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Replacement of Akaroa Wharf: assessment of effects on benthic ecology

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Replacement of Akaroa Wharf: assessment of effects on benthic ecology

Ross Sneddon, Don Morrisey

Prepared for Christchurch City Council

Glossary

Item	Description
µm	Micron
AEE	Assessment of environmental effects
ANZG	Australia and New Zealand (Water Quality) Guidelines
aRPD	Apparent redox potential discontinuity
Bent	Wharf sub-structure cross frame
BMP	Biosecurity management plan
CCC	Christchurch City Council
CR	(Waters managed for) contact recreation
DGV	Default guideline value
DO	Dissolved oxygen
DRP	Dissolved reactive phosphorus
ECan	Environment Canterbury
GPS	Global Positioning System
GV-High	Guideline value – High (criterion)
H'	Shannon–Weiner diversity index
ICP-MS	Inductively coupled plasma mass spectrometry
J'	Pielou's evenness index
kHz	Kilohertz (cycles per second)
mg/kg	Milligrams per kilogram (parts per million)
MSL	Mean sea level
n	Number of individuals / replicates in a sample
N	Abundance (or nitrogen)
NIS	Non-indigenous species
nMDS	Non-metric multi-dimensional scaling
pH	Measure of acidity or basicity ($-\log_{10}[H^+]$)
PVC	Polyvinyl chloride
S	Number of species (species richness)
SE	Standard error of the mean
SG	Waters managed for shellfish gathering
SIMPER	Similarity percentage
Taiāpure	Estuarine or coastal areas that are significant for food, spiritual, or cultural reasons
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSS	Total suspended solids
USEPA	United States Environmental Protection Agency
WWTP	Wastewater treatment plant

Contents

Executive summary

Christchurch City Council (CCC) proposes demolishing the existing Akaroa Wharf in French Bay, Akaroa Harbour, and rebuilding it to a new design on effectively the same footprint. The wharf deck will be raised by at least 500 mm to allow for sea-level rise and storm surges, and the configuration of attached floating pontoons changed to increase usability and reduce the current occasional congestion issues. It is expected that piles for the existing structure would be cut off at the seabed and new concrete and steel piles would be driven using a combination of impact and / or vibratory methods. The council has engaged Cawthron Institute (Cawthron) to assess the marine ecological effects of the proposed demolition, reconstruction and future operation on the surrounding marine environment.

French Bay, in the upper-central part of Akaroa Harbour, faces west across the harbour's central axis. On either side of the wharf, intertidal beaches of gravel, pebbles, cobbles and boulders (and ephemeral layers of sand) extend into the shallow subtidal zone, where they transition into sandy mud. Concentrations of organic matter in sediment samples collected from around the wharf were typical of relatively sheltered coastal habitats and trace metal concentrations were generally below guideline trigger levels. However, two samples indicated slightly elevated concentrations of mercury in sediments from the bay on the northern side of the wharf, exceeding the low-risk criterion at which ecological effects are considered possible. The biota of shallow subtidal sediments were found to be typical of other previously sampled areas of Akaroa Harbour, and comparable to similar habitats around the country. The adjacent intertidal habitat was found to support a similarly typical community, its limited diversity likely due to the absence of bedrock reef and the relatively mobile nature of the cobble and pebble substrate. No marine invertebrates, macroalgae or fish listed as Threatened or At Risk are known to occur around the site of the proposed work, but since potentially suitable habitat for at least one such species is present, their absence cannot be categorically established. The survey results further suggested that no identified kaimoana species occur at population densities sufficient to comprise a significant harvestable resource, and nor was there any evidence that the site may be more important in this regard than other areas of the harbour. On these bases, the intertidal and shallow subtidal habitats around the wharf were ranked as of low value.

Some direct disturbance to harbour bed habitats will result from demolition and construction activities. This will arise mainly from the removal by excavation of the land formation at the base of the wharf, the removal and driving of piles, the use of anchoring systems for marine plant and scour from the propellers of support vessels. All these effects will be of short duration and highly localised to within and directly adjacent to the footprint of the structure. Communities of animals and plants are expected to recolonise disturbed areas quite rapidly (months), including the encrusting communities that re-establish on the new wharf piles. Direct disturbance effects are therefore expected to be negligible or less than minor at the spatial scale of Akaroa Inlet.

Indirect effects from propagation of turbidity plumes are likely to extend no more than low hundreds of metres from the site, and except directly adjacent to the source, are expected to be of negligible severity / magnitude relative to naturally occurring nearshore resuspension events. Although slightly elevated levels of mercury were found in two of six sediment

samples from around the wharf, limited further dispersion of such contamination within low-intensity plumes is not expected to result in discernible ecological effects. Noise from construction activities, especially pile-driving, has the potential to cause avoidance behaviours in fish, but such effects are very unlikely to persist beyond the duration of the source activities.

As with all construction activities within the marine environment, there is a possible risk from accidental spillage of potentially harmful materials such as fuel, oils and uncured cement. Fine sediments entrained in stormwater run-off from landside earthworks can also impact nearshore habitats. These risks can be mitigated by rigorous application of standard management protocols and contingency plans.

Biosecurity risks during construction are potentially the most important because import of vessels, equipment and materials from other parts of the country may introduce non-indigenous species that can have significant adverse ecological, cultural and economic effects. However, these risks can also be mitigated by application of standard protocols within a project-specific biosecurity management plan, including criteria for aspects such as inspection schedules, biofouling thresholds and maintenance practices.

Long-term adverse effects from the operation of the new wharf will be limited because the scale and function of the facility is not expected to change significantly with the new structure. Furthermore, such increases in vessel usage that are encouraged by an improved design are expected to derive principally from existing harbour users. Hence, the new wharf is not expected to bring about a material increase in visits by vessels arriving from other ports with the increased biosecurity risks that this may entail.

The limited spatial scale and duration of effects from the project were such that, when considered with existing stressors within the harbour environment, no significant increase in cumulative effects was identified.

1. Introduction

1.1 Background

Akaroa Wharf, located in French Bay on the eastern side of Akaroa Harbour (Figure 1), was built in 1887 and is now at the end of its design life and no longer economic to maintain. Christchurch City Council (CCC) intends to remove the existing structure and rebuild it at its present location, with some modifications to improve its function and allow for future sea-level rise and storm surges.

The council has engaged Cawthron Institute (Cawthron) to assess ecological effects of the proposed works and facility on the surrounding marine environment. The assessment covers the effects related to the removal of the existing structure, construction of the new wharf and its subsequent operation in the long term.

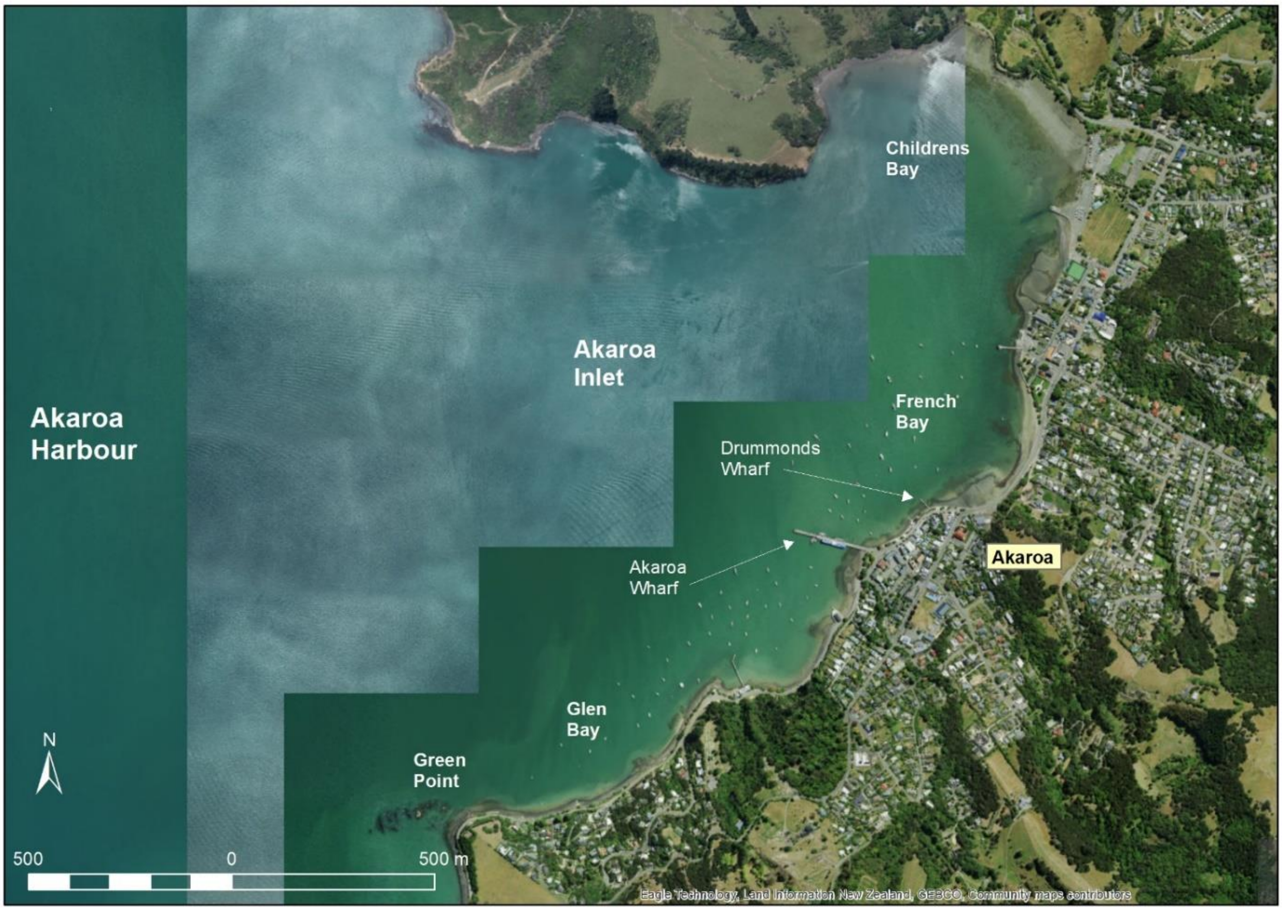

Figure 1. Composite aerial view of the Akaroa township showing locations for Akaroa and Drummonds wharves within the central harbour region. Basemap: NZ Imagery (Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors).

1.2 Proposed works

Specification for the new / renovated structure

The wharf is to be rebuilt in the existing location. To allow for minor adjustments in the alignment of the wharf through detailed design, a construction envelope is proposed for the new wharf. This envelope covers the existing alignment of the wharf, and the option to move the wharf to the north by up to 2.5 m. The alignment may also be adjusted to avoid clashes with the existing pile layout. The wharf deck and supporting piles will all be constructed within this envelope. The wharf will have a total span of 185 m and width of 8 m (essentially the same as the present wharf but 1 m wider; Figure 2). There will be the following changes from the current structure:

- The replacement wharf height will be raised by 500–600 mm to allow for sea-level rise and storm surges.
- Increasing the height of the wharf deck requires changes to the integration with the land, including removal of part of the original 1887 earth and concrete abutment structure. This, and any lateral shift of the wharf, will be accommodated by a longer piled structure and a small area of reclamation, enclosed by a concrete 'L-wall' seawall, on the northern side.
- Wharf materials will include reinforced concrete decking, steel-encased concrete piles, timber fender piles and timber deck elements along with various wharf fittings (bollards, lighting, etc.).
- New floating pontoons will be arranged on the northern and southern faces of the main wharf in a layout that maximises berth space. The final position of the pontoons is yet to be decided. These will be floating and retained by piles, with gangways and small piled platforms linking them to the wharf.
- The current wharf provides a diesel supply facility for commercial vessel operators. The southern floating pontoon will include infrastructure for diesel refuelling of vessels.

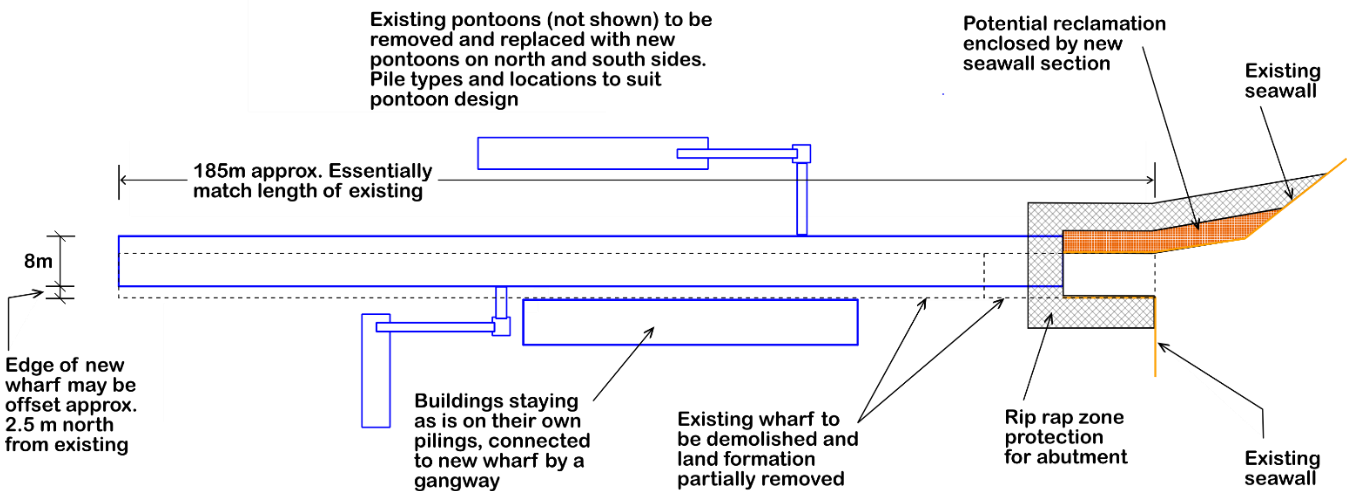

Figure 2. Schematic showing layout of the proposed replacement wharf, including changes in the wharf footprint that may occur with the proposed redevelopment.

Construction programme and methods

An estimate for the duration of the works is for an overall programme over 11-14 months comprising site setup, demolition, piling and deck construction and installation of deck furniture, services and pontoons.

The construction methodology for Akaroa Wharf is likely to include the following:

- The existing buildings alongside the southern side of the wharf and their supporting structure will remain *in situ*.
- All material and soil from the abutment removal will be reused in the 'L-Wall' or disposed of to an authorised facility on land. If larger rocks are present, they may be reused as riprap protection.
- Placement of materials on the seabed will be confined to the design footprint for the wharf and pontoons. The existing piles will either be removed or cut off at the seabed.
- The majority of construction materials will be transported to the site via barge. A crane pad and crane may be required at a laydown / staging area at the Akaroa public boat ramp for loading construction materials and unloading demolition materials.
- Steel and concrete piles are preferred to timber on the basis of immediate and long-term cost (timber piles have a shorter working life). 45–55 steel-cased concrete piles (710 mm diameter) will be driven for the main wharf.
- Installation of 18 timber piles between the wharf and the Black Cat and Blue Pearl buildings.
- A number of timber fender and gangway protection piles will also be installed.
- Demolition and construction works will largely be completed by marine-based plant or will be staged on the constructed sections of the wharf. Most wharf demolition materials will be shuttled by marine plant to the laydown area at the public boat ramp for unloading.
- Piles will be driven using a combination of vibratory, percussive and (potentially) bored installation methods.

The wharf will be rebuilt in stages incorporating the following sequential elements:

1. Construction of the 'L-wall' and abutment (excavation, concrete works, etc.) to provide support and staging space for the piling.
2. The piling rig (crawler crane) to track out to the first bent on the wharf.
3. The piling gate (two piles) will be placed on the existing wharf deck and secured in place.
4. The piling rig to pitch and place the steel piles. The piles will have a steel driving tip welded to the end to enable driving into the weathered basalt.
5. Vibro piling methods (ICE 28RF vibro hammer) will be used to drive the piles as far as possible. A percussion piling hammer will then be used to drive the piles until the desired embedment into the basalt is achieved. If the required embedment cannot be achieved with percussive piling, the pile may need to be removed, and a drill used to pre-drill a socket into the basalt before the pile is redriven.
6. Once the piles are installed, they will be filled with concrete and the capping beams will be put in place.

7. Temporary platforms/grillage will be installed on the capping beam to allow the piling rig to advance to the next bent. Temporary piles may be required to support these temporary works, but they will be the same diameter (or smaller) than the permanent piles.
8. A second, marine-based piling crew, will undertake a similar operation with a piling rig based on the barge. The marine-based rig will work from the outer end, install piles and then demolish the existing wharf. Once it has met up with the land-based rig, it will assist the land-based operation with the capping beams and placement of concrete in the piles. The marine plant will also be used to remove all the old timber piles that clash with the new, with the remainder cut at seabed level using hydraulic shears. (Note: the piling rigs will not undertake piling concurrently, but the work fronts will advance together.)
9. Any remaining sections of wharf will be demolished, and the wharf deck constructed, comprising placement of precast deck elements on the capping beam, installation of temporary formwork, and pouring of the topping slab.
10. Install wharf services, furniture and fittings.
11. Install floating pontoons (north and south), including the piled platforms, gangways and associated services (water, power and fuel on the southern pontoon only). It is expected that approximately 12–16 steel piles (710 mm diameter) will be required.
12. Undertake any surface treatment on the landside (i.e. asphalt, pavers, street furniture, etc.).

1.3 Scope of this assessment

The scope of this marine ecological assessment is aligned with CCC's request for proposals[1] (RFP) and includes the following aspects:

- Review of available existing information on the marine ecology at and near the site of the proposed works.
- Design and implementation of a site investigation covering the construction footprint and adjacent habitats that could be impacted by the works, including any areas that have (or historically have had) habitats supporting kaimoana species.
- Description of the current marine ecological environment based on existing information and the findings of the investigation. Consideration is given to:
  - the nature of the seabed (i.e. sediment type and contamination status)
  - high-value habitats
  - threatened species that may be present.
- Assessment of the ecological effects of the project phases (demolition, construction and operation) on the marine environment. This will include impacts on species and habitats, with a specific commentary on kaimoana species.
- Conclusions focusing on the nature and scale of the effects with and without mitigation.
- Evaluation of biosecurity risks from the construction activities and operational phases.

[1] The RFP was first provided October 2022 but was updated with some refinements in October 2024.

- Assessment of potential cumulative effects.
- Provision of recommendations on management of any adverse effects identified, via specific control measures or amendments to project design.

Note that potential adverse effects on marine mammals are considered in a separate report (Clement and Pavanato 2025). We also note that, while the field investigation allowed for the possibility of dredging around the wharf to facilitate vessel access, the current construction methodology includes no dredging for navigation purposes.

2. Description of the marine environment

Although the scope of this component of the assessment of ecological effects is to describe the marine ecology at and near the site of the proposed works, we have also included general information on intertidal and shallow subtidal habitats in Akaroa Harbour. This is because:

1. Existing information specific to the area around the wharves in French Bay is limited.
2. It allows the benthic communities and habitats of French Bay to be characterised in the context of the wider harbour.

2.1 Akaroa Harbour

Environment values

All of Akaroa Harbour is a taiāpure, reflecting its significance to iwi as a source of food and establishing it as an area of community fisheries management. Fishing is allowed within the taiāpure, but the area has its own rules on the maximum daily number of particular species of fish and the combined daily number of finfish that may be taken or possessed. Taking or possessing shellfish from the Onawe area is prohibited.

The intertidal flats of the upper harbour are classified as Areas of Significant Natural Value in Schedule 5.5 of the Regional Coastal Environment Plan (Environment Canterbury 2005), but this classification does not extend to intertidal areas of the central and lower harbour (such as French and Childrens Bays).

Water quality

Akaroa Harbour has generally good water quality and is intensively used for recreation and tourism, with associated demands on land-based infrastructure such as wharves and jetties (Christchurch City Council 2007). Water quality in most of the harbour, including French Bay but excluding Childrens Bay, is classed by Canterbury Regional Council (ECan) as being suitable for shellfish gathering and contact recreation ('Class Coastal SG Waters' under Schedule 4 of the Regional Coastal Environment Plan [Environment Canterbury 2005]) and management is aimed around maintaining this classification. However, some bays within the harbour, including Childrens Bay, are managed for contact recreation and aquatic ecosystem values but not shellfish gathering ('Class Coastal CR Waters').

