Port Otago inshore dredging disposal programme

Recommendations for long-term ecological monitoring

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Prepared by:
Graham Fenwick
Jeanie Stenton-Dozey

For any information regarding this report please contact:
Graham Fenwick
Principal Scientist
Marine Ecosystems and Aquaculture
+64-3-348 -8987
graham.fenwick@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 8602
Riccarton
Christchurch 8011

Phone +64 3 348 8987

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1 Introduction

Port Otago Ltd (POL) holds a resource consent (RM11.153) for three years from 18 December 2013 to deposit dredge spoil at three shallow sites within Blueskin Bay at Shelly Beach, Heyward Point and Aramoana Spit. The brief duration of this consent is to enable continued use of these disposal sites whilst environmental assessment work is completed to support an application for long-term disposal beyond the present consent's term. One condition of the present consent requires the design and completion of a long-term ecological monitoring plan to assess the potential effects of dredge spoil on benthic ecology of two of these disposal sites, Heyward Point and Aramoana Spit.

We understand that POL's objective is to meet conditions 9 and 10 of the current resource consent by developing the plan to assess the ecological health of the benthos associated with the two disposal sites, the potential ecological impacts of continued disposal there, and to ensure any potential adverse ecological effects are managed effectively in the long-term.

Condition 9 stipulates:

- "evaluate the findings of the biological monitoring work undertaken as a condition of the former maintenance disposal consent (2000.472) and
- provide recommendations as to suitable suite [sic] of benthic fauna indicator species that could be adopted for the long-term adaptive management of disposal activities at the Heyward and Aramoana sites".

Condition 10 requests recommendations for a long-term ecological monitoring programme, plus identifying measures for managing the effects of disposal activities on benthic communities. We understand that epifauna (fauna on the sediment surface) and infauna (fauna within the sediment), as well as consideration of benthic features (such as burrows and worm tubes) should be included within this monitoring plan.

This report overviews available information for the area, notably biological monitoring completed by Benthic Science Ltd (Paavo 2011, 2013). Based on this work, we discuss candidate indicators for assessing and monitoring any effects of disposals on the benthic ecology at each site. These indicators include potential indicator species, as well as measures of overall benthic community status. We also recommend a draft ecological monitoring programme to support adaptively managing disposal at these sites in the longer term (30+ years).

2 Disposal site environment: review

Paavo (2011) provided a comprehensive discussion and assessment of existing benthic ecology around the disposal sites and the wider Blueskin Bay area, based on investigations over 2003 to 2010. There is also substantial information on the marine benthic ecology of the capital dredge spoil disposal area (30–40 m depth) and wider Blueskin Bay (e.g., Paavo & Probert 2005; Paavo 2007, 2011; Willis et al. 2008; Fenwick 2013). Although not directly relevant to these two inshore disposal sites, these other studies outline the broader benthic ecology of Blueskin Bay and inshore Otago soft bottoms.

Benthic community structure (species and densities) are shaped by several natural environmental factors. Water depth, hydrodynamics and bottom sediments are the most important and are closely linked to each other. The Heyward Point site's bathymetry is complex (Figure 1), with a natural cone of sediments off Heyward Point created by complex hydrodynamics in this part of Blueskin Bay (Weppe et al. 2011). Landward of this cone, the seabed is almost level before shoaling steeply around Heyward Point and more gently to the beaches either side. To seaward of the cone and southern end of the disposal site, the seabed sloes steeply to the gently sloping floor of Blueskin Bay to seaward.

Bathymetry around the Aramoana disposal site shows a gently sloping seabed, although this is close to the Long Mac breakwater, and the mole adds to this site's hydrodynamic complexity.

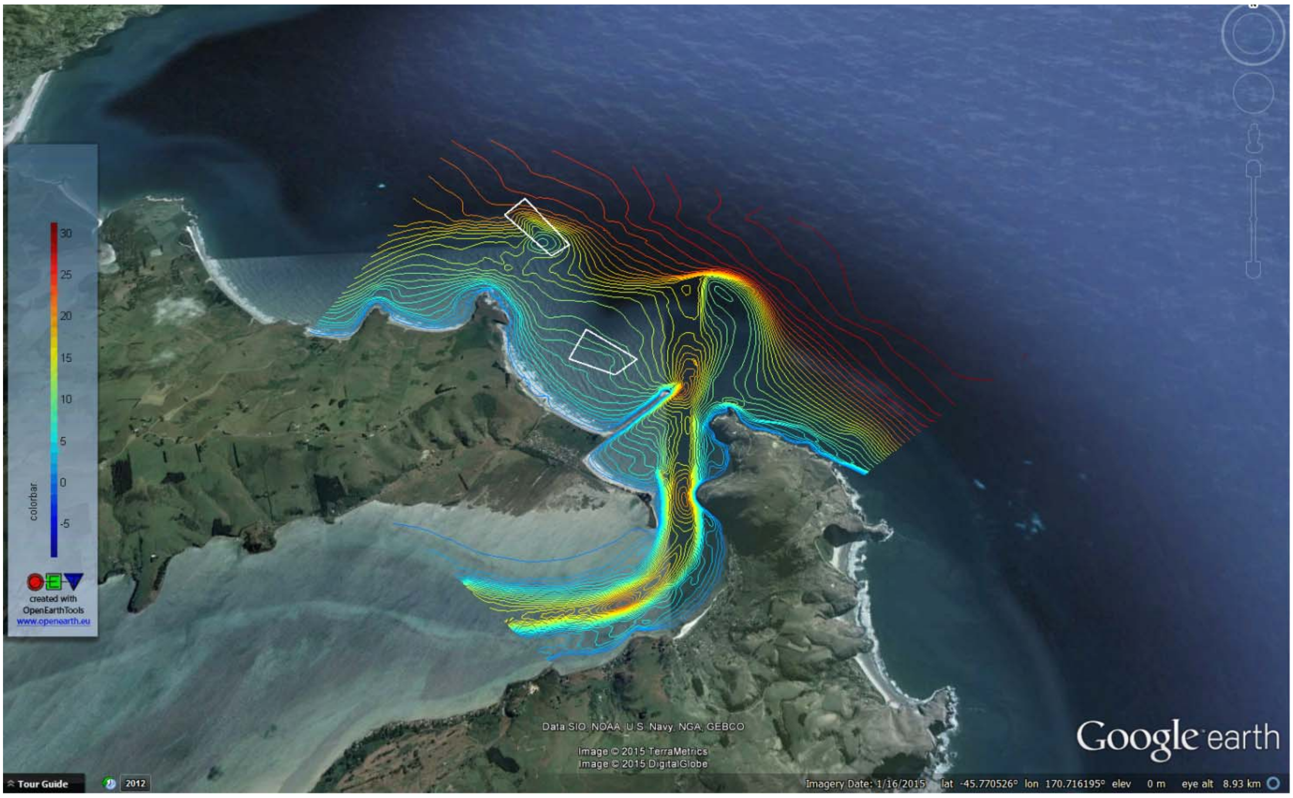

Figure 1: Bathymetry around the two maintenance dredge spoil disposal grounds in Blueskin Bay. White boxes show the approximate locations and sizes of the Heyward Point (upper) and Aramoana (lower) disposal sites. Source: Peter McComb, MetOcean Solutions Ltd.

2.1 Hydrodynamics

The area between Taiaroa Head and Karitane Peninsula is subject to high-energy waves, strong tidal and oceanic currents, and large but variable volumes of sediment transferred across the continental shelf and nearshore seabed (Bell et al. 2009). Hydrodynamic modelling indicates a residual anti-clockwise eddy within the bay that influences sediment movement and patterns within the coastal region (Figure 2). Superimposed on this, and perhaps having a substantial effect on sediments, are very complicated hydrodynamic patterns during storm events (Figure 3). Indirectly, therefore, these tidal and wave-driven currents determine the spatial distribution and composition of sediments and the infauna. Within the disposal sites, this interrelationship is probably modified, at least immediately after each disposal event, with the communities reverting to more natural states as the hydrodynamics re-sorts and disperses fines from the site.

