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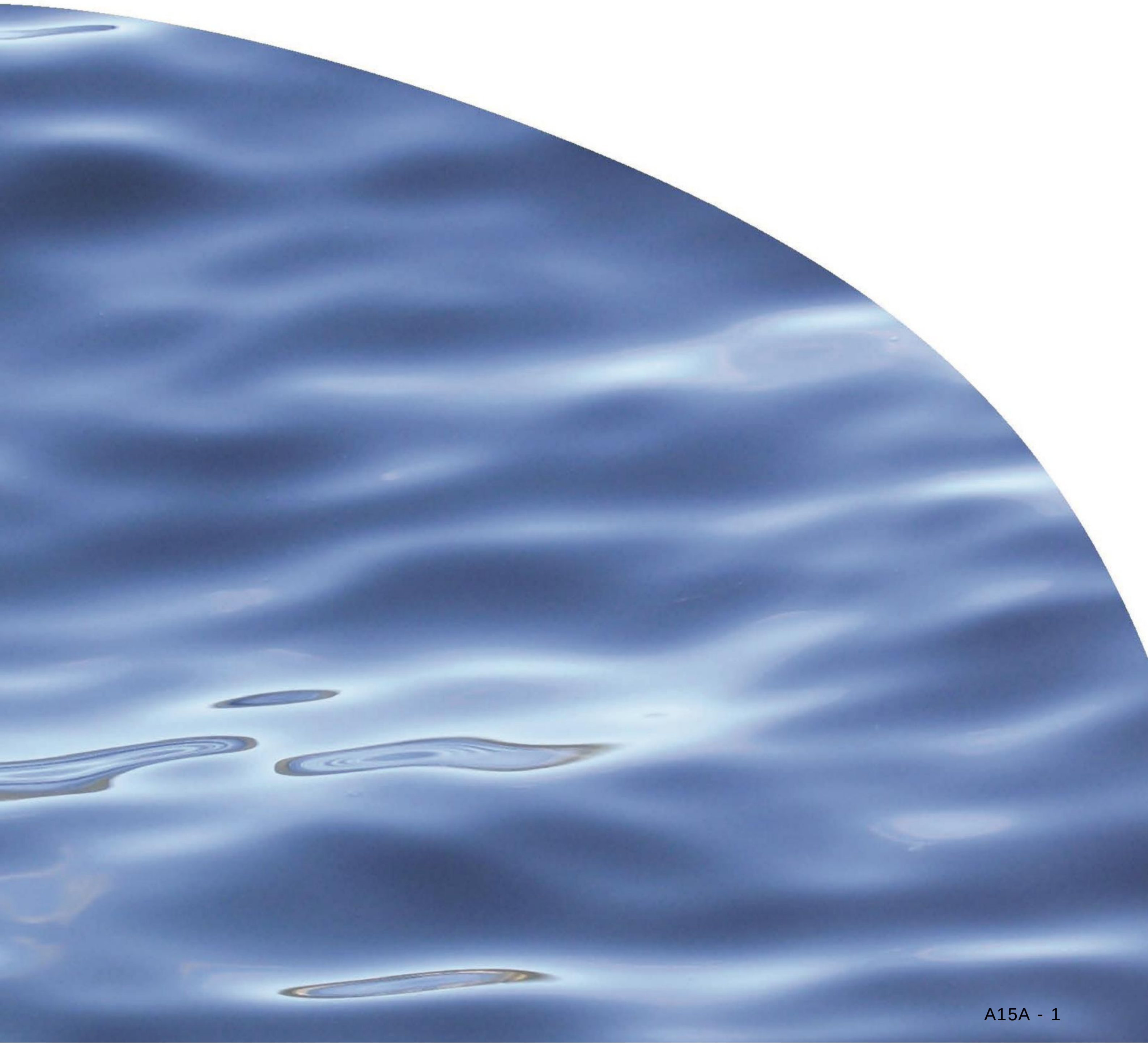
MARINE ECOLOGY ASSESSMENT

REPORT NO. 2860

ASSESSMENT OF IMPACTS TO BENTHIC ECOLOGY AND MARINE ECOLOGICAL RESOURCES FROM THE PROPOSED LYTTELTON HARBOUR CHANNEL DEEPENING PROJECT



ASSESSMENT OF IMPACTS TO BENTHIC ECOLOGY AND MARINE ECOLOGICAL RESOURCES FROM THE PROPOSED LYTTELTON HARBOUR CHANNEL DEEPENING PROJECT

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Prepared for Lyttelton Port Company Ltd

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ISSUE DATE: 28 September 2016

RECOMMENDED CITATION: Sneddon R, Atalah J, Forrest B, Mackenzie L, Floerl O. 2016. Assessment of impacts to benthic ecology and marine ecological resources from the proposed Lyttelton Harbour Channel Deepening Project. Prepared for Lyttelton Port Co Ltd. Cawthron Report No. 2860a. 190 p. plus appendices.

EXECUTIVE SUMMARY

Lyttelton Port Company Ltd (LPC) proposes to extend its existing dredged approach channel out to approximately 5 km ENE of Godley Head, widen it by 20 m and deepen it to a depth of 17–18 m (CD) to accommodate larger vessels. This Channel Deepening Project (CDP) would be undertaken in at least two stages and see the removal of approximately 18 million cubic metres of benthic sediments, which would be deposited in a spoil ground of area 1,250 ha, to be centred approximately 7.8 km ENE of Godley Head in water depths of approximately 20 m. Due to sediment in-fill, the approach channel, ship-turning basin and berth areas also need to be regularly dredged to maintain navigable depths. As part of the production of a full Assessment of Environmental Effects of the dredging and spoil disposal operations, the Cawthron Institute was contracted to provide an assessment of effects on benthic habitats and marine ecological resources.

Field survey work, focussing on the proposed channel extension and the wider vicinity of the proposed spoil ground, was carried out over 2007/2008. Characterisation of the benthic environment employed a combination of discrete benthic sampling and broad survey methods including:

- Collection of benthic sediment samples for physical, chemical and ecological analyses.
- Sampling of benthic epifauna (surface-dwelling fauna) using a research dredge.
- Broad-scale side-scan sonar imaging of the seabed over the wider area.

Extensive dive survey work was undertaken in February 2016 to characterise the shoreline reef habitats and communities from the central Harbour area to Little Akaloa Bay on the northern Banks Peninsula coast, and including sites in Port Levy/Koukourārata and Pigeon Bay. Intertidal reef sites were also surveyed at this time and further benthic sampling conducted in the Harbour and offshore. The field data were supplemented with information from several other surveys conducted within the Harbour over the past decade.

Soft sediment benthic habitats

Benthic substrates in both the channel extension area and the proposed spoil ground were found to be relatively uniform semi-consolidated muds with the channel extension area having a slightly greater proportion of silt/clay particulates. Side-scan sonar coverage of both sites confirmed that the benthic substrate and habitat was effectively uniform over the study area. Contaminant status of surficial sediments, based on concentrations of indicative metals, was found to be low with levels generally well below national sediment guideline levels. The substrate at benthic sites within Lyttelton Harbour/Whakaraupō was variable in texture ranging between soft mud and very fine sand.

Both epifaunal and infaunal communities were found to be relatively sparse across the areas sampled, with 23 and 90 taxa identified, respectively. Overall, polychaete worms represented eight out of the twelve most abundant infaunal taxa and around 70% of all individuals counted. The proposed channel extension area was characterised by a poorer benthic community assemblage (in terms of both abundance and diversity) than sites further

offshore. Benthic communities sampled within the Harbour were highly variable due mostly to the influence of sediment texture. Both substrate and biological characteristics were consistent with a number of previous surveys of the Pegasus Bay benthic environment indicating that the seabed area off Godley Head is typical of the benthic ecology of the wider benthic area in similar water depths.

Shoreline reef habitats

The nearest shorelines to the project areas are relatively steep rocky profiles ranging from the exposed high-energy shores of Godley and Adderley heads and Baleine Point to more sheltered areas further into Lyttelton Harbour/Whakaraupō and the inlets of Port Levy/Koukourārata and Pigeon Bay. Subtidal and intertidal ecological surveys indicated reef communities typical of the wider area but exhibiting gradients in community assemblage according to exposure to wave energy. Sediment-tolerant taxa formed a component of the species inventory but settled sediment was generally limited to thin veneers in these surge-affected areas.

Kelp forest of varying density was a consistent feature of transects in 4 m water depth; however, large canopy-forming macroalgae such as these were sparse at 7 m depths. Pāua were found across all areas and were counted and measured along 50 m littoral fringe transects at 0.5 m (CD) water depth. High pāua densities were observed at many sites but shell length was relatively low with only 2% measured at greater than the legal size limit.

Overall, no intertidal or subtidal organisms or communities of special scientific or conservation interest have been identified from the surveys carried out for this work. A reportedly unique community of brachiopods, including one listed by the Ministry for the Environment (MfE) as Nationally Critical, was not found during a survey of the intertidal Harbour location (Ripapa Island) from which it was last recorded in the 1960s.

Assessment of effects

The CDP will affect approximately 135 ha of previously undredged area. Altogether around 280 ha of seabed will be subject to future maintenance dredging, effectively preventing its complete ecological recovery to an undisturbed state. However, this is not likely to be significant in terms of the functioning of benthic ecosystems over the wider area.

The deposition of 18 million m^3 of spoil will result in significant smothering impacts for the 1,250 ha offshore spoil ground and may also affect a margin of up to 500 m around its boundary. However, there are several mitigating factors which suggest that the ecological recovery of this area will be rapid:

- The benthic community does not include habitat-forming species; rather, it is dominated by taxa which are able to rapidly recolonise a disturbed area (*e.g.* weeks to months).
- The CDP will occur in not less than two stages with a potentially significant period between stages.

- Deposition will be incremental over extended time periods (9 - 14 months per dredging stage) and spatially distributed, allowing recovery to commence within project time-frames.
- There will be a high degree of textural and compositional similarity between the deposited spoil and the current benthic substrate of the spoil ground.
- The sediment deposited at the offshore spoil ground will have generally low levels of trace metals and other contaminants.
- Suspended sediments will be incorporated into the significant natural sediment resuspension and deposition processes operating within inshore Pegasus Bay.

The principal water-borne stressor associated with the project will be that of elevated suspended solids concentrations (SSC) within turbidity plumes generated by resuspension of benthic sediments. The most important factor in the tolerance of marine communities to suspended solids and turbidity is the background levels of these parameters to which they are adapted. The waters of Lyttelton Harbour/Whakaraupō and inshore Pegasus Bay are naturally turbid with high fine sediment inputs from riverine discharges, run-off and coastal processes (*e.g.* erosion, wave resuspension).

The results of plume modeling for both dredging and spoil deposition indicate that the majority of suspended material will be near the seabed and ecologically significant concentrations will be spatially limited to the vicinity of disturbance. The soft-sediment benthic community, with its prevalence of polychaete species, is inherently tolerant of sustained conditions of high suspended sediment loadings, including the increased deposition rates which this engenders. In neither case are concentration contours of 10 mg/L above background predicted to impinge upon shoreline areas except possibly the Port itself (adjacent to the swing basin) and Shag Reef.

Shallow reef communities in the area are generally adapted to highly variable but persistently turbid conditions. If unforeseen factors result in sediment plumes impinging upon shoreline areas, it is unlikely that these aged plumes will be at concentrations where these communities will suffer acute stress. However, turbidity sustained above typical background levels may result in a shift in the prevalence of sediment-tolerant taxa and a decrease in macrophyte cover and the depth to which it extends. The degree to which these changes may occur depends upon the severity and the duration of these conditions but it is very unlikely that such shifts would occur irreversibly.

Potential effects on fish and fisheries

Lyttelton Harbour/Whakaraupō and southern Pegasus Bay are of noted importance as recreational and commercial fisheries areas. The main potential issue for fisheries resources in the region is considered to be the temporary loss of benthic habitat represented by the proposed spoil ground and areas immediately adjacent to its boundaries. Since the area potentially affected comprises less than 1% of the seabed area inside the 50 m contour within Pegasus Bay, there is very unlikely to be a significant effect on the wider fishery.

Local fish populations are expected to be naturally tolerant of elevated suspended sediment levels to some extent, especially benthic or demersal species such as flatfish, elephant fish and gurnard. Avoidance of areas of particularly high suspended solids is likely to be the principle response of finfish species to increasing stress from turbidity plumes which are expected to be spatially limited. Plume extent within the Harbour is not expected to significantly hinder fish movement.

In terms of catch weight, most commercial fishing along this Pegasus Bay coast occurs predominantly in waters deeper than 30 m; hence there is considered to be little spatial overlap with the majority of fishing activity on this basis. A spatially constrained area offshore from Godley Head (but not extending over the capital spoil ground) appears to be especially productive for flatfish, despite close proximity to LPC's consented maintenance dredge spoil ground. The target species (yellowbelly flounder) is known to prefer very turbid conditions and an impact from the CDP upon the utilisation of this area by this species is considered unlikely.

While areas of Lyttelton Harbour/Whakaraupō are believed to serve as nursery habitat for a range of fish species and near-shore sediment habitat in Pegasus Bay is used by elephant fish for egg-laying, there is little information suggesting that the central to outer Harbour and proposed spoil ground area are of critical regional importance in this regard.

As with shoreline reef habitats generally, populations of pāua and lobster are effectively located outside the effects footprint of the capital dredge project, including plume concentration contours likely to cause stress to these species. Similarly, current mussel farming operations located on the northern Banks Peninsula coastline and within the inlets of Port Levy/Koukourārata and Pigeon Bay are outside the region predicted to experience turbidity plumes at levels of potential concern.

Biosecurity considerations

Three broad sources of marine biosecurity risk potentially arise as a result of the CDP:

- Introduction of new harmful marine organisms (HMOs) to New Zealand from the dredge that will be brought into the country from overseas.
- Increased HMO risk due to dredging, spoil transfer and disposal.
- Increased HMO risk due to changed shipping activities enabled by the deepened channel (and simultaneous Port development).

The risks from the CDP activities are likely to be negligible, and do not warrant the implementation of any mitigation measures. Vessel movements from overseas are considered to be the key risk. Although HMO-specific risks from vessel movement are unknown and unpredictable, adherence to the Ministry of Primary Industry's border standards (the mandatory IHS for ballast water and sediment, and voluntary Craft Risk Management Standard (CRMS) for biofouling) will greatly mitigate the potential for HMO introductions.

Given the specific biofouling risk represented by slow-moving, structurally complex vessels such as dredges, it is suggested that the dredge utilised for the CDP is required to adhere to CRMS requirements and that, as a condition of the consent, a specific Biosecurity Management Plan (BMP) is developed for the contracted dredge and submitted to MPI.

Monitoring of ecological receptors

In order to gauge the significance and spatial extent of plume-mediated effects from the CDP, the soft sediment benthic environment is considered to represent the most useful easily-monitored ecological receptor. Such monitoring will also provide the most reliable data for interpretation since the ubiquity and uniformity of this habitat allows the observation of spatial gradients in effects. It additionally provides the best opportunity for documenting the post-deposition recovery of the capital spoil ground and therefore a direct indication of the health of the food web base upon which less easily monitored receptors (such as fish and dolphins) ultimately depend.

A pattern of 19 soft sediment benthic monitoring stations is recommended, covering central and outer Lyttelton Harbour/Whakaraupō and southern inshore Pegasus Bay. Of these, 14 should be subject to monitoring at intervals during each dredging stage/campaign and a further five contributing to baseline and post-campaign records. Sampling should be based on triplicate grab samples from each station.

To provide for direct monitoring of high-value shoreline receptors, a subset of six of the 21 subtidal sites and four of the five intertidal reef sites surveyed for this investigation is recommended to be re-surveyed immediately prior to, and at intervals during and following each stage of the CDP.

Future maintenance dredging

The proposed establishment of a new maintenance dredging spoil ground offshore from Godley Head was also investigated. The existing benthic habitat and community in this area was found to be similar to that of the capital spoil ground and the Harbour approaches. Hence much of the assessment regarding effects from maintenance spoil deposition is similar to that for the use of the capital spoil ground. Based on spoil deposition plume modelling, significant turbidity plumes are very unlikely to impact shoreline receptors despite the greater proximity of the maintenance ground to shoreline reef habitats at Godley Head.

Where the maintenance dredge spoil ground differs from capital dredging is its ongoing periodic use which may be expected to establish a cycle of impact and recovery for benthic habitat within its boundaries. While such cycling may effectively prevent complete recovery of communities (beyond an intermediate successional stage), the existing benthic environment features high rates of natural resuspension, minimal physical structure and low community complexity. The long-term benthic monitoring of Port Lyttelton's existing maintenance spoil grounds has shown that this type of habitat experiences rapid recovery from spoil deposition and exhibits minimal longer-term change compared to adjacent undisturbed areas.

There is some potential for an effect from offshore maintenance dredge spoil deposition on local flatfish catch yield from the relatively productive area adjacent to Godley Head. This may arise from trawl gear interactions with an altered seabed as well as from direct disturbance to local flatfish populations.

There is some uncertainty regarding the eventual pattern of usage of the existing and proposed spoil grounds for maintenance dredging; therefore it is recommended that the 5-yearly benthic monitoring required by the current consent be retained, but that three additional benthic stations be incorporated to cover the establishment of the proposed offshore ground.

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GLOSSARY

Abbreviation	Definition	Type
µm	Microns	Unit
2-D	2-dimensional	Abbreviation
ADP or ADCP	Acoustic Doppler Current Profiler	Acronym
AFDW	Ash Free Dry Weight	Acronym
AMP	Adaptive Management Program	Acronym
ANZECC	Australia New Zealand Environment Conservation Council	Acronym
aRPD	Apparent redox potential discontinuity (layer)	Acronym
BOD_5	Five day biochemical oxygen demand	Acronym
CD	Chart datum	Acronym
CDP	Capital Dredging Project	Acronym
CELA	Catch effort landing returns	Acronym
cm	centimetre	Direction
CMA	Coastal Marine Area	Acronym
Cr	Chromium	Abbreviation
CTD	Conductivity-temperature-depth	Acronym
Cu	Copper	Abbreviation
CV-AAS	Cold vapour – atomic absorption spectroscopy	Acronym
EEZ	Exclusive economic zone	Acronym
ESE	East-south-east	Direction
FMA	Fisheries Management Area	Acronym
FSA	Fisheries statistical area	Acronym
FTU	Formazin turbidity units	Acronym
$gm^{-2}year^{-1}$	Grams per square metre per year	Unit
GPS	Global positioning system	Acronym
H'	Shannon-Weiner Diversity	Index
Hg	Mercury	Abbreviation
ICP-MS	Inductively coupled plasma – mass spectrometer	Acronym
ICP-OES	Inductively coupled plasma – optical emission spectrophotometer	Acronym
ISQG-High	Interim Sediment Quality Guideline – High threshold	Acronym
ISQG-Low	Interim Sediment Quality Guideline – Low threshold	Acronym
J	Pielou's evenness	Index
km	Kilometre	Unit
kt/year	Kilotonnes per year	Unit
LPC	Lyttelton Port Company Ltd	Acronym
m	Metre	Unit
m^2	Square metre	Unit
m^3	Cubic metre	Unit
MDS	Multi-dimensional scaling	Acronym
mg/kg	Milligrams per kilogram	Unit
mm	Millimetre	Unit
MPI	Ministry for Primary Industries	Acronym
MSL	Mean sea level	Acronym
Mt/year	Megatonnes per year	Unit
n	Number of replicate samples	Abbreviation
N	Nitrogen Abundance	Index
NE	North-east	Direction
Ni	Nickel	Index
NIWA	National Institute of Water and Atmospheric Research	Acronym
Nm	Nautical mile	Unit
NTU	Nephelometric turbidity units	Acronym
NW	North-west	Direction

OBS	Optical back scatterance	Acronym
PAH	Polycyclic aromatic hydrocarbon	Acronym
PAR	Photosynthetically active radiation	Acronym
Pb	Lead	Abbreviation
PCO	Principal coordinates ordination	Acronym
PVC	Polyvinyl chloride	Acronym
QMA	Quota Management Area	Acronym
QMS	Quota Management System	Acronym
r^2	Coefficient of determination	Coefficient
RCEP	Regional Coastal Environment Plan	Acronym
S	Species richness	Index
S.G.	Specific gravity	Acronym
SCUBA	Self-contained underwater breathing apparatus	Acronym
SE	Standard error	Acronym
SE	South-east	Direction
SVOC	Semi-volatile organic compound	Acronym
TACC	Total allowable commercial catch	Acronym
TOC	Total organic carbon	Acronym
TSHD	Trailer suction hopper dredge	Acronym
WGS84	World Geodetic System 1984	Acronym
Zn	Zinc	Abbreviation

1. INTRODUCTION

1.1. Background

Lyttelton Port Company Ltd (LPC) proposes to deepen and extend its existing dredged approach channel in Lyttelton Harbour/Whakaraupō. This Channel Deepening Project (CDP) would extend the maintained channel 4 km beyond the present pilotage limit, out to approximately 4.7 km ENE of Godley Head in southern Pegasus Bay (Figure 1). Dredging would also slightly widen (by 20 m) the existing channel and establish depths of approximately 17 m (at chart datum). This will result in the removal of approximately 18 million cubic metres of benthic sediments. It is further proposed that these sediments be deposited at a spoil ground of some 1,250 ha area, to be centred approximately 8.2 km ENE of Godley Head.

The increased area of the deepened channel and the ship turning basin will in turn increase the quantity of sediments required to be removed during future maintenance dredging. Part of the CDP therefore includes the establishment of a new maintenance dredge spoil ground in Pegasus Bay offshore from Godley Head (Figure 1).

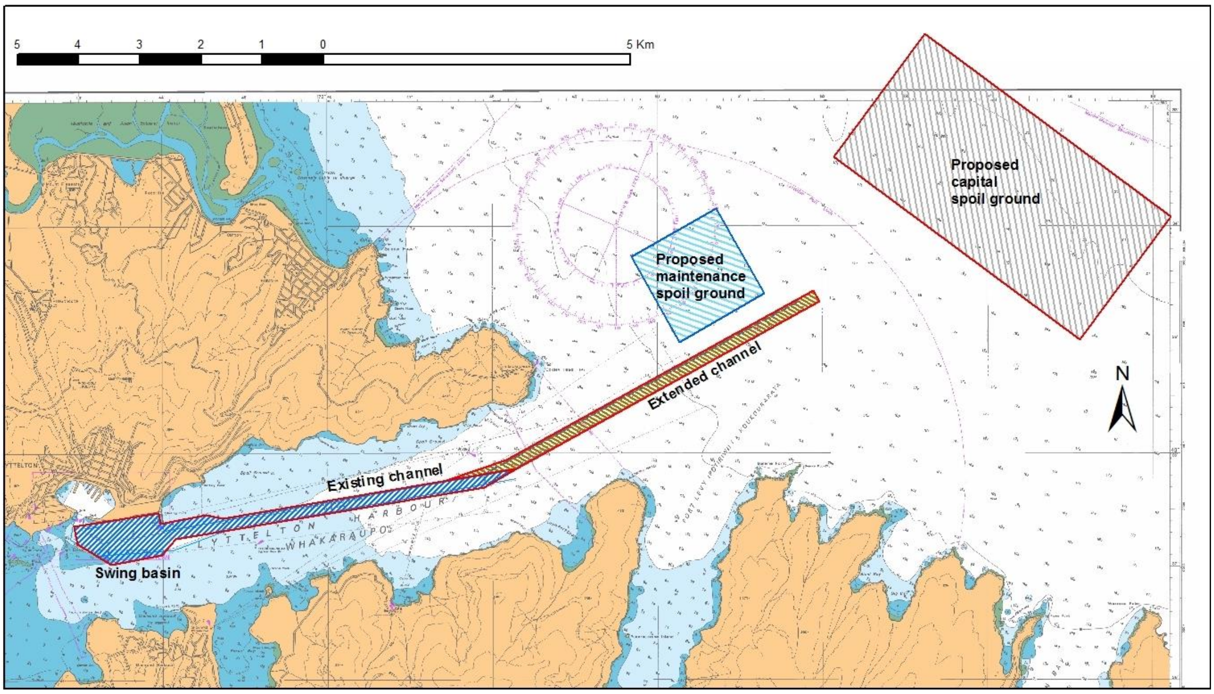

Figure 1 Chart showing the location of project components in relation to Lyttelton Harbour/Whakaraupō and approaches. (Part Chart NZ6321).

As part of the production of a full Assessment of Environmental Effects (AEE) for the dredging and spoil disposal operations, Cawthron Institute (Cawthron) was contracted to provide an assessment of effects on benthic habitats and marine ecological resources.

This entailed the completion of extensive field surveys of benthic and coastal ecology, including the collection and analysis of benthic samples and a review of the relevant scientific, fisheries and area-specific literature. In particular, the assessment relies on predictions of sediment plume propagation and bed movement from hydrodynamic modelling of the dredging and spoil deposition processes.

1.2. Objectives and scope

The primary objectives of the investigation were to describe the benthic and shoreline habitats that may be affected by the CDP and to provide an assessment of the likely marine ecological impacts.

Specifically, this study was designed to:

1. Characterise the benthic substrate and ecology existing in the vicinity of the areas of the proposed channel extension and offshore spoil ground.
2. Characterise the adjacent and far-field shoreline hard substrate communities (both intertidal and subtidal).
3. Assess whether any benthic habitats or communities of special scientific or conservation interest exist in the vicinity of the proposed activities.
4. Assess the potential effects on fisheries resources in inshore Pegasus Bay and Lyttelton Harbour/Whakaraupō.
5. Provide an assessment of the sensitivity of the benthic environment and wider coastal marine area to impacts from the proposed dredging and spoil deposition activities.
6. Describe the likely severity and temporal and spatial extent of benthic ecological effects from the project.
7. Provide recommendations for monitoring of potential ecological receptors.

2. PROJECT DESCRIPTION

2.1. Capital dredging

For a full description of the activities, location and methodologies proposed as part of the Channel Deepening Project, refer to Section Two (Project Description) of the Assessment of Environmental Effects

2.1.1. Dredging method

The type of dredge used is likely to be a trailing suction hopper dredge (TSHD). The pumping action of a THSD entrains a significant proportion of seawater with the spoil dislodged by the drag head, resulting in a slurry being deposited in the hopper. As this slurry settles out in the hopper, it can be advantageous to overflow some of the overlying water back into the water column; however, due to more rapid settlement rates, hopper overflow is usually more effective with sandy sediments rather than the fine loess sediments of Lyttelton Harbour/Whakaraupō. Hence overflow periods exceeding 20 minutes are not anticipated. It is a common practice to release over-flow discharges at depth to help minimise the severity and extent of surface turbidity plumes.

Sediment-laden seawater can also be discharged briefly at the beginning and end of a dredging pass. At the beginning, the discharge may be conducted until the dredged slurry reaches sufficient density (approximately 1.3 tonnes/m^3) to begin loading of the hopper. At completion of loading, seawater may be pumped to clear the drag head and pipe of sediment, with this being jettisoned via the overflow.

In contrast to the 1,000 m^3 TSHDs routinely used for maintenance dredging of the current channel, the dredges used for capital works are likely to have a hopper capacity of between 4,000 m^3 and 18,000 m^3. It is anticipated that the project would entail a 24-hour, 7 day-a-week dredging operation.

2.1.2. Dredge spoil disposal

To attain the channel depths specified above, it is anticipated that the capital dredging project will generate approximately 18 million cubic metres of spoil material[1]. It is intended that this dredged spoil will be deposited further offshore in the spoil ground site shown in Figure 1. This will be located some 6 kilometres from Godley Head and 5 kilometres from Baleine Point at its nearest points. It will comprise a rectangular area oriented roughly north-west to south-east and 5 km and 2 km on each side respectively. Aligned with the 20 m isobath, water depths within this area vary between 17.5 m and 21.0 m chart datum (CD) from the landward to seaward sides respectively.

[1] At a mean specific gravity of 1.68 tonnes/m^3, this represents a total of approximately 31 million tonnes of sediment to be removed

At the spoil ground, each hopper load will be released at a precisely predetermined location to ensure a controlled distribution upon the seabed. The bottom-opening hoppers on modern TSHDs ensure that each load is released at depth, minimising the suspension of sediments in the upper layers of the water column. Upon release, the load sinks to the seabed as a dense fluid that impacts the bottom and spreads out horizontally and radially away from the impact point until the advancing front loses momentum and settlement processes become prevalent.

2.1.3. Staging and duration of works

The deepening to ultimately meet the needs of a 14.5 m draught ship will occur in not less than two stages. However the actual number and the scope of each stage are yet to be determined.

If the dredging was undertaken in two stages, and assuming a vessel of around 10,000 m^3 is used, each stage would take approximately 9–14 months to complete. This assumes the cycle time from beginning dredging, travelling out to the disposal ground, depositing the spoil and return to the dredge location takes around 2–3 hours.

2.2. Future maintenance dredging

Regular maintenance dredging of the channel is required, primarily due to wave-mediated resuspension, transport by prevailing currents and re-deposition. The volume of material dredged per year from the existing channel in the last 10 years has varied from approximately 280,000 m^3 to 590,000 m^3, except during 2009 when just over 800,000 m^3 needed to be dredged over two campaigns due to greater than normal swell conditions. LPC holds a coastal permit (CRC135318) to carry out maintenance dredging and to deposit the spoil in designated spoil grounds on the north-side of the central to outer Harbour.

Although the amount of spoil required to be dredged from the *existing* areas of maintained depths will not change appreciably with deepening, the increased area of such maintenance resulting from an extended and widened channel and swing basin will mean that overall maintenance dredge volumes will increase.

For the post-capital dredging Harbour configuration, it is proposed to establish a new maintenance dredge spoil ground between Godley Head and the capital dredging spoil disposal ground. The site is 1.6 km by 1.6 km, located approximately 2.25 km offshore from Godley Head (Figure 1). Although it is proposed to continue to use the current spoil grounds for deposition of some dredged material, the new spoil ground is expected to accept up to 0.9–1.2 million m^3 annually, dependent on harbour system stabilisation at Godley Head. It is expected that a trailer suction hopper dredge of capacity 1,840 m^3 will be used for this maintenance dredging.

3. COASTAL MARINE ENVIRONMENT

3.1. Overview

The east coast of the South Island around Banks Peninsula is exposed to a prevailing oceanic swell. This region marks the northernmost position of the Subtropical Convergence, also known as the Southland Front, and is frequently exposed to high energy oceanic swells and storm waves. Annual ocean temperatures range from 8.5°C to 19°C. Softer rock types, such as limestone and siltstone, dominate much of the coastline of the eastern South Island. Together with riverine inputs and agricultural run-off, this often produces a heavy sediment load in inshore waters, making underwater clarity poor.

3.1.1. Banks Peninsula

Banks Peninsula consists of the remnants of two primary shield volcanoes and individual lava flows have created a series of steep-sided spurs, with deep valleys in the interflow areas. The numerous bays of the peninsula have formed as a result of the flooding of these valleys by rising seas at the end of the Pleistocene. Most of these embayments have sediment fills composed of fine silts and clays of marine origin (Stephenson & Schulmeister 1999). The shoreline of Banks Peninsula is characterised by numerous shore platforms, sandy beaches, stone and boulder beaches, mudflats (at the heads of inlets) and sea caves.

3.1.2. Pegasus Bay and Lyttelton Harbour/Whakaraupō

Pegasus Bay is a wide bay extending from the Waipara River mouth in the north to Banks Peninsula[2] in the south. Most of the coastline comprises low-lying and generally stable sand and gravel beaches backed by extensive sand dune systems. The continental shelf at this point is wide, extending well offshore. Inshore regions are relatively shallow, deepening only gradually seawards with the 20 and 30 metre contours at 10 km and 35 km from the coastline, respectively, at Godley Head. The nearshore is characterised by fine sands which extend out to a water depth of around 12–15 m. Mean sediment grain sizes decrease in size with distance from the shore. Beyond depths of 15–20 m, the seabed becomes increasingly dominated by muds (Allan *et al.* 1999).

The site of the proposed capital dredging and spoil disposal project is in the south of this region at a point where the soft coastline of the major part of the Bay changes to the exposed rocky headlands and cliffs of Banks Peninsula, punctuated by its many small bays and deep harbours. The northern Peninsula inlets of Port

[2] The Regional Coastal Environment Plan (Environment Canterbury 2012) defines the southern extremity of Pegasus Bay as the Avon / Heathcote estuary, but Banks Peninsula forms its physical/hydrodynamic boundary.

Levy/Koukourārata and Pigeon Bay are rocky and steep-sided with salt-marshes at their heads. The shallow reefs of the exposed coastline are dominated by giant kelp (*Macrocystis pyrifera*) and bull kelp (*Durvillea antarctica*), with a variety of other algae and associated species extending sub-tidally (DOC 2007).

Lyttelton Harbour/Whakaraupō is a large rock-walled inlet approximately 14 km long by 1.9 km wide, covering an area of ~43 km^2. It has negligible freshwater inputs and hence is not estuarine in character. Tidal range at Lyttelton varies 1.4–2.1 m.

3.1.3. Wave exposure

Coastal winds in Christchurch are characterised by strong onshore north-easterlies during summer and slightly weaker south-westerlies in winter that blow off shore Low pressure systems can be expected to pass through Pegasus Bay on an average every 6–7 days, often with associated southerly waves. These events generally last longer in winter compared to summer (URS 2004).

The area seaward of the Lyttelton Harbour/Whakaraupō entrance is open to the north through south-east, and is exposed to a prevailing oceanic swell. However, Banks Peninsula provides a measure of protection from the generally more severe southerly weather and swell conditions. North-easterly waves are generated by local sea breezes or under lee trough conditions or are associated with subtropical depressions tracking south down the east coast.

Some mixed wave field penetration of the harbour entrance occurs but energy is rapidly lost by refraction with the hard boundary of the harbour walls.

3.1.4. Currents

Near-shore transport around Banks Peninsula is a combination of tidal, wind-driven, freshwater and differential heating-induced baroclinic currents along with influences from oceanic currents (Reynolds-Fleming & Fleming 2005). The principal oceanic current which may affect circulation in the area is the Southland current which sweeps up the south-western coastline of the South Island. This current moves swiftly enough to carry sand and is well supplied with sediments by the large braided rivers which discharge to the Canterbury Bight, as well as from coastal erosion (Stephenson & Schulmeister 1999). OCEL (2009) noted that the north-setting flood tide is the stronger of the tidal currents past Banks Peninsula and reinforces the flow of the Southland current; however, southern Pegasus Bay is effectively in the lee of the Peninsula and currents within inshore regions are generally weak.

Although Reynolds-Fleming and Fleming (2005) found that strong along-shore winds in Pegasus Bay may dominate current flow throughout most of the water column, they were able to confirm, via the deployment of an Acoustic Doppler Current Profiler

(ADCP), the occasional presence of an anti-clockwise eddy or gyre operating in the Bay immediately to the north of Banks Peninsula.

Curtis (1985) identified tidal currents, averaging 0.22 m/s, as the primary hydraulic process operating in Lyttelton Harbour/Whakaraupō. It was found that a stronger flood flow on the southern side of the harbour was accompanied by a stronger ebb flow on the north side, leading to a general clockwise circulation pattern in the outer Harbour.

3.1.5. Specific area of the proposed project

The hydrographic charts NZ63 and NZ6321 show that the offshore edge of the proposed spoil disposal area is approximately aligned with the 20 m depth contour on a seabed composed of mud and shell (Figure 1). Depths in the area range from 18 m to 20 m relative to mean sea level (MSL). Field surveys have indicated that the benthic area offshore from Lyttelton Harbour/Whakaraupō around the 20 m contour is composed of relatively uniform soft sediments (Sneddon 2007, 2008).

Based on deployments of an ADCP as part of the fieldwork for this study, Mulgor Consultants Ltd (2008) established that weak (up to 0.1 m/s) shore-parallel tidal currents represent 60–70% of the current energy at the proposed spoil ground. Average residual (non-tidal) currents were found to be relatively very weak (~0.02 m/s) but an irregular residual current event was observed to occur over 1-2 days with a return period of 1-2 weeks. During these events, residual currents could be up to 0.11 m/s directed to the ESE (parallel to the coastline) and may result from the intermittent gyre noted by Reynolds-Fleming and Fleming (2005). Pegasus Bay seiche currents were also identified by this work but were very weak at the spoil ground site (~0.025 m/s).

Deployments of an ADCP in the mouth of Port Levy/Koukourārata (immediately east of Adderly Head) indicated very weak (~0.04 m/s) residual currents flowing into the inlet, and tidally reversing currents of up to 0.08 m/s across its mouth. Weak seiche currents were also principally across the mouth of the inlet (Mulgor Consultants Ltd 2008).

The presently maintained shipping channel is aligned approximately ENE down the centre of Lyttelton Harbour/Whakaraupō between Lyttelton Port and Godley Head. This has been maintained by dredging to depths of 12 m since before 1985. The adjacent benthic areas range from 4.5 m to 12 m (CD). LPC's annual maintenance dredging program has been consented to deposit spoil in an area along the northern shoreline of the harbour. Cawthron has been involved in the monitoring of the maintenance spoil disposal operation since 1992. The benthic substrate in the vicinity of the dredged channel is primarily fine unconsolidated mud with a relatively high rate of deposition from high sediment fluxes in the outer harbour (Curtis 1985). Benthic areas of fluid mud up to 15 cm thick have been identified on the northern side in the harbour entrance and within the dredged channel. The profile of the seabed in Lyttelton Harbour/Whakaraupō is unusually flat, indicative of a relatively fluid substrate condition (OCEL 2009).

The proposed extension to the dredged channel is aligned in a more NE direction and extends approximately 6 km offshore from the seaward end of the presently maintained channel (Figure 1). Depths range from approximately 12.4 m (CD) at the end of the presently dredged channel to 17 m (CD) at its offshore extremity. As for the existing channel area, benthic substrates are relatively uniform unconsolidated or semi-consolidated muds.

The shoreline of Lyttelton Harbour/Whakaraupō adjacent to the shipping channel is characterised by relatively steep rocky profiles and ranging from the exposed high-energy regions of Godley and Adderley heads to moderately sheltered areas further into the inlet.

3.2. Background turbidity

In Pegasus Bay, water clarity/turbidity is quite variable due to a number of major driving factors including:

- High riverine inputs of fine sediments to both Pegasus Bay and the Canterbury Bight
- Sediments carried by the northward-flowing Southland current
- Wave-induced resuspension of fine sediments
- Erosion of coastal formations (cliffs, gravel beaches *etc.*)
- Resuspension from bioturbation processes (re-working of benthic sediments by sediment-dwelling fauna)
- Tidal currents carrying sediments in discharges from estuaries and inlets, especially during high rainfall and storm conditions

In addition, there can be a marked variation of turbidity with depth. Near-bottom turbidity layers and inshore areas of fluid mud (OCEL 2013; Curtis 1986) are important features in this respect.

Sediment transport and circulation processes operating along the coastline both north and south of Banks Peninsula are very active. Most of the coastline comprises a high-energy marine environment with significant erosion and accretion. The southern coast, south of the Rakaia River, is transgressive, retreating at about 1 m/yr, whereas the Pegasus Bay coastline progrades as a highstand, wave-dominated delta (Leckie

2003). The persistent southerly swell conditions set up high rates of net northwards longshore drift.

Fine sediments from all of these processes are entrained within the Southland current, local eddies and tidal movements, resulting in the transport of large amounts of material through near-shore coastal environments. Figure 2 shows four satellite photographs of Banks Peninsula where coastal turbidity plumes are distinct against the darker offshore waters.

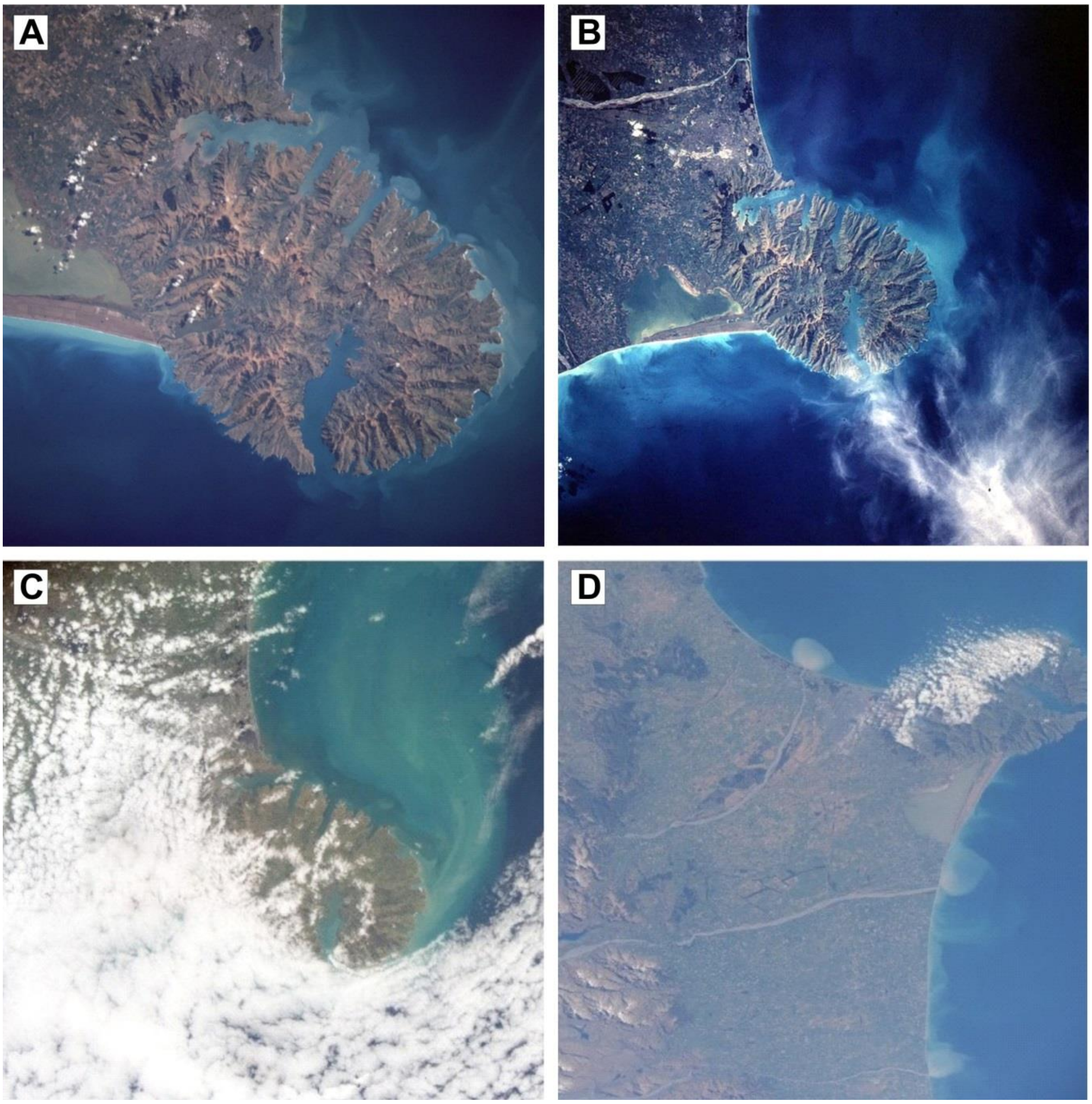

Figure 2 Satellite photographs of Banks Peninsula showing near-shore turbidity plumes in coastal waters. **A.** 1 September 1994. **B.** 2 October 1997. **C.** 19 November 2002; showing coastal plume swept northward around Banks Peninsula. **D.** 6 December 2003, showing

distinctly visible plumes from the Waimakiriri, Rakaia and Ashburton Rivers. Source: NASA Technical Information Program.

Only very limited data on background levels of turbidity and suspended solids were available for inshore Pegasus Bay. KMA (2003d) measured the turbidity of surface waters between the Ashley and Waimakariri rivers at three sites off-shore and found a range of between 0.8 and 1.9 nephelometric turbidity units (NTU). Turbidity profiles measured 1500 m and 2500 m offshore between the two rivers showed turbidity values up to 1 NTU between 1–6 m depth and increasing at deeper levels to a maximum of 5.2 NTU at 15.3 m. Profiles taken offshore from the Waimakariri River mouth showed a turbid 2 m layer at the surface of 4 NTU, corresponding to the buoyant freshwater river plume.

A limited dataset for sea surface turbidity was obtained from Environment Canterbury. This covered low frequency sampling events spanning a period from July 2007 to December 2013 (Table 1). While these samples were taken year-round and provide an indication of the range in surface waters, it is unlikely that samples were collected in other than calm conditions.

Table 1 Summary statistics for total suspended solids (TSS) and turbidity measured at locations in Pegasus Bay and Lyttelton Harbour/Whakaraupō between 2007 and 2014. Data provided by Environment Canterbury.

Location	TSS (mg/L)					Turbidity (NTU)				
	n	Mean	Med	Min	Max	n	Mean	Med	Min	Max
Pegasus Bay										
3 km offshore Amberley Beach	28	10	7.3	<3	31	28	1.7	1.2	0.4	6.5
3 km off shore Ashley River mouth	28	11	7	3.5	46	28	2.3	1.9	0.3	6.3
3 km offshore Waimakariri Riv mouth	28	14	12	3.6	34	28	3.5	2.6	0.5	13
3 km offshore New Brighton pier	28	9	6	<3	39	28	1.8	1.5	0.3	4.9
Lyttelton Harbour										
Port entrance between breakwaters	42	17	11	3	110	53	5	4.1	0.8	12
Near entrance to Hbr	51	11	8.9	<3	38	62	3	3.2	<0.1	8
Midway Ripapa Is. & Batttery Point	51	16	13	<3	42	51	5	4.5	0.8	10

Thompson and Barter (2005) and Sneddon and Bailey (2010) generated hydrographic profiles for 12 maintenance dredge monitoring stations throughout Lyttelton Harbour/Whakaraupō from field deployments of a CTD (conductivity-temperature-depth) meter equipped with an optical back-scatterance (OBS) turbidimeter. Outer Harbour profiles showed the presence of a high-turbidity benthic layer which varied in thickness from 1 m to 5 m (Figure 3). This layer was most pronounced for a site in the central channel area south of Livingstone Bay (DD-04; see Figure 7) in 2004, reaching an extreme value of 60 FTU[3] at the seabed. During the 2004 survey, surface turbidity values ranged from 5 FTU for points off Godley Head, just outside the Harbour entrance, to 8 FTU south of Gollans Bay, whereas in shallow areas of the upper Harbour (in the vicinity of Quail Island), water column values ranged from 12–24 FTU. In contrast, surface turbidity was relatively much lower during the 2010 survey; however, photosynthetically active radiation (PAR) still decreased rapidly with depth, approaching zero by 10 m from the surface (Figure 3).

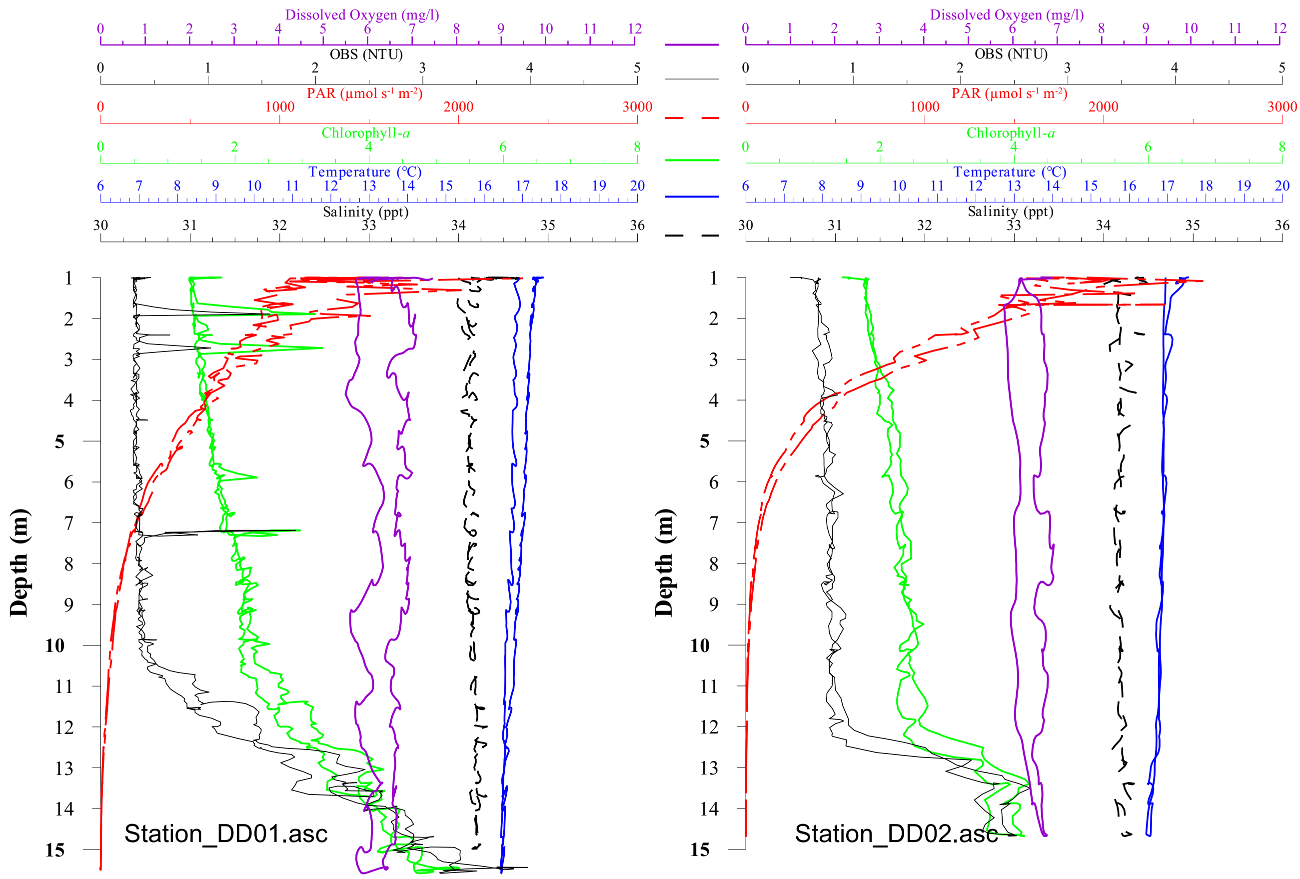

Figure 3 Hydrographic water column profiles for two monitoring stations near Godley Head (see Figure 7) recorded 6–7 January 2010, showing distinct benthic high turbidity layer (black line) and attenuation of photosynthetically active radiation (PAR; red line) to zero. From Sneddon & Bailey (2010).

KMA (2003d) claimed that the relatively shallow nature of Pegasus Bay inshore waters results in the re-suspension of bottom sediments and leads to a vertical profile of decreasing clarity with water depth. Gibbs (2001) noted that locally high turbulent

[3] Although generally equivalent, Formazin Turbidity Units (FTU; for OBS based on 180 degree scatterance) and Nephelometric Turbidity Units (NTU; 90 degree scatterance) are not exactly analogous.

intensities in benthic boundary layers contribute to the development of bottom layers containing high concentrations of suspended particulate matter. Much of the recently settled material may be resuspended several times before being locked in the sediments, and thus contribute to the pool of suspended particulates in the lower water column.

Even in calm conditions, resuspension of fine bottom sediments can be significant in inshore waters. Thermal or salinity induced density stratification can support internal seiches with large amplitudes on the density discontinuity. This seiching motion leads to high shear and may result in intense mixing above the sediments. In reporting sediment trapping data from 20 m depths over fine soft substrates in Tasman Bay Gibbs (2001) found trapping rates of up to 200 $gm^{-2}day^{-1}$, consistent with there being substantial resuspension of surficial sediments from the sea floor.

3.3. Sediment inputs and transport along the Canterbury coast

3.3.1. Riverine sediment sources

The Canterbury coastline is abundantly supplied with sediment by a number of large, braided rivers which drain from the Southern Alps. These rivers have among the highest known specific annual sediment yields in the world, transporting 1856± 261 tonne $km^{-2}yr^{-1}$ compared to a global average of 182 tonne $km^{-2}yr^{-1}$ (Leckie 2003). During flood events, the elevated sediment carried in these rivers can cause visible plumes around the mouth and along the coastline where sediment is carried by inshore currents (*e.g.* Figure 2D).

A GIS dataset generated by NIWA and Landcare Research (Hicks *et al.* 2003), permits estimation of the mean annual yield of river/stream suspended sediment output for any defined catchment boundary in New Zealand. The dataset consists of 100 m grids with each grid cell representing the suspended sediment (SS) yield in tonnes/km^2/year. Therefore, by overlaying individual catchments and taking the sum of all grid units within each catchment, the total suspended sediment load from each catchment (in kt/catchment/year) can be calculated. A map of the estimated sediment yield for the major catchments draining to the Canterbury coast is presented in Figure 4 and the data tabulated in Table 2.

Figure 4 and Table 2 show that the two primary catchments emptying into the natural bight comprising Pegasus Bay/south Hurunui are those of the Hurunui and Waimakiriri rivers, with estimated annual sediment inputs of 1048 and 3137 kt/year respectively. These estimates are the sum of all the individual 100 m^2 grid values that fall within each catchment, shown in the base Figure 4 map as a graduated colour. The other 11 catchments listed, from the Jed River southwards to Banks Peninsula, are much smaller and range from 1 to 83 kt/year. It should be noted that only catchments with

4th order water courses or greater were used in these calculations since the smaller catchments (*i.e*. with 1st to 3rd order streams only) do not contribute an appreciable volume of sediments on an annual basis in this context. From these calculations the total annual sediment load entering Pegasus Bay/south Hurunui waters from riverine sources is 4,455 kt/year.

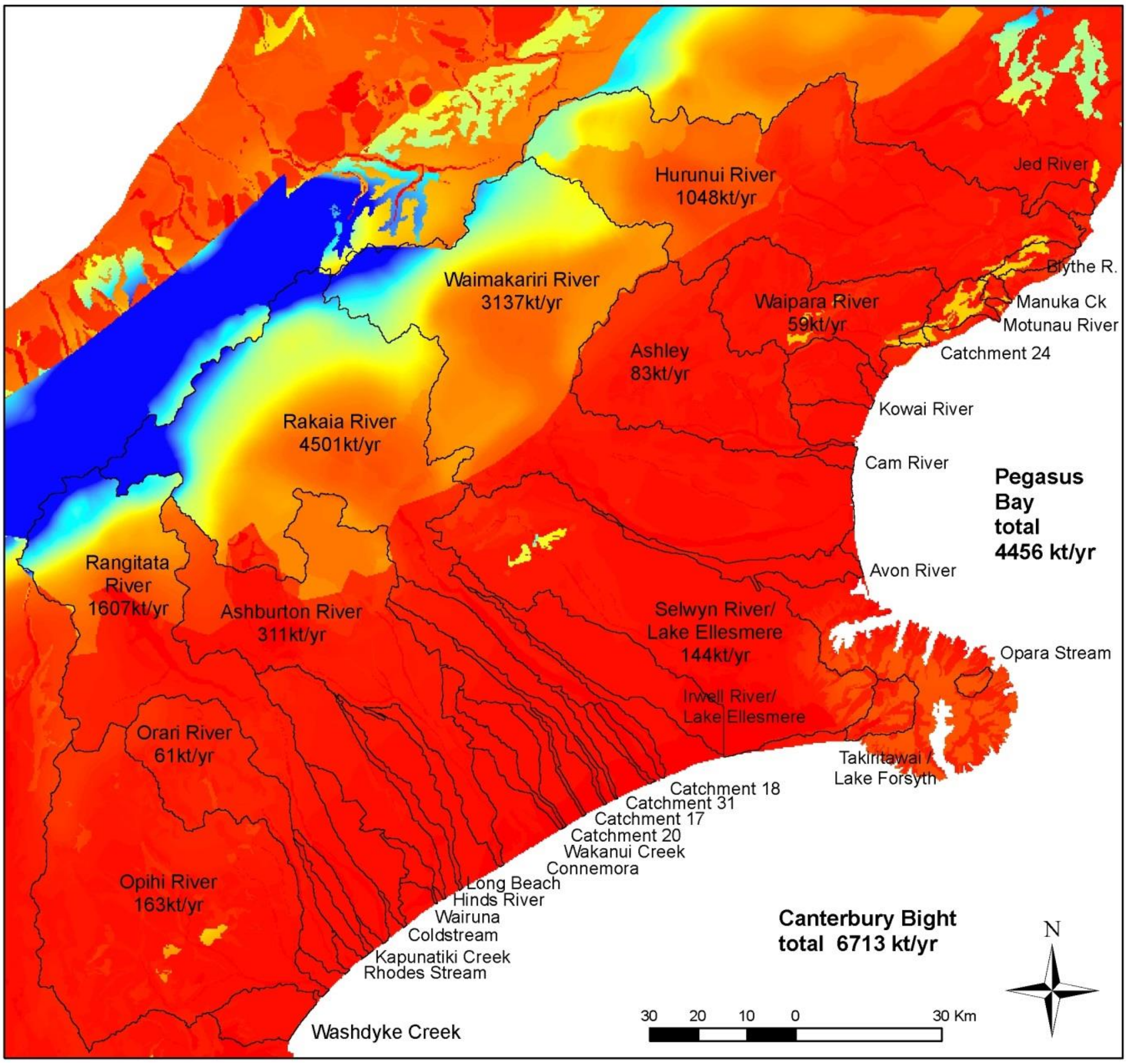

Figure 4 Catchment boundaries for the Canterbury region, showing estimated annual sediment yields for the major rivers draining to the Canterbury Bight and Pegasus Bay/sourth Hurunui. Data from NIWA sediment yield model (Hicks *et al.* 2003).

Kirk and Lauder (2000) provide another source of riverine sediment yield estimates for the area and are included for comparison in Table 2. Their estimated yield for the Waimakiriri River has it contributing some 5.4 million tons of suspended sediment to Pegasus Bay each year, 70% higher than that provided by the NIWA sediment yield model.

Table 2 Estimates of suspended sediment yield for catchments draining to the Canterbury coast. Catchments listed north to south as represented in Figure 4. Calculated using NIWA sediment yield model (Hicks *et al*. 2003). Catchments that discharge to coastal lakes/ lagoon systems are not included.

Catchment name	Order[1]	Area (km)	Yield (kt/yr)	% of total	Yield[2] (kt/yr)
Jed River	4	64	6	0.1%	
Hurunui River	6	2669	1048	9.4%	2680
Blythe River	4	65	32	0.3%	
Manuka Creek	4	22	6	0.1%	
Motunau River	5	94	49	0.4%	
Catchment 24	4	14	12	0.1%	
Waipara River	6	726	59	0.5%	460
Kowai River	5	198	9	0.1%	
Ashley River	7	1150	83	0.7%	
Cam River	4	35	1	0.0%	
Waimakariri River	7	3609	3137	28.1%	5357
Avon River	4	170	5	0.0%	
Opara Stream	4	27	8	0.1%	
Rakaia River	7	2830	4501	40.3%	4332
Catchment 18	4	33	1	0.0%	
Catchment 31	5	255	13	0.1%	
Catchment 17	4	67	2	0.0%	
Catchment 20	4	161	7	0.1%	
Wakanui Creek	4	133	4	0.0%	
Connemora	4	121	4	0.0%	
Ashburton River	6	1600	311	2.8%	310
Long Beach	5	193	7	0.1%	
Hinds River	6	452	22	0.2%	
Wairuna	4	46	1	0.0%	
Coldstream	5	202	6	0.1%	
Rangitata River	6	1816	1607	14.4%	1679
Kapunatiki Creek	4	67	2	0.0%	
Rhodes Stream	4	65	2	0.0%	
Orari River	6	715	61	0.5%	
Opihi River	7	2376	163	1.5%	2372
Washdyke Creek	5	184	4		
Total		**19978**	**11169**	**100%**	

1. Catchment order relates to the number of sub-catchments incorporated.
2. Kirk & Lauder (2000).

Kingett Mitchell (2003a) cite Reed (1951) as showing that the sediments in Pegasus Bay are derived mostly from greywacke and include quartz and feldspars and sedimentary rock fragments, and concluding that most sediment in the southern part of Pegasus Bay is derived from the Waimakariri River.

Pegasus Bay may be represented as a quasi-discrete cell in terms of water and sediment circulation based on its natural boundaries (in particular Banks Peninsula) and the apparently episodic gyre formed by the Southland Current (Reynolds-Fleming & Fleming 2005). Although there is little information available to establish precise boundaries for such a Pegasus Bay coastal cell, it is reasonable to assume that the influence of a counter-clockwise gyre in the lee of Banks Peninsula may extend as far north as the mouth of the Kowhai River. The semi-bounded nature of the cell with respect to sediment budget would be consistent with the Waimakiri River's dominance in the sediment supply.

Direct annual riverine sediment inputs to the Pegasus Bay cell would total 3,235 kt/yr based on the yield model for the relevant catchments (Table 2) although it is important to note that, with the cessation of the gyre, the cell would break down and sediment inputs from the Southland current may become significant. The satellite photograph in Figure 2C appears to show such a case, with a turbidity plume being carried around Banks Peninsula into Pegasus Bay.

3.3.2. Non-riverine sediment sources

Coarse sediment supply in the Canterbury Bight is controlled primarily by coastal erosion rather than fluvial input, with the Rakaia River providing only 11.7% of the annual sediment budget for the coastline along its mouth (Stephenson & Schulmeister 1999). It is well established that the coastline of the Canterbury Bight between Timaru and the southern end of Kaitorete Barrier at Taumutu is in long term erosion. Hemmingsen (2008) reports that average erosion rates are in the order of 1–1.5 m/yr and cites Flatman (1997) as calculating that coastal cliff erosion, from the Rangitata River to the Rakaia River, contributes 228,339 m^3/yr of sediment to the coast. His study found that cliff erosion rates varied from 0.03 m/yr to 1.09 m/yr.

Single (2006) reported that the main sources of transported sediment in the South Canterbury coastal region are the Waitaki River and erosion of the alluvial cliffs and estimated the volume of fine sand transported northward on the seabed to be in excess of 600,000 m^3/yr. Sediments are also lost from the beaches due to abrasion of coarse material into fine sands, silt and mud. Such abrasion rates may be a significant proportion of beach volume along this high wave-energy coastline.

The northward movement of sediments in the Canterbury Bight is responsible for the formation of Kaitorete Barrier between Lake Ellesmere and the sea. Stephenson and Schulmeister (1999) report that, since the last closure of the barrier in the previous few hundred to a thousand years, there has been massive transport of gravel along the barrier onto the Banks Peninsula coastline beyond, filling several valleys.

Where the Southland current slows past the constriction represented by Banks Peninsula, the fine sand it carries is deposited and this has led to the formation of a banner bank extending northwards from the north eastern side of Banks Peninsula, offshore from Pegasus Bay. This is an area of higher relief on the seafloor, most evident between the 18 m and 40 m isobaths, and is 20 km long and 7 km wide at its widest point. Finer sediments carried by the Southland current have the potential to be carried into Pegasus Bay depending upon prevailing near-shore current conditions.

4. SURVEY METHODS

Investigative field survey work associated with the CDP has been carried out since 2007. The initial surveys of the capital spoil ground area were conducted over three periods during the summer months of 2007/2008, the first from 25–26 October, the second from 11–12 December and the third over 19–20 January 2008. All of this earlier survey work was conducted from the University of Canterbury's 7.7 m vessel Rapaki.

Additional field surveys were undertaken in February-March 2016, using Cawthron's 7.2 m survey vessel *Waihoe,* to include the reef shorelines of Pegasus Bay and Lyttelton Harbour/Whakaraupō and also to expand the spatial extent of the benthic investigation. Most recently, a benthic sampling survey of the vicinity of the proposed offshore maintenance spoil ground was conducted on 2 August 2016.

The assessment has also benefitted from several recent monitoring surveys of Harbour benthic and intertidal habitats undertaken to meet the requirements of LPC's maintenance dredging consent and other Harbour projects.

Characterisation of the benthic environment has employed a combination of discrete benthic sampling and broad survey methods, outlined as follows:

- Collection of benthic sediment samples for physical, chemical and ecological analyses
- Sampling of benthic epifauna (surface-dwelling fauna) using a research dredge
- Broad-scale sonar imaging of the seabed over the wider area
- Semi-quantitative intertidal surveys
- Quantitative ecological surveys of shallow subtidal reef substrates.

4.1. Benthic sample stations

The collection of benthic samples was based around the establishment of a series of sampling stations within the Harbour, the area of the proposed extended channel and inshore Pegasus Bay within the vicinity of the proposed capital and maintenance spoil grounds. The spatial arrangement of these stations is represented in Figure 7 and Figure 8 (Section 5.1) with location coordinates and depths being listed in Appendix 1.

The benthic stations were arranged spatially to give suitable coverage of the areas of interest as well as those immediately adjacent to the proposed spoil grounds and points closer to the Banks Peninsula shoreline.

