6

EFFECTS ON AQUACULTURE AND MAHINGA KAI

REPORT

Lyttelton Port Company Channel Deepening Project Assessment of Ecological Effects - Marine Farms

Prepared for
Lyttelton Port of Christchurch

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Executive summary

Lyttelton Port Company Limited (*LPC*) is seeking a resource consent to deepen the Lyttelton Harbour/Whakaraupō shipping channel to enable larger ships to access the Port, thereby maintaining the existing container service and providing for future growth. The Channel Deepening Project (*CDP*) will involve using a trailing suction hopper dredge to move 18 million cubic metres of seabed material from the Harbour channel, swing basin/berthage areas to an offshore disposal site to the north of Banks Peninsula, which is to be located approximately 4.0 km from the southern head of Double Bay at its nearest point, and is approximately 6.0 km from Godley Head. The increased area being dredged will result in an increase in maintenance dredging volumes following the channel deepening. A new maintenance disposal area is therefore also being proposed, located approximately 2.25 km off Godley Head.

This report presents an assessment of the marine ecological effects of the dredge and disposal activities on marine farms on the northern side of Banks Peninsula. It assesses the potential effects of the project, with the primary concern being the potential for turbidity plumes to move to marine farm sites and associated coastal areas.

The northern coast of Banks Peninsula is an area of commercial marine farming. Consented marine farms occupy space from Port Levy (Koukourarata) in the West to Squally Bay in the East. Only one species is produced on the farms; the green-lipped mussel *Perna canaliculus*. The farm site at Big Bay is 4.1 km away from the proposed dredge disposal area and is the closest in proximity.

Canterbury coastal waters are naturally turbid, especially in the area near Banks Peninsula. There are a number of features that contribute to the turbidity, including sediment inputs from large braided alluvial rivers in flood, high loess runoff inputs from Banks Peninsula, the gently sloping seabed in Pegasus Bay, wave-induced resuspension of fine sediments, and tidal currents carrying sediments in discharges from estuaries and inlets.

MetOcean Solutions Ltd undertook a numerical modelling exercise to determine the likely degree of dispersion of plume material from the dredging and disposal activities. The modelling indicated that sediment plumes are highly unlikely to reach the farm sites or the shoreline. One important factor contributing to this finding is that dominant water currents move along shore; there are only weak residual currents that could drive plume advection toward the shoreline.

Despite the low likelihood of suspended material reaching marine farms or the shore, as a precautionary approach, a review of the scientific literature was completed to determine the capability of farmed and kaimoana species to tolerate possibly elevated levels of turbidity. Filter-feeding bivalves such as *P. canaliculus* have evolved in nearshore environments, where sediments are periodically resuspended within a high turbidity layer. *P. canaliculus* has been experimentally tested in its ability to extract food from water with high suspended sediment concentrations. During the experiments natural silt (taken from the surface layer of mudflats) was added to the water. The mussels were able to cope, and regulate their feeding, at suspended sediment concentrations greater than 1000 mg/L, far in excess of concentrations that are predicted to occur at the mussel farm sites.

The proposed dredging and spoil disposal activities are not predicted to cause adverse effects on shellfish aquaculture. The principal reasons are the distance from the potential source of sediment suspension relative to weak residual currents driving the advection of turbidity plumes towards the shoreline, the periodically higher natural background turbidity occurring within the inlet and the inherent tolerance of the cultured species (*P. canaliculus*) to elevated levels of suspended solids.

On the basis of the Ecological Impact Assessment (EcIA) guidelines produced by the Environment Institute of Australia and New Zealand (EIANZ, 2015), it was concluded that the proposed dredging

and disposal activities are likely to have a very low overall ecological effect on mussel farming and for wild (non-cultured) mahinga kai species on the Northern Side of Banks Peninsula.

Given the importance of these resources, and on a precautionary basis, however, we support the intention as indicated in the Environmental Monitoring and Management Plan for real-time sediment plume monitoring be carried out during the works to confirm the actual extent of sediment plume movement. We also support the allowance for dredge and disposal activities to be modified in real time, if necessary, to eliminate adverse effects on mussel farms and on wild (non-cultured) mahinga kai species.

1 Introduction

LPC is applying for a resource consent application for a channel deepening project (*CDP*) to deepen the shipping channel into Lyttelton Harbour. The purpose of the project is to enable larger ships to access the Port, thereby maintaining existing container service and providing for its future growth. Globally, container ships are increasing in size and most major New Zealand ports are preparing for their potential arrival.

1.1 Description of proposed dredging and disposal activities

The existing dredged approach channel for Lyttelton Port runs east-west (bearing 260°39') approximately 7 km, from the entrance to the Port to a point south of Mechanics Bay (see Figure 2.1). It is currently maintained at a depth of 12.0 m relative to chart datum (CD), allowing vessels of up to 12.4 m draught to transit at high tide. It is proposed that, in order to accommodate vessels of draught up to 14.5 m on all tides, the channel will be deepened by up to approximately 4.5 m to 16.85-17.85 m CD and widened to 200 m (from the current 180 m). This will also entail the extension of the dredged channel to the ENE, to a point approximately 4 km from the present pilotage limit (between Godley and Adderley Heads). The greater (17.85 m) depth will be required for this outer section to allow for the additional underkeel clearance necessitated by the effects of swell and squat outside the Heads. It is also necessary to enlarge and deepen the ship turning basin, deepen berth areas and approaches and provide for new berthing area at the Te Awaparahi Bay reclamation.

To attain these channel depths, it is anticipated that the capital dredging project will generate approximately 18 million cubic metres of spoil material. It is intended that this dredged spoil will be deposited further offshore in the spoil ground site shown in Figure 2.1. This will be located some 6.2 km from Godley Head and 3.3 km from Baleine Point at its nearest points. It will comprise a rectangular area of approximately 5 km x 2 km, with its long axis oriented roughly north-west to south-east, aligned with the 20 m isobath. Water depths in this area vary between 17.5 m and 21.0 m from the landward to seaward sides respectively. The disposal material will be released evenly across the entire disposal site, which will raise the seabed level by approximately 1.5 m.

The increased area being dredged will result in an increase in maintenance dredging volumes following the channel deepening. A new maintenance disposal area is therefore proposed, located approximately 2.25 km off Godley Head (see Figure 2.1).

1.2 Purpose of this report

This report presents an assessment of ecological effects, with a focus on marine farming activities, for the resource consent application for this dredging and disposal project. The assessment:

- Describes the existing commercial marine farming sites and species that are produced in closest proximity to the dredge and disposal sites;
- Describes the existing natural baseline turbidity regime in the general vicinity of the marine farming sites;
- Assesses the MetOcean Solutions Ltd numerical modelling outputs, summarising the turbidity conditions that could arise at mussel farm sites, associated with the CDP proposed disposal site, and with the proposed maintenance dredge disposal site;
- Reviews existing literature on bivalve capacity to tolerate turbidity, at different exposure periods;
- Evaluates this capacity in the context of predicted suspended solid concentrations that would result from the dredge and disposal activities;

- Uses this information to assess the environmental effects for farmed species;
- Includes a qualitative assessment of potential effects on key wild (non- cultured) mahinga kai species.

The report is divided into sections corresponding to each of the above objectives.

In this report, the word ‘turbidity’ is used in a general sense, as the cloudiness or haziness of water, caused by particles in that water.

This assessment is intended to support an application to Environment Canterbury for resource consents for the dredging and disposal activities. This report will form part of the overall Assessment of Environmental Effects in the application.

2 Commercial marine farming: sites and value

The commercial marine farming sites on the northern side of Banks Peninsula are presented in Figure 2.1. More detailed Environment Canterbury data on each of the consented sites are attached in Appendix A. There are 24 active consents held by 6 different consent holders. Consents have been issued to authorise the growing of a number of species, including green shell mussels (*Perna canaliculus*), blue shell mussels (*Mytilus galloprovincialis*), algae (*Macrocystis pyrifera*, Ecklonia *radiata*, *Gracilaria* spp., *Pterocladia lucida*, and *Undaria pinnatifida*), and for the collection of mussel spat (CRC 2016). While the growing of all these species is permitted, the only commercial activity undertaken at the sites is the growing of green shell mussels, and the collection of green shell mussel spat.

The longline method of mussel cultivation is used, where the mussels are suspended in the water column, and are dependent on the natural supply of food (Ogilvie 2000). The longline ropes are attached to a series of about 50 plastic buoys, and screw-anchored to the seabed at both ends. The mussels are attached to a continuous rope that is lashed to the longline at the surface, and loops down to around 10 m water depth. A typical farm consists of 8-10 longlines, of about 100 m length, in an area of 2-3 hectares. The larger sites outlined in Figure 2.1, such as at Squally Bay, are broken up into multiple smaller blocks.