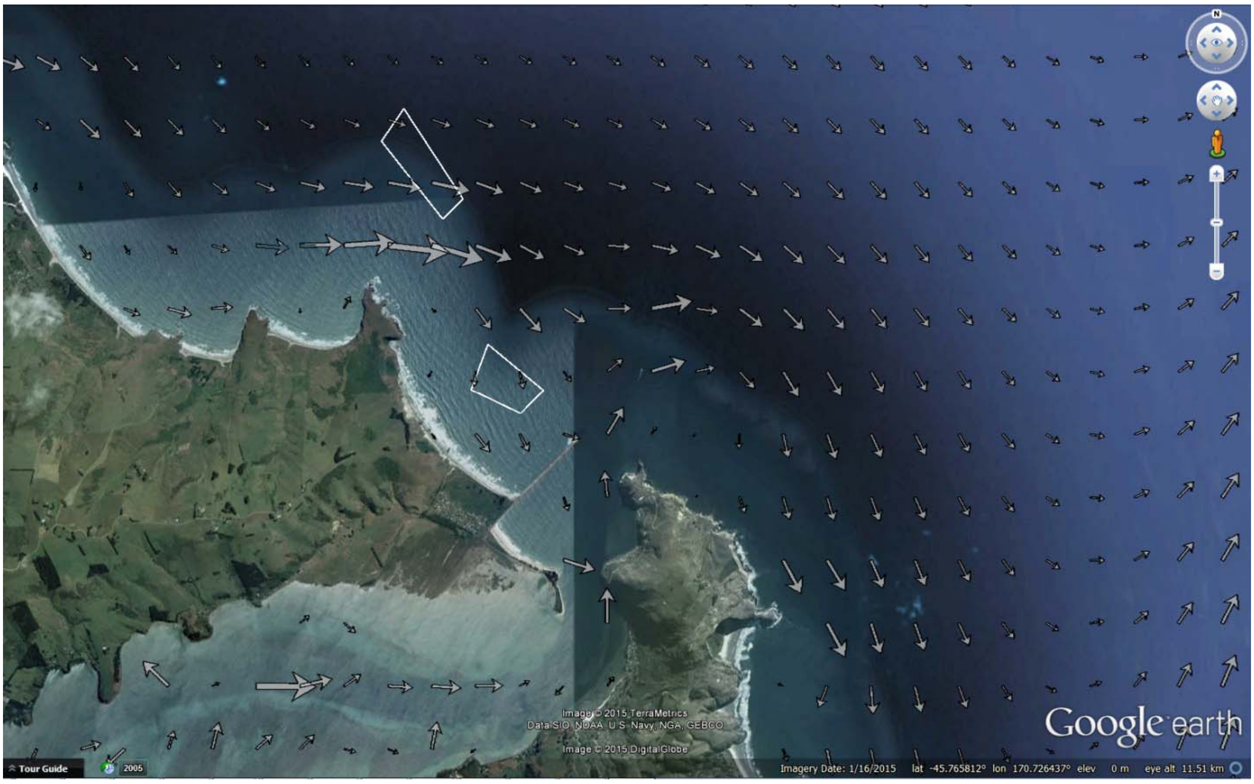

Figure 2: The clockwise residual tidal eddy in Blueskin Bay. Source: Peter McComb, MetOcean Solutions Ltd.

2.2 Sediments

Maintenance dredge spoil from the port comprises medium to fine sand (Paavo 2011), matching the particle size composition of sands at the two deeper disposal grounds, apparently originating from the same source (Single 2013). Thus, sediments at each site appear largely unmodified by spoil deposition since at least the 1950's (Single 2013), with hydrodynamics re-working and selectively dispersing any finer fractions after each deposition event (Paavo 2011). Given the active hydrodynamics at both disposal grounds, any zone of spoil and native sediment mixing is likely to be narrow.

The Heyward Point site, averaging c. 9-23 m deep (Figure 1), appears to be more hydrodynamically active than the other site based on residual tidal current modelling (Figure 2), so that any finer fractions within spoil deposits will disperse quickly (Paavo 2011; Single 2013). The seabed in the immediate vicinity of the shallower Aramoana site (6-12 m) is also dynamic due to its much more active wave environment (Figure 3) (Paavo et al. 2011) and any fine sediments are rapidly dispersed, with a net shoreward movement of sediment. Thus, currents are the primary hydrodynamic force at the Heyward Point ground, whereas wave energy drives hydrodynamics at the Aramoana disposal ground.

The more dynamic environment at Aramoana compared with Heyward Point disposal site is clearly evident when bathymetry in 2002 is compared with that in 2009 (Figure 4). This reveals displacement shoreward of sediments from the seaward margins of both disposal grounds; specifically, appreciable re-deposition to the northwest of each ground's shallowest points (located in the southeast corner of each ground) (Figure 4). This movement appears inconsistent with the residual tidal eddy described for the area (Figure 2), and more consistent with the modelled storm wave-driven circulation (Figure 3), suggesting that the sedimentary environments at both grounds, as across the whole area, is periodically re-set by storm-driven hydrodynamics.

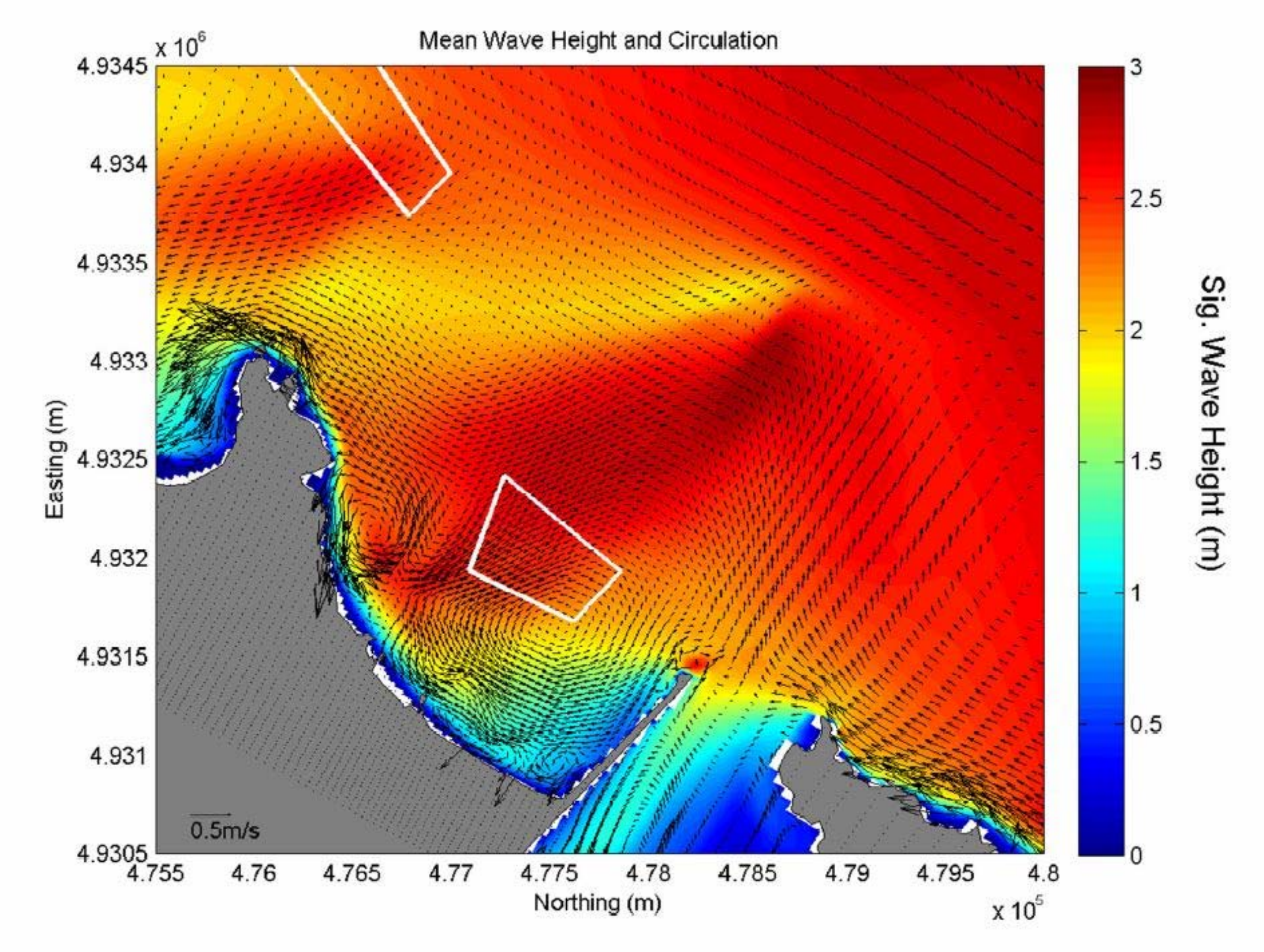

Figure 3: Mean wave heights and wave-drive circulation across the Heyward Point and Aramoana disposal sites in Blueskin Bay modelled for a modelled storm event. Source: Peter McComb, MetOcean Solutions Ltd.

