PORT OTAGO LIMITED

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30th May 2011

Otago Regional Council
Private Bag 1954
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OTAGO REGIONAL COUNCIL
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31 MAY 2011
FILE No. RM...
DIR TO ...

Attention : Suzanne Watt

Dear Suzanne,

RE Application for renewal of resource consent – Disposal of Dredged Material

As per our discussion of earlier today please find enclosed with this letter the application form and supporting AEE for the renewal of resource consent. Appended as part of the AEE are the supporting scientific reports authored by the experts. I have also included the $5,000 deposit cheque.

If you have any queries, please do not hesitate to contact myself or Mary O'Callahan from GHD Christchurch.

Yours sincerely

Lincoln Coe
GM Infrastructure

PO Box 8, Port Chalmers, New Zealand. Telephone 03-472-7890, Facsimile 03-472-7891
Email pol@portotago.co.nz

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Port Otago Limited

Disposal of Dredged Material

Application to Renew Resource Consent

May 2011

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

Contents

Figure Index

Appendices

1. Form 9

APPLICATION FOR RESOURCE CONSENT UNDER SECTION 88 OF THE RESOURCE MANAGEMENT ACT 1991

TO: Otago Regional Council
70 Stafford Street
Private Bag 1954
Dunedin 9054

Port Otago Limited applies for resource consents to authorise the disposal of dredged material within the Otago Harbour.

1. **The type of resource consent sought is as follows:**

   Coastal permit.

2. **Description of the activity to which this application relates:**

   The disposal into the sea of up to a maximum of 450,000m^3 per year of dredged material for the purpose of disposal of material derived from dredging the channel and berth areas in and about the Otago Harbour in accordance with the following specific maximum annual discharge quantities at each location:

   (i) Heyward Point 200,000m^3

   (ii) Aramoana Spit 200,000m^3

   (iii) Shelly Beach 50,000m^3

   A term of 3 years is sought for this coastal permit. The proposed activity is the same as that permitted by Consent No. 2000.472. A detailed description of the activity is included in the attached application.

3. **The owners and occupiers of land to which the application relates are:**

   The land to which the application relates is Crown land.

4. **The location to which this application relates is:**

   The locations to which this application relates are:

   (i) Heyward Point, being an area of approximately 38.2 hectares.
   45° 45.07'S 170° 42.09'E
   45° 44.95'S 170° 42.27'E
   45° 44.44'S 170° 41.78'E

45° 44.63'S 170° 41.60'E

(ii) Spit Beach, being an area of approximately 28.3 hectares.

45° 45.18'S 170° 42.74'E

45° 46.05'S 170° 42.93'E

45° 45.72'S 170° 42.47'E

45° 46.04'S 170° 42.47'E

(iii) South Spit Beach (Shelly Beach), being an area of approximately 14.5 hectares.

45° 46.82'S 170° 42.56'E

45° 46.65'S 170° 42.79'E

45° 46.75'S 170° 42.96'E

45° 46.95'S 170° 42.77'E

5. The following additional resource consents are required in relation to this proposal:

Nil. This consent will replace Consent No. 2000.472 which is due to expire on 1 December 2011, or alternately any substitution of Consent No. 2000.472 as a result of the current application to amend that consent (as part of the Project Next Generation suite of consents).

6. The following information is attached:

In accordance with the Fourth Schedule of the Resource Management Act 1991, an assessment of environmental effects in sufficient detail that corresponds with the scale and significance of the effects that the proposed activity may have on the environment has been attached.

Furthermore, any information required to be included in this application by the Otago Regional Plan: Coast, the New Zealand Coastal Policy Statement 2010 and the Resource Management Act 1991, or any regulations made under that Act, has been attached.

Signature: Port Otago Limited

By

____

Lincoln Coe

Date: 30 May 2011

Address for service: PO Box 8
15 Beach Street
Port Chalmers
Attention: Lincoln Coe

Telephone: (03) 472 7890
Fax: (03) 472 7891

Email: lcoe@portotago.co.nz

2. Introduction

Port Otago Limited is seeking a short-term replacement consent to allow for the continued disposal into the sea of up to 450,000m³ per year of dredged material. This will extend the current coastal permit, 2000.472, which expires in December 2011, or alternately any substitution of Consent No. 2000.472 as a result of the current application to amend that consent (as part of the Project Next Generation suite of consents). Port Otago is seeking to continue to dispose of dredged material in accordance with the terms and conditions currently applying to coastal permit 2000.472 or as amended by the current change of conditions application to incorporate material derived from capital dredging, in addition to that arising from permitted maintenance and incremental improvements.

A term of three years is being sought for the consent. After this time, it is intended that a 35-year disposal consent will be sought. This will allow for a suitable long-term consent framework and monitoring programme to be developed which takes full account of both the historic maintenance dredging disposal and disposal associated with maintaining the deeper channel sought through the Project Next Generation resource consents (consent numbers 2010.193-200, 2010.202-203, RM10.193.01 and 2000.472-V1) which are currently under consideration by Otago Regional Council (ORC).

3. Existing environment

3.1 Otago Harbour

Otago Harbour is a long and narrow inlet aligned SW-NE. The harbour is approximately 21km long, 2km wide and has a mean surface area at high spring tides of 46km².

Peninsulas at Port Chalmers and Portobello and their adjacent islands divide the harbour into an upper and lower basin. The harbour is relatively shallow with an average depth of 3.3m below mean sea level. Outside the main channels water depths are mostly less than 2m and nearly 30% of the harbour comprises exposed sediment flats at low spring tides.

The main channel between Port Chalmers and Dunedin is maintained to a depth of 7.5m below Chart Datum but from Port Chalmers to the entrance the channel depth is maintained at 13m with a 14.5m depth outside the Mole (depths relative to Chart Datum).

The only other naturally deep areas (>20m) are several holes in the main navigation channel from Harrington Bend to the Mole and between Quarantine and Goat Islands (up to 30m in depth). The shipping channel extends along the western shore for much of the harbours length.

3.2 Disposal sites

Dredged material is disposed of at three sites.

3.2.1 Heyward Point

Heyward Point is the northern most disposal site. The site lies in waters varying from 9 to 23 metres deep off the cliffs and rocky reefs of the Heyward Point headland. Approximately 437,484m³ of material has been deposited at Heyward Point over the last 10 years, with 1.5M m³ in total having been deposited here over the past 26 years.

3.3 The Spit

The Spit site is also known as the Aramoana site. It lies in waters varying from 6 to 12 metres in depth and is seaward of the Aramoana beach and "The Spit" surf break. "The Spit" is a nationally recognised surf break in the New Zealand Coastal Policy Statement 2010.

Approximately 745,369m³ of material has been deposited at The Spit ground over the last 10 years, with nearly 3.3M m³ in total having been deposited here over the past 26 years.

3.3.1 South Spit (Shelly) Beach

The South Spit (Shelly) Beach site is the inner-most disposal site in Otago Harbour. It is a shallow disposal site in around 3-8 metres of water.

A number of sand beaches in the Dunedin area are subject to either long-term or short-term natural erosion of sediment volume. At present Port Otago Ltd places dredged material in the nearshore off Shelly Beach to offset losses of sediment from the narrow dune system of the South Spit.

The quantity of sand placed off Shelly Beach is resulting in gradual shoaling of the nearshore, maintenance of a small foredune and some growth of the dune system. The work to date is fulfilling the desired purpose of mitigating erosion that was prevalent during the 1980s and early 1990s. Over the last 10 years, some 237,092m³ of dredged material has been deposited at the Shelly Beach site.

3.4 Coastal processes and environment

A map showing the disposal areas is attached as Appendix A and a detailed discussion of the coastal environment surrounding the 3 disposal sites is contained within Appendix C.

3.5 History of disposal in Otago

The first dredging in Otago Harbour occurred just after the Otago gold rush in 1865 when convict labourers manned a small travelling grab dredge to deepen alongside of jetties in the Dunedin basin. Since that time, the harbour has undergone major development including the dredging of shipping channels, basins and berth pockets, the reclamation of large areas of foreshore and the construction of many wharves and jetties. Other works such as the stabilisation of the entrance channel with the construction of the Mole and placement of various rock groynes to train the tidal flow have also been carried out to assist in maintaining channel position. All of this work has been carried out to service the region by enabling shipping to progressively continue to meet the demands for world trade.

The initial development of the channels and berth areas involved dredging large quantities of material. Much of this material was able to be utilised to form reclamations around the foreshore of Dunedin, with reclaimed land now encompassing the shoreline from Anderson's Bay to Logan Park. As reclamations were completed, the only other economical option for disposal of dredged material was to take it out to sea to deposit it back to where much of the material had come from. This practice has been carried out since at least 1882 when attempts were first made to deepen the sand bar at the entrance to the harbour.

Prior to 1985 all dredged material was placed at the Heyward Point site. This included material derived from both development and maintenance dredging. In 1985, the Spit disposal site was first used and this has since become the preferred location in recent years because it is closer, resulting in the dredge spending less time going to and from the disposal site and it reduces the amount of material needing to be disposed of at the Heyward Point site. However the Heyward site continues to be preferred in rough weather as it can often be calmer than the Spit site due to the greater depth of water available.

A third location, South Spit (Shelly) Beach was added as a further option in 1987. Sediment was placed here to assist in re-nourishing Shelly Beach which was suffering from erosion. The site has a limitation in that only sand from claims seaward of and including Taylers Bend is able to be disposed of there to ensure that material moving onto the beach is of a similar composition to the sand that already exists there. Shelly Beach has been a useful location when the weather has been too rough to take the suction dredge out to sea, although this only occurs on a few days each year. There is also a limit to the quantity of sand that can be disposed at this site, as whilst the sand does get gradually moved onto the beach during calmer weather, it is moved eastwards along the beach during periods of more extreme events leading to erosion. Some sand placed at Shelly Beach eventually gets carried across the rock groyne at the eastern end of the beach on the flood tide to be deposited further up the harbour. Therefore this site has been used sporadically at times as the beach dunes have stabilised and also because the site is limited to disposing at or near high water to maintain a safe under keel clearance for the dredge.

As with other tidal ports all around the world, the channels and basin areas within Otago Harbour need ongoing dredging to maintain the depths obtained. Disposal at sea is the key economically viable way to dispose of dredged material. A detailed discussion on alternatives is provided in Section 4.4 of this report.

3.6 The siltation process

The littoral drift system sees sediment transported up the coast of the South Island by the prevailing currents. A proportion of the sediment being transported past the harbour is ducted into the harbour on the flood tide and whilst some of this material is also transported out of the harbour on the ebb tide, there is a net retention of material within the harbour. This sediment is moved progressively up the harbour channel towards Dunedin, with deposition occurring on the insides of the bends and also within areas where the channel is wider and the current strength is thereby reduced.

Another factor in the siltation process is wave action which is responsible for putting into suspension fine silt and clay sediments from the large area of shallows. Tidal and wind generated currents carry this suspended material, some of which is deposited into the upper Dunedin basin area where tidal and wave action is weak. Where the sea bed gradients are steep around the harbour basin perimeter, there is a secondary means of moving sediment by gravity into the basin and berth areas.

Fine silts also enter the harbour during periods of heavy rainfall via the Leith River and the many small creeks and stormwater drains that also discharge into the harbour.

It should be noted that whilst not part of the natural siltation process, the sides of dredged channels also contribute some material that needs to be dredged to maintain an efficient channel. It has been noted that any development phase of dredging has generally always been followed by increased maintenance dredging requirements until the side slopes settle to their natural angle.

Port Otago carries out at least annual hydrographical surveys to identify areas of sedimentation which then determines its annual maintenance dredging program.

4. The proposal

4.1 The proposed activity

Port Otago Limited is seeking a short-term replacement consent to allow for the continued disposal into the sea of up to 450,000m³ per year of dredged material. This will replace the current coastal permit, 2000.472, which expires in December 2011, or alternately any substitution of Consent No. 2000.472 as a result of the current application to amend that consent (as part of the Project Next Generation suite of consents). Port Otago is seeking to continue to dispose of dredging material pursuant to the terms and conditions applying to coastal permit 2000.472.

The material is derived from dredging of the channel and berth areas in and about the Otago Harbour. It is proposed to be carried out in accordance with the following specific maximum annual discharge quantities at each location:

Heyward Point, being an area of approximately 38.2 hectares, to receive up to 200,000m³ of material

45° 45.07'S 170° 42.09'E

45° 44.95'S 170° 42.27'E

45° 44.44'S 170° 41.78'E

45° 44.63'S 170° 41.60'E

Spit Beach, being an area of approximately 28.3 hectares, to receive up to 200,000m³ of material

45° 45.18'S 170° 42.74'E

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45° 45.72'S 170° 42.47'E

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South Spit Beach (Shelly Beach), being an area of approximately 14.5 hectares, to receive up to 50,000m³ of material

45° 46.82'S 170° 42.56'E

45° 46.65'S 170° 42.79'E

45° 46.75'S 170° 42.96'E

45° 46.95'S 170° 42.77'E

4.2 Disposal records

The actual volume of material deposited at each of the sites has varied over the years. Disposal records for the last 26 years are attached as Appendix B. Earlier disposal records are detailed in a report prepared by David Lusseau in October 1999, entitled "A Review of Dredging Activities in Otago Harbour and their Relocation: 1899 – 1998". Key facts from the Lusseau report are:

- Records do not clearly quantify where material was disposed of prior to 1914, although we know much was relocated to reclamations or otherwise taken to sea.

- Between 1914 and 1971, material dumped at sea was described under various hearings, i.e. "Heads", "At Sea", or Heyward Point, although it is thought that most of this material was disposed in the vicinity of Heyward Point (13.5M m^3 1914 – 1998).
- Until the early 1970s much of the dredge material was relocated to reclamations in Dunedin, which also includes volumes listed as "Vulcan's Pit" (8.7M m^3 1914 – 1998).
- The significant quantity disposed of, to a dump site at sea, was in 1976 when 3.3M m^3 of material was dumped at Heyward Point, following development dredging of the lower harbour channel. This disposal site was subsequently moved seaward to allow this large volume of material to disperse.
- Following the 1976 development of the lower harbour channel and berths, the disposal quantities was high for a number of years, as side slopes stabilised, with a maximum quantity of 0.63M m^3 disposed of at Heyward Point in 1982.
- The Spit disposal site was established and first used in 1985 as an alternative and closer site.
- The South Spit (Shelly) Beach site was established in 1987 after discussions with the Department of Conservation to address the erosion (or lack of sand supply) at this site.

The information contained in Appendix B is a summary of the last 26 years of disposal (i.e. from 1985 to 2010). It has been observed, that whilst the main dredge has worked out of port on several occasions over recent years and had several periods of extended layup, there has been a decrease in the amount of dredging carried out in the most recent 10 year period. The key facts are summarised below:

- The average annual quantity of material disposed of at sea (over the 3 disposal sites) over the last 26 years is 203,852m^3. Over the last 10 years the total average was 141,995m^3.
- The maximum annual volume disposed was 367,116m^3 in 1988. The maximum annual volume during the term of the last consent was 257,524m^3 in 2000.
- Over the last 26 years, the breakdown of material going to each of the sites was on average:
  - Heyward Point = 29%
  - The Spit = 62%
  - South Spit (Shelly) Beach = 9%
- Over the recent 10 year period the amount of material disposed of at the Shelly Beach site has increased, which has altered the split, as follows:
  - Heyward Point = 31%
  - The Spit = 52%
  - South Spit (Shelly) Beach = 17%

Disposal quantities at Shelly Beach have been up and down over the last 20 years that it has been used. With the more recent disposal to this site combined with the calmer weather (less NE winds), the beach is currently in very good condition, indicating that this beach re-nourishment is working well.

4.3 Dredging and disposal methodology

There are five main areas that require dredging in the Otago Harbour: the entrance Channel; the lower harbour channel; the Port Chalmers Inner Basin and Berths; Victoria Channel and the Dunedin Basin and Berths.

The dredging is able to be carried out almost entirely with the trailer suction dredge *New Era*, which has been owned and operated by Port Otago since 1986. This dredge has a large suction pump and trailing dredge pipe with a drag-head containing a rotating visor at its base. The operation is similar to that of a vacuum cleaner. The drag-head is lowered to the sea floor and dragged along the bed as the dredge moves forward. A mixture of sand, silt and sea water is pumped up through the dredge pipe and this mixture is deposited into the dredge hopper. In the hopper the solids quickly settle out, and the water and some of the finer material such as silt that remains in suspension flows back overboard through the discharge chute, into the harbour channel. A full load of sand is firm enough to walk on in the hopper and is very close to the natural or in-situ density of undisturbed sand on the sea bed.

Figure 1 Port Otago suction dredge *New Era*

Port Otago also uses a barge mounted grab dredge *Vulcan* to dredge less accessible areas and for materials which tend to be more difficult to remove, including clays and weathered rock. The *Vulcan* operation is supported by two dumb barges towed by a small workboat.

Figure 2 Port Otago grab dredge *Vulcan*

The time taken to dredge the various channel areas is generally proportional to the amount of silt and clay within the dredge material. A load of clean sand from the entrance area can be dredged in 1 hour whereas it may take up to three hours to obtain a full load from the Leith claim near the Dunedin basin, which has a higher silt content. The higher proportion of silt results in slower settlement of material in the hopper.

The vessel containing the dredge material is motored or towed to within the disposal ground boundaries and the vessel is then split in half using the onboard hydraulic system. As the vessel continues moving through the water, the dredged material falls from the hopper from a height of about 1-2 metres below surface water level with any remaining material being washed from the hopper sides. All of the current dredging plant is the split hopper variety which generally discharges the entire load.

The trailer suction dredge has differential GPS to navigate to the disposal grounds, whereas the workboat that tows the barges works from shore based transit marks to ensure the discharge occurs in the correct location.

A discussion of the five main areas that require dredging in the Otago Harbour is provided below.

4.3.1 Entrance Channel

The entrance channel is bounded along its eastern edge by a large accumulation of sand forming a bar. The tidal currents on the ebb tide assist in maintaining the position of this channel.

However, once seaward past the outer end of the Mole, the ebb tide strength decreases and sand is constantly being deposited along the eastern channel toeline. This accretion or build up of sand is further exacerbated during easterly storms as the increased wave height and energy deposit large quantities of material over the bar.

The dredging of the entrance channel is a significant component of the dredging effort required to maintain the lower harbour with an estimated 60,000m^3 per annum removed in order to maintain a channel toe line design depth of 14.5 metres. The material dredged from the entrance channel is generally clean fine to medium grained sand.