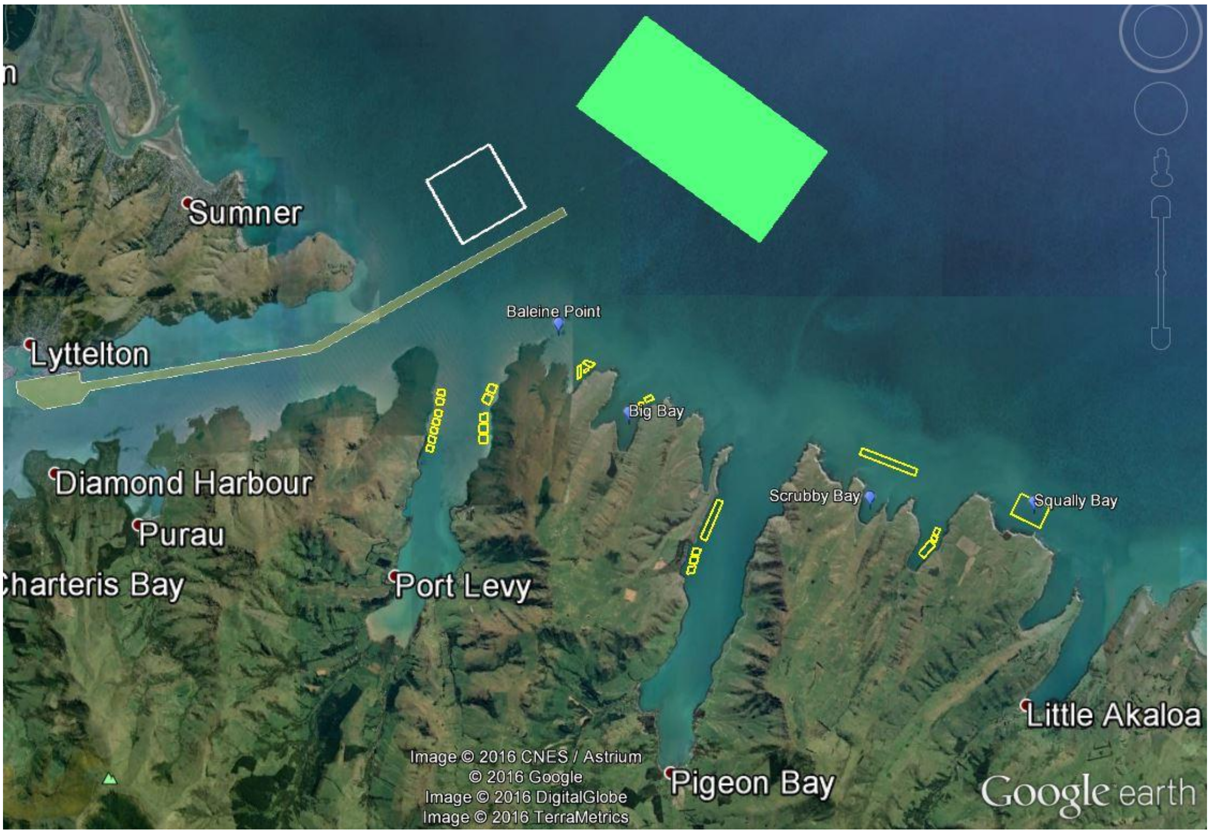

Figure 2.1: Site location map showing existing marine farm sites (yellow open polygons) along the northern side of Banks Peninsula, the approximate proposed dredge area (yellow closed polygon), the proposed offshore capital dredge disposal area (green polygon), and the proposed new maintenance disposal area (white open square). See Appendix 1 for further information, obtained from Environment Canterbury, about the marine farm permits.

There are eight general areas that have resident mussel farms, from Koukourarata (Port Levy) in the West, to Squally Bay in the East. The sites have varying degrees of exposure to the open ocean, with the most inshore sites being in Pigeon Bay and Port Levy, and the most exposed sites being offshore

from Scrubby Bay and Squally Bay. The site at Big Bay is closest to the proposed CDP disposal area, being about 4.1 km.

At the time of writing this report, there are around 123 ha of mussel farms on the northern side of Banks Peninsula. This was estimated using Google Earth, by creating polygons around actual farm sites (Figure 2.1). Advice from the mussel farming industry is that the capital value (i.e. the value of the permit) for each hectare ranges from $125k to $200k, with the variability dependent on whether the site is used for mussel growing or for spat catching. It is difficult to determine an exact breakdown of activity type, so the estimated permit value of the farms ranges between $15,375,000 and $24,600,000. In addition, each longline structure has a capital value of $15,000 (Thomas Hildebrand, Ngai Tahu Seafood, pers. comm.). There are 297 visible longlines, which adds another $4,455,000. The estimated overall capital value of the mussel farms is between $19,830,000 and $29,055,000.

Figures from Aquaculture NZ (Rebecca Clarkson, pers. comm.) show that over the last 6 financial year's mussel production averaged 2,000 tonnes per annum from Banks Peninsula. The average market value for mussels in 2015 was $3,191 per tonne, giving an estimated gross production value of $6,382,000 per annum.

On the basis of these figures it would be reasonable to expect that marine farming on Banks Peninsula is of local and national commercial importance. This information is used further below in the Assessment of Environmental Effects section.

It is noted here that for the present analysis, we have included only sites that had visible mussel growing structures present at the time of writing this report. It is possible that there are additional sites that have been permitted for marine farming, but that haven't yet been developed. The value of these sites is not included in the estimated value presented here.

It is also noted that there is a large marine farm permit, of approximately 2,800 hectares, in Pegasus Bay, situated about 22 km north of the northern-most part of the proposed CDP disposal site (see Appendix B). We haven't included this permit within the present analysis, as it was considered to be well outside the area of direct influence of the proposed dredging and disposal activities.

3 Existing natural baseline turbidity around Banks Peninsula

It is clear from Section 2 above that mussel farming on Banks Peninsula is a commercially productive activity. It exists within the existing natural turbidity regime of the area. This section is a description of the existing natural baseline turbidity regime in the general vicinity of the marine farming sites, to allow a comparison of potential changes in turbidity that might result from the dredging and disposal activities, and to therefore understand the inherent propensity of the marine farms to cope with turbidity.

Variable, including high, turbidity is a natural feature of this part of the Canterbury coast, especially in the area near Banks Peninsula (Fenwick *et al*. 2003). This is caused by a combination of large braided alluvial rivers with high sediment loads when in flood (Figure 3.1), the proximity to Banks Peninsula with its high loess inputs to the coastal system, the shallow depth and gently sloping bottom of Pegasus Bay, wave-induced resuspension of fine sediments, and tidal currents carrying sediments in discharges from estuaries and inlets, especially during high rainfall and storm conditions. Together these factors result in the continual supply, deposition and re-suspension of very fine sediment within the near-shore environment.

Sediment is transported from south to north around the Peninsula (Fig. 3.1), especially when the northerly-flowing coastal current, flood tidal streams and south-easterly swells coincide (Dingwall 1974). The frequent wind and wave-induced water movement continually re-suspends this material around Banks Peninsula and within Pegasus Bay. Resuspension also occurs from bioturbation processes, including the re-working of benthic sediments by sediment-dwelling fauna (Sneddon *et al*., 2016).

Figure 3.1: NASA satellite images of the Pegasus Bay-Banks Peninsula region. Left image taken on 19 May 2016, during a flood event of the Waimakariri River, visible turbidity plume is flowing into Pegasus Bay. Right image taken on 6 June 2016 showing the turbid coastal zone with complex hydrodynamics.

Figure 3.2. Aerial image of sediment plume from the Waimakariri River during flood conditions (MSL, 2016).

There is limited existing data on background turbidity and total suspended solid concentrations for the Pegasus Bay and Banks Peninsula shorelines. Environment Canterbury supplied a dataset, with sampling undertaken from July 2007 to December 2013, presented in Table 1.

Table 1: Summary statistics for total suspended solid concentration and turbidity measured at locations in Pegasus Bay and Lyttelton Harbour between 2007 and 2014. Data provided by Environment Canterbury

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

The measured total suspended solids concentration range is <3 to 110 mg/L, supporting the assertion that variable, including high, total suspended solid concentrations is a natural feature of this part of the Canterbury coast. These levels are higher than those observed in other coastal environments around New Zealand. South Taranaki measurements of 2-18 mg/L were made by Pinkerton et al. (2013) and Zhou (2012). Hawke's Bay measurements of < 50 mg/L were made by Madarasz (2006). As none of the data in Table 1 was collected near rivers, it is also possible that higher turbidity events could occur as a result of river flooding. The above tabulated values are several orders of magnitude less than the estimated average surface water suspended solid

concentrations at the mouth of the Waimakariri River, estimated to be an average of 1,400 mg/L, rising to 210,000 mg/L during flooding events (Mulder & Syvitski, 1995, Figure 3.2).

To put this data into context for the present report, an important consideration is that for the numerical modelling of suspended solid concentration plume movements from the proposed disposal sites, MSL (2016, 2016a) chose exceedance values of 10, 50, and 100 mg/L. While total suspended solid concentration (presented in Table 1) is measured in a subtly different way to suspended solid concentration, it is nevertheless reasonable to expect that the exceedance values chosen in the MSL reports fall within the measured natural total suspended solid concentration levels presented in Table 1. This is a prudent approach to ensure that dredging and disposal activities have effects that are within conservative limits. This idea is advanced further in the next section.

It is also notable that because mussel production is successful at the farm sites on the Northern side of Banks Peninsula, these mussels are able to cope with the measured turbidity conditions, and in fact are also likely to cope with higher turbidity levels that might occur during river flooding events. The inherent capability of mussels to cope with high turbidity levels is advanced further in Section 5 below.

4 Numerical modelling of sediment plumes

Dredging, and disposal of dredged material, releases sediment into the water column, forming a sediment plume. This occurs in two phases (Figure 4.1): the dynamic phase (where the plume moves under its own energy) and the passive phase (where the plume moves due to other influences acting upon it).

In the dynamic phase, plume behaviour is mainly determined by the nature and concentration of the material and how it is placed into the water column. The main causes of such plumes are dredge overflow, pipeline discharge into the aquatic environment and hopper discharge either through the bottom opening or pumped discharge.

In the passive phase, plume movement is controlled to a greater extent by the hydrodynamic environment (mainly the strength and direction of the water currents). Sources include losses into suspension during the dynamic plume phase and various actions that cause the plume to respond or 'move' during dredging operations (John *et al.,* 2000).

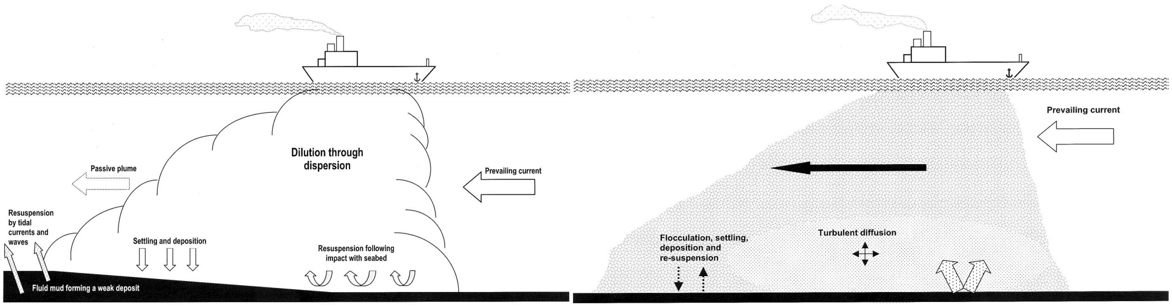

Figure 4.1. Dynamic plume (left) and passive plume (right). From John et al. (2000).

