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Biological resources of Otago Harbour and offshore: assessment of effects of proposed dredging by Port Otago Ltd

NIWA Client Report: HAM2008-152
February 2009

NIWA Project: POL08201

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Biological resources of Otago Harbour and offshore: assessment of effects of proposed dredging by Port Otago Ltd

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Prepared for

Port Otago Limited

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Contents

Executive Summary			iv
1.	Introduction		1
	1.1	Background	1
	1.2	Scope of this report	2
2.	The physical environment		3
	2.1	The harbour	3
	2.2	Hydrodynamics	3
	2.3	Sediment type	5
	2.4	Contaminants	8
	2.5	Sediments	8
3.	Biological resources		10
	3.1	Harbour benthic communities	10
	3.2	Offshore benthic resources	14
	3.3	Planktonic communities	18
	3.4	Birds of the Otago harbour and coast	18
	3.5	Marine mammals	19
	3.6	Fisheries resources	19
4.	Description of proposed dredging operation		21
5.	Effects of proposed dredging operation in Otago harbour		23
	5.1	Physical changes (summarised from Bell et al. 2009)	23
	5.1.1	Currents and tides	23
	5.1.2	Turbid plume in harbour	24
	5.1.3	Sedimentation in the harbour	25
	5.1.4	Dispersion and deposition at disposal sites	28
	5.1.5	Habitat changes – bathymetry etc.	32
6.	Effects of dredging on biological resources		35
	6.1	Effects of dredging operations in the harbour	36
	6.1.1	Effects on dredging on benthic communities - physical disturbance and recovery	36
	6.1.2	Effects of dredging on benthic communities – suspended sediments and turbidity	38
	6.1.3	Effects of dredging on zooplankton	41
	6.1.4	Effects of dredging on contaminants and nutrients	41
	6.1.5	Effects of dredging on benthic communities - settlement of suspended	41
	6.1.6	Changes to hydrodynamic regime and geomorphology	44
	6.1.7	Effects of dredging on birds	44
	6.1.8	Effects of dredging on fisheries and shellfisheries	47
	6.1.9	Effects of noise and blasting on aquatic animals	49
	6.2	Effects of the disposal of dredged material	50
	6.2.1	Selection of disposal options	50

6.2.2 Discharge of dredged material at the disposal site 50
6.2.3 Effects of disposal on plankton communities 51
6.2.4 Effects of disposal on benthic communities 52
6.2.5 Spread of invasives 54
6.2.6 Effects of disposal on birds 54
6.2.7 Effects of disposal on mammals 56
6.2.8 Effects on disposal on fisheries 57
6. Acknowledgements 72
7. References 73

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Executive Summary

Port Otago Ltd is carrying out investigations for a proposed modification to the shipping channel to accommodate the next generation of container ships. The modification would involve dredging the approaches to Port Chalmers and berth area and deepening of the channel. A few areas would also require widening. It is proposed to use a trailing suction hopper dredge except in shallow areas of the Swing Basin and potentially the few rocky areas where a smaller backhoe dredge and possibly blasting may be used. Less than 10,000 m^2 will be removed for the channel widening and mostly immediately opposite the Port. Depending on the final plans up to 7.5M m^3 of sediment will be dredged and disposed of with the most likely disposal site being about 7.3 km to the NE of Taiaroa Head.

Other than the main channel, Otago Harbour is mostly shallow with extensive tidal flats. The Harbour is the only large non-estuarine inlet on the south-east coast of New Zealand but has been significantly modified by human activities and experiences episodic inputs of suspended sediments increasing turbidity.

Sediments in the Harbour graduate from finer muddier sediments in the Upper Harbour to coarser fine sand towards the entrance, with fine sand on the intertidal flats. Offshore sediments are fine well-compacted sands with higher silt content in the middle of Blueskin Bay. Contaminants in the Port area and channel to be dredged were found to be low and below the ANZECC guidelines for maintaining biological systems.

The Lower Harbour is a mosaic of benthic habitats that can be divided into 6-10 habitat classes dominated by medium sands and relict shells (24% of area), extensive intertidal flats (35%) and inlet features with seagrasses and cockle beds (24%). Sea lettuce is episodically abundant and much of the intertidal area is covered in extensive algal mats.

One hundred and thirty-four benthic invertebrate taxa were recorded in the latest surveys and the community was dominated by amphipods and molluscs. Highest diversity was recorded across a range of habitats including parts of the channel and middle of intertidal flats. No distinct macrofaunal assemblages associated with particular habitats were identified during surveys in the Lower Harbour. Most species were found across a range of habitats thus the Harbour can essentially be treated as “one system”. One exception is the deep sessile community found in pockets of the main channel and comprised of animals such as sponges and tunicates. Cockles occur in patches throughout the tidal flat areas with highest densities in the Lower Harbour opposite Acheron Pt and south of Harwood. There were surprisingly few benthic animals on the Aramoana flats with the most common being small bivalves.

Offshore the density of benthic invertebrates was lowest in inner Blueskin Bay where silt content was higher than elsewhere. Benthic invertebrate density and diversity were highest just north of the Otago Harbour entrance. The fauna was dominated by the gastropod (snail) *Antisolarium egenum*, followed by three polychaete worms and the ubiquitous bivalve *Nucula nitidula.* Site A1 was more turbid and total faunal densities were higher than at Site A2, but

the latter contained more epifauna (large tubeworms, whelks etc.). The fauna in this area is typical of nearshore sand zones and no rare or unique species were found.

There is a diverse coastal fish and shellfish fauna in Otago Harbour and the waters adjacent to Otago Peninsula. The fish and shellfish fauna present in these waters is predominantly comprised of common species that are widely distributed throughout central New Zealand coastal waters.

The extensive intertidal areas of Otago Harbour contain a significant population of cockles (*Austrovenus stutchburyi*). Customary, recreational and commercial fishing and seafood gathering takes place along the Otago coast and customary and recreational fishing in the Otago Harbour. Recreational salmon fishing is a significant activity along the lower Otago Harbour channel and around the Harbour entrance during the summer months. The waters of Blueskin Bay are important to Otago commercial fishing vessels that fish for flatfishes and other inshore species there.

The lower Otago Harbour and the adjacent offshore marine environment support a diverse array of bird life including one nationally critical species (grey-headed mollymawk), two nationally endangered species (black-fronted tern, black-billed gull), six nationally vulnerable species (including yellow-eyed penguin and Stewart Island shag), and five species in decline. Thirty-four species of seabird have been reported from Otago coastal waters, 13 of which breed on the coast and 6 commonly frequent the intertidal areas. The Otago area has the only mainland breeding colony of northern royal albatross and Steward Island shag. Large numbers of shorebirds feed within Otago Harbour and on sandflats of Aramoana but most breed elsewhere.

Four seal and six cetacean species have been reported from the Otago coast. All of these species spend time in the coastal waters off Otago, and several species of seal use areas on the Otago Peninsula as haul-out areas and breeding grounds. Mammals with special conservation status are the southern elephant seal, Hectors dolphin, southern right whale, New Zealand sea lion and bottlenose dolphin.

The main effects of dredging on ecology of the Otago region will be direct impacts through removal and disturbance, smothering of benthic communities, increased suspended sediments and turbidity, reduced water clarity, release of contaminants, effects of blasting and potential for spread of invasive species. Each of these potential impacts have been considered for the benthic communities, fish, birds and mammals. The most significant effects are likely to be through direct removal of organisms, and the increase in suspended sediment and sediment deposition. These could potentially be of high severity but would be restricted in extent and duration.

Habitats and communities in the channel are already modified through maintenance dredging. However, most of these communities will be removed in areas that are dredged and marginal areas where the channel is to be widened. Most of these communities are well represented elsewhere in the Harbour except for the deep, sessile communities in the deeper subchannels and hollows. Recovery of animals like polychaete worms could be on a timescale of months while longer lived species could take 2-3 years and deep sessile communities several years to recover. The area to be removed by widening is less than 0.5% of the intertidal habitat in the Lower Harbour and will thus only have a very localised effect.

Harbours are naturally turbid at times and communities are adapted to periods of high suspended sediment concentrations and low water clarity. Many benthic animals can tolerate high levels for short periods. Modelling indicates that levels could reach over 1000 mg/l but only for short periods and only in patches in the immediate vicinity close to the main channel. Fish and mammals are very mobile and can avoid areas of high suspended sediments while zooplankton and larval fish can tolerate the levels predicted. The highest levels predicted could have a moderate effect on seagrasses but this would be for less than 5% of the time and would be very localised in extent. The communities would recover when dredging ceases.

Most animals and plants found in harbours and estuaries can survive small amounts of sediment deposition (generally <20 mm in an event for benthic animals and <0.25 mm/d for seagrasses). Modelling indicates that most non-channel areas of the Lower Harbour would receive less than a median of 2 mm over the dredging period with up to 5 mm or more in intertidal areas close to the Port. Parts of the channel close to the Port could receive up to 6cm but this would affect less than 10 % of the area and would be dispersed relatively quickly by the strong currents. Other parts of the channel would receive less with a maximum at the Spit of 20 mm. Only a very small part of the area around Portobello and off Harwood would receive 3 mm or more over the 108 days it may take for dredging.

The levels of contaminants and potential for water quality issues are low. If they did occur any impact would be for a very short period due to rapid flushing. Levels of contaminants in sediments to be dredged are below ANZECC guidelines for protection of biological communities.

There may be limited areas of rock substrate (<1% of area) that will require blasting. It is expected that only fish in the immediate vicinity of the blasting will be impacted. With appropriate mitigation most mobile species can avoid the blasting. Only macroinvertebrates at the site itself would be impacted.

The main effects at the disposal site are predicted to be the direct effects of smothering of the benthic community, increased levels of suspended sediments and reduced water clarity. Virtually all benthic plants and animals in the immediate disposal area would not survive smothering (at least 1.2m depth on average). Recovery could take up to a year for some animals and longer for some larger animals, depending on the disposal operations. Careful consideration has gone into the selection of a site to avoid important biogenic sites offshore (bryozoan community) and the potential for significant dispersal inshore to Blueskin Bay and the outer Otago peninsula. No unique or special communities have been identified within the footprint of the disposal site.

The increased levels of suspended sediments and reduced water clarity will affect the immediate disposal site but the levels of suspended sediments will be rapidly diluted away from the site. Away from the disposal site (~2 km in diameter) suspended sediment concentrations will be less than 10 mg/l, well below the level which would affect plankton and the level set to protect birds like terns and gannets. Most seabirds found in the area feed well offshore (e.g., endangered grey-headed mollymawk and northern royal albatross) or are predominantly bottom feeders at depths over 40m (e.g., sooty shearwaters and yellow-eyed penguins). Some shag species may feed in the disposal area and along with some fish species may be affected in the immediate area. Most birds however, could avoid areas of high suspended sediments. Feeding grounds in the vicinity of the disposal site could be affected short-medium term. Similarly mammals generally feed over very large areas and could avoid the short-term disruption associated with the disposal. Hectors dolphins tend to forage to the east and north of the disposal grounds and would be unlikely to be impacted.

Because of the low levels of major contaminants at the dredging sites the effects from release of contaminants at the disposal site is likely to be low and very short-term.

A number of invasive species have been reported from Otago ports with 25 species (mostly sponges) not previously described from New Zealand waters. While the seaweed *Undaria* has been present since at least 1990 the seasquirt *Styela* has not yet been recorded. It is highly unlikely that species like *Undaria* would become established at the proposed disposal site because of the lack of hard substrate, depth and exposure.

1. Introduction

1.1 Background

The next generation of container ships that will come into New Zealand will have up to 50% more capacity and be considerably larger than existing ships. In order for Port Otago Ltd (POL) to expand its operation to include these new ships, the Port Company proposes dredging the approaches to Port Chalmers and berth area by deepening the channel to between 14 and 15 metres. Depending on the final channel alignment and depth this will involve dredging up to 7.5M m^3 of material.

The material to be dredged has been characterised based on coring and will be mostly fine sand, with finer silt and clay dominated sediments in the channel from Port Chalmers out to Te Ngaru-Cross Channel. A few locations that need to be dredged or widened around Acheron Pt and Pulling Pt contain rock substrate. There are a number of potential environmental issues associated with this dredging, including sediment disturbance and turbidity, sedimentation, and effects on hydrodynamics and ecology. All of these need to be addressed in the environmental assessment process.

There are three generic methods of disposing of dredged material, namely use in beach nourishment/coastal protection works, reclamation and marine disposal. Because of the quantities of material involved marine disposal is considered the most likely method of disposal for most of the material. Therefore issues around marine disposal are a priority area for assessment.

The approach taken with assessing the potential ecological effects of this project is consistent with the guidelines produced by Environment Australia (2002) and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, commonly referred to as the London Convention.

The first stage of this investigation was to produce an annotated bibliography which identified studies that have been carried out in the Harbour itself and region offshore which could be potentially a receiving area for dredged material. A feasibility report was then prepared (James et al. 2007) which gave a brief overview of the present status of knowledge of the ecology of the region, identified gaps and scoped the type of work that would be required as part of a detailed Assessment of Environmental Effects (AEE). In order to fill the gaps and update our knowledge a number of subsequent studies were undertaken. In addition to extensive consultation these studies included the following:

- Benthic survey of Lower Harbour environment

  A survey of benthic habitats and assemblages was carried out in the Lower Harbour in March-June 2008 to fill gaps in our knowledge. The results of those surveys are reported in Paavo and Probert (2008).

- Benthic survey offshore in region of proposed disposal of material

  An offshore benthic survey was carried out using sidescan sonar, splashcam and grab sampling in April/May 2008 at the proposed dredge spoil disposal sites and wider area to the east and north to Cornish Head. The results from these surveys are reported in Willis et al. (2008).

- Foraging and roosting behaviour of birds

  An observational survey was carried out in March 2008 to examine foraging behaviour of wading birds, provide baseline data in the vicinity of the Aramoana ecological area and to assess the significance of roosting sites on high shell banks in the vicinity of Port Chalmers. These areas were identified by the Department of Conservation as important areas that needed further work. The results from these observations are reported in Sagar (2008).

- Fisheries

  Extensive reviews were carried out of available information to describe the fish and shellfish resources in the Otago Harbour and adjacent Otago coast with an emphasis on resources important for customary, recreational and commercial purposes. This study included examining the extensive fisheries literature, fisheries statistical data and consultation with the fisheries sector. The results of that study are reported in Boyd (2008).

1.2 Scope of this report

The scope of this report is to provide an assessment of potential effects of the proposed dredging operation on the ecology of the Otago Harbour and offshore environs. The specific objectives of the assessment were to:

- Describe the communities and habitats in the Lower Harbour and offshore area that may be sensitive to dredging operations, including a summary of results from recent surveys undertaken for POL.

- Summarise the physical environment and potential changes that may result from the dredging operation that could impact on the ecology.

- Summarise potential effects of dredging operations, based on published papers and reports and unpublished information.

- Assess the effects of the proposed dredging operation and disposal of dredge material on the benthic environment, birds, fish, and marine mammals.

2. The physical environment

2.1 The harbour

Otago Harbour is a long and narrow shallow inlet aligned SW-NE, about 21 km long, generally about 2 km wide, with a mean surface area at high spring tides of 46 km^2. Peninsulas at Port Chalmers and Portobello and their adjacent islands divide the Harbour into upper and lower basins (Figure 1). Other than the main channel, the Harbour is mostly shallow with water depths of less than 2 m, and nearly 30% of its area comprises exposed sediment flats at low spring tides. The main channel between Port Chalmers and Dunedin is maintained to a depth of 10 m but from Port Chalmers to the entrance the channel is up to 13 m depth with 14.5 m depth outside the Mole. The only other naturally deep areas (> 30 m) are holes next to the Quarantine and Goat Islands. The shipping channel extends along the western shore for much of the Harbour's length. Otago Harbour is the only large non-estuarine inlet on the southeast coast of New Zealand and has a number of important sheltered water habitats that are not widely represented elsewhere in this biogeographic region.

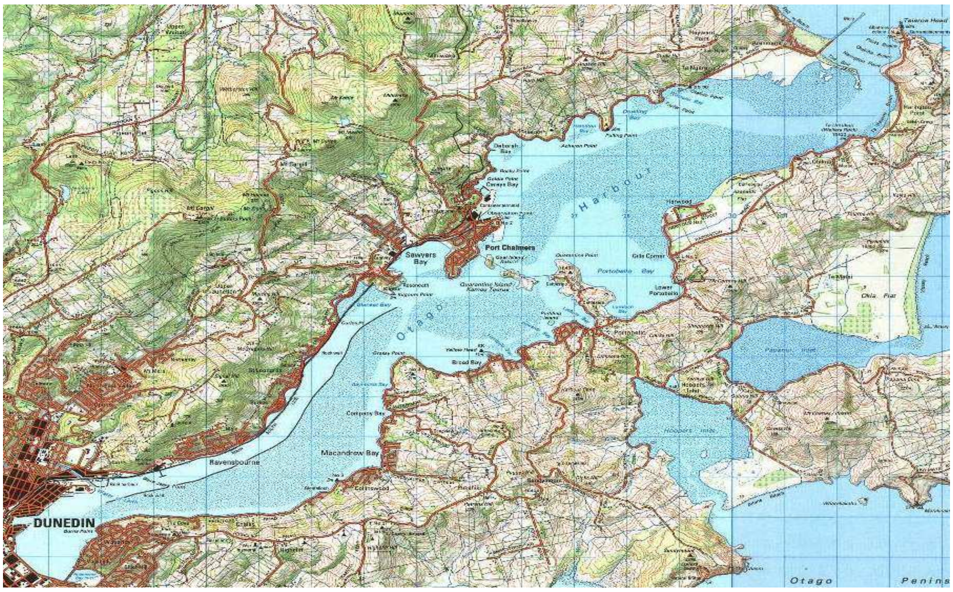

Figure 1: Geographical sites in Otago Harbour [*Source:* ©LINZ 1:50,000 topographic maps]. (From Bell et al. 2009).

2.2 Hydrodynamics

Peak flows of 1.59 m/s occur on flood tides at the southern end of the Spit on the western side of the channel. On ebb tides peak flow is 1.36 m/s on the eastern side of the channel near the centre at Harrington bend (Single and Benn 2008). Peak spring tides around Goat Island produce currents of around 0.8 m/s on the flood tide and 0.6 m/s on the ebb tide (Barnett 1988). More recent measurements have recorded peak currents at Harington Bend and within the tidal jet at the Harbour entrance of up to 1-

1.5 m/s on flood tides whereas the maximum ebb tide current only reaches 1m/s. (Old & Vennell 2001). Slower currents were recorded in Portobello Bay and the Eastern Channel during recent surveys (1998) with peaks of 0.3-0.37 m/s and 0.44 m/s respectively.

The tidal range is 1.98 m for spring and 1.25 m for neap tides at Port Chalmers which is 0.1m lower than at Dunedin. High tide at Port Chalmers occurs around 10-15 minutes after high tide at the Spit. The difference for spring low tides is 50-60 minutes and neap low tides 35 minutes. For the existing Harbour bathymetry, the main Harbour channel is flood-dominant in relation to flood-tide velocities being greater than ebb-tide velocities due to the shorter flood tide. This pattern is emphasised more on a spring tide.

The tidal prism (total water volume) has been estimated at 6.8 x 10^7 m^3 going out on ebb tide and 6.5 x 10^7 m^3 on subsequent flood tide. The residence time has been estimated at 1.6 days for Upper Harbour waters (Heath 1976). The Upper Harbour is less well flushed, and salinity decreases towards the mouth of the Water of Leith, the main riverine inflow. However, this input is relatively small and salinity in the Upper Harbour rarely falls below about 30 ppt. Generally the Harbour can be considered more of an extension of the sea than an estuary.

The ebb tide jet flow off the entrance to Otago Harbour has been described by Old and Vennell (2001) and further current measurements were made by Barnett (1988). The average residual current was 4.5 km/d to the north off the Harbour entrance based on recent current measurements. Further offshore in the region of the underwater bank the tidal residual currents are much slower and plumes from the Clutha and Southland current become more prominent (both moving in a north to north-east direction).

Figure 2 below shows that the Southland Current is strong and persistent and on the inner shelf there is a anticlockwise eddy in Blueskin Bay at depths greater than 20m (Bell et al. 2009). Recent hydrodynamic modelling and empirical measurements (ADCP current profiles) have shown that a small gyre of about 5 km in diameter often sets up to the north-east of the entrance as a result of the combined effects of a large gyre in outer Blueskin Bay, the jet from the entrance and the offshore northward flowing Southland Current.

A constraints mapping exercise early in the process identified the region to the north-east of Taiaroa Head as a potential area for disposal of dredged material. The small clockwise gyre identified in this region appears to be relatively persistent and could have implications for the inner disposal site that was originally proposed, 4 km NE of Taiaroa Head (Figure 2 -Site A1). The prevailing currents in most cases at this site are to the SE driven largely by the prevailing winds from the SW and NE. At times there can be a slight deviation in current direction to more of a southward flow during winds from a more northerly direction. Two other disposal sites have been considered, one is on the northern end of the submerged Peninsula Spit (Figure 2, Site A2) and the other and more likely site is A0, 7 km north-east of Taiaroa Head. Both Site A2 and A0 would appear to be more embedded in the Southland Current with strong offshore flows to the north, than Site A1.

Recent current measurements at a site in Blueskin Bay (Bell and Hart 2008) show considerable variation in direction depending on the state of the tide, wind and state of the Blueskin Bay gyre. At times the currents were driven by alternate NE and SW winds while at other times the current drift was more to the north during strong SW winds. Off Heyward Point the prevailing net current is generally eastwards but at times can be driven more to the NW (Bell and Hart 2008).