4.3.2 Lower Harbour Channel

The areas within the Lower Harbour Channel where deposition occurs and which particularly require regular maintenance are located along the inner edge of the bends. This is primarily due to the currents being considerably weaker in this region with the result that they are no longer able to transport the sediments either in suspension or as bed load.

The material dredged from the Lower Harbour Channel comprises predominantly fine grained sand, although some areas contain a component of shell. The proportion of silt contained within the dredged material increases with distance from the harbor entrance. Floating seaweed is at times collected by the dredge although this tends to be seasonal and is particularly prevalent following a period of strong winds. Sea tulips can become established in the areas that are less frequently dredged.

The areas within the channel that require dredging amounts to approximately 5% of the total area of the channel invert area, the remaining areas being deeper than the design depth of 13.0 metres as a result of the natural scour of the tidal currents.

4.3.3 Port Chalmers Inner Basin and Berths

The material within the Port Chalmers inner basin and berths varies from clayey silt at the container berths to rock at the Beach Street berth on the eastern side of the basin.

The dredging of these areas is carried out using the grab dredge suspended off a barge mounted crane. The suction dredge is unable to dredge the silt, clay and rocky bed and has difficulty manoeuvring within the confined areas of the basin.

Deepening adjacent to the Beach Street berth was carried out in the early 1990's. This required drilling and blasting to fracture and dislodge the rock. Some isolated areas that were not taken down to the permitted design depth at that time continue to be worked on using the grab dredge progressively as the rock becomes more weathered.

4.3.4 Victoria Channel

The natural scour of the channel means that limited areas require dredging, particularly where sediment builds up on the bends of the channel.

4.3.5 Dunedin Basin and Berths

The sediment within the Dunedin Basin which extends to the end of Victoria Channel near the mouth of the Leith River is predominantly silt. The material has a low density and once mixed with water takes a long time to settle out. Its removal is not well suited to the use of a trailing suction dredge and the grab dredge is predominantly used to load the material into a dumb barge, which is then towed to sea for disposal.

Because of the distance to the disposal grounds from the upper harbour the trailing suction dredge *New Era* is at times used as a barge when grab dredging this area. This method of dredging is slow.

As in Port Chalmers, the currents within the basin and berth area are quite low and whilst the natural scour of the channel penetrates some distance into the basin, the siltation occurs over a wide area and requires exact positioning to dredge the correct spots.

4.4 Disposal site selection

The South Spit Beach (Shelly Beach) site has been chosen in order to provide nourishment to the adjoining beach and dunes. In addition, disposal at this location also benefits the Aramoana saltmarsh that the spit shelters. Other locations and methods would not provide these ecological and amenity benefits.

The other two sites have been used for many years without any identified adverse effects. These two sites have been selected for their naturally moving sandy bottoms and they are of sufficient area to ensure that the additional disposition is absorbed into the natural coastal movement of material.

All three sites are specifically recognised and provided for under the Otago Regional Plan: Coast, as sites for the disposal of dredged material.

4.5 Consideration of alternatives

Alternatives to the disposal of dredged material at the three existing disposal sites are outlined below.

4.5.1 Off-shore disposal

An offshore site ("AO") which is currently the subject of a consent application proposed to be used for the capital dredging project (Next Generation) is generally less suitable for the disposal of material from maintenance dredging once the capital work on the channel is completed. Its distance from shore both restricts access by the New Era when seas are rough and also increases the cost of disposal.

Alternative sites to the south-east of Taiaroa Head are often too rough for safe passage of the dredge/barges and significant steaming out into open water would be required to clear the flood tide movement into the Otago Harbour. This would be both expensive and an additional hazard for a fully laden dredge or barge to use for regular day-to-day disposal work. The disposal sites must be clear of the natural venturi into the harbour in respect of deposited material. This is difficult to achieve to the south of Taiaroa. Other sites to the west of Taiaroa that avoid the flood tide movement are little different to those for which consent is sought.

4.5.2 Lower harbour disposal

There could potentially be other suitable inner harbour disposal sites, however to date, these have not been identified and are not considered necessary, given the suitability of the sites historically used for the disposal activity. Retaining the existing sites is considered preferable as the monitoring of these areas is now well established, which assists with management of the effects. Such long term monitoring information is invaluable and can not be automatically applied to other harbour locations, making other lower harbour locations less suitable.

4.5.3 Upper harbour disposal

Suggestions have previously been made by interest groups for a series of man-made islands to be constructed within the upper harbour, as a means of disposing of dredged material and creating habitat areas. Islands could be planted out to support wildlife. Other suggestions have raised the possibility that silt material could be used to reclaim intertidal portions of the Upper Harbour area to restore muddier inter-tidal habitats that have been lost as a result of development works in the past.

Any reclamation or harbour restoration disposal for the benefit of the community and/or environmental enhancement would need to have detailed engineering design work carried out and environmental feasibility studies completed, before this could be pursued further. Adverse effects on recreational boating (e.g. sailing and board sailing) from any upper harbour reclamation are possible, given the shallower waters are important for these activities. Also, access for the dredge could be difficult, potentially creating additional transportation constraints and costs. Furthermore, given the small volumes of material likely to be required to create habitat areas, such options are not considered viable for the disposal of all of the dredged material, thus the need for the ability to continue to dispose of material in the manner proposed in this application.

Further reclamation within the harbour is not permitted without a resource consent and whilst there are groups who support this option, it is not an available option at this time as others, such as Otakou Runanga, oppose any large scale reclamation of any sort in the harbour. This was outlined in evidence presented by iwi at the Project Next Generation hearing.

4.5.4 Land based disposal

Trucking material to a landfill has been assessed as being cost prohibitive, due to the transportation costs involved in moving material to any existing landfills. Further, there would be costs and environmental effects associated with establishing new disposal sites capable of taking the volumes of dredging material necessary.

4.5.5 Use for concrete aggregate

Port Otago is open to providing dredged sand to other places and uses, if a demand is identified.

The total ready mixed concrete production in the Dunedin region is approximately 40-50,000m^3 per annum, of which approximately 40% volume is sand. The sand used in ready mixed concrete is graded with the very fine dredged sand representing approximately 14% of the total sand requirement, amounting to approximately 2,500 m^3 per annum. This is a very small fraction of the total quantity that is dredged from the harbour and as such is not considered to be a suitable method for total disposal.

The use of aggregate for construction is inappropriate due to the comparatively small amount of material required within the region, relative to that which is produced by Port Otago's dredging programme. In addition, recovery, unloading and transport costs would be likely to make consumers of aggregate outside of Dunedin conclude that this is an economical unviable proposition. Consequently, the requirement for disposal to sea would still exist.

4.5.6 Use for sand aggregate

There is a commercial use for sand although the annual volume is small. Use of sand in the region includes:

- Foundry mounding sand – less than 1,000m³ per month or 10,000m³ per annum. This sand generally is supplied from Waldronville.
- Concrete aggregate sand – about 1-2,000m³ per annum supplied from Tomahawk lagoon entrance.
- Building concrete slab fill – less than 1,000m³ per annum.
- Road aggregate – blended mix.

The use of dredged material for sand aggregate is impractical due to the comparatively small amount of material required within the region, relative to that which is produced by Port Otago's dredging programme. We also note that recovery, unloading and transport costs would make the supply of sand to areas outside Dunedin uneconomic for the end user of the material. Consequently, the requirement for disposal to sea remains.

4.5.7 Reclamation

Port Otago is unaware of any commercial, community or private plans for major reclamation works in the vicinity of Port Chalmers or along the margins of Otago Harbour that would benefit from receipt of significant portions of dredged sand material. While there has been interest expressed for additional community land resources along the margin of the harbour in Careys Bay and Deborah Bay, there is no immediate requirement for reclamation fill. In terms of the current roading works around the harbour, it is noted that the volumes of material for this work are small and dredge access would not be available due to shallow depths, therefore it would be fairly impractical to use the material for this work.

Although such small reclamations may offer community benefits, they would also result in associated environmental and economic costs, and disposal of the remaining majority of the dredged material by another means would still be required. Consequently, the requirement for disposal to sea would still exist.

4.5.8 Beach re-nourishment

A number of sand beaches in the Dunedin area are subject to either long-term or short-term erosion of sediment volume. For example, the existing South Spit disposal site places dredged material in the near shore off Shelly Beach to offset losses of sediment from the narrow dune system of the South Spit.

Small bays within Otago Harbour have been replenished with sand in the past to restore and protect local recreational resources and some property. Beach re-nourishment requires sand of an appropriate size, texture, colour and cleanliness to be effective and acceptable to the beach users. In assessing the potential use of the dredged material for beach re-nourishment in the Dunedin area, these factors have been considered and areas of suitable sand identified. In addition, the total volume required for possible beach re-nourishment projects has been estimated.

- **Ocean Beach re-nourishment**

Dredged sand from the harbour channels has proven to be satisfactory sand for beach renourishment of Ocean Beach (St Clair, Middle and St Kilda Beaches). According to the emergency response plan of the Dunedin City Council, the estimated volume required to mitigate the adverse effects of erosion could be approximately 100,000m³ every 5 years.

The method used previously in 2007 is suited to Port Otago's current dredging operation. An excavator at a city wharf can extract 400-450 m³ of sand from the New Era hopper while the vessel is laid up over night. The sand is then trucked the short 4km distance across South Dunedin to Ocean Beach. In 2007 the sand was stored near the beach and placed as necessary along the foreshore and dunes. Approximately 1,000 to 2,000m³ of sand was stockpiled at a time.

Referring to the disposal records in Appendix B, the quantity of sand historically provided to the Dunedin City Council for Ocean Beach renourishment is:

- 11,528m³ in 2007;
- 9,622m³ in 2008; and
- 5,045m³ in 2009.

As there is a limit to the amount of sand required at any one time for Ocean Beach, an area would be required to stockpile the material and the stockpile would require management to avoid wind blown sand and sediment runoff. Accordingly, this option is best undertaken at the time that re-nourishment is needed. This current consent application will not limit this alternative from taking place in the future, as has been demonstrated during the term of the existing consent.

- **Te Rauone Beach**

The Te Rauone community is concerned about the erosion of the beach frontage at Te Rauone. Re-nourishment using dredged sand is a possible solution to erosion at the northern end of the beach, and concept design plans prepared by Port Otago in conjunction with the Te Rauone Beach Coast Care Committee indicate a maximum of 90,000m³ of sand would be required. Further work would be required to hold the sand in place, and so re-nourishment would be a part of an integrated management programme including engineering work, dune fencing, planting and regular renourishment over time.

Design and consultation work for the Te Rauone Beach community project is currently being resourced by Port Otago as a separate exercise. Current channel bathymetry shows that it would not be possible to deposit sand onto the beach directly from the dredge-hopper, as there is insufficient depth of water to manoeuvre the dredge inshore. The likely solution would be to pump the sand onto the beach and then spread with a bulldozer once the sand settles out and the excess water drains. A temporary mooring for the dredger would be required in conjunction with either a pumping system to move the dredged material from the hopper or low point in the channel and along a pipeline to the beach site. These pump out operations are time consuming and relatively expensive. However, Port Otago is pursuing this project. As it is a new activity, it will be separately consented.

The renewal of the disposal consent will not impede the use of sand for community beach re-nourishment projects and while a reasonable amount of sand can be disposed of through such projects, there remains a requirement for Port Otago to have the ability to use the existing off-shore dredge disposal grounds also.

4.5.9 Conclusion

There are some viable alternatives to using the historic disposal sites. Port Otago has in the past, and will continue to keep an open mind regarding alternative methods of dredge material disposal. However, these alternatives are able to accommodate only some small volumes of the material which has to be dredged to maintain access to the Port. There is no practical alterative which can handle the total dredged material volume on an ongoing basis, thus retaining the ability to dispose dredged material to the three disposal sites is crucial to ongoing use of the Port and for providing access for other users of the harbour channel.

5. Activity status

5.1 Otago Regional Plan: Coast

The relevant statutory document is the Regional Plan: Coast for Otago (RCP). The RCP was made operative on 1 September 2001. The sites for dredging disposal are specially identified in Schedule 5 of the RCP as "Dredge Spoil Grounds". There are no other notations applicable to the disposal areas.

The relevant rules are contained within Chapter 9: Alteration of the Foreshore and Seabed of the RCP.

5.1.1 Dredging

The activity of dredging is a **Permitted Activity** under the RCP pursuant to Rule 9.5.3.2 which states:

> *The disturbance of the seabed for the purposes of maintenance dredging of the existing channel and berths within Otago Harbour is a **permitted** activity provided:*
>
> *(a) It is for the purposes of maintaining water depth in the following areas to the following depths:*
>
> *(i) The upper berths and swinging areas: 10 metres*
>
> *(ii) The upper channel: 8.5 metres*
>
> *(iii) Port Chalmers berths and swinging areas: 14.5 metres*
>
> *(iv) Lower channel: 13 metres; and*
>
> *(b) It is for the purposes of ensuring the safe and convenient navigation of ships in navigation channels and at berthing and mooring facilities.*
>
> *Note: The depths are based on the Chart Datum on the latest navigational chart NZ6612, of Otago Harbour published by the Hydrographic Office of the Royal New Zealand Navy.*

The requirements of this rule are satisfied by the ongoing maintenance dredging activity.

Capital dredging and dredging to maintain the depths at the new permitted levels are covered by the consents sought for Project Next Generation.

5.1.2 Disposal of dredged material

The disposal of dredged material derived from a maintenance dredging operation is a **Discretionary Activity** under the RCP pursuant to Rule 9.5.4.1 which states:

> *The deposition of sand, shell, shingle, or other natural material from a maintenance dredging operation in any 12 month period is a **discretionary** activity if:*

(a) *The sand, shell, shingle, or other natural material is deposited at the sites as shown in Schedule 5 and described below:*

(i) *Heyward Point*

(ii) *Spit Beach*

(iii) *South Spit Beach (Shelly Beach).*

The disposal of dredged material derived from incremental and capital dredging is a **Discretionary Activity** under the RCP pursuant to Rules 9.5.4.2 and 9.5.4.3 which state:

> *Except as provided for by Rule 9.5.4.1, any activity involving the deposition of any sand, shell, shingle, or other natural material on the foreshore or seabed in quantities greater than 50,000 cubic metres in any 12 month period is a discretionary activity and a restricted coastal activity.*
>
> *Except as provided for by Rules 9.5.4.1 and 9.5.4.2, any activity involving the deposition of sand, shell, shingle, or other natural material in the coastal marine area is a discretionary activity.*

Rule 9.5.4.2 requires, except as provided for by Rule 9.5.4.1, that the deposition of material in quantities greater than 50,000m^3 in any 12 month period, is a discretionary and restricted coastal activity (RCA). Policy 29 of the recently gazetted New Zealand Coastal Policy Statement 2010 (NZCPS) revokes the requirement for all restricted coastal activities. The NZCPS requires that the RCP be amended to reflect this and where the regional plan has not been updated (as in this case) provides interim effect in removing the RCA status for existing rules within the RCP. Accordingly, only the discretionary activity status applies to this proposal.

5.1.3 Discharge of water or other contaminants

The discharge of water from maintenance dredging of the Otago Harbour to the coastal marine area as permitted by 9.5.3.2 is a **Permitted Activity** pursuant to Rule 10.5.6.1(e) of the RCP.

Any other discharge of water or contaminants into the coastal marine area associated with the activity is a **Discretionary Activity** pursuant to Rule 10.5.6.2 of the RCP.

5.1.4 Overall status

The application to dispose of dredged material must be considered as a **Discretionary Activity**.

6. Assessment of environmental effects

6.1 Introduction

Under Section 104 of the RMA, when considering an application for resource consent the consent authority must, subject to Part 2, have regard to any actual and potential effects on the environment. The actual and potential effects of the proposed activity have been evaluated as required by Section 88 of the RMA.

6.2 Positive effects

It is legitimate to consider positive effects of the proposal as the definition of "effect" in the Resource Management Act includes positive effects.

This application seeks the ability to continue to provide for ongoing disposal to sea of dredged material. This activity has significant positive effects for the port company and in turn the wider community in terms of social and economic wellbeing, created through direct and indirect economic outputs and through the retention of jobs within the local community.

The activity provides for the renourishment of Shelly Beach, which was subject to erosion prior to 1987 when disposal at this location commenced. The proposal potentially assists with preventing erosion of other beaches, for example Aramoana Beach and the beaches to the north of this. Further detail on beach health effects are included in the report prepared by Martin Single in Appendix D.

The proposed activity is intrinsically linked with a number of monitoring programmes within the harbour which assist with improving knowledge and understanding of sediment transport, waves and benthic habitats. Accordingly, the proposal has positive effects in terms of scientific knowledge.

Research undertaken to date indicates that the disposal activity has positive effects in terms of the Aramoana surf break. Further detail is provided in Section 6.7 below.

It is important that these positive effects are fully taken account of in forming an overall judgement under Section 104(1). To ignore the substantial benefits that arise from the continuation of dredging disposal would create an unbalanced picture of the overall effects of the activity.

6.3 Effects on coastal processes

The disposal of sediment can lead to a number of potential consequences related to coastal processes, including:

- Concentrations of sediment and seabed deposition from suspended-sediment plumes;
- Changes to coastal shorelines and margins from differences in waves and currents;
- Changes in wave height arising from the physical size and shape of the disposal mound; and
- Long term sediment transport.

The effects of the 3-year continuation of the dredging disposal activity in terms of sediment transport and beach morphology have been addressed by Martin Single of Shore Processes and Management Ltd. Dr Single's report is attached as Appendix C. This report provides a detailed description of the physical coastal environment and describes the processes and effects of the disposal activity, which has been subject to detailed monitoring over a number of years.

Dr Single's report draws on his earlier study of the beaches and shoreline morphology of Blueskin Bay from the entrance to Otago Harbour north to Karitane. The "beach morphology" report, which has information on long-term change, as well as short-term beach change described from beach profile surveys, is included as a background report, in Appendix D.

