Blueskin Bay inshore dredged sediment deposition

assessment of ecological effects

Prepared for Port Otago Ltd

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Executive summary

A detailed review of marine benthos associated with two dredged sediment deposition sites (Aramoana and Heyward Point) close to shore in Blueskin Bay was undertaken to support Port Otago Ltd's application to renew both consents and for expanding both grounds to facilitate more effective adaptive management of effects. This assessment of ecological effects reviews specialist consulting reports, published scientific papers and other available information to understand the Blueskin Bay hydrodynamic and sedimentary environment, its ecological values, any potential and actual ecological effects of dredgeate deposition, and monitoring and other measures to manage any adverse effects.

The Aramoana ground covers gently sloping fine sand seabed over 8-12 m depth. The Heyward Point ground straddles 15-24 m depth, with historical deposition creating a seaward bulge of the sloping seabed at this point over 12-18 m depth, with the bottom comprising well-sorted fine sand at shallower depths and a small mud component increasing with depth (Paavo 2007). Both deposition grounds are hydrodynamically very active due to a south-flowing eddy of the Southland current, exposure to waves from two predominant wind direction (NE and SE), and wave refraction and focussing due to sand bars off Otago Harbour mouth. As a result of both bathymetry and hydrodynamics, sediment transport rates vary across each ground from low to high.

Detailed modelling of deposition footprints of the suspended sediment component from single dredge loads indicated a negligible footprint for fine sand, and a much larger footprint for silt dredgeate that increases in area with water depth. These results also showed that the deposition footprint for suspended sediment resulting from the smaller dredge (New Era) was much lighter and smaller than that from the larger dredge (trailer suction hopper dredge). Most (>90%) dredged sediment released falls directly to the seabed and a load from New Era at Aramoana formed a c. 60 m wide deposit. Muddy dredgeate dispersed very quickly to resemble pre-deposition sediment particle size composition after 26 days.

Dredged sediment deposition may disrupt the natural, dynamic equilibrium within inshore benthos through variously survivable burial and suspended sediment effects. These effects are minimised by ensuring that each site receives dredged material that is similar to its natural bottom sediments, and by the hydrodynamically active environments at these grounds. Effects on kelp beds around Blueskin Bay are unlikely, unless operational changes alter the nature and sediment loads within dredge passive plumes.

Blueskin Bay soft-bottom, benthic biodiversity is well studied, comprising >265 species, most of which are widely distributed within the bay and elsewhere around New Zealand. There was no evidence of any species restricted to this area, or any soft-bottom communities of special biodiversity value. There was no evidence that the placement grounds (and adjacent soft bottoms) comprise any regionally or nationally significant habitat.

Actual effects of dredgeate deposition on soft bottom benthos within these grounds varied and apparently did not extend beyond the immediate deposition area. Dredged sediment deposition appears to reduce benthos densities and diversities at both grounds, but there was considerable variability in these measures, both for benthos within and outside the grounds. This variability was evident in the poor discrimination between ground and control stations for both grounds in multivariate analyses and graphical representations of faunal similarities. A large field experiment at Aramoana resolved continual change in benthos over time, regardless of exposure to dredged

sediments, and reduced densities and diversities following dredgeate deposition. Benthos recovery was well advanced within 12 days of deposition.

Based on the available information summarised here, placement at Aramoana of up to 100,000 m^3/year (averaged over any five-year period; present consented volume 50,000 m^3/year) and at Heyward Point of up to 300,000 m^3/year (averaged over any five-year period; present consented volume 350,000 m^3/year) within each of these grounds is considered unlikely to have any significant adverse ecological effects on the soft bottom benthic ecosystem beyond the ground boundaries. The potential for adverse ecological effects will be significantly reduced by enlarging the existing Heywood Point ground to c. 2.25 km^2 and disposing of dredged sediments across this enlarged ground (equivalent to deposition of an average of 3 mm layer/week over the entire ground), with deposition stratified by depth according to sediment types. Potential adverse effects on kelp forests around Blueskin Bay due to increased suspended sediment from continued use of these deposition grounds is unlikely unless operational changes alter suspended sediment plumes.

We recommend using a smaller dredge (i.e., New Era) because its smaller passive plume and depositional footprint poses a much lower risk to marine benthic ecosystems than do those modelled for the proposed, larger trailer suction hopper dredge.

An adaptive management approach is recommended to ensure that unforeseen effects are identified, prioritised and resolved early via a collaborative process involving relevant stakeholders. Periodic monitoring of benthic infaunal community composition and structure following a consistent plan is required as a key part of this process. Monitoring of kelp forests and rocky reef benthos around Blueskin Bay seems unwarranted unless sediment plumes generated during dredging operations increased.

1 Background

Port Otago Ltd's (POL) resource consent (RM11.153) to deposit dredged sediment (also termed dredgeate) at three shallow sites within Blueskin Bay at Shelly Beach, Heyward Point and Aramoana Spit (= Spit Beach) requires renewal by 18 December 2016. This report presents the ecological component for an assessment of environmental effects (AEE) to support an application for long-term dredged sediment placement[1] at these grounds beyond the present consent's term.

Future placement at these sites will comprise predominantly maintenance dredged sediment, plus small volumes of dredged sediment from the capital works as these works proceed. Consent for placement over a larger area at Heyward Point is sought to better manage the previously consented volumes of maintenance dredged sediment, including reducing any adverse effects on the benthos within the present, smaller deposition ground.

POL has developed a plan for and commenced monitoring the ecological health of the benthos associated with the two main placement grounds (Heyward Point and Aramoana) (a condition of its present inshore dredge material disposal consent). This monitoring encompasses the proposed enlarged Heyward Point ground and the Aramoana ground.

1.1 Approach

NIWA's approach for this AEE is a review of relevant, available information on the local environment, its biodiversity and benthic ecosystem, as well as considering relevant information on likely effects from investigations elsewhere. Results of proposed direct monitoring of the benthos at the three sites will be incorporated as it becomes available. Detailed investigations of hydrodynamics and sediment dynamics in these areas are also used in developing our assessment. These are summarised within this report because they are important drivers of benthos composition and the spatial extent of any effects of disposal activities at these three disposal grounds.

The following review:

- summarises the general hydrodynamic and sedimentary environment of Blueskin Bay,
- identifies all known ecological values for the benthos within and adjacent to the disposal sites,
- assesses the suitability of the sites for disposal activities,
- identifies and assesses actual and potential ecological effects of dredgeate on the benthos, and
- considers monitoring and/or other measures that may ameliorate any adverse effects.

1.2 Dredged sediment placement history and proposal

Dredging to maintain navigable depths within Otago Harbour commenced in the 1860's, with the port's first dredge built in 1868 (Davis 2009), and maintenance dredging continues today. Silty sediments dredged from the upper harbour for maintenance purposes apparently originate mostly (75%) from rural run-off from grazing lands and 23% from storm-water, with c. 2% (mostly in the

[1] The term placement (= deposition, dumping, disposal) is used here to reflect the expected benefits, in terms of beach nourishment and shore dynamics (e.g., surf characteristics), resulting from well managed deposition of dredged sediments.

lower harbour) originating from coastal processes (Avery 1991, reported in Paavo 2007). Over the harbour's life, some 7 million m^3 of dredge material went to the Heyward Point site (Davis 2009). Reported annual "dredging volumes disposed from Otago Harbour" have generally decreased from a maximum of 360,000 in 1988, to less than 150,000 m^3 annually, on average, until 2011, with greater quantities deposited at Heyward Point in 2012 and 2014 (Figure 1-1). An estimated 44% of the dredgeate deposited at these grounds persists within them as sand mounds (POL 2010) as seen in Figure 1-2 and Figure 2-1.

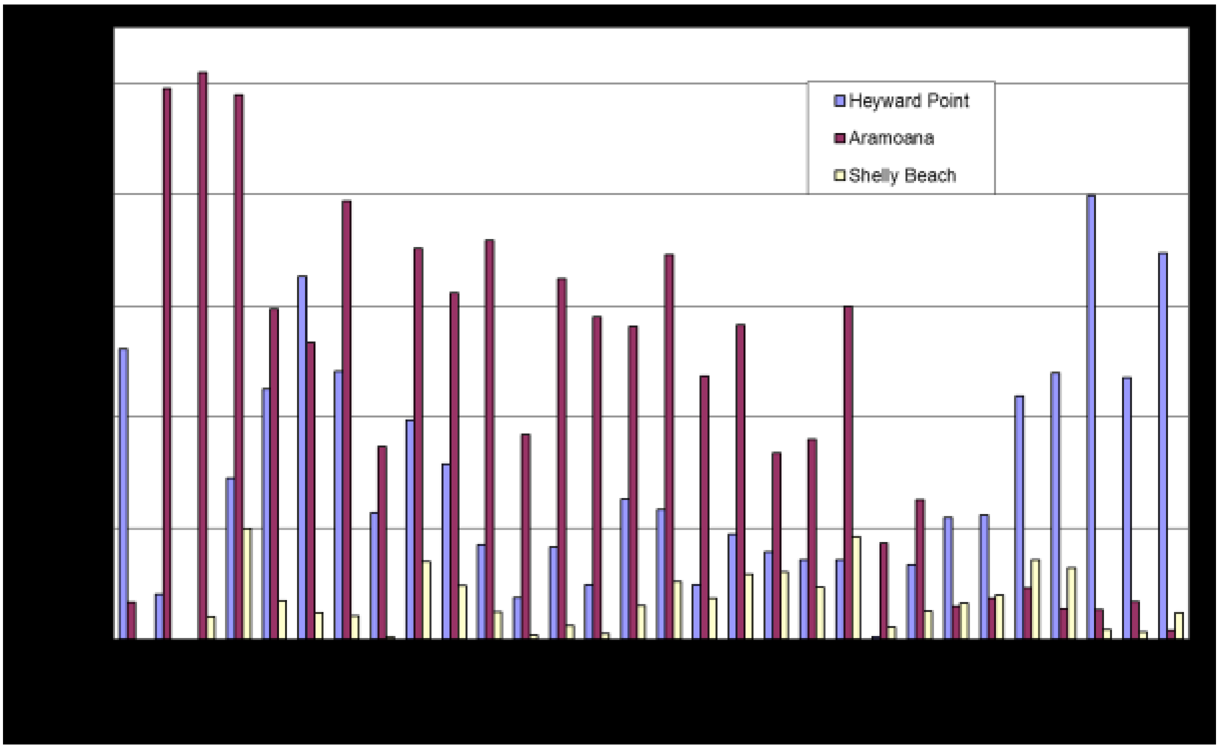

Figure 1-1: Dredged sediment deposition at each of the three inshore grounds over 1985-2014. From: POL (2014) deposition records.

All dredged material (capital and maintenance) went to the Heyward Point ground before 1985 (POL 2010). It received 3.2 million m^3 from capital works in 1977, after which this deposition ground was relocated, some 600 m northeast into deeper water (Paavo 2007). Up to 350,000 m^3 of sand and mud is now deposited at this 11-24 m deep site annually, with no more than 200,000 m^3 per year deposited in water shallower than 18 m depth. Dredgeate was spread between all three grounds since 1987 (Figure 1-1), with placement continuing at one ground for several consecutive days before commencing at another ground (Paavo 2007). During 2002-2005, c. 65% of all dredgeate was deposited at Aramoana, 23% went to the Heyward Point ground and the balance (c. 12%) was placed at Shelly Beach ground (Paavo 2007).

The Aramoana ground received dredged sediment from 1985 onwards. Slightly closer to the harbour entrance and spanning 9-12 m depth, this gently sloping ground receives up to 200,000 m^3 of sand and mud annually (POL 2010).

The Shelly Beach ground is shallow and relatively flat, spanning c. 0-6 m depth (Paavo 2007). Deposition of up to 50,000 m^3 annually of medium-fine sands at Shelly Beach is principally to replenish sands eroded by natural processes and, thus, protect the dune system and important salt marsh habitats in the area. Patches of habitat-forming biota (ascidians, sponges, algae) occur at this location (Paavo 2007).

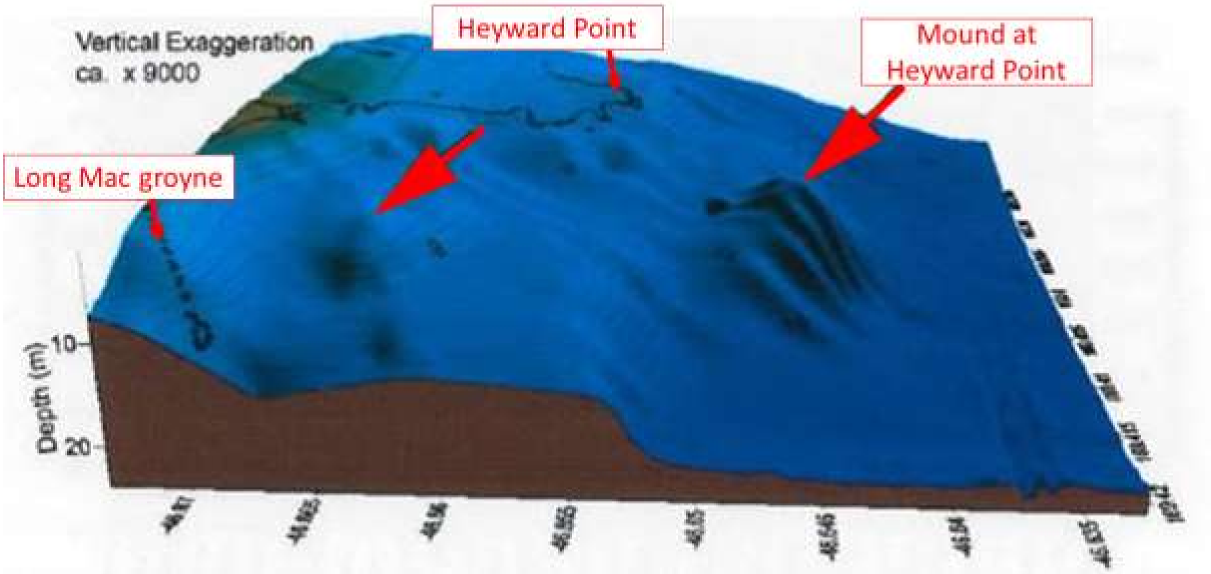

Figure 1-2: Vertically exaggerated bathymetry over the Aramoana (unlabelled left arrow) and Heyward Point (right arrow) maintenance dredge sediment placement grounds. Isobaths (m) corrected for tide, based on data from POL; contours adjacent to shore are artefacts of interpolation. Modified from Paavo (2007), Fig. 1.6, p. 15.

POL now seeks consent for extending the present (2015-16) deposition regime:

- Up to 400,000 m^3 annually to be deposited over Heyward Point and Aramoana grounds combined.
- Up to 300,000 m^3 of dredgeate per year (averaged over any five-year period) to be deposited at an enlarged (1500 x 1500 m; 2.25 km^2 cf. present c. 0.4 km^2) Heyward Point ground (Figure 1-3).
- Sediments to be deposited consistent with natural sediments: sand only at Aramoana and Shelly Beach; silt at Heyward ground only at depths deeper than 18 m (north-eastern margin); rock material to be deposited at Heyward Point only and within the ground's northern corner in water >18 m depth.
- Up to 100,000 m^3 of dredged sediment per year (averaged over any five-year period) to be deposited at the enlarged (360,000 m^2; was 280,000 m^2), rectangular (450 x 800 m, oriented parallel to shore) Aramoana ground (Figure 1-3).
- Up to 50,000 m^3 of dredged sand sediment per year to be deposited at Shelly Beach, in addition to the 300,000 m^3 provided for across Heyward Point and Aramoana.

Figure 1-3: Proposed enlarged dredgeate placement grounds for maintenance dredging sediments off Heyward Point and Aramoana. From: MetOcean (2016).

2 Inshore coastal benthic environment

Neretic or coastal water predominates over the placement grounds, which sit within a south-flowing eddy or counter-current of the north-flowing Southland Current (Murdoch et al. 1990). There is an intense refraction of the southerly swell around an ebb-tide sandbar that extends about 2 km north from the end of the Otago Peninsula to east of Heyward Point (Figure 2-1) (Hodgson 1966, Bell et al. 2009). A second submerged sand bar, referred to as the Peninsula Spit (Carter 1986), extends for 25 km north from Cape Sanders, gradually attenuating on the middle shelf opposite Karitane. Tidal flows through the harbour entrance are a minor contributor to the currents on the inner shelf, while the wind-generated currents and the Southland Current dominate (Bell et al. 2009).

Currents on the inner shelf are characteristically influenced by NE winds, which average 10-16 knots. Winds from the southeast are important 20-25% of the time. The grounds are largely sheltered from south to southwest winds by land (Paavo 2007).