In 2007, a semi-randomised process was used to establish positions for twelve stations within the boundaries of the proposed capital spoil ground (two stations randomly with a buffer distance, in each of six quadrants). A further five stations were located adjacent to the spoil ground within 700 m of its boundary and two far-field stations were established on an approximate isobath with the spoil ground's principal (NW–SE) axis at a distance of approximately 2 km from its north-western and south-eastern boundaries. These far-field stations were to potentially act as reference stations and to better establish the spatial extent of benthic variables. However, the extent of benthic sampling was further expanded to the south and east by surveys carried out in 2016. Six stations (C1-C6) were positioned approximately equidistant along the axis of the proposed extension to the dredged channel.

In 2015, the proposed capital spoil ground was rotated slightly anti-clockwise to move its south-eastern boundary further away from the adjacent coastline and better align it with the 20 m isobath. In March 2016, a further 10 stations were sampled, four between the northern Banks Peninsula shoreline and the spoil ground and six within the mid- and lower harbour area. The subsequent proposal for an offshore maintenance dredging spoil ground resulted in the sampling, in August 2016, of an additional 10 benthic stations offshore from Godley Head.

The role of the benthic sample stations was to provide data on the physical, chemical and ecological nature of benthic habitats within the surveyed area. At each station, sediments were collected using a 0.1 m^2 stainless steel Van Veen grab (Figure 5A) for a number of analyses as follows:

- Sediment grain size distribution (surficial substrate texture) and organic content
- Sediment chemistry; specifically indicative metal contaminants
- Sediment-dwelling macroinvertebrate communities (infauna).

Triplicate grabs were conducted at each station and for each, the grab contents were sub-sampled for the sediment and infauna analyses.

4.1.1. Sediment texture and chemistry

The analysis of sediment texture (particle grain size distribution) defines the coarseness of sediments and provides an important measure of the physical characteristics of a site that can be used to investigate and interpret differences between sites for other environmental parameters. Chemical contaminants are primarily retained within fine sediments (Förstner 1995). Metals especially, can adsorb to particulates and may accumulate over long time periods. Both sediment texture and organic content play an important role in determining the capacity for adsorption and retention of contaminants and allow the assessment of associations between substrate type and the associated sediment faunal communities.

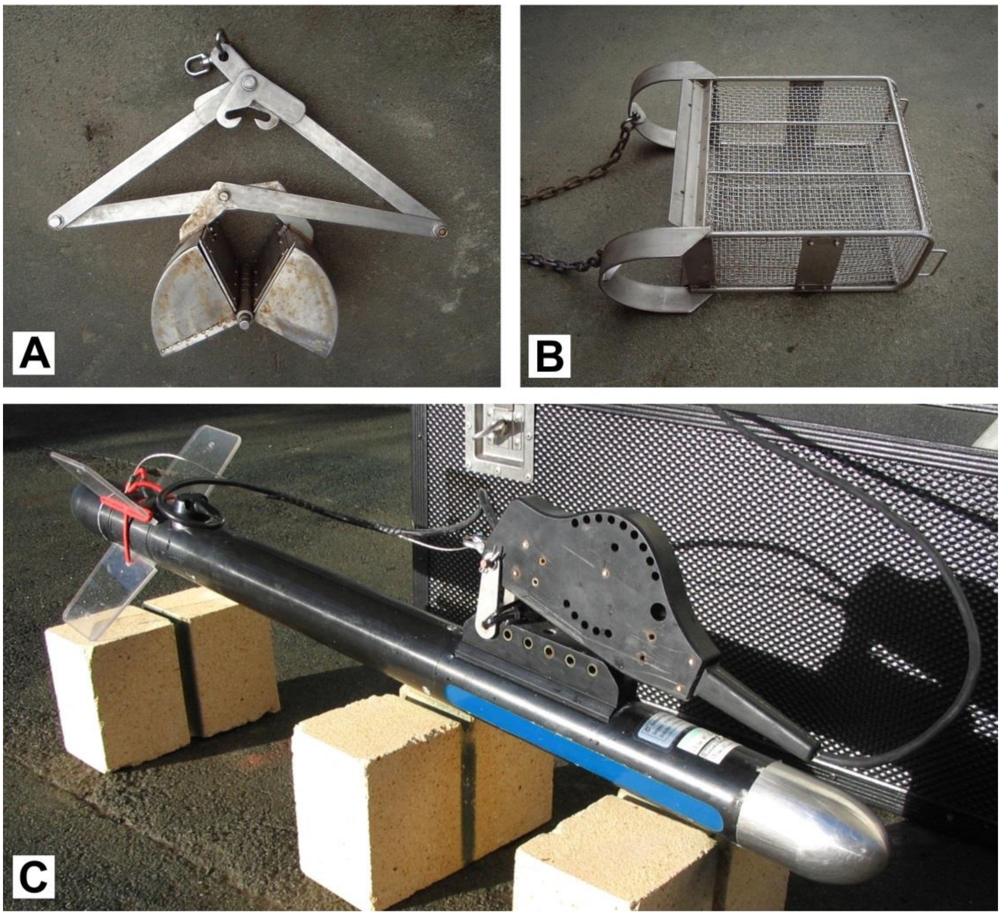

Figure 5 Benthic sampling and survey equipment employed. **A:** Van Veen grab sampler. **B:** Research dredge. **C:** Side-scan sonar fish.

Sub-sampling for sediment physico-chemical analyses

Two 62 mm diameter cores were taken from the contents of each replicate grab. The Perspex® corers were driven into the contents of the grab to a depth of up to 120 mm, then extracted and the cores photographed before sub-sampling (Appendix 2). The colour of the sediments, any noticeable odour and the presence/absence of anoxic patches within the sample were noted, as well as the depth to any apparent redox potential discontinuity (aRPD) layer[4].

The top 5 cm of each of the two cores was sub-sampled and combined to provide a composite sample for the analysis of metals concentrations [chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn)], organic content and particle size distribution. For samples collected in 2016, additional analyses included arsenic (As) and cadmium (Cd). Samples from three Harbour stations were composited from triplicate grabs and analysed for polycyclic aromatic hydrocarbons (PAHs). All

[4] The aRPD refers to the often distinct colour change, between surface and underlying sediments, brought about by the changing redox environment with depth in the profile. This gradient of colour change is in reality continuous but may be reduced to an average transition point (sediment depth) for descriptive purposes.

samples were chilled with ice for transport back to the laboratory. A summary of sediment analyses and analytical methods is given in Table 3.

Table 3 Summary of analytical methods used for sediment characterisation.

Analyte	Method Number	Description
Particle grain size distribution (sediment texture)	Cawthron SOP No. 33074	Wet sieved through screen sizes: >2 mm = Gravel <2 mm – >1 mm = Coarse Sand <1 mm - >500 µm = Medium Sand <500 µm - >250 µm = Medium/Fine Sand <250 µm - >125 µm = Fine Sand <125 µm - >63 µm = Very Fine Sand <63 µm = Mud (Silt & Clay) Size classes from Udden-Wentworth scale
Organic Content as Ash-Free Dry Weight (AFDW)	Luczak *et al.* 1997 (modified)	Sample dried at 105°C then ashed at 550°C
Total organic carbon - 2016	Hill Laboratories in-house method	Acid pre-treatment to remove carbonates if present, neutralisation, [Elementar combustion analyser].
Polycyclic aromatic hydrocarbons (PAHs)	USEPA 8270C	Sonication extraction, SPE clean-up, GC-MS SIM analysis (gas chromatography mass spectrometry selected ion monitoring mode).
Trace metals (Cu, Pb, Ni, Cr, Zn) – 2007.	USEPA 2002 (modified)/APHA metals	Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) following aqua regia acid digestion
Trace metals (Hg; 2007)	USEPA 245.6 mod.	Sample digested with HNO_3/H_2SO_4 + $KMnO_4$, reduced by acidic solution and the Hg vapour released by a nitrogen stream. Determined by cold vapour atomic adsorption spectroscopy
Trace metals (As, Cd, Cu, Pb, Hg, Ni, Cr, Zn) – 2016	USEPA 200.2	Detected by ICP-MS (inductively coupled plasma mass spectrometry) following nitric/hydrochloric acid digestion

4.1.2. Benthic macrofauna

The ecological assemblage of small animals (larger than 0.5 mm) living in the upper 10 cm of the sediment profile is generally referred to as macrofauna or macroinvertebrates. Analyses performed for this study focused on the infauna, animals living within the sediment matrix. Infauna have been used for several decades to assess the effects of human impacts in marine environments, as various studies have demonstrated that they respond relatively rapidly to anthropogenic and natural stress (Pearson & Rosenberg 1978; Dauer 1993; Borja *et al.* 2000).

One infauna sediment core was extracted from the contents of each of the three grabs conducted at each benthic sample station. The corer consisted of an elliptical section made from 130 mm diameter PVC pipe, with a 0.5 mm nylon mesh bag attached to act as a sieve. Each corer was manually driven into the grab contents to a depth of 100 mm. The core was then gently withdrawn and emptied into the mesh bag.

The contents of the corer were sieved by gently rinsing seawater through the bag to remove the majority of the fine sediment matrix. The residue was transferred to a sample container for preservation in a solution comprising 3% glyoxal and 70% ethanol. In the laboratory, macrofauna within the preserved samples were identified and counted with the aid of a binocular microscope. Identifications were made to the lowest practicable taxonomic level. For some groups of infauna, species level identification is very difficult and, in such instances, infauna were grouped into recognisable taxa (morphologically similar groups). In this manner a list of taxa and their relative abundance was compiled for each station.

Infauna data analysis

Infaunal count data were analysed to ascertain levels of abundance (individual species density), species richness and standardised indices of community diversity and evenness for each station (Table 4). These indices were compared between stations and significant differences interpreted with respect to key factors such as seasonal timing, water depth and substrate characteristics.

Table 4 Descriptions of macro-invertebrate community indices.

Index	Equation	Description
No. species (S)	$\sum s$	Total number of species in a sample.
No. individuals (N)	$\sum n$	Total number of individual organisms in a sample.
Evenness (J')	$J' = \frac{H'}{log_e S}$	Pielou's evenness. A measure of equitability, or how evenly the individuals are distributed among the different species. Values can theoretically range from 0.00 to 1.00, where a high value indicates an even distribution and a low value indicates an uneven distribution or dominance by a few taxa.
Diversity (H' log_e)	$H' = -\sum P_i \, log_e \, (P_i)$	Shannon-Wiener diversity index (log_e base). A diversity index that describes, in a single number, the different types and amounts of animals present in a collection. Varies with both the number of species and the relative distribution of individual organisms among the species. The index ranges from 0 for communities containing a single species to high values for communities containing many species with each represented by a small number of individuals.

The infaunal assemblages recorded at each site were contrasted using non-metric multidimensional scaling (nMDS; Kruskal & Wish 1978) ordination and cluster diagrams using Bray-Curtis similarities between samples in PRIMER v6 statistical software (v. 6.1.6 ©PRIMER-E 2000; Clarke & Warwick 1994; Clarke & Gorley 2001). Abundances were fourth-root transformed to de-emphasise the influence of the dominant species (by abundance). The major taxa contributing to the similarities of each grouping of benthic stations were then identified using analysis of similarities (SIMPER; Clarke & Warwick 1994; Clarke & Gorley 2001).

4.2. Benthic epifauna sampling

A small research dredge with a 250 mm x 500 mm throat and fitted with a 10 x 10 mm stainless steel wire mesh (Figure 5B) was used to sample benthic epifauna in the vicinities of the proposed channel extension and capital spoil ground. Eight trawls, each of approximately 150 m length, were conducted during preliminary survey work in October and December of 2007, associated with the trial deposition of dredged sediments (Sneddon 2007, 2008). A further 14 dredge trawls were conducted on 19 January 2008, two within the proposed channel extension area and 12 spread across the proposed spoil ground and adjacent seabed. In February 2016, four trawls were conducted between the proposed spoil ground and the northern Banks Peninsula coastline. In August 2016, five trawls were conducted in the vicinity of the proposed offshore ground for maintenance dredge spoil. For all trawls, location coordinates were recorded by GPS for start and finish points. Dredge contents were photographed, identified, and the number of individuals counted. Where identification was not possible in the field, voucher specimens[5] were preserved in a solution of 70% ethanol and 3% glyoxol for later classification in the laboratory.

4.3. Side-scan sonar imaging

In order to validate the uniformity of the sampled benthic habitat over a wider area, a side-scan sonar survey of the seabed was conducted along the length of the proposed channel extension and in the vicinity of the spoil ground.

A TritechTM sonar 'fish' (Figure 5C) was towed at a speed of approximately 2-3 knots, using a swathe width of 30 m either side of the vessel. GPS position tracks were simultaneously logged to an onboard laptop computer using TritechTM software, enabling the relocation of any areas of particular interest for subsequent verification.

The sonar survey was carried out over two field survey dates. The first was conducted 26 October 2007 in the vicinity of two points considered as options for a trial deposition of sediments (coincident with benthic stations S6 and S9 of this study).

[5] Voucher specimens refer to representative examples of a taxonomic group preserved for later description and identification.

The second survey was completed 12 December 2007 and covered the broader area of the spoil ground and adjacent seabed in a loose grid pattern of east-west and north-south oriented vessel passes (see Figure 22).

Sonar image outputs were used to evaluate the variability of the seafloor with respect to low-resolution changes in substrate texture (*e.g.* a change from mud to cobble or reef substrate) and to detect benthic features of potential ecological significance. To ground-truth the side-scan sonar images, they were matched to information from the benthic samples collected. Notes were also made on the output of the vessel's depth-sounder.

4.4. Characterisation of shoreline reef habitats

4.4.1. Subtidal surveys

A subtidal ecological survey of shallow coastal reef habitats was conducted over 22-29 February 2016 at 22 sites along the Banks Peninsula coastline of Pegasus Bay, the inlets of Port Levy/Koukourārata and Pigeon Bay and within Lyttelton Harbour/Whakaraupō. Sites were classified into four general geographical areas:

- Banks Peninsula outer coast (area BP)
- The inlet of Port Levy/Koukourārata (PL)
- The inlet of Pigeon Bay (PB)
- The coastline within Lyttelton Harbour/Whakaraupō (LH).

Within each of these four areas, between 4 and 9 sites were selected to maximise spatial coverage of the area during the fieldwork period. Decisions on final site location were made according to direct observation of suitable reef habitat (by vessel-mounted side-scan sonar and/or diver). The spatial layout of the sites surveyed is shown in Figure 23 (Section 5.5).

The subtidal survey methodology was based on standard quadrat and transect sampling using scientific SCUBA divers (Kingsford & Battershill 1998), allowing comparisons to be made with earlier surveys (Schiel & Hickford 2001; Shears & Babcock 2007).

At each site a 100 m down-shore transect line was positioned perpendicular to the shore, by anchoring one end onto high shore rocks and the other end (offshore) in the seabed using a shot weight (Figure 6). The GPS coordinates of both ends of the transect were recorded to allow relocation for repeat surveys. The dive surveys were conducted along three subtidal transect lines running transversely out from the down-shore transect at three nominal depth ranges and roughly parallel to shore:

i. **Deep transect (nominal 7 m)**: between 6–8 m depth and 30 m in length, running near the maximum extent of non-coralline macroalgae.

ii. **Shallow transect (nominal 4 m)**: between 3–5 m depth and 30 m in length, within kelp forest habitats (where these were present).

iii. **Littoral fringe transect**: between 0.0–1.0 m depths (relative to chart datum; CD) and 50 m long, within the shallow subtidal.

Transects at all depths were located within nominal depth ranges (as above) rather than at precise depths. The reason for this is that the three-dimensional (and sometimes near-vertical) structure of the reef did not allow precise depth control along a transect line. There was also some variation in the depth of the target habitats from site to site due to changes in substrate and exposure characteristics and it was considered important to survey habitats that were generally comparable between sites. At each site, allowance was made for tidal state to adjust general target depths for the transects. This was especially important for the littoral fringe transects, since there is a difference between chart datum and mean sea level (MSL) of approximately 1.3 m and the surveys coincided with a period of neap tides.

Quadrat transects

Along each 4 m and 7 m depth transect (run out as a 30 m measuring tape), eight 1 m^2 quadrats were haphazardly placed, determined by pre-set interval of ~4 m between consecutive quadrat centres, with two divers alternating along the 30 m tape. Because of the deeper extent of reef substrate at BP sites, it was possible to survey both shallow (4 m) and deep (7 m) transects at all but one site. At site BP13 and all sites in areas LH, PL and PB, it was not possible to survey a 7 m transect due to the absence of suitable rocky reef habitats in that depth band.

For each individual quadrat, the following data was recorded:

- Water depth (from wrist-mounted dive computer)
- An estimate of the percentage cover of substrate type: bedrock, boulders, cobble, sand, silt and shell hash
- Estimates of the percentage cover of canopy forming and understory algae
- Estimates of the percentage cover of encrusting invertebrates (e.g. sponges, ascidians, mussels)
- Counts of solitary epifauna (*e.g.* snails, urchins, seastars).

Count transect

At each (50 m) littoral fringe transect, divers counted and measured large invertebrate and mahinga kai species within a 1 m band (*i.e.* over an area of 50 m^2). Due to the effective absence of kina (*Evechinus chloroticus*) in this depth range, the targeted species were limited to black foot pāua (*Haliotis iris*) and kaakara or Cook's turban (*Cookia sulcata*). Pāua were counted and measured using digital logging callipers, whereas Cook's turban were only counted. Quadrat methods could not be used for this zone due to shallow water surge conditions at most sites and the presence of large macrophytes in constant movement.

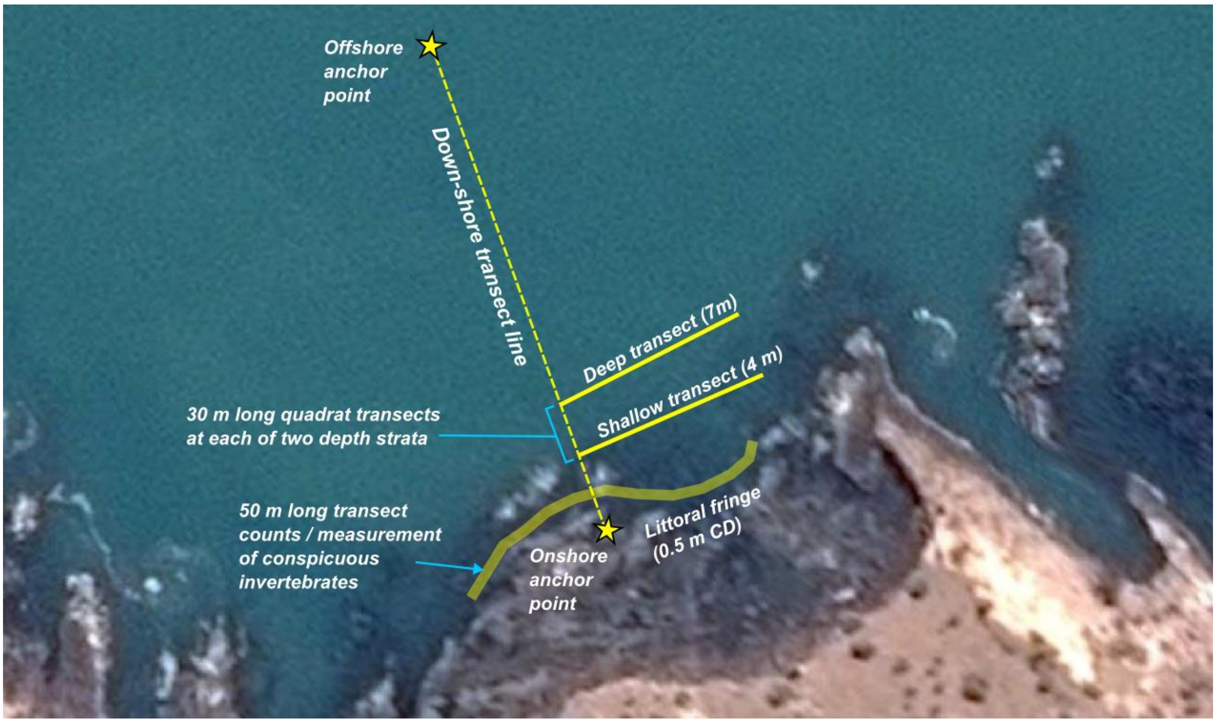

Figure 6 Generalised example layout of subtidal shoreline transects used to characterise subtidal reef habitats.

4.4.2. Statistical analyses

Subtidal quadrat data were analysed to ascertain levels of abundance (total cover and number of individuals), species richness (diversity) and standardised indices[6] of community diversity and evenness for each station (see Table 3). For the purposes of analysis, several subtidal taxa were aggregated into morphologically similar groups.

Differences in subtidal community structure were determined statistically with respect to water depth, area and sites using a distance-based permutational analysis (PERMANOVA, Anderson 2001) based on Bray-Curtis similarities of the log (x +1) transformed data and 9,999 permutations. Significant terms were then investigated using pair-wise comparisons with the PERMANOVA *t* statistic and 999 permutations.

[6] Similarity measures and diversity indices are not usually constructed from such "mixed" data sets, but there are no impediments to doing this (Anderson & Underwood 1994). However, there may be problems for the interpretation when data are naturally in different original scales. Thus, the data were log transformed, which preserved information concerning relative abundance or cover of species consistently across samples, but eliminated any large differences in scale among variables (Clarke, 1993).

Assemblage differences among treatment levels were visualized by Principal Coordinates Ordination (PCO). Similarity Percentages analysis (SIMPER, Clarke 1993) was used to identify the contribution of each species (or taxon) to observed differences among treatments. Taxa that consistently discriminated between treatments and had a correlation >0.3 with the PCO axes were displayed as vectors in the PCO plots. All statistical analyses were conducted using PRIMER 6 (Clarke & Gorley 2006; Anderson *et al.* 2008) and R software (R Core Team 2014).

4.5. Intertidal surveys

Intertidal biological communities were surveyed semi-quantitatively at five sites at low tide during February 2016. Two sites were established in Port Levy/Koukourārata (PL03 and PL16), representative of one of the long, sheltered, inner inlets of Banks Peninsula. Three sites were established in Lyttelton Harbour/Whakaraupō; LH07 on Ripapa Island, LH05 at Kamautaurua Island (Shag Reef) and LH10 on the outer southern shoreline of the Harbour (Figure 31, Section 5.6). These sites are representative of both the relatively exposed rocky shore of mid- to outer Lyttelton Harbour/Whakaraupō (LH07 and LH10), and the relatively sheltered flat rocky shore of the upper Harbour (LH05).

At each intertidal site, approximately 50 m of shoreline was surveyed over low tide, with substrate characteristics and zonation patterns of intertidal fauna and flora recorded. The abundance of fauna and flora was described at each intertidal zonation (high, mid, low and rock pools) using a categorical scale, ranked subjectively as ‘rare’, ‘occasional’, ‘common’, or ‘abundant’. Representative photographs of habitats and taxa were also obtained. Where field identification was not possible, specimens of individual fauna and algae were collected and later identified where possible. All taxonomic nomenclature was based on the World Register of Marine Species (WoRMS Editorial Board 2016).

Similar intertidal surveys have been undertaken at several other sites within Lyttelton Harbour/Whakaraupō since 2010. These have been associated with other LPC projects and consents and, since they have utilised the same methodology as the 2016 surveys, this data significantly expands the spatial extent of the characterisation of Harbour intertidal reef habitats. Summary details for all intertidal sites for which recent survey data are available are presented in Table 5. The spatial layout of the sites is shown in Figure 31 (Section 5.6).

Table 5 Details of semi-quantitative intertidal surveys of reef habitats within Lyttelton Harbour/Whakaraupō since 2012.

Location	Site code	Date	Latitude	Longitude	Date	Tide (MSL)
Pukerauaruhe Is	PL03	26/02/2016	-43° 37.6007’	172° 49.6378’	26/02/2016	-0.83 m
Port Levy E	PL16	26/02/2016	-43° 36.9618’	172° 50.7055’	26/02/2016	-0.83 m
Ripapa Is	LH07	27/02/2016	-43° 37.1727’	172° 45.2357’	27/02/2016	-0.80 m
Shag Reef	LH05	28/02/2016	-43° 36.9395’	172° 42.2090’	28/02/2016	-0.77 m
Camp Bay E	LH10	29/02/2016	-43° 37.0155’	172° 47.3015’	29/02/2016	-0.73 m
White Patch Pt	DD03	23/03/2015	-43 35.70758	172 47.35993	23/03/2015	-1.23 m
Rapaki Bay	DD12	24/03/2015	-43 36.49274	172 41.14719	24/03/2015	-1.18 m
Livingstone Bay	-	11/12/2013	-43 35.85217	172 45.80633	11/12/2013	-1.02 m
Battery Point	-	11/12/2013	-43 36.26183	172 44.48983	11/12/2013	-1.02 m
Godley Head	DD02	2/10/2012	-43 35.54288	172 48.28997	2/10/2012	-0.81 m

5. SURVEY RESULTS

5.1. Sediment grab samples

Locations for benthic stations sampled by Van Veen grab during the field surveys of 2007 and March 2016 are shown in Figure 7, together with stations routinely sampled for LPC's maintenance dredging consent. Stations sampled in August 2016 to survey the vicinity of the proposed offshore spoil ground for maintenance dredge spoil are shown in Figure 8. The associated position coordinates and depths for these stations are listed in Appendix 1.

5.1.1. Field observations

The seabed at all stations sampled in 2007 within the channel extension area and in the vicinity of the capital spoil ground was found to consist of fine soft sediments and no difficulties were experienced with grab penetration. The grab contents indicated a relatively uniform benthic substrate of fine cohesive mud with little in the way of larger shell or mineral particulates. An indistinct apparent redox potential discontinuity (aRPD) layer was observed at 40–70 mm for cores from the channel extension area (see Appendix 2). Although the offshore core samples often had discernibly darker sediments deeper in the profile, a transition layer was less easily identified. None of the sediment samples were characterised by any strong odour.

Sediments sampled in 2016 closer to the Banks Peninsula shoreline and in the vicinity of the proposed maintenance dredge spoil ground in both instances exhibited characteristics similar to those of the earlier capital spoil ground samples, being soft grey mud with an indistinct transition to darker underlying material at 40–70 mm. Sediments from the six Lyttelton Harbour/Whakaraupō stations were variable with cores from the outer two stations similar to sediments offshore; LH2, LH3 and LH4 being noticeably sandy and light grey-brown in colour with no visible change in the top 100 mm of the profile. The innermost Harbour station (LH1) featured grey semi-consolidated mud with a transition to darker sediments at ~50 mm and an overlying ~20 mm layer of unconsolidated silt.

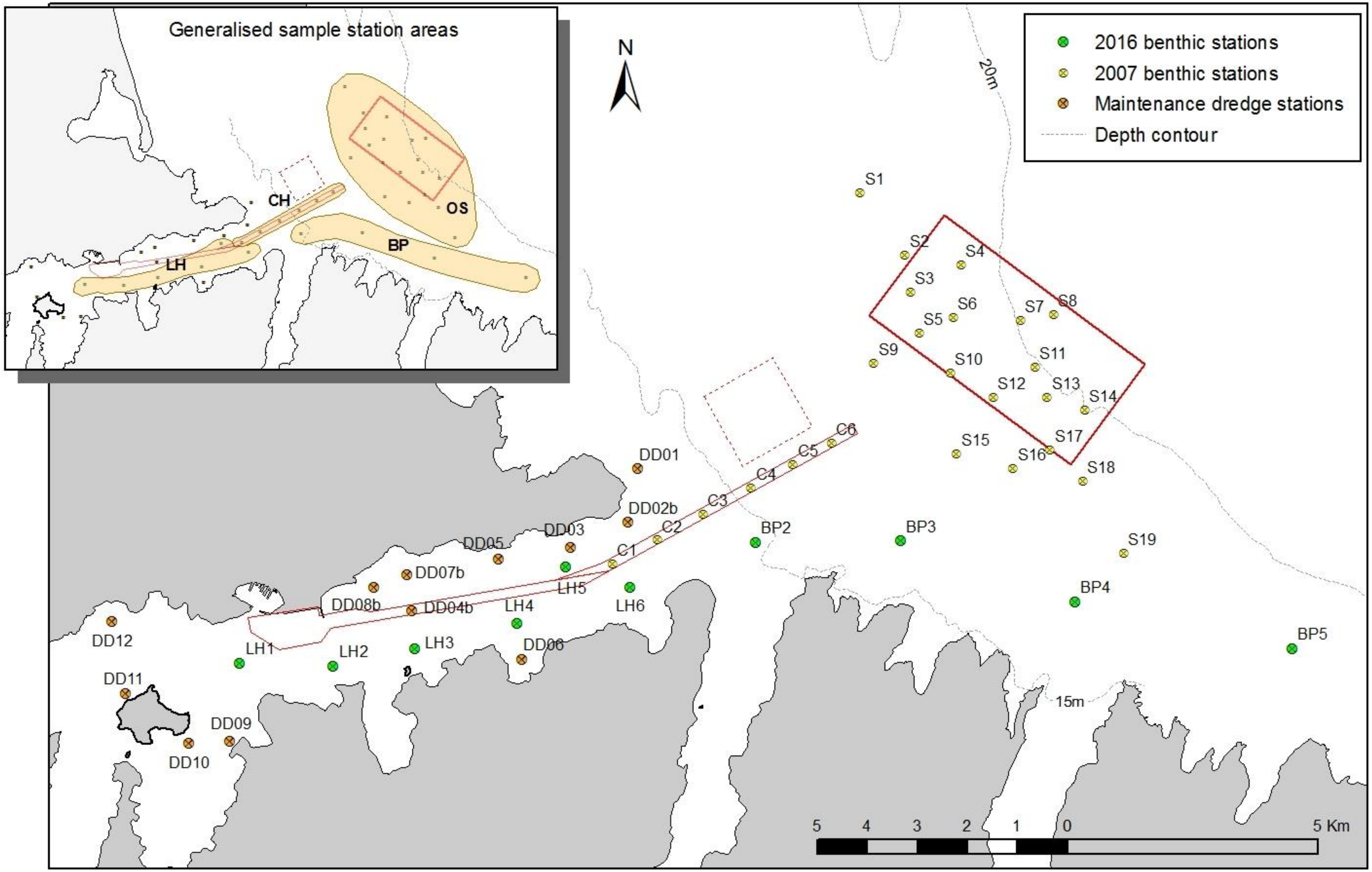

Figure 7 Spatial layout of benthic grab-sampling stations. Field surveys conducted October – Decemeber 2007 and in February 2016. Benthic sampling stations (1992–2015) associated with LPC's maintenance dredging consent are also shown.

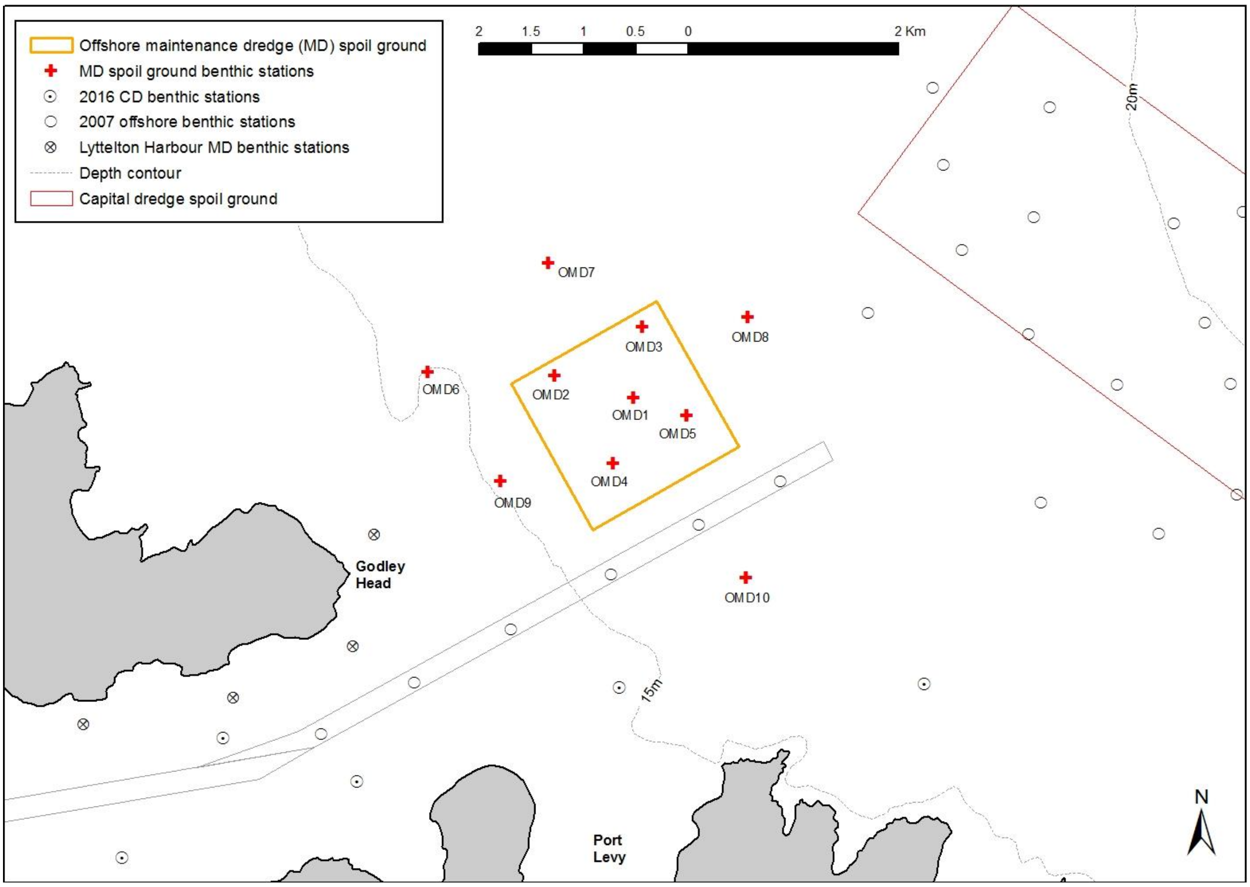

Figure 8 Spatial layout of benthic grab samples collected in August 2016 to survey the vicinity of the proposed maintenance dredge spoil ground.

5.1.2. Sediment texture and chemistry

Sediment grain size distribution did not vary greatly between sample stations outside the Harbour, with all samples being dominated by the fine mud and silt fraction (particle sizes of less than 63 µm) (Figure 9). No sample replicates for stations in the extended channel and capital spoil ground vicinity returned a proportion greater than 1% for any of the five particle size class coarser than very fine sands (*i.e.* size classes > 125 µm). The small amount of variation observed was most notable in the very fine sand component (63–125 µm) with channel sediments generally exhibiting lower mean values (range 1–4%) than off-shore samples (1–16%) and a correspondingly slightly greater silt/clay content. Differences in sediments from the channel extension area would be expected to arise from hydrodynamic factors such as partial shelter from wave action and greater tidal currents.

Outliers within the capital spoil ground area samples, with higher proportions of very fine sands were stations S1 (10.1%), S8 (16.0%), and S15 (10.4%) which were widely separated spatially and represent the full range in water depths encountered in the 2007 offshore survey (Figure 7, Figure 9). Stations S8 and S15 were also characterised by relatively high variability between replicates and it is considered that the values may result from small-scale heterogeneity or patchiness in the substrate. Without these outliers, the remaining offshore samples represented a range in the very fine sand size class of 1–7%.

The four stations adjacent to the Banks Peninsula coastline sampled in March 2016 returned slightly greater proportions of sediments coarser than 125 µm (1.8%–3.8%) and contained gradually decreasing proportions of the silt and clay fraction with distance from the Harbour heads (Figure 9). Samples from the proposed maintenance dredge spoil ground also featured slightly greater fine sand fractions (0.6–3.0%; Figure 10) but variability in the texture of sediments collected outside the Harbour heads was very small overall.

Sediment samples collected from the six Lyttelton Harbour/Whakaraupō stations in March 2016 were variable in texture, with LH2 and LH3 standing out as being predominantly very fine sand. LH4 appeared transitional to the finer silt/clay sediments of the outer two Harbour stations (LH5, LH6).

Mean sediment organic content, as indicated by Ash Free Dry Weight (AFDW), was relatively low overall, ranging from 1.7% to 3.5% for the capital spoil ground stations and 2.5% to 3.8% for the channel extension area. Similar ranges[7] were observed for sediments collected in February 2016 from the four stations nearer the Banks Peninsula coastline and six Lyttelton Harbour/Whakaraupō stations (Figure 9). AFDW was not analysed for the samples collected from the vicinity of the proposed offshore maintenance dredge spoil ground, although total organic carbon (TOC) exhibited a similar range (0.41–0.73%; Figure 10) to those from the Banks Peninsula offshore stations.

As noted, the extracted cores were generally light grey in colour and did not exhibit any distinct layering. The absence of a distinct aRPD layer is consistent with their relatively low organic content and suggests sufficient oxygenation of the sediments through diffusion, resuspension and bioturbation[8] processes.

[7] An AFDW range of 2.3-3.9% for these samples was found to correspond to total organic carbon (TOC) of 0.25-0.73%, respectively.

[8] The displacement and mixing of sediment particles by benthic fauna or flora. The mediators of bioturbation are typically annelid worms (*e.g.* polychaetes, oligochaetes), bivalve and gastropod molluscs and echinoderms (*e.g.* holothurians, burrowing urchins).

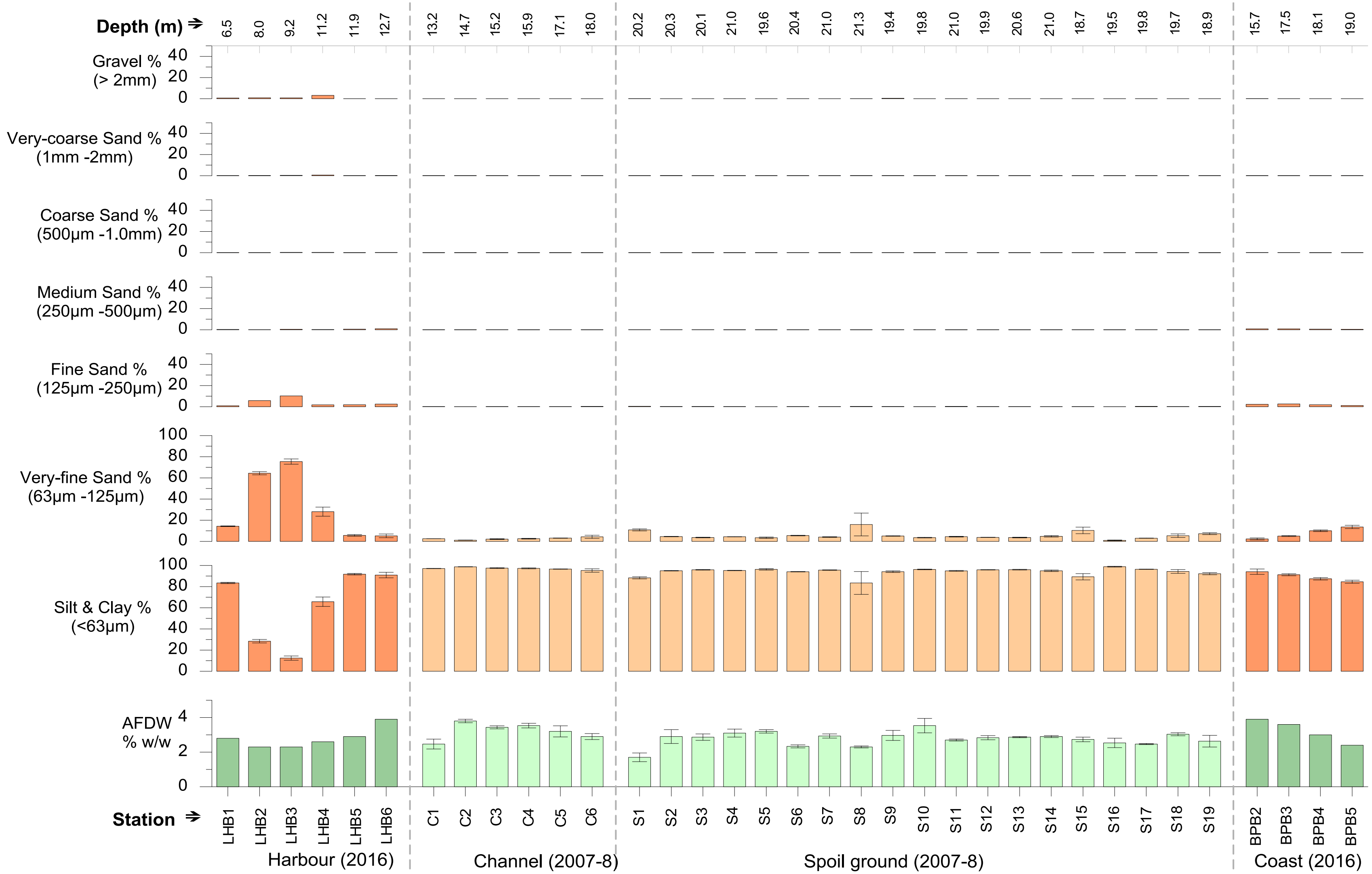

Figure 9 Mean particle size fractions and organic content (ash free dry weight) of sediment samples collected from benthic stations in the Harbour, the channel extension, the vicinity of the proposed spoil ground and near the Banks Peninsula coastline. Error bars represent ±1SE (n=3).

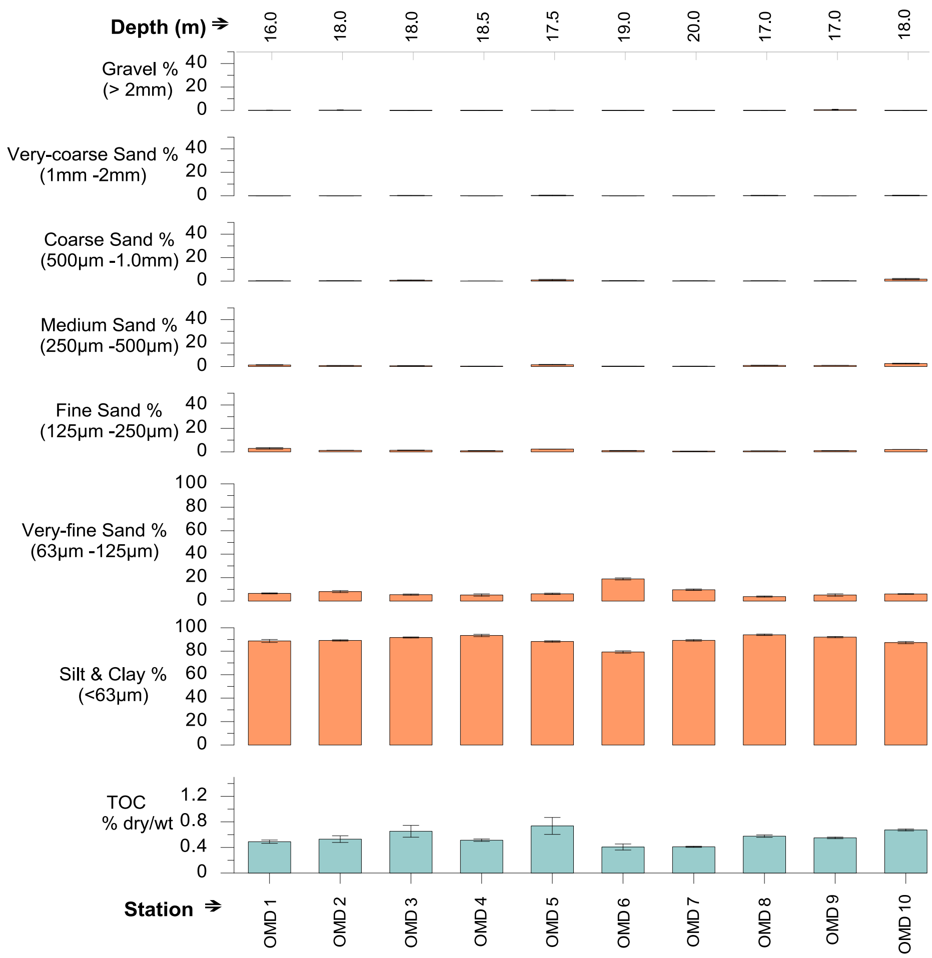

Figure 10 Mean particle size fractions and organic content (total organic carbon; TOC) of sediment samples collected from benthic stations in the the vicinity of the proposed new maintenance spoil ground off Godley Head. Error bars represent ±1SE (n=3).

Levels of indicative trace metals in composite sediment samples were essentially uniform across all of the offshore stations in the vicinity of the proposed capital spoil ground (S1–S19; Figure 11) and are considered representative of natural background concentrations in fine benthic sediments in Pegasus Bay. All were well below the corresponding trigger levels listed in the ANZECC (2000) sediment quality guidelines[9].

Apart from the furthest inshore channel extension station (C1), the contaminant status of approach channel sediments was similar to that of the offshore samples. The composite sediment sample from C1 exhibited elevated copper and chromium levels relative to those from all other stations. At 84 mg/kg, chromium slightly exceeded the ISQG-Low guideline level (80 mg/kg) at station C1 although copper was lower than ISQG-Low (65 mg/kg) at 54 mg/kg.

[9] The Interim Sediment Quality Guidelines (ISQG) -Low and -High levels represent the two threshold levels under which biological effects are predicted. The lower threshold indicates a *possible* biological effect while the upper threshold (ISQG-High) indicates a *probable* biological effect.

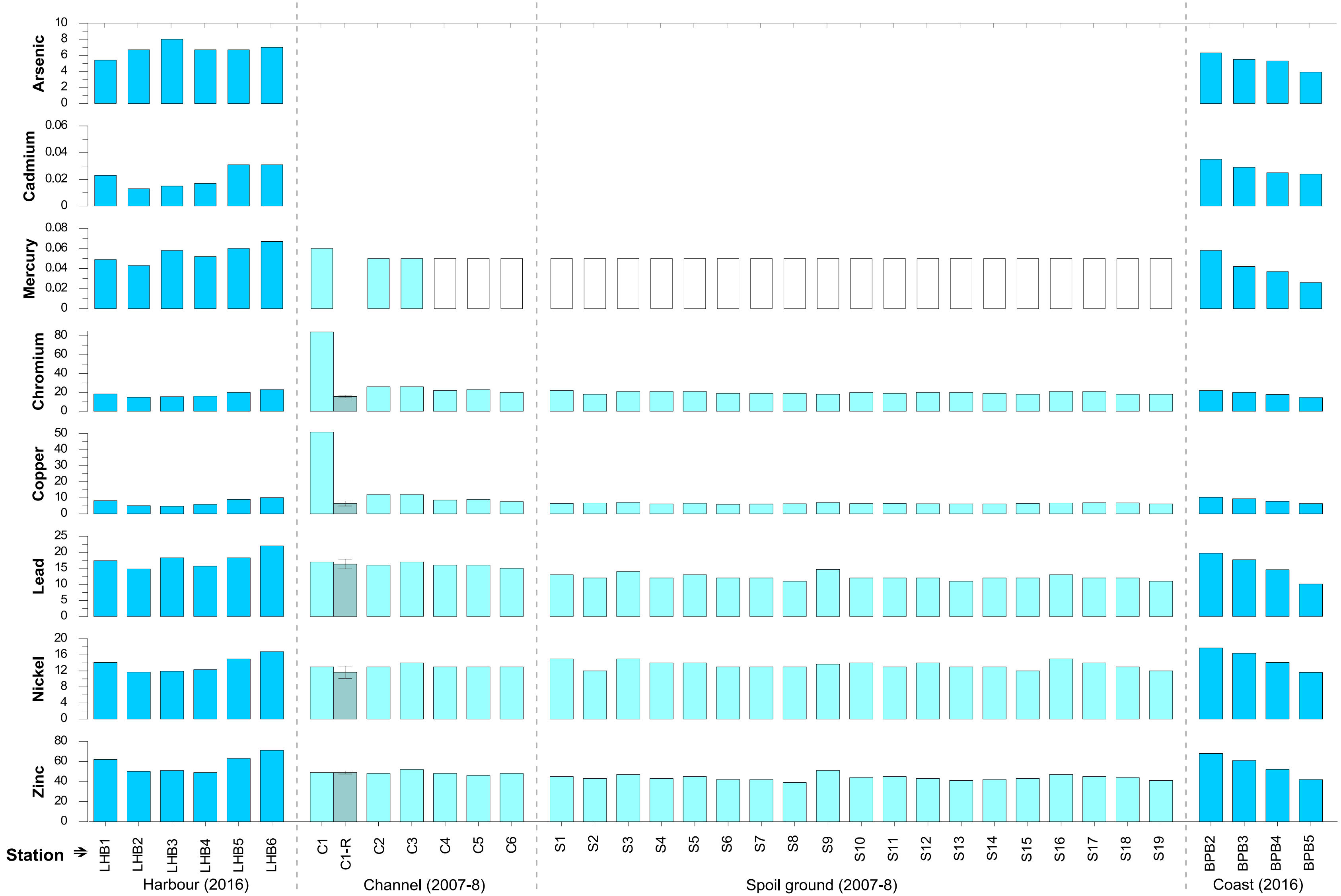

Figure 11 Metal concentrations (mg/kg) in sediments collected from the Harbour, the channel extension, the vicinity of the proposed spoil ground and near the Banks Peninsula coastline. Results based on analyses of composited triplicate samples. Station C1-R = station C1 re-sample. No fill = <ADL.

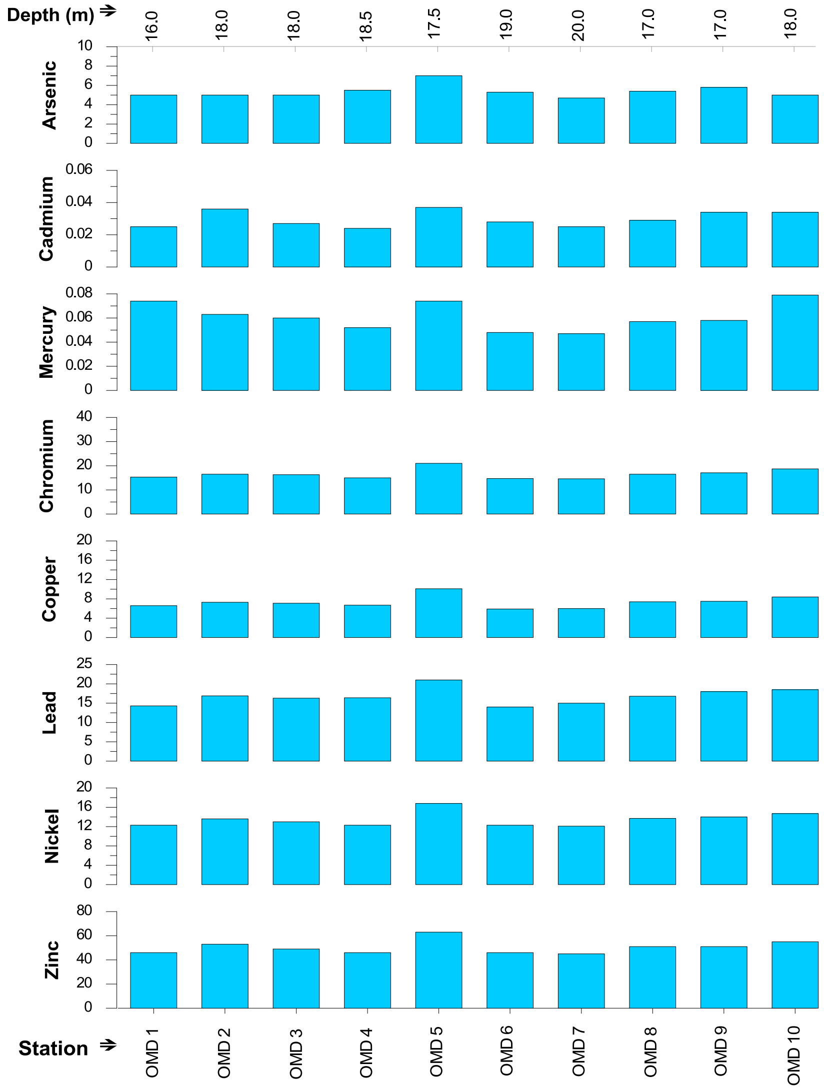

Figure 12 Metal concentrations (mg/kg) in sediments collected from the vicinity of the proposed new maintenance dredging spoil ground offshore from Godley Head. Results based on analyses of composited triplicate samples.

Station C1 sediments were re-sampled in triplicate (C1R) and results indicated that, for all metals tested[10], concentrations at the station were in fact consistent with those of the other stations in the area of the proposed channel extension. This suggests that the original C1 result was a spike, indicative either of chance inclusion of discrete particulate matter high in Cr and Cu or contamination of the sample (the former being more likely). The single composite samples collected from each station for metals analysis mean that a high result can potentially result from discrete particulate contamination (such as a flake of paint from hull anti-fouling coatings).

[10] Mercury was not re-analysed in this case.

Concentrations of copper, chromium, lead and zinc were generally slightly higher for channel extension stations compared to those from further offshore. However, concentrations remained well below corresponding ISQG-Low values and the difference is considered to be related to the slightly greater proportion of silt- and clay-sized particulates in the channel samples.

Sediment mercury was below the analytical detection limit (0.05 mg/kg) for all offshore (spoil ground) stations, but was detected at stations C1 (0.06 mg/kg), C2 (0.05 mg/kg) and C3 (0.05 mg/kg) in the proposed channel extension area. However, at all of these stations, mercury was well below the ISQG-Low value of 0.15 mg/kg. Mercury analyses of samples collected in 2016 had lower detection limits and indicated a background sediment concentration varying 0.03–0.08 mg/kg.

It should be noted that there was a change in analytical laboratory between the sample sets collected in 2007and those from 2016 and—importantly—changes in analytical method. In 2007, sediment trace metals were analysed with inductively coupled plasma optical emission spectroscopy (ICP-OES) and mercury with cold vapour atomic absorption spectroscopy (CV-AAS). In 2016, the method used for all metals was inductively coupled plasma mass spectrometry (ICP-MS). It is likely that at least some of the slight differences in level and variability observable between the two sets of samples could have arisen from this change.

The decreasing concentrations of trace metals with distance seawards from the Harbour heads (stations BP2-BP5; Figure 11) coincided with a generally decreasing proportion of both silt-and-clay sized particles and organic carbon in these samples. However, correlations across all 2016 samples were greatest between metals and TOC (R^2 up to 0.81 for Cu:TOC).

Despite some variability, there was very little difference between metals concentrations in sediments from within the Harbour compared to those collected from locations outside the heads. There was furthermore no distinct spatial gradient in sediment trace metals along the Harbour axis. As noted, the observed variability correlates principally with the silt/clay fraction and TOC.

Samples collected from the vicinity of the proposed maintenance spoil ground exhibited metals concentrations consistent with the other sample data sets (Figure 12). The slightly higher concentrations of all metals in the OMD5 composite sample coincided with higher organic carbon.

5.1.3. Sediment organic contaminants

Composited sediment samples from the three innermost Harbour stations and six stations in the vicinity of the proposed offshore maintenance dredge spoil ground were analysed for polycyclic aromatic hydrocarbons (PAHs). PAHs are a group of complex hydrocarbons comprised of two or more fused benzenoid rings. They are common constituents of fuels (including coal) and lubricating oils, but most typically arise from the incomplete combustion of organic material. Many PAHs have a number of natural sources (*e.g.* combustion of organics during forest fires or as primary or secondary products of natural plant and microbial metabolism). However, significant environmental contamination has resulted largely from human activity. Most PAHs will not dissolve easily into water and they tend to bind to sediments and particulate organic matter.

Table 6 presents the results of sediment PAH analysis. All analytes have been normalised to 1% organic carbon[11] to enable comparison against ANZECC (2000) ISQG criteria. Since total organic carbon in all three Harbour samples was less than 0.5%, this has the effect of more than doubling the actual concentrations of PAHs in the sediments. Of the 15 analytes, all except naphthalene, acenaphthylene and acenaphthene were at detectable concentrations in sediments from all three stations (Table 6). However, even with normalisation to TOC, all were well below their corresponding ANZECC (2000) ISQG-Low trigger values, where a biological effect might be expected. The highest concentrations of PAHs were in the sample from Station LH3, south of Gollans Bay (Figure 7). Relative to its corresponding ISQG-Low trigger value, the low molecular weight PAH fluorene was at the highest level across all three samples (reaching 63% of ISQG-L at LH2). In monitoring for LPC's coalyard stormwater discharge consent (CRC960549), fluorene was also at relatively higher levels in sediments than other PAHs and exceeded ISQG-Low in one of four samples from Te Awaparahi Bay (to which the stormwater discharges) and one from Gollans Bay (which receives spoil from infrequent maintenance dredging of the Inner Harbour) (Sneddon 2014a).

Although phenanthrene, and all high molecular weight PAHs except dibenzo[a,h]anthracene were detected in the (OMC) composite samples from the maintenance spoil ground stations offshore from Godley Head, these were at significantly lower concentrations ranging from 14% to 28% of the Lyttelton Harbour sediments on average.

[11] This allows for the fact that many organic contaminants bind strongly to organic matter, decreasing bioavailability and hence toxicity.

Table 6 Sediment concentrations of polycyclic aromatic hydrocarbons (PAHs; normalised to 1% total organic carbon) in samples collected from the three innermost Lyttelton Harbour/Whakaraupō benthic stations and two samples (composited from three stations each) from the vicinity of the proposed offshore maintenance spoil ground.

	Lyttelton Harbour			Spoil ground [a]		*ANZECC (2000)*	
	LH1	**LH2**	**LH3**	**OMC1**	**OMC2**	***ISQG-L***	***ISQG-H***
Total Organic Carbon	0.47	0.25	0.26	0.45	0.58		
Naphthalene	<0.011	<0.010	<0.010	<0.013	<0.013	*0.16*	*2.1*
Acenaphthylene	<0.003	<0.002	0.012	<0.003	<0.003	*0.044*	*0.64*
Acenaphthene	<0.003	<0.002	<0.002	<0.003	<0.003	*0.016*	*0.5*
Fluorene	0.009	0.012	0.008	<0.003	<0.003	*0.019*	*0.54*
Anthracene	0.013	0.012	0.035	<0.003	<0.003	*0.085*	*1.1*
Phenanthrene	0.049	0.052	0.081	0.011	0.012	*0.24*	*1.5*
Low molecular weight PAHs [b]	0.079	0.083	0.141	0.039	0.034	*0.552*	*3.160*
Pyrene	0.100	0.096	0.246	0.025	0.021	*0.665*	*2.6*
Fluoranthene	0.102	0.096	0.273	0.022	0.021	*0.6*	*5.1*
Benzo[a]anthracene	0.045	0.044	0.115	0.013	0.009	*0.261*	*1.6*
Chrysene	0.051	0.052	0.119	0.013	0.009	*0.384*	*2.8*
Benzo[a]pyrene (BAP)	0.060	0.064	0.158	0.020	0.012	*0.43*	*1.6*
Benzo[b]+[j]+[k]fluoranthene	0.102	0.104	0.246	0.042	0.028	*0.76* [c]	*6.48* [d]
Indeno(1,2,3-c,d)pyrene	0.043	0.044	0.104	0.016	0.010	*0.50* [c]	*4.21* [d]
Benzo[g,h,i]perylene	0.053	0.052	0.100	0.022	0.016	*0.51* [c]	*4.37* [d]
Dibenzo[a,h]anthracene	0.009	0.008	0.019	<0.003	<0.003	*0.063*	*0.26*
High molecular weight PAHs [c]	0.366	0.360	0.931	0.097	0.073	*1.70*	*9.60*
Total PAHs [b,c]	0.445	0.443	1.071	0.136	0.107	*4.00*	*45.00*

a. Composite samples from the vicinity of the proposed offshore maintenance dredging spoil ground. OMC1 from OMD2, OMD6, OMD7 and OMC2 from OMD4, OMD9, OMD10 (Figure 8).
b. Where values are less than the ADL, summations use the convention of substituting ADL/2.
c. ANZECC lists high molecular weight PAHs as the sum of concentrations of benzo(a)anthracene, benzo(a)pyrene (BAP), chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene; hence benzo[b]+[j]+[k]fluoranthene, indeno(1,2,3-c,d)pyrene and benzo[g,h,i]perylene are omitted from this summation.
d. ISQG trigger not provided by ANZECC (2000). Value assigned relative to ISQG for fluoranthene from ratios between PSML values, Puget Sound sediment quality guidelines (PSDDA 1989).

5.2. Benthic macrofauna

5.2.1. Patterns in community indices

Abundance and taxa richness

Average infaunal abundance (number of individuals), richness (number of different taxa) and diversity indices at each station are presented in Figure 13. Average abundance in the Harbour (LH) was highly variable and, on average, ranged from 43 to 250 individuals per core. Infaunal abundance in the extended channel area (CH) was relatively lower than in other areas and station averages varied 32 to 71 individuals per core. Abundance in the vicinity of the proposed spoil ground (OS) was consistently higher than in other areas, ranging between 66 and 194 individuals per core. The four Banks Peninsula offshore (BP) stations sampled in 2016 averaged between 71 and 151 individuals per core with an apparent spatial gradient increasing away from the Harbour entrance.

Similar to infaunal abundance, species richness was highly variable across the six Harbour stations (LH), ranging between 4 and 28 taxa per core on average. Richness in the channel was comparatively lower than in other areas, ranging between 9 and 12 species per core. Communities in the proposed spoil ground were richer relative to the other areas, ranging 18–33 taxa per core. For the four BP stations, there was an apparent trend of increasing species richness with distance from the Harbour, ranging 9–19 taxa per core.

Although the samples collected during the October 2007 survey appear to reflect slightly lower abundance and species richness than in December 2007, it is noted that repeat samplings of ‘4C’ and ‘4M’ (being S1 and S6 respectively) show values for these parameters at the low end of the observed December variability. This suggests, therefore, that seasonal variation is probably less of a factor than background spatial variability (*i.e.* patchiness in community distribution).

Diversity and evenness

The Shannon-Weiner diversity index (H’) followed spatial trends similar to those described above for abundance and richness (Figure 13D). H’ was highly variable across the Harbour (LH) stations, with a station mean ranging between 0.6 and 2.7. In contrast, the channel area exhibited relatively uniform H’ values, ranging between 1.6 and 2.1 and reflecting the lower number of taxa recorded in these samples. The spoil ground area returned consistently higher H’ index values, with station means ranging from 2.3 to 2.9. Samples from the BP stations presented relatively lower and more variable values (range 9–19), which generally increased with distance from the Harbour, reflecting the patterns described for abundance and richness.

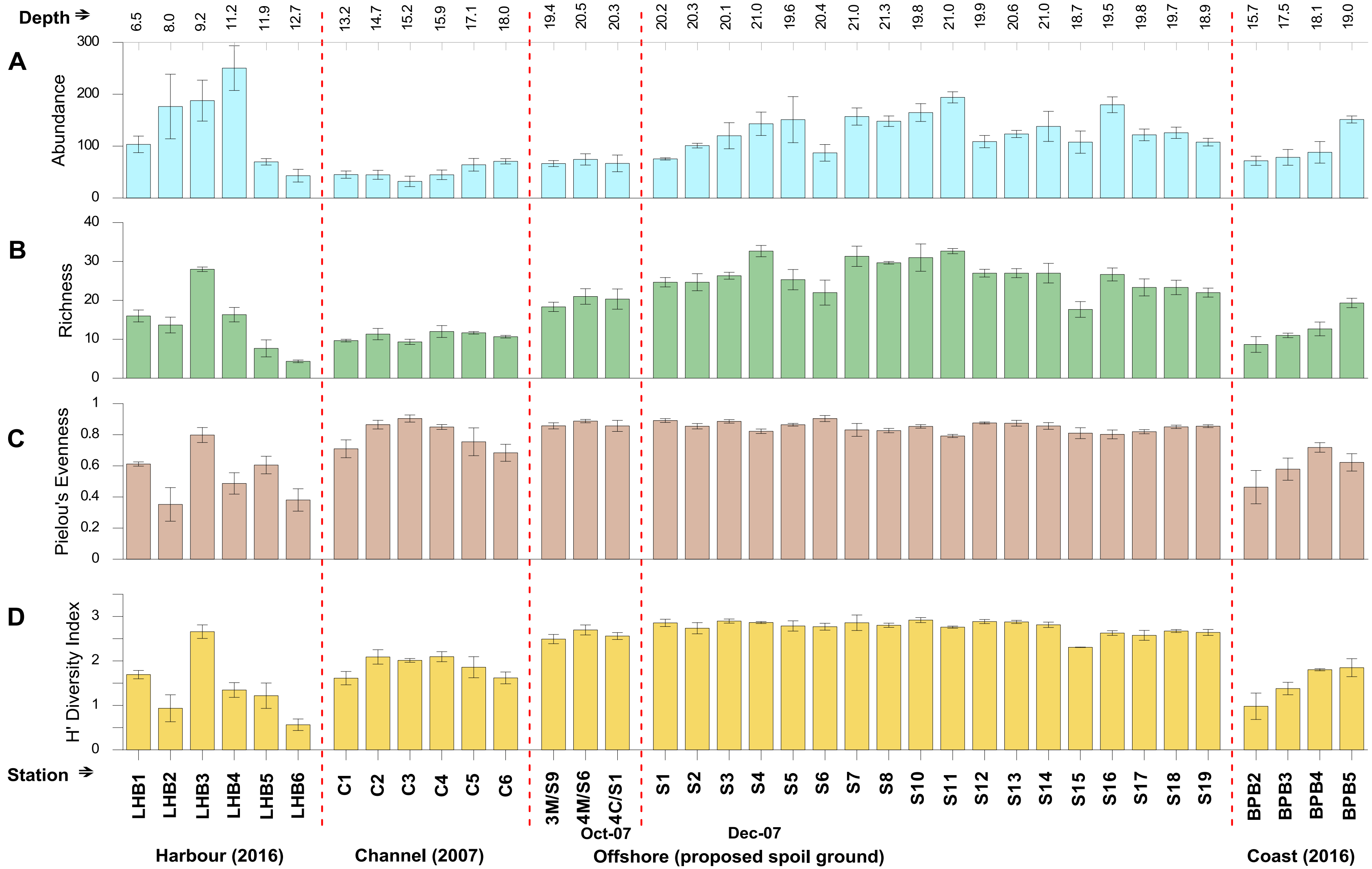

Figure 13 Mean infauna indices for each sample station (n = 3). **A:** Number of individuals per 0.013 m^2 core. **B:** Number of taxa per core. **C:** Pielou's Evenness. **D:** H' Shannon-Weiner Diversity index. Error bars represent ±1 SE for the triplicate.