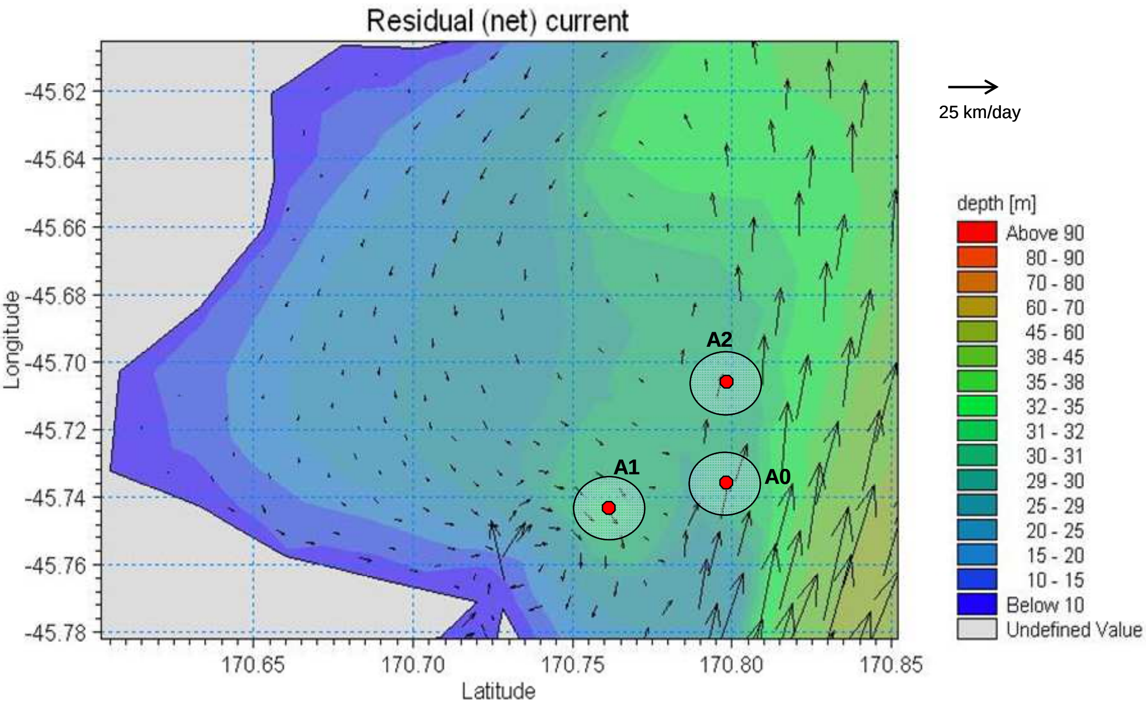

Figure 2: Residual net current patterns and Location and extent of disposal site options investigated during the offshore plume modelling process.

2.3 Sediment type

Sediments in the Otago Harbour range from silt to coarse shell-sand with a progression from finer grained and muddier sediments in the Upper Harbour to coarser sand sediments in the Lower Harbour. Similarly the area that POL propose to dredge progresses from sediments dominated by silt and clays with sand in the area closest to Port Chalmers to predominantly fine sand at the entrance to the Harbour.

A geotechnical survey was undertaken in 2008 by POL Otago to better characterise the sediments to be removed. Clay/silt was most common in the Swing Basin to Cross

Channel and silty/clay was most prominent around Acheron Pt. Rock was encountered at Rocky Pt and Acheron Pt. Sediments in the Lower Harbour close to the entrance were dominated by sand, in some places rippled fine sand or fine sand with shell relicts.

Offshore the sediments are generally well consolidated, homogeneous, well-sorted fine sands with little very fine material, as a result of dispersal alongshore or well offshore by currents and wind action. Silt content and organic matter were highest in the centre of the bay (Figure 3). Shallower parts of the bay and the area east of Taiaroa Head had slightly coarser fine sand (Figure 4). Areas with medium sand were only significant east of Taiaroa Head where tidal currents were strongest.

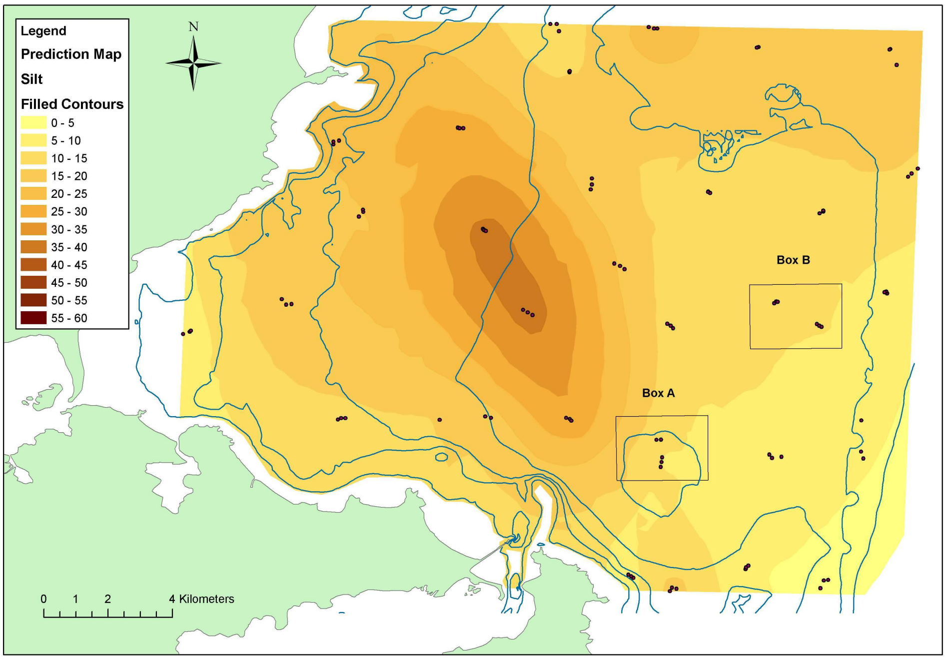

Figure 3: Distribution of silt (grain size < 63 µm) content (%) in the sediments of Blueskin Bay (from Willis et al. 2008). Depth contours are at 5 m intervals from 10 m to 30m. Note that Box A and Box B in this diagram are referred to as Site A1 and A2 respectively in this and the physical processes report.

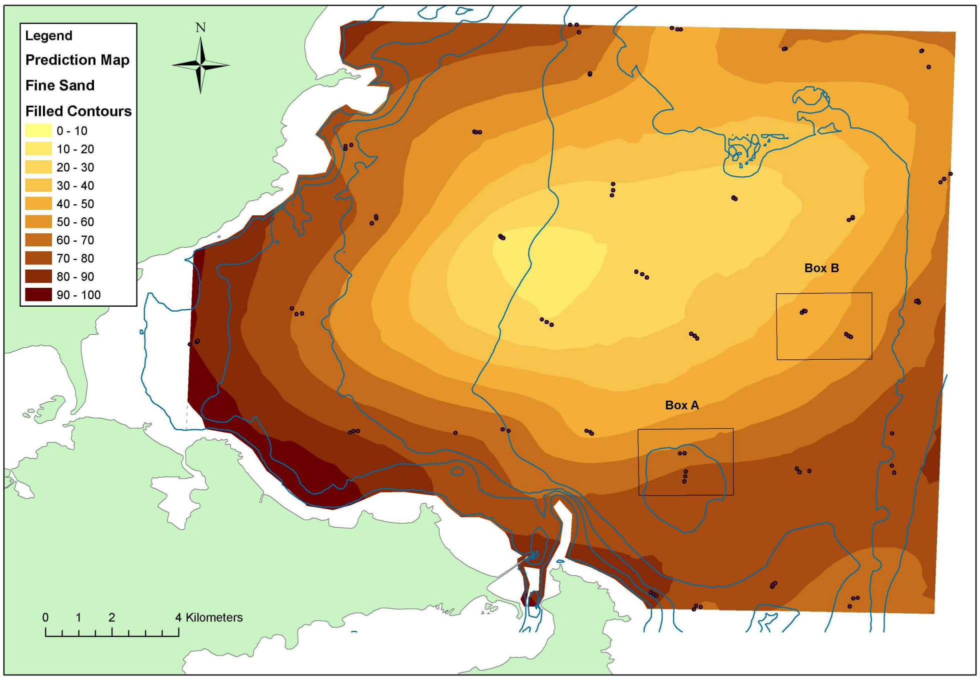

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Figure 4: Distribution of fine sand (grain size 125-250 µm) content (%) in the sediments of Blueskin Bay (from Willis et al. 2008). Note that Box A and Box B in this diagram are referred to as Site A1 and A2 respectively in this and the physical processes report.

The adjacent continental shelf is relatively narrow, only about 10 km across at its narrowest point off Otago Peninsula, but widening to about 30 km in Blueskin Bay to the north. Most of the sands of the nearshore region and the Lower Harbour are derived ultimately from the Clutha River and to a lesser extent the Taieri River (Single and Benn 2007). This is consistent with the sediment budget produced by Hicks and Shankar (2003) with, in the order of 0.39 M tonnes (gross drift estimated at 450-500,000 m^3 per year, Kirk 1980), discharged from the Clutha and moving up the coastline each year. Approximately half of this is stored within the large nearshore sand-wedge (Peninsula Spit) and one third transported north to be deposited on beaches and nearshore north of Otago Peninsula.

It has been estimated that up to 47,000 m^3 of fine sands is transported up the coast and is interrupted annually by the Otago Harbour channel with much of this settling in the Lower Harbour. Although there is only limited freshwater inputs to Otago Harbour significant quantities of suspended sediments enter the Harbour from the local catchments with some transported to outside with the ebb flow and some settling in the sheltered Upper Harbour bays and deeper basins such as Port Chalmers. Annual loadings have been estimated at 26,000 tonnes (Currie and Robertson 1987) with 75% of this from pasture runoff and 23% urban stormwater.

2.4 Contaminants

A series of sediment cores were collected along the channel (to below the depth at which the material will be dredged) and analysed by Hill Laboratories for a range of potential contaminants including heavy metals, Polycyclic Aromatic Hydrocarbons (PAHs), Polychorinated Biphenyls (PCBs) and petroleum hydrocarbons. The results from those analyses are summarised and compared with ANZECC guidelines in Table 1. No contaminants exceeded the guidelines indicating there are unlikely to be issues with contamination during dredging or at the disposal site.

Table 1: Summary of chemical testing for Port Otago's "Next Generation" dredging.

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Parameter	Detection Limit (mg/kg)	Guidelines (mg/kg) ANZECC[1]	Sample Concentrations (mg/kg)
Metals			
Arsenic	2	20	<2.0 - 7.9
Cadmium	0.1	1.5	<0.10
Chromium (Total)	2	80	2.5 - 17
Copper	2	65	<2 – 6.7
Lead	2	50	0.79 – 7.1
Nickel	0.4	21	2.1 - 11
Zinc	4	200	6.8 - 44
Organic Compounds			
PCB (Total)	0.02	0.023	<0.001
TPH (Total C7 – C36)	60	-	
PAH			
Anthracene	0.0020	0.085	0.002
Fluroanthene	0.0020	0.6	0.002
Phenanthrene	0.0020	0.24	<0.002 – 0.0049

Notes:

- Only those PCB, TPH and PAH compounds above detection limit are listed, otherwise only the total is listed.
- [1] Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000), low trigger value.

2.5 Sediments

Most estuarine and harbour environments experience periods of high turbidity resulting from increased concentrations of suspended sediments during periods of runoff, resuspension caused by winds and wave action and other point source discharges (e.g., sewage, industrial waste). There is no ongoing monitoring programme of suspended sediments or turbidity in Otago Harbour but suspended sediments concentrations are known to range from 5.6-1146 mg/l and up to 2300 mg/l in stormwater discharge following heavy rain (Portsmouth Drive, ORC 1991).

A monitoring programme was initiated by POL to measure turbidity (NTU) continuously and suspended sediments and light attenuation at regular intervals at two sites, one in the Lower Harbour and one in the Upper Harbour. Optical properties in the Otago region were measured by Pfannkuche (2002) at 31 stations in the Harbour and offshore. K_d (a measure of the rate of reduction of light with depth) varied from 0.05 m^{-1} off Taiaroa Head, 0.78 m^{-1} at Port of Dunedin, 0.26-0.33 m^{-1} at Port Chalmers and similar levels out to the Harbour entrance. Measurements taken for Port Otago Ltd at upper and Lower Harbour sites for 3 months from August 2008 showed that turbidity varied between 1 and 6 NTU with an average about 2 NTU. Highest suspended sediment concentrations occurred during a storm on 21 November 2009 when 6.44 NTU and a suspended sediment concentration of 6.5 mg/l was recorded. K_d varied from 0.11 m^{-1} to 0.33 m^{-1} but rose to 2.14 m^{-1} during the storm event.

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Summary
Other than the main channel Otago Harbour is mostly shallow with extensive tidal flats. The Harbour is the only large non-estuarine inlet in this biogeographical area but it has been significantly modified by human activities and experiences episodic inputs of suspended sediments.

The tides are flood dominant in terms of velocities with peak tidal currents of 1.59 m/s and with a tidal range of 1.25 to 1.98 m. Offshore hydrodynamics are driven by the Southland Current and jet from the Harbour entrance which can produce local eddies and a larger gyre in Blueskin Bay.

Sediments in the Harbour graduate from finer muddier sediments in the Upper Harbour to coarser fine sand towards the entrance with fine sand on the intertidal flats. Offshore sediments are fine well-compacted sands with higher silt content in the middle of Blueskin Bay. Contaminants in the Port area and channel to be dredged were found to be low and below the ANZECC guidelines for maintaining biological systems.

3. Biological resources

3.1 Harbour benthic communities

Benthic habitats of the wider marine environment include sheltered rocky shores, intertidal sandbanks, and subtidal soft sediment bottoms within Otago Harbour, and open ocean habitats immediately outside the Harbour, notably wave-exposed rocky shores, sandy beaches, and soft sediment bottom habitats of the continental shelf.

An annotated bibliography and summary of existing ecological information on the benthic habitat and communities in the Otago Harbour is provided in James et al. (2007). For the purposes of this report we have summarised new findings from surveys of benthic habitats and assemblages undertaken for Port Otago Ltd in March-June 2008. The aim of this work was to fill gaps in our knowledge of the spatial distribution of different habitats/communities that are important because of conservation, fisheries value or sensitivity to dredging operations. Habitats/communities of particular concern that were identified through consultation with various interest groups included seagrass distribution, cockle beds, and the ecological areas around Aromoana (Department of Conservation's Ecological Protected Area) and unmodified areas around Quarantine and Goat Islands. A preliminary photographic survey was conducted to broadly define habitat types and determine the best sampling strategies. This was followed by a full survey using photographic methods, diver observations and grab samples. Full results are provided in Paavo and Probert (2008). Surveys of rocky shore habitats are yet to be undertaken and will be reported separately.

The Lower Harbour is a mosaic of benthic habitats. Based on the recent surveys at 86 locations it can be divided up into at least 6-10 broad habitat types and is dominated by areas with medium sands and relict shells (24% of classified area), extensive intertidal sandflats supporting algal mats (35% of area), and inlet features with seagrasses and cockle beds (24%). Ten percent was macrofaunal tube mats, 6% clean rippled sand and about 1% deep sessile community. The habitat types identified by Paavo and Probert (2008) were:

1. Relict shell on medium sand with sparse patches of algae.
2. Relict shell on medium sand with sparse patches of algae but with silty or flocculent layer, no sand ripples, recent bioturbation obvious.
3. Medium sand with ripples.
4. Thick algal mats.
5. Seagrasses on medium sands.
6. Macrofauna burrows/mounds, indications of burrowing bivalves minimal.

7. Cockle beds.

8. Sediment surface dominated by closely packed macrofaunal tubes.

9. Deeper habitat with cobble-sized stones and mollusc shells fused together, signs of high water flows.

10. Shell hash.

These habitats can be reduced to 6 major categories and distribution is shown in Figure 5.

The Harbour seafloor is predominantly well sorted medium sands with seagrass and algal meadows on the sandflats and occasional shell deposits in the channel from Deborah Bay to the entrance. Muddy sands were encountered in sheltered areas of Deborah Bay and Portobello Bay. The sea lettuce (*Ulva*) is episodically abundant and was often encountered drifting in the channel. Encrusting coralline "paint" alga were found on shell and cobble deposits where flow meant hard substrates were exposed. Macrothallus algae were restricted to shallow southern portions of the Harbour. Small clumps of filamentous algae were found on shells and stones at most subtidal sites except in the deepest part of the channel. It was concluded that shaded areas on aerial maps can not be reliably correlated with seagrasses because of the extensive algal mats and other features which overlapped. The tunicate sea-tulip (*Pyura pachydermatina*) was found attached to hard substrates at a few sites in the channel.

Sampling in the Lower Harbour found 134 taxa (Paavo and Probert 2008). The macrofauna was dominated numerically by amphipod and mollusc species with larger conspicuous fauna including crabs (e.g., hermit crabs, *Macrophthalmus hirtipes* and *Nectocarcinus antarticus*), and mantis shrimp (*Heterosquilla tricarinata*). Several snails were common including *Turbo smaragdus, Micrelenchus tenebrosus, Stiracolpus symmetricus and Maoricolpus roseus*. Also present but less common were the tunicate *Ascidiella adspersa*, sponges, several limpets, chitons, barnacles, serpulid polychaetes attached to shells, and seastars. The fauna was conspicuous for the lack of polychaetes. The small bivalves *Perrierina harrisonae* and *Nucula* were abundant in the inlet estuarine/inlet classified areas. Eationellid snails were abundant at a few central sandflat areas.

High diversity was recorded across a range of habitats including in the channel and on the central intertidal sandflats in the centre of the Lower Harbour (highest abundance of annelids and molluscs). Although abundance tended to be lowest in the channel and on the margins between the port and Cross Channel, abundance data did not show any reliable relationship with the 6 or 10 habitat classifications above, thus the benthic habitat structure classifications do not appear to be a useful proxy for benthic communities with many species being found across a range of habitat classes. The banks closest to the channel and at Aramoana contained the lowest diversity. No distinct assemblages were identified except for the deep sessile community in parts of the channel, and most species were found across a range of habitats thus the Harbour can essentially be treated as "one system".

Additional sampling was undertaken in areas identified as being of special significance by various stakeholders. These included the cockle beds close to the swing basin in Port Chalmers where POL are proposing to widen the channel and remove some of the banks. Four transects were also sampled on the DOC designated Ecologically Protected Area of the Aramoana sandflats which has special significance for birdlife.

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04/03/09

The cockle (*Austrovenus stutchburyi*) was found at a number of sandflat sites in densities ranging from 15-625 m^{-2} with highest densities recorded in this survey just south of Harwood and on the banks opposite Acheron Pt. Patches of cockles are known to occur in many areas of the Lower Harbour and can even be patchy at the scale of metres. Densities on channel margins close to the swing basin (areas to be removed as part of the widening operation), are generally less than 200 m^{-2} (this survey and Southern Clams, pers. comm.).

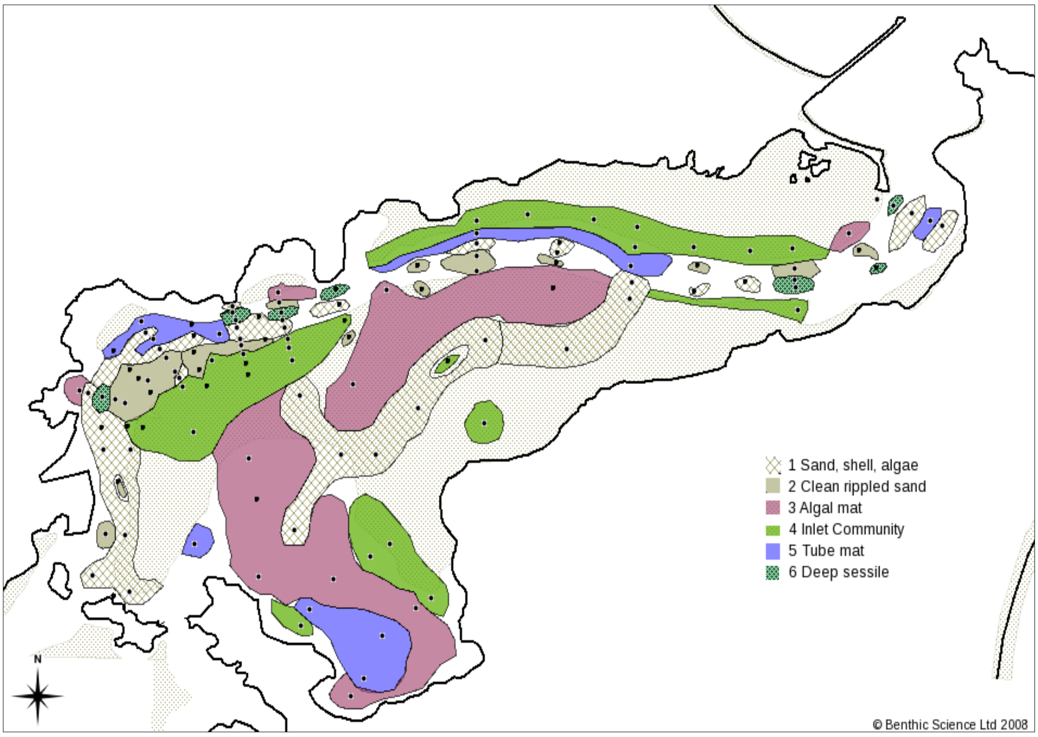

Figure 5: Map of habitat types in the lower Otago Harbour (From Paavo and Probert 2008).

The margins of the sandflats were dominated by the seagrass (*Zostera muelleri*) (Fig 5) and faunal habitats typically associated with sheltered harbour and estuarine environments. Deep cobble and clean-swept medium sand habitats were restricted to the channel and dense aggregations of bioturbators were found in areas with medium to fine sands with organic debris. The dense algal beds were generally associated with secondary channels or shallow subtidal areas with moderate flows.

The small bivalve *Perrierina harrisonae* dominated the fauna on the Aramoana sandflats followed by several species representative of three amphipod families. Polychaetes were not very numerous in the samples from the sandflats.