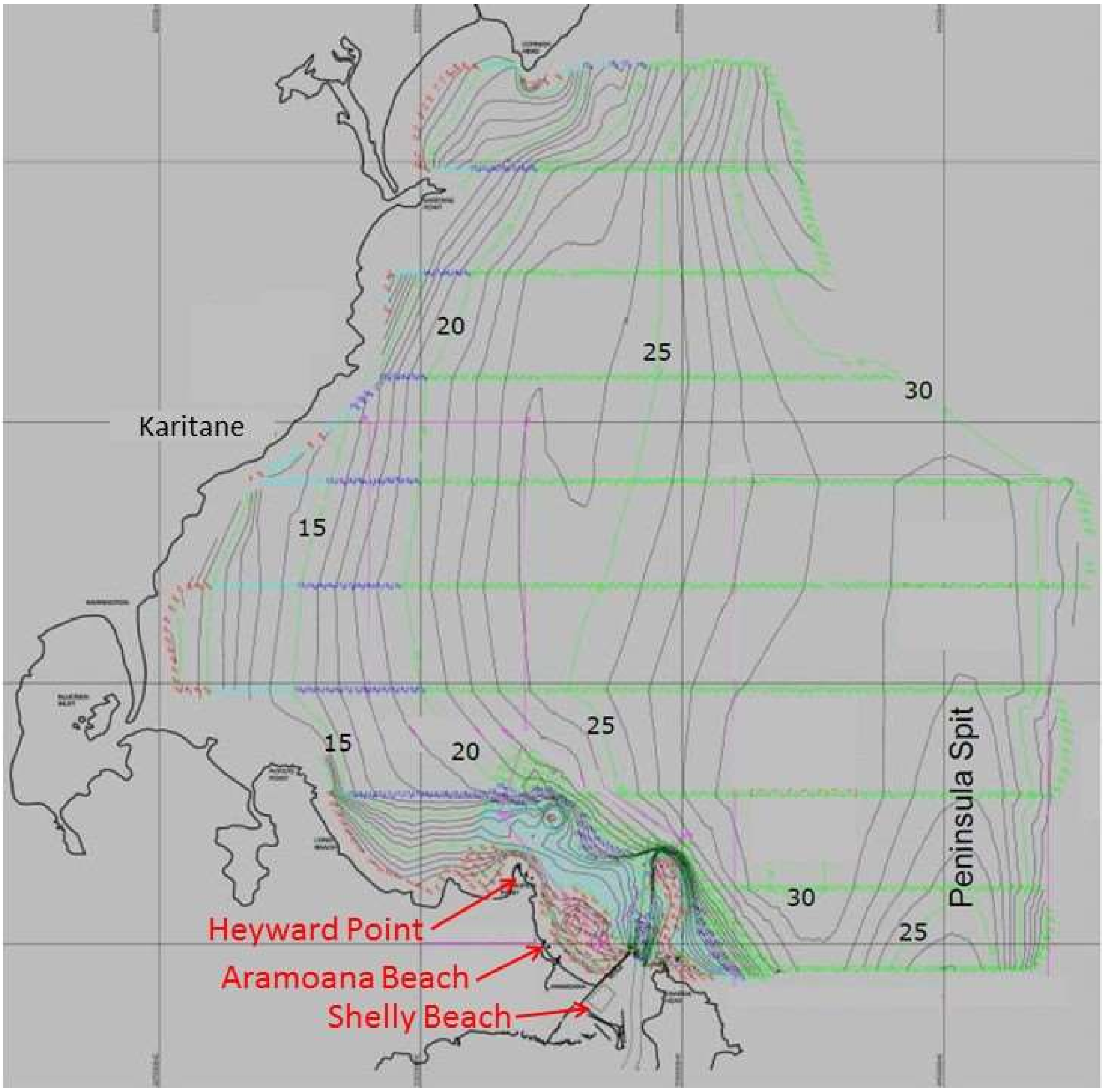

Figure 2-1: Detailed bathymetry (below chart datum; 1 m contours) of Blueskin Bay. Green and blue (thick or wavy) lines, sounding tracks. Modified from Bell et al. (2009).

The shoreline between Otago Harbour and Karitane comprises a series of infilled bay-head beaches within hard rock headlands, Kaikai Beach, Murdering Beach, Long Beach, Doctors Point and Karitane, as well as three spit beaches, Aramoana/Shelly Beach, Purakanui and Warrington Spit (Single 2013) (Figure 2-1). These beaches, nearshore environments and sand bars are predominantly quartz sands from Otago schists, delivered from the Clutha River and, to a lesser extent, the Taieri River via the Southland Current (Single et al. 2010). Although suspended mud-size particles (silt-clay) make up over half of the modern sediment input, little is retained on the Otago nearshore; approximately half is stored within the large nearshore sand-wedge, and the balance is transported north out of the area by wave processes and nearshore currents (Carter 1986). The beaches, therefore, experience cycles of erosion to and accretion from nearshore sediments. Surveys of beach changes in recent years indicate that the present state is stable and robust to changes in the wave environment, with no net retreat of the shoreline (Single 2013).

2.1.1 Bathymetry

The width of the continental shelf out from Taiaroa Head is approximately 30 km. The seabed slopes gently to depths of 100-250 m at the edge of the shelf with a series of drowned Quaternary shorelines being identified across the shelf (Figure 2-1) (Single 2010 et al). The seabed of Blueskin Bay slopes to a depth of 30 m at a distance of about 17 km from Warrington Spit. The contour at 30 m forms a near straight line from south to north starting from about 5.5 km offshore of Taiaroa Head. The Peninsula Spit is located landward of the 30 m contour (on right in Figure 2-1). The spit's crest slopes from c. 20 m depth at the southern end to c. 30 m depth at its northern end, with a large gently sloping basin inshore.

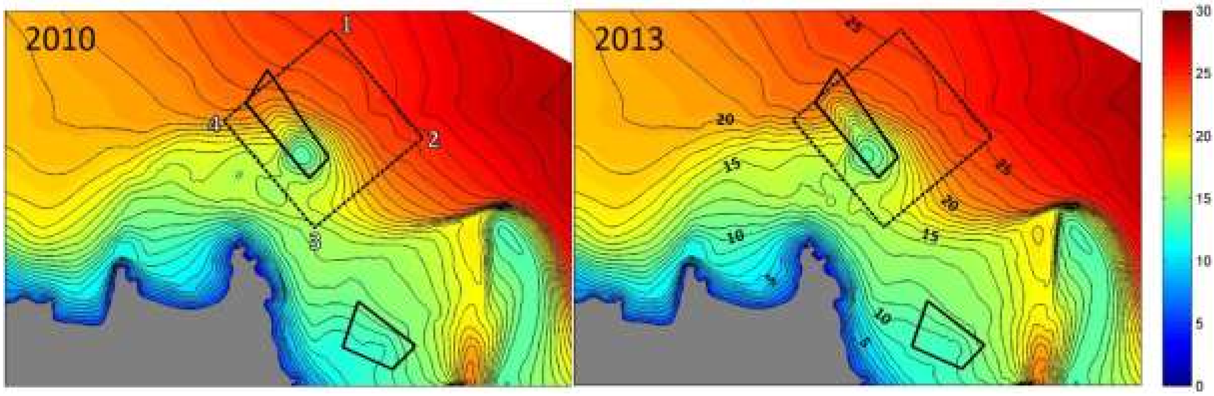

Figure 2-2: Bathymetries (1 m contours) of the Hayward Point (upper left box) and Aramoana (lower right box) placement grounds in 2010 and 2013. Solid boxes, present ground boundaries; dashed box, proposed enlarged Heyward Point ground. 2010 figure: white numbers identify locations of sites for plume modelling; 2013 figure: black numbers show depths. Modified from MetOcean 2014b, fig. 2.13; updated courtesy of MetOcean Solutions Ltd, contour labels added by NIWA.

The present maintenance dredgeate placement grounds are situated inshore at c. 6-23 m depths (Figure 2-3). The Heyward Point ground is deepest (c. 23 m) at the north-east corner and shallowest (c. 10 m) over a dredged sediment mound towards its southern end. The Aramoana ground, south of the Heyward Point ground, spans c. 6-12 m depth.

2.1.2 Hydrodynamics

An inshore component of the Southland Current peels off to the northeast east of Karitane to form a large, anti-clockwise gyre in Blueskin Bay (Figure 2-3) (Murdoch et al. 1990; Bell et al. 2009). This relatively weak gyre is diverted around the bay at the c. 20 m isobath, rather than sweeping inshore. Together with the wind and wave processes, this gyre directly affects nearshore processes within Blueskin Bay, as well as the coast south of Taiaroa Head to Cape Saunders. A small (c. 5 km diameter) clockwise gyre also occurs just north of Taiaroa Head (Figure 2-3), but this is unlikely to influence currents over the three inshore dredged sediment placement grounds, especially because it appears to transport material towards Otago Heads (Bell et al. 2009).

Waves also are a significant component of Blueskin Bay's hydrodynamics, but their influence varies. Generally, the wave climate in Blueskin Bay is more moderate than that on the outer Otago shelf and beaches south of Otago Peninsula (Single et al. 2010). Of the waves that do enter Blueskin Bay, the strongly refracted southerly swell dominates, but refraction lessens the intensity (Figure 2-5). The north-easterly waves are unimpeded within Blueskin Bay, although they are generally less powerful than the southerlies. Overall, the regime within Blueskin Bay can be described as a low energy coastal environment that experiences periodic high-energy storm waves propagating from the south.

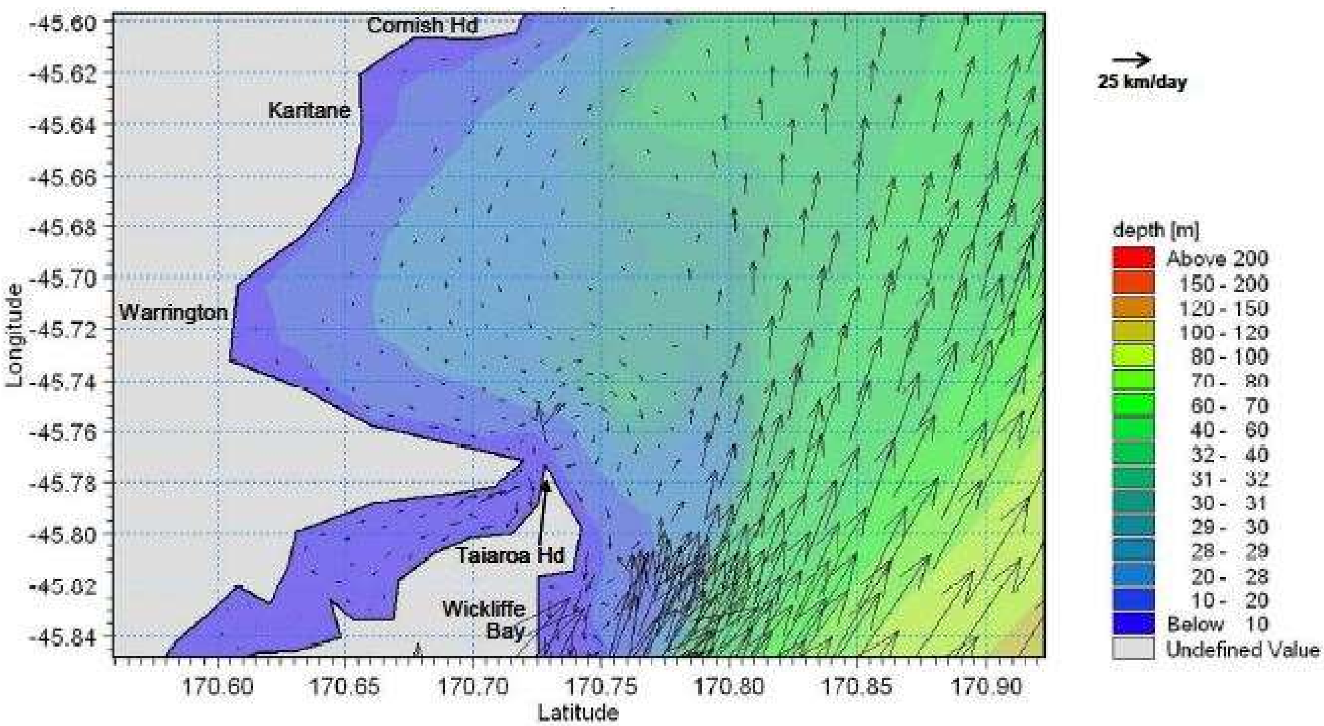

Figure 2-3: Residual depth-averaged current pattern over the Otago inner shelf and Blueskin Bay. From Bell et al. (2009, Figure 10.4).

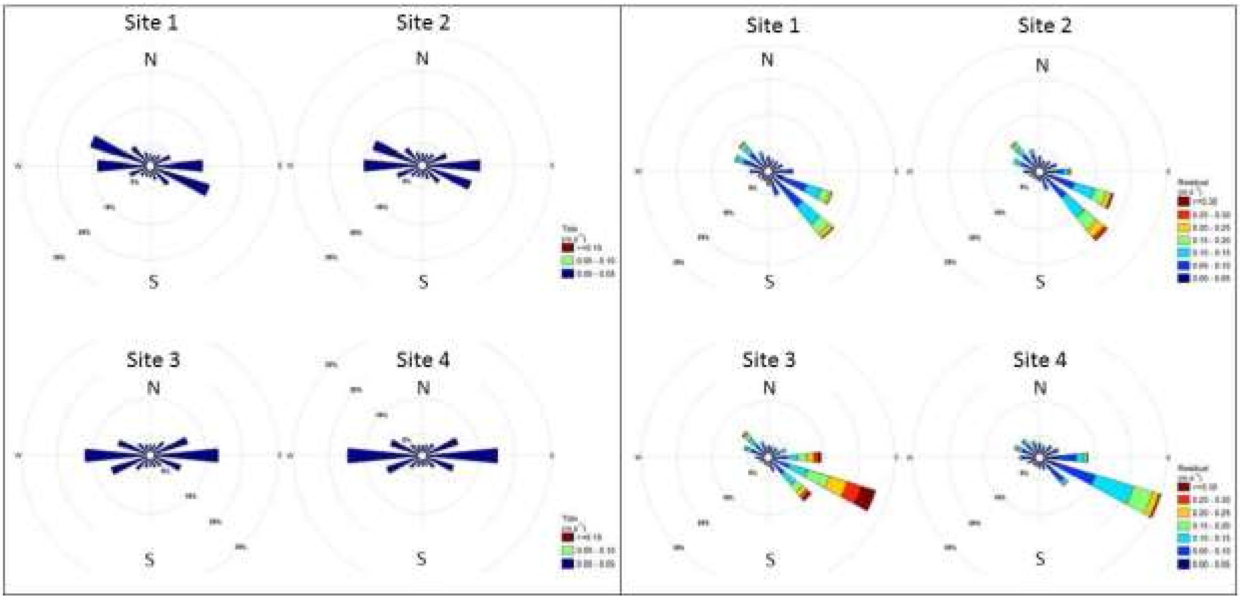

Figure 2-4: Modelled tidal (left) and residual current (right) roses for each corner of the proposed enlarged Heyward Point placement ground. Site 1, north; site 2, east; site 3; south; site 4; west). From MetOcean (2015, figures 3-1, 3-2).

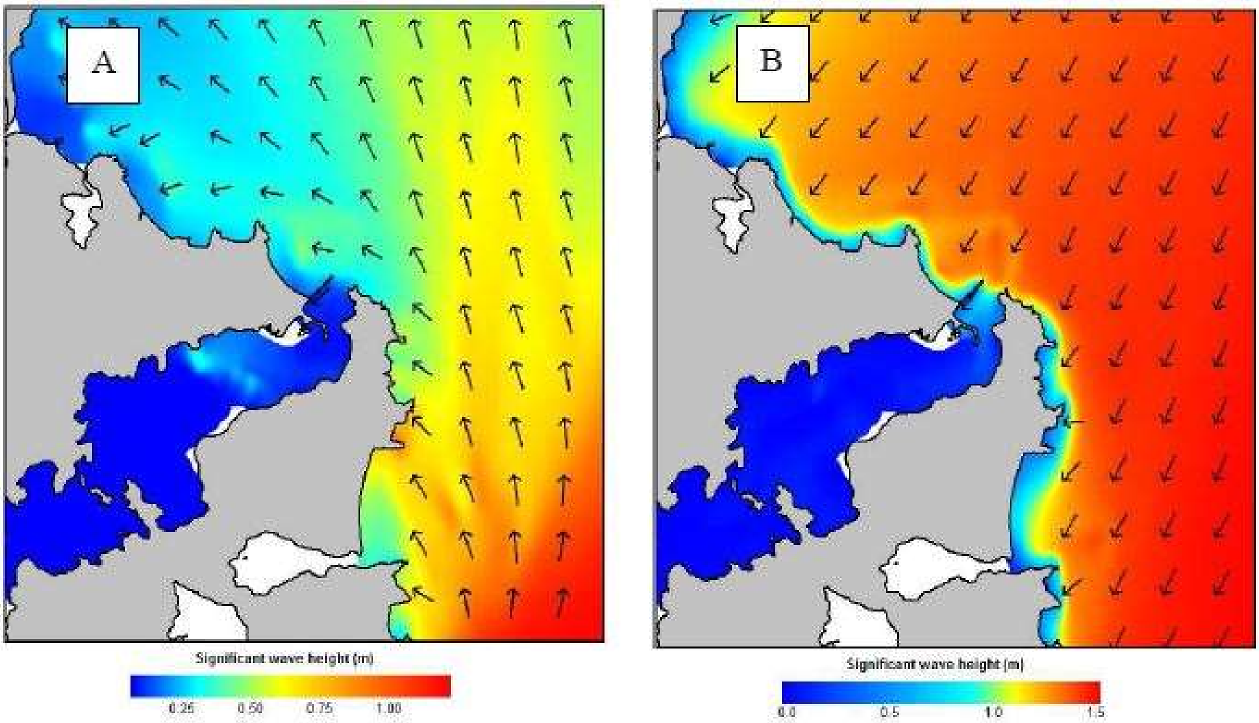

Figure 2-5: Typical wave height and direction patterns for waves approaching the Aramoana-Heyward Point area from the southeast (A) and northeast (B). Note, wave height scales differ between figures. From Bell et al. (2009, Fig. 8.6).