2.3 Spoil deposition effects on benthos

Four main effects of spoil deposition on benthic communities may be important at the two disposal sites, and one or more of these is likely to underlie any observed effects on the benthos. Thus, although these factors may have diagnostic value if an effect is detected, we recommend monitoring only one or two of them (see section 3.5) for practical reasons. Instead, the ecological monitoring seeks to confirm no significant effects beyond the disposal areas, and the proposed adaptive management will facilitate appropriate diagnosis and remedial actions.

2.3.1 Sediment deposition

Direct burial. Occurs when spoil is discharged at the surface covers the bottom and buries any benthic invertebrates. Deep burial will make it impossible for even the best burrowers to regain their optimal position relative to the sediment-water interface, so that mortality is essentially complete due to immobilisation, inability to obtain oxygen and/or an inability to feed. At some point towards the margins of each drop zone, more individuals of each species will survive and recover.

Burial by bed-load transport. Re-distribution of spoil sediment via transport within the seabed boundary layer (i.e., very close to the seabed) may bury (perhaps repeatedly) or otherwise disrupt or kill the benthos through immobilisation, starvation and de-oxygenation.

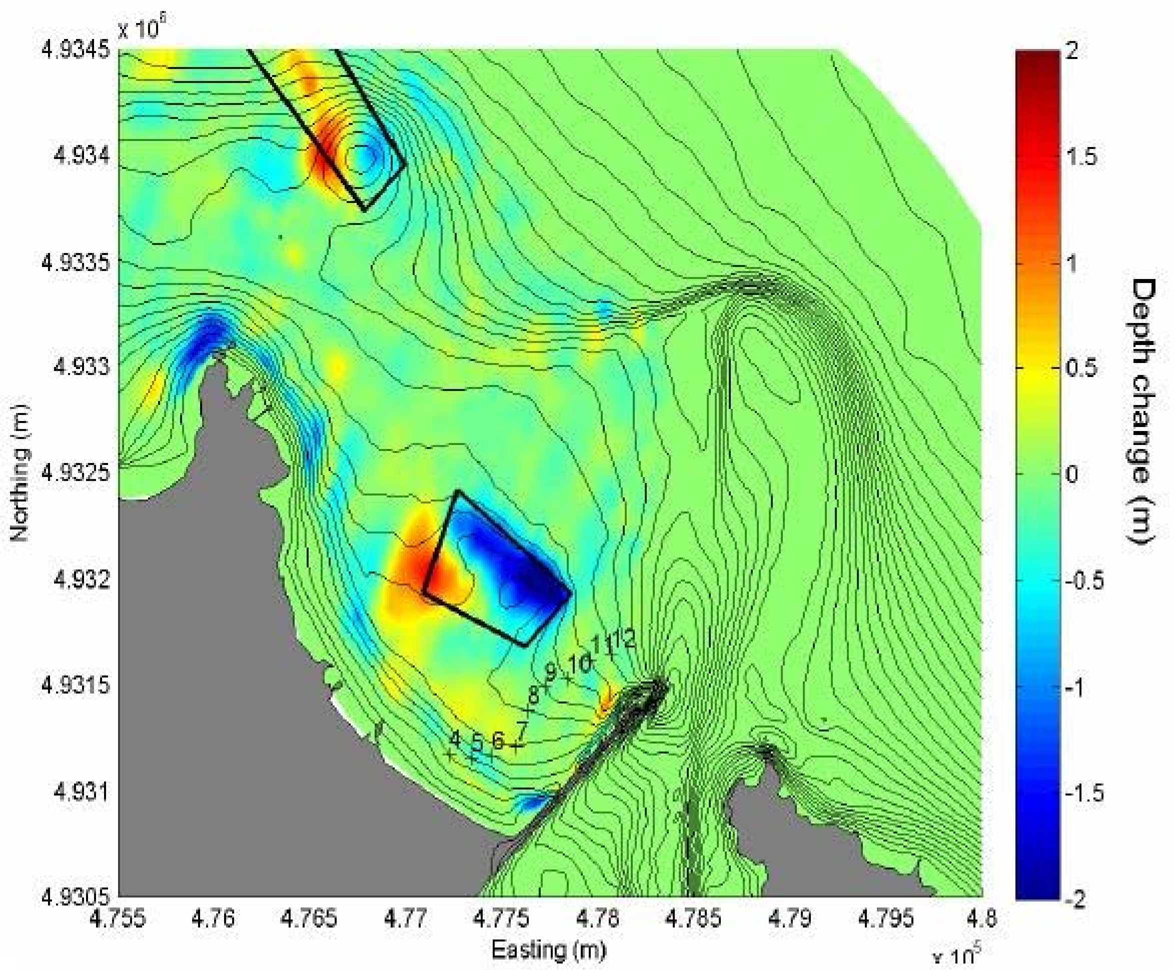

Figure 4: Sea-bed level changes from 2002-09 at Heyward Point (southern end) and Aramoana disposal sites. Determined from 2002 bathymetric contours and historical bathymetric measurements. From Weppe et al. 2011.

2.3.2 Suspended solids

Spoil deposition is generally associated with increased particulate solid matter (generally fine inorganic sediment and fine organic particles) suspended within the water column, which usually sink to the seabed over time (hydrodynamic conditions permitting). Some benthic invertebrates cannot tolerate increased suspended solids because these clog or reduce the efficiency of feeding and/or respiratory functions. Also, suspended sediment inevitably reduces the amount and quality of sunlight penetrating to depth. This may reduce photosynthesis by macro- (benthic) and micro-algae (includes benthic and planktonic algae), reducing their ability to survive and grow, and, in turn, algal biomass available for herbivorous invertebrates and fishes.

2.3.3 Changes to sediment characteristics

The nature of benthic communities and species abundances at any particular site is very strongly correlated with bottom sediment characteristics, notably grain size composition (= texture), which is intimately linked to hydrodynamics or sediment stability (e.g., Rhoads 1974, Gray 1981; Probert 1984). Dredge spoil sediments may differ from those at their deposition sites in two key respects and affect the natural benthos at the disposal site accordingly.

Chemistry: organic content. Another of the primary determinants of soft-bottom benthos composition and structure is its organic carbon content (e.g., Rhoads 1974, Gray 1981; Probert 1984), with more organic carbon corresponding to increased food availability for deposit feeding species (but excessive quantities can be detrimental). Organic carbon is typically associated with and bound to fine sediment particles, so organic carbon in dredge spoil sediments is expected to disperse rapidly at these hydrodynamically active sites.

Spoil sediments (0-3% Loss On Ignition[1] (LOI)(Paavo 2011)) appear slightly higher in organic content natural sediments (0.8-1.5% LOI (Willis et al. 2008)), although we note some uncertainty in comparing the two sets of results. The difference, if real, seems likely to promote benthic community recovery, but even Paavo's (2011) higher values for the disposal sites (3% LOI) appear within the natural range for similar sediments within Blueskin Bay (Willis et al. 2008).

Particle size composition. Sediments across both spoil disposal sites comprise >70% fine sand (125-250 µm)(Willis et al. 2008). Spoil originating from upper Otago Harbour (location of maintenance dredging) comprise fine sand with mud and silts (Single et al. 2010). Finer fractions within the dredge spoil are likely to have minimal ecological effect on the benthos because they appear to be rapidly dispersed by the substantially greater wave energy at the disposal sites.

2.3.4 Bed topography and hydrodynamics

Changes in seabed topography due to spoil dumping and its redistribution changes the overlying hydrodynamics and stability of the seabed itself. Such effects are better understood at larger scales, but do affect the benthos at finer scales, such as within and between sand ripples (e.g., Fenwick 1984, 2002, Paavo et al. 2011).

2.4 Benthic ecology

2.4.1 Previous investigations

Benthos within Blueskin Bay has been extensively surveyed (e.g., Rainer, 1981; Paavo & Probert 2005; Paavo 2007; Willis et al. 2008; Paavo et al. 2011; Fenwick 2013), including in the vicinity of the two maintenance disposal grounds (Figure 3). Details of surveys conducted over 2003 to 2010 are summarised in Table 1.