There have been limited surveys of the Upper Harbour (Rainer 1981, Grove and Probert 1999). This part of the Harbour is subject to more anthropogenic inputs and point source pollution from discharges. Apart from organically enriched Sawyers Bay where the community was found to be dominated by amphipods, generally the fauna in the Upper Harbour is more characteristic of finer, muddier sediments and dominated by capitellid polychaete worms. The bivalve *Nucula* and several deposit feeding polychaete worms such as those belonging to the Spionidae were also common. The infauna is also influenced by the abundance at times of green macroalgae (mostly sea lettuce).

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Portions of the Harbour have experienced major physical alteration, especially from changes associated with reclamation, shoreline development and dredging. Importantly, most of the Harbour's shoreline is now bounded by a rock wall retaining a road or railway that disrupts the natural shore profile. There are few stretches of unmodified rocky shore left in the Harbour; the only extensive stretches of natural shore occur in the middle reaches. Based on some studies undertaken by Otago University (Keith Probert, Otago University, pers.obs.) the zonational pattern on these shores is typical for sheltered southern locations. Often conspicuous at extreme low water are bladder kelp (*Macrocystis pyrifera*) and sea tulip (*Pyura pachydermatina*). Mid-shore species include necklace weed (*Hormosira banksii*), blue mussel (*Mytilus galloprovincialis*), rock oyster (*Tiostrea chilensis*), snakeskin chiton (*Sypharochiton pelliserpentis*), the topshell *Melagraphia aethiops*, and the red alga *Stictosiphonia arbuscula*. Periwinkles (*Nodilittorina* spp.) and lichens characterise the high-shore. Noteworthy at low water is the brachiopod (lamp shell) *Calloria inconspicua*.

Summary

The Lower Harbour is a mosaic of benthic habitats that can be divided up into 6-10 habitat classes dominated by medium sands and relict shells (24% of area), extensive intertidal flats (35%) and inlet features with seagrasses and cockle beds (24%). The sea lettuce is episodically abundant and much of the intertidal area is covered in extensive algal mats.

134 benthic fauna taxa were recorded in the latest surveys and the community was dominated by amphipods and molluscs. Highest diversity was recorded across a range of habitats including parts of the channel and middle of intertidal flats. Most species were found across a range of habitats thus the Harbour can essentially be treated as "one system". A deep sessile community was found in pockets of the main channel comprised of animals like sponges and tunicates. There are few areas of unmodified coastline. Cockles appear in patches throughout the tidal flat areas with highest densities in the Lower Harbour opposite Acheron Pt and south of Harwood. There were surprisingly few animals on the Aramoana flats with the most common being small bivalves.

3.2 Offshore benthic resources

Shores adjacent to the entrance to Otago Harbour comprise wave-exposed sandy beaches (with a seemingly typical but until recently poorly known fauna dominated by amphipod crustaceans and polychaete worms) and rocky shores characterised by bull kelp (*Durvillaea antarctica*) (low shore), barnacles (*Chamaesipho columna* and *Epopella plicata*) (midshore), and periwinkles (*Nodilittorina* spp.) (high shore). The biotic composition of such shores appears to be typical for the region. Full descriptions of existing ecological information on the benthic habitat and communities offshore from the Otago Peninsula can be found in James et al. (2007).

Limited surveys in the area offshore of Otago Peninsula and Blueskin Bay have revealed amphipod crustaceans, spionid polychaetes and trochid gastropods (*Zethalia zelandica* and *Antisolarium egenum*) to be typically abundant in this zone (Probert and Wilson 1984; Paavo 2006). To gain a better understanding of the different habitats and benthic communities in these areas, an offshore benthic survey was carried out in April/May 2008 at the proposed dredge spoil disposal sites and wider area to the east and north to Cornish Head. The aim of these surveys was to determine the spatial distribution of habitat types and macrofaunal assemblages, identify any species or assemblages of unique or particular biological interest and to understand what factors may be driving the current distributions of animals, with a view to predicting what the likely consequences of spoil disposal may be. The full results from these surveys are reported in Willis et al. (2008) and summarised here.

The benthic fauna in the area surveyed was numerically dominated by the gastropod snail, *Antisolarium egenum*, followed by three polychaete worms and the ubiquitous bivalve *Nucula nitidula*. Depth and type of sediment appeared to be the main determinant of faunal groupings. For example, worms in the polychaete genus *Aricidea* and the Families Cirratulidae and Scalibregmatidae, and an unidentified cumacean (a small crustacean), occurred in their highest densities in the very fine sand/silt basin in the middle of the bay. Conversely, the snails *Antisolarium egenum* and *Zethalia zelandica*, and the polychaete worm *Armandia maculata* were all associated with shallow, inner bay regions. Amphipoda (small crustaceans) and Tellinidae (a bivalve) characterised coarser, deeper habitats (Willis et al. 2008).

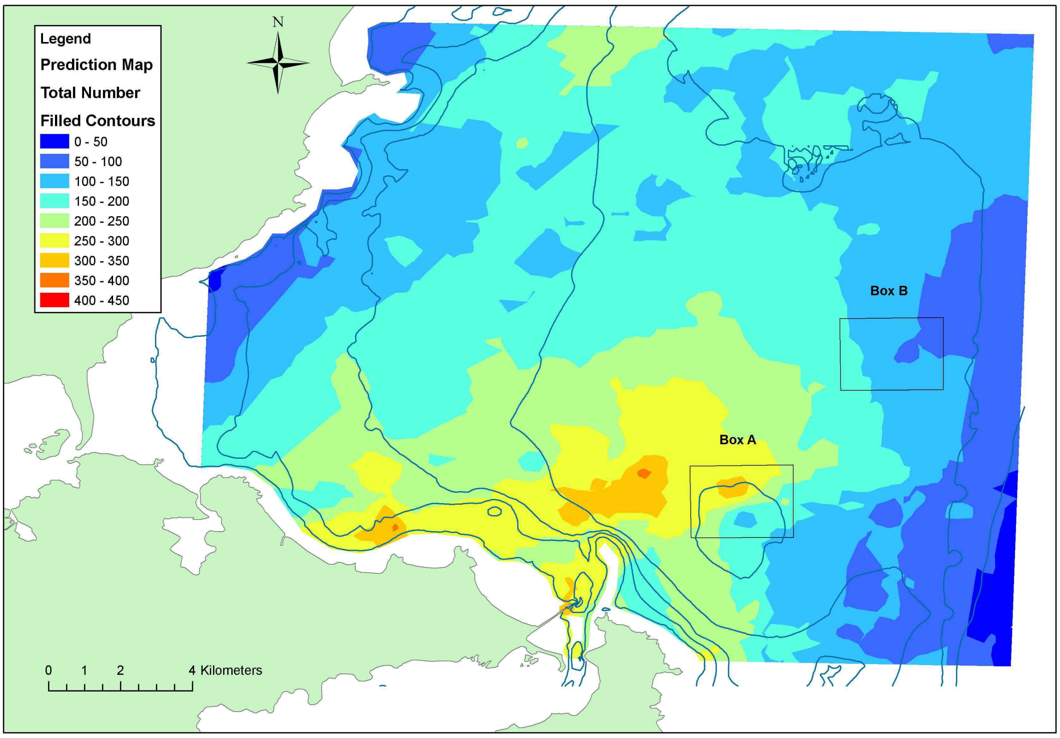

Figure 6: Spatial distribution of invertebrate numbers based on the total collected per sample at each site. Three replicate samples were taken at each of 32 stations (Willis et al. 2008). Note that Box A and Box B in this diagram are referred to as Site A1 and A2 respectively in this and the physical processes report.

The sidescan survey showed that the inner dredge disposal site (Site A1) was generally turbid, dominated by fine sand, and possessed little epifauna (surface dwelling animals). The second disposal site (Site A2) is approximately 10 km off Taiaroa Head and was characterised by high densities of a large tubeworm and other epifauna (including the knobbed whelk, *Austrofusus glans*, and the ostrich-foot shell, *Struthiolaria papillosa*), despite having a similar sediment to Site A1. Horse mussels (*Atrina zelandica*) were found in patches well to the northwest of Site A1. The site that is now more likely as a disposal site (Site A0, Figure 2) would contain a similar community to that at Site A2. Many of the offshore sites sampled at depths over 27 m possessed fine sand habitats with patchy beds of tubeworms. Apart from one site where the substratum was formed by coarse sand and shell gravel, the sediments of the wider area were fine sands, apparently grading into siltier sand closer to Taiaroa Head. Occasional patches of shell fragments were found throughout the surveyed area (Willis et al. 2008).

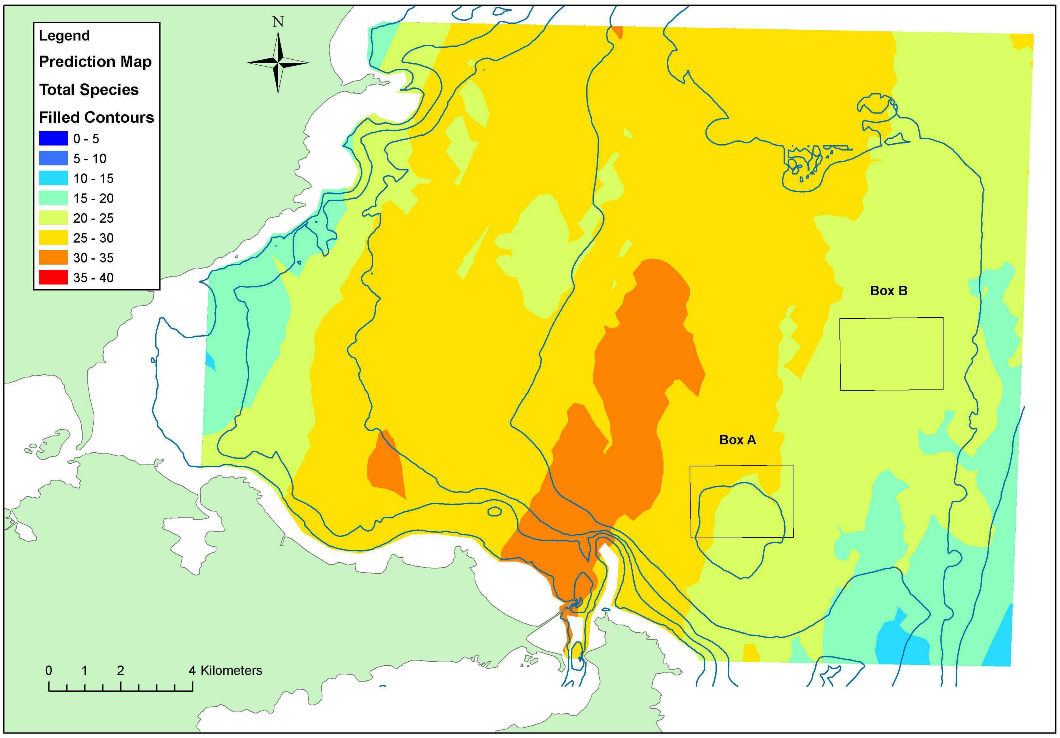

Figure 7: Spatial distribution of number of invertebrate taxa based on the total collected per sample at each site. Note that Box A and Box B in this diagram are referred to as Site A1 and A2 respectively in this and the physical processes report.

Total faunal densities were highest in the area just north of the Otago Harbour entrance (including Site A1), were lower in the middle of the bay and lowest in close to the coast in Blueskin Bay and offshore (Figure 6). Average density across all samples was 160.5 (± 80.0 s.d.) animals per grab (229 x 229 mm ponar grab). Species richness ranged from 10 to 39, with an average of 24.5 (± 6.2 s.d.) taxa per sample (Figure 7). The most species-rich area was also that which contained the highest densities (just north of the Harbour entrance), and the most species-poor area was right in Blueskin Bay and east of Taiaroa Head. Areas with high infaunal (animals living in the sediments) abundance and diversity, contrast with the low abundance and diversity of epifauna (animals living on the sediment). Note that the very small and abundant snail *Antisolarium egenum* is included as infauna.

Multivariate analysis of variance did not suggest that the infauna in the area of the proposed disposal sites are different from immediately surrounding areas (i.e., within ca 4 km). Comparison of the results of the present study with those of previous studies in the same area suggest that the fauna recorded in the present study is typical of the nearshore sand zone that occurs in water depths of ca 30 m off this part of the Otago coast.

The coarser gravelly sediments of the middle and outer shelf provide habitat for attached epifauna, notably several species of bryozoans ("lace corals"). Surveys and mapping of their distribution have found that large colonies form reef-like thickets at depths of about 70-110 m (Probert et al. 1979; Batson and Probert 2000; Jones 2006). Also distinctive of the outermost shelf is the queen scallop (*Psychrochlamys delicatula*), the basis of a local fishery. These communities are found well off-shore and generally south of the proposed disposal grounds (Figure 8) so are unlikely to be impacted by the proposed dredging and disposal. The queen scallop and bryozoan communities cease at the outer shelf break at water depths of 125-150 m. Beyond, the continental slope is incised by submarine canyons with a diverse benthos, but this habitat is unlikely to be affected by the proposed activities.

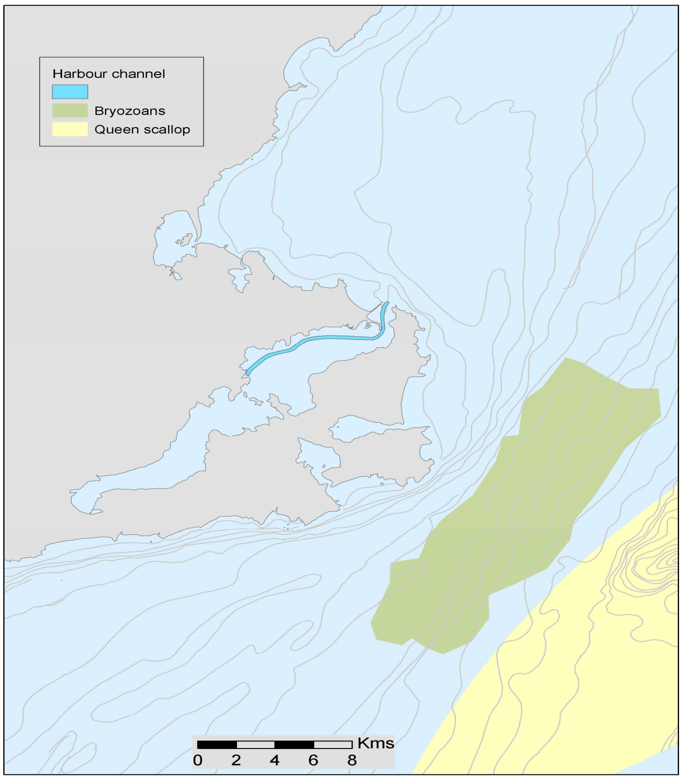

Figure 8: Areas where bryozoans and Queen scallops are found in the Otago Harbour region (redrawn with data from Beentjes and Cole (2002)).

Summary
Faunal densities were lowest in inner Blueskin Bay where silt content was higher than elsewhere. Faunal density and diversity were highest just north of the Otago Harbour entrance. The fauna was dominated by the gastropod (snail) *Antisolarium egenum*, followed by three polychaete worms and the ubiquitous bivalve *Nucula nitidula*. Site A1 was more turbid and total densities were higher than Site A2 and A0 but the latter two contained more epifauna (large tubeworms, whelks etc.). The fauna is typical of nearshore sand zones and no rare or unique species were found.

3.3 Planktonic communities

The upper and Lower Harbour support different zooplankton communities (Quinn 1978). Copepod species were the most abundant members of the permanent zooplankton community. Temporary larvae from a diverse range of benthic species are found in the Harbour, particularly in spring and summer. These include the euphausiid *Nyctiphanes australis* and the krill *Munida gregaria* which are an important source of food for birds when they reach high abundances in summer.

The hydrological regime off the Otago coast is complex and dynamic and includes three major water masses and associated plankton communities (Jillett 1976, Murdoch 1985). Inshore waters have neritic characteristics with communities in the middle of Blueskin Bay comprising mainly meroplantonic larvae and a mixed fauna of oceanic and neritic species over the mid-shelf and north of Blueskin Bay. Physical processes rather than biological processes appear to determine the spatial structure of zooplankton in the region with the eddy systems acting as a recruitment and retention mechanism for coastal species.

3.4 Birds of the Otago harbour and coast

The lower Otago Harbour and the adjacent offshore marine environment support a diverse array of bird life including one nationally critically endangered, two nationally endangered species, six nationally vulnerable species, and five species in decline (Miskelly et al. in press). Species of conservation importance are listed below:

Table 2: Bird species of special conservation status found in the Otago region (Updated from Miskelly et al. in press and based on criteria detailed in Townsend et al. 2008).

Common name	Taxon	Conservation status
Grey-headed mollymawk	*Thalassarche chrysostoma*	Nationally critical
Black-fronted tern	*Sterna albostriata*	Nationally endangered
Black-billed gull	*Larus bulleri*	Nationally endangered
Banded dotterel	*Charadrius bicincta*	Nationally vulnerable
Caspian tern	*Sterna caspia*	Nationally vulnerable
White-fronted tern	*Sterna striata*	Nationally vulnerable
Red-billed gull	*Larus novaehollandiae scopulinus*	Nationally vulnerable
Yellow-eyed penguin	*Megadyptes antipodes*	Nationally vulnerable
Stewart Island shag	*Leucocarbo chalconotus*	Nationally vulnerable
Hutton's shearwater	*Puffinus huttoni*	At Risk – Declining
Flesh-footed shearwater	*Puffinus carneipes*	At Risk – Declining
Sooty shearwater	*Puffinus griseus*	At Risk – Declining
Southern blue penguin	*Eudyptula minor minor*	At Risk – Declining
NZ pied oystercatcher	*Haematopus finschi*	At Risk – Declining
NZ Black-browed mollymawk	*Thalassarche impavida*	Naturally uncommon
Northern royal albatross	*Diomedea sanfordi*	Naturally uncommon
Erect-crested penguin	*Eudyptes sclateri*	Naturally uncommon

These species, and other birds reported from the area, inhabit two major ecosystems within the area of interest to this study – coastal (including the lower Otago Harbour and the offshore area where dredged material may be disposed) and intertidal within Otago Harbour. Sagar et al. (2002) listed 34 species of seabirds previously reported from or are likely to occur frequently in Otago coastal waters. Thirteen of these species breed on the Otago coast and another six commonly frequent the intertidal zone in the Lower Harbour. A summary of information on the species of conservation interest, that occur within the dredging and potential disposal zones, is provided in James et al. (2007).

3.5 Marine mammals

Four seal and six cetacean species have been reported from the Otago coast (Sagar et al. 2002). All species spend time in the coastal waters off Otago, and several species of seal use areas on the Otago Peninsula as haul-out areas and breeding grounds. Mammals with special conservation status are listed below (Hitchmough et al. 2005).

Table 2: Marine mammals of special conservation status known from the Otago region.

Common name	Taxon	Conservation status
Southern elephant seal	*Mirounga leonina*	Nationally Critical
Hector's dolphin	*Cephalorhynchus hectori hectori*	Nationally Endangered
Southern Right whale	*Eubalaena australis*	Nationally Endangered
New Zealand sea lion	*Phocarctos hookeri*	Range Restricted
Bottlenose dolphin	*Tursiops truncatus*	Range Restricted

A summary of information on mammal species of conservation interest, that occur within the potential dredging and potential disposal zones, is provided in James et al. (2007).

3.6 Fisheries resources

There is a diverse coastal fish and shellfish fauna in Otago Harbour and the waters adjacent to Otago Peninsula. Boyd (2008) found that both the fish and shellfish fauna present in these waters is predominantly comprised of common species that are widely distributed throughout central New Zealand coastal waters.

The extensive intertidal areas of Otago Harbour contain a significant population of cockles (*Austrovenus stutchburi*). Customary, recreational and commercial fishing and seafood gathering takes place in Otago Harbour and along the Otago coast. Recreational salmon fishing is a significant activity along the lower Otago Harbour channel and around the Harbour entrance during the summer months. The waters of

Blueskin Bay are important to Otago commercial fishing vessels that fish for flatfishes and other inshore species there.

A full report on the customary, recreational and commercial fisheries resources in Otago Harbour and coastal Otago waters is provided in Boyd (2008).

4. Description of proposed dredging operation

The type of dredge used and dredging operations are dependent on a number of factors, the main one being the type of material to be removed. In the case of Port Otago's proposed dredging the sediment is predominantly silty/clay in much of the area to be dredged from Port Chalmers to Cross Channel, grading through to mostly fine sand towards the entrance but with rocky outcrops around Acheron Pt.

It is proposed to use a trailing suction hopper dredge (TSHD) for the majority of the dredging operation, with a Back Hoe Dredge (BHD) for rocky areas (Rocky Pt, Acheron Pt and Pulling Pt). Blasting will only be used if the rock proves too difficult for the BHD. The TSHD has an operational depth requirement of 9m, so in the areas to be widened by up to 60m (Swing Basin and Harrington Pt are the significant areas) an alternative method, such as a small BHD and TSHD will be needed.

It has been estimated that less than 10,000m^2 or 1 ha of intertidal zone will be removed through widening the channel in the Swing Basin but only a small area is expected to be removed at Pulling Point or Harington Bend and most would be sub-tidal.

A TSHD dredge has a draghead, which is pulled along the seabed, and a hose to pump the sediment from the head to the ships hopper. The hopper acts as a large settling chamber where heavier material (generally sands 63-75um) settles out and finer silts stay in suspension. For coarse sediments, such as sands, dredging generally continues until the hopper is full, or near full, of solid seabed material. The water/fine sediment still in suspension is discharged at the dredging site through an overflow pipe which is 5-9m below the surface. When dredging sediments dominated by fine non-cohesive particles (e.g., silts less than 63um) which do not settle, dredging is completed when the hopper is full and no or little "overflow" occurs.

There are three sources of turbidity during the operation.

