Davidson Environmental Ltd

# Monitoring of a relocated mussel farm in Otanerau Bay, East Bay, Marlborough Sounds: 2002-2014

Research, Survey and Monitoring Report Number 788

A report prepared for:
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# SUMMARY

The site where a mussel farm was removed in East Bay, Queen Charlotte Sound, Marlborough Sounds was monitored between 2002 to 2014. Two sites were sampled under retired mussel growing structures (backbones) and another two under retired warp structures. These data were compared with four control sites located away from mussel farms. Data on percentage cover of mussel shell debris, and the abundance of nine conspicuous surface dwelling invertebrates were collected over a 11 year period (2002-2013). Drop camera photos were also collected on two occasions to visually document impacts under warps and growing structures. Davidson and Richards (2005) collected 22 photos that were repeated at the end of the study in November 2014.

Based on the present study, there is no doubt that mussel farming can produce a detectable impact on the sea floor. This has been the focus of a number of impact studies, however, the present study investigates the changes once a mussel farm has been removed. Documenting change once the source of the potential impact is removed is another way of quantifying the level of impact.

Based on the present study and observation made by divers during the present study the following is suggested.

**Impacts:**

- Mussel shell debris can reach high levels under growing structures, often forming a layer of dead mussels over sediment. Note: in some areas of the Marlborough Sounds, beds or live mussels form under or near mussel farm lines.
- Mussel shell debris can cover a wide area under mussel growing structures.
- Mussel shell debris generally declines with increasing distance from the backbones.
- Levels of shell debris under warp structures were lower than under growing lines. Under warps shell debris is usually restricted to directly below lines.
- A number of species were negatively impacted under growing structures (e.g. giant lampshell, scallop, horse mussel). Species impacts under warps were seldom detected and when observed were minor compared to growing areas.
- Under growing structures, filter feeders (e.g. brachiopods, bivalves, worms) were more likely to be impacted by than deposit feeders (cushion seastar) or predators (11 arm seastar).
- Some species become more abundant under mussel farm growing areas compared to areas away from growing structures (e.g. 11 arm seastar, kina).
- No surface dwelling species were excluded from the areas under mussel growing structures, however, densities of some species were reduced.
- No impacts that could be linked to mussel farms were recorded from control sites. For example, both scallops and horse mussels increased in abundance at control

sites over the duration of the study, despite the presence of mussel farms in the area.

**Recovery:**

- Two types of recovery were recognised (1) species recovery, and (2) physical recovery of the habitat/substratum. The time frame for the recovery of species was less than the recovery of habitats.
- When mussel farming ceased at this site, silt and clay (mud) substrata recovered more rapidly than areas supporting coarse substratum (e.g. sorted shell and fine sand).
- Recovery of deep mud took between 5 and 11 years after the cessation of mussel farming.
- Physical recovery of coarse soft substratum took up to 11 years after the cessation of mussel farming.

It should be noted that the recovery recorded during the present study applies to mussel farms in East Bay. It is probable that mussel farm recovery rates will vary from site to site depending on environmental variables. Based on the present study and other published impact studies we conclude that:

1. Based on the present study, we conclude that the rate mussel shell declined for a mussel farm in the Marlborough Sounds will depend on natural sedimentation rates. Areas with high rates of sedimentation will exhibit a more rapid decline in mussel shell debris as this material will be smothered or buried more rapidly than areas like East Bay with low sedimentation rates.

2. The benthos under mussel farms located in high hydrodynamic regimes (e.g. moderate to strong tidal flows, high wave energy) will be impacted by a mussel farm to a lesser degree than low hydrodynamic areas (low currents, sheltered). Sites with a high impact level will likely take longer to recover than low impacted sites.

3. Sites located close to sediment sources (e.g. inner Pelorus Sound) will recovery quicker compared to sites in low turbidity/sedimentation areas. High sedimentation rates will smother mussel shell returning the benthos to a mud substratum in a relatively short period compared to low sedimentation areas. Recovery will occur at low sedimentation areas, but over a longer time frame. East Bay is located in a low sedimentation area and therefore represents recovery rates at the slow end of the spectrum.

Recovery rates will vary with depth. Deeper areas usually support finer substratum (i.e. mud and mud and shell) compared to shallow areas. This is primarily due to hydrodynamic processes such as waves and currents. At sheltered site, deep areas will recover quicker than shallow coarser substratum areas/substratum types.

# 1.0 INTRODUCTION

Few studies have investigated rates and patterns of recovery after mussel farming has ceased. Stenton-Dozey *et al*. (1999) investigated a mussel farm in Saldanha Bay, South Africa for up to three years after a mussel raft was removed. The authors stated that recovery was slow around “four years or more” and would be dependent on local conditions and the marine farming practices.

Mattsson and Linden (1983) conducted a three year programme at a production mussel farm in Sweden. The authors sampled before installation, over the crop cycle and for a short period following harvest at a low current intermittently ice covered site. The authors reported that mussel farming resulted in mussel shell accumulation up to 2800 +/- 970 individual shells per $m^2$ and that infaunal benthic communities were greatly altered. They reported that alteration of the macrofauna took only 6-15 months, but only a limited recovery was observed 18 months after harvesting.

The present study is the first long-term investigation of recovery patterns and rates after mussel farming. The study also separates biological impacts from two distinct farming areas, under retired growing structures and secondly from retired warps. Farm data are compared with control sites located in the bay, but distant to mussel farms.

# 2.0 THE STUDY

On January 23rd 2002, mussel farm number 8398 located in Otanerau Bay, East Bay, outer Queen Charlotte Sound was relocated from an off-site location to a position further west into its correct position (Figures 1 and 2). This off-site location was farmed for mussels from late 1988 till January 2001, a period of 14 years (K. Heather MDC, pers. comm.).

In February 2002, benthic monitoring of the retired farm (n = 4 sites) as well as control sites (n = 4 sites) was initiated (Davidson and Pande, 2002). The site was monitored a further four times (September 2002, February 2003, January 2004 and January 2005) and a second report was produced (Davidson and Richards 2005).

The present report presents data collected over the entire period including a further five samples (January 2007, January 2008, January 2010, December 2011, January 2013). A total of ten diver samples were collected over the 11 years study. In November 2014, a second set of drop camera images were collected from sites located as close as possible to the original photographs collected in 2005 by Davidson and Richards (2005).

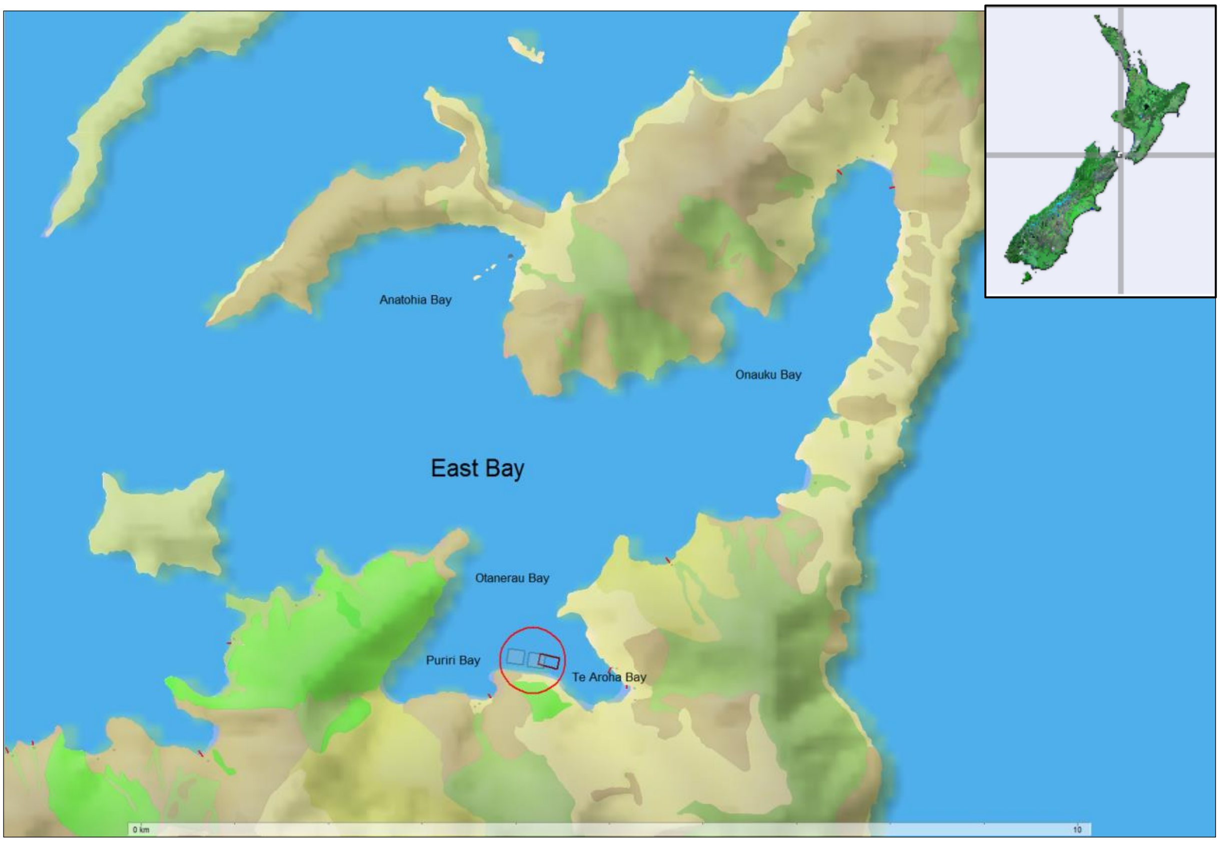


**Figure 1. Study area located in Otanerau Bay, East Bay**.

# 3.0 EAST BAY

East Bay is a large bay is located in outer Queen Charlotte Sound. It is approximately 22 km in length and covers 118 ha of sea area (Figure 1). The bay comprises three major bays Anatohia, Onauku and Otanerau as well as a number of smaller bays (e.g. Te Aroha, Puriri). The benthic environment from offshore areas of East Bay is a relatively uniform depth (i.e. 35 m to 46 m depth). Depths reduce around the bay edges and bay heads (see Navy Chart NZ615). The catchment is relatively small compared to the area of water and is fed by numerous small streams.

The intertidal shoreline of East Bay is composed of very soft, flaky, brittle slabs of weathered greywacke. Shores are characterised as pebble and granule material at bay heads, cobble and small boulder substrata along the bay sides, and bedrock substrata at headland and promontories. The shallow subtidal is an extension of the adjacent intertidal shore. In most areas, it is composed of cobble and small boulder material with or without a sparse macroalgal fringe. Subtidal cobble substratum is usually narrow (<50 m width) and grades into shelly sand and silty slopes. The flat offshore deep benthos of East Bay is dominated by mud (McKnight and Grange, 1991; Cole *et al*., 1999; Davidson and Wethey, 2001).

High sediment loading in many areas of New Zealand is usually derived from river inputs during flood events. The amount of sediment received by the marine environment is influenced by factors such as catchment size, vegetation cover, roading, geology and human activities in the catchment (Waters, 1995; Wemple *et al*., 2001; Wemple *et al*., 2003, Suttle *et al*., 2004; Coe, 2006; MacDiarmid *et al*. 2012). East Bay has no large freshwater inputs, few roads and most catchments are small and clad in regenerating vegetation. These factors act to reduce sediment loading making East Bay less turbid compared to many areas in the sheltered Sounds such as inner Pelorus Sound and Port Underwood. During most occasions, the water in East Bay is noticeably clearer than water in the adjacent Queen Charlotte Sound and Tory Channel.

Low turbidity and sediment loading is an important environmental variable for subtidal communities. Low turbidity habitats in the Marlborough Sounds are generally restricted to the outer Sounds and particular bays within the sheltered part of the Sounds. Other areas in New Zealand subject to low sediment loading include Paterson Inlet (Stewart Island), Fiordland, and offshore islands around northern North Island. It is therefore not surprising that a variety of important subtidal features are known from East Bay including red algae, giant lampshell, burrowing anemone, and spawning habitats for elephant fish (Davidson *et al*., 1995; Davidson and Wethey, 2002; Davidson and Richards, 2004; Davidson *et al.,* 2011).

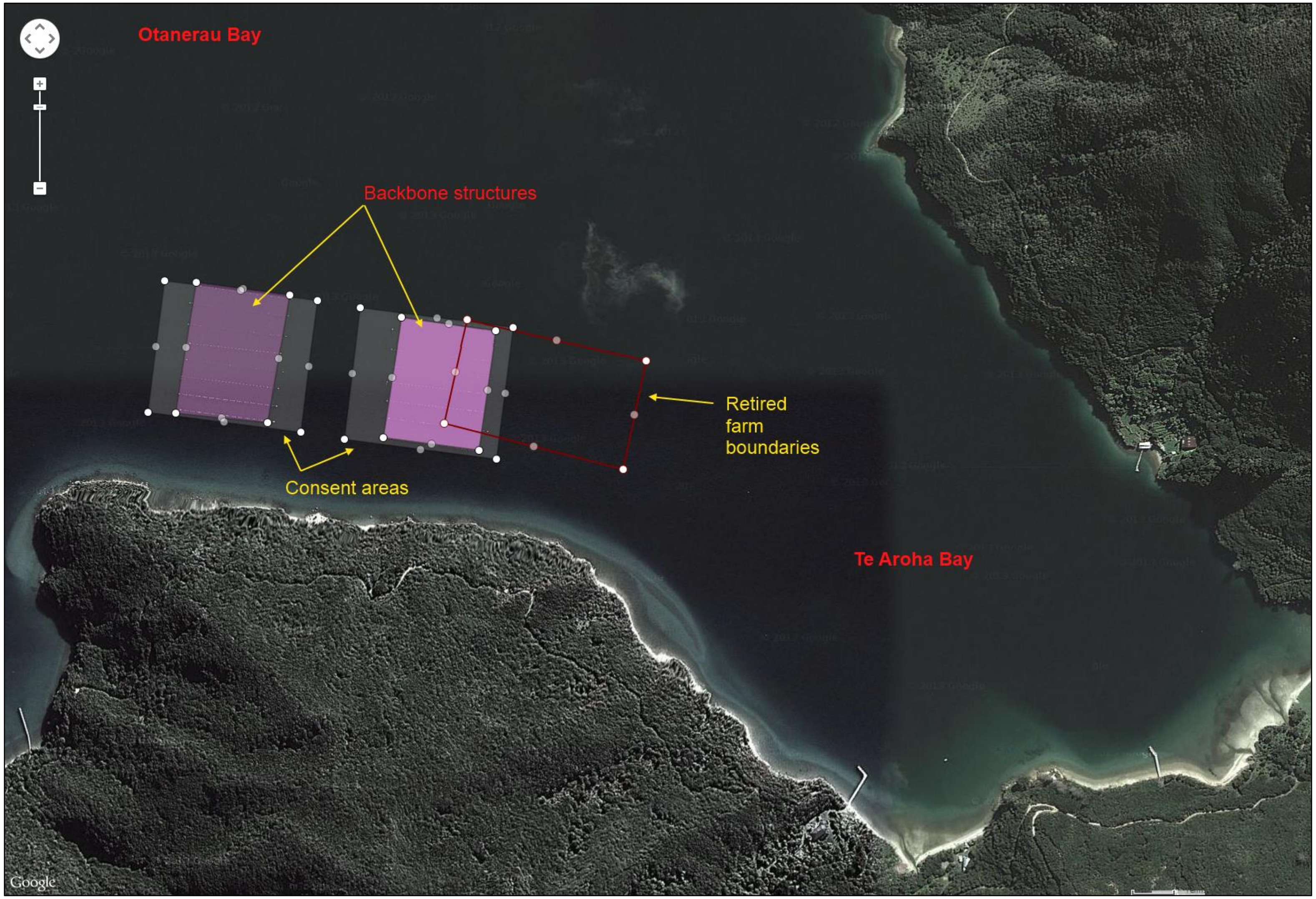


Figure 2. Location of original farm (red rectangle) and present consent areas (grey). The area presently occupied by mussel farm backbones is indicated as pink rectangles.

# 4.0 METHODS

Benthic monitoring was conducted on 10 occasions over a period of 11 years using the same methodology and divers. A Lowrance GPS connected to PC-based navigation software (TUMONZ Professional) was used to establish real time field positions for the deployment of each transect (error +/- 5 m).

## 4.1 Sample sites

A total of eight sample sites were established and repeat sampled on all sampling occasions (Table 1, Figure 3). Two transect lines were deployed where mussel growing structures (backbones and droppers) had been located, while two transects where warps had been situated (Table 1, Figure 3). Four control transects were positioned at representative locations in Puriri and Te Aroha Bays (Figure 3). Control sites have not been farmed and were positioned in comparable depths to retired farm sites.

At each site, a 150 m lead-lined transect was deployed from the survey vessel using GPS positioning. Each transect was deployed in a straight line perpendicular to the shore. Before its release, the line was dragged a short distance to ensure any loose line was straightened. The transect line was marked with plastic labels positioned at 5 m intervals along its length. Each end of the transect line was marked using a small float that extended to the surface.

**Table 1. Position of retired farm and control transects located in East Bay.**

| Transect no. | Treatment | Depth | Coordinates |
|---|---|---|---|
| Transect 1 | Impact (warps) | Deep | 41 10.34152,174 19.98082 |
| | | Shallow | 41 10.41857,174 19.97337 |
| Transect 2 | Impact (warps) | Deep | 41 10.34018,174 19.97049 |
| | | Shallow | 41 10.41623,174 19.95186 |
| Transect 3 | Impact (backbones) | Deep | 41 10.33551,174 19.94443 |
| | | Shallow | 41 10.41221,174 19.91602 |
| Transect 4 | Impact (backbones) | Deep | 41 10.33377,174 19.93610 |
| | | Shallow | 41 10.40599,174 19.90716 |
| Transect 5 | Control | Deep | 41 10.40364,174 19.35092 |
| | | Shallow | 41 10.45433,174 19.43649 |
| Transect 6 | Control | Deep | 41 10.37896,174 20.12277 |
| | | Shallow | 41 10.45822,174 20.09620 |
| Transect 7 | Control | Deep | 41 10.27383,174 20.06306 |
| | | Shallow | 41 10.25850,174 20.16810 |
| Transect 8 | Control | Deep | 41 10.17745,174 20.04987 |
| | | Shallow | 41 10.18383,174 20.15243 |

## 4.2 Sample methods

Three methods were used to sample a variety of benthic features or species.