Pielou's evenness index (J) showed very similar spatial patterns to those described for the Shannon-Wiener diversity index, being notably lower for the BP stations and variable within the Harbour (Figure 13C). Of the Harbour stations, LH3 stands out for high values of all indices, indicating that its high infaunal abundance was not dominated numerically by just a few taxa. The extended channel area also stands out as having been consistently lower in both infaunal abundance and species richness, although evenness remained relatively high.

For stations outside the Harbour heads, Figure 13A shows an apparent increase in overall abundance with depth. Sediments from the channel extension area were not found to be appreciably different in texture or organic content to those further offshore (see Figure 9) and it is likely that habitat differences leading to altered community composition are related to other factors such as depth and wave/current climate which may have a significant effect on substrate stability. It is also in an area where limited under-keel clearance may lead to significant propeller and hull turbulence from vessels entering and leaving the Harbour.

5.2.2. Inter-correlation of benthic station variables

The correlogram (Figure 14) visually presents the degree of correlation between all benthic sample variables and indices (diversity indices, sediment grain-size fractions, trace metals and depth). Positive correlations are displayed in blue and negative correlations in red. Colour intensity and symbol size are proportional to the corresponding correlation coefficient (r^2). The correlogram indicates that diversity indices are generally highly and positively inter-correlated (top left of Figure 14), whereas they are generally negatively correlated with metals and positively correlated with depth (top mid-right Figure 14). The coarser sediment grain-size fractions were generally positively inter-correlated, with the exception of silt and clay (mid-left Figure 14), which dominated at all stations except at LH2 and LH3 in the Harbour, which were sandier (Figure 9). Metals displayed generally strong positive inter-correlation (bottom-left Figure 14), but also with the medium sand fraction. Depth was generally positively correlated with diversity indices and the silt/clay fraction and negatively correlated with some metals (*i.e.* zinc, mercury and lead).

Figure 15 shows the relationships between total abundance and taxa richness, respectively, and selected environmental variables, including depth, sediment lead and copper, and the very fine sand fraction. There was a positive relationship between depth and total abundance, but it was only statistically significant for the stations in the channel and proposed spoil ground areas.

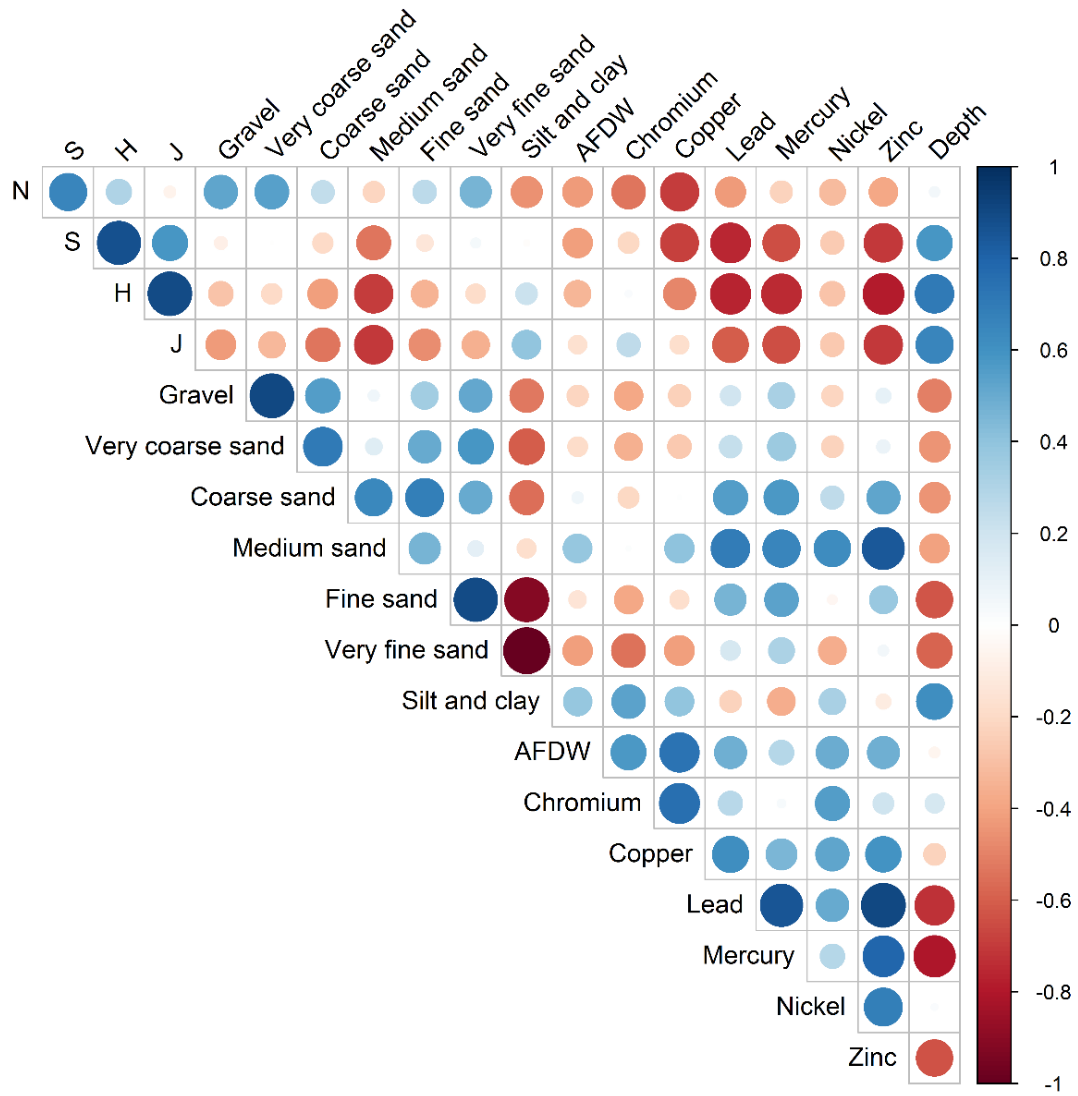

Figure 14 Correlogram of diversity indices and environmental variables for benthic samples. Positive correlations are displayed in blue and negative correlations in red. Colour intensity and the size of the circle are proportional to the correlation coefficients. The scale bar shows the correlation coefficients represented as a colour spectrum.

There was a significant, but weak negative relationship ($r^2 = 0.18$) between infaunal abundance and sediment lead concentration. Similarly abundance was significantly and negatively correlated to sediment copper concentration ($r^2 = 0.48$). On the other hand, overall infaunal abundance increased with the proportion of very fine sand in the sediments (< 125 µm & > 63 µm, $r^2 = 0.2$). Similar trends, were observed for taxa richness (Figure 15B), including an area-dependant relationship with depth and negative relationships with the concentrations of sediment lead ($r^2 = 0.56$) and copper ($r^2 = 0.46$). However, no apparent relationship was detected between richness and percentage of very fine sand.

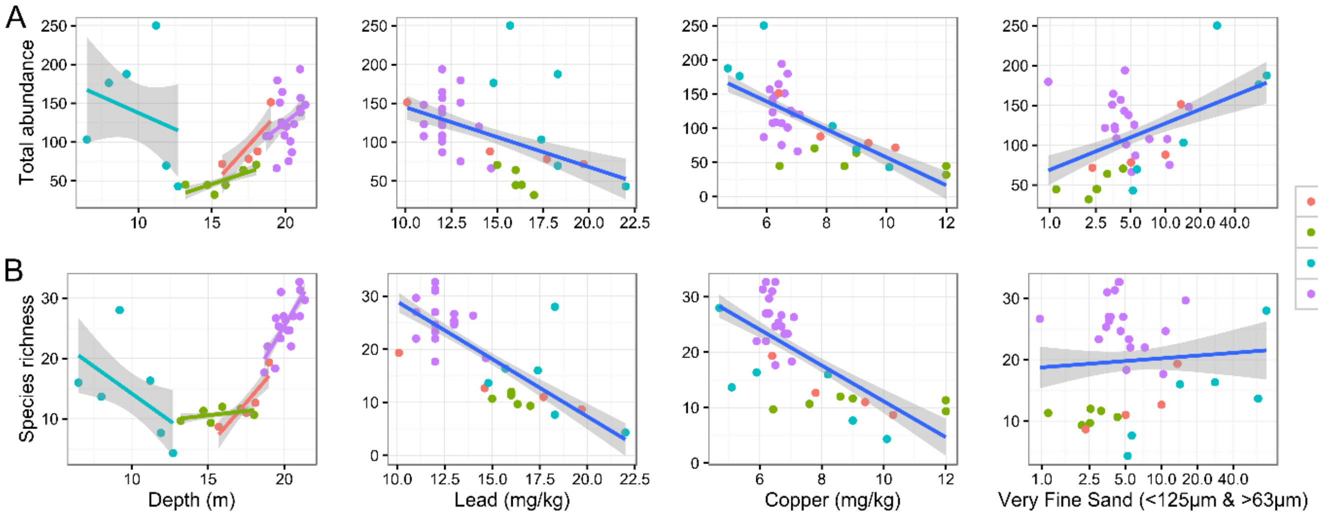

Figure 15 Relationships between (A) Abundance (number of individuals per core) and (B) Taxa richness (number of taxa per core) and selected environmental variables. Sampling areas Harbour (LH), the channel extension (CH), the vicinity of the proposed spoil ground (OS) and offshore from the Banks Peninsula coastline (BP). The blue lines represent a fitted linear regression (± S.E.).

A listing of all macrofaunal taxa identified from core samples collected from Lyttelton Harbour and its approaches is presented in Appendix 3. The 10 most abundant infauna taxa within samples from each of the separate station areas are presented in Table 7**Error! Reference source not found.**. Deposit feeders and scavengers generally predominated. Polychaete worms were by far the most dominant taxonomic group, representing cumulatively around 70% of total abundance. Other taxonomic groups strongly represented were crustaceans (including the stalk-eyed mud crab *Hemiplax hirtipes*, amphipods, cumaceans and ostracods) and, within the Harbour, bivalves (*Theora lubrica* and *Myadora striata*) and the sea pen *Virgularia gracillima*.

The infaunal communities represented by samples from the Harbour area were variable, due to the dissimilar nature of the seabed across stations (substrate and depth). Four stations were dominated by the deposit feeder polychaete *Heteromastus filiformis*, which was recorded at an average abundance of 161 individuals per core across stations LH2 and LH4 (but were largely absent from LH3 or LH6). Two other deposit feeding taxa were also dominant in this area, namely the polychaetes *Cossura consimilis* and Cirratulidae, but these were recorded at considerably lower abundances (mean 12.3 and 5.1, respectively, across all Harbour stations). *C. consimilis* was largely limited to the outer three Harbour stations (LH4-6; 23.3 per core). *V. gracillima* was found in high numbers (58 per core) only at station LH1. High numbers of the bivalves *T. lubrica* (10.3 per core at LH4) and *M. striata* (11.3 per core at LH3) were also limited to single stations. *T. lubrica* is a non-indigenous species considered to be tolerant of pollution, organic enrichment and mud substrates. Other dominant groups included crustaceans, represented by amphipods and cumaceans.

Table 7 Summary table of the 10 most abundant infaunal taxa sampled from each area, listed in order of overall mean abundance. LH= Lyttelton HarbourLyttelton Harbour/Whakaraupō, CH=extended channel, OS=offshore spoil ground, BP=Banks Peninsula offshore, OM=offshore maintenance spoil ground. Grey-shaded cells indicate taxa absent from all samples.

Taxonomic group	Species/Taxa	Common name	Feeding mode	Sampling area				
				LH	CH	OS	BP	OM
Polychaeta	*Heteromastus filiformis*		Infaunal deposit feeder	63.3	14.7	16.4	41.8	41.2
Polychaeta	*Cossura consimilis*		Infaunal deposit feeder	12.3	10.0	10.9	28.7	5.9
Polychaeta	Paraonidae		Infaunal deposit feeder		0.8	21.5	2.2	2.1
Amphipoda	Amphipoda	Amphipods	Epifaunal scavenger	13.4	2.2	6.6	2.1	4.9
Polychaeta	Cirratulidae		Infaunal deposit feeder	5.1	3.1	7.2	3.3	0.9
Decapoda	*Hemiplax hirtipes*	Stalk-eyed mud crab	Deposit feeder & scavenger	1.6	8.0	5.2	1.0	0.3
Polychaeta	*Aglaophamus* sp.		Infaunal carnivore	3.4	1.1	3.9	4.0	1.5
Cumacea	Cumacea	Cumaceans	Infaunal filter or deposit feeder	2.3	2.6	5.1	2.3	4.2
Anthozoa	*Virgularia gracillima*	Sea pen	Passive suspension feeder	9.8		0.1	0.1	0.1
Polychaeta	*Terebellides stroemii*		Infaunal deposit feeder	0.7	0.3	7.4		
Polychaeta	Lumbrineridae		Infaunal carnivore & deposit feeder	0.7	2.1	1.8	2.4	1.1
Polychaeta	Sigalionidae		Infaunal carnivore	1.4	1.2	3.2	1.3	2.0
Ostracoda	Ostracoda	Ostracods	Omnivorous scavenger			6.1		0.1
Bivalvia	*Theora lubrica*	Asian Semele	Selective deposit feeder	2.1	0.2	0.1	0.2	2.9
Nemertea	Nemertea	Ribbon worms	Infaunal carnivore	0.1	0.2	0.9	1.3	0.2
Bivalvia	*Myadora striata*		Filter feeder	2.1				
Bivalvia	*Myllitella vivens vivens*			1.9		0.02		
Polychaeta	Ampharetidae			1.0	0.1	1.6	1.1	1.5
Polychaeta	Goniadidae			1.2	0.3	0.3	0.4	1.8

Communities in the proposed extension to the dredge channel were dominated by the deposit-feeding polychaetes, *H. filiformis* and *C. consimilis*; however, they were recorded in generally lower abundances (14.7 and 10.0 individuals per core, respectively). The stalked-eyed mud crab was also prevalent, with average abundance of 8.0 individuals per core. All other dominant taxa were recorded in averages abundances of ~3 or less individuals per core and included polychaetes of the families Cirratulidae, Lumbrineridae and Sigalionidae, as well as *Prionospio* sp. and *Aglaophamus* sp. Amphipods and cumaceans were also among the 10 most abundant taxa in this area.

Paraonid polychaetes were the numerically dominant taxa over the spoil ground area at 21.5 mean abundance per core (although present in the channel extension area samples, they were not numerically dominant, having a mean abundance per 0.013 m^2 core of just 0.83). In terms of abundance, these were followed by four other deposit feeding polychaetes, namely *H. filiformis*, *C. consimilis* (present in numbers generally similar to those of the channel extension area), *Terebellides stroemii* and Cirratulidae. Four crustaceans were also among the relatively more numerous taxa of infaunal communities in the proposed spoil ground, including amphipods, ostracods (absent from the channel extension samples), the stalked-eyed crab *H. hirtipes* and cumaceans.

Samples from Banks Peninsula offshore (BP) stations were numerically dominated by *H. filiformis* (42 per core) and *C. consimilis* (29 per core). The remaining eight of the 10 most abundant taxa were far less numerous, ranging 1.3–4 individuals per core. These included another six polychaete taxa, cumaceans and phoxocephalid amphipods. A spatial gradient was apparent in the distribution of most of these dominant taxa, with numbers increasing with distance east from Adderley Head (also corresponding to increasing depth).

The results of similarity analyses of the infauna count data are presented as a dendrogram in Figure 16. This shows the relative (percentage) similarity of the stations in terms of infaunal assemblages. Benthic stations from the channel and spoil ground area resolved into distinct groups at the 65% similarity level, with the Banks Peninsula stations being grouped together with two of the outer Harbour stations (LH4 and LH5). The remaining Harbour stations (LH1, LH2; LH3; and LH6) did not form a group and shared <50% similarity in community structure with any other stations.

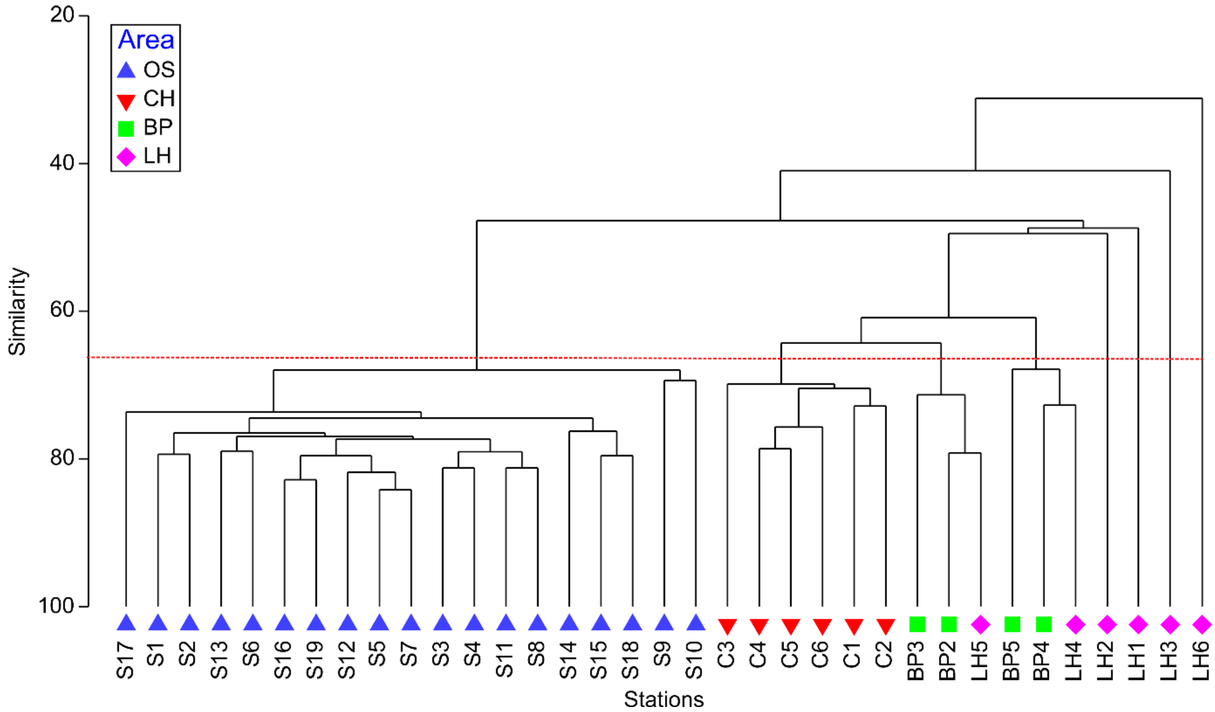

Figure 16 Cluster diagram (dendrogram) showing groupings, by similarity of macroinvertebrate assemblages (mean samples by stations) from all four sampled areas; the Harbour (LH), the channel extension (C), the vicinity of the proposed spoil ground (OS) and near the Banks Peninsular coastline (BP). The red dotted line indicates groupings at 65% similarity. The raw data were forth root transformed for the analysis.

The PERMANOVA analysis indicated significant differences in assemblage structure between all areas (P < 0.001), with the exception of assemblages from Harbour stations that did not differ significantly from Banks Peninsula and channel stations (P > 0.5). Additionally, there was significant variability between stations within areas, with Harbour stations having the largest variability in assemblage structure. These patterns can be visualised in the multi-dimensional scaling (nMDS) plotted in Figure 17. The stress value of 0.11 associated with the nMDS plot indicates that a good degree of confidence can be placed on the groupings portrayed[12]. The nMDS plot indicates a clear separation, at the 65% level of similarity, between the offshore area around the proposed spoil ground (OS), and the extended channel area (CH). Both of these areas are grouped apart from stations in the Harbour (LH) and offshore from the Banks Peninsula coastline (BP). A component of this separation may come from the fact that these two pairs of areas were sampled eight years apart, reflecting broad-scale temporal oscillations as well as seasonal differences. The high variability in community structure across the Harbour stations is evidenced by the wide scatter of these stations in the nMDS plot, although LH4 and LH5 are grouped with pairs of BP

[12] Distances on the nMDS plot have only relative, not absolute, meaning. Thus the stress value is a dimensionless quantity and is a measure of the difficulty involved in compressing the sample relationships into two dimensions. A stress value of <0.1 corresponds to a good ordination with no real prospect of a misleading interpretation, while a stress value of <0.2 still gives a potentially useful 2-D picture. Stress values within the range of 0.2 to 0.3 should be treated with a great deal of scepticism, particularly if in the upper half of this range and for sample sizes of <50.

stations at the 65% level of similarity. This is consistent with the variability in diversity indices and substrate type described for LH stations above.

Changes in taxa abundance and composition contributing to the observed separation between areas CH and OS included a substantially lower abundance of paraonid and maldanid polychaetes in the channel stations, along with the absence of ostracods and a lower abundance of the polychaete *Terebellides stroemii*.

Taxa contributing to the separation between Banks Peninsula stations and the channel and proposed spoil ground included the absence from BP samples of the polychaetes *Terebellides stroemii* and Maldanidae, and also ostracods. While the high variability of the Harbour (LH) stations prevented their grouping together, the main drivers of the observed separation from CH and OS stations were the absence from LH samples of paraonid polychaetes and ostracods and the higher abundance of amphipods.

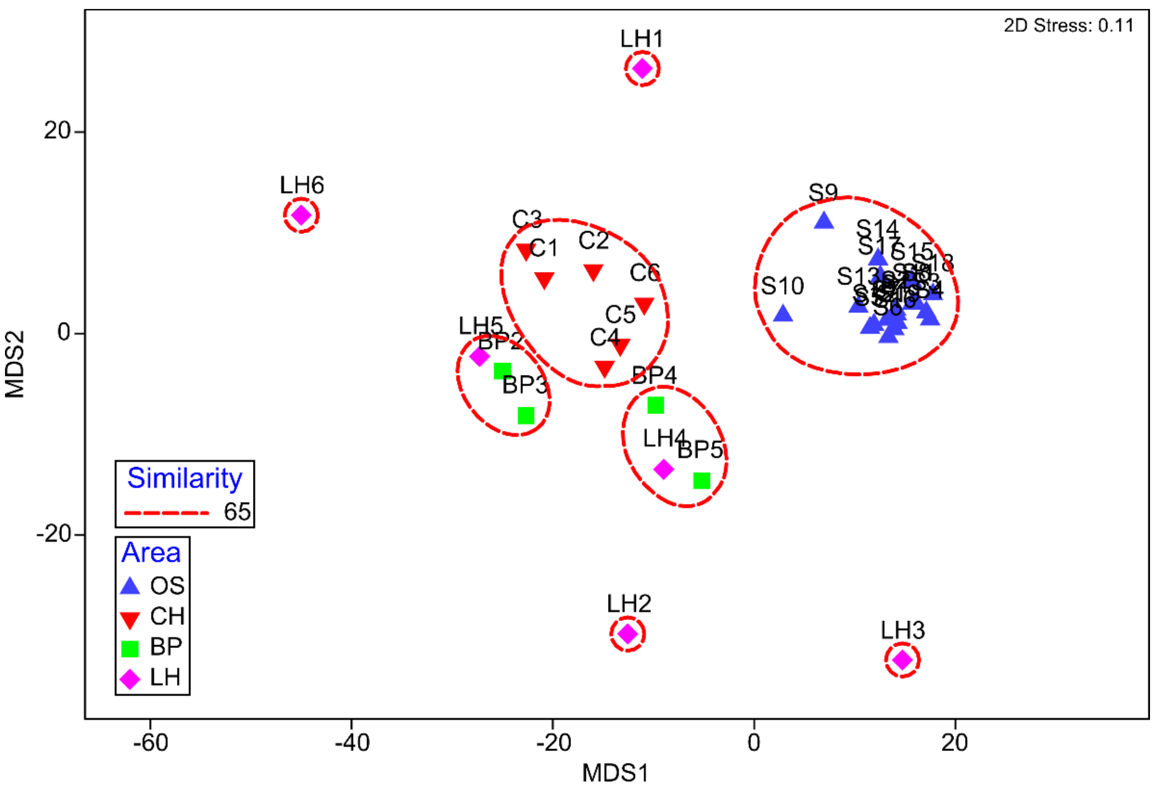

Figure 17 nMDS plot showing the similarity (Bray-Curtis) of macroinvertebrate infauna assemblages for average abundances across stations for all four sampled areas: Lyttelton Harbour/Whakaraupō (LH), the channel extension (C), the vicinity of the proposed spoil ground (OS) and near the Banks Peninsula coastline (BP). The raw data were fourth-root transformed before the analysis.

Multivariate multiple regression indicated that each environmental variable explained a significant proportion of the variability in the infauna data. When variables were considered alone in the marginal test, lead explained the largest amount of variation in infaunal data at 32%, followed by zinc (28%). When considered all together, the set of variables that explained the most variability in the data were fine sand, silt and clay, lead, zinc and depth that together explained 58% of the variability. The full model can be visualised by examining the dbRDA ordination displayed in Figure 18. The first two axes captured 81.4% of the variability in the fitted model and 47.5% of the total variability in the data. The vector overlay shows the first dbRDA axis is strongly related to depth (positively) and zinc, lead and fine sand (negatively) and the second axis is strongly related to silt and clay content.

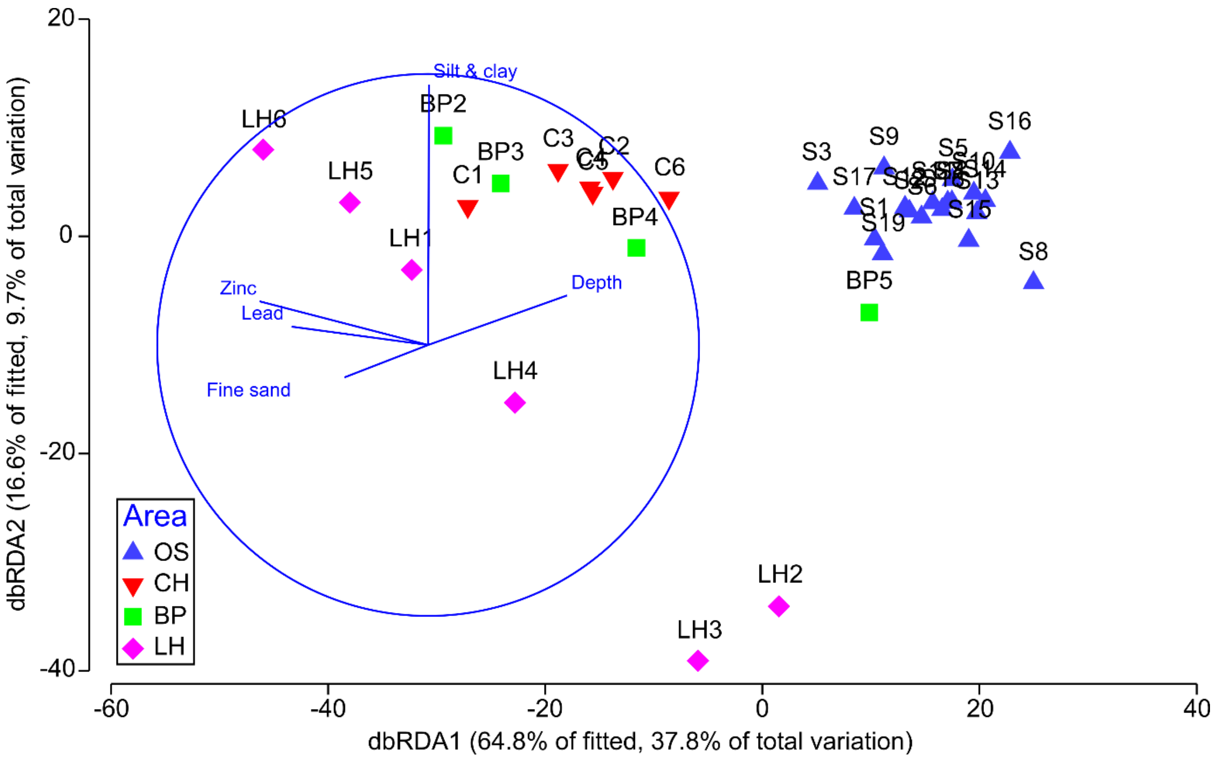

Figure 18 Distance based redundancy analysis ordination for the fitted model of infaunal assemblage data based on the Bray-Curtis similarity after fourth-root transformation in relation to environmental variables displayed as vectors. Symbols represent averaged infaunal data per station (n=3) for each area: Lyttelton Harbour/Whakaraupō (LH), the channel extension (C), the vicinity of the proposed spoil ground (OS) and near the Banks Peninsular coastline (BP).

The separation between areas is relatively clear in Figure 18, with the proposed spoil ground stations being separate from others areas along the first axis by depth and lower zinc, lead and fine sand content. The channel assemblages are clustered along the first axis due to intermediate depth. Harbour assemblages are quite variable, but four cluster apart (LH1, LH4, LH5 and LH6) due to relatively higher lead and zinc content in the sediment, together with Banks peninsula stations BP2 and BP3. Two Harbour stations (LH2 and LH3) are separated from the rest mainly due to their low silt and clay content, which resulted in quite distinct assemblages.

Kingett Mitchell (2003b) considered the results of benthic community analysis from a number of historical studies over a broad area in Pegasus Bay, including sites both inshore and offshore. A significant degree of consistency in infauna community structure was suggested by this review, with the numerical prevalence of polychaete taxa a noted feature. The present work is also highly consistent with the results cited, suggesting that the seabed area off Godley Head is typical of the benthic ecology of the wider inshore area of Pegasus Bay.

As noted above, given the similarities in grain size distribution between the channel and spoil ground areas and their similarly low sediment contaminant levels, other unmeasured factors are likely to play a significant role in community differences. Apart from the role of water depth, there are also differences in wave and current climate. Although depth-dependence of macroinvertebrate communities in Pegasus Bay was also noted by Kingett Mitchell (2003b), the shallower waters of the channel extension area also have slightly more shelter from oceanic wave conditions and are positioned with greater exposure to Lyttelton Harbour/Whakaraupō tidal currents and vessel traffic.

5.2.3. Proposed maintenance spoil ground

Infuana community data for the ten stations sampled in the vicinity of the proposed offshore maintenance dredge (OMD) spoil ground showed that the area supports a benthic ecology very similar to that observed for previous surveys in the region, with the dominant organisms largely common to all areas, including stations within Lytttelton Harbour (Figure 19). Despite variability in the abundance of the most dominant taxa (which may reflect seasonality), community structure places samples from the OMD stations (Figure 8) on a broad continuum between the six channel extension stations (C1–C6) and those of the offshore capital dredge spoil ground (Figure 7; all sampled in 2007).

Average infaunal abundance (number of individuals), richness (number of different taxa) and diversity indices for samples from each of the OMD stations are presented in Figure 19. All values occur within the range established by the previous survey data for the southern Pegasus Bay region. When pooled from all areas, the data demonstrate a strong relationship with water depth, especially for taxa richness ($R^2 = 0.73$).

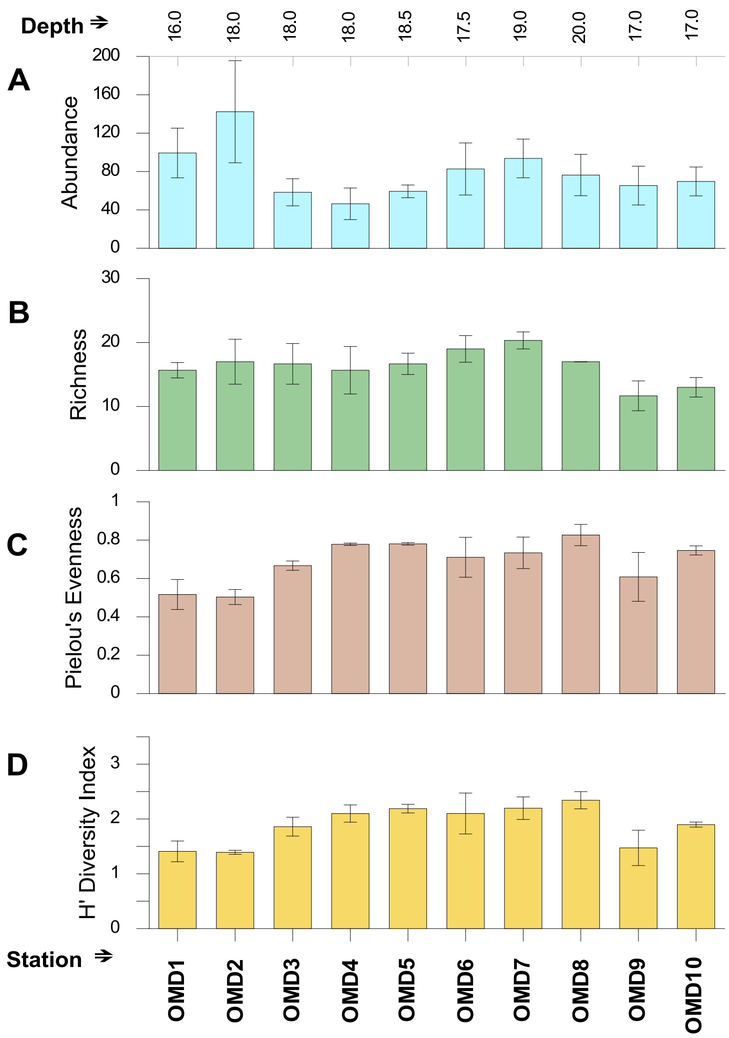

Figure 19 Mean infauna indices for each station sampled in the vicinity of the proposed offshore maintenance dredge spoil ground (n = 3). **A:** Number of individuals per 0.013 m^2 core. **B:** Number of taxa per core. **C:** Pielou's Evenness. **D:** H' Shannon-Weiner Diversity index. Error bars represent ±1 SE for the triplicate.

The nMDS plot in Figure 20 further compares the OMD infauna data with the total regional data set. As expected, it tends to show an overlap with other stations in similar water depths (those of the channel extension area and offshore from the Banks Peninsula coastline) but also stations in the Harbour with similarly fine substrates. However, these data sit somewhat apart from stations associated with the capital spoil ground further offshore. SIMPER analysis showed that dissimilarities between OMD and OS samples stemmed largely from varying patterns of dominance, with key taxa such as the polychaetes *Terebellides stroemii*, Maldanidae, Paraonidae and Cirratulidae, ostracods and the mud crab *Hemiplax hirtipes* being more abundant offshore. By contrast, *H. hirtipes* was more prevalent in epifaunal dredge trawls from the vicinity of the OMD spoil ground (see Table 8).

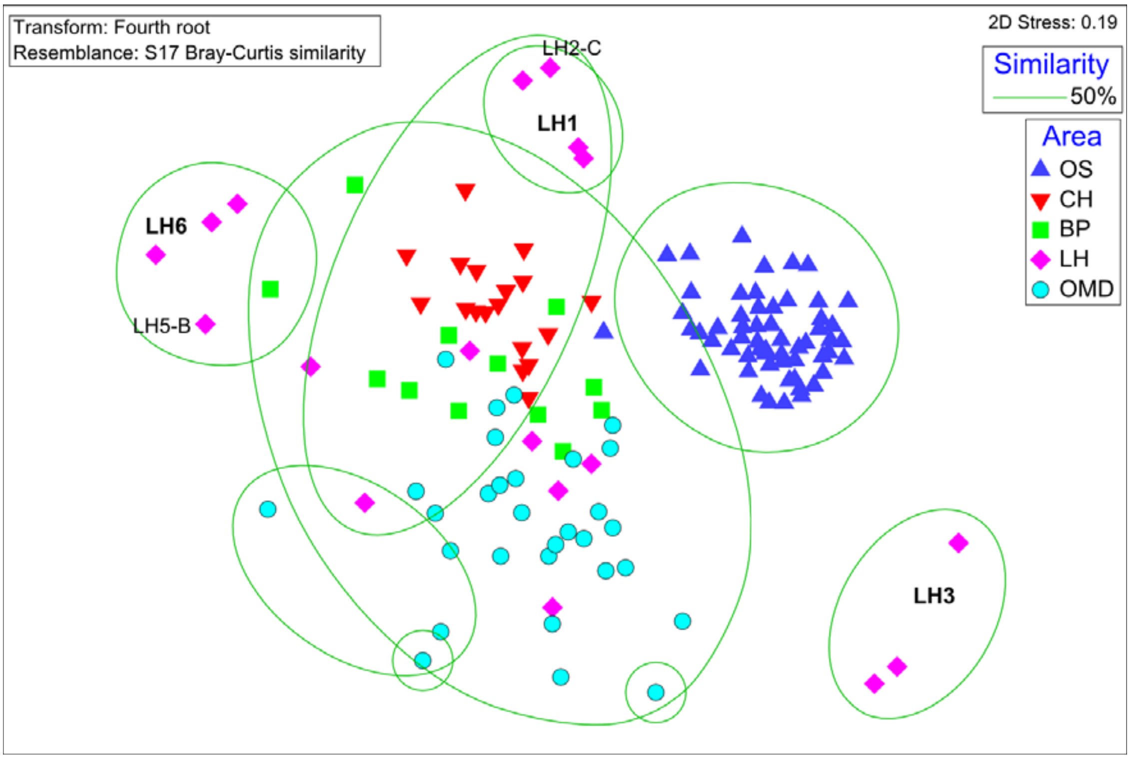

Figure 20 nMDS plot showing the similarity (Bray-Curtis) of macroinvertebrate infauna assemblages across samples for all surveys. The plot presents data from Figure 17 as individual sample replicates with the addition of data from the August 2016 survey of the vicinity of the proposed offshore maintenance spoil ground (OMD).

5.3. Benthic epifauna

In all, 26 separate benthic trawls have been conducted in inshore Pegasus Bay between Godley Head and Otohuao Head. Two of these were in the channel extension area, 20 and five within the vicinity of the proposed capital and offshore maintenance spoil grounds, respectively, and four between the capital spoil ground and the adjacent coast to the south (Figure 21). The 22 trawls conducted in 2007-2008 were spread over three survey dates; 26 October 2007 (six), 12 December 2007 (two) and 19 January 2008 (fourteen). The 2016 trawls were carried out in March (offshore Banks Peninsula coast) and August (offshore maintenance spoil ground). A summary of the mean taxa counts from trawls in each of the four areas is presented in Table 8 and a listing of the contents of the research dredge for each trawl is presented in Appendix 4.

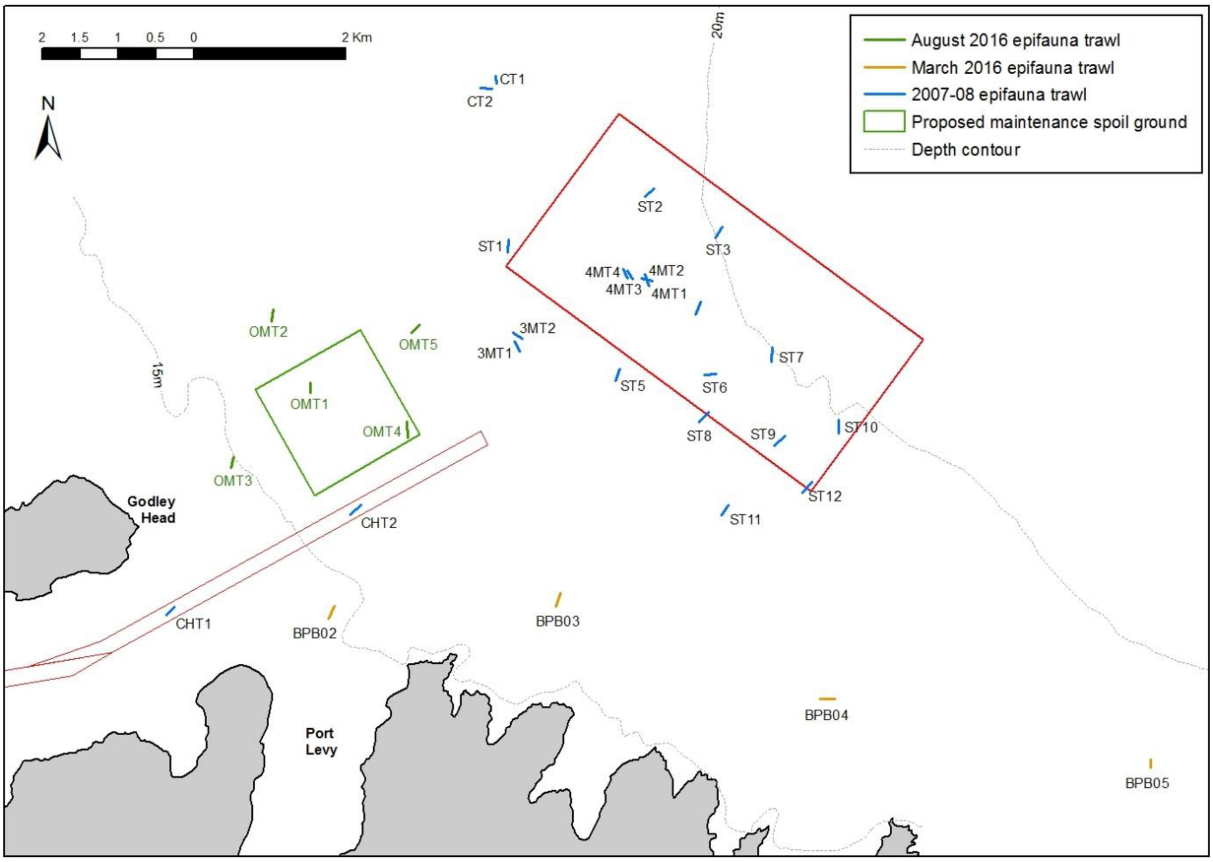

Figure 21 Spatial layout of epifaunal dredge trawls conducted October 2007 to January 2008 and in March and August 2016.

Despite the dredge being effectively full of sediment at the end of each trawl, relatively low numbers of epifauna were collected overall. The mud and fine material packing the dredge volume had to be washed out each time before bringing it aboard the survey vessel. Hence, it is possible that the dredge filled up relatively quickly after commencement and the cohesiveness of the mud reduced subsequent dredging efficiency for the remainder of the trawl. For this reason, the results of this sampling should be considered only semi-quantitative at best. Nonetheless, the dredge contents consistently indicate that surface-dwelling fauna (of relatively low mobility, and larger than 10 mm) is quite sparsely distributed in soft sediment benthic habitats over the area sampled.

The presence of worm casings and small polychaetes in dredge contents which were retrieved with some mud remaining (*e.g.* 4CT1, 4MT4; Appendix 4) suggests that much fauna picked up by the dredge may have been smaller than the 10 mm mesh size and consequently washed out before retrieval. Species found entrained within mud remaining in the dredge comprised a number of infauna taxa including anthozoans, nemerteans, polychaetes, decapods, amphipods and cumaceans and were consistent with sediment communities identified in the infauna core samples.

Table 8 Mean epifauna counts from the contents of epifaunal dredge trawls. Dredge tracks are shown in Figure 21. Trawl areas: BP = Banks Peninsula coastline; CH = channel extension; OS = spoil ground vicinity; OMD = proposed offshore maintenance spoil ground vicinity. Most infauna species identified entrained in dredged mud are not included. P = present; F = fragment; SF = shell fragments only.

Area		BP	CH	OS	OMD
No. trawls		4	2	20	5
Year		2016	2007/8	2007/8	2016
TAXON	Common name				
Mollusca					
Austrofusus glans	Knobbed whelk	0.50		2.3	0.4
Struthiolaria papulosa				0.05	
Phenatoma rosea				0.05	
Neilo australis		0.50		0.2	
Gari sp.	Sunset clam	0.50			SF
Mactra ovata		SF		0.05	
Dosinia sp.		SF		SF	
Zenatia acinaces	Scimitar mactra			SF	
Atrina pectinata zelandica	Horse mussel			SF	SF
Mactra sp.		0.33	SF	SF	SF
Tellina gaimardi	Wedge shell	1.00	0.5	SF	SF
Theora lubrica					0.2
Hiatula nitida	Wafer shell				SF
Philine auriformis	Sea slug			0.05	
Crustacea					
Lysiosquilla spinosa	Mantis shrimp	0.25		0.1	
Neommatocarcinus huttoni	Policeman crab	1.00		0.3	
Hemiplax hirtipes	Mud crab	2.00	2.5	0.05	4
Echinodermata					
Echinocardium sp.	Heart urchin			0.35	
Pateriella regularis	Cushion star			0.15	
Ophiuroidea	Brittle star			F	
Heterothyone alba	Sea cucumber			0.05	0.2
Polychaeta					
Worm casings (Maldanidae)		P	P	P	P
Eurythoe sp.					0.4
Phyllochaetopterus socialis	Parchment worm			0.05	
Trichobranchid polychaete				P	
Aphrodita australis	Sea mouse	0.25		0.15	
Platyhelminthes	Flatworm				0.2
Sipuncula					0.2
Priapulida					0.2

The presence in the dredge contents of shell fragments for a number of suspension- or deposit-feeding bivalve molluscs indicates their occurrence within the wider area, although the absence of live specimens within the dredge contents may also have resulted from the dredge 'bite' not being deep enough into the substrate to reach burrowing species such as *Tellinidae, Mactra* sp. and *Dosinia* sp. The low incidence of such fragments suggests that any existing populations do not occur at high densities at these locations.

5.4. Side-scan sonar imaging

Coverage by side-scan sonar of the seabed along the proposed channel extension and within the vicinity of the spoil ground is shown in Figure 22.

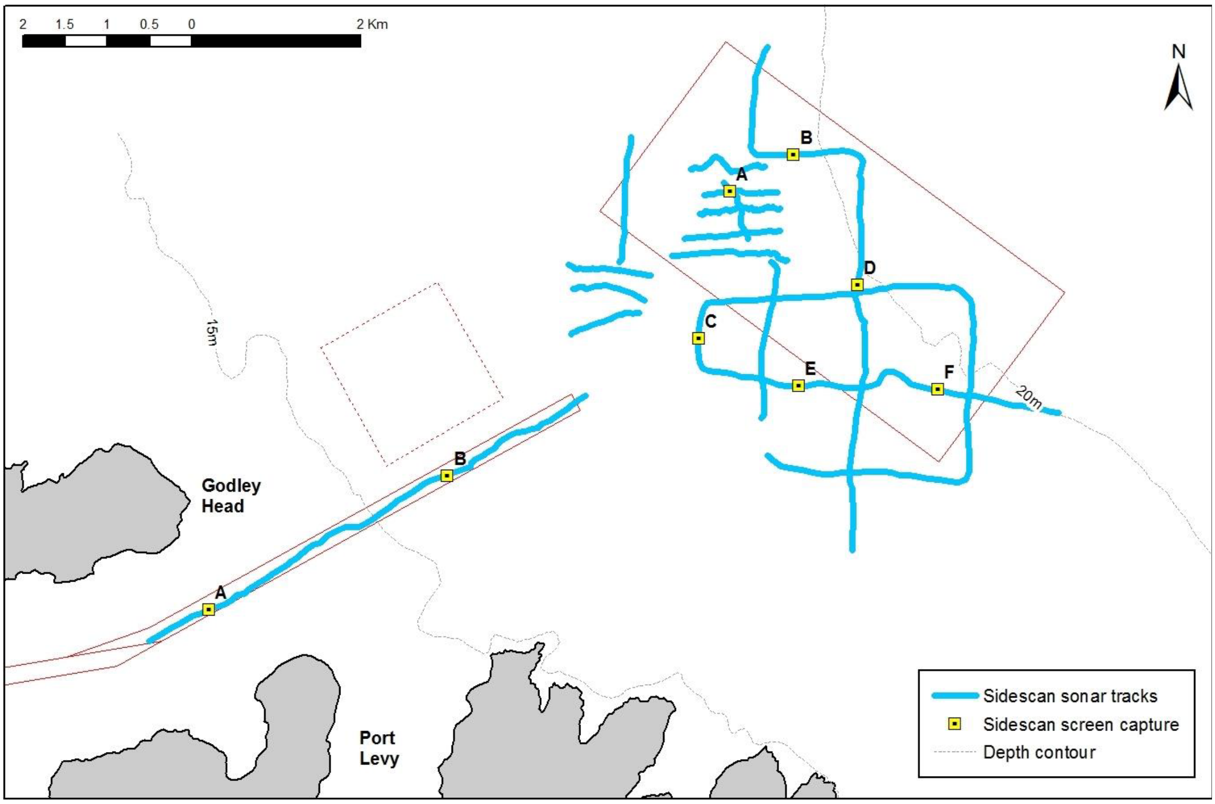

Figure 22 Side-scan sonar coverage of the proposed channel extension and spoil ground areas (60 m swathe width). Locations of screen capture images presented in Appendix 5 are overlaid.

The recorded sonar output showed an effective absence of discernible features or changes in substrate relief and indicated a seabed of unvarying soft sediments. This finding was consistent with all results from benthic grab sampling and epifaunal dredge trawls and was sufficient to verify the essential uniformity of the benthic substrate within both areas potentially directly affected by spoil deposition. Representative 'screen shots' of the sonar output are provided in Appendix 5. The specific locations where these images were recorded are marked on Figure 22. The images cover an area of seabed 30 m on either side of the track centre-line.

During other survey work in October 2007, the support vessel's depth sounder recorded a significant though isolated seabed structure some 430 m east-north-east of station S3 (Figure 7) at coordinates S43° 33.064', E172° 53.050' (WGS84). The obstruction extended 3–8 m clear of the seabed but was very limited in extent and it is possible that it was the wreck marked on hydrological chart NZ6321 as being approximately 400 m further to the south-east. The danger of collision of the sonar fish with this obstruction in the confused sea conditions precluded towing it directly over the site at the time. However, the side-scan coverage and observation of the support vessel's sounder indicated that the target was an isolated instance in an otherwise uniformly level soft-sediment substrate. Upon the completion of the 19 January 2008 sidescan survey, an attempt was made in the calmer conditions to obtain sonar imagery of this target; however the structure was not relocated. Hence the coordinates given above should be regarded as approximate only.

5.5. Subtidal reef habitats

The locations of the shoreline subtidal reef sites surveyed in February 2016 are mapped in Figure 23 and position coordinates listed in Appendix 6.

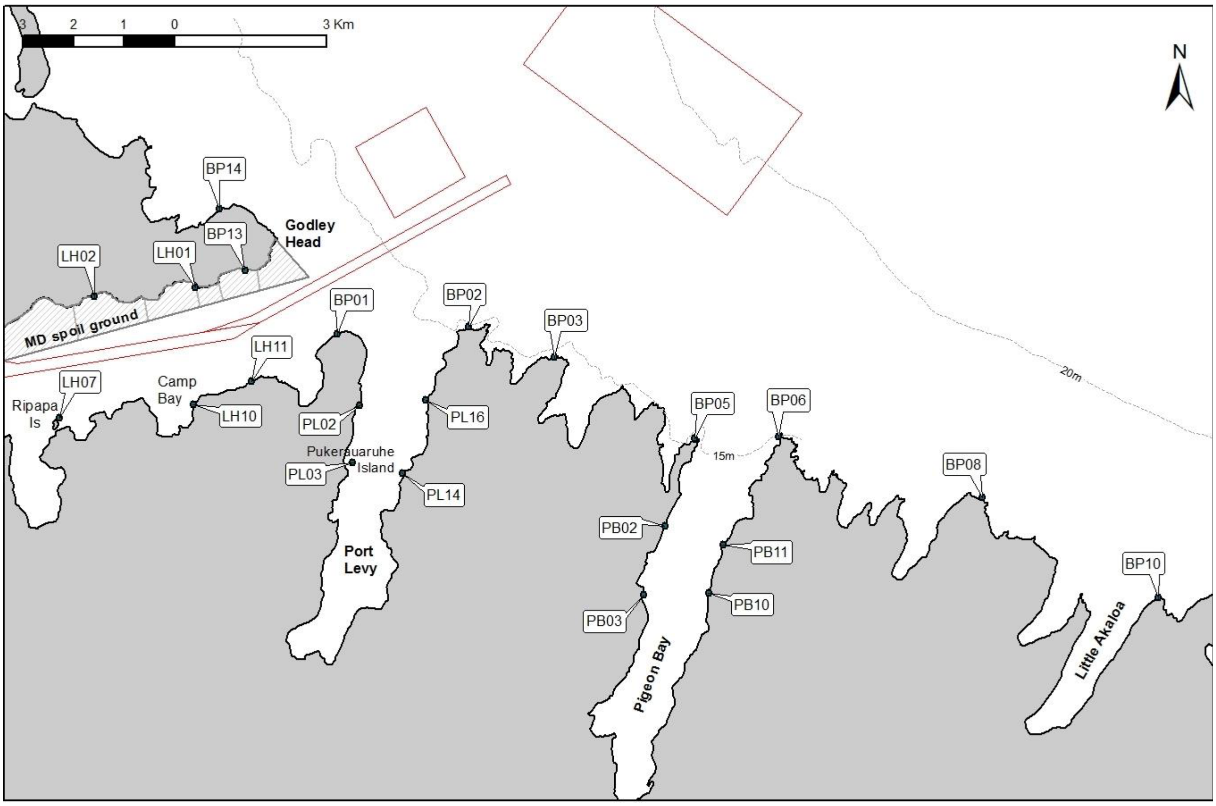

Figure 23 Locations of sites for subtidal reef surveys conducted in February 2016.

5.5.1. Survey conditions

Conditions during the survey period were calm, with winds generally less than 15 knots and swell from an easterly quarter of around 0.5 m. Conditions in the weeks preceding the fieldwork had been generally calm with no significant rainfall. Although the low swell was typical of generally calm conditions on this coastline, surge was problematic for conducting the littoral fringe transects on the outer coast. These transects would not be possible in higher swell conditions.

Underwater visibility was generally poor, but varied significantly from site to site. On the outer coast (BP sites) visibility was typically around 1.5 m. However, at site BP03, visibility along the 7 m transect was less than 1 m and a sharp increase in turbidity was observed at 7.5–8.0 m, with visibility reduced to below 10 cm beneath this depth. This contrasted with conditions at BP14, where visibility of 2–4 m was experienced.

In the inlets of Lyttelton Harbour/Whakaraupō, Port Levy/Koukourārata and Pigeon Bay, underwater visibility was generally very poor, ranging from 0.5 m down to less than 20 cm. This made the collection of quadrat data based on visual observations sometimes very challenging. At 20 cm visibility, conditions were considered marginal for the collection of data of acceptable quality and below this threshold, quadrat surveys were not completed. The presence of the reef edge in close proximity to the 4 m transect line undoubtedly affected visibility as swell penetration resulted in surge at all inlet sites.

Small changes in swell height were observed to have a marked effect upon underwater visibility within the inlets. A slight increase in swell penetrating Port Levy/Koukourārata on 26 February 2016 resulted in a conspicuous shoreline band of highly turbid water out to well beyond the reef edge, making visual dive surveys impossible.

5.5.2. Substrate

On average, the sites were dominated by boulders (46.1% ± 2.7) or bedrock (40.6% ± 2.8) with lower proportions of cobble (8.1% ± 1.0), silt (6.2% ± 1.2) and shell hash (2.9% ± 0.5, Figure 24). Sand substrate was recorded only at site BP14 (7.9% ± 2.3). In general, substrate composition was similar among areas, although Lyttelton Harbour/Whakaraupō (LH), recorded higher bedrock and lower boulder cover relative to other areas (68.7% ± 4.9 and 15.7% ± 5.7, respectively, Figure 24). Of note was a frequent silt veneer of varying thickness evident on the surface of bedrock, boulders and dominant biota (*e.g.* macroalgae and solitary ascidians), particularly in more sheltered areas.

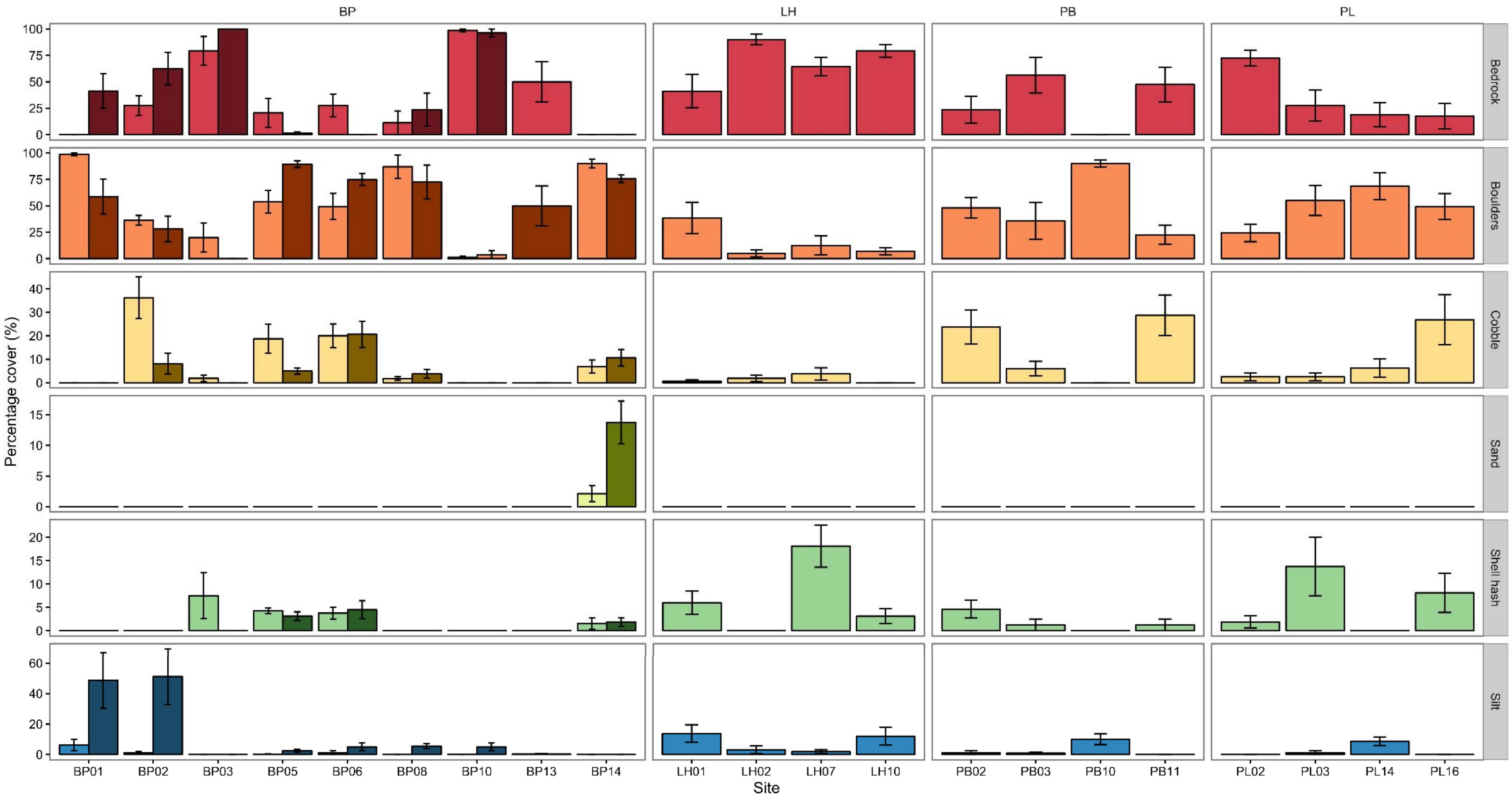

Figure 24 Mean percentage cover (± S.E.) of substrate type along 4 m (light coloured bars) and 7 m (dark coloured bars) depth transects: bedrock (consolidated rock), boulder (>256 mm), cobbles (64–256 mm), sand (2–0.5 mm), silt (<0.5 mm) and shell hash recorded during the subtidal survey within each of four areas: Banks Peninsula outer coast (BP), Port Levy (PL), Pigeon Bay (PB) and Lyttelton Harbour (LH). Error bars represent ±1 S.E.

5.5.3. Reef communities

An inventory of benthic taxa recorded during the subtidal surveys is provided in Appendix 7 along with abundance/coverage data averaged over each of the four areas. Rocky reefs in all four areas supported communities considered representative of the wider bioregion, being comparable to those previously found in the Banks Peninsula region (Schiel & Hickford 2001; Shears & Babcock 2007; Hepburn *et al.* 2010).

Average richness (total number of taxa), abundance (total cover and number of individuals), community evenness (Pielou's index) and diversity (Shannon-Weiner index) at each site are presented in Figure 25. Sites were characterised by a relatively high and uniform taxa richness across sites (71 taxa overall), ranging between 9.3 and 16.4 taxa/m^2 (Figure 25A). Average abundance of organisms classified as non-encrusting ranged from 72 to 216 individuals/m^2 (Figure 25B), with highest abundance and richness recorded at site LH02 in Livingstone Bay. Shannon-Weiner diversity was relatively uniform across all sites, with averages ranging from 1.2 to 2.1 (Figure 25C). Similarly, Pielou's index was comparable across sites and areas, ranging between 0.48 and 0.74 (Figure 25D), indicative of evenly distributed communities (*i.e.* not numerically dominated by just a few taxa).

Reef communities at the 4 m depth level were characterised by 'kelp forest' habitats dominated by the common kelp *Ecklonia radiata* (17% ± 1.4, range 0 – 90%, Figure 26) and the bladder kelp *Macrocystis pyrifera* (3.8% ± 0.9). Other canopy-forming macroalgae included the flapjack *Carpophyllum flexuosum* and the narrow flapjack *C. maschalocarpum*, however these were recorded at less than 1% cover on average. A wide range of understory organisms were found amongst kelp forest habitats. Dominant taxa on rocky habitats at ~4 m depths included encrusting coralline algae (53.0% ± 2.2), whereas the saddle sea squirt *Cnemidocarpa* sp. (32.5% ± 3.0) frequently formed an extensive cover on bedrock and boulders across the deeper (7 m) transects (Figure 26). These habitats also frequently supported an algal understory that included a range of red macroalgae (*e.g.* coralline turf, filamentous, feathery, foliose and branching forms) and brown macroalgae (*e.g. Halopteris* sp., *Ralfsia* sp., *Landsburgia quercifolia* and *Microzonaria* sp.).

Invertebrates included green-lipped mussels (*Perna canaliculus*), barnacles, top shells (*Trochus viridis*), white striped anemones (*Anthothoe albocincta*), hydroids, sea tulips (*Pyura pachydermatina*), branching bryozoans, colonial ascidians (*Didemnum* spp.), pāua (*Haliotis iris*) and various species of encrusting sponges. Fish observed around kelp forest habitats during survey dives included triplefins (family Tripterygiidae), spotted wrasse (*Notolabrus celidotus*), blue cod (*Parapercis colias*), leather jackets (*Parika scaber*), blue moki (*Latridopsis ciliaris*) and banded wrasse (*Notolabrus fucicola*).