1. As the draghead moves along the seabed it loosens material which is mostly extracted by the suction pipe and thus results in little increase in turbidity.

2. The overflow pipe from the ships hopper will discharge turbid water (water/fine sediment mix) below the surface (5-9m). The most significant discharge will be when dredging sand/silt mix and the overflow operates until the hopper is near full. In the case of silt dominated sediment dredging would cease before the hopper is full of the water/sediment mix with minimum overflow.

3. Discharge at the disposal site will result in sediment plumes generated from discharge of finer sediment (silt or sandy/silt) when the hopper may only be one third full of solid sand material. When the discharge is mostly sand most of the material will settle relatively rapidly to the seabed and most of the finer

material will have been washed out at the dredge site. Most of the cohesive material (clay/silty clay) will remain aggregated and settle along with the sand.

There are three generic methods of disposal of dredged material:

- Use in beach nourishment, coastal protection works.
- Reclamation or industrial use.
- Marine disposal either in the estuary/harbour or offshore.

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04/03/09

Because of the volumes involved only a small amount is likely to be required for coastal protection/beach nourishment so most of the material will have to be disposed of at sea. The most likely sites that have been identified from constraints mapping are ~4-10 km north east off the Otago Peninsula in 20-25m water depth (Sites A1, A2 and A0 – Figure 2). Site A0 (~7 km NE) is now the preferred site and the one where the most extensive modelling has been carried out.

The quantity of rock to be disposed of is only small (~1%) and will require a backhoe dredger and hopper barges. If this proves too difficult some blasting may be required. Options for disposal of rock material also include disposal at the main offshore disposal site, disposal along the coast or foreshore in areas requiring protection, to build up reefs, land disposal or use for industrial purposes.

Summary
It is proposed to use a trailing suction hopper dredge except in shallow areas of the Swing Basin and potentially the few rocky areas where a smaller backhoe dredge may be used. Less than 10,000 m^2 will be removed for the channel widening around the Port. When dredging fine non-cohesive sediments dredging will be completed when the hopper is full with little overflow. When dredging coarser sand sediments dredging will continue until the hopper is full of solid material and excess fine material will be discharged through an overflow pipe at 5-9 m water depth.

5. Effects of proposed dredging operation in Otago harbour

5.1 Physical changes (summarised from Bell et al. 2009)

5.1.1 Currents and tides

Tidal range - Deepening of the channel is likely to lead to a slightly larger tidal range within the Harbour. For the 15-m channel configuration, small differences of less than 1% would occur in water levels at main-channel sites throughout a tidal cycle compared to the situation with the existing navigation channel. The largest increase in tide height would be 0.008 to 0.016 m around Port Chalmers, Portobello Bay and Harwood areas of the Lower Harbour, and in the Upper Harbour (Dunedin, Ravensbourne), reducing to up to 0.004 m at the Entrance, mirroring the spatial reduction in tidal phase change down the Harbour. These changes are very small and would not be expected to have an effect on the ecology of the Harbour.

Tidal currents - Modelling of hydrodynamics before and after the dredging operation indicate that there are likely to be only small changes of less than 0.1m/s reductions in peak current speeds and mostly in the Lower Harbour. The differences in the magnitude of peak (maximum) ebb or flood current velocity (no wind scenarios) are small and mostly less than ±0.02 m/s (±0.04 knots) at most channel sites, with negligible changes at Dunedin and off Spit Jetty (Entrance). The exceptions would be changes in peak speeds of up to 0.1 m/s increases on the south side of Harington Bend and decreases in current speed of up to 0.13 m/s along parts of the shipping channel (Port Chalmers and Harrington Bend). Decreases in currents in the Lower Harbour between Harwood and Ohinetu Point would be less than 0.06 m/s.

Phasing - A 15-m deepened channel would alter flood-tide durations by no more than 0-3 minutes (mostly an increase in duration) on a spring tide, with a compensating alteration to the ebb-tide duration. There would be small differences in the timing of high or low tide with a 15-m deepened channel, mostly through a slight advance (i.e., high or low tide occurs slightly earlier), because the tidal wave travels slightly faster in deeper water. The tide phase change would be largest on spring tides. The largest change would only be an average 6 to 8 minutes advance in high or low spring tide that would occur at Port Chalmers and 5 to 6 minutes in the upper section of the Harbour (e.g., Ravensbourne and Dunedin). The average spring-tide phase advance would then gradually reduce towards the Entrance, with a 3 minute change at Harington Bend, and then negligible change off the Spit Jetty.

5.1.2 Turbid plume in harbour

Several model runs were made to examine the concentrations in the plume of turbid water generated during the dredging operation and the extent of dispersion. The full results are reported in Bell et al. (2009). Because most of the sediment will be discharged at depth SSC (suspended sediment concentrations) will be higher towards the seabed and lower towards the surface. Dispersion by tidal currents dominate the transport of sediment in the Harbour rather than other dispersive processes.

An example of the concentrations of SSC in the plume generated by dredging at the inner most site (Port Chalmers) is shown in Figure 9. This is likely to be a worst-case scenario as there is substantial divergence due to strong flows around Quarantine Island and dispersion into the Upper Harbour. Modelling indicates that the highest depth-averaged concentrations of SSC (over 100 mg/l) will occur in the area of the channel, subsidiary side channels and intertidal banks adjacent to channels with some patches over 1000 mg/l in areas immediately adjacent to dredging. The reason for this high level of suspended sediments is that when the swing basin is widened the dredge water overflow pipe will be discharging at 1m instead of much lower in the water column. As a result suspended sediment concentrations in areas close to the dredging will experience larger episodic releases and have higher concentrations, but over short periods.

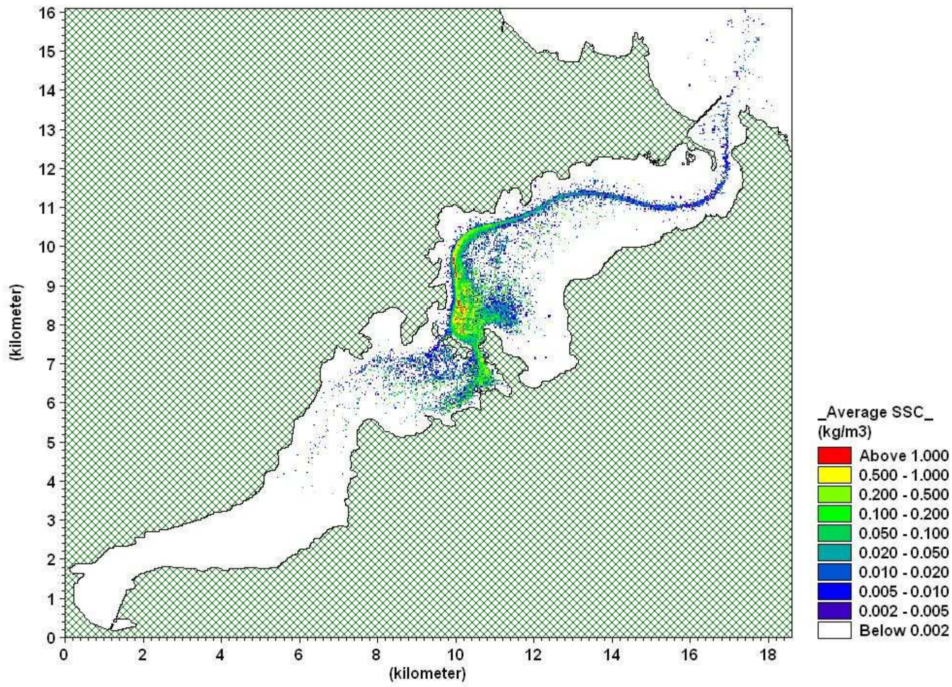

Figure 9: 14-day average SSC in kg/m^3 for a Basin–east discharge source for predominantly-silt claims (TOP) and predominantly-sand claims (BOTTOM) – from Bell et al. 2009).

Similar levels could occur in the Upper Harbour on the eastern side of the channel but for less than 1% of the time. Most of the flats from Te Rauone Beach to Harwood would be largely unaffected except when dredging the Harington Bend site when there could be patches of higher concentrations (100-200mg/l), but mostly in areas close to the main channel (Bell et al. 2009). Depth averaged SSC will generally be low from the Mole to Taiaroa Head but will increase up to 100-200 mg/l for discharges from dredging at Harington Bend.

Leaving aside the main shipping channel the percentage of time that there would be no increase in SSC is quite high—often 80% of the time or more in all sections of the Harbour. This would occur because the dredging discharges are not continuous, but cyclic, with gaps of up to 1.8 hours, and the tidal flows reverse every 6 to 6.5 hours, providing lengthy periods at "upstream" sites for silt-sized material to settle out.

However, there would be few Harbour sub-areas where the depth-averaged SSC exceeds 400 mg/L for 5% of the time or more (over and above the background concentration). This would only occur in sub-areas covering the main shipping channel, close to the relevant discharge source, and three inter-tidal sub-areas adjacent to the main shipping channel in the middle of the Lower Harbour (Bell et al. 2009).

5.1.3 Sedimentation in the harbour

While there will be dispersion of suspended sediments during dredging, sediment will settle and accumulate on the seabed in the channels, bays and on parts of the tidal flats. Modelling of dispersion and settlement (Bell et al. 2009) of suspended sediments gives an indication of the potential deposition that may occur. The modelling of deposition is conservative as it assumes no resuspension.

An example of the spatial distribution of sediments likely to settle out over a 14 day period is shown in Figure 10 below. Assuming a settled bed density of 1300 kg/m^3 then 5 kg/m^2 in the figure equates to 3.8 mm over the 14 day period or 0.3 mm/d (Bell et al. 2009). Full details are given in Bell et al. (2009). The key results from this modelling are:

- Most areas would receive less than 0.01 mm/d deposition.
- Deposition over 0.3 mm/d is largely confined to the main shipping channel, around Goat and Quarantine Islands and some of the intertidal flat margins flanking the channel.
- Discharges from areas where silt predominates would be higher than for sandy areas thus mitigation should focus on reducing the overflows during dredging silty areas.
- There would be no discernable deposition in the Upper Harbour from discharges at Harington Bend seawards.
- Most eastern areas would be subject to little or no deposition except a reach west of Portobello Peninsula during dredging of the upper channel and a

stretch from Te Rauone Beach to Ohinetu point from dredging in the Harington Bend area. During dredging in this latter region and seaward, deposition would increase from 0.03 mm/d to 0.27 mm/d.

Integrating deposition in each sub-area (for details of assumptions see Bell et al. 2009) can be used to assess the potential deposition over the full 100 day period dredging is predicted to take. The results do not take into account resuspension and thus can be considered conservative:

- In the main channel modelled depositions are high but it needs to be kept in mind that much of this would be resuspended and moved by tidal flows.

- Outside the main shipping channel the highest median deposition is around the Port intertidal area where deposition could be up to 5 mm or more over the 100 days. Median deposition in most other non-channel areas is small at less than 1 mm over the 100 days.

- Average deposition would be higher in inter tidal areas around the Port with 10.5 mm over the 100 days but would be less than 2 mm elsewhere (except in the main channel).

- Less than 10% of the area in the channel, at the Port, will receive more than 57mm during the whole dredging period (Bell et al. 2009) with this decreasing to 20 mm at Spit Channel. For non-main channel areas, less than 10% of these areas would receive 6 mm or more over the 100 day period, except the intertidal Port area where 10% would receive 26 mm or more. In the intertidal areas around Portobello and off Harwood only 10 % of the area would receive 3 mm or more over the 100 days.

- Deposition in areas like Aramoana flats, Te Rauone beach and Harwood inter tidal areas would be less than 1 mm over the 100 days with patches up to 5 mm.

- Plume modelling showed that only the main channel and side channel between Quarantine Island and Portobello peninsula would be subject to high initial deposition but these would be reworked. Along with fine material reworked from shallow areas sediment would eventually be exported from the Harbour or settle in sheltered quiescent areas (e.g., Dunedin basin, Careys Bay).

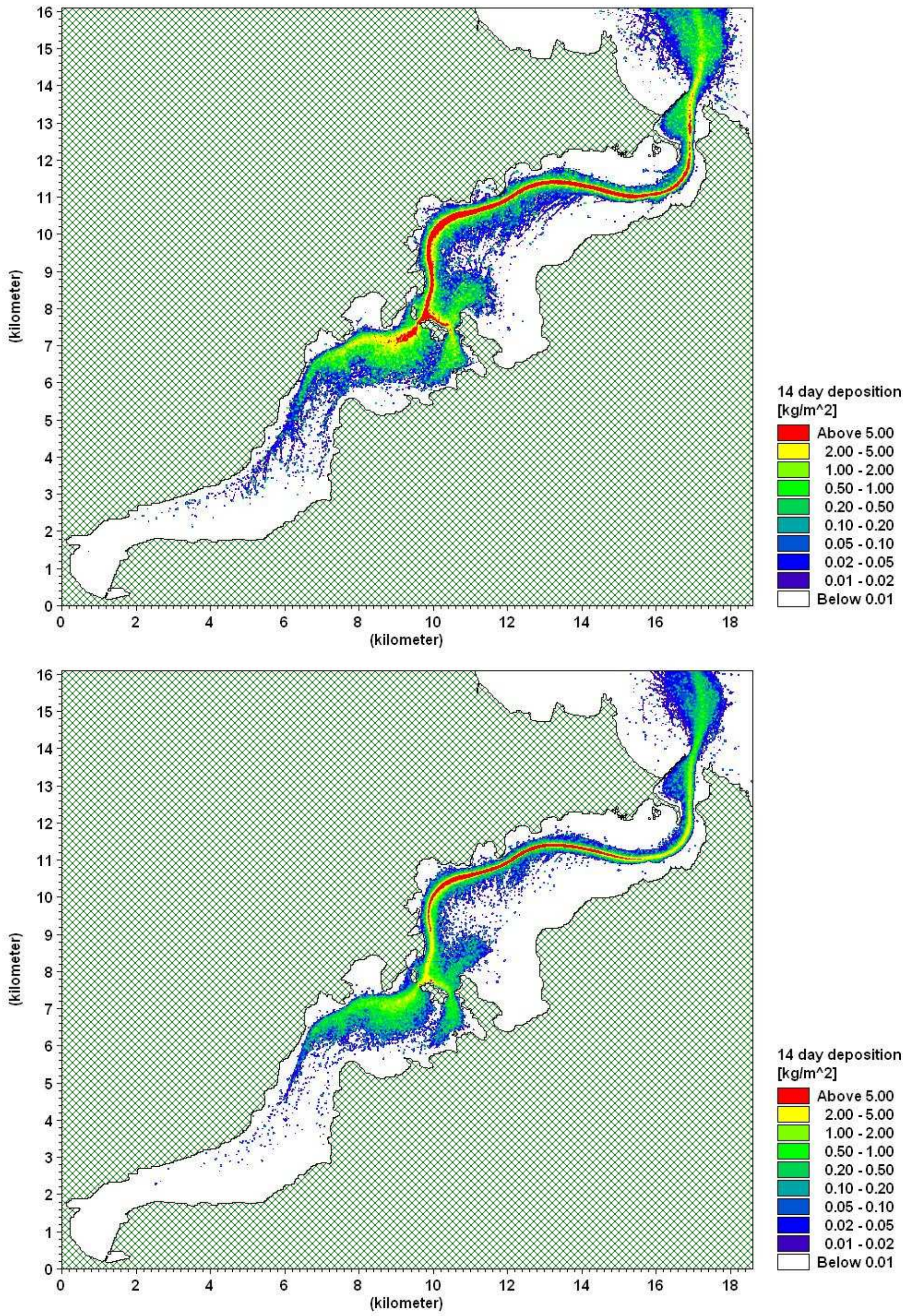

Figure 10: 14-day accumulated seabed deposition in kg/m^2 for a Taylers Bend discharge source for predominantly-silt claims (TOP) and predominantly-sand claims (BOTTOM) – from Bell et al. 2009.

5.1.4 Dispersion and deposition at disposal sites

Physical processes that can have an impact on ecology at a disposal site include:

- Increase in suspended sediment concentrations from finer material that remains in suspension and will be carried away by currents and settle out in time, well away from the disposal site.
- Increase in finer material that falls directly to the seabed at the disposal area and disperses along the bottom in immediate surrounds.
- Deposition of coarser material that drops straight to the seabed.
- Increase in suspended sediment from resuspension of finer material at the disposal site and redeposition away from the site.

Modelling of these processes was carried out to characterise the potential extent and fate of the plume of fine material and the deposition footprint that would result from disposal of dredge spoil material. Full details and assumptions are provided in Bell et al. (2009). Essentially the fate of material was followed by particle tracking based on 4 classes of sediment size, a discharge at 5m below the surface, a 10 minute disposal time for each load, and dispersion coefficient formula. Hydrodynamic modelling showed that tidal effects away from the Harbour were minor and the Southland current relatively persistent to the NE, so the modelling scenarios focussed on covering the key wind conditions. Five subareas at the disposal site were used sequentially for disposal of material over each 48 hour period then summed for a 108 day disposal period. Again no resuspension is built into models so deposition can be considered conservative.

A dredge volume of up to 7.5M m^3 would require a disposal area of 2 km diameter assuming a mound height of 1.5-2 m and that most material would deposit directly onto the seabed. The early constraints mapping exercise identified an area NE of Taiaroa Head as a potential disposal area with early simulations being based on Sites A1 (4 km to the NE) and A2 on the northern end of the submerged Peninsula Spit (Figure 2). Hydrodynamic modelling however, indicated that there was likely to be significant onshore dispersal of material from Site A1 so plume modelling focussed further offshore at a new site - Site A0 (Figure 2), which is 7.3km to the NE. This would place the disposal site outside the area that would result in onshore movement or movement back towards the Harbour entrance. While material from Site A2 and A0 was unlikely to impinge on the immediate Peninsula coast, some fine material could reach the coastline north of Cornish Head if material was disposed of at Site A2 thus modelling eventually focussed on Site A0 as the disposal site (Bell et al. 2009).

Key findings from Bell et al. (2009) relevant to ecological assessments were:

Dispersal and suspended sediment concentrations (SSC)

- For average hopper mixtures at the disposal site, highest SSC would be in bottom layers with fine sand reaching 1600-1700 mg/l under light NNE wind conditions (less for stronger winds and winds from other directions). Total maximum SSC for all classes combined would be around 2100 mg/l at the disposal grounds.

- Maximum surface layer SSC would be considerably lower with a maximum of 30-60 mg/l for each size class in the vicinity of the disposal site (highest during light NNE winds) and total surface layer SSC would be around 185 mg/l.

- The edge of the near-bed plume would occasionally encroach on the shoreline between Taiaroa head and northern Wickcliff Bay but maximum surface concentrations would be elevated by 0.7-1.5 mg/l on top of ambient for fine and medium silts, with a total SSC reaching 2.2 mg/l for short spells (concentrations in bottom waters could reach 2.8 mg/l).

- The edge of the near-bed plume could reach shoreline areas north of Karitane, except during strong NNE winds, but would elevate surface concentrations by only about 0.02 mg/l in the Karitane area and up to 0.09 mg/l further north. Maximum bottom layer concentrations would be no more than 0.4 mg/l (for example shown in Figure 11).

- For silt hopper loads the highest levels for silt derived SSC in the bottom layers would occur in the vicinity of the disposal grounds (around 910 mg/l) and combining all size classes would be around 1150 mg/l in the bottom layers. The SSC is lower for silt hopper loads because of the much smaller sand volume in the latter.

- When the plume reaches the coastline with silt hopper loads the SSC would not be higher than for average hopper loads, but may be spread further.

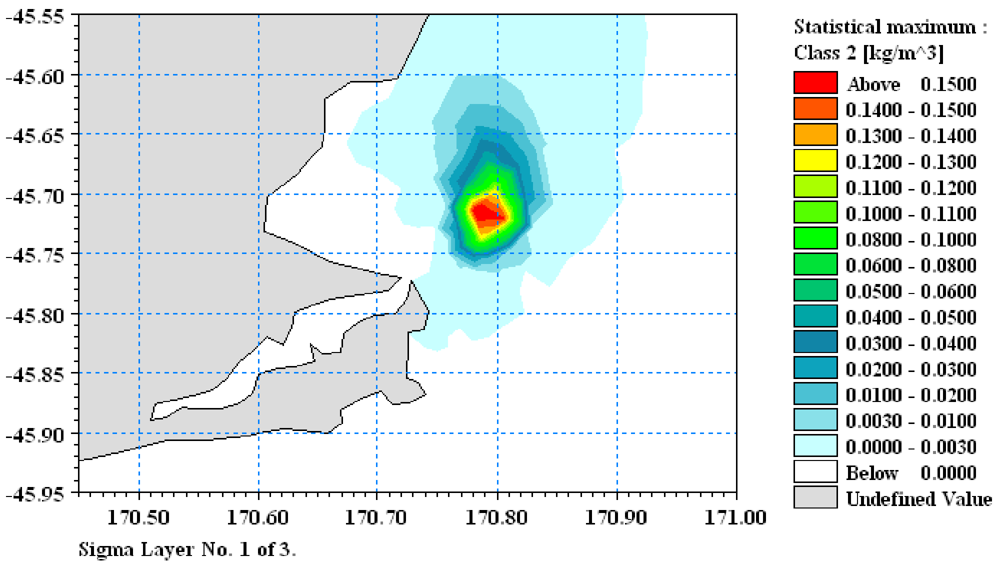

Figure 11: Max SSC composite envelopes for size class 2 over 24 disposal cycles for wind scenario of light NNE wind (Bell et al. 2009).