**(1) Stratified 1m$^2$ quadrats**

The stratified quadrats were positioned by divers at 10 m intervals along each transect (n=15). Divers estimated percentage cover of mussel shell debris and the number of two species of lampshell.

**(2) Random stratified 1m$^2$ quadrats**

Three random stratified quadrats were sampled within seven predetermined 10 m intervals along each transect (i.e. 140-130 m, 120-110 m, 100-90 m, 80-70 m, 60-50 m, 40-30 m, 20-10 m). A total of 21 random stratified quadrats were sampled along each transect. Divers were instructed to swim between 2 and 8 kicks in a haphazard direction within each sampling zone. At the end of these kicks the quadrat was deployed onto the benthos with divers being careful not to look when quadrats were deployed. Once the quadrat was counted, the process was repeated until three quadrats had been collected within each sample zone. Divers estimated percentage cover of mussel shell debris, two species of lampshell and a range of conspicuous invertebrates.

**(3) Stratified 10 m$^2$ quadrats**

Large stratified quadrats consisted of 10 m long by 1 m wide quadrats sampled using a 1m$^2$ quadrat deployed contiguously, parallel and within 3 m of each side of the transect line. Divers recorded the abundance of nine pre-selected conspicuous macroinvertebrates.

### 4.2.1 Mussel shell debris

For the purpose of the study, mussel shell debris was defined *as "mussel shell originating from the activity of growing mussels*". Mussel debris included live and dead green and blue mussels that had originated from growing lines or had been scraped or fallen from backbones, floats and warps. Natural shell debris such as scallop, dog cockle and horse mussel shells were not regarded as mussel debris and were therefore not included in percentage cover estimates. Trained divers estimated percentage cover of mussel shell debris from 1m$^2$ quadrats using stratified and random stratified methods.

### 4.2.2 Density of brachiopods (lampshells)

Divers counted the number of live giant lampshell (*Neothyris lenticularis*) and common lampshell (*Terebratella sanguinea*) from 1m$^2$ quadrats using stratified and random stratified methods.

### 4.2.3 Conspicuous macroinvertebrates

Divers recorded the abundance of nine conspicuous surface dwelling macroinvertebrate species from large stratified quadrats (10 m long by 1 m wide) and 1 m$^2$ random stratified quadrats (Table 2). Occasionally other rare or uncommon invertebrates were observed but these were not sampled. Some species were very small and could not be reliably sampled visually by divers.

**Table 2 Conspicuous invertebrate species selected for sampling.**

| Common names and species |
|---|
| Scallop (Pecten novaezelandiae) |
| Horse mussel (Atrina zelandica) |
| 11 arm seastar (Coscinasterias muricata) |
| Kina (Evechinus chloroticus) |
| Cushion seastar (Patiriella regularis) |
| Sea cucumber (Stichopus mollis) |
| Snake star (Ophiopsammus maculata) |
| Pink urchin (Pseudechinus albocinctus) |
| Brooch seastar (Pentagonaster pulchellus) |

### 4.2.4 Drop camera stations

Drop camera photographs were collected in January 2005 (Davidson and Richards 2005) and at the same sites in November 2014. Davidson and Richards (2005) collected photos from within the retired farm site and adjacent areas (Figure 4). Photos were also collected from the retired warps area (i.e. photos under and east of transect 2) and from retired backbones or growing structures (i.e. photos west of transect 2). A number of photos were also collected inshore of the retired consent area. At each station, an underwater splash camera fixed to a tripod was lowered to the benthos and a still photograph collected where it landed. Davidson and Richards (2005) selected photograph stations in an effort to:

1. Obtain a representative range of habitats within the retired farm site.
2. Collect images from under retired warp and growing structures.

3. Gather information of the extent of spread of mussel shell debris on the benthos.

All photographs collected in 2005 are displayed in Appendix 2 In: Davidson and Richards (2005). Photographs collected in November 2014 were taken as close as possible to the original photos using GPS real time methodologies (Appendix 1).

## 4.3 Statistical analyses

Data collected using the random stratified methodology consisted of 21 quadrats ($1m^2$) collected from along each transect (i.e. one transect per site). Stratified data consisted of 15 quadrats, each measuring 10 $m^2$, collected from each transect (total area = 150 $m^2$ per transect. Data for all (a) all control (n = 4), (b) all retired warp (n = 2) and (c) all retired backbone sites (n = 2) were pooled for analyses. For samples collected using the random stratified methodology the numbers of values in each treatment were therefore: control n = 84, retired warp n = 42 and retired backbone n = 42. For stratified samples the number of data values was: control n = 60, retired warp n = 30 and retired backbone n = 30.

Data collected using the two sampling methods were not pooled for a number of reasons including different quadrat sizes and the irregular distribution of mussel farm impacts due to the deployment of mussels on parallel, spaced backbones. An initial test of data failed the normality test in all years and samples. The nonparametric Mann-Whitney Rank Sum Test was adopted to compare raw data collected on each sampling occasion between the three treatments for the two sampling methods. This method has a greater efficiency than the t-test on non-normal distributions, such as a mixture of normal distributions, and it is nearly as efficient as the t-test on normal distributions. The test compares mean ranks rather than medians with ranks being either different (high ranks will belong to one condition) or both being similar (high and low ranks will be distributed fairly evenly between conditions and the rank totals will be fairly similar. The null hypothesis was that distributions of each group were equal so that the probability of an observation from one treatment (X) exceeding an observation from the second treatment (Y) equals the probability of an observation from Y exceeding an observation from X. That is, there is a symmetry between populations with respect to probability of random drawing of a larger observation. A small P value rejects the null hypothesis that the difference is due to random sampling, and conclude instead that the populations are distinct. For a large U value, the data does not give any reason to reject the null hypothesis. This is not the same as saying that the two populations are the same, i.e. there is simply no compelling evidence that they differ. For a small U value there is less chance of the difference to have occurred by chance. All comparisons had sufficient power to perform the test.

Statistical tests for snake stars, pink urchin, and brooch seastar were not attempted as densities were extremely low making interpretation unrelaiable.

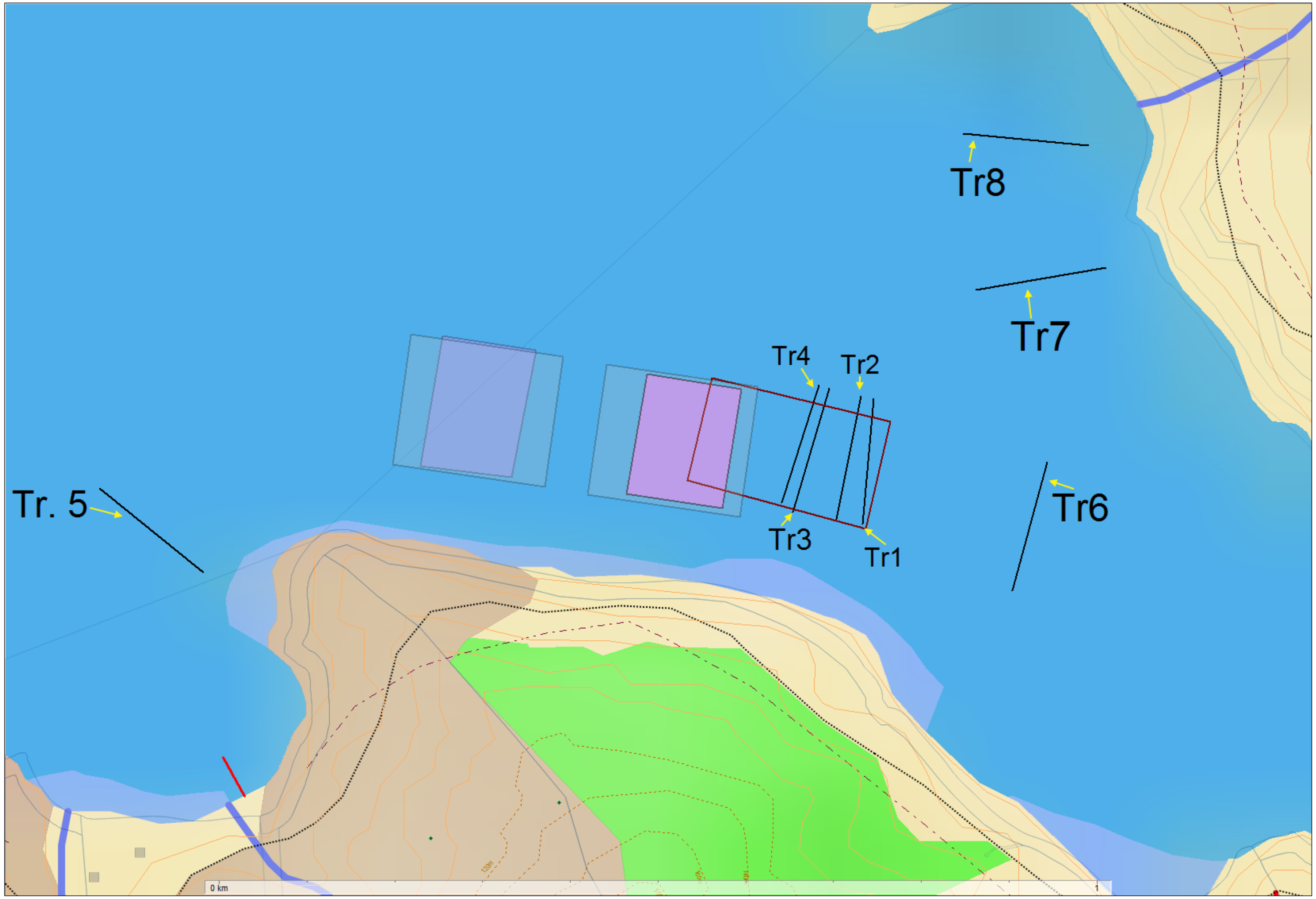


Figure 3. Location of two retired warp transects (1 and 2), two retired growing structure transects (3 and 4) and control sites (transects 5-8) in East Bay.

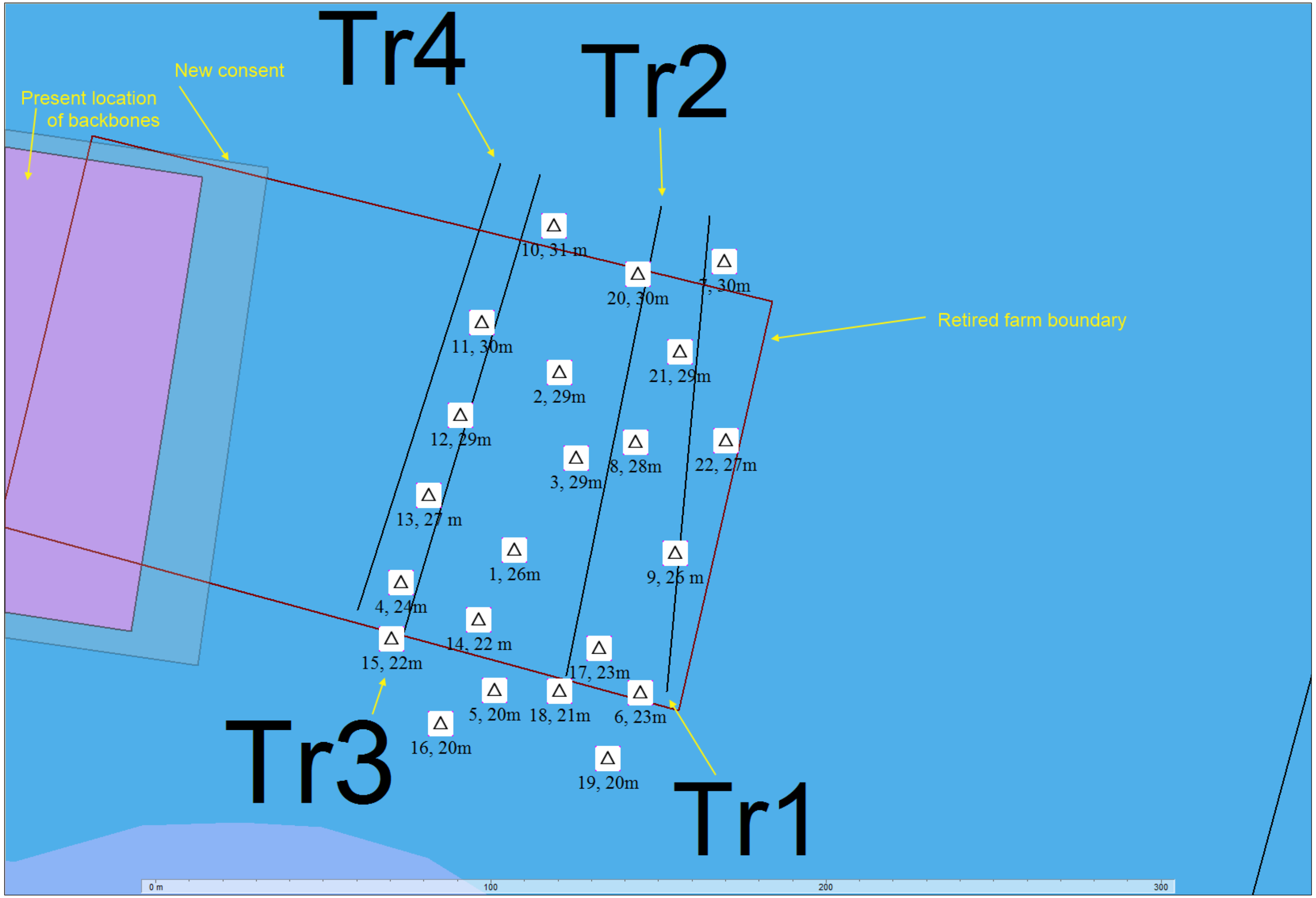


Figure 4. Location of drop camera stations and depths (triangles). Four impact transects are also depicted (black lines).

# 5.0 RESULTS

Monitoring commenced one month after removal of farm backbones and warps, some 14 years after these structures were first installed by the mussel farmer (Table 3). A second sample was collected 7 months after structures were removed (September 2002). For the following six years, monitoring occurred annually in December or January. From 2008 monitoring was reduced to once every second year with the last diver sample in January 2013. Diver collected data spanned 11 years following removal of farming structures, 25 years after structures were first installed (Table 3). Photographic data were collected on two occasions (2005 and 2014). Over the study two reports were previously produced, a baseline report by Davidson and Pande (2002) and an interim report by Davidson and Richards (2005).

## 5.1 Depth, habitat and substratum

Throughout the Marlborough Sounds the types of substratum and habitats and the depths they are found, vary according to environmental variables such as tidal currents, wave intensity, proximity sediment sources (rivers) and catchment type. The following section describes habitats, substratum and relates them to depth in East Bay. These relationships between substratum and depth should not be applied to other areas in the Marlborough Sounds as each location will have its own attributes.

Based on diver observations, depth and substratum remained relatively consistent at each of the control sites over the duration of the study. Divers reported small changes at the retired warp sites in relation to the decline in mussel shell debris. At retired growing structure sites, divers reported considerable change in the cover of mussel shell debris over the duration of the study, especially at depths > 26 m.

Transects installed at impact sites ranged from 30.5 m to 17 m depth, while control site transects ranged from 33 m to 14 m (Table 4). Control sites 5 and 6 did not extend to the maximum depths recorded at other control, warp and growing structures transects.

### Table 3. Monitoring events relative to farm establishment and removal of structures.

| Date | Event | Farm establishment | Since farm removal |
|---|---|---|---|
| Late 1988 | Mussel farm establishment | 0 years | |
| 23-01-2002 | Removal of mussel farm | 14 years | 0 |
| February, 2002 | Establish baseline data set | 14 years | 1 month |
| Mid 2002 | Produce baseline report | | |
| September 2002 | Repeat baseline | 14 years | 7 months |
| February 2003 | Repeat baseline | 15 years | 12 months |
| January 2004 | Repeat baseline | 16 years | 24 months |
| January 2005 | Repeat baseline & collect photos | 17 years | 36 months |
| Mid 2005 | Produce baseline report | | |
| January 2006 | Repeat baseline | 18 years | 4 years |
| January 2007 | Repeat baseline | 19 years | 5 years |
| January 2008 | Repeat baseline | 20 years | 6 years |
| January 2010 | Repeat baseline | 22 years | 8 years |
| December 2011 | Repeat baseline | 23 years | 9 years |
| January 2013 | Repeat baseline | 25 years | 11 years |
| November 2014 | Repeat drop camera photographs | 26 years | 12 years |

### Table 4. Substratum and depth range from maximum to minimum depth for each transect.

| Transect | Deep (m) | Deep substratum | Shallow (m) | Shallow substratum |
|---|---|---|---|---|
| Transect 1 | 30 | Silt and clay, mussel shell | 22 | Silt, fine sand, natural broken and whole shell, mussel shell |
| Transect 2 | 29 | Silt and clay, mussel shell | 19 | Silt, fine sand, natural broken and whole shell, mussel shell |
| Transect 3 | 30 | Silt and clay, mussel shell | 17 | Silt, fine sand, natural broken and whole shell, mussel shell |
| Transect 4 | 31 | Silt and clay, mussel shell | 19 | Silt, fine sand, natural broken and whole shell, mussel shell |
| Transect 5 | 22 | Silt and clay, red algae | 16 | Silt, fine sand, natural broken and whole shell |
| Transect 6 | 26 | Silt and clay, natural broken shell | 22 | Silt, fine sand, natural broken shell |
| Transect 7 | 33 | Silt and clay, natural broken shell | 19 | Silt, fine sand, natural broken and whole shell |
| Transect 8 | 29 | Silt and clay, natural broken shell | 14 | Silt, fine sand, natural broken shell, occasional cobbles |

## Mud (silt and clay)

Deep areas (approximately >26 m) in Otanerau Bay and the wider East Bay were dominated by silt and clay (mud) substratum (Plate 1, left). A small component of natural shell material was often observed with this deep substratum (Table 4). Mud areas located under the retired warps were comparable in appearance to control sites with very small quantities of natural shell with occasional mussel shell debris (Plate 1, middle). Deep mud substrata under retired backbones supported very small quantities of natural shell as well as variable quantities of mussel shell debris (Plate 1, right). With decreasing depth the level of natural shell usually increased at control (Plate 2, left), retired warp (plate 2, middle) and retired growing structures (plate 2, right). The natural shell component was often comprised broken shell from dead horse mussels, spire shell and other shell fish.