Offshore waves approach Blueskin Bay predominantly from the northeast and southeast (Figure 2-5) (Single et al. 2010, Weppe et al. 2011) as a result of the local geography, with north/northeast and south/southwest the most frequent wind directions. Although the southerly swell is still a dominant wave within Blueskin Bay, its intensity and effectiveness is considerably reduced by the effect of wave refraction, and local winds play a more important role in wave propagation (Hodgson 1966). Waves from the southerly quarter influence hydrodynamics at greater depths than those from the northerly quarter, however, because of their generally longer wave period. The gradual shelf slope within Blueskin Bay means that shorter period waves undergo little refraction until they are close to the shore. Consequently there is little loss of deep-water wave energy as the north-easterly waves move across the shelf. This results in most of the wave energy from this source being expended at the shore (Figure 2-5).

Wave modelling shows that the submerged sand bar northeast of the harbour entrance (see Figure 2-1) strongly focuses incident wave heights towards Aramoana Beach, where a zone of increased wave height is clearly evident (Figure 2-6) (Weppe et al. 2011). A side effect of this focusing is a wave shadow immediately west of the sand bar, and a strong wave height gradient along the shore. Maximum wave energy is typically located mid-beach for a northeast event and shifts progressively northwest as angles of incidence increase. In contrast, the south-eastern end of the beach generally receives low wave energy in these conditions. Similar wave focusing processes also occur leeward of the deposition mound at the Heyward Point ground (Figure 2-6) (Weppe et al. 2011).

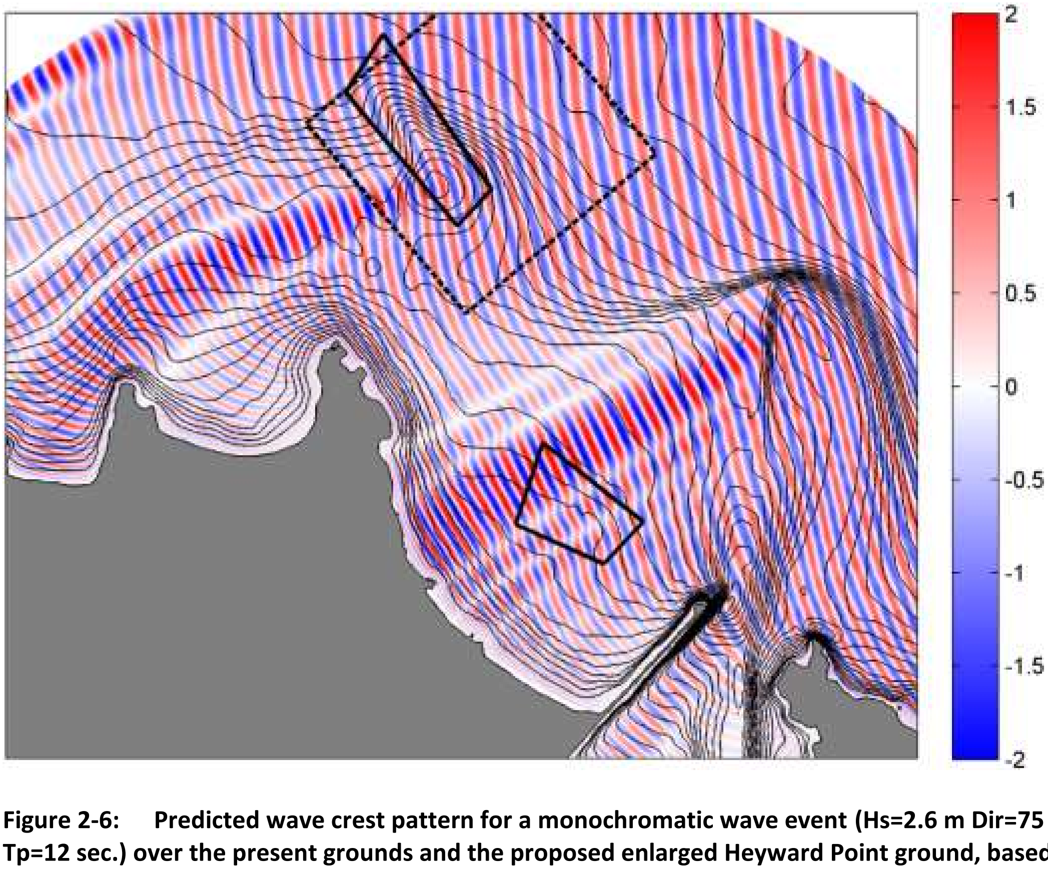

Figure 2-6: Predicted wave crest pattern for a monochromatic wave event (Hs=2.6 m Dir=75 degrees, Tp=12 sec.) over the present grounds and the proposed enlarged Heyward Point ground, based on 2013 bathymetry. Solid boxes, present ground boundaries; dashed box, proposed enlarged Heyward Point ground. From MetOcean 2014b, Fig. 3.21; updated courtesy of MetOcean Solutions Ltd.

Two key physical processes determine the wave height gradients along Aramoana beach: (1) strong focusing of incident waves over the offshore sand bar (ebb tide sand bar, Figure 2-1) due to wave refraction and (2) snapping of adjacent wave crests in the lee of this sand bar (McComb 2013). These processes result in distinct wave height gradients along the beach (i.e., zones of low and high waves) and off-sets wave crests (i.e., wave crests become aligned with wave troughs). Combined, these two processes create different hydrodynamic environments for benthic communities along Aramoana Beach.

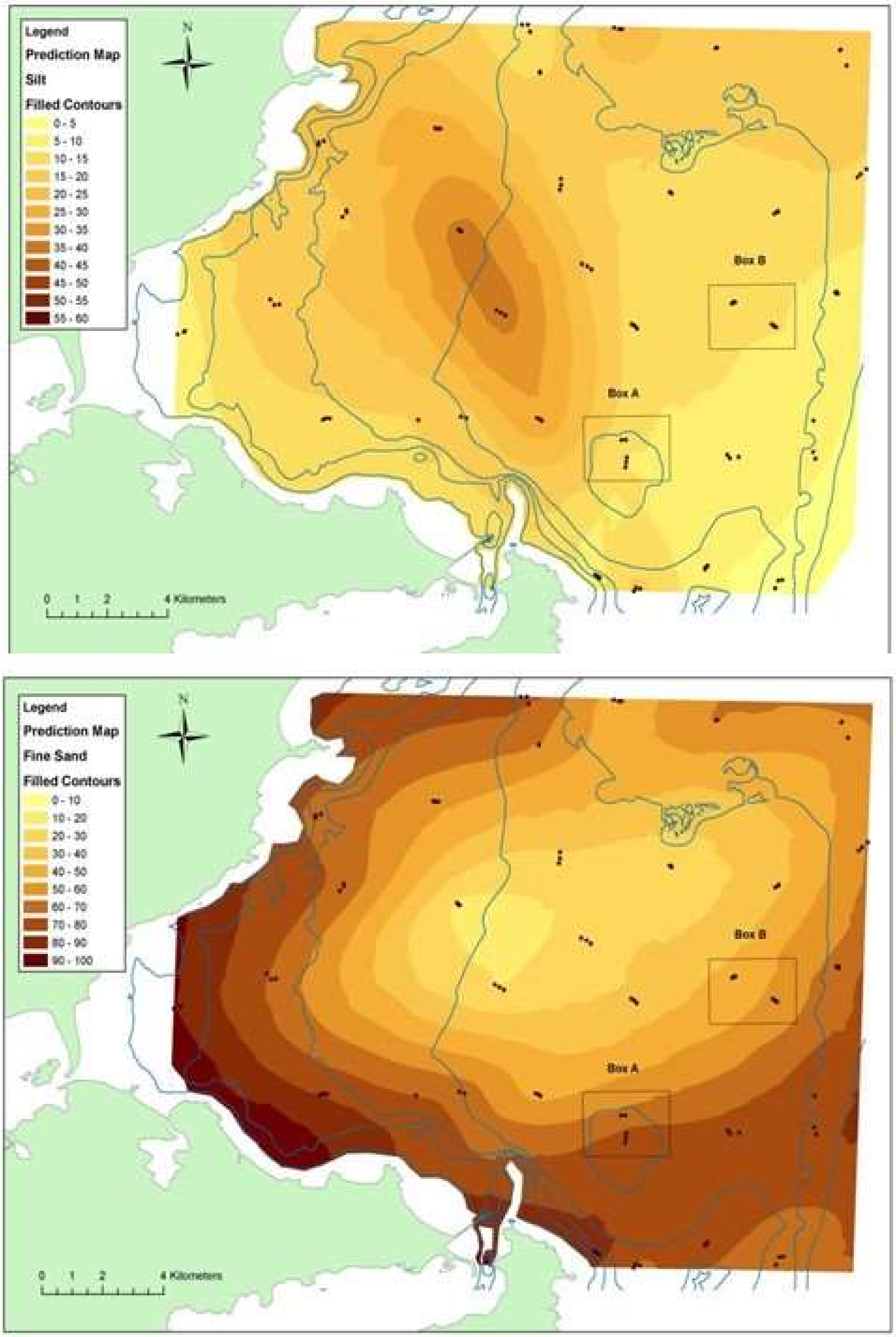

Figure 2-7: Distribution of silt and fine sand in bottom sediments of Blueskin Bay. From Willis et al. (2008, Figures 11, 13).

2.1.3 Sediments

Inshore bottom sediments in Blueskin Bay are predominately fine to medium sand (mean diameter 125-140 µm), are well sorted and relatively homogeneous, with very fine sands and silts (< 63 µm) dominating the central, deeper part of the bay (Willis et al. 2008). Slightly coarser sand occurs along the bay's shallow margins (Willis et al. 2008, Single et al. 2010) (Figure 2-7). Sediments of the beaches and nearshore between Taiaroa Head and Karitane are fine sand to medium sand (150 to 330 µm), with fine sand (170-240 µm) predominating.

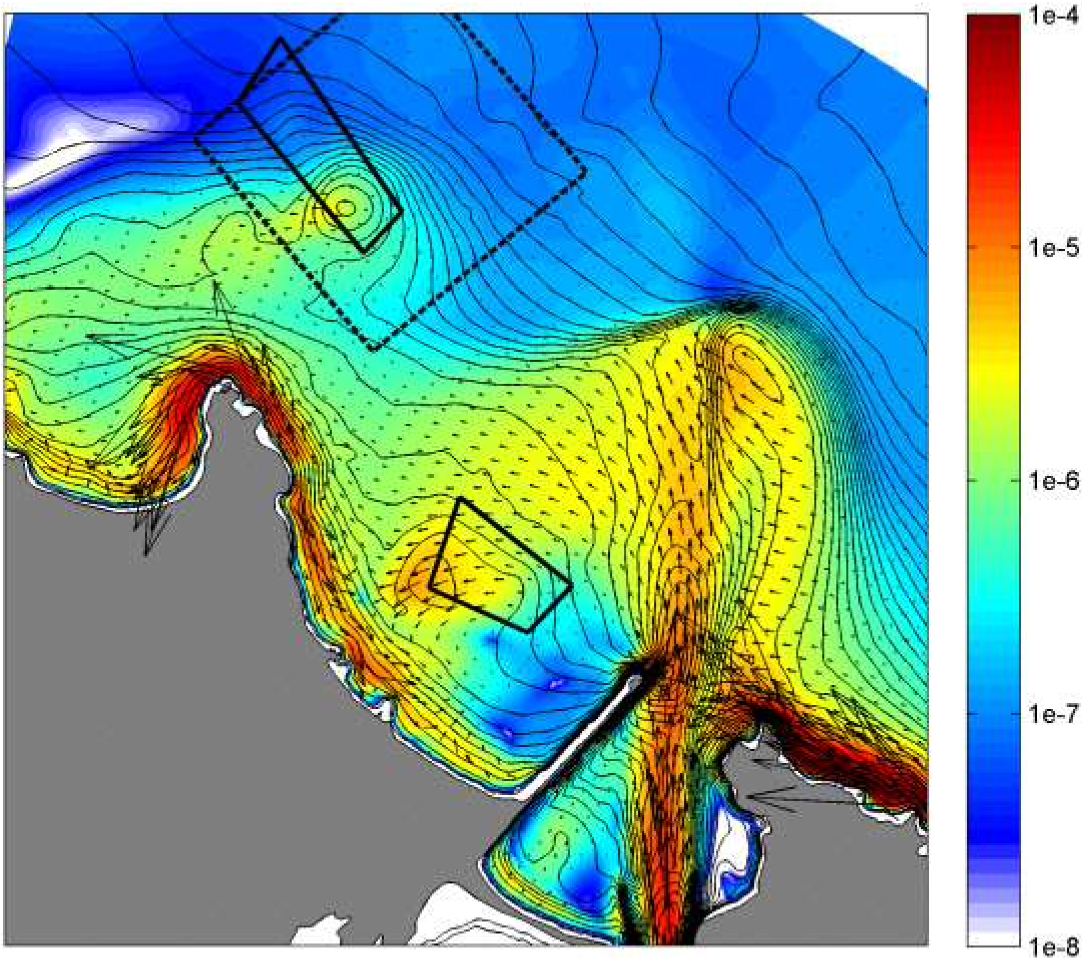

Figure 2-8: Net sediment transport (m^3/second/metre) across the dredged sediment placement grounds and greater Blueskin Bay. Modelled using weighted average representative events, 2007-09 wave climate, 2007 bathymetry. Solid boxes, present ground boundaries; dashed box, proposed enlarged Heyward Point ground. Scale: $1e^{-6}$ = 1 millionth m^3, equates to 1 cm^3/second/metre; $1e^{-5}$ equates to 10 cm^3; etc. From MetOcean 2014a, Fig. 5-16; updated courtesy of MetOcean Solutions Ltd.

Net sediment transport in the vicinity of Aramoana ground is dominated by sediment movement from the harbour channel in an arc from Aramoana Spit, northwest, west then southwest over the deposition mound at the ground's western corner (Figure 2-8). Net sediment movement differs markedly across the ground, from negligible in the southern and eastern corners, to substantial across the ground's north-western half. The much greater sediment transport over the north-western portion of this ground is apparently from two factors: the pattern of wave approach (Figure 2-5), and the ebb tide sand bar's effect of focusing wave energy onto this section of Aramoana beach (Figure 2-6).

When completed, the deepened and extended shipping channel consented under POL's Project Next Generation will have two effects on the inshore Aramoana seabed (MetOcean 2016). First, the channel will trap 60-100% more sediment, increasing the volumes that must be dredged to maintain the channel (MetOcean 2016). Second, this increased sediment trapping will reduce sediment volumes by-passing the harbour entrance and replenishing the western beaches. Aramoana beach was estimated to require 70-90,000 m^3/y of sand to maintain equilibrium sediment processes, historical bathymetry and beach location post-Project Next Generation (MetOcean 2016).

Net sediment transport over the Heyward Point ground is less than that over the north-western part of the Aramoana ground (Figure 2-8). Greatest transport involves westward winnowing from the deposition mound crest (net volumes c. 5 cm^3/second/metre; Figure 2-8), whereas that over much of the rest of the area is <1 cm^3/second/metre), largely because of the greater water depth and associated reduced current and wave energy.

Recent modelling indicated losses of c. 50,000 m^3/y from the entire Heyward Point ground, of which c. 30-40,000 m^3/y were from the deposition mound (MetOcean 2016), a feature that enhances the nationally significant surf break at Whareakeake Beach. The proposed enlarged ground will permit better management of both this feature and the immediate ecosystem effects by providing a greater area for placement of dredgeate and ensure sufficient sandy seabed for sand placement and silty seabed for placing silty dredgeate (MetOcean 2016).

3 Assessment of effects

3.1 Dredged sediment deposition

Most dredge material released from a dredge descends directly and rapidly to the sea bed as the active plume (probably >90% of the total sediment load; see MetOcean 2015). In the process, some sediment becomes suspended within the water column (both from the active plume and from the sea bed due to forces associated with the bulk sediment impacting the bottom) as the passive plume. Ultimately, sediments within the passive plume settle to the seabed, but they may be transported beyond the immediate placement location before this occurs. Understanding both plumes and their resulting deposits is essential to assessing the likely effects of dredgeate on benthic ecosystems.

3.1.1 Passive plume dispersion and deposition

Detailed modelling of the passive plume sediment dispersal and deposit was completed by MetOcean (2015). The modelling assumed that the passive plume comprised 10% of the total spoil released, a high and thus ecologically conservative value, given available information indicating that passive plumes may comprise as little as 1% of the total spoil load deposited (see discussion in MetOcean 2015: 3).

Based on that work, MetOcean determined probabilistic particle excursion footprints (quantified probabilities of finding particles around the release location based on annual hydrodynamic conditions) for the passive plume. Probabilistic sediment deposition contours around the proposed Heyward Point ground 12 hours after release of single dredge loads at specific points were derived from the excursion footprints. Separate deposition contours were produced for the two main spoil types (silt, fine sand) and for two dredges: POL's dredger, New Era (load volume 600 m^3; release depth c. 2 m depth) (Figure 3-1), and a large trailing suction hopper dredger (TSHD, load volume 22,000 m^3; release depth at c. 7 m below surface) (Figure 3-2, Figure 3-3) that may be used in the future. It is important to note that: these deposition contours are for the passive plume alone, not for the >90% of spoil that descends directly to the seabed as the active plume from each release. Also, these contours are not measures of actual deposition that will occur, but rather indicative values of likely deposition during average conditions; actual deposition will vary between loads, with location of the release, other aspects of vessel behaviour during release, and weather, tidal and hydrodynamic conditions, among other factors.