Sampling for benthos baseline data for the capital dredging spoil disposal (POL 2010) on the large grid to the east (Figure 3) is not directly relevant to this project because both sediments and fauna at these greater depths are different from those at the maintenance dredge spoil sites. Results from previously sampled stations close to the maintenance dredge spoil disposal sites provide insights into some likely impacts and potential ecological indicators at these sites.

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[1] Measuring loss of sample dry weight after combustion at 375-450 °C over 2-16 hours (temperature and duration vary with size and nature of material involved) is a standard technique for determining organic content of sediments, soils and other material.

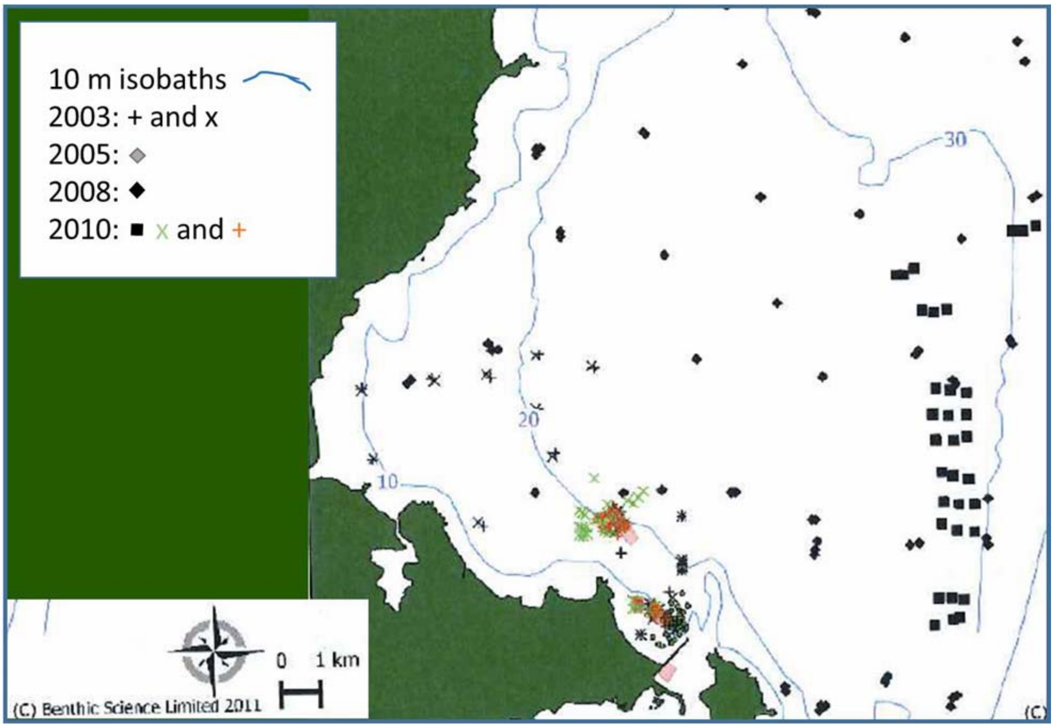

Figure 5: Sites sampled for benthic invertebrates within Blueskin Bay and offshore between 2003 and 2010. Disposal grounds shown in pink. After Paavo (2011).

Table 1: Summary of all benthic surveys (2003 to 2010) associated with dredge spoil disposal within Blueskin Bay. SSS, side-scan sonar. After Paavo (2011).

Year	Sampling stations	Methods	Purpose	References
2003	Transect seaward across Blueskin Bay, In vicinity of the Heyward and Aramoana sites	Grabs	Benthic fauna distribution towards the shore, coarse bathymetry, some meiofauna analysis	Paavo and Probert (2005); Paavo (2007)
2004–2005	Around the Aramoana site	Grabs, SSS	Incremental faunal recolonization rates around Aramoana	Paavo (2007)
2008	Broader coastal environment in a grid formation around sites and in Blueskin Bay beyond the 30 m depth isobath – an area of approximately 160 km^2; no sampling stations near the three sites	Grabs, SSS, video transects and sediment analyses	To provide impact context at the sites against the broader benthic environment.	Willis et al. (2008)
2010	Seaward edge of sandy shelf near 30 m depth isobath	Grabs SSS, dredging and benthic images	To provide impact context at the sites against the benthic infauna in the path of the predominantly northward-moving water masses. SSS used to delineate sand, mud and gravel on the seabed	Paavo (2011)
2010–2011	Around the Heyward and Aramoana sites	Grabs quarterly for one year	To provide high spatial and temporal resolution of infauna assemblages and identify potential indicator species as well as identifying seasonal trends	Paavo 2011

2.4.2 Benthic habitats

Benthic habitats across the two disposal grounds differed in water depth, hydrodynamics and, thus, sediment texture (or particle size composition) and organic content. Previous surveys reported a fine sand wedge extending from about 20 m depth to beyond 40 m depth throughout the study area (Figure 3). Inshore of this wedge, sediments were slightly coarser near the harbour entrance, grading to finer sediments at the centre of Blueskin Bay near the 20 m isobath.

Finer sediments at depths greater than 20 m contained more organic carbon (Willis et al. 2008), consistent with the usual patterns of sediments being finer and containing more organic carbon at greater depths. Sediments throughout this shallower zone lacked any subsurface structure (stratification, layers, changes in colour, etc.) to at least 50 mm below the sediment surface (Paavo 2007).

2.4.3 Benthic fauna

The benthic fauna at the Aramoana and Heyward Point sites is generally representative of the benthos inhabiting the inner Otago Shelf. Some taxa disappear and others appear with decreasing depth and where sediments are de-stabilised by wave action and/or dredge spoil disposal operations (Paavo 2013). For these two sites, Paavo (2013) noted:

- Shallow subtidal regions are dominated by robust mobile species (e.g., the gastropod *Zethalia zelandica* and the worm *Armandia maculata*, although small patches of tubicolous fauna are present).
- Around 15 m depth there is an increase in biogenic features (permanent burrows) associated with shrimp and other large infauna.
- At 20–50 m depth, epifaunal taxa become more common (hermit crabs, sea stars and predatory gastropods).
- Beyond 50 m depth, there is an outer shelf community with spatially discrete bryozoan patches.

Diverse sampling methods were used for the various surveys within the area because each investigation had a different purpose. Most used a grab to sample the benthic infauna quantitatively, making their results generally comparable (although different types of grabs differ in their abilities to sample deeper into the sediment and may collect quite different volumes of sediment relative to the surface area sampled). Paavo (2005, 2007, 2011) supplemented benthic grabs sampling with a diver-operated airlift to excavate the burrows of large, deep-burrowing species (e.g., mantis and ghost shrimps) and a dredge to sample larger, more mobile epibenthos to ensure that all components of the benthos were sampled and identified.

We recommend using one or two methods only, the usual for most monitoring surveys, as a compromise between the benefits of sampling more comprehensively and resource (including cost) constraints.

2.4.4 Available measures of ecological effects

Reports and information provided to NIWA included a useful discussion of the effects of maintenance dredge spoil deposition on the benthos within and adjacent to the disposal sites. We extracted information from Paavo (2011) on several key variables to summarise the nature and magnitude of any effects (Table 2). Note, this information was taken primarily by measuring values from graphs and by assessments of relative importances from values on other graphs. Although they are approximate and may contain errors, they reveal that:

- total benthos mean densities, their variabilities and species richness tended to be lower within deposition grounds compared with outside these areas; and
- there was no obvious pattern in species' relative abundances within either general area (i.e., within or near Heyward Point or within and near the Aramoana ground).

This information also shows the high variability in densities of most benthos species both within and outside the spoil grounds, indicating that replicate sampling is essential to identify any effects at these sites. Information in the table also shows that whole community measures of community/ecosystem condition are likely to provide more useful measures of any effects than might be obtained from abundances of a smaller number of indicator species.

Table 2: Measures of benthic ecosystem condition for two dredge spoil deposition grounds. Mean and interquartile ranges (IQR) for community variables inside boundaries of disposal grounds and outside (only "near field" and "external" sites reported here) measured from graphs; relative abundances for individual taxa extracted from maps. From Paavo (2011).