## Silt, fine sand, natural broken and whole shell

At the shallow end of control transects (< 25 m depth) the benthos was characterised by silt, fine sand with natural broken and dead whole shell. At most transects the shallow areas supported sufficient quantities of natural shell to be described as shell hash (Table 4, Plate 2, left). For retired warp transects there was also a small component of mussel shell but natural shell was dominant (Plate 3, middle). Mussel shell debris was regularly observed in shallow areas under retired backbones. In early years mussel shell debris often obscured the natural shell component (Plate 2, right).

## Red algae

A red algae bed was recorded at one site (control site 5) located west of the farm in Puriri Bay. The red algae bed extended from approximately 100 m to 150 m along the transect at the offshore end of the line. The red algae bed was present on all occasions and often covered 100% of the underlying substratum.

**Plate 1. Deep silt and clay (mud) substratum. Left = control; middle = Photo 8, 28 m under retired warps; right = Photo 11, 30 m under retired backbones).**

**Plate 2. Silt and clay (mud) and natural shell. Left = control; middle = Photo 9, 26 m under retired warps; right Photo 13, 27 m under retired backbones).**

**Plate 3. Silt, fine sand, shell hash. Left = Photo 16, 20 m inshore control; middle = Photo 17, 23 m under retired warps; right Photo 14, 22 m under retired backbones).**

## 5.2 Mussel shell debris

### Pooled mean mussel shell debris over time

Mussel shell debris was recorded from retired growing structure transects on all sample occasions. Mussel shell debris was not observed or recorded from control transects. At the start of the study, significantly more mussel shell debris was recorded from transects at the retired backbone sites compared to the retired warps (random stratified U = 51.5, P < 0.001, stratified U = 73, P < 0.001). At the end of the study, significantly more shell debris was recorded under retired backbones compared to retired warps although the difference was considerably less compared to the study start (random stratified U = 420, P < 0.001, stratified U = 104, P < 0.001) (Figure 5).

At the start of the study (2002), mean mussel shell debris under retired warps was <10% cover compared to retired growing structures where mean shell debris was 53 % (stratified) and 36% (random stratified). By 2005, warps values had dropped to <2% mussel shell cover compared to 25 to 40% cover for retired growing structures (Figure 5). Over the study, mussel shell debris continued to steadily decline under the retired growing structures to an all-time low in 2013 (6.4% stratified, 2% random stratified).

### Mussel shell depth distribution

On all sample occasions, percentage cover of mussel debris under retired growing structures declined with increasing distance from shore and depth (Figure 6). In 2002 for example, all quadrats sampled between 0 and 60 m distance (i.e. inshore areas) supported high levels of mussel shell debris with four quadrats exceeding 70% shell cover. In contrast, quadrats collected on the same occasion at greater depths supported values <60% cover with many <40% cover. From September 2002 to January 2008, the percentages of mussel shell cover at greater depths and distance from shore (i.e. > 80 m distance) declined with most values dropping below 40% cover. Over the same period inshore values (0 to 60 m distance) remained high relative to deep areas. These alterations caused a steepening of regression lines with shallow areas remaining high and deeper areas exhibiting a decline. From January 2010 onwards, the percentage cover of mussel shell debris also declined at shallow inshore areas (i.e. 0-60 m distance) leading to flatter regression lines. At the end of the study, highest shell debris values remained in the shallow inshore areas, however, values were all ≤ 10% cover. In 2013, no values exceeded 3% in offshore deep areas (Figure 6).

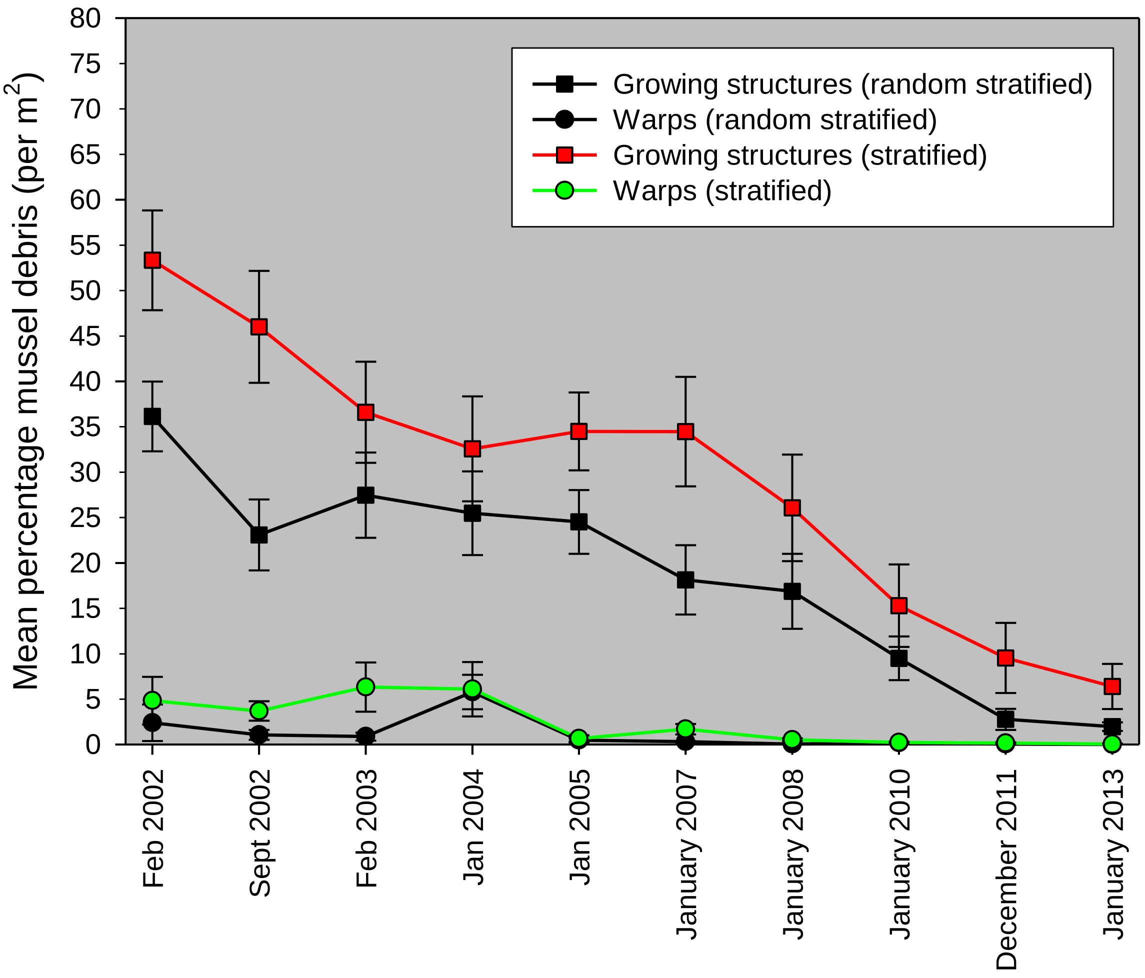


**Figure 5. Mean percentage cover of mussel shell debris (per m$^2$) collected using both sampling strategies over the three year period from under retired growing structures and under retired warps. Error bars are +/- 1 s.e.**

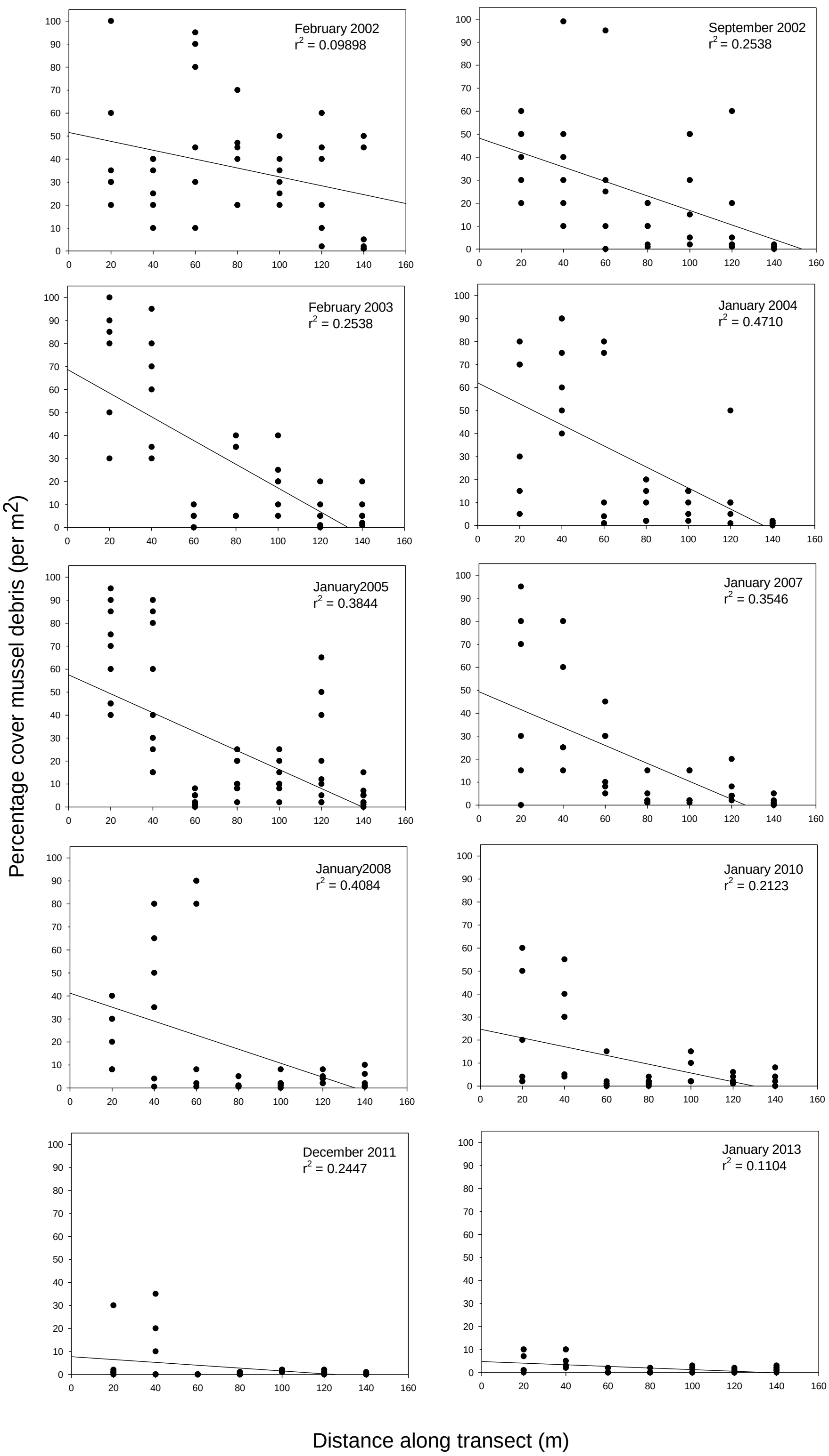


**Figure 6. Mussel shell debris from random stratified quadrats collected from two transects (n=42 per sample event) under retired growing structures plotted against distance along each transect (0 = shallow, 160 = deep).**

## 5.3 Species densities

### Lampshells

Giant lampshell (*Neothyris lenticularis*) was recorded from retired warp, retired growing structure and control transects throughout the study. For the four pooled controls their density ranged from 0.5 to 1.75 individuals per $m^2$ (Figure 7). Lowest control densities occurred at the start and end of the study (February 2002 and January 2013). Giant lampshell were always most abundant at control sites 7 and 8. These sites were located along the eastern shore of Te Aroha Bay, were steeper and extended to greater depths than control sites 5 and 6 located in central Te Aroha Bay and along the southern shore of Puriri Bay (Figure 3).

Giant lampshell abundance under the retired warps also varied between years. In 2002 their abundance at warp sites was comparable to controls, however, numbers declined to a low in 2005 (Figure 7). Post 2005, their abundance under retired warps gradually returned to densities recorded at the start of the study. For five of the ten samples, giant lampshell densities under retired warps were within the range of densities recorded at controls. No comparable drop in their numbers occurred at controls. For most years, the density of giant lampshell was lowest from the two retired growing structure transects (Figure 7). From 2008 onwards, however, their abundance steadily increased, ending at the lower range of values recorded for controls.

Red lampshell (*Terebratella sanguinea)* densities at retired growing structures remained low (mean < 0.25 individuals per $m^2$) throughout the study (Figure 8). Densities at control and retired warps transects remained relatively low apart from small peaks in 2002, 2003 and 2005. In the last three years of the study, their density at retired warps transects declined to zero or very low levels. This also occurred at three of the four control sites, with the remaining control site supporting higher numbers (Site 8).

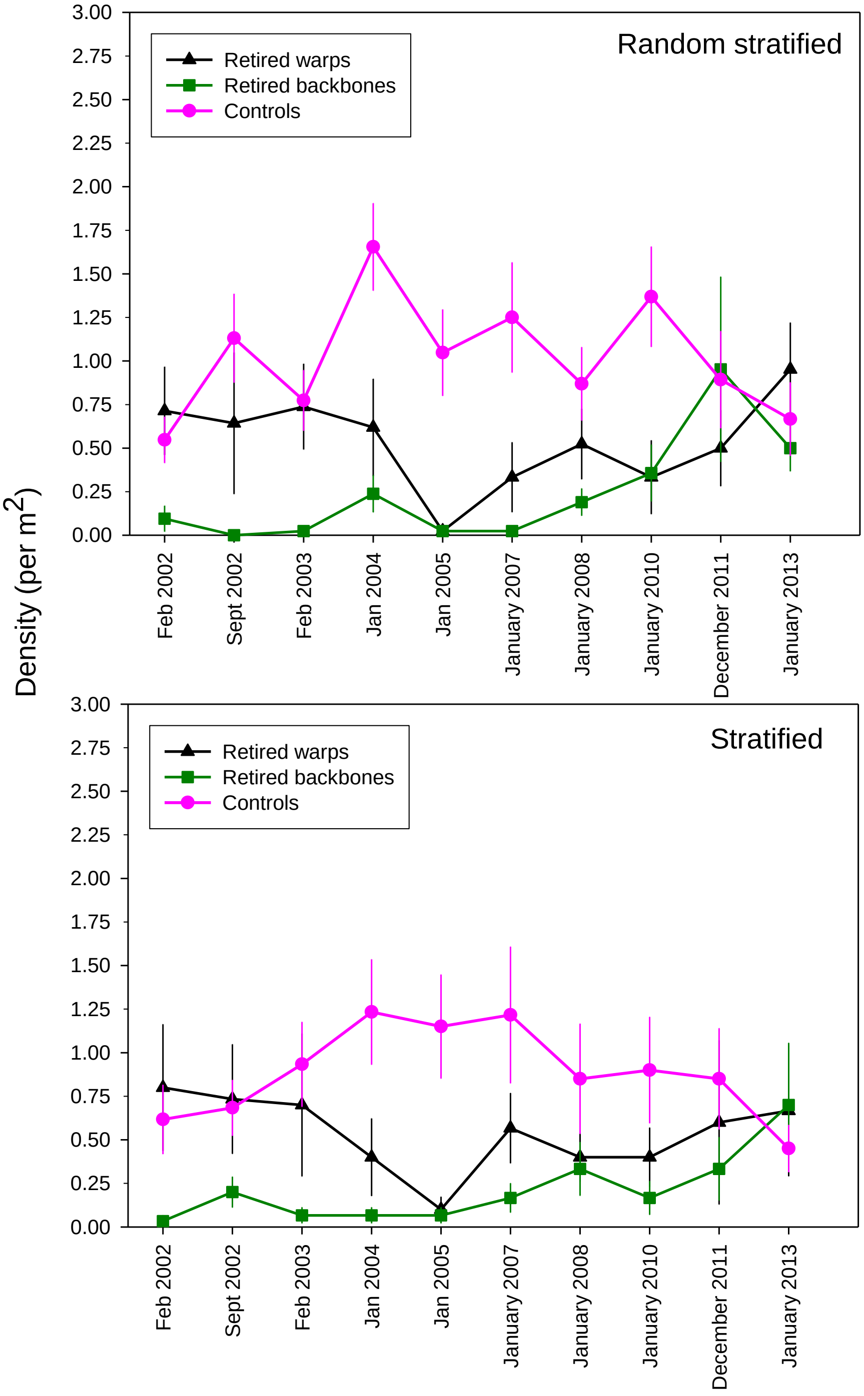


**Figure 7. Mean density of giant lampshell using random stratified and stratified methodologies from 2002 to 2013. Error bars are +/- 1 s.e.**

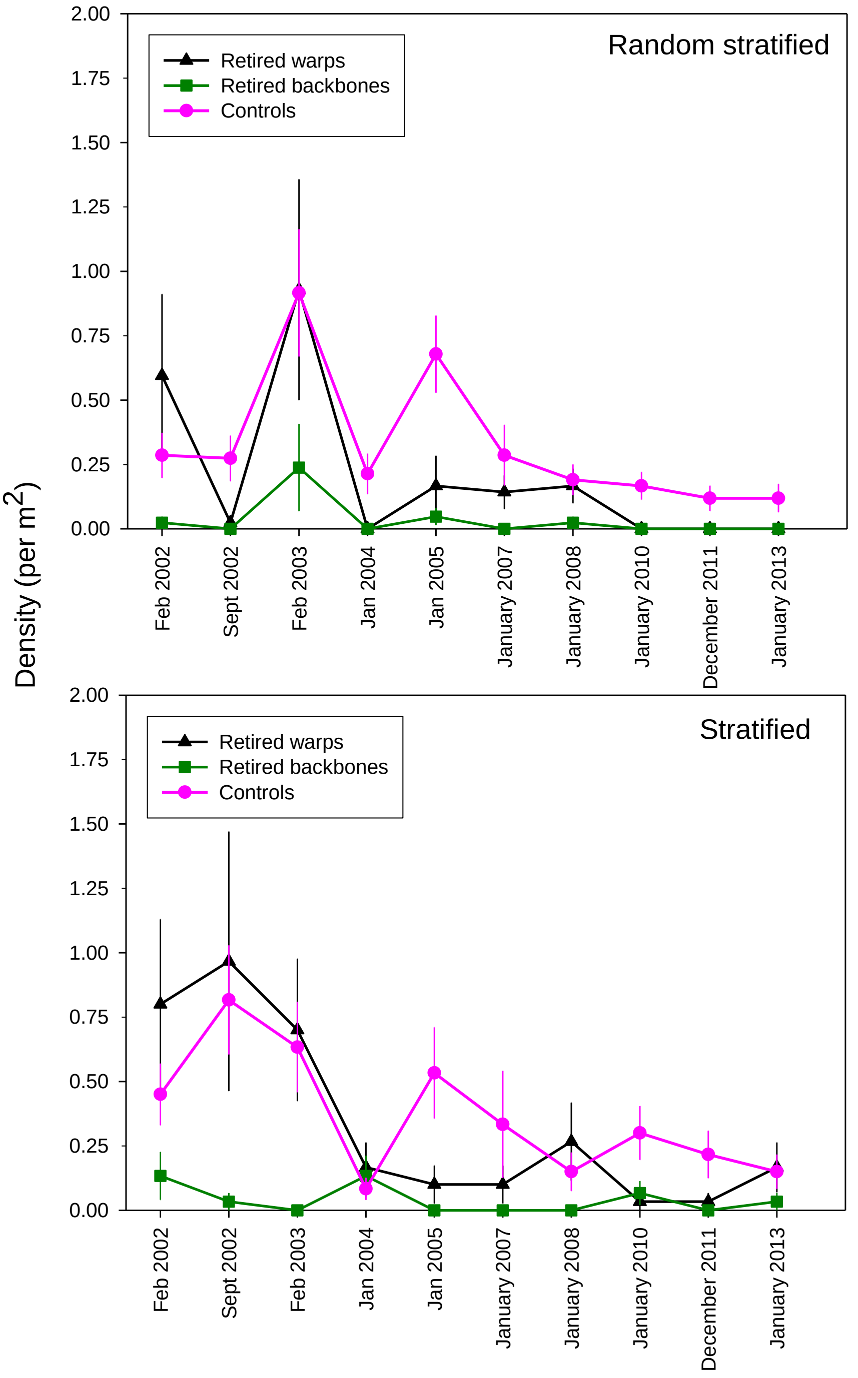


**Figure 8. Mean density of red lampshell using random stratified and stratified methodologies from 2002 to 2013. Error bars are +/- 1 s.e.**

**Scallop**

Scallop (*Pecten novaezelandiae*) density at controls exhibited a large increase over the study (Figure 9). The abundance of scallops from retired warp and retired growing sites also increased over the study but their densities were only significantly different in 2007 (U = 588, P < 0.001), despite a second peak under retired warps in 2011 (Figure 9). The abundance of scallops from control sites was significantly higher compared to retired warp sites from 2004 onwards (U = 1454, P = 0.025) and also retired growing sites from 2004 onwards (U =1449, P < 0.04).