The zone of impact of the dynamic plume is relatively small, usually affecting an area less than 100-200 m from the dredge, although the suspended solids concentration (SSC) within a dynamic plume is higher than that within a passive plume; it can be several thousand milligrams per litre.

The sediment concentrations within a passive plume are relatively low and the settling velocity of the particles may be sufficiently low for them to remain in suspension for a prolonged period. For the finest particles, this may mean several hours or even days. Thus the zone of influence of the passive plume may be much larger than for the dynamic plume, and is dependent upon the magnitude and direction of tidal currents and the magnitude and nature (including settling velocity) of sediments released.

4.1 Passive turbidity plumes at the offshore disposal ground

LPC commissioned MetOcean Solutions Ltd (MSL) to undertake a numerical modelling exercise to determine the dispersion of the passive plume associated with the discharge of sediment at the proposed offshore disposal ground (MSL, 2016).

The modelling exercise for the offshore disposal grounds, was approached in three parts. Firstly, the general dynamics of the plume dispersion was investigated based on short-term simulations during a range of hydrodynamic and atmospheric forcing conditions considered to be representative of the disposal site.

Secondly, statistical estimations of the plume dispersion were derived by running long-term (10 year) simulations of disposal activities within the historical hind cast context for the disposal site, to capture natural variability of the forcing conditions at the site. Figure 4.2 shows that output for the

location within the proposed disposal site that is nearest to marine farms, i.e. the southern corner of the disposal area.

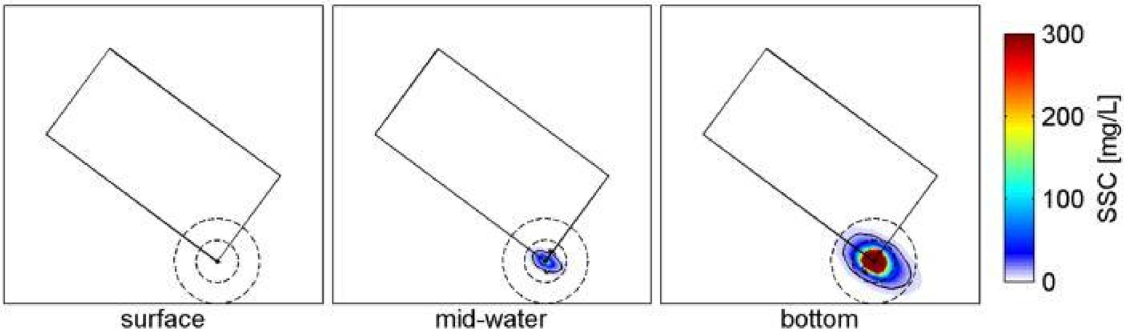

Figure 4.2. Zoomed-in view of mean Suspended Solids Concentration (SSC) fields resulting from the disposal of one hopper load of the Asia vessel (V=10,800 m^3), derived from the 10 year hind cast simulations. The 10 mg/L SSC contour line is shown in dark. Dashed circles are 500 and 1000 m from the disposal point. Figure from MSL (2016).

The third part of the modelling was to estimate the suspended sediment concentration exceedance times with respect to key thresholds relating to three ambient levels present in Pegasus Bay (10, 50 and 100 mg/L). Figure 4.3 shows exceedances for each of these concentrations, during typical summer conditions. Modelling for winter conditions gave similar results (MSL, 2016).

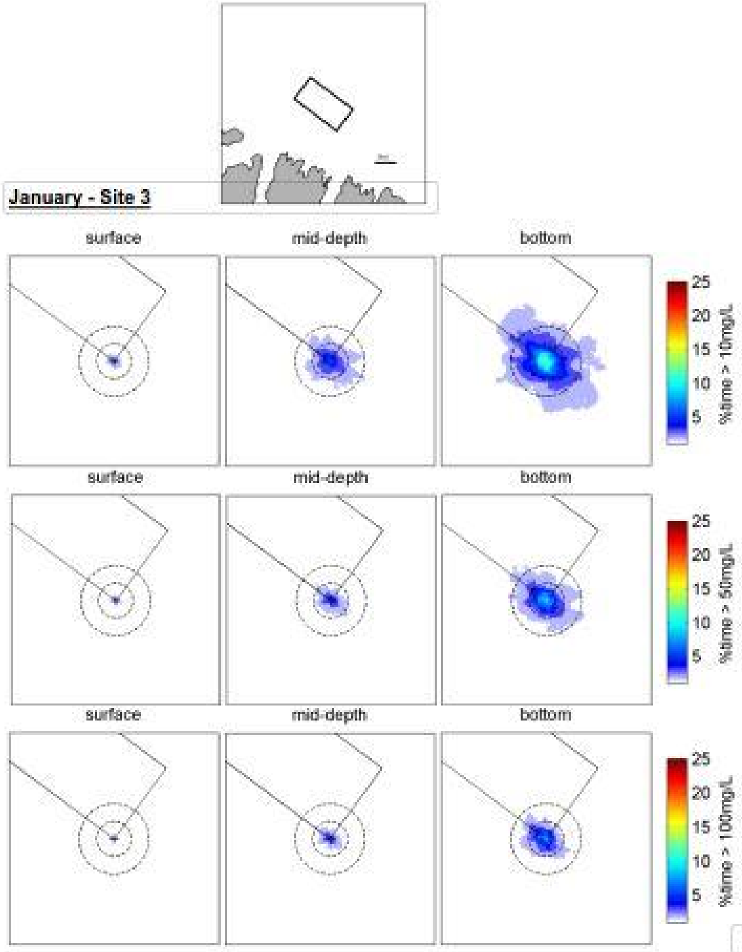

Figure 4.3: Percent of time SSC thresholds of 10, 50, and 100 mg/L are exceeded during the summer month of January, (assuming 2-hourly disposal of 10,800 m^3) at the point in the disposal area that is nearest to the shoreline marine farming activity. Dashed circles are 500 and 1000 m from the disposal point. Figure from MSL (2016).

As an extra safety factor, in addition to plume modelling, the 10-year plume hindcast modelling was used to predict the fate of individual sediment particles. This showed that it is exceptionally unlikely that individual sediment particles will get closer than 600 m to the shoreline (see Figure 4.4), which is outside all of the marine farm locations.

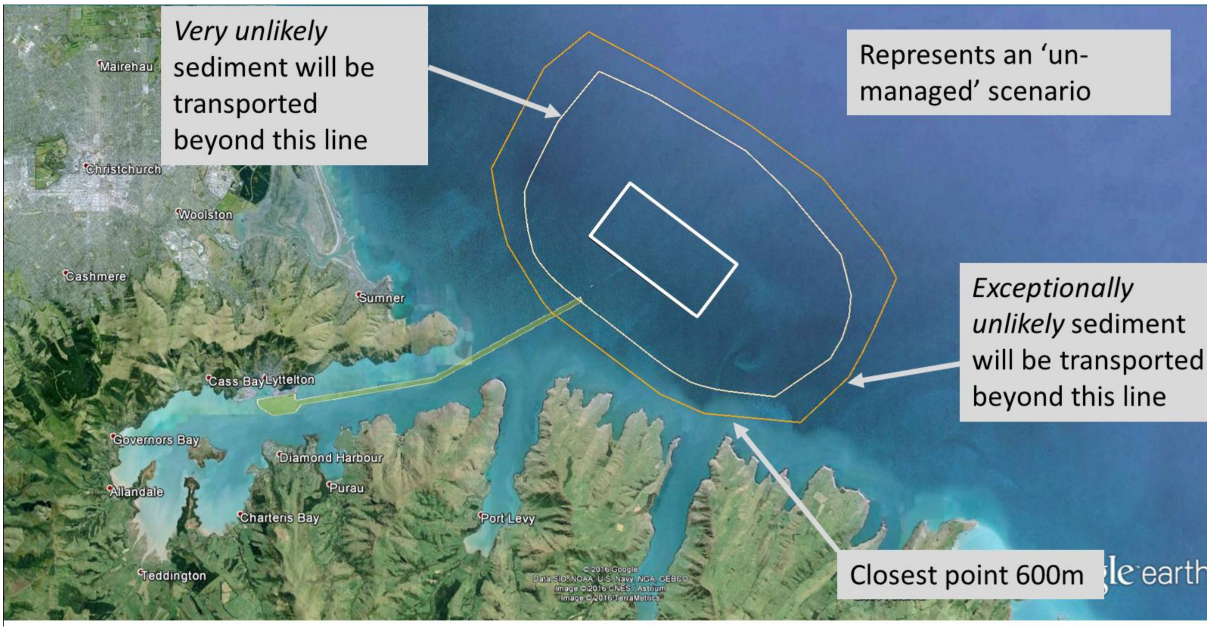

Figure 4.4: Individual sediment particle excursion from all sites within the disposal area, over the 10-year hindcast period. Data from MSL (2016).

The main outcomes from this modelling were that:

1 The most significant suspended sediment concentration levels occur at the seabed, because sediment is suspended into the water column by the density current that is formed when the sediment hits the seabed. These higher concentrations are contained within a 300 m radius of the release point, and settling is rapid given the close proximity to the seabed;

2 Mean suspended sediment concentrations derived from the 10-year plume hind-cast of sediment disposal indicates elliptical-shaped plume patterns with the long axis of the ellipse consistent with the northwest-southeast direction of the dominant ambient currents at the disposal site. This pattern can be clearly seen in Figure 4.2;

3 In the bottom layer, the 10 mg/L contour line generally stays within 1 km of the disposal point and within 500 m in the mid-water layer. In the surface layer, SSC plumes are very limited, with typical magnitudes below 10 mg/L;

4 It is exceptionally unlikely that individual sediment particles will be transported any closer than 600 m from the coastline and thus marine farms.