	Heyward Point ground		Aramoana ground	
Benthos variable	**Outside**	**Inside**	**Outside**	**Inside**
Community measures				
Mean density: Dec	250	100	111	37
Density IQR: Dec	175	88	124	52
Mean density: Sept	110-125	91	94	22
Density IQR: Sept	50-67	58	98	24
Mean richness: Dec	19.5	16.5	14.0	12.5
Richness IQR: Dec	4.1	9.0	7.0	2.5
Mean richness: Sept	21-22	18.5	11.5	8.3
Richness IQR: Sept	3.1-5.1	2.8	5.0	5.0
Individual species relative densities (within ground)				
Antisolarum egenum	3-5	1-4	0	1
Zethalia zelandia	1-3	1-4	1-5	2-3
Nephthyid polychaetes	1-5	1-5	2-4	1-2
Spiophanes spp.	1	1-4	1-4	1-2
Armandia maculata	1-2	2-3	1	1-4
Cirratulidae	1-2	1	1	1
Prionospio spp.	1-2	1-2	1-5	1-2
Tawera spp.	1-5	1-3	1	1
Amphipods	1-5	1-4	1-5	1-5

3 Monitoring benthic ecological condition

3.1 Purpose

This plan for monitoring the ecological condition of benthic communities potentially affected by dredge spoil deposition is based on our understanding that no sampling is required within either spoil ground. Generally, ecological monitoring is required to manage any ecological effects of spoil deposition beyond the disposal ground boundaries, with any ecological impacts within spoil disposal grounds deemed acceptable by the consenting authority.

Communities inhabiting shallow (6–23 m depth) soft sediment bottoms around the disposal sites appear generally similar to those at similar depths elsewhere within Blueskin Bay (e.g., Paavo 2011; Paavo et. al 2011) and, therefore, disturbed sediments within the disposal areas are likely to be re-colonised rapidly after each spoil disposal event. Monitoring within the disposal sites to confirm and track recolonization and to show that communities re-establishing are similar to those naturally occurring in the area, while appealing, seems unnecessary from an adaptive management perspective.

3.2 Indicator species and community indicators of ecosystem condition

The most useful indicator species are ones for which changes in their behaviour, abundance and/or physiology in response to stresses in their environment are well known and correlated with other responses in their ecosystems (Rogers & Greenaway 2005). None of the species present in the vicinity of these disposal sites (Table 3) is sufficiently well-known to be effective indicators of ecosystem condition (and ecosystem response to dredge spoil disposal) on their own.

Table 3: Numerically dominant (percent of total individual invertebrates identified) benthic taxa from Blueskin Bay and the nearby offshore areas. From Paavo (2011).

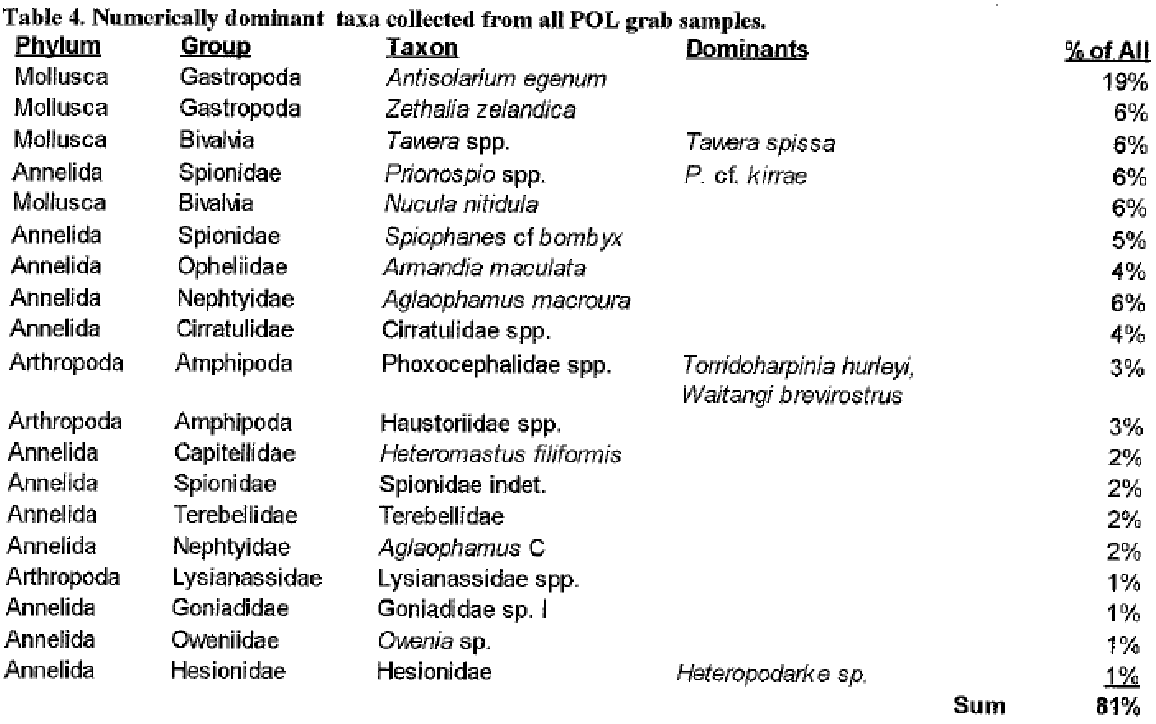

Table 4. Numerically dominant taxa collected from all POL grab samples.

Phylum	Group	Taxon	Dominants	% of All
Mollusca	Gastropoda	*Antisolarium egenum*		19%
Mollusca	Gastropoda	*Zethalia zelandica*		6%
Mollusca	Bivalvia	*Tawera* spp.	*Tawera spissa*	6%
Annelida	Spionidae	*Prionospio* spp.	*P.* cf. *kirrae*	6%
Mollusca	Bivalvia	*Nucula nitidula*		6%
Annelida	Spionidae	*Spiophanes cf bombyx*		5%
Annelida	Opheliidae	*Armandia maculata*		4%
Annelida	Nephtyidae	*Aglaophamus macroura*		6%
Annelida	Cirratulidae	Cirratulidae spp.		4%
Arthropoda	Amphipoda	Phoxocephalidae spp.	*Torridoharpinia hurleyi,* *Waitangi brevirostrus*	3%
Arthropoda	Amphipoda	Haustoriidae spp.		3%
Annelida	Capitellidae	*Heteromastus filiformis*		2%
Annelida	Spionidae	Spionidae indet.		2%
Annelida	Terebellidae	Terebellidae		2%
Annelida	Nephtyidae	*Aglaophamus* C		2%
Arthropoda	Lysianassidae	Lysianassidae spp.		1%
Annelida	Goniadidae	Goniadidae sp. I		1%
Annelida	Oweniidae	*Owenia* sp.		1%
Annelida	Hesionidae	Hesionidae	*Heteropodarke sp.*	1%
			Sum	**81%**

We also note that species abundances and community composition change over short distances (depths) in the vicinity of these disposal grounds (Paavo, 2011; Paavo et al. 2011), typical of changes observed on other high energy shores (e.g., Knox & Fenwick 1981; Fenwick 1999). This means that, even if sufficiently well-known species were available to serve as meaningful indicators, multiple indicator species would probably be required for each site, cancelling many of the potential cost advantages associated with simply monitoring a smaller number of indicator species.

Thus, rather than relying on a suite of untested indicator species, we recommend monitoring total benthos composition, with particular attention to species with abundances differing between control and impact sites (and that may prove to be effective indicator species with further monitoring). Monitoring total benthos is now generally regarded as the best way to test for ecological effects because species tend to differ in their responses to stresses, such as dredge spoil deposition (Somerfield et al. 1995; Rogers & Greenaway 2005).

At a practical level, quantifying smaller invertebrate indicator species from benthos involves much of the manual work required for full benthic community analysis, so that the small additional cost of obtaining a considerably richer understanding of full community response to stress (ANZECC & ARMCANZ 2000; Hewitt et al. 2005; Rogers & Greenaway 2005) seems very worthwhile. Also, the relatively low community richness/diversity across this depth range within Blueskin Bay (Paavo 2011; Paavo et al. 2011) further simplifies analysis of the total macrofauna.