The Canterbury Regional Council and its predecessors have sampled water quality at several sites in Akaroa Harbour since 1989. Sites in Childrens Bay and at the mouth of Akaroa Inlet provide an assessment of water quality in this part of the upper-central harbour. Reviewing the data from 1989 to 2009, Bolton-Ritchie (2013) reported that concentrations of total phosphorus (TP) and dissolved reactive phosphorus (DRP) decreased from the upper harbour to the outer harbour. Nitrate and nitrite nitrogen concentrations, in contrast, were higher in the central and lower harbour than the upper harbour. Concentrations of these nutrients had not increased over the period 1989–2009. Total suspended solid concentrations were similar among all sampling sites and the range in concentration at each site over time was small. The discharges from the Rakaia River, Lake Ellesmere / Te Waihora and Lake Forsyth / Wairewa influence water quality in Akaroa Harbour, particularly in the central and lower harbour.

In addition to tidal influx from the adjacent coast, other major sources of nutrients to the harbour are streams and wastewater treatment plants (WWTPs). Three WWTPs discharge into the harbour, including an offshore outfall at the southern end of French Bay (in Red House Bay, south of Green Point). Bolton-Richie (2013) estimated their contribution of ammoniacal nitrogen to the harbour to be two or three times greater than that of the streams (although concentrations in the harbour were well below the guideline for the protection of aquatic life; ANZG 2018). However, streams were estimated to deliver more than seven times as much total nitrogen (TN) than the WWTPs. Plans have been approved to improve the quality of wastewater from both the Akaroa and Duvauchelle WWTPs and divert it to land irrigation.[2,3]

Monitoring concentrations of faecal indicator bacteria at five sites around Akaroa Harbour (Wainui Bay, Barrys Bay, Duvauchelle Bay, Robinsons Bay and Glen Bay [Green Point]) in 2010 showed that blue mussels (*Mytilus galloprovincialis*) from Wainui Bay were not suitable for human consumption (MfE and MoH 2003) on any of the three sampling dates (Bolton-Ritchie 2013). Shellfish from Barrys Bay sampled during dry weather were not safe to eat and those collected during wet weather were marginal for safety. Shellfish from Robinsons Bay collected after a rainfall event were not safe to eat. Wainui Stream was identified as the likely source of contamination in Wainui Bay, and Robinsons Bay Stream for the Robinsons Bay sample. There was no clear source of contamination in Barrys Bay. In the case of stream sources, evidence suggested that the inputs to Wainui Bay included mammals (e.g. livestock), birds and diffuse sources, such as land run-off. Inputs to the other two bays appeared to be from diffuse sources.

Concentrations of dissolved oxygen (DO) between 1989 and 2009 showed that there was sufficient oxygen in the water to maintain the ecological health of the harbour. Phytoplankton blooms occur in Akaroa Harbour, often following breakdown of stratification of the water column in mid- to late autumn. Bolton-Ritchie (2013) did not investigate whether nutrients from wastewater outfalls and the streams influence phytoplankton blooms in the harbour.

Seabed characteristics

The bathymetry and sediment texture of Akaroa Harbour were mapped by Hart et al. (2009), who collected intertidal and subtidal sediments at 89 stations. They found that silt and silt / clay substrates were widespread throughout most of the harbour, including French Bay. High gravel concentrations occurred in only three isolated areas: the steep intertidal and inner nearshore parts of central Wainui Bay, at 5.7 m water depth off the headland at the northern side of the entrance to Akaroa Inlet, and at 3.8 m depth close to the south-facing headland between Duvauchelle and Robinsons Bays (see Figure 3). The presence of sands in shallower inner parts of embayments such as Childrens Bay was considered to have arisen from the winnowing effect of waves, preventing finer particles from settling and accumulating.

2 https://ccc.govt.nz/services/water-and-drainage/wastewater/wastewater-projects/akaroa-wastewater-scheme/

3 https://ccc.govt.nz/services/water-and-drainage/wastewater/treatment-plants/duvauchelle-wastewater-treatment-plant/

Fenwick (2004) sampled subtidal soft sediments at 10 stations along the axis of Akaroa Harbour, including one in the central Akaroa Inlet off French Bay. Across all samples, the proportion of mud in the sediments was strongly related to water depth and decreased from the shallower, upper harbour stations to the fine, silty sands of the lower harbour. Concentrations of organic matter, TN, lead and zinc varied with the mud content of the sediment, but other trace metals did not show any distributional pattern. Overall, however, sediments were generally similar among all of the sampling stations.

Sneddon and Clement (2014) sampled subtidal sediments along a transect running approximately north–south in the central channel of Akaroa Harbour (Figure 3). The seabed substrate at all stations was uniformly soft mud with very little variability in texture. Samples were dominated by the silt / clay fraction (63–80% < 63 µm) and had low concentrations of trace metals and moderate concentrations of nutrients and organic enrichment. Variability between stations was very low for all sediment parameters and no clear spatial trends were observed along the sampling transect.

Benthic communities

Fenwick (2004) collected macrofaunal community samples in October 2003 using an anchor-box dredge (0.06 m^2) to 100 mm depth. A total of 136 taxa were identified for triplicate samples from 10 stations harbour wide. Both total infaunal abundance and taxa richness were found to increase southwards along the central axis of the harbour. Molluscs were more abundant in the upper harbour, whereas polychaete worms and crustaceans were dominant at the outer harbour stations. Some species, such as the polychaete *Terebellides stroemii* and the gastropod *Stiracolpus symmetricus*,[4] occurred at most stations throughout the harbour, but the latter was particularly abundant at upper harbour stations (1,580–1,800 individuals/m^2).

[4] Listed by Fenwick (2004) as *Zeacolpus* (now *Stiracolpus*) *symmetricus* but possibly the same species identified by Sneddon and Clement (2014) as *Z. vittatus*.

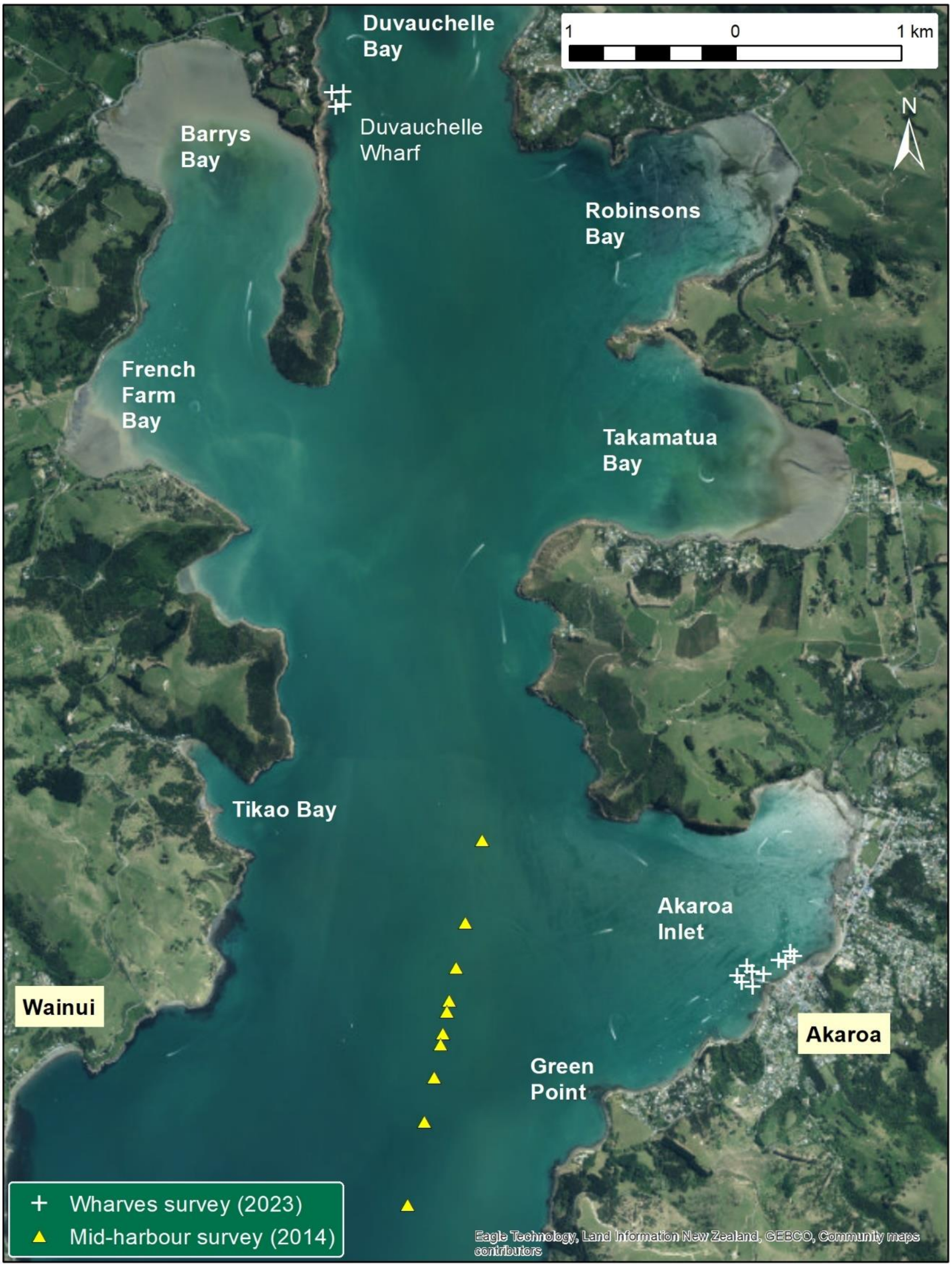

Figure 3. Benthic sampling stations (white crosses) for the present survey around Drummonds Wharf and Akaroa Wharf in French Bay, and Duvauchelle Wharf in the upper Akaroa Harbour. Also shown are stations along a transect sampled in 2014 (yellow triangles; Sneddon and Clement 2014). The 2014 stations (part of the AEE for a proposed but since cancelled offshore wastewater outfall) follow the main harbour axis. Source: NZ Imagery basemap (Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors).

A total of 53 macroinvertebrate taxa were identified by Sneddon and Clement (2014) from triplicate diver-collected core samples from 10 stations (Figure 3). Community structure was generally consistent with the mid-harbour data from Fenwick (2004). Sample assemblages featured quite high numbers of nematode worms, paraonid polychaetes and the gastropod *Stiracolpus symmetricus.* There were also moderate numbers of cirratulid polychaetes and the mud crab *Hemiplax hirtipes.* Other taxa present included phoxocephalid amphipods, the sea pen *Virgularia gracillima*, terebellid polychaetes, the capetellid polychaete *Heteromastus filiformis* and the bivalve *Arthritica bifurca.* The relative uniformity of the substrate along the 2 km transect was reflected in the benthic community data, although some patchiness typical of such communities was evident. The benthos was assessed as being typical of shallow protected coastal environments in the region.

2.2 Akaroa Inlet and Akaroa Wharf

Water quality

Canterbury Regional Council monitors bacteriological water quality at Akaroa Beach in French Bay weekly between November and March. Over the last 5 years, concentrations of enterococci (a marker of sewage contamination) met national water quality standards on 91% of sampling occasions (data from LAWA[5]). Water quality was designated unsuitable for swimming on 7% of occasions. The long-term grade for suitability for swimming at the beach was assessed to be 'poor', indicating a > 10% risk of illness and a 95th-percentile concentration of enterococci more than 500 cfu/100 mL.

Nature of the seabed and intertidal areas

A description of the seabed topography of Akaroa Inlet was given by Hart et al. (2009):

> The bathymetry of Akaroa Inlet approximates, but is slightly steeper than, the five large and shallow upper harbour bays ..., with average foreshore slopes of 1:200 along cross-sections from both Childrens Bay and French Bay ...This bathymetry is perhaps reflective of the position of the inlet within the harbour: north of the exposed Wainui Bay but south of the relatively sheltered upper harbour, the latter of which is situated north of the constriction caused by the Takamatua Hill and Rocky Peak promontories. The intertidal mudflats of Akaroa Inlet are also narrower than those of the upper harbour bays but wider than those of Wainui, ranging from around 200 m in width in Childrens Bay towards the north of the inlet, to around 50 m in French Bay. The latter includes a swimming beach constructed with imported sand. Intertidal mudflats are absent in Glen Bay at the south end of Akaroa Inlet [see Figure 3]. It is considered that this pattern of mudflat development reflects the orientation, shape and hydrodynamics of the inlet.

Hydrographic chart NZ6324 indicates that the primary seabed substrate in French Bay is soft mud. This is consistent with the studies by Hart et al. (2009) and Fenwick (2004). Hart et al. (2009) collected intertidal and subtidal sediments at 14 stations in Akaroa Inlet. While most of the inlet was characterised as soft muds, the intertidal and shallow subtidal areas of Childrens Bay were fine sands. They cited an

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[5] https://www.lawa.org.nz/explore-data/canterbury-region/swimming/akaroa-main-beach/swimsite (accessed 6 July 2023).

earlier study (Hicks and Marra 1988) as concluding that this distribution reflected the degree of wave exposure and water depth. The coarsest material occurred in intertidal areas where turbulence from breaking waves is sufficient to prevent mud from settling. Fenwick's (2004) single sampling station in 5 m water depth in the central part of Akaroa Inlet yielded samples with approximately 98% mud, with very small amounts of fine-coarse sand.

Hale (2020) collected subtidal sediments from five stations along a shore-parallel transect around the wastewater outfall in Red House Bay just south of Akaroa Inlet. The outfall is 100 m from the shore in a water depth of approximately 6 m. A sixth station was located 25 m inshore of the outfall. The percentage of mud in the sediments increased from south to north, while sand and gravel (mainly shell hash) showed the opposite pattern. The percentage of organic carbon in the sediments generally varied with the fine silt and clay fraction. Concentrations of trace metals were similar across all stations and all were well below ANZG (2018) guidelines for the protection of aquatic life.

Biota of subtidal soft sediments

Fenwick's (2004) subtidal station in Akaroa Inlet supported around 30 taxa and was intermediate in taxa richness between upper (18–19 taxa) and lower harbour stations (35–58 taxa). Polychaetes were the most diverse group at the Akaroa Inlet station, followed by crustaceans, gastropods and bivalves. While gastropods were numerically dominant, the variability of both gastropods and crustaceans among replicate samples was very large. The average[6] total abundance of individuals across all taxa was relatively low (1,906 m^2) compared to other stations in Akaroa Harbour (e.g. 7,727 m^2 near the western shoreline south of Wainui). In multivariate statistical comparisons of the types and numbers of infauna at each station, samples from Akaroa Inlet showed greater similarity with those from upper harbour stations than those in the lower harbour.

The most abundant infaunal species in shallow subtidal samples from around the offshore wastewater outfall in Red House Bay (Hale 2020) were the bivalves *Arthritica bifurca* and *Nucula nitidula*, and the polychaetes *Prionospio yuriel*, *Heteromastus filiformis* and *Owenia petersenae*. Epibiota in the vicinity of the outfall (collected by a small dredge-like sled) included brown, green and red seaweeds; polychaete worms; nine species of gastropod; crabs (the stalk-eyed mud crab *Hemiplax hirtipes* being most abundant); starfish (most commonly the cushion star *Patiriella regularis*); and triplefins (*Forsterygion* sp.). Macroalgae included the giant kelp (*Macrocystis pyrifera*) and the introduced kelp *Undaria pinnatifida*.

Biota of rocky intertidal areas

We are not aware of any previous intertidal surveys around the wharves in French Bay and Childrens Bay.[7] Hale (2020) surveyed the biota of intertidal cobble and pebble habitats in Red House Bay along shore-perpendicular transects (high to low shore). One transect began at the overflow discharge pipe for the Akaroa WWTP, with another two 35 m either side. The green alga *Ulva* (*Enteromorpha*) (species not given) was abundant in the upper shore below the discharge pipe (this genus is tolerant of fresh water). *Ulva* was also present in the lower shore in the transects either side, with the coralline alga *Corallina* sp. and the red alga *Porphyra* sp. also present in the mid- or lower shore along these

6 Average of three replicate grab samples.
7 There have been few surveys of rocky intertidal areas in Akaroa Harbour in general (Johnston 2019).

transects. A previous survey of the same locations (Golder Associates 2007) reported similar species and distributions.

The diversity and abundance of fauna recorded by Hale (2020) increased from the high to low shore. The most abundant species were the top shell *Diloma aethiops* and the half-crab *Petrolisthes elongatus*. *Diloma* was generally present over the whole shore, while *Petrolisthes* was very abundant in the mid- and low shore. Other frequently recorded species were the rock crab *Hemigrapsus sexdentatus*[8] (upper, mid- and lower shore) and the barnacle *Austrominius modestus* (lower shore). Also present were the anemone *Isactinia olivacea*, serpulid tubeworms (*Serpula* sp.), mussels (*Xenostrobus neozelanicus* and *Mytilus galloprovincialis*), chitons (*Chiton glaucus* and *Sypharochiton pelliserpentis*), limpets (*Cellana denticulata*, *Siphonaria australis*), whelks (*Cominella maculosa*), cat's eye snails (*Lunella smaragda*), the snails *Micrelenchus purpureus* and *Zeacumantus lutulentus*, the cushion star *Patiriella regularis* and the rockfish *Acanthoclinus* sp.

Fenwick's (2004) surveys of rocky shores at Tikao Bay, Cape Three Points and Lucas Bay, on the western side of Akaroa Harbour, provide general information on the nature of the biota of this habitat. Of the three sites, Tikao Bay (Figure 3) was the northernmost and is the closest and most similar to French Bay, at least in terms of wave exposure. However, the direction of exposure is different, and Tikao Bay is probably more shaded from midday and afternoon sun by the steep hillsides to the northwest (Fenwick 2004).

Large brown macroalgae were reported by Fenwick (2004) as dominant in the sublittoral fringe in Tikao Bay, and included *Sargassum sinclairi*, *Carpophyllum maschalocarpum*, *Macrocystis pyrifera* and *Ecklonia radiata*. Higher up the shore, above spring low water, macroalgae were sparse and represented only by *Hormosira banksii*. Barnacles (*Chamaesipho columna*) were dominant, with a second barnacle species, *Austrominius* (*Elminius*) *modestus*, present in crevices and under boulders. Crustose coralline algae also covered a large proportion of the rock surface in these low-shore areas. Top shells (*Diloma* [*Melagraphia*] *aethiops*), tubeworms (*Pomatoceros caeruleus*[9]) and chitons (*Sypharochiton pelliserpentis*) were also present.

Barnacles were dominant around neap low water, together with the predatory mulberry whelk (*Haustrum [Lepsiella] scobina*), limpets (*Cellana ornata* and *Siphonaria zelandica*) and top shells. Above mid-shore, abundances of barnacles reduced slightly and patches of the red macroalga *Bostrychia arbuscula* and the mussel *Xenostrobus pulex* were present. Top shells, periwinkles (*Austrolittorina* spp.), limpets and whelks were confined to crevices. Barnacles were replaced by black lichens further up the shore.

In general, the sites surveyed by Hale (2020) and Fenwick (2004) supported species and habitats that are widely distributed around Banks Peninsula and the South Island east coast.

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8 Golder Associates (2007) recorded this species as *H. edwardsii* at the same locations – the species has been renamed since their study.

9 Since renamed *Spirobranchus cariniferus*.

3. Methods

Given the limited available information on the intertidal and subtidal habitats and communities areas of French and Childrens Bays, including immediately around Akaroa Wharf, a field survey was undertaken to support the assessment of potential effects of the proposed wharf redevelopment works. The survey was conducted over 20–23 March 2023 as part of efforts to gather site information for three separate wharf projects in the harbour, the others being Duvauchelle Wharf at the head of the harbour (Figure 3) and Drummonds Wharf (also in Akaroa Inlet).