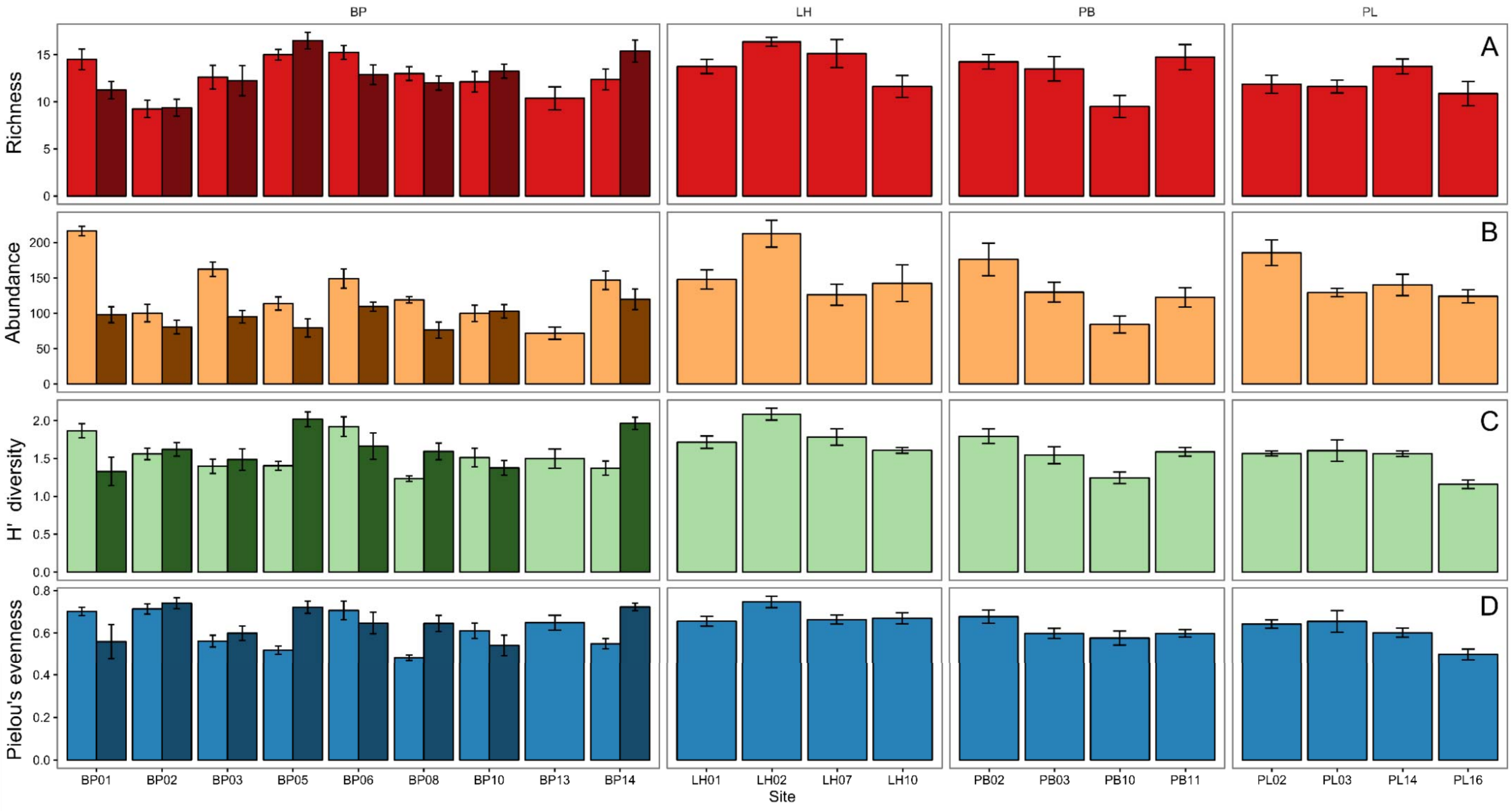

Figure 25 Mean diversity indices for each 4 m (light bars) and 7 m (dark bars) transect (n = 8). A: Number of taxa per quadrat. B: Abundance per quadrat. C: Pielou's Evenness. D: H' Shannon-Weiner Diversity index within each of the four general areas surveyed: Banks Peninsula outer coast (BP), Port Levy/Koukourārata (PL), Pigeon Bay (PB) and Lyttelton Harbour/Whakaraupō (LH). Error bars represent ±1 S.E.

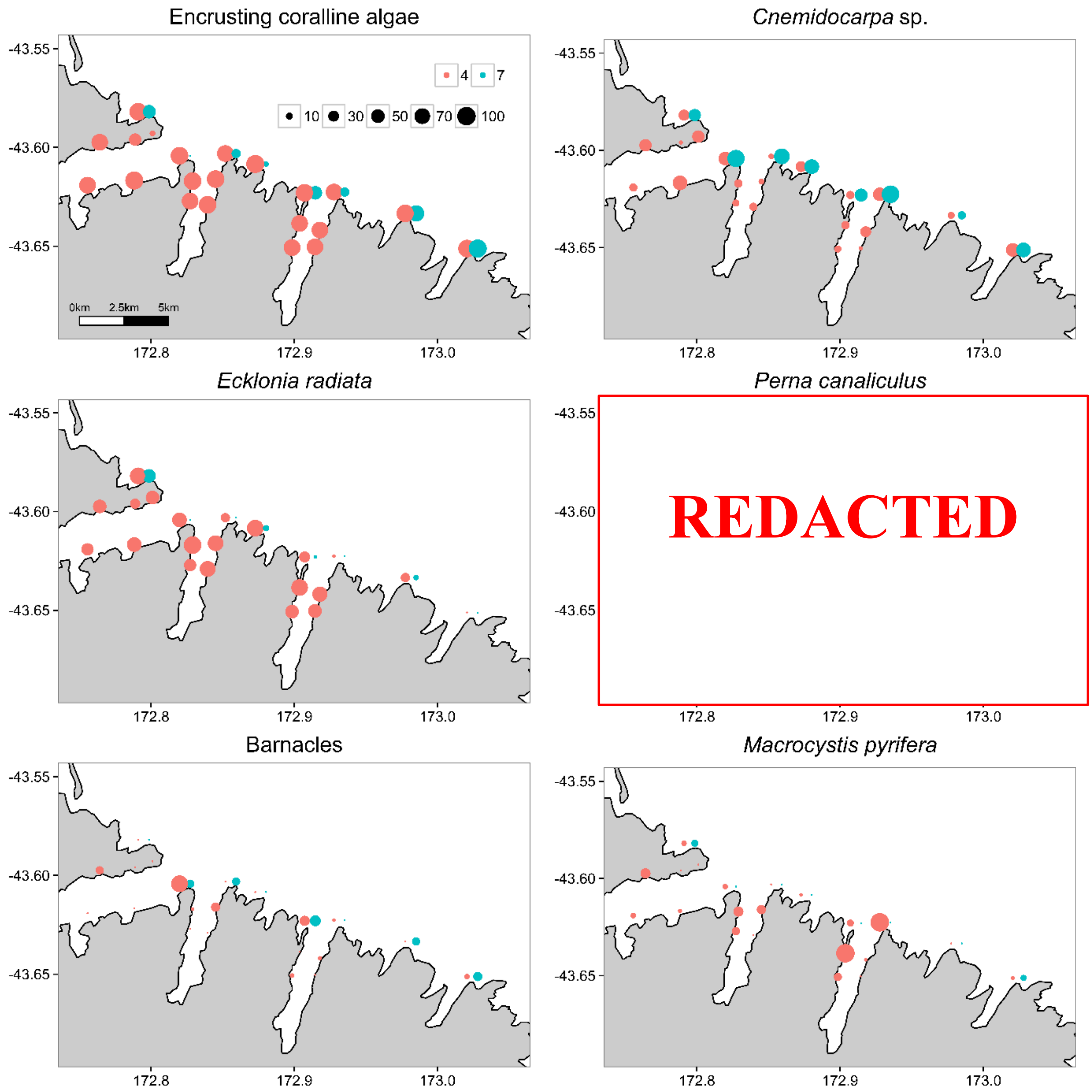

Figure 26 Maps showing the percentage cover and spatial distribution of six dominant taxa by depth: 4 m (red circles) and 7 m (green circles) at each site within the surveyed area.

As expected, permutational analysis using PERMANOVA indicated significant differences between the structure of communities found at 4 m and 7 m water depths ($P < 0.001$). The PCO plot (Figure 27A) illustrates this pattern, showing a separation in the transect data according to depth. The differences were mainly due to the consistently higher cover of *Eklonia radiata* (9.3% contribution to the overall dissimilarity), encrusting coralline algae (8.2%) and green-lipped mussels (4.3%) at the 4 m level. Conversely, communities at 7 m depth had higher cover of *Cnemidocarpa* (7.0% contribution to the overall dissimilarity), the anemone *Anthothoe albocincta* (4.3%) and barnacles (3.7%) compared to those found at 4 m (Figure 27A).

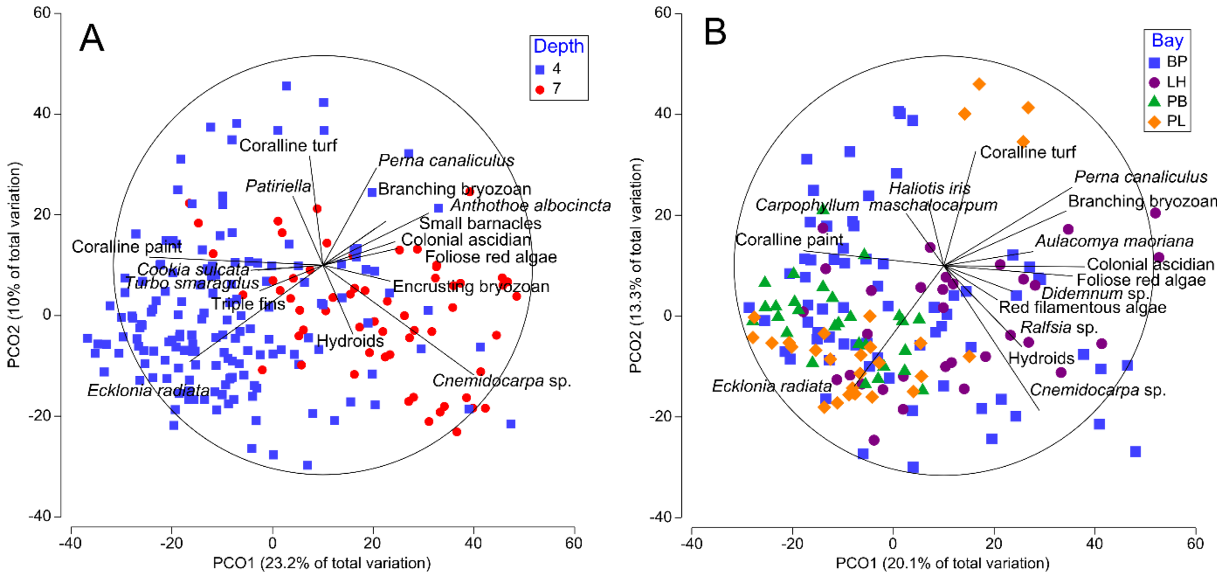

Figure 27 Principal Coordinates Ordination (PCO) plots of individual 1 m² quadrats on the basis of Bray-Curtis similarities of the log (x +1) transformed data of subtidal assemblages at: (A) 4 m (blue squares) and 7 m depth (red circles), and (B) at each of the four areas: Banks Peninsula (BP, blue squares), Lyttelton Harbour/Whakaraupō (LH, purple circles), Pigeon Bay (PB, green triangles) and Port Levy/Koukourārata (PL, orange diamonds). Taxa that consistently discriminated between depths and areas are displayed as vectors.

The PERMANOVA analysis also identified significant differences in community structure between the four different survey areas ($P < 0.05$). The PCO plot (Figure 27B) illustrates that communities within Lyttelton Harbour/Whakaraupō were distinguishable from others areas. The SIMPER analyses showed that this difference was due to a higher cover of green-lipped mussels in LH compared to PB and BP (9.4 and 7.8% contribution to the overall dissimilarity, respectively). The two sites on the northern shore of Lyttelton Harbour/Whakaraupō (LH01 and LH02) supported extensive mussel beds, with an average cover of greater than 55%. To a lesser extent, other taxa contributing to the observed differences between areas included the saddle sea squirt, common kelp, encrusting coralline algae and foliose red algae. Additionally, the greatest variability in community structure was detected among sites nested within areas, indicating a significant spatial variation at the scale of sites within each area ($P < 0.001$).

5.5.4. Individual survey areas

Marginal visibility at many sites made underwater photography during the survey challenging. For this reason, the recording of photoquadrat images was not possible. However, divers were sometimes able to take acceptable close up photographs of a number of encrusting communities using a wide angle lens. A selection of these images considered to help represent what was observed within each categorical area (BP, LH, PB, PL) were included in the survey data report (Atalah & Sneddon 2016). Due to the limited depth to which shoreline reefs extended for all but the outer coast sites, transects at the 4 m depth level only were surveyed for sites within Lyttelton Harbour/Whakaraupō, Pigeon Bay and Port Levy/Koukourārata.

Banks Peninsula outer coast (BP)

A total of 63 taxa were recorded at the nine rocky reef sites surveyed at the outer coast BP sites. The reef habitat at the 4 m depth level was characterised by kelp forest, dominated by *Ecklonia radiata* (18.4 ± 3.7%), *Macrocystis pyrifera* (4.4 ± 2.0%) and *Carpophyllum maschalocarpum* (2.1% ± 1.5). Bedrock and boulders were covered mainly by crustose coralline algae (51.6 ± 6.3%), saddle sea squirts (*Cnemidocarpa* sp.) (11.4 ± 3.4%), small barnacles (7.5 ± 1.3%) and green-lipped mussels (*Perna canaliculus*) (3.6 ± 1.4%). Other epifauna commonly found among the kelp were *Pyura pachydermatina* (4.2 ± 1.3 individuals/m^2), *Trochus viridis* (2.4 ± 0.7 individuals/m^2) and *Haliotis iris* (2.2 ± 1.1 individuals/m^2).

Deeper reef habitats (7 m) were characterised by sparser canopy-forming algae, including *Ecklonia* (2% ± 1.7), and *Macrocystis* and *C. maschalocarpum* (<1 % cover). Understory algae were represented by filamentous and feathery red algae (2.8% ± 1.4 and 1.9% ± 0.9, respectively), coralline crustose algae (78% ± 4.6) and the brown crustose alga *Ralfsia* sp. (< 1% cover). Dominant epifauna included *Cnemidocarpa*, recorded at significantly higher coverage (32% ± 5.7) than at 4 m, and the anemone *Anthothoe albocincta* (4.2 ± 1.7 individuals/m^2). Other common invertebrates included small barnacles, branching bryozoans, *Perna* and *Trochus*.

Despite often limited visibility, a range of fish species were also observed within the kelp forest habitats of BP sites, including triplefins, spotties, blue cod, leather jackets, blue moki and banded wrasse. Fish were more frequently observed at outer sites (*e.g.* BP08 and BP10) and at Taylor's Mistake (BP14).

Findings from the survey work on the outer coastline area are consistent with earlier studies of the area. In their study of subtidal reef habitats on the east coast of the South Island, Schiel and Hickford (2001) described reef habitats at Godley Head and Taylors Mistake. They characterised the algal cover at Godley Head as follows:

> *The giant kelp <u>Macrocystis pyrifera</u> occurred at 2–4 plants per m^2 at 3–6 m depth but the canopy covered an average of 55–85% of the*

> *substratum. The fucoids Carpophyllum maschalocarpum and Landsburgia quercifolia occurred in the understorey at 3–6 m but had only minimal cover. The most abundant plant was Ecklonia radiata, which occurred at 13–15 plants per m^2 at 9–12 m depth and had a canopy cover of 10–30%.*

At the Godley Head and Taylor's Mistake sites, Schiel and Hickford (2001) also described a very high abundance of the tunicate *Pyura pachydermatina*, and a rich understorey of bryozoans, mussels (*Perna canaliculus*), ascidians and sponges. Mobile gastropod species were also abundant, predominant species being the pāua *Haliotis iris,* the topshell *Trochus viridis* and the turbinid *Cookia sulcata*. The sea urchin *Evechinus chloroticus* also occurred at 3–5 m depths. They recorded fish assemblages similar to those observed during the current survey, most notably including banded wrasse, spotties and leather jackets. It was reported that, while the invertebrate understorey was notably rich, this type of habitat is extensive around Banks Peninsula.

For Banks Peninsula North sites, Shears and Babcock (2007) characterised the subtidal reef habitat as follows:

> *Large brown algae extended to a maximum depth of 8 m at Banks Peninsula North sites and all fleshy macroalgae were rare in the deepest stratum (10–12 m). Carpophyllum maschalocarpum formed a patchy band in the shallow depth stratum, with Marginariella urvilliana, D. antarctica and Macrocystis pyrifera also occurring. At this depth Haliotis iris was abundant (3.5 ± 2.0/m^2), along with the stalked ascidian Pyura pachydermatina (16 ± 7.0/m^2) and the mussel Perna canaliculus. The brown algal species Glossophora kunthii, Desmarestia ligulata, Halopteris sp. and Microzonia velutina were also common in the shallow subtidal. Macrocystis pyrifera and C. flexuosum were the dominant macroalgal species at 4–6 m of depth and Ecklonia radiata also occurred at this depth. Below 6 m, large brown algae were rare and the substratum was mainly covered by sediment and solitary ascidians. Red foliose and red turfing algae were rare at all sites and only small amounts of Rhodophyllis gunnii, Anotrichium crinitum and Plocamium spp. were found at 4–6 m and 7–9 m. Low numbers of Evechinus chloroticus were recorded at all depths; however, patches of E. chloroticus were common in the shallow subtidal at c. 3 m of depth. Similarly, patches of H. iris (< 125 mm shell length) were also observed at this depth. Trochus viridis occurred at moderate numbers at mid-depths, whereas low numbers of Cellana stellifera, Cookia sulcata and Turbo smaragdus were also found at depths down to 9 m.*

Although the density of holdfasts was not recorded for the current surveys, the density of *Ecklonia* was lower than that reported by Schiel and Hickford (2001), especially for

7 m depth transects, below which there was little canopy-forming macroalgae. In general, the macroalgal data was consistent with the description by Shears and Babcock (2007) with large brown macroalgae occurring only sporadically below 6 m. No site on outer Godley Head was surveyed in February 2016 due to rock-fall hazard following recent earthquake events; however, it was noted at nearby Taylors Mistake that *Ecklonia* was more prevalent at 7 m depth (8.5% coverage) than elsewhere on the Banks Peninsula outer coast (< 2% coverage), possibly due to typically lower turbidity at this location.

Lyttelton Harbour/Whakaraupō (LH)

Across the four Lyttelton Harbour/Whakaraupō sites, there were a total of 50 taxa recorded. As on the outer coast, the reef habitat was characterised by kelp forest, largely dominated by *Ecklonia* (23.1% ± 2.8) and *Macrocystis* (3.0% ± 1.0), and to a lesser extent *C. maschalocarpum* (1.6% ± 1.0). Higher cover of *Perna* (33.3% ± 7.0) was recorded relative to other areas and these formed dense and extensive beds at REDACTED the Harbour, with mean coverage at 72% and 55%, respectively. Interspersed within these beds, the ribbed mussel (*Aulacomya maoriana*) was recorded at relatively low cover (1.3% ± 0.4), but was not recorded from other survey areas. Bedrock and boulders were mainly covered by a mix of crustose coralline algae (39.1% ± 5.4), *Cnemidocarpa* (15.9% ± 3.0), red foliose algae (4.2% ± 0.8), hydroids (7.5% ± 1.3) and *Ralfsia* (3.0% ± 1.0). The anemone *A. albocincta* was also more common (4.4 ± 1.3 individuals/m^2) and pāua were less often recorded in quadrats; however, these are believed to be due to the prevalence of *Perna* coverage which in places effectively replaced the underlying substrate. Differences may be expected between the northern and southern shorelines of Lyttelton Harbour/Whakaraupō on the basis of finer benthic substrates generally north of the shipping channel (Curtis 1986; McLaren 2012) and the long-term use of the northern bays for the deposition of dredge spoil from LPC's maintenance dredging programme (Sneddon *et al.* 2015). However, apart from the dense *Perna* beds and generally poorer underwater visibility at the northern sites, similar assemblages and numbers of taxa were recorded.

Pigeon Bay (PB)

A total of 44 taxa were recorded from quadrats at the four sites in Pigeon Bay. Reef habitats at 4 m depth were characterised by kelp forest comprising *Ecklonia* (24.6% ± 4.1) and *Macrocystis* (10.2% ± 4.5), the latter being recorded at a particularly high percentage cover (mean 33%) at site PB02 on the western shoreline. Understory communities were dominated by crustose coralline algae (57.5% ± 3.6), with *Cnemidocarpa* (5.5% ± 1.3), *Ralfsia* (1.9% ± 0.5) and hydroids (1.8% ± 0.5) also present at lower coverage. Red turfing algae appeared to be less common in Pigeon Bay than elsewhere. Mobile invertebrates included pāua, *Cookia sulcata* and the cushion star *Pateriella regularis*, all at densities of less than 4 individuals/m^2.

Port Levy/Koukourārata (PL)

A total of 43 taxa were recorded in quadrats at the four Port Levy/Koukourārata sites. Relative to other areas surveyed, Port Levy/Koukourārata featured the greatest cover of *Ecklonia* recorded (32.3% ± 4.8), but mixed with *Macrocystis* (4.6% ± 1.6). Understory communities were largely dominated by a high coverage of crustose coralline algae (62.7% ± 4.8). Red coralline turf was recorded at a particularly high coverage (36.3%) at one site (PL02 on the western shoreline) but was not recorded from the other three sites within the inlet. The Port Levy/Koukourārata quadrat data set differed from those of Lyttelton Harbour/Whakaraupō and Pigeon Bay with an absence of the two *Carpophyllum* species, but otherwise supported communities very similar to those of Pigeon Bay. *Cnemidocarpa*, *Ralfsia*, hydroids and *Perna* were present at < 5% on average. Triplefins were also commonly recorded, generally at densities ~3 individuals/m^2.

5.5.5. Littoral fringe transects

Pāua (Haliotis iris)

A total of 1,413 pāua were measured within the littoral fringe transects (0.5 m CD) across all sites. Pāua size within these transects ranged between 60.5 mm and 132.5 mm, with densities ranging between 12 and 185 individuals per 50 m^2 (Table 9).

Only 30 individuals (2.1%) were measured at above the legal size limit of 125 mm (Figure 28). Average pāua length was greatest within Lyttelton Harbour/Whakaraupō (107.2 ± 0.8 mm; Table 9). However the largest individual pāua (134 mm) was recorded in Pigeon Bay REDACTED. These results are consistent with earlier surveys undertaken within Port Levy/Koukourārata (Hepburn *et al*. 2010), where an average pāua length of 100 mm was reported and only 0.38% were above the legal size limit.

Figure 29 shows the spatial distribution of pāua densities at each of the surveyed sites. The highest density of 185 pāua /50 m^2 at 0.5 m CD was recorded for the REDACTED. Lowest average density was recorded within Pigeon Bay (48.3 ± 14.5 individuals/50 m^2). However densities were highly variable. Perhaps most importantly, the greatest densities of pāua observed were frequently at depths 1 m–2 m below the 0.5 m CD transect.

Table 9 Summary statistics for size frequency distribution and density (individuals/50 m^2) of pāua within the littoral fringe transects of each surveyed area: Banks Peninsula (BP), Lyttelton Harbour/Whakaraupō (LH), Pigeon Bay (PB) and Port Levy/Koukourārata (PL).

	Length (mm)					Density (individuals/50 m^2)				
Area	Mean	Minimum	Maximum	S.E.	n	Mean	Minimum	Maximum	S.E.	n
BP	101.0	60.5	127.5	0.5	509	65.8	16	139	16.6	8
LH	107.2	60.5	132.5	0.8	320	80.0	42	140	21.1	4
PB	100.8	60.5	134.0	1.0	193	48.3	12	79	14.5	4
PL	102.5	69.5	127.5	0.5	391	93.5	27	185	36.9	4

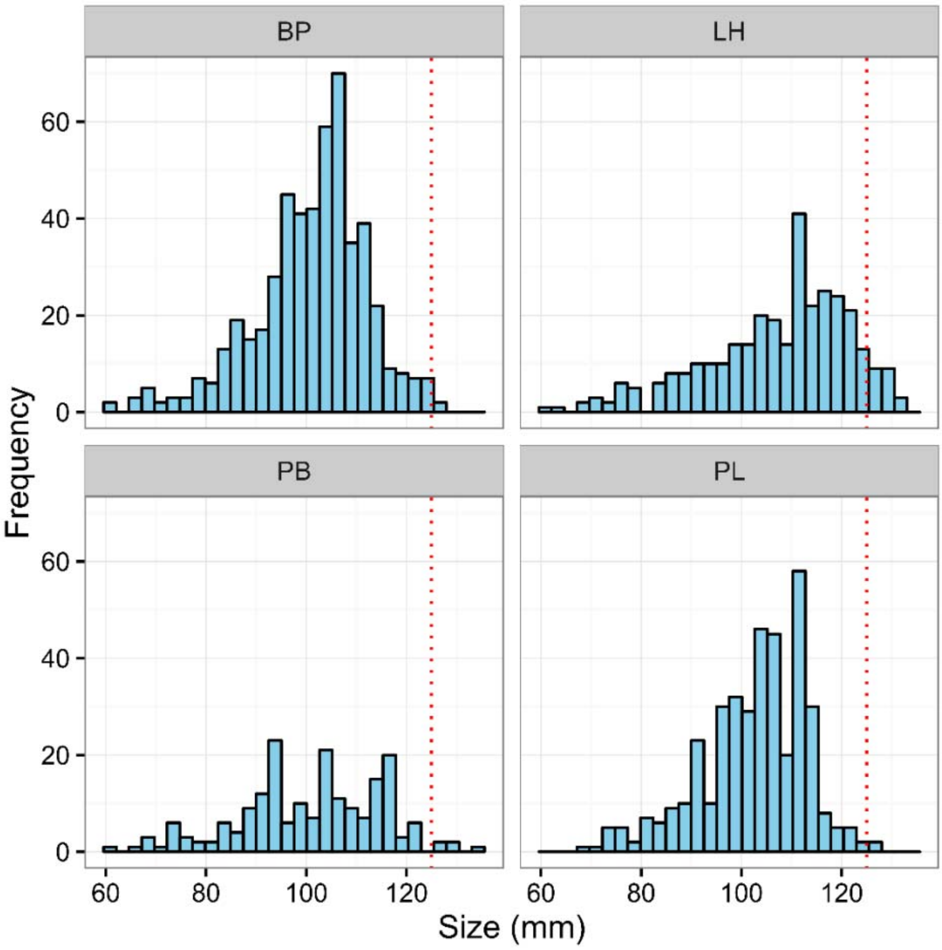

Figure 28 Size frequency (no. of individuals) distribution of pāua within the littoral fringe transects of each survey area: Banks Peninsula (BP), Lyttelton Harbour/Whakaraupō (LH), Pigeon Bay (PB) and Port Levy/Koukourārata (PL). The red dotted line indicates the legal size limit of 125 mm.

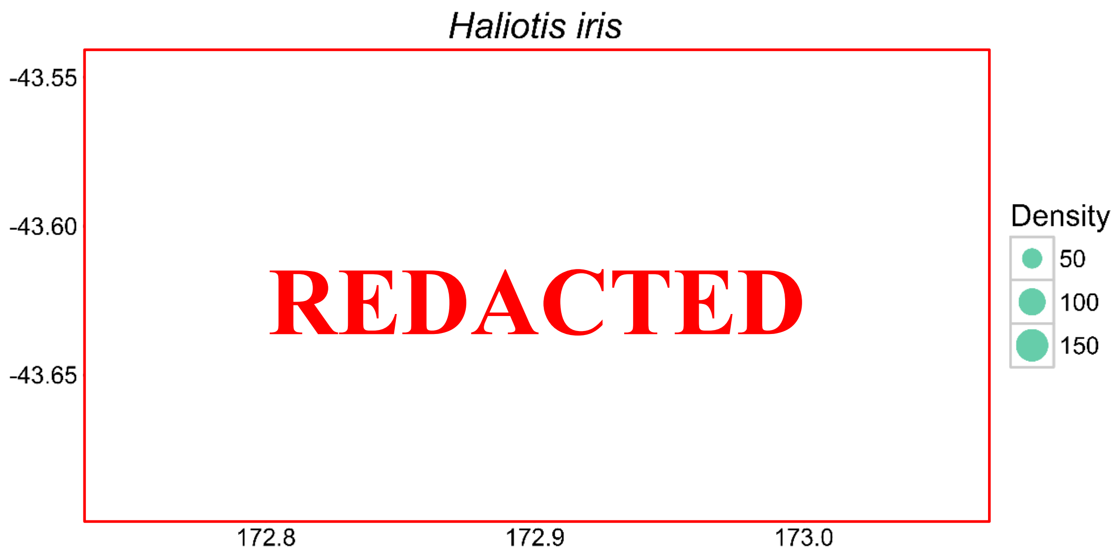

Figure 29 Density (individuals/50 m^2) of pāua within the littoral fringe transects at each site within the surveyed area.

Cook's turban (Cookia sulcata) density

The spatial distribution of recorded densities for *Cookia sulcata* across the surveyed sites is shown in Figure 30. Overall, densities were lower and more variable than for pāua. At 32.0 ± 10.4 individuals/50 m^2, the highest densities were recorded within Port Levy/Koukourārata and the lowest at Pigeon Bay (3.5 ± 1.2). Densities at the outer coast (BP) sites were also relatively high (21.0 ± 11.6 individuals/50 m^2); however counts were recorded for this species only at five of the nine sites (BP01, BP03, BP10, BP13 and BP14).

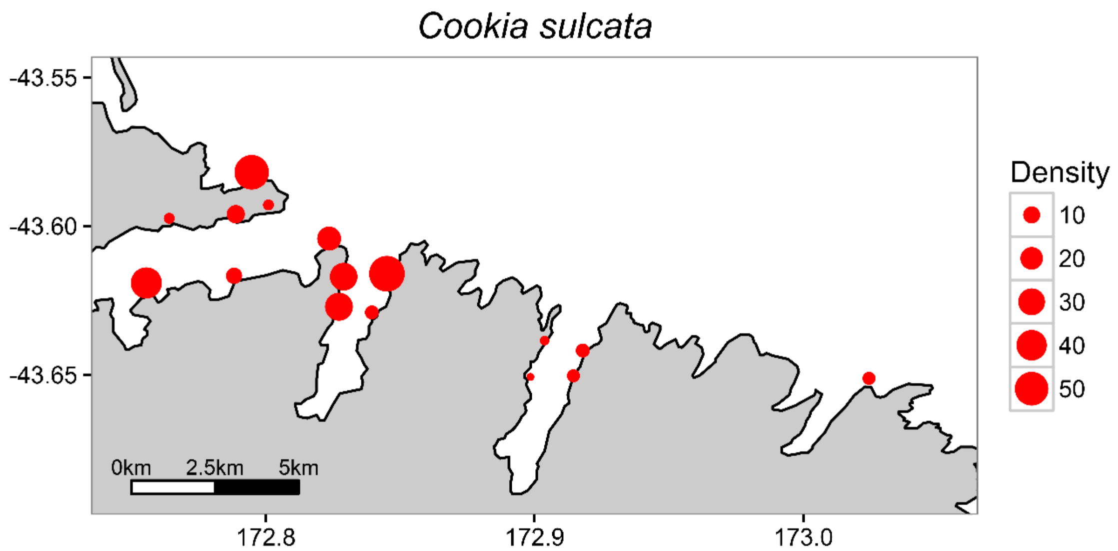

Figure 30 Density (individuals/50 m^2) of Cook's turban recorded within littoral fringe transects at sites in the surveyed area.

5.6. Intertidal reef habitats of Lyttelton Harbour/Whakaraupō and Port Levy/Koukourārata

Intertidal community data for a further five Lyttelton Harbour sites surveyed between 2012 and 2015 has been added to that collected for the five sites surveyed in February 2016 data. Hence a total of ten intertidal sites have been surveyed: eight in Lyttelton Harbour/ Whakaraupō and two in Port Levy/Koukourārata (Figure 31). The locations of sites in Lyttelton Harbour/Whakaraupō represent a gradient in environmental conditions and exposure from the entrance to the upper Harbour. Two sites are representative of the relatively exposed rocky shores of the outer Harbour (Godley Head and White Patch Point). Four sites are representative of the central Harbour region: two on the northern shoreline (Livingston Bay and Battery Point) and two on the south coast of the Harbour (Ripapa Island and Camp Bay). The two sites located west of the Port (Rapaki Bay and Shag Reef) are representative of the more depositional environment of the upper Harbour. Two sites surveyed in the outer section of Port Levy/Koukourārata were located one on either shoreline of the inlet: one on the west (PL03 on Pukerauaruhe Island) and one on the east (PL16).

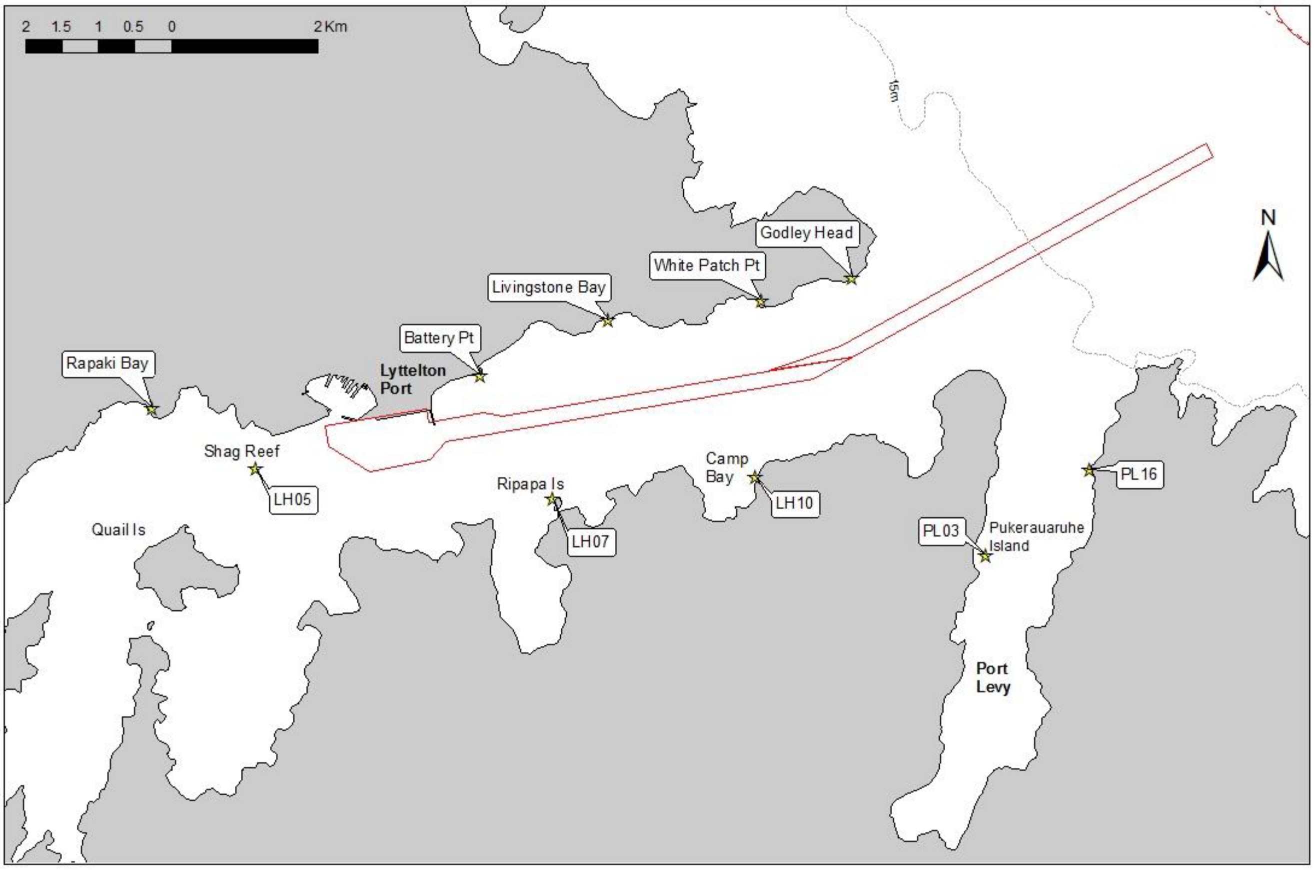

Figure 31 Locations of semi-quantitative intertidal surveys conducted 2012–2016.

5.6.1. Zonation patterns

The intertidal assemblage of animals and plants recorded from the Lyttelton Harbour/Whakaraupō and Port Levy/Koukourārata sites are considered to be generally characteristic of the region. Typical of such shorelines, diversity generally increased down the shore profile at all sites (Figure 32), and communities appeared relatively diverse and healthy. The total number of taxa recorded from the high shore zone ranged between 3 and 21; from 12 to 34 in the mid-shore and 24 to 50 in the low shore zone.

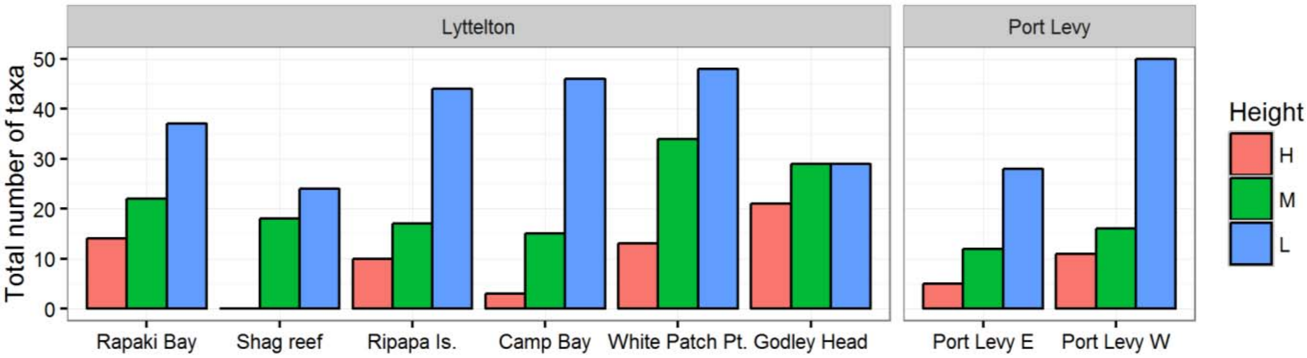

Figure 32 Total number of intertidal taxa within each shore height (H= high, M = mid and L = low) at Lyttelton Harbour/Whakaraupō and Port Levy/Koukourārata sites. Due to the broad expanse and flat profile of Shag Reef, no data were collected for the high-shore zone.

Communities characteristic of the general area

The upper-intertidal zone at most sites was patchily dominated by barnacles (*Chamaesipho columna* and *Epopella plicata*), periwinkles (*Nodilittorina cincta* and *Nodilittorina unifasciata*), spotted topshell (*Diloma aethiops*) and limpets (*Cellana ornata and C.radiata*). The little black mussel *Xenostrobus pulex* was also abundant and characteristic of the high to mid-shore with the blue mussel (*Mytilus galloprovincialis*) also extending into this zonation (Figure 33A).

The mid-shore featured a band of the polychaete tubeworm *Spirobranchus cariniferus* (Figure 33B) which can attain dense colonies in shaded locations with reduced water movement. The blue mussel (*M. galloprovincialis*) and barnacles were also dominant sessile invertebrates of the mid-shore. A range of grazing and predatory gastropods were present, including limpets, whelks (*Haustrum haustorium, H. scobina, Cominella* sp.), cat's eye snails (*Turbo smaragdus*), *D. aethiops* and several species of chitons. Macroalgae were generally scarce to occasional in the mind-shore, but included patches of *Gelidium caulacantheum*, coralline turf, *Porphyra columbina*, encrusting coralline and some brown algal species in tide pools, most notably *Hormosira banksii* where wave energy was not too vigorous (Figure 33C).

Surveys of the low shore were sometimes constrained by the necessity to schedule fieldwork at other than spring-tidal timing (see Table 5); hence some extreme low-shore and shallow sub-tidal taxa may have been missed or under-represented in data from these sites. Nonetheless, as expected, the low-shore supported the highest diversity of invertebrates and macroalgae. There were abundant patches of blue and green-lipped mussel, with a range of brown and red macroalgae growing amongst them (Figure 33D). These included encrusting and turfing coralline algae, zig-zag weed (*Cystophora torulosa*), foliose and filamentous red algae.

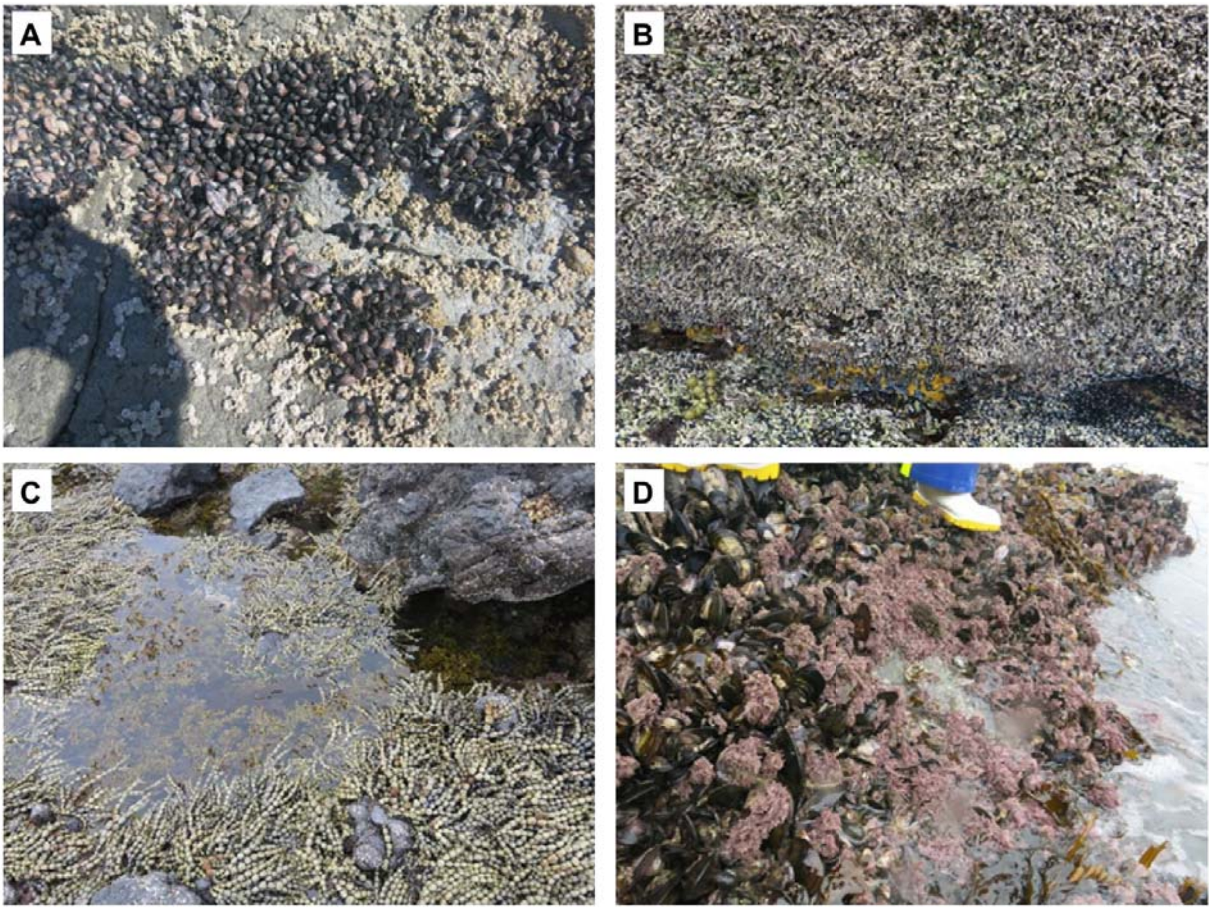

Figure 33 Representative images of intertidal habitats within Lyttelton Harbour/Whakaraupō: (a) the high- to mid- shore was generally dominated by barnacles and blue mussels, (b) the mid-shore often featured a conspicuous band of blue tube worm, (c) rock pools were common in the mid- to low shore where a range of macroalgae was recorded, (d) green-lipped mussels formed dense beds mixed with coralline turfing algae in the low-shore to shallow subtidal.

In the shallow subtidal and tidal pools (where present) some canopy forming macroalage were recorded (*e.g. C. maschalocarpum*). *M. pyifera*, *Ecklonia radiata* and the bull kelps (*Durvillea antartica* and *D. williana*) occurred along the littoral fringe. Additionally, there was a variety of invertebrates in low shore tidal pools; including porcelain crabs (*Petrolisthes elongatus*), slipper limpets (*Sigapatella novaezelandiae*), cushion seastars (*Patiriella regularis*), anemones (*e.g. Oulactis mucosa, Anthothoe albocincta*) and chitons (*e.g. Chiton pelliserpentis, C. glaucus*).

Over all surveys, no intertidal organisms or communities of special scientific or conservation interest have been identified. The non-indigenous seaweed *Undaria pinnatifida* was recorded in the low shore to immediate subtidal on both shores of the Harbour. Pāua (*Haliotis iris*) were notably common within pools on the low shore at the Livingstone Bay site in December 2013. Although deposited sediment appears to be a natural feature of the upper Harbour Rapaki Bay and Shag Reef sites, there have been no observations of fine sediment accretion at any of the central and outer Harbour sites.

5.6.2. Variation in intertidal communities with wave exposure

Being a large rock-walled inlet, the shores of Lyttelton Harbour/Whakaraupō are lined for most of their length with narrow intertidal and shallow subtidal reef habitats, occasionally broadening into limited rock platforms and shelves. At its head and occasional deep bays there are broad mud flats and beaches of silty sand.

Due to the length of the Harbour and the relatively straight shorelines of its outer and central sectors, its intertidal reef habitats exhibit a relatively smooth environmental gradient in wave exposure and sedimentation from the entrance to the upper Harbour. This gradient derives from the rapid attenuation along the Harbour length of long-period swell waves which penetrate the inlet. This attenuation is caused by the effects of shoaling and friction, and by refraction from the centre of the harbour to the northern and southern shorelines where the waves break (Mulgor Consultants Ltd 2014).

Due to moderate wind fetch, the shallow upper reaches of the Harbour are subject to short period wind chop which easily resuspends fine sediments from the intertidal flats. As a result, the upper Harbour is frequently more turbid than the outer regions. This continual reworking of sediments results in their deposition on upper Harbour shoreline reefs, accumulating in pools and crevices until wave action resuspends them again. In the outer Harbour, the persistent surge conditions at the shorelines effectively prevent the accumulation of fine sediments in more than thin films or veneers, keeping the intertidal reefs free of even moderate sediment deposits.

Generally, there is expected to be a gradient in species richness on reef substrates from the heads to the mouths of harbours, with outer sites featuring greater water movement supporting richer communities, until extremes of wave exposure on high energy coastlines again see a decrease in richness. This gradient in wave exposure and associated environmental conditions is also generally reflected in a change in the assemblages of species represented. A general pattern for the changing assemblages in Lyttelton Harbour/Whakaraupō in relation to wave energy was described by Morton and Miller (1973) and this is largely supported by the current data for intertidal sites in the Harbour.

The low energy upper Harbour sites of Rapaki Bay and Shag Reef generally supported a more limited range of conspicuous taxa compared to mid- and outer-Harbour sites. At Shag Reef, only 32 taxa were identified, although allowing for the effective absence of a high-shore zone makes it generally comparable to the 45 taxa identified at Rapaki Bay. The narrow rocky margin at Rapaki Bay also reflects broader habitat availability from physical characteristics which give it a greater prevalence of tidal pools compared to Shag Reef.

Notable changes in species in relation to exposure include high abundance of the estuarine barnacle *Elminius modestus* at sites further up the harbour where it replaces the columnar barnacle *Chamaesipho columna*. Other changes, include the absence or lower abundance of kelp and *Carpophyllum* at upper Harbour sites, where they are replaced by other algae such as, *H. banksii* and *Cystophora scalaris*, which are absent at the exposed Godley Head site.

The low-shore zones of the wave-exposed outer sites support a dense and diverse macroalgae community, including *Ecklonia* and *Durvillea*. Moving up the Harbour, one sees the disappearance of *Durvillea* to be replaced in the moderately exposed central Harbour shorelines (Battery Point, Ripapa, Is. and Camp Bay), by *Macrocystis* and *Carpophyllum* sp. The low shore and shallow subtidal of the central and outer Harbour sites also constitute preferred habitats for pāua and green-lipped mussels.

5.6.3. Port Levy/Koukourārata intertidal communities zonation patterns

The intertidal regions surveyed in Port Levy/Koukourārata consisted mainly of bedrock with some boulder substrate. The two surveyed sites, PL03 and PL16 (on the western and eastern sides of the inlet, respectively) are in the mid-outer areas of the inlet and have similar physical characteristics (intertidal rock platform / shelf, some tidal pools) and exposure. PL03 was situated on the seaward side of the small Pukerauaruhe Island and featured a relatively broad and level mid-tidal rock platform. The reef shoreline at PL16 was steeper in profile and significantly narrower (< 5 m wide).

A total of 66 taxa were found at these two intertidal sites (57 taxa at PL03 and 35 at PL16), with species richness increasing down the tidal profile. The greater overall species richness at PL03 is related to the much greater width of its intertidal zone and especially the higher prevalence of tidal pools on its rock platform. The two sites were similar in terms of zonation patterns, assemblage structure and dominant taxa recorded and were comparable to the mid-Lyttelton Harbour/Whakaraupō sites (Ripapa Island, Camp Bay, Battery Point and Livingstone Bay).

6. FISH AND FISHERIES RESOURCES

6.1. Recreational fishing

6.1.1. Lyttelton Harbour/Whakaraupō

No commercial fishing occurs within Lyttelton Harbour/Whakaraupō; however, Lyttelton Port is located only 20 minutes' drive from Christchurch. It is therefore an important access point for recreational fishing for the local community. A wide variety of fish species have been anecdotally reported in Lyttelton Harbour/Whakaraupō, including instances of strandings in the Lyttelton Dry-dock (Table 10). But while recreational fishing is known to occur in Lyttelton Harbour/Whakaraupō, it does not appear to be rated very highly by recreational fishers (Greenaway 2014). Regions in the proximity of the harbour mudflats are recognised as important nursery/roosting areas for wildlife and habitats for fish species such as sole (*Peltorhamphus novaezeelandiae*), red cod (*Pseudophycis bachus*), spotted stargazer (*Genyagnus monopterygius*) and flounder (*Rhombosolea* sp.) (DOC 1990)

During summer, the port area is frequented by juvenile fish of species such as red cod, yellow-eyed mullet (*Aldrichetta forsteri*), blue warehou (*Seriolella brama),* spiny dogfish (*Squalus acanthias*) and green pufferfish (*Contusus richei*). Adult fish such as red cod and quinnat salmon (*Oncorhynchus tshawytscha*) have also been caught from the wharves. No stock abundance figures were available for the Harbour itself but the area cannot be neglected as a possible spawning and nursery ground for many of these species. In a study of the reproductive biology of the pufferfish (*Contusus richei*) from Lyttelton Harbour/Whakaraupō, Habib (1979) found pufferfish start to spawn at summer time from October to March. Catches by recreational fishers within the harbour indicate that the sheltered, relatively shallow waters of the Harbour may make it attractive to other species as a spawning and nursery ground.

The upper Harbour is targeted for flatfish. Drag nets not exceeding 40 m in length may be used in Lyttelton Harbour/Whakaraupō and setting nets for flatfish in the inner parts of the Harbour is legal from April 1 to 30 September.

A 1985 MAF Fisheries set net survey of Lyttelton Harbour/Whakaraupō (two overnight sets of three 60 m nets) caught 93 juvenile school sharks and eight juvenile rig. Although it was reported that school sharks usually appear to prefer clearer water found over sandy substrata on open coasts, it was noted that turbidity was already high during the survey and it was concluded that both species appear to tolerate highly turbid environments (Francis *et al.* 2011).

While reporting that juvenile rig spend their first 6–8 months of life in estuaries and harbours before departing for deeper water in autumn-winter, Blackwell and Francis

(2010) noted that new-born rig have been found in Pegasus Bay as well as the Avon-Heathcote Estuary and Lyttelton Harbour/Whakaraupō.

Table 10 List of fish species targeted or caught incidentally by recreational fishers within Greater Lyttelton Harbour/Whakaraupō; based on historical data and reliable anecdotal evidence [Canterbury Anglers Club, Lyttelton Dry Dock, Ministry of Fisheries (Recreational Fisheries), University of Canterbury (School of Biological Sciences)]. Adapted from Bennett & Sneddon (2006).

Common name	**Scientific name**
Red cod	*Pseudophycis bachus*
Sand flounder	*Rhombosolea plebeia*
Sole	*Peltorhamphus novaezeelandiae*
Quinnat salmon	*Oncorhynchus tshawytscha*
Monkfish / Stargazer	*Kathetostoma giganteum* or *Genyagnus monopterygius*
Trevalli	*Caranx georgianus*
Ling	*Genypterus blacodes*
Kahawai	*Arripis trutta*
Terakihi	*Nemadactylus macropterus*
Blue cod	*Parapercis colias*
Butter fish	*Odax pullus*
Blue moki	*Latridopsis ciliaris*
Red gurnard	*Chelidonichthys kumu*
Garfish/ piper	*Hyporhamphus ihi*
Yellow-eyed mullet	*Aldrichetta forsteri*
Spotted wrasse	*Notolabrus celidotus*
Puffer fish	*Contusus richei*
Conger eel	*Conger vereauxi*
Stingray or skate	*Sasyatis brevicaudatus*
Spiny dogfish	*Squalus acanthias*
Seven gill shark	*Notorynchus cepedianus*
School shark/lemon shark	*Galeorhinus australis*
Rig	*Mustelus lenticulatus*

6.1.2. Pegasus Bay

The relatively shallow and semi-sheltered waters of Pegasus Bay support a range of demersal and pelagic fish species, all of which are widespread in occurrence and distributed widely along the east coast of the South Island.

Benn (2009) indicates recreational fishing values throughout the near-shore coastal environment of Banks Peninsula, listing blue cod, red cod, red gurnard, butterfish, sea perch, rock lobster, pāua, kina, mussels and blue moki as target species. Many of these species are strongly or exclusively associated with near-shore reef habitats.

In their study of subtidal reef habitats on the east coast of the South Island, Schiel and Hickford (2001) reported that, around Banks Peninsula, the most common fish species were the wrasses *Notolabrus fucicola* and *N. celidotus*. Leatherjackets

(*Parika scaber*) and butterfish (*Odax pullus*) were also recorded. In addition to these species, the subtidal surveys conducted along the Banks Peninsula coastline for this investigation recorded blue cod (*Parapercis colias*) and blue moki (*Latridopsis ciliaris*).

Kingett Mitchell (2003c) cited the results of the 1996 national marine recreational fishing survey for the zone between Sumner Beach and Conway River (Fisher & Bradford 1999) as reporting the most important recreational species taken being blue cod (*Parapercis colias*), flatfish, dogfish, kahawai, red cod, salmon and yellow-eyed mullet. They further cited a limited inshore survey by Knox *et al.* (1978) which identified flatfish (sole sp.), slender stargazer (*Crapatalus novaezealandiae*), spiny dogfish, rig (*Mustelus lenticulatus*), sprat (*Sprattus* sp.) and yellow-eyed mullet as the key inshore species, with others found within 3,000 m of the shore including red cod, school shark, giant stargazer and elephant fish.

Although some species, such as flatfish, kahawai, salmon and yellow-eyed mullet are taken by shore fishing or small drag nets at the river mouths and within estuaries, species such as red cod and dogfish are taken mainly by boat fishing throughout Pegasus Bay. However, most boat fishing activity occurs near Banks Peninsula where the greater predominance of reef shorelines supports sought-after species such as blue cod (Kingett Mitchell 2003c).

6.2. The Pegasus Bay inshore fishery

6.2.1. Commercial fisheries context

New Zealands' Quota Management System (QMS) divides the Exclusive Economic Zone (EEZ) into 10 Fisheries Management Areas (FMAs; Figure 34). For each quota management species, separate stocks are defined by Quota Management Areas (QMAs). The QMA may be the same as an FMA or a grouping of FMAs, depending on the geographical distribution of that fish stock. Commercial catch limits are set annually for each fish stock, as total allowable commercial catch (TACC).

Fisheries catch data have historically been collated from catch effort landing returns (CELR) into a Ministry of Fisheries (MFish) database by fisheries statistical area (FSA) within the EEZ. For each species group, fishers reported catches to a unique FSA. For the last decade, such data have been recorded, for vessels longer than 6 m, at specific locations (latitude and longitude instead of broad statistical areas). The catch-effort database 'Warehou' is administered by the Ministry for Primary Industries (MPI). The proposed spoil ground would be situated within statistical area 020 and Fisheries Management Area 3 (FMA 3; Figure 34).

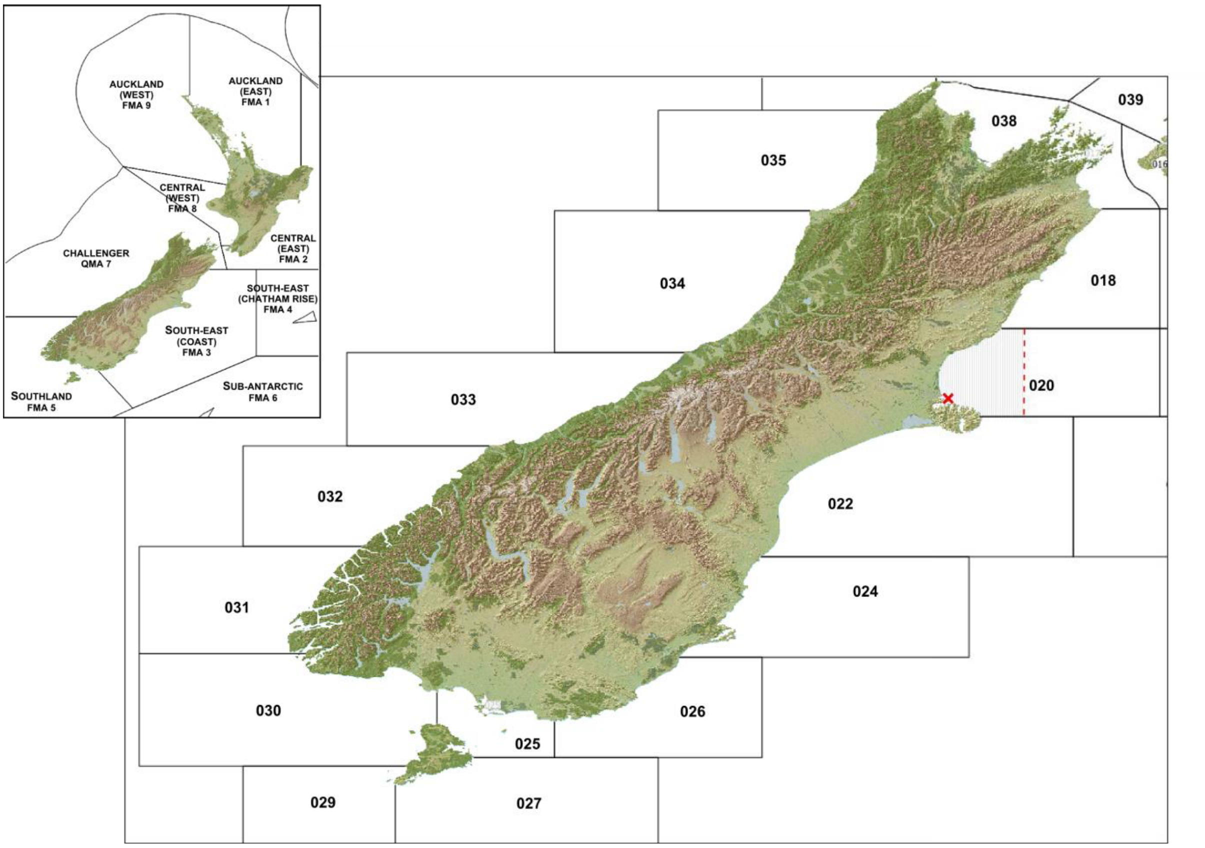

Figure 34 Fisheries management areas (FMAs) and fisheries statistical areas (FSAs) for the South Island coastal regions. Location of the proposed spoil ground is designated by a red cross. The inshore region of statistical reporting area 020 covered by the Ministry for Primary Industries (MPI) data request is also shown.

6.2.2. Inshore Pegasus Bay fishing restrictions

The 1,170 km² Banks Peninsula Marine Mammal Sanctuary extends 4 Nm offshore from Sumner Head to the Rakaia River south of Banks Peninsula. Legislation introduced in 2008 as part of the Hector’s and Maui’s Dolphin Threat Management Plan prohibits commercial and amateur use of set-nets on the east coast of the South Island offshore to four nautical miles (Nm) between Cape Jackson in the Marlborough Sounds and Slope Point in the Catlins. Trawl gear restrictions apply in the near-shore area to 2 Nm off the coast between Cape Jackson in the Marlborough Sounds and Slope Point in the Catlins. Trawling within 2 Nm is restricted to the use of nets with defined low headline heights (vertical height of no more than 1 m; MPI 2014; www.fish.govt.nz).

Trawling is prohibited in inshore Pegasus Bay from the Waimakariri River to Okains Bay on Banks Peninsula to protect the elephant fish (*Callorhinchus milii*) egg laying area DOC (2007). This No Trawl Zone is constrained inshore by nodes at Godley Head, Baleine Point and Long Lookout Point (see Figure 36 and Figure 37).

6.2.3. Inshore trawling effort

MPI has released total trawl catch weight graphics to 1 Nm resolution for the territorial sea areas (out to 12 Nm) for the years 2007–2010 (Figure 35). These show the highest intensity of inshore trawling in the Pegasus Bay area to be east and north of the eastern extremity of Banks Peninsula. However, there is an area of fishing intensity immediately east of Godley Head in the vicinity of the proposed spoil ground.

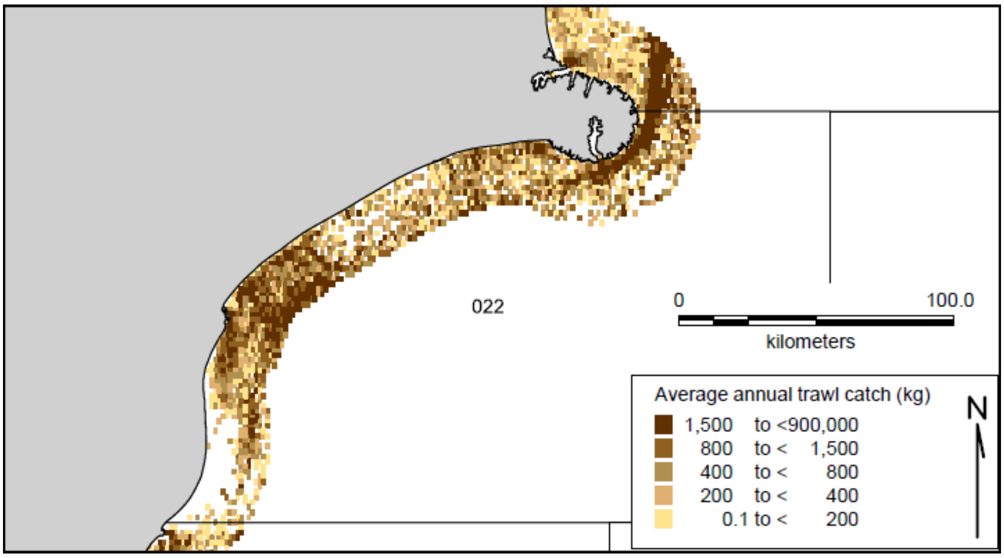

Figure 35 Spatial pattern of trawl fishing activity within the 12 Nm territorial limit of fisheries statistical areas (FSA) 022 and 020. Total annual catch of all species harvested by trawling, averaged for all events starting in each 1 Nm grid cell and for three fishing years 2007–2010. Source http://www.fish.govt.nz.

6.2.4. Fisheries species important to inshore Pegasus Bay

Trawling along the east coast of the South Island mainly targets red cod in waters 20-100 m deep and flatfish in depths less than 30 m, with some tarakihi (*Nemadactylus macropterus*) also taken (the latter in deeper water to the northeast of Banks Peninsula). Sand flounder (*Rhombosolea plebeia*) occur in shallow water from the shore out to 50 m depth. URS (2004) cite Mundy (1968) as finding that *R. plebeia* move extensively throughout the shallower depths of Pegasus Bay and identified a major spawning ground off the Waimakiriri river mouth, with fish gathering to spawn there in winter and spring. This species and New Zealand sole (*Peltorhamphus novaezeelandiae*) may make up a significant part of commercial catches in the inshore regions of Pegasus Bay (URS 2004).

Based on a dataset covering the species bluenose (*Hyperoglyphe antarctica*) and tarakihi as a review of the Adaptive Management Program (AMP), fisheries within statistical area 020 have been subject to a number of fishing methods, targeting more than 20 species since 2004. In the AMP review of the GUR 3 fishery, landing information by statistical area suggests that area 020 is an important fishing ground for red gurnard (*Chelidonichthys kumu*), accounting for around 15% of the total gurnard landings from QMA3 in recent years. The majority of this catch was landed by bottom trawl, with only a small proportion taken by Danish seine, setnet and mid-water trawl (Starr *et al.* 2007). GUR 3 is a bycatch fishery, targeting mainly red cod, flatfish, barracouta and giant stargazer, suggesting these species may also be an important fishery resource in area 020.