Deposition

Spatial distributions of the deposition footprint for each 48 hour period were summed over 108 days and all size classes of sediment combined. The model runs assume no resuspension and do not make allowances for material that overflowed during dredging thus can be considered conservative. Key results from Bell et al. (2009) were:

- Deposition at site A0 would be predominantly on the disposal grounds and to the north. Maximum deposition in the 2 km diameter disposal area would be 1.9 m in the centre with an average deposition of 1.2 m and dispersal of 40% of the material beyond the 2 km area.
- Fine silt would be deposited over the widest area, with sand predominantly at the site.
- Deposition along the coastline, where the deposition footprint plume comes into occasional contact (e.g., Otago Heads, north of Cornish Head), would be very small with less than 0.5 mm over the 108 day period. In reality much of this would be mobilised by wave activity and continue to disperse.
- The area affected by over 10 mm of deposition would be approximately 15.5 km in a N-S direction and 5 km wide or 78 km^2 (Figure 12). 30 km^2 would receive over 50 mm and 20 km^2 would receive over 100mm.
- Long term transport from the disposal area (A0) would be to the north along the submarine Peninsula Spit but for sands moving along the seabed this would only occur when wave activity was strong enough. Finer material is

likely to continue to be re-mobilised and further disperse in small amounts over a wide area of the Otago shelf. Most of this material will eventually disperse to the north and north-east before depositing in deeper waters and canyons offshore, although small amounts could deposit in the middle of Blueskin Bay as a result of the gyre.

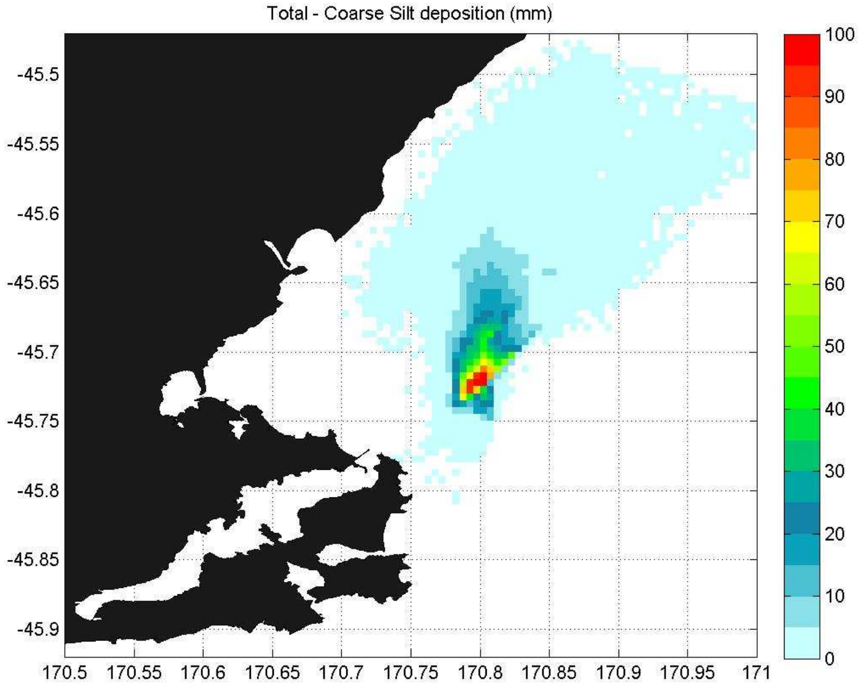

Figure 12a: Spatial distribution of deposition (mm) estimated for class size 3 (coarse silt) over a 108-day dredging programme for the 15-m deep channel option. Note: the dotted line near the top marks the northern boundary of the model (Bell et al. 2009).

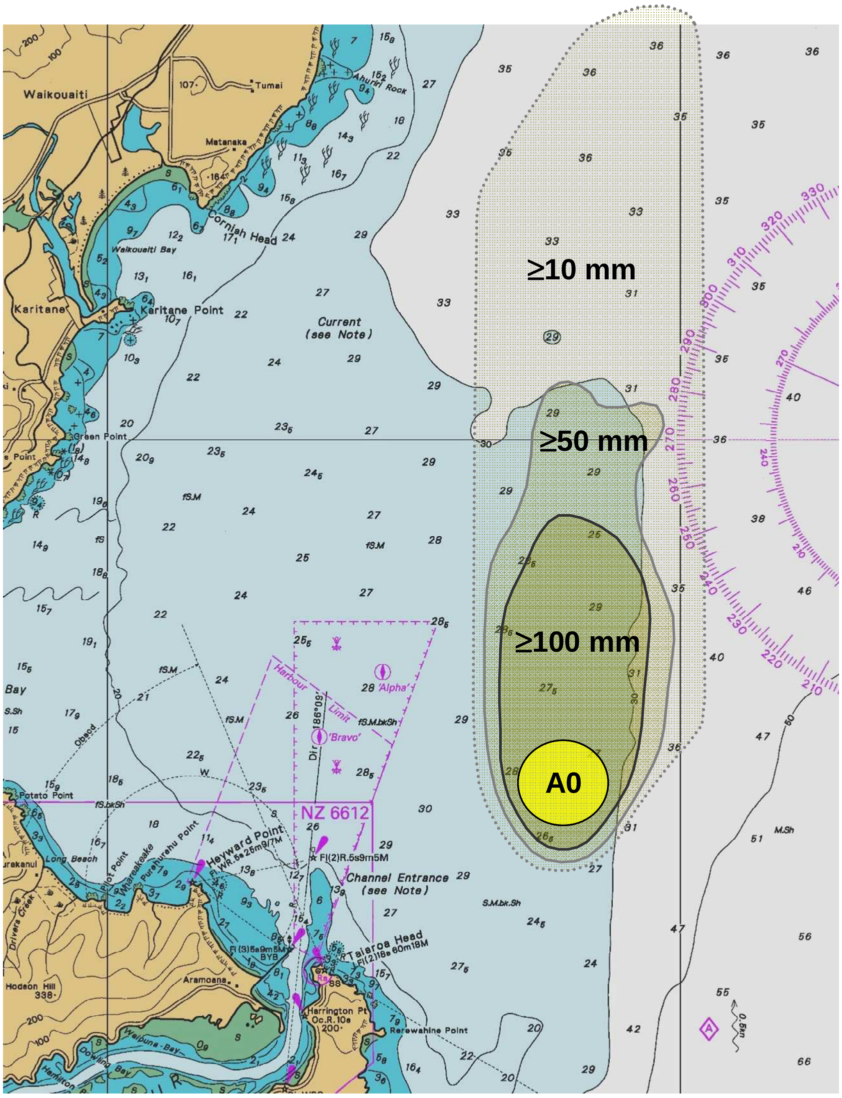

Figure 12b: Total deposition zones for sands/silts from the disposal plume modelling for a 108-day dredging programme for the 15-m shipping channel option. The 50+ mm and 100+ mm zones are indicative of the transport pathway and extent of sand transported through the disposal mound at A0. [*Source of background map*: Chart NZ661, LINZ] (Bell et al. 2009).

Longer term sediment transport from the mound created was also modelled. Generally currents rarely exceed the speed required to entrain sediment but wave orbital speeds were high enough at times to entrain all size classes of sediment. Key findings of this modelling show that there would be very little sediment transport at Site A0, apart from to the north, which contrasts with varying directions if A1 was to be used. The ultimate fate of silts that disperse form the disposal site will eventually be mainly into deeper waters and canyons offshore (Bell et al. 2009).

5.1.5 Habitat changes – bathymetry etc.

In addition to the environmental effects that may occur as a **direct** result of dredging and disposal activities, consideration must also be given to the environmental effects that may occur as a result of the physical changes to bathymetry and hydrodynamic processes that dredging induces. For the proposed dredging these changes could include:

- Changes to harbour or estuary morphology, for example changes to sediment pathways and spatial and magnitude changes in siltation patterns (see above).
- Changes to tidal regimes (height, timing), water currents and wave conditions which might effect navigation, recreation and ecological interests (see above).

Based on the modelling to date sedimentation would result in very small increases in bed height in the Harbour as a direct result of the dredging operations. Level increases due to sedimentation outside the channel areas over a 100 day period would be less than 5 mm with possibly up to 10mm in a few intertidal areas close to the Port. Thus there is unlikely to be any significant effects on the ecology of the Harbour short-term, as a result of changes to topography/bathymetry. Long-term changes to the Upper Harbour may occur as a result of changes to flows and sedimentation patterns but would be difficult to distinguish from natural processes. However apart from the immediate effect of removal of sediment volume, the modelling indicates there is unlikely to be significant geomorphological effects on the Harbour seabed and thus there is unlikely to be impacts on ecological components above those expected from other natural events.

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Summary
Modelling has shown that as a result of dredging there will only be very small changes to hydrodynamics within the Harbour. Current velocities would change by no more than 0.02 m/s except off Port Chalmers and at Harrington Bend where it could up to 0.06 m/s. The timing of the flood tide would be altered by no more than 5-8 mins at Port Chalmers and Upper Harbour. Actual water levels would increase by no more than 0.004-0.016 m.

Modelling of the sediment plume during the dredging operation indicates that suspended sediment concentrations would be highest in the channel (depth averaged levels over 100 mg/l) and marginal areas close to the port (over 1000 mg/l in a few marginal areas very close to dredging but for very short periods – less than 3% of time). Concentrations on the intertidal flats would not increase above background levels most of the time (over 80% of the time in many areas) but may reach similar levels (100-200 mg/l) for very brief periods towards the channel. When there was an increase in suspended sediment then it would be less than 20 mg/l for most of the time and for most intertidal areas.

Most areas would receive less than 0.01 mm/d deposition over the dredging period. Deposition would be highest in the channel areas around the Port (0.3 mm/d) with lower levels on the intertidal flats (daily deposition averaging less than 0.03 mm/d). Over a 100 day dredging programme the modelling indicates the total accumulation would be up to 6 cm in the channel (but this would be in less than 10% of the area and would rapidly disperse), less than 26 mm in marginal areas close to the channel and less than 3 mm on most intertidal flats away from the channel.

Offshore, concentrations of suspended sediments in the vicinity of the disposal site the maximum total surface layer SSC would be around 185 mg/l (maximum of 30-60 mg/l in surface waters, 2,100 mg/l in bottom waters) during disposal of dredge material. Rapid dilution of the plume (through advection of the plume away from the disposal site and sediment falling through the water column) would result in low concentrations (less than 100 mg/l a few km to the north) away from the disposal site. The plume could reach the Otago Heads and Karitane north under certain wind conditions but with low concentrations of 2.2 mg/l and less than 1 mg/l for surface waters respectively.

Constraints mapping and preliminary modelling have narrowed down the proposed disposal site to A0, approximately 7 km NE of Taiaroa Heads. Assuming a dredge volume of up to 7.5M m^3 then this would result in a mound 2 km in diameter and average depth of 1.2m. Over 10 mm would be deposited in an area approximately 15.5 km by 5 km centred on the site and to the north and an area of 30 km^2 would receive over 50 mm. The plume could result in minor deposition along the coastline off Otago Heads and north of Cornish Head but the depth of deposition would be less than 0.5 mm in total and much of this would disperse through wave activity.

6. Effects of dredging on biological resources

Prediction of the potential effects that might be caused by dredging and disposal in a marine environment require a good understanding of the general processes associated with dredging disturbance. These need to be combined with site-specific data on the existing environment, dredging operations and sediment type to be dredged, changes as a result of dredging and sensitivity of communities. Generally, the potential major impacts of dredging and disposal can be summarised as follows:

- Direct impacts through removal of benthic species and communities in the channel itself.
- Suspended sediments and turbidity. Short-term increases in the level of suspended sediment can give rise to changes in water quality (including clarity), which can in turn affect marine flora and fauna, both favourably and unfavourably, such as clogging of gills and feeding apparatus, reduced light levels for benthic and water column plants.
- Release of contaminants, organic matter and nutrients, depending upon the nature of the material in the dredging area.
- Settlement of suspended sediments can result in the smothering or blanketing of subtidal/channel communities and adjacent intertidal communities.
- Effects on the benthic community (plants and animals) can indirectly affect higher trophic levels through impacts on food resources and foraging.

The impact of the dredging and disposal of dredged material largely depends on the nature of the material to be dredged (sediment type, degree of organic enrichment, presence of contaminants) and the characteristics of the disposal area (sediment type, accumulative or dispersive areas for sediment). The potential impacts of the disposal of dredged material on the marine environment can be minimised by restricting the disposal of heavily contaminated sediments and careful consideration of disposal sites (e.g., disposal in areas of like sediments), and often these form conditions as part of the consenting process.

The evaluation of the environmental effects of dredging and disposal must take account of both the short-term and long-term effects that may occur both at the site of dredging or disposal (near field) and the surrounding area (far field). The IADC/ CEDA (1998) document provides a useful guide that illustrates the temporal and spatial scales in which various environmental effects of dredging might be realised. Near field effects are simply defined as ‘phenomena occurring within the geographic bounds of the activity, or less than approximately 1 km from the activity’. For dredging operations near-field short-term effects include removal of organisms, increased turbidity, smothering of organisms, reduced faunal densities/biomass and diversity, reduced water quality and potential chemical toxicity/anoxia in extreme cases, while potential long-term effects include removal of contaminated sediments, change to substrate type and community structure, accumulation of deposits, bioaccumulation and chemical toxicity. Generally far field effects ‘occurring more than approximately 1 km from the activity' are not expected to be significant short or long-term but there can be dispersal of some fine sediments, chemicals and pollutants if they are present and changes to geomorphology and hydrodynamics. However, caution should be used when adopting an arbitrary distance to distinguish between near and far field effects, due to the site-specific nature of the potential effects that arise from dredging. These are discussed later in reference to Otago Harbour.

6.1 Effects of dredging operations in the harbour

6.1.1 Effects on dredging on benthic communities - physical disturbance and recovery

Dredging operations involving removal of material from the seabed also remove or heavily disturb the animals and plants living on and in the sediments. With the exception of some very deep burrowing animals or mobile surface animals that may in some cases be able to avoid dredging operations, dredging may initially result in the complete removal of at least the larger animals and most plants from the dredging site (some smaller animals may be returned via overflow pipes but most will be removed).

The effects of dredging operations on benthic communities and the animals that rely on them will depend on the method used, type of sediment to be removed, existing benthic habitat and community structure, and changes to the physical regime (tides, currents, geomorphology). Most of the benthic animals in the channel from Port Chalmers to the entrance, where it is to be dredged, will be removed or heavily disturbed by the proposed dredging operation. This is likely to result in loss or modification, at least temporarily, of all benthic assemblages and processes within the channel and areas that are widened. If the channel is dredged down to 15 m this would represent approximately 48% of the channel to Port Chalmers being directly impacted (some parts do not require dredging). The potential impact on cockle beds at the edge of the channel is difficult to assess but they will only be directly physically disturbed at the channel margins and in the areas to be widened. Assuming that the area around the Port that will be dredged during the widening is up to 10,000 m^2 then this represents less than 0.5% of the area classified as typical inlet features with cockle beds (green area in Fig 5) in the Lower Harbour. Densities of cockles on the margins of the channel where it is to be widened close to the Port basin, are generally less than 10 m^{-2} (Paavo and Probert 2008) with low numbers recorded right on the margin in surveys by Southern Clams (Sites G0, Roger Belton, pers. comm.). Highest densities were found on the flats to the north-east and close to Harwood. Thus the widening of the channel is likely to have a minimal direct impact on the overall extent of cockle beds in the Lower Harbour. The effects of increased turbidity and settlement are discussed elsewhere.

If a channel or port area has been continually dredged for maintenance purposes, it is unlikely that well-developed benthic communities will occur in or around the area. However, the sensitivity and types of communities still need to be taken into consideration. For example dense mats of compacted tubeworms and some deep sessile communities prevail in areas of the channel from Port Chalmers out to the entrance despite maintenance dredging. The deep sessile communities are generally found in deeper pockets or channels embedded in the main channel. While some of these species and communities will be lost, their existence now with maintenance dredging suggest that in the medium to longer term they would recover (months to years). It must be noted that most sediments in the channel region are already highly modified and disturbed.

The recovery of disturbed habitats and benthic communities following dredging depends on the extent of the disturbance, nature of sediment and potential for re-colonisation. Recovery is most rapid where the channel is predominantly silt/muds as they tend to be occupied by opportunistic/early succession species and communities. Recovery usually takes longer in habitats with coarser sediments and for longer lived benthic animals such as cockles. Recovery often depends on recolonisation by larval stages (from the water column) but can also be through horizontal bed transport of juveniles and adults in highly mobile environments which can recover quicker.

Published rates of recovery vary considerably from a few weeks/months for disturbed muds/clay/silt, 1-2 years for sands/gravel and up to 10 years for shell/sand habitats (Nedwell & Elliot 1998; Newell et al. 1998). Impacts and recovery with the proposed dredging will vary with the inner areas, which are mostly silt, likely to recover quicker (months) than the lower reaches which are predominantly sand (a few years). However, a highly mobile sand habitat such as that near the entrance will likely recover more quickly through dispersion of larvae and bed transport than isolated and fragmented sand habitats.

Discrete benthic assemblages were not evident in this study of the Lower Harbour but rather the same or similar species were found across a range of habitats supporting a “one-harbour” system i.e., there does not appear to be discrete communities associated strictly with one habitat type. A large proportion of the macrofauna taxa are found scattered throughout the Harbour. This means that local disturbances (e.g., the area to be widened) will be recolonised by neighbouring fauna relatively quickly unless a totally new habitat type was created or the whole Lower Harbour were to be disrupted. An example of new habitat creation would be the exposure of rock or cobbles via the removal of existing overlying soft sediments. However, there is no evidence that this will occur (Lincoln Coe, Port Otago Ltd, pers. Comm.).

The central intertidal sand flats support an abundant and diverse fauna that should be readily recolonised through transport of adult benthos and larval transport. The deep sessile, diverse communities (tunicates, sponges etc.) found in patches and rippled sand areas in the primary channel, exists because of strong tidal flows (~1% of channel area has this habitat). While the communities in these habitats are mostly filter feeders and likely to be sensitive to increased sediment loads, the areas will be quickly flushed of finer sediment and be recolonised in time. This could take a few years however, because the fauna found here tend to be long-lived and slow colonisers.

6.1.2 Effects of dredging on benthic communities – suspended sediments and turbidity

An increase in suspended sediments and water turbidity is associated with most dredging operations as a result of physical disturbance of the seabed, release of sediment/water mix during dredging and disposal and subsequent resuspension of settled sediments during periods of high wave activity. Increased levels of suspended sediments and turbidity will impact on marine fauna and flora through direct physical effects and indirectly through changes to water clarity and light availability.

In assessing the effects of suspended sediments in the area being dredged there are a number of considerations. The most obvious one is the resulting plume of water/fine sediment mix that is released during the operation. Material that settles out on the seabed can also subsequently be resuspended. The degree of resuspension of sediments from dredging depends on the type of sediments being dredged, methods of dredging, hydrodynamic regime, geomorphology, and weather conditions.

Direct physical effects of suspended sediments include clogging of gills, and impairment of respiration and feeding via filtration. Suspension feeding animals such as cockles, mussels and zooplankton are particularly vulnerable to high sediment levels and persistent high turbidities can result in changes in assemblages from dominance by suspension feeding fauna to ones dominated by deposit feeders. Impacts of increased turbidity are likely to be greatest in low energy areas where water exchange and wave action are limited.

Considerable work has been done overseas and in New Zealand on the effects of high sediment levels at which condition and suspension feeding processes of benthic animals are potentially impacted.

Experiments in the laboratory and observations in the field suggest that like a number of molluscs, cockles and mussels benefit from small amounts of suspended sediments and in the case of the cockle *Austrovenus stutchburyi*, Hewitt and Norkko (2007) found they benefitted at suspended sediment concentrations up to 400 mg/l and even higher in field observations, before condition started to decline. Persistent high levels and very high levels of suspended sediments dominated by clays for more than a week however, were found to have a significant impact. Field transplants showed that small cockles can withstand similar levels but mortality tends to be higher than for adults. Development of oyster eggs was found to be impacted at suspended sediments concentrations of 188 mg/l of silt and larvae at 750 mg/l of silt (Clarke and Wilber 2000). Similarly Hawkins et al. (1999) found the filtering rate for the Green-shell mussel, *Perna canaliculus*, did not start decreasing until suspended sediments levels were above 1000 mg/l. The horse mussel (*Atrina*) appears to be more sensitive with filtering rate declining at 120 FTU (Formazin Turbidity Unit) and condition was affected if suspended sediments concentrations were over 80 mg/l (Ellis et al. 2002). *Atrina* were not recorded in the sampling of the lower Otago Harbour.

Taking 400 mg/l as the level of SSC (suspended sediment concentrations) that would start to impact on the cockle and other benthic invertebrates then other than the main channel the only areas where dredging could have an impact would be intertidal areas close to the channel around the Port (including around Goat Island) for most of the time and around Pulling Point and Tayler Point when the dredge was operating in those areas. It should be noted that apart from the immediate area near the Port these intertidal areas would be subjected to these high levels for less than 5% of the time, a time period that most invertebrates could survive high SSC conditions. The intertidal area immediately opposite the Port would be subjected to greater than 400 mg/l for less than 5% of the time, except when the dredge was operating on the eastern side of the basin, and then could be for up to 24% of the time. The main cockle beds in this area are opposite Pulling Point and thus the largest population would not be subjected to these levels for long periods. It should also be noted that these animals are adapted to frequent turbid events at these levels.

Increased suspended sediments will cause decreases in water clarity and the availability of light for phytoplankton in the water column, benthic plants and microphytobenthos (benthic microalgae like diatoms). The most sensitive communities to the indirect impacts of the proposed dredging are likely to be the seagrass communities, particularly those close to where the channel is to be dredged and widened. The extent of the plumes of higher turbidity will partly be determined by wind direction and state of tide but generally the most significant impacts of increased turbidity and smothering will be restricted to the channel areas and area east and south-east of the Port, where seagrasses are not common.

Dispersion means that the plumes will be diluted away from the dredging activity and will be considerably lower away from the channel. Predictions are that most of tidal flats would be largely unaffected except close to the channel where concentrations could be up to 100-200 mg/l. Concentrations above 1000 mg/l could occur in patches immediately adjacent to dredging but would only be for brief periods during actual dredging (i.e., less than 10% of the time). In areas like Harwood and the intertidal flats well away from the channel margins, increased suspended sediment concentrations would be undetectable for most of the time and there would only be very short episodic periods when concentrations were above 20 mg/l.

