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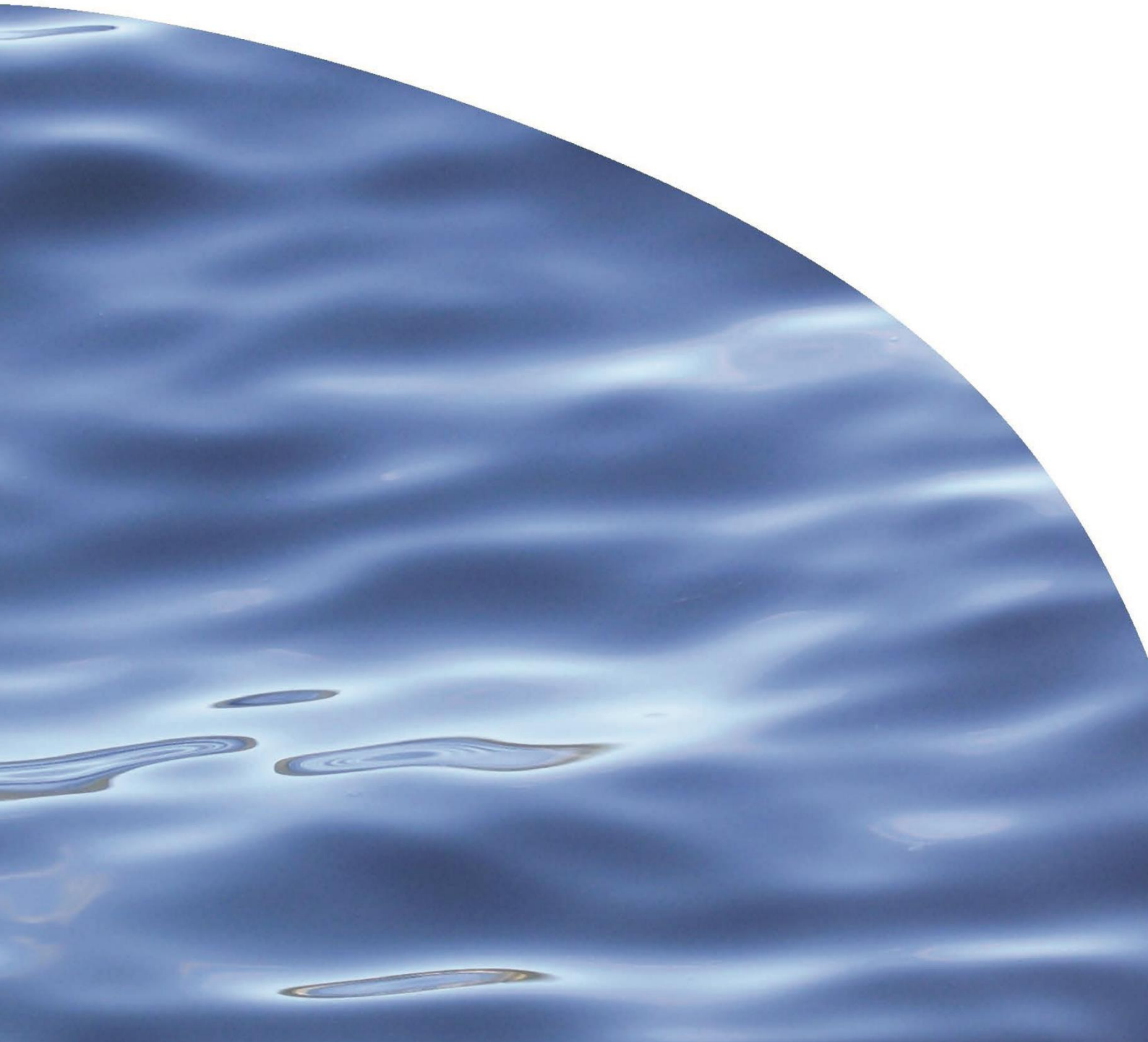
ASSESSMENT OF DIRECT MARINE ECOLOGICAL EFFECTS FROM COAL DUST



ASSESSMENT OF DIRECT MARINE ECOLOGICAL EFFECTS FROM COAL DUST

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EXECUTIVE SUMMARY

Lyttelton Port Company (LPC) manages a coal stockyard at Te Awaparahi Bay in Lyttelton Harbour. The stockyard processes generate coal dust particulates, which become airborne with the potential for adverse ecological effects to the surrounding marine coastal areas. LPC's discharge permit (CRC940431) for the dust generated from the coal stockyard, expires in February 2022. To inform their re-consenting application, LPC have requested that Cawthron provide a targeted assessment (both under the current coastal conditions and following the completion of adjacent reclamation activities) of marine ecological effects (AE) from coal-yard dust deposition on the adjacent marine coastal area, with specific focus on the direct effects on the benthos, water quality and mahinga kai.

The deposition of coal dust from the LPC coal stockyard on the sea surface is predicted to occur most notably in the immediate vicinity of the coal yard (< 1.5 km). The direct potential effects of this deposition considered in this assessment (with specific reference to mahinga kai values included) were 1) changes to the coastal water physicochemistry (including increased total suspended solids and turbidity) and 2) changes to sediment physicochemistry. In both cases there was predicted to be, at worst, a **very low** risk of having a **very low** level of effect from the deposition of coal dust to the sea surface, within the immediate area of interest, with little evidence of effects further afield. As the potential direct effects are predicted to be less than minor, the potential indirect effects were not considered further in this assessment.

It is expected that under most circumstances, the future reclamation activities in Te Awaparahi Bay (managed under a separate consent) will act as a barrier between the coal stockyard and the coastline, resulting in a net reduction in the amount of coal dust deposited directly to the marine environment. It's likely that any coal dust deposited in the reclaimed area will be adequately managed and monitored through a treated stormwater system. Given this, the likelihood and magnitude of any water related physicochemical effects, following completion of the reclamation, are also expected to reduce.

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1. INTRODUCTION

Lyttelton Port Company (LPC) manages a coal stockyard (est. 1976) at Te Awaparahi Bay in Lyttelton Harbour (Figure 1). The stockyard processes generate coal dust particulates, which become airborne with potential for adverse ecological effects to the surrounding marine coastal areas. Dust is generated primarily from wind blowing across coal particulates, most notably the coal stockpiles; but also from vehicle movements and other yard activities. The later including, unloading, stacking/ removing/shaping stockpile coal with front-end loaders and bulldozers, conveyor transport, and ship transfers.

LPC currently hold a discharge permit (CRC940431) for the dust generated from the coal stockyard, however the permit expires February 2022. To inform their re-consenting application, LPC have requested that Cawthron provide a targeted assessment of marine ecological effects (AE) from stockyard dust deposition on the adjacent marine coastal area. As requested, the assessment has specific focus on the direct effects on the benthos (the seabed and its communities), water quality and mahinga kai, with respect to 1) the current coastal conditions and 2) following completion of the adjacent Te Awaparahi Bay reclamation (Figure 1). This report presents the findings of the investigation, following the desktop approach described below (further detail provided in the preceding project-scoping and information-gap exercise, Johnston 2020).

LPC wishes to seek a renewal of its current air discharge permit for a duration of 20 years. At present, LPC does not have any planned changes for the stockyard layout or infrastructure and therefore other processes associated with the activity are not expected to change.

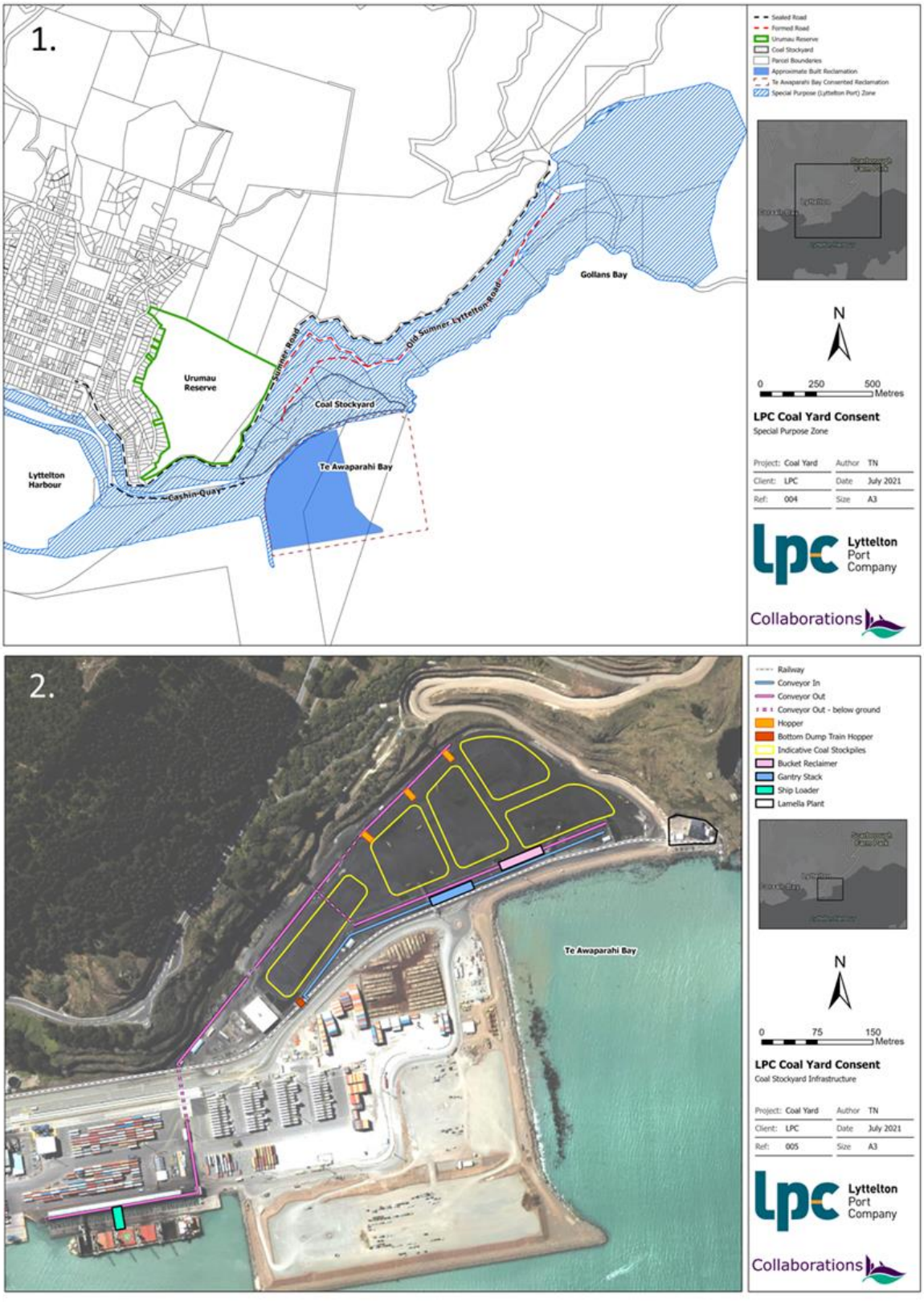

Figure 1. 1) The LPC Coal Stockyard's location within the Lyttelton Port Special Purpose Zone, with polygon (dashed lines) representing the future Te Awaparahi Bay reclamation area. 2) Recent aerial image of the Coal Stockyard components and reclamation. Images source: LPC, July 2021.

2. ASSESSMENT METHOD

Following recommendations in the New Zealand Ecological Impact Assessment Guidelines (EIAG 2018), the potential effects, gaps in information and project approach were identified through an early scoping[1] phase, via a technical memo (Johnston 2020). Using this approach, the focus of this AE is direct benthic, water quality and mahinga kai effects, with indirect effects only to be assessed if there was/is a high potential of a direct (causal) effect occurring (Johnston 2020).

Given the breadth of existing monitoring information in the immediate coastal area, a predominantly desk top-based investigative approach, with focused chemistry and fate-related investigations, was identified in the memo as being appropriate for this AE (Johnston 2020). The findings are summarised in the following sections.

2.1. Information review

Various information sources (targeted investigations and monitoring reports) were reviewed to obtain background information on the characteristics and behaviour of coal dust and the Lyttelton Harbour receiving environment (in terms of the benthos, water column and mahinga kai). In order to understand the potential direct effects to these features, literature that described effects from coal, either in Lyttelton Harbour, in New Zealand, or internationally, was reviewed. The findings were used to inform the effects assessment component of this report (Section 6).

The literature review showed an extensive array of marine ecological information sources in the vicinity of the LPC coal stockyard, with numerous past and current monitoring stations. Of particular relevance to this assessment is the 5-yearly LPC coal stockpile stormwater effects monitoring (Barter 2003; Conwell 2008; Sneddon 2014d, 2019a). The monitoring includes collection of shellfish for bioaccumulation (tissue) tests, and sediment for determining physicochemical characteristics (grain size, total organic carbon, total petroleum hydrocarbons, polycyclic aromatic hydrocarbons, metals/metalloids and coal content estimates). The majority of the sampling stations are located to the southwest and the east of the coal stockyard, along a transect parallel to the stormwater outfall location (~500 m from the shoreline), with control sites located further east.

Other relevant marine ecological investigations carried out by Cawthron for LPC over the last 20+ years relate to capital and maintenance dredging, cruise berth development, inner harbour sediment contaminant status and land reclamation (e.g.

[1] A preliminary ecological assessment at the early planning stage that formed the basis for selecting those valued ecological resources to be subject to detailed assessment due to potentially serious impacts. The preliminary assessment also allowed for early identification of impact strategies. The results of scoping often feed into "project shaping" where project design is reviewed and possibly modified (EIAG 2018).

Gillespie et al. 1992; Gillespie & Asher 1995; Barter 2000a, 2000b; Keeley & Barter 2001; Barter 2003; Thompson & Barter 2005; Bennett & Sneddon 2006; Conwell 2008; Barter 2009a, 2009b; Sneddon 2009; Sneddon & Barter 2009; Sneddon 2010b, 2010a, 2010c, 2010d; Sneddon & Baily 2010; Sneddon 2011a, 2011b, 2011c, 2012, 2013b, 2013a; Floerl et al. 2014; Sneddon 2014d, 2014c, 2014b, 2014a; Sneddon & Dunmore 2014; Sneddon 2015; Sneddon et al. 2015; Sneddon 2016; Sneddon et al. 2016; Sneddon 2017; Sneddon & Floerl 2017; Sneddon 2019b, 2019a, 2020). These data have been used to address the benthic and water quality effects of potential dust deposition in the more developed port area. As well as this, there are a number of peer-reviewed papers available that have specifically studied the biological effects of unburnt coal in the marine environment (Ahrens & Morrisey 2005; Shanchez 2014; Berry et al. 2016). Together, the compiled ecological data and studies adequately characterise the marine receiving environment in the vicinity of the coal stockyard, and provide necessary context for this assessment.

The literature review identified the need for information relating to the spatial extent and concentrations of coal dust in the marine receiving environment. To address this gap, depositional modelling (airborne and hydrodynamic) and/or sediment tracer studies can be useful. For this assessment, estimates of the spatial extent of the initial coal dust deposits to the sea surface were provided through airborne depositional modelling and physical coastal dust monitoring stations (Chilton draft 2021). To better understand the hydrodynamic behaviour of the dust once it is deposited on the sea surface, a simulated coal dust sample was created from the LPC coal stockyard and the water column was tested to obtain coal dust settling velocities. The settling velocities and coal densities were then used with past dispersal modelling data generated for the Te Awaparahi Bay area by Met Ocean Solutions Ltd (2017) who provided some broad predictions on the spatial extent of coal dust particles once deposited on the sea surface (MetOcean 2021). A comparable investigation tracking coal dust particles in China, was also reviewed for context (Yao et al. 2016).

There was also a lack of information relating to the specific coal dust chemical/contaminant composition and potential water quality effects, with only limited data available for the coal stockyard stormwater composition to draw from. To address this, an elutriate test of a representative coal dust sample was performed by RJ Hill Laboratories (Appendix 1). Based on the coal dust toxicity investigative approach recommended by Ahrens and Morrisey (2005), coal chemistry and toxicant bioavailability is the first tier of assessment. If the coal toxicants are deemed to be biologically unavailable at this initial tier, then further investigation[2] of coal dust toxicity effects is not deemed necessary.

[2] Tiers of investigation for coal dust effects, as identified by Ahrens and Morrisey (2005): 1) coal chemistry and bioavailability, 2) bioaccumulation (tissue burden) testing, 3) ecotoxicity testing and 4) population and assemblages in the receiving environment.

Further to the assessment approach described in Johnston (2020) it was requested that this effect assessment include effects to the current receiving environment (pers. comm., Gareth Taylor, 22 February 2021), and the environment following the conclusion of reclamation activities (which is expected to be completed in the following couple of years). Each of these receiving environment scenarios is described in Section 4.

2.2. Identification of potential direct marine ecological impacts

The ecological impacts that were identified through the scoping process (Johnston 2020) and which are targeted in this AE (with respect to the benthos, water column and mahinga kai) involve direct changes to water and seabed physicochemical characteristics (e.g. increased turbidity, suspended solids, smothering potential, and contaminants). Considerations relating to each of these potential effects has been described as part of a comprehensive review on the biological effects of unburnt coal in the marine environment by Ahrens and Morrisey (2005).

Other resulting indirect effects (e.g. potential ecotoxic effects, and changes to species distribution/community composition) were only to be assessed in detail if there was a high potential of a direct effect occurring.

2.3. Risk assessment

Ecological risk was assessed using principles from Burgman (2005) and the Ecological Impact Assessment Guidelines (EIAG 2018). Both approaches consider the magnitude or consequence of an activity, but EIAG (2018) places the emphasis on potential risk to threatened habitats and taxa, whereas the Burgman (2005) approach focusses more on the likelihood of the effect actually occurring. When considered in unison the two results can be complementary. Both the Burgman (2005) and EIAG (2018) approaches to risk assessment include a measure of confidence in the data used.

To determine if any threatened habitats and taxa (referred to by EIAG as ‘determining factors’ for assessing species/habitat value) were present in the vicinity of the coal stockyard, previous monitoring findings were reviewed and a representative subtidal and intertidal species list was compiled from five different area of interest (AOI[3]) surveys (Handley et al. 2000; Fenwick 2003; Sneddon & Barter 2009; Sneddon 2011b; Sneddon & Dunmore 2014). This list was cross-referenced with relevant conservation status reports (Freeman et al. 2013; Nelson et al. 2019). As well as this, potentially significant mahinga kai species/habitats within the AOI were identified and

[3] See text box at end of Section 3.3 for AOI description.

their presence/absence were used as an equivalent[4] EIAG 'determining factor,' for assessing species/habitat value. The 'value' of taxa and habitats, 'magnitude' of effects, and 'risk to ecological values', was determined using EIAG (2018) value methods (Table 1). The spatial scale/extent of effects, and the persistence/duration of the effect were first considered to help determine appropriate values for 'consequence' and 'likelihood' (Burgman 2005).

[4] Equivalent to threatened habitats and taxa 'determining values'.

Table 1. Modified definition tables for assigning, value, magnitude and overall risk, EIAG (2018).

Value	Species/taxa - determining factors
Very high	Nationally threatened – critical or vulnerable
High	Nationally at risk – declining
Mod–high	Nationally at risk – recovering, relict or naturally uncommon
Moderate	Locally uncommon/rare, not nationally threatened or at risk
Low	Not threatened nationally, locally common indigenous species
Negligible	Exotic species, including pests, species having recreational value

Value	Habitat - determining factors
Very high	Supporting more than one national priority type*
High	Supporting one national priority type or naturally uncommon ecosystem
Moderate	Locally rare or threatened, supporting no threatened or at-risk species
Low	Nationally and locally common, supporting no threatened or at-risk species

** The principles of Protecting Our Places (MfE 2007) National Priorities.*

Magnitude	Description
Very high	Total loss of, or very major alteration to, key elements/features of the existing baseline conditions, such that the post-development character, composition and/or attributes will be fundamentally change and may be lost from the site altogether; AND/OR loss of a very high proportion of the known population or range of the element/feature.
High	Major loss or major alteration to key elements/features of the existing baseline conditions such that the post-development character, composition and/or attributes will be fundamentally changed; AND/OR loss of a high proportion of the known population or range of the element/feature.
Moderate/ medium	Loss or alteration to one or more key elements/features of the existing baseline conditions, such that the post-development character, composition and/or attributes will be partially changed; AND/OR loss of a moderate proportion of the known population or range of the element/feature.
Low/minor	Minor shift away from existing baseline conditions. Change arising from the loss/alteration will be discernible, but underlying character, composition and/or attributes of the existing baseline condition will be similar to pre-development circumstances or patterns; AND/OR having a minor effect on the known population or range of the element/feature.
Negligible	Very slight change from the existing baseline condition. Change barely distinguishable, approximating to the 'no change' situation; AND/OR Having negligible effect on the known population or range of the element/feature.

Level of effect (M x E)		**Ecological Value (E)**				
		Very high	High	Moderate	Low	Negligible
Magnitude (M)	Very high/severe	Very high	Very high	High	Moderate	Low
	High	Very high	Very high	Moderate	Low	Very low
	Moderate/medium	High	High	Moderate	Low	Very low
	Low/minor	Moderate	Low	Low	Very low	Very low
	Negligible	Low	Very low	Very low	Very low	Very low
	Positive	Net gain	Net gain	Net gain	Net gain	Net gain

Level of effect	Effect range terminology
Nil	Nil effects
Very low	Less than minor adverse effects
Low	Minor adverse effects
Moderate	More than minor adverse effects
High	Significant adverse effects that could be remedied or mitigated
Very high	Unacceptable adverse effects

Table 2. Spatial scale, persistence, likelihood (L), consequence (C), risk (L x C) and confidence definitions (derived from Burgman 2005).

Spatial scale	Distance from discharge source
Extensive	10 km +
Large	2–10 km
Medium	500 m–2 km
Localised	10–500 m
Immediate vicinity	< 10 m

Persistence/duration	Timeframe
Indefinite recovery, even if stopped	10 years +
Long-term recovery if stopped	Years
Moderate recovery if stopped	Months
Rapid recovery if stopped	Days
Temporary	Hours

Level	Likelihood	Likelihood (%)	Description
1	Certain	100%	Will occur
2	Likely	50–99%	Likely to occur
3	Possible	25–50%	Uncommon but possible
4	Unlikely	1–25%	Occurring in exceptional circumstances
5	Remote	< 1%	Highly unlikely to occur

Level	Consequence	Effects
1	Catastrophic	Local extinction, ecosystem collapse
2	Massive	Regional and long-term adverse impacts
3	Major	Regional medium-term adverse impacts
4	Moderate	Local medium-term adverse impacts
5	Minor	Local short-term adverse impacts
6	Negligible	No detectable adverse effects

Level	Risk	Definition
1–2	Extreme risk	Unacceptable
3–4	High risk	Manageable using measures to avoid remedy of mitigate
5–9	Medium risk	Acceptable using measures to avoid remedy of mitigate
10–16	Low risk	Acceptable with less than minor impacts anticipated
17–30	Very low risk	Negligible with no impacts

Confidence	Definition
Low	No data - lack of data, relies on expert judgement
Medium	Combination of existing data and expert judgement
High	Based on monitoring data and expert judgement

2.4. Assessment limitations

This assessment is specifically targeted towards direct effects to the seabed, water column and mahinga kai. Only the primary ecological characteristics of the water column and the benthos relating to this have been included in this assessment (Section 4). Other ecological characteristics/influences that have potential for indirect influences, or were addressed in other assessments, were outside of the project scope and have not been included in this assessment, e.g. seabirds, marine mammals, climate change, or in-depth fisheries assessments.