Within the report attached as Appendix C, Dr Single concludes:

> *"... the overall character of physical coastal environment including beach changes over the long-term and as a result of adjustments to variations in wave energy and sediment inputs also indicates that the effects of continued placement of dredged sediment at the existing disposal sites will not result in adverse effects to the environment. Indeed, ongoing disposal of dredged sediment is likely to have beneficial effects in providing sediment to the nearshore and beaches that mitigate erosional effects of storm events.*
>
> *The sediment character of the nearshore, beaches and wider Blueskin Bay is near homogenous. The dredge disposal sites do not show as anomalies to the adjacent seabed and beaches. Shoaling within the disposal sites has resulted in an improved wave break for surfing at Aramoana, and a reduction in erosion of Shelly Beach. There is no evidence that wave energy is focussed on to the beaches, generating sites of increased erosion during storms. Aramoana and Shelly Beaches appear to respond naturally to storm events and periods of more quiescent wave energy. The beaches adjust naturally to storm events with some erosion of the dunes and movement of sand from the beach to the nearshore, and they accrete again during lower energy swell conditions. Beaches north of Heyward Point also appear to respond naturally to variations in wave energy, and do not show any adverse effect from the presence of the disposal sites.*
>
> *Renewal of the disposal consent for up to three years should result in no effects that are different to those that have been experienced in the past. However monitoring through annual measurement of the seabed topography in the vicinity of the disposal sites, beach surveys and observations related to the resource use of the beaches will provide a means to further assess the sustainability of the disposal operation. In particular the short-tem and longer-term cumulative effects of the dredge spoil placement can be quantified."*

The data obtained through the monitoring recommended by Dr Single will provide a means to assess the sustainability of the disposal operation and prepare an operational management plan to apply to the long-term consent which is intended to be sought within the next 3 years.

Wave, current and sediment effects are also addressed in the report prepared by Peter McComb of Met Ocean Solutions Ltd attached as Appendix E. Dr McComb has developed a model to study the hydrodynamic and sedimentary processes operating within the entrance to Otago Harbour, to assist with understanding and predicting the effects associated with dredging and disposal activity within the Harbour. Dr McComb does not identify any concerning effects from past disposal activity. In addition, Dr McComb also addresses the predicted effects of disposal at the maximum volumes sought for each site (which are higher than recent disposal rates, as detailed in Section 4.2 of this report). The predicted effects of higher rates of deposition are discussed in detail in Section 6.8 below.

On the basis of the specialist reports prepared, we conclude that the coastal processes have not been adversely affected by the disposal activity in the past and this is not expected to change as a result of this short-term consent. The environment appropriately responds to and accommodates the mechanical movement of sediment within the harbour that is necessary to maintain access to the port.

6.4 Effects on water quality

There is no ongoing monitoring of water quality in terms of suspended sediments or turbidity in the Otago Harbour but three months of monitoring by NIWA for Port Otago at two sites, one in the Lower Harbour and one in the Upper Harbour, found that turbidity varied between 1 and 6 NTU with highest concentrations of 6.4 NTU and 6.5 milligrams per litre (mg/l) suspended sediments during a storm event. Kd (a measure of the rate of reduction of light with depth) varied from 0.11 m-1 to 0.33 m-1 but rose to 2.14 m-1 during the storm event. Occasional measurements in the past have recorded concentrations in the range 5.6-215 mg/l in the Lower Harbour and up to 1146 mg/l in Sawyers Bay in the Upper Harbour.

Dredging disposal is associated with a temporary reduction in water clarity, when the vessel discharges its load. The effects of dredging on water quality at disposal sites is described by Mark James in his statement of evidence for Project Next Generation on behalf of Port Otago, dated March 2011. Dr James stated that the main effects at the disposal site (in that case A0) and immediately downstream are predicted to be the direct effects of smothering of the benthic community, increased levels of suspended sediments and reduced water clarity. Dr James stated that the increased levels of suspended sediments and reduced clarity will affect the immediate disposal site but the levels of suspended sediments will be rapidly diluted away from the site. Dr James stated that with *New Era* dredging, the predicted suspended sediment concentrations for all silt classes are estimated to be less than 11 mg/l in surface water layers and less than 57 mg/l in the bottom layers, even in the immediate vicinity of the disposal site. Therefore turbidity effects are low and effects on water quality are confined.

Dr James did not highlight any species that would be unable to persist during dredging disposal. Overall, effects on water quality will continue to be the same or similar to those experienced in relation to this activity in the past.

It is noted that the environment in which the activity takes place is dynamic and natural coastal processes (for example larger wave events and wind) will at times cause material to be resuspended in the water column. In addition, periods of high rainfall can lead to high turbidity associated with runoff from land. These natural effects are not dissimilar to the water quality effects associated with dredging disposal.

6.5 Contamination

Sediments predominantly in the swinging basin adjacent to Port Chalmers and the middle to lower harbour were analysed for a wide range of contaminants in 2010 by GHD Limited for Project Next Generation. The results of that investigation were summarised by Christopher Wayne Hickey in his statement of evidence for Project Next Generation on behalf of Port Otago (dated April 2011). Dr Hickey concluded that there is very low concern for chemical contaminant related adverse effects associated with the proposed dredging and disposal operation for Project Next Generation. Sediments at the dredge sites have been tested and apart from slightly elevated arsenic in a few locations, all are below the Australia New Zealand Environment and Conservation Council (ANZECC) guidelines for fresh and marine water quality and the New Zealand Guidelines for Sea Disposal of Waste (NZGSDW) low level guidelines for concentrations that are known to impact on biota.

Dr James (March 2011) stated that any contaminants that were released into the water column would be rapidly diluted and dispersed. Therefore, in the absence of any contamination issues being identified by Drs Hickey or James, there is no contamination effect expected to arise as a result of the continuation of dredging disposal.

6.6 Benthic effects

The main benthic effects within and around the disposal sites relate to the direct effects of smothering of the benthic community, increased levels of suspended sediments and reduced water clarity.

The benthic environment in the vicinity of the disposal sites has been studied by Brian Paavo of Benthic Science Ltd and the results are discussed in the report included in Appendix F. Dr Paavo's work has focused on the benthic environment around the Heyward Point and Spit Beach sites. The South Spit (Shelly) Beach site has not been studied in detail, given that disposal here is acknowledged as being necessary for conservation reasons.

Dr Paavo reports that the disposal related effects of the sites studied are limited as follows:

- Heyward Point – effects are limited to the central portion of the site and an area 100-500 metres west of its shoreward boundary.
- Spit Beach (Aramoana) – effects are limited to the inshore portion and not more than 250 metres beyond.

There are no areas of significant conservation value within the areas identified by Dr Paavo. Dr Paavo reports that *"there is no evidence that dumping has deleterious ecological effects beyond these areas"*. He goes on to confirm the following:

> *"Dredge-related effects at Aramoana appear spatially stable in comparisons between 2005 and 2010 and the area retains a 'buffer zone' of animals well-suited to colonise sandy spoil. Dredge-related effects also appear spatially stable at Heyward Point in comparisons between 2005 and 2010..."*

On the basis of Dr Paavo's assessment, we conclude that effects on the benthic environment from the continued disposal of dredged material at the three disposal sites will continue to be minor and will impact upon a relatively small area, of historically modified seafloor within the coastal environment.

6.7 Effects on recreation

Otago Harbour and the coastal environment are used for a number of waterbased recreational activities, including boating, fishing, diving, swimming and surfing.

Recreational boating activity within Otago Harbour includes sailing, motor boats, kayaking and rowing. Fishing from boats occurs within the harbour and the entrance channel is a particularly popular site for salmon and other species. Fishing from the Mole and Taiaroa Head near the entrance channel is also popular as is surfcasting from many beaches and rocky headlands. The ongoing disposal of dredged material is unlikely to cause any conflict with boating and recreational fishing activities within the coastal marine area, as no conflicts have been identified to date. Neither the dredge movements nor the disposed material are considered to be a danger to navigation.

Recreational diving is very popular at the Mole which is a voluntary marine reserve. This area is not directly affected by the disposal activity. Reduced water clarity could have a minor impact on some recreational activity, however, reduced water clarity is a temporary effect and the popular swimming and diving areas are not close to the actual disposal sites.

Surfing is a popular pastime at many locations along the Otago coastline including a number of beaches from Aramoana through to Karitane. Of particular note are northern coast beaches. The Aramoana surf break ("The Spit") is specifically recognised in the New Zealand Coastal Policy Statement 2010 and is located close to the Spit Beach disposal ground. Dr Single confirmed in the report in Appendix C, that shoaling in recent years within the disposal sites has resulted in an improved wave break for surfing at Aramoana. The research undertaken to date by Dr McComb confirms there is a relationship between the disposal mound and the waves generated at Aramoana. The effect of continued disposal activity at the Spit Beach disposal ground on wave generation at Aramoana could be both positive and negative. So Port Otago intends to work with local surfers during the term of the 3-year consent to get a better understanding of the relationship between disposal and "surfability" at Aramoana, in order to develop a management plan which minimises any long term negative effects on this surf break.

In the meantime, on the basis of the specialist work undertaken, the effects on surfing from the ongoing disposal activity will not be adverse and is expected to continue to be a positive effect within the term of the consent sought.

Overall, the continuation of the dredging disposal activity is expected to generate less than minor adverse effects on recreational activity.

6.8 Effect of disposing at greater volumes than recent years

The historic rates of disposal were outlined in Section 4.2 of this report. The maximum annual volume of material disposed of in the Blueskin Bay area occurred in 1976 with 3.3M m^3 of material deposited at the Heyward site. Since detailed disposal records have been prepared, the highest annual disposal occurred in 1988, with 367,116m^3 of material disposed of that year (across the three sites).

The maximum annual volume disposed of during the term of the current consent (the last 10 years) was less than those earlier volumes, at 257,524m^3. Consent is sought for the same volume which applies on the current consent, being 450,000m^3 per annum. Accordingly, it is appropriate to comment on the potential effects that might arise from disposal carried out at this maximum volume, within the term of this short-term renewal consent.

Dr McComb considers the effects of disposing at greater volumes than recent years, based on the predictive modelling work undertaken. The key conclusions are summarised below.

6.8.1 Heyward

For the Heyward site, sediments within the shallow parts can become mobilised by wave action and tend to migrate westward, while the deeper regions (i.e. greater than about 15 m) are clearly retentive. Accordingly, the effects deposition at the full consent volume will depend on the areas used for disposal within the ground. Over the term of this consent it is proposed to manage the disposal volumes within discrete regions of the Heyward ground in order to conclusively define the retentive and dispersive quantities.

6.8.2 Spit

Sediments deposited at the Spit site have long residence times. Significant transport beyond the immediate area (i.e. the wider Aramoana Beach system) is likely to occur infrequently and only during high storm conditions.

Material placed at the Spit ground will slowly migrate shoreward and gradually disperse along the wider Aramoana Beach system. While the region into which this material will disperse is relatively broad, it is considered that a deposition rate of 200,000 m^3 per year is not a sustainable practise over the long term. Approximately 750,000 m^3 of material has been deposited at the Spit ground in the last 10 years and nearly 3.3M m^3 in total over the last 26 years. It is considered that the effects from a maximum of 200,000 m^3 per year for the next three years (i.e. 600,000 m^3 in total) will be similar to the effects of the last 10 years. Future studies over the next three years will determine the optimum sites and volumes for the deposition of dredged sediments. A possible consequence if the maximum volume of 600,000 m^3 is deposited over the next 3 years at the Spit may be a delay in future depositions to allow the system to adjust.

In the short term, the presence of the disposal mound will modify the incoming wave field producing subtle differences in the wave height gradients along the beach in the surf zone. The mound acts as a secondary focusing feature, redistributing wave energy into zones of slightly increased and decreased wave height. This has a slight effect on the local coastal processes, and influences surfing wave quality. Focussing effects that increase the local wave heights along the adjacent beach are likely to confer positive outcomes for surfing. However, the wave focussing process is highly dependent on the mound shape. Therefore as the mound erodes over time and the sediments are distributed shoreward and eventually spread along the beach and nearshore regions, the effects will also change.

Over the term of this consent it is proposed to manage the disposal within the Spit in a way which enables effects on the surf break to be monitored, involving local surfers in the qualitative assessment of surfability. This will be used to develop an operational management plan which minimises negative effects on the surf break being developed in the future, in the event that disposal is continued at this site. The key finding reported by Dr McComb is that effects for the next 3 years will be similar to the last 10 years, even with a deposition rate of 200,000 m^3 per annum.

6.8.3 Shelly

At the Shelly Beach ground, the effect of disposal to 50,000 m^3 per year is not expected to produce outcomes that differ from the past 10 years. The exercise of the full consent volume for this ground over the three-year period will continue to provide a short term sediment supply to Shelly Beach.

6.9 Cultural matters

The disposal sites are not within any area identified in the RCP lists as having Kai Tahu cultural and spiritual values. Notwithstanding this, Port Otago recognises that the entire Otago Harbour and Blueskin Bay are of special significance to iwi.

The Cultural Impact Assessment[1] prepared for Project Next Generation provides detailed information on the resources and significance of Harbour and Blueskin Bay to iwi. Tangata whenua have a long association with this area in terms of travel, settlement and fishing. Key species and ecosystems of significance to tangata whenua include tuaki, flat fish, seagrass and kelp. Restricting the disposal activity to the existing disposal sites should minimise effects on these resources.

Consultation with iwi in relation to dredging disposal has been continuing throughout the term of the existing consent. Iwi are represented on the existing working party established to discuss and review the annual monitoring report, pursuant to condition 10 of the existing consent. The monitoring reports required by condition 11 of the existing consent are also presented to the working party. In addition, iwi have been specifically consulted in relation to this renewal application.

Consultation is being carried out through Kai Tahu Ki Otago Ltd (KTKO Ltd) and the working party to address any matters of significance to tangata whenua. No issues have been identified in relation to the short-term renewal application, to date. Initial feedback on the short-term consent has been favourable and the indication is that iwi are not concerned about this consent but wish to be involved in the preparation of the application for the long-term disposal consent. In this regard, it was suggested that the initial 2-year period sought for the short-term consent may not be sufficient to complete technical work and provide for comprehensive consultation prior to lodgement. Accordingly, Port Otago adjusted the short-term consent to 3-years, to allow for adequate consultation time prior to lodgement of the long-term consent.

Given the proposal relates to a continuation of a long established activity and that both the dredging areas and the disposal grounds have been subject to significant disturbance for decades, it is unlikely that any cultural artefacts or other material will be encountered.

6.10 Economic effects

Maintaining an efficient Port has positive implications for economic efficiency and for regional income and employment.

The value of export cargo shipped through Port Chalmers in the 2008-2009 financial year was $5.35 billion, or 14% of New Zealand's total export value. Port Chalmers is the country's third largest export port (by cargo value).

Port Otago itself currently generates direct economic output of $53 million per annum, $41 million of which is business and household income (including $21 million in wages & salaries), and 320 jobs. The inclusion of downstream multiplier effects means that the operation of Port Otago currently generates regional output of $85 million per annum, $56 million of which is regional business and household

[1] Cultural Impact Assessment Project Next Generation Otago Harbour 2010, prepared by Tim Vial, KTKO Ltd

income (including $26 million in wages and salaries), and generates 480 jobs in the region. In addition to this is all the employment and income generated by land freight taking cargo to and from Port Chalmers.

Should the required dredging and associated disposal required to maintain the operation of the Port not be carried out, the ships would have restricted access to the harbour and the above figures would be significantly impacted.

Restriction on access to the Port could cause shipping companies to review their options of calling at Port Chalmers in favour of other ports, thereby significantly increasing the costs for local producers and manufacturers to export their products to competitive global markets. As an example of the significance of the costs associated with cargo having to move through another New Zealand port if access to Port Chalmers was not maintained, additional freight costs to ship dairy produce from Otago and Southland would add approximately $7 million to annual supply chain costs for the dairy industry alone. Manufacturing profits would potentially decline by 10 – 20%. These negative effects would reduce farming profitability and rural land values, and would affect manufacturers' location choices, with consequential flow on effects to other sectors of the economy.

Accordingly, retaining access to Port Chalmers is reliant on regular dredging, which in turn requires the disposal of dredged material to sea. The continuation of the disposal activity has significance economic benefits for Otago and Southland, and the wider New Zealand economy also.

6.11 Conclusion

This assessment has demonstrated that the adverse effects of continuing dredging disposal in the manner allowed for historically, for a further 3 years will be minor and there are a number of positive effects associated with the activity.

We note that the ORC compliance team confirmed to us that there have been no complaints received in relation to the operation of the existing disposal consent and there have been no compliance issues with the existing consent. This indicates that Port Otago is a responsible consent holder.

7. Objectives and Policies

A discussion of the objectives and policies of the RCP is provided below. A discussion of the other relevant planning documents, being the New Zealand Coastal Policy Statement 2010, the Otago Regional Policy Statement and the , is also provided.

7.1 The New Zealand Coastal Policy Statement

The New Zealand Coastal Policy Statement 2010 (NZCPS) was made operative on 3 December 2010. The following provisions are considered to be relevant to the dredging disposal activity:

7.1.1 Objectives

Objective 1

To safeguard the integrity, form, functioning and resilience of the coastal environment and sustain its ecosystems, including marine and intertidal areas, estuaries, dunes and land, by:

- *maintaining or enhancing natural biological and physical processes in the coastal environment and recognising their dynamic, complex and interdependent nature;*
- *protecting representative or significant natural ecosystems and sites of biological importance and maintaining the diversity of New Zealand's indigenous coastal flora and fauna; and*
- *maintaining coastal water quality, and enhancing it where it has deteriorated from what would otherwise be its natural condition, with significant adverse effects on ecology and habitat, because of discharges associated with human activity.*

The safeguarding of coastal processes and ecosystems is of upmost importance when considering this proposal in relation to the NZCPS. Based on the specialist reports appended to this report, it is clear that the 3-year continuation of the dredging disposal activity in the same manner as the past 10 years, will maintain coastal processes and ecosystems, consistent with Objective 1 of the NZCPS.

Objective 6

To enable people and communities to provide for their social, economic, and cultural wellbeing and their health and safety, through subdivision, use, and development, recognising that:

- *the protection of the values of the coastal environment does not preclude use and development in appropriate places and forms, and within appropriate limits;*
- *some uses and developments which depend upon the use of natural and physical resources in the coastal environment are important to the social, economic and cultural wellbeing of people and communities;*
- *functionally some uses and developments can only be located on the coast or in the coastal marine area…*

The continuation of dredging disposal within the existing disposal sites is essential in maintaining social, economic and cultural wellbeing. It is considered that the significant portion of disposal activity is only practicable within the coastal marine area.

7.1.2 Policies

Policy 9: Ports

Recognise that a sustainable national transport system requires an efficient national network of safe ports, servicing national and international shipping, with efficient connections with other transport modes, including by:

- *ensuring that development in the coastal environment does not adversely affect the efficient and safe operation of these ports, or their connections with other transport modes; and*
- *considering where, how and when to provide in regional policy statements and in plans for the efficient and safe operation of these ports, the development of their capacity for shipping, and their connections with other transport modes.*

This application is necessary for the maintenance of a safe and efficient port within Otago Harbour. The application is in accordance with the disposal grounds identified in the RCP providing for the operation of the Port.