The usual approach with such community level monitoring includes tracking the status of species that are widespread, abundant, and ecologically important or some combination of these. The more detailed information from tracking these incipient indicators frequently helps to explain differences and changes in the benthos overall, and in assessing the ecological significance and identifying likely causes of any observed community-level changes. At least five of the species present in Blueskin Bay should be thus tracked as potential indicator species, in addition to monitoring total benthos composition:

- *Zethalia zelandica* (gastropod snail) (Aramoana, Heyward Point; 5–20+ m depth; probably deeper parts at Shelly Beach) is reasonably well known, common in Blueskin Bay and in the general area of both deposition sites. It was most abundant in shallower (<20 m depth) waters. It also survives burial better than many other species (Paavo 2007).

- *Nucula nitidula* (small bivalve gastropod) (Heyward Point, mostly deeper than 15 m; can survive burial by up to 50 cm of sediment (Paavo 2007).

- *Antisolarium egenum* (gastropod snail) (Heyward Point, rare at Aramoana; mostly >15–30 m depth) is less well known than *Z. zelandica*. It was the most abundant species on inshore bottoms (Paavo 2011).

- *Aglaophamus macroura* (polychaete worm) (Aramoana, Heyward Point; 5–30+ m depth) is reasonably well known, common in Blueskin Bay and its habitat coincides with the deposition sites. Its distribution in Blueskin Bay was similar to that of the gastropod *A. egenum* (Paavo 2011).

- *Armandia maculata* (polychaete worm,) (Aramoana, Heyward Point; 5–20 m depth) appears to be an inshore species, at least in Blueskin Bay (Paavo 2011) that was equally abundant across Heyward Point and Aramoana deposition sites. Its distribution and abundance appears very similar to that of *Prionospio* spp., so that either or both could serve as useful indicator species.

Changes in benthic community composition (and indicator species status) due to human impacts, spoil deposition, in this case, are usually explored using various well established measures and numerical methods (e.g., Hewitt et al. 2005). Measures of biodiversity or species richness and community abundance are frequently identified as the more important and useful ecological indicators, notably because of widely established links between human impacts and biodiversity (e.g., ANZECC & ARMCANZ 2000; Hewitt et al. 2005; Whomersley et al. 2008). Other measures may also prove effective indicators of spoil deposition effects, but the cause-effect relationships seem less direct.

The most commonly used measures of community composition are:

- Total benthos abundance.
- Total benthos richness or diversity.
- Species diversity (Shannon-Weiner diversity, H') evenness (Pielou's evenness, J').

Comparisons with control or unimpacted situations using readily available, standardised multivariate routines enables statistical evaluation of differences in these measures and individual species abundances associated with the human activity, in this case, dredge spoil deposition. Statistical tests (t-tests, analyses of variance, etc.), as well as a suite of multivariate analyses (notably the PRIMER programmes package), provide powerful tools (e.g., Somerfield et al. 1995; Wilber & Clarke 2007) that should be used for comparing the benthos at control and impact sites.

3.3 Detecting ecologically significant effects

Trigger or threshold values for potentially harmful environmental variables (e.g., suspended sediment, changed sediment texture, etc.) or for indicators of impending ecological decline are conceptually appealing for managing potential adverse environmental effects. Following an adaptive management approach, trigger levels for key variables (physical, chemical or biological) are agreed (usually involving operational, scientific and stakeholder input) in advance (ANZECC & ARMCANZ 2000; also see the Limits of Acceptable Change literature, e.g., Cole & Stankey 1998). When a trigger level is reached during operations, some agreed action is taken. This may involve representatives from all interested parties reviewing the situation and deciding on actions (including taking no action) to implement.

Such trigger values are best determined following substantial background validation, and these have been developed for several potentially harmful toxicants based on detailed laboratory toxicology tests with a small number of species. There are few or no equivalent values for the effects of dredge spoil deposition (or similar sediment inundation) for individual species, and none for the communities and locations involved here because, as noted above, natural biological communities, including shallow marine benthos, tend to vary substantially in quantitative composition over diverse spatial scales. Thus, initial trigger levels tend to be set largely arbitrarily (Wilber & Clarke 2007) and refined as each monitoring programme develops (ANZECC & ARMCANZ 2000).

Multivariate approaches, notably PRIMER and its ANOSIM routine, facilitate powerful comparisons of faunas and environmental conditions between sites and determine their statistical significance. We note that differences determined to be statistically significant are not necessarily ecologically significant, nor causally related to the human activity being monitored. However, the detection of any statistically significant differences of spoil ground benthos, either from control sites at the same sampling time, or from the same site at previous sampling times, should prompt more detailed analysis of available data to better understand the nature, magnitude and spatial extent of associated changes, and, hence, their likely ecological significance, to support management decisions.

Based on the information available and following similar monitoring plans (e.g., Turner & Felsing 2005), we recommend using variance-based statistics of community composition as preliminary trigger points. Using a significant body of prior monitoring data and information, Turner & Felsing (2005) developed a probability distribution of the absolute differences between control-impact pairs of samples on each selected benthos variable, and set trigger levels at the 0.25 and 0.05 probabilities (i.e., 1 in 4 and 1 in 20 that differences are due to chance alone)(i.e., at 75th and 95th percentiles). They noted that these trigger points were specific to their area and designated methodology, and that these triggers did not signify any ecological significance, but served as alerts to potential or emerging change that should be investigated further.

We recommend adopting 0.2 (1 in 5 chance that two values differ by chance alone)(not 0.05) as the probability for determining whether differences between control and impact on a given variable should trigger further investigation. This 0.2 trigger probability level (TPL) equates to differences between mean values of ±1.3 standard deviations (see Table 4 for indicative example). This TPL should serve as an interim level only. More ecologically meaningful trigger levels can probably be determined by analysing the data reported by Paavo (2011) along with results of the first monitoring survey.

The initial response to any exceedance of any of these interim TPLs should be an immediate review of available information, including all monitoring data for all sites and spoil disposal data, by experienced scientists. Ideally, Port Otago Ltd will work with its dredging disposal working party, which includes the consenting authority, to review the further analysis and agree actions (including an implementation plan).

Table 4: Example calculation of preliminary trigger probability level (TPL) for one benthos variable for a dredge spoil disposal site. Data are fictitious; result shows impact site density is outside acceptable level range, indicating need for further investigation; SD, sample standard deviation. Note: In this example, Student’s t-test is significant at both the conventional 0.05 probability and the 0.2 probability proposed as the interim trigger level.

	Replicate	Control	Impact
Total faunal density	1	250	140
	2	323	185
	3	196	206
	4	343	155
	5	398	210
	Mean	302	**179.2**
	SD	79.5	30.9
Upper trigger	Mean + (1.3 x SD)	405.3	
Lower trigger	Mean – (1.3 x SD)	**198.7**	
Student’s t-test (2-tailed)	t = 3.09	dfs = 4	p = 0.022

3.4 Sampling requirements

3.4.1 Control-impact design

We recommend a control-impact sampling design for monitoring for any potential ecological effects outside these disposal grounds, because the long history of spoil deposition at these sites renders a before-after sampling design inappropriate. Also, the reported seasonal differences (Table 2) and likely inter-year variability in benthos demand this design in order to minimise the confounding effects of these extraneous factors.

A control-impact design involves sampling near each deposition ground (impact site) and at an adjacent, but unimpacted (by dredge spoil deposition), control location on each sampling occasion. Data on benthos at the control location will be compared with data on benthos at the impact site for any differences exceeding the trigger level and that may be attributable to the deposition activities. Comparisons with data from previous samplings also should be undertaken to identify any obvious changes or emerging trends.

Based on previous work in Blueskin Bay, we suggest that impact sites should be located 30-60 m outside the boundaries of their respective disposal grounds. Each control site should be located at least 200 m from any disposal ground, and must be similar in depth and hydrodynamics to its respective disposal ground and associated impact site. Two control and two impact sites are recommended for the Heyward Point ground because its spans c. 9-21 m depth. We note that because of the complex bathymetry at the Heyward Point site and the complicated hydrodynamics at Aramoana, in particular, determining the optimal locations for control sites is challenging. For these reasons, the control sites proposed here may be subject to review as more information becomes available.

3.4.2 Replication

Because benthic communities vary naturally, even at the same depth, meaningful comparisons require replicate sampling to quantify biological variability under each set of conditions. That is, sufficient replicate samples of an adequate size are necessary to provide the statistical power required to detect meaningful effects.