3.1 Subtidal habitats

Side-scan sonar

Side-scan sonar imagery of the seabed was collected using a Lowrance StructureScan HD® system (800 kHz frequency) with a vessel-mounted transducer. This gave a swathe width of 60 m, within which changes in seabed relief and reflectivity could be identified if present. Side-scan recordings were made at a vessel speed of 2–3 kn while navigating a pattern giving suitable coverage of the area in the vicinity and offshore from Akaroa Wharf. During the side-scan transects, any features of potential interest were marked as GPS waypoints. This enabled the relocation of such areas for subsequent inspection by divers. The sonar imagery was processed using the Reefmaster 2.0 software package to convert the sonar files to geo-referenced mapping (.kml) files.

Diver ground-truthing of benthic habitat

Based on depth, spatial considerations and observations of the side-scan sonar images during recording, eight observational dives were completed in the vicinity of Akaroa Wharf (Figure 4). A shot line was placed at designated coordinates and a single tethered diver descended to the harbour bed with an Olympus TG6 compact camera. To the extent allowed by underwater visibility, the diver recorded key aspects of the substrate and epibiotic communities in the vicinity of the shot. Two of the dives (AKD7 and AKD8; Figure 4) were made at wharf piles to document encrusting communities on the structure and benthic habitats immediately adjacent to it.

Sampling of benthic sediments

Subtidal sediments were collected using a frame-mounted 0.1 m^2 stainless-steel van Veen grab at six stations within the vicinity of the wharf (Figure 4). The stations were pre-established from sonar mapping as being clear of hard substrates nearer to shore. This sampling method collects a relatively undisturbed section of surficial sediment down to a depth of 10–12 cm in the profile. Upon retrieval, the grab contents were sub-sampled using standardised corers to provide material for sediment and infauna analyses.

Figure 4. Vicinity of Akaroa Wharf showing locations of benthic grab samples, spot dives and intertidal transect surveys undertaken on 20–23 March 2023. Basemap: NZ Imagery (Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors).

From one side of the grab, three 62 mm-diameter core samples were extracted using clear Perspex corers. These were photographed and notes made on odour, colour, consistency and the depth within the profile to any apparent redox potential discontinuity (aRPD) layer.[10] The surficial 5 cm of material from each sediment core was sub-sampled and composited for physicochemical analyses.

From the other side of the grab, benthic infauna[11] were sampled using a PVC corer of cross-sectional area 133 cm^2 to a depth of 10 cm. The core contents were gently rinsed through a 0.5 mm mesh and the residue containing the infauna was emptied into a plastic container and preserved with 70% ethanol with 1% glyoxal as a fixative.

10 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.

11 Macrofauna are defined as animals retained on a 0.5 mm sieve mesh. The infauna are the component of this group that live within the sediment matrix.

3.2 Sediment physicochemical analysis

The sediment samples from the six stations were analysed for the following attributes and contaminants:

- grain-size distribution (seven size classes)
- total organic carbon
- trace metals.

Brief analytical method descriptions are listed in Appendix 1.

The analysis of particle grain-size distribution defines the overall texture of sediments. This represents an important site physical characteristic that informs the interpretation of differences between sites for other environmental parameters. Bioavailable contaminants such as metals are primarily retained within fine sediments (e.g. Förstner 1995), where they adsorb to particulates and organic matter and may accumulate over long time periods. Both sediment texture and organic content also play important roles in the structure and diversity of sediment faunal communities.

Concentrations of trace metals / metalloids within sediments can be compared against expected background levels, providing an indication of general levels of contamination at a site. Total recoverable concentrations of a suite of eight metals were analysed and the results compared against the applicable national sediment guideline criteria (ANZG 2018; DGV)[12] and available data from previous surveys of the harbour.

3.3 Sediment infaunal communities

Sediment infaunal communities have been used for several decades to assess the effects of human impacts in marine environments. Various studies have demonstrated that they respond relatively rapidly to anthropogenic and natural stress (Pearson and Rosenberg 1978; Dauer et al. 1993; Borja et al. 2000).

Organisms within the preserved infauna samples were sorted and counted with the aid of a binocular microscope. Identifications were made to the lowest practicable taxonomic level. The raw count data were analysed to ascertain levels of abundance (individual species density), species richness, and standardised indices of community diversity and evenness for each sample (Table 1). These values were compared among stations to assess variability. Significant differences were interpreted with respect to other environmental factors such as substrate characteristics and water depth.

[12] The ANZG (2018) DGV and GV-High levels represent the two thresholds under which biological effects are predicted. The lower threshold (DGV) indicates a *possible* biological effect, while the upper threshold (GV-High) indicates a *probable* biological effect.

Table 1. Descriptions of macroinvertebrate community indices.

Index	Equation	Description
No. species (*S*)	$\sum s$	Total number of species (*s*) in a sample.
No. individuals (*N*)	$\sum n$	Total number of organisms (*n*).
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' $\log_e$)	$H' = -\sum P_i \, log_e \, (P_i)$ P_i is the proportion of *N* comprised of the *i*th species	Shannon–Wiener diversity index describes, in a single number, the different types and amounts of taxa present in a sample. The index ranges from 0 for communities containing a single species to high values for communities containing many species, each represented by a similar number of individuals.

All multivariate statistical analyses of infaunal communities were conducted using PRIMER v7 (Anderson et al. 2008; Clarke and Gorley 2015). The assemblages recorded at each site were contrasted using non-metric multi-dimensional scaling (nMDS; Kruskal and Wish 1978) ordination and cluster diagrams applying Bray–Curtis similarities between samples. Abundances were first square-root transformed to de-emphasise the influence of numerically dominant taxa. The principal taxa contributing to dissimilarities in sample groupings were identified using SIMPER (Clarke et al. 2014).

3.4 Intertidal habitats

Semi-quantitative transect surveys of intertidal habitat and communities were conducted on either side of Akaroa Wharf. The transects were located from the seawall to the immediate south (AKT1) and 50 m north (AKT2) of the base of the wharf (Figure 4). A 50 m graduated tape was run out across three intertidal zones (high, mid and low). Communities and habitat were documented photographically, and notes were compiled on the taxa present and their relative abundance. The field record was compiled to generate a characterisation of the intertidal environment.

4. Results

4.1 Subtidal habitats

Broadscale description

The seabed around and offshore from the wharf was generally uniform and relatively featureless (Figure 5). Isolated hard objects were generally identifiable as the anchor blocks for swing moorings for vessels moored in the bay (Figure 4). These often had discernible 'haloes' around them, representing coarser sediment caused by scour from chain sweep and possibly mussel shells and other hard biofouling that has fallen from the line and surface buoy. The fringe of lighter-coloured, reflective material around the wharf possibly also represents mussel shell and other hard biofouling debris (see Appendix Figure A3.4).

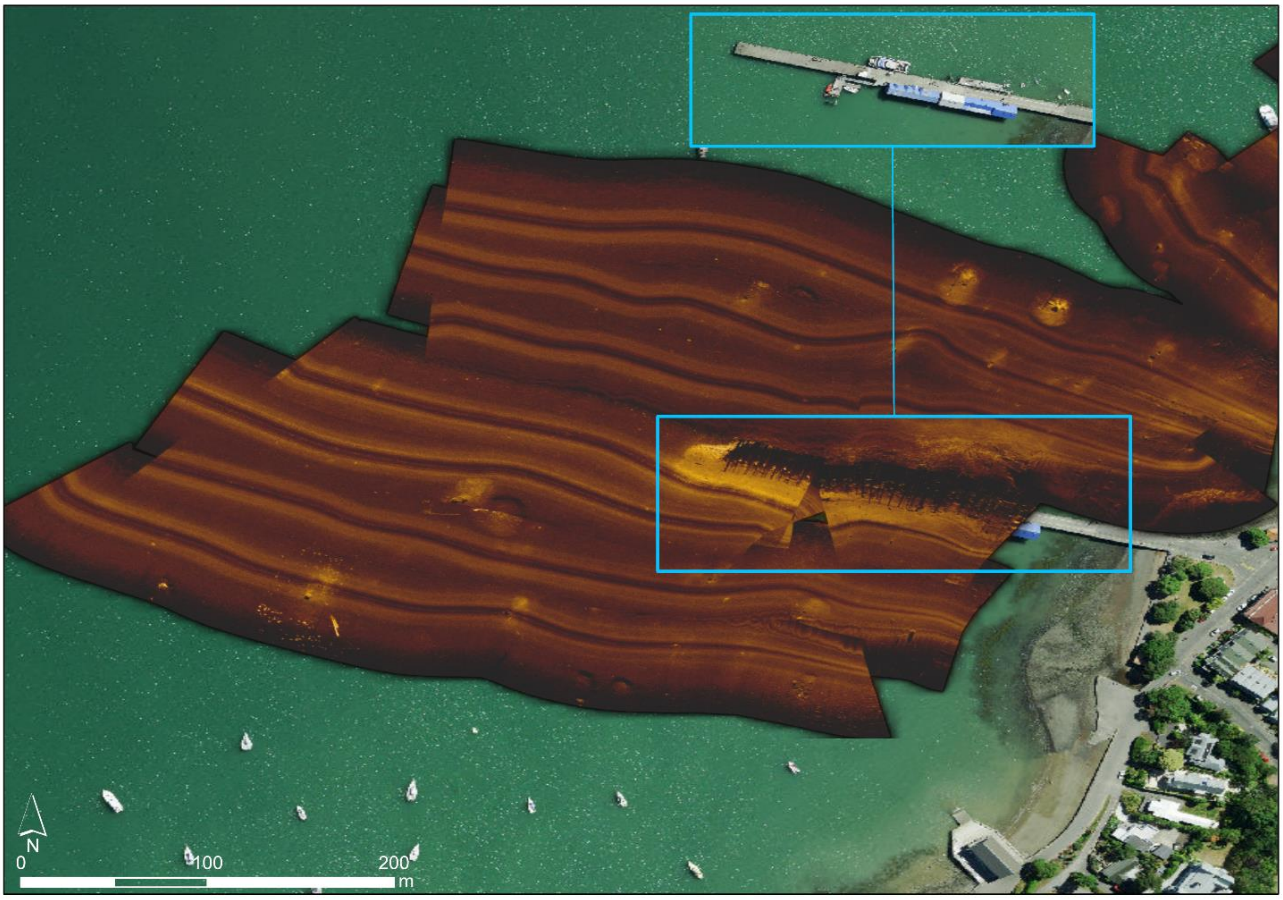

Figure 5. StructureScan overlay showing the seabed in the vicinity of Akaroa Wharf in March 2023. Inset shows wharf structure. The visible track pattern represents the central 'shadow' of the swathe. Basemap: NZ Imagery (Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors).

Diver observations

The seabed at the offshore dive stations (AKD1–3; Appendix Figure A3.1) consisted of soft mud with microalgal (diatom) films, crab burrow openings, clumps of blue mussels (*Mytilus galloprovincialis*; Figure A3.1C), cushion stars (*Patiriella regularis*; Figure A3.1D) and terrestrial plant debris (Figure A3.1G). Clumps of mussels were also present in the area of vessel scour off the northern side of the wharf (ADK4: Figure A3.1J–O), together with cushion stars and calcareous tubeworms (Figure A3.1L).

At the inshore stations (AKD5–6; Appendix Figure A3.2) the seabed sediment was sandier than offshore. It also featured crab burrow openings and cushion stars, plus woody debris (Figure A3.2B), hydroids (Figure A3.2E and G), polychaete worm tubes (Figure A3.2F) and drift macroalgae (Figure A3.2I).

Upper parts of wharf piles (Appendix Figure A3.3) were colonised by blue mussels, hydroids and macroalgae (*Codium* sp., *Ulva lactuca* and unidentified red algae). Green-lipped mussels (*Perna canaliculus*) occurred further down the piles, with cushion stars, solitary ascidians and top shells. The seabed around the bases of the piles consisted of mud, mussel shells and shell gravel, with cushion stars, hydroids and drift algae.

Sediments

Grain-size distribution and organic carbon content
All sediments consisted predominantly of mud (58.3–98.2% silt and clay material by dry weight; Table 2), but the percentage increased with distance from shore. Most of the balance of sediment composition at all sites was made up of very fine and fine sand.

Sediments from the offshore stations (AKG1–4; Figure 4) contained the highest percentages of silt and clay and correspondingly smaller percentages of sand fractions (Table 2). The sediment profiles at all stations were pale brown with grey mottling throughout (Appendix 2).

The amount of organic matter (total organic carbon, TOC) in the sediments was typical of sheltered coastal fine sediments but did not closely follow the usual relationship with the proportion of silt and clay (Table 2).

Table 2. Sediment particle size categories and total organic carbon composition (each as a percentage of total dry weight) at dive stations AKG1–6.

	AKG1	AKG2	AKG3	AKG4	AKG5	AKG6
Gravel	0.9	0.05	0.05	0.2	0.2	0.1
Very coarse sand	0.3	< 0.1	< 0.1	< 0.1	0.2	< 0.1
Coarse sand	0.3	< 0.1	< 0.1	0.1	0.4	0.2
Medium sand	1	0.5	0.9	0.5	1.1	0.8
Fine sand	1.9	0.8	1.5	1.8	8	2.5
Very fine sand	6.8	5.4	9.8	8	31.7	19.3
Silt and clay ('mud')	88.9	93.2	87.7	89.2	58.3	77.1
Total organic carbon	1.92	1.48	1.53	1.74	1.74	1.83

Trace metals

Concentrations of trace metals in sediments were mostly well below those at which adverse ecological effects are possible ('DGV' of ANZG 2018; Table 3). However, concentrations of mercury at stations AKG4 and AKG6, off the northern side of the wharf (Figure 4), exceeded the DGV (0.15 mg/kg) but were below the concentration at which effects are considered likely (GV-High = 1 mg/kg).

Because metals tend to bind to finer sediment particles, concentrations are generally higher in muddy than in sandy sediments. In the present case, however, this pattern was less clear. For example, the relatively sandy sample from AKG6 had the highest concentrations of arsenic, cadmium and mercury, and the second-highest concentration of copper (Table 3).

Table 3. Sediment trace metal concentrations (mg/kg) at dive stations AKG1–6. The guideline values above which ecotoxic effects are considered possible (DGV) and probable (GV-High) are shown for each metal. Exceedances of the DGV are shown in bold type.

	AKG1	AKG2	AKG3	AKG4	AKG5	AKG6	DGV	GV-High
Arsenic	7.7	7.6	7.9	7.9	5.3	8.4	20	70
Cadmium	0.068	0.056	0.061	0.084	0.067	0.092	1.5	10
Chromium	16.5	15.7	14.2	14.8	12.7	14.0	80	370
Copper	11.4	10.9	10.3	12.8	9.3	12.4	65	270
Lead	17.1	18.4	16.2	19.1	13.1	18.2	50	220
Mercury	0.09	0.10	0.10	**0.22**	0.07	**0.26**	0.15	1.0
Nickel	10.8	10.7	9.1	9.7	7.8	9.2	21	52
Zinc	61	63	61	72	57	68	200	410

Concentrations of arsenic and cadmium around Akaroa Wharf were lower than those around Duvauchelle Wharf at the head of Akaroa Harbour (Sneddon and Morrisey 2023a), while concentrations of copper, lead and mercury were higher in the Akaroa Wharf samples. Concentrations of chromium, nickel and zinc were similar between the two regions.

Concentrations of arsenic, lead and zinc were similar to those found by Sneddon and Clement (2014) in samples collected from the central harbour (Table 4, Figure 3). However, concentrations of cadmium, copper and mercury were higher around Akaroa Wharf, while those of chromium and nickel were lower. All concentrations in the harbour axis transect samples were below guideline trigger values for the protection of aquatic life.

Table 4. Average sediment trace metal concentrations (mg/kg, triplicate samples) at stations off Akaroa Inlet, mid-Akaroa Harbour (see Figure 3). Source: Sneddon and Clement (2014, appendix 2).

	1000N	500N	250N	100N	50N	50S	100S	250S	500S	1000S
Arsenic	7.5	7.2	7.4	7.5	8.3	8.3	7.8	6.9	7.4	7.2
Cadmium	0.047	0.044	0.037	0.044	0.039	0.04	0.046	0.039	0.038	0.041
Chromium	23	23	23	23	23	23	24	24	24	23
Copper	9.5	9.7	9.4	9.9	9.6	9.6	10	9.9	10.2	9.9
Lead	18.5	18.5	18.3	18.1	18.4	18.2	18.7	18.3	18.3	17.9
Mercury	0.061	0.042	0.041	0.042	0.042	0.042	0.048	0.053	0.038	0.051
Nickel	15.5	15.6	15.4	15.7	15.6	15.4	15.7	15.9	16.1	15.4
Zinc	62	62	61	60	60	64	62	63	62	60

It is notable that concentrations of mercury in Duvauchelle Bay (Sneddon and Morrisey 2023b) and the 2014 central harbour transect were lower (and all below the DGV criterion) than around Akaroa Wharf. This would appear to rule out a catchment source (such as volcanic soils) for the relatively elevated concentrations around the wharf in general and at the two sites north of the wharf in particular. Plotting the concentration of mercury against the proportion of mud (silt plus clay) in the sediment produced a wide scatter of points (Figure 6). Apart from the two samples exceeding DGV both occurring at the muddier end of the range, there was no clear relationship between concentration and sediment texture. The amount of variation among the samples is unusual – if concentrations simply represented natural background concentrations, they would likely be more homogeneous. Nonetheless, excluding stations AKG4 and AKG6, concentrations of mercury around Akaroa Wharf were similar to background concentrations in Lyttelton Harbour / Whakaraupō (0.04–0.08 mg/kg; Cawthron Institute, unpublished data).

As far as we are aware, Akaroa township has never supported any industrial activity that might result in mercury contamination. The relative proximity to the wharf of the two stations with the highest mercury concentrations might suggest a source in antifouling paints, which before the 1960s sometimes contained mercury. Hull cleaning on a tidal grid or similar facility near the wharf might have released mercury in paint flakes. Cargo spillages are another possible source. Rock phosphate, for example, contains trace amounts of mercury.[13] The fact that concentrations around Akaroa Wharf were higher than in most of the Duvauchelle Bay and mid-channel samples is consistent with a now diffuse historical source such as spillage of break-bulk cargo.

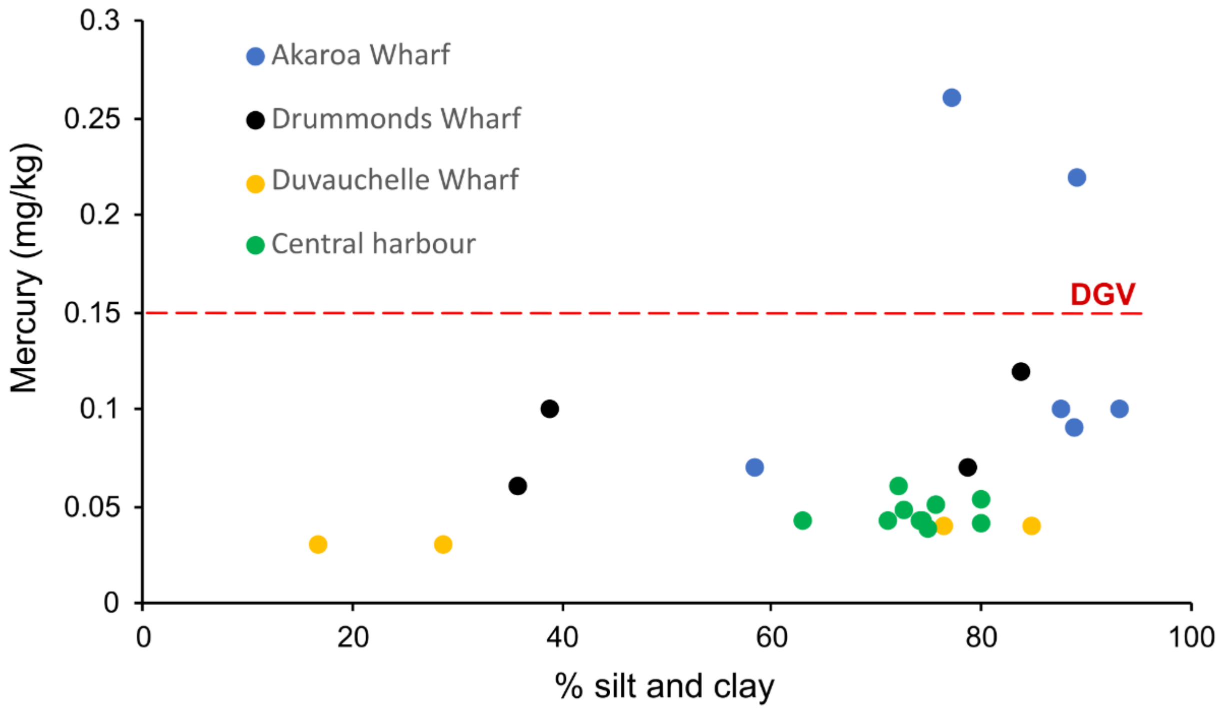

Figure 6. Concentrations of mercury against the percentage of silt and clay in sediments from around three wharves in Akaroa Harbour (2023 survey, including present study) and in the central harbour channel (data from Sneddon and Clement 2014). The default guideline value (DGV) for mercury is overlaid.