Policy 16: Surf breaks of national significance

Protect the surf breaks of national significance for surfing listed in Schedule 1, by:

- *ensuring that activities in the coastal environment do not adversely affect the surf breaks; and*
- *avoiding adverse effects of other activities on access to, and use and enjoyment of the surf breaks.*

"The Spit" is listed as a surf break of national significance in Schedule 1 of the NZCPS. This surf break is immediately inshore of the Spit Beach disposal site. The effects on this surf break are addressed in the reports prepared by Drs Single and McCombs. Dr Single confirms that *"shoaling within the disposal sites has resulted in an improved wave break for surfing at Aramoana"*. On the basis of the monitoring work undertaken, effects on surfing from the ongoing disposal activity will not be adverse, and is expected to be a positive effect for surfing activity within the term of the consent sought. On this basis, it is considered that the proposal will protect the surf break of national significance, in line with this policy.

Policy 23: Discharge of contaminants

... (5) In managing discharges from ports and other marine facilities:

- *require operators of ports and other marine facilities to take all practicable steps to avoid contamination of coastal waters, substrate, ecosystems and habitats that is more than minor;*
- *require that the disturbance or relocation of contaminated seabed material, other than by the movement of vessels, and the dumping or storage of dredged material does not result in significant adverse effects on water quality or the seabed, substrate, ecosystems or habitats;*

- *require operators of ports, marinas and other relevant marine facilities to provide for the collection of sewage and waste from vessels, and for residues from vessel maintenance to be safely contained and disposed of; and*
- *consider the need for facilities for the collection of sewage and other wastes for recreational and commercial boating.*

The proposal will not result in significant adverse effects on water quality or the seabed, substrate, ecosystems or habitat as addressed in Section 6 of this report, so satisfies this policy.

Policy 29: Restricted Coastal Activities

1. *The Minister of Conservation does not require any activity to be specified as a restricted coastal activity in a regional coastal plan.*
2. *Local authorities are directed under sections 55 and 57 of the Act to amend documents as necessary to give effect to this policy as soon as practicable, without using the process in Schedule 1 of the Act, with the effect that:*
    - *any activity specified as a discretionary activity and a restricted coastal activity becomes a discretionary activity only;*
    - *any activity specified as a non-complying activity and a restricted coastal activity becomes a non-complying activity only.*
3. *Any application for a coastal permit for an activity specified as a restricted coastal activity that has been publicly notified before the date the amendments in clause (2) are made shall continue to be treated as an application for a restricted coastal activity for the purposes of section 117 of the Act.*
4. *Any other application for an activity specified as a restricted coastal activity made before the date of the amendments in clause (2), shall be considered as a discretionary or non-complying activity in accordance with the regional coastal plan or proposed regional coastal plan's classification and section 117 of the Act does not apply.*

In relation to Policy 29, we understand that scenario 4 applies in this case and the application will not be dealt with as a restricted coastal activity. Accordingly, it is a discretionary activity under the RCP.

7.2 Otago Regional Policy Statement

The purpose of a Regional Policy Statement is to promote the sustainable management of natural and physical resources. Otago's Regional Policy Statement (RPS) does this by giving an overview of the resource management issues facing Otago, and by setting policies and methods to manage Otago's natural and physical resources.

The Regional Policy Statement contains no rules but rather establishes the framework for the regional plans. The objectives and policies of the RPS are also given effect to by the RCP. The provisions of the RPS have been reviewed and no conflicts have been identified.

7.3 Otago Regional Plan: Coast

The following provisions are taken from the RCP, Chapter 9: Alteration of the Foreshore and Seabed.

7.3.1 Objectives

9.3.1 *To recognise and provide for values associated with:*

(a) Areas of cultural significance; and

(b) Areas of conservation value; and

(c) Areas of public amenity;

when considering any alteration of the foreshore or seabed within the coastal marine area.

9.3.2 *To preserve the natural character of Otago's coastal marine area as far as practicable from the adverse effects associated with any alteration of the foreshore or seabed.*

9.3.3 *To take into account the effects of natural physical coastal processes when considering activities which alter the foreshore or seabed in the coastal marine area.*

9.3.4 *To restrict the disturbance of the foreshore and seabed to those activities which require a coastal location.*

The proposal will not adversely affect any areas of cultural significance or conservation value. Effects on amenity values, in this case recreational uses, have been considered, along with effects on coastal processes. The coastal processes are assessed as being stable and no adverse responses have been observed through monitoring. A coastal location is deemed necessary, as detailed in the earlier discussion of alternatives.

7.3.2 Policies

9.4.1 *In order that any proposed alteration of the foreshore or seabed that will, or is likely to, have an adverse effect on cultural values, can be identified by kaitiaki runanga, Kai Tahu will be:*

(a) Treated as an affected party for non-notified resource consent applications to alter the foreshore or seabed within areas, or adjacent to such areas, identified in Schedules 2 and 3 of this Plan as having cultural or spiritual values to Kai Tahu; and be

(b) Notified about notified resource consent applications to alter the foreshore or seabed within the coastal marine area.

None of the disposal sites are within areas identified in Schedules 2 or 3 as having cultural or spiritual values to Kai Tahu. However, the Shelly Beach site is adjacent to Coastal Protection Area 15, Aramoana, which is recognised within Schedule 2 of the Plan as being an area of cultural and spiritual significance to Kai Tahu.

As required by condition 10 of the previous consent, 2000.472, a working party including representatives of Te Runanga Otakou and Kati Huirapa Runanga ki Puketeraki was established in 2003. This group has met at least annually, with the most recent meeting being held on 24 March 2011.

It is considered that the involvement of iwi in the working party and the consultation undertaken with KTKO Ltd in relation to this consent application fulfils the aim of the above policy.

> **9.4.2** *For activities involving the alteration of the foreshore or seabed, priority will be given to avoiding adverse effects on values associated with any area identified in Schedules 2 and 3 of this Plan as being a coastal protection area, a coastal recreation area, an area of outstanding natural features and landscapes or an area important to marine mammals or birds.*

The disposal areas are in the vicinity of the following Coastal Management Areas identified in Schedules 2 and 3:

- Coastal Protection Area 15 Aramoana - Kai Tahu cultural and spiritual values.
- Coastal Development Area 4 Otago Harbour - Commercial port facilities
- Coastal Recreation Area 8 Spit Beach - Swimming, walking and surfing.
- Outstanding Natural Features and Landscapes 8 Heyward Point - Outstanding headland, sand beaches, and spit at the entrance to Otago Harbour.
- Coastal Hazard Area 5 The Spit - Sandy beach erosion (spit and saltmarsh at risk)

The disposal activity appropriately responds to the above matters. Cultural and spiritual values are addressed through Port Otago's consultation with iwi and the iwi representatives on the working party. The proposal is a core part of the commercial port activity recognised by the Coastal Development Area 4 notation in the RCP. Effects on recreation have been considered in Section 6.7 of this report and the activity will not have any visual or other effects on landscape values. The disposal at Shelly Beach is aimed at reducing erosion to The Spit and saltmarsh.

> **9.4.5** *The area to be disturbed during any operation altering the foreshore or seabed will be limited as far as practicable to the area necessary to carry out that operation.*

The depositing of material will be limited to the specific areas provided for within Rule 9.5.4.1 of the Plan.

> **9.4.6** *The integrity of natural features such as beaches, sand dunes, salt marshes, wetlands, and barrier islands, and their ability to protect areas above the line of mean high water springs from natural physical coastal processes will be maintained and enhanced wherever practicable.*

The specialist reports, in particular the report prepared by Dr Single in Appendix C, demonstrate that natural physical coastal processes will be maintained.

> **9.4.8** *For the following activities, consideration will be given to the reasons for undertaking the activity in the coastal marine area, the public benefit to be derived and to any other available alternatives:*
>
> *(a) Any reclamation; or*

(b) The removal of sand, shingle, shell or other natural materials for commercial purposes; or

(c) Any deposition of material.

...In some situations, such as the deposition of material associated with the maintenance dredging of Otago Harbour, there are very few other practicable options for disposing of the dredged material.

As acknowledged within the explanation to Policy 9.4.8, disposal at sea still remains the only sustainable way to dispose of continuous volumes of dredged material.

9.4.10 *Alterations of the foreshore and seabed should blend as far as is practicable with the adjoining landscape to minimise the visual impact of the alteration on the character of the area.*

Disposing the material to the seabed will ensure that it does not impact on the visual qualities of the surrounding landscape.

7.4 London Convention & NZ Guidelines for Sea Disposal of Waste

The New Zealand Guidelines for Sea Disposal of Waste[2] ("the NZ Guidelines") have been jointly prepared by the Maritime Safety Authority of New Zealand and the Ministry for the Environment. They are New Zealand's way to give effect to the London Convention (1972) ("the London Convention") and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (1996) ("the 1996 Protocol").

The NZ Guidelines were modelled on the guidelines produced by Environment Australia in 2002. The Australian 2002 guidelines were subsequently updated in 2009 but the NZ Guidelines have not been updated.

It is notable that the London Convention, the 1996 Protocol, and other European guidelines which also give effect to the London Convention, were largely designed around considering disposal of material with high concentrations of contaminants, which is far more common in that part of the world.

The NZ Guidelines aim to assist applicants to safely dump waste at sea (including dredged material). Section 4 of the NZ Guidelines describes a process for characterising waste including dredged materials. The guidelines refer to a four-stage process of characterisation, increasing in detail and complexity depending on the nature of the material from Level 1 to Level 4.

The NZ Guidelines provide guideline concentrations for contaminants that may be present in waste proposed for dumping at sea (referred to as the 'Action List'). The Action List is largely based on the ANZECC 1998 Guidelines for Fresh and Marine Water Quality ("the ANZECC Guidelines"). The ANZECC Guidelines are primarily based on biological effects guidelines developed overseas, with modifications to reflect New Zealand conditions.

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[2] New Zealand Guidelines for Sea Disposal of Waste (Advisory Circular, Maritime Safety Authority of New Zealand), 30 June 1999

There is no obligation for regional councils to have regard to the guidelines, but they are available to assist councils, if required. Under Section 104(1)(c) of the RMA the NZ Guidelines contain relevant provisions that may be considered as *"any other matter the consent authority considers relevant and reasonably necessary to determine the application"*. While the NZ Guidelines are most relevant, in our view, the relevance of these guidelines to this short-term 3 year consent is limited. Notwithstanding this, as detailed in Section 6.5 above, sediments at the dredge sites have been tested and apart from slightly elevated arsenic in a few locations, all are below the ANZECC guidelines for fresh and marine water quality and the NZGSDW low level guidelines for concentrations that are known to impact on biota.

7.5 Kāi Tahu ki Otago Natural Resource Management Plan

The KTKO Natural Resource Management Plan (NRMP) 2005 is relevant to the consideration of this application pursuant to Section 104(1)(c) of the RMA. The NRMP is divided into catchments, with specific provisions for the whole Otago area and for each catchment. The current proposal is located within the Otago Harbour Catchment.

The 2005 Natural Resource Management Plan contains objectives and policies for the coastal environment. The particularly relevant provisions are discussed below.

Objective 5.8.3 – The spiritual and cultural significance of taku tai moana me te wai māori is recognised in all management of the coastal environment.

Policy 5.8.12 - To require that dredging and reclamation works avoid physical damage to kai moana sites, habitat and the integrity of the seabed.

Policies 8.2.3 - To encourage research and monitoring into sediment deposition at Blueskin Bay and Pūrākaunui.

- *To encourage the dumping of all dredging material beyond the continental shelf.*
- *Dredging activity should not impact on tuaki and other marine life.*

Consultation with iwi is being undertaken to ensure that the spiritual and cultural significance of this location is recognised and provided for in this application. The disposal activity relates only to the historic disposal sites so no physical damage to kai moana sites, habitat or seabed will result from this proposal. The applicant has been engaging with iwi through the working party established in relation to the existing consent, which provides input into the research and monitoring of sediment deposition in and around Blueskin Bay.

In relation to the policy which seeks that all sediment deposition be carried out beyond the continental shelf, it is noted that the Cultural Impact Assessment prepared for Project Next Generation accepted that this was not economically viable for that project. This applies to the current application also.

In terms of effects on tuaki and other marine life, marine biota and sediment paths have been the subject of ongoing monitoring during the term of the existing consent and no adverse effects have been identified.

7.6 Conclusion

Overall it is considered that the proposal is consistent with the objectives and policies of the New Zealand Coastal Policy Statement, the Otago Regional Policy Statement, the Otago Regional Plan: Coast, the London Convention & NZ Guidelines for Sea Disposal of Waste and KTKO's Natural Resource Management Plan.

8. Part 2 of the RMA

Part 2 of the RMA sets out the purpose and principles of the RMA, which is relevant to this proposal.

8.1 Section 5

The purpose of the RMA (Section 5) is to promote the sustainable management of natural and physical resources. The Act defines "sustainable management" as:

> *"managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while*
>
> *(a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
>
> *(b) Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
>
> *(c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment."*

Applying Section 5 involves an overall judgement of whether a proposal would promote the sustainable management of natural and physical resources. In practice, there are two general elements that must be considered when assessing the resource consent application. They are:

- Enabling people and communities to provide for their social, economic and cultural wellbeing.
- Safeguarding environmental quality and avoiding, remedying or mitigating adverse effects.

Section 6 of this report addressed the contribution that this activity will continue to make to enabling people and communities to provide for their social, economic and cultural wellbeing and health and safety, in particular through the economic benefits that dredging disposal offers.

The specialist reports and other discussion in Section 6 of this report have addressed how the proposed development will sustain the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations, and how the life supporting capacity of the environment will be safeguarded. It is noted also that the port facilities are a significant physical resource in their own right.

In terms of the requirement to avoid, remedy or mitigate adverse environmental effects, we consider the effects of the ongoing dredging disposal activity have been comprehensively studied and assessed through the monitoring work carried out over the last 10 years and in preparation for this application. All adverse effects have been identified and can be appropriately avoided, remedied or mitigated through the use of appropriate conditions.

8.2 Sections 6, 7 and 8

Sections 6, 7 and 8 of the RMA set out the principles to be applied in achieving the purpose of the Act. These principles are subordinate to the overriding purpose of the Act. Potentially relevant matters include:

- Section 6(a) natural character of the coastal environment;
- Section 6(d) maintenance and enhancement of public access;
- Section 7(c) maintenance and enhancement of amenity values;
- Section 7(d) intrinsic values of ecosystems;
- Section 7(f) the quality of the environment; and
- The Maori provisions contained in Sections 6(e), 7(a) and Section 8.

Based on the assessment of effects undertaken, we conclude that there to be no matters within these sections that would suggest the ongoing disposal of dredged material, undertaken in accordance with the proposed conditions, will be inappropriate in terms of the relevant Section 6, 7 or 8 matters.

8.3 Section 107 of the RMA

Section 107 of the RMA is designed to protect water quality after reasonable mixing. As discussed in Section 6.4 of this report, this proposal will have very minor and localised turbidity effects which will quickly dissipate after disposal. Accordingly, it is concluded that the effects identified in Section 107 of the Act will not arise after reasonable mixing.

9. Consultation and notification

9.1 Requirement to consult

Pursuant to Section 36A(a) of the RMA, neither the applicant nor the Council are required to consult over resource consent applications, however, a discussion of the consultation that has been carried out is provided below.

9.2 The working party

Condition 10 of resource consent 2000.472 required that a formal working party be established and meet at least annually to discuss and review the annual monitoring report that was required by Condition 11.

The condition required that the working party include representatives of Te Runanga Otakou, Kati Huirapa Runanga ki Puketeraki, the Department of Conservation and Otago Regional Council.

The working party has met at least annually since its first meeting in January 2003, with 10 meetings having been carried out to date. As well as those parties required by the consent, members of the University of Otago Marine Science Department have been involved with the working party. The minutes of meetings have been forwarded to Otago Regional Council each year, in accordance with the consent requirements.

The following briefly discusses the activities of the working party to date.

27 January 2003

This was the first meeting of the party. Progress reports from Land and Water Studies International Ltd and from Drs Probert and Paavo (University of Otago Benthic Study) being prepared to fulfil conditions 5, 6 and 7 of the consent were considered. No monitoring had been undertaken at this stage as the reports were still being worked on.

The party agreed that in upcoming meetings, Barry Strong (ORC Compliance Manager) would update the group on other ORC coastal studies that were being carried out in order for the group to have a more holistic understanding of Port Otago's activities in relation to the coastal environment.

23 January 2004

Progress reports from Land and Water Studies International Ltd and from Drs Probert and Paavo were again considered. The Probert and Paavo study was 50% complete when the working party met, with the sampling and counting phase having been completed.

Dr Single advised the group that the Land and Water Studies International Ltd report was complete. The effects of the disposal of dredged material on Heyward, Aramoana and Shelly Beach were discussed.

Alan Sutherland of Port Otago Ltd advised that the dredging figures were being finalised and would be circulated to the working party. It was discussed that 2003 was an unusual year in that the New Era was away from the harbour on contract for 4 months.

Based on the information presented at the first two meetings, the working party agreed that Port Otago Ltd was disposing in accordance with the resource consent and that all the requirements in terms of the monitoring studies were being met.

26 January 2005

A follow on report to the Land and Water Studies International Ltd report was presented and discussed. This report looked at the sediment retention at each of the three sites however was not complete at the time of the meeting.

A progress report was presented on the University of Otago study. The final data on species diversity and numbers was being processed however guidance was sought from the working party on the indicators with which to recommend on-going biological monitoring.

A general discussion followed, the conclusion being that the need for on-going monitoring could only be determined once the assessment of effects on diversity and numbers was available. It was discussed that there may not be an applicable New Zealand indicator or bench mark and so the University may need to formulate its recommendation on on-going monitoring based upon overseas examples.

30 November 2005

The working party considered the following final reports:

- Sediment transport pathways around Otago Harbour and north to Karitane Peninsula. Kat Bunting, Dr Martin Single and Professor Bob Kirk, November 2003.
- Effects of the disposal of dredge spoil at Shelly Beach, Otago Harbour. Kat Bunting, Dr Martin Single and Professor Bob Kirk, November 2003.
- Infaunal assemblages in coastal sediments at dredge spoil disposal sites of Otago, New Zealand. Brian L. Paavo and Keith Probert, 2005.
- Coastal evolution of Shelly Beach 2005. Javier Leon, March 2005.
- Change in seabed elevation of dredge spoil disposal sites at Heyward Point, Aramoana and Shelly Beach. Javier Leon, March 2005.