DOC (2007) generalises that, in the inshore fishery, flatfish, red gurnard, rough skate, and elephant fish are caught in waters less than 50 m deep and lemon sole, red cod, red gurnard, tarakihi, warehou, spiny dogfish, and barracouta are caught between 50 m and 100 m. In the middle depth fishery between 100 m and 200 m the main trawl species are red cod, barracouta, warehou, ghost shark, jack mackerel, and spiny dogfish. In a review of trawl survey data undertaken up to 2001 off the east coast of the South Island, Beentjes *et al.* (2002) reported a catch variety of some 100 species belonging to 56 families.

In a review of fishery information for Pegasus Bay, Kingett Mitchell (2003c) identified 18 main commercially caught finfish species, a number of which are more prevalent in deeper waters (> 50 m) well offshore (see Table 11). It was noted that all are widespread, occurring either all around the South Island coastline or throughout New Zealand.

Table 11 Fishery species listed for statistical area 020. Shaded records indicate finfish identified by Kingett Mitchell (2003c) as being the main species found in Pegasus Bay [along with additional species kahawai (*Arripis trutta*), yellow-eyed mullet (*Aldrichetta forsteri*), jack mackerel (*Trachurus declivis*), rig (*Mustelus lenticulatus*) and spiny dogfish (*Squalus acanthias*)].

Species code	Common_name	Scientific_name
BNS	Bluenose	*Hyperoglyphe antarctica*
ESO	NZ sole	*Peltorhamphus novaezeelandiae*
FLA	Flatfish	
	Lemon sole	*Pelotretis flavilatus*
	Sand flounder	*Rhombosolea plebeia*
	Yellowbelly flounder	*Rhombosolea leporina*
	Black flounder	*Rhombosolea retiaria*
RCO	Red cod	*Pseudophycis bachus*
TAR	Tarakihi	*Nemadactylus macropterus*
GSH	Ghost shark	*Hydrolagus novaezealandiae*
GUR	Gurnard	*Chelidonichthys kumu*
LIN	Ling	*Genypterus blacodes*
WAR	Common warehou	*Seriolella brama*
HOK	Hoki	*Macruronus novaezelandiae*
BAR	Barracouta	*Thyrsites atun*
STA	Giant stargazer	*Kathetostoma giganteum*
SCH	School shark	*Galeorhinus galeus*
MOK	Blue moki	*Latridopsis ciliaris*
ORH	Orange roughy	*Hoplostethus atlanticus*
BYX	Alfonsino & Long-finned beryx	*Beryx splendens, B. decadactylus*
SPE	Sea perch	Helicolenus spp.
BCO	Blue cod	*Parapercis colias*
ELE	Elephant fish	*Callorhinchus milii*
SWA	Silver warehou	*Seriolella punctata*
HAK	Hake	*Merluccius australis*
SQU	Arrow squid	*Nototodarus sloanii, N. gouldi*
RIB	Ribaldo	*Mora moro*

Flatfish

New Zealand's flatfish species are characterised by small size, rapid growth, short life-spans and relatively high fecundity. Flatfish are distributed widely throughout New Zealand, being frequently encountered in coastal inlets, embayments and estuaries. The ecology of juvenile flatfish is notable for the widespread use of specific nursery areas and low recruitment variability relative to other marine fish species. Inlets and lagoons functioning as nursery areas rely on being sufficiently open to the sea for recruitment to occur (Jellyman 2011). The flatfish fishery is comprised of eight species although typically only a few are dominant in any one QMA and some are not found in all areas. For management purposes all species are combined to form a unit fishery (MPI 2013).

For QMA3, Beentjes and Manning (2010) reported that the only three flatfish species caught in any quantity by trawling were New Zealand sole (*P. novaezeelandiae*), lemon sole (*P. flavilatus*), and to a lesser extent sand flounder (*R. plebeia*). However, these observations were qualified by depth range, with *R. plebeia* inhabiting the shallow coastal areas down to and probably inside 10 m, *P. novaezeelandiae* predominantly in 10–30 m, with *P. flavilatus* extending deeper again into the mid, and occasionally, outer continental shelf.

Although both sand flounder (*R. plebeia*) and yellowbelly flounder (*R. leporine*) occupy similar depth ranges, the available literature indicates that the latter is the more inshore species of the two, favouring harbours and estuaries and generally slightly finer substrates. The difference in range for these two species noted by Pegasus Bay fishers may relate principally to the proximity of shallow inlets (*e.g.* Lyttelton Harbour, Avon Heathcote Estuary), although sandier substrates existing beyond the deepest contour of the spoil ground ecological survey area (~21 m) may also be a factor. Both species are known to exhibit seasonality in their occurrence and distribution although their natural ranges overlap to a significant extent. Neither species is particularly specific in its food source and will take a variety of prey taxa which are known to be common within the wider area, particularly polychaete worms, crabs and molluscs.

Sheltered estuaries and harbours are typical nursery areas for sand flounder and juveniles are seasonally very abundant in such habitats around New Zealand. Juveniles are generally confined to the shallow tidal flats and along the shores near stream mouths (Morrison *et al.* 2014).

From the results of extensive tagging surveys covering Lyttelton and Akaroa harbours and the Avon-Heathcote estuary, Coleman (1978) established that *R. plebeia* spawned in 35–40 m depths both near Akaroa Heads and in the vicinity of Timaru during the late winter-spring months. It was reasoned that the planktonic eggs and larvae are then carried northwards by the Southland Current to colonise the bays and harbours of Banks Peninsula and Pegasus Bay.

Elephant fish (*Callorhinchus milii*)

In New Zealand, elephant fish (*Callorhinchus milii*) range from the eastern Bay of Plenty to the southern margin of the Snares Shelf. They are most abundant around the South Island, with high densities occurring in Pegasus Bay, Canterbury Bight and Te Waewae Bay. They typically occupy a depth range from the surface to 100 m (NABIS lineage for *C. milii*) and have historically formed an important commercial resource in Pegasus Bay, with catches increasing in the years following the introduction of quotas in the 1980s. They feed primarily on shellfish and molluscs including the clam *Maorimactra ordinaria* but also take crustaceans and some fish.

Elephant fish aggregate in shallow inshore waters (between the surf zone and 30 m) around the South Island during October and November to mate and lay their eggs, often in depths shallower than 10 m. The egg cases are laid in sand or mud and take 5–8 months to hatch. Females are known to spawn multiple times per season. Following spawning, they disperse again into deep water (60–200 m); however, juveniles remain in shallow waters for up to three years. During this time, juveniles are vulnerable to incidental trawl capture but are of little commercial value. Trawl fishers in the Canterbury Bight have implemented a Code of Practice to protect these spawning areas from disturbance by not trawling within 1 Nm from shore, limiting bottom disturbance shallower than about 10–15 m (Parker *et al.* 2009). A similar voluntary restriction may apply in Pegasus Bay.

Areas where egg cases are deposited in considerable numbers include Marlborough Sounds, Pegasus Bay and Canterbury Bight. Other known egg-laying sites (or those inferred by the occurrence of small juveniles) include Porirua and Pauatahanui Inlets, Wellington Harbour, West Coast of South Island, Blueskin Bay, Otago Harbour, and Te Waewae Bay. It is believed that most egg-laying occurs in waters shallower than 30 m.

The distribution of egg-laying sites of *C. milii* is not known. While it is possible that suitable sites may be restricted to certain parts of Pegasus Bay, the no-trawl zone established between Godley Head and the Waimakiriri rivermouth for the purpose of avoiding disturbance to elephant fish egg-laying areas suggests, at least anecdotally, that shallow inshore areas north of Godley Head are suspected. It has furthermore been observed that from April onwards sometimes very large numbers of egg cases are washed up on the beaches between Sumner and the mouth of the Waikmakariri River. This suggests that benthic areas favoured by this species for egg-laying are not limited to the southern part of this range.

Parker *et al.* (2009) reported that the target fishery for elephant fish based on data collected 1995–2006 was concentrated between Banks Peninsula and Oamaru, with 67% of total catch weight for Quota Management Area 3 (east coast of the South Island) occurring in statistical area 022 and 17% coming from Area 020 (Pegasus Bay). However, it has been reported that juveniles in Pegasus Bay and Canterbury Bight have different modal lengths and grow at different rates during the first three years of life, indicating that there is little or no movement around Banks Peninsula (Francis 1997).

Red gurnard (*Chelidonichthys kumu*)

Red gurnard are widely distributed around New Zealand. They occur from 10 m to 200 m water depths over muddy or sandy substrates. Although generally plentiful, red gurnard are more predominant in Northern waters. Morrison *et al.* (2014) reported that surveys for the east coast of the South Island found red gurnard generally in depths of less than 100 m, with the greatest catches north and south of Banks Peninsula, off

Pegasus Bay, and between Timaru and Oamaru. Although a major bycatch species of inshore trawl fisheries in most areas of New Zealand, including fisheries for red cod in the southern regions (MPI 2013) they are not believed to be directly targeted in Pegasus Bay.

Red gurnard have a long spawning period which extends through spring and summer with a peak in early summer, although ripe, running ripe[13] and spent fish are caught around most of New Zealand throughout the year. There are indications that fish move into deeper water as they get older, and on a seasonal basis to spawn (Morrison *et al.* 2014). However, spawning grounds appear to be widespread, there being no indications of any major geographical spawning aggregations or areas. Egg and larval development takes place in surface waters. Recently settled juveniles are found in shallow harbours and estuaries between February and March, but in low numbers only, suggesting such habitats are of limited importance as nursery areas.

Rig (*Mustelus lenticulatus*)

Rig occur all around the New Zealand coastline. Although they are caught from depths ranging 0–600 m, they are most common in shelf waters down to 100–200 m. Hurst *et al.* (2000) noted that for east coast South Island trawl surveys, rig were caught at fewer than 20% of stations, being most common in less than 30 m of water. Rig in Golden Bay were found to feed mainly on benthic invertebrates such as pagurid and brachyuran crustaceans, and echiurans (King & Clark 1984). In harbours and estuaries, the diet of juvenile rig appears to consist mainly of benthic crustaceans, especially the mud crab *Hemiplax hirtipes* and snapping shrimp (*Alpheus richardsoni*), although other prey include mantis shrimp, hermit crabs, squat lobsters, caridian shrimps and polychaete worms. However, molluscs were rarely part of the diet and fish notably absent (Getzlaff 2012).

Rig are highly mobile and there is little information suggesting the existence of separate stocks (Blackwell & Francis 2010). They undertake seasonal inshore–offshore migrations which are believed to be related to their reproductive cycle. While the winter habitat of rig is poorly known and coincident with low commercial catches, they are known to aggregate annually in spring and summer in shallow coastal waters to breed (Morrison *et al.* 2014). Gestation is believed to be around 10–11 months and pregnant female rig can travel large distances in a short time (www.nabis.govt.nz lineage document; spawning rig). They are believed to enter estuaries and harbours to give birth in spring, after which they mate and remain in inshore summer feeding grounds. However, full-term pregnant females have been recorded only in relatively small numbers and the locations of pupping and mating sites are not known. Francis *et al.* (2012) considered Kaipara, Raglan, Waitemata, Tamaki and Porirua harbours to

[13] During the spawning period, females are referred to as 'ripe' when they have nearly-mature eggs scattered throughout their gonad and 'running ripe' once these mature eggs have ovulated and are ready for release.

meet the shark nursery criteria of Heupel *et al.* (2007), containing higher densities and abundance of 0+ rig[14] than adjacent coastal waters.

While reporting that juvenile rig spend their first 6–8 months of life in estuaries and harbours before departing for deeper water in autumn-winter, Blackwell and Francis (2010) noted that new-born rig have been found in Pegasus Bay as well as the Avon-Heathcote Estuary and Lyttelton Harbour/Whakaraupō. Inshore trawl surveys in Canterbury Bight and Pegasus Bay have recorded juvenile rig mainly from waters less than 30 m, both in the discontinued summer series and the (April–May) winter surveys. Malcolm *et al. (*2013) suggested that bays, surf beaches and open coastline waters less than 10 m deep throughout much of mainland New Zealand may function as either primary or secondary nursery areas.

School shark (*Galeorhinus galeus*)

School shark occur in both the northern and southern hemispheres. They are found all around the New Zealand coast, mainly in depths of less than 200 m, but are known from waters as deep as 800 m, as well as oceanic waters (Morrison *et al.* 2014). In comparison to rig, school shark are considered to prefer clearer water and are more often found over sandy substrata on open coasts; however, both species appear to tolerate highly turbid environments. The diet consists of both benthic and pelagic fish and cephalopods. Juveniles will also take crustaceans, annelids and gastropod molluscs.

Similar to rig, school sharks commonly aggregate in inshore waters during warmer months and disperse across the shelf and upper slope during autumn and winter. Based on a study in south-eastern Australia, Morrison *et al.* (2014) considered it likely that mating occurs in deeper water in New Zealand over the autumn-winter months. Gestation is believed to be around 12 months with a breeding cycle for females of 2–3 years, during which they are believed to move into shallow water in the spring-summer months to give birth.

Well-defined nurseries have not been identified in New Zealand, but juveniles up to two-years old are regularly caught in inshore trawl surveys (Morrison *et al.* 2013). Pupping areas are likely to include a range of coastal environments and 0+ juveniles have also been caught in open coastal waters.

Both the summer and winter trawl surveys along the east coast of the South Island recorded school shark of generally much smaller size than for other regions in which they were prevalent. These catches were furthermore greatest in shallow waters (30 m or less) during summer, occurring at around 100 m depths in winter (Beentjes & Stevenson 2000). The general area of Pegasus Bay appears to be one of a number of broad hot-spot areas for juvenile school sharks around the New Zealand coastline.

[14] Fish in their first year of life.

However, tagging surveys have shown considerable interchange of adult fish between the North and South islands and also significant trans-Tasman migration. The species is considered to comprise one biological stock in New Zealand waters (Blackwell & Francis 2010).

6.2.5. MPI fisheries data extract for Pegasus Bay

A request to MPI Data Management Group was submitted under the Official Information Act. Originally, this covered catch data over a three year time period for one aggregate group (flatfish) and nine other individual species to a spatial resolution of 6 Nm cells. The species selections were based on the fisheries literature and some consultation with Lyttelton commercial fishers and included those that are generally targeted (or are significant as by-catch) in waters of less than 50 m depth (Table 12). The species primarily targeted in inshore waters were flatfish, with elephant fish (*C. milii*) and red gurnard (*Chelidonichthys kumu*) representing high value by-catch.

Table 12 Fisheries species included to compile the aggregate data for southern Pegasus Bay. The data extract for the flatfish aggregate also included catch information encoded to ‘FLA’, 'SOL', 'FLO' and 'SDF.

Species code	Common name	Scientific name
FLAT	**Flatfish aggregate**	
BFL	Black flounder	*Rhombosolea retiaria*
BRI	Brill	*Colistium guntheri*
GFL	Greenback flounder	*Rhombosolea tapirina*
LSO	Lemon sole	*Pelotretis flavilatus*
ESO	New Zealand sole	*Peltorhamphus novaezeelandiae*
SFL	Sand flounder	*Rhombosolea plebeia*
TUR	Turbot	*Colistium nudipinnis*
WIT	Witch	*Arnoglossus scapha*
YBF	Yellowbelly flounder	*Rhombosolea leporina*
FIN	**Finfish aggregate**	
RCO	Red cod	*Pseudophycis bachus*
TAR	Tarakihi	*Nemadactylus macropterus*
GUR	Gurnard	*Chelidonichthys kumu*
WAR	Common warehou	*Seriolella brama*
STA	Giant stargazer	*Kathetostoma giganteum*
SCH	School shark	*Galeorhinus galeus*
ELE	Elephant fish	*Callorhinchus milii*
SPO	Rig	*Mustelus lenticulatus*
RSK	Rough skate	*Dipturus nasutus*

MPI’s data management group advised that, as the extract parameters initially stood, approximately 35% of records would be withheld according to their 3 client / 3 vessel rule[15], representing approximately 9% of the total catch weight. The data request was consequently modified to aggregate the listed species into two groups (representing flatfish and finfish) rather than decrease the spatial resolution from the specified 6 Nm grid size. This adjustment reduced the number of records that failed the 3x3 rule to 20%, representing just 0.19 % of the overall catch weight. Hence the records withheld represented only a very small proportion of the overall catch relative to the other cells.

The time frame covered by these data was from 1 October 2011 to 14 August 2014. Catch by all fishing methods was included. The area covered was defined as the inshore section of Statistical Area 020 out to longitude E174 25’. A breakdown of the two species aggregates is given in Table 12. Rounding rules were applied to align cell boundaries to 0.1 degrees, equivalent to a six nautical mile grid, with locality established by start position (*e.g.* of trawl track). The data outputs were represented spatially for each species aggregate using ArcGIS software (Figure 36 and Figure 37). Catch weight for each grid cell is given and represented by proportional symbols[16] to facilitate interpretation of the data.

Figure 36 shows that catches of flatfish species are relatively concentrated in the grid cell situated at the Harbour entrance. The reported catch weight of 63 tonnes at this location for the last three years represented 33% of the 191 t total for the area covered by the data extract. Given the reported spatial restrictions upon trawling (see Section 6.2.2), this catch weight value is constrained to have come from only a small offshore section of the defined grid cell, indicating significant fishing intensity in this area. The two cells within which the proposed spoil ground is located reflect smaller catch weight relative to cells further inshore in Pegasus Bay. The combined weight from these two cells represents 5.7% of the Bay total, although the benthic area potentially affected by capital dredging spoil disposal is likely to be only a small proportion of this area.

Figure 36 appears to show that the majority of fishing effort for flatfish occurs inshore and northwest of the spoil ground. It was reported from a meeting with commercial fishers on 1 July 2007 that fishing boats catch the more valuable yellowbelly flounder (*Rhombosolea leporina*) outside a line between Godley Head and Baleine Point over 6–8 months in each year. It was noted that sand flounder (*R. plebeia*) occur at the proposed capital dredging spoil deposition site and that the seabed becomes sandier in nature about 5–6 miles out. These two species, together with some sole, are likely to be the principal component of Pegasus Bay flatfish catches.

[15] Where fewer than 3 vessels or clients are represented within a defined cell and stratum, the data must be withheld as potentially commercially sensitive.

[16] The Flannery compensation technique available in ArcMap™ v10 GIS has been used. This adjusts symbol sizes upwards to account for the fact that plot readers tend to underestimate the size of circular symbols.

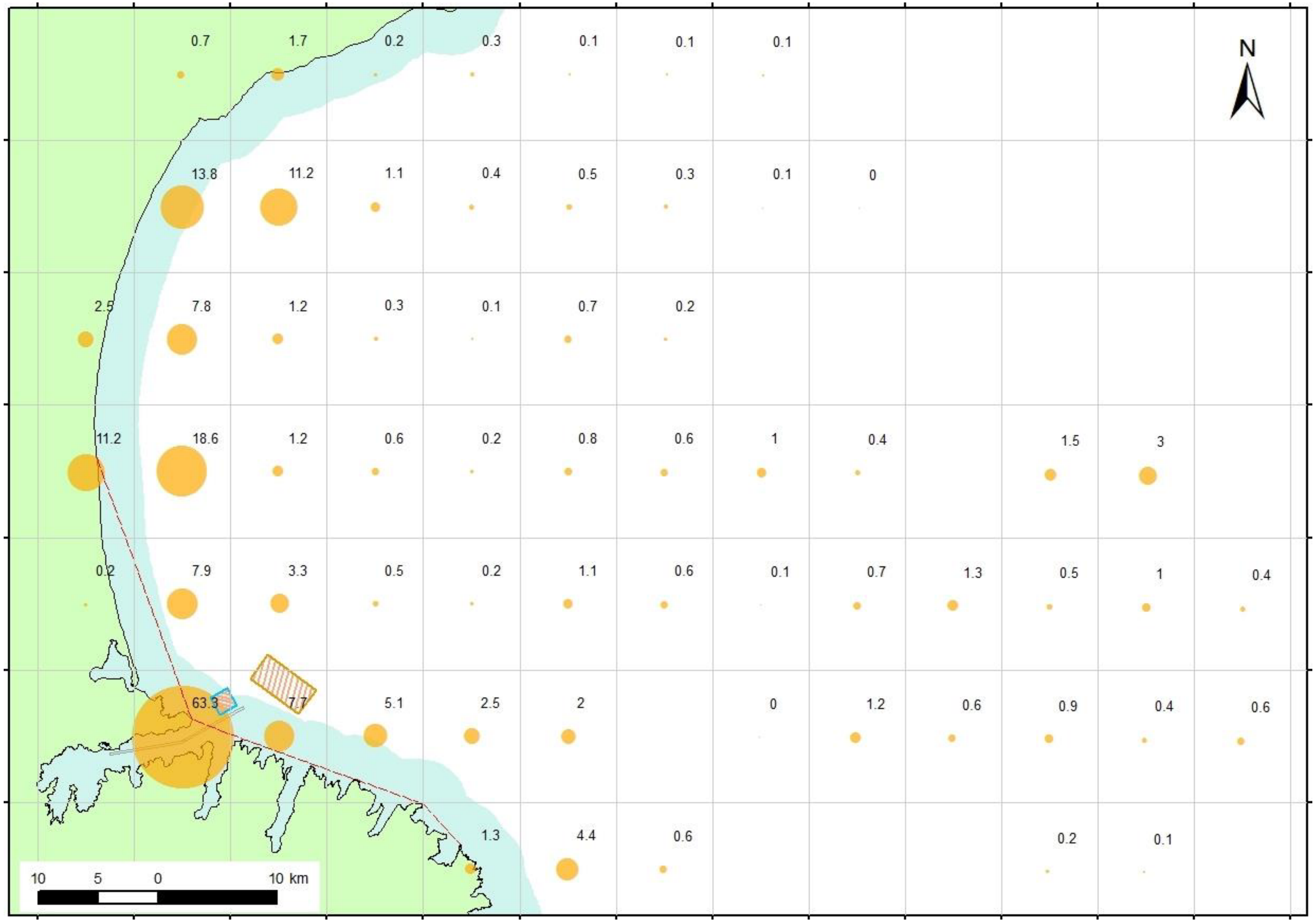

Figure 36 Recorded commercial catch weight (tonnes) for aggregated flatfish species in Pegasus Bay (1 Oct 2011 to 14 Aug 2014) for 0.1 degree grid squares. Shaded area designates 2 Nm trawl height restriction. Red line designates inshore trawl prohibition boundary.

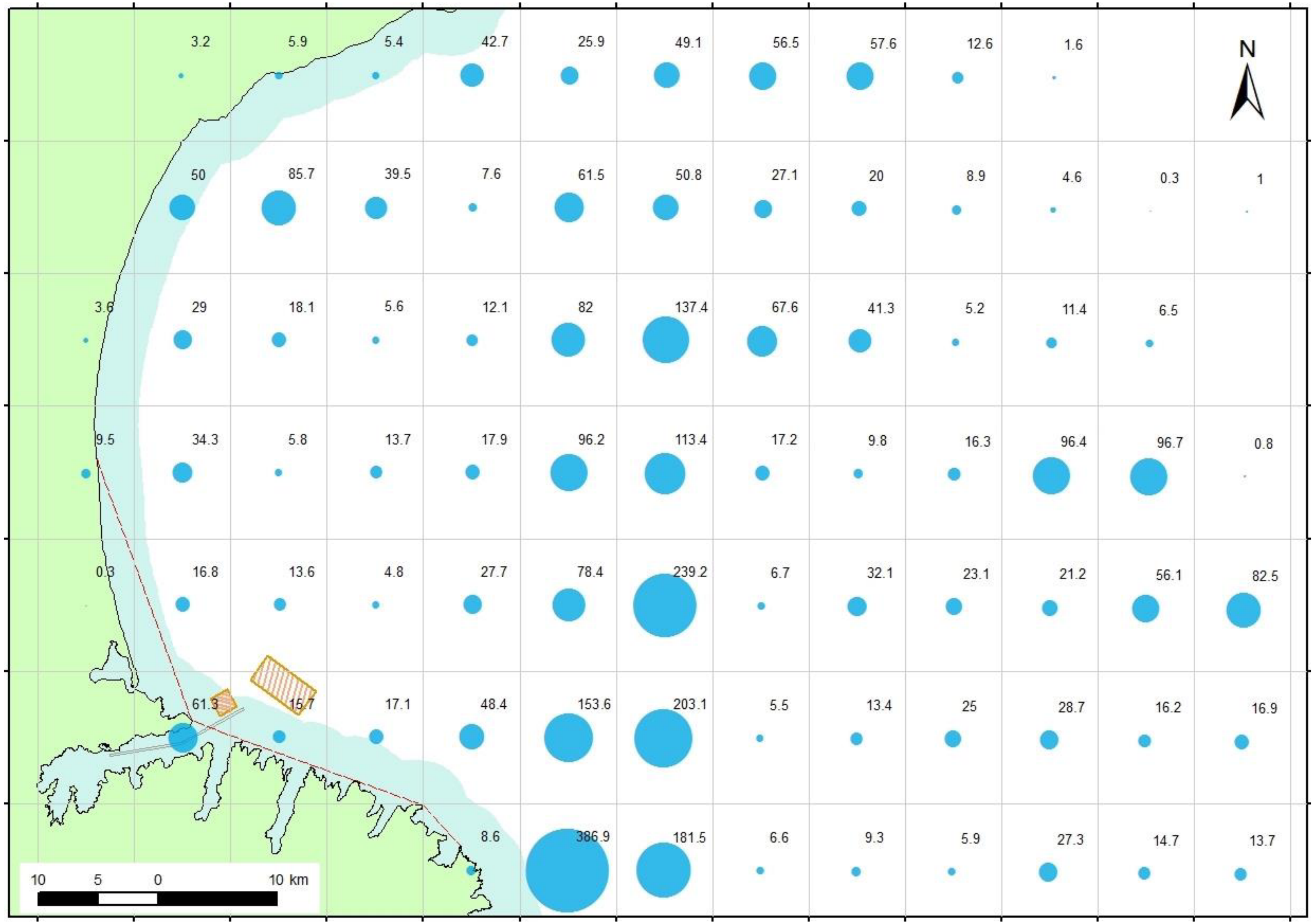

Figure 37 Recorded commercial catch weight (tonnes) for aggregated finfish species in Pegasus Bay (1 October 2011 to 14 August 2014) for 0.1 degree grid squares. Shaded area designates 2 Nm trawl height restriction. Red line designates inshore trawl prohibition boundary.

The plot for the nine aggregated finfish species (Figure 37) is clearly different to that for flatfish. Catch weights are concentrated well offshore from the Harbour and spoil ground locations. The catch weight recorded against the area offshore from the easternmost longitude of Banks Peninsula (effectively from outside Pegasus Bay) represented 83% of the total. The two grid cells associated with the proposed spoil ground represent a combined catch weight of 0.8% of that for the total area considered.

A degree of proportionality with flatfish catch weight is noted for the two columns of grid cells furthest inshore ($R^2 = 0.66$), so it is likely that this mainly represents by-catch species (*e.g.* elephant fish, gurnard, rough skate) from trawlers targeting flatfish.

6.3. Pāua and rock lobster

6.3.1. Pāua

Pāua can refer to three New Zealand species but the main species harvested commercially and recreationally is *Haliotis iris*. They are herbivores, feeding to a large extent upon drift algae, and can form large aggregations on reefs in shallow subtidal coastal habitats. Their range of movement is over a sufficiently small spatial scale that they may be considered effectively sedentary. Pāua are broadcast spawners and spawning is thought to be annual (late summer-autumn), although Sainsbury (1982) found the reproductive cycle of *H. iris* to be very irregular with spawning recorded in only two of four potential spawning seasons in Peraki Bay on the Banks Peninsula south coast. Pāua larval dispersal longevity is relatively short, with the non-feeding veliger larvae settling after between three to ten days. This means that the larval population can undergo only limited dispersal from the spawning adult population (Freeman 2006).

Newly settled larvae pāua live in reduced flow environments, mostly on crustose coralline algae habitats, where they can attach and grow. Once they become juveniles (40 to 45 mm in shell length) they move to and live in cryptic habitats, such as beneath rocks and boulders, until they are between 60 to 70 mm in shell length (3–5 years old) and have reached sexual maturity. They then prefer relatively exposed situations and are found generally in water depths less than 5 m, but up to 10 m (Freeman 2006). Hence habitat-related factors are an important source of variation in the post-settlement survival of pāua. Growth, morphometrics, and recruitment can vary over short distances and may be influenced by factors such as wave exposure, habitat structure, availability of food and population density.

Populations, distribution and commercial catch

Pāua are found in the outer Lyttelton Harbour/Whakaraupō as well as along the Banks Peninsula coastline of Pegasus Bay (Section 5.5). They have also been observed to occur at relatively high densities in the low intertidal zone along the northern shoreline as recently as 2009 (pers. comm. Oliver Floerl, Cawthron Institute) and specifically in the vicinity of Livingstone Bay (Sneddon & Dunmore 2014).

The NABIS lineage document for *Haliotis iris* notes that pāua are most common in clear water coastal situations, living from low water to 15 m. It is further reported that for a number of areas, including parts of Northland and Bay of Plenty, Taranaki, and Banks Peninsula, adult individuals are of smaller size, with only a limited proportion reaching the legal shell length of 125 mm.

Sainsbury (1982) reported that pāua at Peraki Bay (Banks Peninsula) grow more slowly and reach a smaller maximum size than those at Kaikoura. It was hypothesised that this may be related to lower water movement within the bays on Banks Peninsula and consequently sub-optimal rates of delivery of the drift algae on which pāua graze.

A query of MPI's NABIS website for the three years of catch data 2011–2014 showed no catch reported for the statistical areas of southern Pegasus Bay and the northern coast of Banks Peninsula (P322-P328 in Management Area PAU 3). This is in contrast to the southern coastline of Banks Peninsula, where the statistical areas west of Akaroa Harbour (P334 and P335) recorded 28.5 t and 18.2 t, respectively, for the same period (Figure 38).

Bradford (1998) and Boyd & Reilly (2003) analysed data from the 1996 and 1999/2000 National Marine Recreational Fishing Surveys. They reported *H. iris* being harvested in PAU 3 (eastern South Island from Clarence River to Waitaki River) as representing just 8.8% and 6.7%, respectively, of total estimated harvest nationally.

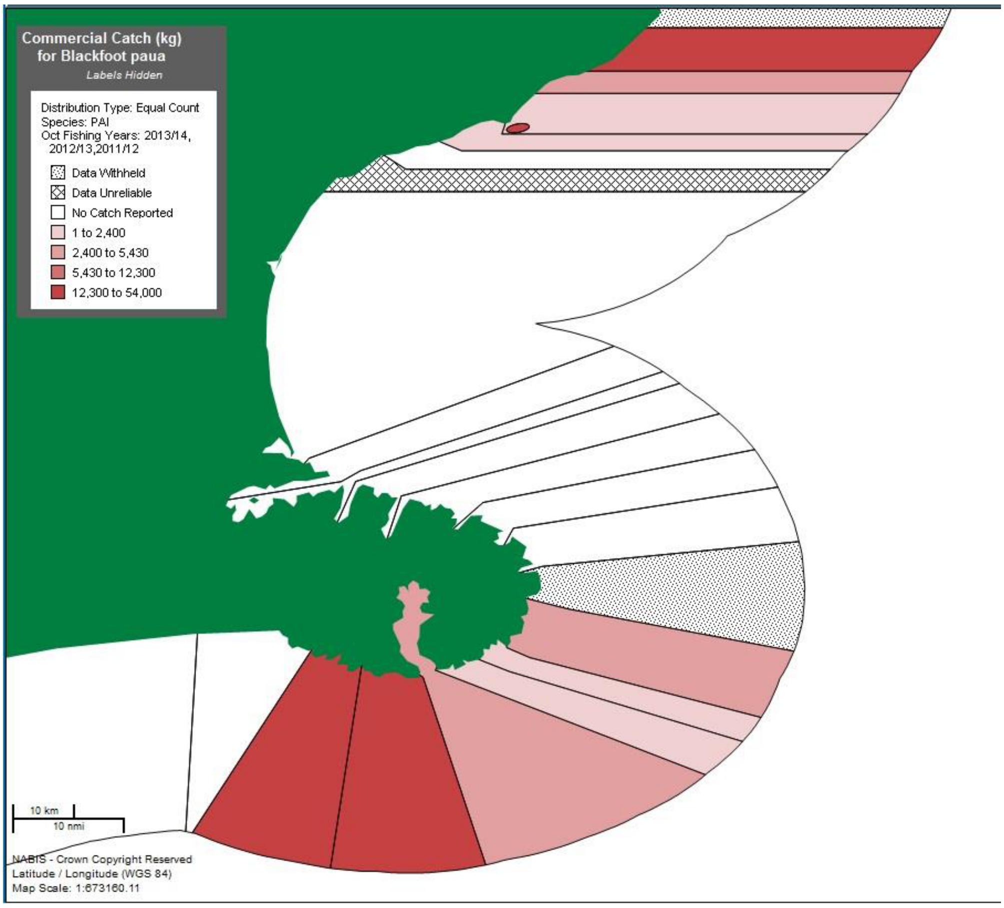

Figure 38 Reported catch weights for blackfoot pāua (*Haliotis* iris) in Banks Peninsula statistical reporting areas for 2011-2014. Results from a query of the MPI NABIS website http://www.nabis.govt.nz/.

6.3.2. Lobster

Rock lobsters are typically the largest and most abundant invertebrate predators on coastal rocky reefs throughout New Zealand. Two species are taken commercially, but the packhorse lobster (*Sagmariasus verreauxi*) is limited mainly to the north of the North Island. Spiny lobsters (*Jasus edwardsii*) are more widely distributed and are often an important structural and functional component of rocky reef assemblages (MacDiarmid *et al.* 2013).

Life cycle

Mating in *J. edwardsii* takes place after moulting in autumn. After the eggs hatch in spring, a long (1–2 years) pelagic larval phase begins wherein the larvae pass through three pre-settlement stages; the short-lived naupliosoma, a phyllosoma larval stage of at least 12 months and the final phyllosoma stage. The phyllosoma larvae metamorphose into the puerulus which settles on reef substrates mainly at depths less than 20 m. Settlement indices measured on collectors can fluctuate widely from year to year (MPI 2012).

Movement and migrations

Adult lobsters have a strong site association. Foraging occurs at night and is typically spatially limited although foraging distances on rocky reefs have been observed to increase with body size. In some places, at certain times of the year, larger males may migrate offshore across sand flats to feed on shellfish. Egg-brooding females are more active toward the end of the 3.5 month brooding season around September and October and may also form offshore aggregations in areas of high water current in spring at the time of larval hatching (MacDiarmid *et al.* 2013). Additionally, long distance mass migration of juvenile or sub-adult red rock lobsters is well documented around the southern coasts of the South Island although the numbers moving varies from year to year (Booth 1997). During spring and early summer, these migrations of variable proportions of immature individuals occur against the prevailing current flow from the east and south-eastern coasts of the South Island around Stewart Island towards Fiordland and southern Westland.

It is not known if such migrations are a feature of the Banks Peninsula area, but the mud substrates of inshore Pegasus Bay may restrict such behaviour. In tagging studies, Freeman *et al.* (2009) found that lobster movement patterns were sex- and size-dependent, but nearly all recaptured individuals were found on the same rocky reef on which they were tagged, indicating that lobsters were reluctant to cross muddy sediments between reefs.

Larval dispersal and population connectivity

The long pelagic larval phase allows them to be carried hundreds or thousands of kilometres by oceanic currents. However, in some situations large offshore eddies may maintain the larvae close to their source populations. Hence populations may have varying degrees of connectivity based on larval dispersion patterns. This connectivity was explored by Chiswell and Booth (2008) using ocean current data to numerically model larval tracks for different source locations and evaluate statistically where such larvae were likely to settle (*i.e.* larval sinks), as well as assigning the likely origins (sources) of existing populations.

Freeman *et al.* (2012) noted that because the long larval lifespan of this and many other marine species results in larvae potentially settling thousands of kilometres from their source, with the consequence that recruitment and adult abundance are decoupled. MPI (2012) reported that there is no evidence for genetic subdivision of lobster stocks within New Zealand based on biochemical genetic and mtDNA studies. It was further noted that the observed long-distance migrations in some areas and the long larval life probably result in genetic homogeneity among areas.

Commercial fishery

Rock lobster are taken by potting on or near rocky shores or rocky reefs and seabed from the shallows and out to at least 100 m depth if the substrate remains suitable. The fishery is highly seasonal, with the main catches taken in the winter months of

July and August. Catch data for *J. edwardsii* are available only on a fishing statistical area basis, and as so few fishermen are involved in this commercial fishery the data cannot be partitioned on a smaller spatial scale. Relatively low landed catch weights for lobster than for many finfish species are balanced by much higher market value per kilogram. The relevant statistical unit is area 918 that includes the entire Banks Peninsula coastline south of the Waimakiriri Rivermouth.

The Catch Effort and Landing Return (CELR) data for spiny lobster show that it is most abundant in the southeast of the North Island, northeast of the South Island, in Fiordland and western Foveaux Strait, around Stewart Island, and at the Chatham Islands (NABIS lineage for *J. edwardsii*).

A query of MPI's NABIS website showed that catch weight for statistical area 918 (Banks Peninsula) over the three years up to and including 2014 was just 24 t. This was significantly less than the 618 t for statistical area 917 (Kaikoura-Motunau) or the 106 t for 920 (North Otago coast) in the northeast and southwest of the South Island (158–999 t). The 2012 plenary report on spiny lobster listed catch data for only one year in the prior six, either because there was no fishing or due to the rule that data be withheld because fewer than three vessels were fishing (MPI 2012).

7. ASSESSMENT OF ECOLOGICAL EFFECTS

7.1. Loss or alteration of habitat

7.1.1. Increase in the long-term dredged area

The purpose of dredging is to bring about a lasting change to a benthic area; that of increased depths for the purposes of navigation. Since water depth and the nature of surficial sediments are key factors in the variability of benthic communities in shallow coastal areas, significant and potentially lasting effects within the specific area of dredging are unavoidable.

In the case of the Lyttelton Harbour/Whakaraupō channel extension, the area directly affected by the proposed capital dredging is approximately 125 ha, in water depths varying from 12 m to 17 m (at Chart Datum). Together with the increase in the width of the current channel (by 20 m) and the size of the swing basin area, this represents a near doubling of the approximately 150 ha of the current channel and swing basin area already maintained by dredging. In the context of similar habitats and water depths, the additional dredged area of the extended channel represents around 5% of the benthic area of the Harbour entrance and its approaches, but a much smaller proportion of soft substrate areas at similar depths in inshore Pegasus Bay.

The resultant greater water depths and potential sediment textural differences from changes in depositional conditions will result in a slightly different habitat from those outside the channel, and this is likely to be sustained, to an extent, by periodic maintenance dredging. However, benthic monitoring as part of the current maintenance dredging consent indicates that these differences are of themselves unlikely to constitute more than a minor change in terms of the functioning of benthic ecosystems over the wider area (Sneddon *et al.* 2015).

7.1.2. Offshore capital spoil ground

Although the predicted overall spoil volume (approximately 18 million cubic metres) is substantial in this case, lasting structural and ecological impacts in the vicinity of the proposed spoil ground are considered unlikely. Mitigating factors are listed as follows:

- The channel deepening project will occur in not less than two stages.
- Deposition will be incremental over extended time periods (9–14 months each stage for a 10,000 m^3 TSHD) rather than occurring in a single event.
- The spoil will comprise marine sediment with a high degree of textural and compositional similarity to that which comprises the current benthic substrate of the spoil ground.
- The sediment deposited at the offshore spoil ground will have generally low levels of trace metals and other contaminants.

- The benthic communities of the spoil ground area are dominated by small-bodied invertebrate taxa with generally short life-cycles and adapted to a dynamic sediment environment. Major habitat-forming species are absent.
- Spoil sediments which remain in suspension or are resuspended will be incorporated into sediment transport processes operating within inshore Pegasus Bay.
- The deposition will not result in shallowing of the area to an extent which will significantly affect hydrodynamic processes.

Size and ecological significance of the area affected by direct deposition

The rectangular area of the site proposed for the spoil ground is 1,250 ha. The volume of spoil generated from capital dredging is anticipated to be some 18 million m^3. Morphological modelling undertaken by MetOcean Solutions (2016a) assumed completion of dredging in a single stage, resulting in a layer of nominal thickness 1.44 m. In reality, the project will be undertaken in at least two stages and the duration of each stage (9–14 months) means that the process of bed-load dispersal through wave resuspension will be coincident with spoil deposition.

With regard to single deposition events, OCEL (2007) identified a nominal 300 m radius benthic spreading zone beneath the point of deposition. This was based on an earlier trial carried out in water depth of less than 10 m by a TSHD of 965 m^3 capacity. It was noted that, in greater water depths, the spoil material would be expected to disperse further across the seabed. They further noted that;

> *allowing for a final on-seabed specific gravity of 1.7 gives a volume of sediment equal to 400 m^3 per* (965 m^3) *hopper load. Spread over the area of a circle 300 m in radius, this volume equates to an average depth of sediment equal to 1.4 mm approximately over the area.*

Use of a vessel-mounted ADP to monitor sediment dispersal during a trial deposition of 1,000 m^3 of dredged sediments at the offshore spoil site in 2007 indicated that the advancing seabed plume front following release from the hopper became indistinguishable from the background well before the 300 m radius was reached (OCEL 2013). Since it is likely that a significantly larger dredge will be used for the capital dredging project (hopper capacity potentially on the order of 10,000 m^3), this result may not be directly applicable, but it does indicate that the benthic area affected by dynamic spreading of the spoil material will be relatively limited and generally confined to within hundreds of metres of the spoil ground boundary.

Kingett Mitchell (2003b) considered the results of benthic community analysis from a number of historical studies over a broad area in Pegasus Bay, including sites both inshore and offshore. A significant degree of consistency in infauna community structure was suggested by the reviewed results, with the numerical prevalence of polychaete taxa a noted feature. The present ecological characterisation of the vicinity of the proposed spoil ground is also highly consistent with the results cited. This suggests that the benthic habitat within and around the spoil ground is part of a much larger area of similar substrate and ecology within Pegasus Bay. Hence the area adversely affected by spoil deposition is not considered to be representative of a habitat limited in extent within the wider region.

Spoil physical characteristics

Geotechnical investigations have identified that the outer Harbour bed sediments can be characterised as a very fine clay/silt mixture typically defined as 1% fine sand (50 250 µm), 45% silt (5–50 µm) and 54% clay (<5 µm) (OCEL 2013). A hard underlying layer of very stiff, cohesive sandy silt has been identified in places along the dredged channel beneath current maintenance dredging depths. This would be penetrated by the proposed capital dredging and thereby constitute a proportion of the total spoil material (Gary Teear, OCEL Consultants; pers. comm). Outside the Harbour heads, the bed material comprises fine sandy silt with the silt/clay fraction remaining predominant.

Approximately 80% of the channel extension area to be dredged extends outside a line between Godley and Adderley heads. Surficial sediments in the channel extension area sampled in 2007 indicated around 3% fine sand (63 µm–250 µm). This compares to a mean of 6% fine sands for samples from the proposed spoil ground (Figure 9). Samples from the currently dredged channel adjacent to Livingstone Bay, collected as part of monitoring for LPC's maintenance dredging were also broadly similar in texture to sediments from the proposed capital dredge spoil ground, having a silt/clay content of 73–95% (surveys 1999, 2004. 2009 in Sneddon & Bailey 2010).

It is unclear whether the underlying stiff silt material represents a grain-size distribution similar to surficial sediments; however, observations where this material was struck during maintenance dredging indicate that its cohesiveness would be maintained within the dredged spoil as larger chips (pers. comm. Gary Teear, OCEL Consultants Ltd). Such coarse material has the potential to alter, at least temporarily, the sediment habitat of the spoil ground, leading to an altered benthic community structure which re-establishes following spoil deposition. However, given the composition and likely overall proportion of such material, this change will be relatively subtle and will not persist in the longer term.

Smothering effects

For the benthic habitat within the spoil ground, the deposition of dredge spoil over an extended period (for each stage) is equivalent to a series of extreme sedimentation events, significantly exceeding those of natural occurrences such as from periodic swell events. This will lead to substantial smothering effects to the existing benthic community. In assessing the impact on the benthic environment within the spoil ground boundaries, the principal mitigating factors are the incremental nature of the deposition and the expected high degree of physical similarity between the majority of the spoil and the existing sediments of the spoil ground.

Benthic organisms are adapted to the natural processes of sediment movement, erosion and deposition. In the case of the proposed spoil ground, the benthic community is characterised by species adapted to a dynamic sedimentary environment. However, these fauna will have varying degrees of tolerance to such inundation, based at least partly on their vertical mobility within the sediments. The steady incremental rate of deposition over quite long time periods will give many fauna time to migrate vertically within the spoil layer. Highly motile rapid burrowers, quick tube-builders and rapid colonisers are likely to survive as remnant populations and re-establish rapidly, even within project time-scales. Species which create significant biogenic structures such as heavy tube casings or other semi-permanent anchorage within the sediments are less likely to survive such inundation. However, such species are largely absent from the benthic communities sampled (Sections 5.2 and 5.3). Even mobile species may be subsequently affected by the loss of substrate consolidation and sustained very high near-bottom suspended solids levels which can decrease suspension feeding efficiencies to levels which may threaten survival.

As noted, the physical structure of the substrate within and adjacent to the spoil ground boundaries may remain altered in the months following the completion of deposition, with less consolidation of the surface sediments and areas of fluid mud which may make it difficult for the survival or re-establishment of the original communities. Since such fluid mud patches have been identified by Curtis (1986) as existing in the vicinity of the channel extension area off Godley Head, the slightly sparser benthic communities identified for this area may be comparable to a successional stage during the recovery of the spoil ground area.

The greater mobility of unconsolidated surface sediments will potentially result in the benthic footprint of spoil deposition impacts being slightly larger than the spoil ground boundaries. The spread of fine mobile benthic material will be dependent upon the period over which it remains unconsolidated and the processes (principally wave events) which resuspend it. The erosion and redeposition patterns of the nominal 1.44 m deposition ‘mound’ was modelled by MetOcean (2016a) over a five year period. Although some net accretion (on the order of 0–5 cm) was seen to occur outside the spoil ground boundaries (consistently towards the west), this had been remobilised and dispersed by year 5, after which the model had predicted erosion of the entire sediment volume initially placed in the disposal ground[17].

[17] MetOcean stress that quantitative predictions should generally be considered carefully since the morphological model could not be specifically calibrated; however, the approach is expected to provide a reasonable picture of the net sediment dispersion footprint around the mound on an annual basis. The predictions are also additionally conservative in assuming the project has been completed in a single stage.

Significant depositional effects are likely to be limited to the spoil ground itself and a relatively narrow boundary margin or spreading zone. Probert and Anderson (1986) reported that shelf sedimentation rates of at least 40 mm/yr may be required before conditions become stressful for some soft-bottom infauna. Furthermore, while impacts may be significant with even relatively thin deposited layers where introduced sediments are distinctly different to those of the receiving environment (*e.g.* Gibbs & Hewitt 2004), the spoil in this case is of marine origin and has a high degree of similarity to benthic sediments in wider Pegasus Bay. Hence it is likely that the limited amount of deposition or increased bed-load sediment flux occurring outside the immediate margins of the spoil ground will be assimilated into Bay-wide sediment processes with negligible ecological effects.

Highly mobile demersal species, including fish, are likely to move out of the immediate area of deposition unless the disturbance facilitates the availability of their food sources. Fish are discussed in more detail in Section 8.

Recovery

Environments that experience relatively frequent wave-, wind-, and current-induced disturbances are typically inhabited by low-diversity, ‘r-selected’ benthic assemblages (fast-growing, small, opportunistic) that can readily re-establish themselves under conditions of high frequency disturbances (Dauer 1984; Clarke & Miller-Way 1992, Ray & Clarke 1999). These communities are naturally held in early successional stages and are therefore able to recover more rapidly than communities in more stable environments (Newell *et al.* 1998; Bolam & Rees 2003).

The generally accepted benthic successional paradigm (Pearson and Rosenberg 1978, Rhoads & Germano 1986) is that, following initial decreases to benthic diversity, abundance, and biomass that immediately follow a disturbance, pioneering (Stage I) organisms, such as small, tube-dwelling polychaetes and small bivalves colonise the surficial sediments. These opportunistic taxa occur in relatively high abundances and low diversity and over time are replaced by larger, longer-lived and deeper-burrowing (Stage II) species. The Stage III assemblage is comprised of a more diverse but less abundant group of larger taxa such as maldanid polychaetes. Thus, the absence of larger deposit feeders and mid-depth burrowers is indicative of areas that are in a state of recovery.

Rapid recolonisation of soft-bottom benthic habitats is frequently associated with either unconsolidated fine grain sediments (Cruz-Motta & Collins 2004) or the rapid dispersion of fine-grained dredged material by currents (Van Dolah *et al*. 1984). Desprez (2000) noted that, in cases where there is a change in sediment type, an altered community structure can last for many years. In relation to the Port of Otago spoil disposal site, James *et al.* (2009) commented that recovery times are shortest when dredged and spoil ground native sediments are well matched (*i.e.*, similar gain size distribution). Studies of the deleterious effects of increased sedimentation within estuaries (*e.g.* Gibbs & Hewitt. 2004), have focussed mainly on terrigenous[18] sources where marked differences can exist in the physical nature of introduced versus natural bed sediments.

For the proposed spoil ground, the processes of recolonisation and recovery will begin as soon as spoil deposition begins, as the dredger distributes the spoil around the site with each hopper load of the dredging cycle. Many benthic infaunal organisms such as burrowing polychaetes, amphipods and molluscs can colonise newly deposited sediments through vertical migration. Therefore, if deposited sediment depths and/or rate of deposition are within the vertical migration capacity of these organisms (up to 20–30 cm), recovery rates may be quicker than if colonisation is dependent solely upon lateral migration from adjacent areas and larval settlement. On this basis, populations of many of the actively burrowing species identified by the survey (including many of the polychaetes, crustaceans and some of the bivalve molluscs) are unlikely to completely disappear, even temporarily, from the spoil ground. However, the overall community structure is expected to be altered, in the short term, by spoil deposition.

Early recovery of benthic communities at the spoil ground is likely to proceed similarly to that of maintenance dredging spoil disposal sites within Lyttelton Harbour/Whakaraupō. Changes to benthic communities in the existing maintenance spoil grounds, while observable, have been found to be relatively subtle within a few months of the cessation of deposition activities (Sneddon *et al*. 2015). Multivariate statistical analysis established common community characteristics for samples from areas disturbed by maintenance dredging or spoil disposal. However, the differences between this group of samples and those from other similar Harbour stations outside the spoil grounds were minor, relating to patterns of relative dominance rather than the communities being fundamentally different.

The rapid recovery of soft sediment communities following dredge spoil deposition has been reported by other investigators. Roberts and Forrest (1999) also found very little effect evident in benthic communities of a similarly dynamic sedimentary environment in Tasman Bay after decades of annual spoil disposal from maintenance dredging in Port Nelson. Six months after the last deposition, the infauna community was found to be statistically indistinguishable from control sites which did not receive spoil. This was attributed to the dispersive nature of the site.

Notwithstanding the overall scale of spoil deposition at the proposed spoil ground, effectively complete recovery of the benthic habitat is expected over time. This is due mostly to benthic communities adapted to a dynamic sediment environment and the similar texture and composition of the deposited spoil layer to existing sediments.

[18] Terrigenous sediment refers to that derived from the land, generally through erosion and entrainment within run-off.

Spoil contaminants

Trace metal concentrations in surficial sediment samples collected from within the Harbour (2016) and the channel extension area (2007) have generally been below ANZECC (2000) ISQG-Low criteria and comparable to levels in sediments from Pegasus Bay (Figure 11). The one exception to this was a single sample from Station C1 in the channel extension area (Figure 7) exhibiting elevated concentrations of copper and chromium. But upon resampling at C1, the result was not repeated and it was concluded to be the result of the chance inclusion of contaminated particulate material rather than being representative of the bulk sediment (Section 5.1.2).

Three sediment samples from the central Harbour area were analysed for polycyclic aromatic hydrocarbons (PAHs; Section 5.1.2). Although 13 of the 15 PAH compounds were detected in these samples, all were well below the corresponding ISQG-Low criteria.

As part of LPC's Maintenance Dredging Consent (CRC135318), sediment samples are collected from 12 benthic stations around the Harbour (Figure 7). These are analysed to gauge whether disposal of dredged sediments at the spoil ground along the northern shoreline of the harbour is resulting in elevated contaminant concentrations in the receiving environment. Sampling undertaken in 2015 returned trace metal concentrations consistently below ISQG-Low for all sites (Sneddon *et al.* 2015) and indicated that levels in the Harbour (excluding the Inner Harbour of the Port) are generally comparable to those of Pegasus Bay sediments. It was noted though, that previous sampling specifically within the maintenance spoil grounds (1994, 1999 and 2004) has occasionally returned sediment mercury concentrations on the order of the ISQG-Low trigger value (0.15 mg/kg). Of the 71 analytes in the suite of semi-volatile organic compounds (SVOCs), the only organic contaminants detected in these samples were PAHs and only in two composite samples from Gollans Bay, which receives maintenance dredge spoil from the Inner Harbour.[19]

Apart from single instances of elevated mercury and the PAH compound 2-methylnaphthalene in samples from Gollans Bay in 1999 (Barter 2000) and 2015 (Sneddon *et al*. 2015), respectively, all contaminants within benthic Harbour sediment samples have been below ISQG-Low. But because the greatest proportion of the capital dredge spoil volume will comprise sediments from strata deeper than those affected by anthropogenic inputs, any low levels of contaminants in surficial sediments will have very little potential to affect the contaminant status of bulk sediments deposited at the spoil ground.

[19] The SVOC suite gives detection limits significantly higher than for the dedicated PAH suite. This would explain why most PAHs were detected at low levels in the February 2016 Harbour samples (Section 5.1.2), but not in most of the samples collected for the 2015 maintenance dredge monitoring survey.

7.1.3. Wider Lyttelton Harbour/Whakaraupō

Harbour hydrodynamics and sedimentation

Lower Lyttelton Harbour/Whakaraupō and its approaches represent a very dynamic benthic environment. The Harbour has been subject to regular maintenance dredging of the current channel and berthage areas for many decades. Sediment inputs from maintenance dredging have been identified as constituting a major part of overall fine sediment fluxes in the outer Harbor region (Curtis 1986, OCEL 2013). This has resulted in very active sediment redistribution processes operating to stabilise the harbour bathymetry under both natural and dredging conditions. Modeling carried out by MetOcean (2016b) indicated that recycling of sediment deposited in the current maintenance dredge spoil grounds back into the dredged channel was likely to be significant.

Curtis (1985) claimed that asymmetric tidal circulation transports fine muddy sediments predominantly towards the harbour entrance where they accumulate in the channel and on the northern side, resulting in grain size contours which run parallel rather than normal to the harbour's longitudinal axis, a situation atypical of most coastal inlets. Based on the spatial correlation of seabed grain sizes, McLaren (2012) suggested that fine dredged sediments placed on either side of the Harbour will be moved, first towards the middle of the Harbour and then seawards. . Although circulation patterns in the outer Harbour appear to be more complex than the single large gyre postulated by Curtis (1985), the observed spatial patterns in sediment texture are explained by an asymmetry in tidal flows. MetOcean (2016b) established that the Godley Head sector of the spoil ground (which has been used extensively since 2009) is located on a strong transport pathway that is directed into the Harbour. They noted that, in all elevated wave conditions, the expected sediment flux from the spoil ground is directed approximately toward the south-west and that the entrained sediments preferentially accumulate within an accretion zone of the channel in the vicinity of Breeze and Mechanics bays.

The soft sediment benthic habitats of the Harbour represent a continuum of overlapping communities governed to a large extent by variability in sediment texture and without distinct transitional boundaries (Knight 1971; Hart *et al.* 2008). While changes to the bathymetry of the outer Harbour from the channel deepening will have some localised effect on hydrodynamics, the tidal asymmetry operating in the outer Harbour will effectively be preserved MetOcean (2016c). Since this asymmetry in flows in the outer Harbour is considered to be the major driver of the distribution of sediment substrates, its retention suggests that any redistribution of the textural patterns of benthic sediment is likely to be only subtle, and any consequent changes to benthic communities will be similarly minor.

Although the extended channel will be effectively aligned with the Lyttelton Harbour/Whakaraupō shoreline morphology and tidal flow regime, modeling has indicated that the deeper channel will modify the wave climate in the Harbour entrance region (MetOcean 2016b). As one of the key drivers in species distribution, significant changes in wave energy will affect community structure in intertidal or shallow subtidal areas along the outer Harbour shorelines. Since wave energy is naturally attenuated with distance up the Harbour, any such changes will manifest as small spatial shifts (up- or down-harbour) in transitional areas between ranges of overlapping taxa. Since the spatial gradient in changes to intertidal reef communities from the outer to central Harbour has been observed to be quite gradual (Section 4.5), shifts resulting from the deeper channel are likely to be largely indiscernible.

Upper Harbour

It is generally accepted that Lyttelton Harbour/Whakaraupō sediments are predominantly of terrestrial rather than marine origin. Hart *et al.* (2008) reported that the main source of material for sedimentation in the upper harbour is catchment erosion of loess and loess colluvium (volcanic detritus). CRC (2008) reported that through thousands of years of accretion, eroded soils from the hillsides has filled in the harbour basin with up to 47 m of sediment.

Hart *et al.* (2008) reported that catchment erosion rates are an order of magnitude greater in the upper Harbour and stated that

> *The limited literature that exists suggests that, due to the harbour current patterns, and the lower harbour and dredged channel being an efficient sediment sink, little sediment entering the harbour from Pegasus Bay, or recirculated from dredge spoil deposition in the northern bays of the lower harbour, is transported into the upper harbour.*

While the deeper and extended channel will slightly alter the wave climate and tidal current velocities in the lower Harbour, the effects of these changes on the upper Harbour are expected to be negligible. The tidal prism and bathymetry of the upper Harbour will remain unchanged and the deepened swing basin and channel will continue to function as a sink for sediments resuspended in the central and lower Harbour.

7.1.4. Offshore maintenance spoil ground

The 256 ha area of the proposed offshore maintenance dredge spoil ground is expected to receive spoil volume from the outer Harbour and approach channel of 900,000 m^3 to 1.2 million m^3 annually. This represents a nominal layer thickness of 35 cm to 47 cm. Given this level of deposition and the generally similar benthic environments, much of the assessment relating to potential alteration of the capital spoil ground benthic environment (Section 7.1.2 above) applies directly to the maintenance spoil ground. On this basis, it is appropriate to consider first where the two sites and associated activities differ.

Compared to the capital spoil ground, the site of the proposed maintenance ground;

- Is in slightly shallower water depths
- Features a nearly identical bed substrate
- Is subject to relatively similar sediment transport field patterns (MetOcean 2016b)
- Supports a similar though slightly less diverse benthos
- Is closer to shoreline reef habitats (at Godley Head) and the Harbour generally

Compared to the activity of capital dredging, maintenance dredging;

- Is ongoing and periodic (typically annual)
- Involves spoil comprising relatively recently settled sediments
- Is likely to be carried out using a smaller capacity TSHD (in this case probably 1,840 m^3).

According to the modelling of sediment dynamics carried out by MetOcean (2016b), sediment dispersion from the maintenance spoil ground subsequent to deposition will be elliptical but skewed in the direction of wave propagation; that is, towards Godley Head and the Harbour. However significant changes in bed level outside the spoil ground boundary over time were not predicted by the model, indicating that the site is sufficiently dispersive to prevent such changes.

Since a high degree of physical similarity can be expected between the maintenance spoil and the native sediments, the dispersion of the spoil mound over time has no significant implications for the surrounding areas. While sediments recently settled in the navigation channel have greater potential to carry contaminant loading than those generated by capital dredging, the chemical analysis record for central to outer Harbour sediments indicates that the risk from sediment contaminants is less than minor. It is understood that dredge spoil from the Inner Harbour will continue to be deposited at the Gollans Bay spoil ground.

Similar to the capital spoil ground, the scale of deposition is such that significant smothering impacts to the benthic community are unavoidable at the site, but similar conditions also apply to the resilience of such communities and relatively rapid rates of recovery. The periodic nature of maintenance dredging means that there is potential for the spoil ground benthic community to be effectively held in an intermediate successional stage where complete recovery of the habitat is effectively never reached in the intervals between dredging campaigns. However, monitoring of the current maintenance spoil grounds along the northern side of the Harbour has shown that differences in community structure between areas within and outside the grounds have been relatively subtle even a month following deposition (Sneddon & Bailey 2010). As discussed for the capital spoil ground, this is attributed to the dynamic sediment environment serving to prevent further successional development in these communities, ultimately having the effect of facilitating rapid recovery from larger episodic disturbances (Section 7.1.2). On this basis, longer-term changes to the benthic environment and communities within the spoil ground are expected to be minor.

7.2. Water quality and far-field stressors

7.2.1. Release of contaminants, nutrients and organic material

As discussed in Section 7.1.2, the low metal concentrations found in sediments from the channel extension area and the central to lower Harbour (see Figure 11) indicate generally low levels for these and other anthropogenic contaminants. The detection of a range of PAH compounds at low concentrations in central Harbour sediments (Section 5.1.2) is consistent with previous investigations (*e.g.* Sneddon 2014a) and may be related to coal particulates or other historical inputs. Higher levels of contamination for both metals and organic compounds appear to be limited to spatially constrained areas within the Inner Harbour which occur outside the capital dredging footprint (Sneddon 2014b).

Many contaminants bind strongly and preferentially to particulate surfaces (accounting for their frequent accumulation within the benthic sediments of depositional zones such as estuaries) and will not easily partition to the water column, even when this material is resuspended. A substantial proportion of the total capital dredge spoil will come from strata unaffected by anthropogenic inputs. While some surficial sediments in the central Harbour may contain contaminants at concentrations slightly above background, release of these to the water column through resuspension (either during dredging or at the spoil ground) is expected to be minimal. Given the expected sediment plume concentration contours from both dredging and spoil disposal activities (see Section 7.2.2), the quantities of sediment-associated contaminants potentially transported to far-field receptors (including the shoreline) will be negligible.

The release of significant quantities of nutrients and organic matter from resuspended sediments can potentially result in oxygen depletion effects within the water column. Although nutrients were not specifically analysed in sediment samples from the channel extension area, the relatively low sediment organic content and the absence of symptoms of anoxia in the surficial cores indicate that the resuspension of sediments will not result in rapid or extensive oxygen depletion. Sediments deeper in the profile are not expected to be organically enriched relative to surface layers.

Barter (2000) took samples from two hopper loads of sediments dredged from the Inner Harbour for LPC's maintenance dredge spoil monitoring. These returned total nitrogen, total phosphorus and 5-day biochemical oxygen demand (BOD_5) concentrations that were not unusually elevated. Total nitrogen levels in particular were low in comparison to those normally found in uncontaminated fine-textured estuarine sediments and may have reflected the negligible freshwater inputs to Lyttelton Harbour/Whakaraupō. The results were consistent with sediment profile observations for the 12 benthic sites sampled throughout the Harbour and it was concluded that these sites were relatively unenriched.

It is further considered that the exposed and well-flushed nature of both the capital dredge and spoil disposal areas would also serve to make the occurrence of any such acute water quality effects from sediment resuspension very unlikely.

7.2.2. Turbidity and suspended solids

The scale of the CDP and the anticipated volume of spoil produced mean that the production of turbidity plumes and their subsequent movement with ambient currents will be the principal stressor for the local marine environment. The fine nature of benthic sediments along the Harbour axis means they will be easily resuspended by disturbance from the dredge, entrained at high concentrations within hopper overflow water and will be slow to settle out of the water column.

The severity of ecological effects from high turbidity and suspended solids depends on a number of factors, including:

- The nature of the suspended matter (composition, size range, reactivity *etc.*)
- Concentration within the water column
- Duration of the turbidity event and rate of dilution and dispersion
- Rate of settlement of suspended particulates out of the water column
- The level of background turbidity to which ecological communities are naturally adapted.

The last factor, relating to the inherent tolerance of marine communities to high turbidity/suspended solids, is an important consideration. For benthic communities, this depends to an extent upon the nature of the existing substrate. Those living on or within fine soft sediments will be inherently tolerant of near-seabed turbidity layers resulting from natural resuspension processes and relatively high rates of deposition. In contrast, reef communities may be much less tolerant, especially at sites where clear water is the norm. Much depends on the levels and ranges of turbidity to which communities are naturally accustomed.

Background turbidity

Inner Pegasus Bay and Lyttelton Harbour/Whakaraupō are relatively turbid marine environments. The variability in turbidity is high in surface waters but water of high clarity does not typically occur and underwater visibility is consistently poor. Benthic resuspension layers frequently reduce underwater visibility at the seabed to zero over fine sediment substrates. Shoreline reef areas are significantly affected by their

proximity to fine sediment substrates in shallow water depths (Section 5.5.1) and near-shore areas of higher turbidity can be conspicuous (Figure 2).
To place the turbidity plumes expected from dredging and spoil disposal operations into context with natural processes, it is useful to consider the scale of background fine sediment inputs to the local coastal waters. Riverine inputs of sediments to the Canterbury coastline and Pegasus Bay can be very high. Another source of fine sediments is the abrasion of gravel beaches in the Canterbury Bight from which suspended sediments are carried northwards by the Southland Current (Section 3.3). However the available numerical data for background values of turbidity and suspended solids is as yet relatively limited.