Sediment infaunal communities

Total infauna abundance, taxa richness, Shannon–Wiener diversity (*H'*) and Pielou's evenness were variable among samples (Figure 7). Abundance (number of individuals) was lowest in samples from the muddier and deeper offshore stations (AKG1 and AKG2), while taxa richness and H' diversity were highest at AKG1 (88.9% mud; Table 2) and AKG5 (58.3% mud). Apart from AKG5, diversity and evenness tended to increase with distance from the shore (and increasing water depth). Number of taxa showed no clear pattern.

13 https://environment.govt.nz/publications/mercury-inventory-for-new-zealand-2008/section-ii-mercury-contributors1-introduction/3-sources-of-mercury/#:~:text=Trace%20levels%20of%20mercury%20are,of%2038%20kg%20Hg%2Fyear

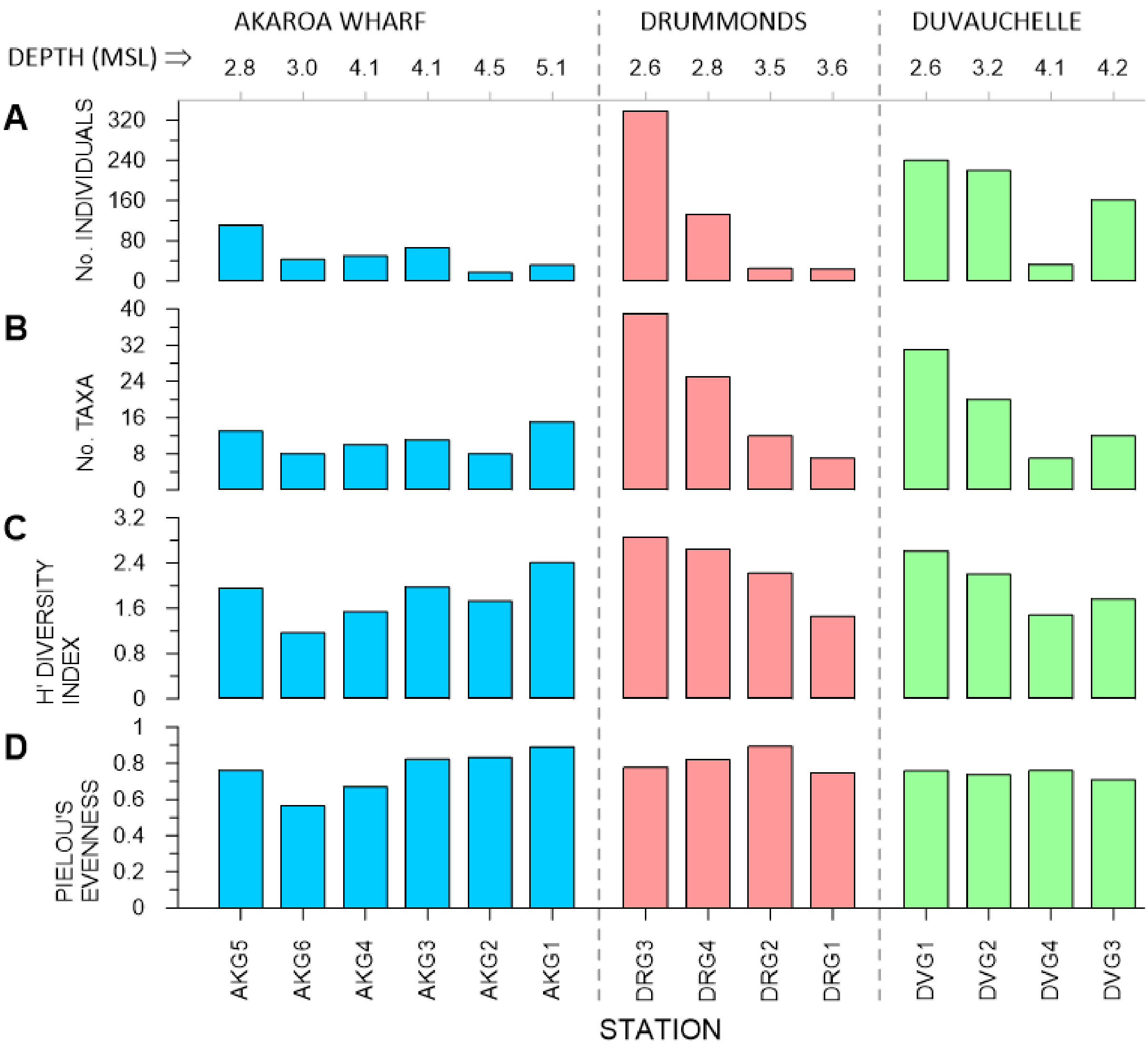

Figure 7. Infaunal community indices for shallow subtidal samples from stations around Akaroa Wharf (blue), Drummond Wharf (red) and Duvauchelle Wharf (green). Stations are ordered (left to right) according to increasing water depth at each wharf.

To provide context for the subtidal infaunal samples collected from around Akaroa Wharf, these were compared to similar data for samples from around Drummonds Wharf (French Bay) and Duvauchelle Bay (Figure 7), and from the central channel of the harbour off French Bay (Figure 8). Numbers of individuals and taxa were broadly similar in samples from Duvauchelle and Drummonds wharves, decreasing with increasing water depth at both locations (though less consistently at the former; Figure 7). Both indices were lower at Akaroa Wharf, even in samples from similar water depths. Patterns of diversity and evenness were similar at Duvauchelle and Drummonds, diversity decreasing with water depth and evenness showing little variation among stations. In contrast, both indices increased with depth around Akaroa Wharf. It is noted that the lowest diversity and evenness values at the Akaroa Wharf site occurred for the two stations with elevated mercury concentrations (AKG4 and AKG6; Table 4), although this was not reflected in abundance and taxa richness.

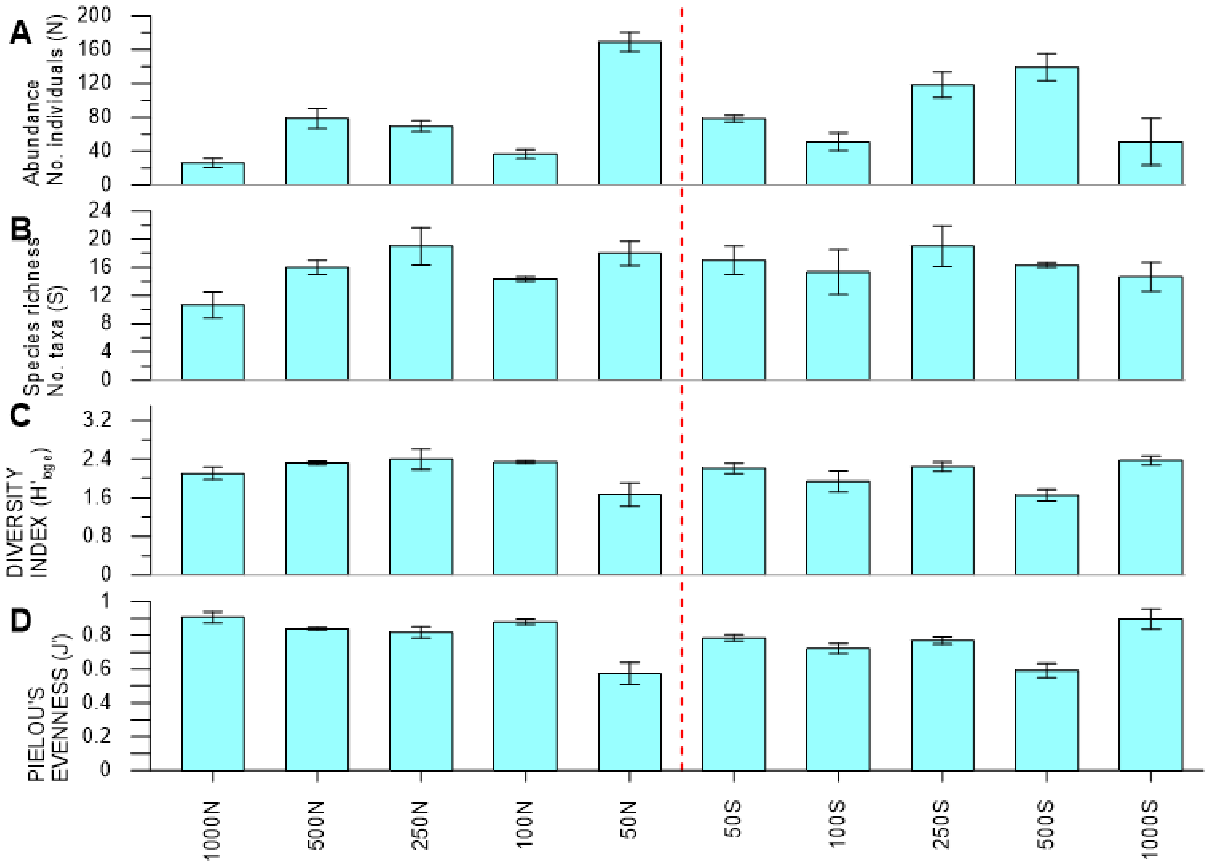

Figure 8. Infaunal community indices for subtidal samples from stations in the central channel of Akaroa Harbour, collected in 2014. Sampling stations are arranged from north to south along the central harbour axis (see Figure 3). The dotted red line indicates the relative position of a proposed WWTP outfall (not built). Source: data from Sneddon and Clement (2014).

Infaunal abundances in Akaroa Wharf samples were comparable to all but the three highest values from the 10 stations sampled from the central channel of the harbour in 2014 (Figure 8). However, despite having similarly soft, muddy sediments, the numbers of taxa and H' diversity were generally lower around Akaroa Wharf than in the central channel (Figure 8). Ranges of evenness values were similar in both sets of samples.

Polychaete worms represented 36% of the total numbers of organisms in the samples from Akaroa Wharf (Table 5) and included five of the 10 most abundant taxa overall (Table 6). Bivalve molluscs represented 32%, nematode worms 15%, oligochaete worms 10% and amphipod crustaceans 4%. Small crustaceans (crabs and cumaceans) made up the remainder of the total. Differences in community indices among samples from Akaroa Wharf are reflected in the relative numbers of the most abundant taxa present in each sample (Table 6).

The bivalve *Theora lubrica* was more abundant at the inshore sites on the north side of the wharf (AKG4 and AKG6) than on the south side (AKG3 and AKG5), being a primary driver in the lower diversity and evenness values at the former stations (Figure 7). This species is characteristic of muddy sediments, which is consistent with its relatively low abundance at the sandier AKG5 station, but does not indicate why it was not more abundant at AKG3, where the sediment was as muddy as at the sites on the north side, nor why its abundance was also low at AKG1 and AKG2.The station with the sandiest sediment, AKG5, contained higher numbers of nematodes, the bivalve *Arthritica bifurca* and phoxocephalid amphipods than the muddier sites. Sigalionid polychaetes were the only taxon that was limited to the four muddiest sites (AKG1–4).

The suite of most abundant taxa in samples from Akaroa Wharf was very similar to that compiled for both Drummonds and Duvauchelle wharves (Sneddon and Morrisey 2023a, 2023b), indicating that this infaunal assemblage is widely represented throughout Akaroa Harbour.

Table 5. Relative abundance of key infaunal taxonomic groups in the Akaroa Wharf samples (percentage of the total number of individuals), averaged across all samples.

Polychaetes	36.4%
Bivalves	32.0%
Nematodes	15.4%
Oligochaetes	10.3%
Amphipods	4.1%
Crabs	0.9%
Total	**99.1%**

Table 6. Numbers per 133 cm^2 sample of the 10 most abundant taxa (representing 93% of total abundance) at sampling stations around Akaroa Wharf. Stations are arranged left to right in order of increasing water depth.

General group	Taxa	AKG5	AKG6	AKG3	AKG4	AKG2	AKG1
Depth (MSL)		2.8	3.0	4.1	4.1	4.5	5.1
Bivalvia	*Theora lubrica*	8	30	4	27	6	3
Nematoda	Nematoda	45		2	1		1
Oligochaeta	Oligochaeta	10	3	18	2		
Polychaeta: Spionidae	*Prionospio yuriel*	3	3	15	4		2
Polychaeta: Cossuridae	*Cossura consimilis*	2	2	5	9	5	2
Bivalvia	*Arthritica bifurca*	18	1	4			1
Polychaeta: Spionidae	*Prionospio* sp.	6		12	1		1
Amphipoda	Phoxocephalidae	8		1	1	1	1
Polychaeta: Sigalionidae	Sigalionidae			3	2	1	4
Polychaeta: Chaetopteridae	*Spiochaetopterus* sp.						8

When the similarities among the wharf site infauna samples are represented visually in an nMDS plot (Figure 9, top), those from Akaroa Wharf align with a depth gradient (shown in the plot by the relative sizes of the circular symbols representing each sample) from the lower central part of the plot to the upper right. Samples from around Duvauchelle and Drummonds wharves are distributed from left to right across the plot, also along a gradient of increasing depth. Very similar patterns of distribution occur when the size of the sample dots represents the proportion of mud in the sample (Figure 9, bottom).

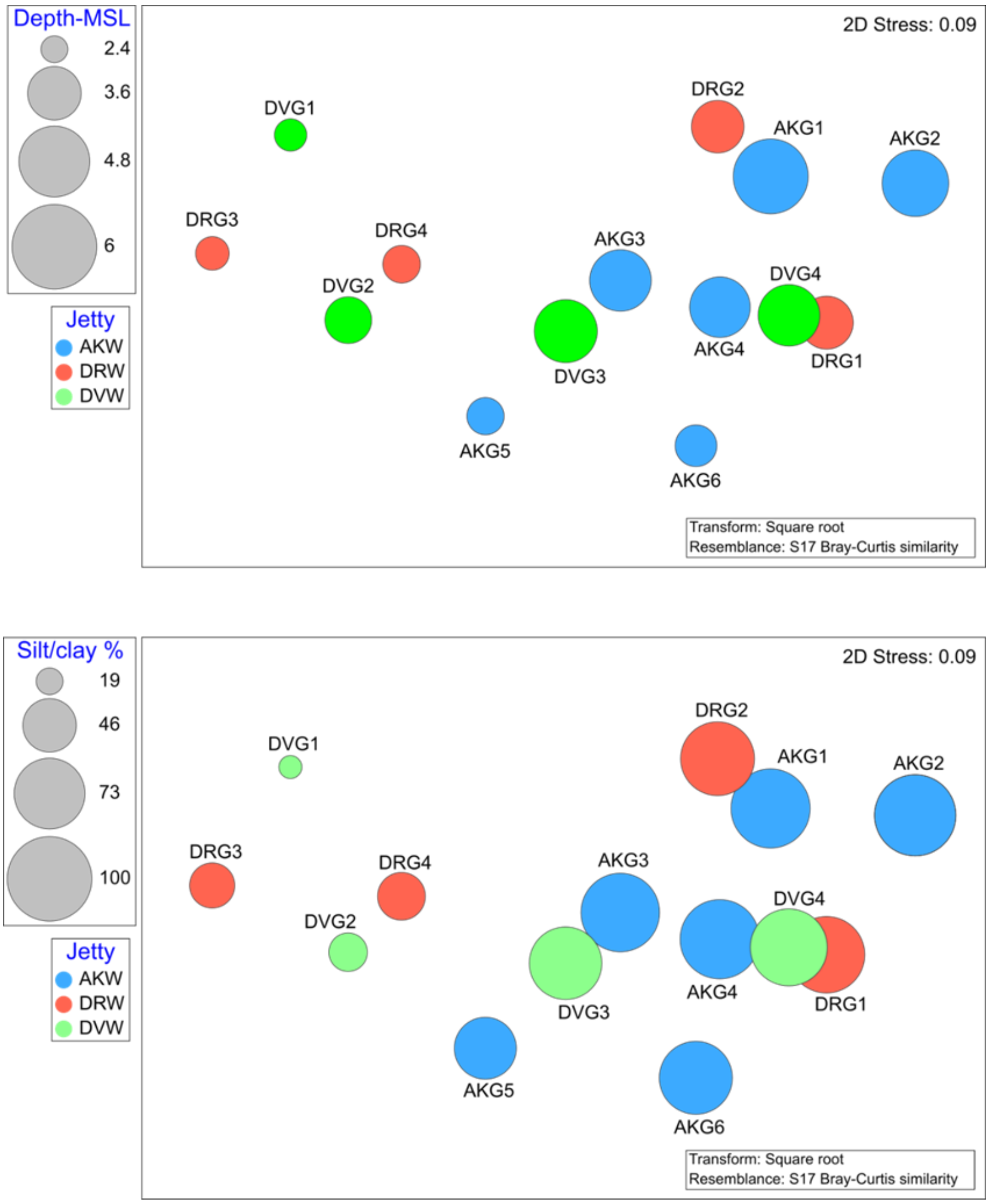

Figure 9. Non-metric multi-dimensional scaling (nMDS) plot showing the relatively similarities among the fauna of sediment samples from Duvauchelle (DVW), Drummonds (DRW) and Akaroa (AKW) wharves. Samples are represented by solid circles, the size of which reflects water depth (upper plot) or proportion of silt / clay in the sediment (lower plot). The stress value is a measure of how well the plot represents the relationships among the samples in terms of the similarities of their fauna. A value of 0.09 indicates good representation.

4.2 Intertidal habitats

Intertidal transects were located on either side of Akaroa Wharf (Figure 4). Both featured an upper shoreline modified by the presence of seawall structures above a mixed substrate beach of boulder, cobble and pebble material with interstitial silty sand and some open sand patches. There was no exposed bedrock reef at either transect, and the mobile nature of the cobble and pebble material possibly precluded the establishment of biogenic features such as extensive tubeworm or macrofaunal cover, or shellfish beds. A series of 10 haphazard 0.25 m^2 photo quadrats for each of the three tidal zones along each transect is provided in Appendix 4.

The intertidal communities observed on both transects were made up of common species typical of intertidal hard substrate habitats in the wider harbour area. Similar intertidal communities have been documented in Akaroa Harbour north of Drummonds Wharf (Sneddon and Morrisey 2023a), and at Duvauchelle Wharf (Sneddon and Morrisey 2023b), Red House Bay (Hale 2020) and Tikao Bay (Fenwick 2004) (see Section 2.2).

Transect AKT1

Transect AKT1 was located on the south side of Akaroa Wharf, running from the seawall at its base to the mouth of Aylmers Stream, which discharges across the beach (Figures 4 and 10).

Figure 10. Boulder / cobble beach at Transect AKT1. Photographed at low tide on 22 March 2023 looking northeast towards Akaroa Wharf.

Substrata

The high zone at AKT1 was 1 m seawards of the tidal wrack line of desiccated seaweed and consisted of pebble / cobble material at the end nearest the wharf, transitioning to mostly cobbles at the southern end. Occasional boulders and accumulated drift weed were also present. The mid-zone was composed of a sandy strip (mixed silty sand and gravel) between high and low cobble fields, with sporadic surficial boulders and cobbles. Along the low-zone transect, sand that was present on the first day of the survey had been washed out by wave action by the following day. When the transect was surveyed, the area had been highly impacted by surge, with the habitat affected by mobilised cobble material and evident scour.

Communities

No conspicuous organisms were observed in the high-tide zone. Being mostly open sand, the mid-zone supported a sparse community associated with sporadic embedded boulders. The only such biota observed were the grazing gastropod *Diloma aethiops* and barnacles (*Chamaesipho columna*).