Density values recorded using the stratified methodology showed a similar patter to random stratified methods, however the scale of change was lower (Figure 9). For stratified data, control densities were highest in all years. Little difference in scallop density at retired warp and retired growing structures sites were observed, but warp densities were usually slightly higher compared to retired growing structure data. Retired warp and retired growing site values ended close to where they started, whereas control densities showed an increase.

Data collected using the random stratified methodology exhibited greater variability and greater values compared to stratified methods (Figure 9).

**Horse mussel**

In 2002, horse mussel (*Atrina zelandica*) densities were highest at control sites compared to the retired farm sites, especially the retired growing structure sites (U = 1344, P < 0.001) (Figure 10). Over the duration of the study their abundance increased for all treatments, especially at retired structure and warp sites.

By the end of the study horse mussel density for retired growing structures had steadily increased, coming close to the density range recorded for controls. Data collected using the random stratified methodology again exhibited greater variability compared to stratified methods (Figure 9).

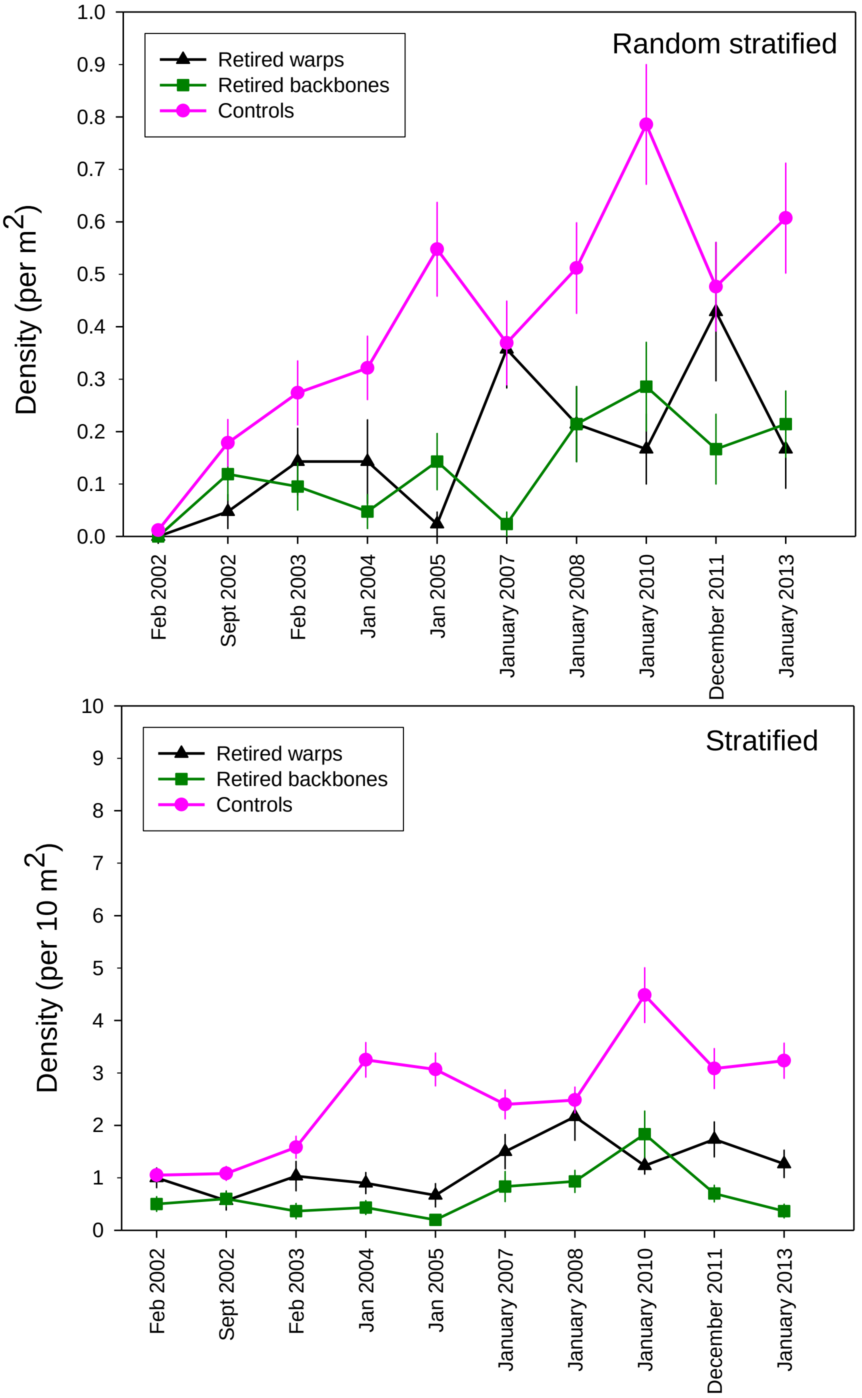


**Figure 9. Mean scallop density using random stratified and stratified methodologies from 2002 to 2013. Error bars are +/- 1 s.e.**

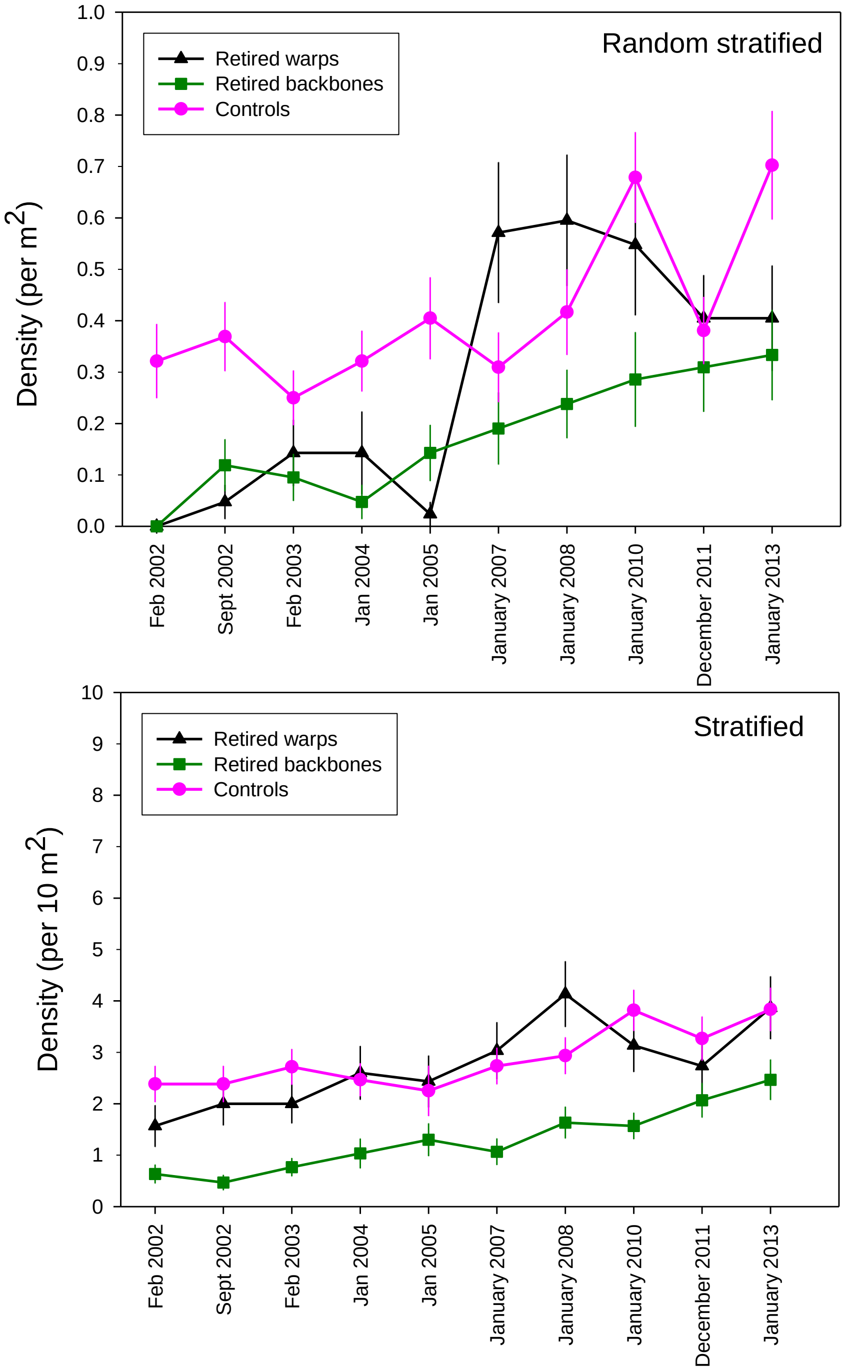


**Figure 10. Mean horse mussel density collected using random stratified and stratified methodology from 2002 to 2013. Error bars are +/- 1 s.e.**

### 11 arm seastar

For most of the study 11 arm seastar (*Coscinasterias muricata*) density remained relatively low and stable (<0.15 individuals per m$^2$) (Figure 11). In February and September 2002, however, seastars were more abundant at retired growing sites compared to later years, however this was only significant in February 2002 (U = 1510, P = 0.003). In these early months, the difference between the retired growing structures and the two other treatments was relatively large.

At retired warp sites a small increase in their numbers was recorded at the end of 2002 and early 2003. For the rest of the study seastars were more abundant at controls compared to the retired farms sites, but this difference was not significant. In December 2011 the number of 11 arms seastars increased at controls to a level that was almost significant (U = 1575, P =0.055, however, the following year their numbers dropped back to a density below warps sites and at comparable level to back bone sites) (Figure 11).

### Kina (urchins)

Kina (*Evechinus chloroticus*) were recorded from all transects all years (Figure 12). Kina densities from the retired growing structures were initially higher than retired warps and controls and also under retired backbones compared to samples collected for the rest of the study. These early random stratified densities from retired backbones were significantly higher than controls (U = 1293, P<0.001).

In most remaining years kina density was highest from retired growing structures compared to retired warp and controls but this was not significant apart from 2010 when their numbers peaked at the retired backbone site (U = 1524, P = 0.046).

In most years, however, differences between treatments were not statistically significant, however, for stratified data retired growing structure densities increased at the end of the study compared to control values (2011, U = 1676, P = 0.004; 2013, U = 321, P = 0.013).

### Cushion seastar

Apart from random stratified samples collected in 2005, cushion seastar (*Patiriella regularis*) were recorded from all transects throughout the study (Figure 13). Cushion seastar density at retired growing structure and warp sites fluctuated with highs in 2003 and 2013.

In contrast, controls started relatively stable, but numbers of cushion seastars climbed in 2008 onwards, peaking well above the retired farm densities. Their increase in their abundance at control sites occurred at all four control sites. These changes occurred for stratified data but were less dramatic compared to random stratified data.

The density of cushion seastars at retired growing and retired warp sites ended at levels close to where they started in 2002.

### Sea cucumber

Sea cucumber (*Stichopus mollis*) were often most abundant at retired growing structures compared to retired warps and controls, but this difference was only significant for random stratified data in 2003 (U = 1415, P = 0.002) and 2004 (U = 1578, P = 0.032) (Figure 14).

For stratified data, retired growing structures, retired warps and controls their density fluctuated little apart from control densities in 2011 (Figure 14). In 2011 their densities increased dramatically in Puriri Bay (site 5). This was short-lived with numbers returning to background levels in 2013. Their abundance was highest where red algae beds were located. Divers reported most individuals at Puriri Bay in 2011 were juveniles or young adults.

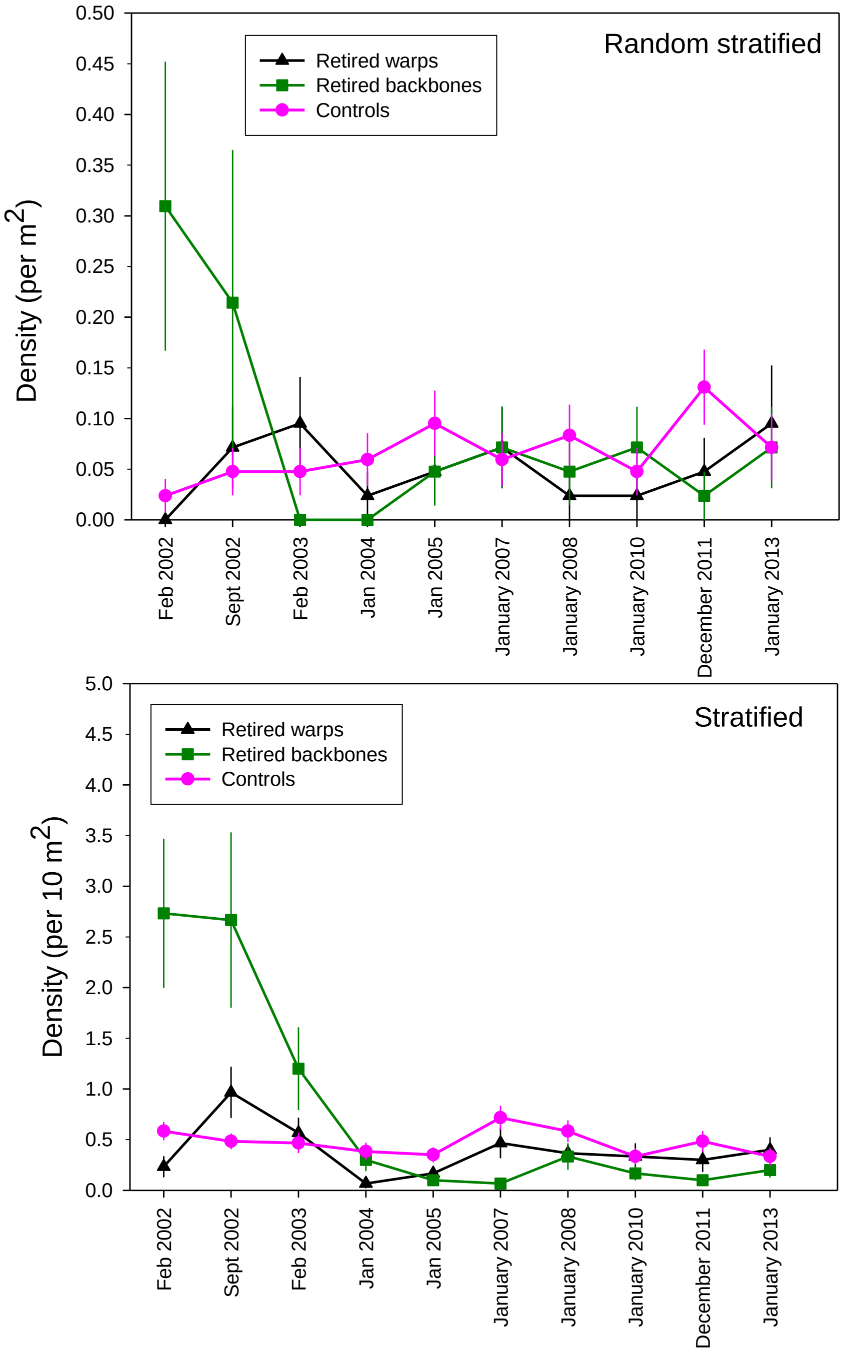
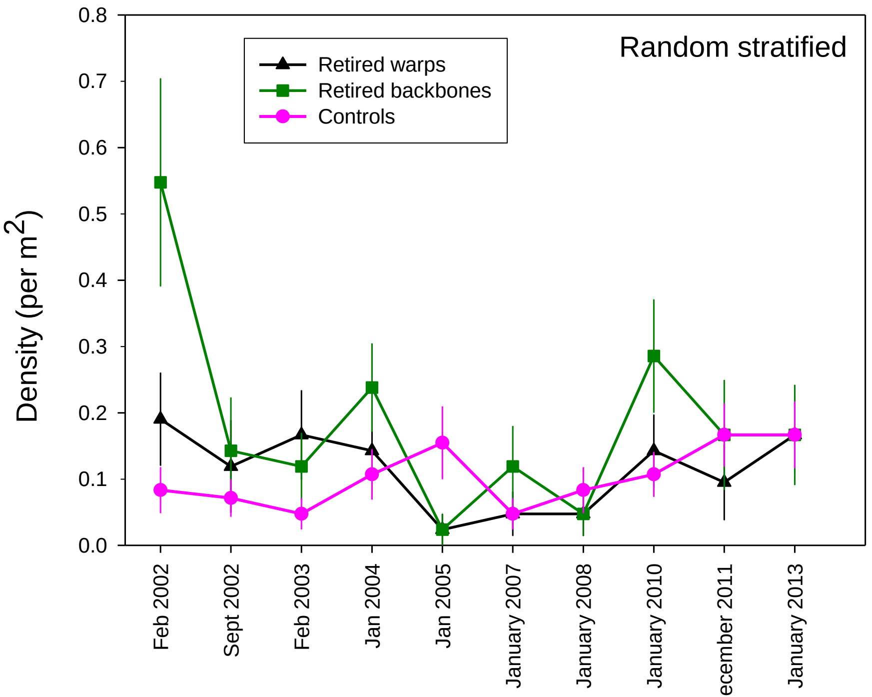