13 April 2007

A report on stormwater discharges from Brian Turner of Dunedin City Council was considered by the group and it was agreed that no further action was required on this matter.

On-going monitoring was discussed, with funding for indicator species monitoring to be confirmed by Port Otago Ltd. The Otago Regional Council Compliance Officer also undertook to report back to the party on the availability of guidelines for the evaluation of the comprehensive monitoring.

Disposal data was discussed, as was the potential for a new disposal site. It was concluded that there was no foreseeable future need for a new disposal site for maintenance dredging, and that the Heyward site should instead be used more often.

It was suggested that a specific study be carried out into the different effects of sand and mud disposal. Consideration will be given to including this in the benthic study for the renewal application.

31 January 2008

It was agreed at this meeting that the working party would review the existing conditions of consent and consider their relevance for the renewal application. Conditions 1, 3 and 8-13 were considered by the working party as being appropriate to impose on the new consent. The remaining conditions were commented on as follows:

2. It was raised whether the wording of the consent could cover dredging areas outside of the main shipping channels. It was agreed that any additional areas would need a consent for the dredging and under this process the testing for contaminants may be required to ensure such material would not be taken to disposal sites.

4. It was suggested that rock and clay type material be disposed at Heyward rather than the Spit, as material would be in deeper water and away from possible dispersion onto nearby beaches, as could potentially happen at the Spit.

5. The report by Kat Bunting and Martin single has fulfilled this condition.

6. The report by Javier Leon has fulfilled this condition.

7. The report by Brian Paavo and Keith Probert has fulfilled this condition.

Discussion was had regarding whether the current consent should be amended to allow for the disposal of sand ashore for the re-nourishment of the Dunedin Beaches as undertaken at times during 2007. Port Otago Ltd advised that any consents that would need to be sought separately and could be done so by Dunedin City Council. Port Otago Ltd agreed to keep all members of the working party informed of updates/progress on this matter.

Dredging records were discussed, as was the need for early preparation of the reports for the 2011 application so that all parties could be aware of any issues that need further consideration.

22 January 2009

The proposed work scope and programme of works to be undertaken in advance of the renewal of the existing consent in December 2011 was discussed. It was stated that the scope and program would build on the works undertaken since the start of the consent in 2001, and would include and incorporate the discussions and work of the working party.

No specific effects over the past 12 months were identified by the working party that would require additional mitigation measures.

28 January 2010

Discussion was had by the working party regarding the differences in the Next Generation consent and the consent that is required for the on-going disposal of maintenance dredging material. Discussion was also had regarding the reports that would be completed for each application.

27 January 2011

Progress was reported on the monitoring work programme since the last meeting.

24 March 2011

An extraordinary meeting was held to consult on the 3-year renewal application. Draft specialist reports were presented by Drs Single, Paavo and McComb. The feedback from the working party was to support the 3-year consent. Members noted it provides the opportunity to complete monitoring work in anticipation of seeking a 35-year consent based on adaptive management principles. Port Otago indicated that a draft copy of the application would be circulated to members in due course.

9.3 Other interested parties

Port Otago staff and Dr McComb met on 24 March 2011 with representatives of South Coast Board Riders group to discuss the monitoring work undertaken in relation to effects on wave formation. This was an informal meeting which was essentially a precursor to future meetings and involvement with monitoring surfability at The Spit.

Port Otago is corresponding directly with the Department of Conservation and local iwi through KTKO Ltd. General feedback on the activity and the appropriateness of the approach of seeking a short-term consent has been favourable to date. The only issue identified was concern whether the term for the short-term consent was sufficient to allow the monitoring work to be completed and an adaptive management programme to be developed, with sufficient time for consultation as a part of this also. This feedback has been taken accepted by Port Otago, and the initial 2-year period proposed has amended to 3-years. Consultation with the Department of Conservation and KTKO Ltd is ongoing.

Consultation is being undertaken as a matter of courtesy. These parties are not considered by the applicant to be adversely affected by the proposal, given the short-term nature of the consent sought.

9.4 Notification

The criteria for the consenting authority in making a decision whether it is necessary to notify an application are outlined in Section 95 of the RMA. In accordance with Section 95A of the RMA, the applicant considers the application can be processed on a non-notified basis due to the following reasons:

- The adverse effects of the proposal will be no more than minor.
- There is no rule in a national environmental standard that requires public notification.
- The applicant does not request notification.
- It is considered that there are no special circumstances warranting the need for public notification.

Section 6 of this report has outlined that the adverse effects of the activity will be minor. It is considered that the first notification test required by Section 95A of the RMA has been met. Following this, section 95B of the RMA requires that under Section 95E(1) the consent authority is to determine whether there are any affected persons.

Overall, no persons are considered to be adversely affected to a degree greater than the public in general, as the effects relate to the public coastal environment. Therefore, as no persons are affected beyond the public generally, it is considered that the proposal meets the tests of Section 95E.

10. Monitoring

This application essentially seeks a short extension to an existing consent. In this regards, a term of three years is being sought for the consent. After this time, it is intended that a 35-year disposal consent will be sought. For the long term consent monitoring framework, Port Otago intend to work with key stakeholders and the ORC to develop a suitable long-term consent framework and monitoring programme, which is intended to be based on the principles of adaptive management, i.e. adjusting the disposal activity in response to any issues identified through regular monitoring activities. Suitable biological monitoring indicators will be determined during the next 3 years to feed into this long term monitoring framework.

The key monitoring work intended to be carried out by Port Otago over the next 3-years includes sediment transport work to report on:

- Completion of long-term shoreline change analysis from aerial photographs;
- Correlation of sediment transport modelling and rollability results with identified areas of seabed elevation changes;
- A sediment budget for the inner Blueskin Bay area across the outer harbour channel; and
- A proposal for an adaptive management framework for the long term management of sediment transport effects associated with disposal activities.

Also proposed is verification of the dominant wave-driven circulation features identified in the work of Dr McComb, which will include liaising with the local surfing community on the quality of the Aramoana surf break at different times.

Additionally, Port Otago intend to commission work to provide recommendations for a long term ecological monitoring programme (including indicator species) and advice for development of the adaptive management framework for managing the effects on biota of disposal at and about the disposal sites. This will take into account the results of biota monitoring undertaken as a condition of the existing maintenance disposal consent.

Port Otago intend to work with stakeholders and interested parties on the monitoring work, either through the current working party, or the Technical Group proposed as part of the Project Next Generation development.

Noting the work and effort proposed for the 35 year consent, Port Otago seek that any monitoring required for the 3-year consent sought under this application, be either a continuation of existing monitoring (as required by the existing consent) or contributing to information required to formulate a long term monitoring programme for the Port company's future dredging disposal activity.

11. Conclusion

Port Otago Limited is seeking a short-term replacement consent to allow for the continued disposal into the sea of up to 450,000m³ per year of dredged material. This will replace the current coastal permit, 2000.472, which expires in December 2011. Port Otago is seeking to continue to dispose of dredging material pursuant to the terms and conditions applying to coastal permit 2000.472, as appropriate.

This application seeks the ability to continue to dispose of dredged material to sites which are specifically recognised for this activity within the RCP. Consent is only sought for a short term, being 3-years from the date that the consent is granted.

The adverse effects of the proposal will be minor, taking into account the specialist reports prepared for this application, which are based on monitoring undertaken over the last 10 years. The activity has a number of positive effects also.

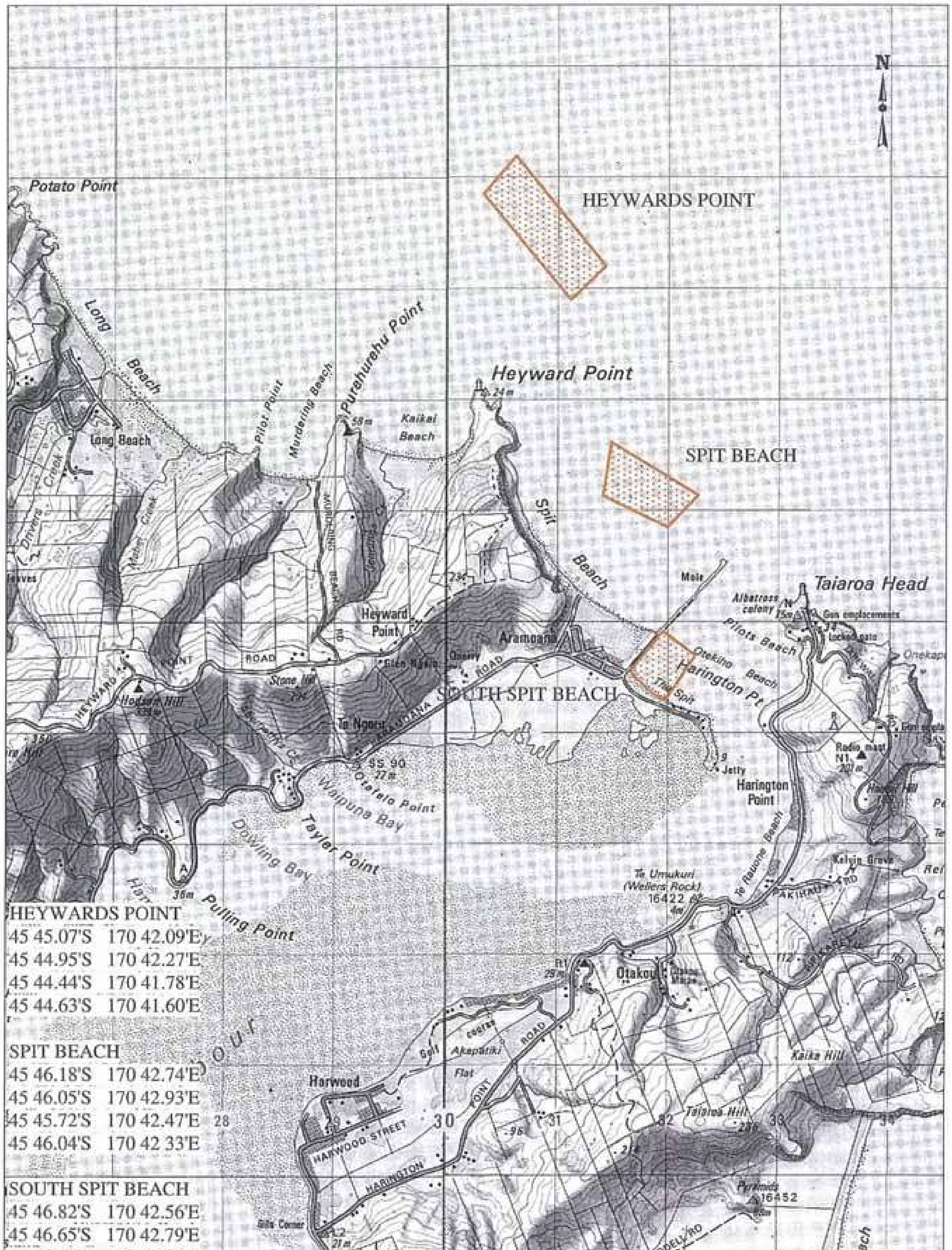
The proposal is consistent with the objectives and policies of the NZCPS, the RPS and the RCP. The proposal is not contrary to the London Convention or the NZ Guidelines for Sea Disposal of Waste.

The proposal represents sustainable management as defined in Part 2 of the RMA. The coastal processes are stable and no Section 6 or 7 matters will be adversely affected by the continued disposal activity. Accordingly, the application meets the requirements of the Resource Management Act.

We consider that consent can be granted, subject to appropriate conditions of consent. We would appreciate the opportunity to comment on conditions, to assist with ensuring conditions of consent are reasonable and can be met by the applicant.

Appendix A

Location of Disposal Sites



Dredge Spoil Grounds

Appendix B

Disposal Records

Port Otago Maintenance Dredging Disposal - 1985 -2010 (Previous 10 years in red)

Year	Heywards			Spit			Shelly	3 Dumpsites	Reclaim			Other			Total Drg Qty
	New Era	Vulcan	Hey Pt Total	New Era	Vulcan	Spit Total	New Era	Yrly Total	New Era	Vulcan	Total	New Era	Vulcan	Total	Yrly Total
1985	121,032	9,720	130,752	16,591	0	16,591	0	147,343	0	2,520	2,520	(1) 567		567	150,430
1986	20,088	0	20,088	247,520	0	247,520	0	267,608	0	0	0	(2) 520	0	520	268,128
1987	0	0	0	243,085	11,618	254,703	10,098	264,801	0	0	0	0	(2) 246	246	265,047
1988	72,022	585	72,607	231,925	12,688	244,613	49,896	367,116	0	0	0	0	(2) 23,279	23,279	390,395
1989	98,670	14,040	112,710	111,106	37,556	148,662	17,409	278,781	0	0	0	0	(2) 4,107	4,107	282,888
1990	152,035	11,073	163,108	95,088	38,491	133,579	12,084	308,771	0	0	0	0	(3) 142	142	308,913
1991	111,217	9,442	120,659	135,605	61,461	197,066	10,520	328,245	0	0	0	0	0	0	328,245
1992	46,602	10,491	57,093	36,210	50,315	86,525	1,140	144,758	(9) 1,870	(3) 1,183	3,053	0	0	0	147,811
1993	95,310	3,055	98,365	152,105	23,594	175,699	35,055	309,119	(9) 5,470	(10 8,993	14,463	0	0	0	323,582
1994	73,110	5,436	78,546	109,620	46,297	155,917	24,295	258,758	0	(11) 2,468	2,468	0	0	0	261,226
1995	37,990	4,573	42,563	131,755	47,702	179,457	12,240	234,260	(9) 1,900	0	1,900	0	0	0	236,160
1996	7,120	11,745	18,865	62,365	29,640	92,005	1,775	112,645	(9) 108,930	(12) 465	109,395	0	0	0	222,040
1997	41,275	100	41,375	161,695	411	162,106	5,995	209,476	(9) 25,940	0	25,940	0	(4) 5,543	5,543	240,959
1998	21,545	3,093	24,638	123,255	21,705	144,960	2,570	172,168	0	0	0	0	0	0	172,168
1999	59,960	3,163	63,123	137,905	2,687	140,592	15,115	218,830	0	0	0	(5) 5,150	(6) 115	5,265	224,095
2000	54,115	4,495	58,610	165,235	7,744	172,979	25,935	257,524	0	0	0	0	0	0	257,524
2001	24,000	475	24,475	107,035	11,392	118,427	18,445	161,347	0	0	0	0	(6) 188	188	161,535
2002	46,740	715	47,455	123,725	17,681	141,406	29,140	218,001	0	0	0	0	0	0	218,001
2003	39,180	0	39,180	73,895	9,894	83,789	30,470	153,439	0	0	0	0	0	0	153,439
2004	30,400	5,480	35,880	67,580	22,170	89,750	23,440	149,070	0	0	0	0	(6) 465	465	149,535
2005	31,730	4,146	35,876	126,850	22,834	149,684	46,022	231,582	0	0	0	(7) 605	0	605	232,187
2006	600	390	990	21,810	21,507	43,317	5,265	49,572	0	0	0	(8) 600	0	600	50,172
2007	27,177	6,348	33,525	52,208	10,630	62,838	12,700	109,063	0	0	0	(13) 11,528	0	11,528	120,591
2008	45,970	9,049	55,019	12,700	1,965	14,665	16,080	85,764	0	0	0	(13) 9,622	0	9,622	95,386
2009	54,600	1,280	55,880	11,935	6,495	18,430	19,680	93,990	0	0	0	(14) 5,525	(15) 550	6,075	100,065
2010	90,435	18,769	109,204	22,942	121	23,063	35,850	168,117	0	0	0	(16) 610		610	168,727
26 yr Tot	1,402,923	137,663	1,540,586	2,781,745	516,598	3,298,343	461,219	5,300,148	144,110	15,629	159,739	34,727	34,635	69,362	5,529,249
26 yr Ave	53,959	5,295	59,253	106,990	19,869	126,859	17,739	203,852	5,543	601	6,144	1,336	1,332	2,668	212,663
Last 10 yr Tot	390,832	46,652	437,484	620,680	124,689	745,369	237,092	1,419,945	0	0	0	28,490	1,203	29,693	1,449,638
last10yr Ave	39,083	4,665	43,748	62,068	12,469	74,537	23,709	141,995	0	0	0	2,849	120	2,969	144,964

1 - Unknown
2 - Off beacon 74 u/h
3 - Long Mack Groyne
4 - ex Oamaru Harbour
5 - Green Island Outfall (4500m3) and Careys Bay Beach (650m3)
6 - Various - Barges Opening
7 - At gap in islands (305m3) and Off Napier (300m3)
8 - Off Napier (300m3) and Off Gisbourne (300m3)
9 - Discharge ashore for reclaim
10 - Long Mack Groyne (8085m3) and Back Beach Reclaim (908m3)
11 - Back Beach Reclaim (1946m3) and Various (522m3)
12 - Boiler Point Reclaimation
13 - Discharge ashore for Dunedin Beaches
14 - Discharge ashore for Dunedin Beaches (5,045m3) & Off Banks Peninsula (490m3)
15 - Material discharged A/S disused section of Victoria Wharf after hydraulic failure on New Era
16 - Discharge at sea off Timaru (305m3) and Banks Peninsula (305m3).

Appendix C

Martin Single, Shore Processes and Management Ltd – Report on Physical Coastal Environment

Port Otago maintenance dredging consents - Physical coastal environment

Prepared for

Port Otago Ltd

Martin Single

May 2011

Shore Processes and Management Ltd

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Contents

List of Figures

List of Tables

1. Introduction

This report describes aspects of the physical coastal environment of Blueskin Bay. It has been commissioned in order to provide information for a Port Otago Ltd (POL) application for resource consent to dispose dredged sediment at existing disposal sites between Heyward Point and Otago Harbour. The aim of this report is to describe the general physical coastal environment of Blueskin Bay in order to provide information. The report also presents an assessment of the effects of the POL maintenance dredging disposal activity on the physical coastal process environment. This report should be read in conjunction with Single (2011) and MetOcean Solutions Ltd (2011).

1.1 Proposed activity

Port Otago Limited (POL) is seeking a short-term replacement consent to allow for the continued disposal into the sea of up to 450,000m^3 per year of dredging spoil. This will replace the current coastal permit, 2000.472, which expires in December 2011. Port Otago is seeking to continue to dispose of dredging material pursuant to the terms and conditions applying to coastal permit 2000.472.