Environmental limits have been placed on a number of dredging operations overseas. In most cases there is a two stage approach if these are exceeded, with the first being an investigation of what caused the exceedance and if necessary a mitigation stage which could involve changes to the dredging operation as a last resort. An impact matrix was devised by Doorn-Groen (2007) for reclamation works in Singapore and included sensitivity of seagrass beds, corals and mangroves. Based on relatively high suspended sediments backgrounds in excess of 5mg/l for more than 20% of time and in excess of 10 mg/l for less than 20% of the time then there would be a "slight impact", with over 75 mg/l for less than 1% of the time termed "moderate" in severity.

The recent Port of Melbourne dredging programme (Port of Melbourne 2008) set site-specific environmental limits which ranged from 15-35 NTU (Nephelometric turbidity units) above background levels for benthic invertebrates (including 35 NTU to prevent impacts on a *Pyura* sea tulip species) , 15 NTU for seagrasses, and 15-70 NTU above background for fish (some sites had seasonal limits). These limits are generally based on a 2 week moving average with higher levels based on a 6 hourly average.

Most of the seagrass beds in Otago Harbour appear to be intertidal rather than subtidal (Mark Morrison, pers comm.). These habitats have been shown to be very important as nursery areas for juvenile fish and thus there can be significant flow-on effects if these beds are significantly impacted. Surprisingly Miller (1998) found no differences in macroinvertebrate abundance or diversity at sites with and without seagrasses. Overseas studies and recent ones for the New Zealand *Zostera* species (Anne-Maree Schwarz, pers comm.) indicate that 15-40% of surface light is required, on average, to protect these seagrass beds with 15% being conservative. Measurements of Kd in the Harbour vary naturally between 0.1 and 0.3 m^{-1} and can reach over 2 m^{-1} during storms with corresponding suspended sediment concentrations of about 6 mg/l. Aside from areas very close to the main channel the tidal flats in the Lower Harbour will be subjected to no increase in SSC most of the time (often 90% or more), as a result of the dredging. Seagrasses would be able to tolerate levels up to 100 mg/l but only for very short times so the impact is likely to be "moderate" in intertidal areas close to the main channel but "slight" in most areas where they occur.

It must be remembered that these environments are naturally turbid relative to open waters as they are subject to episodic high sediment turbidity and settling events and the communities including seagrasses are adapted to these conditions. As demonstrated above however, beyond a critical threshold even the hardiest communities can be impacted if levels are high for extended periods. The predicted levels are within the natural range that these communities are adapted to and most inter tidal areas will not be subject to increases in concentrations at all. Indications are that for beds close to the channel then during dredging they could be subject to relatively high levels (100 mg/l) but for very short periods and thus there could be a short-term "moderate impact" at a localised level. Impacts are likely to be only "slight" in places like the intertidal areas off Harwood. The impact on seagrasses would be mitigated if dredging took place during winter when growth is slower. Miller (1998) found that when surface stems are removed new shoots were observed within two months so as long as the whole plant was not impacted recovery will depend on the time of year when dredging takes place.

6.1.3 Effects of dredging on zooplankton

Many benthic species and most fish have a larval phase which is critical for dispersion and recruitment. These larval stages, along with permanent zooplankton (mostly copepods) and crustaceans, are generally adapted to episodic high levels of suspended sediments that occur in estuaries and harbours. Experiments over two weeks have shown that mortality is high at levels over 10,000 mg/l and generally have not shown any impact at the levels experienced from dredging (Clarke & Wilbur 2000).

6.1.4 Effects of dredging on contaminants and nutrients

Contaminants released from benthic sediments during dredging could potentially bioaccumulate and become concentrated in species at the top of the food chain (large benthic fauna like cockles and eventually large fishes, birds, marine mammals) and could ultimately affect human health and the value of commercial fish catches if there were persistent high levels of contaminants.

While this has been an issue in some harbours and was a major concern with dredging by the Port of Melbourne, testing of cores from the Port Chalmers area and channel for contaminants indicated that there were no sites with levels above the ANZECC guidelines for acceptable levels that will protect aquatic ecosystems (see Table 1). The guidelines also recognise that some systems like those commonly found in harbours servicing major cities and around shipping ports are already highly disturbed. Bioaccumulation can result in higher levels further up the food web but at the levels found in the sediments we would not expect there to be a significant effect at higher levels.

Nutrients are necessary for the growth of primary producers (e.g., phytoplankton), but excess nutrients can cause algal blooms and periphyton growths. Zooplankton and filter-feeding benthos might benefit from excess food resources associated with increased phytoplankton, but could be negatively affected by hypoxia or toxicity associated with some phytoplankton blooms. Darker sediments indicative of enriched sediments and low oxygen were only recorded in cores from one site close to the port itself but are unlikely to cause significant issues when dredged because of the high flows and restricted area where this occurred.

6.1.5 Effects of dredging on benthic communities - settlement of suspended sediments

When sediments settle out in the vicinity of a dredged area, they can smother benthic organisms and depending on the amount of sediment settling, can change the sediment characteristics and community structure and in extreme cases cause mortality of fauna and flora. Small and recently settled life-stages of many species are especially vulnerable to smothering, as are organisms that must maintain contact with the sediment-water interface.

Estuaries and harbours are naturally turbid and macrofauna are probably conditioned to deal with high sediment deposition rates. Understanding potential impacts requires some knowledge of background turbidity conditions and animal sensitivities. Beyond a critical threshold, sediment will have a negative influence on even the hardiest estuarine benthic communities.

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04/03/09

Generally, habitats with fine silt and sediments, such as those found in the Port Chalmers area and out towards Cross Channel, had lower abundance of most macroinvertebrate taxa. Settling of silts in these areas is unlikely to cause a shift in community structure. In the lower regions of the channel which are characterised by sand substrates there could be a temporary shift in benthic food webs from suspension- to deposit-feeding species. However, high flows in these areas would quickly flush the fine sediment out towards the entrance and eventually offshore with the Lower Harbour community reverting back to its original state. The deep sessile communities are very patchy but do contain taxa such as sponges which are susceptible to high sedimentation and would be impacted at least in the short to medium-term until the areas can be recolonised. Doorn-Groen (1998) suggested that less than 1.7mm/14 days would not have an impact on corals.

Cockles, other bivalves and benthic animals and plants found in intertidal flats of habitats in Otago Harbour are often exposed to high turbidity and sediment loads from storms and catchment runoff. Experiments with clay deposits in the Whitford area of Auckland have demonstrated that clay layers as thin as 0.3 to 0.7 cm had some impacts on macrofauna, but they were relatively short-term. Rapid accumulations on the other hand (over 2 cm in one event) were found to smother entire benthic communities (Norkko et al. 1999). Recovery of sediment properties and benthic communities was found to take a few months for opportunistic species like many polychaete worms, but several months to a few years for larger taxa like some gastropod molluscs.

Shrimps and some crab species have been shown to survive up to 9cm of deposit (Norkko et al. 1999) but cockles can only survive short periods of burial under these fine sediments and generally molluscs responded at lower levels with 2-3 cm the critical depth of deposits. Many crab species on the other hand actually show a strong preference for finer silt/mud habitats and are less sensitive.

Norkko et al. (2001) carried out a comprehensive study of macroinvertebrates and their sensitivity to increasing silt/clay sediments in the Whitford embayment. Benthic species found in the recent surveys of Otago Harbour span a range of responses with species like the limpet *Notoacmea helmsi* and the whelk *Cominella glandiformis* being highly sensitive and other species such as the common polychaete *Boccardia syrtis*, cockle *Austrovenus stutchburyi* and Syllid and Cirratulid polychaete worms being sensitive to silt and clay content. Norkko et al. (2001) found that once the silt/clay content reached over 60% cockles tend to decrease in abundance. Three cm of clay can significantly alter community structure after 10 days of exposure and repeated 3 mm deposits over several months has been found to reduce densities and diversity (Lohrer et al. 2004). Large bivalves tend to be more resilient than smaller ones.

As would be expected surface grazing animals like the gastropod snail *Zeacumantus lutulentus* are relatively robust, at least in the short-term, to increased sedimentation of fine material (Nicholls et al. 2003). Although *Zeacumantus lutulentus* is not common in Otago Harbour, we would expect similar taxa to also be robust to sedimentation events. It should be noted that most experiments on New Zealand species were conducted with clay sediments.

Deposits of up to 3-7 mm can have a negative effect on microphytes and, although responses vary, repeated additions of 3 mm over several months can have a cumulative effect at these levels of deposition (Gibbs and Hewitt 2004).

While most of the fine sediment being disturbed or dredged up with the proposed dredging will initially settle in the channel area, fine silt and clay particles that are presently found in the inner reaches of channels have slow fall velocities and are thus likely to be transported much further than sand particles before settling out. As can be seen in Figures 9 and 10 the sediment plume with highest concentrations of suspended sediment is confined to the channel area and margins but the plume does spread out after several tidal cycles and material would initially settle out on the tidal flats. Most areas would be subject to little or no deposition with the rate of deposition on the intertidal flats is predicted to average less than 0.1 mm/d for most areas with higher rates of 0.3 mm/d largely confined to the shipping channel and around Goat and Quarantine Islands. Over the period of the dredging small parts of the channel could receive deposits of up to 60 mm but non-channel areas would receive less than 5 mm except the intertidal area opposite the Port which could receive 26 mm or more but only in a few areas.

Deposition in areas like Aramoana, Te Rauone beach and inner Harwood would receive less than 1 mm over the dredging period with only a few patches up to 5 mm. The greatest abundance of annelids (worms), molluscs and arthropods (amphipods etc.) occurs in the intertidal areas away from the main channel and close to Harwood. The levels likely to be experienced in these areas are unlikely to have significant adverse effects on the benthic community.

The highest potential impacts would be relatively localised, short-term and within the main channel itself where the material is likely to be resuspended and rapidly flushed out in time. However there could be short-medium term impacts on the deep-sessile community in the channel but these would recover in time once the fine sediment had been flushed out.

The faunal community in the Upper Harbour is dominated by polychaete worms and the bivalve *Nucula*. These habitats are characterised by finer silt/mud sediments and are subject to epidodic events with high runoff and constant point source discharges so the communities are conditioned to events similar to the dredging operation. The mean deposition in the Upper Harbour over the whole dredging period has been estimated through modelling as less than 0.3 mm over the dredging period which would have no impact on these communities (Bell et al. 2009).

Although there were no surveys before and after the capital works dredging in 1976, unpublished data from University of Otago (see Raffaelli 1979) indicated that suspended material in the Harbour increased by a factor of three during the operation in some parts of the Harbour. Experiments being run at the time however, found that grazing molluscs were able to keep the substrate clean of mud which is consistent with the observations above (settlement being in the order of a few mm).

Settlement of fine material may result in smothering and burial of seagrasses. Smothering can have direct physical effects and can also reduce light availability and thus photosynthesis. Most seagrasses can survive moderate levels of settlement. Although there is no data for New Zealand seagrasses, overseas studies of similar species suggest that they can grow through 2 cm in 4 months and thus to maintain seagrass beds short-term sedimentation over time spans less than 2 months should not exceed 5 cm (Vermaat et al. 1997). From the modelling to date areas occupied by seagrasses should not exceed this sedimentation threshold.

6.1.6 Changes to hydrodynamic regime and geomorphology

Capital dredging works can alter the sediment transport regime resulting in increased siltation but longterm effects are difficult to distinguish from natural processes. The changes to hydrological regime indicated by modelling of the proposed dredging by POL are very small and thus are unlikely to cause significant geomorphological changes further up the Harbour. Thus there is unlikely to be an impact on the benthic communities.

6.1.7 Effects of dredging on birds

The effects of dredging on birds within Otago Harbour are likely to occur as a result of the:

(1) direct removal of invertebrates as a food source during widening of the channels;

(2) settlement of sediments in intertidal areas;

(3) increased turbidity levels throughout the Harbour; and

(4) removal of roosting sites.

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Otago Harbour and the area around Taiaroa Head are of particular importance as a breeding and feeding ground for a number of species including some that are endangered or vulnerable. Recently, the conservation status of the endemic black-fronted terns was changed from Serious Decline to Nationally Endangered on the basis of improved knowledge and continuing decline of the population, particularly due to predation and disturbance at its braided river breeding sites (Hitchmough et al. 2005). Lalas (1979) reported that 50-70 black-fronted terns overwinter in the Otago Harbour region, where they roost on the Aramoana tidal flats. He also reported that larger numbers, up to almost 200 birds, have been recorded there occasionally, especially soon after they first arrive in January or during winter (May-July). Consequently, observation of a flock of 86 black-fronted terns roosting on the Aramoana tidal flats during recent observations (Sagar 2008) is consistent with these earlier observations. While occupying coastal areas, the diet of black-fronted terns consists mainly of planktonic crustaceans, which they locate visually and obtain from sheltered waters such as harbours and estuaries, and also at sea up to 6 km offshore (Lalas 1979).

Removal of invertebrates during channel widening

Dredging activity would result in some mortality of sessile shellfish such as cockles, especially where they occur along the edge of the Harbour channel that is being widened. Observations of feeding wading birds over a tidal cycle (Sagar 2008) show that generally these birds feed along the water's edge of the receding tide. Consequently, some feeding habitat will be lost at the lower tidal levels as a result of channel widening but this would only be a very small area close to the port. Shellfish and other macrofauna would be expected to recolonise the banks within a few years and smaller benthic animals (e.g., polychaete worms) within a few months of the completion of the operation.

The species of most conservation concern that tended to feed along the water line were pied oystercatchers (At Risk – Declining) and bar-tailed godwits. In Otago Harbour, the latter have been identified as a species of particular concern because of their declining population worldwide and need to ensure that they are able to accumulate sufficient reserves to undertake their extreme migration to their northern hemisphere breeding grounds.

No detailed studies of the feeding of bar-tailed godwits have been made in Otago Harbour. However, they have been studied elsewhere in New Zealand, particularly the Firth of Thames and Farewell Spit. Bar-tailed godwits use their long bills to probe into soft substrate to obtain their prey; female godwits have longer bills than males – females 97-129 mm, males 69-97 mm (Battley & Brownell 2007) which allows resource partitioning within the species. For example, on firmer substrates including rocky tidal flats near Kaiaua, foraging godwits are almost exclusively males whilst in soft mud such as off Miranda it is almost invariably females that feed deeply on the outgoing and incoming tides (Battley & Brownell 2007). Godwits feed mainly on large polychaetes (Battley et al. 2005), but they are also capable of feeding on hard-shelled prey such as crabs and bivalves (Battley 1996). On Farewell Spit, Battley et al. (2005) calculated that the relevant prey for godwits in the invertebrate community were the bivalves *Paphies australis* and *Macoma liliana* (≤ 15 mm), the bivalve *Austrovenus stutchburyi*, the small black mussel *Xenostrobus pulex* (≤ 10 mm), the bivalve *Nucula hartvigiana*, all polychaetes ≥ 10 mm, and all crabs. In the Firth of Thames the polychaetes *Aonides oxycephala*, *Nicon aestuariensis* and *Orbinia papillosa*, plus crabs and small *Nucula* and *Austrovenus* are likely to be godwit prey (Battley & Brownell 2007).

The level of any impact through the reduction in feeding habitat will depend upon the proportion of area lost as a result of channel widening and the time taken for sessile invertebrates to recolonise areas. The area likely to be directly impacted (10,000 m^2 at the Port) is very small compared with the area of similar habitats. Smaller polychaete worms are likely to recolonise rapidly (months) with larger molluscs taking longer, with timing depending on the time of year that dredging takes place.

Settlement of sediments in intertidal areas

Overall, the degree and duration of any adverse effects on fish and shellfish resources, and the birds that feed upon them, from dredging activity in Otago Harbour will depend on the duration of dredging, the quantity and particle size of material to be removed and the ultimate fate of suspended sediments as they settle out of the water column. In addition to pied oystercatcher and bar-tailed godwit, the main species of conservation concern feeding over intertidal areas is the banded dotterel (Nationally vulnerable). Cockles and other sessile organisms that are filter feeders would be potentially affected by high suspended sediment concentrations or a significant depth of sediments over them on the seabed as the sediments settle out of the water column. The levels of suspended sediments predicted however, are unlikely to be at a level that would significantly impact on the filtering by benthic animals such as cockles, away from the channel margins (see above). Levels of suspended sediments that could impact on the likes of cockles (>400 mg/l for more than 5% of the time) would be confined to areas very close to the Port and not areas such as Aramoana where large numb

The level of any impact of the dredging operation will depend mainly upon the particle size and accumulation rate of material. Modelling indicates that the latter is likely to be at a level that will enable the benthic communities in most cases to avoid suffocation, and so avoid disruption.

Increased turbidity levels

Dredging activity will have some potential short term effects on fishery uses of the Harbour. Migrating fish are likely to avoid high suspended sediment levels and this may have some effect on the birds that feed on the fish. Gulls and terns are the bird species of conservation concern most likely to be affected by reduced occurrence of small fish and reduced ability of the birds to see the fish because of turbid water. These species of birds feed primarily upon planktonic crustaceans and larval fish, which they locate visually and obtain particularly from sheltered waters such as harbours and estuaries, and at sea within a few km of the shore.

The turbidity levels predicted for the proposed dredging operations are within the natural range reported from Otago Harbour. Consequently, the level of any impact of the dredging operation will depend mainly upon whether dredging extends the duration of high suspended sediment levels that are avoided by small fish, and so both reduce the availability of prey to the birds and inhibit the ability of the birds to see their potential prey. In the Port of Melbourne case 25 mg/l and 17 NTU above background were set as the thresholds to protect seabirds (crested terns and gannets)**.** The predicted levels on the Aramoana flats during dredging would only be above this level for less than 0.5% of the time. Avoiding dredging in the period leading up to migration of godwits (March/April) would avoid impacting on their ability to store reserves for their migration.

Removal of roost sites

Large numbers of a variety of birds use the sand islands opposite Port Chalmers for roosting at high tide. Such roosting sites are important because they provide refuge from terrestrial predators and disturbance. The removal of any sand islands during the dredging operation could have a negative impact on the birds that use this part of Otago Harbour. Consequently, it is recommended that if sand islands are removed, then creating new island roosting sites using the spoil from the dredging operation should be investigated.

6.1.8 Effects of dredging on fisheries and shellfisheries

Mobile fishes, swimming crabs and rock lobster are more able to avoid effects than sessile shellfish species, such as cockles, which are part of the benthic community.

A number of the potential effects of dredging have been discussed in the immediately preceding sections of this report. Some of these potential effects may impact fish and shellfish. Effects of physical disturbance, suspended sediments and sediment deposition on benthic organisms (which include sessile shellfish species such as cockles and oysters) have been discussed in sections 6.1.1, 6.1.2, and 6.1.5 respectively. Effects on larval fish and shellfish, which are part of the zooplankton, are addressed in section 6.1.3. Effects from the release of any contaminants or nutrients are dealt with in section 6.1.4.

Fishes are well adapted to avoid potential threat and typically swim away from any disturbance or noise in their vicinity. They will also avoid high suspended sediment levels that occur during dredging activity. Fishes can be expected to return to dredged areas as soon as the dredge ceases operation to forage for benthic organisms exposed during dredging. Some of the benthic organisms that species such as flatfishes feed on will be smothered by sediment deposition adjacent to the Harbour channel but the mobility of fish means that they can move to other areas to feed.

Suspended sediments can interfere with gas exchange in fishes as well as clogging gills at high concentrations but fish will avoid high suspended sediment concentrations by moving into unaffected or less affected areas. Larval fishes in the sediment plume may not survive high levels of sedimentation as they will not have sufficient ability to swim away. The fisheries literature indicates that the majority of common fishes for which data is available spawn on the open coast outside of the Harbour, although some larvae are transported into the Harbour by tidal currents. The planktonic eggs and larval phase of sessile shellfish species such as cockles are likely to remain within Otago Harbour and are potentially more at risk.

In the Port of Melbourne assessment it was suggested that 100 mg/l of SS and 70 NTU was necessary to protect fish eggs and larvae. Appleby and Scarratt (1989) summarised a number of studies that have assessed the effects of suspended sediments on fish. Most fish eggs and larvae do not show a significant effect until concentrations get above 500 mg/l and adult fish can tolerate at least 2000 mg/l for extended periods before mortality occurs. Larval bivalves have shown a similar level of response with no significant effect on pacific oyster larvae to concentrations up to 500-800 mg/l (Cardwell et al. 1976).

The physical disturbance or loss of benthic biota from dredging will have some short to medium term indirect impacts on fishes that normally reside within the impacted areas and feed on benthic organisms in these locations. As described earlier there is a mosaic of benthic habitats and biota within the Harbour. A small area of these benthic habitats will be altered as a result of dredging or sedimentation. New populations of benthic organisms will begin to establish in affected areas almost immediately. Any impacts of physical disturbance or loss of benthic biota on the availability of feeding areas for fish will therefore be localized and temporary.

There will be some loss of cockles that lie adjacent to the Harbour channel due to the widening of the turning basin and channel. The affected areas represent a small part of the extensive cockle beds present in Otago Harbour.

There is potential for sediments to adversely affect rocky habitats of importance to fish or shellfish within Otago Harbour if significant sedimentation occurs as a result of the dredging activity. Most of the benthic habitats within Otago Harbour are comprised of soft sediments, but the Mole at the Harbour entrance is a rocky habitat supporting a number of reef dwelling fish and shellfish species, including paua. The Mole is exposed to wave action on its northern side and waves and tidal currents on its southern side which will assist in dispersing any sediments that settle there. Modeling predicts that sediment deposition around the Harbour entrance will be low.