**Figure 11. Mean density of 11 arm seastar using random stratified and stratified methodology between 2002 and 2013. Error bars are +/- 1 s.e.**



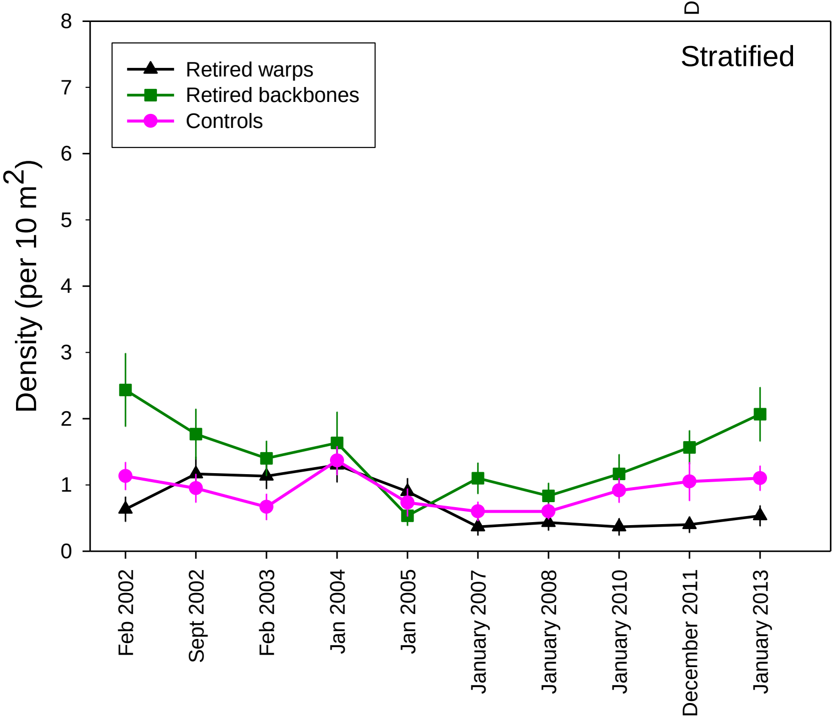


**Figure 12. Mean density of kina using random stratified and stratified methodology from 2002 to 2013. Error bars are +/- 1 s.e.**

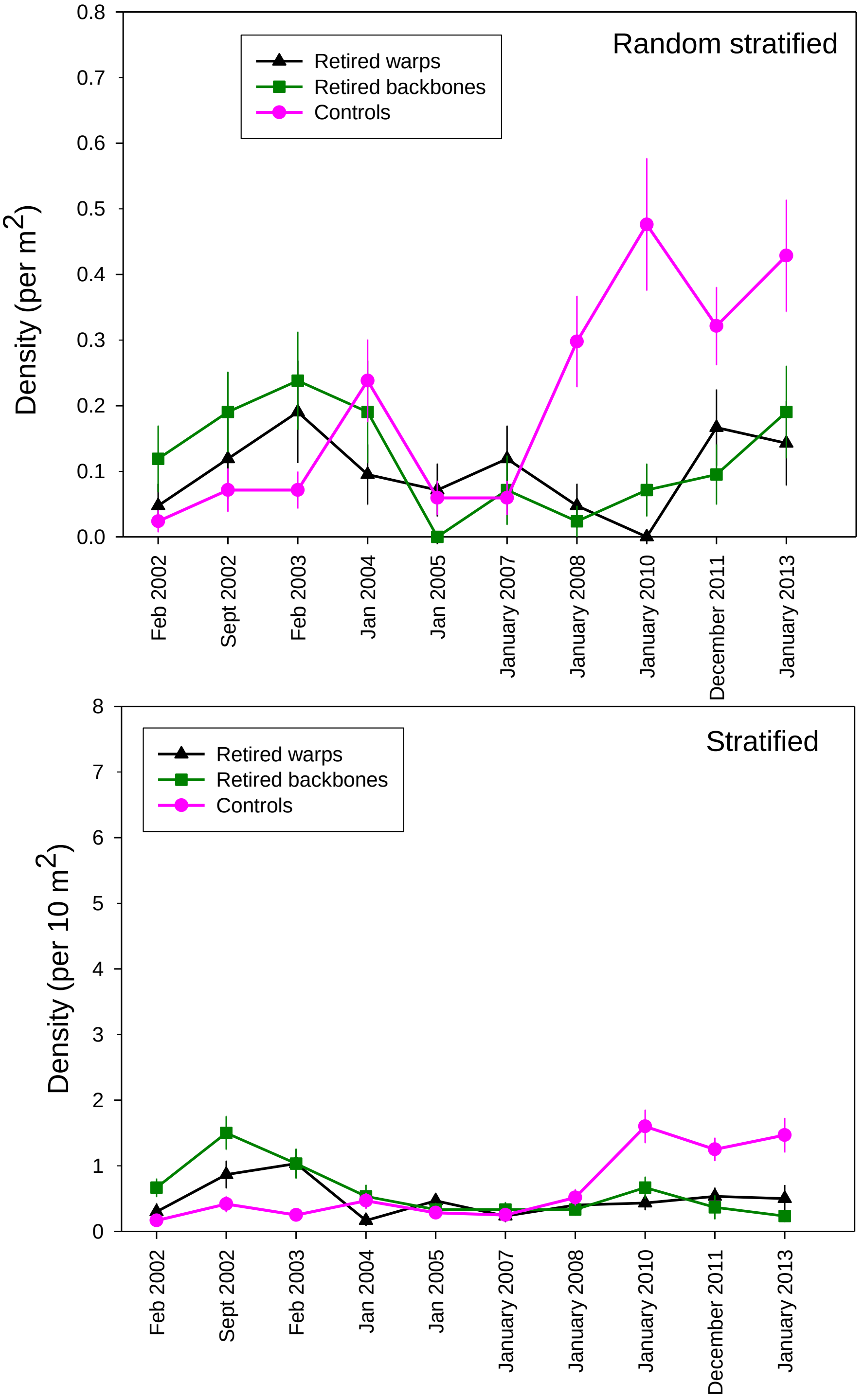


**Figure 13. Mean density of cushion seastar using random stratified and stratified methodology between 2002 and 2013. Error bars are +/- 1 s.e.**

### Snake star

Snake stars (*Ophiopsammus maculata*) were generally uncommon or absent from all treatments (Figure 15). At retired growing structure sites they were either absent or were recorded at very low densities. Snake stars were most often observed from controls, but were also usually present at retired warps.

At control and retired warp sites their abundance was variable between years, with highs and lows usually occurring in the same years.

### Pink urchin

Pink urchins (*Pseudechinus albocinctus*) were recorded from all sample occasions (Figure 16). Their density was relatively low between 2002 and 2008 at all treatments. From 2010 to 2013 their density increased at all treatments, peaking in 2011 and 2013. There appeared little difference between densities under retired warps, growing structures and controls.

### Brooch seastar

Brooch seastars (*Pentagonaster pulchellus*) were relatively rare and when encountered were found as lone individuals (Figure 17). Brooch seastars were not seen under the retired growing structures and only one was recorded under retired warps. No obvious pattern or trend was recorded over the study.

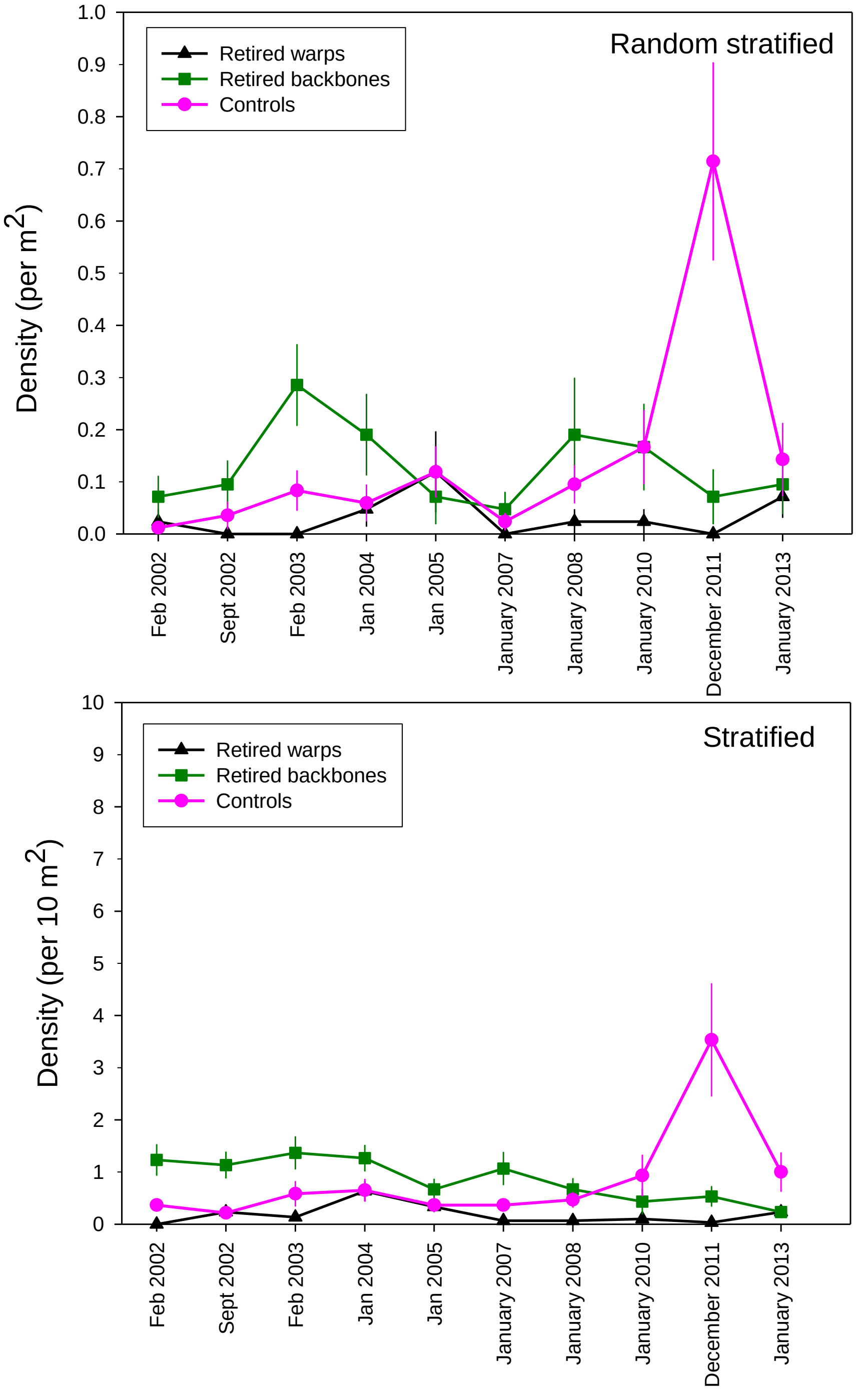


**Figure 14. Mean density of sea cucumber using random stratified and stratified methodology between 2002 and 2013. Error bars are +/- 1 s.e.**

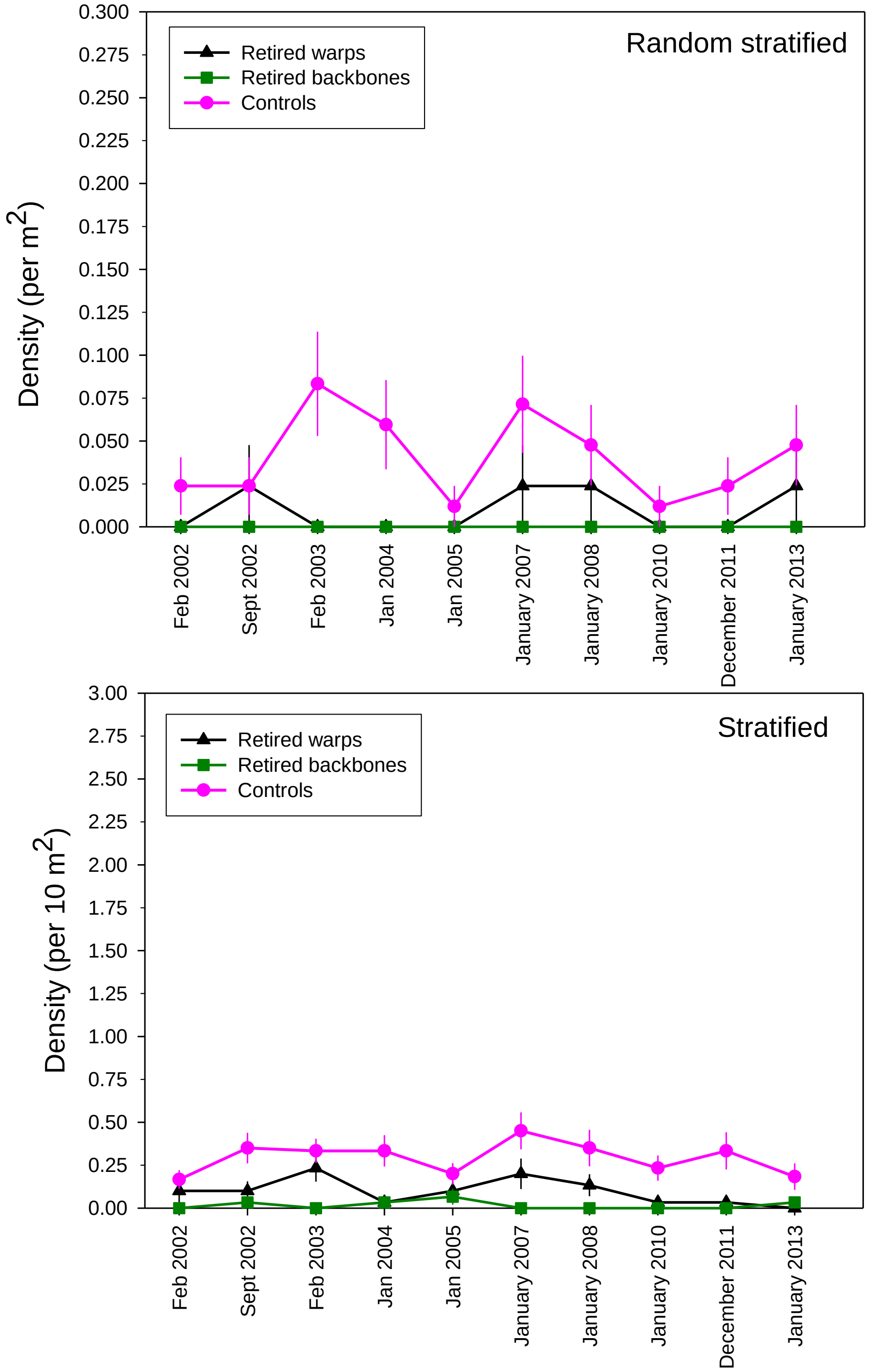


**Figure 15. Mean density of snake star using random stratified and stratified methodology between 2002 and 2013. Error bars are +/- 1 s.e.**

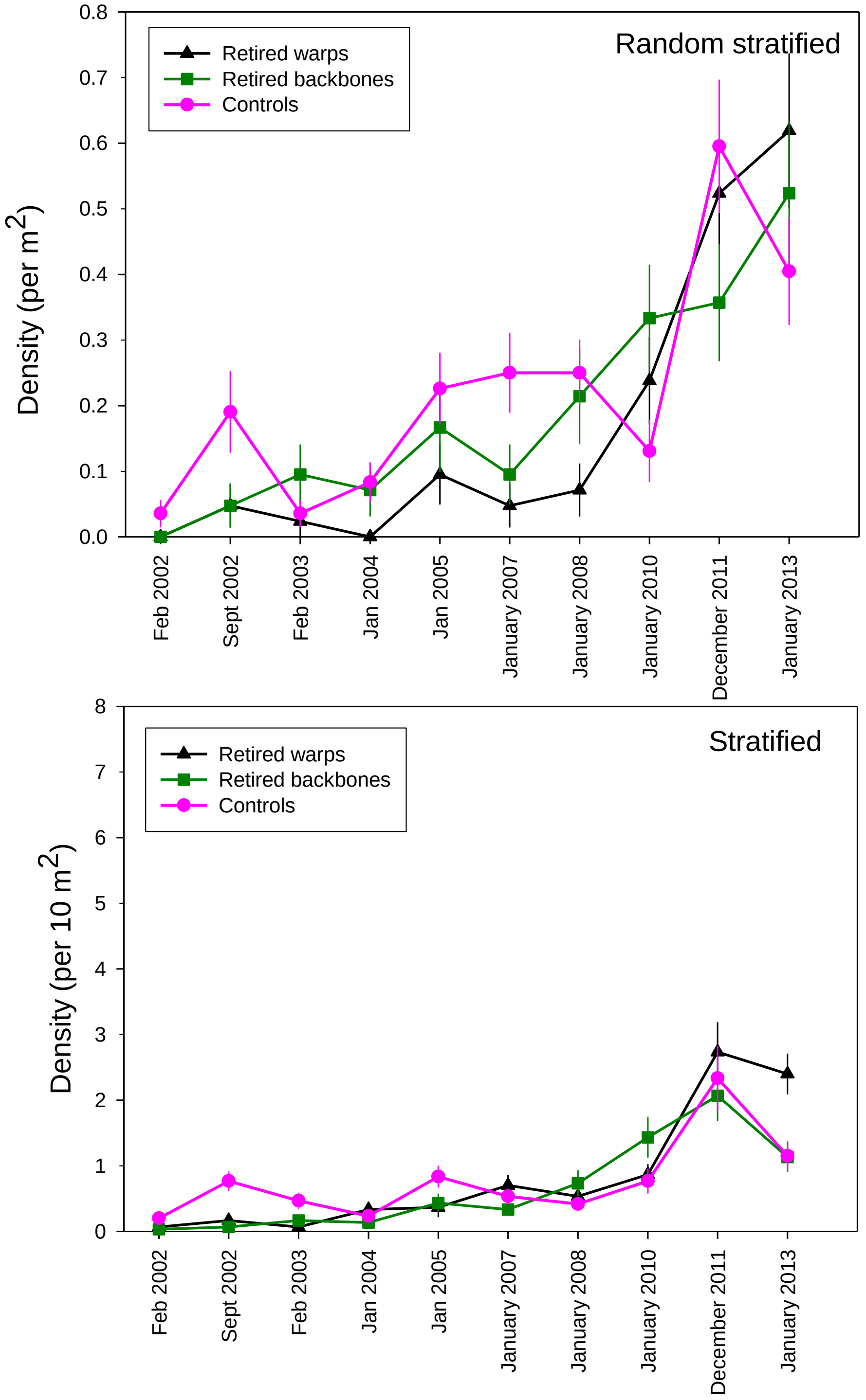


**Figure 16. Mean density of pink urchin using random stratified and stratified methodology between 2002 and 2013. Error bars are +/- 1 s.e.**