Twelve-hour, passive plume deposition contours were produced only for the proposed new ground at Heyward Point: one release location in each corner and a fifth at the ground's centre. Equivalent contours were not produced for the Aramoana ground, because it receives only fine sand dredgeate (the naturally predominant bottom sediment there), which settles rapidly with negligible associated suspended sediment (Figure 3-1). Also, releases of fine sand dredgeate produce negligible suspended sediments, so that the 12 h passive plume deposition contours are tightly constrained around the release location (Figure 3-1; MetOcean 2015). Equivalent passive plume deposition contours for the much larger loads released from the TSHD are consistently smaller because of that dredge's greater release depth (7 m) and are not shown here.

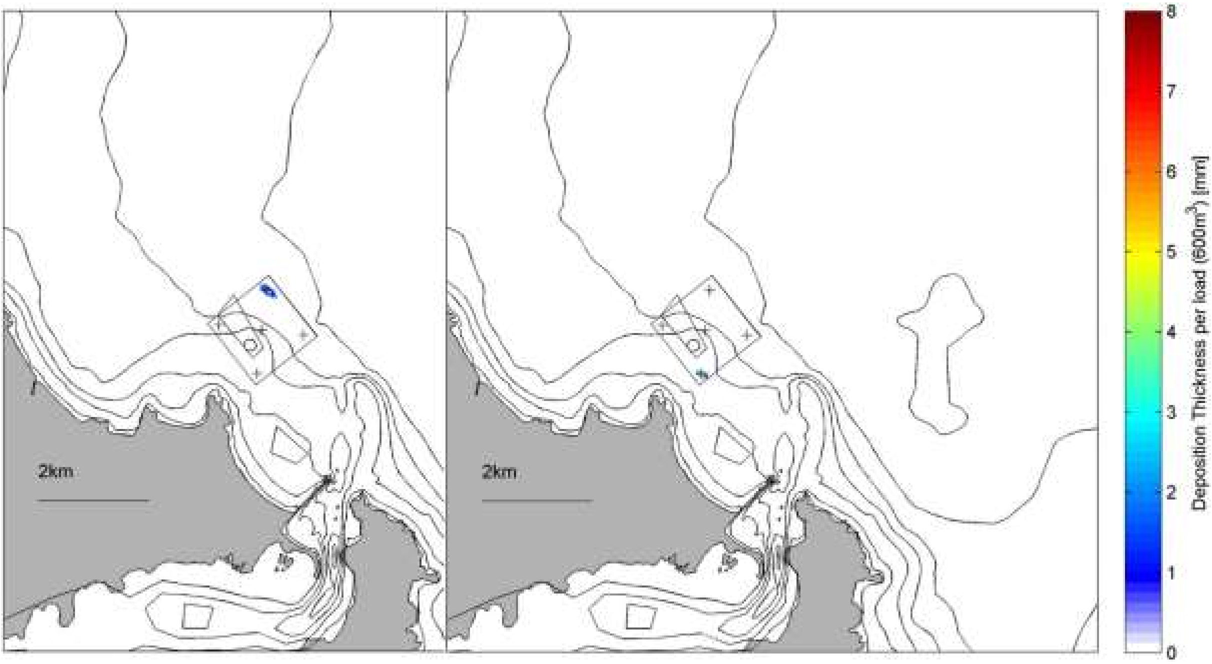

Figure 3-1: Suspended sediment (passive plume only) settlement contours 12 hours after release (c. 2 m depth) of 600 m^3 of fine sand dredgeate from dredge New Era at each of two points (left, site 1, greatest dispersion; right, site 3, least dispersion) within the proposed enlarged Heyward Point dredged sediment placement ground. Hydrodynamic conditions averaged over a full year. Courtesy of MetOcean Solutions Ltd.

Deposition contours after 12 h for sites with least and greatest dispersion (Figure 3-1, Figure 3-2, Figure 3-3) show that

- there is essentially no passive plume deposition resulting from release of fine sand from either the New Era or the TSHD (Figure 3-1; New Era releases only shown; plots for both dredges essentially indistinguishable);
- silt in the passive plume disperses and is deposited more widely than sand, with much of this extending beyond the proposed ground's boundaries;
- dispersion of the passive plume is greatest and the deposition footprint largest when silt is released in deeper water;
- New Era's passive plume's silt deposition footprint is very light (almost all <0.025 mm thickness; Figure 3-2; note deposition thickness scale is 100 times greater for THSD in Figure 3-3);
- The TSHD's passive plume disperses more widely and much thicker sediment layers (mostly 0-1 mm) result, especially for loads released in shallower water (Figure 3-3).

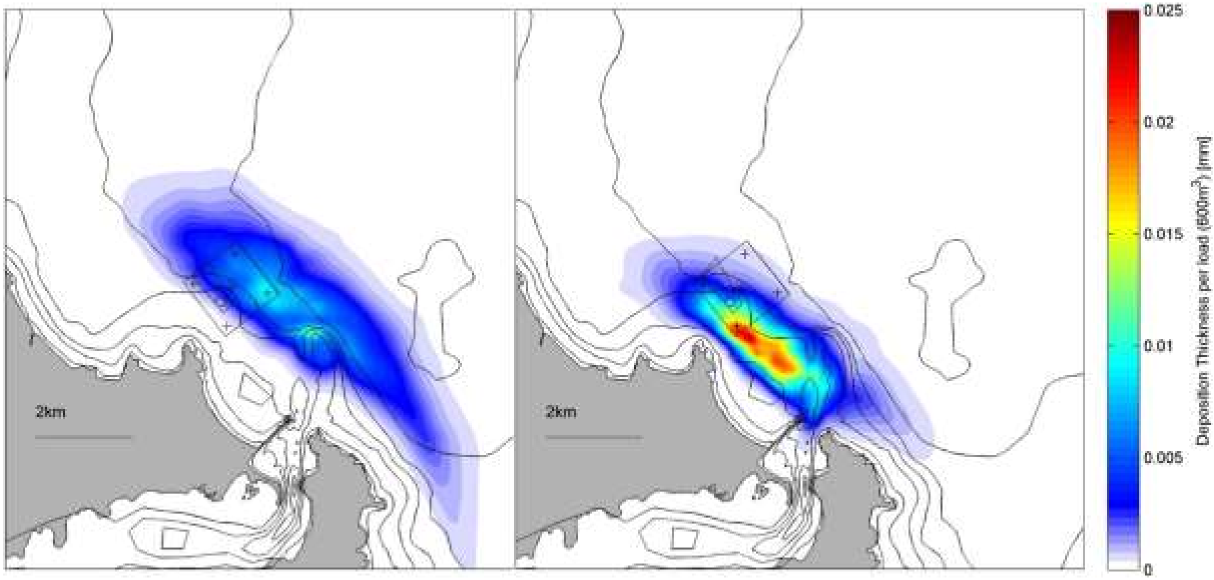

Figure 3-2: Suspended sediment (passive plume only) settlement contours 12 hours after release (c. 2 m depth) of 600 m^3 of silty dredgeate from dredge New Era at each of two points (left, site 2, greatest dispersion; right, site 3, least dispersion) within the proposed enlarged Heyward Point dredged sediment placement ground. Note, deposition scale differs from that in Figure 3-3. Hydrodynamic conditions averaged over a full year. Courtesy of MetOcean Solutions Ltd.

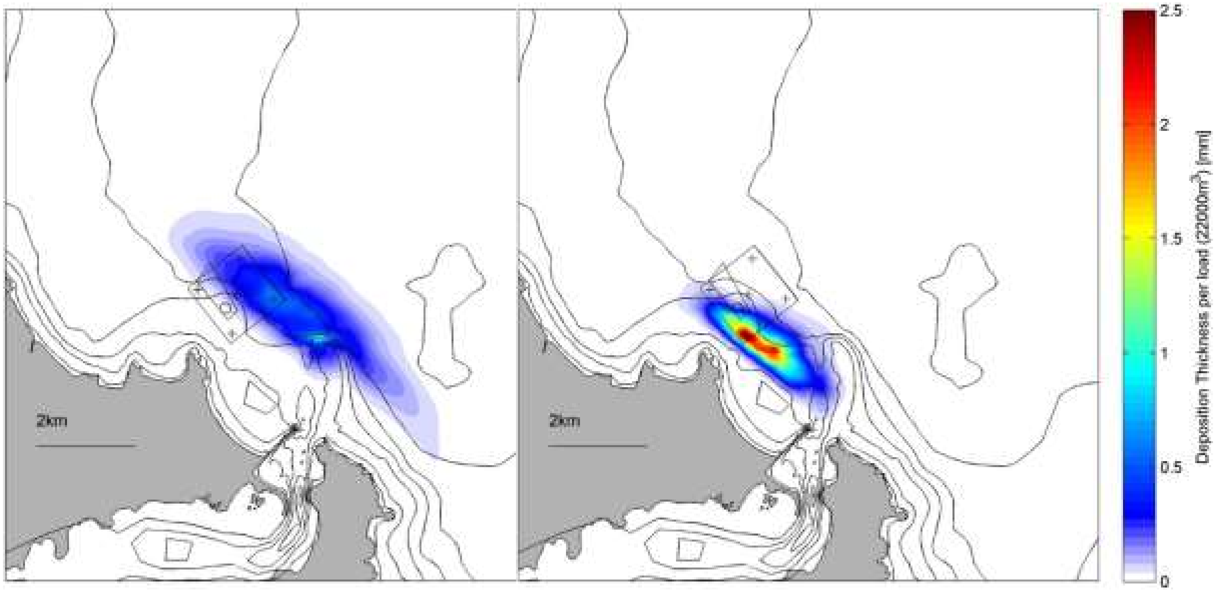

Figure 3-3: Suspended sediment (passive plume only) settlement contours 12 hours after release (c. 7 m depth) of 22,000 m^3 of silty sediments from a hypothetical trailer suction hopper dredge (TSHD) at each of two points (left, site 2, greatest dispersion; right, site 3, least dispersion) within the proposed enlarged Heyward Point dredgeate placement ground. Note, deposition scale is 100 times greater than that in Figure 3-2. Hydrodynamic conditions averaged over a full year. Courtesy of MetOcean Solutions Ltd.

3.1.2 Overall dredge material plume deposition and re-working

Field observations following separate experimental deposits of c. 800 m^3 of sand and silt material at Aramoana from POL's dredge New Era (Figure 3-4) indicated a c. 45 m diameter deposition crater surrounded by a thinner outer zone of dredgeate (height not given) aligned to the dredge's travel direction at time of depositing (overall diameter c. 60 m) (Paavo 2007). Muddy dredgeate dispersed quickly at this ground, and the experimental deposit of c. 800 m^3 essentially disappeared within 26 days of deposition (Paavo 2007). In some situations, deposited sediments may become slightly anoxic, as reported for a few small samples from Heyward Point (Paavo 2011).

The sediment particle size composition of separate experimental deposits of silty and sandy dredge material adjacent to the south-eastern end of the Aramoana ground and around the deposited sediment (Paavo 2007, 2011) changed over time after deposition. Sandy dredged sediment was largely indistinguishable from this site's natural fine sand sediments five days after deposition, even at the centre of the dredgeate deposit (Figure 3-5). Sediments at sites receiving muddy sediments took 12-26 days to resemble their natural particle size compositions (Paavo 2007) (Figure 3-5). This remarkably brief period for sediment recovery in an area with intermediate sediment transport rates (Figure 2-8) appears due to seabed hydrodynamics keeping "surface sediments in the Aramoana disposal area … in an almost constant state of motion during the calmest period of the year" (Paavo 2007: 232).

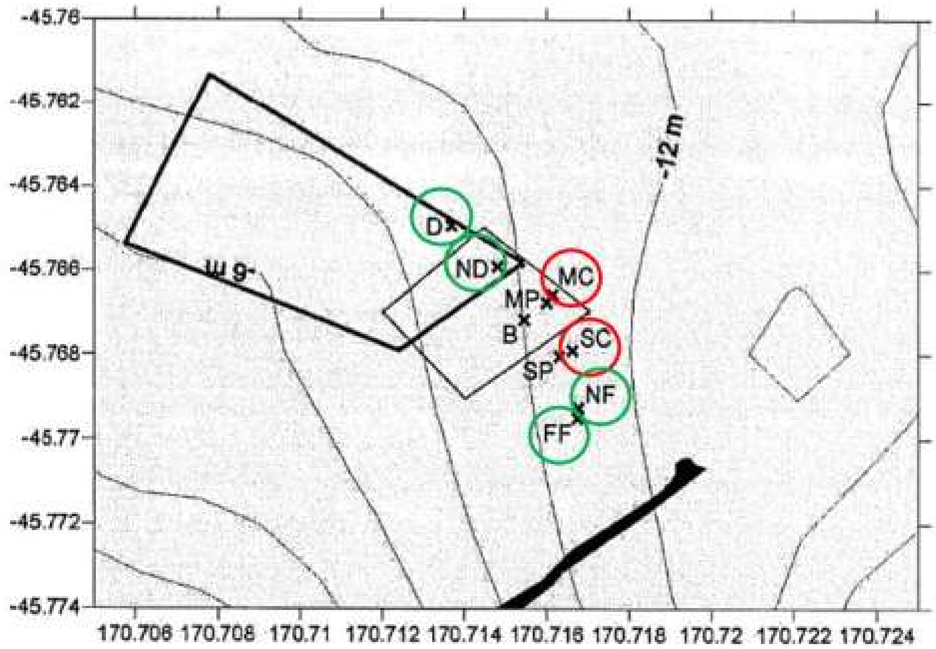

Figure 3-4: Locations of impact (red), control (green) and intermediate (no circles) sampling stations relative to existing Aramoana deposition ground (heavy rhomboid), no-deposition zone (light rhomboid) and experimental mud (MC) and sand (SC) deposits. D, far control at deposition ground margin; ND, control within no-deposition zone; MC, mud deposition centre; SP, margin of mud deposit; B, between mud and sand deposits; SC, sand deposit centre; SP, edge of sand deposit; FF, NF, far controls. Modified from Paavo (2007, Fig. 5.6).

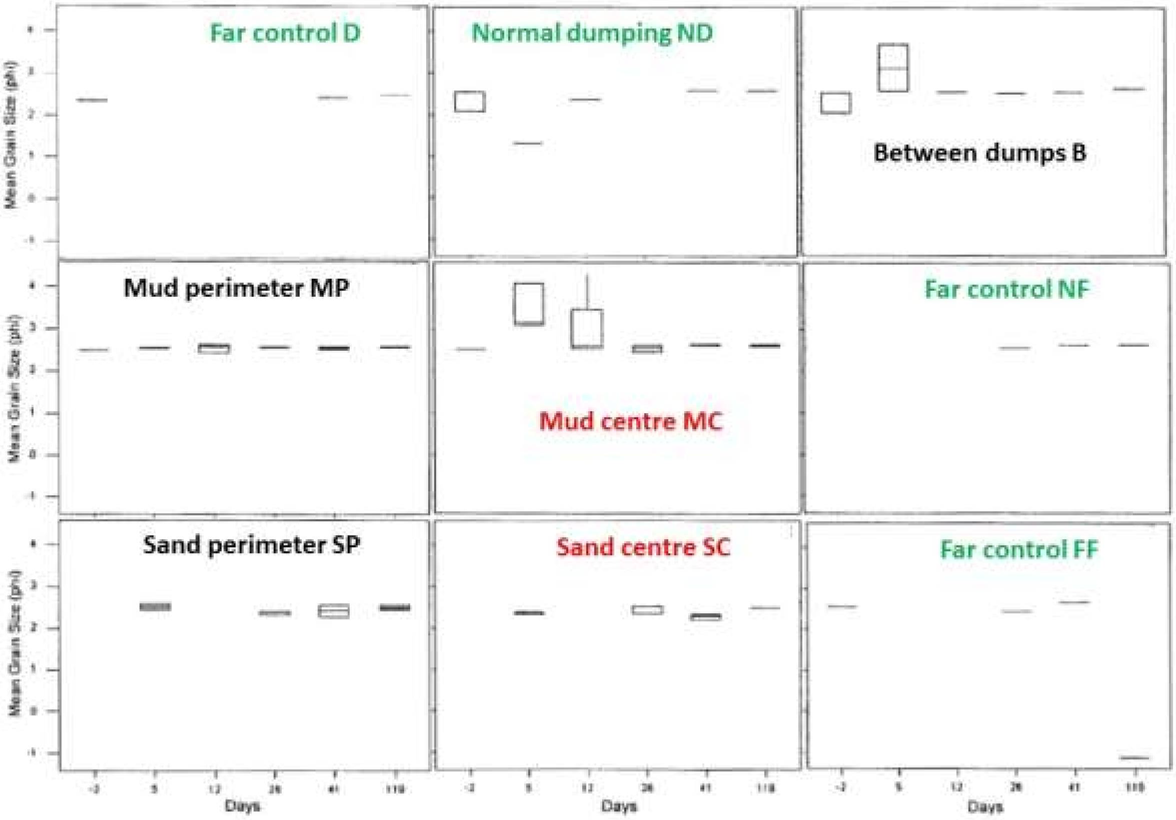

Figure 3-5: Bottom sediment grain size (in phi units) composition at impact (red), control (green) and intermediate (black) locations before (-2 days) and at increasing intervals (5, 12, 26, 41 119 days) after separate c. 800 m^3 deposits of muddy and sandy sediment on day 0 (day 0 not identified on x-axis). N.B., grain size decreases with increasing phi number. Coloured lettering: red, impact or direct exposure to deposition; black likely indirect exposure; green, control or no direct or indirect exposure. Boxes, values for 25% of samples either side of mean; horizontal line, mean value. D, normal deposition continued; ND, control, unimpacted for >180 days prior to first sampling; MC, mud deposit centre; MP, margin of mud deposit, 25 m from SC; B, between, 60 m from MP, 110 m from SP; SC, sand deposit centre; SP, edge of sand deposit, 30 m from SC; FF, NF, far controls, never received any dredged sediment. Modified from Paavo (2007, Fig. 5.16).