It is my understanding that the mahinga kai findings of this assessment (Section 4.6) were discussed between Gareth Taylor (LPC) and Te Hapū o Ngāti Wheke on 23 June 2021. The questions from Te Hapū o Ngāti Wheke relating to this assessment were addressed during this meeting (pers. comm., Gareth Taylor, 29 June 2021).

3. COAL DUST DESCRIPTION

The causes of the coal stockyard dust, other sources of contamination and disturbance to the receiving environment, and the general characteristics of the coal dust being deposited are discussed in the following sections.

3.1. Activities causing the coal dust dispersal

The major sources of particulates at the existing coal stockyard and ship loading facilities have been identified as being from:

1. windblown dust from coal stockpiles, roads and stockyard areas
2. unloading coal into the receival hopper from the wagons and from the gantry stacker
3. stacking and removing of coal onto the stockpiles using front-end loaders and shaping of stockpiles using bulldozers
4. removing of coal from the stockpiles using a bulldozer and front-end loaders and placing in the load-out hoppers for conveyance to a ship
5. transporting coal on the conveyors, and
6. transferring coal onto the ship.

3.2. Other contaminant and disturbance sources

Lyttelton Port (Inner Harbour and immediate Outer Harbour, extending west along the coastline as far as Gollans Bay) is an established Port Operational Area, and is classified as a ‘Special Purpose Zone’. As might be expected, the area has a heavily modified marine environment with a number of anthropogenic activities and potential contaminant and disturbance sources. These activities are outlined in Table 3.

Table 3. Summary of other activities potentially contributing to the presence of contaminants and disturbance in the vicinity of the Lyttelton Port Company (LPC) coal stockyard.

Activity	Description
Coal stockyard stormwater	The coal stockyard also contributes coal particulates via treated stormwater, together with untreated hillside stormwater, discharged into the coastal water at Te Awaparahi Bay. This is managed under the consent CRC960549 and is monitored on a 5-yearly basis (physicochemistry of sediments and tissues from shoreline mussels) and the next survey is due in 2024.
Cashin Quay and cruise berth upgrades and operation	The wharf at Cashin Quay has undergone a number of earthquake repairs and upgrades since 2011. It is noted that some reference to coal particulate contamination was made in this location (notably, the eastern end of Cashin Quay), perhaps resulting from coal losses occurring during ship loading. The cruise berth is located on the eastern side of the Inner Harbour entrance beside Cashin Quay, spanning 148 metres long by 10 metres wide. There were two components of construction: 1) landside works began in July 2018 and 2) wharf construction in 2019; completion of the berth was November 2020.
Capital dredging (The Channel Deepening Project)	The areas directly adjacent Cashin Quay and in close proximity to Te Awaparahi Bay have been dredged as part of the wider Lyttelton Harbour channel deepening project. This process can be assumed to have removed a portion of the long-term deposited coal dust (if any) from the seabed in close proximity to the coal stockyard. In the first stage of this project (completed in 2018) the existing shipping channel adjacent to Cashin Quay was lengthened by approximately 2.5 km, widened by 20 metres and deepened by up to 2 metres. The channel now allows all-tide access for ships with a 14.5m draught. The dredged sediment was relocated to a designated 2.5 x 5 km spoil ground located approximately 5 km off Godley Head. The second stage (still to be completed) involves deepening and extending the channel further seawards.
Maintenance dredging	Maintenance dredging of the main navigation channel and the areas where ships berth and maneuver happen reasonably regularly (roughly yearly). This dredging removes the naturally accumulating sediment within the channel and the wharves. By the same token, it can be expected to regularly remove some of the newly deposited coal dust (if any) on the seabed in close proximity to the coal stockyard. The dredged material is deposited at either the offshore disposal ground, located approximately 2 km east of Godley Head, or the Gollans Bay disposal ground within the harbour.
Land reclamation (Te Awaparahi Bay Reclamation Project)	LPC holds resource consents to build a 34 ha reclamation and associated wharf facility within Te Awaparahi Bay, Lyttelton Harbour. The reclamation will extend into Te Awaparahi Bay (~500 m) from the western breakwall to Battery Point and is directly in front of the existing coal stockyard. The first stage of the reclamation was completed in 2019, and the second stage was completed in December 2020[5]. Some of this new land (~16 ha) is already being used for storage. It will be approximately two years before the remaining reclamation works (~18 ha) can begin (see area outline in Figure 1). The newly reclaimed land is planned to be a modern container terminal and will increase the distance between the coal stockyard and the future marine coastal zone.

[5] https://www.lpc.co.nz/harbourwatch/projects/reclamation/

Activity	Description
Lyttelton wastewater outfall	Treated residential wastewater is discharged into Lyttelton Harbour via three outfalls: Lyttelton, Governors Bay and Diamond Harbour (Bolton-Ritchie 2011). The closest outlet within the AOI is the Lyttelton Harbour outfall, which is near the LPC SW outfall on the eastern side of the Sticking Point breakwater, so that treated effluent is carried out of the harbour (Buckenham et al. 2001). Wastewater is a source of nutrients, micro-organisms, fresh water, (potentially low concentrations of) heavy metals and other chemicals to harbour water (Bolton-Ritchie 2011). There are no consent requirements for the measurement of wastewater chemistry. The maximum allowable volume of wastewater consented to be discharged from the Lyttelton outfall is 12,096 m^3 /day, though usually it does not exceed 3500 m^3/day (it varies with rainfall infiltration). The influence of wastewater discharge into the marine environment is expected to cease some time in 2021–2022, as a result of the Lyttelton Harbour wastewater project[6]. Once complete, the new system will transfer all of Lyttelton Harbour's wastewater to Christchurch's main treatment plant.
Other port activities	There are a number of other activities occurring in the Inner Harbour and Cashin Quay area including: shipping movements (fishing trawlers, container storage, log cargo, bulk cargo, general cargo), lay-up berth (dry dock), old moorings, water/grit blasting, and tugboat activities (Keeley & Barter 2001). As a result, there has been a long history of investigation of sediment and water contaminants in the Inner Harbour (e.g. Butler 1999; Bennett & Sneddon 2006; ECAN 2008; Sneddon 2010c, 2010d; Bolton-Ritchie 2011; Sneddon 2011c, 2011a; Bolton-Ritchie & Barbour 2013; Woods 2014, 2015, 2016, 2017).

[6] https://ccc.govt.nz/services/water-and-drainage/wastewater/wastewater-projects/lyttelton-harbour-wastewater-project.

3.3. Coal dust dispersal characteristics

In order to understand the spatial extent and concentrations of coal dust in the marine receiving environment, a range of relevant depositional modelling studies (both airborne and hydrodynamic) and advice and sediment tracer studies (Lyttelton dust monitoring and international examples) are described below.

3.3.1. Airborne depositional modelling

Tonkin & Taylor were commissioned to provide airborne depositional modelling, resulting in spatially defined monthly surface deposition rate (g/m^2/30-day) estimates for coal dust (Chilton draft 2021). Each consecutive deposition contour in Figure 2 decreases (in deposition rate) with increasing distance from the coal stockyard. The highest (relative) level of airborne deposition on marine surface waters was predicted to occur in the inner Te Awaparahi Bay, with lower rates along the Cashin Quay and east of Battery Point. However, it is not clear what the particle size range was for the depositional modelling. It is noted that other modelling predictions for finer coal dust fractions (2.5 to 10 µm) were also made, however they were 24 hour average concentration values (rather than monthly surface deposition rates) and were not directly comparable (pers. comm., Richard Chilton, Principal Air Quality Scientist, 20 January 2021). The modeller recommended that the physical dust monitoring data be used as a more robust means of quantifying the likely coal dust contributions to the marine environment (pers. comm., Richard Chilton, Tonkin & Taylor, 1 March 2021).

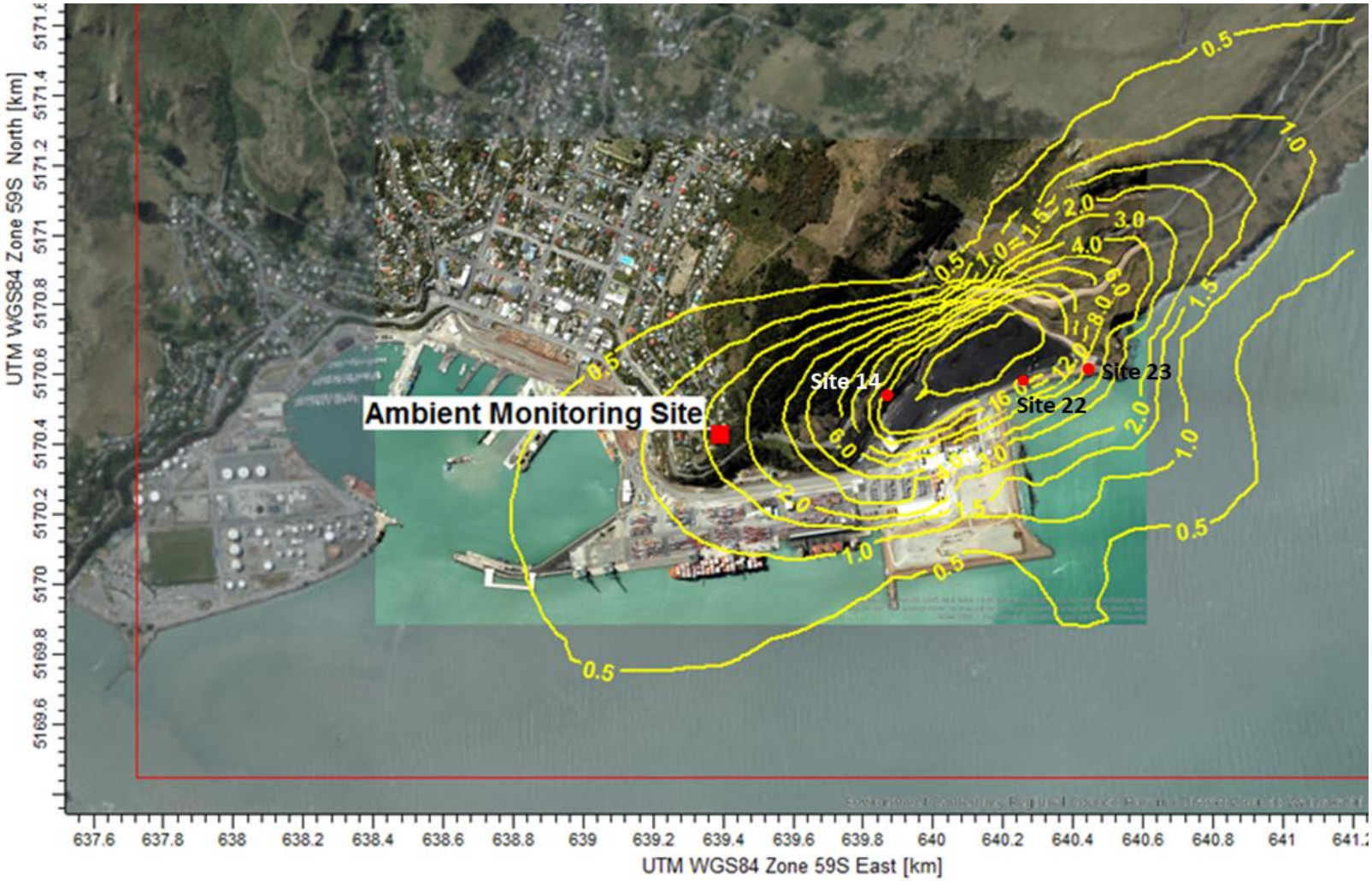

Figure 2. Maximum model predicted monthly dust deposition (g/m²/30-days) contours (yellow), with relevant LPC dust monitoring sites identified. Map excerpt taken from Chilton draft (2021). Note the infrequently used coastal road is directly beside Sites 22 and 23.

3.3.2. Dust deposition monitoring stations

The dust deposition stations positioned around Lyttelton are designed to capture dust that settles via gravity. They do not include the finer dust particles that behave more like gas and are more widely dispersed. LPC does have instruments used for monitoring the fine particles (ambient air quality); these instruments (beta attenuation monitor and nephelometer) draw in air samples and do not rely on gravity. However, based on recommendations from the modeller, this assessment uses the depositional monitoring station results as our proxy. It is noted though, that while the larger particles will settle out closer to the source, the finer particles are still relevant for the assessment as they show the maximal potential zone of influence.

Coal dust deposition is traditionally monitored from 17 stations throughout Lyttelton. Historic monthly dust deposition monitoring data (Chilton draft 2021) began in December 2008 and spans to April 2020 (Chilton draft 2021). These data show that the levels of coal dust deposition were highest during 2008 to 2010 (relating to increased coal throughput) with decreasing rates of deposition apparent in more recent years (Chilton draft 2021). To supplement the existing database, two coastal sites were added to the monitoring program[7] (Sites 22 and 23, Table 4). Data from the new coastal sites span three months of monitoring (February to April 2021, Table 4).

Table 4. Total deposited dust per day (mg/m^2/day), from the additional LPC coastal monitoring sites results. Due to sampling inaccuracies, no data was recorded for Site 23 on March 2021 (pers. comm., Gareth Taylor, LPC, 25 May 2021).

	Total dust deposition (mg/m^2/day)			
	22		23	
	Coal	Total	Coal	Total
Feb-21	700.7	824.4	166.9	556.2
Mar-21	127.6	186.8	-	-
Apr-21	224.8	264.5	49.2	140.5

The elevated February results (Table 4) were not reflective of normal activity and were believed to be caused by trucks using the adjacent road for reclamation seawall repairs (around 120 vehicle movements, pers comm. Gareth Taylor, LPC). Site 22 in particular is located within 1–2 m of the coastal road (pers comm., Gareth Taylor, LPC). While vehicles may use the reclamation haul road from time to time, additional trucking activities did not occur during March and April, which is reflected by the lower depositional results (average of 134 mg/m^2/day) which mirrors the deposition rate at other close proximity sites (e.g. site 14). While it may not be typical for the coal

[7] It is noted that only Site 23 will be included in the long term monitoring program (pers. comm., Gareth Taylor, 21 July 2021).

stockyards coastal road to have high levels of traffic, there is potential for higher coal deposition to the coastal environment if the road use increases.

As the data from the new coastal monitoring sites were collected on only two or three occasions, the most representative monitoring results for evaluating the coal dust deposition rate that may occur over the marine area were advised to be from Site 14 (pers. comm., Richard Chilton, Tonkin & Taylor, 1 April 2021). Site 14 was considered a worst-case example, due to its close proximity to the coal stockyard. Summarised monitoring data for Site 14 from 2016 to 2020 (pers. comm., Richard Chilton, Tonkin & Taylor, 1 April 2021) alongside recent site 22 and 23 data are shown in Table 5.

Table 5. Coal dust deposition rate monitoring data for sites 14, 22 and 23. LPC coal stockyard data (site 14 data, pers. comm., Richard Chilton, Tonkin & Taylor, 1 April 2021, sites 22 and 23 data pers. comm., Gareth Taylor, LPC, 25 May 2021).).

	Coal deposition rate	
Monitoring sites and dates	mg/m²/day	kg/m²/year
Site 14 (2016 - 2020)*		
Min	100	0.037
Ave	112	0.041
Max	129	0.047
Sites 22 & 23 (March – April 2021)		
Min	49	0.018
Ave	134	0.049
Max	225	0.082
Sites 22 & 23 (February – April 2021)		
Min	49	0.018
Ave	254	0.093
Max	701	0.256

*As an annual average

While Site 14 may be reflective of typical dust deposition levels, it is noted that Site 3 had notably higher depositional rates of 1,031, 1,172 and 1,298 mg/m²/day (August 2014, November 2014, September 2015, respectively). As with the new coastal monitoring sites, this appeared to coincide with nearby quarry road construction activities, resulting in spikes an order of magnitude higher compared to the maximum at Site 14 (0.25 vs 0.025 teaspoon/m^2/day) and occurring outside of what would be considered the ‘highest risk’ time of year (dry/windy summers). Results suggest that although trucking activity is infrequent, there is potential for higher coal deposition to the coastal environment if the road use increases. For this reason, both the maximum

coastal result from Site 22 (701 mg/m²/day or 0.256 kg/m²/year), influenced by trucking activities) and a more typical deposition rate from Site 14 (112 mg/m²/day or 0.041 kg/m²/year) are considered in this assessment for calculating sediment and water concentrations.

No comparisons between modelled predictions and actual dust monitoring results were available. However, given two modelled contours lie directly over dust monitoring stations 22 and 23, with maximum average monthly dust deposition estimates of 16,000 and 6,000 mg/m^2/30-days[8], respectively. This suggests deposition rates would be 3 times lower at site 23, compared to site 22. The limited comparable dust monitoring results between sites 22 and 23 (n = 2) suggest that deposition might be closer to a 4 to 5 times reduction[9].

3.3.3. Hydrodynamic depositional modelling advice

A high-level assessment was undertaken by MetOcean Solutions (MetOcean 2021) to better understand the fate of the coal dust once it settles on the water and is transported by currents within Lyttelton Harbour. The coal dust characteristics (density, settling velocities) and information on depth and current speeds at the study area were used to calculate the fate of coal particles in the marine environment.

The coal density used was 1.26–1.38 g/cm^3 and the proportion of particle sizes less than 10 µm (PM10) was 2.2%, with 47% of particles being greater than 70 µm and 15% less than 70 µm (Yao et al. 2016; MetOcean 2021). Results are summarised as follows:

- For the smaller particles (75 µm) and the fastest current flows (spring tide), the maximum distance travelled before settling was estimated to be approximately 6 km in a period of 5 h.
- Larger particles (200 µm), under the fastest flow (spring), will settle within approximately 10 minutes at a distance of 200 m. Under a neap tide flow (low flow) at Area 3 (east of Battery Point), particles settle 40 m from their starting point at the surface.

Distances for < 75 µm-sized coal particles were not calculated (MetOcean 2021), presumably because of the low representation of these smaller fractions in the coal dust (< 15%). Following examples in Yao et al. (2016) and Johnson and Bustin (2006), using a settling velocity of 0.0000784 m/sec for 0–40 µm-sized coal particles, at a depth of 10 m, coal particles would take about 35 hours to settle to the seafloor (assuming no resuspension). This suggests the finer coal particles, which also remain airborne for longer, will remain in suspension for longer, with potential to travel much further than the 75 µm particle used in the MOS (2021) assessment. Studies by

[8] Or 533 and 200 mg/m^2/day for sites 22 and 23, respectively.
[9] Site 22 vs 23, February 2021: 700.7/166.9 = 4.2 times reduction, April 2021: 224.8/49.2 = 4.6 times reduction.

Johnson and Bustin (2006) showed that coal particles < 53 µm, when placed in open jars of still seawater, remained on the water surface after a month, agglomerating into balls up to 1 cm in diameter due to their electrostatic attraction or formed a thin film due to the particles' hydrophobicity. Other large particles that did not sink initially, settled out rapidly following agglomeration (due to their combined density/radii). Similar observations were noted when particles were deposited 'dry' on the water's surface. The entire < 200 µm fraction floated and formed clumps (pers. comm., Nigel Newman, Verum Group, 24 June 2021). However, when the coal dust was applied as a wet slurry (as in the settlement velocity testing), the water column became visibly clear overnight. However, the settlement of finer particles (< 45 µm) was influenced by the density currents in the water column and resuspension of these finer coal particles is probable. While it's not known exactly how long the finer coal particles will remain entrained in the surface layer (or for that matter, be resuspended), it is assumed they will eventually sink through the water column, following agglomeration, extensive mixing, dispersal and weathering (pers. comm., Nigel Newman, Verum Group, 24 June 2021). Additionally, as the finer particles represent a minor proportion of the small volume of dust deposited on the sea surface (< 15%), only particles > 75 µm will be considered for this assessment.

The travel distances estimated by MOS (2021) for the coal dust particles (above) assume the flow speed is constant, unidirectional and follows the dominant current direction. However, when the tidal flow reverses, the distance travelled will be shorter and spread in different directions (not in a straight line). In reality, dispersion would be two-dimensional, so the spatial extent will typically be more localised. Given this, the spatial extent of the coal particles > 75 µm can be considered to be well within 6 km (given tidal reversing every 6 hrs, and the 5 hr/6 km particle travelling timeframe), and the Te Awaparahi Bay area would be likely to exhibit the highest concentrations of coal particles (as a worst case).

The completed reclamation areas will work as an obstacle to the nearshore flow, reducing the current speed west and east of the reclaimed areas and narrowing the zone of higher flow in front of the development (MetOcean 2021). This suggests that under most circumstances, the future reclamation will reduce the distance travelled of the particles.

3.3.4. Physical validation and coal particles in the seabed

The stormwater monitoring program also includes provision for estimating coal content in the sediments in Te Awaparahi Bay (Royds 1996; Conwell 2008; Sneddon 2014d, 2019a). However, as differing size fractions were being analysed between surveys (with fractions varying from > 75 µm to > 180 µm to total coal), temporal comparisons are difficult and results should be treated as estimates only. Nonetheless, Sneddon (2019) found the coal content in surficial sediments had decreased by at least an order of magnitude from 2013 to 2018 (0.15–1.53%, to

0.019–0.086%, respectively), with a similar (yet not clearly correlated) decrease in polycyclic aromatic hydrocarbons (PAH)[10] concentrations.

Coal was detected in low proportions in the sediments as far as Gollans Bay, 500 m from the eastern edge of the coal stockyard (reference sites, approx. 0.10 – 0.27% total sample, Conwell 2008; Sneddon 2014d). The reference site was changed[11] to Livingstone Bay (2 km east of the coal stockyard) in 2018; however, due to the hard-packed sediment type, no viable sample was able to be obtained at this location (Sneddon 2019a). The presence of PAHs in the sediments (a potential indicator of coal particles in sediments) has also only been detected as far as eastern Gollans Bay, with sampling stations approximately 1.5 km the east of the coal stockyard (Sneddon 2021). There was no evidence of detectable PAHs in the adjacent shipping channel, or further afield at the Godley Head disposal station (~8 km away from the coal stockyard). This suggests the PAH contaminants associated with coal particles, and the coal particles themselves, are only detectable in the sediments as far east as Gollans Bay (1.5 km).

Coal content (% of total weight) was also analysed as part of the reclamation investigations (Sneddon & Barter 2009), with a range of stations around Te Awaparahi Bay. Results showed higher levels of coal particles in close proximity to the SW outfall (station 1: 3.8% total coal), adjacent the LPC dust deposition monitoring Site 23, with lower proportions to the west, adjacent the LPC dust deposition monitoring Site 22 (station 3: 0.4% total coal).