Canterbury Regional Council's water quality sampling carried out 2007–2013 (Table 1) gives some indication of the background for inshore surface waters with the constraint that sampling would have been undertaken in relatively calm weather conditions. Samples taken from off the Wamakiriri rivermouth furthermore suggest that sampling did not occur in conditions where the river had been in flood. Suspended solids concentrations varied up to a maximum of 39 mg/L for a site 3 km offshore from the New Brighton Pier, with median 6 mg/L (n = 28). For the Harbour heads, concentrations varied up to 38 mg/l with a median of 9 mg/L (n = 51). For the central Harbour, a median and maximum of 13 mg/L and 42 mg/L were recorded (n = 51).

Dredging plume propagation and potential effects in Lyttelton Harbour/Whakaraupō

Capital dredging will take place mostly within an area of tidally reversing currents within the central and lower Harbour, its entrance and immediate approaches. MetOcean (2016c) used a particle tracking model to examine dredging-generated plumes which will be subsequently transported by ambient currents and diffusion processes. Model assumptions included the amounts of sediment put into suspension from the drag head, prop wash and overflow discharge. The model was run for 11 dredging locations along the channel, for TSHDs of three different capacities, and a full range of tidal conditions, giving a spatial envelope for the average plume at each dredging position. Model runs also included simulation of a range of hopper overflow discharge times; no discharge, 10, 20 and 30 minutes.

The results indicated that the bulk of suspended material would be near the seabed, within the constrained channel, and that tidal transport would be strongly directional along the Harbour axis with little transport towards the harbour shorelines. Although a cross-harbour component was identified, increasing through the Harbour entrance, this was secondary to the main axial flow until well past the heads. The suspended sediment plumes (and associated deposition) are therefore expected to be largely constrained to within, or near to, the channel. The model did not predict plumes from dredging to extend to the rocky shorelines of the harbour or the outer coast but indicated that there is the potential for plumes to reach Shag Reef during dredging of the swing basin at the western end of the channel.

The waters around Shag Reef are typically very turbid. There was insufficient underwater visibility to conduct a dive survey in February 2016, despite generally settled conditions. An intertidal survey recorded deposited fine sediments as a prominent feature of the reef, and a correspondingly silt-tolerant community assemblage was documented (Section 5.6). However, a significant increase in the concentration and duration of exposure to suspended sediments above the current background condition is likely to have an effect on the biota supported by the reef, especially on some taxa for which present SSC conditions may be marginal.

While most sediment put into suspension by dredging will settle out close to the point of disturbance, material that is slower to settle will be transported by ambient currents. Entrainment within tidal flows is the principal mechanism by which sediment is transported within the Harbour. Modeling work carried out by Mulgor Consultants Ltd (2014) to examine the tracks of neutrally buoyant particles indicated that sediments that remain in suspension can be carried from the Port swing basin to locations as far west as Rapaki Bay and Quail Island on a single flood tide. This restricted potential range will limit the quantity of suspended sediment that can be transported to the upper Harbour regions.

Suspension of sediments from spoil deposition

MetOcean (2016d) modelled the deposition of spoil and the generation and propagation of turbidity plumes at the proposed spoil ground. Using TSHDs of three different sizes (5,000, 10,800 and 18,000 m^3 hoppers), they used 10 years of hindcast data to predict the range of conditions which may be expected at the site.

The spoil load carried by the dredger represents a heavy slurry which, when jettisoned, behaves as a dense fluid released into the less dense seawater surrounding it. A deposition event was described as occurring in three phases:

1. Convective descent during which the material falls from the hopper under the influence of gravity
2. Dynamic collapse when the descending mass impacts the sea bed and flows out horizontally (100-500 m) as a density current from the impact point under its momentum
3. Passive dispersion whereby all material left in suspension after the first two phases begins a process of settlement and is transported by dispersion and ambient currents.

It is the last phase which is the subject of plume modelling because the passive plume has the potential to affect a spatial area an order of magnitude greater in extent than the dynamic plume (which settles quickly). It is estimated that 73% of the material released from the hopper will deposit directly to the seabed and not contribute to the generation of sediment plumes.

Three sources were identified for the material involved in passive dispersive transport:

1. Surface losses – sediment entrained vertically around the hull of the dredger due to turbulence associated with the discharge of sediment (1%)
2. The de-entrainment (stripping off) of sediments throughout the water column from the descending mass of spoil during convective descent (5%)
3. Material left suspended near the seabed by the density current generated by the dynamic collapse phase (21%).

Although the surface loss component will represent only a very small fraction of the material released, it is likely to be visibly distinct in the immediate vicinity of the dredge.

The extent assumed for the seabed density-current plume is consistent with a trial deposition of 1,000 m^3 of sediments from maintenance dredging undertaken at the proposed spoil ground site in October 2007. The horizontal outflow of sediment from the seabed impact point was tracked using a vessel-mounted ADP. The advancing seabed plume front associated with the outflow of material became indistinguishable from the background less than 300 m from the release point (OCEL 2013).

Propagation of spoil disposal plumes

The model suggests that most of the circular near-bed SSC component of the passive plume will settle within 500 m of the release site in the 30–45 minutes following disposal. The cumulative effect of multiple deposition events near the spoil ground boundary will result in a margin of deposited sediment around the spoil ground but the thickness of this layer will decrease rapidly with distance.

The passive plume will continue to settle and disperse via diffusion. The simulations indicated that a plume concentration contour of 10 mg/L (above background) would generally stay within 1 km of the disposal location in the bottom layer and within 500 m in the mid-water layer. Near the seabed at the spoil ground, the background concentration is likely to be significantly greater than 10 mg/L most of the time and therefore benthic communities will be adapted to these levels. Hence effects on the native substrate or benthos from these particulates settling out of the water column are not expected to be detectable at 1 km from the spoil ground boundary.

7.2.3. Maintenance dredge spoil disposal

As for considerations of depositional effects (Section 7.1.4), there are many similarities between potential water quality effects from the disposal of sediments at the capital and maintenance dredge spoil disposal grounds.

The nature of maintenance dredge spoil deposited at the proposed offshore maintenance ground is not expected to differ appreciably from that currently dredged from the navigation channel. Since a greater proportion of maintenance spoil will be sourced from areas in the outer Harbour and approaches, the risk of release to the water column of chemical contaminants, nutrients and organic matter is expected to be low to negligible.

The modelling of plume propagation from maintenance spoil deposition by MetOcean (2016e) took into account the use of a smaller capacity dredge (1,840 m^3) than that which may be used for capital dredging. One year time-averaged simulations covering the full range of expected conditions at the site indicated that the 10 mg/L (above background) turbidity contour will generally stay within 1 km of the deposition site for all layers of the water column (surface, mid and bottom). That is, plumes of a strength greater than 10 mg/L above background are not expected to extend more than half the distance to the nearest shoreline receptors (at Godley Head). Given the nature of seabed habitats within the area encompassed by these contours and the information available regarding background turbidity in near-shore Pegasus Bay, these plumes, or their subsequent depositional footprints, are not expected to result in significant adverse ecological effects.

The predicted absence of effects on shoreline reef habitats from deposition-derived plumes is consistent with observations and surveys of intertidal and subtitdal communities within the current maintenance dredge spoil grounds (Sections 0 and 5.6).

7.3. Habitat sensitivity to suspended sediments

The introduction of suspended sediment from human activities is increasingly recognised as a significant environmental stressor in many aquatic ecosystems (Gray 1997). An important consideration in the establishment of site assessment criteria for dredging and spoil disposal operations is the proximity to areas of special scientific or biological importance as well as to habitats with sensitive receptors (DEWHA 2009). Lyttelton Harbour/Whakaraupō and southern Pegasus Bay have a number of features and areas of high marine ecological value. These include the fringing reefs of the outer heads and coastline, and the salt marshes and tidal flats of the upper Harbour and Banks Peninsula inlets which support a range of wading birds and waterfowl and are likely to represent nursery grounds for a number of fish species.

The steep rocky shorelines of Godley and Adderley heads are approximately 750 m and 950 m, respectively, from the nearest point of the proposed extended channel area. The mid-point of the entrance to Port Levy/Koukourārata is approximately 1 km from the navigation channel dredging area. The nearest shoreline to the proposed capital spoil ground is that between Port Levy/Koukourārata and Pigeon Bay, over 3 km to the south. The proposed offshore maintenance spoil disposal ground is over 2 km from the Godley Head shoreline (Figure 1).

The modelling conducted by MetOcean (2016c,d) indicates that sediment plumes from the dredging activities will not reach these receptors at concentrations that would be detectable above the natural background. Nonetheless, in addition to near-field benthic areas, the following sections consider the sensitivity of far-field communities which may be reached by aged plumes as a result of unforeseen factors.

No trigger values for suspended sediments or turbidity is given in the ANZECC (2000) guidelines for New Zealand coastal waters. The wide range of background values for different coastal environments means that assessment must be approached on a site-specific basis. However, a range of adverse ecological effects can occur when suspended sediment concentrations are sustained in excess of background concentrations. Knowledge of the specific sensitivities of different classes of organism is relatively limited; hence consideration of the background levels to which communities are naturally adapted becomes an important component of any assessment.

7.3.1. Soft sediment benthos

Pegasus Bay benthic areas

The area within the capital spoil ground will be subject to substantial sediment inundation and smothering effects from deposited spoil (see section 0). The size of the spoil ground and the necessarily even pattern of deposition over the area, combined with weak residual currents, means that high-strength turbidity plumes are unlikely to be sustained everywhere within its boundaries. However, there is potential for near-bed SSC to remain above background levels for a time following the completion of spoil deposition if consolidation of the sediments is slow to occur and this may limit the rate of benthic recovery. But generally, effects from SSC within either of the proposed spoil grounds are expected to be secondary to smothering effects and more transient.

The soft sediment benthic areas of southern inshore Pegasus Bay are characterised by fine sediments which are subject to resuspension by wave-induced shear, producing a persistent near-bed layer of potentially high turbidity. Hence the soft-sediment benthic communities are inherently tolerant of sustained conditions of high suspended sediment loadings, including the increased deposition rates which this engenders. This is consistent with the relatively sparse benthic epifauna identified by trawl sampling (Section 5.2.3).

Light penetration at the seabed is expected to be naturally very low in offshore areas, so elevated surface and mid-water turbidity following spoil deposition are not expected to result in significant effects to the benthic environment 15–20 m from the surface. The assemblage of sediment dwelling infauna, with its prevalence of polychaete species, is also considered highly tolerant of sustained high suspended sediment levels.

The suspension- and deposit-feeding molluscs identified by epifaunal sampling as being part of the resident benthos may possibly be affected by high suspended sediment levels sustained in areas surrounding the spoil grounds. Gibbs and Hewitt (2004) found that horse mussels (*Atrina zelandica*) exhibit increasing stress at increasing suspended sediment levels and wedge shells (*Macomona liliana*) were adversely affected at levels above 300 mg/L but these studies concerned the introduction of terrigenous rather than the marine sediments to which resident species will be accustomed. Populations of bivalve mollusc species indicated in sample dredge contents from the capital spoil ground area and Harbour approaches (Appendix 4) are acclimated to the naturally turbid conditions. They furthermore appear to be sparsely distributed; hence do not represent a significant structural feature of the benthic habitat in this area.

Lyttelton Harbour/Whakaraupō

Background suspended sediment concentrations within the lower Harbour region are already generally high, especially near the seabed, and ambient turbidity tends to increase with distance towards the shallow upper reaches.

Benthic communities in the central to lower Harbour appear to be quite spatially variable although all taxa identified would be classed as turbidity-tolerant (section 0). Monitoring of benthic habitats required by LPC's consent for maintenance dredging and spoil disposal covers areas within the maintenance spoil grounds on the northern side of the Harbour channel as well as sites in the upper Harbour (Figure 7). This programme has also identified spatial variability in communities linked primarily to varying sediment texture. However, there has also been temporal variation in patterns of dominance by key organisms.

By far the most dominant taxonomic group represented in benthic samples from the Harbour has been polychaete worms, being up to 70% or more of the total by abundance, but often a significant proportion of this has been represented by a single species, the capiteliid polychaete *Heteromastus filiformis. H. filiformis* is generally most prevalent within samples from the lower Harbour sites. High abundance of capitellids is frequently considered indicative of disturbed conditions (*e.g.* ANZECC 2000); however, its occurrence in high densities extends well outside the maintenance spoil grounds (Sneddon *et al.* 2015). Other prevalent groups and taxa recorded from the most recent consent monitoring survey in 2015 included molluscs (9.6%) amphipods (9.3%) and cumaceans (5.9%). The sea pen *Virgularia gracillima* (3.9%) was found almost exclusively at upper Harbour stations, associated with fine muddy substrates.

From a benthic survey of Lyttelton Harbour/Whakaraupō focusing generally on the upper Harbour reaches, Hart *et al.* (2008) suggested that;

> *… within Lyttelton Harbour there is a continuum of overlapping communities associated with the mud crab Macrophthalmus (Hemiplax) hirtipes. This community type has been described elsewhere in New Zealand. Overall, it is concluded that the Lyttelton Harbour communities are related to substrate sediment texture composition and that there is a characteristic fauna associated with fine sediments.*

It is not possible to determine whether the background turbidity of Lyttelton Harbour/Whakaraupō has changed since before the development of the Port and surrounding catchment area. With Harbour bed sediments derived from the fine loess material of the region, turbidity is likely to have always been high. However, since the late 1800s, benthic communities have adjusted to an increased sediment supply represented by the ongoing maintenance dredging program in the lower Harbour, and to increases in supply from catchment erosion in the upper Harbour (Hart *et al*. 2008). Curtis (1985) proposed that the Harbour is in a quasi-stable state of dynamic equilibrium with respect to sediment supply, whereby the system is relatively insensitive to external forces in the form of increased sediment suspension, especially near the harbour entrance. In view of only limited areas near to the dredging activity and along the channel axis predicted to be exposed to SSC significantly above the background condition of the Harbour, effects on the benthos are expected to be no more than minor.

7.3.2. Shoreline reef habitats

Key to the assessment of potential suspended sediment effects to reef ecosystems is an understanding of the relative sensitivity of reef communities. However, only very limited information exists concerning actual sensitivity thresholds for key taxonomic groups. Rather it is the distribution of these taxa across the spectrum of suspended sediment conditions which provides an insight into individual tolerances.

The reef communities of the Harbour entrance and inner Pegasus Bay area are typical of those established on exposed high energy coastlines of the South Island (Shears & Babcock 2007) and are generally tolerant of the frequent turbid conditions associated with periodic storm and swell events. Reef communities within the central Harbour are adapted to lower energy conditions and higher background levels of suspended sediments. The following paragraphs consider the main mechanisms by which adverse impacts may occur and discuss the likely sensitivity or resilience of these habitats.

Sedimentation by settlement from the water column

Smothering impacts generally do not occur along high energy shorelines. In the case of shoreline reefs near and within outer Lyttelton Harbour/Whakaraupō, the communities are not only accustomed to frequently high turbidity, but the exposure of

the reef to wave action ensures that sediments remain in suspension until settlement can occur in quiescent zones in deeper waters.
Schiel *et al.* (2006) found that even a fine layer of sediment greatly reduced the attachment of both *Hormosira banksii* and *Durvillaea* sp. germlings, and a slightly thicker layer entirely prevented attachment. However, despite the presence of patchy sand habitats that occurred just below the *Durvillaea* zone, they noted that neither sand nor other sediments was observed to accumulate on the high-energy sites in the intertidal zone. It was concluded that, while deposited sediment can cause high levels of mortality if burial is deep and prolonged, these effects were more likely to occur along the shorelines of sheltered harbours and sites of lower wave exposure.

Monitoring of intertidal communities at White Patch Point on the northern shoreline of the Harbour has been a component of consent monitoring requirements for LPC's maintenance dredging program since 1992. This site at the eastern end of Breeze Bay is within the consented area for the deposition of maintenance spoil and has undergone 5-yearly semi-quantitative surveys to monitor the health of intertidal communities. Despite its proximity to spoil deposition close inshore, the site has been consistently found to be in a relatively healthy state and free of deposited sediments (Sneddon *et al.* 2015). This was contrasted with a lower-energy site at Rapaki Bay in the upper Harbour where the accumulation of fine sediment deposits was observed in the low shore, with sediment trapped amongst seaweeds (particularly turfing algae) and in crevices and tide pools. The survey of Shag Reef carried out for this assessment (Section 5.6) also indicated a more depositional environment where settlement away from areas of the Harbour exposed to surge has resulted in a muddier reef environment. There is a natural gradient of wave energy decreasing with distance up-harbour and this is clearly reflected in the amount of fine sediment deposited in shallow reef environments.

The ecological surveys of subtidal shoreline reef habitats on the Banks Peninsula coastline identified a contrast in deposited sediments at 4 m and 7 m depth levels. This observable depth gradient is common to turbid environments exposed to significant wave energy since conditions become more quiescent with depth and deposited sediment is more likely to stay in place. Relatively heavy silt veneers were observed on the transects at 7 m depths, often entrapped by encrusting biota such as dense saddle squirt colonies (*Cnemidocarpa* sp.) or turfing algae.

An increase in sediment supply in the form of elevated SSC is unlikely to increase the thickness of deposited veneers at open coastal locations except in atypical periods of very low wave energy. This is because the amount of deposition is mediated by the amount of water movement but is relatively less sensitive to the amount of sediment in suspension. Shoreline receptors are considered to be too far from the source of any plumes for the occurrence of short-term smothering events where the atypical formation of a veneer of settled silt material occurs in calm conditions and persists for long enough to affect communities poorly adapted to such events. However, a sustained increase in the flux of suspended sediment may favour the increased prevalence of psammophytic (sediment tolerant) algae such as red filamentous and turfing forms, which are not only capable of adjusting to sediment stress, but also trap and bind sediment (Airoldi 2003).

Light attenuation

High turbidity reduces light levels (as photosynthetically active radiation—PAR[20]) reaching the seabed. When this is sustained, photosynthetic organisms can be adversely affected. On reefs, a reduction in PAR may affect structurally and trophically important seaweeds. Shears and Babcock (2007) noted that light penetration is an important factor explaining vertical distribution and variation in algal communities in rocky reef habitats.

Shifts in the background turbidity, if sustained, will result in a thinning of the canopy of large macrophytes at depth as light conditions decrease below optimum levels for individual species. Eventually, a decrease in the depth at which such species begin to establish and thrive will be observable, with encroachment by species tolerant of lower light conditions. Significant changes in macrophyte prevalence and cover in reef habitats can potentially result in indirect effects on pāua populations.

Macroalgae on Harbour entrance and inner Pegasus Bay shorelines are adapted to high natural levels of turbidity and the depths to which canopy-forming species extend (7 m or less) are observed to be shallower than in other locations with greater water clarity. While all such populations will respond and adjust to prevailing conditions, the rate at which such adjustments would occur, and therefore when they would become discernible, is presently unknown.

Effects on feeding mode

Reef-dwelling suspension feeders vary in their tolerance to suspended inorganic particulates based on their ability to selectively remove organic food particles to maintain growth. The predominant filter feeders observed on shoreline reefs in the area were mussels (principally *Perna canaliculus*), ascidians and sponges, most of which are relatively tolerant of elevated concentrations of inorganic particulates. This is supported by the observation that these taxa (and especially *Perna*) were conspicuous features of the subtidal survey sites on the northern shoreline of Lyttelton Harbour/Whakaraupō where the fine sediment substrate offshore is consistently resuspended by wave action.

Negative effects from sedimentation on the abundance of gastropod grazers have been documented in numerous observational and manipulative studies (Airoldi 2003; Hawkins 2007). Deposited sediment can impair the movement and attachment of grazers. Reduction in grazing activity can be caused either by direct physical

[20] PAR designates the spectral range (wave band) of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis.

interference or indirectly via increases in the cover of turf-forming algae that they are unable to consume (Jenkins *et al.*1999). Additionally, larval mortality rates of both pāua and urchins increase in response to sedimentation early in development (Phillips & Shima, 2006; Walker 2007). The reduction in grazing activity by sedimentation has been postulated as one of the mechanisms through which sedimentation controls algal structure on rocky shores (Airoldi & Hawkins 2007).

Abrasive or scouring effects

The scouring effect of deposited and suspended sediments in high energy zones can adversely affect the more delicate encrusting organisms in reef environments. Atalah and Crowe (2010) found that the cover of two types of crustose algae (crustose coralline algae and *Ralfsia* sp.) can be negatively affected by sedimentation and considered this most likely due to the abrasive and scouring effects of sediment moved by wave action, rather than smothering.

Observations of sediment films and accretion on the reef habitats of the Banks Peninsula outer coast (Section 5.5) show that there must be a level of natural tolerance to sediments in these communities. Furthermore, the very fine nature of dredge plume sediments which remain in suspension long enough to reach the shoreline suggests that scour effects would not be a significant component of any observed effects.

Potential cumulative effects from a shift in background SSC

Sedimentation plays a significant role in structuring rocky reef communities, both intertidal and subtidal. However, it is important to recognise that natural gradients in sedimentation rates and water turbidity are a natural feature of coastal systems. Specific areas of the New Zealand coast feature naturally large sediment loads, including the Banks Peninsula ecoregion (Carter 1975; Shears & Babcock 2007). As a result, these areas support communities with distinctive attributes. One of the challenges for management decision-making is to separate the influence of anthropogenically-derived sedimentation on the ecology of coastal communities from that of natural sources.

It is very unlikely that sediment plumes from dredging and spoil deposition operations will increase SSC at the shorelines (MetOcean 2016c,d). It is therefore very unlikely that any shoreline impingement of aged plumes will result in acute stressor events. Rather, any observable changes, should they occur, are likely to be subtle, resulting from a shift in the background levels of turbidity and suspended sediments over the duration of dredging operations. If this were to occur, it would manifest as changes in community structure and may include the following:

- An increase in the prevalence and cover of psammophytic taxa at the expense of those more sensitive to suspended sediments
- A decrease in the cover of erect canopy-forming macrophyte species

- A decrease in the depth to which canopy-forming and other macrophytes extend
- Changes to the prevalence and community structure of grazers.

The degree to which these changes may occur depends upon the concentration of the plume and the duration for which these conditions persist. It should be noted also that the shifts described above, should they occur, are reversible with a return to normal background conditions.

7.4. Species of special conservation status: Brachiopods

The current conservation status of brachiopods in Lyttelton Harbour/Whakaraupō marks them out as representing a special case for consideration. Brachiopods are hard-shelled, filter feeding organisms also known as roman lamp shells although they are not molluscs. They are known in fossil records from early Cambrian times, some 540 million years ago, appearing along with trilobites and graptolites in the early sedimentary rock layers. At their height they included some 30,000 species, but only about 300 are left now globally, preferring cooler waters in habitats from low tide to depths greater than 200 m deep. There are 32 brachiopod species known from New Zealand waters. Nine of these species (of which eight are endemic) occur at depths of less than 30 m, giving New Zealand a greater diversity and abundance of shallow-water brachiopods than any other comparable region in the world (MfE 2014). This section provides a preliminary assessment of the current knowledge of important brachiopod species and communities within Lyttelton Harbour/Whakaraupō.

7.4.1. Pumilus antiquatus

The brachiopod species *Pumilus antiquatus* is small (≈5 mm in length), relatively inconspicuous and may be rare or very limited in distribution. It has been known to occur on hard substrates near low tide and is recorded from Otago Harbour, Karitane and Lyttelton Harbour/Whakaraupō. It was first listed by MfE as Nationally Endangered (Hitchmough *et al.* 2007). This status was recently updated to Nationally Critical, to reflect an apparent decline in abundance at the sites it has previously been recorded from. The classification applies to species which are subject to *very high ongoing or predicted decline [>70%])* (Freeman *et al.* 2013). This makes it one of only a limited number of marine invertebrates that has a 'threatened' classification[21]. Pollution and habitat disturbance were identified as the key threatening processes although little is known about its distribution, population biology, reproduction or ecology. Similarly, little is known about the environmental factors that drive its distribution. The noted decline in abundance likely refers to recent efforts to locate populations of *P. antiquitus* in Otago Harbour (Robinson 2010).

[21] The listing process requires the establishment of an expert panel and panel leader. It includes a period of public consultation and call for submissions, and a meeting(s) to discuss and agree on threat listings. The outcome of the classification process is peer-reviewed and published (pers. comm. Debbie Freeman, DoC).

Moreover, there is a record for Lyttelton Harbour/Whakaraupō of *P. antiquatus*' unique co-occurrence, intertidally, with two other brachiopod species *Calloria inconspicua* and *Notosaria nigricans* at Ripapa Island. Consequently, the Island is listed as a sensitive site in Environment Canterbury's Marine Oil Spill Contingency Plan (MOSCP, Annex 4), which states

> *Three endemic genera of brachiopod occur on Ripapa Island and are only known in New Zealand at this location. They are of international significance, being the only place in the world where three such species coexist*. (ERM 2013)

What is less clear is how well studied this community is (especially in terms of distribution beyond the Ripapa Island setting) or even whether it has been revisited since 1960 to establish its current status.

7.4.2. History of occurrence in Lyttelton and Otago Harbours

P. antiquatus was first described from specimens collected from Lyttelton Harbour/ Whakaraupō (Atkins 1958) and was later found to occur *on boulders off Gladstone Wharf* by Rickwood (1968). It was discovered in Otago Harbour in 1964, and was collected ca. 2007 from Pudding Island but no published studies on the species have been carried out there since 1968. It is also known incidentally from Karitane (~1990), from a small piece of rock collected by a diver working in low visibility conditions to collect *C. inconspicua* at ~15 m water depth. Rickwood (1968) searched for, but failed to find, *P. antiquatus* 'on the exposed seaward shores of the Banks and Otago peninsulas, the rocky shores between these points and the shores of the west coast of South Island from Karamea to Jackson's Bay'; nor was it found at Rangitoto Island (Auckland) or Half Moon Bay, Stewart Island.

Robinson (2010) carried out a dedicated search for *P. antiquatus* at seven sites within Otago Harbour; the three from which it was previously recorded and four more where the conditions were judged to have been suitable. This was conducted by up to four observers wading in the water at very low tides and diving where the water was too deep for wading. In addition, two stretches of coastline at Karitane and Moeraki were included in the survey. *P. antiquatus* was not found at any of the surveyed sites, but a 2013 study by an Otago University student once again found specimens in the Pudding Island locality. It was noted that the sites in Otago Harbour were often quite muddy with thin layers of silt on most surfaces and suggested that sediment build-up in the harbour had encroached onto previously 'clean' areas.

Subsequent to the observation of *P. antiquitus* at Gladstone Wharf in the late 1960s, it appears that the species has not been further studied in Lyttelton Harbour/Whakaraupō. However, it is worth noting that *C. inconspicua* was also known previously from the Inner Harbour location. Percival (1944) reported that:

> *The animals were found on the breastwork of a disused jetty at Governors Bay and on the inner face of the retaining wall at the Gladstone Wharf of the Inner Harbour at Lyttelton. The animals are abundant at the latter place and in both localities, the brachiopods occur up to about half tide mark. They are attached to stones and other solid objects but are hidden in places where the water is gentle in its movements.*

Intertidal surveys carried out in the eastern Inner Harbour basin by Handley *et al*. (2000) and Fenwick 2003 did not identify the presence of either *P. antiquitus* or *C. inconspicua*.

Comprehensive biosecurity surveys carried out in 2002 and 2004 sampled a variety of habitats within the Port operational area, including within the Inner Harbour (Inglis *et al.* 2006, 2008). These included the sampling of epibenthic fouling communities on hard substrata as well as soft-sediment communities. While they were focussed principally on the identification of invasive species, the consecutive surveys identified and listed all organisms sampled, recording 245 and 269 species or higher taxa, respectively. Of the 109 and 127 native species identified from pile scraping samples, none were brachiopods. However, only 69 species (41% of the total number) were recorded from both surveys, reflecting the large number of comparatively low abundance species in the assemblage. It was suggested that non-detection of many sparsely occurring species probably accounted for much of the difference observed between the two surveys (Inglis *et al*. 2008). It is also noted that more natural hard substrates such as boulders were not sampled.

A cursory search for *P. antiquatus* at Ripapa Island on 9 August 2014 identified the 'brachiopod pool' described by Percival (1960) but found no trace of any brachiopod species. The intertidal reef at Ripapa Island, including the pool, was surveyed in February 2016 (Section 5.6). While relatively high ecological diversity was apparent, this survey confirmed the absence of brachiopods from this specific location. The neap tides occurring at the time of the survey precluded searching on the very low shore in the vicinity of the pool. The more common *C.* i*nconspicua* was noted in quadrat surveys at 4 m depth at Adderley Head (site BP01) and *P. antiquitus* may yet prove to also be present in the shallow subtidal areas of the Harbour.

7.4.3. Potential sensitivity to dredging effects

Due possibly to studies of brachiopods in Fiordland, there is sometimes a perception that brachiopods generally prefer clear waters and low levels of sediment deposition. However, *C. inconspicua* (with which *Pumilus* is known to co-occur), is known from highly turbid and muddy habitats such as Rangitoto Island (Auckland). Furthermore, the description of the 'brachiopod pool' at Ripapa Island by Percival (1960) states that

> *a deposit of very fine material normally rests on the brachiopods as elsewhere. It consists almost entirely of organic matter; there remains only a trace of ash on ignition. This itself indicates very quiet conditions among the stones*.

The occurrence of *P. antiquatus* in noted high turbidity conditions at Gladstone Wharf and the relatively unimpacted site of Karitane is also indicative of its probable tolerance of (if not preference for) such conditions.

It is also noted that dredging of the channel adjacent to Ripapa Is, and Port activities in general, predate by over half a century the discovery of *P. antiquitus* in Lyttelton Harbour/Whakaraupō and its last known observed occurrence at Gladstone Wharf. Whether it was more prevalent in the Harbour prior to the onset of Port activities cannot be ascertained.

8. FISH AND FISHERIES ASSESSMENT

The critical factors associated with the capital dredging project that will potentially affect fisheries resources in the region are considered to be

1. the permanent alteration of benthic areas which will also be subject to ongoing maintenance dredging and associated spoil disposal
2. the temporary loss of benthic habitat represented by inundation and disturbance at the proposed spoil ground and areas immediately adjacent to its boundaries
3. the elevated suspended sediments concentrations and poor water clarity within turbidity plumes potentially generated by dredging and spoil disposal activities.

8.1. Significance of seabed areas directly impacted

8.1.1. Benthic habitat

As benthic habitats, neither the proposed navigation channel dredge area or spoil ground have been identified as being of special ecological or conservation importance; however, the wider areas of Lyttelton Harbour/Whakaraupō, Pegasus Bay and Banks Peninsula are of some importance as recreational and commercial fisheries areas. In particular, the area offshore from Godley Head appears to be productive for the flatfish trawl fishery (Section 6.2.5).

The relative importance to fisheries species of seabed habitat lost, altered or temporarily disturbed as a result of the proposed activities depends to an extent upon the proportion of similar habitat within the surrounding region.

The channel extension area represents an area which will be effectively permanently lost as natural seabed habitat due to the ongoing need for periodic dredging to maintain depths. The area is approximately 125 ha and covers around 5% of the benthic area of the Harbour entrance and its approaches in similar water depths, but represents a much smaller proportion of the total area of similar soft sediment habitat within inshore Pegasus Bay. Hence, in terms of the area of productive seabed directly affected, the loss of this area to fisheries species is considered no more than minor.

The benthic area in the vicinity of both the proposed capital and maintenance spoil grounds has been well-characterised and does not encompass physical habitats or biogenic features which significantly differentiate it from much of inshore Pegasus Bay. Hence there is little evidence to suggest that this specific area has an importance to certain species that sets it apart from other inshore areas of similar water depths.

The offshore benthic area that would be potentially affected (with respect to fisheries) by both capital and maintenance dredge spoil deposition may be conservatively estimated at around 2,500 ha. This is equivalent to an area incorporating a margin around both spoil grounds of width 500 m. The survey results indicate that this comprises a benthic habitat generally equivalent to that occurring between the 15 m and 22 m contours in southern Pegasus Bay. The total area of such habitat (from as far south-east as Okains Bay and north to the Waimakiriri River mouth) is some 48,000 ha of which the affected area is approximately 5%. However, most commercially important benthic species occupy a much greater range of depths and occur over a varying range of substrates. If the seabed area inside the 50 m contour is considered for the entire Pegasus Bay benthic region (from Okains Bay to Point Gibson/Hurunui River), the available habitat area increases to in excess of 300,000 ha, of which, the potentially affected area represents less than 1%.

8.1.2. Commercial fisheries

Kingett Mitchell (2003c) noted that most commercial fishing along this coast occurs predominantly in waters deeper than 30 m. This is consistent with the catch weight record for the inshore species aggregates for the years 2011–2014 (Section 6.2.5). As such, the effects footprint of the CDP is not considered to have a significant spatial overlap with the majority of fishing activity in terms of catch weight.

However, the small but significant fishery specifically targeting flatfish (principally *Rhombosolea leporine* and *Rhombosolea plebeian*) occurs in shallow near-shore waters over the whole length of Pegasus Bay, including the proposed spoil ground. Furthermore, fisheries catch data for the years 2011–2014 indicate that an area immediately offshore from Godley Head (but not including the proposed capital spoil ground) yields a significantly higher catch weight of flatfish than other areas in Pegasus Bay. The reason for this is not immediately clear, although the movement of fish in and out of the Harbour may be a factor. Both the channel extension to be dredged and the site proposed for the new offshore maintenance dredging spoil ground coincide with this area of relatively higher flatfish catches (Figure 36). In contrast, the immediate vicinity of the spoil ground is the source of relatively low proportions of landed catches for the inshore sector of fisheries statistical area 020.

Tagging studies indicate that both yellowbelly and sand flounder move offshore to deeper water in the late winter-spring months with juveniles appearing in high numbers in estuaries over the summer. Although the yellowbelly flounder is generally more abundant around the North Island, it is understood from consultation with local fishers that this species is targeted in the inshore area off Godley Head. As a species, the yellowbelly flounder is associated with generally muddier environments than the sand flounder and it is suggested to be a predominantly nocturnal non-visual feeder (Morrison *et al.* 2014). It is possible that the very fine sediment substrates around Godley Head are a preferred habitat and it is noted that the 2011–2014 catch record coincides with a period of preferential use of the Godley Head sector of the Harbour spoil ground for disposal of sediment from maintenance dredging (annual average 746,000 tonnes; Sneddon *et al.* 2015).

In the flatfish target fishery, elephant fish (*Callorhinchus milii*), rig (*Mustelus lenticulatus*) and gurnard (*Chelidonichthys kumu*) are likely to represent high-value bycatch. Of these species, only elephant fish are limited to the near-shore zone for critical life stages (in this case breeding and egg-laying; Section 8.2.2 below).

Flatfish and other inshore fisheries species are highly mobile and will avoid the immediate area if stressed by the effects of dredging and spoil deposition. Spoil deposition may result in an additional short-term food supply in the form of invertebrates entrained within the deposited material and encourage feeding by benthic foraging species such as flatfish, gurnard and red cod following each deposition event. However, in general, the disturbance to the seabed by this activity is likely to represent a temporary loss of suitable habitat. It is likely that the immediate vicinity of the capital spoil ground will be lost as a fishing ground for the duration of the project and a subsequent period of habitat recovery. Recovery after disturbance is likely to be rapid, however, and the recovery process may itself result in a short-term increase in the food supply due to enhanced growth of the disturbance/recovery community (Gillespie & Asher 1995), encouraging the rapid return of bottom-foraging fish.

Longer-term changes in the seabed area in the approaches to the Harbour may have localised implications for the commercial flatfish fishery. Bottom contact trawl methods will potentially be compromised by the bathymetric discontinuity of the extended channel off Godley Head and possibly also by changes to the degree of consolidation of the seabed within the offshore maintenance spoil ground. However, there is insufficient information to provide a robust assessment of the impact of maintenance spoil disposal on the ongoing suitability of the area off Godley Head as habitat for flatfish. The available information concerning historical spoil disposal at Godley Head suggests that yellowbelly founder are resilient to such disturbances occurring in relatively close proximity.

It is important to consider also the context of commercial fishing activities themselves; specifically, in areas fished relatively intensively, the extent to which bottom-contact trawl gear itself contributes to the ongoing disturbance of the seabed. For areas outside the maintenance spoil ground boundary, this physical disturbance (and the localised benthic turbidity arising from it) is likely to be greater than that caused by spoil deposition and will be occurring intermittently on a continuous basis.

Monitoring of the current maintenance dredging spoil grounds on the north side of the Harbour has indicated that changes to benthic communities (which represent the food supply for benthic species such as flatfish) from spoil deposition are relatively subtle and recovery is rapid (Sneddon *et al.* 2015). On this basis, it is considered that, while spoil deposition will undoubtedly be disruptive to flatfish within the proposed spoil ground during maintenance dredging campaigns, any significant changes in habitat will be largely confined to within the spoil ground boundary.

8.2. Fish movements and critical habitats

In consideration of the potential effect of the CDP on critical seasonal stages in fish life-cycles, it is noted that the 9–14 month duration anticipated for each proposed continuous dredging stage effectively encompasses all seasons.

8.2.1. Migration

Although a number of species are known to move from inshore estuarine and harbour environments to offshore areas on a seasonal basis for spawning or as part of a change of habitat preference with development from juvenile to adult stages, there is no information which suggests that Lyttelton Harbour/Whakaraupō represents a relatively more important location in this regard.

The seasonal offshore movement of the two flounder species is relatively well documented but the available data support long spawning periods for both. These species are noted for high fecundity and low recruitment variability (Morrison *et al.* 2014). From surveys of ichthyoplankton off Kaikoura, Hickford and Schiel (2003) recorded sand flounder larvae as being relatively common. This suggests that, even if the CDP disrupted the migration of adults offshore to breed, the summer influx of larvae to the Harbour would not be correspondingly affected.

Movements related to mating and pupping are also documented for the two small ovoviviparous[22] shark species, school shark and rig; but since they do not require specific habitats for egg-laying, they are likely to avoid the immediate areas of benthic disturbance without significant disruption to the life cycles of populations utilising Lyttelton Harbour/Whakaraupō. It has been noted that pregnant female rig can travel large distances in a short time (www.nabis.govt.nz lineage document; spawning rig).

The movements of other inshore species are more generalised and are not specifically linked to estuarine or harbour environments.

Future maintenance dredging of the shipping channel represents an ongoing periodic disturbance. While maintenance dredging has occurred for many decades, the expanded channel area represents an increase in such activity. However much of the increase will be occurring within the more open waters beyond the Harbour heads where it is less likely to represent a barrier to fish movement.

[22] Mode of reproduction whereby eggs are hatched within the body, so that the young are born alive but without placental attachment.

8.2.2. Spawning and nursery areas

As noted above, elephant fish were the only important fisheries species identified as utilising the near-shore region of Pegasus Bay for spawning. Eggs are laid in spring, in water depths of 5–30 m, and take 5–8 months to hatch. The exact distribution of egg-laying sites of *C. milii* is not known and it must be accepted that the deposition of dredge spoil may disrupt breeding or egg-laying within the area defined by the spoil ground. Breeding adults may, to an extent, avoid the area of disturbance and any egg-cases laid are unlikely to survive inundation. However, it is noted that no evidence of elephant fish egg-cases was found during benthic surveys of the Harbour approach area of inshore Pegasus Bay, despite 22 individual epifaunal dredge trawls undertaken between late October 2007 and mid January 2008, during the period of incubation for the benthic egg cases of this species. Furthermore, the area of direct disturbance will be spatially constrained and represents a small part of a much larger suitable inshore habitat.

Both species of flounder move into deeper waters annually to spawn. Spawning grounds for sand flounder from Pegasus Bay have been identified in 35–40 m depths near Akaroa Heads and in the vicinity of Timaru (Section 6.2.4). Spawning grounds for red cod have not been identified, but spawning is believed to occur in deeper waters over the continental slope. Red gurnard are similarly believed to spawn over inner and mid-shelf areas (Hurst *et al.* 2000).

While rig aggregate annually in spring and summer in shallow coastal waters to breed, specific areas of importance are not documented. Both this species and school shark are highly mobile and the existence of separate stocks is not indicated (Blackwell & Francis 2010). Francis *et al.* (2011) reported that Lyttelton Harbour/Whakaraupō is known to represent a nursery ground for school shark and rig although it was noted that few data exist to quantify the importance of the Harbour in this regard.

There is no information which implicates the area of the proposed spoil ground as being of specific importance as a nursery area for any species. Like most inlets with fine sediment substrates nation-wide, Lyttelton Harbour/Whakaraupō serves as a nursery area for a number of flatfish species, but it is the shallow upper reaches and embayments of the Harbour which are important in this regard. As such, the dredging project is not expected to have a significant effect on juvenile flatfish within the Harbour.

8.3. Effects on fish from suspended sediment

As noted for marine ecosystems generally, the most significant mechanism for potential far-field exposure to dredging-related stressors will be via the generation and propagation of turbidity plumes. Since the dredged material is expected to be generally low in contaminants, nutrients and organic material, the tolerance and behavioural response to potentially high suspended solids concentrations are the key issues in considering effects on fish populations.

High background turbidity is a natural feature of Lyttelton Harbour/Whakaraupō and inshore Pegasus Bay. Periodic meteorological, swell and flood events also bring about high variability in this background and occasional extreme levels of suspended sediment concentrations will occur in shallow regions near the coast. The severity of suspended particulate matter as a potential stressor is related to the size distribution and composition of particulates as well as their concentration. The documented effects of terrigenous sediments with high clay fractions are considered to arise at least partly from their difference to native sediments to which local marine communities are adapted. Turbidity plumes generated by dredging and spoil disposal activities will comprise marine sediments from local sources which are also continually resuspended by natural processes. Therefore, a degree of natural tolerance to resuspension events is expected in local fish populations, especially benthic species such as flatfish and gurnard.

Potential impacts to finfish from high suspended solids concentrations include the following:

- gill clogging and abrasion
- egg smothering and abrasion
- reduced foraging success
- increased vulnerability to predation.

It was noted by Wilbur & Clarke (2001) that many fish thrive in turbid conditions and that increased turbidity can be favorable to some species where it confers protection from predation and cover from which to hunt their prey. In their review of published studies of biological effects from suspended sediments, they also reported that, for spawning salmonids, the greatest mortality rates (> 75%) were elicited by suspended sediment dosages that exceeded those typically generated by hydraulic cutterhead dredges. It is likely that most if not all species utilising Lyttelton Harbour/Whakaraupō are similarly adapted to such extremes, although the total duration of exposure may be a factor in exceeding such tolerance.

In considering the potential duration of exposures to high SSC, it is worth noting that finfish are generally very mobile and are able to avoid areas of localised stress or disturbance. However, where areas of very high turbidity are significant in extent or completely cover suitable habitat or territory, adverse effects on populations may arise. Most investigations of the effects of suspended solids on fish and shellfish species have focused on riverine or estuarine habitats where subsequent dispersal of turbidity plumes is constrained and the potential for avoidance by local populations is limited.

In the case of the relatively unconstrained areas of inshore Pegasus Bay, there will be substantial attenuation of plume strength with distance from the source (MetOcean 2016c,d). Plumes of suspended sediments with concentrations high enough to be of concern are not expected to extend more than a few hundred metres from the point of suspension. Avoidance of areas of particularly high suspended solids is likely to be the principal response of finfish species to increasing stress.

Lyttelton Harbour/Whakaraupō has been subject to maintenance dredging and spoil disposal for many years. Effects on fish populations from these activities have not been documented although anecdotal evidence points to the harbour being frequented by a range of commercially targeted and other species. While the CDP does not involve spoil deposition within the Harbour, it will significantly exceed annual maintenance dredging in both scale and duration.

The relatively narrow and channel-aligned plumes generated by dredging within the Harbour (MetOcean 2016c) will not extend across the Harbour width at concentrations which might present a barrier to fish movement. There is also likely to be an intermittent aspect to the exposure of a particular location to high plume concentrations due to reversing tidal currents in the Harbour and changing wind-field influences on surface currents.

Except within the plume spatial envelopes modelled by MetOcean (2016c) in the vicinity of the dredged area, the operation is not expected to result in suspended solids concentrations within Lyttelton Harbour/Whakaraupō significantly exceeding those experienced during maintenance dredging and natural benthic resuspension as identified by Curtis (1986) and OCEL (2013).

8.4. Pāua and lobster

Both pāua and lobster are effectively limited to hard substrate habitats, as are their principal food sources. Therefore, effects on these populations from the activities associated with the proposed CDP are largely restricted to those potentially arising from sediment dispersal and deposition from plumes. As noted in Section 7.3, the plume modelling carried out by MetOcean (2016c) does not indicate that plumes from spoil deposition will reach the reef shorelines of Banks Peninsula at concentrations exceeding natural background variability. However, the possibility exists that plume effects will be experienced by these habitats as a result of unforeseen factors.

8.4.1. Pāua

Pāua are abundant along the shoreline reefs of southern Pegasus Bay where they occur at depths down to at least 7 m; however, they appear to be most abundant in depths of around 2–3 m CD (section 0). They are also plentiful within the central to outer Harbour area reaching relatively high densities in the low intertidal zone along the northern shoreline. However, the population within the wider area of Banks Peninsula appear to be somewhat stunted in size (Section 6.3.1). Of individuals specifically surveyed in February 2016, less than 5% occurring at depths of 0–1 m CD were above the legal size limit of 125 mm (section 0).

Sensitivity to suspended and deposited sediments

Early life stages of pāua are particularly vulnerable to toxicants and other stressors; however, few published studies have examined the effects of suspended sediments in the water column on larval stages of marine invertebrates. Phillips and Shima (2006) examined the effects of suspended sediments from terrestrial runoff on larval development, survival, and settlement of kina (*Evechinus chloroticus*) and pāua (*H. iris*). Results indicated that kina larvae appeared to tolerate exposure to suspensions of terrigenous sediment better than those of pāua. For both species, however, short term exposure to high sediment loads was generally worse if exposure occurred early rather than later in larval life. The mechanism by which exposure to sediment increased mortality in both species was not determined but it is important that a distinction should be made between terrigenous sediments and resuspended marine sediments to which pāua may be better adapted.

Elevated turbidity may also affect the settlement success of invertebrates such as pāua (Francis *et al.* 2011). However, it is noted that pāua occur abundantly in very turbid waters elsewhere around Banks Peninsula, notably along the south coast (Sainsbury 1977).

Sediment deposition upon substrates favoured by pāua may limit larval settlement and post-settlement survival. Freeman (2006) reported that sedimentation or shifts in sand deposits could cause significant post-settlement mortality in juvenile pāua. However, sedimentation on such substrates at outer Harbour and Pegasus Bay locations is very unlikely to occur at a level which would affect pāua for the following reasons:

- Plumes are not predicted to reach shoreline areas at high suspended sediment concentrations
- Fine particulates within aged plumes which reach shoreline areas will not effectively settle due to significant water movement at these sites.

In flume experiments, Schiel *et al.* (2006) found that the finest size fractions of silt were washed from sediment traps (designed to gauge deposition) beyond a flow rate of around 0.2 m/s. However, they reported *an almost perfect correlation between sediment cover on the reef and measurements from traps*. These same hydrodynamic processes, principally arising from wave action, ensure that the shoreline reef areas of southern Pegasus Bay remain effectively free of deposited sediment even after extreme natural turbidity events. An intertidal monitoring site near Godley Head was resurveyed following the Canterbury earthquakes. While it was noted that a large amount of rock-fall material had settled at the base of the slope and extended into the intertidal zone, there was no physical evidence of accumulated sediments, even in the interstices between boulders (Sneddon 2013).

Adult pāua may be somewhat resilient to deposition events. Macpherson (2013) studied the recovery of a section of the Te Angiangi Marine Reserve in southern Hawke Bay after it was subjected to a large-scale sedimentation event in April 2011. Catastrophic coastal landslides had inundated the immediate intertidal platform adjacent to the hill side, including significant pāua and kina habitat. The landslide debris immediately began to be eroded by wave action into fine-sized particles and transported offshore but the number of adult pāua within the reserve remained high after the sedimentation event. Five to eight months after the event, the marine reserve populations began to recover where habitats had been smothered even though significant erosion of the residual landslide debris was still occurring.

The occurrence of apparently healthy populations of pāua along the northern shoreline of outer Lyttelton Harbour/Whakaraupō is notable since this puts them within the long-utilised spoil disposal grounds for LPC's maintenance dredging program. The only access to these sites is by boat but landing is difficult due to the frequent surge conditions. Hence this population may be under relatively low harvesting pressure. However, these observations indicate that turbidity plumes potentially originating from dredge spoil deposition within 100 m of shore have not significantly impacted the population.

Southern Pegasus Bay and the northern coast of Banks Peninsula do not currently represent a very productive pāua fishery. While the reasons for this are not entirely clear, the indicated slower growth and smaller maximum size in this population are undoubtedly key factors.

8.4.2. Lobster

Spiny lobster are widespread around the New Zealand coastline but the Banks Peninsula lobster fishery (statistical area 918) appears relatively less productive than adjacent rocky coastal areas to the north and south.

Lobster occur over a broad range of natural turbidity but information regarding the effects of suspended solids on this species is very sparse. It is considered that direct effects of turbid plumes on adult individuals are likely to be minimal. However, any prolonged impingement of rocky reefs by high strength plumes has the potential to result in a reduction in the depth of the photic zone, which may in turn impact on fish and lobster populations in these areas through reduction in macroalgal cover.

In a technical review of the application by Trans-Tasman Resources Ltd to conduct iron ore extraction and processing in the South Taranaki Bight, Huber *et al.* (2014) concluded that the impacts of turbidity plumes on lobster larval phases were likely to be minor, due to the highly localised geographic extent of the source and the variable oceanic conditions (including variations in suspended sediments) tolerated by larvae prior to settlement within inshore areas.

8.5. Potential effects on aquaculture

The principal mechanism by which impacts may occur to marine farms is via turbidity plume propagation from dredging activities. But as is the case for shoreline reef habitats, current aquaculture sites (mussel farms) are well outside the area for which significant plume impingement is predicted (MetOcean 2016c,d). The closest marine farms to the proposed channel are within the outer reaches of Port Levy (~2.5 km). Those closest to the proposed spoil ground are on the outer coast between Port Levy and Pigeon Bay (~4.5 km) and to the immediate east of these inlets.

Due to run-off and wave resuspension processes, these coastal sites are likely to already experience higher levels of suspended sediments than points further offshore. The deep inlets of Port Levy and Pigeon Bay in particular have limited flushing and fine sediment substrates in their shallow upper reaches which are easily resuspended. Although no suspended sediment data for coastal sites was available, the greater turbidity of the inlets is reflected in observations of relatively lower underwater visibility (Section 5.5.1; also Hepburn *et al.* 2010).

Mulgor Consultants Ltd (2008) analysed ADCP data collected from the mouth of Port Levy, identifying the occurrence of localised turbidity events. However these were noted not to coincide with periods of maintenance dredging being undertaken by the Port. Rather, it was suggested that mussel farms in Port Levy are likely to be subjected to stronger turbidity plumes originating from within the inlet than those propagating from outside.

All filter feeding bivalves are affected by the quality and quantity of seston, being the total particulate matter suspended in the water column and including plankton, organic detritus (collectively particulate organic matter or POM), and inorganic material (PIM). Green-lipped mussels (*Perna canaliculus*) are relatively tolerant of high levels of suspended particulates, but feeding efficiency will be affected if the proportion of useable organic particulates relative to the inorganic fraction drops below a certain level. During turbidity events, *P. canaliculus* is able to raise its feeding rates and has been found to select for nutritious particles when particulate organic matter was reduced to ≤ 16% (Teaioro 1999). However, increased feeding rates are accompanied by higher respiration, resulting in lower overall growth rates if such conditions are sustained.

Hawkins *et al.* (1999) reported that rates of filtration and ingestion in *P. canaliculus* continued to rise as the total dry particulate mass (TPM) of available seston increased up to (the relatively very high) level of 1000 mg/L. Only above this level did a decline in filtration rate suggest any physical overloading of feeding mechanisms. They noted that;

> *A high capacity for filtration and the ability to adjust clearance rate enabled P. canaliculus to optimize particle selection and absorption efficiencies at levels that maintained organic absorption rate independent of the reduction in organic content of available seston as TPM increased to at least 1000 mg/L*.

It was noted that these results;

> *… suggested a potential for significant expansion of farming away from traditional 'clear water' sites to more turbid areas*.

In reference to a related tropical species, *Perna viridis*, Wong & Cheung (1999) reported that

> … *feeding processes of green mussels appear well adapted to cope with changes in food quantity and quality. At high particle concentrations but simultaneous low food values in the water column, green mussels have high rates of seston filtration and pseudofaeces production, together with preferential organic ingestion act to compensate for the dilution of organic matter in suspension.*

Where exposure is prolonged, effects on mussel physiology may occur at lower particulate concentrations than is indicated by these studies. However, the available information suggests that, in order for suspended sediments to have an adverse effect upon farmed mussels, levels reaching areas such as Port Levy would need to be sustained at levels substantially higher than background concentrations. Sediment plumes are not predicted to reach such areas at concentrations detectable above the current background (MetOcean 2016c,d).

During the reef ecology survey work, the densest beds of green-lipped mussels (average 72% coverage at 4 m depth) were observed at two sites on the northern shoreline inside Lyttelton Harbour/Whakaraupō (Figure 23). Both of these sites (LH01, LH02) were located within the current maintenance dredge spoil grounds. Disposal of up to c. 500,000 tonnes of maintenance spoil occurs annually to this area (Sneddon *et al.* 2015). The apparent health of these mussel beds suggests that plumes generated from neither the dredging of the adjacent channel, nor spoil deposition in close proximity, significantly affect this species at the population level. Furthermore, from modelling of wave-induced shear stress on benthic sediments within the outer Harbour, MetOcean (2016b) reported that the vicinity of the current Godley Head disposal ground was highly mobilised in all of the wave events studied. Hence it is likely that significant sediment resuspension and turbidity is a persistent feature of this area.

9. MARINE BIOSECURITY ASSESSMENT

9.1. Overview

Marine biosecurity is the exclusion, eradication or effective management of risks posed by pests and diseases, including phytoplankton species associated with harmful algal blooms. Collectively, these groups can be referred to as harmful marine organisms (HMOs; Sinner *et al.* 2013a). There are three broad sources of marine biosecurity risk that arise as a result of LPC's CDP, which are as follows:

1. **Introduction of new HMOs to New Zealand due to dredge transfer from overseas:** To undertake the CDP, LPC intend to contract a dredge from overseas. This is the most significant HMO risk addressed in this report. A number of examples exist that illustrate the potential for dredges to transfer HMOs among regions or countries (Clapin & Evans 1995; Coutts & Forrest 2007; Wells *et al.* 2009).

2. **Increased HMO risk due to dredging disturbance and spoil disposal:** Dredged material will be excavated from Lyttelton Harbour and dumped at a spoil disposal ground in Pegasus Bay. The associated biosecurity aspects to consider are: (i) the inadvertent transfer of HMOs present in the dredge location to the spoil disposal grounds; and (ii) alteration and disturbance of the seabed by dredging and spoil disposal, increasing the susceptibility of seabed habitats to colonisation by HMOs.

3. **Increased HMO risk due to changed shipping activities enabled by the deepened dredge channel:** The purpose of the CDP, together with post-earthquake rebuild and development, is to enable larger ships to access Lyttelton Port. Changes in ship size or type, an increase in vessel traffic, or altered patterns of trade (*e.g.* ship arrivals from new global source regions) are all factors that have the potential to increase marine biosecurity risk (Taylor *et al.* 1999; Kolar & Lodge 2001; Perrings *et al.* 2005).

These issues are addressed in the sub-sections below, with much of the text devoted to the first issue, as it is the most significant from a biosecurity perspective. First, however, the next section provides some context regarding marine biosecurity and risk management in New Zealand generally and in Lyttelton specifically.

9.2. Marine biosecurity in New Zealand

9.2.1. Vessel movements and HMOs in New Zealand

New Zealand has in excess of 2000 merchant ship arrivals in New Zealand each year (Campbell 2004), with additional movements into the country of vessels such as yachts, fishing boats and barges, and structures such as drilling rigs. These types of craft have to date been responsible for the inadvertent introduction of ca. 200 non-indigenous 'hitch hiking' species to New Zealand (Hayden et al. 2009). Among these non-indigenous species are a number of HMOs that have adversely affected marine ecosystems and associated values. HMOs that establish in New Zealand usually become a permanent part of the ecosystem (*i.e.* any adverse effects are irreversible), and typically spread from their point of first introduction, thus have the potential to affect values at regional scales or greater; *i.e.* HMOs do not become diluted with distance from their source populations in the sense that 'traditional' contaminants do.

There are many examples in New Zealand that provide evidence of significant adverse impacts of HMOs on natural ecosystems and associated uses such as aquaculture (Read & Gordon 1991; Creese *et al.* 1997; Hayward 1997; Sinner *et al.* 2000; Rhodes *et al.* 2001; Hayward *et al.* 2008; Lohrer *et al.* 2008; Castinel *et al.* 2013; Forrest *et al.* 2014). The Ministry for Primary Industries (MPI) has a current list of 11 designated 'marine pests' (MPI 2015), a number of which are formally classified as 'unwanted organisms' under the Biosecurity Act 1993. Most of these species are targeted during six-monthly Marine High-Risk Site Surveillance; an MPI-funded programme that includes Lyttelton Harbour/Whakaraupō.

9.2.2. HMOs in Lyttelton Port and environs

Lyttelton Port is one of New Zealand's busiest shipping ports, with figures in Inglis (2008) indicating that it receives well over a thousand domestic and international ship arrivals each year. The same report cites 654 overseas arrivals of vessels > 99 gross tonnes between 2002 and 2005 inclusive, which originated from 44 different countries representing most regions of the world. Clearly, therefore, past and present vessel visits from overseas and from other New Zealand ports represent a risk of HMO introduction, and three high profile HMOs already exist in the Port and wider Harbour (Morrisey *et al.* 2014). These are the Asian kelp *Undaria pinnatifida*, the clubbed tunicate *Styela clava* (a type of 'sea squirt') and the Mediterranean fanworm *Sabella spallanzanii*.

In addition to these recognised HMOs, Lyttelton Port has a range of established non-indigenous species, as evident from baseline ecological surveys conducted in the Port as part of a national MPI-funded study. The first survey was in 2002 (Inglis *et al.* 2006) and the second in 2004 (Inglis *et al.* 2008). The 2004 survey recorded 269 species or higher taxa, of which 23 species were non-indigenous, 55 species were cryptogenic (those whose geographic origins are uncertain) and a further 40 taxa could not be identified to species level.

9.2.3. HMO management

In recent years *Undaria*, *Styela, Sabella* and a number of other species have been subject to pest management responses led by MPI or other stakeholders. MPI initiated responses to *Styela* and *Sabella* in Lyttelton Port when these species were first detected, but these programmes are no longer ongoing, reflecting the difficulties in marine pest population management (Hunt *et al.* 2009; Forrest & Hopkins 2013). Additionally, despite the fact that New Zealand has a list of designated HMOs, it is recognised that many other species also have the capacity to adversely affect coastal ecosystems and associated values; however, there is considerable uncertainty regarding what the next problem species will be, and in fact whether problem species from overseas will also be significant if introduced into New Zealand.

Partly as a result of these types of challenges, there has been a shift in emphasis by MPI and some regional councils[23] to a focus more on preventing or reducing marine HMO introduction and spread, which can be achieved through management of human transport pathways (*e.g.* vessel movements). Although many HMOs have some capacity for natural dispersal, human activities can greatly exacerbate the rate and extent of their international, national and regional spread. A focus on risk pathways is inclusive of all potential HMOs associated with the pathway, irrespective of their known risk status. MPI is responsible for the development of management systems for international risk pathways, and has recently started working with regional councils on domestic pathway management.

9.3. Marine biosecurity risks from transfer of a dredge from overseas

9.3.1. Overview

LPC's proposal to contract an overseas dredge may appear at face value to be of limited concern given the high volume and diversity of other traffic. However, there are a number of instances where similar one-off events have been implicated in the introduction of HMOs to New Zealand, classic examples being international movements of barges (Coutts & Forrest 2005; Hopkins & Forrest 2010). Like barges, dredge movements are of interest because they have a number of attributes that make them potentially important as pathways for HMO transfer (GISP 2008; Bridgwood & McDonald 2014). These attributes relate to the specific type of dredge and its risk mechanisms, dredge maintenance and voyage history, and duration of operation in New Zealand.

LPC are likely to contract a trailing suction hopper dredge (TSHD), which 'vacuums' material from the seabed and stores it in a hold (hopper) for transportation to the disposal ground. As the specific dredge has not yet been contracted, this report can provide only a generic assessment of potential HMO risk resulting from the movement of the dredge to New Zealand, based on LPC's current expectations. Additional

[23] Note that Environment Canterbury has not been extensively involved to date in marine biosecurity and does not list any marine species in its Regional Pest Management Strategy.

dredge-specific assessment and possibly mitigation of risk will be required in order that the dredge meets the border standards that we have outlined in Section 9.3.4.

9.3.2. General attributes of dredges that can contribute to biosecurity risk

Range of risk mechanisms

The relevant risks will be specific to the actual dredge contracted by LPC, but on a TSHD the mechanisms are likely to be as follows:

- **Ballast water:** ballast water is used to aid the stability of vessels, and often carried on larger dredges. Ballast water can contain a wide range of marine organisms, usually in microscopic or planktonic life-stages, and has been globally implicated in the spread of many HMOs (Carlton 1985; Drake *et al.* 2007; Barry *et al.* 2008). For stability reasons, it is likely that a dredge would carry ballast water during its voyage to New Zealand, and need to discharge ballast water as dredged material was taken on-board. As such, ballast water discharge will need to comply with the border standards described in Section 9.3.4.

- **Sediment:** Some dredges use large volumes of dredged material as ballast, rather than water, but this is not expected on TSHD. However, sediment may be associated with equipment and deck spaces used to acquire (*e.g.* dredge head, suction pipes) and hold (*e.g.* dredge hopper) dredged material, and may occur in ballast water tanks, or be associated with anchors, chains, pumps and so on (Hopkins *et al.* 2013a; Bridgwood & McDonald 2014). Sediments can contain a variety of marine organisms and, potentially, HMOs (Hewitt *et al.* 2009).

- **Biofouling:** marine plants and animals that are attached to (or associated with) submerged surfaces in the sea are referred to as biofouling. Examples exist that illustrate significant biofouling on dredges moved internationally (Wells *et al.* 2009). On most vessels, including TSHDs, biofouling is managed by coating exterior surfaces with an antifouling paint. However, a number of factors described below affect the efficacy of such coatings.

Presence of many 'niche' areas

The term 'niche' areas refers to the 'nooks and crannies' of the hull that tend to readily accumulate biofouling or may trap sediment and water. Some niche areas do not get antifouled during dry-docking, or the antifouling coating is subjected to excessive wear, and some niche areas provide relatively sheltered environments for marine growth. For example, 'sea chests' are recesses in the hull that house pipework for taking water on-board, and can contain considerable biofouling, as well as mobile organisms such as crabs, fish and sea stars (Coutts & Dodgshun 2007; Frey *et al.* 2014). Other niche areas on a TSHD are likely to include internal seawater systems, gratings, areas around cathodic protection anodes, the propeller and shaft, anchor chain lockers, and dry-docking support strips, among others. Niche areas need careful consideration in terms of biosecurity risk.

Extended duration in recipient region

It is expected that the LPC proposal will require the dredge to be working for many months; an initial estimate of 9–14 months per dredging stage is currently considered. A long duration stay is likely to represent a greater biosecurity risk than arising from a short-stay vessel with a rapid turn-around time in port (*e.g.* a merchant ship with a turn-around time of 2–3 days). The key reason is that longer time period increase the window for HMOs to be 'released' from a vessel and successfully establish in the recipient port. For example, a biofouling organism attached to a dredge may have sufficient time to grow and reproduce over the operational timeframe anticipated by LPC.

9.3.3. Specific dredge attributes that contribute to biosecurity risk

In addition to the above general attributes, there are further risk factors that will need to be considered for the specific dredge contracted by LPC. These relate to maintenance, voyage and operational history. Such information, when it becomes available, can be used to provide some preliminary insight into the potential biosecurity risk of the dredge and the likely mitigation effort required.

Maintenance history

The type of maintenance that has been conducted on the dredge in relation to the mechanisms outlined above will influence its specific risk. For example, it will be important to know when the dredge was last dry-docked, whether and when it last had an antifouling coating applied, the types of marine growth prevention systems used in sea chests and internal seawater systems, and any inspection and cleaning undertaken.