3.2 Potential ecological effects of dredged sediment placement on inshore benthic communities

Almost all ecological systems exist in a state of perpetual change, or dynamic equilibrium, in response to diverse factors in their environments and constrained by the adaptabilities of their component species. Periodic disruption of this equilibrium is common to most ecosystems, frequently due to weather or climatic events (e.g., Bolam et al. 2006), and these disruptions may be integral to the persistence of some ecosystems (e.g., dependence of eucalyptus forests on fire). Usually these disruptions set an ecosystem on a path towards a slightly different equilibrium, so that the mix of species present once the ecosystem stabilises post-disruption is inevitably different to that present pre-disruption (e.g., Kenny & Rees 1996; Bolam & Rees 2003; Paavo 2007). This disruption-recovery cycle is well studied in ecology, with various stages distinguished by the types of organisms and the structure of the biological assemblages present at each stage in the process. For example, early recovery assemblages for marine benthic ecosystems typically comprise high densities of fewer species, and these species, termed opportunists, tend to be small in size, reproduce prolifically early in their lives, and disperse quickly (e.g., see Newell et al. 1998; Bolam & Rees 2003). Assemblages that have not been disturbed for longer times tend to comprise more species, which are similarly abundant, diverse in size range and reproductive strategies (e.g., Bolam & Rees 2003). Opportunistic species usually persist within these more mature assemblages, albeit at densities much lower than immediately post-disturbance.

Deposition of dredge material unpredictably and variously disrupts the equilibrium of benthic faunas. This disruption may be catastrophic within the immediate dredgeate deposit where a sediment mound covers the original sea bed and benthos, but less harmful to the benthos farther from the immediate drop zone where there is less sediment cover. The severity of any ecological effects and the rate of recovery depend on the nature of deposited material, its similarity to the pre-existing sediment, the depth of sediment deposited, and its persistence. The effects also are very dependent on the nature of the benthos present: some benthic invertebrates that are well adapted to life in turbulent, highly mobile sediments can withstand repeated shallow sediment deposition episodes. Other invertebrates, for example, those constructing delicate tubes and burrows in much calmer waters where there may be little or no mobile sediment, may be easily smothered.

From an ecosystem management perspective, management of dredge material placement should not focus on restoring the previously present species populations or community. Instead, the primary concern is ensuring ecosystem complexity (biodiversity), ecosystem resilience (ability to variously recover from future unpredictable change), and ecosystem functioning (so that the affected area is sufficiently productive to support other biodiversity, notably higher trophic level organisms, such as fishes). This is the main reason to using benthic community measures to monitor ecosystem resilience and recovery.

Dredged sediment placement has been widely investigated and reported. The main effects of dredged sediment on benthos are outlined below. We understand that sediments in areas to be dredged contain no contaminants potentially harmful to benthos at these sites, so this matter is not considered further here.

3.2.1 Burial effects

Adults of many macrobenthic species can migrate vertically through 10-30 cm of deposited sediments to escape burial (e.g., Maurer et al. 1979), with half of the species in the one study surviving sediment deposition by burrowing through 4-15 cm of sediment to the water interface (e.g., Kukert 1991; Miller et al. 2002). One benthic snail (*Zethalia zelandica*) present on sandy sediments at the Aramoana ground (common on sandy bottoms in the region over c. 7-30 m depth) survived (100%) burial under 50 mm of sand, but survival reduced within increasing burial depth (94% survival after burial under 100 mm; 68% under 150 mm, 33% under 200 mm) (Paavo 2007). Thus, some benthic species in the region can recover from significant burial by similar sediments, especially with periodic placement and deposition events. We expect that smaller species will be less well adapted to recovery from such deep burial, although more actively mobile species may avoid potentially lethal burial by behavioural responses (e.g., swimming upwards as sediment descends).

Survival of burial by dissimilar sediments may be quite different. For example, *Zethalia*'s ability to survive burial in mud was much lower: 60% survived burial under 25 mm of mud, and c. 20% survived 50 mm (Paavo 2007). POL's approach of diverting dredge material to grounds with most comparable sediment grain sizes minimises any such adverse effects.

3.2.2 Suspended sediment effects

Suspended sediments resulting from dredge spoil deposition may affect the benthos in three ways: directly through burial as the sediments sink to the seabed and by interfering with benthic species' respiratory and feeding mechanisms, and indirectly by reducing light available for primary production. Burial effects were considered above and are not explored further.

Generally, species vary in their tolerances of suspended sediment, but many fish and bivalve mollusc species are well adapted to increased turbidity, probably because storm-induced, high turbidities are natural in many shallow coastal environments (e.g., Newell et al. 1998). Adults tend to be more tolerant than larval forms and juveniles, and deposit feeders tend to tolerate higher turbidities better than suspension feeders. However, prolonged exposure to elevated suspended sediment loads may reduce the suspension-feeding component of the benthos, with a corresponding increase in deposit feeders (Newell et al. 1998).

Laboratory and field investigation of New Zealand species indicates beneficial effects of low suspended sediment concentrations for some bivalves (e.g., mussels). New Zealand cockles (*Austrovenus stutchburyi*) appear to thrive when exposed to suspended sediment loads of up to 400 mg/L, but persistent exposure to clay-size particles was detrimental (Hewitt & Norkko 2007). Green-lipped mussels (*Perna canaliculus*) continued to feed at suspended loads up to 1000 mg/L (Hawkins et al. 1999). In comparison, the condition of horse mussels (*Atrina zelandica*), pipi (*Paphies australis*), heart urchins (*Echinocardium australe*) and a deposit-feeding polychaete (*Boccardia syrtis*) declined with continued exposure to just 80 mg/L of suspended sediment (Hewitt et al. 2001; Ellis et al. 2002; Nicholls et al. 2009). Other organisms were adversely affected only after prolonged exposure: wedge shells (*Macomona liliana*) only after nine days' exposure to 300 mg/L, whereas the small mud snail, *Zeacumantus lutulentus*, appeared unaffected by 650 mg/L of suspended sediment after 14 days (Nicholls et al. 2009).

Increased suspended sediment or turbidity can reduce the amount and quality of light reaching benthic plants (including microscopic diatoms), thus reducing photosynthesis and plant productivity. This effect is greatest for rocky shore and shallow estuarine environments (see section 3.3.3), and may be important for phytoplankton (including diatoms) within turbulent surf beach environments also (e.g., McLachlan et al. 1981) and offshore.

Neither effect is likely to be of any consequence at the two grounds considered here. Most benthic species at the Aramoana sites are deposit feeders (75% of the dominant 20 species in Paavo's (2011) Table 4). Just one of these appears to be a suspension feeder and its persistence in the area indicates that its copes with suspended sediment loads from historical dredge material deposition in the area. Similarly, analysis of the feeding modes of the 20 most abundant species found in deeper waters of the Heyward Point ground and farther afield in Blueskin Bay reveals some 60% as obligate deposit feeders and another 25% (mostly infaunal amphipods) that appear to switch between deposit feeding and scavenging (our analysis of Willis et al's (2008) Table 3). Thus, suspended sediment from dredge placement activities seems unlikely to affect their feeding.

No change or adverse ecological effect due to suspended sediment is expected at the Aramoana ground, assuming that only fine sand material is released here and that it is delivered by the dredge New Era. The same is true for any deposition of sand at the enlarged Heyward Point ground. Passive plumes at the Heyward Point ground generated from silt deposition seem likely to increase. First, plumes are larger for loads deposited in deeper water and >60% of the proposed enlarged Heyward Point ground is in deeper water. Second, these larger plumes will persist longer and those from successive loads may interact at times to increase any adverse effects. Third, delivery of silty dredged material via the TSHD is potentially problematic. Although its delivery depth is greater and this reduces plume formation, the impact of its much larger active plume appears to generate a disproportionately larger, more concentrated passive plume that persists longer.

Inshore waters in the general vicinity of these two placement grounds are naturally quite turbid and subject to protracted periods of higher suspended sediment loads resulting from storms. Also, herbivores are inconspicuous in the benthos, whereas detrital deposit feeders dominate, indicating little direct dependence on benthic primary production in these habitats. Thus, we consider that there will be no overall adverse effect on the benthic ecology of this area attributable to plume-induced changes in light availability.

3.2.3 Net effects on benthos diversity and abundance

Spoil deposition generally reduces diversity and densities of benthos within the immediate areas receiving spoil. The magnitude of these reductions, as well as their spatial extent and temporal persistence, varies widely and can be difficult to determine because adults of some macrobenthic species may begin re-colonising within less than one day (e.g., see Probert 1984). However, temporary complete defaunation may occur at the middle of the dredge material deposit where the thickness of newly deposited material precludes any of the underlying organisms burrowing to the new sediment surface and surviving (e.g., Norkko et al. 2002; Thrush et al. 2003). Within hours, however, scavenging species are likely to move into the area to feed, along with mobile invertebrates, especially those which actively migrate into the water column at night. Benthos density and diversity may be enhanced in areas adjacent to the immediate deposition zone, apparently in response to organic matter (including dead benthic organisms) released from the dredged material (Newell et al. 1998). This stimulation may off-set some of the ecological destruction, and the increased benthic productivity at the spoil periphery probably leads to increased reproductive output that, in turn, facilitates recolonization of the newly deposited dredge material.

Benthos recovery appears highly variable between different situations. Recolonization usually commences immediately, with some buried individuals returning to their normal habitats, and individuals from beyond the affected area may actively colonise the area to utilise available resources (space, dead invertebrates, other organic matter, etc.). Adults and larvae of some species may be carried over the new sediment by currents and wave action, and establish within it. For these reasons, recolonization seems quickest when, as with the Heyward Point and Aramoana grounds:

- the deposited material is very similar in grain size and organic content to that naturally at the recipient site; and
- the deposition location is hydrodynamically active (this implies a dynamic sedimentary environment, sediments mostly fine to coarser sands, benthos predominantly free-living active burrowers, species composition includes several with more opportunistic life-history traits) (Norkko et al. 2002; Bolam & Rees 2003; Hewitt et al. 2003; Bolam et al. 2006).

3.3 Ecological values of benthos at the sites and wider Blueskin Bay

3.3.1 Benthos of Blueskin Bay and the two deposition grounds

The bottom sediments of the Otago shelf were described in detail from intensive sampling of a c. 32 x 40 km area covering Blueskin Bay and east of the Otago Peninsula by RV Munida (Andrews 1973). That study also distinguished five benthic invertebrate communities[2] or assemblages based on living bivalves and gastropods (124 species) (12 other invertebrate groups with mineralised skeletal material were considered, but with minimal taxonomic resolution). Two of these are relevant here.

- A *Zethalia*[3]-Foraminifera community inhabited hard, clean sand "from nearshore to 10-18 m" (Andrews 1973: 818) depth, forming an almost continuous margin around the eastern Otago Peninsula (no sampling along the southern coast) and into Blueskin Bay (gaps at Long Beach and north of Warrington) (Andrews 1973).
- Seaward of this community (and extending into shore in places), hard sand-silty sand bottoms supported an *Antisolarium*[3]-Foraminifera community, extending over 10-27 m depth (rarely from 0 m depth). This community occupied a narrow (c. 1 km) ribbon east of the peninsula, and a much wider (up to 20 km wide) zone within Blueskin Bay.

An investigation of the ostracod fauna of the Otago shelf and coastal waters using the same set of samples noted "the remarkably good correlation between these two sets [ostracods and Andrews' analysis] of assemblages" (Swanson (1979: 42). All eight species of ostracods reported from two stations in the vicinity of Heyward Point and Aramoana grounds occurred more widely within the coastal waters, notably around Blueskin Bay (see Table 3-1). Further, the diversity of the total ostracod fauna at these two grounds was not obviously different from that at other shallow (0-31 m depth) stations (see Figure 3-6). Live specimens found near these two grounds belonged to one species only, *Waiparacythere joanae*, which was also found alive at four other shallow (22-30 m depth) stations (Swanson 1979).

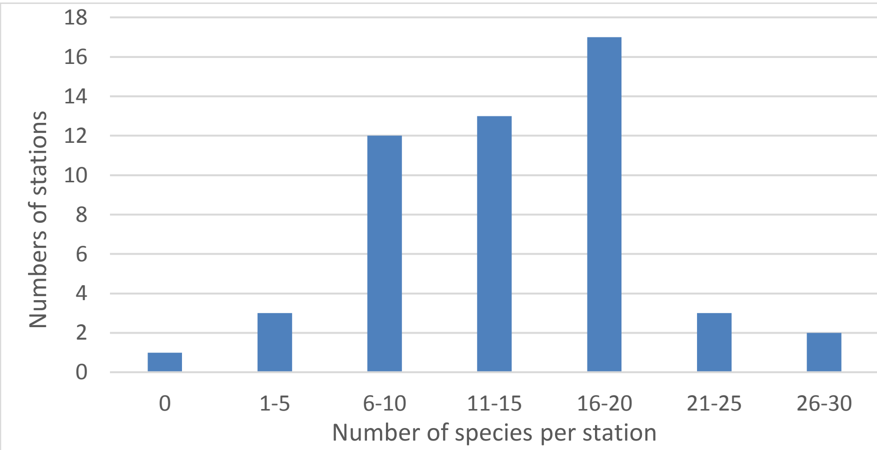

Figure 3-6: Frequencies of total (living and dead specimens) benthic ostracod community diversities (total numbers of species) at inshore (0-31 m depth) stations in Blueskin Bay and off Otago Peninsula. Heywood Point area, 8 species; Aramoana, 4 species. Data from Swanson (1979).

[2] We use the terms community and assemblage as synonyms for the fauna that occurs within an area with similar environmental conditions.
[3] *Zethalia zealandica* and *Antisolarium egenum* are small gastropod molluscs (snails), inhabitants of shallow (5-30 m depth) fine sand bottoms around much of New Zealand.

Table 3-1: Numbers of stations in Blueskin Bay and the Otago shelf at which ostracod species found at Heyward Point and Aramoana grounds were reported as dead and live specimens, and reported depth ranges for live specimens. *, live specimens present. From Swanson (1979); note sampling station 68-55 apparently mislabelled as 68-57 in Appendix.

Species	Number of stations			
	Dead & live specimens		Live specimens	
	Aramoana	Heyward Pt	Total stations	Depth ranges (m)
Bairdoppilata (*B.*) sp.	0	101	7	54-116
Loxocythere crassa	0	79	4	22-25
"Munseyella" aequa	65	65	2	100-128
Munseyella brevis	0	77	8	47-93
Kotoracythere formosa	0	66	9	19-65
Hemicythere munida	102	102	2	5-44
Waiparacythere joanae	79*	79*	5	11-30
Semixestoleberis taiaroaensis	0	68*	5	12-30

Another investigation (focussed mostly on Otago Harbour benthos) confirmed the presence of these two communities and their relative depth distributions, but too few stations were sampled to enhance understanding of the geographic extent of the communities (Rainer 1981). The *Zethalia*-dominated community (8-19 m depth) f comprised 21-37 species and *Zethalia* dominated at mean densities of 147/m^2. In comparison, the slightly deeper *Antisolarium* community (19 m depth) comprised 9-24 species, with *Antisolarium* at mean densities of 57/m^2 (Rainer 1981). The study also revealed that many of the species comprising these two inshore Blueskin Bay communities and present in the vicinity of the placement grounds occurred in some habitats within Otago Harbour.

An investigation of mostly deeper (14-150 m depth) macro-benthos (retained on 2.5 mm mesh) east of Otago Peninsula reported abundant *Antisolarium* at shallower (21-25 m depth), silty stations, and not at the shallowest fine sand stations (14-16 m depth) nor in waters >30 m depth (Probert & Wilson 1984). *Antisolarium* and *Zethalia* were the most characteristic molluscs inhabiting inshore sand in this area (Probert & Wilson 1984), again confirming the widespread distributions of these species and, presumably, of other species usually inhabiting the same environments.