Various theoretical approaches to determining numbers of replicates are available (e.g., Vezina 1988), but practical matters frequently dictate using some rules of thumb, based on experience with the specific benthic communities to be monitored. Our experience indicates 3–5 replicate samples, ideally each of c. 0.1 m^2 of seafloor, penetrating to at least 10 cm into the sediments (benthos retained on 0.5 mm mesh) is appropriate for these environments and benthic communities. Three replicates are often sufficient beyond c. 20 m depth where communities appear more uniform, whereas five for each set of conditions (i.e., five within each impact site, five within each control area) seems warranted for statistically robust monitoring in these shallower waters.

3.5 Physical and chemical monitoring

An effective long-term adaptive management plan for POL's two inshore dredge spoil disposal grounds should include monitoring key physical and chemical factors (i.e., sediment texture and organic carbon), in addition to ecological monitoring. These attributes should be monitored because they are usually very important drivers of benthos composition and may be manageable via operations.

We recommend monitoring the sediment subsurface structure to at least 10 cm below the sediment surface, and the particle size composition and organic content of the upper 5 cm of bottom sediments at each sampling site during each sampling event.

Results from these analyses should be analysed and reported along with the ecological monitoring data. In addition, we recommend bathymetric mapping of each site and of any detectable sediment deposits beyond the disposal site boundaries at least annually (we understand that this is completed biennially as part of Port Otago Ltd’s disposal consent condition requirements).

4 Draft ecological monitoring programme

4.1 Purpose

Monitoring of any ecological effects associated with deposition of dredge spoil at two inshore grounds within Blueskin Bay is required for consent compliance and to support adaptive management of any effects. The grounds have received dredge spoil for several years, so impact sites must be compared with control sites. These control sites must be selected carefully because of steep environmental gradients across shallow depths on this coastline.

4.2 Plan[2]

Quantitative sampling of the benthos is required to obtain statistically robust data on soft bottom benthic infaunal community composition adjacent to each disposal site and at control sites.

4.2.1 Sampling

- Sample and compare benthic infauna adjacent to Aramoana and Heyward Point spoil grounds and at one suitable (i.e., very similar depths and hydrodynamic environments) control site for each ground.
- All sampling stations within each set of stations must be taken at the same depth (±1 m depth) corrected to mean sea level, because depth (and associated factors) strongly influences benthic fauna composition and abundance.
- Sampling sites[3] for each spoil disposal ground should be located at or close to the following points:
    - Aramoana impact site: 30-50 m northwest from about the disposal ground's north western boundary and at 7-8 m depth (below mean sea level).
    - Aramoana control site: c. 200-300 m south of the ground's south eastern boundary at 7-8 m depth (mean sea level).
    - Heyward Point impact sites (2): 30-50 m north to northwest from the disposal ground's north western boundary (a) at 13-14 m depth (mean sea level), and (b) at 19-20 m depth (below mean sea level).
    - Heyward Point control sites (2) c. 200 m south to southeast of the disposal ground's south-eastern boundary at (a) 13-14 m depth (below mean sea level), and (b) at 19-20 m depth (below mean sea level).
- Far control stations off Pilot Point or Whareakeake (Murdering Beach) at 7-8, 13-14 and 19-20 m depth (below mean sea level) should also be sampled to control for any far-field effects (Fenwick & Stenton-Dozey 2015).
- Five replicate samples are required at each sampling site, with individual samples sufficiently large in area (c. 0.02 m^2) and depth (≥10 cm below sediment surface) to adequately quantify the invertebrate infaunal communities. All invertebrates retained on 0.5 mm mesh should be identified and counted for each sample.

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[2] Specifications presented here focus primarily on requirements for robust monitoring, based on our understanding that independent tenderers are likely to recommend different ways of implementing this plan.

[3] Impact sites are located down-current and control sites up-current of their respective disposal grounds, based on residual current directions provided by MetOcean Solutions Ltd (see Figure 4). Sampling locations proposed accommodate both present and proposed future disposal ground boundaries.

- Control and impact sampling must collect, and sample processing must distinguish (identify as far as practical, at least to family for most taxa) the majority of species, including rarer species[4], inhabiting the area. It is probably impractical to sample and quantify some larger, deep-burrowing species (e.g., callianassid and stomatopod crustaceans) for this monitoring.
- A separate sample of the upper 5 cm of undisturbed bottom sediments should be taken from at least two samples at each impact site and at each control site at the same times that ecological monitoring sampling occurs. These samples should be analysed separately to determine sediment particle size compositions and sediment organic contents at each site. Any sediment depth stratification and other sediment structure (e.g., any redox discontinuity layers, etc.) should be recorded for at least one sample at each sediment sampling site.
- All repeat sampling should occur at the same set of sites and use the same methods to minimize variability due to sampling error between sampling events. Repeat sampling should occur within the same six week period in sampling years to minimise the effects of any seasonal changes in benthos.
- Epibenthos should not be sampled because of the substantial sampling effort required for meaningful, quantitative comparison (Fenwick & Stenton-Dozey 2015).
- Because both disposal grounds receive spoil essentially continuously, sampling should occur biennially (every two years) for at least the first six years. Thereafter, the frequency of sampling events should be reviewed based on results of the previous surveys.

4.2.2 Reporting

- A report on the initial sampling should be delivered within three months[5] of completing the sampling. This must include delivering to Port Otago Ltd an electronic copy of the survey data.
- This report should include a detailed analysis of the sedimentary environment at each sampling site. Results of each survey should be compared with those from previous surveys to detect and quantify any recent changes and/or emerging trends or other patterns.
- A comprehensive analysis of the community composition and its variation across all sampling sites is required. Abundances of the more common, widespread and ecologically significant species within and between sites must be detailed (these include the potential indicator species *Zethalia zelandica, Nucula nitidula, Antisolarium egenum, Aglaophamus macroura, Armandia maculata, Prionospio* spp.). Details of any ecologically important or threatened species should be included.
- The report should integrate information on the sediments, spoil disposal, community composition, trigger variables and trigger levels. Results from successive surveys should be compared to understand any recent changes, emerging trends or other patterns.

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[4] The proposed sample size and number of replicates should ensure that most species will be sampled to provide a reasonably reliable measure of species richness, a key monitoring variable. Density estimates for rarer species are likely to be considerably less reliable, simply because they are encountered and measured less frequently.

[5] Although more immediate reporting is preferable, the significant post-sampling labour content with such surveys usually takes 8–12 weeks to complete.

- In the event that any TPL is reached (difference statistically significant at 0.2 probability) or exceeded and/or other evidence of ecologically significant change is detected, Port Otago Ltd must be informed immediately to initiate the adaptive management process, including discussions with the Working Party.
- The report should recommend any measures identified for improving the sampling design for subsequent impact surveys, identify any specific indicators and suggest changes to variables monitored and trigger levels.
- Based on the spatial extent and severity of any effects observed during samplings, the report should evaluate the timing for future sampling.
- It should also provide any recommendations for minimising future effects of spoil deposition on the Blueskin Bay marine environment, if relevant.

5 Adaptive management

Adaptive management approaches are increasingly common and a very effective means of minimising environmental harm from human activities with uncertain effects on the environment and associated values (Plummer 2009, Williams & Brown 2012). Involving stakeholders in the adaptive management process increases the effectiveness of this approach because it accommodates different perspectives, ensuring that any effects are managed to minimise compromising those values considered most important by the stakeholders involved. For these reasons, we recommend using such an approach here through the existing Working Party (which is required as a condition of resource consent RM11.153).

5.1 Adaptive management process

The adaptive management process is conceptually simple and helps to develop optimal outcomes in situations where ecological effects are largely unknown in advance and where the consequences of operational activities also are largely unpredictable. The process (Figure 6) involves assessing and defining the operational problem (maintaining ecological values in the area while using these sites for spoil deposition), designing a management approach to achieve the objectives, implementing that approach, monitoring the significant values of interest (or surrogates of them; i.e., the benthic fauna), evaluating the status of these values based on monitoring results, adjusting the operational activities and/or monitoring approach, re-evaluating the operational problem and objectives, re-designing the approach (if necessary), etc.

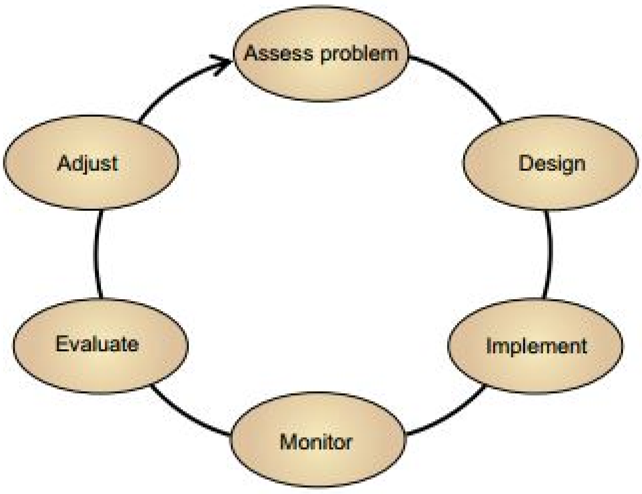

Figure 6: Overview of the adaptive management process. From Williams et al. 2009: Fig. 1.1.