The most stable substrate in the low zone was the concrete base of the Akaroa Wharf structure. This was colonised by a range of sessile biota, including ribbed mussels (*Aulacomya maoriana*), calcareous tubeworms (*Spirobranchus cariniferus*), barnacles (*C. columna*) and non-geniculate coralline algae. Conspicuous mobile biota included *D. aethiops*, limpets (*Cellana ornata*), chitons (*Sypharochiton pelliserpentis*) and the whelk *Haustrum scobina*.

The algal community along the transect was sparse. Neptune's necklace weed (*Hormosira banksii*) was present but only as isolated individual plants. Small patches of crustose coralline algae occurred on some cobbles (often associated with residual macroalgal holdfasts, which suggested displacement from subtidal areas). Sporadic small patches of black and brown encrusting algae were also observed. As with algae, low-tide fauna were sparse and mostly limited to the larger embedded boulders. However, *D. aethiops* was common where such stable substrates occurred, as were *S. cariniferus* and barnacles (*C. columna* and *Austrominius modestus*). Several limpets were also present (*C. ornata, Patelloida corticata, Notoacmea* sp.), along with very occasional blue mussels (*Mytilus galloprovincialis*).

Transect AKT2

Transect AKT2 was on the north side of Akaroa Wharf, starting 50 m from the wharf base and running to a point approximately 50 m from Drummonds Wharf (Figures 4 and 11).

Figure 11. Boulder / cobble beach at Transect AKT2. Photographed at low tide on 22 March 2023 looking southwest towards Akaroa Wharf.

Substrata

The high zone was adjacent to the seawall and consisted of boulders and cobbles with interstitial gravel material. There were two stormwater discharge pipes positioned to discharge directly onto the upper beach. The mid-zone featured a similar mixed substrate but with fewer large boulders. In the low zone, medium to coarse sands were more prevalent among cobble material. The surveys were undertaken during a significant southerly wind event in Akaroa, and open sand patches that had been observed on the low shore the day before the survey had been washed out by waves overnight.

Communities

Conspicuous high-zone fauna were completely absent from exposed substrate surfaces and were observed only under boulders, where the top shell *Diloma aethiops*, the whelk *Haustrum scobina* and small limpets (*Notoacmea parviconoidea*) could be found, along with shore crabs (*Cyclograpsus lavauxi*) and half crabs (*Petrolisthes elongatus*).

In the mid-zone, there was a sparse presence of calcareous tube worms (*Spirobranchus cariniferus*) and barnacles (*Chamaesipho columna*), along with sporadic *D. aethiops*, *H. scobina* and limpets (*Cellana ornata*). Beneath boulders, *P. elongatus* were quite prevalent and the chiton *Chiton glaucus* was also observed.

The low-shore zone featured sparse macroalgae comprising occasional *Hormosira banksii*, a black encrusting algae and very occasional pink crustose coralline algae. Drift *Cystophora scalaris* appeared mostly to have been washed ashore by wave action, often still attached to displaced small cobbles. The diversity of fauna in the low shore was greater but still relatively limited. *Diloma aethiops* was very common but mostly in shaded niches, and barnacles (*C. columna*) were sometimes dense in patches on larger boulders. Also present were occasional mussels (*Mytilus galloprovincialis*) but these were mostly small. There was evidence of flat oysters (*Ostrea chilensis*), although only shells were observed. Other fauna recorded included the cat's eye snail (*Lunella smaragda;* single individual), limpets (*C. ornata*, *N. parviconoidea*) and the 11-armed starfish *Coscinasterias muricata*.

5. Ecological risk assessment

5.1 Potential effects

Short-term / construction effects

Currently, it is expected that existing piles will be cut off at the seabed by divers using chainsaws and that removal of most of the wharf structure will be piecemeal using barges. A self-propelled barge will also likely be used to bring in much of the construction material, except where this can be transported out across completed inner sections of the new wharf. New piles will be driven in by a barge-mounted pile-driver, although some of this may also be staged from completed sections. Since barges will need to be towed into position by a tug or similar vessel, these movements will comprise significant activity during the construction period. The size of the vessels and limited water depths mean that disturbance of the seabed by propeller wash and anchoring systems during positioning will be the primary direct benthic impacts outside the immediate construction footprint. It should be noted, though, that propeller scour disturbance is already associated with use of the wharf by commercial and private vessels. The likely greater impact from barge traffic will be somewhat offset by the lower frequency of such movements during construction.

While no dredging is proposed for navigation and wharf access, there will be excavation and removal of much of the 30 m earth formation at the base of the existing wharf. While the direct disturbance of seabed habitat from this excavation will be spatially very limited, there will likely be some resuspension of sediment and, potentially, associated contaminants in nearshore waters. These will be dispersed and redeposited by water movement. Properly managed, the land-based disposal of excavated material should not present a further risk to marine environments.

Benthic disturbance from pile-cutting and pile-driving will involve disturbance of the seabed and suspension of seabed sediment (and any sediment-associated contaminants), but disturbance effects will be highly localised. Effects on a broader scale will potentially accrue from the associated underwater noise experienced by fish (and marine mammals) in the vicinity. Noise effects on fish, where they occur, are likely to be primarily behavioural and short-lived. Suspended sediment plumes can also propagate to the wider area via ambient water currents and wave action. While the eventual settlement of such sediments has the potential to affect benthic habitats and communities in the wider area, plumes from such localised disturbances are unlikely to result in significant or persistent effects more than tens of metres from the source.

Removal of the existing wharf structure will represent a temporary loss of pile habitat for encrusting plants and animals, but colonisation of the new piles with the same or similar communities is likely to be relatively rapid following project completion.

Landside activities, particularly earthworks, have the potential to affect adjacent marine environments via stormwater run-off.

Accidental discharges or spills of fuel or other toxic or smothering contaminants (e.g. cement) during construction have the potential, if not quickly contained or neutralised, to adversely affect communities living on the intertidal area around the wharf, the piles and adjacent seabed.

Long-term and operational effects

The small size of the wharf footprint relative to the surrounding harbour bed and the fact that it is essentially a like-for-like structural replacement means that the effects of its presence on benthic habitats and the water column are likely to be similar to those of the existing wharf in both nature and extent. For instance, the use of artificial lighting on the structure is expected to be of comparable intensity and spread.

As with the present wharf, there may be some dampening of waves that impinge on the adjacent shore, but the slight increase in width and any changes in the piling density will be offset by the removal of all but 10 m of the land formation abutting the inshore end. Hence, apart from possibly increased shoreline sediment transport, the ecological effects are expected to be insignificant.

The increase in height of the wharf deck is unlikely to alter any existing effects. Effects of shading of the seabed on plant growth will also be similar to those of the existing structure, and given the size of the wharf, are expected to be insignificant at the scale of the inlet.

The basic function and use of Akaroa Wharf is not expected to change with the new structure. The design aims to better serve existing users, particularly in easing present occasional congestion issues. However, increases in usage are expected to be limited to background growth in harbour activity generally, with some allowance for response to the improved facility. Hence, for the purposes of this assessment, it is assumed that the nature and volume of vessel movements and other operations around the wharf will not change more than incrementally.[14] Hence, there is likely to be no more than minimal net change in ongoing operational effects.

Biosecurity

Introductions of non-indigenous marine species (NIS) can have irreversible, adverse effects on biodiversity and ecosystem function, and may result in economic costs to industries such as aquaculture and shipping (Fletcher and Johnston 2019). In addition to the natural dispersal capabilities of NIS, human activities can assist their movement between geographical areas. This is particularly important where natural dispersal is restricted by a barrier, such as areas of unsuitable habitat or unfavourable water currents. In these situations, human-mediated transport can significantly increase the rate and extent of spread.

Assessment of potential biosecurity risks associated with the proposed work requires detailed information of the plant and materials to be used in the reconstruction, and on projected vessel use of

[14] Although the wharf will be better configured to cater to cruise ship tenders, this is an existing use, and it is understood that the improvement is aimed at easing wharf congestion rather than catering to an increased overall usage of Akaroa Harbour by cruise vessels.

the reconstructed wharf. Much of this information is not presently available. This assessment is, therefore, based on consideration of general types of risk that may arise.

The importation of materials, vessels and equipment from outside Akaroa Harbour for the demolition of the old wharf and construction of its replacement has the potential to introduce NIS not currently present in the area. The risk is particularly high for vessels that tend to spend relatively long periods idle in locations where NIS are present, such as dredgers and barges.

NIS may be introduced as fouling on vessel hulls and on materials and equipment if these have previously been deployed elsewhere. Discharge of ballast water from vessels, or other releases of water and sediment (for example, on anchors, spuds or other equipment that contacts the seabed), can also result in the introduction of NIS. Most vessels and equipment required for construction will likely arrive from locations outside Akaroa Harbour and will have an associated risk of importing NIS on their hull and in-water structures, in ballast and bilge water, and in residual sediments or biofouling on ancillary equipment.

Any change in the use of the wharf following reconstruction, in terms of increased numbers and types of vessels (current use is shown in Table 7), particularly increased visits from vessels from outside Akaroa Harbour, has the potential to introduce novel NIS. As noted, we understand that the nature and scale of vessel use of the wharf is not expected to change more than incrementally after reconstruction.

Table 7. Details of vessel categories using Akaroa Wharf. LOA = length overall. Source: Christchurch City Council.

Vessel class	LOA (m)	Beam (m)	Draught (m)	Max. tonnage (t)
Commercial fishing	22	4.5	1.5	45
Commercial tourism	24	7.1	1.6	70
Cruise tenders	16	5.0	–	43
Recreational vessels	10	3.0	1.2	5.5

5.2 Assessment of risk

Values of affected species and habitats

The ‘value’ of organisms and habitats was determined using Roper-Lindsay et al.’s (2018) value method for ecological impact assessment (Table 8 and Table 9).

Table 8. Assigning value to species / taxa for assessment purposes (adapted from approach by Roper-Lindsay et al. 2018). Determining factor categories derived from the New Zealand Threat Classification System (NZTCS; Michel 2021).

Determining factors	Value
Threatened – Nationally Critical, Nationally Endangered or Nationally Vulnerable	Very high
At Risk – Declining	High
At Risk – Recovering, Relict or Naturally Uncommon	Moderate–high
Locally uncommon / rare, not nationally Threatened or At Risk	Moderate
Not Threatened nationally, common locally	Low

Table 9. Assigning value to habitat for assessment purposes. Source: Roper-Lindsay et al. (2018).

Determining factors	Value
Supporting more than one national priority type*	Very high
Supporting one national priority type* or naturally uncommon ecosystem	High
Locally rare or threatened, supporting no Threatened or At Risk species	Moderate
Nationally and locally common, supporting no Threatened or At Risk species	Low

* See MfE and DOC (2007). National Priority 1: To protect indigenous vegetation associated with land environments (defined by Land Environments of New Zealand at Level IV) that have 20% or less remaining in indigenous cover. National Priority 2: To protect indigenous vegetation associated with sand dunes and wetlands; ecosystem types that have become uncommon due to human activity. National Priority 3: To protect indigenous vegetation associated with 'originally rare' terrestrial ecosystem types not already covered by priorities 1 and 2.

Under the New Zealand Coastal Policy Statement 2010 (DOC 2010), any adverse effects of human activities on species and habitats meeting the criteria of Policy 11(a), and any significant adverse effects on species and habitats meeting the criteria of Policy 11(b), must be avoided. Policy 11(a)(i) refers to 'indigenous taxa that are listed as threatened or at risk in the New Zealand Threat Classification System [NZTCS] lists'.

Based on the intertidal and subtidal surveys conducted for this assessment and from existing available information on Akaroa Harbour, no marine invertebrates listed as Threatened or At Risk under the NZTCS (Funnell et al. 2023) have been recorded from the area of the proposed wharf redevelopment.

Furthermore, based on habitat requirements and known distributions, none of the marine invertebrate species categorised as Threatened are likely to occur in Akaroa Bay, except possibly the brachiopod *Pumilus antiquatus*. This species is listed as Threatened: Nationally Critical and its value is, therefore, **Very high** (Table 8). It has been recorded on rocks and boulders below the low-tide mark from three locations in the South Island: Lyttelton Harbour / Whakaraupō, near Karitane and Otago Harbour (Bowen 1968). In Lyttelton Harbour it has been found intertidally at Ripapa Island and on Gladstone Wharf, Lyttelton Port. However, these records date from the 1960s and recent searches of the rockpool on Ripapa Island (by Ross Sneddon and Paul South, Cawthron) failed to find any individuals. Given that its distribution is poorly known, it is possible that it could occur in Akaroa Harbour, including on subtidal hard substrates and wharf piles in Akaroa Inlet. It lives in sheltered, shallow rocky areas hidden from light and protected from strong waves, and has been found under rocks and in the holdfasts of giant kelp (*Macrocystis pyrifera*). Giant kelp was recorded from Red House Bay by Hale (2020) and from Tikao Bay in the middle harbour by Fenwick (2004), but, as noted below, has not so far been recorded from the immediate vicinity of Akaroa Wharf.

The golden limpet (*Cellana flava*), listed in the NZTCS as At Risk: Declining, is described by Willan et al. (2010) as frequent or common in mid- to low intertidal areas from Dunedin to East Cape and the Chatham Islands. This species could potentially occur in Akaroa Inlet and the wider harbour but has not been recorded to date. Its conservation value is categorised as **High** (Table 8).

There is no current NZTCS list for marine bony fish in Aotearoa New Zealand. Two species of grouper are protected under the Wildlife Act 1953, but neither is likely to occur in Akaroa Harbour. The central harbour region is, furthermore, unlikely to support any of the cartilaginous fish (sharks, rays, etc.) listed in the NZTCS (Duffy et al. 2018).

The macroalga *Macrocystis pyrifera* is listed as At Risk: Declining under the NZTCS (Nelson et al. 2019) and its value is, therefore, **High** (Table 8). It is present in Akaroa Harbour (Fenwick 2004), including at Red House Bay just south of Akaroa Inlet (Hale 2020), but has not been reported from the vicinity of the French Bay wharves to date. Among other large, conspicuous macroalgae that are unlikely to be overlooked if present, none of the species of *Durvillaea* listed as At Risk: Declining is known from French Bay but *D. antarctica* and *D. willana* have been recorded in Lucas Bay in the outer harbour and Cape Three Points in the central harbour, where they were the dominant cover in the shallow subtidal area (Fenwick 2004).[15] Given their habitat preference for sites of persistent wave energy, French Bay is probably too sheltered to support them. Consequently, is it also unlikely that either of the At Risk: Declining algae that are dependent on *Durvillaea* species (as epiphytes or endophytes) will be present in the bay.

Other algal taxa classified as Threatened or At Risk: Declining that have not been recorded to date but that could potentially occur at the site (based on their geographic distribution) are the green alga *Prasiola novaezelandiae* (Threatened: Nationally Endangered) and the red alga *Gigartina dilitata* (At Risk: Declining). The brown alga *Notheia anomala*, an epiphyte on Neptune's necklace (*Hormosira banksii*), is listed as At Risk: Naturally Uncommon. It could potentially occur around Akaroa Wharf, given that its host is present (see Section 4.2). It occurs in intertidal areas of Ripapa Island in nearby Lyttelton Harbour / Whakaraupō (Sneddon and Dunmore 2021).

The cobble and boulder substrata of the intertidal and shallow subtidal areas and the wharf piles, and the subtidal sands and muds around Akaroa Wharf, are widespread in Akaroa Harbour and the wider area. These habitats, and the organisms they contain, are therefore ranked as **Low** value (Table 9).

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[15] Following a marine heatwave in 2017–18, *Durvillaea* spp. disappeared from several locations in Lyttleton Harbour / Whakaraupō and cover was reduced at other sites around Banks Peninsula (Thomsen et al. 2019). It is not known if *D. willana* is still present in Akaroa Harbour.

Akaroa Wharf is 8 km from the nearest boundary of the marine reserve on the eastern side of the entrance to Akaroa Harbour. The reserve has **Very high** value but because of its distance from the proposed works, adverse effects resulting from, for example, suspended sediments and contaminants, are considered very unlikely. However, the introduction of NIS could potentially have a significant adverse effect on the values of the reserve.

Kaimoana species and their habitats

The findings of historical and recent benthic surveys in central Akaroa Harbour suggest that the incidence of invertebrate and algal kaimoana species is primarily limited to shoreline intertidal and littoral fringe habitats. Side-scan sonar imaging, diver observations and sampling of the soft sediment substrates offshore in French Bay yielded no evidence of significant shellfish beds in the vicinity.

Cross-referencing of taxa records from the current and earlier surveys in the vicinity with recognised kaimoana[16] yielded an indicative list of candidate species. In intertidal and shallow subtidal mixed substrate, these included pāua (*Haliotis iris*), kūtai / blue mussels (*Mytilus galloprovincialis*) and pūpū / cat's eye snails (*Lunella smaragda*). There are catch limits for these species in the Akaroa taiāpure regulations. Set-netting for flatfish is permitted in the part of the harbour north of the southern boundary of French Bay (Green Point), suggesting their potential value as kaimoana in this area. Maximum daily catch limits are specified for the taiāpure for tuangi / cockles (*Austrovenus stutchburyi*), but these have not been recorded from the area around Akaroa Wharf.

In addition, the cobble and boulder shoreline of the eastern central harbour supports limpets (*Cellana* spp.) and other gastropods, oysters, kuku / green-lipped mussels (*Perna canaliculus*), and a range of macroalgae (of which some may have been used as kaimoana) (Fenwick 2004; Hale 2020; present study).

We were not able to source any published information on historical or current use of the potentially affected area for gathering kaimoana. While we are not qualified to provide a detailed assessment of the cultural value of the identified kaimoana species, or of potential adverse effects of the proposed work on their role as kaimoana, we can broadly assess the status of populations at the site as a harvestable resource. The survey of the immediate vicinity of the wharf suggests that none of the identified species occur at population densities sufficient to comprise a significant harvestable resource or that the site may be more important in this regard than other areas of the harbour. Nonetheless, potential adverse effects on these organisms and their habitats are addressed more generally in Section 5.2.

Risk assessment

The approach to risk assessment was based on modifications of those proposed by Roper-Lindsay et al. (2018) and incorporating Burgman's (2005) use of 'likelihood' as a factor. The levels of risk were derived from the sequential consideration of the following factors (with the categories for each factor shown in Table 10):

16 https://www.mpi.govt.nz/dmsdocument/22054-List-of-species-of-importance-to-Tangata-Whenua-Table-

- the ecological or conservation value of the organisms or habitats affected (see Section 5.2)
- the spatial scale and duration of the effect
- the magnitude of effect, or consequences, of the effect occurring
- the likelihood of the effect occurring.

The level of ecological risk is derived from a combination of the value of the ecological feature and the magnitude of the effect (Table 10).

Table 10. Level of risk of an adverse effect.

		Ecological value			
		Very high	**High**	**Moderate**	**Low**
Magnitude	**High / severe**	Significant	Significant	Moderate	Low
	Moderate / medium	Significant	Moderate	Very low	Negligible
	Low / minor	Low	Very low	Very low	Negligible
	Negligible	Very low	Negligible	Negligible	Negligible

Demolition and construction phases

Encrusting communities living on the piles would be removed with them during demolition. Although the present timber piles will be replaced with new ones made of steel and concrete, recolonisation of the new piles is expected to replace the lost communities fairly rapidly (although it may take several years for communities to fully develop). The associated level of risk is **Negligible** (Low value × Low / minor magnitude; Table 11).

Disturbance of the seabed during removal of existing piles and installation of the new ones, including associated propeller wash from barge movements, is likely but the spatial extent (tens of metres) will be relatively small and the duration short.

Recovery / recolonisation of the areas disturbed during demolition and construction is likely to be rapid (months) given the large area of similar habitat around the site of the proposed works and the general absence of biogenic structures or emergent epifauna in soft sediment areas. With an expected low to negligible magnitude of effect, the resultant level of risk is **Negligible** for the surrounding rocky habitat (or **Very low** if the golden limpet, *Cellana flava*, was found to be present) and also **Negligible** for the sediment habitat (Table 11).