In an intensive, multi-year investigation, Paavo (2007) examined benthos around the Aramoana ground in some detail in 2003. That investigation included experimental deposition effects in full scale, field trials, plus effects on one of the key species. Dredged sediment deposition at this ground averaged 143,350 m^3/y for the five years preceding this investigation (and more during the previous ten years) (Figure 1-1). In assessing the general environment, bottom sediments were generally coarser in shore and finer offshore, all sediments were sell-sorted and low in organic carbon content. Multivariate classification of sampling stations based on sediments distinguished three zones along the on-shore-offshore depth gradient. The macrofauna comprised some 265 taxa (putative species), of which some 28 contributed >60% of abundance, and some 20-50% of taxa were shared between shallower and deeper sampling stations at any one location. Diversity (numbers of species or richness) increased with increasing depth and abundances differed between the two seasons investigated. Mobile amphipod crustaceans dominated the benthos at the Aramoana ground, whereas the small gastropod snail *Zethalia* dominated at the Heyward Point ground. Paavo (2007) noted that the macrofauna differed with depth and sediment particle size composition, with the faunal "assemblages neither homogeneous nor strongly divided" (Paavo 2007: 141). Thus, most species were widely distributed in the Blueskin Bay area, but their actual and relative abundances differed between locations (i.e., scales of 20-100 m) due to local environmental factors. Benthic community compositions changed most markedly at c. 15 m depth: physical environmental factors (wave energy and coarse sediments) were most pronounced at shallower depths, whereas biological interactions exerted greater control over community compositions below this depth (Paavo 2007).

Another investigation of benthos in the area collected three replicate, 0.05 m^2 grab samples from 32 stations in the general area (Willis et al. 2008), providing a detailed understanding of the benthos across Blueskin Bay (see Figure 3-7, Figure 3-8) and distributions of some of the key species. Six inshore stations were within the depth range of the two inshore dredged sediment placement grounds (i.e., 10-25 m depth) are relevant here. These nearshore areas were dominated by well-sorted fine sands (Figure 2-7). The gastropod *Antisolarium* was a consistent and dominant (80% of benthos individuals) element of the benthos at these locations, with densities of 50-100/m^2 (Figure 3-9) over wide areas (Willis et al. 2008). It also extended seaward, albeit at lower densities.

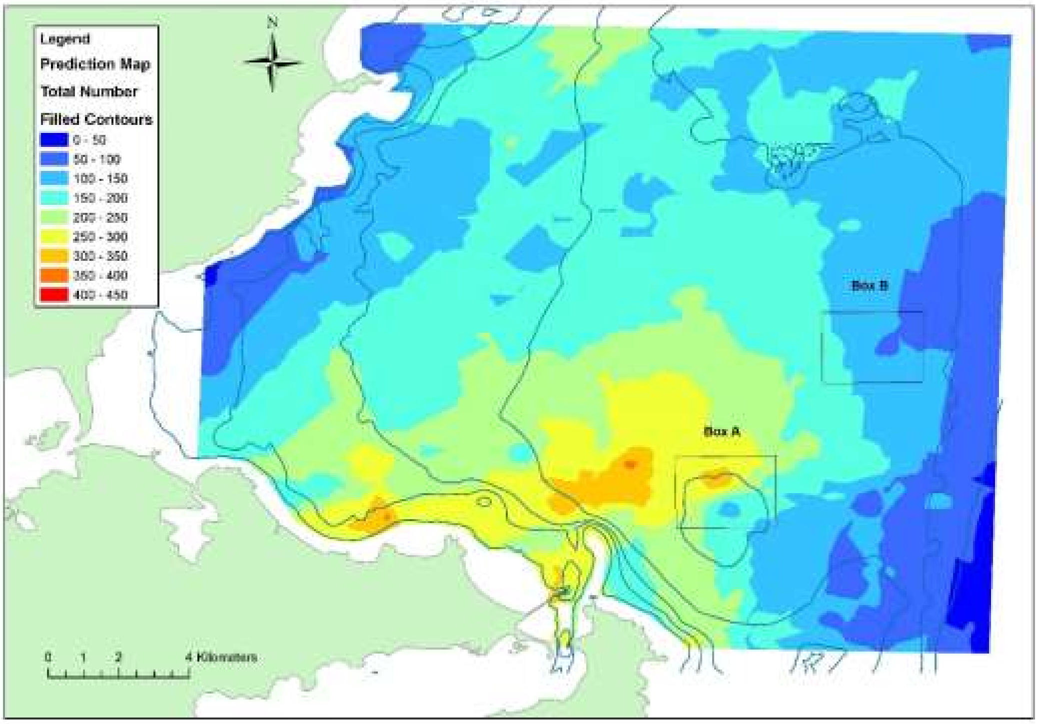

Figure 3-7: Total benthos densities across Blueskin Bay. Densities are numbers per 0.05 m^2 grab sample; boxes A, B not relevant here. From Willis et al. (2008): Figure 16.

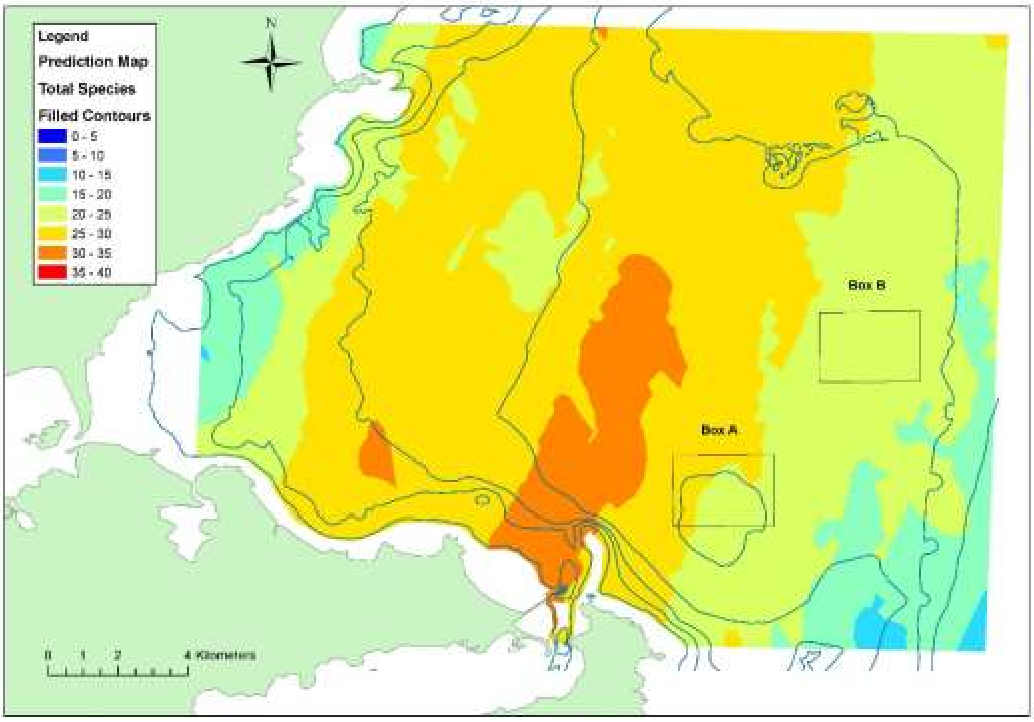

Figure 3-8: Total benthos diversity (number of species) in Blueskin Bay. Boxes A, B not relevant here. From Willis et al. (2008): Figure 17.

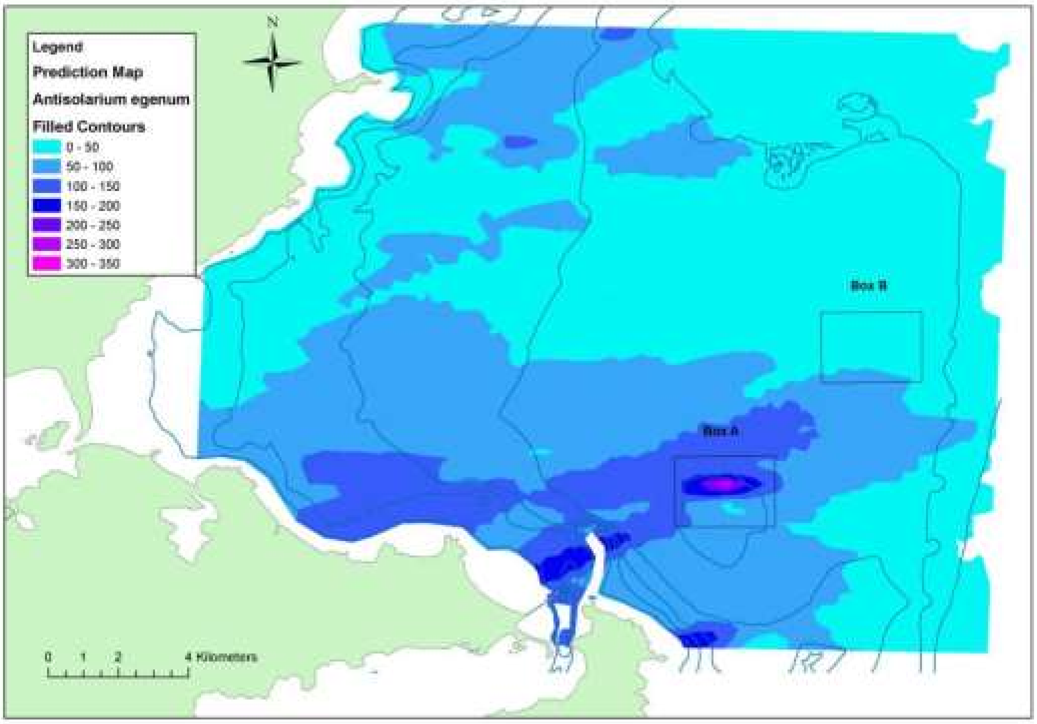

Figure 3-9: Density of the gastropod *Antisolarium egenum* in Blueskin Bay. Boxes A, B not relevant here. From Willis et al. (2008): Appendix 3, p. 42.

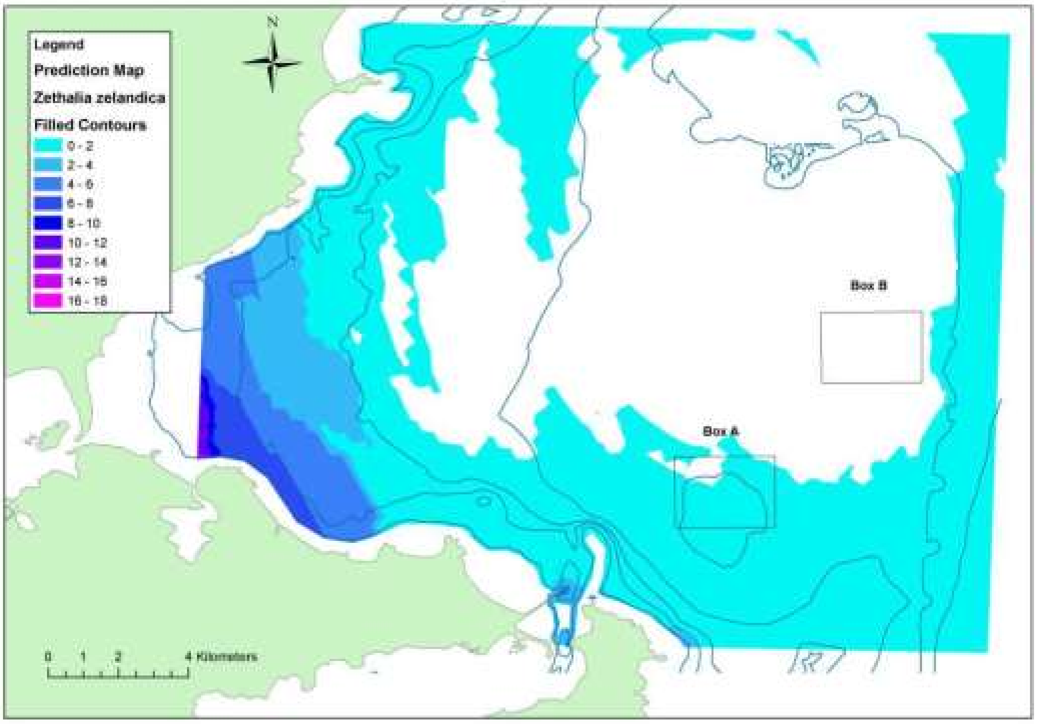

Figure 3-10: Density of the gastropod *Zethalia zelandica* across Blueskin Bay. Boxes A, B not relevant here. From Willis et al. (2008): Appendix 3, p. 53.

Four points from these maps are important.

- The area off the mouth of Otago Harbour and inshore to the north of it appear to support higher densities of benthic invertebrates (Figure 3-7).
- The benthos over much of this area has a higher diversity than areas farther away (Figure 3-8).
- *Antisolarium* dominates in inshore habitats, as well as being a consistent element of the benthos across the whole area and depth range (Figure 3-9).
- *Zethali*a, like *Anisolarium*, occurs across much of the area, but highest densities are close inshore in shallower waters (Figure 3-10).

Perusal of maps for the other 23 species plotted (Willis et al. 2008, Appendix 3) shows that all occur widely across the area and there is no indication of any adverse effects of prior dredged sediment placement at Heyward Point or Aramoana on the benthos. Also, one station (station 24, 22-24 m depth) was close to (c. 100-150 m from northern boundary), but slightly deeper than, the Heyward Point ground, and probably within the proposed enlarged ground. Multivariate analysis of benthos data for these sampling stations showed that inshore areas in southern Blueskin Bay, notably adjacent to both grounds (but slightly deeper) were 55% or more similar (Figure 3-11, Willis et al., 2008).

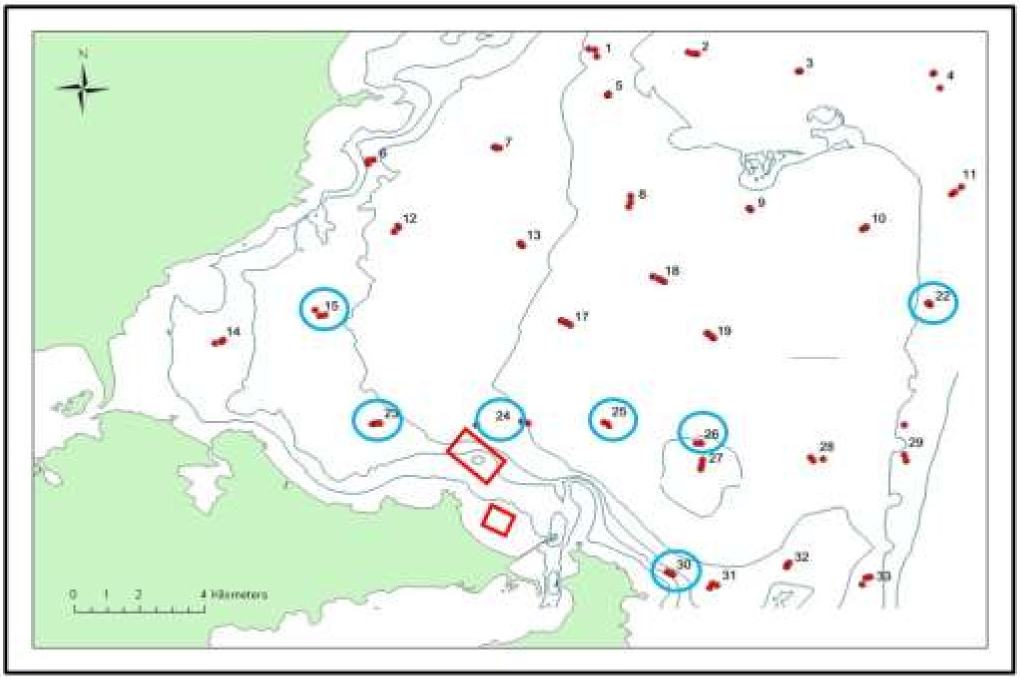

Figure 3-11: Locations of faunistically similar (>55% Bray-Curtis similarity) inshore benthic sampling stations in Blueskin Bay. Red dots, replicate sample locations; numbers, station numbers; blue circles identify stations with similar benthos; red boxes, approx. locations of dredged sediment placement grounds. Modified after Willis et al. (2008) Figure 1.

The Aramoana ground and at least part of the Heyward Point ground are located within the *Zethalia*-Foraminifera assemblage (<9-13 m depth). The deeper (14->22 m depth), seaward portion of the existing Heyward Point ground appears to include some of the *Antisolarum*-Foraminifera assemblage (Andrews 1973; Paavo 2007). Based on the above information, both assemblages appear widespread in the area. The shallower *Zethalia* assemblage appears resilient to sediment disturbance, but intolerant of silt-clay (mud) sediments (Paavo 2011).

Examination of the invertebrate species reported from the overall inshore soft bottom habitats within and beyond the two grounds reveals no species restricted to this area, no communities or associations of benthic invertebrates that hold any special biodiversity value, and no indications that the area of the existing and proposed placement grounds comprises any regionally or nationally significant habitat. The presence of a large stomatopod crustacean is noted (Paavo 2011). This representative of a widespread, yet primitive crustacean group appears to occur in low densities below c. 22 m depth (Paavo 2011), a habitat that is very extensive within Blueskin Bay, and elsewhere around New Zealand.

3.3.2 Actual ecological effects of dredged sediment on the benthos

Previous investigations: Heyward Point

A quantitative, multivariate analysis grouped one inshore station (station 24) with six others (15, 22, 23, 25, 26, 30) based on faunal similarities (Willis et al. 2008). These stations were clustered at >55% similarity (Bray-Curtis measure) reflecting their adaptation to similar environmental conditions and the natural variability of benthic ecosystems. They were 2.5-7 km distant from the ground to the southeast, east and northwest (see Figure 3-11). The similarity of the benthos (at station 24) so close to the deposition ground, indicates that any effects of dredged sediment deposition on the benthos

2.5 km from the ground (i.e., at station 24) were minimal in spatial extent. Further, the stations with benthos most similar (c. 64-69% similarity) to that at station 24 were stations 22 (c. 12 km east) and station 15 (c. 5.5 km northwest).