The spoil is derived from maintenance dredging and incremental improvements to the channel and berth areas in and about the Otago Harbour. The proposed disposal activity is to be carried out in accordance with the following specific maximum annual discharge quantities at each location:

- Heyward Point, being an area of approximately 38.2ha and to receive up to 200,000m^3 of spoil;
- Spit Beach, being an area of approximately 28.3ha and to receive up to 200,000m^3 of spoil; and
- South Spit Beach (Shelly Beach), being an area of approximately 14.5ha and to receive up to 50,000m^3 of spoil.

A term of two or three years is being sought for the consent. After this time, it is intended that a 35-year disposal consent term will be sought. This will allow for a suitable long-term consent framework and monitoring programme to be developed which takes account of both maintenance dredging disposal and disposal associated with capital dredging sought through the Project Next Generation resource consent that is currently under consideration by the Otago Regional Council.

1.2 Scope of this report

This report refers to and includes detail from reports prepared as part of the application for consent for capital dredging in Otago Harbour (Project Next Generation). Rather than re-write earlier reports, this report synthesises the available information that is directly relevant to the disposal of maintenance dredge spoil. Additional information not assembled for the capital dredging project but necessary to assess the effects of the maintenance disposal is identified and where possible addressed further, as are potential further work streams that will provide for an assessment of effects on the physical coastal environment suitable for a 35-year consent term.

The specific objectives of the report are to:

- Describe the physical coastal environment of the shores and nearshore of Blueskin Bay, and to describe the sediment transport patterns for the area offshore of Otago Peninsula between Taiaroa Head and Karitane Point.

- Assess the effects of the proposed placement of dredged sediment on the physical coastal environment and processes of Blueskin Bay.

The following section presents a brief description of past studies, including those collated for Project Next Generation and as a result of studies carried out as part of the conditions of coastal permit 200.472. Section 3 presents a synthesis of that information plus additional detail specific to the requirements for assessing the effects of the maintenance dredge spoil disposal. A description of changes to the seabed topography is presented in Section 4. Gaps in the information on the physical coastal environment and coastal processes are discussed in Section 5.

Section 6 of this report addresses the effects of the proposed activity on the physical coastal environment. This includes the effects on the shores, sediment characteristics, and sediment transport and shore processes adjacent to the disposal sites, and for the wider Blueskin Bay area. Assessment of the effects has used an approach consistent with international practice (for example PIANC EnviCom Working Group reports on *Environmental risk assessment of dredging and disposal operations*, *Dredging management practices for the environment* and *Dredged material as a resource*), the requirements of the RMA and NZCPS (2010).

2. Basis of existing knowledge on the physical coastal process environment of Blueskin Bay

Single and Benn (2007) provide a summary of the existing information on the physical coastal environment of Otago Harbour and the wider Blueskin Bay area. In preparing that work, a review of literature on coastal and continental shelf processes of Otago Harbour and Blueskin Bay was undertaken (Benn and Single 2007). The review provided a summary of the main understandings of coastal and shelf processes in the study area, and also identified significant gaps in the current knowledge base.

Relevant research carried out before 1990 was summarised in previous reports written as part of the technical assessment of effects of maintenance dredging (Kirk 1980, Single and Kirk 1994, Bunting *et al.* 2003a, 2003b). Smith (1994, 1999), Lusseau (1999a) and Tonkin and Taylor Ltd (2000) also present substantial bibliographic reference lists relating to the Otago Coastal environment.

Benn and Single (2007) identified and referred to three main sources of relevant material: A) Papers published in scientific journals; B) Client based technical reports produced by consulting companies, university staff and post graduate students, and C) Post graduate research theses, diplomas and dissertations. Some information was also gathered from general history accounts.

The general physical coastal environment of Otago Harbour and Blueskin Bay are described in Single and Benn (2007). The findings include:

- The process environment is dominated by high-energy, southerly swell waves, and a south to north current (oceanic, tidal and wave generated) with an anticlockwise eddy in Blueskin Bay.
- Sand on the seabed comes from the Clutha River via the nearshore shelf. The sediment transport rate past Taiaroa Head is moving north at rate of about 1.1 million tonnes per year.
- Approximately 250,000 m3 to 450,000 m3 of sediment is transported into Otago Harbour each year, and is dredged from the shipping channel and deposited onto disposal sites off Heyward Point, Aramoana Beach and Shelly Beach. In effect, the maintenance dredging operation works to bypass the sediment across the harbour inlet.

Leon (2005a, 2005b) carried out studies on the processes of Shelly Beach. His work is of direct relevance to the maintenance dredging consent renewal. The first study investigates the physical coastal processes around Shelly Beach and the Spit disposal site. The second study is based on an analysis of soundings of the Spit, Aramoana and Heyward disposal sites, and assesses the retention and loss of sediment in these areas in relation to the volume of sediment placed there from maintenance dredging. Marshall and Single (2010) update this work to include seabed surveys and analysis to 2010.

Shears (2009) provides an analysis of sediment accumulation in Otago Harbour, with a subsequent development of a sediment budget for the harbour. She concludes that the harbour is no longer infilling, but is maintained in a slight sediment deficit due to changes to the tidal bypassing processes and dredging of the shipping channel.

3. The Physical Coastal Environment of Otago Harbour and Blueskin Bay

3.1 General geography of the area

Figures 2.1 and 2.2 locate places referred to in the text, and show the general location of Otago Harbour and the adjacent coastal area. The two coastal areas at the focus of this report are the harbour and the offshore area from Taiaroa Head to Karitane Peninsula. This area of open coast is often referred to as Blueskin Bay, a name also used for the estuary southwest of Warrington. In this report, the estuary will always be referred to as Blueskin Bay Estuary, while the general open coast area will be referred to as Blueskin Bay.

Otago Harbour is approximately 23km long and averages 2.3km in width. The harbour is bounded to the south and east by Otago Peninsula, and to the north and west by the hills of Mt Cargill. The harbour is effectively divided into upper and lower sections by Quarantine Island located between Port Chalmers and Point Quarantine. The harbour has extensive areas of intertidal sand flats, located mainly on the southern side of the harbour, but also extending south from Aramoana (Figure 2.2).

In effect, the harbour is a long, narrow, shallow inlet, with the mouth only 400 metres wide. Near the mid-way point of the harbour, Quarantine and Goat Island (sometimes referred to as The Halfway Islands) together with the Portobello Peninsular physically restrict the harbour width to 480 metres, effectively separating the harbour into an upper and lower harbour. Port Chalmers is in the lower harbour, and the Port of Dunedin city is at the upper end of the upper harbour.

The port areas of both Port Chalmers and Dunedin are serviced by an artificially maintained shipping channel. Sediment dredged from the channel is deposited at receiving grounds outside the harbour at Heyward Point, off Aramoana Beach (Spit Beach site) and at Shelly Beach.

Apart from Port Chalmers, the other main communities located around the lower harbour are Careys Bay and Deborah Bay, just north of Port Chalmers, Aramoana, which lies at the northern side of the entrance to the harbour, the settlements of Otakou and Te Rauone Beach, on the shore of the eastern side of the harbour south of Harington Point, and Harwood, to the southwest of Te Rauone Beach (Figure 2.2).

Areas of interest in Blueskin Bay include the settlements of Purakanui, Waitati, Warrington and Karitane, and the shores of Kaikai Beach, Whareakeake (Murdering Beach), Long Beach, Purakanui Bay, Warrington Spit, the rocky shore from Warrington to Karitane.

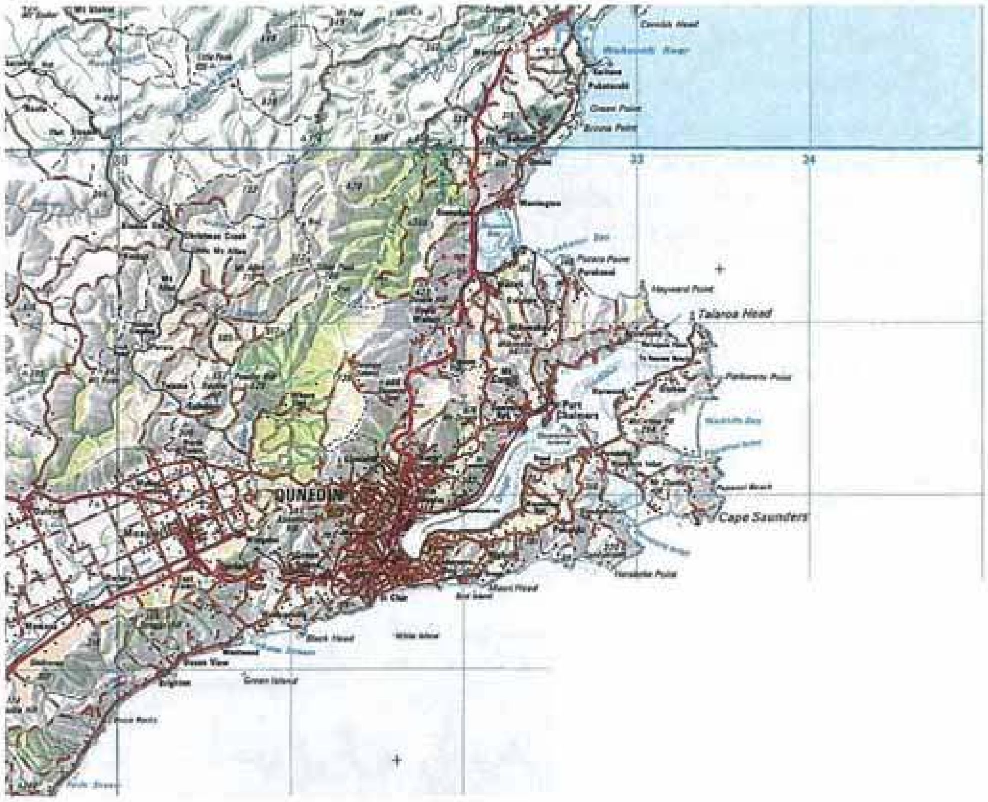


Figure 3.1 Location map of the Otago Harbour area (from NZMS 260 Series via TopoMap).

Figure 3.2 The lower harbour (from NZMS 260 Series via TopoMap).

3.2 Regional Setting

3.2.1 Geology

Figure 3.3 presents a generalised regional map of the geological make-up of the study area and the wider hinterland. The Dunedin volcanic complex and modern alluvial deposits dominate the shorelines of Otago Peninsula and Blueskin Bay. The coastline north of Blueskin Bay estuary to Karitane is characterised by Tertiary Sediments and remnants of the volcanic flows that now form the sea cliffs along this section of shore.

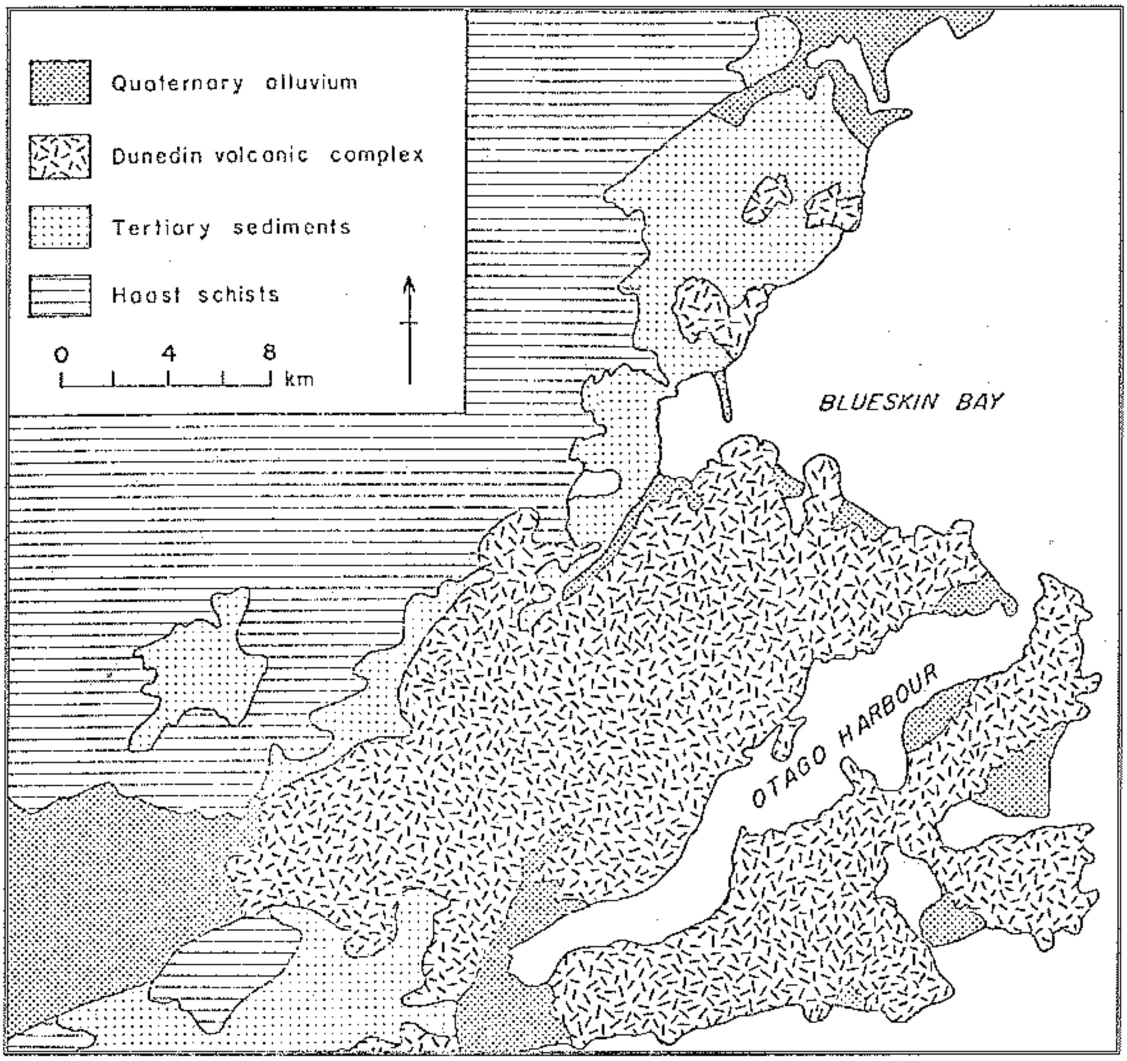


Figure 3.3 A generalised map of regional geology of Blueskin Bay and surrounding hinterland (Source: Nicholson, 1979).

Otago Peninsula, Dunedin and Otago Harbour are located on what is thought to be the centre of the Dunedin Volcano. Alluvium was laid down over the volcanic rocks during the Quaternary (last 1.8 million years). Loess deposits are also present. The source is likely to be the area that is now seabed, as during glacial periods sea level was at a significantly lower elevation than today.

The glacial and interglacial periods that featured during the Late Quaternary through to the Holocene were the main controlling factors of the morphology of the Otago Shelf and the sedimentary deposits on the shores. The area has been subject to prolonged periods of sediment supply from offshore, progradation of the shores and infilling of the harbour and estuaries. Sand deposits on the shores are relatively young, and probably reflect processes and sediment supply to the shore since the last glaciation.

3.2.2 Bathymetry

Figures 3.4 and 3.5 show the bathymetry of the area offshore from Otago Harbour.

The width of the continental shelf out from Taiaroa Head is approximately 30km. The seabed slopes gently out to depths of 100-250m at the edge of the shelf. The seabed of Blueskin Bay slopes to a depth of 30m at a distance of about 17km from Warrington Spit. The contour at 30m forms a near straight line from south to north starting from about 5.5km offshore of Taiaroa Head.

A submarine feature in the form of a submerged spit is situated off Otago Peninsula (referred to as 'Peninsula Spit' by Carter and Carter, 1986). It is a product of the inner continental shelf sand-wedge. The submerged spit can be seen in Figure 3.5. It is approximately 25 kilometres long, tapering from 3 to 4 kilometres width where it abuts the northern shore face of Cape Saunders and fades out northwards on the mid shelf off Karitane. Separate to this submarine feature, is the ebb-tide delta of Otago Harbour. The shipping channel truncates the ebb-tide delta. There is also a prominent accumulation of sediment immediately to the east of the shipping channel. This feature takes the form of a bar, trending north from Taiaroa Head for approximately 2km.

The dredged sediment disposal grounds at Heyward Point and Aramoana form small sand-hills on the general seabed topography. Leon (2005b) investigated the changes in bathymetry of the maintenance dredge spoil disposal grounds. Marshall and Single (2010) updated this work to include surveys of the seabed topography up to May 2010. Changes to the seabed in the vicinity of the disposal sites include the accumulation of sediment at these sites as a result of placed sediment and sediment passing through the area naturally due to nearshore sediment transport processes.

3.2.3 Seabed sediments

The quartz sands of the nearshore zone off Otago are derived from Otago Schists. They are made up of quartz, sodic plagioclase, chlorite, epidote, zoisite, garnet, wollastonite, and biotite. The dominant source for the modern sediment (younger than 6,500 years) is the Clutha River, which delivers in the order of 3.14 million tonnes of sediment to this coastal system each year. Smaller sources of sediment include the Taieri River, which provides about 0.6 million tonnes per year, and nearshore and biogenic productivity, which provide about 0.4 and 0.25 million tonnes of sediment per year respectively. Carter (1986) proposed that of all the sand and gravel sized material delivered to the Otago coast by the Clutha River; approximately half is stored within the large nearshore sand-wedge, with approximately 1.1 million tonnes per year transported north under the influence of wave processes and nearshore currents.

The textural characteristics of the nearshore sediments (size, shape and arrangements) can be described as medium to fine sand, with a mean diameter between 0.125mm and 0.14mm, well to very well sorted, and strongly positively (finely) skewed. The only exception to this textural trend is that of the ebb tide delta situated at the harbour entrance. The sediments in this area are very coarsely skewed. The relatively homogenous nature of the seabed sediments is consistent with a single dominant source for the material.

The sediments present on the inner shelf have important implications with regard to the type of material found at the beaches of Blueskin Bay, as the source of the beach sediments is almost entirely from offshore. Figures 3.4 and 3.5 show that although fine sands dominate the area, very fine sands and silts dominate the central region of the bay, with slightly coarser fine sand dominating sediments in shallower nearshore areas.