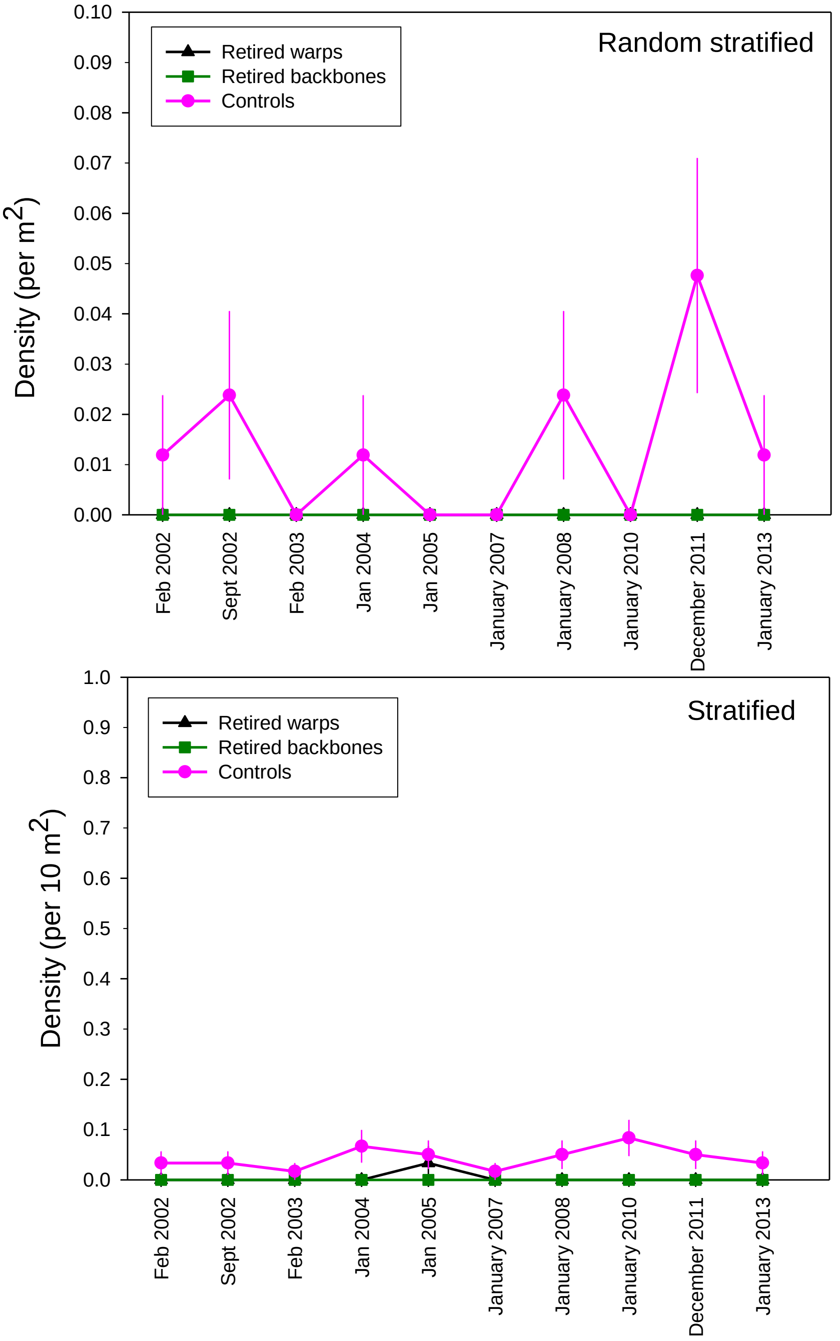


**Figure 17. Mean density of brooch seastar using random stratified and stratified methodology between 2002 and 2013. Error bars are +/- 1 s.e.**

# 6.0 DISCUSSION

## 6.1 Methodology effects

The abundance of benthic invertebrate species and the percentage cover of mussel debris from retired warp, retired growing structure and controls often varied depending on sampling methodology.

**Mussel debris**

Mussel shell debris percentage cover values sampled using stratified and random stratified methods yielded the same temporal pattern, however, stratified values were consistently higher than random stratified means. This methodology difference was lost after 2005 when percentage cover values for retired warp transects dropped to very low levels.

The relatively consistent difference between methods under the retired growing structures area was unlikely due diver variability. The same diver sampled the stratified quadrats throughout the study and apart from the first sample the same diver collected all random stratified data. It is more likely the higher values from stratified samples were related to shell debris patchiness. Mussels are hung on dropper lines from rows of backbones orientated parallel to the shore and perpendicular to the transect line. Mussel debris percentage cover is highest close to droppers and declines with increasing distance. The shell debris therefore forms rows of high density shell with less shell between the rows. The stratified sampling technique sampled shell debris using 10 m long by 1 m wide quadrats sampled across these rows or shell debris. Stratified quadrats therefore always collected data from all retired backbone rows and everything between. Random stratified quadrats were 1m$^2$ and were deployed randomly within 10 m strata. This means the full range of mussel debris values would likely be under estimated as highest shell debris areas would be sampled less often compared with using stratified methods. Stratified sampling is therefore likely to provide the best representative value for shell debris cover in the retired mussel farm.

**Species abundance**

Surface dwelling fauna were also sampled using both sampling methods. Random stratified values were usually higher, exhibited greater variability and had greater standard errors compared to stratified data. For random stratified samples a total of 21 quadrats were sampled covering a total area of 21 m$^2$ per transect. A total of only 15 stratified quadrats were collected per transect, but the total area covered an area of 150 m$^2$ (7 times larger than random stratified samples). The sample method had three potential effects on data. Firstly, the sizes of error bars from stratified samples were reduced due to lower variability between the larger 10m$^2$ quadrats compared to small quadrats. Secondly, divers collecting data from stratified quadrats had to search a large area in often poor visibility conditions. This increases the probability that animals would be missed compared to the random stratified sample where the diver searched a considerably smaller area. Animal numbers were potentially underrepresented for the larger stratified quadrats. Lastly, the effect of shell debris deposited in rows (as discussed in the previous section), may also influence the abundance of animals particularly if they respond positively or negatively to the presence of shell debris.

Overall the stratified data revealed the most reliable description of spatial and temporal trends over the duration of the study, however the abundance of fauna was probably under represented. The abundance of species is better described by random stratified data, however these data were highly variable due to low number and small size of quadrats. For any further sampling it is recommended that the number of random stratified quadrats be increased from three to five.

## 6.2 Mussel debris

As expected, no mussel debris was recorded from control transects. Control sites used in the present study have never been farmed for mussels and were located well distant to other mussel farms.

Under mussel farms mussels are deposited onto the benthos often forming a layer of living and/or dead mussel shell (Plate 4) (DeJong, 1994; Gibbs *et al*., 1989; Gillespie, 1989; Forrest, 1995; Cole and Grange, 1996; Davidson, 1998; Davidson and Richards, 2004; Keeley *et al*., 2009). For example, Davidson and Richards (2004) recorded up to 100% cover of mussel shell debris under mussel droppers located at two mussel farms in East Bay. The authors showed that mussel debris declined with increasing distance from droppers with relatively low levels recorded by 15 to 20 m distance from growing structures.

**Plate 4. Living and dead mussels under a shallow mussel farm in the Marlborough Sounds (12 m depth).**

### Warps

Warps are a single rope that connects the screw anchor with the surface lines (backbones). Warps (22-28 mm diameter) are spliced to form a bridle where they attach to the surface floats (Plate 5). Warps are not used to grow mussels, however, many species including mussels, tubeworms, hydroids, and algae settle and grow on these ropes. Fouling species often accumulate and may intermittently drop to the seafloor due to their weight or may occasionally be removed by the marine farmer.

Under the retired warps, the percentage cover of shell debris was low compared to the retired growing structure area (section 5.2). Most material recovered under retired warps was present in distinct patches with much of the benthos remaining free of debris.

**Plate 5. Warp attached to surface floats with encrusting flora and fauna in the Marlborough Sounds.**

### Backbones

For most of the study shell debris under retired growing structures was dramatically higher compared to the areas under retired warps. Mussel shell is deposited on to the benthos intermittently from drop-off and during harvesting events. Mussels are also deposited onto the sea floor during cleaning of backbones and floats.

Mussel lines can move from side to side depending on tidal height, currents, wind and the stage of the crop. This movement can act to distribute shell over a wider area than exhibited under warps. Mussels that fall to the benthos in shallow areas often survive and can form beds of live mussels, however, many are eaten by predatory seastars (*C. muricata*) (Plate 4). Those mussels that fall onto deep mud areas are seldom seen alive.

Over the duration of the present study, mussel debris under the retired growing structures steadily declined to levels <10% cover, however, the rate of decline varied depending on depth. In deep muddy areas, shell debris declined relatively quickly with appreciably lower levels recorded after two years and consistently lower levels six years after farm removal. The reason for the relatively quick decline in deeper areas was likely due the soft mud substratum. Mussels were often observed half buried in mud, presumably because they had sunk into the soft fine sediment. Further, sedimentation often settles onto the benthos in deep low current areas acting to bury or smother shell. Divers were able to dig buried mussel shell out of the sediment testifying to the smothering effect.

At the present site, mussel debris declined under backbones more rapidly in depths >26 m where soft silt and clays dominated. In shallower parts of the retired farm, coarser substratum and lower sedimentation ensured shell debris remained on the surface. By eight years after retirement even these shallow areas exhibited a decline in shell debris levels. In these shallower areas, it is unlikely that shell would sink or be smothered by fine sediment as natural shell material is common on the surface in these depths. Rather, shell debris appeared to be broken down and distributed presumably by bioturbation processes. Although some whole mussel shell could still be observed, most had been broken down to smaller shell fragments, becoming difficult to distinguish from natural shell material common in these depths.

## 6.3 Species

### Giant lampshell

Mean giant lampshell abundance at controls fluctuated between 0.4 and 1.75 individuals per $m^2$. The two control sites with deepest and steepest shore topographies regularly supported the highest numbers of lampshells compared to control sites without this deep component and lower gradient shores.

In contrast to control sites, giant lampshell abundance was very low at the retired mussel structures growing sites for the first six years after retirement. From 2010 onwards their abundance under the retired mussel growing lines increased ending above the lower range for recorded for controls. This consistent increase towards the end of the study suggests giant lampshells were negatively impacted under the growing lines while the farm was in operation. The period of recovery under retired growing areas was approximately 11 years. It is unknown why the recovery rate was relatively slow for this species, but may be related to recruitment and environmental factors such as substratum.

At retired warp areas, giant lampshell abundance was comparable to controls for the first two years of the study and at the end of the study. During intervening years their abundance declined to relatively low levels. The reason for their decline is difficult to explain as no mussel farming occurred at this site after 2002. Despite their drop in abundance, numbers steadily increased back to levels recorded at the start of the study. Their abundance at control sites also fluctuated between low levels at the start and end of the study suggesting their abundance naturally varies in East Bay.

Overall giant lampshells under retired warps did not appear to be negatively impacted by the presence of a mussel farm, however, their decline in 2004 and 2005 remains a mystery, but appears most likely part of natural variations in abundance rather than a mussel farming related impact.

### Red lampshell

The density of red lampshell from control and retired warp sites were comparable and followed comparable abundance patterns. Overall their density at warp and control sites fluctuated from year to year with consistent lows recorded in later year of the study. It is unlikely that the low densities recorded in the last three years were due to the adjacent relocated mussel farm as their abundance at retired warp sites was highest when the farm was operating in its original position and considerably closer.

The abundance of red lampshells was lower at sites located under retired growing structures suggesting they were negatively impacted. The lack of recovery for this species suggests mussel farming impacts may be long-term. It is also possible that slow or intermittent natural recruitment rates have extended the recovery period. Another factor was the decline at control and retired warp sites indicating poor recruitment over the study period. Collection of data over a longer time frame would help address the issue of natural recruitment for this species.

### Scallops

At the start of the study, scallop abundance was low for all treatments, however, a large increase was recorded over the study. Lowest scallop densities were recorded in February 2002 at retired growing structure transects suggesting they had negatively impacted scallop abundance. It is probable that the naturally low scallop densities for 2002 masked the real scale of negative impact which may have been larger if scallops were more abundant at warp and controls.

The largest increase in scallop density was recorded at controls, however, densities at retired warps and growing structure sites also increased, but to a lesser extent. The reason for the smaller increase at retired warp and retired growing structure sites may be due to:

a) Long lasting impacts originating from the retired mussel farm.
b) A continued effect from the adjacent relocated mussel farm.
c) Natural differences between sites (e.g. substratum, currents and depth).

As the density of scallops under retired growing and retired warps increased to comparable levels, it is most probable that a habitat difference was the most likely explanation. If the relocated farm was impacting the retired warp sites, it would be most likely that retired growing structure sites would exhibit a greater negative impact as they were located closer to the farm.

### Horse mussel

At the start of the study, horse mussel density was lower at both retired warp and retired growing structure sites compared to controls. Their abundance at the retired warp sites increased to control levels in a period of 2 to 4 years, however, the recovery at retired growing structure sites took longer (11+ years). Based on the steady increase recorded at retired growing structure sites, it is probable that horse mussel densities would catch up with increasing control levels in another 2-3 years. Based on this recovery trend, it is probable that mussel farming activities have a negative effect on horse mussel density for areas located under and close to growing structures. Of note was the increase of horse mussel densities at control sites over the duration of the study. This occurred over the period mussel farm numbers and space occupied by farms increased in East Bay. This again suggests that the impact of mussel farming on horse mussels is restricted to directly under and close to growing structures.

### 11 arm sea star

A number of authors have reported that 11 arm seastars become abundant under mussel farm growing structures compared to areas around and away from farms (see review: Keeley *et al*. 2009). They are predators, feeding on mussels that have dropped from growing structures. In contrast, their density in the present study at control and warp sites were comparable and remained low and stable throughout the study (0 - 0.15 individuals per m$^2$). As expected, their density under retired growing structures was initially high, however, one year after the farm was relocated away, densities dropped to background levels. Over this early period, a small increase in their abundance was recorded at retired warp sites. This was presumably seastars moving away from the retired growing structures in search of more prey source as mussel numbers declined. No corresponding increase was recorded at control sites, suggesting this small change was not detectable at greater distances from the farm.

### Kina

Kina densities from the retired growing structures were initially high compared to samples collected from retired warp and control sites, however, numbers fell to background levels within 1-2 years. This suggests kina numbers were impacted in a positive direction by the presence of a mussel farm, however their numbers declined quickly, presumably due to the removal of the farm. In some subsequent years, kina numbers exhibited small short-lived peaks at the retired growing structure sites. The reasons for these peaks are difficult to determine, but may be related to patchiness rather than actual changes in their abundance.

### Cushion seastar

The density of cushion seastars at retired growing structure and warp sites was initially higher than controls densities, however, values were within the range recorded for controls over the duration of the study. For the first five years of the study the abundance of these seastars was comparable between treatments suggesting little impact from mussel farming activities. For the last six years of the study their abundance at all control sites increased above retired growing structure and retired warp sites. The reason for the increase at controls is unknown, but most likely related to environmental variables. This phenomenon highlights the difficulties and care needed when attributing negative impact status to a human activity (i.e. Type I error or false positive).

### Sea cucumber

Sea cucumber abundance at control sites remained comparable with retired warp sites for most of the study apart from 2011 when they spiked at the control treatment. For most years, their abundance at these treatments remained low suggesting their population was relatively stable. Peak numbers for controls was driven by one site (Site 5, Puriri Bay) where large numbers of juveniles were observed in red algae beds 2011. By 2013 their numbers had dramatically declined suggesting they had either been predated, died or had dispersed.

This phenomenon and the lack of a peak at the control sites without red algae indicated red algae beds may be selected by larvae as a suitable media to settle and grow.

The abundance of sea cucumber at the retired growing structure sites was higher than retired warp and controls in most years, however near the end of the study their densities declined to the background levels suggesting a low level positive impact from mussel farming activities. Adult sea cucumbers are detritivores and may benefit from pseudofaeces and faecal pellets expelled by mussels. It is therefore possible that the sites located in the retired growing structure area still receive some of this material from the adjacent farm thereby providing an improved food source of these animals.

### Snake star

Snake stars were relatively uncommon or absent from the three treatments in most years. At retired growing structure and retired warp sites they were either absent or were at very low densities. Snake stars were most often observed from controls, however, they were very uncommon. Although more snake stars were recorded from controls compared to both farm sites the differences were not significant. It is possible, however, that an impact was masked due to the naturally low numbers of these species.