For deposition of dredge spoil on the Heyward Point and Aramoana spoil grounds, some definition of the objectives is required as a first step. We understand that protecting the ecological values of these locations will be central to these objectives and that stakeholders (Port Otago representatives, and its Working Party) will work collaboratively within this process.

As discussed above (section 3.3), we recommend adopting 0.2 (not 0.05) as the probability for determining whether differences between control and impact on a given variable should trigger further investigation. This 0.2 TPL equates to differences in mean values for a monitored variable between control and impact sites of ±1.3 standard deviations, with, on average, one chance in five that two values differ by chance alone (see Table 4 for indicative example).

It is useful to illustrate this adaptive management process further (Figure 7) for the proposed monitoring and POL's likely processes by extending the fictitious example illustrated in Table 4. There, the data analysis phase of monitoring revealed that the difference between total benthos densities at a control site and its associated impact sites exceeded the statistical trigger probability of 0.2. The likely next steps will involve the scientists involved advising POL of this finding and presenting with the key evidence (before the full monitoring report is completed). Following its adaptive management approach, POL will do two things (Figure 7). First, it will discuss the findings with the scientists and agree any further urgent analyses required to support the next step. Second, it will convene the Working Party to review the anomalous monitoring finding along with results of the urgent analyses prepared under the previous step (i.e., the Evaluate step in the adaptive management process in Figure 6).

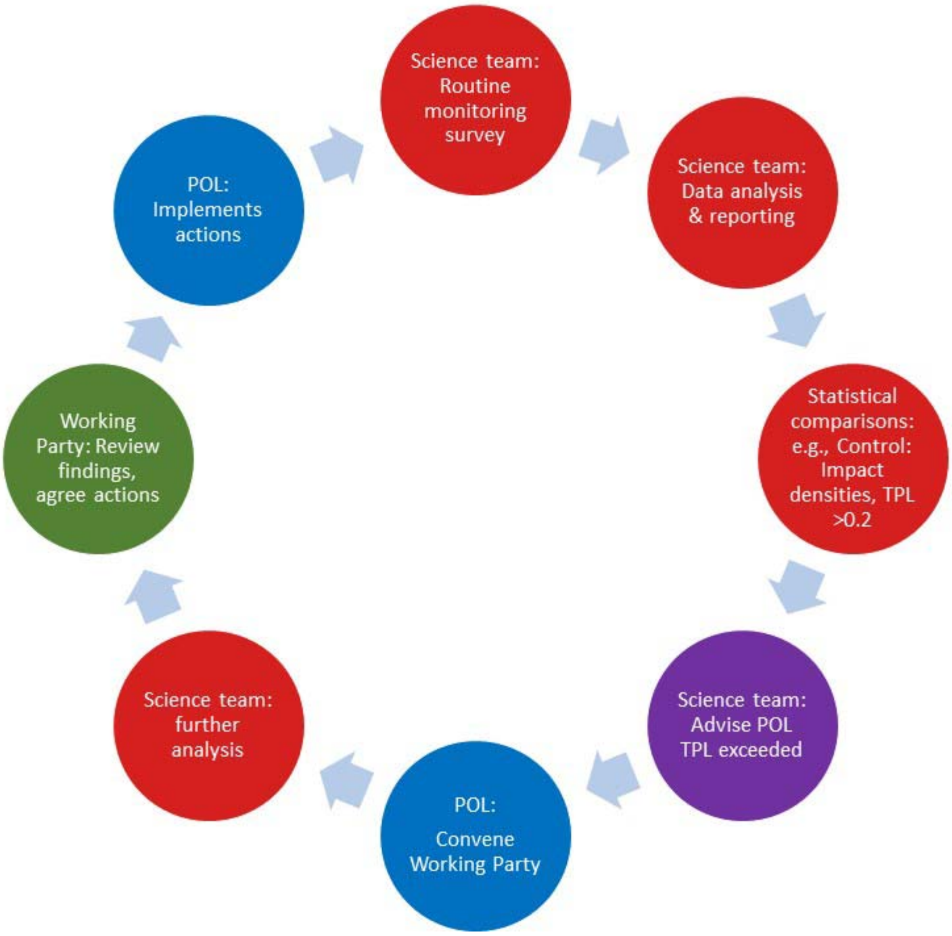

Figure 7: Adaptive management process example for maintenance dredge spoil grounds. Example continues Table 4: trigger probability level exceeded for statistical comparison of control site vs impact site total benthos densities. Red steps, involve only the science team; purple, scientists and POL; blue, POL; green, Working Party.

When convened to evaluate monitoring results, whether routine or unexpected, the Working Party should evaluate all available monitoring results and information, not just those for any monitoring variable that exceeded its TPL. The group's evaluation process may require further background work and additional discussions to determine the implications of any exceedances of a TPL and to determine the most appropriate actions. Once actions are agreed, POL will implement those actions and initiate an agreed supplementary monitoring regime to evaluate the consequences of the remedial action, thus continuing the cyclic adaptive management process summarised in Figure 6 and Figure 7.

5.2 Potential adaptive management actions

One of the central elements to adaptive management is the uncertainty associated with outcomes from the human activities and from operational modifications of these. The implement-monitor-evaluate steps are fundamental to all stakeholders' understanding how the values or ecological processes respond to operational adjustments, and this learning about operational adjustment-ecological response via monitoring will suggest further, perhaps novel, operational adjustments (or management actions).

Thus, it is usually very difficult to identify in advance the ecological responses likely and the potential management actions that may be appropriate or sought by the stakeholders as the adaptive management process proceeds. Certainly, there are no readily available prescriptions because every ecological situation is unique, not least because the species and communities involved differ markedly between locations and environments. Similarly, stakeholders differ in their perspectives, priorities and values. For these reasons, only broader, more generic actions can be identified at this stage in the process.

At a very superficial level, potential management actions might include:

- Do nothing.
- Revise objectives.
- Continue operations while gathering some more specific information.
- Continue operations, but monitor more closely.
- Continue operations and adjust monitoring programme.
- Temporarily modify disposal operations (e.g., discharge spoil over longer time period while steaming at x knots).
- Temporarily relocate spoil deposition while gathering some more specific information.
- Temporarily or permanently reduce rate of spoil discharge at one of both grounds (may require development of a new ground).
- Discontinue using one spoil ground (may require development of a new ground).

Determining just what actions are optimal in any situation will require close attention to the project's objectives and stakeholders' views on values and their priorities. Compromise is inevitable, so a key part of the process is ensuring that the project's agreed objectives are clear, kept in focus and revised as appropriate.

6 Conclusion

The several previous surveys of benthos within Blueskin Bay provided an effective basis for designing this ecological monitoring plan for Port Otago Ltd to adaptively manage inshore dredge spoil deposition. Those studies revealed that sediments deposited on the two grounds are very similar to those that naturally arrive at the spoil grounds; carried by the bay's counter-clockwise residual current flows, they bypass the spoil grounds, enter the harbour, are dredged, then are re-deposited as spoil on the spoil grounds. Thus, they are very similar in particle size composition and readily mix with natural sediments at each site.

The spoil grounds span shallow habitats along a marked hydrodynamic gradient so that, although their sediment particle compositions are very similar, the fauna at each ground is differentially adapted to the effects of wave action. From a monitoring perspective, this means that separate control sites are required for each disposal ground. This difference in community composition and structure at each site also complicates sole reliance on the use of indicator species.

For these reasons, we recommend a statistically robust sampling design to monitor the total community at each disposal ground via comparison with an appropriate (same depth, same sediment composition, same seaward bathymetry) control site for each ground. We recommend using community variables for monitoring ecosystem condition, with variance-based trigger levels for initial use.

Monitoring is not an end in itself, but an input to adaptively managing the problem of dredge spoil disposal. Thus, it is important to ensure a clear process is followed to achieve the best management of disposal for all stakeholders.

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