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CAWTHRON

An evaluation of incursion response tools for invasive species: a case study of *Didemnum vexillum* in the Marlborough Sounds

Prepared for

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An evaluation of incursion response tools for invasive species: a case study of *Didemnum vexillum* in the Marlborough Sounds

Prepared for

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by

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Cover Photo: Divers preparing to wrap wharf piles with polyethylene plastic to eliminate *Didemnum vexillum* on infected wharf piles in Shakespeare Bay, Picton.

EXECUTIVE SUMMARY

On 18 December 2001, Cawthron discovered a colonial sea squirt, *Didemnum vexillum* behaving in an invasive manner on the bottom of the *Steel Mariner* barge moored west of Kaipupu Point, Picton in the Marlborough Sounds. Despite the species presently being considered a native species of New Zealand, it poses a potential threat to the New Zealand Greenshell™ mussel industry because the species appears to have a preference for artificial structures and is capable of smothering mussels.

Given the potential risk that the species would spread to mussel farming areas, Port Marlborough New Zealand Limited (PMNZL) and the Marlborough District Council (MDC) funded an attempted eradication of *Didemnum* in Shakespeare Bay. The attempted eradication required the treatment of four different substrates: 1) Waimahara Wharf piles, 2) the seabed beneath the *Steel Mariner*, 3) the seabed beneath Waimahara Wharf, and 4) moorings. In parallel with the attempted eradication programme, the Ministry of Fisheries (now Biosecurity New Zealand-BNZ) contracted Cawthron to design, test and document the efficacy of the novel treatment methods used to eliminate both *Didemnum* and other organisms on the four infected substrates. Hence the primary purpose of this report was to obtain a level of knowledge that was sufficient to provide BNZ with interim guidance on the efficacy of these methods, and to identify any further investigations needed to refine the various approaches and examine their wider efficacy against other actual or potential pests. A summary of the findings are as follows:

Waimahara Wharf piles

Divers used a combination of black polyethylene plastic wrapping and poly-vinyl-chloride sellotape to wrap 178 wharf piles costing approximately $30,000. The plastic wrappings remained on the piles for 12 months. The wharf pile wrapping method was clearly capable of eliminating both *Didemnum* and other non-target species from wharf piles, provided the wrappings are applied correctly and remain sealed. This method has the potential to cost-effectively treat a variety of artificial structures that cannot be removed from the water.

Seabed beneath the Steel Mariner

Uncontaminated dredge spoil was used to dump on top of *Didemnum* colonies on the seabed underneath the *Steel Mariner,* which occurred prior to the commencement of this contract. This method was 100% effective and cost approximately $6,600. Therefore an experiment was set up to determine the efficacy of using dredge spoil to eliminate soft sediment communities. The results of the study suggest that dredge spoil does have an effect on soft sediment communities within the

first three months of treatment, although recovery was evident within six months. However, the dredge spoil did not eliminate all species during this experiment.

Seabed beneath Waimahara Wharf

Several treatment methods were trialled on *Didemnum* colonies including the application of dredge spoil, lime, concrete powder, hot water blasting, and a petrogen torch. None of these were cost-effective, therefore Bidum A24 grade geotexile filter fabric was used to smother the 200 x 50 m infected seabed area beneath Waimahara Wharf, costing approximately $30,000. The technique failed to achieve a successful eradication of *Didemnum* or eliminate all species on this occasion. However, the efficacy of the technique may have been different if divers spent more time sealing the filter fabric to the seabed and wharf piles. If these limitations can be addressed, filter fabric has the potential to be a relatively cost-effective eradication tool in other environments and circumstances.

Moorings

On land, water-blasting and 48 hours desiccation was used to treat seven moorings infected with *Didemnum,* costing approximately $5,500. The removal and on-land treatment of moorings using 2,000 psi water-blasting and 48 hours of desiccation is capable of eliminating both *Didemnum* and other non-target species.

Recommendations

Based on this study, future attempted eradication programmes in the marine environment should consider the following:

1. Wherever possible infected substrates should be removed and treated on land.
2. High pressure water blasting (i.e., >2000 psi) and desiccation (i.e., > 2 days) should be used if treatment time is not limited.
3. If treatment time is limited, accelerators such as acetic acid (i.e., 1-4%) could be used to treat substrates within 10 minutes (e.g., refer to Coutts and Forrest 2005).
4. Where infected substrates cannot be removed and treated on land, the following *in situ* treatments methods could be used to treat various substrates:
    - Dumping of uncontaminated dredge spoil (i.e., > 100 mm coverage) is capable of treating soft sediment environments, particularly on stable seabed's in protected waters.
    - Filter fabric could be applied for up to three months to treat soft sediment and rocky shores substrates in both protected and high energy areas.
    - Plastic wrapping is capable of treating wharf piles within one week.

5. Further experiments should be undertaken (in the absence of an attempted eradication programme) to develop and test the efficacy of these methods. Where possible attempts should be made to determine the treatment time required to kill various target organisms on different substrates. Furthermore, the identification of reliable indicators for determining the efficacy of the different methods against different species would also be extremely useful (e.g., water quality within encapsulated wrappings).

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1. INTRODUCTION

1.1 Background

In May 2000, New Zealand's newest port, Waimahara Wharf in Shakespeare Bay near Picton, South Island, was opened for trading (Figure 1). Waimahara Wharf is the country's deepest export facility (16 m depth at low tide) for forestry and other bulk products. Scientists at Cawthron identified Shakespeare Bay as a potential source for the arrival of marine pests and subsequently developed a surveillance programme as part of research funded by the New Zealand Foundation for Research, Science and Technology. This involved undertaking a series of baseline surveys of Shakespeare Bay prior to its opening, followed by targeted bi-annual surveys between 2000-2003.

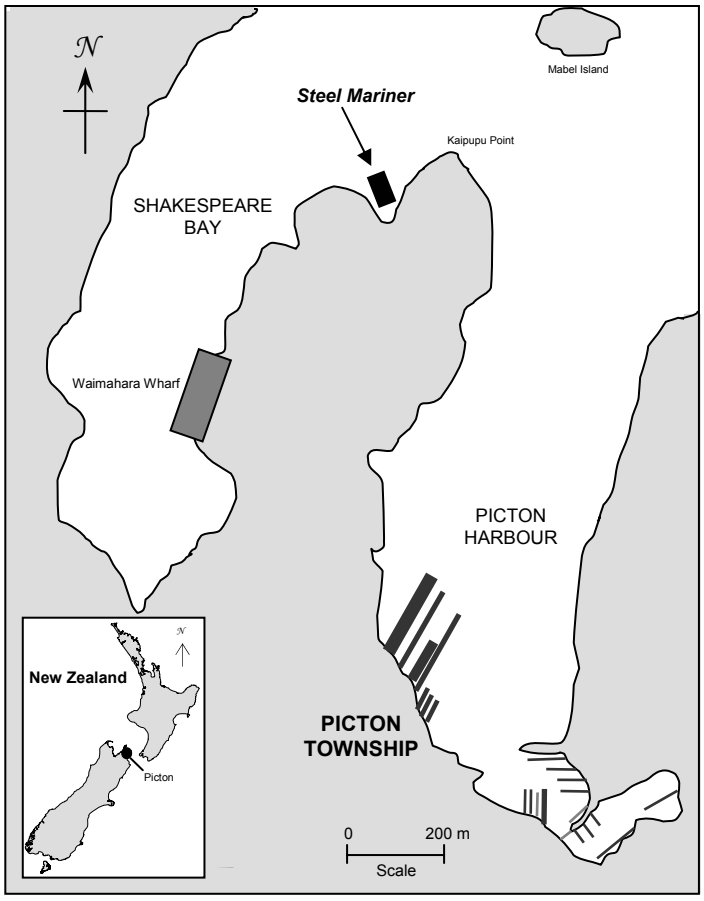

Figure 1. Location of Waimahara Wharf and the *Steel Mariner* barge near Picton, Marlborough Sounds.

During one of Cawthron's routine bi-annual surveys on 18 December 2001, divers noticed a heavily fouled barge, the *Steel Mariner*, moored west of Kaipupu Point (Figure 1). Upon inspection, divers observed a colonial sea squirt, *Didemnum vexillum* (hereafter referred to as *Didemnum*) smothering the bottom of the barge (~1,396 kg wet biomass) and the seabed immediately below (Coutts 2002).

Didemnum is presently considered to be a native species of New Zealand (Kott 2002), and is only known to exit in Tauranga in the North Island where the *Steel Mariner* had formally visited (Coutts 2002). The species presence in the Marlborough Sounds now poses a potential threat to the New Zealand Greenshell™ mussel industry because the species appears to have a preference for artificial structures and is capable of smothering mussels (Coutts 2002; Sinner and Coutts 2003; Coutts and Sinner 2004; Coutts in prep). Therefore, Port Marlborough New Zealand Limited (PMNZL) and the Marlborough District Council (MDC) chose to investigate the potential to manage the spread of the species.

Cawthron was contracted by PMNZL and MDC to undertake 1) a thorough delimitation survey of *Didemnum* throughout the Queen Charlotte Sound, and 2) a benefit-cost analysis with recommendations for managing the *Didemnum* infestation (Sinner and Coutts 2003). The survey revealed that the species was not widespread and was found infecting the following substrates in Shakespeare Bay:

- Waimahara Wharf piles,
- Seabed beneath the *Steel Mariner*,
- Seabed beneath Waimahara Wharf, and
- Infected moorings.

On the basis of the benefit-cost analysis, PMNZL and MDC chose to fund an attempted eradication of *Didemnum* in Shakespeare Bay given the potential risk that the species would spread to mussel farming areas (Sinner and Coutts 2003). A lack of proven eradication tools necessitated the rapid development and application of methods to treat the four areas described above. Preliminary trials suggested that wherever possible infected substrates or structures should be removed and treated using high pressure water blasting, otherwise a smothering or suffocation method should be adopted.

1.2 Scope and purpose of this report

The Ministry of Fisheries[1] viewed the attempted eradication of *Didemnum* as an opportunity to learn more about the development, application and efficacy of the novel treatment methods to eliminate both *Didemnum* and other organisms on the four infected substrates. Hence, in parallel with the PMNZL and MDC work Biosecurity New Zealand (BNZ) contracted Cawthron to address the following four specific objectives:

- To design, test and document the efficacy of wrapping vertical wharf pile communities in polyethylene plastic to eliminate all species.
- To design, test and document the efficacy of using dredge spoil to "cap" soft sediment communities to eliminate all species.
- To design, test and document the efficacy of using dredge spoil to "cap" rocky shore communities to eliminate all species.
- To design, test and document the efficacy of using on-land water-blasting and 48 hours desiccation for treating moorings to eliminate all species.

This report presents the methods and findings surrounding the four stated objectives. However, it is important to acknowledge that the investigations described in this report revolved around the attempted eradication of *Didemnum* and in some cases did not allow for controls to measure the true effect of some of the treatment methods. The primary purpose was to obtain a level of knowledge that was sufficient to provide BNZ with interim guidance on the efficacy of these methods, and to identify any further investigations needed to refine the various approaches and examine their wider efficacy against other actual or potential pests.

[1] Subsequent to funding approved for this project, marine biosecurity responsibilities were transferred from the Ministry of Fisheries to Biosecurity New Zealand, a division of the Ministry of Agriculture and Forestry.

2. OBJECTIVE 1: EFFICACY OF PLASTIC PILE WRAPPING ON FOULING COMMUNITIES

2.1 Background

A delimitation survey of Shakespeare Bay on 15 July 2003 revealed that 177 of the available 178 Waimahara Wharf piles were infected with *Didemnum*. The challenge was to design, test and implement an effective treatment measure for the piles prior to the start of the reproductive season of *Didemnum* in September. A desktop review identified a study by Cookson (1996) describing a plastic wrapping technique which had been used to cover timber pylons in an attempt to kill marine borers.

The theory behind the wrapping method is to deprive organisms of life sustaining light, food and dissolved oxygen. An anoxic environment is eventually produced which becomes lethal to all organisms. Based on the potential efficacy of this type of approach for wharf piles, Cawthron and Commercial Diving Consultants Limited, Picton (CDC) undertook *in situ* trials on concrete and metal RSJ piles at Waimahara Wharf piles using a combination of black polyethylene plastic wrapping and poly-vinyl-chloride (PVC) sellotape.

Because the trials were a success, the same materials and methods were used to treat all 178 Waimahara Wharf piles. In tandem with this work, BNZ contracted Cawthron to design, test and document:

- The efficacy of wrapping vertical wharf pile communities in polyethylene plastic to eliminate all species.
- The recruitment of marine organisms onto the outside of the polyethylene wrappings after three and six months.
- The recruitment of marine organisms onto treated wharf piles, three and six months after the wrappings were removed.

2.2 Methods

2.2.1 Determining the efficacy of plastic wharf pile wrapping

Pre-wrapping assessment

A pre-wrapping assessment of the types and abundance of organisms present on the wharf piles prior to treatment was undertaken on 10 September 2003. This involved randomly selecting 28 piles and sampling locations on each pile that were representative of various strata present amongst the 178 piles. Strata included pile type (round concrete or metal H shaped), location (north or south), light level (illuminated or shaded) depth (0, 4, 12, 16 m) and different strata amongst metal H shaped piles (inside or outside) (Appendix 1). Stainless steel strapping was used to define the boundary of the 28 sampling locations on each of the piles and an underwater camera used to photograph each of these areas (205 x 320 mm). No samples were taken.

Application of plastic wharf piles wrappings

The 178 wharf piles were wrapped with 50 µm x 1 m black polyethylene plastic in rolls 100 m long, using a custom-made plastic wrapping dispenser (Appendix 2). Divers commenced wrapping piles at the bottom and slowly worked towards the surface in a circular motion, aiming to achieve a wrapping overlap of approximately 400 mm on each successive wrap (Figure 2). A second diver followed the first applying 0.48 x 30 m PVC sellotape using a custom-made dispenser to seal the overlap or joins of the plastic wrappings (Figure 2 and Appendix 2). This resulted in the entire wharf pile being tightly encapsulated in plastic from the bottom to above the waterline. This also enabled large volumes of seawater to be displaced to hopefully speed the development of the anoxic environment within the wrappings. Because this was an attempted eradication, no piles remained unwrapped, hence no formal controls were available.

Removal of plastic wharf pile wrappings

The removal of the 178 plastic wharf pile wrappings commenced on 27 September 2004. Divers made a single longitudinal cut from top to bottom of the plastic wrappings, which usually resulted in a single piece of plastic. Divers cleared the wrapping from the wharf piles and then assisted topside-staff transfer all the wrappings and associated fouling into a small boat. All wrappings were contained within 1 m^2 bags and transferred to Waimahara Wharf via a crane. Bags were left to drain for five days and the average weight of ten bags used to estimate the weight of all plastic and associated fouling removed from the wharf piles. All collected material was disposed of at the local refuse station.

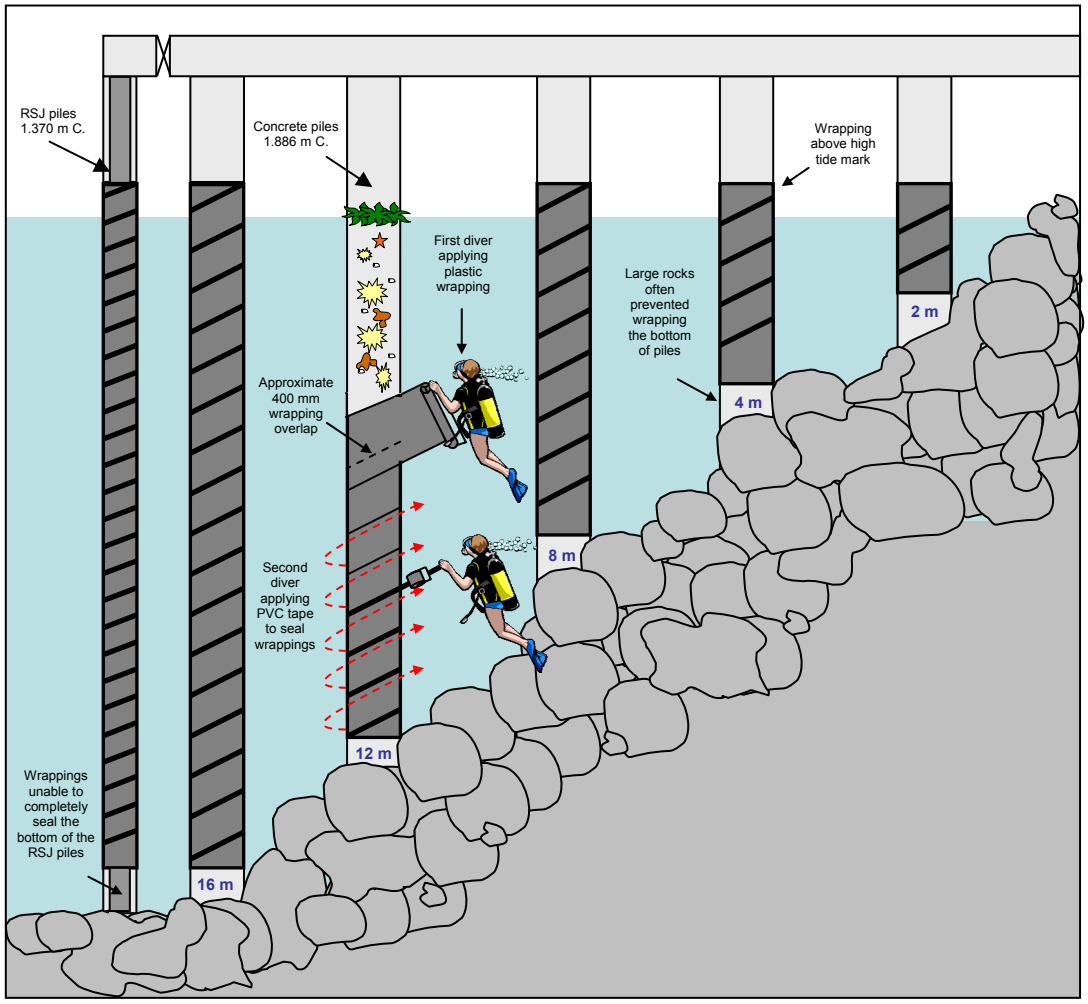

Figure 2. A schematic of the method used to wrap and seal the Waimahara Wharf piles with polyethylene plastic.

Post-wrapping assessment

The post-wrapping assessment was undertaken on 5 October 2004. Photographs were taken of the permanent quadrats as defined by the stainless steel straps. A putty scraper was used to remove and transfer all marine organisms present into pre-labelled plastic bags to assist with determining mortality.

2.2.2 Recruitment of species onto plastic wrappings and treated wharf piles

Baseline assessment

On 8 September 2003, the same 28 wharf piles but different randomly selected sampling locations were used to undertake a baseline assessment to determine the distribution, abundance and frequency of species present amongst wharf piles prior to wrapping with plastic. An underwater

camera was used to photograph the 28 quadrats and a putty scraper used to remove and transfer all organisms within each quadrat to separate pre-labelled plastic bags.

Three and six month assessments - recruitment onto plastic wrappings

The three and six month assessment of recruitment of species onto the plastic wharf pile wrappings was undertaken on 8 December 2003 and 11 March 2004 respectively. Twenty-eight randomly selected photographs were taken amongst the 28 wharf piles. Divers used a knife to remove the plastic wrapping and associated biofouling within each of the 28 photographed areas. All samples were placed inside pre-labelled containers and preserved in 5% glyoxal/25% seawater/70% ethanol mix for later identification.

Three and six month assessments - recruitment onto treated wharf piles

The same methods used above were adopted to undertake the three and six month assessment of fresh recruitment of species onto wharf piles (after the removal of the plastic wrappings) on 6 January 2005 and 11 March 2005 respectively.

2.2.3 Sample processing and data analysis

All samples were processed at Cawthron's marine laboratory in Nelson. Samples from individual quadrat scrapings were processed separately by flushing them with freshwater through a 500 µm sieve. A dissecting microscope and various taxonomic references were used to identify all organisms to the lowest taxonomic level possible. Wherever necessary, unidentified specimens were sent to specialised taxonomists for further identification. A voucher collection was also developed for future reference.