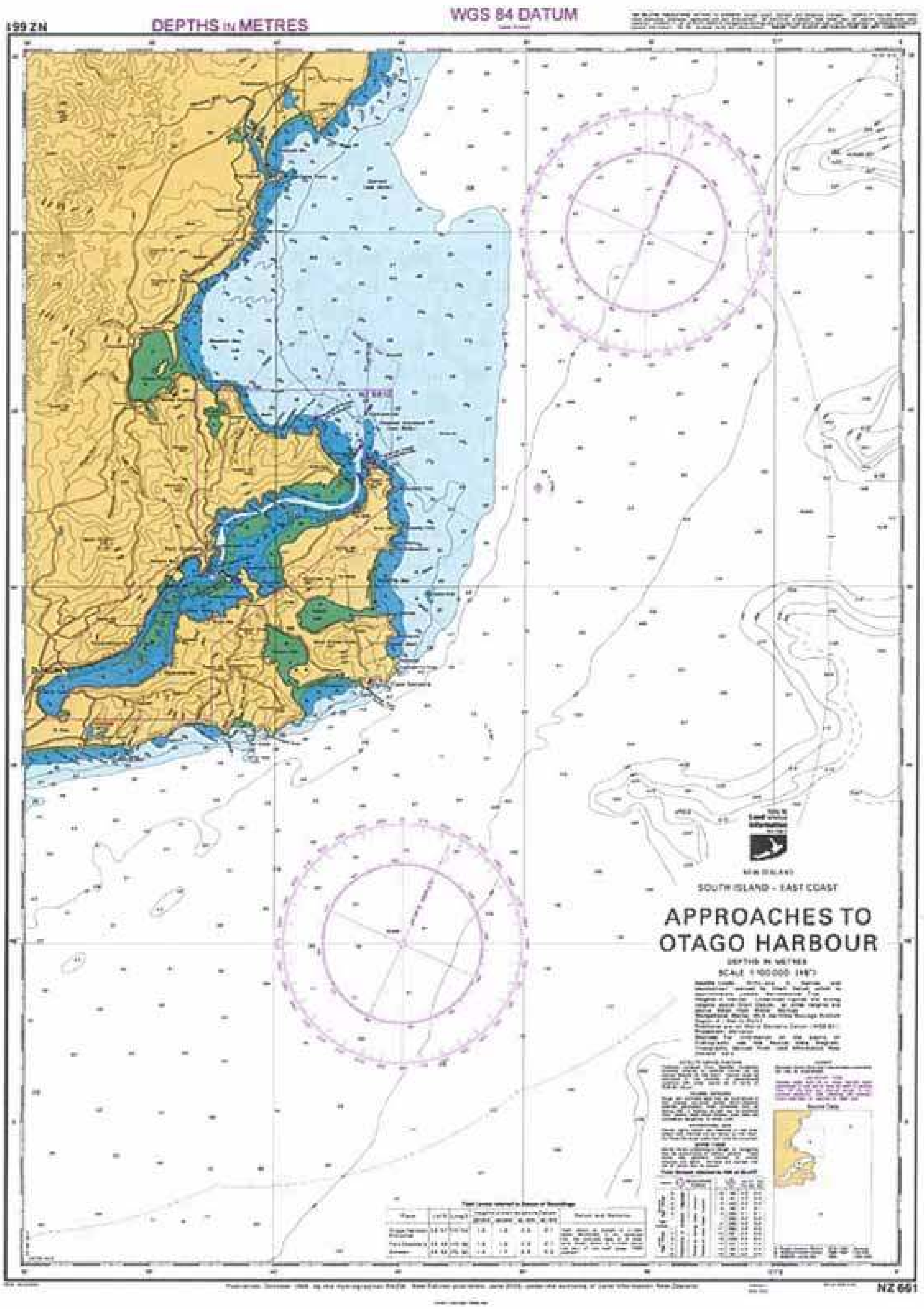


Figure 3.4 New Zealand Hydrographic Chart NZ661 Approaches to Otago Harbour

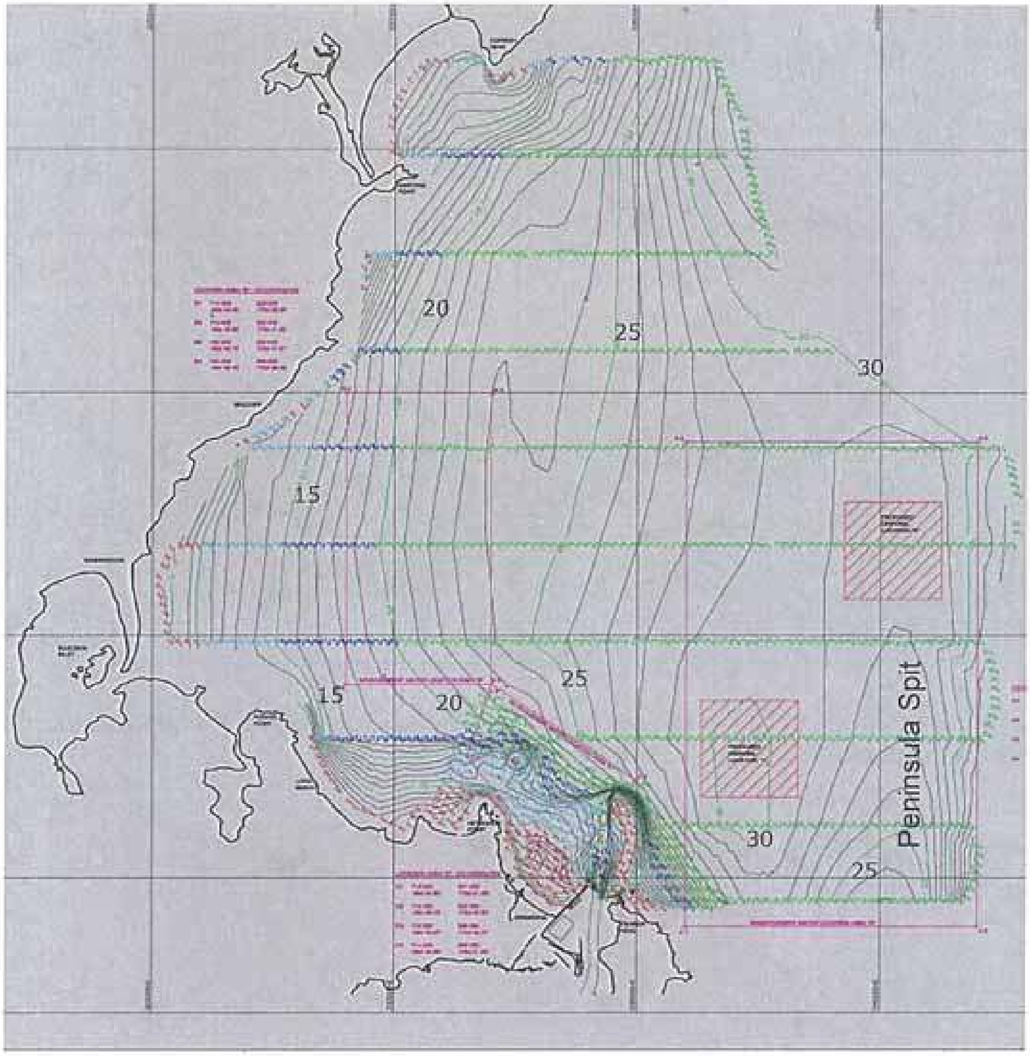


Figure 3.5 POL seabed sounding lines (2 km spacing offshore) and contours at 1 m increments and annotated every 5 m increments (m Chart Datum), illustrating the bathymetry coverage within Blueskin Bay and the inner shelf (Source: Figure 3.1 Bell *et al.* 2009).

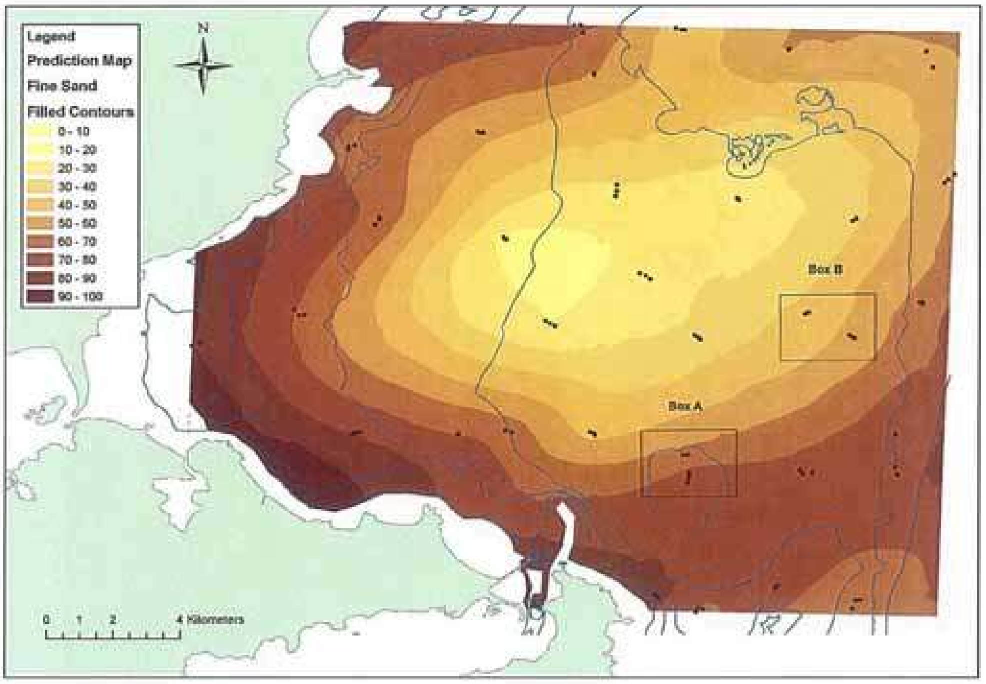


Figure 3.6 Distribution of fine sand (grain size 125-250 µm) content (%) in the sediments of Blueskin Bay (Source: Willis *et al*. 2008).

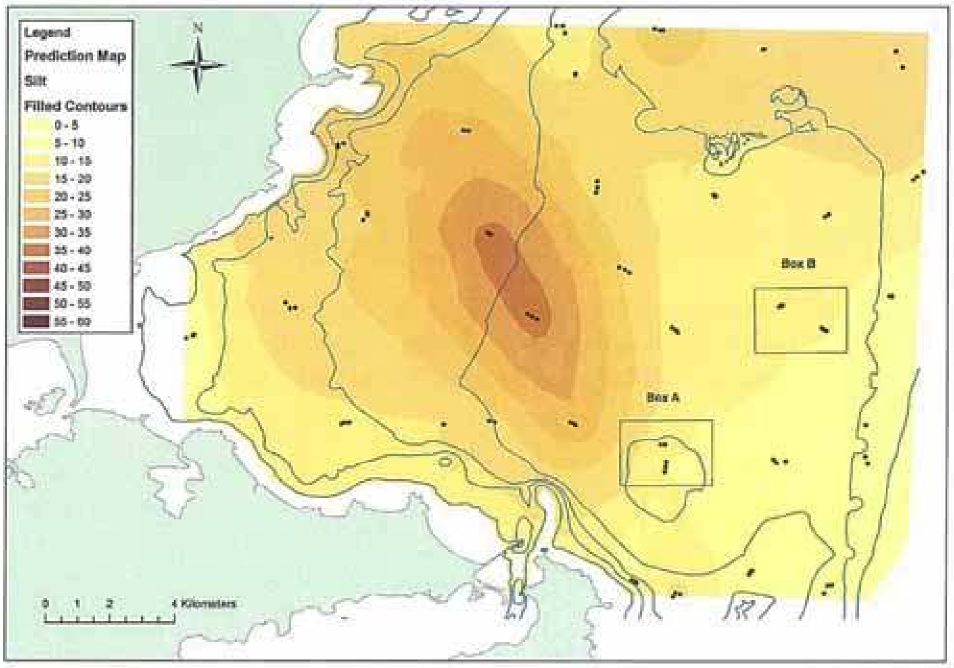


Figure 3.7 Distribution of silt (grain size < 63 µm) content (%) in the sediments of Blueskin Bay. Depth contours are at 5 m intervals from 10 m to 30m (Source: Willis *et al*. 2008).

The sediment of the nearshore is predominantly very well sorted, but reflects the varying degrees of energies acting upon the shoreline between Karitane and Taiaroa Head, with anomalies away from the general trend of very well sorted sediment confined to localised areas.

Bunting *et al*. (2003a) found that the sediments of the beaches and nearshore between Taiaroa Head and Karitane range from 0.15mm to 0.33mm, corresponding to descriptive classifications of fine sand to medium sand respectively. A large proportion (85% of all samples) of the sediments are fine sand size that is 0.17mm to 0.24mm.

The physical nature of the sediments of the coastal system between Taiaroa Head and Heyward Point have not changed significantly over the period since they were first studied by Elliott (1958). The findings of Bunting *et al.* (2003a) also show that the disposal of the sediment dredged from the shipping channel of Otago Harbour offshore at the Shelly, Aramoana, and Heyward Point has not changed the textural nature of the beach and nearshore sediments. These areas do not appear to stand out as anomalies from the surrounding seabed.

3.2.4 Wave Environment

Many studies have shown that the East Coast of the South Island is dominated by oceanic southerly swell waves, with local waves playing a secondary role. The southerly swell component is generally a longer period wave when compared to other waves that are generated locally. An assessment of sea state conditions at Taiaroa Head recorded over a 40-year period (1961 - 2001) showed that swell waves predominantly propagate from the northeast, and these waves are generally low in height. Southerly swell waves are the second most dominant wave, and are larger than those propagating from the northeast. The data also showed a seasonal trend with occasional large wave energy events with wave heights greater than five metres typically experienced during the autumn and winter months. Such waves propagate from the south and southeast and refract around Taiaroa Head into Blueskin Bay.

The most frequent wind directions for the area offshore of Otago Peninsula and Blueskin Bay are from the north / northeast and south / southwest. As a result of the local geography, the direction of wave propagation into the bay is modified such that waves approach predominantly from the northeast and southwest.

MetOcean Solutions Ltd (2011) describes the wave environment of Blueskin Bay in detail, and discusses modelling of waves across the nearshore and sediment disposal sites. In summary, the wave climate of Blueskin Bay is less energetic than the outer Otago shelf and those beaches south of Otago Peninsula, with the bimodality in local wind conditions being reflected also in the wave environment in Blueskin Bay. Of the waves that do enter the bay, strongly refracted southerly swell dominates but refraction lessens its intensity. The northeasterly locally generated waves are unimpeded within the bay, although they are generally less powerful than the southerlies affecting the outer-shelf. 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.

3.2.5 Sediment Transport Paths

Work for previous maintenance dredged sediment disposal consents by Kirk (1980), Single and Kirk (1994) and Bunting *et al.* (2003a, 2003b) determined sources, sinks and transport routes of the nearshore and beach sediments from Taiaroa Head to Heyward Point using a concept of "rollability". This method considers the sediment from the whole environment in a relative manner. Sources and sinks of sediment can be identified. These indicate where sediment is travelling from and to, respectively. This method can be used to infer transport pathways but not rates or volumes of sediment movement. The inferred transport pathways of sediment are from 'sources' to 'sinks'.

Sediments collected by NIWA (Willis *et al.* 2008) were also analysed in the Geography Department, University of Canterbury, using the same rollability method as used by Kirk, Single and Bunting. The inferred transport pathways are shown in Figure 3.8.

The results of the studies from 1980 through to 2008 are relatively consistent in that the main sources and sinks of sediment and major pathways show the same pattern for all studies. The main sediment source areas identified are the shelf south of Taiaroa Head, and areas around Mapoutahi Point (between Purakanui Bay and Blueskin Bay Estuary), Warrington Spit and Potato Point (north end of Long Beach). There are two secondary source areas of sediment. These are the area offshore and the beach at Karitane and the offshore area between

Warrington Spit and Brinns Point. The main sink areas are the entrance channel and nearshore area off Aramoana Beach, and the distal end of the Peninsula Spit.

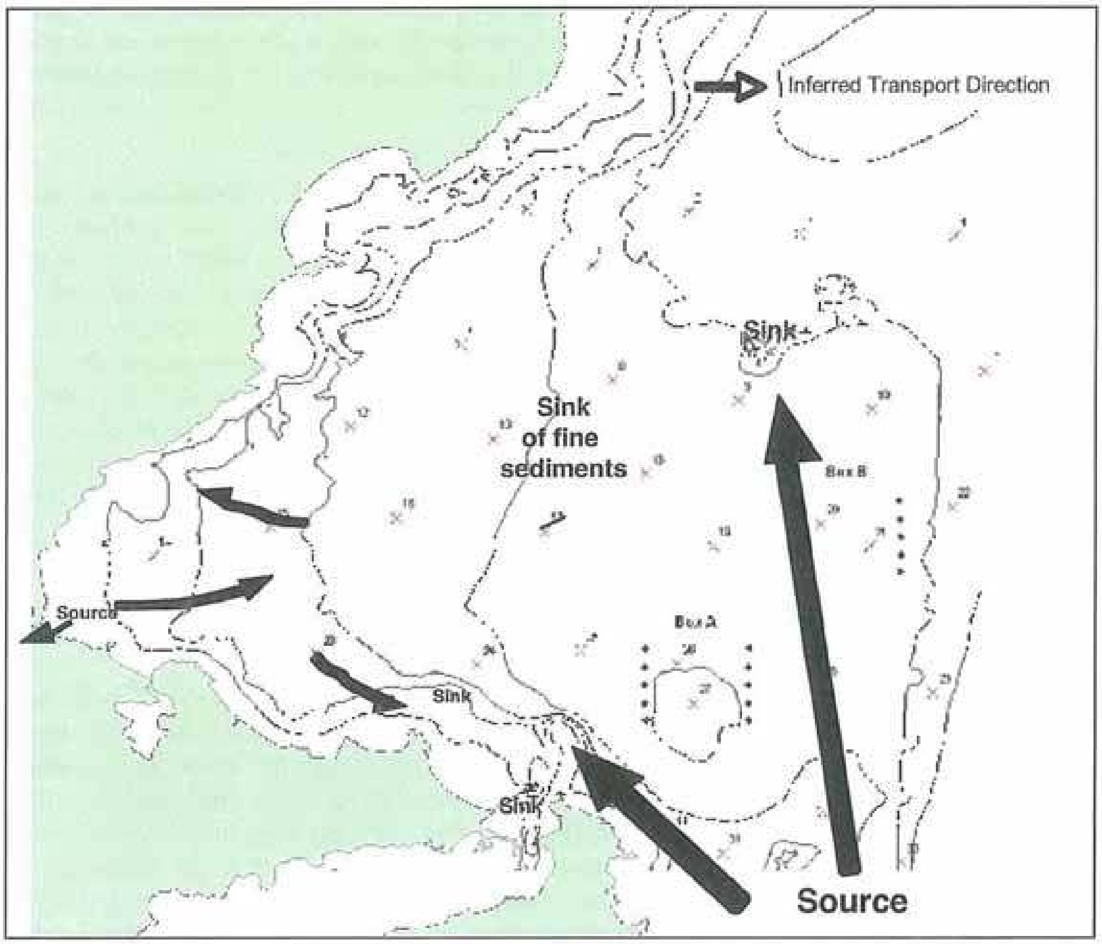


Figure 3.8 Sediment transport paths inferred from rollability analysis of samples (red crosses) collected by NIWA for Willis *et al.* (2008) (Source: Single *et al.* 2010).