Observations of coal particles in the sediments in Lyttelton Harbour have also been made at the eastern most point of Cashin Quay (Keeley & Barter 2001), 500 m south of Cashin Quay (Barter 2000a), within the Inner Port (Woods 2017), and within the reclamation area of Te Awaparahi Bay (Sneddon 2011b).

There are potentially at least three coal particulate pathways to the sediments in Te Awaparahi and Gollans Bay: 1) dredging disposal activities, 2) coal stockyard SW discharge, and 3) coal dust deposition. Thus, it is difficult to determine the contribution of coal dust deposition (if any) and coal dust has never been considered as a contributor (significant or otherwise) in any previous assessments. Regardless, based on particle settlement calculations (for the majority of coal particles) by MetOcean, and physical chemistry results, any detectable sediment or water quality effects are estimated to be within a 1.5 km radius of the coal stockyard.

[10] PAHs are associated with coal particulates, see Section 3.6.

[11] Due to the potentially confounding influence of disposal of dredge spoil from the Inner Harbour in Gollans Bay, a new reference station was established in Livingstone Bay 2 km to the east. Changes to the pattern of maintenance dredging spoil disposal have meant that the consented spoil grounds between Gollans Bay and Godley Head have been effectively unused since 2009. Gollans Bay, however, continues to be used for spoil from the Inner Harbour.

Summary of spatial extent of potential effects

Based on the dispersal characteristics, and current extent of coal dust particles discussed in Section 3.3, it is likely that any detectable effects will be localised within Te Awaparahi Bay and immediately surrounding areas (Gollans Bay, the Inner Port, Cashin Quay and shipping channel), with the majority of larger particles (200 µm) depositing within this area. Finer coal particles (75 µm) are likely to disperse along the east-west predominant flow path (of the dredged shipping channel), settling to the seafloor well within 6 km from the coal yard. The PAH contaminants associated with coal particles in sediments, and the coal particles themselves, have only been detected as far east as Gollans Bay (< 1.5 km).

There was no modelling advice relating to coal dust particles less than 75 µm. Finer coal particles can be expected to travel substantially further than the larger coal particles (> 75 µm) and they may become entrained in the surface water layer for longer. With a greater surface area to volume ratio, finer particles have potential to be more bioavailable than larger particles. However, elutriate testing suggests that toxicity is not likely to be an issue (test particles were as small as 0.98 µm). The fine coal dust particles probably do not represent much of the overall dust volume (~15%), and the majority of dust will be deposited within closer proximity to the coal yard. The spatial extent for consideration of potential effects in this assessment will therefore focus on the areas immediately adjacent, within an approximately 1.5 km radius of the coal yard (otherwise referred to as the 'Area of Interest' or AOI).

Nb. Any coal dust that deposits in the nearby shipping channel and swing basin may from time to time be dredged up and deposited at the disposal site at Gollans Bay or at the at the Godley Head offshore site, or become resuspended in the dredging plume. It is expected that if there were toxic or physical effects from potential coal particles included in the dredge tailings, this would be observed through the maintenance and capital dredging ecological monitoring programs.

3.4. Frequency/persistence of coal dust deposition

The coal stockyard was established in 1976 and the annual throughput has varied depending on overseas demand. Despite this variability over time, it is reasonable to assume that airborne coal dust has been a common input to the marine environment for the last 45 years.

The levels of coal dust deposition (Section 3.3.1) were highest during 2008 to 2010 (relating to increased coal throughput), with decreasing rates of deposition apparent in more recent years (Chilton draft 2021).

The coal stockyard operates 24 hours each day, 7 days per week. Dust is more prevalent in the summer due to high winds and dry conditions.

3.5. Volume of coal dust deposited

LPC's current discharge permit does not have a volume limit on coal storage and the stockyard has an estimated capacity of up to 335,000 tonnes of coal (although in recent times it is in the order of 150,000 to 180,000 tonnes), with up to 7 trains a day (with up to 30 wagons each) delivering coal. The LPC coal stockyard presently receives between 1.5 and 1.8 million tonnes of coal per year.

Using the coal dust deposition figures described in Section 3.3.2, and the relative airborne deposition contours (Figure 2), the annual coal dust loading to the marine environment has been approximated. As the coal dust deposition halves with every contour (Figure 2), it could be assumed that the monitored rates detected at the coastal sites will be halved within approximately 50 m of the monitoring stations, thus, the worst case rate would have reduced from 0.256 kg/m^2/year to 0.128 kg/m^2/year. Assuming the coastal area within this contour is approximately 100 m x 50 m = 5,000 m^2, this would equal 640 kg of coal per year to the marine environment (within that contour only). This is dispersed and diluted over the vast tidal prism of Lyttelton Harbour, in the order of 72 x 10^6 m^3 (spring tides) to 61 x 10^6 m^3 (neap tides)[12]. Given the large-scale dispersive potential of Lyttelton Harbour, the monitoring deposition rates have been interpreted on a more refined scale, e.g. over a 1-day timeframe for water dilutions (due to the immediate dispersive potential) and over a 1-year timeframe for sediment mixing (for consideration of sediment mixing and deposition).

[12] https://www.tandfonline.com/doi/pdf/10.1080/00288330.1976.9515628

3.6. Physicochemical characteristics of coal (dust)

The bituminous (rank) type coal stored at the LPC coal stockyard is derived predominantly from the Stockton mine. The coal varies in content of volatile matter[13] and inorganic compounds and is approximately 85% carbon.

3.6.1. Inorganic chemical properties

The inorganic component of coal is known to vary, which is reflected in differences between the available chemistry data for South Island coals (Ahrens & Morrisey 2005) and Stockton mine coals (Moore et al. 2005), as summarised in Table 6. The concentration ranges of metals/metalloids identified in Table 7 were largely within the ANZG (2018) default guideline values (DGV) range for sediments. The exceptions were Ag, As, Cu, Ni, Pb, Sb and Zn, which exhibited concentration ranges above DGV. Of these, Ni and As in coal from Stockton mine are present at concentrations higher than the ANZG (2018) 'upper' guideline values (GV-high), where you might already expect to observe toxicity-related adverse effects.

However, any meaningful comparisons to the ANZG (2018) guideline values require calculation of the potential concentrations in the receiving environment. The mixing (dilution) required to meet the DGV ranges from 2 times (for silver) to a maximum of 23 times (for arsenic). The mixing required to meet the GV-high value is 6.6 times for arsenic and 2.5 times for nickel. As there is mixing, dispersion, weathering and resuspension of coal dust in the water column prior to seabed deposition, it can be expected that the actual seafloor deposition rate will be orders of magnitude lower than the sea surface deposition rates (Section 3.5). Further dilution would result from sediment mixing (i.e. burial, bioturbation). For example, using the worst-case annual deposition rate, 256 g of coal dust could be deposited over 1 m^2 over a 1 year timeframe (Table 5). If this was mixed to a depth of 150 mm in the sediments (the estimated depth of bioturbation), this would result in 1039 mg of coal per kilogram of sediment[14]. Even at this relatively high loading scenario (and assuming no water column dispersal, resuspension or weathering), the resulting arsenic[15] concentration (used as a worst case), would be as low as 0.28 mg/kg[16], well under the ANZG (2018) DGV for arsenic (20 mg/kg). While this calculation assumes complete mixing in the seafloor sediments, it can be expected that in depositional areas natural sediments will be continually reworked and buried/smothered over time alongside the coal dust inputs. In non-depositional areas, where currents are high (channels, intertidal areas),

[13] Volatile matter is the weight percent of non-water gas released from a coal sample during heating to 950 °C in an oxygen-free environment.
[14] 256,000 mg of coal in 255 kg of sediment (0.15 m^3 > 150 kg x 1.7 conversion factor = 255 kg), or 1039 mg of coal per kilogram of sediment (noting that 1.7 is the conversion factor for Lyttelton sediment used in dredging calculations, pers. comm. Ross Sneddon, 8.6.21).
[15] The highest concentration metalloid/metal recorded in Stockton coal (Table 5), As = 460 mg/kg.
[16] E.g. estimated concentration of toxicant in mixed sediments =((coal mass in sediment/1000000)*coal toxicant mass)/1.7 (noting that 1.7 is the conversion factor for Lyttelton sediment used in dredging calculations, pers. comm. Ross Sneddon, 8.6.21). Assumes complete mixing.

coal dust accumulation is unlikely. Overall, it's unlikely that there will be any toxic loading or concentrations with the current levels of on-going (chronic) coal dust deposition.

In addition, the concentrations of metals in the soft sediments of Te Awaparahi Bay in the vicinity of the coal stockyard are currently within known historical and background concentrations (Sneddon 2019a) and remain below the corresponding ANZG (2018) DGV criteria. Similarly, the detectable levels of metals/metalloids in mussel tissue collected from the intertidal area of Te Awaparahi Bay, directly adjacent the coal stockyard are below FSANZ[17] (2016) standards (Sneddon 2019a).

Table 6. Inorganic chemical properties of particulate coal from the West Coast of the South Island and specifically from Stockton Mine, New Zealand (NZ). The LPC coal is derived exclusively from the West Coast of the South Island, predominantly from Stockton Mine. SB = sub-bituminous, B= bituminous. Note, units in parenthesis are PPM and outside parenthesis are %. The two Stockton coal references are included to show variability of coal properties. Analytical methods of analysis differ between references.

Chemistry % (PPM)	**South Island** (SB, B rank coals) *(Ahrens & Morrisey*	**Stockton coal** (B rank coal) *(Moore et al.*	**Stockton coal** (B rank coal) *(Bathurst 2021)*
Volatile matter		31.1 (311,000)	35 (350,000)
Carbon			84.9 (849,000)
Hydrogen			5.6 (56,000)
Nitrogen	1.2–1.4 (12,000-14,000)		1.28 (12,800)
Sulphur	0.5–3.0 (5,000-30,000)	1.46 (14,600)	1.78 (17,800)
Oxygen			6.44 (64,400)
Phosphorus			0.008 (80)
Cl	0.06–0.33 (600-3,300)	0.095 (950)	
SiO_2		52 (520,000)	50.62 (506,200)
Al_2O_3		25 (250,000)	32.19 (321,900)
Fe_2O_3		15 (150,000)	8.84 (88,400)
CaO		0.77 (7,700)	1.69 (16,900)
MgO		0.53 (5,300)	0.62 (6,200)
Na_2O		0.67 (6,700)	0.54 (5,400)
K_2O		2.7 (27,000)	2.15 (21,500)
TiO_2		1.1 (11,000)	1.53 (15,300)
Mn_3O_4		0.02 (200)	0.04 (400)
SO_3		1.67 (16,700)	1.23 (12,300)
P_2O_5		0.23 (2,300)	0.53 (5,300)
B_2O_3		0.05 (500)	

[17] Relevant food standards and guidelines concerning metals levels include Standard 1.4.1 for Contaminants and Natural Toxicants in Food (FSANZ 2016), which lists the maximum levels (ML) of specified metal and non-metal contaminants and natural toxicants in nominated foods.

Table 7. Inorganic metal/metalloid properties of particulate coal in New Zealand (NZ). SB= sub-bituminous, B= bituminous, L=Lignite. Highlighted cell colours are exceedances to the equivalent coloured guidelines.

Chemistry (PPM)	South Island* (SB, B rank coals) (Ahrens & Morrisey 2005).	North Island (SB, B rank coals) (Ahrens & Morrisey 2005).	NZ coals (SB, B, L coals) (Moore et al. 2005)	Stockton coal (B rank coal) (Moore et al. 2005)	NZ soils range (mean) (Moore et al. 2005)	ANZG (2018) DGV	ANZG (2018) GV-high
Al			4,200–17,000***				
Ag	0.003–0.11	0.012–0.19		< 2		1	3.7
As	< 1.5–27.5	< 2.25	0.77–460	460	1–50 (7)	20	70
B	10–342	47–708	160–7000	160	2–100 (30)		
Ba	8.3–148	21–81		460			
Cd	< 0.3–0.9	< 0.7–1.7	0.11–1.00	1	0.02–100 (0.6)	1.5	10
Co	< 0.1–14.0	0.4–6.8	5.8–210	61	1–40 (9)		
Cr	0.4–20.9	0.6–14.1	7–196	70	5–10,000 (55)	80	370
Cu	0.95–9.4	1.0–13.6	8–176	91	2–100 (25)	65	270
Fe			104–33,265**				
Ga	0.14–3.0	0.2–5.8		50			
Ge	0.07–7.8	0.05–0.5	0.36–276	180	0.1–50 (1.0)		
Hg	0.12–0.56	0.19–0.24	0.02–0.12	0.07	0.01–0.5 (0.1)	0.15	1
Mn	1.3–2.8	7–63	33.4–3090	130	200–3000 (550)		
Mo	< 0.02–0.42	0.12–0.76		12			
Ni	0.6–27.5	2.9–11.0	11–507	130	5–500 (20)	21	52
P	< 1.6–29.3	< 2.2–9.4					
Pb	0.3–18.0	1.3–16.0	3.6–122	95	2–100 (19)	50	220
Sb	< 0.04–3.7	< 0.05–0.29	0.17–47.4	15	0.2–10 (0.7)	2	25
Se			0.22–1.22	1.1	0.1–2 (0.4)		
Sn	0.14–7.5	0.52–17.5		30			
Th				23			
Tl	< 0.004–6.7	< 0.005		43			
U			0.63–8.5	8.5	0.7–9 (2.7)		
V	0.68–13.8	1.3–18.5		97			
Zn	0.7–27.5	1.0–55.5		380		200	410

* Coal stored at the LPC coal stockyard is sub-bituminous and bituminous and derived exclusively from the West Coast of the South Island. ** Sub-bituminous and bituminous coals from Spain and USA. *** Trent et al. (1982) 12 bituminous (medium volatile) coal samples from Virginia and West Virginia on a whole-coal basis.

3.6.2. Organic chemical properties

The volatile matter component of coal comes largely from its organic component (Table 8). The organic components are of biogenic origin, and therefore they are unlikely to include the majority of the volatile and very volatile compounds derived from industry (man-made). The coal stockyard coal's volatile percentage was 31–35% (shown in Table 6), suggesting the coal is a medium-high volatile coal. This is likely to be related to high concentrations of hydrocarbons (TPH/PAHs[18]) and volatile oxides (e.g. Table 6).

There are a number of studies investigating the extractable concentrations of PAH in raw coal (Trent et al. 1982; Zhao et al. 2000; Ahrens & Morrisey 2005; Achten & Hofmann 2009; Burns 2014; Shanchez 2014; Berry 2017). PAH concentrations in coal are influenced by carbon content, volatile matter, H/C ratio, O/C ratio, and potentially sulphur content, but the degree of their influence is unclear (Zhao et al. 2000). Total PAH concentrations tend to peak in raw coal where carbon content is around 84% (by weight) (Zhao et al. 2000; Gao et al. 2019), which is a characteristic of the Stockton coals processed at the LPC coal stockyard (Table 6). However, international literature shows coal PAH concentrations vary widely, with medium to high volatile bituminous coals from Canada and Germany exhibiting PAH concentrations between 68–2,429 mg/kg, but medium to high volatile sub-bituminous and bituminous coals in the USA ranging from 1.6–78 mg/kg (Achten & Hofmann 2009).

There are limited investigations of coal as a TPH or PAH source in marine sediment or waters, particularly with reference to New Zealand coals (Ahrens & Morrisey 2005), and relatively few studies examining the bioavailability of organic contaminants in coal particulates (Ahrens & Morrisey 2005; Achten & Hofmann 2009; Shanchez 2014). In these studies, PAH and TPH are often considered unlikely to be bioavailable due to the high carbon composition of coal (Table 5), which binds organic compounds, reducing their bioavailability. However, there are relatively few studies confirming this binding potential (Jafrennou et al. 2007; Berry et al. 2016). Some studies suggest that the more mobile PAH phases[19] that exist in coal might be expected to have higher bioavailability (Achten & Hofmann 2009; Shanchez 2014), and PAHs have been detected in coal pile leachates (Ahrens & Morrisey 2005). Even so, PAHs leached from particulate coal are subject to break-down in the environment from volatilisation, photodegradation and bacterial degradation (Ahrens & Morrisey 2005).

The uncertainties relating to organic contaminants have been addressed in the following sections through interpreting multiple lines of evidence, e.g. coal input concentrations/mixing calculations and elutriate testing (with receiving environment physicochemical characteristics also discussed in Section 4.2.2).

[18] Total petroleum hydrocarbons / polycyclic aromatic hydrocarbons.
[19] "*Hard coal consists of a macromolecular network phase and a mobile phase, and PAH are part of both*" (Achten & Hofmann 2009).

Table 8. Organic chemical properties of particulate coal worldwide. SB= sub-bituminous, B= bituminous. Bolded individual PAHs are representative of West Coast, New Zealand coals, with phenanthrene being the dominant PAH in West Coast leachate, followed by fluorene, chrysene and benzo(a)pyrene (Barter 2003). Highlighted cell colours are exceedances to the equivalent coloured guideline cells.

Organic compounds (ppm or mg/kg)	**USA coals** Ahrens & Morrisey (2005)[d]	**International coals** Jaffrennou et al. (2007) and Zhao et al. (2000)c	**LPC coal stockyard pile coal** Barter (2003)	**ANZG (2018) DGV**	**ANZG (2018) GV-high**
Total aliphatics[a]	0.2–960			280 (TPH)	550 (TPH)
Total aromatics[a]	17.6–2160				
PAHs	1081.8	0.33–34.2	21	10	50
Anthracene	1.4–2.6	0.06–6.0	0.46	*0.085*[b]	*1.1*[b]
Naphthalene	0.34–3.3	0.08–2.78	3.7	*0.16*[b]	*2.1*[b]
Phenanthrene	0.08–26.8	0.14–6.2	11.4	*0.24*[b]	*1.5*[b]
Benzo(a)pyrene	0.5–1.3		0.34	*0.43*[b]	*1.6*[b]
Benzo(a)anthracene	1.41–1.9	24.8	0.76	*0.261*[b]	*1.6*[b]
Benzo(b)fluoranthene	1.3–6.3	0.05–0.78	0.33		
Chrysene	0.25–15.3		1.17	*0.384*[b]	*2.8*[b]
Fluorene	0.12–7.2	1.8	1.14		
Fluoranthene	1.6–9.2	2	0.39	*0.6*[b]	*5.1*[b]
Pyrene	0.04–7.1	0.12–1.5	0.89	*0.665*[b]	*2.6*[b]
Acenaphthene		1.36	< 0.09		

a. Total aliphatics + total aromatics = total petroleum hydrocarbons
b. ANZECC (2000) ISQG values.
c. Bituminous coal provided by the Western Kentucky University (Zhao et al. 2000). Jaffrennou et al. (2007) coals sourced from Indonesia, Venezuela, South Africa and Colombia.
d. Data derived from predominantly bituminous coals from USA (also includes unknown rank coals from Virginia).

The concentrations of PAHs and total aliphatics/aromatics (TPH) in coals globally (Table 8) and from the stockpile itself, suggest that the majority of parameters would be in exceedance of the ANZG (2018) default sediment guidelines (both DVG and GV-high) for ecosystem health. However, direct comparison of toxicant concentrations with receiving environment guideline concentrations is not appropriate, and comparisons to these guideline values require re-calculation of dilution concentrations in the receiving environment, and normalisation to 1 % TOC[20] in the receiving sediments. Interestingly, in the case of coal dust, PAH and TPH are often considered

[20] To determine the bioavailability of PAHs in sediment, it is important to factor in the amount of organic carbon in the sediment. When organic carbon is present, PAHs bind to it, making the PAHs less available to aquatic life, thus lessening their toxicity.

unlikely to be bioavailable due to the high carbon composition of coal (Table 8), which theoretically binds organic compounds, reducing their bioavailability. However, there are relatively few studies confirming this binding potential (Ahrens & Morrisey 2005; Achten & Hofmann 2009; Shanchez 2014). Even so, mixing/dilution calculations show that at the current levels of deposition[21], any potential PAH in the sediments are likely to be well under ANZG (2018). For example, using the same conservative loading scenario as in Section 3.6.1 (1039 mg of coal per kilogram of sediment, per year[22]), the resulting PAH[23] concentration would be as low as 0.0002 – 0.0005 mg/kg[24] (normalised to 1.9% and 0.4% TOC respectively[25]), well under the ANZG (2018) DGV for PAHs (10 mg/kg).

The LPC coal stockyard occasionally uses dust suppressant chemicals to minimise dust from the coal pile during dry periods when there is low site activity (i.e. over holiday periods). The chemicals used were identified by LPC as *Vital Bon-Matt CDS300* and *Vital Bon-Matt P47*. The common main constituents in both suppressants are organic gums (< 20%), cellulosic material (< 10%), triglycerides (< 30%) and water (40–45%). Vital Bon-Matt P47 also contains the polymer solution styrene acetate (CRC130377). Both the specific suppressants used by LPC (P47 and CDS 300) are considered 'non-hazardous' according to the New Zealand Environmental Protection Authority (EPA) criteria (MSDS 2019b, 2019a), and they are predicted to have low risk of acute and chronic toxicity in the receiving environment (particularly at low application concentrations), based on known properties of components (S&B 2007, 2011).

While there was a range of information available for determining toxicity of coal in general, there was a lack of information relating to the specific LPC coal dust, and its potential water quality effects. To address this, an elutriate test of a representative coal dust sample was performed. Results are discussed in the following section.

3.6.3. Elutriate testing

Elutriate testing on a representative coal dust sample was undertaken to determine the bioavailability of potential coal dust toxicants in the water column. Raw results are in Appendix 1.

[21] Noting that if TOC % fluctuates, or grainsize distribution changes, so too can the bioavailability of PAHs in the sediments, though in this case the influence appears to be minor.

[22] Using the worst-case annual deposition rate, 256 grams of coal dust could be deposited over 1 m^2 over a 1-year timeframe (Table 5), and mixed to a depth of 150 mm in the sediment (the estimated depth of bioturbation), this would result in 1039 mg of coal per kilogram of sediment, i.e. 256,000 mg of coal in 255 kg of sediment (0.15 m^3 > 150 kg x 1.7 conversion factor = 255 kg), or 1039 mg of coal per kilogram of sediment (noting that 1.7 is the conversion factor (i.e. bulk density, g/m^3) for Lyttelton sediment used in dredging calculations, pers. comm. Ross Sneddon, 8 June 2021).

[23] The highest total PAH concentration recorded in Stockton coal = 21 mg/kg, Table 8.

[24] E.g. Estimated concentration of toxicant in mixed sediments =((coal mass in sediment/1000000)*coal toxicant mass)/1.7 (noting that 1.7 is the conversion factor for Lyttelton sediment used in dredging calculations, pers. comm. Ross Sneddon, 8 June 2021), then normalised to 1% TOC. Assumes complete mixing.

[25] TOC% in Te Awaparahi Bay was 1–1.9% (2013), 0.4–0.6 % (2019) (Sneddon 2019b).