Species identified within samples assisted with their identification within photographs. Photographs were used to generate percentage cover estimates for each species or taxa[2] using the random dot method (Meese and Tomich 1992). This consisted of identifying and recording the species or taxa present beneath each of 100 randomly generated points within each photograph. Species too small to be identified from photographs, but were present in samples had there abundances determined via individual counts. All organisms identified to species level were classified into one of three categories (i.e., native, introduced or unknown) according to their place of origin relative to New Zealand waters using Ralph (1953 and 1957), Gordon and Mawatari 1992, Adams (1994), Cranfield et al. (1998) and Vervoort and Watson (2003). For example, a "native" species refers to an

[2] The term "taxa" refers to groups of morphologically similar organisms that cannot be assigned into separate species.

organism that originates from New Zealand waters. Alternatively, an "introduced" species refers to a foreign organism that has been introduced to New Zealand waters where it did not formally exist. Organisms that were unable to be classified to species level (i.e., genus or higher) were identified as having an "unknown" origin. All organisms were classified as either sessile (i.e., permanently attached to the substrate) or mobile (i.e., capable of movement).

The efficacy of plastic wharf pile wrappings was assessed according to the in species richness, percent cover and frequency of occurrence amongst the 28 wharf piles between the pre-wrapping and post-wrapping assessments. PRIMER v5 software package (Plymouth routines in multivariate ecological research) was used to generate a species-area curve to evaluate whether sampling across the 28 piles had representatively captured the species or taxa present. PRIMER was also used to explore similarities in species composition between the various assessment periods (i.e., baseline, three and six month assessments for recruitment of species onto plastic and treated piles) using cluster analysis and multi-dimensional scaling (MDS) techniques on forth-root transformed percent cover data to produce ordination plots. Similarities were calculated using the Bray-Curtis coefficient.

2.3 Results

2.3.1 Application and removal of plastic wharf pile wrappings

It took four divers five days (i.e., 8 to 12 September 2003) to wrap the 178 Waimahara Wharf piles in plastic. Wharf piles ranged from 2 to 16 m deep and took an average of 10 minutes each to wrap. A total of 70 roles of polyethylene plastic and ~ 233 roles of PVC tape were used to wrap an estimated submerged wharf pile area of 3,400 m^2 (Appendix 3). The total cost of wrapping the 178 piles was approximately $30,000 comprising $3,000 for materials and $27,000 for labour and equipment, equating to a cost of ~ $15/m.

The fouling on the wharf piles consisted of some sharp calcareous species such as barnacles (*Elminius modestus*), Japanese oysters (*Crassostrea gigas*) and tubeworms (*Galeolaria hystrix*) which on occasions punctured the polyethylene wrappings. However, a second wrap solved this problem. Despite attempts to completely wrap concrete wharf piles to the seabed, large boulders used to create the foundations of the wharf, and the slope of the seabed, often prevented this from occurring. Furthermore, the plastic wrappings were unable to completely seal the "H" shaped metal piles, hence allowing a partial exchange of water (Figure 2).

A single longitudinal cut from the top to the bottom of the plastic wrappings usually resulted in a single sheet of plastic held together by the PVC sellotape. This made the removal of the wrappings extremely efficient. However, occasionally some of the wrappings separated due to the excessive weight of fouling, or because they were torn on dead *Galeolaria hystrix* tubes. In total, an estimated 7,106 kg of plastic and associated fouling was successfully collected from the 178 wharf piles. Of this ~ 90% was *Didemnum* some of which (~ 15%) was lost during the removal process.

2.3.2 Sampling effectiveness and patterns of fouling amongst wharf piles

Sixty six species were detected during the baseline survey, the highest amongst all assessments. The baseline assessment was dominated by species of molluscs, annelids, crustaceans and chordates (Appendix 4). According to a cumulative species-area curve analysis of the baseline data, 28 quadrats appeared to representatively sample the diversity of species present amongst the different strata of the Waimahara Wharf piles (Appendix 5). Multivariate analyses revealed that there were similarities in species composition amongst the 28 wharf piles, although species composition was most similar amongst wharf pile type (i.e., concrete or metal).

2.3.3 The efficacy of plastic wrappings to eliminate Didemnum

Generally the plastic wharf pile wrapping technique significantly reduced the occurrence of *Didemnum* on wharf piles, but failed to completely eliminate it on this occasion. Although the plastic wrappings remained on the piles for approximately 12 months (12 September 2003 to 27 September 2004), informal inspections underneath the wrappings revealed that *Didemnum* had died after only four days.

Prior to wrapping, *Didemnum* was detected within 24 of the 28 (86%) permanent quadrats with an average cover of 35% (Appendices 4 and 6). However, inspection of the same quadrats after 12 months revealed that *Didemnum* was only present within three of the quadrats with an average cover of ~3%. *Didemnum* occurred on one concrete and two metal piles where the plastic wrappings had either become loose or been damaged as a result of abrasion by ships (Table 1). However, it is not known whether the species survived the wrapping treatment or recruited onto the wharf piles after the wrappings became loose or damaged.

2.3.4 The efficacy of plastic wrappings to eliminate non-target species

Generally the plastic wrapping method was also effective at reducing the occurrence of non-target species on the 28 wharf piles surveyed (Table 1). As was the case for *Didemnum*, however, the

method failed to eliminate all species because of loose or damaged wrappings. While it is acknowledged that no controls were available during these experiments, the wrappings reduced the number of species present of piles from 31 to only eight species after treatment (Table 1 and Appendix 5).

Some of the most frequently occurring and abundant species encountered prior to wrapping were the sponge *Crella incrustans*, unidentified hydrozoans, *Galeolaria hystrix* and *Watersipora subtorquata* (Appendices 4 and 6). However, the post-wrapping assessment found *Cnemidocarpa bicornuta* was the most frequently occurring species present on only 2 piles and *Pyura rugata* was the most abundant (i.e., ~ 3%) (Appendices 4 and 6).

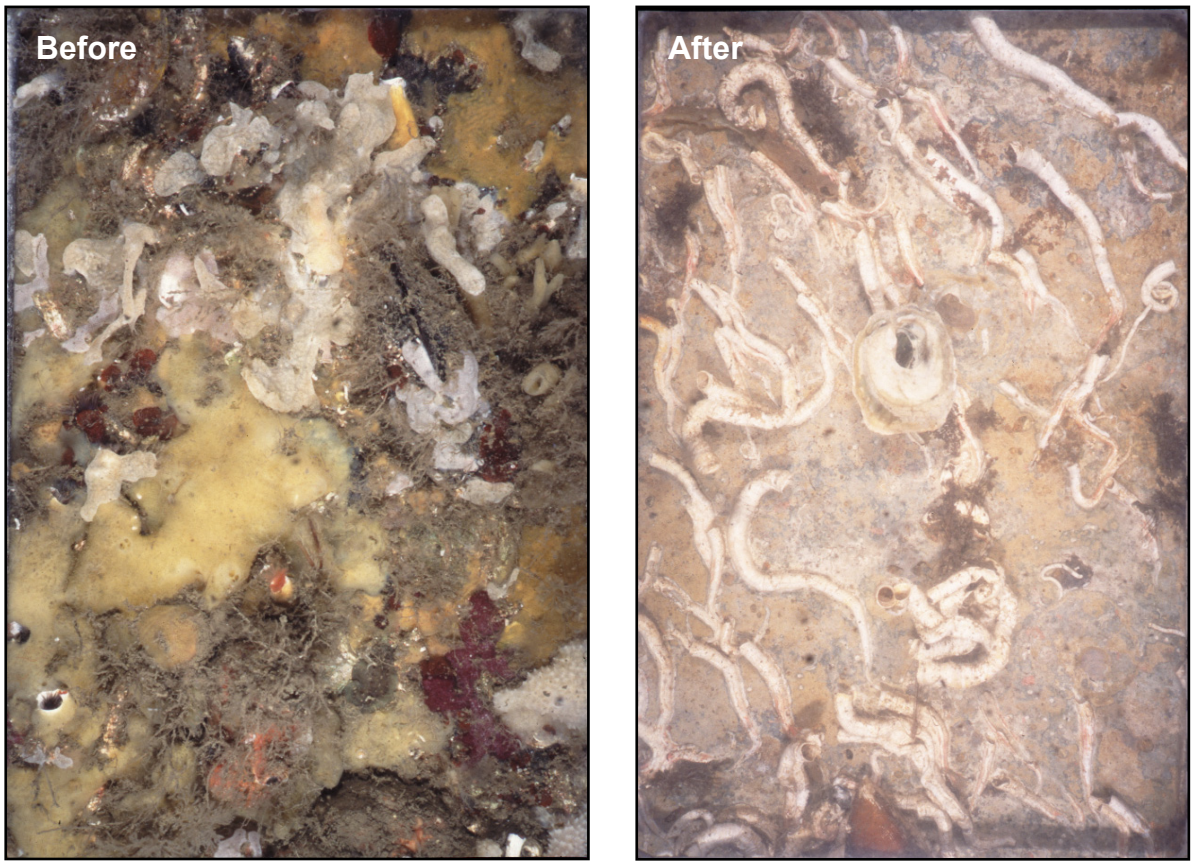

Figure 3. An example of a before and after photograph of the effects of wrapping Waimahara Wharf piles with black polyethylene plastic.

Table 1. A summary of the occurrence of eight species recorded on eight wharf piles during both the pre-wrapping and post-wrapping assessments and the likely explanation and their occurrence. Abundance of species has been determined via † = counts or * percentage cover.

Pile No.	Pile strata	Species	Pre-wrapping abundance	Post-wrapping abundance	Likely explanation	Likely cause
1	Concrete, North, Light, 4 m, Random	*Cnemidocarpa vicomuata**	0	1	Recruitment	Loose wrapping
9	Metal RSJ, North, Light, 4 m, Inside	Nemertea †	0	1	Recruitment	Damaged wrapping - shipping
12	Metal RSJ, North, Light, 12 m, Outside	*Cnemidocarpa bicornuta**	0	1	Recruitment	Damaged wrapping - shipping
19	Concrete, South, Light, 0 m, Random	*Didemnum vexillum**	6	42	Survivorship	Loose wrapping
20	Concrete, South, Light, 16 m, Random	*Cnemidocarpa bicornuta**	0	1	Recruitment	Loose wrapping
21	Metal RSJ, North, Light, 0 m, Inside	*Watersipora subtorquata**	0	1	Recruitment	Damaged wrapping - shipping
21	"	*Didemnum vexillum**	30	33	Survivorship	Damaged wrapping - shipping
22	Metal RSJ, North, Light, 0 m, Outside	*Cnemidocarpa bicornuta**	0	2	Recruitment	Damaged wrapping - shipping
22	"	*Didemnum vexillum**	85	4	Either	Damaged wrapping - shipping
22	"	*Pyura rugata**	5	7	Survivorship	Damaged wrapping - shipping
23	Metal RSJ, North, Light, 16 m, Inside	*Didemnum* sp. No. 1*	0	1	Recruitment	Loose wrapping
23	"	*Didemnum* sp. No. 3*	0	4	Recruitment	Loose wrapping

2.3.5 Recruitment of Didemnum onto plastic wrappings and treated piles

Prior to wrapping *Didemnum* was recorded on 26 (93%) of the 28 wharf piles with an average cover of 38% (Table 2 and Appendix 4). However, the species had only infected one of the 28 plastic wrappings after three months of treatment. By contrast, after six months, *Didemnum* was recorded on 16 (57%) of the 28 wrappings, at an average cover of 10%. Three months after the wrappings were removed the species had infected 11 (39%) of the 28 treated wharf piles with an average cover of 19%. However, after six months, *Didemnum* had infected 20 (71%) of the 28 wharf with an average cover of 29% nearing its original dominance prior to treatment (Table 2).

Table 2. Summary of the occurrence and average percent cover of *Didemnum* on wharf piles during the various assessment periods.

Assessment period	Baseline	Plastic wrappings		Treated piles	
		Three months	Six months	Three months	Six months
Date	8 September 2003	8 December 2003	11 March 2004	6 January 2005	11 March 2005
Occurrence amongst 28 piles	26	1	16	11	20
Average percent cover ± se	35.14±6.52	0.11±0.11	10.39±3.09	18.68±6.32	29.29±6.21

2.3.6 Recruitment of non-target species onto plastic wrappings and treated piles

Species richness

Thirty nine species, including 19 newly recorded species (i.e., absent during the baseline assessment) recruited onto the plastic wrappings within just three months. Of particular interest was dominance of 14 different species of bryozoans (Appendices 4 and 6). After six months, 62 species, including 22 new species had recruited onto the plastic wrappings, again dominated by 21 different species of bryozoans (Figure 4; and Appendix 4).

Sixty five species, including 16 newly recorded species recruited onto the treated wharf piles after just three months of the wrappings being removed. Species of molluscs, bryozoans and annelids were clearly the most represented during this period (Figure 4 and Appendix 4). However, the number of species present on wharf piles after six months was slightly less (i.e., 63), including 11 new species with molluscs, bryozoans and annelids continuing to dominate.

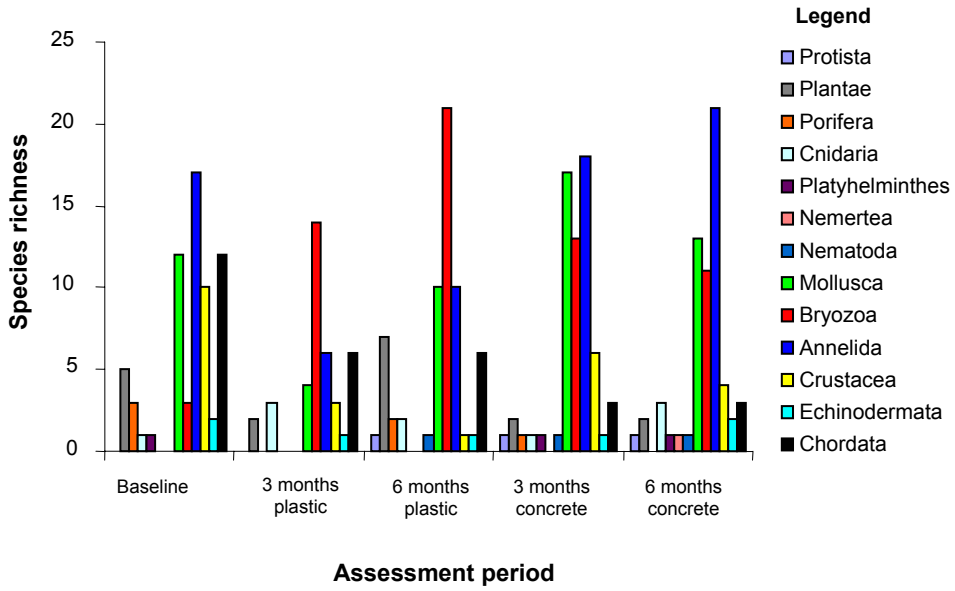

Figure 4. Species richness within each taxonomic group during various assessment periods.

Average abundance

The algae *Cutleria multifida,* hydroid *Obelia longissima* and juvenile mussels were the most abundant species to establish on the plastic wrappings after three months with average abundances of 18%, 19% and 71 individuals respectively (Appendix 6). Compositional patterns on the plastic wrappings after six months changed considerably with juvenile mussels (18 individuals) and Foraminifera (44 individuals) clearly being the most dominant (Appendix 6). The abundances of species established on treated piles after three and six month were relatively low compared to the plastic wrappings. However, the establishment of bivalve and annelids species on the treated wharf piles in low abundances was noteworthy (Appendix 6).

Species composition

Multivariate analyses of the species composition present during the various assessments revealed two main groupings (Figure 5). The composition of the communities that established on the outside of the plastic wrappings after three and six months was more similar to each other than the community present during the baseline or on the treated piles. Similarly the community structure present on the three and six month treated piles were more similar to each other than the other assessments, although the community structure present on the treated piles resembled the baseline community slightly more closely than the communities present on the plastic wrappings (Figure 5).

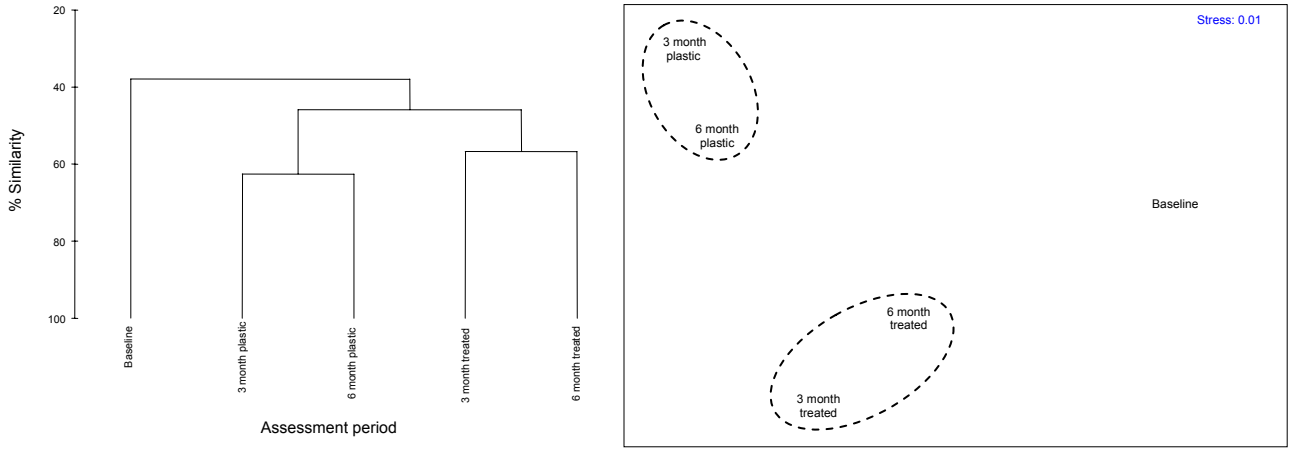

Figure 5. Dendogram and MDS plot showing the similarity in species composition between the baseline, three and six month assessment periods for the recruitment of species onto plastic wharf pile wrappings and treated wharf piles.

2.4 Discussion

2.4.1 Efficacy of plastic wharf pile wrappings method to eliminate all species

The wharf pile wrapping method was completely effective at eliminating all species except where the plastic wrappings either become loose or were damaged by ships. Therefore, the technique is clearly capable of eliminating *Didemnum* and other non-target species from wharf piles provided the wrappings are applied correctly and remain sealed.

The plastic wrapping were initially going to be removed after four weeks. However the delayed treatment of *Didemnum* on the rocky substrate underneath Waimahara Wharf allowed the species to spawn. Therefore the wrappings remained on the wharf piles for 12 months to protect them from being re-infected by the larvae. Informal inspections of the wrappings indicated that *Didemnum* had died within four days of treatment. It is not currently known what period of time is required to ensure 100% mortality of both *Didemnum* and other non-target species. However, subsequent to this study, work by Coutts and Forrest (2005) found that plastic pile wrappings causing 100% mortality of the solitary ascidian *Styela clava* within 3-6 days and are consistent with observations in the present study.

There would be merit in undertaking further plastic wharf pile wrapping experiments to determine the treatment times necessary to achieve complete mortality of various target or surrogate taxa at in different water temperatures and levels of biomass. The monitoring of water quality (e.g., dissolved oxygen, pH, total sulphide, nitrite and total ammonia) within the wrappings could also be

undertaken to provide useful indicators for determining critical treatment times for certain target species while minimising the collateral damage on other species (refer to Coutts and Forrest 2005 for example).

2.4.2 Recruitment of species onto plastic wrappings and treated wharf piles

The application of the plastic wrappings and their removal produced relatively sterile substrates that are vulnerable to re-invasion by other suppressed invasive species. This hypothetical phenomenon is known as the Sisyphus effect (i.e., a successful eradication facilitates the invasion of another; Mack and Lonsdale 2002). One of the most noteworthy changes in species composition as a consequence of the treatment was the accumulation of a diverse community of bryozoan species on the plastic wrappings. Such an observation has been documented by other researchers (e.g., Winston 1982; Stevens et al. 1998). However, the attempted eradication did not appear to suffer from a sisyphus effect, but rather failed considering the rapid recovery and aggressive recolonisation of *Didemnum* on the plastic wrappings and treated wharf piles.