Some sediments will be deposited on rocky habitats around Quarantine Island/Kamau Taurua and Portobello. These habitats could be at risk of adverse effects from any sedimentation but they are also exposed to strong tidal currents. The predicted rate of sedimentation around Goat Island/Rakiriri is less than 1.5 cm over the whole dredging period with no re–suspension taken into consideration. Sedimentation effects in these areas are predicted to be short-term and low–moderate in impact.

Overall, physical disturbance or loss of fish or shellfish and their habitats and any indirect effects on fish feeding are expected to be minor and short-term based on the results of hydrodynamic modeling and the scientific literature.

Dredging activity has the potential to have short term effects on fishery uses of the Harbour. Migrating fish are likely to avoid high suspended sediment levels and this could affect the recreational fishery for chinook salmon which takes place in the Harbour channel during the summer. Turbidity from dredging may affect the ability of the salmon to see trolled lures. Consideration could be given to avoiding dredging during the main salmon migration period (late summer).

6.1.9 Effects of noise and blasting on aquatic animals

There are small areas of rock on the edge of the channel which may have to be removed by blasting as a last resort. Depending on the charges used blasting can impact on some aquatic animals. Invertebrates are unlikely to be impacted by blasting, except those in immediate vicinity, as they do not have gas filled organs. Impacts through pressure waves are considered to be negligible on shellfish and crustaceans (Wright and Hopky 1998). Animals with swim bladders (many fish and marine mammals) and other sensitive organs will be impacted by sudden pressure waves as a result of explosives, causing rupture and possible mortality. Some fish species are more susceptible than others, with those living on the bottom often not having swim bladders and thus being less susceptible.

Localised fish kills would be unavoidable with greatest impact within 30-50m, depending on the type of charge used. A Port of Auckland study provides an indication of the potential area affected by blasting and suggest an LR_{50} of 36m for a charge of 50kg and 50m for 100 kg charge (Ports of Auckland 2001).

Similarly marine mammals within 100m could be impacted. Dolphins enter the Harbour and may be disrupted temporarily by the dredging process if they are close to operations. Generally they can tolerate frequencies below 15 hz. Direct impact on whales from dredging activities within the Harbour is unlikely, although increased avoidance of inner coastal areas close to centres of human and vessel activity is possible. Many mammals rely on sound for navigation/feeding and have sensitive hearing apparatus. However, these animals are large enough to swim away from bothersome background dredging noises, but sudden high-decibel blasts could harm them if they are in close proximity.

Ongoing noise and disturbance from machinery may also affect fish movements or migrations in and out of the Harbour. The Harbour channel acts as a migration path for the likes of salmon with most migration being over summer when they are targeted by recreational fishers.

The main effects on birds during the dredging phase would be excess noise, lights and the appearance of large machinery. Birds in the Harbour are acclimatised to regular ship movement and maintenance dredging.

Surveys before and after blasting by Port Otago Ltd at the Beach Street Wharf, Port Chalmers were carried out in 1993 (Stewart 1993).The presence and effects on marine mammals, shags, penguins, fish and shellfish were monitored over the 3 months of operation and concluded that the blasting appeared to have had little effect on the marine fauna and flora in the immediate vicinity. Small schooling fish were the affected with up to 3500 killed during blasting and a small number of larger fish were also affected. Marine bird life appeared to be totally unaffected and no marine mammals were seen in the vicinity during blasting. Scheduling of blasting to avoid the spawning runs of salmon were recommended as a mitigation option.

Mitigation measures to be considered could include using methods which reduce impact, minimising charges and using smaller detonations to allow animals a chance to leave the area, and stopping operating in an area if mammals are present. Dredging could be timed to reduce potential impact on fish breeding/recruitment or migrations and to avoid nesting time or other key periods in the life cycle of birds.

Summaries of the potential effects of dredging on the benthic and water column ecosystems, birds, mammals and fish are provided in Table 3.

6.2 Effects of the disposal of dredged material

6.2.1 Selection of disposal options

For the purposes of modelling potential changes to physical characteristics and making assessments of the potential effects on ecology we have used assessments based on the disposal site being at Site A0 (Figure 2). Early constraints mapping and modelling suggested locations to the NE of Taiaroa Head would have the least impact on a range of activities and this was subsequently narrowed down to Site A0 where the potential for disposal material to impact on Blueskin Bay, northern coastline and Otago Peninsula, fisheries and general ecology would be minimised.

6.2.2 Discharge of dredged material at the disposal site

Depending on the type and quantity of dredged material being disposed of it can impact on the ecology of the area in a number of ways:

- Fine material can stay in the water column and disperse creating a plume that can have a direct impact on suspension feeding planktonic animals, and reduce water clarity and thus light availability for phytoplankton and benthic algae.

- Fine material can be dispersed and depending on the extent of the plume can impact on inshore areas and sensitive offshore communities.

- Material which reaches the seafloor can blanket and smother benthic organisms in the immediate disposal site.

- Changes in sediment characteristics can result in changes to benthic community structure. Generally muddy sediments have low species richness and are dominated by small surface associated taxa compared with sandy sediments.

- Impacts on benthic and planktonic fauna can in turn impact on food resources and foraging of birds, mammals and fish.

6.2.3 Effects of disposal on plankton communities

As the dredge material is released at the disposal site there will be an increase in turbidity as sediments settle through the water or disperse with the currents. Heavier sediments will settle in the immediate vicinity of the disposal site but finer silts and clays will disperse as a plume with duration and direction depending on prevailing currents. Some of the material that reaches the seabed may subsequently be re-suspended into the water column under certain hydrodynamic conditions.

Although coastal plankton communities are subject to episodic turbid events as a result of increased runoff and riverine input, elevated suspended sediment concentrations as a result of the disposal of dredge material can impact on both zooplankton and phytoplankton. Suspension and filter-feeding zooplankton can be affected by clogging of feeding apparatus. Concentrations in the water column at the disposal site could be up to 1700 mg/l but this is below the level known to have a significant impact on zooplankton communities (10,000 mg/l). If there was an impact the effect would be short-term as zooplankton are short-lived (days to months) so recovery would be relatively rapid through recruitment, depending on the time of year as well as advection from other areas.

Turbidity associated with dredged material disposal would reduce light penetration at the disposal site with potential effects on primary producers (plants) both planktonic and on the seabed. The predicted suspended sediment concentrations are less than 100 mg/l in the plume once you get about 2km away from the site and rapidly dilutes to less than 20 mg/l. Surface layer concentrations would be considerably less with concentrations off the Taiaroa Heads and more than a few km away, being less than 3 mg/l. Disposal will be periodic during the day, thus light limitation is unlikely to be a significant issue for plankton as a result of dredge disposal except during discharge at the site itself. Recent measurements of background levels at Site A0 and in middle of Blueskin Bay varied from 0.3 to 4.1 mg/l (Kim Curry, NIWA, pers. Comm.).

6.2.4 Effects of disposal on benthic communities

Effects on benthic communities, due to the disposal of dredged material, are inevitable. Sudden 20-30 cm thick deposits accumulating up to 1.2 m on average in the 2 km radius of the site will cause mortality of underlying benthos, with the possible exception of some large bivalves and active macroinvertebrates that are adapted for rapid burrowing in mobile sediments. Consequences of species loss depend on the species removed with large long-lived organisms often controlling community structure and ecological functioning.

Recovery will be fastest when dredged sediments and spoil area sediments are well matched (i.e., similar grain size and similar biotic composition). Once disposal ceases, recovery could still take up to a year, and longer for large animals that take years to mature.

Maintenance and development dredging has been in place in Otago Harbour since 1865. Three dredge material disposal sites are currently in use and POL has a Resource Consent to dispose of dredged material from its ongoing maintenance dredging at these sites until December 2011. The Heyward Point site was relocated 600 metres in 1977 following the disposal in 1976 of 3.2 million m^3 from a major dredging programme in the Harbour.

As part of the most recent consent the Port Company was required to undertake a study of the effects of disposal on the biota at the present maintenance dredging disposal sites. The direct impacts on the inner shelf benthos, from the disposal of this dredged material was examined, in particular at the Spit Beach (Aramoana) disposal site, by Paavo (2006). Macrofauna inside the Spit Beach disposal site was found to have lower species richness and abundance compared to adjacent sediments. Disposal related effects beyond the disposal area boundaries appear, at least in part, to be due to the accumulation mound influencing wave and tidal currents.

In order to better understand the environmental effects of disposal at the Spit Beach site, the site was protected from dredge material disposal for an extended period followed by experimental disposal of sandy and muddy dredge material. Macrofaunal samples were collected before disposal and at nine sites within 120 days after disposal. Disposal site samples were depauperate in individuals and taxa compared to an area protected from disposal, for greater than 180 days. A drop in abundance and a dissimilar community coincided with muddy sediments, but fine sediments were dispersed within 26 days and macrofaunal assemblages recovered to the pre-existing state. Disposal of sandy material, while not altering native sediment textures, had a more prolonged impact due to transplantation of macrofauna (polychaetes, amphipods, molluscs) from the dredged area. These animals survived the transplant and persisted for more than 40 days after disposal thus increasing diversity and abundance of some animals (Paavo 2006).

Paavo et al. (subm) also demonstrated that 50% of the common snail *Zethalia zelandica*, one of the commonest benthic animals in the inshore sandy region off Otago, did not survive 24 hrs after burial under 17 cm of sand. If buried under only 3.8 cm of mud the same level of mortality occurred demonstrating the differential effects based on sediment type. The threshold at which only 10% of bivalves such as *Nucula* and *Macomona* may escape burial and re-establish is up to 50 cm (Kranz 1974) and a few polychaete worms 20-30 cm, but most soft-bottom species can only escape maximum burial of up to 5-10cm.

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No sensitive or rare species or communities were found in the surveys around the proposed disposal sites. Site A1 was more turbid and possessed little epifauna but large numbers of the small gastropod *Antisolarium egenum*. Site A2 had higher densities of large tubeworms and epifauna despite all sites having similar sediment characteristics. The most likely disposal site (Site A0) is located in between these two sites but would have similar characteristics to Site A2. Other than a few bivalves, few species encountered at these sites would be likely to survive smothering by sediment of over 10-20cm. Based on the predictions of deposition (Bell et al. 2009) these levels could impact on an area up to ~2km in a footprint to the north of the disposal site and the area receiving over 10 cm would be 20 km^2 (includes the disposal site itself). The community would recover in time with the likes of polychaete worms recovering on a time scale of a few months. Longer-lived species could take a few years although some could migrate into the area and some would manage to burrow through the deposited sediment as it gradually built up during disposal.

Some offshore locations have biogenic habitats (bryozoan thickets, horse mussel beds, sponge gardens, soft-corals) that are ecologically very important as settlement habitat for commercially valued finfish and shellfish species. The potential disposal sites have been carefully chosen so that these communities will not be affected. The proposed dredging site is well inshore and to the north of areas where they occur (75-110m depth) and modelling at Site A0 indicates there would be no dispersion of sediments towards those habitats.

Based on modelling it is unlikely that the benthic community in the Blueskin Bay area will be impacted by the plume of fine material and the coastal area on the outside of Otago Peninsula would receive small amounts on occasions but levels would be well below thresholds that would impact significantly on biota.

In terms of mitigation of the effects of disposal, capping of silts and clays with fine sands is an option but most of this material is likely to readily disperse anyway leaving the coarser silts and fine sand. Systematic disposal (starting at one end of the disposal area and progressing toward the other) rather than haphazard/random dumping would also probably help to limit impacts. Repeated disposal in an area would be worse than one-off disposals, especially for communities dominated by large long-lived "climax" species (see comments above for the dredging operation).

6.2.5 Spread of invasives

Recent surveys of invasive species carried out in Port Otago and Port Chalmers did not find the sea-squirt *Styela* but *Undaria* and 25 other species not previously described from New Zealand waters have been recorded from the Otago region (Gust et al. 2006). These invasions include 23 species of sponge, an amphipod and a polychaete worm. *Undaria pinnatifida* was first identified in the Harbour in 1990 and has since spread along much of the hard shoreline.

It is highly unlikely that species like *Undaria* would colonise at the proposed disposal site because of the lack of hard substrate, depth and exposure. The three species that were found exclusively at Port Chalmers were algae or sponge species which would be unlikely to survive offshore because of a lack of hard substrate.

6.2.6 Effects of disposal on birds

Disposal of the dredged material could have a number of potential short- and long–term effects on fisheries resources (see section of effects on fisheries below). Fish, squid and swarm-forming crustaceans such as *Munida gregaria* are the principal prey of seabirds off the Otago coast. Consequently, disposal of dredge material that affects these prey would also have flow-on effects to seabirds.

A sediment plume will develop in the water column as each load of dredged material is released onto the disposal site. The sediments in this plume will be dispersed away from the site by any prevailing water currents at the time of disposal and may cause a short term reduction of water clarity depending on where the plume disperses. Such effects would be limited to the duration of dredging and disposal and could affect seabirds that detect their prey visually. The concentrations of suspended sediments are low enough once you get a few kilometres away from the immediate disposal site that they would be unlikely to affect foraging by these birds. The main plume also disperses to the north rather than towards Taiaroa Heads.

The critically endangered grey-headed mollymawk is rare off the Otago coast and is considered to forage mainly off the continental shelf, over deep (>500m) water (Marchant & Higgins 1990), and so will not be affected by disposal of dredge material.

The one mainland breeding colony of northern royal albatrosses is situated on Taiaroa Head, Otago Harbour. The location of the breeding colony, high on the promontory, ensures that it will not be affected directly by dredging activity. The important foraging areas off the Otago coast of 18 Northern royal albatrosses from the Taiaroa Head colony, during the incubation stage of their breeding season, was monitored using global positioning system (GPS) loggers (Waugh et al. 2005). This study showed that waters within 100 km of the breeding colony were extremely important for the albatrosses (tagged individuals spent 28% of their time, on average within this area). This area is also frequented by albatrosses from Campbell Island, making it an important feeding habitat for this species. A large amount of foraging also occurred in areas much farther off shore. Birds spent multiple days at sea and travelled over large distances when searching for food (2-19 days at sea, travelling on average 2000 km). Consequently, because of the ability of the birds to forage over such a large area potential impacts to the albatrosses due to dredging and spoil disposal, if they were to occur, are likely to be minimal.

Sooty shearwaters breed in colonies on Otago Peninsula (Sagar et al. 2002). Birds from these colonies forage widely, obtaining their food by diving to depths of over 40 m and have the ability to cover large areas of ocean rapidly. They feed mainly on small fish, squid, krill and other small crustaceans. Their ability to cover large areas of ocean rapidly should ensure that they are not affected by the dredging and the disposal of spoil.

Yellow-eyed penguins and southern blue penguins breed in coastal areas outside the Harbour. They are predominantly pelagic feeders, foraging for food near the ocean floor (Marchant & Higgins 1990). Off the Otago Peninsula, Moore (1999) and Mattern et al. (2007) estimated that yellow-eyed penguins foraged mostly in waters over the continental shelf at depths between 40-80 m. Individuals were shown to retain foraging patterns throughout the breeding season; some birds were markedly inshore feeders, with centres of activity less than 5 km from the coast. Breeding success was related to foraging time. Failed breeders and non-breeders travelled further and for longer periods of time than breeding individuals. In addition, breeding birds that later failed took longer trips during incubation than successful breeders.

Both species of penguin breeding on Otago Peninsula are likely to forage within the proposed offshore dredge material disposal zone. Disruption of benthic communities and associated food sources in this zone could mean that birds will be forced to forage over larger distances. However, yellow-eyed penguins tend to forage mostly at depths greater than 40-80m which is well offshore from the proposed disposal area, and so any effect, if it were to occur, is likely to be minimal.

Four species of shag inhabit the Otago Harbour and the adjacent coastline. Howlett Point is the only mainland breeding location of the Stewart Island shag. The Otago population of Stewart Island and Spotted shags represents about 20% of the species around New Zealand. The diet of these shags was analysed allowing the foraging habits of the birds to be deduced from the habits of their prey (Lalas 1983). Black and little shags generally forage close to shore in shallow water feeding on small fish. Stewart Island and spotted shags feed up to 15 km offshore and mainly on small fish.

Disposal of dredging material may also interrupt habitats and feeding grounds of fish species that make up the majority of the diet of Otago shag species, and so reduce the abundance of prey species. Although these effects are likely to be short-term and restricted in spatial extent, disposal of dredge material would be best timed to occur at least outside the breeding season of Stewart Island shags, which have the more restricted feeding range.

White-fronted terns breed in colonies on the outer coasts of Otago Peninsula (Sagar et al. 2002), while Caspian terns and black-fronted terns do not breed in the area. Thus breeding of these terns should not be affected by dredging. However, Lalas (1977, 1979) reported that 50-70, and occasionally almost 200 birds, of the Nationally Endangered black-fronted tern roosted in Otago Harbour and foraged in adjacent coastal waters on planktonic larvae, taken from the surface or just below the surface. The preferred prey of Caspian and white-fronted terns are fish and crustaceans which they capture by diving. Consequently, dredging could temporarily interrupt habitats and feeding grounds of the terns and their prey species, particularly by reducing the ability of the terns to detect their preferred prey.

Modelling to date however, does indicate that the concentrations are likely to be less than 190 mg/l at the disposal site itself (2 km diameter) and less than 30 mg/l at distances more than a few km to the north of the disposal site. Concentrations outside a few kilometres of the disposal site and Taiaroa Heads would be under 3 mg/l. This is well below the threshold set by Port of Melbourne to protect terns and gannets (25 mg/l) thus the levels likely to be encountered by birds foraging off the Otago coast during disposal of dredge material event are unlikely to have significant effect and any effect would be localised around the disposal site and a small distance to the north.

6.2.7 Effects of disposal on mammals

Fur seals forage up to 78 km from Otago rookeries while sea lions are known to spend several days at sea foraging and completing dives as great as 474m (Harcourt et al. 1995; Gales and Mattlin 1997). Consequently, because of the ability of these species to forage over such a large area and the increasing population, potential impacts due to dredging and dredge material disposal, if they were to occur, would be minimal.

The southern elephant seal (*Mirounga leonine*) and leopard seal (*Hydrurga leptonyx*) are also occasionally sighted on the Otago coast. This area represents the most northern extent of their ranges (although stragglers are found further north) and both species are more commonly found off the Subantarctic Islands and over the Antarctic ice shelf (Sagar et al. 2002) and thus are unlikely to be impacted by the proposed dredging and disposal of dredged material.

The New Zealand (Hookers) sealion (*Phocarctos hookeri*) was declared a threatened species in 1997. The Otago breeding population in 2002 consisted of four breeding females. Over 95% of the breeding occurs at the Auckland Islands and Campbell

Island so the only possible effect of the dredging operation is potential for disturbance when dredging near the entrance where a few have recently taken up residence and are one of the attractions for visitors on the Monarch during summer (Sean Heseltine, M.V Monarch, pers. comm.). It needs to be kept in mind that these animals have taken up residence close to regular boat and ship traffic and maintenance dredging operations with no obvious effects.

Four dolphin species are found off the Otago coast – Hector's dolphin, (*Cephalorhynchus hectori hectori*), dusky dolphin (*Lagenorynchus obscurus*), Bottlenose dolphin (*Tursiops truncates*) and common dolphin (*Delphinus delphis*). Dusky and common dolphins occasionally enter the Otago Harbour, often staying for several days at a time, and travelling as far as the inner basin (Dunedin City Council 2006; Würsig et al. 2007). Hector's dolphins are endemic to New Zealand, and are considered to be at very high risk of extinction in the wild. Hector's dolphins inhabit inshore coastal waters and are generally restricted to local areas, with little movement between areas.

About 20 Hector's dolphins are resident in Blueskin Bay out to Taiaroa Head and are generally found in pods of 3-4 animals (Steve Dawson, University of Otago, pers. comm.). Hector's dolphins in this area spend winter at depths of 60-70m. Although they are found close inshore in summer (3-4km off the coast) they generally forage to the north and west of Taiaroa Head so are unlikely to be affected by the dredging operation. The plume resulting from disposal could head north and although indications are it will avoid the inshore Blueskin Bay area the plume may potentially overlap with the area occupied by Hectors dolphins. However, it is unlikely that concentrations in the plume east of Taiaroa Head will be above 3 mg/l and thus will be unlikely to impact on the planktonic or larger animals in the water column.

The Humpback whale (*Megaptera novaeangliae*) can be sighted off the Otago coast in autumn during their northward migration to breed. The distance from shore and depth of their main migration routes are unknown, however a juvenile Humpback whale was sighted feeding within the Otago Harbour. Sightings of the Southern Right whale (*Eubalaena australiis*) off the Otago coast are also frequently recorded at various locations close to shore. The coastline is part of their migration route, and they probably feed over the entire continental shelf. Direct impact on whales from dredging and disposal activities is highly unlikely as they can avoid areas of activity.

6.2.8 Effects on disposal on fisheries

Disposal of the dredged material will have some potential short and long–term effects on fish and shellfish resources at or near the disposal site. The most immediate biological impact will be the smothering of any benthic fauna at the disposal site including any shellfish and benthic organisms on which fish may feed. Site surveys indicate that the seabed sediments at the proposed disposal sites are predominantly fine sands with a benthic fauna typical of waters of this depth along the Otago Coast.

There are no known shellfish resources of significance at or in the vicinity of Site A0 or the other sites considered in the area. Any impacts of the loss of the benthic fauna on fish feeding is expected to be short-term and minor in the wider context as the proposed disposal areas represents a small fraction of the available benthic habitats at these depths within or near Blueskin Bay.

The dredged material that will be disposed of consists mainly of similar fine sands to those already present at the disposal sites but there is a significant component of fine silt. Following cessation of the disposal activity benthic biota is expected to re–establish itself at the disposal site. Once the biota is fully established, the seabed habitat and biota should be similar to that currently present. There will be no permanent loss of fisheries habitat in Blueskin Bay.