A coal dust sample was simulated[26] by collecting a composite sample of coal from the coal stockyard pile (by Verum Ltd), roadsides and working areas, then sieving it through a 212 µm sieve. It is noted that the final tested particle size range was between 0.98–840 µm[27] (Appendix 1), with 80% of the sample < 220 µm. This shows that the simulated dust sample included some of the finer material that wouldn't otherwise be present if the sample was collected from a dust deposition monitoring station (the monitoring stations are not designed to collect the finer particles). Water for the elutriate testing was collected by a Verum Ltd scientist, from the outermost, seaward end of new reclamation (E1577304/N5172183), taken 1 hour after high water. Elutriate testing was performed by Hill Laboratories using the standard US EPA 503/8-91/001 approach[28] for 'Evaluation of Dredged Material for Ocean Disposal'. The resulting elutriate was tested for dissolved inorganic carbon (DIC), dissolved non-purgeable organic carbon (DNPOC), total metals/metalloids, PAHs (trace) and TPH. These parameters were selected based on the general coal compositional information discussed in the previous sections[29]. Results are present in Table 9.

Concentrations of arsenic, chromium, lead, mercury, PAHs and TPH were all below the analytical detection limits (ADL). There were detectable concentrations of copper, manganese, zinc, sulphur, DNPOC and DIC. Of these only copper, manganese and zinc were notably elevated compared to background concentrations (Table 9). At the standard 1:4 test dilution, copper was above the ANZG (2018) guidelines for a 95% level of species protection (LOP) (but was within the 90-80% levels), manganese exceeded the 80% LOP (99–90% LOPs not available) and zinc exceeded all LOPs (80-99%). However, direct comparison of toxicant concentrations with receiving environment guideline concentrations is not appropriate, thus, dilution concentrations in the receiving environment have been calculated in the following section.

Receiving environment dilution calculations

The low-density characteristics of coal means that it could become entrained in the sea surface layer for some period of time (see Section 3.3.3). This spatial restriction would mean less effective water column dilution for any toxicants and is considered the worse-case for coal dust dilution/dispersion. To obtain a conservative estimate of the potential surface layer coal dust concentrations, two deposition scenarios, derived from the coal dust deposition monitoring figures (Section 3.5), were calculated:

[26] Actual dust deposition monitoring samples did not have enough volume available for elutriate testing.
[27] Noting that the particle size test detected up to 4x larger particles, perhaps due to hydrophobic flocculation (i.e. aggregation of hydrophobic particles in aqueous suspension due to hydrophobic interaction between particles and kinetic energy of sufficient magnitude).
[28] Using 200 ml of sample (simulated coal dust) and adding 800 mL of extract (seawater), mixing for 30 min, settling for 1 hr, then undergoing filtration or centrifugation (pers. comm. Ara Heron, Hill Laboratories, 6 May 2021).
[29] Nb. The elutriate testing considers some the key components of coal dust leachate. The lack of detectability and high dilution of the key chemical components suggests other less-commonly monitored/tested parameters, such as radio-nuclides, where no receiving information exists, are also unlikely to be detectable.

- using the 112 mg/m^2/day scenario: if 112 mg of dust is deposited per day over a m^2 area, to 1 mm depth (the assumed surface layer), then the concentration of coal in the sea-surface layer could be up to = 112 mg/L.
- using the 701 mg/m^2/day scenario: if 701 mg of dust is deposited per day over a m^2 area, to 1 mm depth (the assumed surface layer), then the concentration of coal in the sea-surface layer could be up to = 701 mg/L.

Using the coal dust concentrations above, the relative elutriate concentrations (701 mg/L and 112 mg/L) for the only detectable toxicants (Cu, Mn, and Zn[30]) were calculated (Table 9). Even under unusual circumstances where high levels of coal dust deposition occurred in the coastal environment due to increased roading activity (701 mg/L), the calculated concentrations for Cu, Mn, and Zn remained two orders of magnitude below the concentration required for a 99% level of species protection (ANZG 2018). These results are consistent with previous studies that indicated coal generally does not leach toxic (or bioavailable) levels of trace metals or PAHs into water (Ahrens & Morrisey 2005; Jafrennou et al. 2007; Berry et al. 2016). It is also stressed that the coal dust deposition concentrations used here are highly conservative, as they represent the daily deposition, rather than a point-in-time (as assumed for the elutriate calculations). So, at any one moment, the coal dust will become greatly dispersed by water currents and wind—rather than being restricted to a 1 m^2 area of sea surface for an entire day.

Results suggest even if sea-surface entrainment occurs, there is unlikely to be any water column toxicity in the sea surface layer from coal dust at the current levels of deposition. However, this would need to be reconsidered if the dust deposition rate were to increase significantly or hydrodynamic characteristics were to change.

[30] Cu, Mn and Zn exceeded the ANZG (2018) 80–95% level of species protection at a 1:4 dilution (Table 6).

Table 9. Physicochemical parameters that were present at detectable levels in the simulated coal dust elutriate and Lyttelton Harbour seawater. Elutriate results have been converted into relevant dilutions (as per deposition scenarios identified in Section 3.6.3) and compared against ANZG (2018) guideline values (for 80–99% level of species protection, LOP). Shaded cells exceed guideline values.

		Simulated coal dust (Coal fines - 212µm)			Guideline values			
Detectable parameters (g/m3)	**Lyttelton Harbour Water 0:0 dilution (0 mg/L)**	**Standard EPA elutriate test[a] 1:4 dilution (250,000 mg/L)**	**Calculated 1:1427 dilution (701 mg/L)**	**Calculated 1:8926 dilution (112 mg/L)**	**ANZG (2018) 99% LOP**	**ANZG (2018) 95% LOP[f]**	**ANZG (2018) 90% LOP[g]**	**ANZG (2018) 80% LOP[h]**
Total Copper	< 0.0011	0.0019	0.000005	0.0000009	0.0003	0.0013	0.003	0.008
Total Manganese	0.0054	1.24	0.003	0.0006	-	-	-	0.08
Total Sulphur	930[e]	960	na	na	-	-	-	-
Total Zinc	< 0.0042	0.113	0.0003	0.0001	0.007	0.015	0.023	0.043
Dissolved Non-Purgeable Organic Carbon (DNPOC)	1.3	1.8[b]	na	na	-	-	-	-
Dissolved Inorganic Carbon	26	7.8[c]	na	na	-	-	-	-
Particle size (µm, 100% of particles less than)		840[d]	na	na	-	-	-	-

a. 200 ml sample/800 ml seawater.
b. Only a slight increase.
c. The DIC decrease with the addition of coal may be due to mixing during the elutriate test.
d. Sieved to 212 um, but the particle size test detected 0.98 - 840 µm.
e. Seawater sulphur content typically around 884 ppm. https://web.stanford.edu/group/Urchin/mineral.html.
f. Recommended for application for slightly to moderately disturbed ecosystems.
g. Guideline may not protect key test species from chronic toxicity.
h. Guideline may not protect key test species from acute and chronic toxicity.

4. RECEIVING ENVIRONMENT DESCRIPTION

4.1. Background

Based on the dispersal characteristics, and current extent of coal dust particles in the seabed sediments, discussed in Section 3.3, it is likely that any potentially detectable effects will be localised within the AOI (e.g. Te Awaparahi Bay, Gollans Bay, Inner Harbour, Cashin Quay and the shipping channel).

Two receiving environment scenarios are considered here:

1. the current environment, with partially completed reclamation (Figure 3)
2. the environment following the completion of reclamation (see Figure 3 for boundary of future reclamation).

Much of the water and benthic data presented here relate to recent ecological conditions and can be used for both scenarios. All past data are still considered to be relevant, considering the coal dust has been occurring in the area since 1976. Differences between the two scenarios will only be discussed when differences are expected to occur; if not discussed, the receiving environment conditions can be expected to be the same.

The seabed and water column of the AOI has been surveyed and sampled a number of times in the last 20+ years (Figure 3, and summarised below), the findings of which have been used to characterise the benthic and water column receiving environment of the AOI under the two receiving environment scenarios, and provide useful context for the effects assessment.

- **Land reclamation impacts:** Benthic physicochemical and macrofaunal sampling/ assessments, and water quality assessments were carried out for an earlier reclamation proposal, as well as the reclamation proposal currently underway in Te Awaparahi Bay. The potential marine ecological effects of the current reclamation activity were addressed through an EA (Sneddon et al. 2017) with a number of ecological and hydrodynamic investigations preceding or relating to this (OCEL 2009b; Sneddon & Barter 2009; Sneddon 2010b, 2011b, 2012; Sneddon & Dunmore 2014; Sneddon 2016; Ogilvie 2017; T&T 2017).
- **Stormwater impacts:** Benthic physicochemical sampling and intertidal transects and bivalve tissue testing in Te Awaparahi Bay, Gollans Bay and Livingstone Bay are consent requirements for stormwater discharge from the LPC coal stockyard. The EA for coal stockyard stormwater was completed by Sneddon (2014d) with a number of ecological and hydrodynamic investigations preceding, or relating to this (Royds 1996; Barter 2000a, 2003; Conwell 2008; Sneddon 2014d, 2019a).
- **Maintenance dredging impacts:** Benthic physicochemical and macrofaunal sampling of spoil (sediments from Inner Harbour and channel) and spoil grounds (Godley Head), and intertidal surveys at Godley Head. An extensive EA was

provided for maintenance dredging re-consenting (Sneddon 2013b) including a hydrodynamic/sediment trend study (McLaren & Teear 2012), as well as multiple sediment pre-characterisation reports (Gillespie et al. 1992; Gillespie & Asher 1995; Barter 2000b; Thompson & Barter 2005; Sneddon & Baily 2010; Sneddon 2014c, 2015; Sneddon et al. 2015; Sneddon 2017, 2019b).

- **Capital dredging impacts:** Includes harbour-wide investigations (initially as part of an EA for resource consent) of benthic physicochemical, macrofaunal (benthic and epifaunal) sampling, with extensive intertidal transects including nearby Battery Point, Livingstone Bay and Shag Reef (Sneddon et al. 2016). There have also been a number of other ecological and hydrodynamic investigations preceding or relating to this (OCEL 2009a; Sneddon 2009, 2010a; Fox 2016; Goring 2016; MetOcean 2016b, 2016a). Further field surveys for the capital dredging monitoring are due to be completed in 2021.
- **Cashin Quay and cruise berth impacts:** There have been a number of benthic physicochemical and macrofaunal investigations relating to Cashin Quay operations and repairs/upgrades (Handley et al. 2000; Keeley & Barter 2001; Fenwick 2003; Barter 2009a, 2009b; Sneddon 2013a), as well as the cruise ship berth development and operational changes (Sneddon & Floerl 2017).
- **Inner Harbour**: There has been a long history of benthic physicochemical and macrofaunal investigations and water contaminant investigations in the Inner Harbour (e.g. Butler 1999; Bennett & Sneddon 2006; ECAN 2008; Sneddon 2010c, 2010d; Bolton-Ritchie 2011; Sneddon 2011c, 2011a; Bolton-Ritchie & Barbour 2013; Woods 2014, 2015, 2016, 2017).

Nb: Only the benthic and water column receiving environment parameters relevant to coal dust deposition are presented here, it is not an exhaustive list.

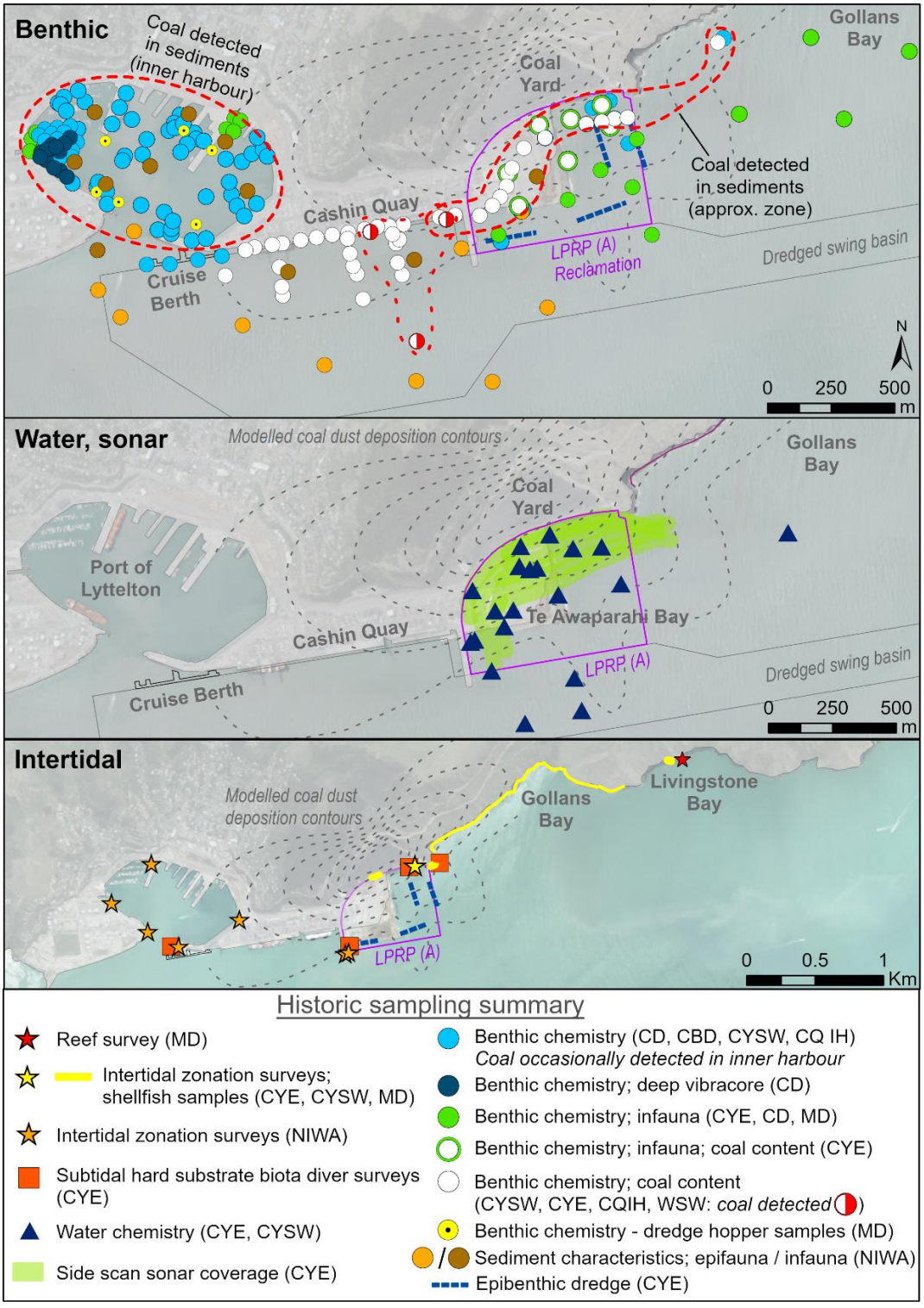

Figure 3. Existing relevant sample locations in the vicinity of the LPC coal stockyard and Te Awaparahi Bay. Note this map includes the known locations where coal particles have been observed in the sediments (via benthic sampling), as well as the modelled coal dust seawater surface deposition contours (MD: maintenance dredging monitoring, CYE: Coal stockyard expansion/reclamation monitoring, CYSW: coal stockyard stormwater monitoring, CBD: cruise berth development, CQIH: Cashin Quay and Inner Harbour monitoring, WSW: wharf stormwater monitoring, CD: capital dredging monitoring).

4.2. Physical environment

Lyttelton Port Operational Area (Inner Harbour and immediate Outer Harbour) (Figure 3) is a heavily modified marine environment with a number of anthropogenic activities and potential contaminant and disturbance sources (discussed in Section 3.2). Based on the dispersal characteristics, and current extent of coal dust particles in the seabed sediments (discussed in Section 3.3), it is likely that any detectable effects will be largely localised within the AOI (e.g. Te Awaparahi Bay, Gollans Bay, Inner Harbour, Cashin Quay and the shipping channel).

4.2.1. Seafloor substrate and features

Much of the shoreline of Lyttelton Harbour comprises rock and boulder substrates; these are especially evident on the northern side of the central and outer Harbour, where they slope steeply to the flat Harbour floor (Sneddon & Barter 2009; Sneddon et al. 2017). Te Awaparahi Bay is the coastal embayment in the immediate vicinity of the LPC coal stockyard, located on the north side of the Harbour, between the Cashin Quay breakwater and Battery Point (Figure 3). The Bay has a relatively flat and uniform soft sediment substrate of semi-consolidated muds or sandy silts. In shallower waters close to shore, the silty sediments become slightly coarser, with an increase in gravel and shell (Sneddon & Barter 2009; Sneddon et al. 2017).

All of the benthic areas in the AOI are subject to some degree of ongoing disturbance from Port activities. To the west is Cashin Quay and the associated dredged swing basin; to the south is the maintained shipping channel and to the east is Gollans Bay. The Gollans Bay ground is the easternmost sector of the spoil grounds consented, under specific conditions, to receive dredged material from annual maintenance dredging of the current shipping channel (Sneddon 2021).

There are a range of intertidal[31] and subtidal[32] marine substrates in the AOI. There are two main types of intertidal substrate; (1) occasional narrow natural rock platforms such as Battery Point (to the east of the coal stockyard, Figure 3), which features numerous small to medium-sized rock pools, extending up to 25 m intertidally (Sneddon & Barter 2009; Sneddon et al. 2017), and (2) man-made rip-rap seawalls (from Cashin Quay to Te Awaparahi Bay). The rock and bolder substrates along the Lyttelton shoreline are steep and typically do not extend very far sub-tidally before they meet the flat plain of the Harbour floor.

The subtidal habitat in Te Awaparahi Bay is categorised into two habitat/community groups, soft sediment and reef. The subtidal profile of the rip-rap structure on the eastern side of the Cashin Quay breakwater is very steep. Side scan imagery

[31] The intertidal zone is the area of seashore above water level at low tide and underwater at high tide (i.e. within the tidal range).
[32] The subtidal zone is the region below the intertidal zone that is continuously covered by water.

(Sneddon & Barter 2009) taken in Te Awaparahi Bay (Figure 4), shows an example of each of the reef and soft sediment subtidal substrates (pre-reclamation).

Intertidal and subtidal substrates are discussed in terms of habitat, in the benthic ecology section (4.3) of this report.

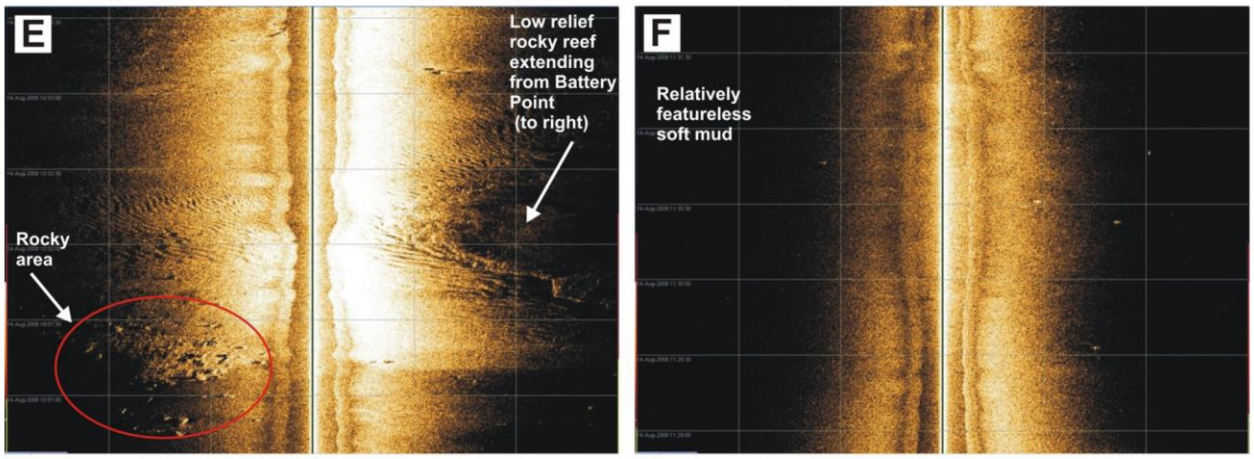

Figure 4. Representative sidescan sonar images of the e) near shore Battery Point natural reef and f) uniform seabed within deeper areas of Te Awaparahi Bay (Images taken from Sneddon & Barter 2009).

4.2.2. Sediment physicochemistry

A spatial gradient of coarsening texture (greater proportions of fine and very fine sand) moving westward from the coal stockyard SW outfall appears to have been consistent over time (Sneddon 2019a). It is thought this is due to increased wave energy at the rip-rap wall (Sneddon & Barter 2009; Sneddon et al. 2017) and the advancing[33] reclamation shoreline (Sneddon 2019a). While the silt and clay fraction has been consistently dominant, both the data and field observations indicate that harbour bed sediments in Te Awaparahi Bay have generally become progressively finer in successive surveys (Sneddon 2019a), with evidence of coarser sediments in Gollans Bay (dredge spoil disposal site) to the east (Sneddon 2021).

Coal particles, total organic carbon (TOC %), specific metals/metalloids[34], polycyclic aromatic hydrocarbons (PAH) and total petroleum hydrocarbons (TPH) can be physicochemical indicators of the presence of coal particles in surficial sediments (Barter 2000a; Ahrens & Morrisey 2005; Sneddon 2019a). Therefore, the concentration of these parameters in the sediments give some indication to the extent

[33] The Te Awaparahi Bay reclamation works have resulted in the shoreline 'advancing' in the south and east directions from the historic coastline since before 2015 (See Table 3).
[34] Notably, Ni and As were elevated in Stockton coals (Section 3.4.1), and Cu, Mn, and Zn, were detected and elevated in elutriate testing, Section 3.4.3).

of seabed potentially affected by coal particles (either airborne dust or stormwater derived).

Sneddon (2019b) found sediment total organic carbon (TOC) (an indicator of the organic compounds, such as PAHs and TPH, present in coal) had reduced since the earlier surveys (e.g. sediment TOC, 1–1.9% in 2013 and reducing to 0.4–0.6 % in 2019; Sneddon 2019a), suggesting that any apparent inputs of coal (an organic carbon) to soft sediments have decreased overtime.

Coal particles have been detected in low percentages in the sediments as far as Gollans Bay, with sampling stations 500 m from the eastern edge of the coal stockyard (reference sites, approx. 0.10–0.27% total sample, Conwell 2008; Sneddon 2014d). Other coal content (% of total) results in the AOI (Sneddon & Barter 2009) exhibited higher levels of coal particles in close proximity to the SW outfall (station 1, 3.8% total coal), adjacent the LPC dust deposition monitoring Site 23, with lower proportions to the west, adjacent the LPC dust deposition monitoring Site 22 (station 3, 0.4% total coal). Coal particles have also been observed (though not quantified) in the sediments in Lyttelton Harbour and on the eastern part of Cashin Quay (Keeley & Barter 2001), 500 m south of Cashin Quay (Barter 2000a), throughout the Inner Harbour (e.g. Sneddon 2010d, 2010c; Woods 2017) and within the now reclaimed area of Te Awaparahi Bay (Sneddon 2011b).