Voyage history

The risk profile of the dredge will in part depend on the countries and ports it has been in since last being dry-docked and antifouled, and their latitudinal range. If the dredge's most recent deployment been in a temperate locality that is similar 'climatically' to New Zealand, there is likely to be an increased risk that Lyttelton will provide a suitable recipient environment. Voyage history may also identify whether the dredge has operated in localities known to harbour species of potential concern to New Zealand. In Australia for example, ballast water discharge in New Zealand is prohibited for ballast water sourced in Tasmania and Port Phillip Bay (see Section 9.3.4).

Operational profile and voyage speed

The recent operational profile of the dredge will influence the importance of the different risk mechanisms. For example, a lengthy idle period prior to deployment in New Zealand will reduce the above-water risk (*e.g.* from sediment) due to prolonged air drying. On the other hand, a lengthy idle period can reduce the efficacy of antifouling coatings and lead to enhanced biofouling.

Voyage speed to New Zealand will have a bearing on the extent of biofouling on arrival. A number of studies have suggested that a slow voyage speed (*e.g.* 5–10 knots) can be a risk factor for dredges (Campbell & Hewitt 2011; Hewitt *et al.* 2011). Slow moving vessels can become heavily fouled (Coutts & Forrest 2007; Davidson *et al.* 2008), and a slow voyage speed is generally considered to favour the survival of associated biofouling (Godwin 2003; Coutts *et al.* 2010a; Coutts *et al.* 2010b).

From a cursory perusal of the marine traffic website[24], a typical TSHD travels at an average speed ranging from ca. 6–12 knots, with a maximum speed of ca. 15 knots on some dredges. A speed of around 10 knots is the approximate threshold where biofouling becomes increasingly dislodged (Coutts *et al.* 2010a; Coutts *et al.* 2010b). Hence, the extent of biofouling transport survival on the dredge contracted by LPC may very much depend on where it falls in this spectrum of typical speeds.

9.3.4. Border standards for international vessel arrivals

MPI has in place border standards that guide the level mitigation that will be necessary or desirable for the dredge.

Ballast water and sediments

New Zealand has a mandatory requirement for mitigation of risk from ballast water and sediment. This requirement is an Import Health Standard (IHS 2015), which applies to ballast water loaded within the territorial waters of an overseas country that is intended for discharge in New Zealand territorial waters.

The IHS provides options for mitigating ballast water risk. The approach adopted to date is risk mitigation based on mid-ocean ballast water exchange *en route* to New Zealand. This procedure involves flushing oceanic water into ballast tanks to displace the higher-risk ballast water from the port of origin, but it is not completely effective (Taylor *et al.* 2007). An additional ballast water management option outlined in the IHS is ballast water treatment (BWT). All vessels will be required to have shipboard BWT systems when an IMO Convention for The Control and Management of Ships' Ballast Water and Sediments 2004 comes into force.[25] In line with this IMO Ballast Water Convention, New Zealand's IHS encourages vessel operators/owners to ensure vessels have a ballast water management plan tailored for their vessel's operations and to keep a record book of actions and procedures undertaken in the

[24] The marine traffic website (https://www.marinetraffic.com) provides near real-time information on global commercial vessel positions, along with ancillary data *(e.g. on vessel size and speed).*

[25] The IMO Ballast Water Convention will enter into force 12 months after ratification by 30 countries, representing 35 per cent of world merchant shipping tonnage; this target appears likely to be reached in the very near future.

implementation of the plan. The IMO Ballast Water Convention provides templates for these purposes.

With respect to sediment, the IHS stipulates that sediment must not be discharged into New Zealand waters. This includes *sediment which has settled and been removed from ballast tanks, ballasted cargo holds, sea-chests, anchor lockers or other equipment*. Among the mitigation measures for the dredge, ensuring it is clean of sediment from these and other dredge-specific surfaces (*e.g.* dredge head, suction pipe, hopper) will clearly be an important consideration.

Biofouling

To address the issue of biofouling, MPI has recently developed a Craft Risk Management Standard for vessels arriving in New Zealand (CRMS 2014). The CRMS is voluntary at present, but will become mandatory in 2018. During the lead in period to 2018, MPI is encouraging vessels owners and operators to be compliant, and is likely to take action against arrivals of heavily fouled vessels. The CRMS is inclusive of sea chests (which are included in the CRMS definition of niche areas).

The CRMS requires that vessels coming to New Zealand arrive with a 'clean hull' which is defined in relation to thresholds of 'allowable biofouling'. These thresholds are defined according to the duration of a vessel's visit. The dredge will be classified as a long stay vessel, as it is remaining in New Zealand for more than 21 days. In this situation, allowable biofouling across all hull areas is restricted to a 'slime layer'[26] with the only allowed visible 'macrofouling' being goose barnacles. Under the CRMS, one of the following 'acceptable measures' must be applied to meet the 'clean hull' requirement:

a) Cleaning before visit to New Zealand (or immediately on arrival in a facility, or by a system, approved by MPI). All biofouling must be removed from all parts of the hull and this must be carried out less than 30 days before arrival to New Zealand or within 24 hours after time of arrival.

b) Continual maintenance using best practice including: application of appropriate antifouling coatings; operation of marine growth prevention systems on sea-chests; and in-water inspections with biofouling removal as required. Following the IMO Biofouling Guidelines is recognised as an example of best practice (IMO 2011).

c) Application of Approved Treatments. Treatments are approved and listed under the Approved Biosecurity Treatments MPI-STD- ABTRT.[27]

[26] Slime layer fouling contains no visible fouling organisms, but comprises the micro-organisms and detritus that "condition" the surface and enable macrofouling to establish (Floerl et al. 2005).

[27] Approved Biosecurity Treatments are described on the MPI website, but not have been developed specifically for marine biofouling. See: http://www.biosecurity.govt.nz/border/transitional-facilities/bnz-std-abtrt.

d) As an alternative to the acceptable measures above, a vessel operator may submit, for MPI approval, a Craft Risk Management Plan, which includes steps that will be taken to reduce risk to the equivalent degree as meeting the requirements of the standard.

Implementation of any of these options would greatly mitigate any potential biofouling-related HMO introduction to New Zealand, such that the subsequent operation of the dredge in Lyttelton and environs could be considered an acceptable level of risk. From this perspective, it is desirable that efforts are made to ensure that the dredge meets the CRMS, even though it is not mandatory at this stage.

9.4. Marine biosecurity risks resulting from dredging and spoil disposal

9.4.1. Overview

As noted in Section 9.1, the biosecurity issues to consider in relation to spoil disposal are the inadvertent transfer of HMOs present in the dredge location to the spoil disposal grounds, and the alteration and disturbance of the seabed by both dredging and spoil disposal, increasing the susceptibility of seabed habitats to colonisation by HMOs. Related concerns include the increased risk to adjacent mussel growing areas on the northern side of Banks Peninsula, as the closest mussel farms are c. 4.5 km from the spoil grounds.

The assessment below indicates that these issues are likely to be of minimal significance from a biosecurity perspective, reflecting factors such as the absence of HMOs in the dredged area, and the close proximity of the dredging and disposal sites, as well as their environmental similarity. For example, the seabed in the dredged channel and disposal site is similar, consisting of primarily muddy sediments, with a small amount of shell material (Section 5.1.2). These points are covered in detail in the following sections.

9.4.2. Transfer of HMOs in dredged material

For any risk to arise as a result of dredge spoil transfer, HMOs would need to be present in the dredged sediments (including associated water), but not the disposal area, and not only survive the transfer process but also establish self-sustaining populations in the disposal area. However, such events would only be of biosecurity significance if spoil transfer was the only (or the major) pathway by which HMO spread and establishment in the disposal area could occur. In these respects, the biosecurity risks from the LPC proposal are negligible. It is also relevant that maintenance dredging has occurred in Lyttelton Harbour/Whakaraupō for at least 40 years, without evident problems arising from HMOs.

Risk species in the Lyttelton Port and wider Harbour

Surveys of the proposed dredge channel and spoil disposal grounds have not recorded any recognised HMOs (section 0), although this situation could have changed since the survey work was undertaken. Past surveys in Lyttelton Port have recorded three formally designated pests, as described in Section 9.2.2. Of these, the fanworm *Sabella* and sea squirt *Styela* are more often prevalent on hard substrata, but have the capacity to live in soft sediment habitats, especially where shell material is present (*e.g.* Grange *et al.* 2011).

Among the other non-indigenous species recorded in the port baseline surveys, five species are primarily soft-sediment organisms, but none are recognised as HMOs or known to be associated with adverse impacts. The most common of these is the small bivalve *Theora lubrica*, but this species is already present in the proposed disposal grounds (Section 5.2.2). The other four species include a crab *Cancer gibbosulus*, which has not previously been recorded in the dredge channel or disposal ground. The remaining three species are amphipods; although amphipods have been recorded in the dredge channel and disposal ground, the level of taxonomic resolution does not enable assessment of whether any of the three non-indigenous amphipod species were present.

In addition to *Sabella* and *Styela*, New Zealand's list of designated marine pests (MPI 2015) includes a number of species that can be associated with soft-sediment habitats, namely: a soft-sediment bivalve (*Potamocorbula amurensis*); two crab species (Chinese mitten crab, *Eriocheir sinensis*; European shore crab, *Carcinus maenas*); the northern Pacific seastar (*Asterias amurensis*); and a green seaweed (*Caulerpa taxifolia*). None of these additional species have yet been recorded in New Zealand.

Transfer risk

Species capable of inhabiting soft-sediments and surviving dredging and spoil disposal could theoretically be translocated in dredge spoil. However, note that sessile species (*i.e.* those that attach themselves to the substratum) such as *Styela* and *Sabella* would not be able to reattach and would be unlikely to survive. On the other hand, many bivalve species and other species more typically associated with soft-sediments would have a greater capacity to survive and re-establish (E-North 2004). Nonetheless, even in the event that HMO species became established in the dredged channel prior to the CDP (or their planktonic life-stages were present in the water column at the time of dredging), the close proximity of the disposal ground (c. 2 km at the closest point) minimises the risk in terms of subsequent spoil transfer. Relative to the life history and reproductive characteristics of many marine species, the distance from the dredged channel to the spoil grounds is short. Any species accidentally introduced to Lyttelton Port (*e.g.* by shipping) that has the capacity to spread via natural dispersal processes to the dredged channel will equally be capable of spreading to the spoil grounds.

Processes of natural spread could include dispersal of planktonic life stages in the water column, or migration of mobile adult life-stages across the seabed. For example, the planktonic durations of the dispersive stages (*e.g.* larvae) of benthic marine species can range from a few hours to many weeks. These durations typically enable spread across scales of hundreds of metres to tens of kilometres or greater in a given reproductive season, unless oceanographic processes or habitat conditions act as dispersal barriers (Kinlan *et al.* 2005; Forrest *et al.* 2009; Shanks 2009). Habitat is not expected to act as a barrier to spread, as the environments of the dredged channel and spoil grounds are similar in terms of their seabed sediment characteristics. The species on the MPI unwanted list that have not yet been recorded in New Zealand are certainly capable of natural spread across the relatively small distance from the dredged channel to the spoil grounds.

9.4.3. Habitat disturbance and alteration in dredged area and spoil grounds

Theoretically, physical disturbance and alteration of sediment textural properties as a result of dredging and spoil disposal could provide habitat conditions that are more suited to certain non-indigenous species. In relation to the LPC proposal, the similarity in sediment textural characteristics between the dredging and disposal site means that long-term habitat change is unlikely. Nonetheless, short-term disturbance may temporarily alter the extent to which seabed habitats are vulnerable to certain species. However, none of the existing HMOs referred to in this report are likely to thrive in disturbed conditions. The only species of interest from this perspective is the small bivalve *Theora lubrica*, which can be abundant under conditions of moderate disturbance or pollution (Forrest & Creese 2006; Inglis *et al.* 2006; Forrest *et al.* 2007). However, this species is already present in the dredging and disposal sites and, although non-indigenous, it is not regarded as an HMO. Short-term locally enhanced abundances would therefore be of negligible significance.

9.4.4. Harmful algal blooms

Harmful algal bloom (HAB) species produce biotoxins that can adversely affect coastal ecosystems, aquaculture, human health, recreational uses and aesthetic values. HABs are a particular concern for shellfish aquaculture, as biotoxins can accumulate in filter-feeding shellfish, leading to illness in human consumers and economic losses to marine farming companies due to closure of growing areas to harvesting (Rhodes *et al.* 2001).

The species of concern in this context are the toxic dinoflagellates, which have microscopic resting cyst stages that can remain viable in seabed sediments for long periods of time. The planktonic form of the dinoflagellate germinates from the cyst when growth conditions are suitable, and if dense cyst beds exist they can lead to the rapid development of HABs.

There is often a special focus on this issue in ports, as cysts can be transported internationally (or nationally) in ballast water and sediments (Drake et al. 2007; Casas-Monroy et al. 2011). However, most dinoflagellates are globally distributed and many of the species of concern in New Zealand are indigenous.

HAB species in Lyttelton Port and Banks Peninsula

Previous studies have shown there are a variety of common coastal dinoflagellate cysts in Lyttelton Port sediments, with five different species (plus two indeterminate taxa) having been identified (Taylor & MacKenzie 2001; Inglis *et al.* 2006; Inglis *et al.* 2008). No non-indigenous or potentially harmful species have been identified. Nonetheless, it is possible there are low densities of toxic cyst forming species in wider Pegasus Bay, but no sampling has been conducted in this area.

A more comprehensive understanding of HAB species and potential risk can be gained from analysis of Banks Peninsula phytoplankton and shellfish biotoxin monitoring data that has been collected over recent years. Phytoplankton and shellfish biotoxin data are irregularly (depending on harvest schedules) collected from shellfish aquaculture farms in Port Levy (Southern Seas Marine Farms), Pigeon Bay (Pigeon Bay Aquaculture Ltd) and Menzies Bay (Pegasus Bay Marine Farms) on Banks Peninsula. A public health monitoring programme run by MPI carries out weekly toxic-phytoplankton monitoring at two sites at Sumner and in Akaroa Harbour. With the permission of the owners of the information, the phytoplankton and biotoxin monitoring database dating back to May 2007 was searched to examine the history of algal biotoxin events and the phytoplankton species involved in this region. This history is summarised as follows:

- Contamination of mussels with diarrhetic shellfish poisoning (DSP) toxins (principally okadaic acid) due to blooms of the dinoflagellate *Dinophysis acuta* occurred in Pigeon Bay and Port Levy in 2009 and 2011. Maximum levels of okadaic acid (OA) reached 0.7 mg/kg in Port Levy on 12 October 2009 (regulatory level 0.16 mg/kg). A related dinoflagellate, *Dinophysis acuminata,* is also common around Banks Peninsula, but this species has a relatively low specific toxicity and it is not as hazardous as *D. acuta*. Populations of *Dinophysis* species naturally wax and wane over multi-year intervals and *D. acuta* has not been observed at the Banks Peninsula monitoring sites since October 2012. *Dinophysis* spp. have no known benthic resting cyst stage in their life cycle and so there is no reason for concern over their dispersion by dredging and spoil dumping.
- Paralytic shellfish poisoning (PSP) is the most serious form of shellfish-toxin contamination caused by cyst-forming dinoflagellates. It occurs regularly in some part of New Zealand (Bay of Plenty, Queen Charlotte Sound). However, there has been no indication of any PSP event at any Bank Peninsula sites in the biotoxin monitoring record since routine monitoring began in 1993.

- There have been a few records (3 observations over 7 years) of potential PSP-toxic *Alexandrium minutum* at Akaroa and Port Levy. In each case the cell numbers were just above the level of detection and sightings such as this are not uncommon at many locations around New Zealand. No blooms of this species have been observed at any Banks Peninsula monitoring site. *A. minutum* is a cyst-producing species; however, its rarity suggests that resting cysts are also rare in the region and the risk posed by this species is low.
- Likewise there have been three records of *Alexandrium ostenfeldii* over the same period. This cyst-forming species is known to produce spirolide and PSP-toxins. However, although commonly observed at many locations around New Zealand, it is rarely (if ever) abundant in the plankton and is regarded as a low risk.
- The most common form of algal-toxin contamination of shellfish from the Banks Peninsula is due to yessotoxin (YTX). This toxin is produced by the planktonic dinoflagellate *Protoceratium reticulatum* and possibly also *Gonyaulax spinifera*. Yessotoxin is common in shellfish throughout New Zealand. There have been over 300 shellfish samples from Port Levy and Pigeon Bay that have tested positive for YTX since May 2007. Toxicology studies have shown that YTX poses a low risk to human consumers and the EU permissible level has been increased to a high level of >3.75 mg/kg in recent years. Only one of the over 300 records of YTX contamination from Banks Peninsula has exceeded that level (4.9 mg/kg at Port Levy, 11 January 2010). The benthic resting cysts of *P. reticulatum* and *G. spinfera* are two of the most common species observed in coastal sediments throughout New Zealand, including the Marlborough Sounds. They will undoubtedly be abundant throughout the Banks Peninsula/Pegasus Bay region. Dredging of Lyttelton Harbour sediments will transport large numbers of cysts of these species but it is unlikely that this will have any detrimental effect such as increasing the incidence of YTX contamination in Pegasus Bay.
- Domoic acid (DA) is a neurotoxin produced by several diatom species within the genus *Pseudo-nitzschia*. At various times of the year *Pseudo-nitzschia* are amongst the most common species of planktonic diatoms in New Zealand coastal waters and frequently occur in very high numbers. Despite this, the occurrence of DA contamination is rare and levels are generally low. Out of > 320 mussel samples analysed from Port Levy and Pigeon Bay since May 2007, 26 showed detectable traces of DA. The highest recorded concentration was 0.6 mg/kg from Port Levy on 24 April 2010. This is well below the EU regulatory level of 20 mg/kg. DA-producing *Pseudo-nitzschia* spp. are not known to have a benthic resting stage in their life cycle.

Dredge spoil transfer and disposal risk

In summary, there is no evidence to suggest that cyst producing toxic micro-algae are a special problem in the harbours and inlets of Banks Peninsula. The various algal toxin contamination events that occur from time to time are caused by common cosmopolitan species. Most of these do not have a resting cyst stage in their life cycle so there is no reason for concern over their dispersion by dredging and spoil dumping. The exception is yessotoxin (YTX) contamination caused by *Protoceratium reticulatum*. However this species is ubiquitous in coastal sediments around New Zealand, and YTX is regarded as being of little risk to human shellfish consumers. Translocation of *P. reticulatum* cysts in dredging spoil is unlikely to have an effect by increasing the incidence of YTX in shellfish in the region and does not pose a hazard to aquaculture developments in Pegasus Bay. Dinoflagellates responsible for PSP are rare in the region and it is believed the risk of their translocation in dredge spoil is low.

Based on this assessment, the incremental risk of HAB issues arising as a result of the proposed channel extension and additional spoil disposal is likely to be negligible. It is also relevant that maintenance dredging has occurred in Lyttelton Port and the inner Harbour channel for more than 40 years in absence of significant HAB problems. The close proximity of the proposed channel extension and disposal grounds (c. 2 km at the closest point) suggests that their water masses will at times be connected (*e.g.* by wind-driven surface currents). As such, a HAB event in the outer Harbour unrelated to the dredging has the capacity to naturally extend to the spoil disposal and beyond. In this respect, the short-distance transfer of spoil from the channel extension to disposal grounds is of negligible significance. Finally, the environmental conditions in the dredged area and spoil ground are similar, with no reason to believe that the disposal area should be any more favourable for cyst germination than the adjacent Harbour.

9.5. Marine biosecurity risks resulting from altered shipping operations

In addition to the CDP, post-earthquake rebuild and development projects involve the construction of two large (350 m long) berths at a new container facility, a dedicated cruise ship terminal and a new enlarged marina within the Inner Harbour. These projects will enable larger ships to enter the Port. At the time of writing, it was unknown to what extent the proposed projects will change the nature and extent of vessels traffic into the Port. However, a change in vessel size or type, frequency of visits or global source ports, are all factors that could alter marine biosecurity risk. This issue has been considered as part of an assessment of effects for the Port redevelopment (Floerl *et al.* 2014), and much of the text below is taken verbatim from that report.

A significant increase in volume of vessel traffic has the potential to increase the risk of introducing HMOs to Lyttelton Port. If a given HMO arrives at Lyttelton Port more frequently via vessel movements, the likelihood that this species will eventually become locally established may increase correspondingly (Drake & Lodge 2004). In general, increasing the frequency of introduction events of invasive species has been found to be of higher relative importance to establishment success than increasing the average abundance of individuals associated with each introduction event (Hedge *et al.* 2012).

The proposed projects will result in Lyttelton Port being able to accommodate Quantum class cruise vessels and Maesk S-Class container vessels. Both vessel types have lengths of c. 350 m and draughts of 9–14 m. Compared to the present situation, this will represent an increase in the size of vessels the Port is able to service on a routine basis. The larger submerged surface area of these vessels potentially enables a greater abundance of organisms to be transported to Lyttelton Port with each visit, although generally the levels of fouling on such vessels are likely to be low. Also, the ability of the Port to accommodate larger vessels may result in Lyttelton Port receiving vessels from a new set of global ports that it has not traded with previously (New Zealand Shippers' Council 2010; Floerl *et al.* 2013). This could result in the transport of new species to Lyttelton Port. However, as noted in Section 9.2.2, the Port is already well connected to a large number of regions via present-day shipping activities, and like Lyttelton, overseas ports themselves are also highly connected. Without knowledge of specific changes in vessel origins it becomes purely speculative about how biosecurity risk may change. Nonetheless, it is reasonable to assume that an increase in the vessel traffic (and possibly different types of vessel), as well as a change in the geographical origin of vessels arriving in the Port, has potential to pose a significant biosecurity risk to the region.

As described in Section 9.6, a lot of the increased traffic volume is likely to arise after 2018, when the CRMS will be mandatory. This will considerably reduce the biosecurity risks posed by biofouling on international vessels. In terms of domestic vessel traffic, it is not known whether and to what extent associated biosecurity risk pathways will also be managed at this time (Sinner *et al.* 2013b), nor whether domestic pathways into Lyttelton Port will change. However, the issue of inter-port pathways and associated marine biosecurity risk is relevant to all regions of New Zealand. Effective domestic risk pathway management will require all regions to adopt a consistent approach.

9.6. Mitigation of marine biosecurity risks

The key biosecurity risks to consider from a mitigation perspective are the transfer of a dredge from overseas, and the altered vessel traffic enabled by the completion of project and the simultaneous earthquake rebuild of the Port. The negligible biosecurity risks from spoil transfer do not warrant the implementation of any mitigation measures for that element of the proposal.

As noted in Section 9.3.4, it is mandatory for all vessels to meet the IHS for ballast water and sediments. The CRMS for biofouling will not be mandatory until 2018, and from current project timelines it appears likely that operational changes in shipping activities will not occur until about that time anyway. As such, all international vessel arrivals will be subject to both IHS and CRMS requirements. On the other hand the dredge is expected to be brought to New Zealand while the CRMS is still voluntary. Given recognition of the potential biosecurity risk from dredges, and the fact that MPI is encouraging voluntary compliance, it is suggested that efforts are made to ensure that the dredge meets or exceeds the CRMS.

Compliance with both IHS and CRMS requirements would address all of the dredge's risk mechanisms, and provide a means of ensuring that its transfer to Lyttelton constituted an acceptable level of marine biosecurity risk reduction to the region. However, it should be recognised that while compliance is expected to greatly reduce marine biosecurity risk, it will not completely negate it. For example, if the dredge meets the CRMS and has no visible macrofouling (other than goose barnacles), the slime layer may nonetheless contain microscopic life-stages of macrofouling species. Recent research shows that such life-stages have the capacity to survive transport on vessel hulls. A long duration deployment may then afford the opportunity for surviving life-stages to grow and reproduce. As such, LPC should consider any opportunities where simple measures could be implemented to further reduce risk (e.g. sourcing a dredge immediately out of dry-dock, and minimising the time spent idle in-water at the source port before departure for New Zealand).

Given that the actual dredge and its particular risks are not yet known, the most straightforward and reasonable means of ensuring an acceptable level of risk is achieved would be to require, as a condition of consent, a specific Biosecurity Management Plan (BMP) for the contracted dredge. This has been the approach adopted with deployments of drilling rigs and their associated vessels (support vessels, and heavy lift vessels used for rig transport) in New Zealand since 2010 (*e.g.* by MPI and Marlborough District Council). Although a TSHD is not expected to have the same level of biofouling as a rig, it shares some other similarities in terms of its risk profile (*e.g.* multiple risk mechanisms, long duration deployment); hence development of a BMP seems an appropriate way forward.

Previous BMPs developed by Cawthron for drilling rigs and their vessels have outlined the mitigation measures to be undertaken, and have involved Cawthron or other organisations undertaking a verification inspection at the overseas port of departure. Following such inspections, an inspection report is submitted to MPI for provisional border clearance, with final clearance subject to a verification inspection by MPI upon arrival in New Zealand. Past approaches have involved cleaning and inspection either in-water using divers (*e.g.* Forrest & Hopkins 2009; Hopkins *et al.* 2013c) or out-of-water, for example in dry-dock (*e.g.* Hopkins *et al.* 2013b). For surfaces above-water during transit to New Zealand, desiccation by natural air drying has been recognised as a complementary mitigation tool in certain circumstances.

10. CONSIDERATIONS AND RECOMMENDATIONS FOR MONITORING

10.1. Monitoring approach

The field surveys, modelling simulations and assessments conducted to characterise the ecological resources and physical conditions of the receiving environment and describe the likely effects from the CDP have identified little potential for significant adverse effects from the project. However, the scale of the proposed activities and the inevitable areas of uncertainty in such investigations require that a robust program of environmental monitoring is established to validate these conclusions and allow timely remedial action in the event of unforeseen outcomes. Together with the practical constraints of data collection, these objectives necessarily result in two general categories of monitoring:

1. Collection of environmental data in actual or near real-time for use in adaptive management of the activity
2. Direct or indirect monitoring of important receptors to provide assurance that significant adverse effects are not occurring.

10.2. Use of monitoring data in project management

Monitoring data which is to be used adaptively in the management of operations must be compiled and interpreted within time-frames which allow effective decision-making before impacts become more than minor. For acute stressors, this means that data must be available in near real-time. For chronic stressors (*e.g.* those associated with environmental loading thresholds or where rapid recovery is possible), timeframes may be somewhat longer.

The time lag between the stressor and its measureable environmental response is also a key factor. A time lag of months (as may be the case for macroalgal response to a decrease in photosynthetically active radiation [PAR]) may enable an effective response but is of limited use in adaptive management since the time-frame of the project does not allow adequate validation of the effectiveness of that response.

The establishment of appropriate trigger levels for adaptive management needs to take into account not only the nature of the monitored parameters but their background levels and variability. Hence such triggers can only be set once sufficient background data have been compiled.

Using a precautionary approach, triggers are most likely to be set within, but towards the high end of, the range of natural background variability. The simplest approach is to base triggers upon percentile values of the background data. However, because the background variability intrinsically exceeds its percentiles, there is a high probability, over project time-scales, of exceedance due solely to natural processes. Therefore, the effective use of such triggers relies on knowing, and allowing for, the influence of external drivers of the measured parameter.

It follows from the above that it is critical to be able to reliably establish a causal link between the measured effect and the project activities (dredging and spoil deposition). Without this ability, effective management is not possible. Where there is uncertainty as to cause, a tiered system of response should therefore include the rapid elimination of this uncertainty. So the system may include increases (or decreases) in the spatial extent and/ or intensity of monitoring itself as data is compiled and interpreted.

10.3. Monitoring variables

10.3.1. Key stressors

Continuously measurable parameters

The key variable potentially able to cause impacts to receptors at some distance from the dredging activity and spoil ground is that of suspended sediment, with turbidity able to be measured and compiled in real-time as a convenient proxy.[28] The propagation of turbidity plumes from resuspension sites is the mechanism by which most other far-field stressors are exerted. The continuous monitoring of turbidity enables rapid operational response, potentially even before the receptor of concern is reached by the detectable plume.

Other continuously measureable plume-related stressor variables of potential interest include PAR, chlorophyll-*a*, dissolved oxygen and pH. PAR has relevance to the health of macroalgae on shoreline reef substrates, benthic microalgae in shallow near-shore waters, phytoplankton productivity and—by extension—the health of filter feeding biota (including cultured mussels). Chlorophyll-*a* concentration is a more direct proxy measurement for phytoplankton biomass. Although changes in PAR may be linked to capital dredging activities via its relationship with turbidity, chlorophyll-*a* is likely to respond to a multitude of external environmental drivers which makes the establishment of a direct causal link difficult. Both dissolved oxygen and pH are unlikely to be significant environmental stressors in this case, except possibly localised to the point of suspension. While continuous monitoring is possible, confirmation of their relative insignificance may be gained by discrete water column profiling.

As a cumulative stressor variable, depth of sediment deposition (sedimentation / smothering) is measureable as bed height but must take into account natural erosion

[28] The direct measurement of suspended sediments is conducted via laboratory analysis of discrete samples rather than by *in situ* instrumentation. It therefore does not lend itself to real-time monitoring.

and accretion processes. Sediment deposition is very unlikely to be cumulative on shoreline reef substrates since they are exposed to significant water movement from surge, even well into the inlets. However, increased depositional flux may be a stressor for reef biota, with consequently increased prevalence and persistence of silt veneers. Direct measurement of depositional flux may be problematic, although there may be potential for an appropriate sediment trap design to be employed on a discrete basis. A change in the potential for deposition may be inferred from turbidity monitoring and the depositional environment may be assessed qualitatively from direct observation during dive surveys.

Discrete measurements and analyses

Potential stressors for which discrete sampling and analysis are required include suspended sediment, nutrients and toxicants. A site- and activity-specific relationship between turbidity and suspended sediment concentration may be derived from sampling or via controlled tank testing. The derivation of such a relationship is important to be able to relate turbidity (as NTU) to the predictions of plume modelling.

Both nutrients and sediment-derived toxicants are considered unlikely to be important stressors from a water quality perspective although the latter may warrant limited validation sampling from identified plumes close to source or periodic deployment of bioaccumulators such as caged mussels.

Frequent opportunities should be taken (*e.g.* piggy-backed onto other monitoring or servicing of *in situ* field equipment) to build up a record of water column profiles whereby instrument casts are used to establish how a range of water quality parameters vary with depth. Parameters commonly recorded in this way include turbidity, salinity/conductivity, temperature, dissolved oxygen, chlorophyll-*a* and pH. While each profile (for each location) will represent only a snap-shot in time, together, they will begin to build up a spatial and temporal picture of the relationship between surface and benthic conditions.

Methods for one-off plume mapping surveys are also possible and could be considered as a specific validation response to low-level trigger exceedance. OCEL (2013) described the use of a vessel-mounted ADCP to track the progress of the benthic plume following a single deposition event. It would also be possible to 'fly' a turbidimeter at a range of depths behind a vessel and continuously log the data (including position coordinates) to a GIS file to map the extent of a detectable plume on a given day of dredging operations.

10.3.2. Ecological response

Direct monitoring of ecological response (effects variables) has the major advantage that it represents the actual effect against which a suitable measure of protection is sought. It also provides crucial validation of the prior assessments (ecological effects, predictive modelling *etc.*) and the effectiveness of project environmental management, allowing remaining uncertainty to be addressed. Limitations include the following:

- Ecological parameters can be highly variable and are influenced by a wide range of stressors, both natural and anthropogenic. Even a year of intensive baseline data will not provide certainty around inter-annual variation due to longer-term cycles and trends (*e.g. el Niño / la Niña* events, climate change). Attributing cause, therefore, becomes a significant problem for interpretation.
- By the time it is detectable, an adverse effect has already occurred. Most monitoring methods for ecological variables are impractical to use at high enough frequency and are not sensitive enough to be of any value in adaptive management. However, they still have a potentially important role in validating the protection of high value ecological receptors. In the context of a multi-stage project, the monitoring results can be used adaptively to inform the implementation of subsequent stages.
- Ecological responses to chronic stressors (*e.g.* low PAR) may take months to years to become apparent. This presents a scenario where overshoot in the response trend is likely. In this case, an operational response, no matter how timely, cannot avoid some further degradation before the trend is reversed. Hence the monitoring programme must utilise multiple lines of evidence to allow both early warning of potential problems and appropriate verification of causality.

10.3.3. Key environmental receptors

In deriving a suitable monitoring schedule, it is important to consider first the potential receptors requiring protection. An exhaustive list is not necessary since individual receptors may be grouped into broad categories or ecosystems with similar exposures (*e.g.* shoreline reef habitat rather than pāua abundance specifically). Within these there may be particular indicators singled out on the basis of high importance (*e.g.* pāua), ease of measurement (*e.g.* macrophyte cover) or particular sensitivity (if specifically identifiable). Monitoring for some potential far-field receptors may be discounted on the basis of negligible risk, low sensitivity or because effective monitoring is already proposed for more proximal receptors along the plume pathway. The key receptors considered are as follows:

Soft sediment benthos

Subtidal soft sediment habitats are fundamentally important as forage areas for higher trophic levels such as fish. However, this importance as a receptor is balanced by the very large area of similar habitats across Pegasus Bay. There are several important advantages to monitoring these habitats:

- It is the only benthic habitat to be directly disturbed by the proposed activity and the closest to the source of sediment plumes.

- Sampling and quantitative physicochemical and ecological analyses have well-established protocols, can be easily replicated and are straightforward to implement.
- The short life-cycles and direct contact with introduced sediment of many infaunal species mean they exhibit relatively rapid response to sediment-associated stressors.
- The variety of possible sediment analyses allows consideration of multiple lines of evidence in interpreting change. For this reason, the co-occurring physicochemical conditions must be included.
- The spatial distribution and relative uniformity of this habitat in relation to the proposed activity lends itself to the identification of effects gradients.

The methodological rigor possible with soft sediment benthic sampling means that it is considered a sensitive monitoring tool. However, the already highly turbid environment of the seabed in Pegasus Bay and Lyttelton Harbour/Whakaraupō, combined with the similarity between dredged and native sediments, suggests that these communities will be somewhat resilient to increases in suspended solids and deposition. But this degree of community stability in the face of such naturally dynamic conditions also increases the probability that changes brought about by significant additional stress will stand out as conspicuous.

Soft sediment benthic monitoring will provide an indication of the spatial extent and magnitude of any significant effects occurring beyond the disposal and dredge area boundaries, as well as indicating the rate of recovery within the disposal area. A tiered spatial arrangement is appropriate, whereby the exceedance of triggers would result in a greater spatial intensity of subsequent monitoring.

One aspect which is not typically included in benthic monitoring is a measure of the consolidation of the substrate. For the spoil ground, where direct deposition will occur, the difference in sediment consolidation between points inside and outside the boundary will not only provide another physical parameter with which to interpret recovery, but has implications for the potential resuspension of the deposited spoil during high wave events.

On the basis of proximity and anticipated rapid response, soft sediment habitat should be the first and most frequent ecological receptor to be monitored following the commencement of the project. It is suggested that this should be 4 months after commencement of a dredging campaign/stage (representing ~30% complete). This (combined with the analysis of telemetered turbidity data) would give an early indication of whether plume impacts are significantly exceeding predictions. Scheduling of such monitoring may include changes in spatial sampling density, either according to a pre-established program or in response to triggers or interpretation of coincident data.

Shore line reef habitats

Reef habitats in Pegasus Bay, and to a lesser extent in Lyttelton Harbour/Whakaraupō, are outside the area for which significant plume impingement is predicted (MetOcean 2016c,d). Within the wider area, these habitats are effectively limited to the shoreline margin. However, as a receptor, coastal reefs have high associated values, including those of key mahinga kai species.

Monitored habitats may be in the intertidal or subtidal zones. The intertidal has the advantage that survey conditions (above water) facilitate the generation of high quality data and allow the coordination of multiple survey personnel. Disadvantages include the scarcity of coincident low-tidal and weather windows of opportunity. On exposed coasts, sea state is critical for landing safely from a vessel in otherwise inaccessible locations and may compromise the quality of data attainable from the low-shore in persistent surge conditions. Surveys in the subtidal zone have all of the usual logistical and procedural challenges of executing a scientific diving operation, exacerbated in this case by surge and low underwater visibility. A principal advantage of monitoring the subtidal in this case is that macroalgae are potentially one of the more sensitive receptors of light attenuation from increased turbidity. It is the density and condition of macroalgae at depth that are likely to respond most to sustained low PAR.

It is the coastal sites closest to the source of turbidity plumes, and specifically those which normally experience the highest PAR at depth, where any light attenuation effects are likely to become first detectable. This means that appropriately placed outer coast sites can function as indicators to ensure the protection of reef habitats within deep inlets such as Port Levy and Pigeon Bay. The relative uniformity of community assemblages at sites surveyed along the Banks Peninsula shoreline (section 0) means that effort can be focussed on comprehensively monitoring a small number of sites at a spatial separation commensurate with the expected width of plumes potentially sustained at the coast. These monitoring sites should be located according to proximity or (adaptively) from knowledge of plume propagation and to allow the identification of spatial gradients in effects. It must be recognised that the resolution of effects attributable to dredging activities will be very difficult unless such effects are relatively substantial and/or clearly supported by data from monitoring of turbidity and/or soft sediment communities located on the plume pathway.

Although there should be an observational and photographic record of fine sediment presence in shoreline reef environments, direct measurement of sediment deposition at shoreline locations is impractical and effectively meaningless. The reason for this is that deposition at any surge-affected location is controlled by water movement. Plumes arriving from distant sources will not carry particulates which will stay in place. Although deposition does occur (in the form of thin silt veneers in periods of calm), the transient nature of such deposits precludes their meaningful measurement.

Measurement of the suspension itself (in the form of turbidity or PAR) provides a more reliable way of monitoring for the protection of such habitats.

Subtidal surveys must be predicated not only by calm survey conditions but a period of preceding settled weather to ensure low surge and adequate underwater visibility. This means that scheduling of such monitoring will have to accommodate seasonal considerations. It cannot furthermore be assumed that intertidal and subtidal monitoring surveys can co-occur. This is due to the probability of coincident spring tidal and optimal sea conditions becoming too small to guarantee meeting the required scheduling requirements of a consent-stipulated monitoring programme.

Even in the event that plumes from dredging activities were to impinge on the shoreline, there is likely to be a considerable time lag (months to a year) before ecological effects become measureable. Therefore, although monitoring of subtidal sites may be triggered by exceedance of limits for other monitored parameters (*e.g.* turbidity, PAR), there is little advantage to a high frequency of such surveys. This places more emphasis on the day to day monitoring of turbidity plumes being suitably comprehensive to alert managers of the potential for effects at the shoreline. Seasonal factors may play a confounding role in the measurement of ecological variables undertaken at different times of the year but it may be difficult to observe strict seasonality in scheduling surveys to the requirements of operationally-based consent conditions.

Intertidal surveys are likely to be able to play a complementary role in documenting the presence or absence of significant effects attributable to plume impingement and are logistically more straightforward.

Fish and fisheries

Benthic and demersal fish are important as prey for Hectors dolphins and larger fish species. As such, they play an important role in food web interactions and wild harvest fisheries. However, the direct monitoring of fish populations is considered impractical in this case. The major difficulties are firstly in adequately defining natural variability and, secondly, in deriving a meaningful causal link with a specific driver.

There are substantial obstacles to obtaining comprehensive data from physical surveys of fish stocks in Lyttelton Harbour/Whakaraupō and the vicinity of the spoil ground. Fish populations are inherently mobile and exhibit seasonal movements for feeding or spawning. Additionally, there can be considerable natural fluctuation in populations over time due to environmental factors including food sources, predator interactions and those driving recruitment into the adult population. These characteristics make the assessment of fish populations very difficult. One-off surveys, unless they are very extensive or are repeated across seasons and years, are unlikely to be conclusive and must be considered within the body of available information. Additionally, the multitude of other factors which influence fish populations add to the difficulty of linking observed variations to a particular activity or set of environmental conditions.

It is considered to be a better strategy to focus monitoring efforts on the soft sediment benthic habitats over which fish forage, along with establishing the spatial extent and strength of turbidity plumes which may affect fish populations. For instance, if benthic communities directly impacted by project activities (*e.g.* within the spoil ground) recover to the extent that they are not effectively distinguishable from the pre-dredging condition (or the wider area), then the re-establishment of benthic foraging fish populations can be reliably anticipated (bearing in mind also that the area may experience ongoing physical disturbance from commercial trawling).

Hector's dolphin

An assessment of potential effects to Hector's dolphin is being covered by a separate report. The species is mentioned here on the basis of its very high conservation value and (since direct monitoring of response in dolphin populations is unlikely to be practical) its relationship, via prey association, with other monitored variables.

Aquaculture

Similar to shoreline reef habitats, mussel farms on the Banks Peninsula coastline and within the inlets are well outside the area for which significant plume impingement is predicted (MetOcean 2016c,d). However, the commercial importance of these operations is such that operators seek reassurance that dredging-related stressors will not constitute a significant risk. The principal mechanism by which impacts may occur is via turbidity plume propagation. As well as direct effects to cultured mussels from the effects of elevated suspended solids, effects on phytoplankton abundance via reduced PAR and sediment-associated contaminants have been identified as specific stakeholder concerns.

Although some concern has also been expressed regarding the potential translocation of marine pests within dredge spoil, the additional risk of such spread by way of the proposed dredging project has been assessed as negligible (Section 9.4).

It is recommended that LPC works with marine farmers to establish principal relevant data sources for monitoring purposes (suspended sediments/turbidity, chlorophyll-*a*, yield) and to increase vigilance for any marine invasive species.

Monitoring approaches to provide assurance that plumes from dredge operations do not exceed predicted scenarios should in the first instance focus upon measurement of turbidity at locations between the farms and the point of generation. Trigger levels generated from the background turbidity on a percentile basis are likely to be conservative with respect to mussel farm sensitivity due to likely higher typical background turbidity at the farm locations.

Monitoring of turbidity or suspended solids at points adjacent to the farms is also a possibility for validation. However, difficulties in establishing a causal link for any high readings associated with farms would need to be addressed, especially since background turbidity at near-shore locations and within the inlets is likely to be frequently higher than offshore at the spoil ground and the outer dredged channel. Additionally, mussel farms themselves are a potential source of suspended sediments during harvesting operations and wave events. The combination of data from the wider area monitoring framework and any on-farm monitoring needs to allow robust interpretation of drivers for any observed perturbation.

Wild mussels have been successfully used as a bioindicator species for environmental contamination (Kimbrough *et al.* 2008) and caged mussels have shown measureable body burden response to sediment-associated contamination in deployments of three months' duration (Conwell & Stewart 2007) as well as for a range of other biomarkers in dredging resuspension scenarios (*e.g*. Bocchetti *et al.* 2008). However, the risk of exposure of marine farms to plume-associated contaminants from the capital dredge project has been assessed as being negligible (Section 7.2.1), and specific bioaccumulation monitoring is not recommended in this instance.

Shoreline soft sediment habitats

Several areas of intertidal and shallow subtidal soft sediments have been identified as potentially important receptor sites. These include the heads of the Port Levy and Pigeon Bay inlets and sites in the upper and south central sectors of Lyttelton Harbour/Whakaraupō. Values associated with these sites include limited local distribution (in the case of sandy intertidal habitat) and mahinga kai species.

Monitoring of shoreline sediment habitats could take the form of sampling for grain-size distribution, infauna community analysis or shellfish population surveys. All of these would require suitable background data to be compiled prior to the commencement of the dredging project.

Since most shoreline soft sediment habitats within the vicinity are in depositional zones, they already incorporate a substantial silt component. The grading of sediment texture at all sites occurs by wave resuspension and transport by ambient currents. Due to the distances between the plume source and these receptor sites, it is considered extremely unlikely that plume strength would be great enough at these locations to bring about a significant change in the habitat via deposition. Furthermore, such change, were it to occur, would be gradual and driven by SSC persistently well above background. In the case of measureable ecological effects at the heads of inlets, turbidity at the coastal reef receptor sites on the plume path would be extreme, and their habitats far more vulnerable. On this basis, direct monitoring of these habitats is not recommended, except potentially as a lower tier response to triggers set for more sensitive or proximal receptors.

10.4. Background and baseline measurement

Regardless of any tolerance to suspended sediments which may be identified for individual key taxa, the more important focus for monitoring triggers are the background levels and variability to which all marine communities are adapted. While individual species will have optimum ranges for a multitude of conditions that define their particular ecological niche, all such populations occur along a continuum within these ranges. On this basis, a number of the taxa identified from field surveys are likely to be already near the extremes of these tolerance ranges. For instance, the habitat-forming macroalgae *Ecklonia radiata* appears to prefer conditions of lower turbidity and moderate water movement. Therefore, while it may have a limited presence at shoreline reefs in the central Harbour, conditions will be naturally sub-optimal for its establishment and growth. These factors are what drive the spatial distribution of a species and its prevalence within any particular community.

The baseline ecological state of an individual habitat is typically defined by its community structure and not necessarily by the health of individual populations represented within it. This means that, unless the values of certain key taxa are judged to exceed those of the community itself, it should be the latter to which protection and monitoring effort are applied. To achieve this, a sound understanding of the background variability of critical parameters of concern is required. In the case of potential far-field effects from the capital dredging project, the most critical stressor variable is that of suspended solids/turbidity (together with the related PAR). To establish the background conditions to which marine communities are currently adapted and assign meaningful trigger values for management of effects, a year of continuous background data is seen as a minimum requirement. It is worth noting, however, that even this will not establish the inter-annual variation which may also be a significant factor affecting such communities.

10.5. Spatial considerations

10.5.1. Adaptive management variables

As part of an adaptive management system, it is intended that LPC will have a number of monitoring stations which provide real-time data via telemetry. It is important that the positioning of these monitoring points for critical variables offer spatial coverage adequate to the receptors requiring protection, especially where such data are to be used reactively for adaptive management. Weighting must be given to monitoring either near receptor points or in recognition of critical plume propagation paths. In the latter case, decisions over placement, must take into account what can be reliably anticipated in the nature and movement of plumes. Ideally, it should not be possible for a sediment plume from spoil deposition to reach the shoreline at a concentration above which there is potential for significant adverse effects without triggering a response of management action.

Conversely, there will be areas where monitoring would serve little purpose in the protection of key values. For instance, monitoring points seawards of the spoil ground are arguably less useful than those between the spoil ground and the rocky coastline of Banks Peninsula. Similarly, monitoring points north of the current channel within the Harbour are also of lower priority in view of the fact that this area is largely taken up by the current spoil ground for maintenance dredging. However, points to the south of the channel have been less exposed to stressors associated with spoil deposition and are therefore likely to be the more sensitive to those from the CDP.

The depth within the water column at which monitoring occurs also requires some consideration. While there are practical challenges for telemetered data collected at depth, benthic plumes are likely to travel further and carry a greater amount of suspended sediments. The collection of water column profiles of turbidity and other parameters within sediment plumes at a range of distances from the source may enable the establishment of typical distributions to be utilised for predictive and validation purposes.

10.5.2. Ecological response: Validation of cause

As noted above, one of the key challenges where a significant change in ecological conditions has been established at a receptor site is the determination of causation. Due to the distances involved between source and receptor, there is likely to be significant uncertainty over provenance unless multiple lines of evidence can be established. These may take the form of:

- The data record for a stressor variable which is consistent with the observed effect. (*e.g.* turbidity trigger exceedance for a point along the logical plume path)
- Multiple effects measured at the site which implicate a specific cause
- Differences between monitoring sites which preclude a spatially ubiquitous shift in condition, including absence of effects at sites which function as reference points
- Establishment of spatial gradients in effects based on proximity to the presumed source.

10.6. Summary of options for ecological monitoring

In summary, Table 13 presents a matrix of factors considered relevant to decisions regarding the type and intensity of monitoring to implement for ecological receptors. While there are sound reasons to discount some monitoring options, any recommendation not to utilise a monitoring method or station does not necessarily preclude its incorporation as a response tier to a specific trigger exceedance.

Table 13 Summary matrix of aspects considered for the monitoring of key marine ecological receptors.

Receptor	Proximity	Potential stressors	Value	Monitoring/considerations	Priority	Proxy or supporting variables
Soft sediment benthos	Directly impacted Near-field Far-field	Suspended sediment Smothering Toxicants	Base of food chain for many demersal fish species and Hectors dolphin Not limited in wider area of Pegasus Bay	Direct sampling and community analysis • Infauna cores • Epifaunal trawl Deposition (bed height)	High	Plume propagation via turbidity Discrete water column profiling Plume mapping
Shoreline reef habitats	Far-field **Channel extension:** 750 m Godley Head 950 m Adderley Head 1 km Port Levy entrance **Spoil Ground:** 4 km Banks Peninsula	Suspended sediment Increased depositional flux	High natural value Mahinga kai Amenity value Limited to coastal margin	Quantitative subtidal survey Semi-quantitative or quantitative intertidal survey	Medium	Plume propagation via turbidity Plume propagation via soft sediment benthos PAR monitoring Discrete water column profiling Plume mapping
Fish and fisheries	Near-field Far-field Wide ranging	Directly by suspended sediment / turbidity Indirectly via effects to benthos Mobile: ability to avoid stressors	High natural value Important as prey to Hectors High commercial value Not limited in wider area of Pegasus Bay but flat fish hot-spot off Godley Head	Direct monitoring by fine mesh trawl surveys • Resource intensive • Statistically insensitive • Causal link problematic Retrospective validation via fisheries data base	Low	Plume propagation via turbidity Soft sediment benthos (forage area)
Hector's dolphin	Far-field (relatively wide ranging)	Indirectly via effects to prey fish species Highly mobile: ability to avoid affected areas	Very high conservation value	Direct population monitoring is impractical	Low	Fish monitoring Soft sediment benthos (food web base)
Aquaculture	Far-field >1 km Port Levy	Suspended sediment Suppression of phytoplankton	High commercial value	Yield / growth monitoring • Causal link problematic Chlorophyll-*a* Caged mussel deployments	Medium	Plume propagation via turbidity PAR monitoring Discrete water column profiling
Shoreline soft sediment habitats	Far field Upper inlets Upper and central Lyttelton Harbour/Whakaraupō	Suspended sediment Smothering unlikely due to distance and high natural sediment flux	High natural value Mahinga kai Limited in wider area	Direct sampling and community analysis • Infauna cores • Shellfish populations	Low	Plume propagation via turbidity More proximal reef habitats along plume path

10.7. Recommendations for ecological monitoring and locations

10.7.1. Channel deepening project

Based on the factors discussed in Section 10.3.3 (summarised in Table 13) and the results of hydrodynamic modelling, the soft sediment benthic environment is considered to represent the most easily monitored and reliable ecological receptor in gauging the significance and spatial extent of plume-mediated effects from the CDP. It also provides the best opportunity for documenting the post-deposition recovery of the capital spoil ground and assurance that the foraging base upon which less easily monitored receptors ultimately depend is not impacted.

A pattern of 19 stations is recommended (Figure 39), with 14 subject to monitoring during each dredging stage/campaign and a further 5 contributing to baseline and post-campaign records. Sampling should be based on triplicate grab samples from each station and provide for the following analyses:

- Sediment physicochemical parameters
    - Grain size distribution
    - Organic enrichment
    - Contaminants (indicative trace metals in composite samples)
- Macroinvertebrate community analysis.

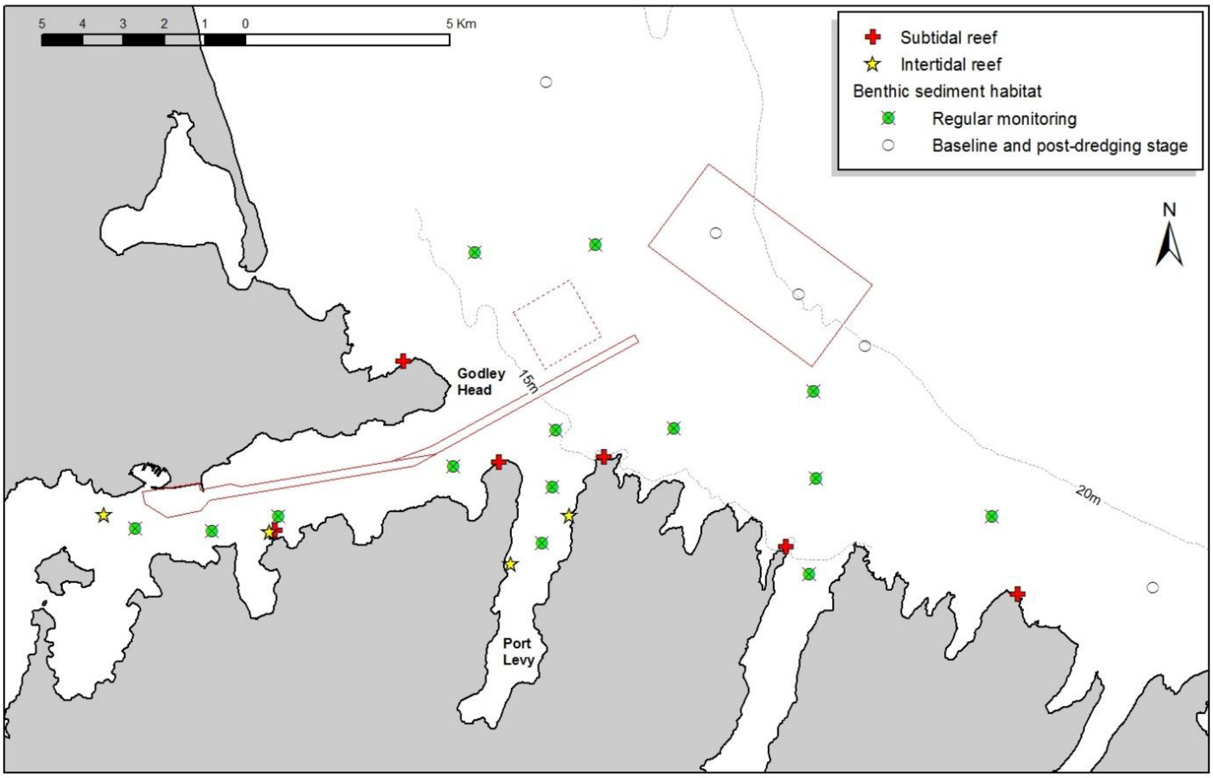

Figure 39 Spatial layout of recommended ecological monitoring sites for the CDP.

To provide for direct monitoring of high-value shoreline receptors, a subset of the subtidal and intertidal reef sites surveyed for this investigation (Sections 5.5 and 5.6) is recommended to be re-surveyed immediately prior to, at intervals during and following each stage of the CDP. Figure 39 shows the spatial layout off these recommended monitoring sites which are identified as follows:

- Subtidal reef sites – quadrat surveys along isobathic transects:
  - LH07 – Ripapa Island
  - BP01 – Adderley Head
  - BP14 – Taylors Mistake
  - BP02 – Port Levy/Koukourārata east headland
  - BP05 – Pigeon Bay west headland
  - BP08 – Otohuao Head
- Intertidal reef sites – semi-quantitative surveys (presence/absence/relative abundance):
  - LH05 – Shag Reef/Kamautaurua
  - LH07 – Ripapa Island
  - PL03 - Pukerauaruhe Island (Port Levy/Koukourārata)
  - PL16 – Port Levy/Koukourārata eastern shore.

The survey methodologies utilised for this investigation (Sections 4.4 and 4.5) are considered appropriate for the recommended ecological monitoring surveys. Survey frequency during each stage of the CDP should be such that, in addition to one survey prior to commencement, at least two are completed during the campaign (likely to require intervals of at most 4–6 months). These should ideally coincide with soft-sediment benthic sampling surveys.

10.7.2. Monitoring of maintenance dredging

The current maintenance dredging consent held by LPC (CRC135318) was issued in 2014 and covers the deposition of dredged sediments within the spoil grounds on the northern side of the Harbour which have been in use for many decades. The consent requires the monitoring of soft sediment benthic habitats at 12 stations throughout the Harbour on a 5-yearly basis, together with semi-quantitative intertidal surveys of two sites and analysis of blue mussels for bioaccumulation from two sites. The benthic stations are located both within and outside of the consented spoil grounds, including four stations within the upper Harbour (Figure 7).

Although it is the intention to retain the use of the current Harbour spoil grounds for deposition of dredged sediments, the eventual pattern of usage of these grounds has is not yet established. On this basis, it is recommended that the current Harbour monitoring program should be retained largely unchanged but that additional benthic stations be added to cover the proposed offshore maintenance ground. In view of the potentially significant volume of spoil deposited at the offshore ground, it is recommended that two stations be located within its boundaries. The existing station DD01 is located off Godley Head directly inshore of the proposed offshore spoil ground and will serve to signal any benthic effects which may indicate a potential risk to shoreline receptors. A further reference station, to be established 1 km north-west of the spoil ground, is also recommended (Figure 40).

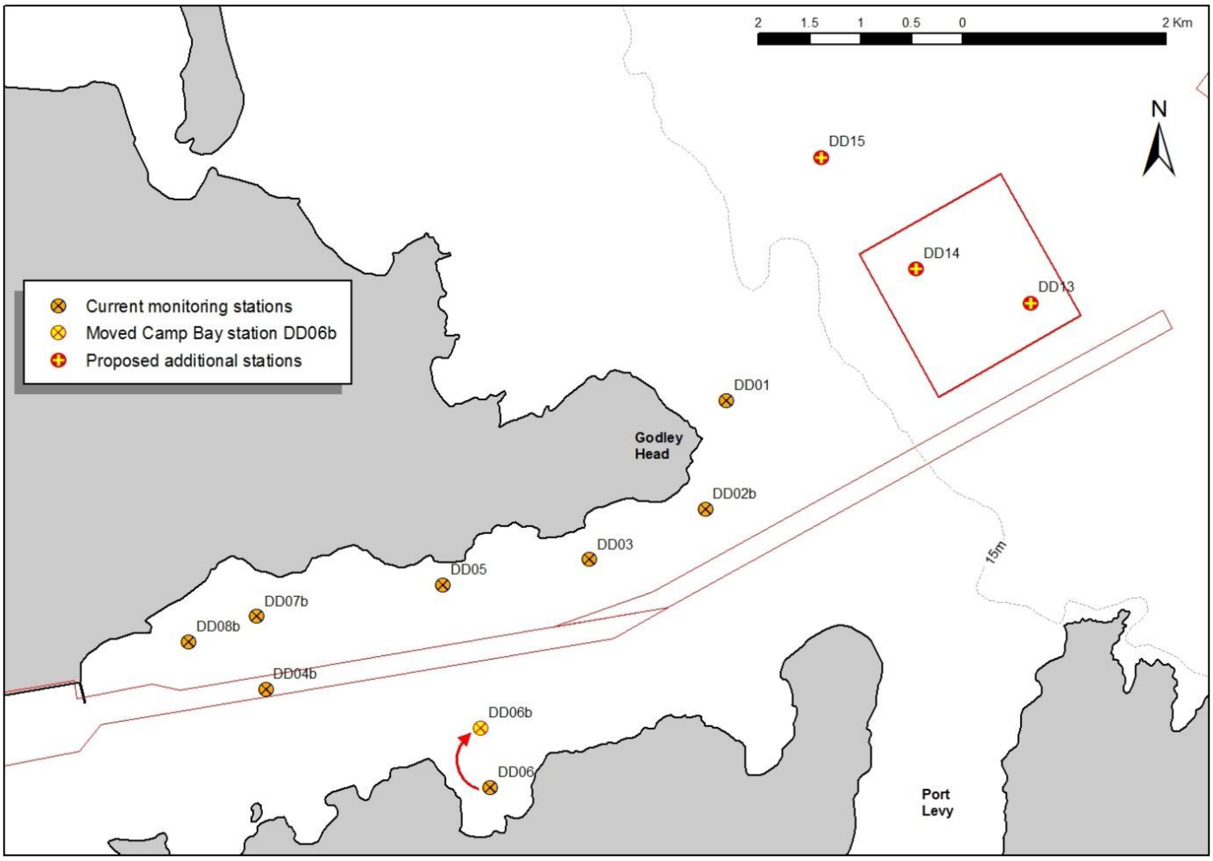

Figure 40 Recommended modifications to the existing 5-yearly benthic monitoring program for maintenance dredging and spoil disposal. Note: The four upper Harbour monitoring stations are not shown in this view.

Following the findings of the most recent benthic monitoring survey for maintenance dredging (Sneddon *et al.* 2015), it is recommended that the current monitoring station (DD06) at Camp Bay on the south side of the Harbour be moved 600 m northward. This new location features sediments more similar to those found at the other monitoring stations and which are more conducive to successful grab sampling.

Additional intertidal monitoring surveys to cover deposition at the offshore ground are not recommended for a new maintenance dredging consent. This exposed location of Godley Head cannot be accessed from land and represents an unsafe situation for access by boat in anything but the calmest conditions. This assessment arises from a trial site on the Godley Head south-east shoreline (Figure 31) surveyed in 2010 and 2012. Godley Head has furthermore been subject to a number of significant rock-fall events associated with the earthquake sequence which started with the 2010–2011 seismic events and including the February 2016 quake. As well as representing a potential safety concern, the recently deposited rock-rubble material deposited along the Godley Head shoreline is likely to confound the interpretation of any observable changes in intertidal communities.

While a similar set of concerns apply to the potential collection of mussels from Godley Head for bioaccumulation analysis, it is further considered that the bulk of the material deposited at the offshore ground will have been dredged from the outer Harbour navigation channel. As such, the combination of deposited bulk spoil of low contamination status and a highly dispersive wave-exposed environment are expected to represent a minimal contaminant exposure risk for shoreline areas. Consequently, it is recommended that bioaccumulation testing remains limited to the Gollans Bay shoreline.

11. SUMMARY AND CONCLUSIONS

11.1. Survey findings

11.1.1. Soft sediment benthic habitats

The benthic substrate of the areas proposed for the extension to the existing navigation channel and the establishment of the offshore capital and maintenance spoil grounds are similarly composed of relatively uniform semi-consolidated mud and lack any natural hard substrate features. This appears to be typical of much of the inshore region of southern Pegasus Bay.

Contaminant status of the surficial sediments based on concentrations of indicative metals, both within areas of the central and outer Harbour and in the vicinity of the proposed spoil grounds was found to be low, with levels generally well below ANZECC (2000) ISQG-Low trigger levels. Analysis of central Harbour sediments for polycyclic aromatic hydrocarbons yielded detectable concentrations but well below ISQG-Low criteria.

Sediment-dwelling macroinvertebrate communities were relatively sparse with quite low species richness. Numbers of species per core sample ranged from 9 to 34 outside the Harbour heads with 4 to 28 taxa from six stations within the central to outer harbour. Overall, polychaete taxa represented eight out of the twelve most abundant taxa over the areas sampled and around 70% of all individuals counted.

The area of the proposed channel extension was found to have a slightly greater proportion of silt- and clay-sized particulates and, together with the proposed offshore maintenance spoil ground, supported generally less diversity and abundance of benthic fauna than the site of the proposed capital spoil ground. Samples from within the Harbour were highly variable in sediment texture with greater prevalence of very fine sand on the south side of the central Harbour.

Benthic epifauna outside the Harbour heads, as sampled using a research dredge with 10 mm mesh, was found to be very sparse with consistently low abundances collected in trawls. Only 29 species were identified overall, some of which were inferred by the existence of shell remnants only. The results of two trawls in the proposed channel extension area suggested a particularly impoverished epifaunal community, with only four species identified.

Side-scan sonar coverage of the channel extension area and the wider vicinity of the proposed spoil ground indicated that the substrate and habitat described from the grab samples existed uniformly over the study area. No features of special scientific or conservation interest were identified by the offshore benthic surveys.

Both substrate and biological characteristics of the offshore soft sediment benthic environment were consistent with a number of previous surveys of Pegasus Bay, indicating that the seabed area off Godley Head is typical of the benthic ecology of the wider area in similar water depths.

11.1.2. Ecological characterisation of shoreline reef habitats

The subtidal habitats and community assemblages of the shoreline reefs in Lyttelton Harbour/Whakaraupō, Port Levy, Pigeon Bay and the northern coast of Banks Peninsula were surveyed in February 2016. Even though the surveys were carried out after a period of settled conditions, poor water clarity was a noted feature of this coastline, with turbidity increasing into the inlets and Harbour and in response to increased shoreline surge. Sediment tolerant taxa formed a component of the species inventory but settled sediment was generally limited to thin veneers in these surge-affected areas.

Substrates recorded were dominated by bedrock and boulder reefs with only minor variation across the areas surveyed. Reef communities were characterised by a relatively high and uniform taxa richness across sites with 71 taxa recorded overall. These communities are considered representative of the wider area, being comparable to those previously found in published studies of the Banks Peninsula region.

Kelp forest of varying density was a consistent feature of transects in 4 m water depths, with the prevalent species being *Ecklonia radiata* and *Macrocystis pyrifera*. However, large canopy-forming macroalgae such as these were sparse at 7 m depths.

Coverage of reef substrate was generally dominated by encrusting coralline algae at the 4 m depth level, whereas beds of solitary ascidians were frequently the dominant cover at 7 m depth. Large green-lipped mussels were also common and formed dense beds at sites on the northern shoreline of Lyttelton Harbour/Whakaraupō.