### Pink urchin

At the start of the study pink urchin density was relatively low with little different between treatments. At all treatments their numbers increased dramatically peaking in 2011 and 2013. The reason for their increase is likely to be independent of the retired farm as comparable changes occurred at all treatments. Monitoring over a longer time frame would indicate if densities returned to low levels and the time frame required for this cycle to follow its natural course.

## 6.4 Assessment of impact, recovery and recovery rates

### Control sites

Over the duration of the study, species abundance at control sites did not always remain stable (Table 4). For example, red lampshell, exhibited a decline in abundance, however, scallop, horse mussel, cushion seastar and pink urchin all showed a relatively large increase in abundance. In contrast, a sea cucumber abundance spike associated with a large recruitment pulse was recorded at only one control site in one sample. Giant lampshell, 11 arm seastar, kina and snake star all remained relatively stable at controls exhibiting only small changes in abundance. Interpretation of changes at retired warp and retired growing structure sites therefore needs to be considered with respect to natural changes occurring at control sites.

Four moderate to large abundance increases were recorded for species at controls. This suggests that over the duration of the present study, East Bay was not suffering any bay wide negative impacts from activities such as forestry, fishing or marine farming. During the study there were no large harvests of pine plantations in the Bay, however, it is noted that a large proportion of the Puriri Bay catchment will be logged in the future. The present data set may therefore provide a useful tool for assessing impacts in relation to that activity.

Over the period 2002 to 2013 the number of mussel farm consents in East Bay increased from 9 to 13 and the area occupied also increased from 33 ha to 43 ha. The increase in the number of farms and the area farmed in the Bay has not resulted in a Bay wide decline in the density of species monitored at control sites in the present study.

**Retired growing sites**

Many authors have reported that mussel farms impact benthic invertebrate communities (Mattson and Linden 1983; Kaspar *et al*., 1985; Stenton-Dozey *et al*., 1999), while others have reported little or no change (Hatcher *et al*., 1994; Hatcher *et al*., 1995; Crawford *et al*., 2003; Danovaro *et al.,* 2004). Some authors have reported both situations (Chamberlain *et al*., 2001; Hartstein and Rowden, 2004). Chamberlain *et al*., (2001) reported the variable impact levels were likely due to variations in local currents. Hartstein and Rowden (2004) reported that impacts at three mussel farms in the Marlborough Sounds varied depending on environmental variables, principally hydrodynamic regimes (i.e. currents and wave energy). The authors reported that at sites with high hydrodynamic regimes no detectable impacts were found, however sites in sheltered areas (low hydrodynamic regimes) resulted in a change in species composition and abundance.

In the present study, four of the 11 species monitored exhibited a reduction in abundance that could be associated with mussel growing structures. Not all impacts were, however, negative with three species increasing in abundance. The remaining four species did not appear to be affected (Table 5). The abundance of both species of lampshell, scallops and horse mussels were low at the start of the study within the area occupied by the retired growing structures. These species are filter feeders and potentially vulnerable to elevated levels of sediment in the form of pseudofaeces or are negatively impacted by physical smothering by shell debris. In contrast, 11 arm seastar are predators and benefit from the presence of a mussel food source. Kina may benefit from the addition of hard substratum in the form of mussel shell, while sea cucumbers likely benefit from the elevated organic content in the sediments they consume. The remaining four species are echinoderms and showed no change that could be attributed to the activity of mussel farming.

The rate that impacted species abundance returned to background levels varied (Table 5). For example, elevated kina and 11 arm seastar densities returned to background levels one year after the farm was removed, while horse mussel densities reached control levels 11+ years after the cessation of farming. Regardless of the species or the direction of recovery required to reach background levels, a recovery did occur for all impacted species. Further the decline in shell debris was considerably faster at depths >26 m compared to shallower areas dominated by coarser soft substratum. Therefore it is likely that rates of recovery are different based on habitat type and depth. Further, the relatively quick disappearance of mussel debris from deep mud areas supports the theory that mussel farm impacts are minimised by placing them over mud habitats (Forrest 1995; Keeley *et al*., 2009).

**Retired warps**

Only two monitored features from retired warps showed a detectable impact compared to control sites (Table 5). A small percentage cover of mussel shell debris was recorded at the start of the study. This shell material was derived from warp lines. Debris was deposited in rows under warps leaving most of the benthos in this area free of shell debris. Shell debris values dropped to near zero three years after the mussel farm was relocated. The only species to show an impact under warps was horse mussels. This species exhibited slightly lower densities compared to controls. Recovery for this species occurred over a 3-4 year period, however, this may be site dependent as this species has intermittent recruitment. It is possible that horse mussels were negatively impacted by elevated levels of sediment originating from the adjacent growing area. The scale of negative impact was smaller compared to the mussel growing area.

For most surface dwelling species, life under warps appeared to have little impact. The one species that showed a negative impact recovered relatively quickly after the farm was relocated. The low impact and the quick recovery are both likely linked to the low levels of mussel debris and the greater distance from the source of pseudofaeces. Warp areas appear little altered both visibly and physically and do not therefore require long recovery periods.

## 6.5 Photographic comparisons

Photos collected in 2005 by Davidson and Richards (2005) were compared with photos collected in November 2014. A number of photo pairs collected from the retired backbone area clearly show a loss of mussel debris (Plates 6 and 7).

**Plate 6. Example of the change in mussel debris recorded between 2005 (left) and 2014 (right) (photo 15, 22 m depth).**

Highest levels of mussel shell were originally recorded from shallow, inshore parts of the retired farm. In many areas shell debris cover was above 70%. At the end of the study this mussel debris had largely disappeared presumably being processed by biological and physical mechanisms.

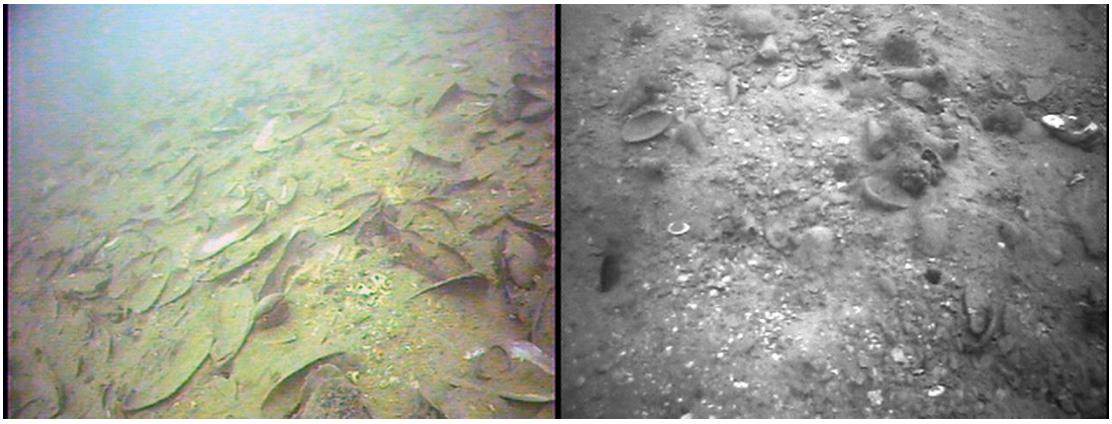


**Plate 7. Example of the change in mussel debris recorded between 2005 (left) and 2014 (right) (photo 14, 22 m depth, under retired backbones).**

# 7.0 CONCLUSIONS

Mussel farms physically alter the benthos by depositing shell (Keeley *et al*. 2009) and biodeposits (Harstein and Rowden 2004). This is most pronounced under structures where mussels are grown (i.e. under growing structures, droppers and backbones). Under warps, the degree of physical change is lower with relatively small and limited impacts compared to growing areas. The present study supports other studies that have shown detectable impacts from shell deposition from mussel farms to be limited to 10 m to 20 m distance from droppers (DeJong, 1994; Forrest, 1995; Davidson, 1998; Keeley *et al*. 2009, MPI 2013).

Under mussel growing structures, some species increased in abundance, some species declined in abundance and some species remained unchanged. This is probably a reflection of each species particular environmental requirements. Species that prefer low sedimentation and are vulnerable to smothering by shell are more likely to decline in abundance, while species that prefer hard substrata and/or prefer mildly enriched sediments, are likely to increase in abundance. Species that inhabit a variety of substrata and are tolerant of sediment and smothering remain unaffected.

Once farming ceases, all impacted species showed a recovery. The recovery rate was, however, different and likely associated with how species coped with a decline in shell debris and pseudofaeces. Recovery rates were also likely to vary based on substratum type and depth.

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**Table 5. Summary of density and abundance ranges for shell debris and a variety of species samples at retired growing, retired warp and control sites from 2002 to 2013.**

| Type | Detectable impact under growing structures | Impacted density range per $m^2$ | Recovery from impact | Detectable impact under warps | Impacted density range per $m^2$ | Recovery from impact | Control density range per $m^2$ | Control trend over study |
|---|---|---|---|---|---|---|---|---|
| Shell debris | Elevated % cover | 50-55% cover | 11 years shallow, 5 years deep | Yes (low) | 2-5% cover | Yes (3 years) | 0 | No change |
| Giant lampshell | Reduced density | 0 - 0.2 | 11 years | No | NA | NA | 0.5 - 1.75 | Stable, small change |
| Red lampshell | Reduced density | 0 - 0.25 | Not determined | No | NA | NA | 0.1 -1.0 | Variable, decline |
| Scallop | Reduced density | 0 -0.5 | Yes (scale of recovery not determined) | No | NA | NA | 0 -0.8 | Variable, large increase |
| Horse mussel | Reduced density | 0 -0.08 | Yes (11+ years) | Yes (low) | 0 - 1.7 | Yes (3-4 years) | 0.2 -0.7 | Moderate increase |
| 11 arm seastar | Elevated density | 0.2 - 0.35 | Yes (1 year) | No | NA | NA | 0.02 - 0.15 | Stable, small change |
| Kina | Elevated density | 0.2 -0.6 | Yes (1 year) | No | NA | NA | 0.5 - 0.2 | Stable, small change |
| Cushion seastar | No | NA | NA | No | NA | NA | 0.02 -0.5 | Stable start, large increase at end |
| Sea cucumber | Elevated density | 0.8 - 0.3 | 3-11 years | No | NA | NA | 0.02 - 0.7 | Stable with one peak at one site |
| Snake star | No | NA | NA | No | NA | NA | 0.015 -0.1 | Stable, small change |
| Pink urchin | No | NA | NA | No | NA | NA | 0.03 - 0.6 | Large increase |
| Brooch star | No | NA | NA | No | NA | NA | 0 - 0.05 | Rare, intermitent records |

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## Appendix 1. Photo comparisons Davidson 2005 (left) and present study (right).

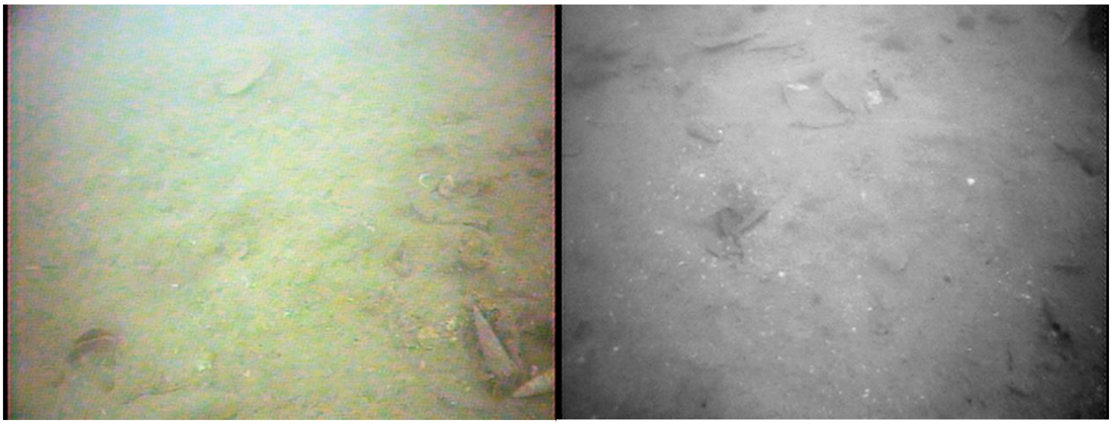

Photo 1 (26 m depth, under retired backbones).

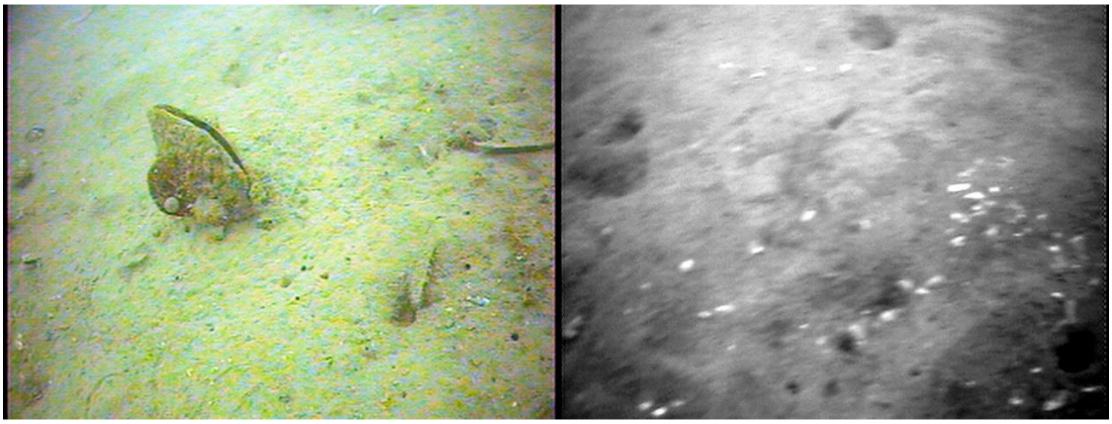

Photo 2 (29 m depth, under retired backbones).

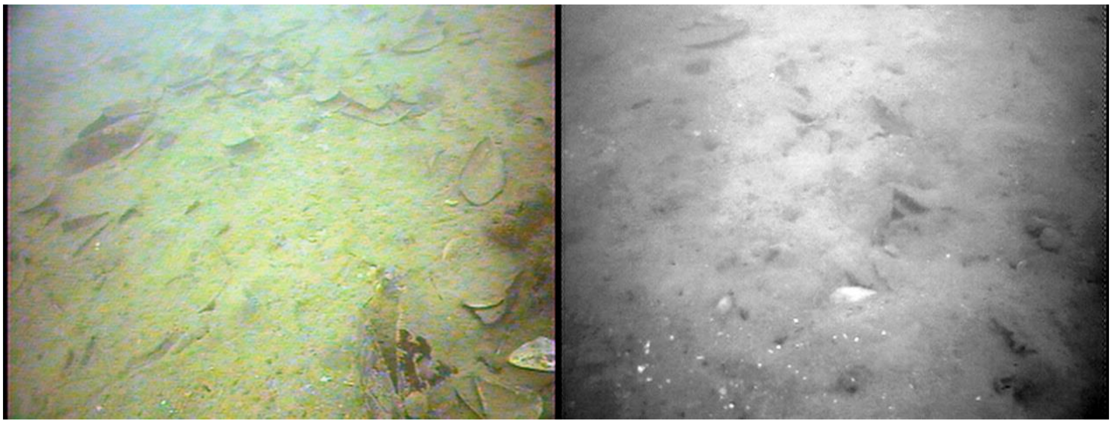

Photo 3 (29 m depth, under retired backbones).

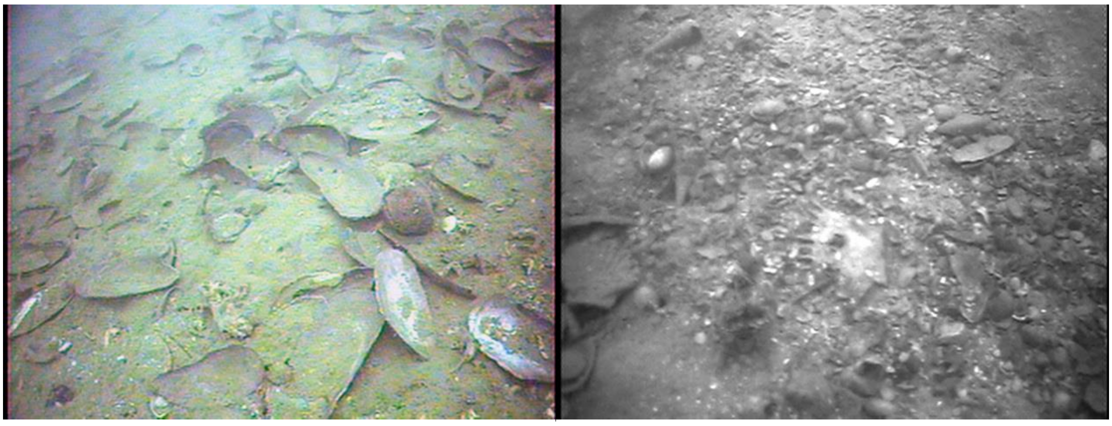

Photo 4 (24 m depth, under retired backbones).

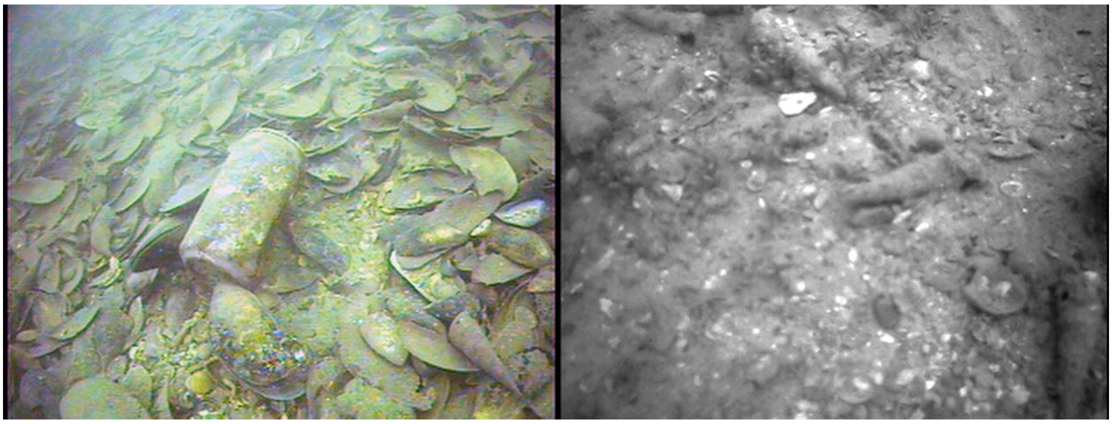

Photo 5 (20 m depth, inshore of retired backbones).