PAHs have been detected in sediments from Te Awaparahi Bay (Royds 1996; Barter 2000a, 2003; Conwell 2008; Sneddon 2014d, 2019a), the Inner Harbour, Cashin Quay (Barter 2000a) and as far as Gollans Bay (1.5 km from the eastern edge of the coal yard, Sneddon 2021). PAHs were not detected in the adjacent shipping channel, or at the further afield Godley Head disposal station (~8 km away from the coal stockyard). Sources of low-level (below DGV) PAH contamination in Gollans Bay were thought to be directly attributable to spoil disposal. Coal particulates from SW discharges may have attributed to PAHs in the Gollans Bay sediment, but they are unlikely to be in a bioavailable form (Sneddon 2021). During the 2003, 2007 and 2013 Te Awaparahi Bay coal stockyard stormwater monitoring surveys, some individual PAHs were in exceedance of the (now superseded[35]) ANZECC (2000) guideline limits with some suggestion of a spatial concentration gradient occurring to the east, seawards from the reclamation (Barter 2003; Conwell 2008; Sneddon 2014d). However, the most recent monitoring results in Te Awaparahi Bay (Sneddon 2019a) have shown a reduction in total PAHs sediment concentrations, being well below the default sediment guideline trigger values for ecological protection (< 10 mg/kg%OC, ANZG 2018).

There have never been any TPHs detected in the Te Awaparahi Bay sediments (Royds 1996; Barter 2003; Conwell 2008; Sneddon 2014d, 2019a), but TPHs

[35] The more recent ANZG (2018) guidelines only provide total PAH trigger values, rather than individual PAHs.

characteristic[36] of particulate coal were detected (inconsistently) along Cashin Quay, along with elevated PAH concentrations, pre-dredging (Barter 2000a).

The most recent coal stockyard SW monitoring results in Te Awaparahi Bay (Sneddon 2019a) have shown a reduction in total metals with all monitoring results having consistently remained within background levels and/or below the default sediment guideline trigger values for ecological protection (< 10 mg/kg%OC, ANZG 2018). Metal contamination in Gollans Bay were thought to be directly attributable to spoil disposal, with the exception of cadmium[37], which was thought to be from discrete particulate material, possibly from phosphate fertilisers (Sneddon 2021).

The most recent benthic physicochemical sampling in the nearby Gollans Bay disposal ground (maintenance dredging monitoring) was performed in 2021 (Sneddon 2021). Overall results showed that general levels of contamination were consistent with the results of previous surveys and no long-term trends were indicated.

4.2.3. Hydrodynamics

The hydrodynamic characteristics within the AOI were described by Met Ocean Solutions Ltd (MetOcean 2021) based on modelling done previously in the same area for the Te Awaparahi Bay reclamation (MetOcean 2017). In summary, the shipping channels to the west of Te Awaparahi Bay area tend to be the main flow pathway on a flooding tide. On ebb tides, flow propagates along the channel and towards the less current-exposed waters of Gollans Bay (Figure 5). Current speed during flood and ebb tide were of similar magnitude (MetOcean 2021), with spring tides ranging from 0.17–0.33 m/s and neap from 0.13–0.2 m/s. It was also noted by Sneddon et al. (2016) that tidal transport of particulates (in relation to channel dredging) would be strongly directional along the Harbour axis, with little transport towards the Harbour shorelines.

Following the completion of the reclamation, the current speeds are predicted to decrease in the more sheltered Gollans Bay area (to the east of Te Awaparahi Bay), with depths around 9 m. Immediately beside the southern margin of the future reclamation, high currents will be closer to the shoreline[38], along with the increased

[36] Quoted from Barter (2003) *Total petroleum hydrocarbons (TPHs) are reported according to three size fractions, and represent the number of carbons in a straight (aliphatic) molecular chain. ...They can also be a good indication of coal inputs because coal is a biogenic compound formed from prehistoric plant material and, as such, can have very high concentrations of plant derived hydrocarbons like pristane (C19) and to a lesser extent phytane (C20). Typical West Coast coals have a very high pristane/phytane ratio. In fact, pristane is the dominant n-alkane in West Coast coals, with varying and lesser concentrations of C21-C32 depending on the source. These same coals have much smaller concentrations of the n-alkanes below C15. Therefore, sediment TPH results that are characterised by high concentrations in the C15-C36 class of n-alkanes, but with lower concentrations of the shorter n-alkanes (i.e. C7-C9 & C10-C14), may be indicative of a coal source."*

[37] Cadmium was not one of the dominant metal species identified as an indicator from the Stockton coal profile or elutriate testing.

[38] The modelled conditions beside the presently existing coastline shows a slower current zone created by the breakwater.

channel depth (from 15–16 m to 18 m) created through channel deepening/capital dredging (MetOcean 2021).

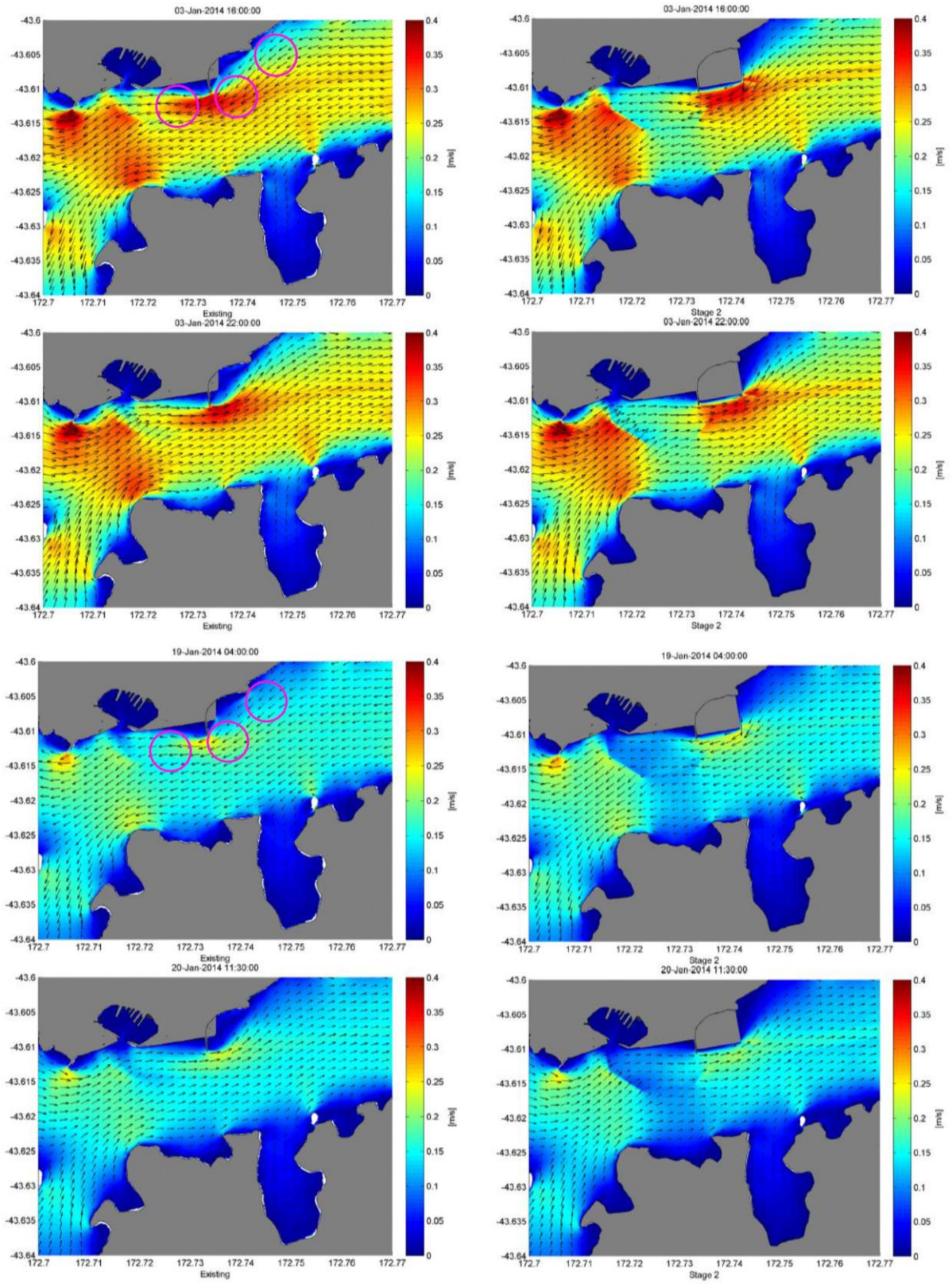

Figure 5. Snapshots of peak ebb and flood tidal flows during spring (top four images) and neap tides (lower four images) for the existing (left) and stage 2 (right) scenarios (MetOcean 2021. Note that the Stage 2 bathymetry includes the shipping channel. Red circles represent spatial areas discussed in the hydrodynamic advice letter (MetOcean 2021).

4.2.4. Wind

Airborne dust and surface water propagation is strongly influenced by wind, and the predominant directions are where it might be expected to see more deposition. The predominant wind direction in the Lyttelton Harbour region is north-east to south-west (Figure 6 and Bolton-Ritchie (2011). The highest average wind speeds (> 7 m/s) at the coal stockyard have generally occurred in an easterly direction in the warmer (drier) summer months, with a more west-southwest direction occurring in the winter (Chilton draft 2021).

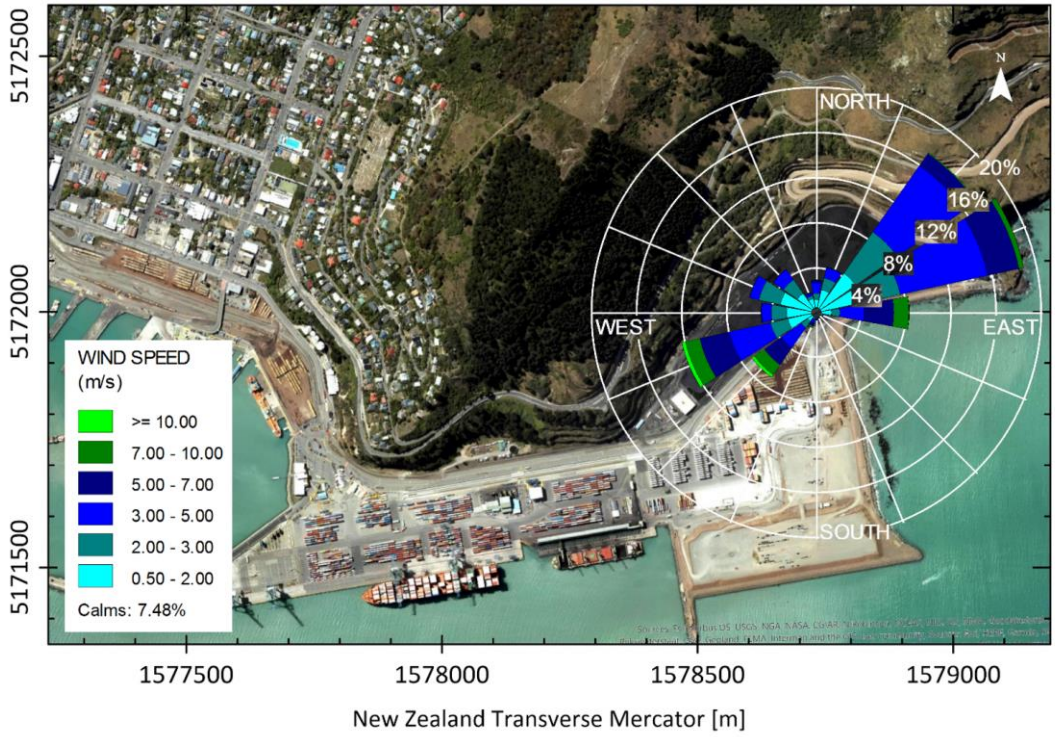

Figure 6. Wind rose generated from Lyttelton Port Companies coal stockyard monitoring site (2016-2017), excerpt taken from the Chilton 2021 draft air quality assessment

4.2.5. Water column & quality

Receiving environment information relating to the water column and water quality focuses mainly on the characteristics of the sea surface, as short-term entrainment (< 5 hours) in this layer was identified as a potential issue in Section 3.3.

Water column profile

From 1992 to 2013[39], water column profiling was performed as part of maintenance dredging benthic surveys (Gillespie et al. 1992; Gillespie & Asher 1995; Barter 2000b; Sneddon 2013b). Results had never shown significant stratification of the water column apart from the frequent and widespread presence of a benthic turbidity layer

[39] Discontinued following this date.

which results from resuspension of sediments via shear forces at the seabed. Benthic turbidity layers appear to be generally typical of the Harbour and inshore Pegasus Bay, especially in areas subject to wave action.

Sea surface temperature, salinity and pH

Sea surface temperature was measured for 17 months (22 February 2013 to 30 June 2014) at three sites within Lyttelton Harbour (Woods et al. 2014). This showed the sea surface temperature closest to the AOI (mid-harbour site) peaked in February 2014 (20.1 °C) and was at its lowest (8.4 °C) during July 2013 (a 11.8 °C seasonal difference). The mean monthly temperature was 18.6 °C in February 2014 and 9.4 °C in July 2013. There appeared to be no seasonal trend in the daily variation of sea surface temperature.

Seawater pH is usually in the range 7.7 to 8.4 in marine surface waters. In estuaries, pH variability is closely linked to salinity changes, photosynthetic processes, and dissolved oxygen cycles, and is often associated with estuarine freshwater inputs (Sneddon 2011b). Field and laboratory pH measurements for the samples collected within Te Awaparahi Bay by Sneddon (2011b) were 8.0–8.2, well within the acceptable range for seawater, consistent with the location in the Lower Harbour and the absence of significant estuarine character for Lyttelton Harbour as a whole (Sneddon 2011b).

Salinity levels at the inner port entrance (closest site to the AOI) measured during a study by Bolton-Ritchie (2011), showed that salinity appears to be lowest in winter and early spring (31–32 ppt), increasing in late spring to be highest in December (34–35 ppt). At this time, difference in salinity at different locations throughout the Lyttelton Harbour were linked to rainfall, stream/river water volumes and water depth.

Turbidity and suspended solids

The most important factor in the tolerance of marine communities to suspended solids[40] and turbidity[41] is the background levels of these parameters to which they are adapted (Sneddon et al. 2016). Due to active sediment transport processes operating within Lyttelton Harbour, background levels of suspended sediments are relatively high (Sneddon et al. 2017), with both turbidity and TSS concentrations typically decreasing with distance down the Harbour (Bolton-Ritchie 2011).

Median background levels of suspended sediments (total, TSS) from 2007–2008, ranged from around 20 mg/L at Governors Bay to 8 mg/L at the Harbour entrance, with maximums of 100 mg/L to 14 mg/L, respectively. At the inner port entrance (closest to the AOI), the median value was 9.3 mg/L and the maximum was 15 mg/L

[40] Total suspended solids (TSS) are a measure of the quantity of particles in water. Such particles include stirred up seabed sediment, soil from the land, detritus, i.e. dead plant or animal material and live organisms.
[41] Turbidity is a relative measure of the light scattering by suspended particles in water and indicates cloudiness or visual clarity of the water

(Bolton-Ritchie 2011). More recent figures (2013–2017) from Statistics NZ[42] give a measure of TSS of 9.96 mg/L directly south of the reclamation site and classing the TSS trend as 'improving' in the inner port entrance.

Median background levels of turbidity (NTU) from 2007–2008, ranged from 9.3 to 3.55 for Governors Bay to the Harbour entrance, respectively, with maximum levels of turbidity ranging from 54 to 6.2, respectively. The median value at the inner port entrance over the same period was 4.45 NTU and the maximum was 5.3 NTU (Bolton-Ritchie 2011). More recent figures (2013–2017) from Statistics NZ[22] give a measure of turbidity level of 4.5 NTU directly south-east of the reclamation site; however, the trend class is indeterminate. It is unclear why a trend classification hasn't been made but based on the work reported by Bolton-Ritchie (2011) the turbidity levels appear not to have changed significantly over this time.

Nutrients

Total nitrogen and total phosphorus nutrient concentrations within the AOI were classified as having an 'improving' (i.e. decreasing concentrations) trend[43] from 2013 to 2017; median concentrations over this time are listed:

- DRP = 0.01225 mg/L (Te Awaparahi Bay channel, indeterminate trend).
- Ammoniacal nitrogen = 0.013 (Te Awaparahi Bay channel); 0.021 (Port entrance, improving trend)
- Nitrate-nitrite nitrogen = 0.009 (Te Awaparahi Bay channel, indeterminate trend).
- TP = 0.025 (Te Awaparahi Bay channel, indeterminate trend); 0.037 (Port entrance, improving trend)
- TN = 0.1865 (Te Awaparahi Bay channel, indeterminate trend); 0.191 (Port entrance, indeterminate trend), however, improving trend middle of Inner Harbour.

The existing Lyttelton wastewater outfall is 1530 m to the east of the inner port entrance water quality sampling site (Bolton-Ritchie 2011). In 2002–2003 the highest ammoniacal nitrogen (NH_3N) concentrations occurred on incoming tides when the wind was WNW and ENE, which was considered to be suggestive of a Lyttelton outfall nutrient influence at this site.

Dissolved oxygen

DO (% saturation) was measured at sites in Lyttelton Harbour in 2007–2008 (Bolton-Ritchie 2011). The DO saturation ranged from 85 to 108%. The (due to be updated[44]) South-east Australia lower limit trigger values (TV) are 80% and 90% for estuaries and marine, respectively. DO saturation of less than 90% occurred in almost a third of the samples, specifically in association with summer months and more frequently in

[42] Coastal and estuarine water quality (shinyapps.io)
[43] https://statisticsnz.shinyapps.io/coastal_water_quality/
[44] The ANZG (2018) trigger values for physical and chemical stressors are due to be updated for New Zealand, and thus the South-east Australia guidelines are recommended to be used in the interim (ANZECC 2000).

the Upper Harbour. However, all of the Lyttelton sites were above the 80% TV for estuarine systems. The lower summer concentrations were considered to be a function of water temperature (rather than oxygen depletion due to specific stressors). More recently, DO concentrations (mg/L) within the AOI show an 'indeterminate' (not classed as deteriorating or improving) trend[45] from 2013 to 2017, with median concentrations over this time being 8.45 mg/L.

Nb. The amount of dissolved oxygen (in mg/L) in water will vary depending on temperature, pressure and salinity.

Contaminants

Water quality parameters have been monitored in the vicinity of and within the AOI itself (Bolton-Ritchie 2011), with limited information relating to chemicals that might be able to be linked to coal dust contamination. Water chemistry spatial and temporal characterisation requires a lot of data to be meaningful due to its inherent variability. This being said, there are some relevant data from previous studies, discussed as follows:

- Water samples have been collected within the AOI as part of the Te Awaparahi Bay reclamation project (Sneddon 2011b). Results from this investigation showed water samples were within the relevant ANZG (2018) guidelines, with no correlation with TSS in the turbidity plumes associated with the reclamation activities.
- A report by Bolton-Ritchie and Barbour (2013) also tested water on two separate occasions for metals/metalloids from a site on Sticking Point (and a number of other locations in/around the port). Results at the site showed detectable levels of Cr, Cu and Pb; however, all were below applicable ANZG (2018) 95% LOP guideline concentrations. The highest concentrations detected were for copper, from a site closest to the port dry dock.
- Water chemistry testing for metals/metalloids (As, Cr, Cu, Pb, Mn, Hg, Zn), TPH, PAHs, dissolved inorganic and organic carbon and sulphur, were also done as part of the elutriate test for this assessment (Section 3.6.3). While this receiving water sample provide only a snapshot in time, it does support the other findings (above), as all test parameters were below detection limits or were within background concentrations.
- Trace metal concentrations in mussel tissues (an indicator of water quality and bioaccumulation potential) were generally similar at Battery Point, Livingstone Bay (Sneddon 2020). Although there were small but statistically significant differences for arsenic, lead and nickel, higher concentrations were not exclusively associated with Battery Point (the closest site to the coal stockyard) for any of these.

[45] https://statisticsnz.shinyapps.io/coastal_water_quality/.

- In the past there have occasionally been low[46] detectable levels of PAHS in mussel tissue (an indicator of water quality and bioaccumulation potential) collected from the intertidal area of Te Awaparahi Bay and directly adjacent the coal stockyard (Royds 1996; Barter 2003; Sneddon 2011b), at Gollans Bay (Sneddon 2021) and at Battery Point and Livingstone Bay (Sneddon 2020). While there are limited data to evaluate temporal trends, the available information suggests that exposures to PAHs for intertidal species in Te Awaparahi Bay, Battery Point and Livingstone Bay may be decreasing over time (Sneddon 2019a, 2020, 2021).

4.3. Benthic ecology

The following sections describe the benthic ecology (subtidal and intertidal habitats and the associated community assemblages) in the vicinity of the LPC coal stockyard.

4.3.1. Intertidal habitats and communities

Organisms in the intertidal zone (described in Section 4.2.1) are adapted to a life of constant environmental fluctuations (e.g. tides, variable salinity, drying between tidal inundations, varying intensity of wave splash/surge, exposure to sunlight, extreme temperature changes, etc.).

Semi-quantitative intertidal surveys (presence/absence and relative cover/abundance of conspicuous biota) were carried out at Battery Point and the Te Awaparahi Bay rip-rap seawall in August 2008 (Sneddon & Barter 2009), at Battery Point again in December 2013 (Sneddon & Dunmore 2014), at Battery Point, Livingstone Bay and Ripapa Island in January 2020 (Sneddon 2020) and throughout the Harbour (including Gollans Bay) in 2021 (Sneddon 2021). A good summary of the characteristics is also provided in (Sneddon et al. 2017), the key points of which are provided below.

Battery Point

The upper intertidal zone was dominated by barnacles (*Chamaesipho columna*), the brown periwinkle (*Nodilittorina cincta* and *Nodilittorina unifasciata*), and the little black mussel (*Xenostrobus pulex*). Limpets (*Cellana ornata* and *Siphonaria zelandica*) were also common in the high shore zone. The polychaete tubeworm *Pomatoceros* sp. was common to abundant from the high to mid-shore (Sneddon et al. 2017).

Mid-shore rocky substrates were covered by barnacles (*C. columna* and *Epopella plicata*). The ubiquitous brown macroalga Neptune's necklace (*Hormosira banksii*)

[46] e.g. maximum PAH concentrations of 0.0009 and 0.0029 mg/kg were detected during the reclamation monitoring, during 2020 and 2011 respectively. These levels are much lower than the maximum levels for **edible** smoked mussels/foodstuffs, e.g. 0.005 mg/kg (benzo[a]pyrene) and 0.03 mg/kg (PAH4), Commission Regulation (EU) No 835/2011 (Sneddon 2020).

was also abundant, particularly in and around rock pools. Common intertidal molluscs such as limpets (*C. ornata, C. radians, S. zelandica, Patelloida corticata* and *Notoacmea parviconoidea*), topshells (*Diloma aethiops*), cat's eyes (*Lunella smaragdu*s) and the snakeskin chiton (*Chiton pelliserpentis*) were noted. The little black mussel (*X. pulex*) was abundant, and a number of brown and green seaweed species were common (e.g. *Cystophora scalaris, Colpomenia* sp. and *Ulva* spp.).