4.2 Passive turbidity plumes at the maintenance disposal site

LPC also commissioned MSL to undertake a numerical modelling exercise to determine the dispersion of the passive plume associated with the discharge of sediment at the proposed maintenance disposal ground offshore from Godley Head (MSL, 2016a).

The modelling exercise was approached in a similar way as described above for the CDP disposal site. Firstly, the general dynamics of the plume dispersion was investigated based on short-term simulations during a range of representative hydrodynamic and atmospheric forcing conditions.

Secondly, statistical estimations of the plume dispersion were derived by 1-year simulations of disposal activities within the historical hind cast context for the maintenance disposal site, to capture natural variability of the forcing conditions at the site. Figure 4.5 shows that output for the location nearest to marine farms, i.e. the southern corner of the maintenance disposal area.

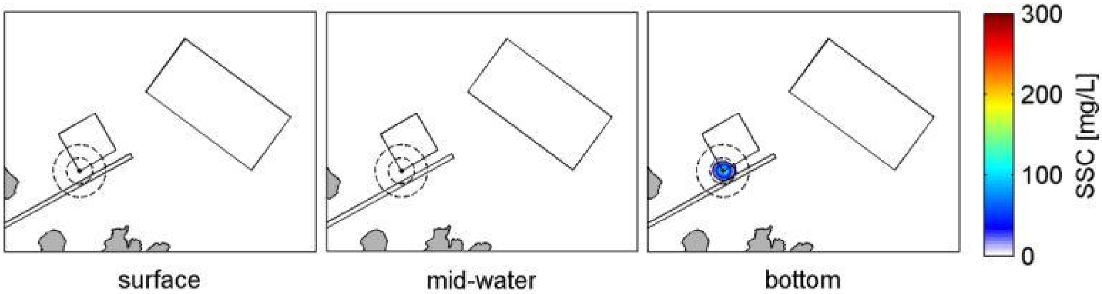

Figure 4.5: Mean SSC field resulting from the disposal of one hopper load of the Mahury vessel (V=1,840 m3), derived from an annual hind cast simulation. The 10 mg/L SSC contour line is shown in dark. Dashed circles are 500 and 1000 m from the disposal point. Figure from MSL (2016a).

The third part was to estimate the suspended sediment concentration exceedance times with respect to key thresholds relating to three ambient levels present in Pegasus Bay (10, 50 and 100 mg/L). Figure 4.6 shows exceedances for each of these concentrations, during typical summer conditions. Modelling for winter conditions gave similar results (MSL, 2016a).

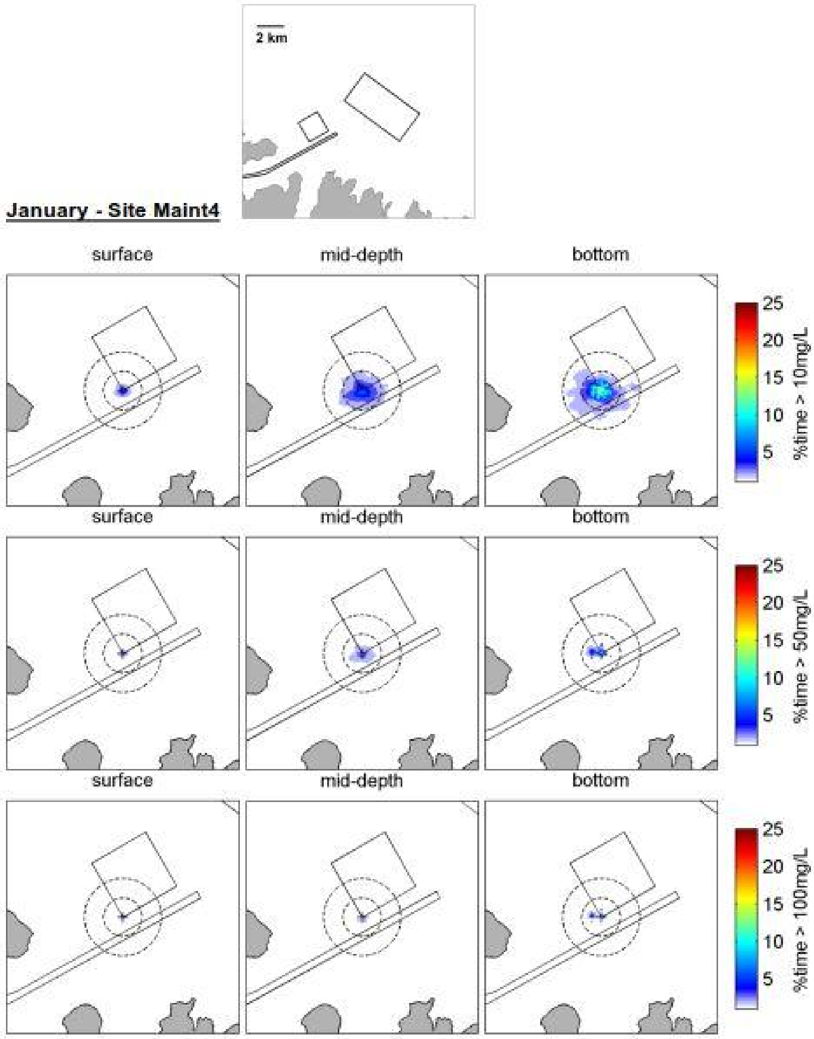

Figure 4.6: Percent of time SSC thresholds of 10, 50, and 100 mg/L are exceeded during the summer month of January, assuming 1.5-hourly disposal cycle of 1,840 m^3 of dredge material, at the point in the disposal area nearest to the shoreline marine farming activity. Dashed circles are 500 and 1000 m from the disposal point. Figure from MSL (2016a).

In addition to plume modelling, 1-year plume hindcast modelling was used to predict the fate of individual sediment particles. This showed that it is very unlikely that individual sediment particles will get closer than 400 m to the shoreline (see Figure 4.7), which is outside all of the marine farm locations.

Figure 4.7: Individual sediment particle excursion from all sites within the maintenance disposal area, over a 1-year hindcast period. Probability descriptions are the same as per Figure 4.4 above. Data from MSL (2016a).

The main outcomes from the proposed maintenance disposal ground modelling were that:

1 The most significant suspended sediment concentration levels occur at the seabed, because sediment is suspended into the water column by the density current that is formed when the sediment hits the seabed. These higher concentrations are contained within a 300 m radius from the release point, and sediment settling is rapid given the close proximity to the seabed;
2 Mean suspended sediment concentrations derived from the 1-year plume hindcast of sediment disposal indicates elliptical-shaped plume patterns with the long axis of the ellipse consistent with the northwest-southeast direction of the dominant ambient currents at the disposal site, a pattern that can be seen in Figure 4.6;
3 In the bottom layer, the 10 mg/L contour line generally stays within 1 km of the disposal point and within 500 m in the mid-water layer. In the surface layer, SSC plumes are very limited, with typical magnitudes below 10 mg/L;
4 It is very unlikely that individual sediment particles will be transported any closer than 400 m from the coastline and thus marine farms.

5 Capability of the farmed marine species to tolerate turbidity

5.1 Literature Review

Given that the mussel *P. canaliculus* is the only aquaculture species that is commercially produced at the marine farm sites on the northern coastline of Banks Peninsula, a key part of this assessment process was to review the literature about bivalve capability to tolerate and process suspended solids in the water column.

Filter-feeding bivalve shellfish have evolved in nearshore environments, such as estuarine mudflats, where sediments may be periodically resuspended within a high turbidity layer (Falconer & Owens 1990). There has been a considerable body of research undertaken on how filter-feeding bivalves function under such turbid conditions.

Perna canaliculus are filter-feeders, they obtain their food by filtering suspended matter and food particles from the water column by passing the water over specialised filtering structures. Filter-feeding behaviour in bivalve shellfish is highly responsive to changes in both the abundance and composition of material suspended in the water column (Bayne 1998), both of which fluctuate wildly in nearshore environments (Bayne & Widdows 1978, Rodhouse *et al*. 1984, Smaal *et al*. 1986, Cranford & Hargrave 1994).

In their study on *P. canaliculus* feeding behaviour, Hawkins *et al*. (1999) experimentally tested feeding capabilities of the species by exposing mussels to artificially high concentrations of suspended sediments. They found that *P. canaliculus* is able to regulate rates of organic absorption (i.e. digestible food intake) and growth independent of ranges of seston (particles in the water, be they organic or inorganic) availability and composition wider than has been observed for any bivalve species. To achieve this regulation, total filtration rates increased with seston concentration to maximal rates at more than 1000 mg/L of total particulate matter. During the experiments, natural silt scraped from the surface layer of local mudflats made up a significant proportion of the seston, but the mussels were able to regulate their feeding. In studies on other bivalve species at high seston concentrations, filtration declined at concentrations of only 100 mg/L in the oyster *Crassostrea gigas* (Deslous-Paoli *et al*. 1987) and 300 mg/L in the cockle *Cerastoderma edule* (Navarro & Widdows 1997). Therefore, *P. canaliculus* has a much enhanced capacity to filter food from silty water compared to these other two species. It seems that this ability to extract food from water with high suspended sediment concentrations is common to species in the genus *Perna*. The green mussel *Perna viridis* is also able to cope with large changes in seston quality and quantity (Wong & Cheung, 1999).

It is established in the literature that the addition of silt to bivalve diets can actually enhance growth rates (e.g. Winter 1976, Griffiths 1980, Kiorboe *et al*. 1980, 1981, Mohlenberg & Kiorboe 1981, Hawkins *et al*. 1996) as a result of greater organic absorption associated with faster clearance rates required to remove the silt. It has also been established that suspension-feeding bivalves can compensate for the 'dilution' of food material (by silt or other inorganic components of the seston) by selective pre-ingestive rejection of filtered inorganic material as pseudofaeces, and so retaining organic matter for ingestion (e.g. Newell & Jordan 1983, Bayne *et al*. 1989, Hawkins *et al*. 1996).