Another investigation analysed data from 457 benthos samples from unspecified locations in and around both dredged sediment grounds and elsewhere in Blueskin Bay (Paavo 2011). Sampling stations were grouped based on their locations inside, outside and external to, near field, and far field from the Heyward Point and Aramoana grounds, but the distances beyond the boundaries, particularly of external and outside groupings relative to each other and near field and far field, are unclear. Results of that investigation indicate lower benthos densities within the ground relative to those at stations outside the ground boundaries at one time, apparently attributable to dredged sediment placement activities (Paavo 2011; Figure 3-12). However, results of a second sampling revealed similar densities inside and outside for Heyward Point, indicating the appreciable variability in benthos and its recolonisation in this environment.

Benthos diversities exhibited a similar pattern (Figure 3-13). They were low to intermediate within the Heyward ground compared with that at sampling stations outside the ground, except that diversity at far field stations during September were lower than those within the ground (Paavo 2011). That is, benthos diversity in the area is naturally variable, and observed reductions inside the ground were within the range of natural variation, suggesting dredged sediment deposition reduces benthos diversity, but that these reductions are temporary for this environment.

Table 3-2: Comparison of mean benthos densities (numbers of individuals/0.1 m^2) and diversities (number of species) within and outside the Aramoana dredged sediment ground in March and September 2003. Modified from Paavo (2007, Table 4.9).

	Density (individuals/0.1 m^2		Diversity (numbers of species)	
	Within ground	Outside ground	Within ground	Outside ground
March 2003				
Mean	134	375	19	27
Standard deviation	50	185	4	2
N	4	2	4	2
September 2003				
Mean	102	347	19	19
Standard deviation	26	437	9	13
N	3	2	3	3

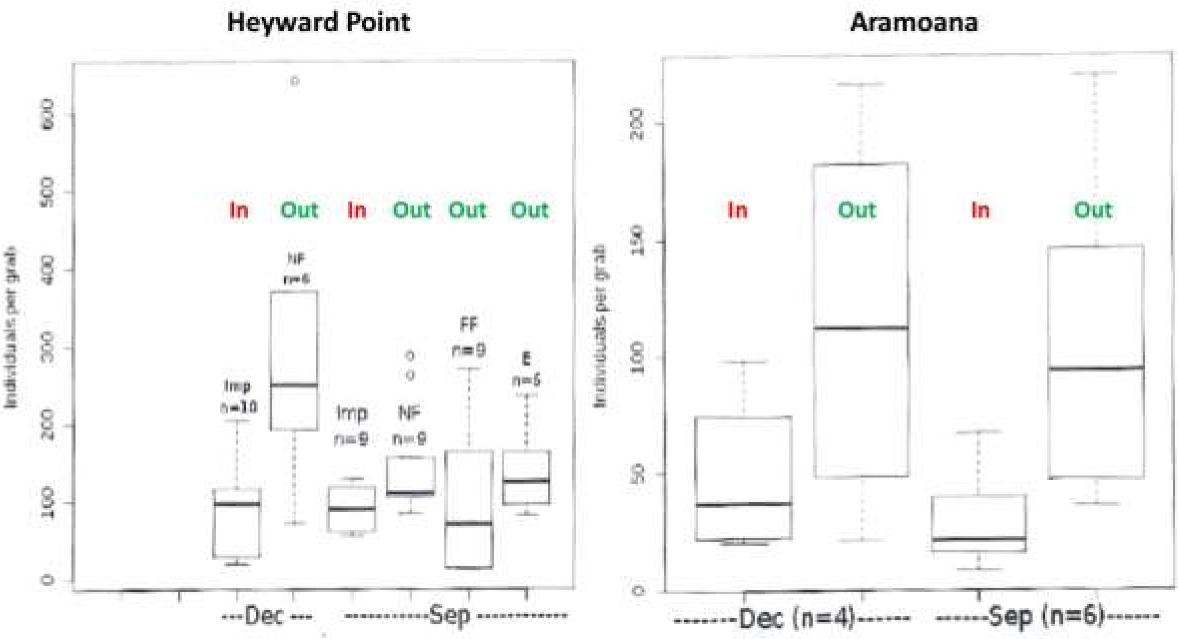

Figure 3-12: Benthos densities (number of individuals per sample) inside (red) and outside (green) the Heyward Point (left) and Aramoana (right) grounds. In, inside deposition ground boundaries (includes impact (Imp) stations); Out, outside ground boundaries (includes near field (NF), far field (FF), external (E) stations). Modified from Paavo (2011, Fig. 25).

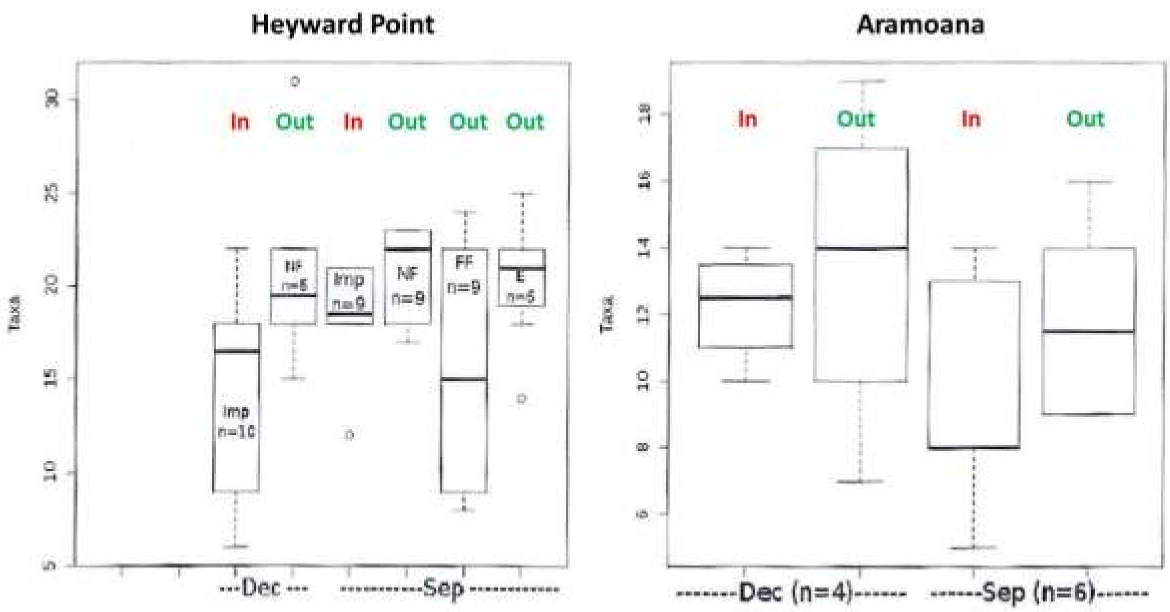

Figure 3-13: Benthos diversities (number of taxa (or species)) inside (red) and outside (green) the Heyward Point (left) and Aramoana grounds. In, impact sampling stations, inside deposition ground boundaries (includes impact (Imp) stations); Out, control sampling stations outside ground boundaries (includes near field (NF), far field (FF), external (E) stations). Modified from Paavo (2011, Fig. 36).

During both samplings, variability or heterogeneity was greatest for benthos outside the grounds and variability at some inside stations overlapped that at some stations outside the deposition grounds (i.e., far field stations, Figure 3-12, Figure 3-13), especially for benthos density, indicating no clear effects of sediment disposal at this ground. Faunal similarities between stations (Figure 3-14; nMDS ordinations of species densities, Bray-Curtis similarities) shows considerable overlap between the fauna at stations inside (I; dashed rings) and outside (O, N, F, E; solid rings) each deposition ground. Conceivably, those inside stations overlapping most with outside stations at both grounds had not received dredged sediment for some time prior to sampling, whereas the distinctly different groups of stations in September (four at Heyward Point; three at Aramoana) and in December (three at Heyward Point; two at Aramoana) were affected by more recent deposition events.

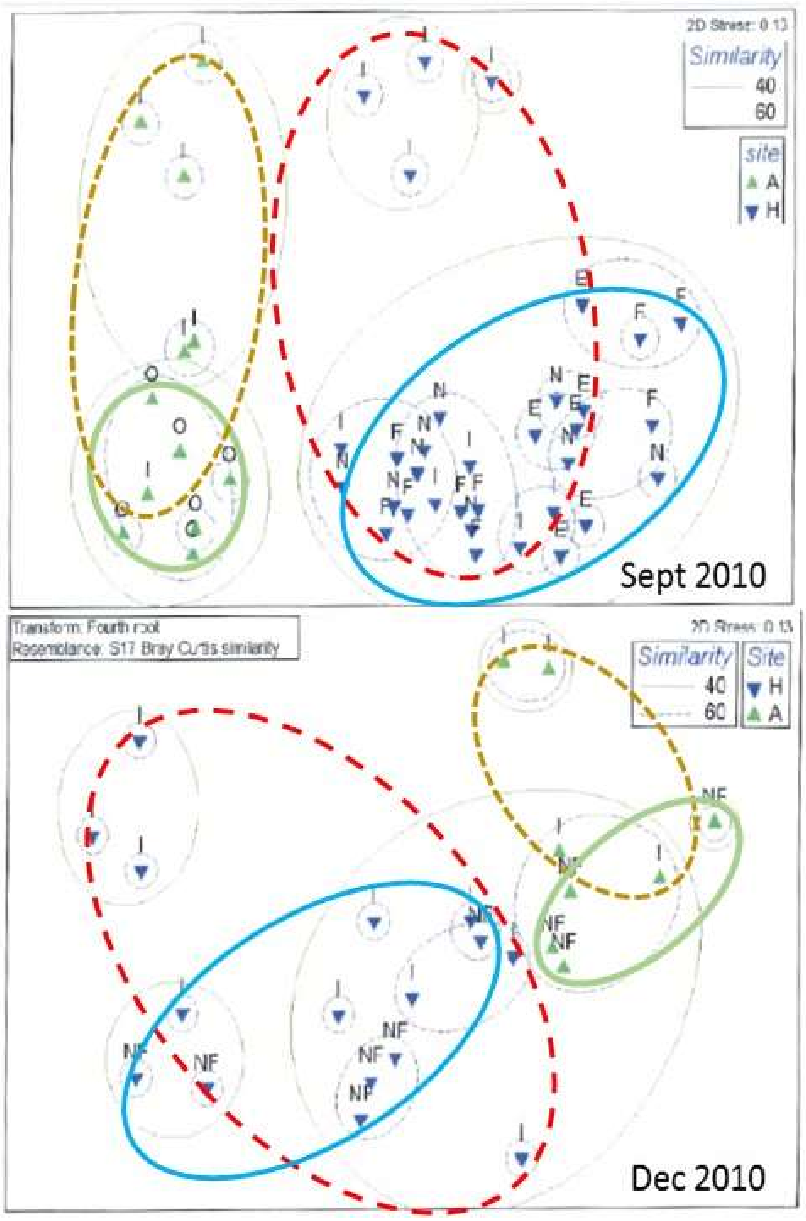

Figure 3-14: Similarities of benthos at the Heyward Point ground (inverted blue triangles) exposed to dredge sediment deposition (I, red ring) and not exposed (O, F, N, E, NF; blue ring) and at the Aramoana ground (green triangles; gold ring, exposed to sediment deposition; green ring, no direct exposure) in September (upper) and December (lower) 2010. Modified from Paavo (2011, Fig. 37).

Previous investigations: Aramoana

Benthos within the Aramoana ground boundaries was less abundant and less diverse than outside its boundaries (Table 3-2; Paavo 2007), apparently a result of dredged sediment deposition.

A large scale field experiment at the Aramoana dredged sediment ground involved no deposition at one end of the site for 12 months, an initial sampling of the sediments and benthos, deposition of c. 600 m^3 of mud and another of sand at adjacent points (sites MC and SC, respectively in Figure 3-4), followed by resampling of sediments and benthos after 5, 12, 26 41 and 119 days (Paavo 2007). Sediment grain size compositions at all sampling stations after 26-41 days were similar to those present prior to the experimental deposition, and to those at control stations (see section 3.1.2).

Results for benthos showed changes between control stations at any one time, as well as between sampling events at each control station (Figure 3-15). Such variability with time is a natural feature of almost all ecosystems, and the seasonal changes reported for benthos in this study (Paavo 2007) probably contributed to the observed changes in this experiment. Benthos at impact stations (notably at MC or mud deposit centre and SC or sand deposit centre) differed from that at control stations, and underwent much greater changes over time than did that at most other stations. Greatest change in similarities were at the sand deposit centre (SC), with benthos at the mud perimeter (MP) exhibiting greater change than that at the mud deposit centre station (MC). Change in the benthos (i.e., similarity) over time was less marked for all other sites (Figure 3-15).

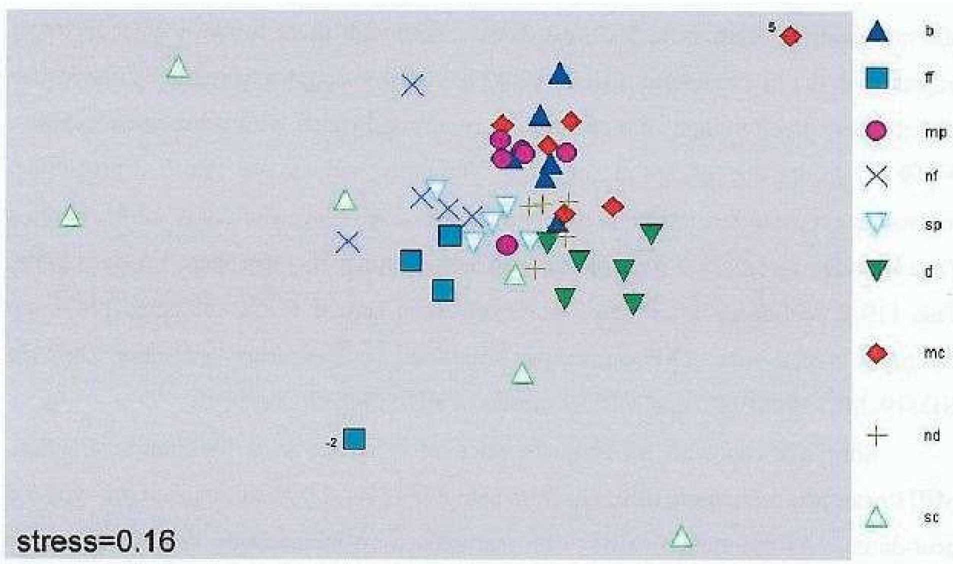

Figure 3-15: Similarities (nMDS plot, pooled replicates, Bray-Curtis similarities) of benthos at the Aramoana experimental sampling sites from before (-2 days) to after (+119 days) deposition of sand and mud at points MC and SC, respectively. D, normal spoil deposition continued; ND, control, unimpacted for >180 days; MC, mud deposit centre; SP, margin of sand deposit, 25 m from SC; B, between, 60 m from MP, 110 m from SP; SC, sand deposit centre; SP, edge of sand deposit, 30 m from SC; FF, NF, far and near-field controls (both never received any dredged sediment). From Paavo (2007, Fig. 5-17).

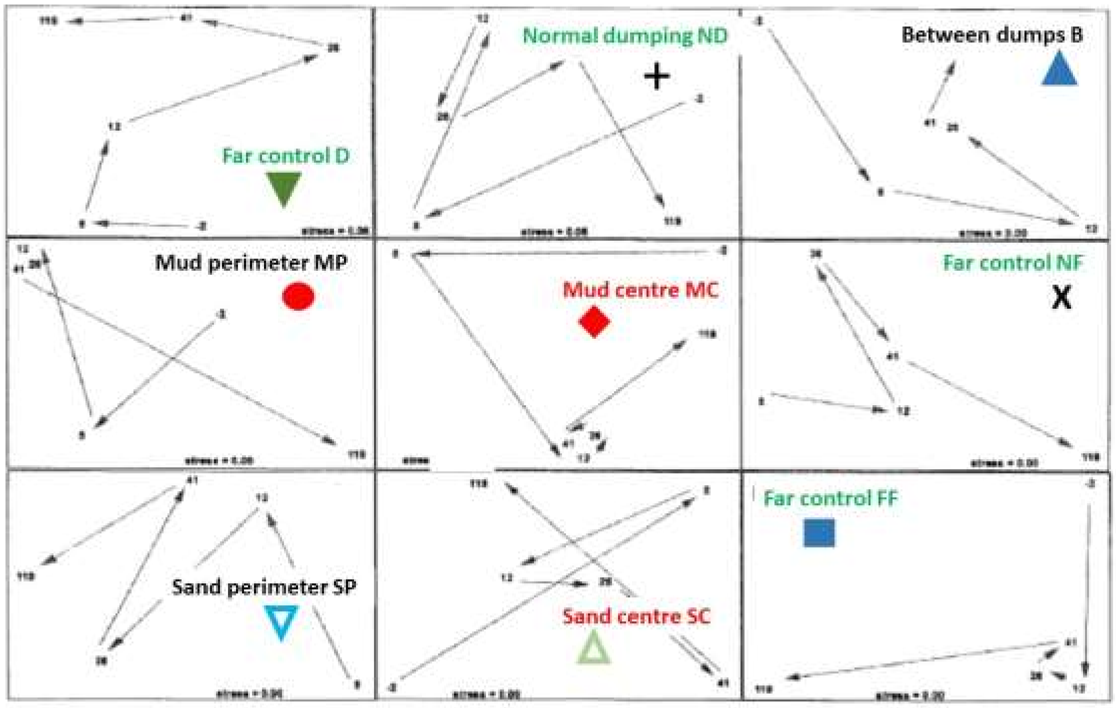

Figure 3-16: Changes in similarities of benthos from before (-2 days) to after (+5-119 days) deposition of sand and mud at points MC and SC, respectively, at each experimental site at the Aramoana ground. Red labels, spoil deposits; black labels, indirect exposure to spoil; green labels, no exposure. D, normal dredgeate deposition continued; ND, control, unimpacted for >180 days; MC, mud deposit centre; SP, margin of sand deposit, 25 m from SC; B, between, 60 m from MP, 110 m from SP; SC, sand deposit centre; SP, edge of sand deposit, 30 m from SC; FF, NF, far controls, never received any dredged sediment. Coloured symbols are those used in Figure 3-15 above. Modified from Paavo (2007, Fig. 5-16).