2.4.3 Advantages of the plastic wharf pile wrapping method

The rapid development and successful application of the plastic wharf pile wrapping method has contributed significantly to our capability of treating artificial structures *in situ*. Some of the noteworthy advantages of the wrapping method include:

- The method is efficient and user friendly to apply considering it only took divers five days to wrap 178 wharf piles ranging from 2 to 16 m depth.
- Wrapping materials are readily available and inexpensive.
- The method is capable of eliminating a wide variety of species on wharf piles if it is applied correctly.
- The wrappings are capable of providing immunity from re-infection.
- Wrappings are relatively easy to remove.
- If the outside of the plastic wrappings become infected, they can be easy removed along with the target organism, thus reducing future inoculum pressure.
- Despite calcareous species with sharp edges (e.g., oysters and tubeworms) puncturing the plastic wrappings, successive wraps overcame this problem. Furthermore, thicker polyethylene plastic (e.g., 80 or 120 µm) is available if this problem persists during future attempts.

- Although the bottoms of the metal piles could not be completely sealed, species were still eliminated from within these areas as a consequence of the reduced water exchange.
- Wrappings are very durable and capable of remaining *in situ* for at least 12 months.

2.4.4 Limitations of the plastic wharf pile wrapping method

Some limitations of the plastic wrapping method and challenges encountered during the attempted eradication include:

- Large boulders surrounding the bottom of the concrete wharf piles prevented the complete application of wrapping in these areas.
- Plastic wrappings were damaged from abrasion from ships. This may require that divers re-apply wrappings until the treatment is effective.
- The plastic wrapping method will also eliminate non-target species.

2.5 Recommendations

- Future attempted eradications (in the aquatic environment) should always consider the cost-effectiveness of removing and treating infected artificial structures on land.
- Otherwise the plastic wrapping method could be adopted to treat a variety of artificial structures *in situ*, provided water encapsulation occurs for a minimum of six days.
- Further research should be undertaken to determine the treatment times necessary to achieve complete mortality of different species in various water temperatures using different levels of biomass.
- Further research should also monitor water quality (e.g., dissolved oxygen, pH, total sulphide, nitrite and total ammonia) within the wrappings to establish useful indicators for determining critical treatment times for certain target species while minimising the collateral damage on other species (refer to Coutts and Forrest 2005 for example).
- Plastic wrappings are very susceptible to being damaged by vessels or other structures rubbing against them. Therefore, wherever possible, the method should avoid these situations. Alternatively, successive wraps, thicker plastic and buffering materials could be utilised in an attempt to overcome this problem.

3. OBJECTIVE 2: EFFICACY OF DREDGE SPOIL ON SOFT SEDIMENT COMMUNITIES

3.1 Background

A delimitation survey of the Shakespeare Bay area for *Didemnum* was undertaken by Cawthron on 15 July 2003 and revealed the species was well established within a confined area on the seabed surrounding the *Steel Mariner* (Figure 6) (Coutts 2002; Sinner and Coutts 2003). Responding to the infestation, a front-end loader and motorized barge was used dump an average 100 mm (~ 320 m^3) of indigenous dredging material stockpiled at Waimahara Wharf onto the infected seabed on 2 September 2003 (Figure 6). This exercise cost approximately $6,600. The dredge spoil was expected to smother *Didemnum,* preventing the organism from filter-feeding causing it to die.

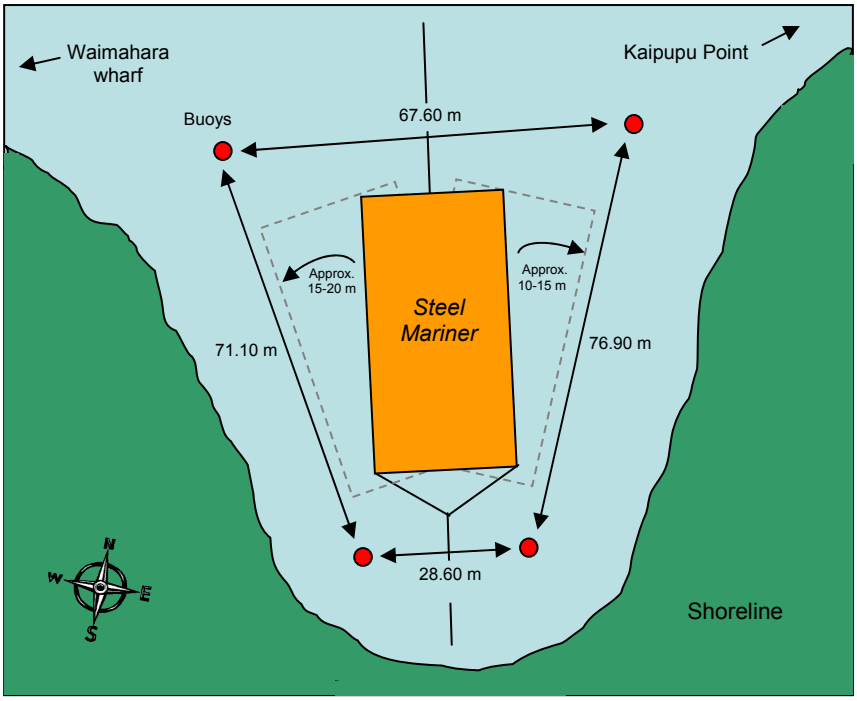

Figure 6. The area of the seabed infected with *Didemnum* surrounding the *Steel Mariner*, west of Kaipupu Point, Picton.

The success of this method was evident from on-going surveys (i.e., 9 December 2003, 14 February, and 24 April 2004), which failed to detect *Didemnum* within the treated seabed area. Given the success of using dredge spoil to smother and kill *Didemnum* on the seabed, BNZ subsequently contracted Cawthron to further examine this method. This involved undertaking the following assessments:

- A baseline assessment to determine the composition of the soft sediment community prior to the application of dredge spoil.
- A three and six month assessment of the efficacy of using dredge spoil to "cap" soft communities to eliminate all species.

3.2 Methods

3.2.1 Experimental design and sample collection

Divers marked out five 2 m^2 plots on the seabed adjacent to the infected seabed area beneath the *Steel Mariner* in ~15 m of water (Figure 7). Each plot was further split into 4 x 1 m^2 sub-plots consisting of a before, control and two separate treatment plots (hereafter referred to as treatment A and treatment B). To establish a baseline, four randomly placed cores (PVC pipe 130 mm Ø) were used to sample the soft sediment community within each of the 5 x 1 m^2 before plots on 31 October 2003.

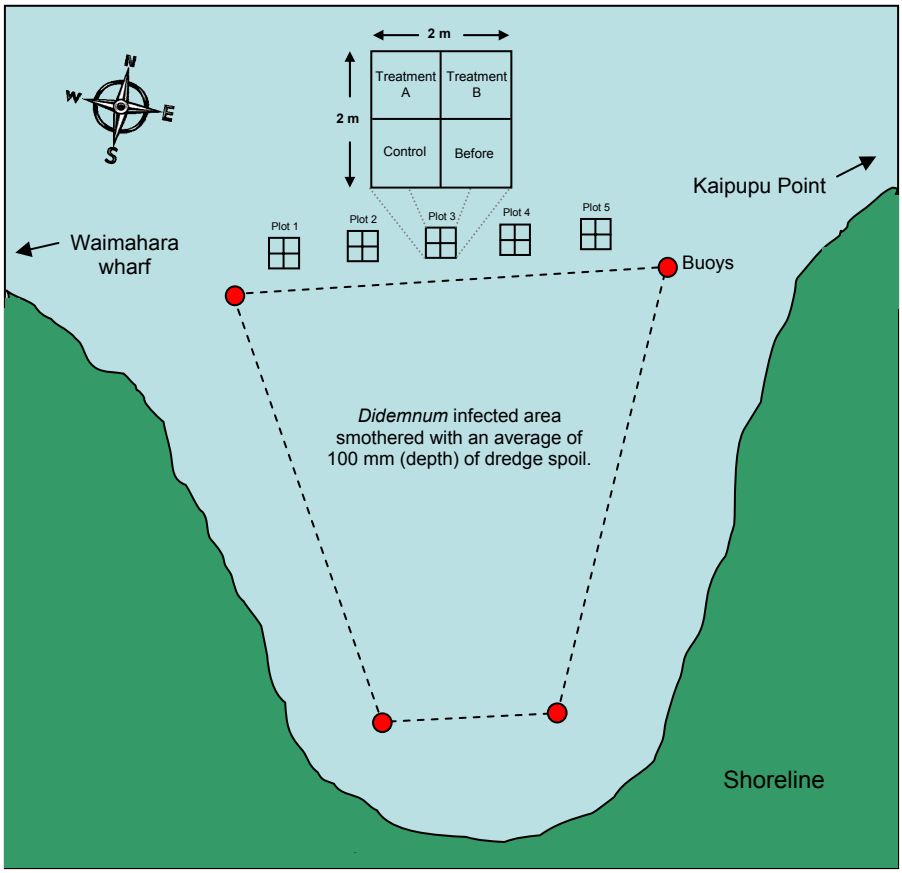

Figure 7. Location and design of the experimental plots used to determine the efficacy of using dredge spoil to 'cap' soft sediment communities.

On 1 November 2003, 50 polypropylene woven bags (840 x 460 mm) were filled with the same indigenous dredging material used to treat the infected seabed area beneath the *Steel Mariner*. The dredge spoil was a mixture of fine mud (70%), sand (20%) and small cobble (10%). Divers emptied the contents of the bags within each of the ten treatment plots to achieve approximately 100 mm (depth) of coverage (i.e., the same coverage achieved within the infected area beneath the *Steel Mariner*) (Figure 7).

On 5 February 2004, the three month assessment was undertaken with divers taking four random cores from within each of the five control, and treatment A and B plots. Poor visibility prevented divers from distinguishing between the top dredge spoil and the underlying soft sediment layer within treatment plots. Therefore, core samples from within these plots included both the top dredge spoil and as much of the underlying soft sediment layer as practically as possible. On 3 May 2004, the six month assessment was undertaken following the same procedures utilised during the three month assessment.

3.2.2 Sample processing and data analysis

The contents of all cores collected throughout the study were gently sieved through attached 0.5 mm mesh bags in order to retain the small bodied macrofauna. For each core, the sieved residue within the mesh bag was transferred to a separate 2 L plastic jar, preserved in 70% ETOH/5% glyoxal/seawater mix and transported back to Cawthron for processing.

All organisms within samples were identified to the lowest practicable taxonomic level (genus and species where possible) using a binocular microscope. The various macrofauna were classified into one of three categories (i.e., native, introduced or unknown) according to their place of origin relative to New Zealand waters as previously described in Section 2.2.3. The total number of individuals representing each species was counted. Where algae was encountered, individual holdfasts were counted.

PRIMER v5 was used to generate a species-area curve, species richness, mean abundance undertake and multivariate statistics. Non-metric multidimensional scaling (MDS) and cluster analysis was carried out (Clarke and Warwick 1994) on forth-root transformed abundance data pooled across plots to produce ordination plots. Similarities were calculated using the Bray-Curtis coefficient.

3.3 Results

The following results suggest that dredge spoil does have an effect on soft sediment communities within the first three months of treatment, although recovery was evident within six months. However, despite a reduction in species richness, average abundance and a general shift in community structure between control and treatment plots after three months, the dredge spoil experiment failed to eliminate all species on this occasion. However, this result could be confounded by inadequate sampling replication or seasonal variations.

3.3.1 Species richness

A total of 72 species were identified during the baseline assessment (Table 3). Although only 59 species were detected amongst control plots during the three month assessment, total and average species richness amongst treatment plots were markedly lower during this period. Furthermore, 15 (25%) species recorded in control plots were not detected in the two treatment plots during the three month assessment suggesting such species were either eliminated by the dredge spoil treatment, or were present but missed in the sampling (Appendix 7). Alternatively, of the 60 species recorded in control plots, 45 (75%) of these species were also detected in treatment plots, suggesting these species either survived the dredge spoil treatment or migrated into the treated plots from the surrounding area (Appendix 7). However, 17 species which were not detected in plots were recorded in treatment plots during the three month assessment indicating such species may have thrived on the disturbance event (Appendix 7).

Table 3. Summary of species richness and average abundance observed amongst control and treatment plots during the various assessment periods.

Assessment period	Baseline	3 month assessment			6 month assessment		
		Control	Treatment A	Treatment B	Control	Treatment A	Treatment B
Date	31 Oct 2003	5 Feb 2004	5 Feb 2004	5 Feb 2004	3 May 2004	3 May 2004	3 May 2004
Species Richness	72	59	42	51	58	58	59
Average Species Richness ± se	13.5±0.99	16.3±0.87	9.25±1.14	11.35±1.98	13.25±0.89	11.1±1.15	13.75±1.09
Average Abundance ± se	24.4±3.14	38.85±03.66	17.45±3.08	29.45±6.92	22.1±1.72	18.95±2.45	24.05±2.60

The six month assessment did not reveal any noticeable differences in total or average species richness between the control and treatment plots (Table 3). Interestingly, only 47 of the 60 species (65%) detected during baseline assessment were also present amongst control and treatment plots during the 6 month assessment. Furthermore, a total of 21 species that were not detected amongst plots during the baseline or three month assessment were recorded during the six month assessment. Such observations could be attributed to the assessments being undertaken at different times of the year and/or possible residual effects of the dredge spoil treatment (Appendix 7).

3.3.2 Species abundance

Generally the average abundance of species encountered amongst the various plots during the different assessment periods was low (Appendix 7). Of particular interest was the reduced average abundance of most species within treatment plots relative to control plots during the three month assessment (Appendix 7). This suggests such species may have suffered from the effects of the dredge spoil treatment.

By contrast some species were notably more abundant within treatment plots relative to control plots within three months of treatment (e.g., nematoda, the introduced bivalves *Limaria orientalis* and *Theora lubrica*, the native bivalve *Corbula zelandica*, and annelids *Notomastus zelandicus*, *Heteromastus filiformis*, Syllidae, Glyceridae and Eunicidae). These species may have survived and thrived on the disturbance event, or were the first species to recruit into the treated plots. The average abundance of the majority of species encountered in the control and treatment plots during the six month assessment were relatively similar, suggesting the community had recovered from any treatment effects (Appendix 7).

3.3.3 Species composition

Multivariate analyses revealed that there was very little similarity in community structure within and amongst baseline plots (Appendix 8). This variation necessitated the pooling of abundance data across plots to reduce variation during multivariate analyses. Furthermore, this was justified by the results of species-area curve analysis (Appendix 8). Multivariate analyses revealed that the community structure was more similar between treatments plots than their associated controls within the same assessment period (Stress 0.01) (Figure 8). However, the community structure was more similar between treatment plots and their associated controls within the same assessment period relative to the baseline assessment (Figure 8). This indicates that assessment period probably had a greater influence on the community structure than the treatment (i.e., the treatment effect was

less pronounced that the temporal change). Moreover, it appears the community structure of the six month assessment resembled the original baseline community structure more closely than the three month assessment, indicating either a seasonality-related influence or the recovery of the community from the dredge spoil treatment.

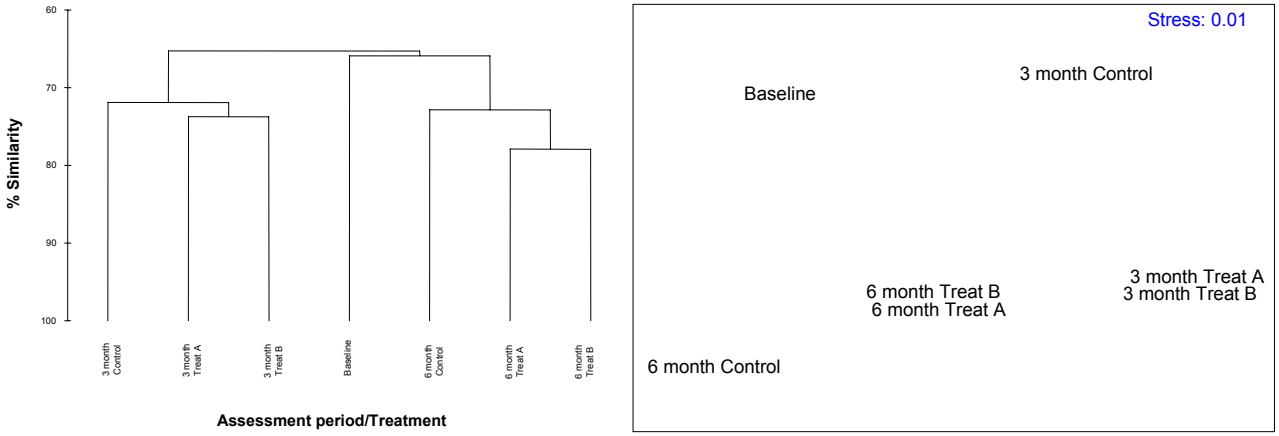

Figure 8. Dendogram and MDS plot showing the similarity in species composition between the baseline, control and two treatments amongst the three and six month assessment periods.

3.4 Discussion

3.4.1 The efficacy of dredge spoil on non-target species

The results of this study suggest that dredge spoil does have an effect on soft sediment communities within the first three months of treatment. However, despite a reduction in species richness, average abundance and a noticeable difference in community structure between control and treatment plots within three months of treatment, the application of dredge spoil failed to eliminate all species within this timeframe.

It is likely, however, that certain species such as those present in control plots, but not recorded in treatment plots after three months were eliminated because they were unable to escape from the dredge spoil (e.g., nemertea, bivalves, certain polychaetes, crustaceans and the heart urchin *Echinocardium cordatum*). Roberts *et al.* (1998) also found that such species were unable to escape overburdens of dredge spoil. Roberts et al. (1998) also identified particular indicator species that were intolerant to overburdens of dredge spoil such as the chiton *Leptochiton inquinatus* and the bivalves *Limaria orientalis*, *Corbula zelandica*, *Leptomya retiaria*, *Tawera spissa*, and *Ruditapes largillierti*. Interestingly, all of these species were recorded during the present study and illustrated a decline in their abundance within treatment plots after three months. It is possible that the dredge

spoil may have eliminated some of these species within the first three months, but their rapid recovery was facilitated by their migration into these treated plots from the surrounding area, especially considering the treatment plots were only 1 m^2 in area.

The six month assessment indicated that the soft sediment community within the treatment plots had significantly recovered with species richness, average abundance and community structure similar to the original baseline assessment. However, despite the community structure after six months resembling the baseline assessment more closely than the three month assessment, the community did not return to its original state. In particular, the average abundance often associated with disturbance was higher amongst the treatment plots after six months compared to the baseline. These included Nematoda; the bivalve *Nemocardium pulchellum*, the annelid Paraonidae, *Prionospio* sp., Cirratulidae, *Notomastus zeylanicus*, *Heteromastus filiformis*, *Sphaerosyllis hirsuta*, *Aglaophamus* sp., Dorvilleidae; Amphipoda, and *Halicarcinus cookie*, all of which have been documented by other researchers as being frequent dominators amongst disturbed benthic environments (e.g., Roberts et al. 1998; Wear 1999 – 2002; Powilleit et al. 2005; Cawthron unpublished data).

3.4.2 Future considerations for using dredge spoil as an incursion response tool

The results of this study indicate that dredge spoil could be utilised as an incursion response or management tool to target particular benthic organisms. However, the efficacy of such a method depends on many factors and its proposed application would need to be assessed on a case by case basis. For example, Maurer et al. (1986) found that vertical migration and increased mortality of macrofauna depended on the persistence of the covering layer, its depth, type of dredge material and temperature. Well adapted species like shallow burrowing and young deep siphonate suspension feeders, and large polychaeta with well developed probosces and parapodia may survive experimental burial depth of up to 0.5 m (Essink 1999). Similarly, Roberts *et al.* (1998) found that the bivalves *Leptomya retiaria, Maoricolpus roseus* and *Corbula zelandica* were capable of escaping overburden in laboratory trials of between 80 and 150 mm.