Hawkins *et al*. (1999) conclude that traditionally, mussel farming in New Zealand has been undertaken in relatively clear water, with low sediment concentrations, and so enhancing the marketing perception of a 'clean' product. However, through experimentation, they demonstrated that through impressive capacities for filtration and particle selection, *P canaliculus* is able to maintain maximal growth rates over a wide range of feeding conditions that include much more turbid environments than had been previously been investigated. The study concludes with the statement that mussel farms could actually be expanded from the more traditional 'clear water' sites to more turbid areas, where production may actually be better.

6 Qualitative assessment of potential effects on key wild (non-cultured) mahinga kai species.

Table 6.1 lists the most important intertidal and subtidal mahinga kai species that may be found in the Lyttelton area. This species list, from Tonkin & Taylor (2014), was created in collaboration with local Runanga members, these species are therefore known to be of local importance as part of the traditional mahinga kai fishery.

Table 6.1: Intertidal and subtidal shoreline mahinga kai species associated with the Lyttelton Harbour area (from Tonkin & Taylor, 2014)

Maori name	English or common name	Species name
Paua	Abalone	*Haliotis iris*
Kina	Sea urchin	*Evechinus chloroticus*
Kutai	Blue mussel	*Mytilus edulis*
	Green shell mussel	*Perna canaliculus*
Koura	Spiny crayfish	*Jasus edwardsii*
Tio	Oyster	*Ostrea lutaria*
	Rock oyster	*Saccostrea commercialis*
Tipa	Scallop	*Pecten novaezelandiae*
Tuaki	Cockle	*Austrovenus stutchburyi*
Pipi	Pipi	*Paphies australis*
Pupu (or boo boos)	Cat's eye	*Lunella smaragdus*
	Scorched monodont	*Diloma aethiops*
	Mudflat snail	*Amphibola crenata*
Tuatua	Tuatua	*Paphies subtriangulata*
Wheke	Octopus	*Pinnoctopus cordiformis* and other species
Kaeo	Sea tulip	*Pyura pachydermatina*
Karengo	Seaweed	*Porphyra, Pyropia,* and *Clymene* species

In terms of direct impacts on mahinga kai species within the proposed dredging and disposal areas, it is possible that the soft-substrate species such as Pipi, Tuaki (cockles), and Tipa (scallops) could be displaced, both by removal from dredge areas, and over-burden at the disposal site. However, it appears that none of these species are present within the works areas. Sneddon *et al*. (2016) surveyed each of the areas, and none of these species are reported in their species lists.

Any effect on intertidal mahinga kai outside of the direct works footprint will depend on the suspended sediment concentration in the sediment plume, its physical extent in relation to these mahinga kai resources, and the duration that the plume is present in the vicinity of these resources. The modelling data indicated that there is negligible chance of disposal material being transported onto the shoreline. Consequently, any effect on these resources is also likely to be negligible.

It is also apparent that there are healthy populations of key mahinga kai species in close proximity to existing maintenance dredge disposal activities on the northern side of Lyttelton Harbour. In a recent survey that included 22 sites in Lyttelton Harbour and the Northern side of Banks Peninsula, Atalah and Sneddon (2016) reported the highest biomass of Green-lipped Mussels (*Perna*

canaliculus) at REDACTED which are both located on the immediate shoreline of the existing consented maintenance dredge spoil grounds (Figures 6.1 & 6.2). The mussel beds at these two sites covered an average area of more than 55% of the habitat. Another important mahinga kai species, the paua (*Haliotis iris*) was also present in reasonably high densities at these sites (Figure 6.3).

In another recent survey of 20 Lyttelton Harbour sites, Lilley *et al*. (2016) observed the highest mussel bed densities at two sites in REDACTED.

Disposal of up to c. 500,000 tonnes of maintenance spoil occurs annually in the subtidal area immediately offshore from these mussel and paua beds (Sneddon *et al*. 2016). The healthy state of these species is evidence that they are not negatively impacted by the existing channel maintenance dredging and/or disposal activity.

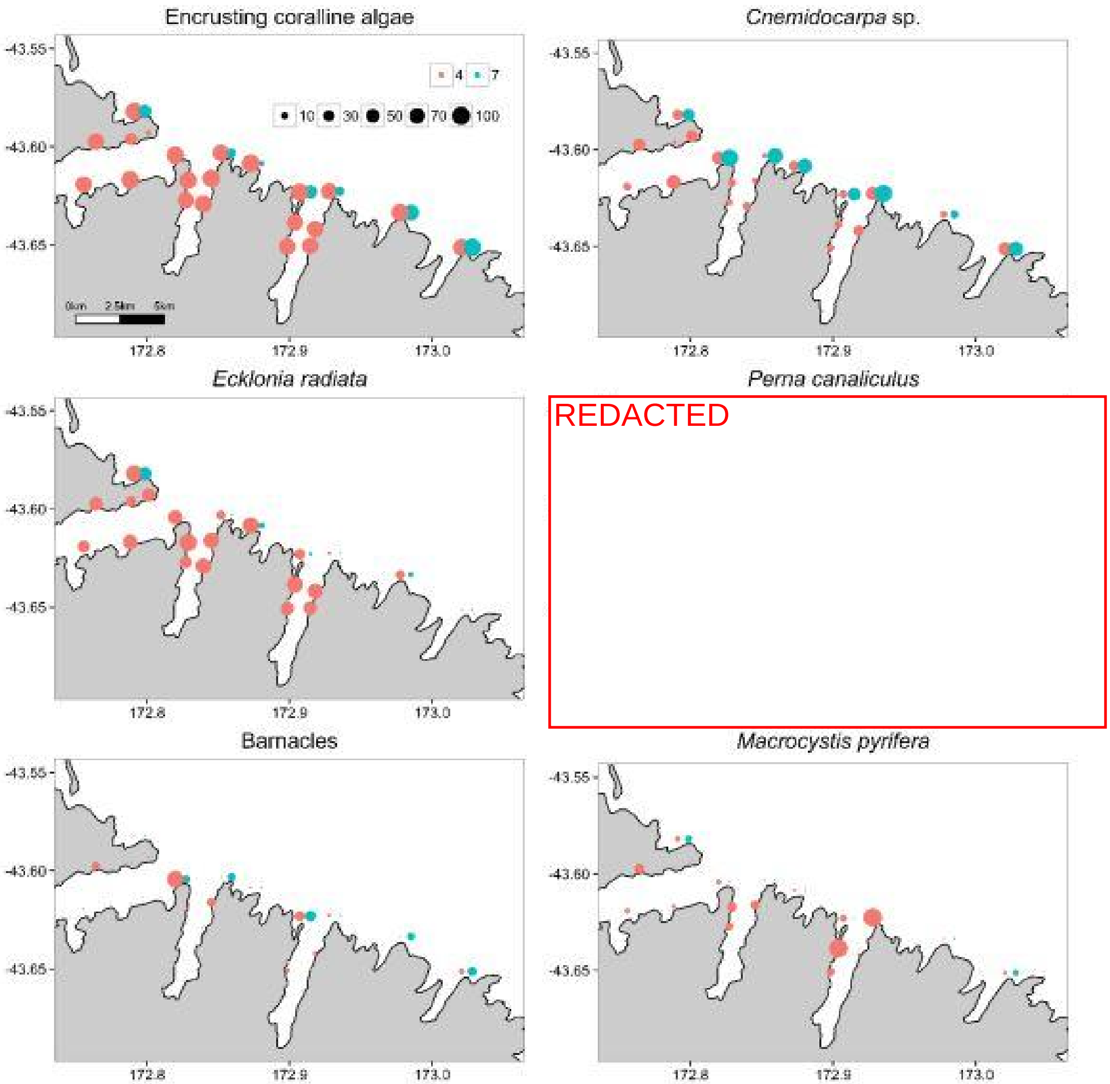

Figure 6.1: Maps of the Northern side of Banks Peninsula, showing percentage cover and spatial distribution of dominant taxa by depth: 4 m (red circles) and 7 m (green circles). Note mahinga kai species, Perna canaliculus. (From Atalah & Sneddon 2016).

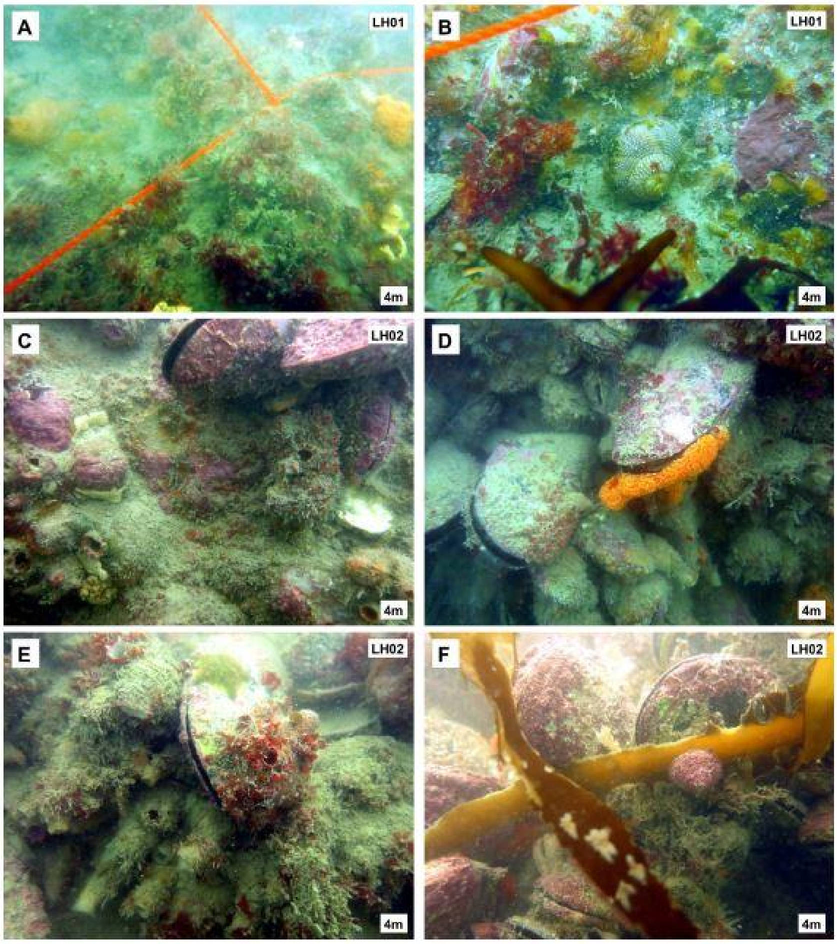

Figure 6.2: Photographs from sites on the northern side of Lyttelton Harbour taken in February 2016. Site location labels are in the top-right-hand corner of each image, LH01 is Breezes Bay, LH02 is Livingstone Bay. Perna canaliculus can be seen in images C, D, E and F. From Atalah & Sneddon (2016), images have been colour-enhanced for clarity.