Plots of similarities of benthos at individual sampling stations at times (Figure 3-16) reveal that the magnitude of change varied widely between sampling times, including for control stations (note, scales differ between these plots for each station; Figure 3-15 shows the magnitude of changes over time (undefined) for each station relative to changes at other stations). These plots also indicate that benthos recovery over time does not mean a return to pre-deposition community composition, but to some other state, demonstrating the naturally variable and dynamic nature of ecological communities. An analysis of the benthos recovery process at the Aramoana ground indicated greatest heterogeneity (patchiness or differences between replicate samples at any one place) over 2-12 days after dredged sediment is deposited, with variability decreasing from day 12 until at least day 119 (Paavo 2007).

Benthos in the vicinity of the Aramoana ground was generally lower in density and diversity than outside the ground (Paavo 2007). The effects of experimental deposition of sand and mud were detectable up to 20 m from the centre of the dredged sediment deposit, but undetectable 30 m away, and the benthos at the centre of these deposits was similar to that present pre-placement after just 12 days (Paavo 2007). Simple re-colonisation and the ability of at least some species (notably *Zethalia*) to survive and emerge from burial, appear to underlie this rapid recovery.

The subsequent investigation focussed more closely on dredged sediment deposition effects on benthos at both grounds (Paavo 2011) confirmed these findings. Benthos densities within the deposition ground were appreciably lower during both samplings (Figure 3-12) and diversities were slightly lower (Figure 3-13). Plotting station similarities based on benthos composition at each station revealed low similarities (<40%) between most inside and outside sampling stations on both sampling occasions (Figure 3-14). As with the Heyward Point stations, the exceptions probably result from inside stations that had not received any recent dredged sediment (one in September, two in December 2010). This finding confirms that the effects of dredged sediment deposition tends to be relatively localised, rather than widespread.

3.3.3 Potential effects on kelp beds

Fine suspended sediment poses a significant threat to kelp forests and the associated algal communities (e.g., Desmond et al. 2015), as well as to other marine algae and invertebrates. Mean daily light reaching 10 m depth along the Otago coast (land use predominantly agriculture) was half that reaching the same depth off forested coasts on eastern Stewart Island (mostly undeveloped native forest), with total kelp biomass 20-30% and individual plant biomass 16-20% of those on the forested coast (Desmond et al. 2015). Similar, but less marked, differences were reported at 2 m depth.

The threat to kelp forests posed by spoil deposition at the Heyward Point and Aramoana grounds is uncertain, but apparently low under the recent operational regime. Suspended sediment plumes are generated by silt deposition events and, to a lesser extent, by subsequent reworking of recent deposits. Modelled depositional footprints (after 24 hours) for passive plumes generated during deposition (Figure 3-2, Figure 3-3) show the extent of dispersion at the sea floor. Modelled dispersion for passive plume sediments at the sea surface, at mid depths and the sea floor (Figure 3-17) indicate that only a small proportion (<1%) of the sediment released remains in suspension beyond these depositional footprints for both types of dredges (MetOcean 2015).

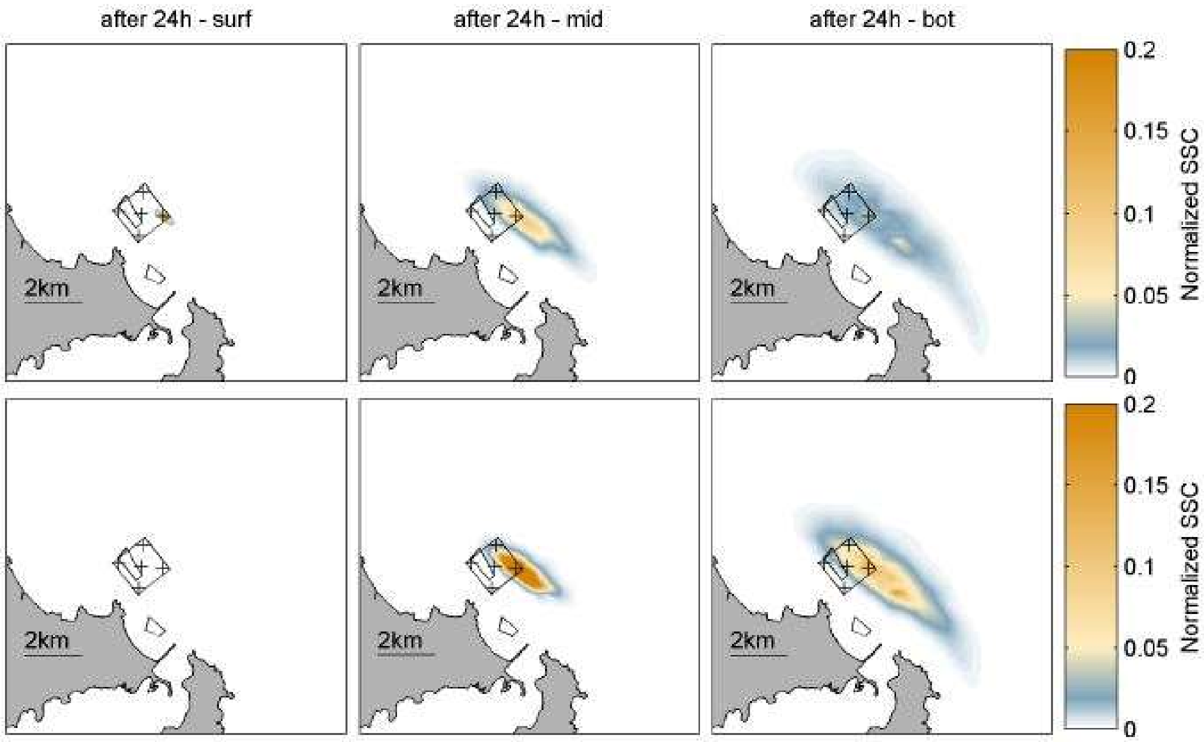

Figure 3-17: Normalised concentrations (proportions) of the total passive plume persisting as suspended sediment at the surface (surf), mid depth (mid) and sea floor (bot) 24 hours after release. Sediment released at site 2 (northeast corner of proposed enlarged Heyward Point ground) from dredge New Era (top) and Trailer Suction Hopper Dredge (bottom). From MetOcean (2015: Figure 3.5).

Several important points must be noted in interpreting these plots of modelled suspended sediment dispersion from release of dredged silty sediment. First, the actual proportion of sediment entrained into a passive plume is unknown, although estimated at c. 10% of the load released (MetOcean 2015). Second, concentrations of suspended sediments are plotted as proportions of the passive plume. Third, the actual plume dispersal is greater for the TSHD than the New Era because its passive plume is much larger (i.e., 22,000 cf. 600 m^3/load (MetOcean 2015)), even though its sediment load is discharged at a greater depth (c. 7 m cf. c. 2 m for New Era). Fourth, this means that the coloured contours in this figure represent quite different suspended sediment concentrations between rows (dredges):, blue contours or 0.02 normalised SSC in Figure 3-17 represents a c. 37 times greater concentration for the TSHD's plume than for the New Era's plume.

The long history of deposition of the same volumes of much the same types of sediments on these grounds suggests that, even if the dredge passive plumes contributed to the turbidity of waters around the kelp forests, continued deposition under an equivalent operational regime is unlikely to have any further effects on them. This is the case at least for suspended sediment plumes resulting from the New Era's operations. Plumes from a larger dredge, such as the TSHD, or from a dredge with different discharge characteristics, however, may be quite different. In the case of the TSHD, passive plumes are much larger, probably take longer to settle, disperse more widely and, therefore, have greater potential to alter the critical light environment for kelp forests and other benthic macroalgae around Blueskin Bay than do plumes from the smaller New Era.

3.4 Ecological assessment of suitability for future dredged sediment placement

The Aramoana ground and at least part of the Heyward Point ground are located within a shallower, hydrodynamically active zone where storm waves periodically disturb the seabed. Sediments deposited here are dispersed more widely (MetOcean 2016) and benthos associated with these shallow sediments appear very resilient, recolonising (or re-emerging from under) deposited sediments within 12 days. The benthos inhabiting areas receiving successive dredge material deposition over decades appear faunistically similar to nearby areas that receive no dredged sediment (Paavo 2011). Based on the available literature summarised here, continued placement of up to 100,000 m^3 per year of predominantly fine sand sediments at the Aramoana site seems unlikely to have any significant adverse ecological effects on the benthic ecosystem beyond the ground's boundaries.

The benthos within and adjacent to the Heyward Point ground and its resilience to sediment deposition is less well known. Part of the ground is within the shallower hydrodynamically active environment, and its benthos, like that at the Aramoana ground, is well adapted to periodic disturbance events, such as burial. Deeper parts receive less disturbance from wave action and currents, and the benthic community inhabiting these finer sediments occurs over large areas of Blueskin Bay. Dominated by deposit-feeding invertebrates, this community is not as well adapted to burial, but the more moderate hydrodynamic environment seems likely to result in rapid recolonization of newly deposited dredgeate by immigrants from the very extensive equivalent community in the immediate vicinity (Hewitt et al. 2003; Bolan et al. 2006; Paavo 2011).

Certainly, dredged sediment deposition alters the benthos within the immediate area of the deposit, but this is localised, short-term and small relative to the total area of similar benthos within Blueskin Bay. Thus, based on the information reviewed in this report, continued delivery of up to the currently consented volumes of sediments within the presently consented ground is unlikely to have any adverse effect on the benthic communities in the general area. Similarly, depositing up to 300,000 m^3 per year of mostly sand across the proposed enlarged ground at Heyward Point (c. 13 cm/year or <3 mm/week over the whole, enlarged ground, on average) is less likely to have any substantive adverse ecological effect on benthic communities beyond the boundaries of this proposed enlarged ground. Both assessments assume that the passive suspended sediment plumes generated by future operations will be no larger nor more concentrated than those generated during operations over the last decade (i.e., by the dredge New Era). The effects any future changed dredging regime are not necessarily adverse, rather they are unknown. Thus, any proposed changes to dredging operations should be carefully evaluated in advance and the effects of implementation monitored via the established adaptive management regime.

4 Recommendations: mitigation, adaptive management and monitoring

Four main factors determine the effect of dredge material deposition on coastal benthos (Bolam et al. 2006): the nature of the receiving environment, the nature of the deposited sediment, volumes of material and the frequency of its deposition. Two operational factors also appear important, especially for benthic algae and probably for some sessile invertebrates. Dredged sediment load size and depth of load release appear important in determining the concentration of suspended sediment in the passive plume and the plume's total size.

We recommend continuing to use these two grounds because of their historical use. Both grounds, particularly Aramoana and the shallower parts of Heyward Point, are naturally hydrodynamically very active (MetOcean 2016). This means that their benthic faunas are pre-adapted to physical disturbance (e.g., Bolam & Rees 2003), making these communities more resilient (i.e., likely to recover more rapidly) to periodic spoil deposition events.

We recommend that each ground receives dredged sediments that are similar to those naturally present, following previous practice: fine sand only should be deposited at Aramoana; shallower (< c. 14 m depth) areas of the Heyward Point ground should receive only fine sand, deeper (> c. 15 m depth) areas should receive mostly silts. Any aggregate or rock material should be concentrated at a single, deeper (c. 25 m depth) location where its effect on sediment hydrodynamics will be minimal. We understand that dredge material is essentially similar to equivalent sediments at these grounds in other respects (organic content, other contaminants).

We support increasing the size of the Heyward Point ground to mitigate any effects of dredge material deposition at that ground. In the absence of more detailed knowledge on the resilience of benthos inhabiting deeper parts of this ground, a precautionary approach seems warranted. The proposed, enlarged area (

Figure 1-3, Figure 4-1), combined with an appropriate dredge material deposition plan, will reduce the volume of material received per unit area and the frequency with which it arrives, reducing two other determinants of the effects of dredge material on marine benthos (Bolam et al. 2006). Further, the recommended placement regime is appropriate because it will deliver dredged sediment at frequencies directly linked to location-specific hydrodynamics and, hence, the ability of the benthos to recover from deposition events.

For the same reasons, we support enlarging the Aramoana ground as a rectangle oriented parallel to shore. This enlargement will slightly reduce annual average deposition, as well as facilitating an ecologically, less disruptive placement regime.

Optimal placement strategies for minimising ecological effects of dredge sediment deposition operations on benthic ecosystems may involve concentrated or dispersed deposition. Concentrated placement minimises the area affected, but the ecological effects within that area may be greater. On the other hand, dispersed placement affects a larger area, although the effect may be less severe. We suggest that more, smaller deposition events spaced as widely as practical will have less overall impact on benthic ecosystems than fewer, larger deposition events. Our reasoning is based on consideration of three factors (and others also may be important). First, smaller sediment deposits will result in shallower over-burden (from the active plume), allowing more of the buried fauna to migrate to the new sediment surface. Second, re-colonisation of new deposits will be quicker for smaller patches than for larger ones because coloniser populations are in closer proximity to the deposits (greater perimeter length/unit area). Third, modelling results revealed that passive plumes and their deposition footprints from the TSHD are much larger than those from the New Era, indicating disproportionately greater areas of the benthos will be affected. For these reasons, we recommend using a smaller dredge for maintenance dredge sediment deposition at these grounds, as far as practical, especially in the longer term.

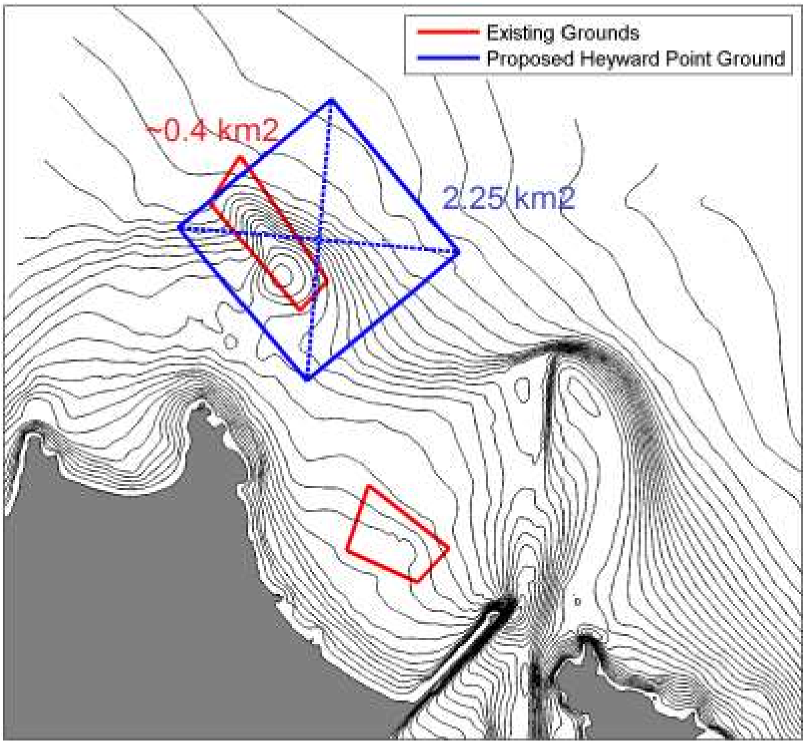

Figure 4-1: Existing dredged sediment disposal grounds (red rhomboids) and proposed enlarged ground (blue square) incorporating the existing Heyward Point ground. Courtesy of Port Otago Ltd.

We recommend an adaptive management regime to ensure that any unforeseen effects (e.g., resulting from dredgeate deposition within new parts of the Heyward Point ground) are detected early and addressed collaboratively with stakeholders. Monitoring of the soft-bottom benthic communities in the general area should be part of this management regime, as described by Fenwick & Stenton-Dozey (2015). Monitoring of benthic communities (e.g., kelp forests, rocky reef benthos) farther afield seems unwarranted, unless there is an appreciable change to sediment plumes generated during dredged sediment release and deposition on these grounds.

From an ecosystem perspective, management of dredge material effects should not focus on restoring the previous benthic communities. Instead, the primary concern is ensuring ecosystem complexity (biodiversity), resilience (ability to variously recover from future unpredictable change) and ecosystem functioning are maintained, so that the affected area is sufficiently productive to support other biodiversity, notably higher trophic level organisms, such as fishes. Indicator species can be useful, but provide single measures only of complex ecosystems that vary naturally in time and space. Benthic community measures, thus provide more robust and meaningful measures for monitoring the ecological effects of dredge material deposition at these two sites (see Fenwick & Stenton-Dozey 2015).

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