The efficacy of dredge spoil would obviously be suited to protected areas where water currents are relatively low, because the persistence of the capping could be significantly compromised in exposed high energy coastal areas (e.g., Roberts and Forrest 1999). Similarly, dredge spoil is unlikely to be effective on steep gradients or rocky environments as described in Section 4.1. Therefore the application of dredge spoil should target low energy areas that are relatively flat and

stable. However, there may be merit in experimenting with certain types of dredge spoil in different environments (e.g., sand versus mud in high current or steep gradient areas), particularly if the target organism is susceptible to the acute effects of dredge spoil, hence the persistence of the capping is only required for a short period. Such short treatment periods may also reduce collateral effects on non-target biota.

Considerations would also need to be given to the availability of uncontaminated dredge spoil. Fortunately a large stock pile of indigenous uncontaminated spoil (formally removed from in front of Waimahara Wharf in Picton) was readily available for responding to the *Didemnum* beneath the *Steel Mariner*. Because the dredge material was indigenous to the area and uncontaminated, *Didemnum* was confined to a relatively small area requiring only 320 m^3, a Resource Consent was not required. It is important, therefore, that Regional Councils are consulted to determine whether a Resource Consent is required and the feasibility of utilising the method.

3.5 Recommendations

- The application of uncontaminated dredge spoil has the potential to be a cost-effective method for treating soft sediment organisms.
- However, the efficacy of such a method depends on many factors and its proposed application would need to consider:
    - Susceptibility of the target organism to treatment,
    - Availability and volume of suitable uncontaminated dredge spoil required,
    - Type of environment and area to be treated,
    - Resource Content issues, etc
- The efficacy of dredge spoil would be greatest in protected areas (i.e., where water currents are relatively low) on relatively flat and stable substrates.

4. OBJECTIVE 3: EFFICACY OF DREDGE SPOIL ON ROCKY SHORE COMMUNITIES

4.1 Background

Considering the success of the application of dredge spoil on the *Didemnum* colonies on the seabed beneath the *Steel Mariner*, it was hoped that the same method could be used to smother the colonies on the rocky shore beneath Waimahara Wharf. Hence, on 20 October 2003, a six inch submersible pump was used to transfer sediment from directly in front of the wharf to the target area beneath it. These preliminary effects revealed two major obstacles to the effective application of the method in this particular situation:

- Considerable effort was required to fill the spaces between large boulders before the spoil accumulated on the tops of the rocks and provide the smothering effect required.

- Even where infilling was achieved, the accumulated spoil often ran down the steep rocky slope back into the original dredging zone in front of the wharf.

Hence, this particular method was not considered feasible for treating *Didemnum* beneath Waimahara Wharf. Several other treatment methods including the application of lime, concrete powder, hot water blasting, and a petrogen torch were trialled on *Didemnum* colonies. While some of these methods successfully killed the organism, none of them could be cost-effectively applied to the infected area of 200 x 50 m beneath the wharf. A final method using several sheets of Bidum A24 grade geotexile filter fabric showed the greatest potential as a treatment method. As such, Cawthron negotiated a revised contract with BNZ to trial this approved method, which involved undertaking the following assessments:

- A pre-treatment assessment to determine the seabed assemblages present prior to the application of filter fabric.

- A three and six month assessment of the efficacy of using filter fabric to 'smother' rocky shore communities to eliminate all species.

However, the three and six month assessment could not be achieved because this was an attempted eradication and accessing the filter fabric may have compromised this objective. Therefore, only a final assessment was achieved after the filter fabric was removed. Furthermore, no formal controls were available during these experiments.

4.2 Methods

4.2.1 Experimental design and sample collection

A pre-treatment assessment was undertaken prior to the application of the filter fabric on 8 December 2003. Three randomly fixed transects extending along the rocky seabed from the shoreline to 16 m deep beneath Waimahara Wharf were deployed. An underwater camera was used to photograph four haphazardly placed quadrats measuring 0.25 m^2 at each of four depths (i.e., 2, 6, 10, 14 m) along each of the three transects. Examples of the types of organisms encountered within quadrats were collected from the surrounding area to assist with their identification in photographs. All samples were preserved for later identification as discussed in previous methods sections.

On 9 December 2003, a barge was used as a working platform in front of Waimahara Wharf to sew strips of Bidum A24 grade geotexile filter fabric (50 x 4 m) together to create a total of 33 sheets (50 x 8 m). Personnel on the shoreline beneath Waimahara Wharf used ropes to haul each sheet from the barge onto the seabed (Figure 9). Divers used polyethylene ropes to join and secure the sheets between each row of wharf piles, thereby forming a continuous blanket covering the 200 x 50 m area beneath Waimahara Wharf. Sandbags were used to anchor and secure the filter fabric to the seabed, thus significantly reducing water movement (Figure 9).

On 14 February 2005, divers separated the 33 individual filter fabric sheets, which were then winched aboard an adjacent barge. Divers relocated the three transects and photographed four haphazardly placed quadrats as above. Examples of the types of organisms encountered were again collected and preserved for identification.

4.2.2 Sample processing and data analysis

All samples were processed at Cawthron's marine laboratory. A dissecting microscope and various taxonomic references were used to identify all organisms to the lowest practical taxonomic level. Wherever necessary, unidentified specimens were sent to specialised taxonomists for identification. Percentage cover estimates of the most recognisable organisms present amongst photographs were assessed using the random dot method (Meese and Tomich 1992) as described in Section 2.2.3. All organisms were classified into one of three categories (i.e., native, introduced or unknown) as previously described in Section 2.2.3. PRIMER v5 was used to generate species richness, average abundance and multivariate statistics. Non-metric multidimensional scaling (MDS) was carried out

(Clarke and Warwick 1994) on forth-root transformed abundance data to produce ordination plots. Similarities were calculated using the Bray-Curtis coefficient.

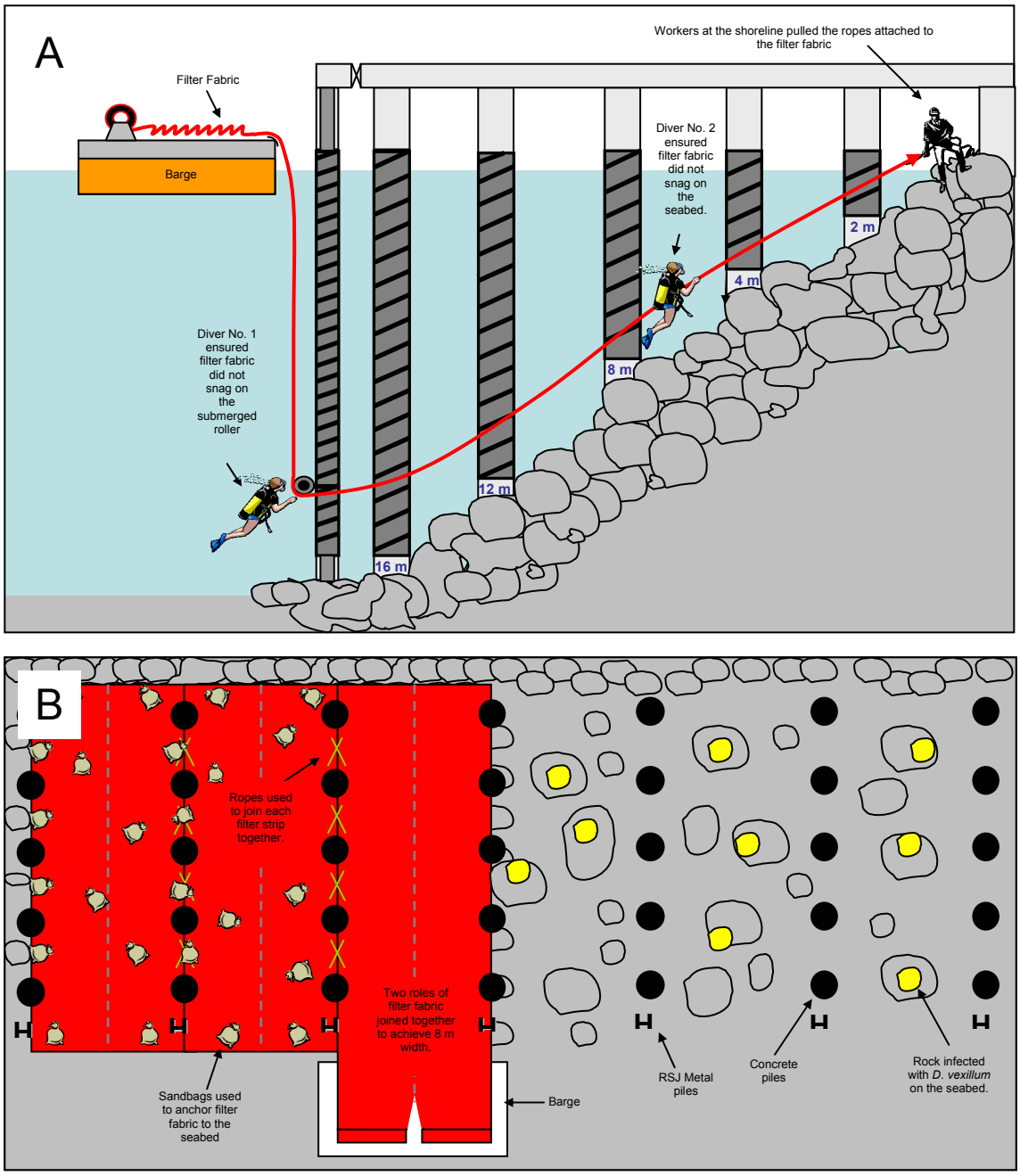

Figure 9. Schematic of A) side and B) above profile illustrating the methods used to cover the seabed beneath Waimahara Wharf with filter fabric.

4.3 Results

The following results demonstrate that the application of the filter fabric on the infected rocky substrate beneath Waimahara Wharf had a treatment effect on both *Didemnum* and other non-target

species after 14 months. However, while the filter fabric caused a reduction in species richness and average abundance of some species, and caused a general shift in the community structure, the treatment failed to eliminate all species from the rocky substrate on this occasion.

4.3.1 The application and removal of filter fabric

It took a team of divers seven days (i.e., 9 to 15 December 2003) to cover an approximate 200 x 50 m area of rocky seabed beneath Waimahara Wharf. The cost of the filter fabric material was approximately $870 a role (i.e., 300 x 4 m) and a total of 11 roles were used. Therefore the cost of the filter fabric and other materials amounted to approximately $10,000 with a further $12,000 for labour. Divers found it difficult to join and seal the individual filter fabric sheets between and around the wharf piles. As a consequence, a complete seal around some wharf piles was not achieved. Hence, water exchange likely occurred between the seabed and the surrounding environment, significantly compromising the smothering effect needed to kill the organisms.

The filter fabric remained on the seabed for a total of 14 months. During this time the sand bags and ropes used to secure the fabric to the seabed worked extremely well. However, some lifting of the filter fabric occurred along the shoreline as a consequence of wind drive wave energy. The removal of the filter fabric took two days at a cost of only $10,000. Hence the entire operation (i.e., application and removal of filter fabric) cost approximately $30,000.

4.3.2 The efficacy of filter fabric on Didemnum

The cover of *Didemnum* prior to the application of the filter fabric was particularly extensive from approximately 2 to 10 m deep prior to the application of the filter fabric (Figure 10). However, the post-treatment assessment after the filter fabric was removed recorded a substantial decline in cover of *Didemnum* across all depths. In the absence of controls it can only be assumed that the filter fabric was responsible for drastically reducing the abundance of *Didemnum* and was unable to eradicate it.

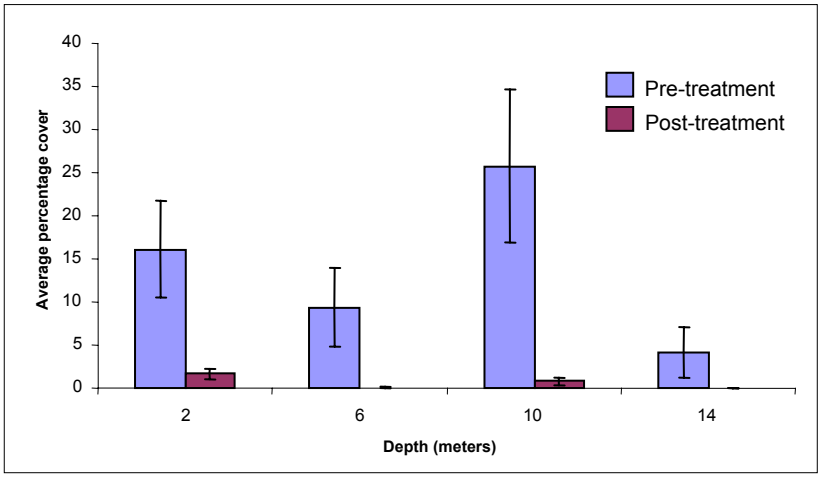

Figure 10. The average percentage cover (± se) of *Didemnum* at various depths during the pre-treatment and post-treatment assessments.

4.3.3 The efficacy of filter fabric on non-target species

A slight reduction in species richness was observed throughout the three transects after the removal of the filter fabric. For example 24 species were observed amongst the three transects during the pre-treatment assessment while only 19 species were present after 14 months of treatment (Table 4). Seven species that were present during the pre-treatment assessment, but not recorded during the post-treatment assessment included the algae Rhodomelaceae, the sponge *Crella incrustans*, unidentified nudibranchs, the gastropod *Maoricolpus roseus*, the introduced bryozoan *Bugula neritina*, and echinoderms *Notechinus albocinctus* and *Asterina regularis*) (Appendix 7). Therefore, it is possible the filter fabric was effective at eliminating these species or encouraging the mobile species to vacate.

Table 4. Species richness and average abundance observed during the pre-treatment and post-treatment assessments**.**

Assessment	Pre-treatment	Post-treatment
Date	8 December 2003	24 March 2005
Species Richness	24	19
Average % cover of fouling ± se	47.67±3.42	34.98±3.76

The overall average cover of species encountered in the photoquadrats prior to the application of the filter fabric was 48%. After treatment this average cover was reduced to 34% suggesting a possible filter fabric treatment effect (Table 4). Furthermore, the average percentage cover of many species was noticeably greater prior to the application of the filter fabric. For example, the most abundant

species encountered during the pre-treatment assessment were the sponge *Crella incrustans*, the bivalve *Aulacomya atra, maoriana*, the annelids *Galeolaria hystrix* and *Spirorbids*, the barnacles *Elminius modestus* and *Didemnum* (Appendix 9). Conversely, the average cover of some species noticeably increased after treatment assessment (e.g., the introduced bryozoan *Watersipora subtorquata* and other native and unknown origin species including *Crassimarginatella* sp., Serpulidae, *Galeolaria hystrix*, Spirorbids, *Coscinasterias calamaria*, *Cnemidocarpa bicornuta* and *Pyura rugata*; Appendix 9).

Multivariate analysis revealed that the community structure amongst transects surveyed during the pre-treatment assessment were 73% similar (Figure 11). By contrast, the similarity in community structure between transects during the post-treatment assessment was much higher (86%). Furthermore, there was only a 61% similarity in community structure amongst transects between the pre-treatment and post-treatment assessments which could be within the realm of natural temporal change or a result of the filter fabric treatment (Figure 11).

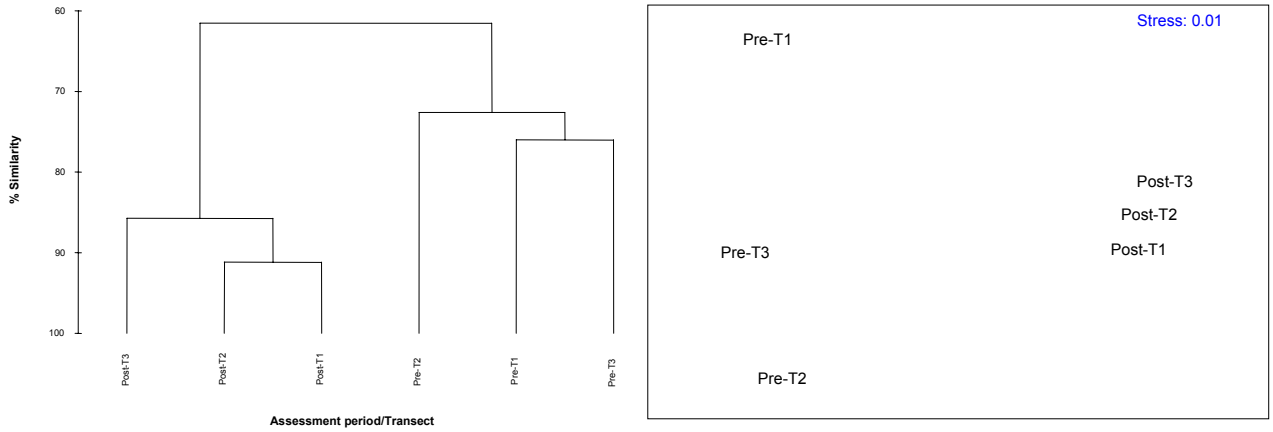

Figure 11. Dendogram and MDS plot showing the similarity in species composition amongst the various transects during the pre-treatment and post-treatment assessments. Pre refers to pre-treatment, Post refers to post-treatment assessment. T1, T2, T3 refers to individual transects.

4.4 Discussion

4.4.1 Efficacy of filter fabric to eliminate all species

The rocky seabed beneath Waimahara Wharf proved to be the most challenging environment to treat throughout the attempted eradication programme. The application of the filter fabric appeared to reduce species richness and average abundance and alter the composition of the rocky shore community beneath Waimahara Wharf. However, without controls present it is not possible to

attribute these changes solely to the treatment. Moreover, the technique clearly failed to achieve a successful eradication of *Didemnum* or eliminate all species on this occasion.

The adoption of the filter fabric technique relied on producing a smothering effect similar to the plastic wharf pile wrappings, in which the water exchange is significantly reduced, hence an anoxic environment evolves which eventually kills all organisms present (e.g., Coutts and Forrest 2005). However, a combination of inadequate joining and sealing of filter fabric sheets between the wharf piles, and the size of the boulders, obviously enabled sufficient water exchange to occur between the seabed and surrounding environment. Furthermore, the gaps between the filter fabric probably failed to retain *Didemnum* larvae, making the seabed population the likely source of re-infection of the plastic wrappings and treated wharf piles described in Section 2.3.6.

Seven species that were detected during the pre-treatment assessment were not detected during the post-treatment assessment (i.e., Rhodomelaceae, the sponge *Crella incrustans*, unidentified nudibranchs, the gastrpod *Maoricolpus rosea*, the introduced bryozoan *Bugula neritina*, and echinoderms *Notechinus albocinctus* and *Asterina regularis*). While it is possible such organisms were eliminated, particularly the sessile species, it is possible the mobile species such as the nudibranchs, *M. rosea*, *N. albocinctus* and *A. regularis* may have escaped.

To the contrary, the smothering effects of the filter fabric may have contributed to the increase in abundance of some species such the introduced bryozoan *Watersipora subtorquata* and other native and unknown origin species including *Crassimarginatella* sp., Serpulidae, *Galeolaria hystrix*, Spirorbids, *Coscinasterias calamaria*, *Cnemidocarpa bicornuta* and *Pyura rugata*. The reduction in abundance of some species undoubtedly provides vacant niches for others to proliferate and has been documented as the Sisyphus Effect (Mack and Lonsdale 2002). However, there was no obvious proliferation of any of these species during the post-treatment assessment.

4.4.2 Potential applications of the filter fabric technique

The rocky substrate beneath Waimahara Wharf provided an extremely challenging environment to successfully apply the filter fabric to significantly reduce water exchange to produce an anoxic environment. However, it is important to acknowledge that the potential for this technique as an eradication tool should not be judged entirely on the outcome of this study. Success in this study was largely dictated by time and money constraints, hence the efficacy of the technique may have been different if divers spent more time (e.g., 2 days) sealing the filter fabric to the seabed and wharf piles. If these limitations can be addressed, filter fabric has the potential to be a relatively

cost-effective eradication tool in other environments and circumstances. Therefore, further experiments should be undertaken to determine the efficacy of filter fabric at killing various types of organisms on different benthic substrates.

The fact that the fabric remained on the seabed under Waimahara Wharf for 14 months illustrates its durability, and suggests that it has the potential to be reused, making it very cost-effective. Furthermore, the filter fabric might be a feasible management measure within highly sensitive areas where other techniques are not feasible, or where they result in "irreversible" habitat changes (e.g., as a technique to smother rocky habitat in areas valued for conservation).