Photo 6 (23 m depth, under retired warps).

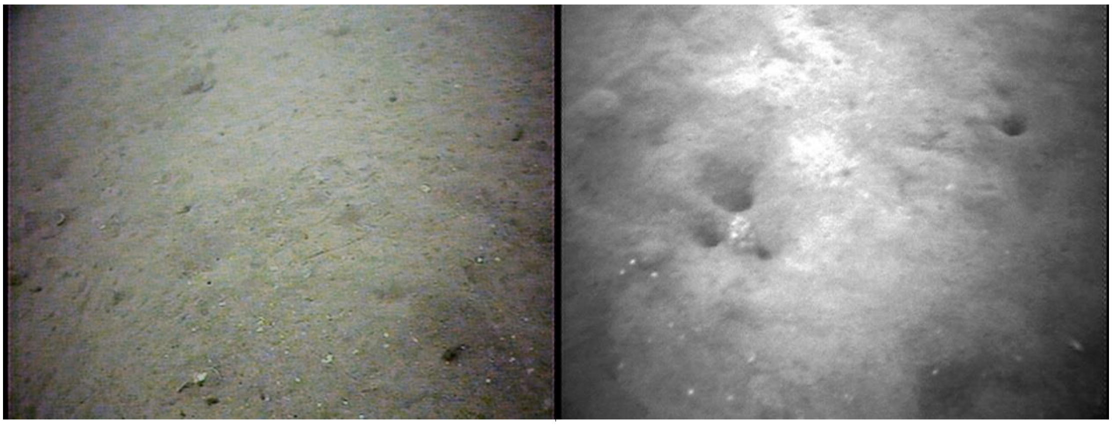

Photo 7 (30 m depth, offshore of retired warps).

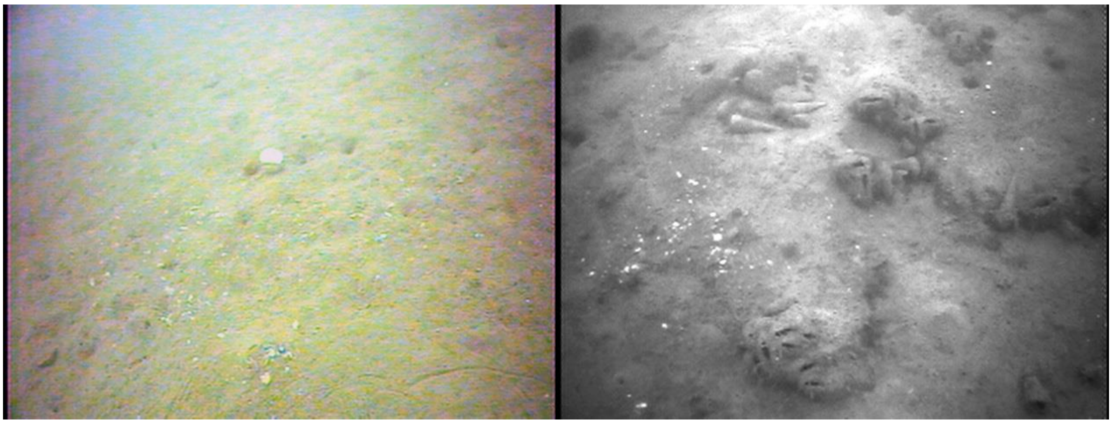

Photo 8 (28 m depth, under retired backbones).

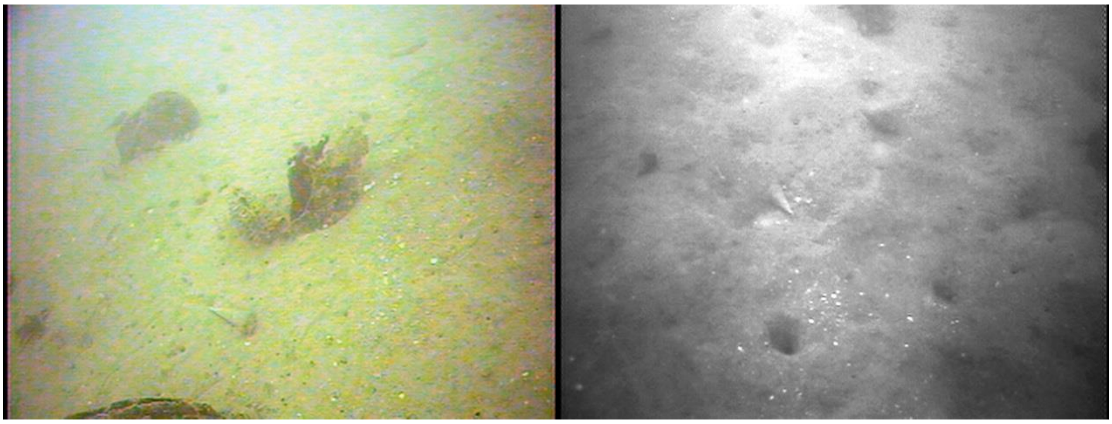

Photo 9 (26 m depth, under retired warps).

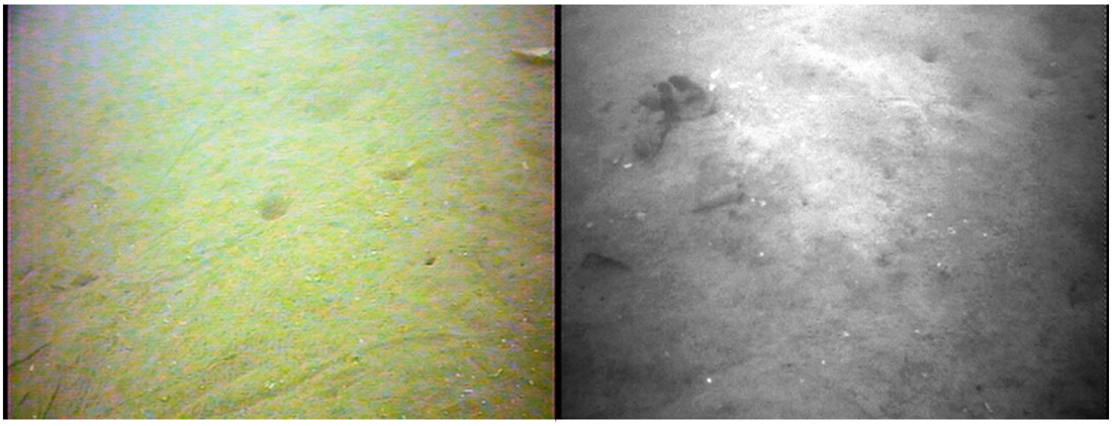

Photo 10 (31 m depth, offshore of retired backbones).

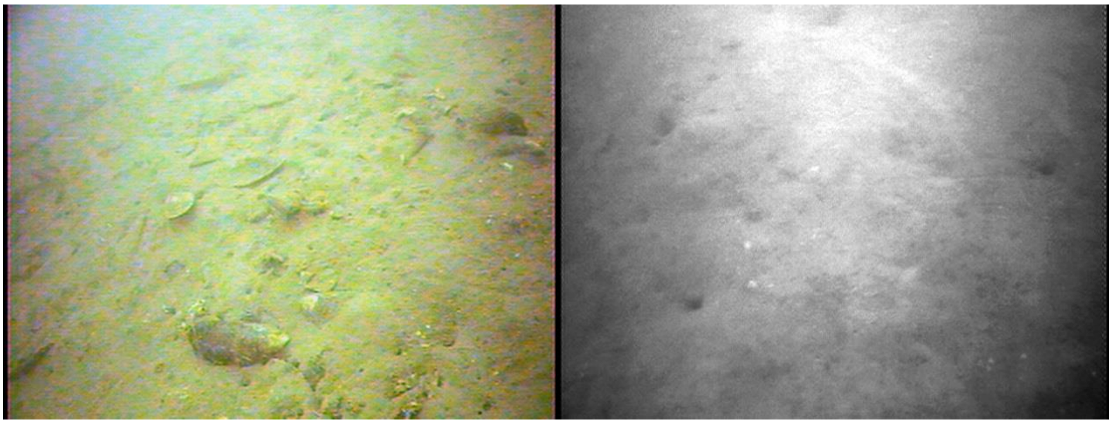

Photo 11 (30 m depth, under retired backbones).

Photo 12 (29 m depth, under retired backbones).

Photo 13 (27 m depth, under retired backbones).

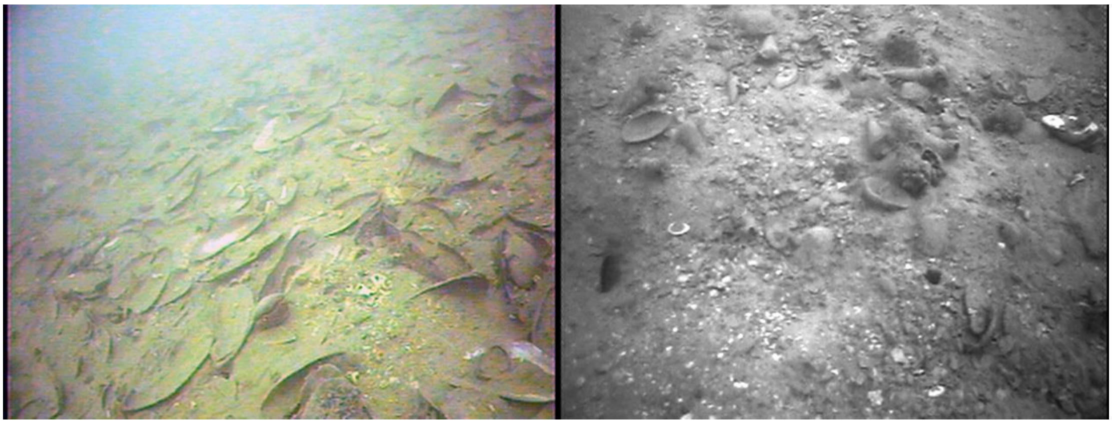

Photo 14 (22 m depth, under retired backbones).

Photo 15 (22 m depth, inshore of retired backbones).

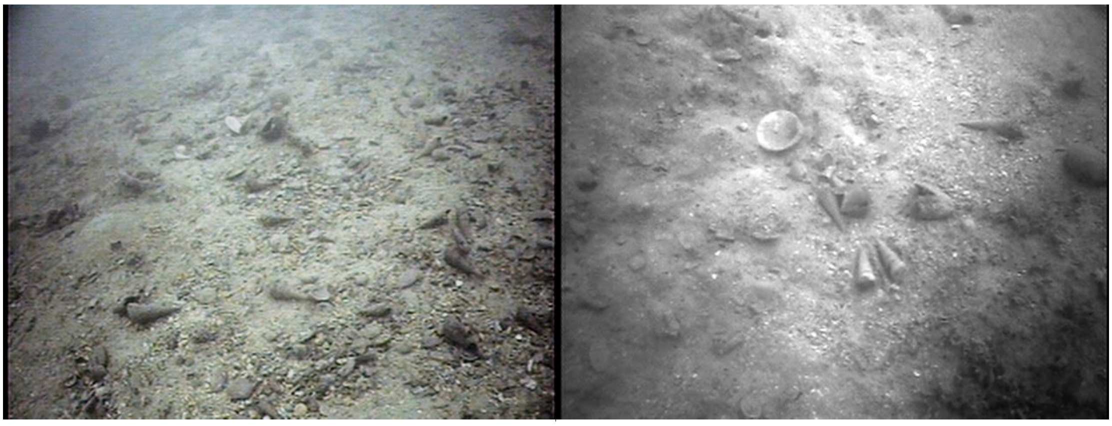

Photo 16 (20 m depth, inshore of retired backbones).

Photo 17 (23 m depth, under retired warps).

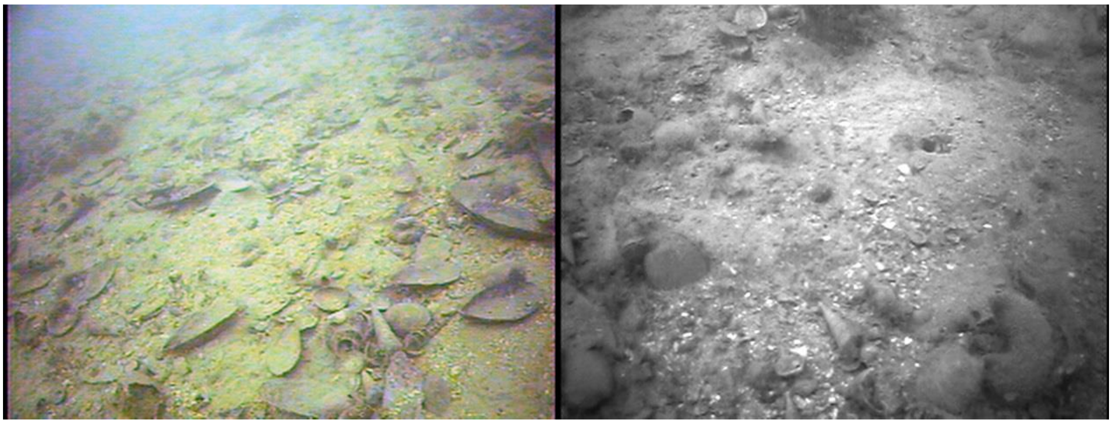

Photo 18 (21 m depth, inshore of retired backbones).

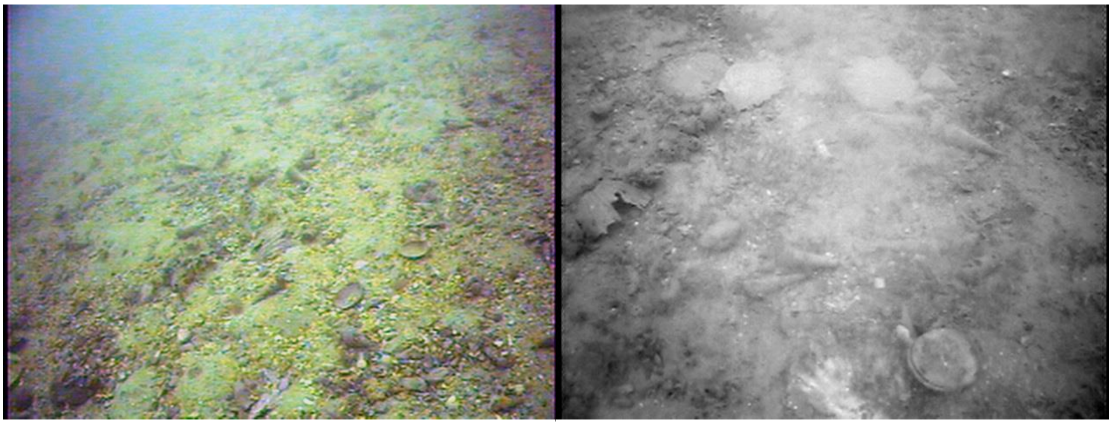

Photo 19 (20 m depth, inshore of retired backbones).

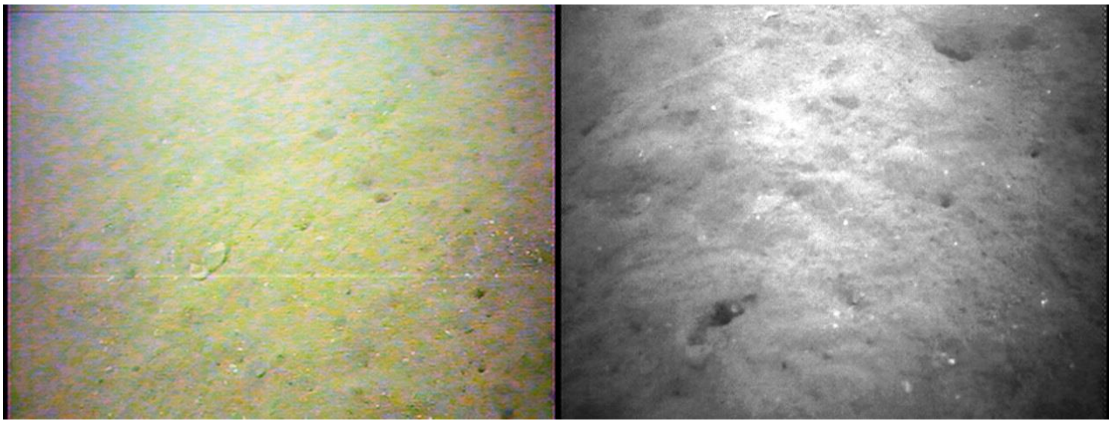

Photo 20 (30 m depth, under retired backbones).

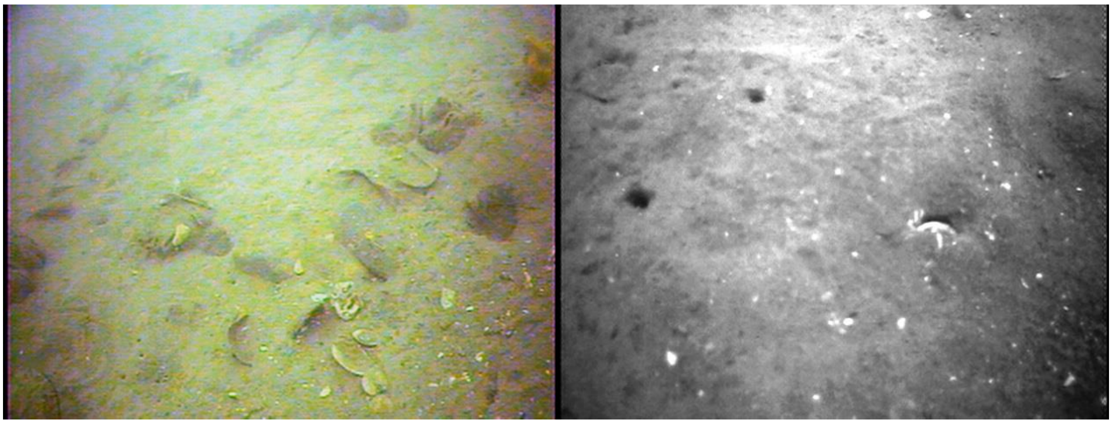

Photo 21 (29 m depth, under retired warps).

Photo 22 (27 m depth, under retired warps).