et al*. (2003) reported less taxa within two farm sites (31 and 26 taxa) than at a control site (41 taxa), but with so few samples taken (15 in total, Table 42) such minor differences in richness mean little.

The results of Hartstein & Rowden (2004) are difficult to compare with those reported herein for off eastern Waiheke Island. First and foremost, for two of the surveyed farms sea-bed depths differed from control site depths. For two mussel farms for which deeper control sites were selected, Harstein & Rowden (*loc. cit.*) reported significantly different species assemblages between sites, with lower species richness beneath farms than at control sites (however the statistical significance of richness difference was not evaluated); for the one farm at which control sites were established at a comparable depth to the farm site, no significant difference in species assemblages was apparent. Harstein & Rowden (*loc. cit.*) attribute the differences in effects on species assemblages between the three farms to hydrodynamic factors.

Off eastern Waiheke Island, during May and August, higher species richness (d), abundance (N), Shannon's index (H') and Simpson's index (1-λ') were recorded beneath the farm than during February. Diversity was similar outside the farm in February and May, except evenness (J') and Simpson index (1-λ'), but during August species richness (d), evenness (J'), Shannon's index (H') and Simpson's index(1-λ') were higher outside the farm. Dewas (2008) also reported highest abundance (N) and richness (d) in shell gravels during the winter months for at least one of her sites off Otata Island, and her summer-collected samples consistently had the lowest abundance (N) and richness (d) values of all. To the contrary, de Jong (1994) recorded overall abundance to be lowest in his winter (June) sampling.

The life histories of the greatest majority of species recorded off eastern Waiheke Island are very poorly known. Pronounced changes in community structure over time, at the same location, need not represent recruitment and subsequent mortality of ephemeral taxa (having completed their life histories

between survey periods), but could equally be attributable to establishment of new recruits into the sediments, followed by mortality, whether this be because of inhospitable or inappropriate environments, predation or other forms of natural mortality, or even migration from the region.

Although de Jong (1994) assigned his species to trophic guilds, and then appraised the distributions of deposit, suspension, filter and carnivorous species relative to a mussel farm, such designation to guilds is not attempted in this current study. Assigning each of the 359 taxa recorded throughout this region, during all surveys, to trophic guilds simply is not possible, given the general lack of understanding of the diets of the great majority of species.

The biological footprint of the mussel farm appears to extend a maximum of 20 m from the physical boundary of the farm, at least during the three seasons over which this was examined. Although side-scan sonar and drop camera revealed the structural footprint of the mussel farm (formation of mussel clumps in the sea bed) extended no further than 30 m from the farm boundary, sedimentary analysis did not reveal any significant difference in grain-size structure along Transect 1; no grain-size footprint is apparent. As intimated earlier in the discussion on sensitive species throughout this region, perhaps the most appropriate indicator to use for rapid assessment of the extent of biological impact on sea-bed communities attributable to the farm off eastern Waiheke Island is the spatial distribution of mussel clumps on the sea bed, as infaunal assemblages during each survey (February, May and August) all have changed well before the relatively narrow *Perna* footprint (< 30 metres) of the farm has ended.

To date no other survey has conclusively demonstrated a significant increase in abundance and richness of taxa beneath a mussel farm in New Zealand, although Giles *et al.* (2006) alluded to this but lacked the data for statistical corroboration. The most species rich and abundant sites throughout the eastern Waiheke Island region occur between Waiheke Island and Pakatoa Island, and

between Rotoroa and Ponui Islands, within gravels, and beneath and in the immediate vicinity of the southern portion of the current mussel farm.

Although the farm is reported to significantly affect sea-bed communities, this effect is manifested in enhanced species richness and abundance beneath it. The proportional occurrences of any regionally *very rare* to *uncommon* species are not unduly changed, and the sea bed is not dominated by elevated abundances and numbers of opportunistic species. These effects on species richness and abundance extend to a maximum of approximately 20 metres from the northern side of the existing mussel farm during any surveyed season.

No universally accepted opportunistic or sensitive species are of much use for rapid assessment of the spatial extent of mariculture-sourced impact on sea-bed communities off eastern Waiheke Island. Several taxa are proposed that could be referred to as mariculture opportunistic and mariculture sensitive species for this region.

Although subtidal muds in the eastern Waiheke Island region appear more species rich and host greater abundances of species than any thus-far reported muds throughout the outer Waitemata Harbour and Hauraki Gulf, for which data are available, an increase in size of the mussel farm by 10 ha in a northerly direction is not likely to have any deleterious effect on the viability, distribution or abundance of any soft-sediment dwelling taxon in this region.

Recommendations

Monographic, systematic reviews of Polychaeta and small-bodied Crustacea (eg. Amphipoda) are urgently required to facilitate identification of benthic invertebrates in this region. Few polychaete, amphipod, tanaid or ostracod taxa could be reliably identified for the sake of this diversity appraisal.

As no baseline study was undertaken prior to establishing this mussel farm off eastern Waiheke Island, it is difficult to identify a proper control site to determine the effect of this activity in the region. New applications for mussel farm development or expansion should be preceded by baseline benthic surveys within and adjacent to the area to enable a greater appreciation of the actual biological effects of this activity. Larger-scale surveys should be undertaken to characaterise sea-bed species assemblages in potentially affected regions.

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