4.5 Recommendations

- Filter fabric has the potential to be a cost-effective treatment tool for a variety of organisms on different benthic substrates provided water encapsulation occurs.
- The filter fabric might be an appropriate management measure within highly sensitive areas where other techniques are not feasible, or where they result in "irreversible" habitat changes.
- However, further experiments are required to determine the efficacy of filter fabric at killing various types of target organisms on different benthic substrates.

5. OBJECTIVE 4: EFFICACY OF USING ON-LAND WATER-BLASTING AND 48 HOURS DESICCATION FOR TREATING MOORINGS

5.1 Background

A delimitation survey undertaken on 15 July 2003 revealed that seven of the 22 moorings in Shakespeare Bay were infected with *Didemnum*. The attempted eradication of *Didemnum* necessitated the treatment of these infected moorings. Given these structures could be removed from the water and treated on land, water-blasting and 48 hours desiccation was proposed. Therefore, BNZ contracted Cawthron to design, test and document the efficacy of using this method for treating mooring communities to eliminate all species. This involved undertaking the following assessments:

- A pre-treatment assessment to determine the composition of organisms present on the moorings prior to treatment.
- A three and six month assessment of fresh recruitment of marine organisms onto treated moorings.

The attempted eradication treated all moorings infected with *Didemnum*, therefore no control moorings were available during the experiments.

5.2 Methods

5.2.1 Experimental design and sample collection

Four of the seven mooring lines infected with *Didemnum* were randomly selected from the available 22 moorings in Shakespeare Bay on 19 September 2003. Permanent labels were used to mark three depths (i.e., 1, 3 and 6 m) on each mooring. An underwater camera was used to photograph fouling within a 320 mm length of the moorings at each of the three depths on each mooring. Representative samples of the fouling organisms present were collected from outside the photographic areas to aid with their identification in the photographs.

On 26 September 2003, the seven infected moorings and accompanying mooring blocks were removed using a hydraulic crane on a motorised barge. All moorings were transferred to a biosecure area[3] at M^{c}Manaway's slipway in Picton where they were water-blasted clean using 2000 psi

[3] The term biosecure area in this instance refers to a facility that is capable of capturing all defouled material (that is disposed of at an approved landfill facility) and waste water filtered to 60 µm via settling tanks.

pressure. Moorings were then desiccated for 48 hours prior to being returned to Shakespeare Bay (Figure 12).

On 18 December 2003 and 11 March 2004, the three and six month assessments were undertaken respectively. This involved divers photographing the fouling present at the same three depth locations on the four moorings used previously. Representative samples of the fouling organisms were again collected from outside the photographic area to aid with their identification in the photographs.

Figure 12. Infected moorings were removed from Shakespeare Bay, water-blasted in a biosecure area (see footnote[3] on previous page for definition) in Picton and returned 48 hours later.

5.2.2 Sample processing and data analysis

All collected samples were preserved and transported to Cawthron for processing. All organisms within samples were identified to the lowest practicable taxonomic level (genus and species where possible) using a binocular microscope. The percentage cover of 20 of the most dominant species was determined using the random dot method (Meese and Tomich 1992) as described in Section 2.2.3. PRIMER v5 was used to generate species richness, average abundance and multivariate

statistics. Non-metric MDS was carried out on forth-root transformed abundance data to produce ordination plots. Similarities were calculated using the Bray-Curtis coefficient.

5.3 Results

5.3.1 Cost-effectiveness of treating moorings

The removal of infected moorings using a hydraulic crane on a motorised barge was extremely efficient. Each mooring took approximately two hours to remove, relocate, and treat. The total cost of removing, treating and returning the seven moorings was approximately $5,500. Some difficulties were experienced when attempting to retain *Didemnum* colonies on the moorings during the removal process. Divers were used to collect as much of the defouled colonies as possible, but some were inherently lost due to poor water clarity.

5.3.2 Efficacy of treating mooring lines to eliminate Didemnum

Didemnum occupied an average cover of 30% amongst the three depths on the four moorings prior to treatment (Appendix 10). The species was not detected in these same locations on moorings during the three month assessment. In the absence of controls, it can only be assumed that the water-blasting and desiccation treatment was the primary cause of this result. However, *Didemnum* was detected on one of the four moorings occupying an average cover of 4% amongst photographs within six months of treatment (Appendix 10). This occurrence was probably a result of fresh settlement rather than survivorship.

5.3.3 Efficacy of treating mooring lines to eliminate non-target species

Prior to treatment, 20 species occupied 100 percent on moorings at various depths (Table 5; Appendix 10). However, three months after treatment, only the alga *Callithamnion consanguineous* was present with an average cover of 90% on moorings. This algal species continued to dominate the moorings after six months, although three other species (i.e., *Didemnum*, *Mytilus galloprovincialis* and *Watersipora subtorquata*) were also present contributing to an overall average cover of 93% on moorings (Table 5; Appendix 10).

Multivariate analysis revealed that there was little similarity in community structure between the pre-treatment and the two three month post-treatment assessments (Figure 13). Furthermore, community structure amongst three and six month assessments of moorings were more similar than

the pre-assessment suggesting the mooring communities had not recovered from a possible treatment effect within this timeframe.

Table 5. Species richness and average abundance observed amongst moorings during the pre-treatment, three and six month assessments.

Assessment	Pre-treatment	Three months	Six months
Date	26 September 2003	18 December 2005	11 March 2004
Species Richness	20	1	4
Average % cover of fouling ± se	100±0	90.0±6.75	92.42±2.71

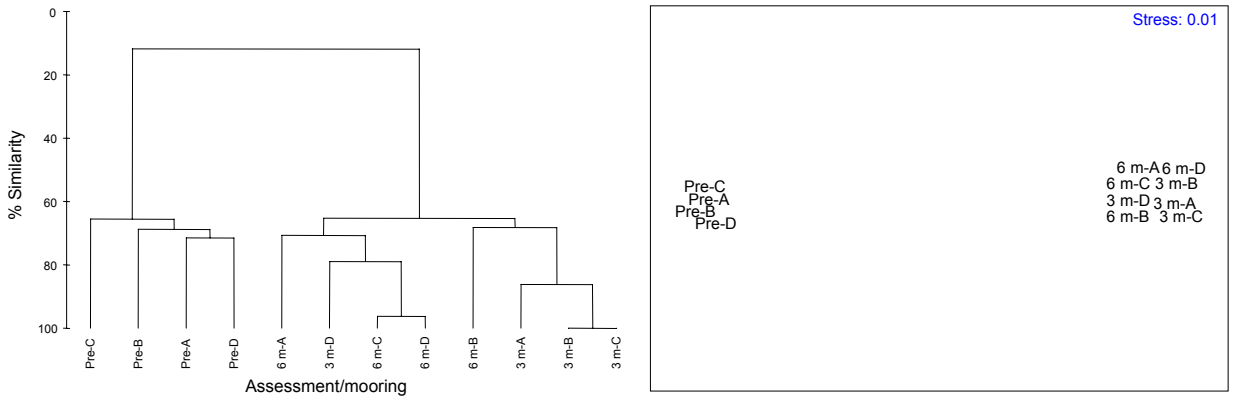

Figure 13. Dendogram and MDS plot showing the similarity in species composition amongst the moorings during the pre-treatment, three and six month assessments. Pre refers to pre-treatment, 3 m and 6 m refer to three and six month assessments. A, B, C and D refer to replicate moorings.

5.4 Discussion

High pressure water-blasting is commonly utilised by the aquaculture and maritime industry and renowned as a cost-effective method for cleaning a wide variety of structures. Therefore, despite the absence of controls, the removal and on-land treatment of moorings using 2000 psi water-blasting and 48 hours of desiccation was the likely cause of eliminating both *Didemnum* and other non-target species. The success of the method is largely attributable to the fact that the artificial structure can be removed and treated on land. Furthermore, a 48 hour desiccation period further enhances the chances of killing any microscopic remnants of organisms.

One of the greatest challenges experienced during the treatment of the moorings was arranging alternative berthage for the recreational vessels during treatment process. Future treatment attempts might be able to avoid this problem by significantly reducing the treatment time. For example, further experiments could be undertaken to determine the efficacy of using water-blasting and various pressures without desiccation. Alternatively, 4% acetic acid contained in domestic vinegar is known to be effective against a variety of fouling organisms (e.g., *Styela clava*, *Ciona intestinalis* and *Undaria pinnatifida*) within seconds to minutes (Carver et al. 2003; Coutts and Forrest 2005; Forrest and Dodgshun, in prep.). Therefore, it might be possible to treat moorings on board a barge within a quarantined area using either of these suggested methods, hence solving the logistics relocating vessels for long periods.

A further limitation of this management measure is it is unable to provide the treated structures with immunity from being re-infected. For example, *Didemnum* had re-established on one of the treated moorings after six months. Therefore, such structures would need to be treated once more if the attempted eradication continued. It might be possible, however for moorings to be treated with a cost-effective antifouling coating.

5.5 Recommendations

- A combination of high-pressure water-blasting and desiccation is a cost-effective method for treating moorings and a variety of other artificial structures.

- Further experiments should be undertaken to determine the feasibility and efficacy of using various pressures of water-blasting and/or concentrations of acetic acid to treat moorings.

6. RECOMMENDATIONS

The results of this study suggest that on-land treatment of infected substrates has more potential of successfully eliminating species than *in situ* treatment. However, the feasibility and cost-effectiveness of removing infected substrates from the water for treatment is not always possible. Fortunately the various *in situ* smothering methods developed during the attempted *Didemnum* eradication programme to treat both natural and artificial substrates are clearly capable of eliminating various organisms provided they are applied correctly and significantly reduce the movement of water.

Therefore, future attempted eradication programmes in the marine environment should consider the following recommendations based on the results of this study:

- Wherever possible infected substrates should be removed and treated on land.
- High pressure water blasting (i.e., >2000 psi) and desiccation (i.e., > 2 days) should be used if treatment time is not limited.
- If treatment time is limited, accelerators such as acetic acid (i.e., 1-4%) could be used to treat substrates within 10 minutes (e.g., refer to Coutts and Forrest 2005).
- Where infected substrates cannot be removed and treated on land, the following *in situ* treatments methods could be used to treat various substrates:
    - Dumping of uncontaminated dredge spoil (i.e., > 100 mm coverage) is capable of treating soft sediment environments, particularly on stable seabed's in protected waters.
    - Filter fabric could be could be applied for up to three months to treat soft sediment and rocky shores substrates in both protected and high energy areas.
    - Plastic wrapping is capable of treating wharf piles within one week.
- Further experiments should be undertaken (in the absence of an attempted eradication programme) to further develop and test the efficacy of these methods. Where possible attempts should be made to determine the treatment time required to kill various target organisms on different substrates. Furthermore, the identification of reliable indicators for determining the efficacy of the different methods against different species would also be extremely useful (e.g., water quality within encapsulated wrappings).

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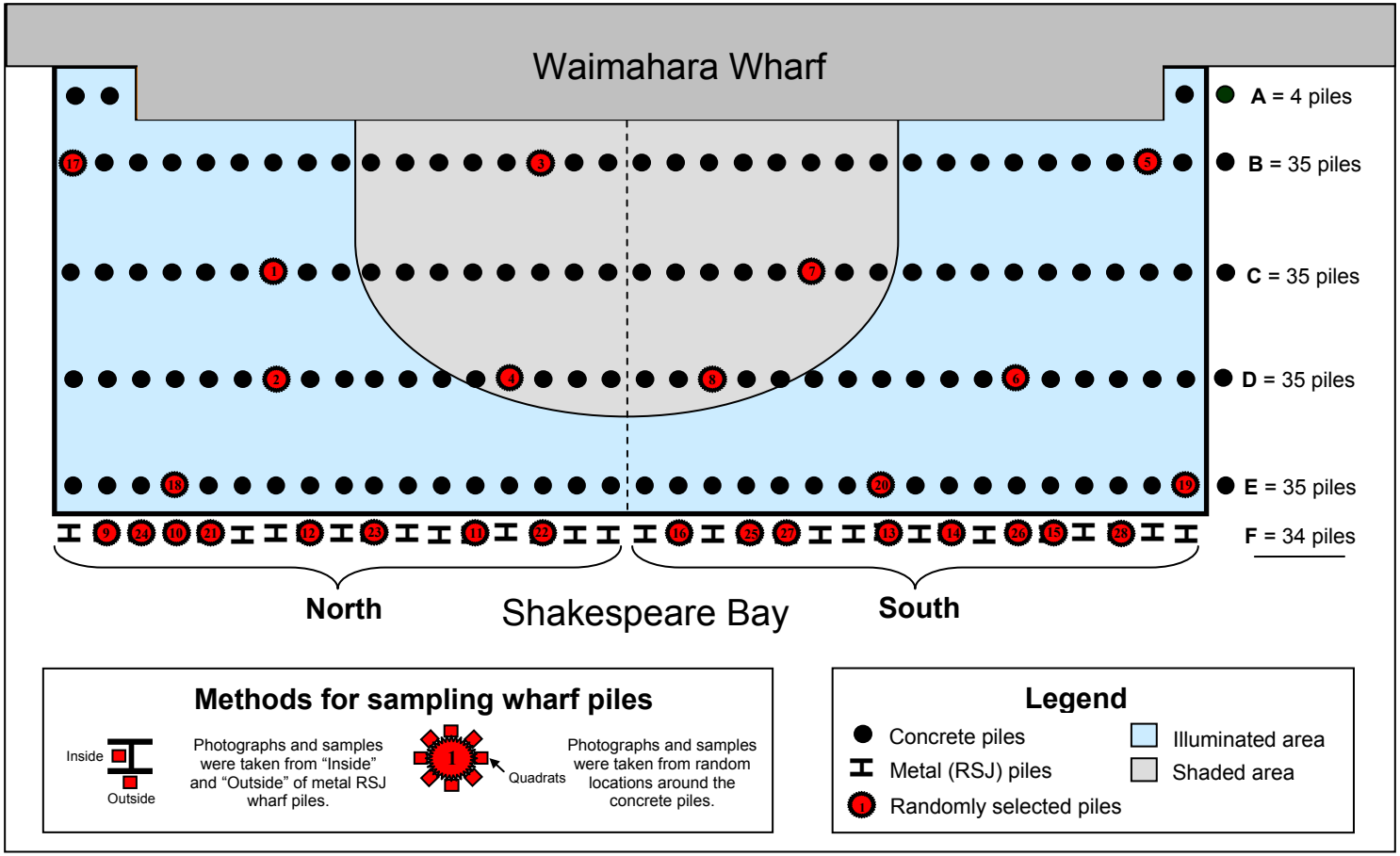
Appendix 1

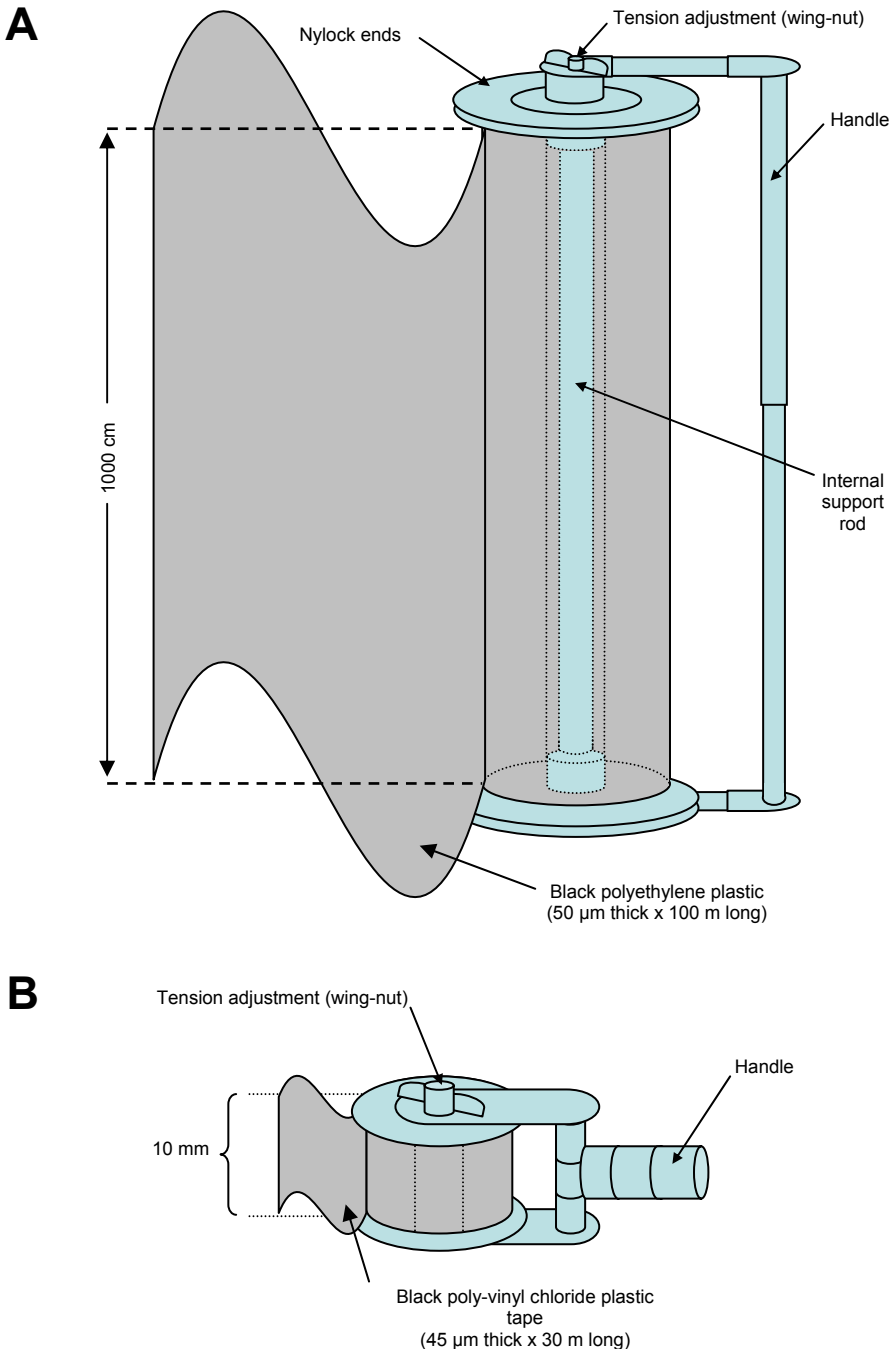


Above view of Waimahara Wharf illustrating the methods used to representatively sample the various strata amongst the 178 wharf piles.

A list of the 28 randomly selected wharf piles according to the various strata.

Wharf Pile Number	Wharf pile type	Location	Light level	Depth (m)	Sample type
1	Concrete	North	Illuminated	4	Random
2	Concrete	North	Illuminated	12	Random
3	Concrete	North	Shaded	4	Random
4	Concrete	North	Shaded	12	Random
5	Concrete	South	Illuminated	4	Random
6	Concrete	South	Illuminated	12	Random
7	Concrete	South	Shaded	4	Random
8	Concrete	South	Shaded	12	Random
9	Metal	North	Illuminated	4	Inside
10	Metal	North	Illuminated	4	Outside
11	Metal	North	Illuminated	12	Inside
12	Metal	North	Illuminated	12	Outside
13	Metal	South	Illuminated	4	Inside
14	Metal	South	Illuminated	4	Outside
15	Metal	South	Illuminated	12	Inside
16	Metal	South	Illuminated	12	Outside
17	Concrete	North	Illuminated	0	Random
18	Concrete	North	Illuminated	16	Random
19	Concrete	South	Illuminated	0	Random
20	Concrete	South	Illuminated	16	Random
21	Metal	North	Illuminated	0	Inside
22	Metal	North	Illuminated	0	Outside
23	Metal	North	Illuminated	16	Inside
24	Metal	North	Illuminated	16	Outside
25	Metal	South	Illuminated	0	Inside
26	Metal	South	Illuminated	0	Outside
27	Metal	South	Illuminated	16	Inside
28	Metal	South	Illuminated	16	Outside

Appendix 2



Schematic diagram of the dispensers used to **A)** wrap the wharf piles with black polyethylene plastic, and **B)** used to secure the black polyethylene plastic with black poly-vinyl chloride plastic (PVC) tape.