Pāua were found across all areas and were counted and measured along 50 m littoral fringe transects at 0.5 m (CD) water depth. Pāua size ranged between 60.5 mm and 132.5 mm, with only 2.1% greater than the 125 mm legal size. Pāua densities ranged between 12 and 185 individuals per 50 m^2 across sites.

Five intertidal reef sites were surveyed semi-quantitatively (presence / absence / relative abundance); three in Lyttelton Harbour/Whakaraupō and two in Port Levy. To this survey information was added data from another 5 sites previously surveyed within Lyttelton Harbour/Whakaraupō. The intertidal assemblage of animals and plants recorded from these sites are considered to be generally characteristic of the region and show variability principally according to the degree of exposure to wave energy.

Overall, no intertidal or subtidal organisms or communities of special scientific or conservation interest were identified during the surveys carried out for this investigation. However, the status and distribution of the rare brachiopod *Pumilus antiquatus*—last observed in Lyttelton Harbour/Whakaraupō during the late 1960s—is at present undetermined. A search at Ripapa Island (from where it has been previously recorded) in February 2016 failed to find any evidence of a current population. While the CDP is not predicted to directly impact this particular site, the formal conservation status of *P. antiquatus* as Nationally Critical means that activities which may adversely affect this species should proceed with conditions appropriate to its ongoing protection.

11.2. Assessment of effects

11.2.1. Soft sediment benthic habitats

Dredging of the channel extension area will effectively bring about the loss of all benthic biota within the 125 ha footprint of the activity. However, this area represents only around 5% of the benthic area of the Harbour entrance and its approaches and a much smaller proportion of soft substrate areas at similar water depths in inshore Pegasus Bay.

Continued maintenance dredging of the approximately 280 ha of combined channel and swing basin area will effectively prevent its complete recovery back to the undisturbed condition; however differences in benthic communities to the surrounding undredged habitat are not of themselves likely to be significant in terms of the functioning of benthic ecosystems over the wider area.

The deposition of 18 million m^3 of spoil represents a layer of nominal thickness 1.44 m across the proposed capital spoil ground. Based on preliminary projections of maintenance dredging, deposition at the proposed offshore maintenance spoil ground (0.9–1.2 million m^3 annually) could result in spoil layers up to 0.5 m. These values represent a substantial inundation for the benthic communities within the boundaries of these spoil grounds. A margin on the order of 300–500 m around each spoil ground will potentially also be affected by direct deposition as the dynamic plume spreads out from the point of impact with the seabed. However, there are several mitigating factors (as follows) and a potentially rapid recovery of this habitat following the cessation of spoil deposition is indicated:

- The seabed habitat at both proposed offshore spoil grounds exists in a dynamic and dispersive sedimentary environment. It is part of a much larger area of similar substrate and ecology within Pegasus Bay; hence it is not considered to be limited in extent within the wider region.

- The benthic communities are dominated by small-bodied invertebrate taxa with generally short life-cycles. Such organisms will rapidly recolonise a disturbed area. Major habitat-forming species are absent.
- The channel deepening project will occur in not less than two stages with a potentially significant period between stages.
- Deposition at the capital spoil ground will be incremental over extended time periods (9–14 months each stage for a 10,000 m^3 TSHD) rather than occurring in a single event.
- Spoil from both capital and maintenance dredging will comprise marine sediment with a high degree of textural and compositional similarity to that which comprises the current benthic substrate of the respective spoil grounds.
- The dredge spoil sediments deposited at both offshore spoil grounds will have generally low to very low bulk concentrations (above background) of trace metals and other contaminants.
- Spoil sediments which remain in suspension or which are subsequently resuspended will be incorporated into the significant natural sediment resuspension and deposition processes operating within inshore Pegasus Bay.
- Shallowing of these areas resulting from deposition will not alter hydrodynamic processes to an extent which will significantly affect ecological receptors.

Together with small wave-focusing effects from spoil deposition mounds, the extended channel will slightly change the wave climate of the outer Harbour and entrance, but any resulting redistribution of the textural patterns of benthic sediment is likely to be only subtle, and any consequent changes to benthic communities will be similarly minor. Very small shifts in the distribution of shoreline reef communities as a result of changes in wave energy may occur at the heads and in the outer Harbour but are likely to be largely indiscernible.

11.2.2. Water quality and plume propagation

The generally low organic enrichment and nutrient and contaminant concentrations within the dredged material will ensure that water quality will not be degraded to the extent that adverse ecological effects ensue from these sediment constituents.

The principal water-borne stressor associated with the CDP and subsequent maintenance dredging will be that of elevated suspended solids concentrations (SSC) within turbidity plumes generated by resuspension of benthic sediments. The most important factor in the tolerance of marine communities to suspended solids and turbidity is the background levels of these parameters to which they are adapted.

Sediment transport processes operating along the coastline both north and south of Banks Peninsula are very active. Most of the coastline comprises a high-energy marine environment with significant erosion, accretion and resuspension of sediments. Added to this are substantial sediment inputs from wave-mediated abrasion of gravel beaches and a number of large, braided rivers which drain from the Southern Alps. However the available numerical data for background values of turbidity and suspended solids in Pegasus Bay and Lyttelton Harbour/Whakaraupō is as yet relatively limited.

The results of plume modeling for dredging within the Harbour have indicated that the bulk of suspended material would be near the seabed and within the constrained channel. Tidal transport of plumes would furthermore be strongly directional along the Harbour axis, with little transport towards the harbour shorelines.

Modelling of spoil deposition plumes has indicated that a concentration contour of 10 mg/L (above background) would generally stay within 1 km of the disposal location in the bottom layer and within 500 m in the mid-water layer. Near the seabed at both proposed spoil grounds, the background concentration is likely to be significantly greater than 10 mg/L most of the time. Hence effects on the native substrate or benthos arising from suspended spoil particulates settling out of the water column are expected to be minimal at 500 m from the spoil ground boundary and undetectable at 1 km.

The soft sediment benthic areas of southern inshore Pegasus Bay are characterised by fine sediments which are subject to resuspension by wave-induced shear, producing a persistent near-bed layer of potentially high turbidity. These near-bed conditions also predominate in the harbour. Hence the soft-sediment benthic community, with its prevalence of polychaete species, is inherently tolerant of sustained conditions of high suspended sediment loadings, including the increased deposition rates which this engenders.

11.2.3. Potential effects at shoreline receptors

Shoreline reef communities in the Lyttelton Harbour/Whakaraupō and Pegasus Bay region occupy a spectrum of wave exposure conditions from the low energy environment of the upper Harbour to the high energy setting of the northern Banks Peninsula shoreline and the Harbour heads. This results in a broad gradient of reef communities with characteristic assemblages defined by this exposure. However, the reef communities of the Harbour entrance and inner Pegasus Bay area are typical of those established on moderately exposed coastlines of the South Island. They are generally adapted to highly variable but persistent turbid conditions.

Hydrodynamic modeling for deposition at both proposed spoil grounds indicated that sediment plumes would not reach shoreline reef habitats at concentrations significantly exceeding background ranges. Similarly, for the central to outer Harbour, model outputs indicate that dredging plumes (and associated deposition) will be largely constrained to within, or near to, the dredged channel. These plumes will travel along the Harbour axis with tidally reversing currents and may impinge upon Shag Reef on the flood tide when dredging the swing basin at the western end of the navigation channel.

The nature of the material in suspension within the dredging and spoil deposition plumes is unlikely to differ significantly from that which contributes to background turbidity from natural wave resuspension processes.

If unforeseen factors result in sediment plumes impinging upon shoreline areas, it is unlikely that these aged plumes will be at concentrations where reef communities will suffer acute stress. However, the main mechanisms by which adverse impacts may occur include:

- Sedimentation by settlement from the water column; but due to persistent surge, settled fine sediments are very unlikely to accumulate to any extent on exposed shallow reef habitats east of the central Harbour.
- Attenuation of light reaching the seabed. A reduction in photosynthetically active radiation (PAR), if sustained, will affect the viability of algae at depth.
- Adverse effects to the feeding modes of some classes of organism; particularly more sensitive filter feeders but also grazers if sedimentation ensues.
- Abrasive or scouring effects; however the existing levels of turbidity and proximity to shallow sediment substrates mean reef communities will already be somewhat resilient to this.

Were shoreline reef habitats to experience frequent and persistent suspended sediment concentrations above the normal background levels over the course of the project, this would most likely result in some or all of the following changes to community structure:

- An increase in the prevalence and cover of psammophytic taxa at the expense of those more sensitive to suspended sediments.
- A decrease in the cover of erect canopy-forming macrophyte species.
- A decrease in the depth to which canopy-forming and other macrophytes extend.
- Changes to the prevalence and community structure of grazers.

The degree to which these changes may occur depends upon the concentration of the plume and the duration over which these conditions persist. It should be noted also that the shifts described above, should they occur, will be reversible with a return to normal background conditions.

11.3. Offshore maintenance dredging spoil ground

Much of the assessment regarding effects from maintenance spoil deposition is similar to that covering the use of the capital spoil ground during the CDP. Despite the greater proximity of the maintenance ground to shoreline reef habitats at Godley Head, plume modelling has indicated that significant turbidity plumes are very unlikely to impact shoreline receptors.

Along with a potentially smaller capacity vessel for maintenance dredging, the principal aspect in which activities at the maintenance spoil ground differ from use of the capital ground is that they are periodic and ongoing. The likely annual maintenance dredge campaigns may be expected to establish a cycle of impact and recovery to benthic habitat within the offshore spoil ground. While such cycling may effectively prevent complete recovery of communities (beyond an intermediate successional stage), the existing benthic environment features high rates of natural resuspension, minimal physical structure and low community complexity. The long-term benthic monitoring of Port Lyttelton's existing maintenance spoil grounds has shown that this type of habitat experiences rapid recovery from spoil deposition and exhibits minimal longer-term change compared to adjacent undisturbed areas. On this basis, persistent benthic effects at the offshore ground are expected to be similarly small.

11.4. Effects on fish, fisheries and aquaculture

The areas of Lyttelton Harbour/Whakaraupō and Pegasus Bay are of noted importance to commercial and recreational fisheries. The project environmental outcomes potentially affecting fisheries resources in the region are considered to be;

1. the permanent alteration of benthic areas which will be subject to ongoing maintenance dredging and associated spoil disposal
2. the temporary loss of benthic habitat represented by inundation and disturbance at the proposed capital spoil ground and areas immediately adjacent to its boundaries
3. the elevated suspended sediments concentrations and poor water clarity within turbidity plumes potentially generated by dredging and spoil disposal activities.

The channel extension area proposed for the CDP represents a very small fraction of the total area of similar soft sediment habitat within inshore Pegasus Bay. The loss of this area to fisheries species is very unlikely to have a significant effect on the wider fishery. The potential area directly affected by spoil deposition compared to potentially suitable habitat in the wider inshore area represents less than 1% of the seabed area in similar water depths inside the 50 m contour within Pegasus Bay.

Despite the substantial volumes of dredge spoil associated with the CDP, loss of fisheries area is believed to be limited to locations within and immediately adjacent to the spoil ground boundary. Furthermore, and perhaps more importantly, such losses are expected to be temporary only, with a return to pre-existing productivity within a period of months to a year following cessation of spoil deposition.

In terms of catch weight, most commercial fishing along this Pegasus Bay coast occurs predominantly in waters deeper than 30 m; hence there is considered to be little spatial overlap with the majority of fishing activity on this basis.

The principally targeted species in the shallow near-shore waters of southern Pegasus Bay are flatfish. In particular, the waters immediately offshore from Godley Head (including the proposed offshore maintenance spoil ground but not the capital spoil ground) yields significantly greater flatfish catch weight than other near-shore areas. Hence there is some potential for an effect, from the use of the offshore maintenance ground, on local flatfish catch yield from this small but relatively productive area. Effects may arise from trawl gear interactions with an altered seabed as well as from direct disturbance to local flatfish populations from spoil deposition. However, the close proximity of the Godley Head spoil ground sector currently used for maintenance dredge spoil disposal suggests that the target species (yellowbelly flounder) may be relatively resilient to the effects from this activity. It is furthermore important to note that benthic impacts outside of the boundaries of the offshore maintenance spoil ground are unlikely to exceed those arising directly from bottom-contact fishing methods.

Local fish populations are expected to be naturally tolerant of elevated suspended sediment levels to some extent, especially benthic or demersal species such as flatfish, elephant fish and gurnard. Avoidance of areas of particularly high suspended solids is likely to be the principal response of finfish species to increasing stress from turbidity plumes. The limited spatial extent of such high-strength plumes from project activities, together with the relatively unconstrained coastal marine area, will facilitate such avoidance behaviours over the course of the project; hence lasting effects to fisheries resources in inshore Pegasus Bay are considered very unlikely.

Like most coastal inlets in New Zealand, areas of Lyttelton Harbour/Whakaraupō serve as nursery habitat for a range of fish species; but there is little information suggesting that the Harbour is of critical regional importance in this regard. Similarly, there is no information which implicates the area of the proposed spoil ground as being of critical importance as a nursery area for any species, although it may be part of a broad swathe of near-shore sediment habitat in Pegasus Bay used by elephant fish for egg-laying.

Fish which utilise Lyttelton Harbour/Whakaraupō either year round or as part of seasonal cycles will be tolerant of the elevated turbidity that is a natural feature of the system. While some avoidance behaviour may potentially occur for areas of extreme sediment resuspension around the working dredge, the plume modelling by MetOcean (2016c) indicates that these areas will not be of an extent that will significantly hamper fish passage up and down the Harbour.

While pāua generally appear to favour less turbid conditions, there is little evidence that suspended particulates are a problem for adult individuals. An established population on the northern shoreline of outer Lyttelton Harbour/Whakaraupō appear healthy, even though it occurs within the currently utilised maintenance dredge spoil grounds. There is potential for high turbidity to affect larval pāua survival and settlement success, although the latter is considered to relate primarily to deposited rather than suspended sediments.

Lobster are not considered to be particularly sensitive to elevated turbidity unless its persistence results in alteration of habitat and food supply. The long pelagic larval stages for spiny lobster mean that localised turbidity effects are very unlikely to impact upon larval survival or future recruitment rates.

Current mussel farming operations located on the northern Banks Peninsula coastline and within the inlets of Port Levy and Pigeon Bay are outside the region predicted to experience even low-strength turbidity plumes from dredging and spoil disposal activities. Even were these locations to experience slightly greater concentrations of suspended sediments as a result of the CDP, the nature of the dredged sediments and the available information on the species *Perna canaliculus* suggests that any response in growth rates or condition of these cultured populations is unlikely to be measureable.

11.5. Biosecurity

Three broad sources of marine biosecurity risk potentially arise as a result of LPC's CDP, which are as follows:

- Introduction of new HMOs to New Zealand from the dredge that will be brought into the country from overseas
- Increased HMO risk due to dredging, spoil transfer and disposal
- Increased HMO risk due to changed shipping activities enabled by the deepened channel (and simultaneous Port development).

The risks from the CDP are likely to be negligible, and do not warrant the implementation of any mitigation measures. Vessel movements from overseas are the key issue to consider. Although the specific risks (*e.g.* with respect to actual HMOs) from vessel movement are unknown and unpredictable, adherence to MPI's border standards (the mandatory IHS for ballast water and sediment, and voluntary CRMS for biofouling) would greatly mitigate the potential for HMO introductions.

With respect to the CRMS, operational changes in shipping activities as a result of the dredging and simultaneous Port development are not expected to occur until 2018, at which time the standard will be mandatory. As such, all international vessel arrivals from 2018 will be subject to both IHS and CRMS requirements. On the other hand the dredge is expected to be brought to New Zealand while the CRMS is still voluntary. Given recognition of the potential biofouling risk from dredges, and the fact that MPI is encouraging voluntary compliance, it is suggested that the dredge is required to adhere to CRMS requirements. Compliance with both the IHS and CRMS (or exceedance of their requirements where feasible) would address all of the dredge's marine biosecurity risk mechanisms, and provide a means of ensuring that its transfer to Lyttelton constituted an acceptable level of risk reduction.

Given that the actual dredge and its particular risks are not yet known, it is recommended that, as a condition of the consent, a specific Biosecurity Management Plan (BMP) is developed for the contracted dredge. The BMP should include, but not be limited to[29], a description of:

1. The dredge and its attributes that affect risk, including key operational attributes (e.g. voyage speed, periods of time idle), maintenance history (including prior inspection and cleaning undertaken), and voyage history since last dry-docking and antifouling (e.g. countries visited and duration of stay).
2. Key sources of potential marine biosecurity risk from ballast water, sediments and biofouling. This assessment should cover the hull, niche areas, and associated equipment, and consider both submerged and above-water surfaces.
3. Risk mitigation prior to arrival in New Zealand, including but not limited to:
    i. Routine preventative treatment measures and their efficacy, considering for example the age and condition of the antifouling coating, and marine growth prevention systems for sea chests and internal sea water systems.
    ii. Specific treatments for submerged and above-water surfaces that will be undertaken to address IHS and CRMS requirements prior to departure for New Zealand. These could include, for example, in-water removal of biofouling, or above-water cleaning to remove sediment.
    iii. Additional risk mitigation planned during transit to New Zealand, including expected procedures for ballast water management.
    iv. Expected desiccation period of above-water surfaces prior to departure and during transit to New Zealand (i.e. period of air exposure since last dredging operations).

[29] International Maritime Organisation guidelines for biofouling (IMO 2011) detail the types of information that should be included in a Management Plan, and a template for documenting biofouling management.

4. The nature and extent of pre-border inspection that will be undertaken (e.g. at the overseas port of departure) to verify compliance with IHS and CRMS requirements.
5. Record keeping and documentation of all mitigation undertaken (i.e. prior to and during transit to New Zealand) to enable border verification if requested by MPI, and to facilitate final clearance.

It is also anticipated that the BMP will be submitted to MPI, and the MPI border reporting requirements will be completed as required by law.

12. ACKNOWLEDGEMENTS

Permission to use the Port Levy and Pigeon Bay phytoplankton and biotoxin analysis data in this report were kindly provided by Southern Seas Marine Farms and Pigeon Bay Aquaculture Ltd and for Sumner and Akaroa by the Ministry for Primary Industries.

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14. APPENDICES

Appendix 1 Location details for benthic grab sampling stations.

Table A1.1 Location and depth data for all benthic sample stations. Depths corrected to mean sea level.

Station	Date sampled	Position coordinates (WGS84) Latitude (S)	Longitude (E)	Depth * (m)
C1	11/12/2007	43° 36.065'	172° 48.331'	13.2
C2	11/12/2007	43° 35.798'	172° 48.992'	14.7
C3	11/12/2007	43° 35.523'	172° 49.679'	15.2
C4	11/12/2007	43° 35.242'	172° 50.391'	15.9
C5	11/12/2007	43° 34.989'	172° 51.013'	17.1
C6	11/12/2007	43° 34.764'	172° 51.589'	18.0
S1	11/12/2007	43° 32.058'	172° 52.017'	20.2
S2	11/12/2007	43° 32.735'	172° 52.679'	20.3
S3	11/12/2007	43° 33.136'	172° 52.754'	20.1
S4	12/12/2007	43° 32.835'	172° 53.507'	21.0
S5	12/12/2007	43° 33.571'	172° 52.884'	19.6
S6	11/12/2007	43° 33.404'	172° 53.391'	20.4
S7	12/12/2007	43° 33.439'	172° 54.388'	21.0
S8	12/12/2007	43° 33.376'	172° 54.879'	21.3
S9	25/10/2007	43° 33.897'	172° 52.214'	19.4
S10	12/12/2007	43° 34.007'	172° 53.351'	19.8
S11	12/12/2007	43° 33.947'	172° 54.603'	21.0
S12	12/12/2007	43° 34.270'	172° 53.980'	19.9
S13	12/12/2007	43° 34.265'	172° 54.786'	20.6
S14	12/12/2007	43° 34.405'	172° 55.347'	21.0
S15	12/12/2007	43° 34.878'	172° 53.442'	18.7
S16	12/12/2007	43° 35.035'	172° 54.279'	19.5
S17	12/12/2007	43° 34.835'	172° 54.832'	19.8
S18	12/12/2007	43° 35.171'	172° 55.316'	19.7
S19	12/12/2007	43° 35.954'	172° 55.919'	18.9
LHB1	01/03/2016	43° 37.119’	172° 42.785’	6.5
LHB2	01/03/2016	43° 37.152’	172° 44.173’	8.0
LHB3	01/03/2016	43° 36.969’	172° 45.387’	9.2
LHB4	01/03/2016	43° 36.699’	172° 46.916’	11.2
LHB5	01/03/2016	43° 36.086’	172° 47.635’	11.9
LHB6	01/03/2016	43° 36.311’	172° 48.588’	12.7
BPB2	01/03/2016	43° 35.829’	172° 50.452’	15.7
BPB3	01/03/2016	43° 35.813’	172° 52.613’	17.5
BPB4	01/03/2016	43° 36.476’	172° 55.199’	18.1
BPB5	01/03/2016	43° 36.981’	172° 58.420’	19.0
OMD1	02/08/2016	43° 34.442’	172° 50.519’	16.0

Station	Date sampled	Position coordinates (WGS84) Latitude (S)	Longitude (E)	Depth * (m)
OMD2	02/08/2016	43° 34.316’	172° 50.001’	18.0
OMD3	02/08/2016	43° 34.072’	172° 50.616’	18.0
OMD4	02/08/2016	43° 34.763’	172° 50.393’	18.0
OMD5	02/08/2016	43° 34.520’	172° 50.932’	18.5
OMD6	02/08/2016	43° 34.300’	172° 49.078’	17.5
OMD7	02/08/2016	43° 33.736’	172° 49.954’	19.0
OMD8	02/08/2016	43° 34.031’	172° 51.385’	20.0
OMD9	02/08/2016	43° 34.853’	172° 49.567’	17.0
OMD10	02/08/2016	43° 35.379’	172° 51.363’	17.0

* Corrected to mean sea level (MSL).

Appendix 2 Photographs of sediment cores.

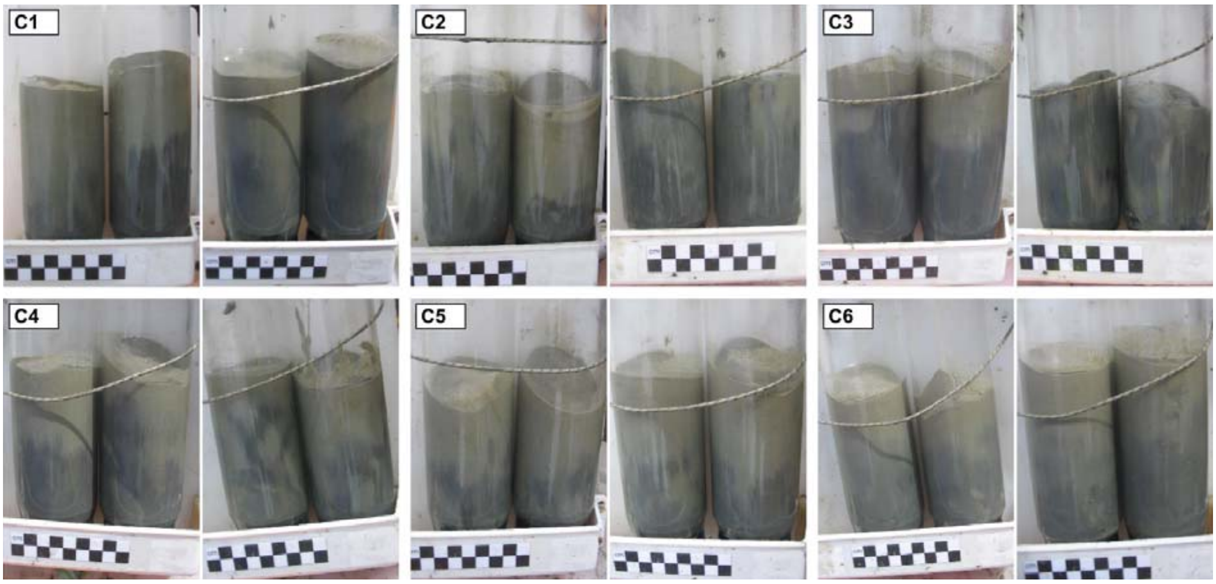

Figure A2.1 Representative 62 mm diameter core samples from stations within the proposed extended channel. Sampled December 2007.

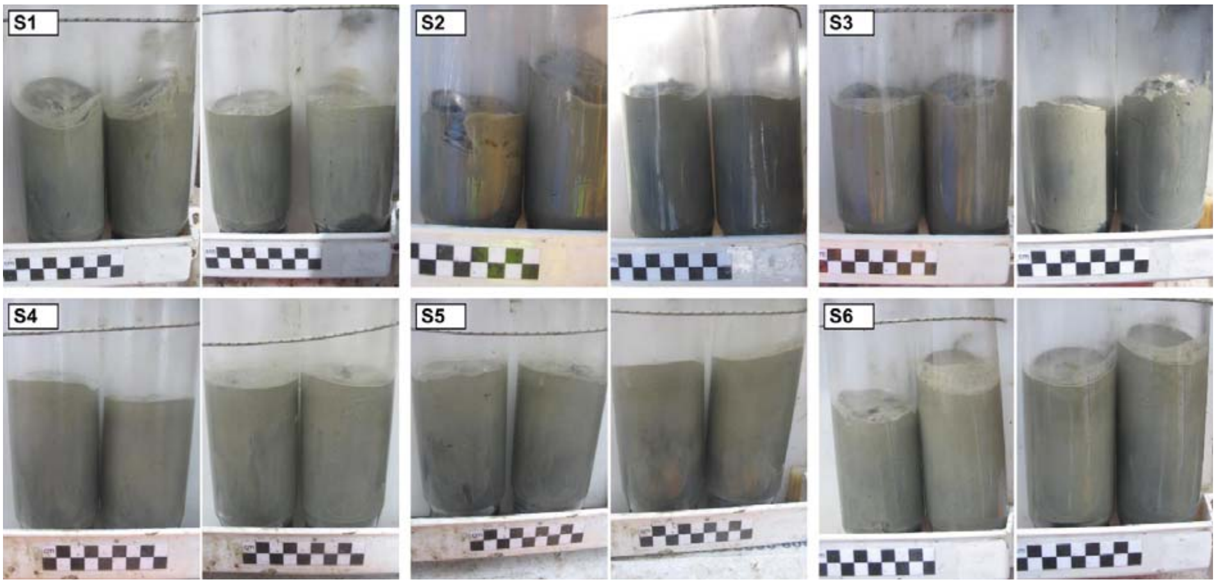

Figure A2.2 Representative 62 mm diameter core samples from stations in the vicinity of the proposed capital spoil ground. Sampled October – December 2007.

Figure A2.2 Continued.

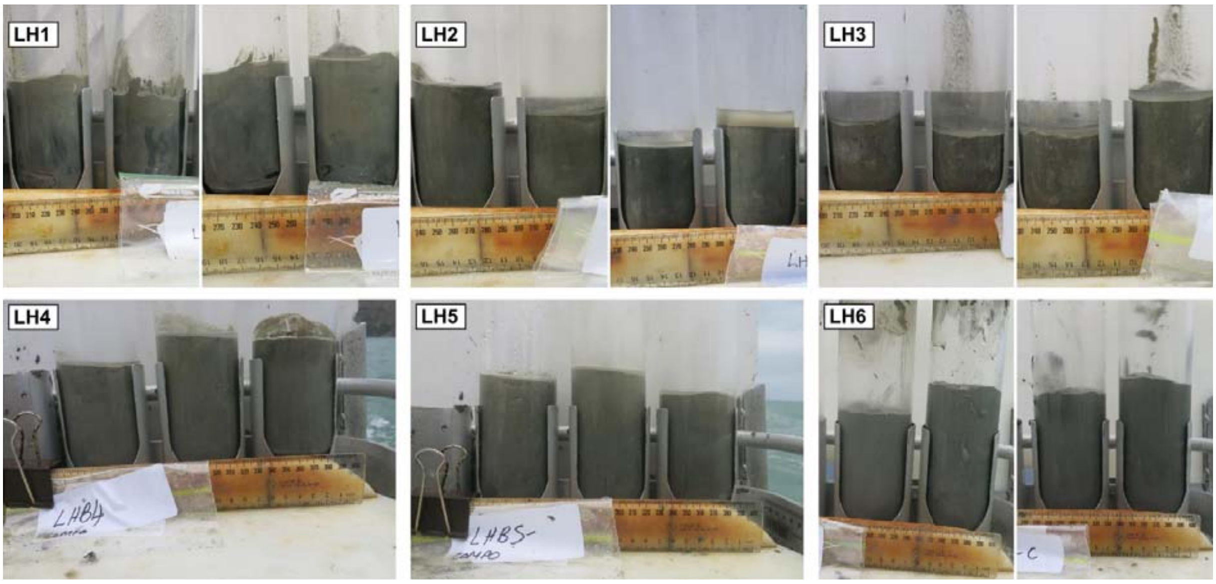

Figure A2.3 Representative 62 mm diameter core samples from stations in central to outer Lyttelton Harbour. Sampled March 2016.

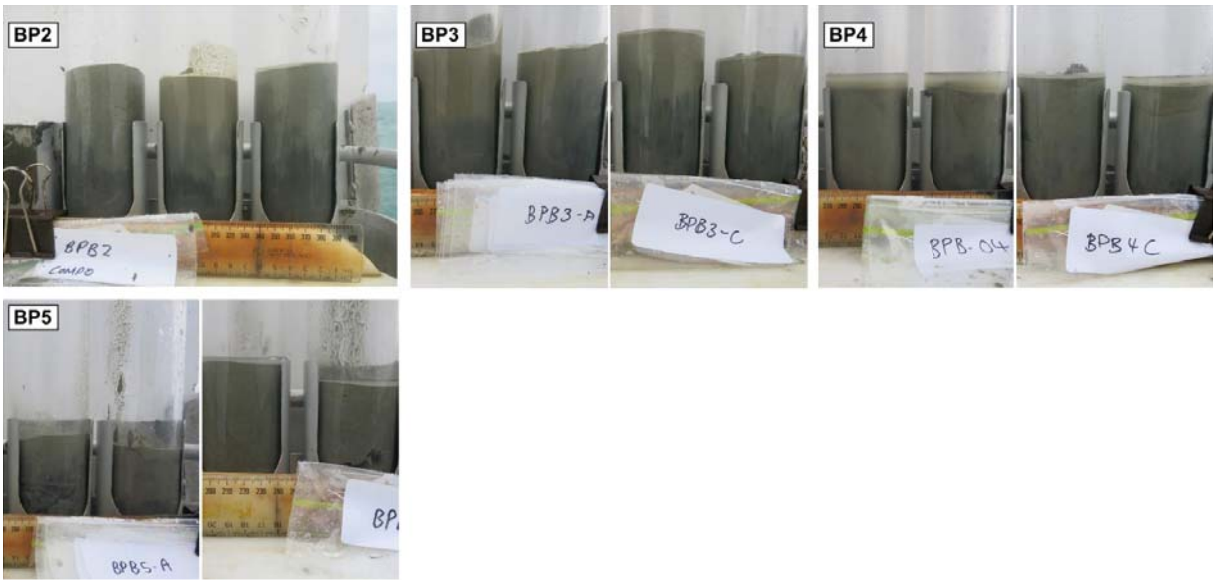

Figure A2.4 Representative 62 mm diameter core samples from stations offshore from the Banks Peninsula coastline. Sampled March 2016.

Figure A2.5 Representative 62 mm diameter core samples from stations in the vicinity of the offshore maintenance spoil ground. Sampled August 2016.

Appendix 3 List of macroinvertebrate taxa recorded from infaunal cores of soft sediment habitats within and offshore from Lyttelton Harbour during sampling surveys in 2007 and 2016. Taxonomic level: P=phylum; O=order; C=class; F=family; G=genus. Lower-case “s” designates “sub-“.

General Group	Taxa	Common Name	Level	Feeding
Hydrozoa	**Hydrozoa**	**Hydroids**	**O**	
Anthozoa	**Anthozoa**	**Anemones, sea pens, corals**	**C**	
	Edwardsia sp.	Burrowing anemone	G	
	Virgularia gracillima	Sea Pen	G	
Platyhelminthes	**Platyhelminthes**	**Flat Worm**	**P**	**Predator**
Nemertea	**Nemertea**	**Proboscis worms**	**P**	
Nematoda	**Nematoda**	**Roundworm**	**P**	
Priapula	**Priapulida**	**Penis worms**	**C**	
Sipuncula	**Sipuncula**	**Peanut Worm**	**O**	**Infaunal deposit feeder**
Mollusca		**Moluscs**	**P**	
Gastropoda		**Snails, limpets, paua**	**C**	
	Gastropoda (micro snails)	Snails		
	Gastropoda (white rissoid like)	Snails		
	Austrofusus glans		G	
	Buccinulum vittatum		G	
	Turbonilla sp.		G	
	Xymene plebeius		G	
	Xymene sp.		G	
Opisthobranchia	Philine auriformis	White Slug	G	
Bivalvia		**Clams**	**C**	
	Mactridae	Bivalve (family)	F	Infaunal suspension feeder
	Tellinidae (juvenile)		F	
	Thraciidae		F	
	Arthritica bifurca	Small bivalve	G	Infaunal deposit feeder

General Group	Taxa	Common Name	Level	Feeding
	Arthritica sp	Small bivalve	G	Infaunal deposit feeder
	Atrina pectinata zelandica	Horse Mussel; Hururoa	G	
	Bassina yatei	Frilled venus shell	G	
	Borniola reniformis	Small bivalve	G	
	Divalucina cumingi	Lace cockle	G	
	Dosinia lambata		G	Infaunal suspension feeder
	Dosinia maoriana		G	Infaunal suspension feeder
	Elliptotellina urinatoria		G	
	Ennucula strangei		G	
	Gari convexa		G	
	Gari lineolata		G	
	Leptomya retiaria retiaria		G	
	Linucula hartvigiana	Nut Shell	G	Infaunal deposit feeder
	Melliteryx parva		G	
	Myadora striata		G	
	Myllitella vivens vivens		G	
	Neilo australis		G	
	Nucula gallinacea	Nut shell	G	Infaunal deposit feeder
	Nucula nitidula	Nut shell	G	Infaunal deposit feeder
	Panopea zelandica		G	
	Soletellina nitida	Golden sunset shell	G	Infaunal suspension feeder
	Tellinota edgari		G	Infaunal suspension feeder
	Theora lubrica	Window Shell	G	
	Thracia sp.	Bivalve	G	
Oligochaeta	**Oligochaeta**	**Oligochaete worms**	**C**	**Infaunal deposit feeder**
Polychaeta		**Polychaete worms**	**C**	
Ampharetidae	Ampharetidae		F	Surface deposit feeder
Aphroditidae	Aphrodita australis	Sea Mouse	G	Infaunal carnivore
Capitellidae	Capitellidae		F	Infaunal deposit feeder

General Group	Taxa	Common Name	Level	Feeding
	Heteromastus filiformis		G	Infaunal deposit feeder
	Notomastus sp.		G	Infaunal deposit feeder
Chaetopteridae	Phyllochaetopterus socialis	Parchment worm	G	Filter feeder
Chrysopetalidae	Chrysopetalidae	Polychaete worm (Family)	F	
Cirratulidae	Cirratulidae		F	Deposit feeder
Cossuridae	Cossura consimilis		G	Deposit feeder
Dorvilleidae	Dorvilleidae		F	Facultative carnivore
Flabelligeridae	Flabelligeridae		F	Infaunal deposit feeder
Glyceridae	Glyceridae		F	Infaunal carnivore & deposit feeder
Goniadidae	Goniadidae		F	Infaunal carnivore
Hesionidae	Hesionidae		F	Carnivore and deposit feeder
Lumbrineridae	Lumbrineridae		F	Infaunal carnivore & deposit feeder
Magelonidae	Magelona dakini		G	Surface deposit feeder
Maldanidae	Maldanidae	Bamboo worm	F	Infaunal deposit feeder
Nephtyidae	Aglaophamus macroura		G	Infaunal carnivore
Nereididae	Nereididae		F	
Onuphidae	Onuphis aucklandensis		G	Infaunal surface deposit feeder/omnivore
Opheliidae	Armandia maculata		G	Infaunal deposit feeder
	Travisia olens		G	Infaunal deposit feeder
Orbiniidae	Leitoscoloplos sp.		G	
	Orbinia papillosa		G	Infaunal deposit feeder
	Phylo felix		G	Infaunal deposit feeder
	Phylo novazealandiae		G	
Oweniidae	Myriochele sp.		G	Infaunal deposit feeder
	Owenia petersenae	Polychaete worm	G	Infaunal deposit feeder
Paraonidae	Paraonidae		F	Infaunal deposit feeder
	Aricidea sp.		G	
Pectinariidae	Lagis australis		G	
Phyllodocidae	Phyllodocidae	Paddle worms	F	Carnivore & scavenger

General Group	Taxa	Common Name	Level	Feeding
Polynoidae	Polynoidae	Scale worms	F	Infaunal carnivore
Sabellidae	Sabellidae	Umbrella worms	G	Infaunal suspension feeder
Sigalionidae	Sigalionidae		F	Infaunal carnivore
Spionidae	Paraprionospio coora		G	
	Paraprionospio sp.		G	Surface deposit feeder
	Polydora sp.		G	Surface deposit & filter feeder
	Prionospio multicristata		G	Surface deposit & filter feeder
	Prionospio pinnata		G	Surface deposit feeder
	Prionospio yuriel		G	Surface deposit feeder
	Spiophanes kroyeri		G	Surface deposit feeder
	Spiophanes modestus		G	
Sternaspidae	Sternaspis scutata	Polychaete worm	G	Infaunal deposit feeder
Syllidae	Sphaerosyllis sp.		G	Omnivorous
Terebellidae	Terebellidae		F	Infaunal deposit feeder
Trichobranchidae	Terebellides stroemii		G	
CRUSTACEA		**CRUSTACEANS**	**sP**	
Cephalocarida	**Cephalocarida**	**Horseshoe shrimp**	**C**	**Epifaunal scavenger**
Tanaidacea	Tanaidacea	Tanaid shrimp	F	
Tetrasquillidae	Lysiosquilla spinosa	Mantis shrimp	G	Epifaunal carnivore
Nebalia	Nebalia		G	Epifaunal deposit feeder
Tanaidacea	Tanaid sp.	Tanaid Shrimp	G	Epifaunal scavenger
Mysidacea	**Mysidacea**	**Mysid shrimp**	**O**	**Filter and deposit feeder**
Cumacea	**Cumacea**	**Cumaceans**	**O**	**Infaunal filter or deposit feeder**
Isopoda		**Isopod**		
	Munnidae		F	
	Paramunna serrata		G	
	Uromunna schauinslandi	Isopod	G	
	Asellota	Isopod	sO	
Amphipoda		**Amphipods**	**O**	

General Group	Taxa	Common Name	Level	Feeding
	Caprellidae	Skeleton shrimp	F	Epifaunal scavenger
	Haustoriidae	Amphipod (family)	F	Epifaunal scavenger
	Phoxocephalidae	Amphipod (family)	F	Epifaunal scavenger
	Ampelisca sp.	Amphipod	G	Epifaunal scavenger
Decapoda		**Crabs, prawns, shrimp**		
	Hemiplax hirtipes	Stalk-eyed Mud Crab	G	Deposit feeder & scavenger
	Nectocarcinus antarcticus	Hairy Red Swimming Crab	G	
	Neommatocarcinus huttoni	Policeman Crab	G	
	Ogyrides sp	Shrimp (long eyes)	G	
	Pilumnus novaezelandiae	Hairy crab	G	
	Pinnotheres novaezelandiae	Mussel Pea Crab	G	
	Brachyura (juv.)	Unidentified Crab juvenile		
	Decapoda (larvae unid.)	Unidentified Crab Larvae		
Ostracoda		**Seed shrimp**		
	Cymbicopia hispida	Ostracod	G	Omnivorous scavenger
	Leuroleberis zealandica	Ostracod (Large)	G	Omnivorous scavenger
	Parasterope australis	Ostracod	G	Omnivorous scavenger
Copepoda	**Copepoda**	**Copepods**	**C**	
Echinodermata		**Urchins, seastars, sea cucumbers**		
Echinoidea	Echinocardium cordatum	Heart Urchin	G	
Asteroidea	Patiriella regularis	Cushion Star	G	
Ophiuroidea	Ophiuroidea	Brittle stars	F	
Holothuroidea	Heterothyone alba	Sea Cucumber	G	
	Paracaudina chilensis	Sea Cucumber	G	
	Placothuria squamata		G	
Ascidiacea	**Ascidian Unid.**	**Sea Squirts**	**C**	
Cephalocordata	**Cephalocordata**	**Lancelets**	**sP**	

Appendix 4 Epifaunal species and counts from the contents of dredge trawls within soft sediment benthic habitats offshore from Lyttelton Harbour. Dredge tracks are shown in Figure 21. Most infauna species identified entrained in dredged mud are not included. P = present; SF = shell fragments only.

Table A4.1 Epifauna dredge trawls carried out off the Banks Peninsula coast on 1 March 2016.

Taxa	**Trawl code**	**BP02**	**BP03**	**BP04**	**BP05**
	Trawl length (m)	100	100	100	100
	Depth (m)	16.0	17.5	18.1	19.0
Mollusca					
Austrofusus glans	Knobbed whelk			1	1
Neilo australis				1	1
Gari stangeri	Sunset clam				2
Mactra ovata				SF	
Dosinia sp.				SF	
Mactra sp.				SF	1
Tellina gaimardi	Angled wedge shell	1	1	SF	SF
Crustacea					
Lysiosquilla spinosa	Mantis shrimp			1	
Neommatocarcinus huttoni	Policeman crab			1	3
Hemiplax hirtipes	Mud crab	3	5		
Echinodermata					
Polychaeta					
Worm casings (Maldanidae)		P	P	P	P
Aphrodita australis	Sea mouse				1

Table A4.2 Epifauna trawls at the proposed offshore maintenance spoil groundon 2 August 2016.

Taxa	**Trawl code**	**OMT1**	**OMT2**	**OMT3**	**OMT4**	**OMT5**
	Trawl length (m)	137	160	147	219	151
	Depth (m)	19.5	19.0	17.0	19.4	20.2
Mollusca						
Austrofusus glans	Knobbed whelk		2			
Gari lineolata	Pink sunset clam		SF			
Atrina zelandica	Horse mussel		SF			
Mactra sp.		SF			SF	
Tellina gaimardi	Angled wedge shell		SF			
Theora lubrica	Window shell				1	
Hiatula nitida	Wafer shell		SF			
Crustacea						
Hemiplax hirtipes	Mud crab	4	2	7	4	3
Echinodermata						
Heterothyone alba	Sea cucumber	1				
Polychaeta						
Casings (Maldanidae)		P	P	P	P	P
Eurythoe sp.				1		1
Platyhelminthes	Flatworm					1
Sipuncula	Peanut worm				1	
Priapulida					1	

Table A4.3 Epifauna counts from the contents of dredge trawls conducted over October - December 2007.

Taxa	Trawl code	4CT1	4CT2	3MT1	3MT2	4MT1	4MT2	4MT3[2]	4MT4[2]
	Date trawled	25/10/07	25/10/07	25/10/07	25/10/07	25/10/07	25/10/07	12/12/07	12/12/07
	Trawl length (m)	150	150	100	150	150	150	150	150
	Depth (m)[1]	19.9	20.3	19.2	19.3	20.4	20.6	20.3	20.3
Mollusca									
Austrofusus glans	Knobbed whelk	1	6	1	5	1	4	4	3
Struthiolaria papulosa									1
Phenatoma rosea							1		
Neilo australis				1					
Mactra ovata									
Dosinia sp.			SF					SF	SF
Zenatia acinaces	Scimitar mactra			SF					
Atrina pectinata zelandica	Horse mussel		SF	SF		SF			
Mactra sp.							SF		SF
Tellina gaimardi	Angled wedge shell								
Philine auriformis	Sea slug								1
Crustacea									
Lysiosquilla spinosa	Mantis shrimp			1					
Neommatocarcinus huttoni	Policeman crab	1							
Hemiplax hirtipes	Mud crab								
Echinodermata									
Echinocardium sp.	Heart urchin				1				1
Pateriella regularis	Cushion star			1		1			
Ophiuroidea	Brittle star								
Heterothyone alba	Sea cucumber								
Polychaeta									
Worm casings (Maldanidae)				P	P	P		P	P
Phyllochaetopterus socialis	Parchment worm	1							
Trichobranchid polychaete		P			P				
Aphrodita australis	Sea mouse								

1. Corrected to mean sea level (MSL).
2. From post-deposition trial survey, conducted 12/12/07.

Table A4.4 Epifauna counts from the contents of dredge trawls carried out on 19 January 2008.

Taxa	Trawl code	CHT1	CHT2	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	ST11	ST12
	Trawl length (m)	150	150	150	150	150	150	150	150	150	150	150	150	150	150
	Depth (m)[1]	14.0	16.4	19.7	20.9	20.5	20.2	19.2	20.1	20.3	19.2	19.8	20.2	19.0	20.4
Mollusca															
Austrofusus glans	Knobbed whelk			5	1	1	2	5		1		1	2	3	
Struthiolaria papulosa															
Phenatoma rosea															
Neilo australis									1	1					1
Mactra ovata									1						
Dosinia sp.				SF						SF					
Zenatia acinaces	Scimitar mactra			SF						SF					
Atrina pectinata zelandica	Horse mussel			SF			SF		SF	SF	SF		SF	SF	SF
Mactra sp.		SF		SF											
Tellina gaimardi	Angled wedge shell	1											SF		
Philine auriformis	Sea slug														
Crustacea															
Lysiosquilla spinosa	Mantis shrimp							1							
Neommatocarcinus huttoni	Policeman crab			1				1			2				1
Hemiplax hirtipes	Mud crab	2	3												1
Echinodermata															
Echinocardium sp.	Heart urchin			1					1	1		1		1	
Pateriella regularis	Cushion star					1									
Ophiuroidea	Brittle star								F						F
Heterothyone alba	Sea cucumber														1
Polychaeta															
Casings (Maldanidae)		P	P	P		P	P	P	P	P	P		P	P	P
Phyllochaetopterus socialis	Parchment worm														
Trichobranchid polychaete															
Aphrodita australis	Sea mouse			1						1	1				

1. Corrected to mean sea level (MSL).

Appendix 5 Representative side scan sonar images from the channel extension area and in the vicinity of the proposed spoil ground.

The images cover an area of seabed 30 m on either side of the track centre-line. The dark central portion of the image shows the 'blind-spot' shadow directly beneath the sonar fish. The horizontal grid-lines are spaced at 30 second intervals so that the distance represented by the height of the image varies with the speed at which the fish was towed. The absence of features with hard edges and dark shadows in all of these images indicates the uniformly soft, low-relief nature of the seabed. Lighter-shaded spots occur occasionally in the images; however, the absence of a distinct accompanying shadow and their presence within the central blank portion of the sonar image suggests that they are mid-water targets, present at some distance from the seabed. It is possible that they represent fish or other marine life within the water column.

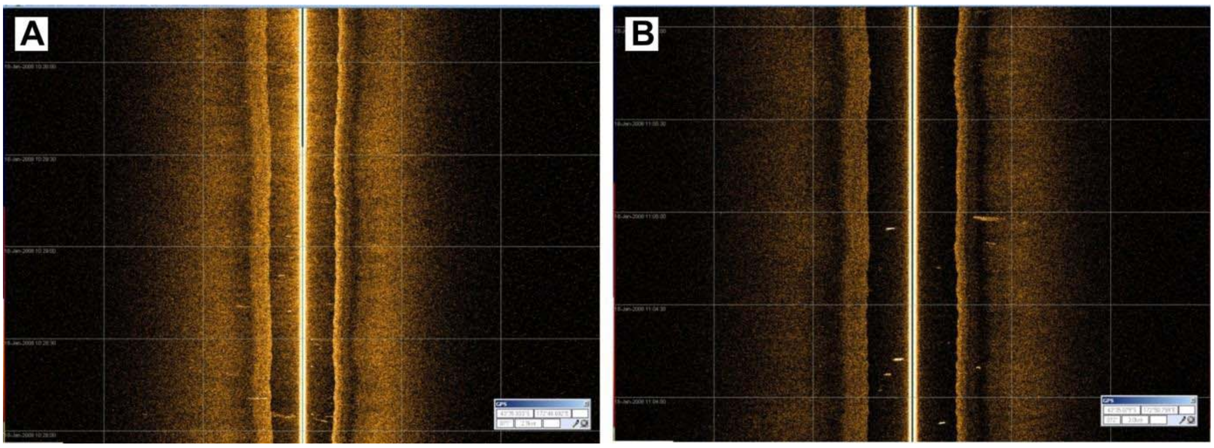

Figure A5.1 Side-scan sonar images of the seabed at two points along the proposed channel extension. Each image covers 30 m of seabed on either side of the sonar fish. Locations for each of these images are shown in Figure 22.

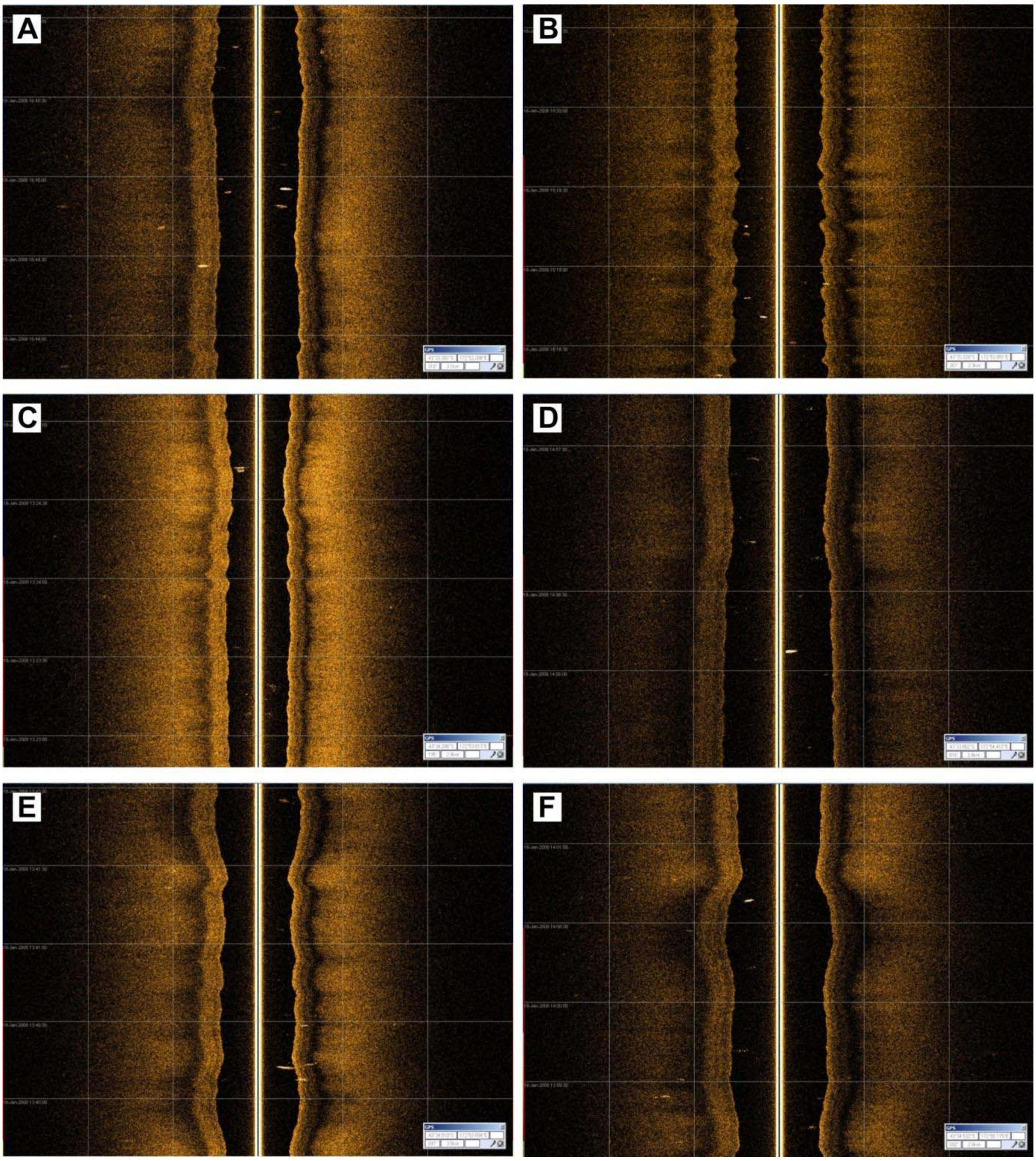

Figure A5.2 Side-scan sonar images of the seabed within and adjacent to the proposed capital spoil ground. Each image covers 30 m of seabed on either side of the sonar fish. Locations for each of these images are shown in Figure 22.

Appendix 6 Summary details of subtidal reef sites surveyed in February 2016 within each of four areas; Banks Peninsula outer coast (BP), the inlets of Port Levy (PL) and Pigeon Bay (PB), and the coastline within Lyttelton Harbour (LH).

Area	Station	Transects	Latitude	Longitude	Date
BP	BP01	0.5 m, 4 m, 7 m	-43.6042°	172.8236°	24-Feb
	BP02	4 m, 7 m	-43.6031°	172.8556°	22-Feb
	BP03	0.5 m, 4 m, 7 m	-43.6084°	172.8765°	23-Feb
	BP05	0.5 m, 4 m, 7 m	-43.6230°	172.9110°	23-Feb
	BP06	0.5 m, 4 m, 7 m	-43.6226°	172.9315°	24-Feb
	BP08	0.5 m, 4 m, 7 m	-43.6334°	172.9814°	23-Feb
	BP10	0.5 m, 4 m, 7 m	-43.6512°	173.0244°	24-Feb
	BP13	0.5 m, 4 m	-43.5929°	172.8010°	25-Feb
	BP14	0.5 m, 4 m, 7 m	-43.5819°	172.7948°	28-Feb
LH	LH01	0.5 m, 4 m	-43.5960°	172.7889°	26-Feb
	LH02	0.5 m, 4 m	-43.5974°	172.7641°	27-Feb
	LH07	0.5 m, 4 m	-43.6191°	172.7556°	27-Feb
	LH10	0.5 m, 4 m	-43.6167°	172.7882°	27-Feb
	LH11	*	-43.6126°	172.8026°	29-Feb
PB	PB02	0.5 m, 4 m	-43.6385°	172.9038°	25-Feb
	PB03	0.5 m, 4 m	-43.6507°	172.8985°	28-Feb
	PB10	0.5 m, 4 m	-43.6503°	172.9145°	28-Feb
	PB11	0.5 m, 4 m	-43.6418°	172.9179°	25-Feb
PL	PL02	0.5 m, 4 m	-43.6170°	172.8290°	25-Feb
	PL03	0.5 m, 4 m	-43.6271°	172.8273°	26-Feb
	PL14	0.5 m, 4 m	-43.6290°	172.8395°	28-Feb
	PL16	0.5 m, 4 m	-43.6160°	172.8451°	25-Feb

* LH11 was not surveyed quantitatively due to insufficient water clarity. Diver notes only.

Appendix 7 List of taxa and summary of count and coverage data recorded during subtidal surveys in February 2016 at each surveyed area: Banks Peninsula (BP, 4 m and 7 m), Lyttelton Harbour (LH, 4 m), Pigeon Bay (PB, 4 m) and Port Levy (PL, 4 m). Shaded cells represent values in the form of percentage cover.

			BP (4 m)		BP (7 m)		LH (4 m)		PB (4 m)		PL (4 m)	
GROUP	**Taxa**	**Common name**	**mean**	**S.E.**	**mean**	**S.E.**	**mean**	**S.E.**	**mean**	**S.E.**	**mean**	**S.E.**
CHROMOPHYTA	*Macrocystis pyrifera*	Bladder kelp	4.27	2.06	0.52	0.25	3.00	1.07	9.17	3.93	4.56	1.61
(Brown Algae)	*Ecklonia radiata*	Common kelp	18.85	2.48	1.37	0.80	23.13	2.83	26.09	3.73	32.34	4.80
	Halopteris sp.		0.83	0.33	1.84	0.50	0.06	0.06	0.03	0.03		
	Ralfsia sp.	Brown encrusting algae	1.40	0.30	1.68	0.36	3.05	1.01	2.28	0.61	6.19	1.50
	Undaria pinnatifida	Asian kelp					0.25	0.16			0.03	0.03
	Carpophyllum flexuosum	Flapjack			0.20	0.16	1.56	0.99	0.63	0.49		
	Carpophyllum maschalocarpum	Narrow flapjack	2.10	1.03	0.39	0.32	0.09	0.09	0.81	0.38		
	Landsburgia quercifolia		0.02	0.02								
	Microzonaria sp.		0.08	0.04	0.02	0.02						
	Dyctiotaceae				0.06	0.04	0.09	0.09				
RHODOPHYTA	Unid. red filamentous algae	Red filamentous algae	0.77	0.56	2.85	1.39	0.13	0.09	0.03	0.03	0.06	0.04
(Red Algae)	Unid. coralline encrusting algae	Coralline encrusting algae	52.04	3.69	19.34	3.22	39.06	5.44	59.69	3.34	62.66	4.83
	Unid. feathery red algae	Feathery red algae	1.01	0.36	2.00	0.69			0.03	0.03		
	Unid. red branching algae	Red branching algae					0.03	0.03				
	Unid. coralline turf	Coralline turf	1.27	0.39	0.37	0.19	2.34	1.58	0.06	0.06	9.06	4.34
	Unid. foliose red algae	Foliose red algae	0.76	0.18	2.07	0.55	4.22	0.80			0.34	0.18
PORIFERA	*Ecionemia alata*	Vase sponge			0.30	0.18						
(Sponges)	Unid. encrusting sponge	Encrusting sponge	0.92	0.19	0.94	0.16	1.16	0.35	1.73	0.36	2.69	0.85
	Unid. erect sponge	Erect sponge	0.03	0.02								
	Tethya bergquistae	Gold ball sponge	0.06	0.03	0.05	0.04						
CNIDARIA	Unid. hydrozoan	Hydroids	2.42	1.09	0.77	0.40	3.72	1.15	2.20	0.50	2.53	0.76
(Anemones)	*Anthothoe albocincta*	White-striped anemone	1.19	0.30	4.84	1.05	4.44	1.29	0.92	0.38	0.05	0.03
	Oulactis muscosa	Sand anemone	0.33	0.13	0.14	0.05	0.06	0.04	0.06	0.04	0.09	0.05

			BP (4 m)		BP (7 m)		LH (4 m)		PB (4 m)		PL (4 m)	
GROUP	**Taxa**	**Common name**	**mean**	**S.E.**	**mean**	**S.E.**	**mean**	**S.E.**	**mean**	**S.E.**	**mean**	**S.E.**
	Unid. Anthozoan	Anthozoan	1.19	0.30	4.84	1.05	4.44	1.29	0.92	0.38	0.05	0.03
POLYCHAETA	Unid. Serpullidae	Serpulid worm					0.25	0.16			0.03	0.03
(Bristle worms)	Unid. Spirobidae	Spirobid worm					0.25	0.16			0.03	0.03
ARTHROPODA	Unid. barnacle	Large barnacle	0.01	0.01	0.09	0.04	0.00	0.00	0.00	0.00	0.00	0.00
(Crustaceans)	Unid. barnacle	Small barnacle	7.52	2.47	3.84	0.83	2.34	0.80	0.41	0.15	0.84	0.62
	Paguridae	Hermit crab	0.40	0.32	0.14	0.05	0.09	0.05	0.06	0.04	0.03	0.03
MOLLUSCA												
Polyplacophora	*Eudoxochiton nobilis*	Noble chiton	0.01	0.01					0.03	0.03		
(chitons)	*Chiton glaucus*	Green chiton					0.09	0.09			0.03	0.03
	Cryptoconchus porosus	Butterfly chiton	0.28	0.08	0.19	0.06	0.53	0.23	0.28	0.14	0.22	0.07
Gastropoda	*Cellana stellifera*	Limpet	0.01	0.01	0.13	0.13					0.03	0.03
(snails, limpets,	Patelloidea	Limpet	0.13	0.07	0.11	0.07			0.19	0.09	0.19	0.09
pāua)	*Patiriella* sp.	Limpet										
	Scutus breviculus	Ducksbill limpet	0.04	0.03	0.03	0.02	0.16	0.07			0.06	0.04
	Sigapatella novaezelandiae	Slipper limper	0.03	0.03	0.06	0.04						
	Maoricolpus roseus	Turret shell	0.06	0.03	0.03	0.03					0.03	0.03
	Cookia sulcata	Cook's turban	1.26	0.19	0.42	0.10	0.31	0.14	1.94	0.53	1.00	0.28
	Trochus viridis	Top shell	2.57	0.45	2.19	0.36	2.88	0.64	1.75	0.41	1.88	0.48
	Haliostis iris	Blackfoot pāua	0.76	0.18	2.07	0.55	4.22	0.80			0.34	0.18
	Haliostis australis	Yellow-foot pāua			0.02	0.02			0.03	0.03		
	Cantharidus sp.	Opal top shell	0.01	0.01			0.16	0.11	0.03	0.03	0.03	0.03
	Calliostoma spp.		0.11	0.05	0.08	0.04	0.09	0.05	0.03	0.03		
	Turbo smaragdus	Cat's eye	0.17	0.08	0.02	0.02	0.41	0.13	0.16	0.07	0.53	0.18
	Penion sp.	Whelk	0.29	0.08	0.27	0.07	0.06	0.04	0.13	0.07	0.13	0.07
	Buccinulum linea	Lined whelk	1.40	0.30	1.68	0.36	3.05	1.01	2.28	0.61	6.19	1.50
	Unid. whelk	Whelk	0.07	0.07	0.02	0.02	0.09	0.07	0.06	0.06	0.03	0.03
	Aphelodoris luctuosa	Nudibranch			0.05	0.05			0.03	0.03		

			BP (4 m)		BP (7 m)		LH (4 m)		PB (4 m)		PL (4 m)	
GROUP	**Taxa**	**Common name**	**mean**	**S.E.**	**mean**	**S.E.**	**mean**	**S.E.**	**mean**	**S.E.**	**mean**	**S.E.**
Bivalvia	*Perna canaliculus*	Green lipped mussel	3.58	0.86	2.85	0.85	33.30	7.02	0.19	0.08	2.45	1.34
	Mytilus galloprovincialis	Blue mussel	0.15	0.14								
	Ostrea chilensis	Flat oyster	0.35	0.14	0.34	0.11	0.06	0.04	0.14	0.06	0.39	0.13
	Aulacomya maoriana	Ribbed mussel					1.25	0.40				
BROACHIPODA (Lantern shells)	*Calloria inconspicua*	Lantern shell	0.17	0.09	0.17	0.07						
BRYOZOA	Unid. bryozoan	Encrusting bryozoan	0.59	0.23	1.14	0.29	0.02	0.02	0.42	0.22	0.13	0.07
	Unid. bryozoan	Branching bryozoan	0.58	0.26	2.53	0.78	1.44	0.67	0.53	0.25	1.63	0.69
ECHINODERMATA	*Australostichopus mollis*	Sea cucumber			0.06	0.03			0.09	0.05	0.28	0.10
(seastars, urchins,	*Coscinasterias muricata*	11-armed seastar	0.11	0.04	0.03	0.02	0.19	0.08	0.03	0.03		
sea cucumbers)	*Stegnaster inflatus*	Ambush seastar	0.03	0.02	0.05	0.03			0.03	0.03	0.03	0.03
	Sclerasterias mollis				0.02	0.02						
	Pentagonaster pulchellus	Biscuit seastar	0.04	0.02	0.05	0.03						
	Diplodontias dilatatus		0.03	0.02	0.16	0.07						
	Patiriella regularis	Cushion star	1.19	0.16	1.06	0.14	1.59	0.25	1.78	0.28	1.34	0.32
	Evechinus chloroticus	Kina	0.14	0.05	0.09	0.04	0.03	0.03	0.19	0.08	0.09	0.05
ASCIDIACEA	*Cnemidocarpa* sp.	Saddle sea squirt	12.32	1.84	32.50	3.04	15.89	3.03	5.95	1.12	5.28	0.76
(Sea Squirts)	*Pyura pachydermatina*	Sea tulip	4.17	0.68	1.38	0.32	0.63	0.21	0.25	0.11	0.13	0.06
	Unid. colonial ascidian	Colonial sea squirt					0.25	0.16			0.03	0.03
	Didemnum jucundum	Colonial sea squirt	0.31	0.17	0.34	0.14	0.19	0.10	1.13	0.40	0.75	0.23
	Didemnum sp.	Colonial sea squirt	0.94	0.20	1.48	0.29	2.11	0.43	1.61	0.38	2.27	0.63
	Aplidium benhami	Colonial sea squirt					0.06	0.04			0.09	0.05
	Unid. solitary ascidian	Sea squirt					0.25	0.16			0.03	0.03
OSTEICHTHYES (Fish)	Tripterygiidae	Triple fins	0.99	0.13	1.20	0.18	3.56	0.46	3.03	0.37	3.03	0.32
Total number of taxa		72	55		57		49		43		46	