The low shore was dominated by blue and green-lipped mussels (*Mytilus edulis, P. canaliculus*), barnacles (*E. plicata and Austrominius modestus*), the brown invasive alga *Undaria pinnatifida* and coralline turf. Limpets (*Notoacmea* spp*., P. corticata and C. radians*), topshells and cat's eyes were common. Encrusting corallines ('paint') were also common, as were a number of brown seaweed species, including flapjack (*Carpophyllum maschalocarpum*), *Halopteris* sp., *Splachnidium rugosum*, and *Colpomenia* sp. Giant kelp (*Macrocystis pyrifera*) was prevalent along the subtidal fringe (Sneddon et al. 2017). See Section 4.7 for more detail on the conservation status some of these algal species.

Te Awaparahi Bay rip-rap seawall

Communities in the high shore intertidal zone were similar to those of Battery Point although the coverage of *Pomatoceros* sp. was denser in places (up to 100%). The mid- to low-shore zone was characterised by many of the same common intertidal species that featured at Battery Point (e.g. tubeworms, barnacles, chitons, gastropods and bivalves) although, apart from *X. pulex*, the mussel species were less in evidence. Dominant red seaweeds abundant in the lower zone were the crustose coralline paint and turf. The green algae *Ulva* sp. and *Codium adherens* also formed part of the assemblage. Low-shore brown macroalgae species were less prominent at the seawall site than at Battery Point (Sneddon et al. 2017).

Notably absent from the seawall habitat were *H. banksii* and other species which require a slightly lower energy environment or the presence of standing pools. In greater abundance were species that favour higher water movement and the greater protection from the sun afforded by overhangs and caves. These included an orange encrusting sponge and stalked ascidians (*Pyura pachydermatina*), which were occasionally found in the lower intertidal zone (Sneddon et al. 2017).

Additionally there has been a recent establishment of naturally-uncommon (though locally common, Atalah & Sneddon 2016) habitat-forming *Macrocystis pyrifera* giant kelp beds (a species sensitive to suspended sediments, Watanabe et al. 2016) on the man-made reclamation rip-rap shoreline adjacent the coal stockyard (pers. comm., Gareth Taylor, LPC, 10 June 2021). The alga appears to be adapting with the advancing reclamation shoreline and is apparently unaffected by the sediment suspensions created by this activity.

4.3.2. Subtidal habitat and communities

The subtidal zone is the region below the intertidal zone that is continuously covered by water. This zone has far more stable environment conditions compared to the intertidal zone, with less fluctuation in temperature, water pressure and sunlight.

The subtidal profile of the rip-rap structure on the eastern side of the Cashin Quay breakwater was very steep.

The subtidal habitat in Te Awaparahi Bay is categorised into two habitat/community groups, soft sediment and reef. Each of these are discussed in more detail in the following subsections.

Soft sediment

Benthic soft sediment communities in the vicinity of Te Awaparahi Bay have been extensively sampled using 130-mm diameter infauna corers (Figure 3). These communities were found to be relatively depauperate (low diversity) in terms of species richness, with polychaete worms numerically dominant. Habitat-forming species such as large or densely-living bivalve molluscs appear to be largely absent. In the coarser substrates closer to the shoreline, community diversity was found to be slightly greater, but species that were abundant in the sediments generally belonged to a relatively limited number of higher taxonomic groups (principally nematode and polychaete worms and amphipods). High levels of benthic turbidity, resuspension and deposition make for a dynamic sediment environment that favours communities dominated by small-bodied invertebrate taxa with generally short life cycles (Sneddon et al. 2017).

Trawls within Te Awaparahi Bay with an epifaunal dredge conducted in March 2017 also indicated a relatively sparse community of larger benthic fauna. Only four individual bivalve molluscs were collected from all four trawls, being one *Perna canaliculus*, one *Dosina zelandica* and two small Mactridae. The tunnelling mud crab *Hemiplax hirtipes* was present in all four trawls but this species is generally small enough to escape through a 10 mm mesh. The pennatulid *Virgularia gracillima* appeared in two trawls. Tube worm casts and a single sipunculid were also noted (Sneddon et al. 2017)

Despite intermittent dredge tailing disposal, diversity and evenness of benthic communities within Gollans Bay were comparable to undisturbed stations along the northern side of the outer Harbour suggesting recovery from deposition and little in the way of persistent effects, spatially or temporally (Sneddon 2021).

Subtidal reef communities in Te Awaparahi Bay and surrounds

Direct observations of subtidal shoreline habitats in Te Awaparahi Bay by diver are challenging due to persistent surge and frequent highly turbid conditions. Benthic

sampling of the bed of the Bay in 2008 was undertaken by divers in zero visibility (Sneddon & Barter 2009). However anecdotal reports have shown that reef habitats were restricted to the shoreline fringe and have noted a compressed zonation pattern, with macroalgae restricted to between 1 m and 2 m depth (Sneddon et al. 2017). The observed spatially limited nature of the subtidal reef was consistent with the 2008 side scan sonar imaging of the seabed (Sneddon et al. 2017)

A semi-quantitative record of subtidal hard substrate biota was compiled during dives conducted in March 2017 at Battery Point, the Te Awaparahi Bay rip-rap seawall adjacent to the coal stockyard and the eastern side of the Cashin Quay breakwater. All three of these dives were made in very limited underwater visibility (0–30 cm) that further decreased with water depth (Sneddon et al. 2017).

Battery Point – natural reef

The subtidal edge of the Battery Point reef was identified by side-scan sonar as extending no more than approximately 40 m into the Bay from the low tide mark (Sneddon & Barter 2009; Sneddon et al. 2017).

On the eastern side of Battery Point, the subtidal profile was found to be quite steep. The bedrock reef descended approximately 6 m to meet a sand and gravel substrate exhibiting prominent wave-mediated rippling (amplitude 8–10 cm). Consistent with anecdotal reports (Sneddon et al. 2017), the maximum depth extent of brown macroalgae (*M. pyrifera* and *Ecklonia radiata*) was 2.2 m. The most prominent encrusting biota were the green-lipped mussels *P. canaliculus*, which were very abundant (near-100% coverage) on all hard substrate down to the sand/gravel interface. The mussels themselves supported a range of red algae (coralline, feathery, foliose and branching forms), hydroids (*Amphisbetia*), barnacles, sponges, solitary and colonial ascidians and anemones (*Anthothoe albocincta*). Isolated breaks in the coverage by mussels featured larger erect sponges and stalked ascidians (*Pyura pachydermatina*). While triplefins (family Tripterygiidae) were noted, visibility was too poor to record the presence of other fish species (Sneddon et al. 2017).

No pāua were observed during the Battery Point dive, although it was noted that the substrate (dense mussel bed) was not typical of preferred habitat for this species. The spatially limited nature of the dive on the eastern face of the Point means that the general absence of pāua cannot be inferred, especially as they have been reported in the area in the past (Sneddon et al. 2017). Dives undertaken further east in Livingstone Bay recorded plentiful pāua at 0.5 m water depth (Sneddon et al. 2016) in kelp forest habitat, with *E. radiata* extending to below 4 m depth. Although the fringing reef habitats along the northern outer shoreline are likely to be broadly similar in nature, a natural spatial gradient in shoreline conditions would be expected to result in declining pāua numbers to the west of the central Harbour (Sneddon et al. 2017).

Te Awaparahi Bay seawall – rip-rap boulder facing

Subtidally, the boulders of the Te Awaparahi Bay seawall facing were interspersed with cobble-sized material. In water depths of approximately 2.5 m, this graded to mostly cobble/pebble, then silty pebble and gravel at 3.3 m depth. The maximum depth extent of brown macroalgae (*M. pyrifera* and *E. radiata*) was around 3 m. Prevalence of red algae was greater than at Battery Point, with turfing and larger foliose branching forms (Rhodymenia) being recorded along with the ubiquitous coralline paint. The green alga sea lettuce (*Ulva* sp.) was common.

The most distinctive difference between the reef communities of the seawall and breakwater structures and those observed during the Battery Point dive was the complete absence of mussels (*P. canaliculus*). The absence of these dense beds effectively meant that hard substrate surfaces for encrusting communities were fundamentally different. Other notable features of the Te Awaparahi Bay community were a greater diversity of sponges, prevalence of the cushion star *Patiriella regularis*, presence of the gastropod grazer *Turbo smaragdus*, and lower abundance of *P. pachydermatina* (Sneddon et al. 2017).

Cashin Quay breakwater – rip-rap boulder structure

The subtidal profile of the rip-rap structure on the eastern side of the Cashin Quay breakwater was very steep. The boulder substrate was unvarying throughout the dive to 7.5 m water depth and is likely to have continued until meeting the sediment interface at around 9 m. The underwater visibility was very poor and decreased to zero at around 5 m water depth with little to negligible light penetration below this level. Foliose red algae (*Rhodymenia*) was prevalent, forming near total coverage in places, although a sparse canopy of *M. pyrifera* was present in the top 2–3 m. The mussel *P. canaliculus* was again absent and no encrusting algal forms were observed. In patches clear of algae, ascidians and sponges were the dominant cover. (Sneddon et al. 2017).

Nb. Past field surveys identified no habitats, communities or organisms of special scientific or conservation interest within the vicinity of Te Awaparahi Bay; nor were the communities described identified as being limited in occurrence within the wider area of Lyttelton Harbour (Sneddon et al. 2017). However, it is noted that since the pre-2019 investigations were performed, NZ conservation status taxa lists have become more easily accessible (Refer to Section 4.7).

4.4. Primary productivity, plankton, toxic algae and nutrient pathways

4.4.1. Chlorophyll-a and algal blooms

Chlorophyll-*a* is the most abundant form of chlorophyll within photosynthetic organisms. It is measured in marine waters as an indicator of phytoplankton abundance and biomass and can respond rapidly to nutrient inputs (sometimes resulting in algal blooms). Chlorophyll-*a* median concentrations between 2007 and 2008 at the inner port entrance surface waters were 0.0021 mg/L, with a maximum of 0.0053 mg/L (appendix 4 of Bolton-Ritchie 2011). Earlier levels recorded at the inner port entrance between 2002–2003 ranged from 0.0007–0.007 mg/L, with a mean of 0.0026 mg/L (appendix 4 of Bolton-Ritchie 2011). Statistics NZ[47] reports a median result of 0.0018 mg/L (closest to the AOI) from 2013–2017, with the concentration trend classed as 'improving' in the Upper and Lower Harbour[48] from 2008–2017.

Phytoplankton blooms occur occasionally in Lyttelton Harbour, typically relating to sunny weather, warmer water temperatures and recent rainfall (causing increased freshwater nutrient inputs). In February 2009, a bloom of *Gymnodinium* spp. resulted in lime-green discoloured water in the Port of Lyttelton (Bolton-Ritchie 2011). In 2012, an algal bloom at the Harbour entrance was reported to be caused by the organism *Mesodinium rubrum*[49], resulting in red/brown discoloration of the seawater. An example of a chlorophyll-*a* concentration that might occur during a conspicuous phytoplankton bloom is 189.5 µg/L (Bolton-Ritchie 2011), however chlorophyll-*a* concentrations as low as 0.005 mg/L can result in discolouration of the water (Bolton-Ritchie 2017). An investigation by Sneddon et al. (2016) reported *there is no evidence to suggest that cyst-producing toxic micro-algae are a special problem in the harbours and inlets of Banks Peninsula. The various algal toxin contamination events that occur from time to time are caused by common cosmopolitan species*.

4.5. Fish and fisheries resources

A wide variety of fish species have been reported as occurring in Lyttelton Harbour (Table 10). Recreational fishing is known to occur in the Lyttelton Outer Harbour, and the Upper Harbour mudflats are recognised as important habitats for fish species such as sole (*Peltorhamphus novaezeelandiae*), red cod (*Pseudophycis bachus*), spotted stargazer (*Genyagnus monopterygius*) and flounder (*Rhombosolea* sp.) (Sneddon 2014b).

[47] Coastal and estuarine water quality (shinyapps.io)
[48] Nb. it's not clear what time of day/season and where in the water column the Statistics NZ measurements were being taken (some algae migrate up and down within the water column). It is assumed that the measurements were taken at the sea surface.
[49] https://www.stuff.co.nz/the-press/7712115/Algal-bloom-discolours-Lyttelton-Harbour

Table 10. List of fish species targeted or caught incidentally by recreational fishers within Greater Lyttelton Harbour (Sneddon 2014b).

Common name	Scientific name
Red cod	*Pseudophycis bachus*
Sand flounder	*Rhombosolea plebeia*
Sole	*Peltorhamphus novaezeelandiae*
Quinnat Salmon	*Oncorhynchus tshawytscha*
Monkfish / Stargazer	*Kathetostoma giganteum* or *Genyagnus monopterygius*
Trevally	*Pseudocaranx georgianus*
Ling	*Genypterus blacodes*
Kahawai	*Arripis trutta*
Tarakihi	*Nemadactylus macropterus*
Blue cod	*Parapercis colias*
Butter fish	*Odax pullus*
Blue moki	*Latridopsis ciliaris*
Red gurnard	*Chelidonichthys kumu*
Garfish / piper	*Hyporhamphus ihi*
Yellow-eye mullet	*Aldrichetta forsteri*
Spotted wrasse	*Notolabrus celidotus*
Puffer fish	*Contusus richei*
Conger eel	*Conger verreauxi*
Stingray or skate	*Bathytoshia brevicaudata* or Dipturus nasutus***
Spiny dogfish	*Squalus acanthias*
Sevengill shark	*Notorynchus cepedianus*
School shark / lemon shark	*Galeorhinus galeus*
Rig	*Mustelus lenticulatus*

* Edit: unaccepted synonym for short-tailed stingray: *Dasyatis brevicaudatus.*

**Edit: Rough skate species name.

During summer, the port area is frequented by juvenile fish of species such as red cod (*Pseudophycis bachus*), yellow-eye mullet (*Aldrichetta forsteri*), blue warehou (*Seriolella brama*), spiny dogfish (*Squalus acanthias*), green pufferfish (*Contusus richei*), scaly gurnard (*Lepidotrigla brachyoptera*), spotted stargazer (*G. monopterygius*), and trevally (*Pseudocaranx georgianus*) (Sneddon 2014b). Adult fish such as red cod and quinnat salmon (*Oncorhynchus tshawytscha*) have also been caught from the wharves with historic studies in the upper and central Harbour areas recording catches of adult puffer fish (*C. richei*), sole (*P. novaezealandiae*), and flounder (*Rhombosolea plebeia*) (Sneddon 2014b). No stock abundance figures were available for the Harbour itself but the sheltered, relatively shallow waters of the wider Harbour area cannot be dismissed as possible spawning and nursery grounds for

many of these species, with evidence of planktonic eggs and larvae being carried northwards by the Southland current to colonise the bays and harbours of Banks Peninsula (Sneddon 2014b).

Sneddon (2014b) noted that a number of the fish species that frequent the Harbour are known prey species for Hector's dolphins. These include yellow-eye mullet, red cod, Ahuru (*Auchenoceros punctatus*) and flatfish species. While the dolphins are not particularly selective in their choice of prey (which also includes arrow squid), they are known to frequent the Harbour more in the summer period, possibly following the available food sources.

4.6. Mahinga kai species/habitats

Mahinga kai is a terms that means 'to work the food' and relates to the traditional value of food resources and their ecosystems, as well as the practices involved in producing, procuring, and protecting these resources. In an effort to characterise the mahinga kai values of the AOI, two aspects of mahinga kai have been looked at in detail in this assessment: 1) kaimoana species and 2) their related habitats.

There was no list of species or habitats of interest provided for this assessment by LPC for which to assess the ecological effects, thus locally important mahinga kai species and habitats have been identified through information gathered from previous iwi engagement meetings and subsequent reports for the Te Awaparahi Bay reclamation project (T&T 2014; Floerl & Fletcher 2017; Ogilvie 2017; T&T 2017).

There are two culturally significant Mātaitai reserves in Lyttelton Harbour (Rapaki and Whakaraupō, Figure 7). Te Awaparahi Bay region (reclamation area) is excluded from the Mātaitai. The bylaws for the Whakaraupō Mātaitai Reserve prohibit the harvest of all shellfish, other than pāua, tuaki (cockles), pipi, kūtai (mussels), pāpaka (crabs) or tio (oysters), with new daily bag limits. The bylaws prohibit taking tuaki (cockles) from Walkers Beach (Ōtamahua/Quail Island) and Rec Bay (Purau). There are also daily finfish bag limits for total fish caught, with specific limits defined for; pātiki (flounder), rāwaru (blue cod), hoka (red cod), mararī (butterfish), moki, and kōiro (conger eel). It is prohibited to take whai repo (skates and rays) or seaweed, other than karengo or wakame (*Undaria pinnatifida*), from within the Whakaraupō Mātaitai Reserve (FNZ 2020b). The daily limits for the Rapaki Mātaitai Reserve are equivalent to those for the adjacent Whakaraupō Mātaitai, and are approximately one-fifth of the limits set for the wider Canterbury area. There are no minimum legal sizes set for Tuaki, Pipi or Tio in the Whakaraupō Mātaitai or the wider Canterbury area (FNZ 2020a).

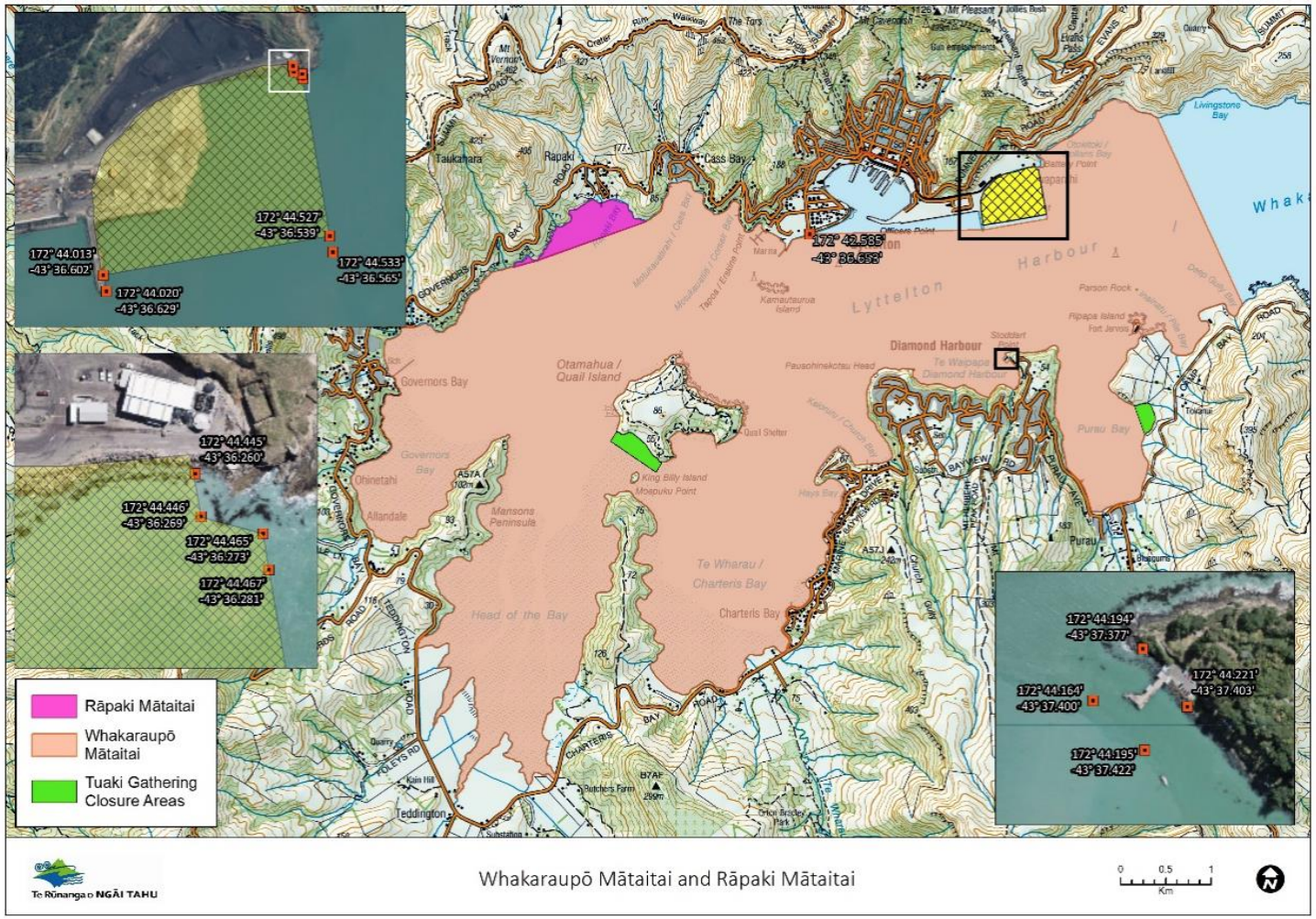

Figure 7. Mataitai reserves and Tuaki gathering closure areas in Lyttelton Harbour (FNZ 2020b). The yellow-gridded areas are the Lyttelton Port Company (LPC) exempt reclamation area (Te Awaparahi Bay).

Of specific relevance to this assessment was a list of kaimoana species considered to be of significance to Te Hapū o Ngāti Wheke, as compiled by Tonkin & Taylor (T&T 2014) following discussions with the Rūnanga (Table 11). This report identifies seventeen non-finfish (invertebrates) taxa and 20[50] finfish as locally-important within Whakaraupō (Lyttelton Harbour), listed here in Table 11.

It is difficult to determine the finfish mahinga kai species present within the AOI, as only the limited observations made in the subtidal and intertidal reefs can be used for comparison. In other investigations the focus has been to exclude finfish species from the assessments and monitoring because they have the ability to move out of Te Awaparahi Bay, making them difficult to manage directly and unlikely to be chronically affected by discharges (refer to table 2 of T&T 2017).

In contrast, the less mobile and more susceptible, non-finfish (invertebrate) kaimoana species have been compared to the available taxa lists for intertidal and subtidal surveys the area by Floerl and Fletcher (2017). The study found no specific evidence of rock oyster (*Saccostrea commercialis*) or crayfish (*Jasus edwardsii*) occurring in Lyttelton Harbour with kina only detected at low abundance in a single location (Table 12). However, there is evidence that historically both crayfish and kina occurred in reasonable numbers in various locations around the Harbour (Floerl & Fletcher 2017).

[50] Noting that the same species of butterfish *Odax pullus* was listed twice and spelt differently: Marari vs Marare.

Table 11. List of mahinga kai species associated with Lyttelton Harbour. Species compiled from T&T (2014) and Ogilvie (2017).