Appendix 3

Row	Pile type	Total number of piles per row	Maximum wharf pile depth (m)	Wharf pile circumference (m)	Area (m^2)
A	Concrete	4	2	1.886	15.088
B	Concrete	35	4	1.886	264.04
C	Concrete	35	8	1.886	528.08
D	Concrete	35	12	1.886	792.12
E	Concrete	35	16	1.886	1056.16
F	Metal (RSJ)	34	16	1.370	745.28
				Total surface area (m^2)	3,400.77

Polyethylene wharf pile wrappings

Assume 0.5 m wrapping overlap	6801.54 m^2
2.5% margin of error	170.04 m^2
Total wrapping area	6971.57 m^2
Number of polyethylene plastic roles required	69.72
Cost per polyethylene role	$27.50
Sub-total	$1,917.18
Plus GST (12.5%)	$239.65
TOTAL COST	$2,156.83

Supplier: Boise Office Solutions
Address: 58 Vincent Street, Nelson, New Zealand.
Ph:; +64-3-548 0356
Fax: +64-3-548 8063
Website: www.boise.co.nz
Product: Polyethylene 100 m x 1 m x 50 µm
Product code: 2250225

PVC sellotape wrappings

Assume same as for polyethylene	6801.54 m^2
Assume same 2.5% margin of error	170.04 m^2
Total wrapping area	6971.57 m^2
Number of PVC sellotape roles required	232.39
Cost per PVC sellotape role	$2.70
Sub-total	$627.44
Plus GST (12.5%)	$78.43
TOTAL COST	$705.87

Supplier: R.L. Button and Company Limited
Address: 223 Annex Road, Upper Riccarton, Christchurch, NZ.
Phone: +64-3-338 2042;
Fax: +64-3-338 2336
Website: www.rlbutton.co.nz
Product: PVC sellotape 48 mm x 30 m
Product code: 1410048

Appendix 4

A list of the species found on 28 randomly selected Waimahara Wharf piles during the various assessment periods. All species were identified to the lowest taxonomic level possible. † refers to mobile species while unmarked species refer to sessile species. Origin refers to each organisms known place of origin relative to New Zealand waters (refer to Section 2.2.3 for further explanation). Pre-wrap, Post-wrap, Baseline, etc refer to the various assessment periods (refer to Section 2.2 for further explanation). Figures refer to the frequency of occurrence of each organism amongst the 28 wharf piles surveyed during each assessment period.

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m treated	6 m treated
PROTISTA	Foraminifera	Unknown					15	5	2
PLANTAE									
Chlorophyceae									
Ulvaceae	*Ulva* sp.	Unknown			1				
Cladophorales	*Cladophora crinalis*	Native					1		
Codiaceae	*Codium fragile novae-zelandiae*	Native							1
Phaeophyceae									
Ralfsiaceae	*Ralfsia verrucosa*	Native	6				10		1
Scytosiphonaceae	*Colpomenia sinuosa*	Native					1		
Punctariaceae	*Punctaria latifolia*	Introduced					2		
Dictyotaceae	*Cutleria multifida*	Introduced				11			
Alariaceae	*Undaria pinnatifida*	Introduced	1		3			1	
Rhodophyceae									
Helminthocladiaceae	*Helminthocladia* sp.	Unknown	1		1				
Corallinaceae	Coralline algae	Unknown				1	13		
Gigartinaceae	*Gigartina circumcincta*	Native			1				
Rhodomelaceae	Unidentified species	Unknown	2				1		
	Polysiphonia strictissima	Native					1	2	
Ceraminceae	Unidentified species	Unknown			2				
ANIMALIA									
PORIFERA									
Cellularia	Unidentified species 1	Unknown	2		7		22		
	Unidentified species 2	Unknown	3		3				
	Unidentified species 3	Unknown	4						

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m treated	6 m treated
ANIMALIA									
PORIFERA									
Cellularia									
Crellidae	*Crella incrustans*	Native	9		8				
Sycettidae	*Sycon ciliata*	Introduced					2	1	
CNIDARIA									
Hydrozoa	Unidentified species	Unknown	14			1	1		
Campanulariidae	Unidentified species	Unknown							6
	Obelia sp.	Unknown						1	
	Obelia longissima	Introduced	3		10	25	13		1
Haleciidae	*Halecium delicatulum*	Introduced							1
	Halecium corrugatissium	Native				1			
PLATYHELMINTHES	Unidentified species†	Unknown			4			3	4
NEMERTEA	Unidentified species†	Unknown		1					9
NEMATODA	Unidentified species†	Unknown					6	2	3
MOLLUSCA									
Gastropoda									
Turbinidae	*Turbo smaragdus*†	Native				1	1		1
	Turbonilla sp. †	Unknown						1	
Trochoidae	*Trochus viridis*†	Native				1		1	
Nudibranchia	Unidentified species	Unknown			1			1	4
Dendrodoriddidae	*Dendrodoris citrina*†	Native			2				
Bivalvia									
Mytilidae	Unidentified species	Unknown				26	17		
	Mytilus galloprovincialis	Introduced	3		5		2	9	5
	Perna canaliculus	Native	3		4	1	2	6	3
	Modiolarca impacta	Native			4		3		3
	Aulacomya atra maoriana	Native			4		11	4	4
Pectinidae	*Chlamys* sp.	Unknown						6	2
	Mesopeplum convexum	Native					2		

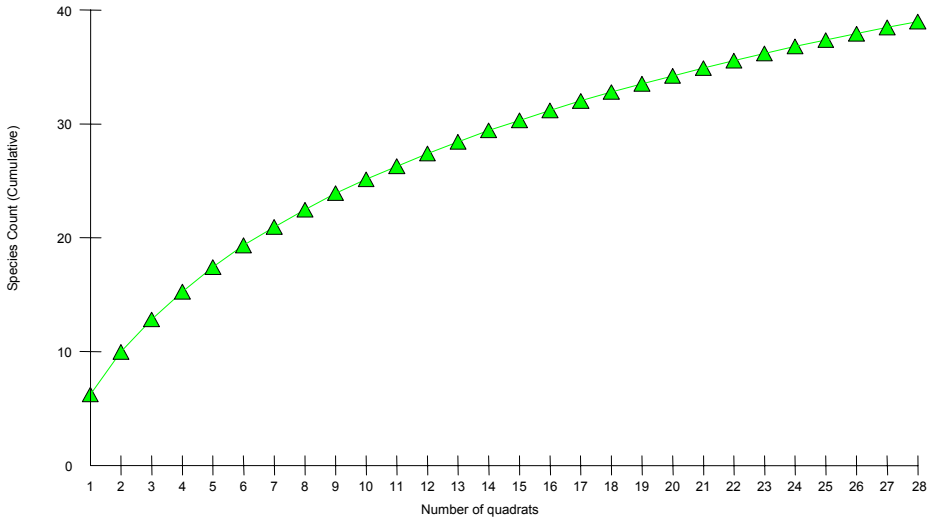
Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m treated	6 m treated
MOLLUSCA									
Bivalvia									
Limidae	*Limaria orientalis*	Introduced						2	
Anomiidae	*Monia zelandica*	Native			8		14	5	7
Erycinidae	*Arthritica bifurca*	Native						1	
Cardiidae	*Nemocardium pulchellum*	Native						3	
Semelidae	*Leptomya retiaria*	Native						8	2
Veneridae	*Tawera spissa*	Native					1	2	1
	Ruditapes largillierti	Native					7	9	7
	Bassina yatei	Native						1	
Mactridae	*Cyclomactra ovata*	Native			1				
Hiatellidae	*Hiatella arctica*	Native			9			13	14
Polyplacophora	Unidentified species	Unknown			1				
Ischnochitonidae	*Ischnochiton maorianus*†	Native							2
Acanthochitonidae	*Cryptoconchus porosus*†	Native	1		7			1	
	Acanthochitona zelandica†	Native			1				
BRYOZOA	Unidentified species 1	Unknown				1			
	Unidentified species 2	Unknown						1	
	Unidentified species 3	Unknown				1			
	Unidentified species 4	Unknown					1		
	Unidentified species 5	Unknown					16	3	
	Unidentified species 6	Unknown					1		
	Unidentified species 7	Unknown							1
	Unidentified species 8	Unknown							1
	Unidentified species 9	Unknown							1
Scruparíidae	*Scruparis ambigua*	Introduced					13	10	1
Membraniporidae	*Conopeum seurati*	Introduced					2		
Electridae	*Electra* cf. *tenella*	Introduced				6	7	1	
Calloporidae	*Crassimarginatella* sp.	Unknown					5	5	13
Chaperiidae	*Chaperiopsis cervicornis*	Native	1			8	13		
Lichenoporidae	*Tubulipora* sp.	Unknown					2	1	

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m treated	6 m treated
BRYOZOA									
Bugulidae	*Bugula flabellata*	Introduced	5		1	13	3	5	
	Bugula neritina	Introduced				5	7	6	2
	Bugula stolonifera	Introduced	1		4		1		
Beaniidae	*Beania* sp.	Unknown				16	19	1	
Cabereidae	*Caberea rostrata*	Native				1		1	
	Caberea zelandica	Native					1		
	Tricellaria occidentalis	Introduced					4		
Eurystomelliidae	*Eurystomella* sp.	Unknown					1		
Archnopusiidae	*Arachnoposia unicornis*	Native				1	1	4	2
Cryptosulidae	*Cryptosula pallasiana*	Introduced	1			3	7	1	3
Watersiporidae	*Watersipora subtorquata*	Introduced	20	1	22	27	27	25	28
Microporellidae	*Fenestrulina* cf. *disjuncta*	Unknown				1	2		
Crisiidae	*Crisia* cf. *zelandica*	Native				1			2
Densiporidae	*Favosipora* sp.	Unknown				1	2		1
ANNELIDA									
Paraonidae	Unidentified species†	Unknown							1
Spionidae	Unidentified species†	Unknown							3
Cirratulidae	Unidentified species†	Unknown						1	2
Capitellidae	*Notomastus zeylanicus*†	Native						2	2
	Heteromastus filiformis†	Native						4	1
Opheliidae	*Armandia maculata*†	Native						3	4
Phyllodocidae	Unidentified species†	Unknown			4			2	14
Polynoidae	Unidentified species†	Unknown			13		2	10	22
Sigalionidae	Unidentified species†	Unknown					1		2
Hesionidae	Unidentified species†	Unknown			18	2	6	11	23
Syllidae	Unidentified species†	Unknown			2				8
	Sphaerosyllis hirsula†	Native					15	13	9
Nereidae	Unidentified species†	Unknown			26	1	12	4	21
	Perinereis amblyodonta†	Native			1				

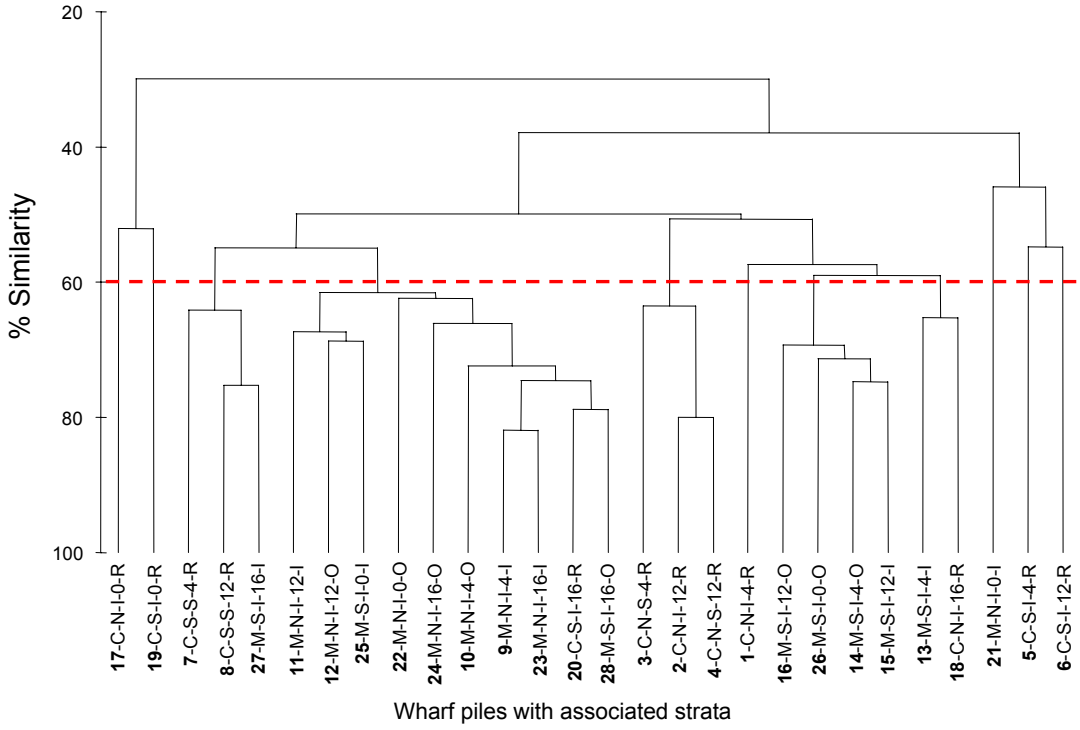
Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m treated	6 m treated
ANNELIDA									
Nereidae	*Perinereis nuntia*†	Native							1
Glyceridae	Unidentified species†	Unknown					1		
Nephtyidae	*Aglaophamus* sp. †	Unknown						1	
Eunicidae	Unidentified species†	Unknown			5			3	2
Lumbrineridae	Unidentified species†	Unknown						2	
Dorvilleidae	Unidentified species†	Unknown			1	1	3	1	15
	Dorvillea australiensis†	Native			1				
Terebellidae	Unidentified species†	Unknown			16		6	5	14
Sabellidae	Unidentified species	Unknown			3				
Serpulidae	Unidentified species	Unknown	11		2	16	19		
	Pomatoceros caeruleus	Native			1			10	1
	Pomatoceros terranovae	Native			1			11	17
	Galeolaria hystrix	Native	18		15	1		7	9
	Vermiliopsis sphaeropomatus	Native			5				
Spirorbinae	*Spirorbids* sp.	Unknown	1		2	15	24	7	15
CRUSTACEA									
Amphipoda	Unidentified species†	Unknown			2				
Isopoda	Flabellifera†	Unknown						2	
Tanaidacea	Unidentified species†	Unknown				1		2	
Decapoda									
Paguridae	*Pagurus* sp. †	Unknown			2				
Porcellanidae	*Petrolisthes novaezelandiae*†	Native			6			1	1
	Petrocheles spinosus†	Native			2				
Majidae	*Notomithrax minor*†	Native			1				
	Notomithrax peronii†	Native			2				
Hymenosomatidae	*Halicarcinus innominatus*†	Native						2	
	Halicarcinus cookii†	Native			3	1		8	1

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m treated	6 m treated
CRUSTACEA									
Decapoda									
Hymenosomatidae	*Halicarcinus ovatus*†	Native							5
	Halicarcinus varius†	Native			4				
Thoracica									
Balanidae	*Balanus* sp.	Unknown			1				
	Balanus trigonus	Introduced			1				
	Elminius modestus	Native	5			20	24	1	2
ECHINODERMATA									
Echinometridae	*Notechinus albocinctus*†	Native							1
Asteriidae	*Asterina regularis*†	Native			1				
	Patiriella regularis†	Native	1		2	1	1	2	3
CHORDATA									
Urochordata	Unidentified solitary species	Unknown				8	1		
	Unidentified colonial species	Unknown				14			
Polyclinidae	*Aplidium* sp.	Unknown	6		2		4	1	
Didemnidae	Unidentified species 1	Unknown	6	1	1	10	18	13	
	Unidentified species 2	Unknown			5				
	Unidentified species 3	Unknown	6	1					9
	Unidentified species 4	Unknown	1						3
	Didemnum vexillum	Native	24	3	26	1	16	11	20
Botrylliinae	*Botrylloides leachii*	Introduced			3	1	1		
Styelidae	*Cnemidocarpa bicornuta*	Native	3	3	4	3	1		
	Cnemidocarpa vicomuata	Native		1	1				
	Asterocarpa cerea	Introduced	1		2				
Pyuridae	*Pyura rugata*	Native	8	1	12				
	Pyura suteri	Native			1				
	Microcosmus sp.	Unknown			1				
	Microcosmus australis	Native			1				
TOTALS	**147**	-	**31**	**8**	**66**	**39**	**62**	**65**	**63**

Appendix 5



Cumulative species-area curve illustrating the relationship between sampling effort (i.e., number of quadrats) verses the detection of a new species.



Dendogram showing the similarity between the percentage cover of species amongst the 28 wharf piles and their associated strata. Labels refer to the following: bold figures refer to the pile number; second letter refers to pile type (M=metal or C=concrete); pile position (N=north or S=south); light level (I=Illuminated or S=Shaded); sample depth (0, 4, 12, 16 m); Sample location within pile (R = random sampling from concrete piles; I = inside metal RSJ and O = outside metal RSJ (see methods for further details).

Appendix 6

A list of species found on 28 randomly selected Waimahara Wharf piles during the various assessment periods. All species were identified to the lowest practical taxonomic level. † refers to mobile species while unmarked species refer to sessile species. Origin refers to each organisms known place of origin relative to New Zealand waters (refer to Section 2.2.3 for further explanation). Baseline, Pre-wrap, 3 m plastic, etc refer to the various assessment periods (refer to Section 2.2 for further explanation). Figures refer to the mean percentage cover of each species amongst the 28 wharf piles surveyed during each assessment period.