The principal mechanisms by which the construction project can impact the marine environment outside the footprint of physical disturbance are the production and advection of turbidity plumes from the resuspension of fine sediments and associated contaminants, and the propagation of underwater sound.

Although piling involves the application of considerable force, this is concentrated at the pile base and has only limited potential to resuspend bed sediments into the water column. Hence, the process is very unlikely to generate conspicuous turbidity plumes at scales greater than the immediate area (tens of metres). Depending on the plant used, a greater source of resuspended bed sediments may come from vessel movements during construction. Consistent with a limited tidal prism and absence of flow constriction in the vicinity, modelling of water movement in Akaroa Harbour by Bell et al. (2014) showed relatively weak currents in French and Childrens Bays. Hence, the wharf site is very unlikely to be subject to ambient water currents great enough to advect plumes of resuspended sediments over any distance before substantial resettlement has occurred. Therefore, the level of turbidity experienced by habitats more than 100 m from the source is unlikely to exceed conditions already occurring from wave action and normal usage of the wharf.

The concentrations of all indicative trace metals except mercury in the sediment samples collected from around the wharf were well below their corresponding ANZG (2018) DGV guideline values. Mercury was slightly elevated in two samples from the bay on the northern side but still well below the corresponding GV-High trigger (Table 3). Based on seawater elutriation testing of Lyttelton Harbour / Whakaraupō sediments with similar mercury levels by Sneddon (2019), this contamination is expected to remain particulate-associated rather than being released to the water column during suspension. Furthermore, the expected low magnitude of resuspension and the very limited potential for transport of plumes means that it is very unlikely that sediment mercury concentrations at points more than tens of metres from the source would be increased measurably. Nonetheless, the limited spatial sampling intensity raises the possibility that some contamination may be more prevalent near the wharf than is suggested by the data. Allowing for this uncertainty, the level of risk associated with the suspension and redeposition of contaminants is considered to range from **Negligible** to **Very low** (Table 11).

All demolition and construction activities will represent a temporary increase in noise. However, the percussive shock and underwater noise associated with pile-driving will be far above ambient levels within the immediate area. This is likely to result in temporary avoidance behaviour by fish and possibly some mobile invertebrates. However, few studies have researched the impact of pile-driving on invertebrates (e.g. Roberts et al. 2017), and there is little information on the longer-term effects on benthic communities beyond the observations that:

- effects of vibration and noise on lower trophic–level organisms do not appear to be highly conspicuous.
- recovery of benthic communities (including return of fish life) following such noise disturbances appears to be rapid.

Hence, any noise effects on the benthos, should they occur, are likely to be no more than transitory. While short in duration, the effects on fish from pile-driving noise will be moderate to large in spatial scale (hundreds of metres). With the possible exception of small benthic species such as triplefins (*Forsterygion* spp.), fish will be able to avoid areas acutely affected and will return with cessation of the activity. The magnitude of effect is therefore considered to be low / minor and the consequent level of risk to be **Very low** (Table 11).

The primary ecological receptors of concern for potential effects from underwater noise, particularly from piling activities, are marine mammals. These are being assessed in a separate report (Clement and Pavanato 2024). Any measures put in place to protect marine mammals by reducing noise generation will also serve to lessen such stresses on other receptors.

Based on the preliminary construction details, no significant discharges have been identified as being intrinsically associated with the demolition and construction processes. Although there may be some contact between uncured cement and seawater during the piling process, this is likely to be very limited and highly localised. The large natural pH buffering capacity of seawater and well-flushed nature of the site will ensure that such risks remain **Negligible** (Table 11).

The risks of accidental spillages of fuel and other materials are inherently difficult to predict because they depend on operational practices that are yet to be established. The handling of potentially harmful substances needs to be governed by appropriate protocols to mitigate spill risk. Best practice standards and protocols exist for most common construction processes, and these should be incorporated into construction management plans.

Long-term and operational effects

As noted in Section 5.1, potential long-term effects of the reconstructed wharf are expected to be no more than incrementally different from the present facility. An additional floating pontoon structure will slightly enlarge the benthic area subject to propeller scour from berthing vessels. Improvements to the wharf as a facility may attract greater usage by existing harbour users, but by largely retaining the original structural footprint such increases will be limited. Any environmental effects from the presence of the structure itself, such as dampening of waves and shading of the seabed, are expected to be negligible because of the very small changes in the scale of the wharf, combined with its more open structure.

Biosecurity risks

Without mitigation, the risk of introduction of NIS via vessels, equipment and materials is significant, particularly if the vessels come from locations where such species occur that are not already present in Akaroa Harbour. Since the primary use of Akaroa Wharf is not projected to alter the current vessel traffic into the harbour, both in the short and longer term, no change in risk is engendered by its operation once built. However, equipment for the wharf's construction is likely to come from one of the larger ports around Aotearoa New Zealand, where the diversity of NIS is invariably higher. The fanworm *Sabella spallanzanii*, for example, is established in Whangārei Harbour, Waitematā Harbour and Lyttelton Harbour / Whakaraupō, and has been recorded from others. The sea squirt *Styela clava* is well established in ports and marinas throughout most of the country, but not yet in Akaroa Harbour. Both species have known costs – for example, to the aquaculture industry.

Relatively few NIS are known to occur in Akaroa Harbour. As far as we are aware, four NIS have been recorded to date (three listed by the Marine Biosecurity Porthole 2023):

- the macroalga *Undaria pinnatifida* (recorded in French Bay and on the headland west of Takamatua, both in the central harbour)

- a small spider crab, *Halicarcinus varius* (recorded from Duvauchelle Bay)
- the small bivalve *Theora lubrica* (recorded in the current survey and by Sneddon and Clement 2014)
- an amphipod, *Hirayacorophium* (*Hirayamaia*) *mortoni* (recorded from Robinsons Bay).

The sea squirt *Didemnum* sp. has also been recorded from the central harbour. While it is uncertain whether this taxon is native or introduced, it is widespread around the country.

Because of the relatively high likelihood that any inadvertently transported NIS are not currently present in Akaroa Harbour, the associated risk of introductions could potentially be **Significant** (Table 11).

While there is some risk of exporting NIS from Akaroa to other areas during the project and in the longer term, this is assessed as **Low** since all species listed above except *H. mortoni* are already widely distributed in Aotearoa New Zealand. The record of *H. mortoni* from Robinsons Bay is the only one nationally to date, but this is possibly because the species is inconspicuous and not easy to identify. Hence, while there is a potential export biosecurity risk associated with equipment and vessel movements from Akaroa Harbour, the significance is very difficult to assess because of a lack of information on its local distribution and prevalence, as well as ecological or other effects associated with its presence.

5.3 Recommendations for mitigation of adverse effects

For most identified potential marine ecological effects, the level of risk without specific mitigation has already been assessed as **Negligible** or **Very low**. In these cases, it is recognised that the commitment of resources to implement anything but standardised duty of care mitigation measures are likely unwarranted.

Discharges

As noted in Section 5.2, the level of risk from accidental spillages is difficult to estimate due to limited available detail on project methodology. However, mitigation can be achieved by application of normal duty of care and best practice procedures to avoid spills of fuel and other materials during demolition and construction. These include:

- rigorous control protocols around activities such as refuelling of equipment and cement pours
- documented contingency plans and associated resources for rapid containment, recovery and clean-up should spills occur.

Biosecurity

Mitigation of the risk of introducing NIS to Akaroa Harbour with vessels, equipment and materials for the proposed work may be achieved by:

- applying specified thresholds for hull antifouling and maintenance for construction vessels, with restrictions on movements of vessels that do not comply
- requiring vessels to follow an approved biosecurity management plan (BMP)
- requiring the use of new (rather than used / relocated) construction materials, where these are sourced outside of Akaroa Harbour.

These measures are expected to reduce the likelihood of effects to Low. The level of risk would then be reduced to **Very low** (Table 11).

In the longer term, possible mitigation options for increased boat arrivals and movements facilitated by the wharf include:

- applying specified thresholds for hull antifouling and maintenance for vessels, with restrictions on movements of vessels that do not comply
- encouraging owners of permanently moored and trailered vessels to follow good maintenance practices
- encouraging best practice with regards to cleaning of submersible equipment.

Underwater noise

Although no specific noise mitigation controls are being recommended for protection of benthic receptors, it is recognised that any noise attenuation measures implemented for marine mammals will also ease such stresses on fish populations.

Run-off from land

Landside earthworks will not be extensive. However, management of such activities should employ interception and containment protocols for the control of fine sediments (e.g. management of flow paths, silt fences, etc.).

Table 11. Summary of potential ecological effects on the coastal receiving environment of the proposed wharf redevelopment. Levels of ecological risk are shown before and after mitigation where relevant (NA = mitigation not considered necessary). The 'High' value assigned to the biota of boulders relates to the possible presence of Threatened or At Risk species, such as Cellana flava. DGV = default guideline value (ANZG 2018) at which ecological effects are possible. BMP = biosecurity management plan.

Potential environmental effect	Ecological receptor or feature	Value	Spatial scale of effect	Duration of effect	Magnitude of effect	Likelihood of effect	Level of risk	Mitigation options	Residual risk
Loss of pile habitat	Encrusting community	Low	Small	Moderate to persistent	Negligible	High	Negligible	NA	
Direct disturbance of seabed by excavation, vessel propeller wash, pile removal and pile-driving	Biota of adjacent intertidal and subtidal boulders	Low to potentially High	Small	Short	Negligible	Moderate	Negligible to Very low	NA	
	Biota of adjacent subtidal sediment seabed	Low	Small	Short	Negligible	Moderate	Negligible	NA	
Dispersal and redeposition of suspended sediments and contaminants	Biota of nearby intertidal and subtidal boulders	Low to potentially High	Small	Short	Negligible (mercury concentrations < DGV) to Low / Minor (mercury concentrations > DGV)	Moderate	Negligible to Very low	NA	
	Biota of nearby subtidal sediment seabed	Low	Small	Short	Negligible (mercury concentrations < DGV) to Low / Minor (mercury concentrations > DGV)	Moderate	Negligible	NA	
	Water column	Low	Small	Short	Negligible to Low / minor	Moderate	Negligible	NA	
	Akaroa Marine Reserve	Very high	Small	Short	Negligible	Low (8 km from source)	Very low	NA	

Potential environmental effect	Ecological receptor or feature	Value	Spatial scale of effect	Duration of effect	Magnitude of effect	Likelihood of effect	Level of risk	Mitigation options	Residual risk
Underwater noise from pile-driving	Fish	Moderate	Large	Short	Low / minor	High	Very low	Noise attenuation as for marine mammals	Negligible
Contaminant discharges	Adjacent water column and benthos	Low	Small	Short	Low / minor	Moderate	Negligible to Very low	Interception / containment / recovery protocols	Negligible
Sediment in run-off from landside earthworks	Adjacent water column and benthos	Low	Small	Short	Low / minor	High	Very low	Interception / containment protocols	Negligible
Introduction of NIS	Biota of intertidal and subtidal habitats in Akaroa Harbour	Low to potentially High	Large	Persistent	Low / Minor to High / Severe	Moderate	Negligible to Significant	• Thresholds for vessel hull antifouling and maintenance • Requirement for BMP • Require use of new construction materials	Negligible to Very low
	Akaroa Marine Reserve	Very high	Large	Persistent	Low / Minor to High / Severe	Moderate	Negligible to Significant		Negligible to Very low

Definition of terms used in table

Spatial scale of effect Small (tens of metres), Medium (hundreds of metres), Large (> 1 km)
Duration of effect: Short (days to weeks), Moderate (weeks to months), Persistent (years or more)
Magnitude of effect: Negligible (no or very slight change from existing conditions), Low / Minor (minor change from existing conditions, minor effect on population or range of the feature), Moderate / Medium (loss or alteration to key element(s) of existing conditions, moderate effect on population or range of the feature) , High / Severe (major or total loss of key element(s) of existing conditions, large effect on population or range of the feature)
Likelihood of effect: Low (< 25%), Moderate (25–75%), High (> 75%)
Level of risk: Negligible (effect too small to be discernible or of concern), Very low (discernible effect but too small to affect other receptors), Low (noticeable but will not cause any significant adverse effects), Moderate (noticeable that may cause adverse impact but could be mitigated), Significant (noticeable and will have serious adverse impact but could be mitigated)

5.4 Cumulative effects

Roper and Lindsay et al. (2018) use a definition for cumulative effects from the Canadian Environmental Assessment Agency guidelines (Hegmann et al. 1999), which state:

‘Cumulative effects are changes to the environment that are caused by an action in combination with other past, present and future human actions.’

The guidelines recommend that, in relation to the project in question, assessments of cumulative ecological effects should encompass:

- a larger (e.g. ‘regional’) area that includes effects due to natural perturbations impacting environmental components as well as other human actions
- a greater temporal range, including other past, existing and future actions
- consideration of effects on valued ecological features or attributes due to interactions with other activities and stressors
- evaluation of contributions to, and interactions with, a range of indirect effects.

In relation to cumulative effects, there are several key aspects to the proposed Akaroa Wharf project:

- direct effects and most indirect effects will be highly localised, even within Akaroa Inlet
- the demolition / construction phase will be of limited duration, with specific component activities relatively brief
- operationally, the wharf is an existing activity, and the nature, scale and intensity of its associated stressors is not projected to change significantly upon completion
- as it is being built on the same structural footprint, there will be effectively no permanent habitat displacement.

Key stressors operating in Akaroa Harbour

Among inputs to Akaroa Harbour, those from its land catchment, via streams, stormwater and direct run-off, will be of primary importance. The key water quality variables affected by these inputs are likely to be fine particulates (total suspended solids [TSS] and subsequent deposition), nutrients, and microbial concentrations (see Section 2.1). Of these, the project will contribute to TSS via the resuspension of benthic sediments and potentially some run-off from earthworks. However, these will each be very limited in scale and duration, and their effects very localised in extent. Hence, their contribution to cumulative water quality in the wider harbour will be minimal. Similarly, wastewater inputs are of concern principally for nutrients and microbial concentrations. While some nutrient release to the water column may occur from resuspended benthic sediments, the low organic carbon content of sediment samples (see Section 4.1) suggests that such release will be negligible. Furthermore, the closest wastewater outfall within the harbour is at Red House Bay, 1.5 km to the southwest, and there is little potential for spatial overlap with its discharge plume.

Other development projects and activities
The only other significant development projects within the Akaroa Harbour coastal marine area we are aware of are the Duvauchelle and Drummonds Wharf redevelopment projects. Both projects were assessed as producing no more than minor and very localised effects (Sneddon and Morrisey 2023a, 2023b). Duvauchelle Wharf is over 6 km from Akaroa, and hence discernible cumulative effects from the two projects are extremely unlikely. Although the Drummonds site is only 120 m from the Akaroa Wharf, its redevelopment is now complete, allowing it to serve vessels displaced from Akaroa Wharf. Hence, there will be no temporal overlap in construction stressors from the two projects.

Caged salmon farming is undertaken at Titoki and Lucas Bays in the outer harbour by Akaroa Salmon Ltd using floating circular pens. The operation is approximately 7 km from the Akaroa Wharf site. Effects associated with finfish farming are nutrient and organic matter inputs and some localised seabed depositional effects.

There is a diversity of marine traffic on the harbour from kayaks, sailing dinghies and personal watercraft, through recreational yachts and fishing boats, commercial tour boats and visiting cruise vessels. A proportion of this traffic, including tourism and cruise ship visits, makes direct use of the Akaroa Wharf facility.

Vessel traffic is a key component of ambient underwater noise in harbours. While construction vessels are unlikely to increase current noise levels more than marginally, construction sounds, including those from excavation and pile-driving, will be overlaid on traffic-associated sound.

Vessels operating in shallow waters can disturb harbour bed sediments via propeller wash and hull turbulence. Further direct disturbance arises from mooring and anchor chain sweep. In terms of scale, it is likely that cruise ship visits are currently the greatest contributor to vessel disturbance effects. Project traffic will add to these effects incrementally and, during construction, will displace existing wharf traffic effects at the site. However, all such disturbance will be highly localised to soft sediment areas that support no significant biogenic features.

As noted, the marine plant potentially used for the construction project will have particular risks regarding introduction of NIS to the harbour but any potential interaction with existing vessel-related vectors (via multiple separate introductions) will likely be very small.

Climate change introduces a range of potential stressors, from sea-level rise and associated changes to coastal processes, to increased storm frequency, warmer sea temperatures, acidification and marine heatwaves. There is some potential for episodic stressors such as storms to coincide with the construction project. Although such eventuality should be considered in project planning to protect against damage during stages of structural vulnerability, such events are unlikely to significantly amplify project effects as assessed. The most notable possible interaction with climate change stressors is the increased likelihood, with generally warmer waters, for the establishment of NIS from lower-latitude source areas. However, this heightened risk is applicable to all such introduction vectors and is not specific to the Akaroa Wharf project.

A summary of co-occurring background stressors for key environmental receptors in Akaroa Harbour is given in Table 12, along with the potentially contributing effects from the wharf project. Environmental receptor components have been kept necessarily broad. Partly this is because of the limited potential for spatial overlap from the highly localised impacts assessed for the wharf project. For instance, there is very little potential for compounding effects on the Akaroa Marine Reserve (as a specific receptor habitat) except through the more general medium of harbour-wide water quality. For similar reasons, catchment inputs to the harbour encompass streams, stormwater and general run-off from land.

The principal mitigating aspect limiting the cumulative effects from the longer-term operation of the wharf is that it is an existing activity that is expected to change no more than incrementally with the establishment of the new structure. The wharf is already a focal point for Akaroa's commercial and recreational marine activity.

Table 12. Summary of effects from key stressors that may co-occur and potentially interact with identified wharf project stressors and effects. ZOI = zone of influence – the spatial area beyond which project stressors are considered to contribute negligibly to cumulative effects. NIS = non-indigenous species. NA (shaded) = not applicable.