Maori name	English or common name	Species name
Invertebrates		
Paua	Abalone	*Haliotis iris*
Kina	Sea urchin	*Evechinus chloroticus*
Kutai	Blue mussel	*Mytilus edulis*
Kutai	Green lipped mussel	*Perna canaliculus*
Koura	Spiny crayfish	*Jasus edwardsii*
Tio	Oyster	*Ostrea lutaria*
Tio	Rock oyster	*Saccostrea commercialis*
Tipa	Scallop	*Pecten novaezelandiae*
Tuaki	Cockle	*Austrovenus stutchburyi*
Pipi	Pipi	*Paphies australis*
Pūpū	Cat's eye	*Lunella smaragdus*
Pūpū	Scorched monodont	*Diloma aethiops*
Pūpū	Mudflat snail	*Amphibola crenata*
Tuatua	Tuatua	*Paphies donacina**
Wheke	Octopus	*Pinnoctopus cordiformis* and other species
Kāeo	Sea tulip	*Pyura pachydermatina*
Karengo	Seaweed	*Porphyra, Pyropia,* and *Clymene* species
Finfish		
Moki	Blue moki	*Latridopsis ciliaris*
Marari (Marare?)	Butter fish	*Odax pullus*
Pioki	Rig	*Mustelus lenticulatus*
Hoka	Red cod	*Pseudophycis bachus*
Hapuku	Groper	*Polyprion oxygeneios*
Whairepo	Stingray	*Bathytoshia brevicaudata**
Pakaurua*	Skate	*Dipturus nasutus*
Patiki	Sand flounder	*Rhombosolea plebeia*
Patiki	Yellow belly flounder	*Rhombosolea leporina*
Patiki rori	Lemon sole	*Pelotretis flavilatus*
Patiki mohoao	Black flounder	*Rhombosolea tapirina*
Whiting	Whiting	*Micromesistius australis*
Aua*	Yellow-eyed mullet (herring)	*Aldrichetta forsteri*
Koiro	Conger eel	*Conger verreauxi*
Maka*	Barracouta	*Thyrsites atun*
Moamoa*	Stargazer	*Genyagnus monopterygius*
Inanga	Whitebait	*Galaxias maculatus* and other species
Makohuarau*	Spiny dogfish	*Squalus acanthias*
Hāmana	Quinnat salmon	*Oncorhynchus tshawytscha*
Manaia*	Sea horse	*Hippocampus abdominalis*

*Edit: originally identified as *P. subtriangulata*, however this species is not found in Canterbury.

**Edit: Unaccepted synonym, *Sasyatis brevicaudatus*

Most of the other kaimoana species have been recorded from most of the sampling locations around the Harbour. Only pāua appear restricted to rocky reefs around the eastern part of the Harbour (Battery Point, Livingstone Bay etc, Table 12).

Te Awaparahi Bay was the only sampling location where the substrate consisted of rip-rap instead of natural rocky reef. Only four of the ten kaimoana species (*Lunella smaragdus, Diloma aethiops, Mytilus galloprovincialis* and *Pyura pachydermatina*) were encountered at this location, while the natural rocky reefs at the other locations featured five to nine of the species (Table 12). Based on this, the natural rocky reefs/ shoreline and subtidal reefs from Battery Point (within and to the east of the AOI) could be considered mahinga kai habitats, and to a lesser extent the man-made rip-rap shoreline now covering much of Te Awaparahi Bay (within and south-west of the AOI). However, previous findings reported that these locations did not represent a more important part of the overall kaimoana and habitat resources than other similar areas of the Harbour (Sneddon et al. 2017).

Nb. With the final completion of the reclamation, the near shore reef habitats in central Te Awaparahi Bay will be completely gone.

Nb. The Kaimoana Management Plan (Floerl & Fletcher 2017; T&T 2017) states the need for further baseline surveys to obtain a more comprehensive understanding of the presence, distribution and abundance of culturally significant kaimoana species.

Table 12. Presence (shaded cells) or absence (no shading) of kaimoana species recorded at 16 intertidal and subtidal sites within Lyttelton Harbour (Floerl & Fletcher 2017).

Scientific Name	Common name	Sandy Bay	Rapaki Bay	Cass Bay	Corsair Bay	Shag Reef	Magazine Bay	Te Awaparahi Bay	Battery Point	Livingstone Bay	White Patch Point	Camp Bay	Pile Bay	Ripapa Island	Purau Bay	Diamond Harbour	Church Bay
Pyropia sp. and *Clymene* sp.	Karengo	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■
Lunella smaragda	Pūpū (cat's eye snail)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Diloma aethiops	Pūpū (spotted topshell)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Haliotis iris	Pāua								■	■	■		■	■		■	
Mytilus galloprovincialis	Kutai/ blue mussel	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Perna canaliculus	Kutai/ green-lipped mussel	■	■	■	■		■		■				■	■	■	■	■
Ostrea chilensis	Tio / flat/dredge/Bluff oyster	■	■	■	■	■	■		■	■	■	■	■	■		■	■
Jasus edwardsii	Koura/crayfish																
Evechinus chloroticus	Kina													■			
Pyura pachydermatina	Kāeo/ sea tulip	■	■	■	■			■	■	■	■	■	■	■	■	■	■

4.7. Threatened species and sensitive or significant habitats

Lyttelton Harbour has a number of features and areas of high marine ecological value (Sneddon 2014b). These include the fringing reefs of the outer heads and the salt marshes and tidal flats of the Upper Harbour that support a range of wading birds and waterfowl and are likely to represent nursery grounds for a number of fish species (Sneddon 2014b), all of which are outside of the AOI. Past field surveys have identified no habitats of special scientific or conservation interest within the vicinity of Te Awaparahi Bay; nor were the communities described identified as being limited in occurrence within the wider area of Lyttelton Harbour (Sneddon et al. 2017).

As well as reviewing previous findings (Section 4.3), a representative subtidal and intertidal species lists was compiled from five different surveys (Handley et al. 2000; Fenwick 2003; Sneddon & Barter 2009; Sneddon 2011b; Sneddon & Dunmore 2014) within the AOI. On cross-referencing with relevant conservation status reports (Freeman et al. 2013; Nelson et al. 2019), the exercise identified four *at risk* and two *data deficient* taxa that are known to occur within the AOI (summarised in Table 13).

As well as this, the nationally critical threatened brachiopod species *Pumilus antiquatus* was reportedly found on boulders off Gladstone Wharf (now the cruise ship berth) in the late 1960s and another brachiopod *Calloria inconspicua* (not listed as threatened) was studied at the same location in the 1940s (Sneddon 2014b and references therein). Since then, no subsequent surveys of intertidal and subtidal in the area have found any evidence of brachiopod populations within the AOI (Sneddon 2014b and references therein).

The ‘at risk’ algae identified in Table 13, *Macrocystis pyrifera* (declining), *Myriogloea intestinalis* (naturally uncommon) and *Petalonia* sp.[51] (naturally uncommon or data deficient) will be considered as species/taxa determining factors in the risk assessment (EIAG 2018). The giant kelp *Macrocystis pyrifera* will also be considered as a ‘naturally uncommon ecosystem’ habitat determining factor (Table 2) in the risk assessment, due to it being a habitat forming[52] species.

The ‘at-risk’ clam *Mysella* sp. is known to occur within the AOI, however it’s not clear if the ‘nationally critical’ lamp shell *Pumilus antiquatus* is still in the area, indeed, with the large amount of anthropogenic disturbance to the breakwall and wharf over the last 80 years and the lack of evidence in subsequent surveys, it’s likely that they are no longer resident. Regardless, as both species could potentially be in the vicinity, they will both be considered important as species/taxa determining factors in the risk assessment (EIAG 2018).

[51] Nb. This identification was only to genus level, therefore it’s not clear which *Petalonia* species this relates too. To be conservative it has been included/considered here as naturally uncommon.
[52] Habitat-forming species are organisms whose structure enhances species co-existence.

There are a number of exotic *Ulva* spp. and *Undaria pinnatifida* algae that are now common throughout the Harbour that are listed in the conservation status reports as 'introduced and naturalised'. There are also a number of other known exotic taxa (e.g. *Sabella spallanzanii, Theora lubrica* etc.) that have been identified through long-term port surveys. The presence of these taxa illustrates the influences from shipping and the disturbed nature of the inner port and the AOI environments. There were also some alga listed that are considered to be 'data deficient' (e.g. *Porphyra sp.* and *Codium sp.*). These taxa were not included in the risk assessment criteria as they are not considered threatened/at risk or sensitive and/or are undesirable.

Table 13. At risk and data deficient taxa within the AOI (summary spread sheet downloaded from NZTCS website containing macroalgae lists from Nelson et al 2019, and the marine invertebrate list from Freeman et al. 2013).At risk taxa are highlighted in green. Cross referenced against subtidal and intertidal species lists obtained from five different surveys (Handley et al. 2000; Fenwick 2003; Sneddon & Barter 2009; Sneddon 2011b; Sneddon & Dunmore 2014) to obtain an indication of the species within the AOI.

Species	Common name	Category	Status	Notes
Codium sp.	Green algae	Data Deficient	Data Deficient	
Porphyra sp.	Red algae	Data deficient	Data deficient	14 species listed as DD
Macrocystis pyrifera	Brown algae	At risk	Declining	
Myriogloea intestinalis	Brown algae	At Risk	Naturally Uncommon	
Petalonia sp.	Brown algae	At risk / data deficient	Naturally uncommon/ data deficient	*Petalonia binghamiae* (at risk and naturally uncommon) and *P. fascia* (data deficient)
Mysella sp.	Clam	At risk	Naturally uncommon	*Mysella* sp. and *Mysella tellinula* both listed as at risk / naturally uncommon

5. POTENTIAL DIRECT ECOLOGICAL EFFECTS

The following sections discuss the potential direct marine ecological effects of coal dust deposition to the marine environment. As described in the introduction, if the potential direct effects are less than minor then the potential indirect effects will not be considered further here.

5.1. Changes to coastal water physicochemistry

Increased levels of coal particles in the water column have the potential to change the water column's physicochemical composition, and directly increase the concentrations of suspended solids and levels of turbidity in the water surrounding the LPC coal stockyard (i.e. reducing water quality). The magnitude of these effects will depend on the volume and characteristics of coal particles in suspension (which will, in turn, depend on rate of supply and patterns of water movement), duration of exposure and existing background water conditions (Ahrens & Morrisey 2005). Therefore, the focus of this effect assessment is whether there is likely to be any measurable difference to background conditions as a result of coal particles.

5.1.1. Magnitude/consequence of effect (M/C)

Once deposited on the sea surface, unburnt coal has the potential to cause a number of indirect effects, such as increased levels of acidity, radionuclides, salinity, trace metals, hydrocarbons, chemical oxygen demand and, potentially, macronutrients to aquatic environments, which pose potential hazards to aquatic organisms (Ahrens & Morrisey 2005). In particular, trace metals and polycyclic aromatic hydrocarbons (PAHs) are present in amounts and combinations that vary with the type of coal (Section 3.5). Whether or not these can be leached from the coal matrix and affect aquatic organisms will depend on the type of coal, its mineral impurities and environmental conditions, which together determine how desorbable these potential contaminants are (Ahrens & Morrisey 2005).

As well as these effects, increased concentrations of suspended particulates in the water column could potentially result in physical abrasion, reduced light (reducing plant growth and influencing primary grazers), smothering of the seabed and macrofauna (clogging of feeding and breathing organs), reduced feeding efficiency of visual predators (e.g. fishes), clogging of feeding/respiratory organs and mortality of eggs/larvae (Ahrens & Morrisey 2005).

A shift in the background levels of water composition (generally) within the AOI would likely manifest as changes in community structure and may include the following (Ahrens & Morrisey 2005):

- bioaccumulation, elevated toxicity in invertebrate tissues

- cellular level biochemical responses (not necessarily cellular damage, but a response to toxic compounds)
- reduced growth, reproduction and abundance
- mortality
- altered population and community structure.

A specific shift in the background levels of turbidity and suspended sediments within the AOI would also be likely to manifest as changes in community structure, but may also have the following consequences (Sneddon et al. 2016):

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

It should be noted also that the shifts described above, should they occur, are considered reversible[53], with a return to normal background conditions when the stress is removed (Sneddon et al. 2016). Thus, the magnitude / consequence is classed as of 'Negligible' magnitude and 'Minor' consequence (local, short-term adverse impacts).

5.1.2. *Likelihood of an effect occurring (L)*

The LPC coal appears to be a sulphur-poor coal (sulphur content 1–2%, Table 6), thus more likely to produce a more pH-neutral runoff (Ahrens & Morrisey 2005). In the marine environment, significant impacts of acidic leachates are unlikely due to the vast buffering capacity of seawater bicarbonate (Ahrens & Morrisey 2005). The limited field and laboratory pH measurements taken for samples collected within Te Awaparahi Bay support this finding, showing that seawater pH is within the acceptable range for seawater (Section 4.2.5).

Coal contains nitrogen and phosphorus in measurable (Table 6) and potentially leachable quantities, with chemical oxygen demand (reducing DO levels) also higher in association with higher suspended solids (Ahrens & Morrisey 2005). Despite this, nutrient concentrations in the Harbour are generally on an 'improving trend,' with an 'indeterminate' trend specified for more recent (2013–2017) DO concentrations. Past DO saturation records suggest the Harbour is within the DO% trigger values for estuaries, and close to that for open marine waters (Section 4.2.5). Salinity and temperature also appear to be within acceptable ranges for seawater in Lyttelton Harbour as a whole (Section 4.2.5).

[53] It is noted that this what's known in the context of typical SS inputs (e.g. from dredging plumes and riverine inputs etc).

Results of the elutriate testing suggest that even under unusual circumstances where high levels of coal dust deposition might occur in the coastal environment due to increased roading activity (701 mg/L), DIC, DNPOC, PAHs and TPH were either not at detectable levels or were similar to background concentrations. However, some metals/metalloids (Cu, Mn, and Zn), were detectable at concentrations above ANZG (2018) guidelines. Nonetheless, estimated receiving environment concentrations (Section 3.6.3) showed the toxicants would probably be at least two orders of magnitude below the concentration required for a conservative 99% level of species protection (ANZG 2018). This supports other findings from limited water quality data available for the AOI (discussed in Section 4.2.5) and is consistent with previous studies that showed coal generally does not leach toxic (or bioavailable) levels of trace metals or PAHs (Ahrens & Morrisey 2005; Berry et al. 2013; Shanchez 2014; Berry et al. 2016; Haury 2017).

Recent stormwater monitoring results have shown detectable levels of metals/ metalloids and occasionally, low levels of PAHs in mussel tissue (Royds 1996; Barter 2003; Sneddon 2011b). However, these were below FSANZ[1] (2016) standards (Sneddon 2019a). The limited temporal data suggest that exposure to PAHs for intertidal species in Te Awaparahi Bay may be decreasing over time (Sneddon 2019a). The most recent relevant monitoring results (Sneddon 2020) have shown a reduction in total metals and PAH sediment concentrations (suggesting improving water chemistry in general), and all monitoring results have consistently remained within background levels and/or below the default sediment guideline trigger values for ecological protection (< 10 mg/kg%OC, ANZG 2018).

The most important factor in the tolerance of marine communities to suspended solids and turbidity is the background levels of these parameters to which they are adapted (Sneddon et al. 2016). Due to active sediment transport processes operating within Lyttelton Harbour, background rates of fine sediment deposition in benthic areas are relatively high (Sneddon et al. 2017), with both turbidity and TSS typically decreasing in concentration with distance down the Harbour (Bolton-Ritchie 2011). It is also noted that even with the chronic deposition of coal dust over the last 45 years, the TSS trend (9.6 mg/L median) has been classified as improving in the inner port area (Section 4.2.5).

Water testing and intertidal/subtidal assessments in the area show no evidence of TSS and turbidity changes occurring. The marine benthic communities are considered to be well-adapted to naturally turbid conditions within Lyttelton Harbour, and have acclimated well to periods of increased sediment supply from the ongoing maintenance dredging programme (Sneddon & Barter 2009). As well as this adaptation, the establishment of giant kelp (*Macrocystis pyrifera*), (a species sensitive to suspended sediments) on rip-rap shoreline adjacent the coal stockyard suggests that the coal dust is making no discernible difference to the background concentration

of suspended sediment and turbidity. Nor has there been any evidence of significant amounts of sediment (silt) deposition on nearby reef habitats (Sneddon 2021).

Some dust suppressants have potential to add toxicity to the coal dust mix. However, both the specific suppressants used by LPC (P47 and CDS 300) are considered 'non-hazardous' according to the New Zealand Environmental Protection Authority (EPA) criteria (MSDS 2019b, 2019a), and they are predicted to have low risk of acute and chronic toxicity in the receiving environment (particularly at low application concentrations), based on known properties of components (S&B 2007, 2011). Dust suppressants in general were investigated as part of the reclamation stormwater effects assessment (Sneddon 2010b). The investigation surmised that the small amounts of highly diluted suppressant which may be released to the Harbour would undergo substantial dilution and dispersion in the tidally flushed waters of Te Awaparahi Bay.

Although many kaimoana species have also been identified as occurring on hard substrates in the immediate vicinity of the coal stockyard (Section 4.6), past survey findings and investigations relating to the reclamation effects reported that these locations do not represent a more important part of the overall kaimoana resource than other similar areas of the Harbour (Sneddon et al. 2017).

Given these findings above, the likelihood of any adverse effect on water quality occurring is considered to be 'remote' (highly unlikely to occur).

5.1.3. Spatial scale of effect

No changes in water column composition has been detected within the AOI; however, there have occasionally been low detectable levels of metals and PAHs in mussel tissue collected from the intertidal area of Te Awaparahi Bay (Battery Point), directly adjacent the coal stockyard (Sneddon 2019a) and as far as Gollans Bay (Sneddon 2021) and Livingstone Bay (Sneddon 2019a, 2020).

The highest (relative) level of airborne deposition on marine surface waters was predicted to be to the inner Te Awaparahi Bay, with lower rates along the Cashin Quay and east of Battery Point (Section 3.3.1). Following deposition on the sea surface, lighter particles could potentially travel as far as 6 km in the water column before reaching the seabed. However the majority of coal dust particles (approximately 85% were greater than 75 µm, see Section 3.3) are unlikely to be entrained in the surface layer for more than a few seconds (settling velocity of 0.09 and 2.7 cm/sec for 75 and 200 um particles, respectively), and they will have travelled horizontally further than a metre in 10 seconds (13 cm/sec on a neap tide, MetOcean 2021), with the larger particles reaching the seafloor between 40–200 m from the deposition point. Supporting this estimate of a more localised spatial extent, coal particles and/or specific indicator chemicals (e.g. PAHs) were specifically observed in

sediments from Te Awaparahi Bay, Cashin Quay, the Inner Harbour and as far as Gollans Bay (< 1.5 km from the coal stockyard), but not as far as the adjacent channel or Godley Head (~8 km, Section 3.3.4).

Thus, while a small amount of finer coal particles could potential travel further, the most likely location to have detectable levels of coal (if any, following mixing) would be immediately adjacent to Te Awaparahi Bay, Gollans Bay and the bordering shipping channel/swing basin areas (the AOI, Section 3.3). Thus, the spatial scale is classed as medium (the 500 m to 2 km grouping, Table 2).

5.1.4. Persistence/duration

The deposition of coal dust itself is chronic (ongoing), with higher deposition rates in the summertime; however, no distinction from background water characteristics is evident in relation to coal dust deposition in the receiving waters. Also, the lack of detectable effects outside of the stormwater zone of influence (following 45 years of coal dust deposition), suggests coal dust deposition is not contributing to cumulative effects. Therefore, the most conservative persistence category is 'a rapid return to background levels' if the dust deposition is stopped.

5.1.5. Species and habitat determining factors

There are five *at-risk* and *threatened* 'species factors' potentially within the AOI that may be sensitive to coal dust deposition, with the giant kelp *Macrocystis pyrifera* also constituting a 'naturally uncommon ecosystem' (habitat factor):

- *Macrocystis pyrifera* – giant kelp beds (at-risk/naturally uncommon).
- *Myriogloea intestinalis* – alga (at-risk/naturally uncommon).
- *Petalonia* sp. – alga (at-risk/naturally uncommon).
- *Mysella* sp. – clam (at-risk/naturally uncommon).
- *Pumilus antiquatus* – lamp shell (threatened/nationally critical).

Though not listed with a specific conservation status, the significant kaimoana species/habitats identified in Section 4.6 are of cultural value and are therefore interpreted in the same way as conservation status taxa in the risk assessment. These taxa and habitat 'factors' are:

- *Haliotis iris* (Pāua) – grazer/herbivore
- *Lunella smaragdus* (Pūpū) – grazer/herbivore
- *Diloma aethiops* (Pūpū) – grazer/herbivore
- *Mytilus galloprovincialis [edulis]* (Kutai) – filter feeder
- *Pyura pachydermatina* (Kāeo) – filter feeder
- the natural intertidal and subtidal reefs from Battery Point (within and to the east of the AOI) appear to be comparably valuable mahinga kai habitats, and to a lesser

extent the man-made rip-rap shoreline now covering much of Te Awaparahi Bay (within and south-west of the AOI).

5.1.6. Additional effects following the conclusion of reclamation activities

The completed reclamation areas are expected to work as an obstacle to the nearshore flow, reducing the current speed west and east of the reclaimed areas and narrowing the zone of higher flow speed in front of the development (Section 3.3). This suggests that under most circumstances, the future reclamation will reduce the distance travelled by the coal particles. Given this will reduce the amount of dust deposited in the marine environment, the likelihood and magnitude of any potential coastal water-related physicochemical effects are likely to be reduced as well.

Based on the effects categories described above and summarised in Table 14, there is a **very low** risk of having a **very low** level adverse water quality effect.

Table 14. Potential effect summary box: changes in water physicochemistry.

Effect category	Changes to coastal water physicochemistry (incl. suspended solids and turbidity)
Species/taxa - determining factors (E)	Very-high: Nationally threatened – critical or vulnerable
Habitat - determining factors (E)	High: Supporting one national priority type or naturally uncommon ecosystem
Magnitude (M)	Negligible: Very slight change from the existing baseline condition. Change barely distinguishable, approximating to the 'no change' situation; AND/OR having negligible effect on the known population or range of the element/feature.
Level of effect (E x M)	**Very low** (Less than minor adverse effects)
Spatial scale	Medium
Persistence/duration	Days - Rapid recovery if stopped
Likelihood of occurring (L)	Remote (5) - Highly unlikely to occur
Consequence (C)	Minor (5) – Local short-term adverse impacts
Confidence	High (based on monitoring data and expert judgement)
Level of risk (L x C)	**Very low** (5 x 5 = 25, negligible with no impacts)

5.2. Changes to seabed physicochemical characteristics

A potential direct effect of coal dust deposition is the change in sediment physicochemical composition (i.e. reduced sediment quality). The focus of this effect assessment is whether there is likely to be (or has been) any measurable difference in background seabed conditions (or evidence of smothering of animals and plants) as a result of coal dust deposition.

5.2.1. Magnitude/consequence of effect (M/C)

A shift in the sediment physicochemical composition within the AOI would likely manifest as changes in macrofaunal community structure and may include the following (Ahrens & Morrisey 2005):

- sediment destabilisation (from change in sediment texture due to lower specific gravity coal particles, and avoidance from deposit feeders)
- elevated toxicity and nonlethal effects (e.g. reduced growth, preproduction) and mortality of benthic organisms
- provision of substratum for nonindigenous organisms (particularly around shipping ports)
- mortality of benthic organisms.

It should be noted also that the shifts described above, should they occur, are considered reversible[54], with an eventual return to normal background conditions (Sneddon et al. 2016). The magnitude/consequence is classed as of 'Negligible' magnitude and 'Minor' consequence (local short-term adverse impacts).