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m concrete	6 m concrete
PROTISTA	Foraminifera	Unknown					44.4±15.36	0.29±0.13	0.11±0.08
PLANTAE									
Chlorophyceae									
Ulvaceae	*Ulva* sp.	Unknown			0.04±0.04				
Cladophorales	*Cladophora crinalis*	Native					0.04±0.04		
Codiaceae	*Codium fragile novae-zelandiae*	Native							0.04±0.04
Phaeophyceae									
Ralfsiaceae	*Ralfsia verrucosa*	Native			0.75±0.31		5.00±2.05		0.11±0.11
Scytosiphonaceae	*Colpomenia sinuosa*	Native					0.04±0.04		
Punctariaceae	*Punctaria latifolia*	Introduced					0.07±0.05		
Dictyotaceae	*Cutleria multifida*	Introduced				18.4±6.09			
Alariaceae	*Undaria pinnatifida*	Introduced	2.50±2.50		4.96±3.26			0.04±0.04	
Rhodophyceae									
Helminthocladiaceae	*Helminthocladia* sp.	Unknown	0.07±0.07		0.21±0.21				
Corallinaceae	Coralline algae	Unknown				0.25±0.25	0.68±0.17		
Gigartinaceae	*Gigartina circumcincta*	Native			0.11±0.11				
Rhodomelaceae	Unidentified species	Unknown	0.32±0.22				0.04±0.04		
	Polysiphonia strictissima	Native					0.04±0.04	0.54±0.44	
Ceramiaceae	Unidentified species	Unknown			0.07±0.05				
ANIMALIA									
PORIFERA									
Cellularia	Unidentified species 1	Unknown	0.36±0.29		0.89±0.39		0.96±0.12		
	Unidentified species 2	Unknown	1.71±1.21		2.71±1.75				
	Unidentified species 3	Unknown	0.39±0.21						
Crellidae	*Crella incrustans*	Native	4.36±1.51		5.07±2.30				
Scyettidae	*Sycon ciliata*	Introduced					0.11±0.08	0.04±0.04	

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m concrete	6 m concrete
CNIDARIA									
Hydrozoa	Unidentified species	Unknown	7.21±1.72			0.04±0.04	0.04±0.04		
Campanulariidae	Unidentified species	Unknown							2.64±1.12
	Obelia sp.	Unknown						0.17±0.71	
	Obelia longissima	Introduced	0.68±0.42		2.79±1.16	18.68±5.28	1.07±3.05		0.14±0.14
Haleciidae	*Halecium delicatulum*	Introduced							0.29±0.29
	Halecium corrugatissium	Native				0.04±0.04			
PLATYHELMINTHES	Unidentified species †	Unknown			0.18±0.09			0.14±0.08	0.14±0.07
NEMERTEA	Unidentified species †	Unknown		0.04±0.04					0.93±0.34
NEMATODA	Unidentified species †	Unknown					0.61±0.32	0.61±0.51	3.71±2.32
MOLLUSCA									
Gastropoda									
Turbinidae	*Turbo smaragdus*	Native				0.07±0.07	0.11±0.11		0.04±0.04
	Turbonilla sp. †	Unknown						0.07±0..07	
Trochidae	*Trochus viridis* †	Native					0.04±0.04	0.04±0.04	
Nudibranchia	Unidentified species †	Unknown			0.07±0.07			0.04±0.04	0.14±0.07
Dendrodoridae	*Dendrodoris citrina*	Native			0.11±0.08				
Bivalvia									
Mytilidae	Unidentified species †	Unknown				70.93±16.4	18.14±4.60		
	Mytilus galloprovincialis	Introduced	0.32±0.19		0.86±0.44		0.07±0.05	0.68±0.23	0.36±0.19
	Perna canaliculus	Native	1.46±1.01		0.18±0.09	0.04±0.04	0.14±0.10	0.32±0.14	0.11±0.06
	Modiolarca impacta †	Native			0.86±0.71		0.25±0.14		0.11±0.06
	Aulacomya atra maoriana †	Native			0.39±0.26		0.75±0.20	0.43±0.24	0.29±0.16
Pectinidae	*Chlamys* sp. †	Unknown						0.50±0.24	0.07±0.05
	Mesopeplum convexum †	Native						0.11±0.08	
Limidae	*Limaria orientalis* †	Introduced						0.14±0.11	
Anomiidae	*Monia zelandica* †	Native			0.57±0.22		1.46±0.37	0.25±0.11	0.29±0.10
Erycinidae	*Arthritica bifurca*	Native						0.04±0.04	
Cardiidae	*Nemocardium pulchellum* †	Native						0.21±0.13	

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m concrete	6 m concrete
Bivalvia									
Semelidae	*Leptomya retiaria* †	Native						1.36±0.57	0.07±0.05
Veneridae	*Tawera spissa* †	Native					0.04±0.04	0.07±0.05	0.04±0.04
	Ruditapes largillierti †	Native					0.89±0.33	1.61±0.69	1.04±0.75
	Bassina yatei †	Native						0.04±0.04	
Mactridae	*Cyclomactra ovata* †	Native			0.04±0.04				
Hiatellidae	*Hiatella arctica* †	Native			0.43±0.16			0.82±0.21	1.21±0.30
Polyplacophora	Unidentified species †	Unknown			0.04±0.04				0.07±0.05
Ischnochitonidae	*Ischnochiton maorianus* †	Native							
Acanthochitonidae	*Cryptoconchus porosus*	Native	0.11±0.11		0.50±0.20			0.07±0.07	
	Acanthochitona zelandica †	Native			0.04±0.04				
BRYOZOA	Unidentified species 1	Unknown				0.04±0.04			
	Unidentified species 2	Unknown						0.07±0.07	
	Unidentified species 3	Unknown				0.04±0.04			
	Unidentified species 4	Unknown					0.04±0.04		
	Unidentified species 5	Unknown					0.68±0.14	0.11±0.06	
	Unidentified species 6	Unknown					0.04±0.04		
	Unidentified species 7	Unknown							0.04±0.04
	Unidentified species 8	Unknown							0.04±0.04
	Unidentified species 9	Unknown							0.04±0.04
Scruparіidae	*Scruparis ambigua*	Introduced					4.29±1.11	2.86±1.09	0.18±0.18
Membraniporidae	*Conopeum seurati*	Introduced					0.14±0.11		
Electridae	*Electra* cf. *tenella*	Introduced				0.25±0.10	0.32±0.13	0.04±0.04	
Calloporidae	*Crassimarginatella* sp.	Unknown					0.86±0.48	2.54±2.28	5.50±2.76
Chaperiidae	*Chaperiopsis cervicornis*	Native	0.04±0.04			0.36±0.13	1.25±0.40		
Lichenoporidae	*Tubulipora* sp.	Unknown					0.07±0.05	0.04±0.04	
Bugulidae	*Bugula flabellata*	Introduced	1.14±0.64		0.04±0.04	0.54±0.12	0.11±0.06	0.21±0.09	
	Bugula neritina	Introduced	0.32±0.32		0.64±0.40	0.18±0.07	0.82±0.54	0.21±0.08	0.07±0.05
	Bugula stolonifera	Introduced					0.04±0.04		
Beaniidae	*Beania* sp.	Unknown				0.82±0.17	2.64±0.60	0.04±0.04	

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m concrete	6 m concrete
BRYOZOA									
Cabereidae	*Caberea rostrata*	Native				0.04±0.04		0.04±0.04	
	Caberea zelandica	Native					0.04±0.04		
	Tricellaria occidentalis	Introduced					0.14±0.07		
Eurystomelliidae	*Eurystomella* sp.	Unknown					0.04±0.04		
Archnopusiidae	*Arachnoposia unicornis*	Native				0.04±0.04	0.04±0.04	0.14±0.07	0.07±0.05
Cryptosulidae	*Cryptosula pallasiana*	Introduced	0.75±0.75			0.11±0.06	0.29±0.10	0.04±0.04	0.32±0.22
Watersiporidae	*Watersipora subtorquata*	Introduced	6.04±1.95	0.04±0.04	3.57±1.20	4.64±1.00	8.07±1.41	3.00±0.45	14.86±2.34
Microporellidae	*Fenestrulina* cf. *disjuncta*	Unknown				0.04±0.04	0.29±0.25		
Crisiidae	*Crisia* cf. *zelandica*	Native				0.04±0.04			0.11±0.08
Densiporidae	*Favosipora* sp.	Unknown				0.04±0.04	0.07±0.05		0.04±0.04
ANNELIDA									
Paraonidae	Unidentified species †	Unknown			0.04±0.04				
Spionidae	Unidentified species †	Unknown							0.11±0.06
Cirratulidae	Unidentified species †	Unknown						0.04±0.04	0.14±0.11
Capitellidae	*Notomastus zeylanicus* †	Native						0.07±0.05	0.07±0.05
	Heteromastus filiformis †	Native						0.18±0.09	0.04±0.04
Opheliidae	*Armandia maculate* †	Native						0.18±0.12	0.14±0.07
Phyllodocidae	Unidentified species †	Unknown			0.21±0.12			0.07±0.05	0.64±0.14
Polynoidae	Unidentified species †	Unknown			0.96±0.29		0.07±0.05	0.64±0.24	1.93±0.53
Sigalionidae	Unidentified species †	Unknown					0.07±0.07		0.07±0.05
Hesionidae	Unidentified species †	Unknown			1.75±0.46	0.14±0.11	0.25±0.10	1.00±0.33	7.04±1.39
Syllidae	Unidentified species †	Unknown			0.07±0.05				0.32±0.10
	Sphaerosyllis hirsula †	Native					1.43±0.31	2.07±0.78	0.93±0.36
Nereidae	Unidentified species †	Unknown			3.36±0.40	0.04±0.04	2.17±0.77	0.18±0.09	2.11±0.60
	Perinereis amblyodonta †	Native			0.04±0.04				
	Perinereis nutria †	Native							0.07±0.07
Glyceridae	Unidentified species †	Unknown					0.04±0.04		
Nephtyidae	*Aglaophamus* sp. †	Unknown							0.04±0.04

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m concrete	6 m concrete
ANNELIDA									
Eunicidae	Unidentified species †	Unknown			0.21±0.09			0.11±0.06	0.07±0.05
Lumbrineridae	Unidentified species †	Unknown						0.07±0.05	
Dorvilleidae	Unidentified species †	Unknown			0.04±0.04	0.04±0.04	0.14±0.08	0.04±0.04	1.14±0.28
	Dorvillea australiensis †	Native			0.04±0.04				
Terebellidae	Unidentified species †	Unknown			1.57±0.49		0.29±0.11		
Sabellidae	Unidentified species †	Unknown			0.14±0.08				
Serpulidae	Unidentified species	Unknown	1.25±0.37		0.07±0.05	4.18±1.11	2.79±0.55	0.18±0.07	1.43±0.54
	Pomatoceros caeruleus	Native			0.04±0.04			2.29±0.70	0.04±0.04
	Pomatoceros terranovae	Native			0.04±0.04			1.82±0.61	3.14±0.89
	Galeolaria hystrix	Native	1.86±0.46		1.00±0.21	0.04±0.04		0.54±0.20	0.82±0.43
	Vermiliopsis sphaeropomatus	Native			0.18±0.07				
Spirorbinae	*Spirorbis* sp.	Unknown	0.11±0.11		0.14±0.11	2.86±0.72	5.00±0.84	1.86±0.72	4.89±1.95
CRUSTACEA									
Amphipoda	Unidentified species †	Unknown			4.39±3.05			11.68±2.60	0.86±0.86
Isopoda	Flabellifera †	Unknown						0.21±0.18	
Tanaidacea	Unidentified species †	Unknown				0.04±0.04		0.43±0.30	
Decapoda									
Paguridae	*Pagurus* sp. †	Unknown			0.07±0.07				
Porcellanidae	*Petrolisthes novaezelandiae* †	Native			0.32±0.14			0.11±0.11	0.04±0.04
	Petrocheles spinosos †	Native			0.21±0.16				
Majidae	*Notomithrax minor*	Native			0.04±0.04				
	Notomithrax peronii	Native			0.11±0.08				
Hymenosomatidae	*Halicarcinus innominatus* †	Native						0.11±0.08	
	Halicarcinus cookii †	Native			0.11±0.06	0.04±0.04		0.54±0.23	0.04±0.04
	Halicarcinus ovatus †	Native							0.32±0.16
	Halicarcinus varius †	Native			0.46±0.25				
Thoracica									
Balanidae	*Balanus* sp.	Unknown			0.04±0.04				
	Balanus trigonus	Introduced			0.04±0.04				
	Elminius modestus	Native	0.25±0.12			1.86±0.30	3.39±0.65	0.04±0.04	0.11±0.08

Taxonomic group	Genus species	Origin	Pre-wrap	Post-wrap	Baseline	3 m plastic	6 m plastic	3 m concrete	6 m concrete
ECHINODERMATA									
Echinometridae	*Notechinus albocinctus*	Native			0.04±0.04				0.14±0.14
Asteriidae	*Asterina regularis*	Native	0.04±0.04		0.07±0.05	0.18±0.18	0.07±0.07	0.14±0.10	0.32±0.22
	Patiriella regularis	Native							
CHORDATA									
Urochordata	Unidentified solitary species	Unknown				0.68±0.31	0.07±0.07		
	Unidentified colonial species	Unknown				0.54±0.11			
Polyclinidae	*Aplidium* sp.	Unknown	3.00±2.03		0.79±0.68		0.21±0.11	1.04±1.04	
Didemnidae	Unidentified species 1	Unknown	0.57±0.28	0.04±0.04	0.07±0.07	0.71±0.26	2.32±0.76	0.79±0.25	
	Unidentified species 2	Unknown			1.61±1.36				
	Unidentified species 3	Unknown	0.93±0.39	0.14±0.14					3.36±1.31
	Unidentified species 4	Unknown	0.18±0.18						2.79±1.72
	Didemnum vexillum	Native	35.14±6.52	2.82±1.87	38.39±5.10	0.11±0.11	10.39±3.09	18.68±6.32	29.29±6.21
CHORDATA									
Urochordata									
Botrylliinae	*Botrylloides leachii*	Introduced			0.68±0.51	0.04±0.04	0.04±0.04		
Styelidae	*Cnemidocarpa bicornuta*	Native	0.25±0.18	0.14±0.08	0.18±0.09	0.25±0.18	0.14±0.14		
	Cnemidocarpa vicomuata	Native		0.04±0.04					
	Asterocarpa cerea	Introduced	0.14±0.14		0.25±0.22				
Pyuridae	*Pyura rugata*	Native	2.64±1.17	0.25±0.25	1.14±0.39				
	Pyura suteri	Native			0.07±0.07				
	Microcosmus sp.	Unknown			0.07±0.07				
	Microcosmus australis	Native			0.07±0.07				
	Overall mean % Cover		**74.89**	**3.46**	**67.86**	**56.07**	**63.07**	**38.89**	**69.86**
	se		**5.21**	**1.92**	**4.44**	**6.20**	**3.44**	**6.48**	**3.87**

Appendix 7

A list of all species found amongst core samples collected during the baseline assessment (prior to the application of the dredge spoil), the three and six month assessments (for control and treatment A and B plots). Figures within the table refer to the average abundance and associated standard error of the species per for various assessment periods. Blank spaces refer to zero abundance. Origin refers to each organisms known place of origin relative to New Zealand waters (refer to Section 2.2.3 for further explanation).

Taxonomic group	Genus species	Status	Baseline	3 Month assessment			6 Month assessment		
				Control	Treat A	Treat B	Control	Treat A	Treat B
PLANTAE									
Rhodophyceae									
Ceramiaceae	*Anotrichium crinitum*	Unknown					0.05±0.05	0.05±0.05	
Delesseriaceae	*Hymenena palmata*	Unknown						0.10±0.10	0.20±0.09
ANIMALIA									
CNIDARIA									
Hydrozoa									
Edwardsiidae	*Edwardsia* sp.	Unknown	0.20±0.09	0.05±0.05	0.05±0.05		0.35±0.25	0.15±0.08	0.20±0.12
PLATYHELMINTHES	Unidentified species	Unknown		0.05±0.05	0.05±0.05	0.05±0.05			
NEMERTEA	Unidentified species	Unknown	0.15±0.08	0.10±0.07	0.05±0.05	0.05±0.05	0.10±0.07	0.20±0.09	0.10±0.07
	Cerebratulus sp.	Unknown		0.05±0.05					
NEMATODA	Unidentified species	Unknown		0.10±0.07	0.10±0.07	0.25±0.10	0.35±0.13	0.15±0.11	0.25±0.10
BRACHIOPODA									
Terebratellidae	*Waltonia inconspicua*	Native	0.05±0.05						
MOLLUSCA									
Polyplacophora	Unidentified species	Unknown	0.05±0.05			0.10±0.10			
Lepidopleuridae	*Leptochiton inquinatus*	Native	0.20±0.12	0.20±0.16	0.10±0.07		0.05±0.05	0.10±0.07	
Ischnochitonidae	*Ischnochiton maorianus*	Native	0.10±0.07						
Gastropoda									
Prosobranchia									
Calyptraeidae	*Zegakrus tenuis*	Native							0.05±0.05
Trochoidae	*Trochus viridis*	Native						0.15±0.08	0.10±0.07
Cephalaspidae	*Eatoniella* sp.	Native	0.05±0.05						
Turritellidae	*Maoricolpus roseus*	Native	0.35±0.18				0.35±0.18	0.05±0.05	0.20±0.12
Muricidae	*Xymene* sp.	Native					0.05±0.05	0.05±0.05	

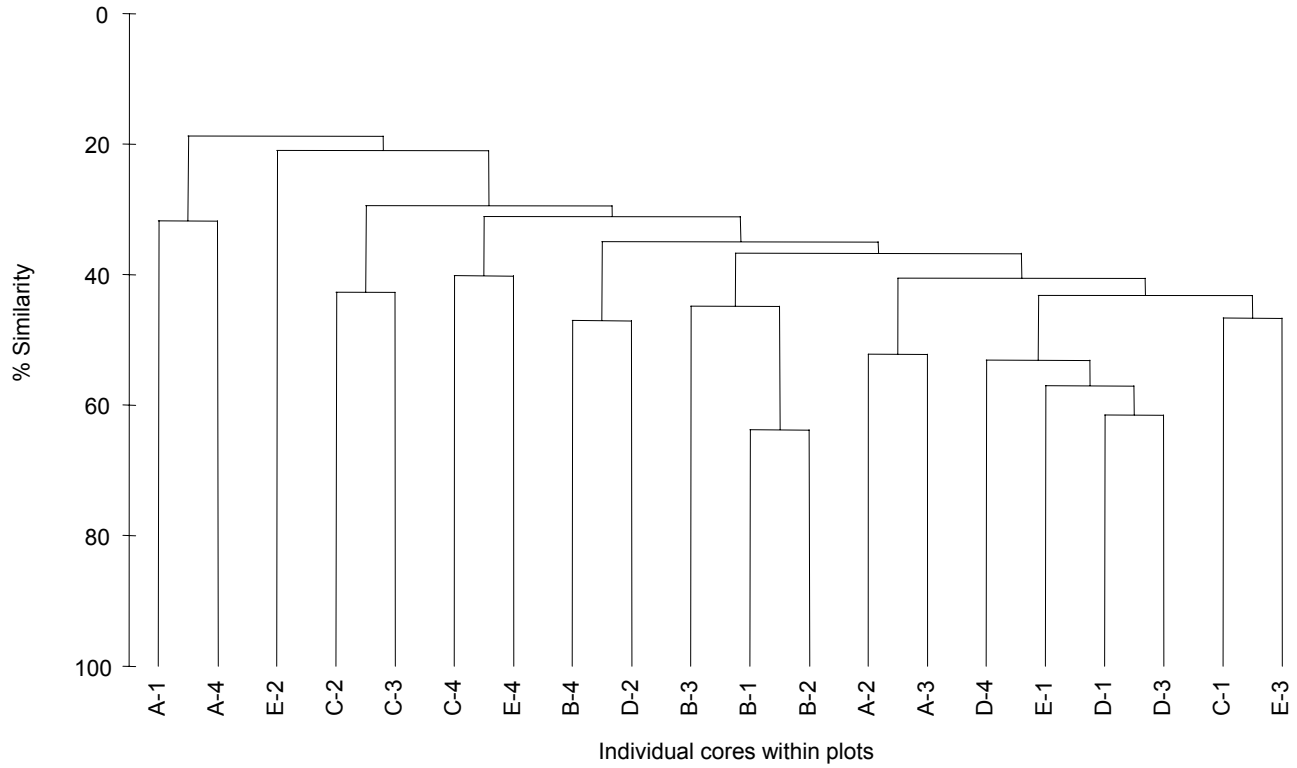
Taxonomic group	Genus species	Status	Baseline	3 Month assessment			6 Month assessment		
				Control	Treat A	Treat B	Control	Treat A	Treat B
MOLLUSCA									
Gastropoda									
Prosobranchia									
Olividae	*Amalda* sp.	Native		0.10±0.07		0.10±0.07			
	Amalda mucronata	Native			0.15±0.08			0.05±0.05	0.05±0.05
Turridae	*Neoguraleus* sp.	Native	0.10±0.07	0.05±0.05	0.05±0.05	0.05±0.05			
Pyramidellidae	*Turbonilla* sp.	Native	0.05±0.05						
Opisthobranchia									
Philinidae	*Philine auriformis*	Native	0.05±0.05				0.05±0.05		
Bivalvia	Unidentified species	Unknown	0.05±0.05	0.05±0.05					
Mytilidae	*Mytilus* sp.	Native	0.05±0.05						
	Modiolarca impacta	Native	0.05±0.05						
	Aulacomya atra maoriana	Native	0.05±0.05	0.05±0.05					
Pectinidae	*Chlamys* sp.	Unknown	0.67±0.15	0.15±0.08					
Limidae	*Limaria orientalis*	Introduced		0.10±0.07		0.25±0.20	0.10±0.07		0.05±0.05
Thyasiridae	*Maorithyas marama*	Native	0.05±0.05		0.05±0.05		0.10±0.25	0.05±0.05	
Ungulinidae	*Diplodonta globus*	Native				0.05±0.05			
Erycinidae	*Melliteryx parva*	Native	0.10±0.25			0.10±0.25			
	Borniola reniformis	Native			0.05±0.05	0.05±0.05			0.05±0.05
	Arthritica bifurca	Native	1.10±0.38	2.21±0.50	1.00±0.43	0.70±0.29	0.20±0.20	0.45±0.17	0.95±0.29
Galeommatidae	*Scintillona zelandica*	Native					0.25±0.12		
Carditidae	*Cardita aoteana*	Native				0.05±0.05			
	Pleuromeris sp.	Unknown	0.05±0.05		0.05±0.05				
Cardiidae	*Nemocardium pulchellum*	Native	0.20±0.12	0.70±0.21	0.50±0.20	0.25±0.14	0.10±0.07	0.35±0.15	0.35±0.21
Tellinidae	*Serratina charlottae*	Native	0.05±0.05	0.05±0.05				0.05±0.05	
Psammobiidae	*Soletellina* sp.	Native							0.05±0.05
Semelidae	*Theora lubrica*	Introduced	2.25±0.91	7.00±1.26	4.00±1.81	7.50±2.35	1.60±0.36	1.35±0.43	1.55±0.56
	Leptomya retiaria	Native	1.45±0.91	3.45±0.62	0.60±0.21	1.10±0.37	0.25±0.12	0.05±0.21	0.40±0.15
Veneridae	*Dosina zelandica*	Native	0.40±0.15	0.05±0.05		0.05±0.05		0.05±0.05	0.05±0.05
	Dosinia greyi	Native	0.05±0.05						
	Dosinia lambata	Native	0.05±0.05			0.05±0.05	0.05±0.05	0.05±0.05	0.05±0.05