	Co-occurring inputs, activities and stressors					Akaroa Wharf project		
Environmental component	**Catchment run-off**	**Wastewater discharges**	**Direct disturbance**	**Climate change**	**Finfish aquaculture**	**Contribution or interaction**	**Spatial ZOI**	**Duration**
Water quality	Suspended fine sediment Nutrients	Toxicants Nutrients Algal blooms	Sediment resuspension	Marine heatwaves	Nutrients	Sediment resuspension Contaminant release	French Bay	Construction
Sediment quality and communities	Sedimentation Increase in fine component Contaminant accumulation	Organic enrichment Contaminant accumulation Nuisance macroalgae	Propeller wash Mooring chain sweep Vessel anchors	NIS establishment (conditions suit warm-water species)	Local organic enrichment Nuisance macroalgae	Piling works	Structural footprint	Construction
						Propeller wash	Wharf-adjacent (< 100 m)	Indefinite
						Plume deposition	French Bay	Indefinite
						NIS introduction	Whole harbour	Indefinite
Intertidal habitat	Stormwater outfalls / discharge	Organic enrichment Nuisance macroalgae	Recreational activities Kaimoana harvest	Increased storm surge, erosion Desiccation NIS establishment	Nuisance macroalgae	Excavation	Wharf-adjacent (< 100 m)	Construction
						Plume deposition	French Bay	Construction
						NIS introduction	Whole harbour	Indefinite
Subtidal reef habitat	Turbidity Sedimentation	Nuisance macroalgae	Kaimoana harvest	Macroalgal die-back NIS establishment	Nuisance macroalgae	NIS introduction	Whole harbour	Indefinite
Ambient underwater sound	NA	NA	Vessel traffic	NA	Vessel traffic On-water plant	Piling, excavation and construction noise	Akaroa Inlet to central harbour region	Construction
						Operational noise	Akaroa Inlet	Indefinite

Main findings and summary of risks

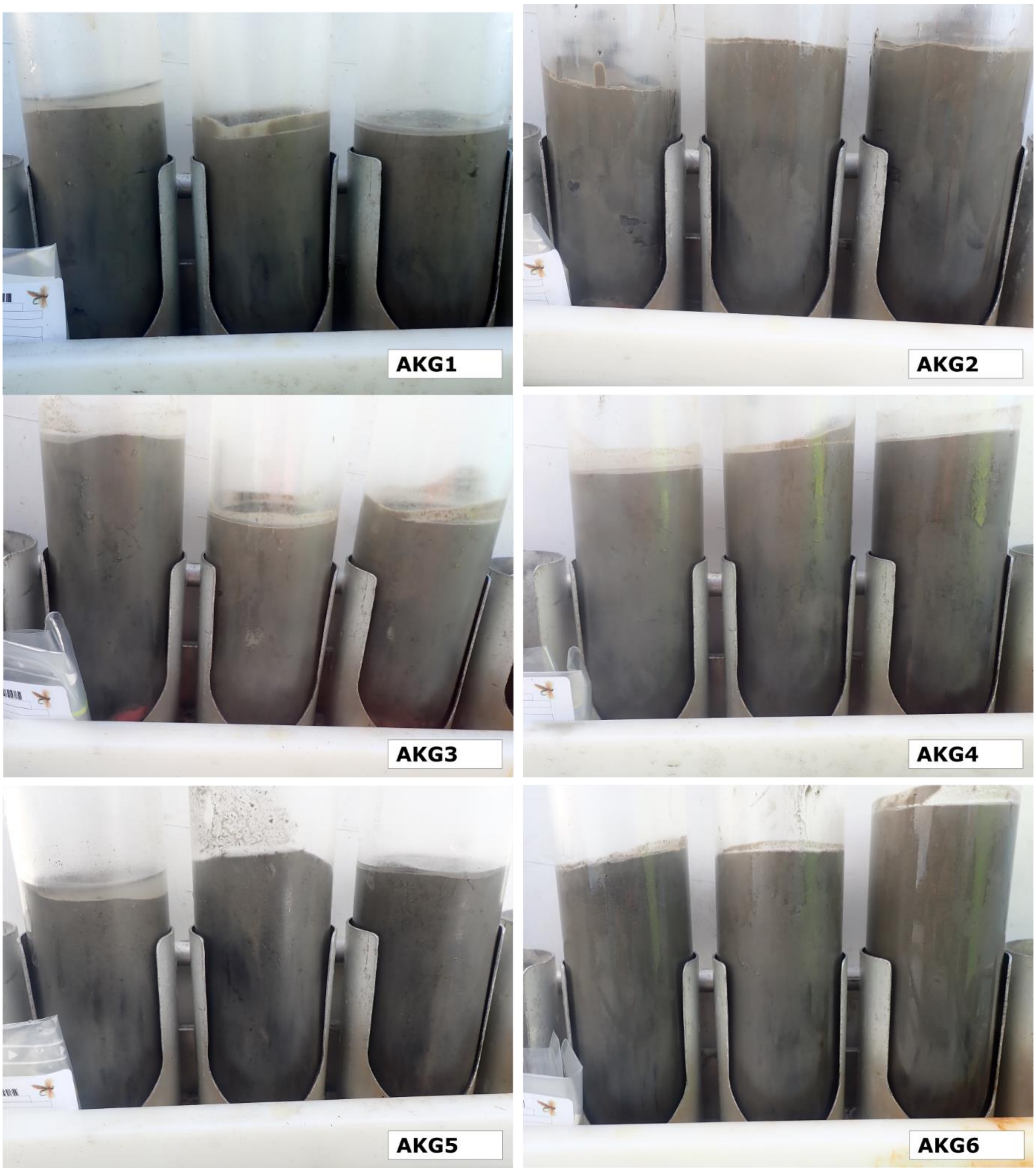
- The demolition and construction activities will occupy a small spatial footprint relative to Akaroa Inlet and will be of limited duration. Direct disturbance of the seabed is unlikely to exceed the wharf's structural footprint by more than tens of metres.
- Indirect effects (from propagation of turbidity plumes) are likely to extend no more than low hundreds of metres from the site. Plumes are not anticipated to exceed natural resuspension events in severity / magnitude except very close to the source.
- Effects on benthic communities from underwater noise, if any, will be transitory. Fish may avoid the area of Akaroa Inlet during piling works but will return soon after cessation of the activity.
- No high-value or at-risk habitats or taxa and no significant kaimoana resources have been identified within the expected zone of influence from the activities.
- Potential introduction of NIS via construction equipment represents the greatest risk to marine ecological receptors, but this can be effectively mitigated with suitable controls during the project.
- Akaroa Wharf is an existing facility, and a replacement wharf of similar structure and function is unlikely to materially change the nature or intensity of its usage over the longer term. Therefore, the ecological effects from its presence within Akaroa Inlet will be similarly little altered.
- The spatial scale and duration of effects from the project are such that, when considered with existing stressors within the harbour environment, no significant increase in cumulative effects was identified.

6. Appendices

Appendix 1. Specifications for sediment physicochemical analyses (Hill Laboratories Ltd, Hamilton)

Analyte	Method number	Description
Sample preparation		Air-dried at 35 °C and sieved, < 2 mm fraction. May contain a residual moisture content of 2–5%.
Particle grain size	Hill Lab in-house method	Wet sieved through screen sizes: > 2 mm = Gravel < 2 mm to > 1 mm = Coarse Sand < 1 mm to > 500 µm = Medium Sand < 500 µm to > 250 µm = Medium / Fine Sand < 250 µm to > 125 µm = Fine Sand < 125 µm to > 63 µm = Very Fine Sand < 63 µm = Mud (Silt and Clay) Size classes from Udden–Wentworth scale.
Total organic carbon		Acid pretreatment to remove carbonates present followed by catalytic combustion (O_2), separation, thermal conductivity detector [Elementar Analyser].
Trace metals / metalloids (total recoverable)	USEPA 200.2	Dried sample sieved as specified (if required). Nitric / hydrochloric acid digestion. Detected by ICP-MS, trace level.

Appendix 2. Photographs of sediment cores extracted from benthic grab samples



Appendix 3. Subtidal photographs from the vicinity of Akaroa Wharf

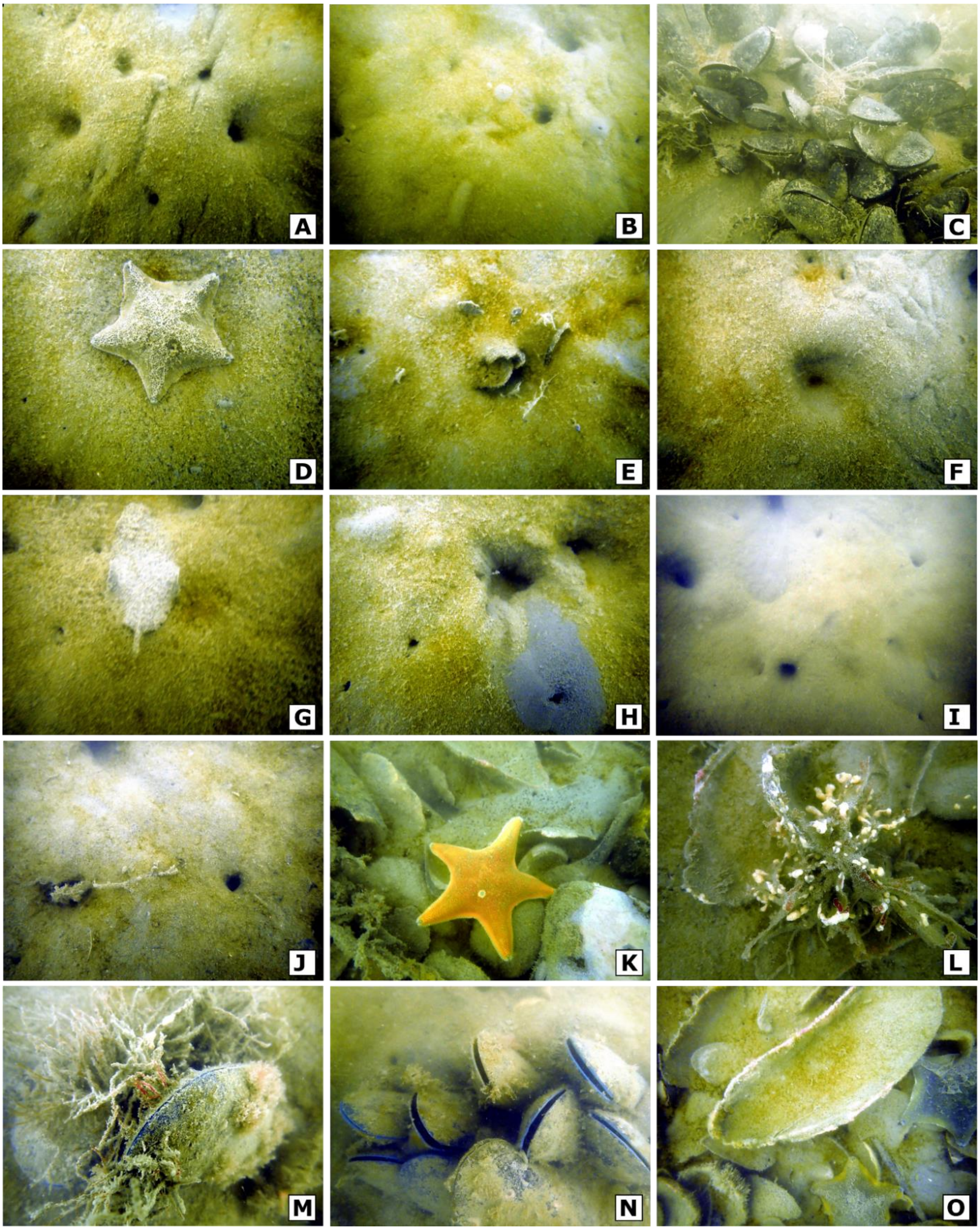


Figure A3.1. Benthic habitat in offshore soft sediment areas. Dive sites AKD1 (A–E) and AKD2 (F–H) (both water depth 5.4 m MSL) and AKD3 (I, depth 4.7 m MSL). Area of vessel scour at dive site AKD4 (J–O, water depth 4.5 m MSL).

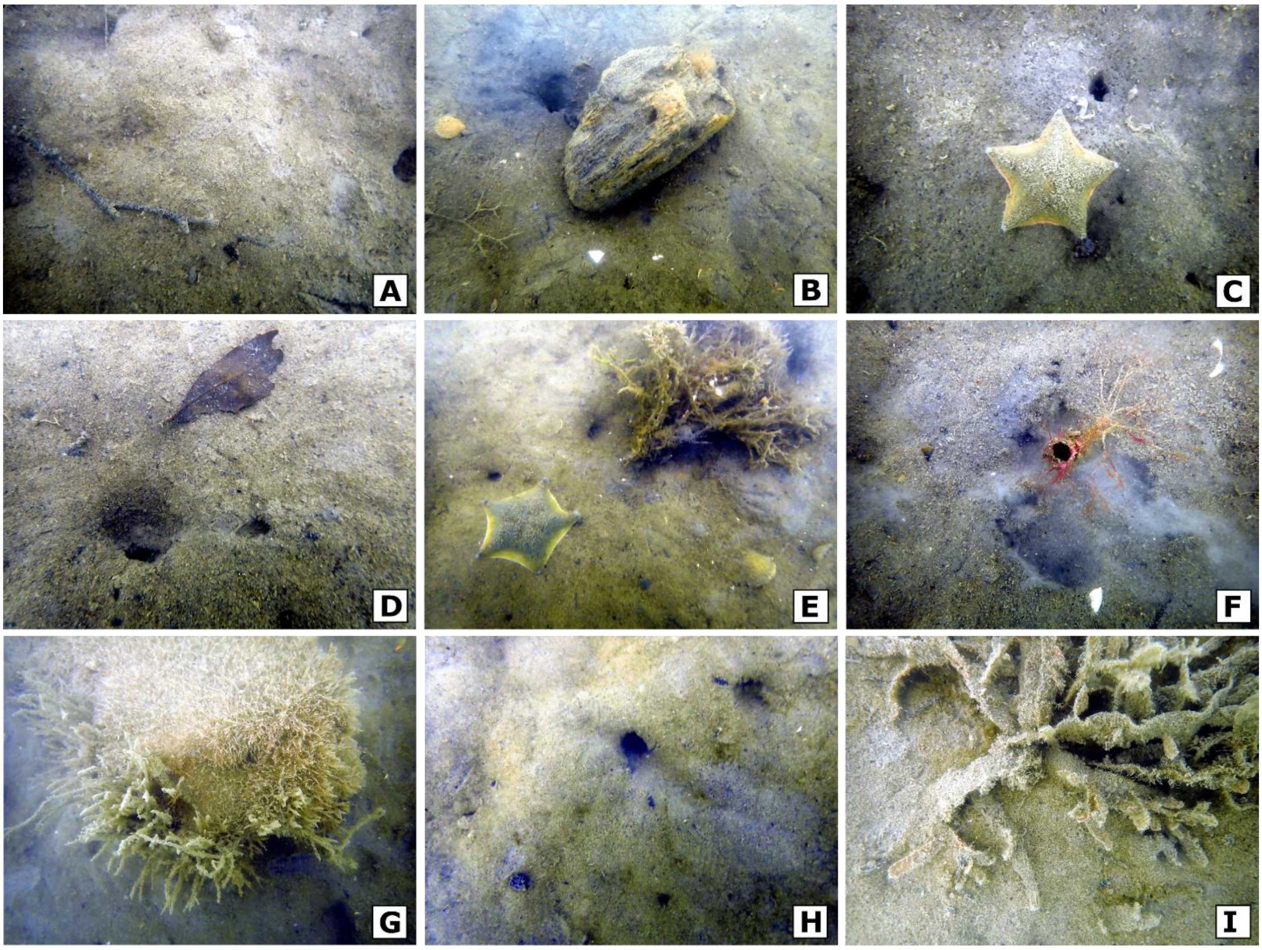


Figure A3.2. Benthic habitat in inshore soft sediment areas. Dive stations AKD5 (A–F, water depth 2.7 m MSL) and AKD6 (G–I, water depth 3.0 m MSL).

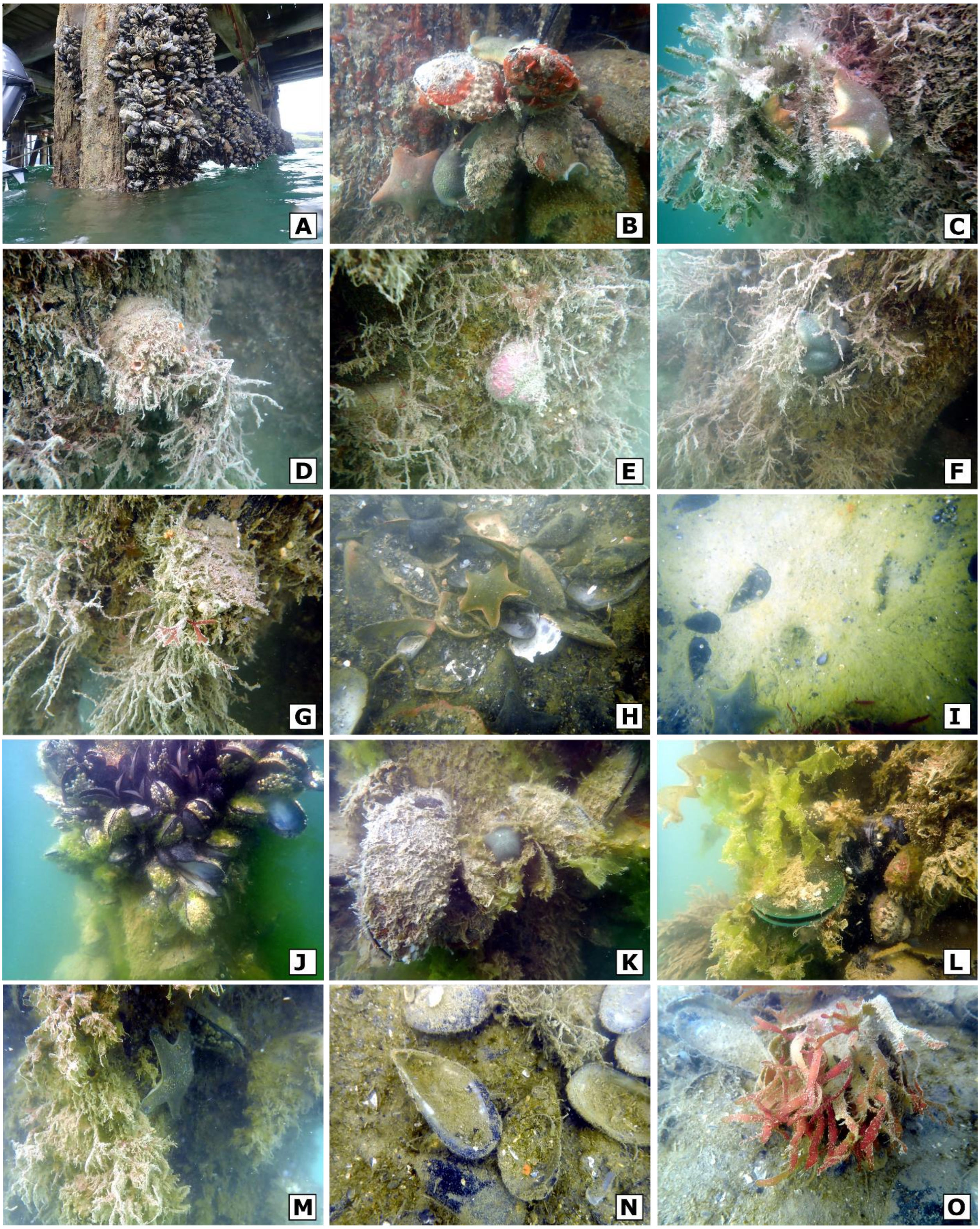


Figure A3.3. Encrusting biota on wharf piles and benthic habitat at pile base. Dive stations AKD7 (descending A–I, water depth 3.2 m MSL) and AKD8 (descending J-–O, water depth 2.8 m MSL).

Appendix 4. Intertidal quadrat photographs from the shoreline transects on either side of Akaroa Wharf.

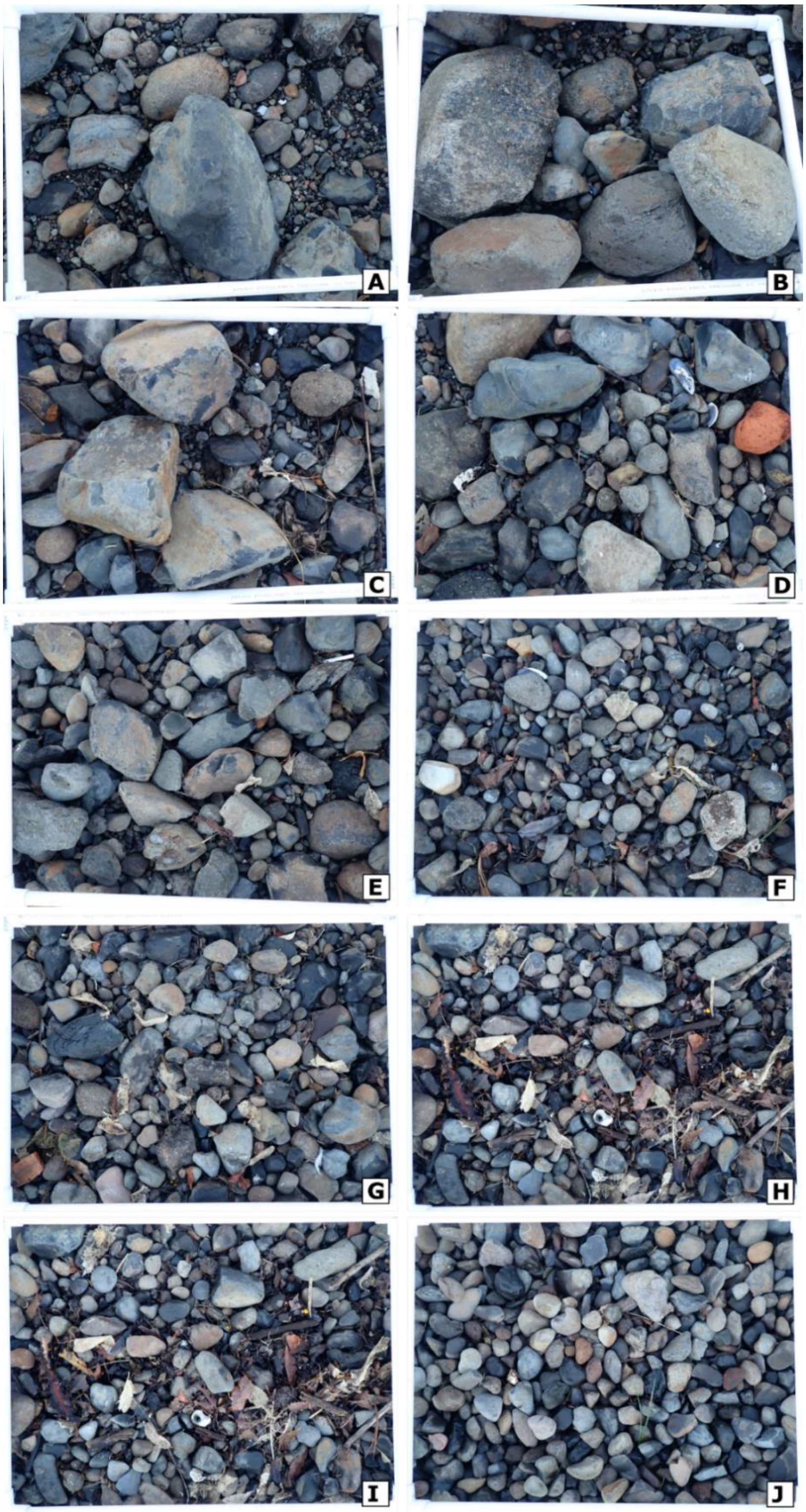


Figure A4.1. High-tide transect AKT1. Sequence south to north.