5.2.2. Likelihood of an effect occurring (L)

The sediment texture in Te Awaparahi Bay may have[55] exhibited some fining of sediment particle size attributable to the nearby reclamation activities (Sneddon 2019a). In contrast, Sneddon (2019b) found the coal content in surficial sediments had decreased by at least an order of magnitude since the earlier surveys, with a similar (yet not clearly correlated) decrease in PAH concentrations and the overall reduction in sediment TOC %. As coal particles are less prevalent in the sediments than in previous surveys (Section 4.2.2), it's unlikely they are contributing to any apparent fining of sediments in the area.

Other coal content (% of total) results (Sneddon & Barter 2009) exhibited higher levels of coal particles in close proximity to the SW outfall (station 1, 3.8% total coal), adjacent to the LPC dust deposition monitoring Site 23, with lower proportions to the west, adjacent the LPC dust deposition monitoring Site 22 (station 3, 0.4% total coal).

[54] It is noted that this is what's known in the context of typical SS inputs (e.g. from dredging plumes and riverine inputs etc).
[55] Some uncertainty around this trend, see Section 4.2.2.

This is counter to what would be expected if coal dust was contributing significantly to the coal sediment content (the highest coastal dust deposition rate was at 'Site 22'). Observations of coal particles in the sediments in Lyttelton Harbour have also been made at the easternmost point of Cashin Quay (Keeley & Barter 2001), throughout the Inner Harbour (e.g. Sneddon 2010d, 2010c; Woods 2017), and within the reclamation area of Te Awaparahi Bay (Sneddon 2011b), though their presence is more likely related to loading of coal onto vessels and coal stockyard stormwater contributions.

Concentrations of PAHs have been monitored in the soft sediments in the vicinity of the coal stockyard, as part of the Te Awaparahi Bay coal stockyard stormwater monitoring consent (Royds 1996; Barter 2000a, 2003; Conwell 2008; Sneddon 2014d, 2019a). During the 2003, 2007 and 2013 monitoring surveys (Barter 2003; Conwell 2008; Sneddon 2014d), some individual PAHs were in exceedance of guideline limits (Section 4.2.2), with some suggestion of a spatial concentration gradient occurring to the east (seawards from the reclamation). However, the most recent monitoring results (Sneddon 2019a) have shown a reduction in total PAHs sediment concentrations, well below the default sediment guideline trigger values for ecological protection (< 10 mg/kg%OC, ANZG 2018).

There have never been any TPHs detected in the Te Awaparahi sediments (Royds 1996; Barter 2003; Conwell 2008; Sneddon 2014d, 2019a), but TPHs characteristic[56] of particulate coal have been detected (inconsistently) along Cashin Quay, along with elevated PAH concentrations; however, this was 21 years ago and prior to sediment removal via dredging (Barter 2000a).

As well as this, the most recent monitoring results (Sneddon 2019a) have shown a reduction in total metals with all monitoring results consistently within background levels and/or below the default sediment guideline trigger values for ecological protection (<10 mg/kg%OC, ANZG 2018).

For the same rationale as provided in Section 5.1, no significant accumulation of dust suppressant chemicals in benthic sediments is expected to occur (Sneddon 2010b).

Although many kaimoana species have also been identified as occurring on hard substrates (mahinga kai habitat) in the immediate vicinity of the coal stockyard (Section 4.6), past survey findings and investigations relating to the reclamation effects reported that these locations do not represent a more important part of the overall kaimoana resource than other similar areas of the Harbour (Sneddon et al. 2017).

Given these findings above, the likelihood of an effect occurring is considered to be 'remote' (highly unlikely to occur).

[56] See footnote in Section 4.2.2.

5.2.3. Spatial scale of effect

The highest (relative) level of airborne deposition on marine surface waters was predicted to be to the inner Te Awaparahi Bay, with lower rates along the Cashin Quay and east of Battery Point (Section 3.3.1). Following deposition on the sea surface, the larger coal dust particles are predicted to settle through the water column to the seafloor between 40–200 m from the deposition point (Section 3.3). While the finer coal particles could potentially travel further before reaching the seabed (< 6 km), the most likely location to have detectable levels of coal (following mixing) would be immediately adjacent to Te Awaparahi Bay, Gollans Bay, the Inner Harbour and bordering shipping channel/swing basin areas (the AOI, Section 3.3). Supporting this estimate of spatial extent, coal particles and/or chemical indicators (e.g. PAHs) have not been detected at the adjacent shipping channel or Godley Head. Thus, a conservative estimate of the spatial scale is classed as medium (the 500 m to 2 km grouping, Table 2).

5.2.4. Persistence/duration

The deposition of coal dust itself is chronic, with higher deposition rates in the summertime. However, coal dust in the sediments themselves appear to be on a reducing trend between the last three coal stockyard SW surveys, regardless of the dust deposition contributing similarly throughout time (over 45 years). This suggests there are little or no cumulative effects occurring, and that the majority of coal dust in the sediments is attributable to coal stockyard SW sources, with the coal dust proportion (if any) being difficult to separate from background coal stockyard SW contributions. Given this the persistence of coal dust in the sediments would be at worst moderate, assuming it contributes at all.

5.2.5. Species and habitat determining factors

Both soft-sediment and hard substrate habitats can be sensitive to seabed physicochemical changes. The only *at-risk* species identified that potentially inhabits soft sediments within the AOI is the clam *Mysella* sp. (Table 13). The other four *at-risk* and *threatened* species potentially inhabit hard substrates:

- *Macrocystis pyrifera* – giant kelp beds (at-risk/naturally uncommon).
- *Myriogloea intestinalis* – alga (at-risk/naturally uncommon).
- Petalonia sp. – alga (at-risk/naturally uncommon).
- *Pumilus antiquatus* – lamp shell (threatened/nationally critical).

The giant kelp *Macrocystis pyrifera* also constitutes a ‘naturally uncommon ecosystem’ (habitat factor).

Though not listed with a specific conservation status, the significant kaimoana species/habitats identified in Section 4.6 are of cultural value and are therefore

interpreted in the same way as a conservation status taxa in the risk assessment. These taxa and habitats are:

- *Haliotis iris* (Pāua) – grazer/herbivore
- *Lunella smaragdus* (Pūpū) – grazer/herbivore
- *Diloma aethiops* (Pūpū) – grazer/herbivore
- *Mytilus galloprovincialis [edulis]* (Kutai) – filter feeder
- *Pyura pachydermatina* (Kāeo) – filter feeder
- the natural intertidal and subtidal reefs from Battery Point (within and to the east of the AOI) appear to be comparably valuable mahinga kai habitats, and to a lesser extent, the man-made rip-rap shoreline now covering much of Te Awaparahi Bay (within and south-west of the AOI).

5.2.6. Additional effects following the conclusion of reclamation activities

The completed reclamation areas are expected to work as an obstacle to the nearshore flow, reducing the current speed west and east of the reclaimed areas and narrowing the zone of higher flow speed in front of the development (Section 3.3). This suggests that under most circumstances, the future reclamation will reduce the distance travelled of the particles. Given this will reduce the amount of dust deposited in the marine environment, the likelihood and magnitude of any potential sediment related physicochemical effects is likely to be reduced as well.

Based on the effect's categories described above and summarised in Table 15, there is a **very low** risk of having a **very low** level of effect.

Table 15. Potential effect summary box: changes in sediment physicochemical composition.

Effect category	Changes in water chemistry
Species/taxa - determining factors (E)	Very high: Nationally threatened – critical or vulnerable
Habitat - determining factors (E)	High: Supporting one national priority type or naturally uncommon ecosystem
Magnitude (M)	Negligible: Very slight change from the existing baseline condition. Change barely distinguishable, approximating to the 'no change' situation; AND/OR having negligible effect on the known population or range of the element/feature.
Level of effect (E x M)	**Very low** (Less than minor adverse effects)

Spatial scale	Medium
Persistence/duration	Months – Moderate recovery if stopped
Likelihood of occurring (L)	Remote (5) – Highly unlikely to occur
Consequence (C)	Minor (5) – Local short-term adverse impacts
Confidence	High (based on monitoring data and expert judgement)
Level of risk (L x C)	**Very low** (5 x 5 = 25, negligible with no impacts)

6. SUMMARY

The deposition of coal dust from the LPC coal stockyard on the sea surface is likely to occur chronically in the immediate vicinity of the coal stockyard. The direct potential effects investigated in this assessment were:

1. changes to the coastal water physicochemistry (including increased TSS and turbidity)
2. changes to sediment physicochemistry.

Specific reference to mahinga kai values has been included in each of the assessments.

In both cases there was predicted to be, at worst, a **very low** risk of having a **very low** level of effect from the deposition of coal dust to the sea surface, within the immediate AOI, with little evidence of further afield effects (outside of 1.5 km from the coal stockyard). As the potential direct effects are predicted to be less than minor, the potential indirect effects have not been considered further in this assessment.

It is expected that under most circumstances, the future reclamation will act as a barrier between the coal stockyard and the coastline, resulting in a net reduction in the amount of coal dust deposited directly to the marine environment, with any coal dust deposited in the reclaimed area being managed and monitored through a treated stormwater system. Given this, the likelihood and magnitude of any water-related physicochemical effects are expected to reduce as well.

6.1. Monitoring recommendations

Assuming the rate of coal deposition, coal composition, transportation/loading and roading activities and storage capacity at the coal stockyard remains within the current status quo (or management improves), the current stormwater monitoring program is considered sufficient for ensuring the potential ecological effects identified in this investigation remain less than minor and within the risk assessment predictions.

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8. APPENDICES

Appendix 1. Physicochemical test results for simulated coal dust elutriate and reference seawater sample (Hill Laboratories report no. 2565005).

Hill Laboratories
TRIED, TESTED AND TRUSTED

R J Hill Laboratories Limited
28 Duke Street Frankton 3204
Private Bag 3205
Hamilton 3240 New Zealand

T 0508 HILL LAB (44 555 22)
T +64 7 858 2000
E mail@hill-labs.co.nz
W www.hill-laboratories.com

Certificate of Analysis

Client:	Cawthron Institute (Nelson)	**Lab No:**	2565005 SPv1
Contact:	Olivia Johnston	**Date Received:**	23-Mar-2021
	C/- Cawthron Institute (Nelson)	**Date Reported:**	16-Apr-2021
	Private Bag 2	**Quote No:**	110311
	Nelson Mail Centre	**Order No:**	XCOALAIR
	Nelson 7042	**Client Reference:**	Elutriation testing on Coal dust
		Submitted By:	Olivia Johnston

Sample Type: Saline

Sample Name:		Lyttelton Harbour Water				
Lab Number:		2565005.1				
Individual Tests						
Total Arsenic	g/m³	< 0.0042	-	-	-	-
Total Chromium	g/m³	< 0.0011	-	-	-	-
Total Copper	g/m³	< 0.0011	-	-	-	-
Total Lead	g/m³	< 0.0011	-	-	-	-
Total Manganese	g/m³	0.0054	-	-	-	-
Total Mercury*	g/m³	< 0.00008	-	-	-	-
Total Sulphur*	g/m³	930	-	-	-	-
Total Zinc	g/m³	< 0.0042	-	-	-	-
Dissolved Non-Purgeable Organic Carbon (DNPOC)*	g/m³	1.3	-	-	-	-
Dissolved Inorganic Carbon*	g/m³	26	-	-	-	-
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq*						
Acenaphthene*	g/m³	< 0.000008	-	-	-	-
Acenaphthylene*	g/m³	< 0.000008	-	-	-	-
Anthracene*	g/m³	< 0.000008	-	-	-	-
Benzo[a]anthracene*	g/m³	< 0.000008	-	-	-	-
Benzo[a]pyrene (BAP)*	g/m³	< 0.000008	-	-	-	-
Benzo[b]fluoranthene + Benzo[j] fluoranthene*	g/m³	< 0.000008	-	-	-	-
Benzo[g,h,i]perylene*	g/m³	< 0.000008	-	-	-	-
Benzo[k]fluoranthene*	g/m³	< 0.000008	-	-	-	-
Chrysene*	g/m³	< 0.000008	-	-	-	-
Dibenzo[a,h]anthracene*	g/m³	< 0.000008	-	-	-	-
Fluoranthene*	g/m³	< 0.000008	-	-	-	-
Fluorene*	g/m³	< 0.000008	-	-	-	-
Indeno(1,2,3-c,d)pyrene*	g/m³	< 0.000008	-	-	-	-
Naphthalene*	g/m³	< 0.00004	-	-	-	-
Phenanthrene*	g/m³	< 0.000008	-	-	-	-
Pyrene*	g/m³	< 0.000008	-	-	-	-
Total Petroleum Hydrocarbons in Water*						
C7 - C9*	g/m³	< 0.10	-	-	-	-
C10 - C14*	g/m³	< 0.2	-	-	-	-
C15 - C36*	g/m³	< 0.4	-	-	-	-
Total hydrocarbons (C7 - C36)*	g/m³	< 0.7	-	-	-	-

Sample Type: Miscellaneous

Sample Type: Miscellaneous						
Sample Name:		Coal fines - 212µm				
Lab Number:		2565005.4				
Individual Tests						
Particle size analysis*‡		See attached report	-	-	-	-

Sample Type: Aqueous						
Sample Name:		Coal fines - 212µm [Elutriation extract]				
Lab Number:		2565005.5				
Individual Tests						
Total Arsenic	g/m³	< 0.0042	-	-	-	-
Total Chromium	g/m³	< 0.0011	-	-	-	-
Total Copper	g/m³	0.0019	-	-	-	-
Total Lead	g/m³	< 0.0011	-	-	-	-
Total Manganese	g/m³	1.24	-	-	-	-
Total Mercury	g/m³	< 0.00008	-	-	-	-
Total Sulphur	g/m³	960	-	-	-	-
Total Zinc	g/m³	0.113	-	-	-	-
Dissolved Non-Purgeable Organic Carbon (DNPOC)	g/m³	1.8	-	-	-	-
Dissolved Inorganic Carbon*	g/m³	7.8	-	-	-	-
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq*						
Acenaphthene	g/m³	< 0.000008	-	-	-	-
Acenaphthylene	g/m³	< 0.000008	-	-	-	-
Anthracene	g/m³	< 0.000008	-	-	-	-
Benzo[a]anthracene	g/m³	< 0.000008	-	-	-	-
Benzo[a]pyrene (BAP)	g/m³	< 0.000008	-	-	-	-
Benzo[b]fluoranthene + Benzo[j] fluoranthene	g/m³	< 0.000008	-	-	-	-
Benzo[g,h,i]perylene	g/m³	< 0.000008	-	-	-	-
Benzo[k]fluoranthene	g/m³	< 0.000008	-	-	-	-
Chrysene	g/m³	< 0.000008	-	-	-	-
Dibenzo[a,h]anthracene	g/m³	< 0.000008	-	-	-	-
Fluoranthene	g/m³	< 0.000008	-	-	-	-
Fluorene	g/m³	< 0.000008	-	-	-	-
Indeno(1,2,3-c,d)pyrene	g/m³	< 0.000008	-	-	-	-
Naphthalene	g/m³	< 0.00004	-	-	-	-
Phenanthrene	g/m³	< 0.000008	-	-	-	-
Pyrene	g/m³	< 0.000008	-	-	-	-
Total Petroleum Hydrocarbons in Water*						
C7 - C9	g/m³	< 0.10	-	-	-	-
C10 - C14	g/m³	< 0.2	-	-	-	-
C15 - C36	g/m³	< 0.4	-	-	-	-
Total hydrocarbons (C7 - C36)	g/m³	< 0.7	-	-	-	-

Analyst's Comments

‡ Analysis subcontracted to an external provider. Refer to the Summary of Methods section for more details.

Appendix No.1 - Waikato University report

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Saline			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
Total Digestion*	Boiling nitric acid digestion. APHA 3030 E (modified) 23rd ed. 2017.	-	1, 5

Sample Type: Saline			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Total Digestion of Saline Samples*	Nitric acid digestion. APHA 3030 E (modified) 23rd ed. 2017.	-	1, 5
Total Arsenic	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 23rd ed. 2017.	0.0042 g/m³	1, 5
Total Chromium	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 23rd ed. 2017.	0.0011 g/m³	1, 5
Total Copper	Nitric acid digestion, ICP-MS, ultratrace. APHA 3125 B 23rd ed. 2017.	0.0011 g/m³	1, 5
Total Lead	Nitric acid digestion, ICP-MS, ultratrace level. APHA 3125 B 23rd ed. 2017.	0.0011 g/m³	1, 5
Total Manganese	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 23rd ed. 2017.	0.0011 g/m³	1, 5
Total Mercury*	Bromine Oxidation followed by Atomic Fluorescence. US EPA Method 245.7, Feb 2005.	0.00008 g/m³	1, 5
Total Sulphur*	Nitric acid digestion, ICP-OES (method may not fully account for H_2S due to volatilisation during digestion). All forms of oxidised and organic sulphur will be determined by this method. APHA 3120 B 23rd ed. 2017.	0.5 g/m³	1, 5
Total Zinc	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 23rd ed. 2017.	0.0042 g/m³	1, 5
Dissolved Non-Purgeable Organic Carbon (DNPOC)*	Acidification, purging to remove inorganic C, super-critical persulphate oxidation at 375°C, IR detection. APHA 5310 C (modified) 23rd ed. 2017.	0.3 g/m³	1, 5
Dissolved Inorganic Carbon*	Filtered sample, supercritical persulphate oxidation, IR detection. APHA 5310 C (modified) 23rd ed. 2017.	0.35 g/m³	1, 5
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq*	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.000005 g/m³	1, 5
Total Petroleum Hydrocarbons in Water			
C7 - C9*	Solvent extraction, GC-FID analysis. In-house based on US EPA 8015.	0.10 g/m³	1, 5
C10 - C14*	Solvent extraction, GC-FID analysis. In-house based on US EPA 8015.	0.2 g/m³	1, 5
C15 - C36*	Solvent extraction, GC-FID analysis. In-house based on US EPA 8015.	0.4 g/m³	1, 5
Total hydrocarbons (C7 - C36)*	Calculation: Sum of carbon bands from C7 to C36. In-house based on US EPA 8015.	0.7 g/m³	1, 5

Sample Type: Miscellaneous			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
Elutriation testing*	Extn with (client supplied) water, eg seawater, Sed:Water 1:4 by vol, mix 30 min, settle 1 hr, filtration or centrifugation. US EPA 503/8-91/001, "Evaluation of Dredged Material for Ocean Disposal".	-	4
Particle size analysis*	Malvern Laser Sizer particle size analysis from 0.05 microns to 3.4 mm. Samples are measured in volume %. Subcontracted to Earth Sciences Department, Waikato University, Hamilton.	-	4

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 30-Mar-2021 and 16-Apr-2021. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

Analysis - Under

Malvern Instruments

Malvern

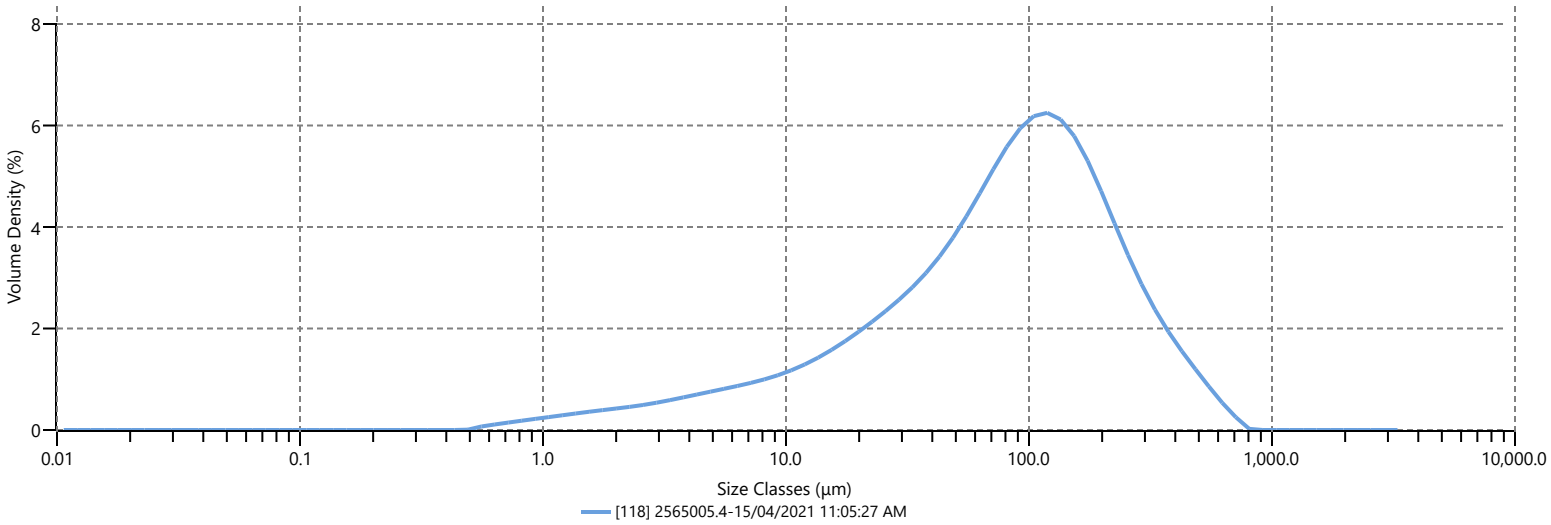
Measurement Details	
Sample Name	2565005.4
SOP File Name	HydroLV.cfg
Lab Number	2021073/1
Operator Name	rodgers

Measurement Details	
Analysis Date Time	15/04/2021 11:05:27 AM
Measurement Date Time	15/04/2021 11:05:27 AM
Result Source	Measurement

Analysis	
Particle Name	Carbon C (carbon black)
Particle Refractive Index	1.746
Particle Absorption Index	1.000
Dispersant Name	Water
Dispersant Refractive Index	1.330
Scattering Model	Mie
Analysis Model	General Purpose
Weighted Residual	0.33 %
Laser Obscuration	15.31 %

Result	
Concentration	0.0385 %
Span	3.020
Uniformity	0.948
Specific Surface Area	306.8 m^2/kg
D [3,2]	19.6 µm
D [4,3]	118 µm
Dv (10)	10.3 µm
Dv (50)	85.3 µm
Dv (90)	268 µm
Volume Below (10) µm	9.80 %
Volume Below (20) µm	16.58 %

Frequency (compatible)



Result

Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under
0.0500	0.00	7.80	8.10	88.0	51.17	350	94.66	1410	100.00
0.0600	0.00	15.6	13.71	105	58.15	420	96.85	1680	100.00
0.120	0.00	31.0	23.13	125	65.25	500	98.39	2000	100.00
0.240	0.00	37.0	26.45	149	72.23	590	99.37	2380	100.00
0.490	0.00	44.0	30.14	177	78.50	710	99.90	2830	100.00
0.980	0.59	53.0	34.72	210	83.95	840	100.00	3360	100.00
2.00	2.14	63.0	39.67	250	88.44	1000	100.00		
3.90	4.43	74.0	44.88	300	92.18	1190	100.00		