Taxonomic group	Genus species	Status	Baseline	3 Month assessment			6 Month assessment		
				Control	Treat A	Treat B	Control	Treat A	Treat B
MOLLUSCA									
Bivalvia									
	Dosinia lambata	Native	0.05±0.05			0.05±0.05	0.05±0.05	0.05±0.05	0.05±0.05
	Tawera spissa	Native	0.55±0.17	1.15±0.22	0.90±0.33	0.30±0.11	0.15±0.08	0.45±0.17	0.25±0.12
	Ruditapes largillierti	Native	0.25±0.10	0.70±0.24	0.60±0.20	0.35±0.17	0.15±0.11	0.25±0.12	0.05±0.05
	Bassina yatei	Native	0.05±0.05			0.05±0.05			
Corbulidae	*Corbula zelandica*	Native	0.45±0.17	0.25±0.18	0.05±0.05	0.30±0.16	0.30±0.13	0.35±0.22	0.35±0.15
Hiatellidae	*Hiatella arctica*	Native	0.05±0.05	0.05±0.05		0.05±0.05			
Thraciidae	*Thracia* sp.	Unknown				0.35±0.35			
Myochamidae	*Hunkydora* sp.	Unknown			0.05±0.05	0.05±0.05			
SIPUNCULA	Unidentified species	Unknown				0.10±0.07			0.05±0.05
	Phascolosoma annulatum	Native						0.05±0.05	
ANNELIDA									
Orbiniidae	Unidentified species	Unknown		0.15±0.08				0.05±0.05	0.20±0.09
	Orbinia papillosa	Native	0.15±0.11			0.05±0.05	0.20±0.09	0.05±0.05	0.10±0.10
Paraonidae	Unidentified species	Unknown	0.15±0.11	0.70±0.23	0.55±0.18	0.55±0.23	0.10±0.07	0.30±0.18	0.40±0.11
Cossuridae	Unidentified species	Unknown		0.05±0.05					
	Cossura consimilis	Unknown	0.10±0.07	0.10±0.07	0.20±0.12	0.05±0.05	0.05±0.05		
Spionidae	*Prionospio* sp.	Unknown	0.15±0.11				0.85±0.27	0.05±0.05	0.55±0.21
	Prionospio pinnata	Native		0.05±0.05	0.05±0.05			0.15±0.11	0.05±0.05
	Unidentified species	Unknown	0.25±0.12	0.55±0.20	0.15±0.08	0.65±0.27		0.10±0.10	0.15±0.08
Cirratulidae	Unidentified species	Unknown	0.60±0.18	0.80±0.20	0.50±0.20	0.65±0.29	0.50±0.18	0.90±0.28	0.70±0.22
Capitellidae	Unidentified species	Unknown	0.20±0.12						
	Notomastus zeylanicus	Native	0.65±0.18	0.85±0.20	0.70±0.27	0.90±0.23	0.80±0.19	0.80±0.26	0.90±0.19
	Heteromastus filiformis	Native	0.25±0.10	1.20±0.53	0.60±0.28	1.35±0.60	0.35±0.13	0.40±0.15	0.50±0.24
Maldanidae	Unidentified species	Unknown	0.60±0.21	0.85±0.27	0.05±0.05	0.35±0.20	0.80±0.25	0.10±0.22	0.60±0.21
Opheliidae	*Armandia maculata*	Native				0.10±0.07	0.20±0.12	0.10±0.07	0.45±0.18
Phyllodocidae	Unidentified species	Unknown	0.10±0.10	0.05±0.05			0.05±0.05	0.05±0.05	0.15±0.15
Polynoidae	Unidentified species	Unknown	0.15±0.11	0.05±0.05		0.20±0.09	0.30±0.13		0.10±0.07
Sigalionidae	Unidentified species	Unknown	2.10±0.58	3.75±0.58	0.07±0.21	1.55±0.46	0.80±0.16	0.40±0.11	1.15±0.37
Hesionidae	Unidentified species	Unknown	0.85±0.10	0.40±0.53	0.40±0.54	0.45±0.55	0.50±0.13	0.65±0.15	0.35±0.24
Syllidae	Unidentified species	Unknown	0.50±0.10	0.05±0.05	0.50±0.35	0.55±0.31	0.15±0.08	0.20±0.12	0.30±0.13

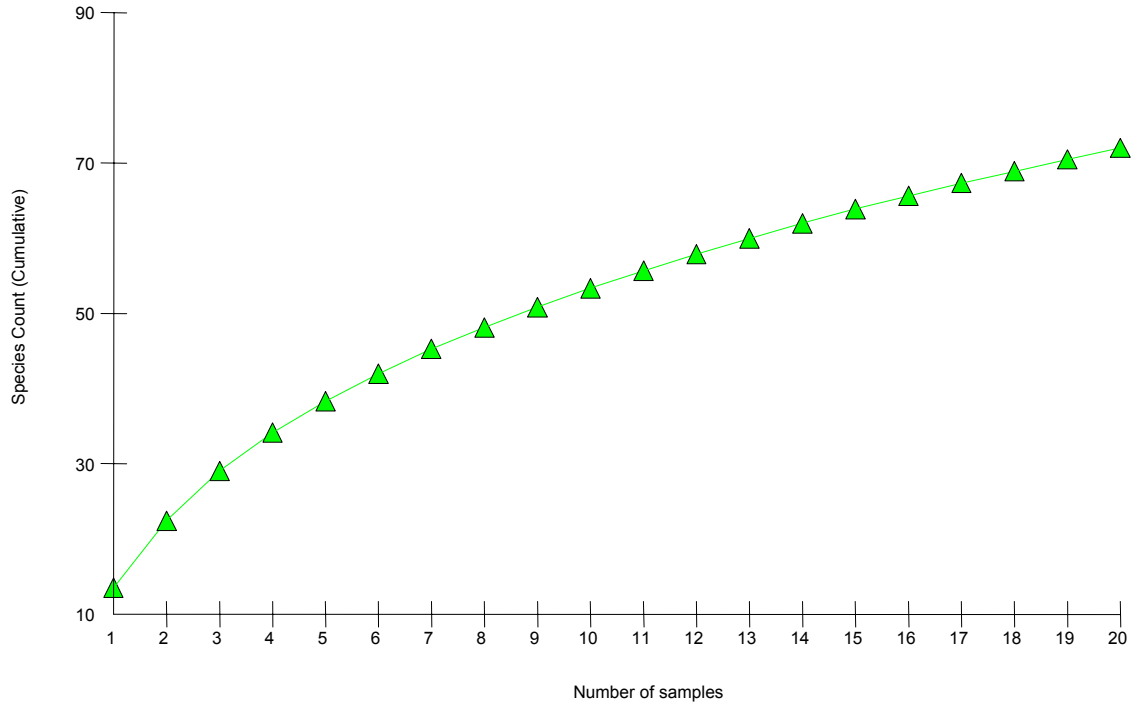
Taxonomic group	Genus species	Status	Baseline	3 Month assessment			6 Month assessment		
				Control	Treat A	Treat B	Control	Treat A	Treat B
ANNELIDA									
Syllidae	*Sphaerosyllis hirsuta*	Native	0.20±0.12	0.50±0.15	0.30±0.21	0.65±0.37	0.20±0.09	0.45±0.20	0.30±0.13
Nereidae	Unidentified species	Unknown			0.15±0.11	0.25±0.18		0.05±0.05	
Glyceridae	Unidentified species	Unknown	1.00±0.25	1.10±0.35	0.75±0.22	1.30±0.38	0.35±0.18	0.90±0.22	0.80±0.24
	Glycera sp.	Unknown					0.05±0.05		
	Glycera americana	Native					0.05±0.05		
Goniadidae	*Goniada* sp.	Unknown	0.05±0.05				0.55±0.21	0.15±0.11	0.20±0.16
Nephtyidae	Unidentified species	Unknown		0.05±0.05					
	Aglaophamus sp.	Unknown	0.95±0.25	2.30±0.52	0.25±0.10	0.85±0.26	1.70±0.34	0.85±0.29	1.15±0.27
Eunicidae	Unidentified species	Unknown		0.30±0.11	0.10±0.07	0.85±0.45		0.15±0.11	0.15±0.11
Lumbrineridae	Unidentified species	Unknown	0.70±0.23	1.00±0.23	0.60±0.23	0.15±0.41	0.90±0.19	0.60±0.13	0.50±0.20
Dorvilleidae	Unidentified species	Unknown	0.10±0.10	0.35±0.11	0.20±0.12	0.30±0.16	0.15±0.11	0.40±0.27	0.30±0.13
Oweniidae	*Owenia fusiformis*	Native							0.05±0.05
Flabelligeridae	Unidentified species	Unknown	0.05±0.05						
Pectinariidae	Unidentified species	Unknown		0.15±0.11	0.05±0.05			0.05±0.05	
	Pectinaria australis	Native							0.10±0.07
Ampharetidae	Unidentified species	Unknown					0.05±0.05		
Terebellidae	Unidentified species	Unknown	0.15±0.11	0.20±0.09		0.20±0.12	0.30±0.13	0.10±0.07	0.20±0.09
Sabellidae	Unidentified species	Unknown	0.15±0.11	0.05±0.05			0.50±0.17		0.30±0.13
	Sabella sp.	Unknown					0.05±0.05		
Serpulidae	Unidentified species	Unknown	0.05±0.05	0.05±0.05					
PRIAPULA	Unidentified species	Unknown	0.10±0.07						
CRUSTACEA									
Ostracoda	Unidentified species	Unknown	2.65±0.67	2.65±0.52	0.65±0.21	1.40±0.47	2.00±0.26	1.55±0.36	2.55±0.47
Phyllocarida	*Nebalia* sp.	Unknown	0.05±0.05	0.15±0.11			0.10±0.10		0.05±0.05
Mysidacea	Unidentified species	Unknown		0.05±0.05					
Tanaidacea	*Tanaid* sp.	Unknown		0.65±0.40	0.05±0.05	0.15±0.08	0.15±0.08	0.10±0.07	
Isopoda	Flabellifera	Unknown	0.05±0.05				0.05±0.05	0.05±0.05	
Amphipoda	Unidentified species	Unknown	1.05±0.29	2.25±0.39	0.90±0.23	1.75±0.53	3.20±0.51	3.10±0.65	3.85±0.67
Cumacea	Unidentified species	Unknown		0.05±0.05		0.15±0.08	0.10±0.07	0.10±0.07	0.25±0.12

Taxonomic group	Genus species	Status	Baseline	3 Month assessment			6 Month assessment		
				Control	Treat A	Treat B	Control	Treat A	Treat B
CRUSTACEA									
Decapoda	Unidentified species	Unknown							0.15±0.11
Natantia	Unidentified species	Unknown							0.15±0.11
Crangonidae	*Pontophilus australis*	Native	0.05±0.05						
Alpheidae	*Alpheus* sp.	Unknown					0.05±0.05	0.05±0.05	
Paguridae	Unidentified species	Unknown	0.70±0.26	0.15±0.08	0.40±0.15	0.10±0.07		0.15±0.08	0.05±0.05
	Pagurus sp.	Unknown	0.05±0.05				0.20±0.12	0.05±0.05	0.20±0.12
Majidae	*Notomithrax minor*	Native							0.05±0.05
	Notomithrax ursus	Native	0.10±0.07						
Hymenosomatidae	*Halicarcinus* sp.	Native	0.05±0.05						
	Halicarcinus cookii	Native	0.05±0.05	0.20±0.09	0.05±0.05		0.60±0.32	0.15±0.11	0.25±0.05
	Halicarcinus ovatus	Native	0.05±0.05	0.05±0.05					
ECHINODERMATA									
Asteroidea									
Echinoidae	*Echinocardium cordatum*	Native		0.10±0.07				0.05±0.05	
Asteriidae	*Patiriella regularis*	Native	0.10±0.07				0.05±0.05		
Ophiuroidea	Unidentified species	Unknown	0.10±0.07	0.15±0.08	0.15±0.08	0.25±0.16	0.25±0.12	0.40±0.18	0.40±0.21
Echinoidea									
Fibulariidae	*Echinocyamus polypous*	Native	0.05±0.05						
Holothuroidea	Unidentified species	Unknown		0.10±0.07		0.05±0.05			
Chiridotidae	*Trochodota dendyi*	Native			0.05±0.05		0.15±0.08	0.15±0.11	0.05±0.05
	Chiridota nigra	Native					0.05±0.05		
CHORDATA									
Urochordata									
Styelidae	*Cnemidocarpa* sp.	Native					0.05±0.05		

Appendix 8



Dendogram showing the similarity in community composition amongst core samples taken from five replicate plots during the baseline assessment.



Cumulative species-area curve illustrating the relationship between sampling effort (i.e., number of quadrats) verses the detection of a new species.

Appendix 9

A list of species found at various depths on the rocky substrate underneath Waimahara Wharf. Figures within the table refer to the average percentage cover and associated standard errors of each species calculated amongst 12 quadrats per depth during each assessment periods. Origin refers to each organisms known place of origin relative to New Zealand waters (refer to Section 2.2.3 for further explanation).

Taxonomic group	Genus species	Origin	Pre-treatment assessment				Post-treatment assessment			
			2 m	6 m	10 m	14 m	2 m	4 m	10 m	14 m
PLANTAE										
Rhodophyceae										
Corallinaceae	Coralline algae	Unknown		0.08±0.08	2.83±1.29	3.92±1.32		1.17±0.46	2.17±0.72	3.25±0.58
Rhodomelaceae	Unidentified species	Unknown			1.42±1.00	1.67±1.42				
ANIMALIA										
PORIFERA										
Cellularia	Unidentified species 1	Unknown	0.42±0.34	2.25±1.78	3.33±3.33		0.92±0.31		0.50±0.36	
	Unidentified species 2	Unknown	1.83±1.83	3.42±2.84		0.92±0.92		0.25±0.25	1.67±0.74	
Crellidae	*Crella incrustans*	Native	4.42±2.39	10.50±3.18	11.58±5.61	6.33±3.53				
MOLLUSCA										
Nudibranchia	Unidentified species	Unknown				0.67±0.67				
Gastropoda										
Prosobranchia										
Turritellidae	*Maoricolpus roseus*	Native				0.17±0.17				
Bivalvia										
Mytilidae	*Mytilus galloprovincialis*	Native	3.42±2.99	1.17±0.79			3.00±1.25	1.33±0.68		
	Perna canaliculus	Native	0.50±0.50	4.08±2.22			0.83±0.41	1.17±0.68		
	Aulacomya atra maoriana	Native	12.58±5.89	1.67±0.87			7.42±2.02	1.17±0.93		
Anomiidae	*Monia zelandica*	Native	0.50±0.50			0.08±0.08	0.08±0.08	0.58±0.19	1.17±0.24	0.33±0.22
BRYOZOA										
Bugulidae	Bugula neritina	Introduced	0.58±0.58		0.33±0.33					
Calloporidae	Crassimarginatella sp.	Unknown					6.50±1.50	4.25±1.33	2.25±0.92	1.17±0.51
Watersiporidae	Watersipora subtorquata	Introduced	0.75±0.54		0.25±0.25		5.58±1.91	0.42±0.42		

Taxonomic group	Genus species	Origin	Pre-treatment assessment				Post-treatment assessment			
			2 m	6 m	10 m	14 m	2 m	4 m	10 m	14 m
ANNELIDA										
Serpulidae	Unidentified species	Unknown	1.67±0.57	0.42±0.29			5.17±0.64	3.25±0.95	0.50±0.42	0.08±0.08
	Galeolaria hystrix	Native	3.67±0.99	3.25±1.33	2.33±0.64	1.92±0.50	7.58±1.82	8.50±1.94	8.67±1.31	3.33±0.50
Spirorbidae	*Spirorbids sp.*	Unknown	7.67±2.29	2.92±1.89		0.58±0.58	10.75±1.00	4.42±1.13		
CRUSTACEA										
Thoracica										
Balanidae	*Elminus modestus*	Native	8.58±1.71	5.00±1.59			12.00±1.13	4.25±1.55		
ECHINODERMATA										
Echinometridae	*Notechinus albocinctus*	Native	0.08±0.08							
Asteriidae	*Asterina regularis*	Native	0.50±0.50							
	Patiriella regularis	Native	0.92±0.40	0.25±0.18		0.50±0.50				0.25±0.13
	Coscinasterias calamaria	Native					0.67±0.47	0.33±0.33		
CHORDATA										
Urochordata										
Polyclinidae	*Aplidium* sp.	Unknown		1.67±1.67	1.92±1.36	8.92±4.61			0.67±0.58	
Didemnidae	*Didemnum vexillum*	Native	16.08±5.63	9.33±4.56	25.75±8.84	4.17±2.90	1.67±0.59	0.08±0.08	0.83±0.41	
Styelinae	*Cnemidocarpa bicornuata*	Native	0.33±0.26				3.92±1.13	3.67±1.06	2.58±0.75	1.33±0.38
Pyuridae	*Pyura rugata*	Native	0.42±0.34		0.17±0.17		2.67±0.33	3.42±0.50	2.08±0.23	0.08±0.08

Appendix 10

A list of species found on moorings during various assessment periods. Figures within the table refer to the average percentage cover and associated standard errors of each species calculated amongst 12 quadrats per assessment (i.e., 3 depths x 4 moorings). Origin refers to each species place of origin relative to New Zealand waters (refer to Section 2.2.3 for further explanation).

Taxonomic group		Genus species	Origin	Pre-treatment	Three months	Six months
PLANTAE	**Chlorophyceae**					
	Ulvaceae	*Ulva* sp.	Unknown	1.42±1.08		
		Enteromorpha sp.	Unknown	0.42±0.41		
	Phaeophyceae					
	Ralfsiaceae	*Ralfsia verrucosa*	Native	0.25±0.18		
	Alariaceae	*Undaria pinnatifida*	Introduced	1.83±1.83		
	Rhodophyceae	Unidentified species	Unknown	3.67±2.57		
		Apophlaea lyallii	Native	0.25±0.25		
		Callithamnion consanguineum	Native	0.25±0.18	90.00±6.72	77.42±3.41
ANIMALIA	**CNIDARIA**					
	Hydrozoa					
	Campanulariidae	*Obelia longissima*	Introduced	23.00±3.72		
	MOLLUSCA					
	Bivalvia	*Mytilus galloprovincialis*	Native	25.25±6.95		7.00±0.58
	Mytilidae	*Perna canaliculus*	Native	5.58±3.49		
		Aulacomya atra maoriana	Native	0.83±0.36		
	BRYOZOA					
	Bugulidae	*Bugula flabellata*	Introduced	1.00±0.61		
	Watersiporidae	*Watersipora subtorquata*	Introduced	2.00±1.02		5.33±1.89
	CHORDATA					
	Urochordata					
	Polyclinidae	*Aplidium* sp.	Unknown	0.08±0.08		
	Didemnidae	*Didemnum vexillum*	Native	29.17±8.42		3.42±2.46
	Styelidae	*Cnemidocarpa bicornuta*	Native	1.25±1.08		
		Asterocarpa cerea	Native	0.92±0.69		
	Pyuridae	*Pyura rugata*	Native	2.50±0.72		
		Pyura subtorquata	Native	0.08±0.08		
		Microcosmus australis	Native	0.25±0.02		