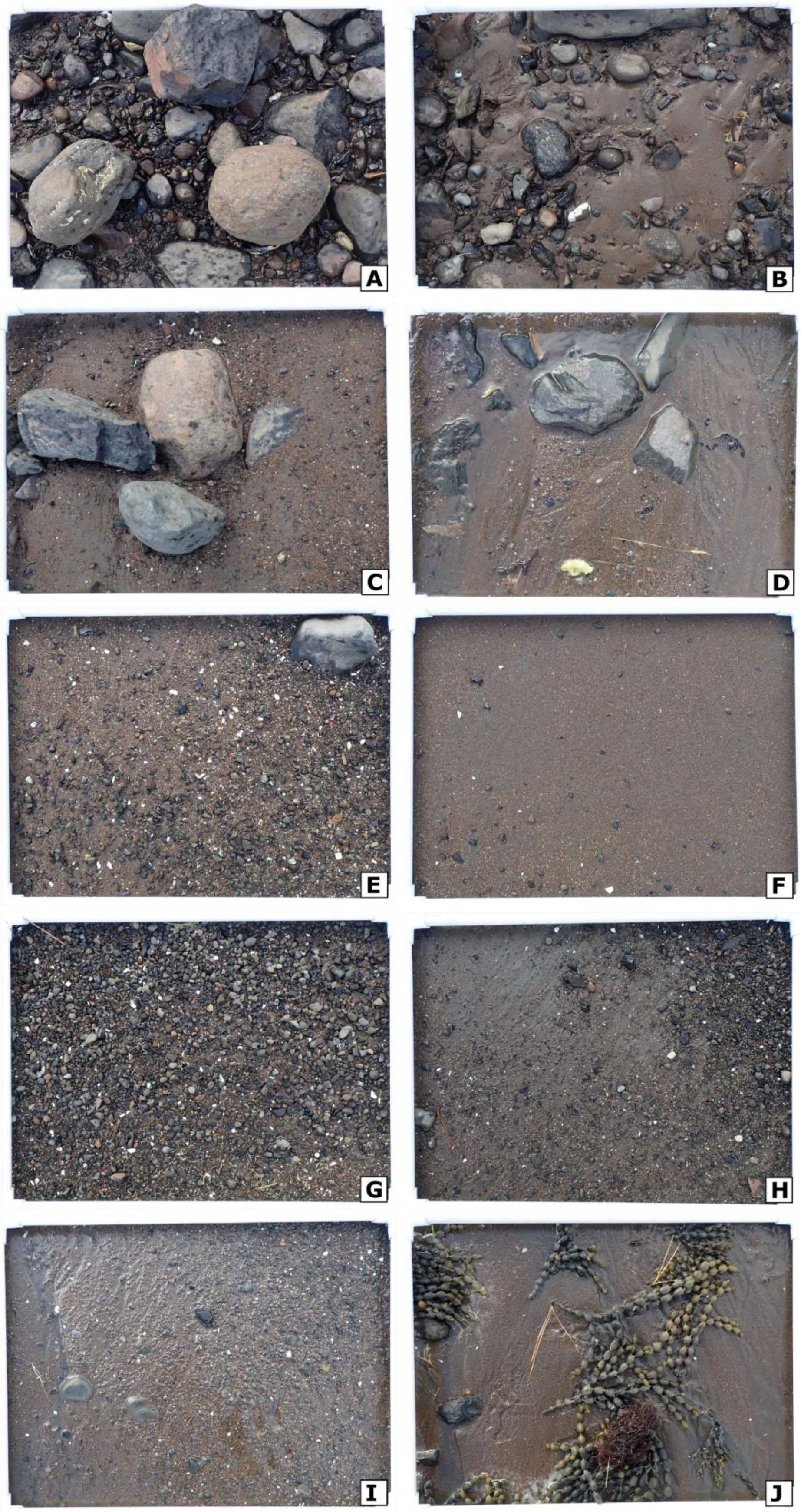


Figure A4.2. Mid-tide transect AKT1. Sequence south to north.

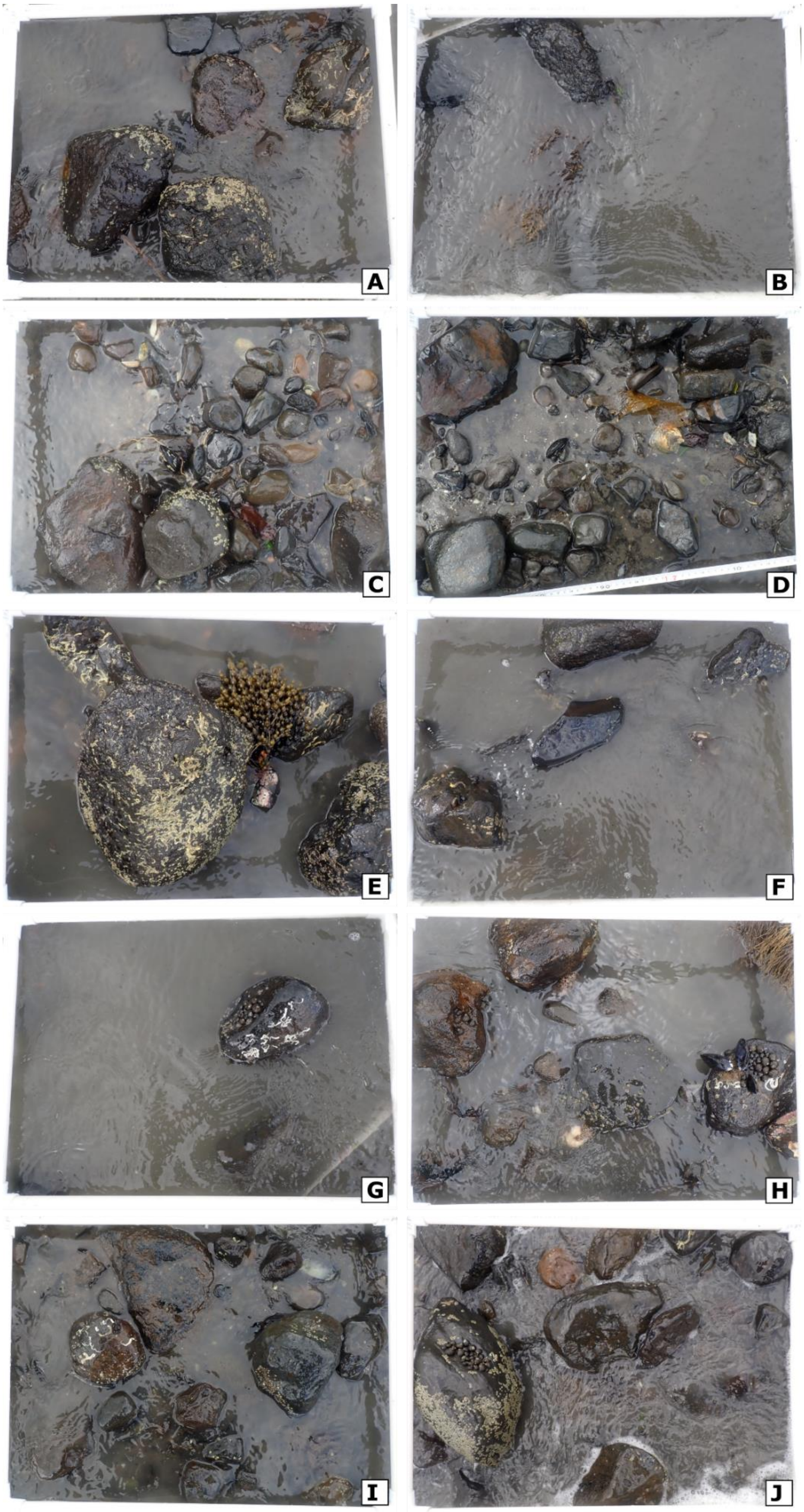


Figure A4.3. Low-tide transect AKT1. Sequence north to south.

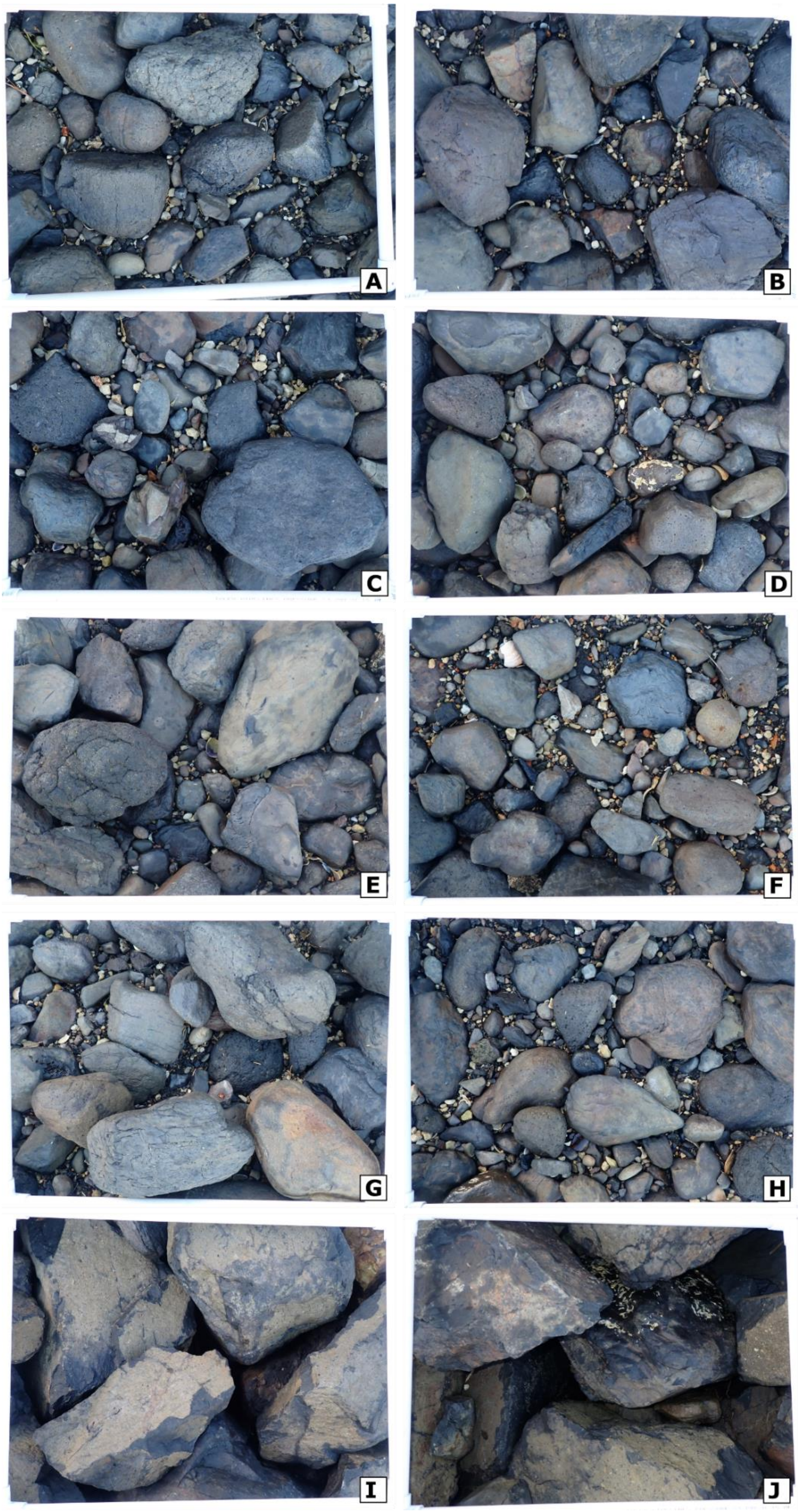


Figure A4.4. High-tide transect AKT2. Sequence north to south.

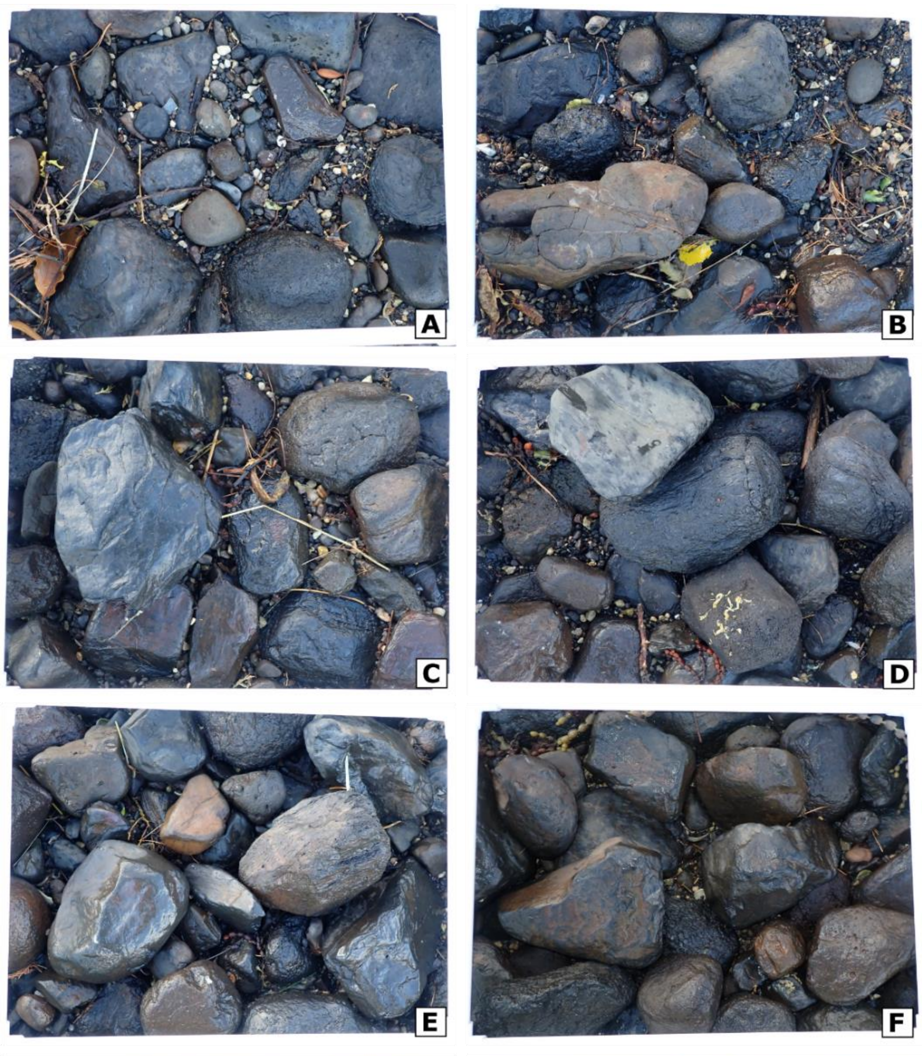


Figure A4.5. Mid-tide transect AKT2. Sequence north to south.

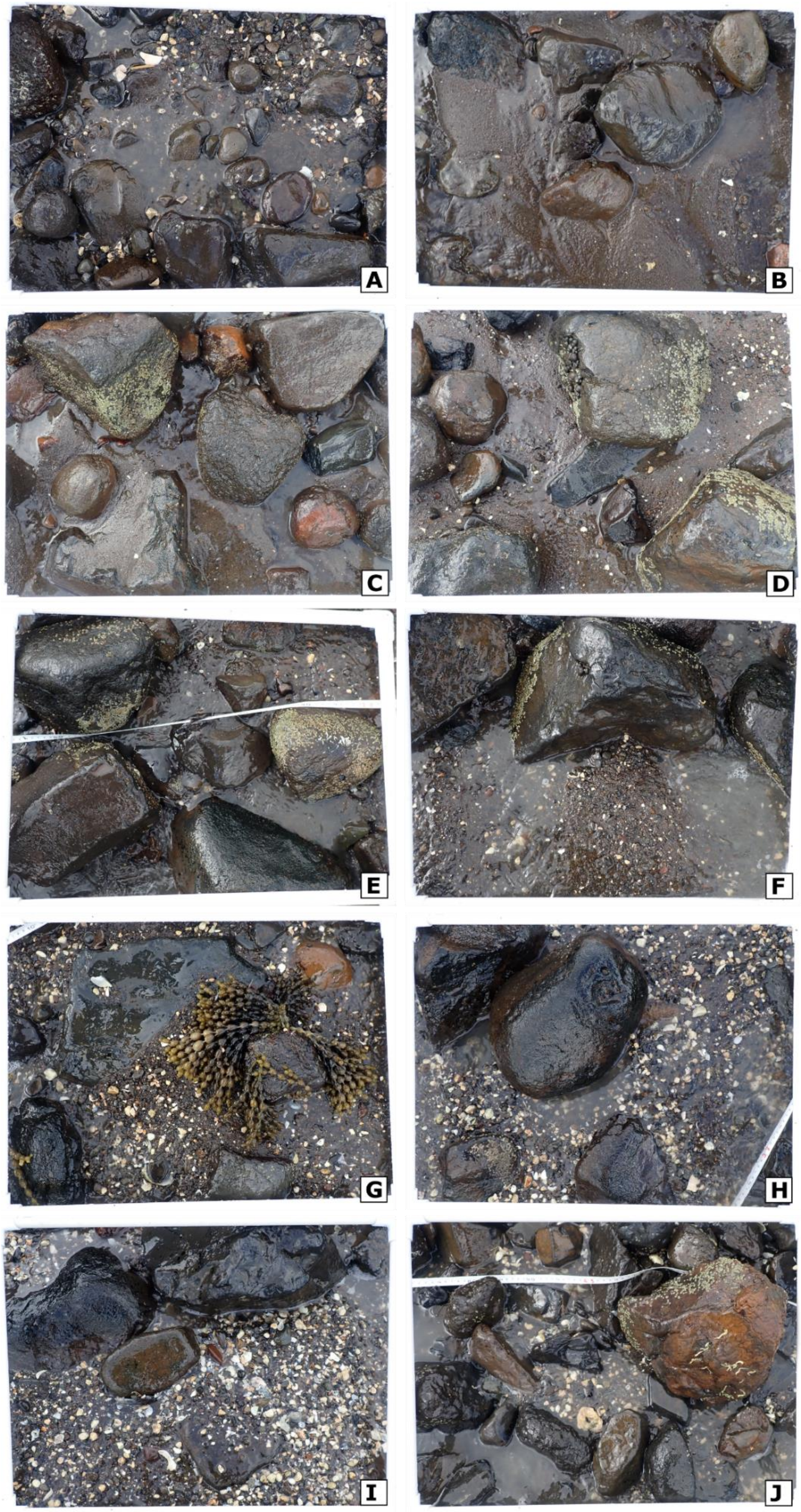


Figure A4.6. Low-tide transect AKT2. Sequence north to south.

7. Acknowledgements

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