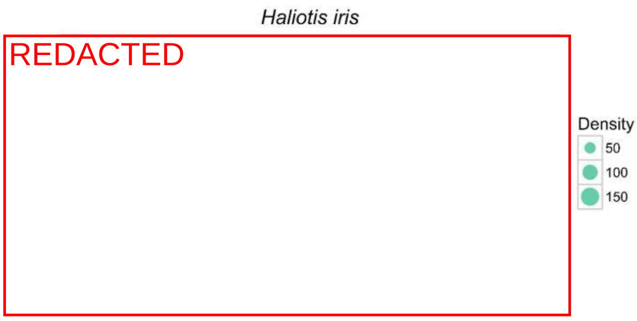

Figure 6.3: Density (No. per 50 m^2) of paua within the littoral fringe transects at 22 surveyed sites on the Northern side of Banks Peninsula (From Atalah & Sneddon 2016).

7 Assessment of Ecological Effects

7.1 Effects assessment framework

The assessment of ecological effects presented here uses the Ecological Impact Assessment (EcIA) guidelines produced by the Environment Institute of Australia and New Zealand (EIANZ, 2015). The EcIA approach uses the following steps:

1. Assigning ecological values on a scale of Low, Moderate, High or Very High based on the ecological values of species, communities, and habitats identified. A list of criteria that are considered is listed in Section 5.2 of the EIA guidelines, and a version which has been adapted slightly to make it more appropriate for use on this project is presented in Table 7.1 below;
2. Evaluating the magnitude of the effect of the project on ecological values in the area as Negligible, Low, Moderate, High and Very High. The criteria for describing the magnitude of effects are presented in Table 7.2 below;
3. Using a matrix to assess the overall level of ecological effect, based on ecological values and magnitude of effects on these values. The matrix for determining the overall ecological importance of the effect is presented in Table 7.3 below. In an RMA sense, the effects in the shaded cells (Moderate or greater effect) are typically considered to represent 'more than minor' (moderate) or 'significant' (high or very high) effects. Cells of Low or Very Low level of effect indicate a combination of low values and low to high magnitude of effects on these values and/or low magnitude of effects on values which may be low to high, but do not necessarily indicate low ecological values *per se*;
4. Using the overall ecological importance of effect to determine if mitigation is required. Effects assessed as being 'Moderate' or greater in Table 7.3 (i.e. 'more than minor' in an RMA sense) are considered to warrant efforts to avoid, remedy and mitigate effects.

Table 7.1: Assignment of values to species, vegetation and habitats (adapted from EIANZ, 2015)

Value	Species Values	Vegetation/Habitat Values
Very High	Nationally Threatened – Endangered, Critical or Vulnerable, or a resource which is of national commercial or cultural importance.	Supporting more than one national priority type. Nationally Threatened species found or likely to occur there, either permanently or occasionally.
High	Nationally At Risk – Declining, or a resource which is of regional commercial or cultural importance.	Supporting one national priority type or naturally uncommon ecosystem. At Risk – Declining species found or likely to occur there, either permanently or occasionally.
Moderate	Nationally At Risk – Recovering, Relict or Naturally Uncommon, or a resource which is of local commercial or cultural importance.	Other At Risk species found or likely to occur there, either permanently or occasionally.
Moderate or Low	Not Nationally Threatened or At Risk, but locally uncommon or rare.	Locally rare or threatened, supporting No Threatened or At Risk species.
Low	Not Threatened Nationally, common locally.	Nationally or locally common, supporting no Threatened or At Risk species.

Table 7.2: Summary of the criteria for describing the magnitude of effect (adapted from EIANZ, 2015)

Magnitude	Description
Very High	Total loss or major alteration to one or more key elements or features of the existing baseline conditions; Loss of high proportion of the known population or range of the element/feature.
High	Major loss or alteration to one or more key elements of existing baseline conditions; Loss of high proportion of the known population or range of the element/feature.
Moderate	Loss or alteration to one or more key elements of existing baseline conditions; Loss of a moderate proportion of the known population or range of the element/feature.
Low	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; Minor effect on the known population or range of the element/feature.
Negligible	Very slight change from the existing baseline conditions; change barely distinguishable from the 'no change' scenario; Negligible effect on the known population or range of the element/feature.

Table 7.3: Matrix for describing overall levels of ecological effects.

Magnitude of effect	Ecological Value			
	Very high	High	Moderate	Low
Very high	Very high	Very high	High	Moderate
High	Very high	Very high	Moderate	Low
Moderate	Very high	High	Low	Very low
Low	Moderate	Low	Low	Very low
Negligible	Low	Very low	Very low	Very low

Although not directly comparable, the level of effects determined using the criteria in Tables 7.1 to 7.3 may be interpreted within the context of standard RMA terms outlined in Table 7.4 below, which is modified from EIANZ (2015).

Table 7.4: Interpretation of assessed ecological effects against standard RMA terms

Level of Ecological Effect (refer Table 7.3)	RMA Interpretation	Description
Very high	Unacceptable adverse effects	Extensive adverse effects that cannot be avoided, remedied or mitigated.
High	Significant adverse effects	Adverse effects that are noticeable and will have a serious adverse impact on the environment but could potentially be mitigated or remedied.
Moderate	More than minor adverse effects	Adverse effects that are noticeable and may cause an adverse impact on the environment, but could be potentially mitigated or remedied.
Low	Minor adverse effects	Adverse effects that are noticeable but that will not cause any significant adverse impacts.
Very low	Less than minor adverse effects	Adverse effects that are discernible day to day effects but which are too small to adversely affect the environment or other persons.
Nil	Nil effects	No effects at all.

An assessment of the ecological effects of the proposed dredging is presented below. We have assessed the project effects on ecological values within the project footprint based on criteria identified in the EIA guidelines.

7.2 Ecological effects assessment for *P. canaliculus* marine farms

Farming of *P. canaliculus* on Banks Peninsula is of local and national commercial importance (see Section 2 above) and so its value~~,~~ is assessed as high. In terms of magnitude of effect, we have assessed that at the mussel farm sites the proposed activities are unlikely to cause any change to existing baseline conditions, and therefore the magnitude of effect will be negligible.

<u>Assessment of effects on *P. canaliculus* marine farms:</u>

High value + Negligible magnitude of effect = Very low overall ecological effect.

7.3 Ecological effects assessment for wild (non-cultured) mahinga kai species

The wild mahinga kai species on Banks Peninsula, in particular paua (*Haliotis iris*) and greenshell mussels (*P. canaliculus*), are a natural resource of cultural importance, well-known on a local and regional scale. The value would therefore be assessed as high (Table 7.1). In terms of magnitude of effect, we have assessed that at the coastal mahinga kai sites the proposed activities are unlikely to cause any change to existing baseline conditions, and therefore the magnitude of effect will be negligible.

<u>Assessment of effects on naturally-available mahinga kai species:</u>

High value + Negligible magnitude of effect = Very low overall ecological effect.

8 Monitoring the dredging and disposal activities – marine farm considerations

The dredging and disposal feature that is of most relevance to potentially impacting on marine farming activities, and on wild populations of mahinga kai species, is the movement of sediment plumes into the marine farms and onto shoreline habitats. While the MSL modelling indicated that there was only a negligible chance of disposal material being transported to marine farm sites or onto the shoreline, as an extra layer of safety, it would be prudent to set up a system to monitor the real-time movement of the turbidity plumes during the dredging operation.

LPC have contracted the services of Vision Environment (an Australian company) to undertake real-time monitoring of the dredging activities. A network of instruments that measure key environmental parameters, including water currents, turbidity, and sediment particle settlement, will be deployed throughout Lyttelton Harbour and out to the proposed disposal sites (Figure 8.1). The instrument capability will include real-time telemetry of data that will be made publicly available so that, for example, the mussel farming industry can observe the turbidity situation in real time. The planned monitoring will include 12 months of baseline monitoring before the dredging and disposal activities begin, followed by ongoing monitoring throughout the time of the proposed activities.