A sediment plume will develop in the water column as each load of dredged material is released onto the disposal site. The sediments in this plume will be dispersed away from the site by any prevailing water currents at the time of disposal and may cause a short term reduction of water clarity. Modelling indicates this effect is likely to be restricted to a plume extending to the north of the disposal site and would be insignificant by the time it reaches the coastline. Any effects from the plume would be limited to the duration of dredging and disposal and a short time after. Indications are that the plume is more likely to head north and will have concentrations of suspended sediments well below levels likely to impact directly on fish or shellfish eggs, larvae or adults.

There may also be a sediment plume around the entrance to Otago Harbour as a result of tidal outflows from the Harbour during or shortly after dredging activity. This plume is likely to be dispersed over a large area around the entrance to the Harbour. Water clarity will be reduced by the suspended sediments until they are sufficiently diluted through dispersion or settle out. The turbidity will have short term adverse effects on visibility for recreational and commercial divers adjacent to the Harbour entrance. Diving is a popular recreational activity around the Mole in summer and there is periodic commercial diving for paua in the area south of Taiaroa Head.

Some of the sediments that initially settle at the disposal site are likely to be dispersed away from the site over time. The long term fate of sediments at the disposal site will depend on the volume and particle size of the dredged material that is deposited and the direction and velocity of currents along this part of the coast. The existing seabed types along this part of the coast probably give the best indication of where any sediments transported from the disposal site are most likely to permanently settle. Offshore from proposed disposal site the Southland Current moves northward along the coast indicating that transported sediments should generally move from the disposal site in the same direction. This is consistent with the modelling results. Current meters deployed at disposal Site A1 indicated that the prevailing drift is to the SE due to the more frequent winds from the SW and NE. This site has now been discarded in favour of a site further offshore which ensures any plume reaching the coast would have very low levels.

Paua diving occurs in very shallow waters south and west of Site A0 along the coastal fringe. Along this exposed coastline wave activity would prevent any sediments from settling on the rocky habitats, if it were to reach this area. Rock lobster fishing occurs around patches of rocky habitat along the coast from Pipikaretu Point to Te Whakarekaiwi, around Hydra Rock outside Wickliffe Bay and around Cape Saunders. These rock lobster fishing areas are well south of Site A0. Most rock lobster fishing along the Otago Coast occurs north of Blueskin Bay and south of Brighton.

Commercial trawling, set-net, line and cod pot fishing occurs throughout inner and outer Blueskin Bay with fishing effort widely distributed depending on species, season and method. Dredge disposal activity and its associated effects may impact on commercial fishing that takes place at or near the proposed disposal sites from time to time. Any such impacts will be temporary and localized. It is probable that dredge disposal will also attract some fish that will forage on benthic organisms exposed in the dredged material at the time of each release at the disposal site.

Summaries of the potential effects of disposal of dredge material on the benthic and water column ecosystem, ecology, birds, mammals and fish are provided in Table 4.

7. Summary of potential effects

In most cases, existing regulations, careful dredging practice and selection of disposal sites are sufficient to avoid significant long-term effects on harbour and coastal ecology. Where adverse effects are identified or a precautionary approach is considered necessary the following actions may be taken to mitigate impacts:

- timing of dredging and disposal operations (seasonal);
- selection of dredging methods;
- promotion of beneficial use of dredge material;
- careful selection of disposal sites; and
- monitoring and record keeping.

To summarise the potential significance of the effects of dredging we used three criteria:

- severity - which is a measure of the degree of harm, without consideration of duration or spatial extent;
- duration - which is the time between the initial effect and recovery once operations have ceased; and
- extent of impact - which is the spatial distribution of the impact.

The following rating levels for each of the three criteria are consistent with IADC/CEDA (1998) guidelines and have been adapted from Emmett (2002) as they would apply to an assessment of the significance of potential effects of the proposed dredging operation:

1. **Severity:**

Severity	
LOW	• No threat to critical food supply, species life-cycles • Minimum impact on species important for structure or function • No significant changes to species diversity and abundance/biomass • Minimum impact on habitat complexity/diversity/productivity • Minor changes to ambient environmental quality
MEDIUM	• Loss of non-critical food supply/reduction in critical food supply • Displacement of non-reproductive activity • Species important for structure or function may be lost or impacted • Changes to species diversity and abundance/biomass • Reduction in habitat complexity/diversity/productivity • Changes to ambient environmental quality

HIGH	• Major changes to fauna and flora (e.g., through loss of critical food supply, interruption of reproductive life-cycle) • Substantial reduction in abundance/biomass of species important for structure and function • Significant impact to biodiversity and ecological functioning • Loss of complex or vital habitat • Major impacts on ambient environmental quality

2. **Duration:**

Duration	
SHORT-TERM	• Short-term impacts last for less than 1 year
MEDIUM-TERM	• Medium-term impacts last for periods of 1-5 years
LONG-TERM	• Long-term impacts last for more than 5 years

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3. **Extent of Impact:**

Extent of Impact	
SITE-SPECIFIC	• Impact or disturbance is restricted to the site at which the activity is occurring
LOCAL	• Impact or disturbance extends up to 1,000 m beyond the boundary of the site at which the activity is occurring
REGIONAL	• Impact or disturbance extends further than 1,000 m beyond the immediate boundaries of where the activity is occurring

Emmett (2002) recommended that, in general, impacts are considered significant if:

- **Severity** ranks high;
- **Duration** is long-term, and **severity** is medium or high; or
- **Extent of Impact** is regional, and **severity** is medium or high.

The following tables apply these criteria to the likely impacts of the proposed dredging and disposal operations based on extensive literature searches, results from modelling and recent surveys and discussions with marine ecologists.

Table 3: Assessment of the significance of potential ecological effects associated with the proposed dredging operation in the Lower Otago Harbour with respect to ecology.

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
Direct impacts on benthic communities – removal and loss of organisms	Bivalves (cockles) Polychaetes Deep sessile communities, sponges	Virtually all animals would be removed from sections to be widened Most animals would be removed, some will remain in suspension and resettle Some of these communities will be removed depending on where located	Sediments and communities already modified in channel by maintenance dredging. Most of the communities will be removed in areas where the channel is widened. Animals such as polychaete worms will recolonise rapidly i.e., within a few months depending on time of year and availability of recolonisers. Most of the deep sessile community in areas dredged will not survive and be transported out of the channel but the subchannels/hollows will reform in time and recolonise (expected to be 2-3 years). Area to be removed around the Port is 10,000m^2 which is less than 0.5% of the intertidal habitat classified. Mitigation • If possible dredge in winter when populations less vulnerable, not reproducing and will allow rapid recolonisation in following spring. • Potentially cockles could be collected from areas to be widened could be replanted but this would possibly require consents.	High	Medium	Site specific (confined to immediate area that is being widened and channel bottom)
Smothering of benthic communities	Suspension feeders (e.g., bivalves, some polychaete worms) Deposit feeders (snails, some polychaete worms)	Animals and plants in the channel, and parts of margins and intertidal area will be smothered, potentially affecting feeding and respiration of suspension feeding animals and physically impacting on benthic plants (seagrasses/algae) as well as reducing photosynthetic	Most animal species can survive small amounts of sediment (e.g., many in a Manukau /Whitford study survived 20 mm in an event and repeated deposition of 3mm over 6 months). Modelling suggests sedimentation rates would be less than 20 mm over the dredging period on the margins and away from the channel except a small area directly opposite the port	Low (on tidal flats) Med – High (in channel and small part of margins) – note that	Short –term in all areas but may be medium term for deep sessile communities.	Medium to high severity would be "local"- (mostly confined to vicinity of channel but

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
D R	Seagrasses/algae	capability. Some deposit feeders may benefit (gastropod snails, polychaete worms)	where the intertidal area could receive over 20 mm. The maximum in the channel would be closest to the Port with 60mm but for only 10% of the sub-area. Similarly deposition rates in intertidal areas where seagrasses occur are below the thresholds which have been found to impact on seagrasses (<0.25mm/d Doorn-Groen 2007), except in a few small areas opposite the Port itself. Mitigation • If possible dredge in winter when populations less vulnerable, not reproducing and will allow rapid recolonisation in following spring.	these habitats would already be heavily disrupted by the dredging operation.		will be quickly flushed), or "regional" around the Port area and in the channel up and downstream.
A F T 04/03/09	Bird and fish life	If there are significant effects on benthic communities through smothering then this can have a direct impact on higher trophic levels through effects on their food resource and foraging.	Fish and birds are very mobile and able to move to other areas to feed in order to avoid temporary or localised impacts on their food resources. However these areas may be limited if the impact is significant over a large area. Modelling indicates there would be few areas with deposition over 20mm outside the channel itself and areas like Aramoana would receive very small amounts of deposited material. Thus food supply is unlikely to be significantly impacted over large areas of the Lower Harbour.	Low	Short –term in all areas.	Regional but low severity in most areas important for bird and fish foraging.

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
Increased suspended sediments and turbidity	Suspension feeders (e.g., bivalves, some polychaete worms) Deposit feeders (e.g., gastropod snails, amphipods, some polychaete worms)	Increased levels of suspended sediments will affect animals and plants in parts of the channel, margins and intertidal area by impacting on feeding and respiration in suspension and deposit feeding animals. If the sediment characteristics change then there can be changes to the community structure and significant changes can cause shifts to communities characteristic of finer/muddy sediments.	Harbours are naturally turbid with episodic events with very high turbidities and communities are adapted to these conditions. Most of the species present can tolerate up to 400 mg/l and even 1000 mg/l of suspended sediments. Predicted values on intertidal flats are generally less than 200 mg/l but with small patches up to 400mg/l or more for short periods and thus SSC are unlikely to have a significant effect overall. Impacts will also depend on the type of sediment being dredged with sand having less impact than finer silts and clays. Where there are impacts recovery will likely be a few months for silt/clay sediment communities and months-years for sand communities (although bed movement and colonisation could be relatively rapid). Mitigation • If possible dredge in winter when benthic populations less vulnerable and will allow rapid recolonisation in following spring. • Dredging and disposal should occur outside the breeding period for birds, fish and mammals if possible to mitigate any effects (i.e. Feb/Mar to Aug/Sept).	High locally especially in channel, low-medium away from channel.	Short-term	Most severe would be site specific in immediate vicinity of dredging, less severe locally or regionally.
	Birds	Bird feeding could be disrupted if suspended sediments are high in the intertidal areas and could be impact on foraging through effects on benthic species that form their main prey.	Some bird species could be affected if their food supply was impacted in areas such as at Aramoana but this is likely to be only short-term and there is no evidence that significant SSC would occur in key places like Aramoana. Increased sedimentation in the water column	Low	Short-term	Local but very mobile so unlikely to be impacted

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
			that reduces visibility and foraging success and indirect affects on fish and invertebrates that make up their diet could impact on shag and tern populations and intertidal shorebirds that are visual feeders.			
	Mammals and Fish	Highly turbid conditions can affect feeding and migration of mammals and fish. Many benthic species have a larval planktonic phase and it is possible that changes in the composition and abundance of zooplankton associated with a long period of higher turbidity could drive changes in the abundance of benthic species. Similarly feeding by fishes on benthic organisms could be affected by high suspended sediment levels in the intertidal and subtidal zones.	While dolphins and whales are occasionally sighted in the Harbour most of their foraging grounds are along the coast and in the case of Hector's dolphins further north. There will be some increase in turbidity at the entrance and Outer Harbour during dredging but this is unlikely to have a significant impact on these mammals as they are very mobile. Fish are also mobile and able to move to other areas to feed in order to avoid temporary or localised impacts. The levels of turbidity predicted during dredging are unlikely to impact on zooplankton and thus larval stages.	Low-Medium (medium for some fish that may not be able to avoid areas of high turbidity)	Short-term	Local but very mobile so unlikely to be impacted, low impact regionally.
Decrease in water clarity and effects on plants	Seagrasses/algae/ microphytobenthos	Photosynthetic capability and production of seagrasses, algae and microphytobenthos can be impacted by reduced water clarity and in extreme cases communities lost.	Light penetration is reduced through increased turbidity and thus can reduce benthic plant growth. Harbours are naturally turbid at times. 15% reduction in surface light and 15 NTUs is often set as a threshold to maintain seagrasses. Over 25 mg/l above background for less than 5% of the time can have a moderate impact on seagrass communities. The maximum turbidity likely to be experienced in the intertidal zone would have a moderate impact but would be site specific and for a very short time.	Low for most of the time and for intertidal areas but will be short periods when moderate severity close to dredging (<5% of time)	Short-term, beds would recover when dredging ceases.	Site specific, low severity at local scale

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
Release of contaminants/ nutrients	Water quality	Water quality can be impacted by increases in contaminants that can bioaccumulate in the food chain and increased nutrients can cause algal blooms. Increased nutrients can benefit algal growth but at high levels can eventually lead to anoxia. The disruption of muddy benthic habitats will cause more oxygen issues than the dredging of sandy habitats, as muds are more organically enriched and have shallower redox depths.	Tests on the sediments to be dredged have shown that levels are all below those in the ANZECC guidelines for levels that would impact on biological communities. Potential for effects will depend on the duration and magnitude of nutrient enrichment relative to background. These effects are likely to be minor/undetectable and any increase would be rapidly diluted by tidal movement.	Low	Short-term	Local as any effect would spread with the plume but be rapidly diluted
Blasting effects	Mammals and fish	Pressure waves can cause rupture of organs and potentially mortality.	Effects depend on the blasting methods. Generally invertebrates are not affected except directly right at the site but it can impact on fish in immediate vicinity and possibly mammals if they were nearby. Mitigation • use small explosions to warn fish and mammals away, • avoid blasting when mammals present and during critical fish migration periods.	Low except within 30-50m where high for fish	Short-term	Site specific
Spread of invasives	Native species and biodiversity	Transferring and disturbing sediment during dredging can potential spread invasive species through fragmentation and removal of whole plants/animals.	Invasive species are already present in the port areas and no new species would be likely to invade. Strong water flows in the channel and maintenance dredging would have already resulted in any potential spread	Low	Medium-long	Local but mostly site specific

Table 4: Assessment of the significance of potential ecological effects associated with the proposed disposal of dredge material off Otago Peninsula.

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
Direct impacts on benthic communities - smothering	Bivalves/ gastropod snails/ amphipods Polychaetes worms Bryozoans, horse mussels, sponges, soft corals	Effects on benthic communities, due to the disposal of dredged material at a disposal site, are inevitable. Underlying benthos will not survive sudden 20-30 cm thick deposits. Communities that are very sensitive to sedimentation and of high ecological significance and value in the wider area include biogenic habitats (bryozoan thickets, horse mussel beds, sponge gardens, soft-corals).	It is likely that virtually all benthic animals and plants in the immediate area will not survive the smothering of sediments, possibly up to 1.9m thick. Consequences of species loss depends on the species that are smothered; large long-lived organisms will take longer to recover. Recovery will be fastest when dredged sediments and spoil area sediments are well matched (i.e., similar grain size and similar biotic composition). Fine silts would be expected to disperse over a large area in a thin layer. Once dredged material disposal ceases, recovery could still take up to a year, and longer for large animals and biogenic habitats that take many years to mature. Careful consideration has gone into selection of potential sites which will minimise impacts on significant biogenic habitat. No unique or special communities have been identified in the proposed areas. Area identified is ~3-4 km^2 with similar sediments and habitats to surrounding area and with species and communities common in coastal areas around New Zealand. Some offshore locations have biogenic habitats (bryozoan thickets, horse mussel beds, sponge gardens, soft-corals) that are ecologically important as settlement habitat for commercially valued finfish and shellfish species. These communities will not be affected as the proposed dredging site has been carefully chosen to be well inshore and to	High	Medium-term	Site specific (i.e., confined to immediate area of the disposal ground for high impact, some impact locally and regionally with footprint of up to ~ 20 km^2 to the north receiving over 10 cm during the disposal period.

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
			the north of areas where they occur (75-110m depth). Mitigation • If possible dredge in winter when populations less vulnerable, not reproducing and will allow rapid recolonisation in following spring. • Systematic disposal (starting at one end of the disposal area and progressing toward the other) rather than haphazard/random dumping would probably help to limit impacts. Repeated disposal in an area would be worse than one-off disposals, especially for communities dominated by large long-lived “climax” species. • If significant quantities of fine silt was to settle out then capping with fine sand should be considered, however these fine sediments are likely to rapidly disperse.			
	Fish and birds	If there are significant effects on benthic communities then this can have a direct impact on foraging of higher trophic levels and their food resource.	Fish and birds are very mobile and able to move to other areas to feed in order to avoid temporary or localised impacts. Modelling however indicates there would still be a significant area impacted in the short-term by deposition. Up to 30 km^2 could receive up to 5 cm over the disposal period. Some of this would disperse but some of this area, particularly close and within the disposal area itself would receive enough material to impact on food resources for birds and fish that feed in this area, over the short-medium term.	Med-High	Short-medium term	Regional but highest impact likely to be restricted to less than 5-6 kms to the north of the disposal site.

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
Increased suspended sediments and turbidity – effects on fauna	Bivalves/ gastropod snails/ amphipods Polychaetes worms Bryozoans, horse mussels, sponges, soft corals	Spoil disposal will increase turbidity and reduce water clarity as the sediment settles through the water or is dispersed as a plume. Resuspension of deposits may also occur under certain hydrodynamic conditions. Benthic communities at offshore sites with typically low turbidity and to the north of the immediate disposal grounds may also be impacted by elevated suspended sediment concentrations associated with dredging. Impacts would be similar to those of elevated turbidity at the dredging site (see above), with the caveat that some offshore communities are typically more sensitive to fine sediments than estuarine communities adapted to high turbidity.	The height of the dredged material mound and the hydrodynamic regime at the site will affect sediment dispersal and redistribution. Obviously, fine particles are more easily resuspended than coarse particles. Coarse sediments at a dredge disposal site are indicative of turbulent water movements capable of removing fine particles. Some of the dredged material will contain finer silt which would disperse and could affect the surrounding sandy communities (potentially reducing grainsize, altering water clarity, affecting suspension feeders, adding organics/ nutrients/ contaminants). The size of the footprint which could impact on some of the benthic community is up to 2km north of the proposed site. The disposal site has been carefully chosen to avoid turbid plumes reaching sensitive communities such as the bryozoan beds offshore and to minimise impacts in coastal areas such as Taiaroa Heads, Karitane and further north.	Low	Short-term	Site specific/ Local but could be “regional” for bird feeding up to a few km to the north of the site (note this is a small area compared with available foraging areas)
	Birds, mammals and fish	Birds and mammals could be affected through direct impacts of disposal operations and increased turbidity reducing their foraging grounds. The feeding of demersal fish species such as flatfishes could be affected by high turbidity and smothering of the benthic communities on which they feed.	Because of the ability of albatrosses and shearwaters to forage over a large area any potential impacts due to dredging and spoil disposal are likely to be reduced. Penguins are unlikely to be affected directly by the dredging operations or at the proposed offshore site as they forage at depths of 40-80m, further offshore. Away from the disposal site (>2km) suspended sediment concentrations will be less than 10 mg/l, well below the level set to protect birds like terns and gannets.			

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
			Demersal fish such as flatfish are well adapted to turbid conditions found in estuaries and harbours.			
Turbidity/ decrease in water clarity – plankton and benthic plants	Phytoplankton Benthic algae Zooplankton	Turbidity associated with material that stays in suspension or is resuspended at the disposal site and in the footprint area can reduce light penetration, with potential effects on primary producers. Increases in suspended sediments can clog feeding apparatus of filter and suspension feeding zooplankton	Effects on larger benthic plants are likely to be minor because submerged aquatic vegetation is rare in offshore sand habitats. Primary production in offshore areas is predominantly associated with phytoplankton in the water column. The potential site has been carefully chosen to avoid sensitive areas with significant biogenic habitats. Dredged material disposal is expected to be periodic during the day, and predicted levels in the plume are very low thus unlikely to be a major issue. Increased turbidity can impact planktonic animals particularly those that filter and suspension feed. Experiments have shown that levels up to 500 mg/l are unlikely to impact on zooplankton populations. Predicted levels even at the disposal site are well below this level.	Low/ moderate in immediate vicinity and a few kms north but would disperse rapidly.	Short term	Local for moderate impact, regional for low impact
Release of contaminants/ nutrients	Bioaccumulation in foodwebs	Contaminants that are present in sediments at the dredge site are at very low levels but some will be transported to the disposal site. If these had been above threshold limits they could affect the offshore biota through direct toxic effects and bioaccumulation. Due to sediment and water transport, the influence of contaminated dredged materials will not necessarily be limited to	Sediments at the dredging sites have been tested and are below the ANZECC guidelines for levels that are known to impact on biota. If sediments were contaminated and a decision was made to dispose of contaminated sediments offshore, these sediments can sometimes be successfully "capped" by dumping additional layers of clean sand atop the contaminated sediments. However tests have indicated there are low levels of contaminants.	Low	Short-term	Site specific/local

POTENTIAL EFFECT	ECOLOGICAL ASSET	POTENTIAL CONSEQUENCES	ADDITIONAL INFORMATION/MITIGATION	SIGNIFICANCE OF EFFECT		
				SEVERITY	DURATION	EXTENT
		the area of the disposal site.	The dilution of nutrients in the open coastal sea (and the sporadic nature of the disposal schedule) will minimise the chance for formation of phytoplankton blooms and associated issues, but these are unlikely to occur.			
Spread of invasives	Biodiversity	Although most invertebrates will not be likely to survive dredging and transport to the spoil site, there is a possibility of releasing viable algal cysts and sediment microbes at the offshore spoil site.	The release of algal cysts in combination with dredging induced nutrient enrichment could result in harmful algal blooms. The possibility exists, but seems unlikely. A number of invasive species have been reported from the Port Chalmers area. The sea-squirt *Styela* has not yet been recorded but *Undaria* has been recorded from the Otago region. It is highly unlikely that species like *Undaria* or other species of concern in the port areas would colonise at the proposed disposal site because of the lack of hard substrate, depth and exposure.	Low	Short-term	Site specific/local

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