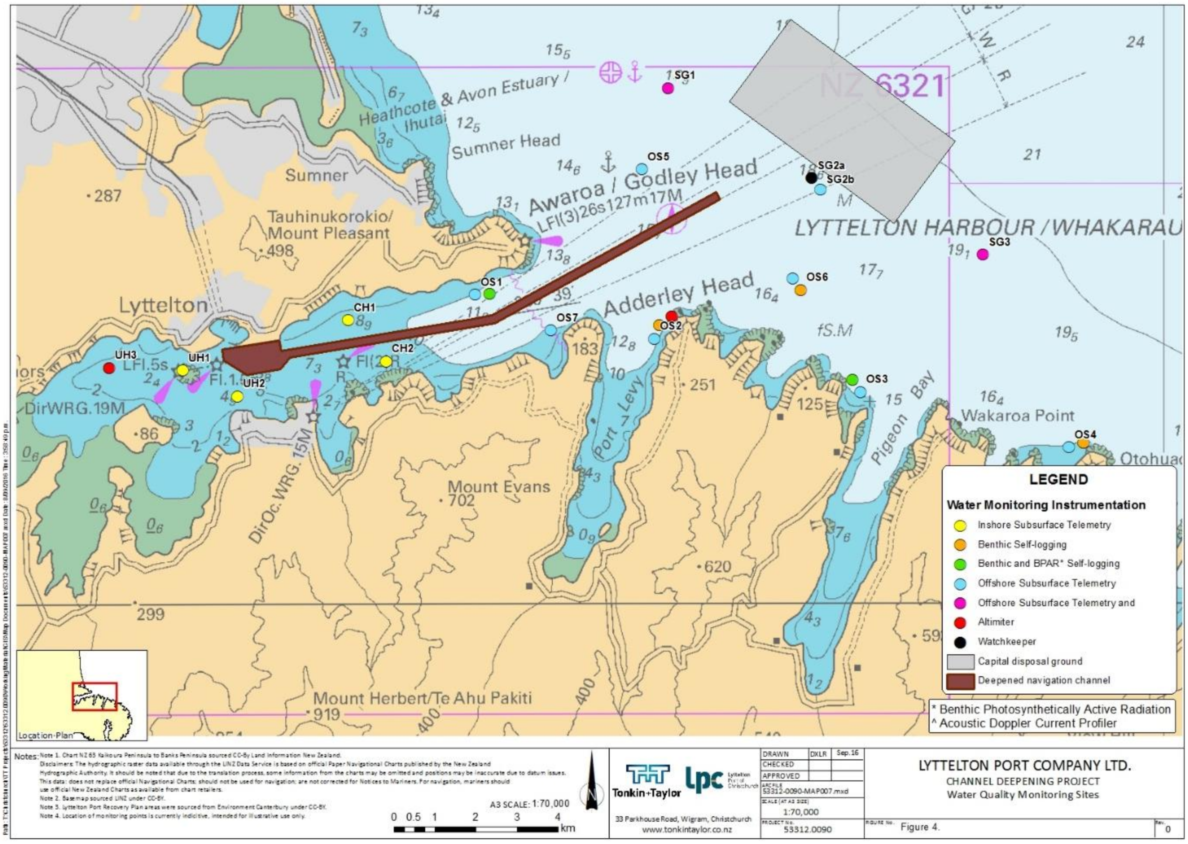

Figure 8.1: Network of monitoring instruments deployed by Vision Environment, to enable real-time telemeted monitoring of key environmental parameters, including water currents, turbidity, and sediment particle settlement. The array of instruments deployed was decided in collaboration with a Technical Advisory Group that includes Mana Whenua and key stakeholders including mussel farming industry representatives.

The instrument locations and configurations have been strategically chosen so as to act as a "safety net" to monitor movement of disposal sediment plumes towards sensitive receiving environments on the shoreline. Mussel farms and wild mahinga kai resources have been a central consideration

during the formulation of the monitoring array, and as such the following specific considerations were incorporated into the process:

- Given that suspended sediment concentration is an indicator of potential effects on mussel farms and mahinga kai, an instrumentation and telemetry system was chosen to enable monitoring suspended solid concentration on a real-time basis;
- The real-time data will be available publicly (via a website and/or app) to allow interested parties, such as Mana Whenua and mussel farming industry representatives, to keep a close eye on what is happening;
- Locations of monitoring instruments: instruments are to be positioned between the disposal sites and mussel farm and mahinga kai sites, with intermediary positions as primary and secondary warning systems;
- The monitoring system is able to measure pan-environmental events, such as high river levels, and consequent discharge of high turbidity water throughout all of Pegasus Bay, are the cause of increases in turbidity;
- The monitoring will begin by gathering 12 months of baseline data, before the proposed dredging and disposal activities commence. This will allow the creation of a robust data set of naturally-occurring turbidity conditions at the sites, ensuring a higher degree of certainty about actual changes that might be caused by the dredging and disposal activities;
- Real-time data gathered during the dredging and disposal activities will form the basis of an active response process, where the activity can be modified real-time, for example moving to an alternative site within the designated disposal area, further away from sensitive receiving environments, if turbidity measurements go above designated trigger levels.

While the proposed dredging and disposal activities are likely to have a very low overall ecological effect on mussel farming, as an extra level of safety (if there was the desire) mussels could be monitored on-farm. A robust methodological approach might involve measuring mussel survival, growth rates, and condition for the 12 months before, and during the proposed dredging and disposal activities. Three mussel farms could be chosen as representative sites. At each farm 50 mussels could be randomly selected at each of three different water depth ranges, and given a permanent identification tag (Ogilvie 2000). The shell length of each mussel could then be measured monthly, to give survival and growth rate statistics. In addition, a further 50 randomly-selected mussels from each farm could be sacrificed each month, to measure condition (mussel shell length to meat weight ratio).

9 Conclusions

A summary of the key elements relating to potential impacts of the proposed dredging and disposal activities is given visually in Figure 9.1.

On the basis of numerical modelling of turbidity plume movement at the CDP disposal site, it is concluded that it is exceptionally unlikely that plume particles will reach the shoreline, or mussel farms. On the basis of numerical modelling of the proposed maintenance disposal site it is concluded that it is very unlikely that plume particles will reach the shoreline, or mussel farms.

On the Northern side of Banks Peninsula, the strongest prevailing residual currents move parallel to the coastline, onshore currents are relatively weak. These are important contributors to the numerical modelling conclusions made above.

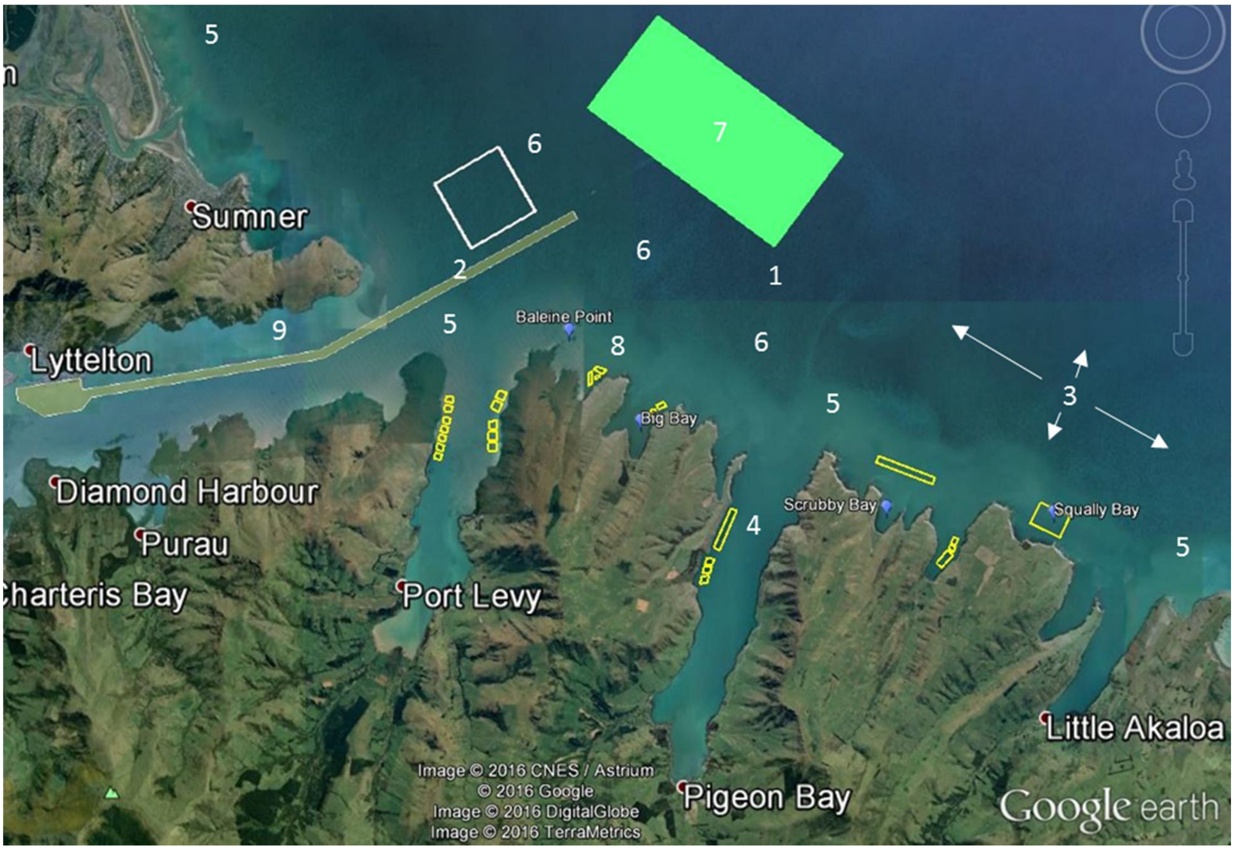

Figure 9.1: Visual summary of key elements pertinent to this AEE. Legend: 1. Numerical modelling for capital dredge disposal ground shows exceptionally unlikely chance of turbidity plume moving to shore. 2. Numerical modelling for maintenance dredge disposal ground shows very unlikely chance of turbidity plume moving to shore. 3. Strongest prevailing residual currents are parallel to the coastline, onshore/offshore are relatively weak. 4. Scientific literature on the farmed mussel species shows it is naturally tolerant of turbidity. 5. Natural baseline turbidity concentrations are significant, e.g. periodic riverine inputs can be high. 6. Real-time telemetered monitoring of activity is a safety net. 7. Activity itself can be modified in real-time to eliminate risks of onshore plumes. 8. Within-farm mussel survival, growth, and condition monitoring, over 12-month baseline, and during the dredge and disposal activity itself. 9. Real life 'experiment' with mussels and paua, both are doing well here, despite dredge spoil deposited in close proximity over many years.

It is also concluded that variable, including high, turbidity is a natural feature of the waters of this part of the Canterbury coast. There are no indications that these high sediment loads pose any problems for the natural biota or farmed marine species, based on the abundant soft and hard-bottom biotas throughout the region (Sneddon *et al*. 2016).

It is also concluded that the mussel species farmed on Bank Peninsula, *P. canaliculus*, is naturally tolerant of turbidity. The species has evolved to live on the seabed, where suspended sediment concentrations are naturally high, because of the high-energy interface where water movement stirs up the substrate. Scientific literature on this matter (e.g. Hawkins *et al*. 1999) concludes that predominant cultivation practices in New Zealand, such as having mussel farms on the water surface in areas of high water clarity (like the Marlborough Sounds) are unlikely to result in optimal mussel growth rates. In fact Hawkins *et al*. (1999) conclude that there is significant potential for expansion of New Zealand mussel farming by moving away from traditional 'clear water' sites to more turbid areas. This might explain the high growth rates reported for farmed mussels in Pigeon Bay on Banks Peninsula (Fenwick *et al*. 2003).

On the basis of the Ecological Impact Assessment (EcIA) guidelines produced by the Environment Institute of Australia and New Zealand (EIANZ, 2015) it is concluded that for mussel farming and wild (non-cultured) mahinga kai species on the Northern Side of Banks Peninsula, the proposed dredging and disposal activities are likely to have a very low overall ecological effect.

However, given the importance of these resources, and as a precautionary approach, we support the intention, as part of the Environmental Monitoring and Management Plan, that real-time sediment plume monitoring be carried out during the works (Vision Environment, 2016) to confirm the actual extent of sediment plume movement, and if necessary, to allow the dredge and disposal activities to be modified in real time to eliminate adverse effects.

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11 Applicability

This report has been prepared for the exclusive use of our client Lyttelton Port of Christchurch, with respect to the particular brief given to us. It may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Dr Shaun Ogilvie	Dr Brett Ogilvie
Contract Consultant	Project Director

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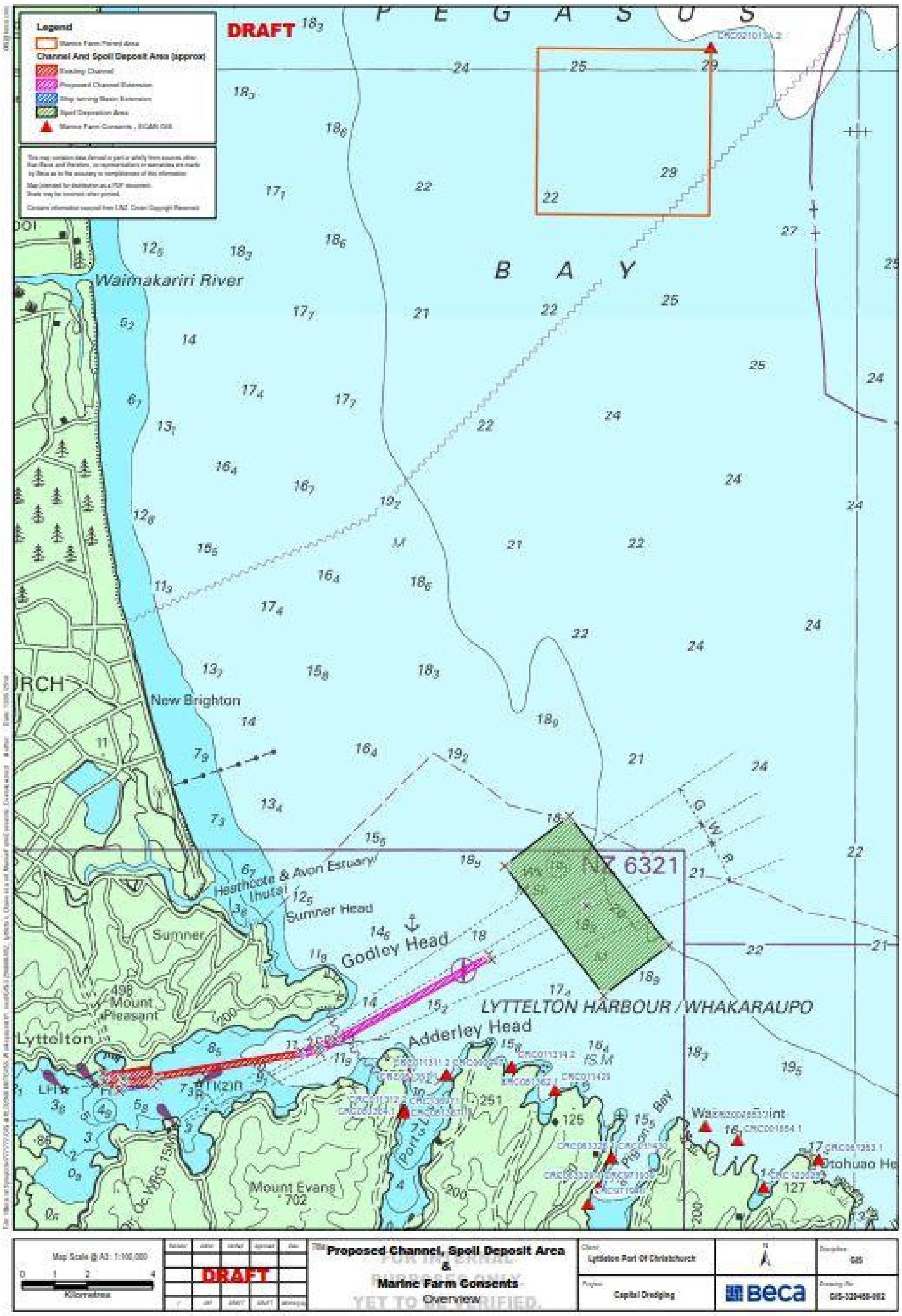
Appendix A: Environment Canterbury marine farm permit information for the northern side of Banks Peninsula

Consent No	Activity Type	Consent Status	Permit Type	Location	Holder Name
CRC001853.1	MARINE FARM	Issued - Active	Coastal Permit	Northern Coastline, BANKS PENINSULA	Ocean Marine Farm Limited
CRC001854.1	MARINE FARM	Issued - Active	Coastal Permit	Northern Coastline, BANKS PENINSULA	Ocean Marine Farm Limited
CRC063353.1	MARINE FARM	Issued - Active	Coastal Permit	Scrubby Bay, BANKS PENINSULA	Ocean Marine Farm Limited
CRC063359.1	MARINE FARM	Issued - Active	Coastal Permit	Scrubby Bay, BANKS PENINSULA	Ocean Marine Farm Limited
CRC081353.1	MARINE FARM	Issued - Active	Coastal Permit	Squally Bay, BANKS PENINSULA	Pegasus Bay Marine Farm Limited
CRC154277	MARINE FARM	Issued - Active	Coastal Permit	Squally Bay, BANKS PENINSULA	Pegasus Bay Marine Farm Limited
CRC011429	MARINE FARM	Issued - Active	Coastal Permit	Big Bay, BANKS PENINSULA	Pigeon Bay Aquaculture Limited
CRC011430	MARINE FARM	Issued - s124 Continuance	Coastal Permit	Pigeon Bay, BANKS PENINSULA	Pigeon Bay Aquaculture Limited
CRC063319.1	MARINE FARM	Issued - Active	Coastal Permit	Big Bay, BANKS PENINSULA	Pigeon Bay Aquaculture Limited
CRC063326.1	MARINE FARM	Issued - s124 Continuance	Coastal Permit	Pigeon Bay, BANKS PENINSULA	Pigeon Bay Aquaculture Limited
CRC063329.1	MARINE FARM	Issued - s124 Continuance	Coastal Permit	Pigeon Bay, BANKS PENINSULA	Pigeon Bay Aquaculture Limited
CRC141982	MARINE FARM	Issued - Active	Coastal Permit	Pigeon Bay, Western Shore, Banks Peninsula	Pigeon Bay Aquaculture Limited
CRC141982	MARINE FARM	Issued - Active	Coastal Permit	Pigeon Bay, Western Shore, Banks Peninsula	Pigeon Bay Aquaculture Limited
CRC971939	MARINE FARM	Issued - s124 Continuance	Coastal Permit	Adj Little Pigeon Bay Road, PIGEON BAY	Pigeon Bay Aquaculture Limited
CRC971940	MARINE FARM	Issued - s124 Continuance	Coastal Permit	Adj Little Pigeon Bay Road, PIGEON BAY	Pigeon Bay Aquaculture Limited
CRC081362.1	MARINE FARM	Issued - Active	Coastal Permit	Beacon Rock East, BANKS PENINSULA	Sanford Limited
CRC081364.1	MARINE FARM	Issued - Active	Coastal Permit	Port Levy South, BANKS PENINSULA	Sanford Limited
CRC081367.1	MARINE FARM	Issued - Active	Coastal Permit	Port Levy North, BANKS PENINSULA	Sanford Limited
CRC136970	MARINE FARM	Issued - Active	Coastal Permit	Port Levy North, BANKS PENINSULA	Sanford Limited, Marlborough
CRC136971	MARINE FARM	Issued - Active	Coastal Permit	Port Levy South, BANKS PENINSULA	Sanford Limited, Marlborough
CRC136972	MARINE FARM	Issued - Active	Coastal Permit	Beacon Rock East, BANKS PENINSULA	Sanford Limited, Marlborough
CRC000947	MARINE FARM	Issued - Active	Coastal Permit	Port Levy, BANKS PENINSULA	Southern Seas Marine Farms Limited
CRC081357.1	MARINE FARM	Issued - Active	Coastal Permit	PORT LEVY, BANKS PENINSULA	Southern Seas Marine Farms Limited
CRC122028	MARINE FARM	Issued - Active	Coastal Permit	Menzies Bay, BANKS PENINSULA	Te Wharau Investments Limited

Data accessed from Environment Canterbury 22nd April 2016.

Appendix B: Chart showing location of large marine farm permit in Pegasus Bay

The red square at the top of the chart shows the location of the large marine farm permit.



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