Sediment sinks dominate the coastal area south of Heyward Point to Taiaroa Head, including the entrance to Otago Harbour. Two strong sink areas exist, one being located between Heyward Point and the Heyward Point dredge placement site, and the other north of Taiaroa Head, east of the harbour channel. This latter sink is likely to be the product of sediment being deposited as part of the general northward transport of sediment and the deposition of sediment that has been flushed out from Otago Harbour by the ebb tide.

Overall, both rollability and sediment textural characteristics show that the inner Blueskin Bay area acts as a source of sediment to the central and southern part of the bay in conjunction with sediment delivered from the south by the southern current. The two dredged sediment receiving areas (Heyward Point, Spit) do not appear to supply sediment north into the central area of Blueskin Bay, nor do they appear to supply sediment back into the entrance channel, The Shelly Beach site will under some energetic wave conditions with a flood tide lose some sediment back into the entrance channel, however it is likely that most of the sand entering the entrance channel from Shelly Beach will have travelled in the surf-zone or along the beach, whereas dune sand is also lost to the backshore as a result of NE winds.

The rollability assessment is consistent with the findings from analysis of current and wave measurements and modelling of sediment transport potential from a hindcast wave field.

3.2.6 Shores

Single (2011) presents a description of the beach and shoreline morphology of Blueskin Bay. The shoreline is separated into a series of infilled bay-head beaches within hard rock headlands, Kaikai Beach, Murdering Beach, Long Beach, Doctors Point and Karitane. There are also three spit beaches, Aramoana/Shelly Beach, Purakanui and Warrington Spit. All of the beaches are composed of fine to medium sand, sourced from the nearshore seabed, but derived from Otago schist predominantly brought to the coast down the Clutha and Taieri Rivers. Vegetated dune fields back all of the beaches except Karitane.

The beaches are subject to adjustment to changes in the wave environment. In response to storm events, the beaches erode, presenting lowered beach surfaces and scarped dunes. During periods of quiescent wave energy, the beaches accrete, dunes reform and sand-binding vegetation colonises the seaward face of the dunes.

Surveys of beach change show that the present state of the beaches can be considered as healthy, in that they are able to readily respond to changes in the wave environment with no net retreat of the shoreline. The net shoreline position appears stable to slightly accreting. There is no evidence to suggest that the beaches are either under-supplied or oversupplied with sediment.

3.3 Sediments in the Lower Otago Harbour

Sediments in Otago Harbour range from silt to coarse sand containing shell fragments. Finer grained sediments including mud and silts can be found with the fine sand in the Upper Harbour, while coarser sand sizes are found with the fine sand in the Lower Harbour.

Geotechnical investigations were carried out by Opus International Consultants (Opus) to characterise in detail the sediments to be dredged during a proposed Capital Dredging program and to determine whether or not the dredged sediment would be contaminated.

Subsurface samples were taken from within the area proposed for dredging. The area is adjacent to and beneath the existing channel, and beside the swing basin at Port Chalmers.

The geological description based on logging of cores received from all 43 locations is presented in Table 3.1. Results are summarised according to the channel sections where each hole was located. Sand is most commonly encountered in the channel sections near the entrance to the harbour and beyond, namely from the Harington Bend to the Entrance sections. Clayey silt is most prominent from the Swinging Basin to the Cross Channel sections. Silty clay was the least common sediment type encountered and is most prominent in the area around Acheron Head. Rock was only encountered at Rocky Point and Acheron Head, and consisted of completely weathered basalt (cobbles and boulders) near the seabed and moderately weathered basalt at depth.

It can be seen that the sediment to be dredged is predominantly fine sand, with a secondary modal volume of clayey silt. Port Otago Ltd propose to dispose to the existing disposal grounds only sediments similar in character to those dredged during historical maintenance dredging. The sediment disposed from maintenance dredging has been mainly sand with a low silt percentage.

Chemical analysis of the sediments was carried out by Opus and by NIWA. Both analyses found that the samples contained only trace levels of contaminants. None of the parameters analysed exceeded the guideline values used. Based on these results, it was concluded that the materials to be dredged are not contaminated

Table 3.1 Overview of geological description of materials found in borehole grouped by channel section (After Opus 2008).

Section Name	Geological Description of Materials	Boreholes & Vibrocores in Section
Swinging Basin	Grey, sandy SILT and fine SAND. Silt is soft to very soft and non-plastic. Sand is loosely packed	B1, B2, VC1, VC1c, VC5, VC6, VC8
Deborah Bend with Rocky Point	SILT in the southern part close to Carey's Bay and silty CLAY closer to Acheron Head. Sediments soft to very soft and plastic where clay present. Completely to moderately weathered basalt in borehole 3 along the north side of the existing channel.	B3, VC9, VC10, VC12 - 14
Hamilton Bend with Acheron Head and Pulling Point	Clayey SILT with some sand, soft to very soft, non-plastic to slightly plastic. Silty CLAY, soft to very soft and plastic close to Acheron Head. Completely to moderately weathered basalt in boreholes 4 at Acheron Head. Basalt cobbles at Pulling Point	B4, B5, VC15, VC17, VC18, VC21, VC22
Taylors Bend	Clayey SILT at Dowling Bay end of section and sandy SILT at Waipuna Bay, soft to very Soft, plastic where clay content is high.	VC23, VC26, VC27, VC29, VC32
Cross Channel	Clayey SILT, soft to very soft, slightly plastic sand content increasing toward eastern end of section.	VC34, VC36, VC39
Harington Bend	Fine SAND near Otakou changing to clayey SILT near Harrington Point and the Spit.	B6, VC41, VC42, VC44 - 46
Howletts	Fine SAND with some Silt near the eastern side around Pilot Beach.	VC47 - 50
Entrance	Fine SAND	VC54, VC56, VC57, VC59

4. Port Otago harbour development and dredged sediment disposal

The nautical history of Otago Harbour includes significant developments of the harbour entrance and shipping channels. This history has been reviewed by a number of authors including McLintock (1951), Armstrong (1978), McLean (1985), Single and Kirk (1994), Goldsmith (1995a, 1995b), Bennett (1995), Wright (1997), Single and Stephenson (1998), Lusseau (1999a, 1999b), Leon (2005a, 2005b) and Davis (2009).

Development and maintenance dredging of the main shipping channel have been features of the management of the harbour entrance since 1865. Dredging of the lower harbour is an ongoing activity as sand infilling the shipping channel from the entrance to Port Chalmers necessitates dredging to maintain it at sufficient depth and configuration for all ships. This requires large quantities of sediment to be removed from the channel, the turning basin and berthing areas. Sediment has been used as fill for reclamations in and around Otago Harbour, for beach nourishment in the harbour and at Ocean Beach (St Clair), and it has also been disposed of outside the harbour entrance.

The Heyward Point site was the sole disposal site from 1930 up until the 1970's. Due to the distance from Otago Harbour, much of the costs incurred were for the transportation of the sediment to the site. By 1976, that period of capital development and reclamations at the port had ceased, and alternative sites for the spoil were investigated. In 1983 a second disposal site, offshore from Aramoana, was established and put into regular use in 1985. During the late 1980's the Aramoana (also known as the Spit) disposal site replaced Heyward Point as the principal site. In 1987, Shelly Beach became the third location for the dredge spoil. The disposal off Shelly Beach had a secondary purpose. By 1986 erosion of South Spit Beach had progressed to such an extent that it was probable that a breach of the spit would occur. To offset this erosion the dredged spoil was used to nourish the beach.

Prior to the Resource Management Act, local Catchment Boards (now Regional Councils) administered the Water and Soil Conservation Act 1967. Pursuant to Section 21 of the Water and Soil Conservation Act 1967, the act of discharging dredge spoil into natural water required authorisation from the Catchment Board in the form of a Water Right.

POL held Water Right 0367C dated June 1991 from the Otago Regional Council (ORC), which authorised POL to discharge up to 450 000m^3 of dredged spoil from in and around Otago Harbour. This Water Right was granted for a period of ten years, expiring 1 May 2001 and permitted the disposal of up to 200 000m^3 offshore from Heyward Point and Aramoana, and up to 50 000m^3 off Shelly Beach (Note, the beach off Aramoana is called Spit Beach, while the beach between the North Mole and the Long Mac at the harbour entrance is called The Spit or sometimes South Spit or Shelly Beach).

The consented volume takes into consideration the need for capacity to clear large influxes of sediment to the channel during storms, and the episodic nature of sediment movement north past the entrance channel.

Subsequent renewal of authorisation of the activity in the form of a new Resource Consent under the RMA requesting the right to continue this operation in the exact same manner as that authorised under the original consent (Water Right 0367C) was applied for in 2001. The new Resource Consent application (Coastal Permit 2000.472) was publicly notified and subsequently heard by ORC on 10 October 2001. The consent was granted for a duration of 10 years, expiring 1 December 2011. The co-ordinates for all three dump sites and their associated areas are shown in Table 1.

Table 4.1 Co-ordinates of the three disposal sites that receive dredged spoil from the shipping channels of Otago Harbour.

Site	Latitude	Longitude	Size of Dump Area
Heyward Point	45° 44.33764 S	170° 41.77148 E	38.2 ha. Approx.
	45° 44.52434 S	170° 41.58689 E	
	45° 44.85336 S	170° 42.25537 E	
	45° 44.97036 S	170° 42.09000 E	
Aramoana	45o 45.68547 S	170o 42.45971 E	28.3 ha. Approx.
	45o 45.94576 S	170o 42.32239 E	
	45o 45.94947 S	170o 42.91596 E	
	45o 46.08271 S	170o 42.72763 E	
Shelly Beach	45o 46.55893 S	170o 42.80550 E	14.5 ha. Approx.
	45o 46.65761 S	170o 42.97831 E	
	45o 46.73640 S	170o 42.55690 E	
	45o 46.85165 S	170o 42.77227 E	

Lusseau (1999b) provides data on historical dredging and disposal for channel development in Otago Harbour between 1872 and 1998. Data from 1977-1998 is presented in detail, correlating to the period of channel maintenance. Lusseau found that maintenance dredging has historically always increased after capital dredging stages, but decreased as the area (channel slopes and basin) stabilised. For maintenance dredging and relocation consents, it was considered impractical to accurately predict the volumes required as weather and sea conditions made sediment movements in the harbour highly variable.

Table 4.2 shows the dredge disposal volumes since 1985. The total volumes placed at the disposal sites varies widely, depending on the dredge demand (the amount of channel infilling that has occurred), location of dredging (as type of dredged sediment is a factor in where it is placed), availability of dredge equipment and other uses of the dredged sediment (such as beach nourishment). The maximum consented disposal volume has not been reached for the period shown, but there have been extended periods when the disposal volumes were relatively high (such as 1986 through 1991, and 1993 through 1995).

Table 4.2 Dredge demand quantities and disposal 1985 to 2010 (volumes in m^3) (Source: POL data)

Year	Total Drg Qty Yrly Total	Disposal Heywards	Disposal Spit	Disposal Shelly	Consented Sites Yrly Total	Disposal to Shore	Disposal to Other
1985	150,430	130,752	16,591	0	147,343	2,520	567
1986	268,128	20,088	247,520	0	267,608	0	520
1987	265,047	0	254,703	10,098	264,801	0	246
1988	390,395	72,607	244,613	49,896	367,116	0	23,279
1989	282,888	112,710	148,662	17,409	278,781	0	4,107
1990	308,913	163,108	133,579	12,084	308,771	0	142
1991	328,245	120,659	197,066	10,520	328,245	0	0
1992	147,811	57,093	86,525	1,140	144,758	3,053	0
1993	323,582	98,365	175,699	35,055	309,119	14,463	0
1994	261,226	78,546	155,917	24,295	258,758	2,468	0
1995	236,160	42,563	179,457	12,240	234,260	1,900	0
1996	222,040	18,865	92,005	1,775	112,645	109,395	0
1997	240,959	41,375	162,106	5,995	209,476	25,940	5,543
1998	172,168	24,638	144,960	2,570	172,168	0	0
1999	224,095	63,123	140,592	15,115	218,830	0	5,265
2000	257,524	58,610	172,979	25,935	257,524	0	0
2001	161,535	24,475	118,427	18,445	161,347	0	188
2002	218,001	47,455	141,406	29,140	218,001	0	0
2003	153,439	39,180	83,789	30,470	153,439	0	0
2004	149,535	35,880	89,750	23,440	149,070	0	465
2005	232,187	35,876	149,684	46,022	231,582	0	605
2006	50,172	990	43,317	5,265	49,572	0	600
2007	120,591	33,525	62,838	12,700	109,063	11,528	0
2008	95,386	55,019	14,665	16,080	85,764	9,622	0
2009	100,065	55,880	18,430	19,680	93,990	3,075	3,000
2010	168,727	109,204	23,063	35,850	168,117	0	610
26 yr Tot	5,529,249	1,540,586	3,298,343	461,219	5,300,148	183,964	45,137
26 yr Ave	212,663	59,253	126,859	17,739	203,852	7,075	1,736

5. Seabed elevation changes at the existing disposal sites

Marshall and Single (2010) presents the results of GIS analysis carried out on bathymetric survey data collected by POL at the Heyward, Spit (Aramoana) and Shelly Beach disposal sites from 1976 to 2010. The work updated a study by Leon (2005b) that assessed the changes to the seabed elevation at the disposal sites over the period 1976 to 2004. Combined, these studies provide a picture of the changes to the seabed in the vicinity of the disposal sites and assess the potential retention and dispersal of placed sediment. Examples of the output of the surveys are shown in Figure 4.1.

A mound on the surrounding seabed is evident at the Heyward site since the late 1970s. The position of the mound at the SW corner of the disposal site is fairly constant, but the size of the mound varies significantly over time. The mound appears to grow between 1978 and 1985 resulting in shoaling of the seabed. However by the late 1980's the mound appears deflated. Shoaling and seabed lowering continued through the 1990s and 2000, with the apparent cyclic trend of growth and reduction approximately coincident with periods of high and low dredge spoil disposal at the site.

The seabed in the immediate vicinity of the Spit site is also dynamic, with substantial changes in both the size and position of a raised part of the bed since 1982. Formation and reduction of the shoal in the northern part of the site, combined with movement toward the nearshore at Aramoana appears to have happened twice since 1982. Recent deflation of the seabed along the offshore edge of the disposal site and onshore movement of the shoal may be an effect of reduction in disposal volumes at the Spit site since 2004. However a similar pattern of deflation offshore and shoaling in the nearshore occurred in the late 1980s with no associated reduction in disposal volumes.

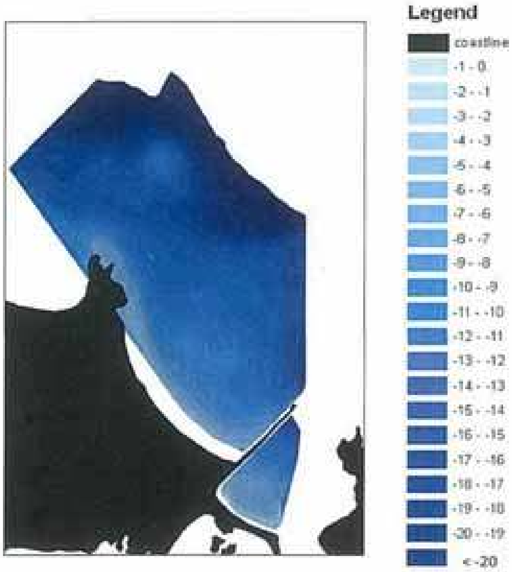
The surveys of the Shelly Beach site from 1987 to 2009 show an area of shoaling in the southwest corner of the disposal site. This is a common feature of the disposal site until 2002, when dredged sediment was placed closer to the central area of the site. Patterns of change are indicative of the location of placement of the dredge spoil within the disposal site, and movement of the placed sediment within the embayment, onshore and southeast along the nearshore.

Changes to the wider area of seabed between the Mole and just north of Heyward Point indicate that the seabed is in a natural net erosional state. Dredge spoil placement appears to be mitigating (or moderating) this erosion by supplying sediment to the general area adjacent to the Heyward disposal site.

Historically, the Aramoana area has accreted, resulting in formation of the spit enclosing Otago Harbour. The construction of the Mole caused reorientation of the seabed contours out to about 8 m depth and stabilisation of the Spit (Shelly Beach) and the Aramoana area. Dredge spoil placement at the Spit site is likely to have contributed further to accretion of the nearshore seabed and stability of the backshore and dunes. Recent deflation of the nearshore seabed is consistent with the sediment loss observed in the vicinity of the Heyward site, and may be a function of a reduction in sediment input to the wider Blueskin Bay sediment budget over recent years, and long-term variability in the wave environment. There may also be some effect of a reduction in placement of dredge spoil at Aramoana and Heyward sites in recent years.

1984

2004



2010

Figure 5.1 Examples of plotted surveys of the seabed in the vicinity of the maintenance disposal sites.

Shelly Beach has been cut off significantly from natural sediment inputs (especially from the north and west) since the construction of the Mole (Leon 2005b). The beach is therefore susceptible to changes in the amount of dredge spoil placed at the site. This is evident with fluctuations in sediment volume in the nearshore associated with periods of decreased dredge spoil disposal. Although there was a negative sediment balance between 2002 and 2010 for the broader area around the Heyward and Spit sites, the Shelly area showed accretion through to 2010.

6. Gaps in the information on the physical coastal environment and coastal processes

The work to date is broad in scope and has resulted in an in-depth understanding of the physical coastal environment of Blueskin Bay. However there are aspects of the environmental process response system that could be better defined to provide certainty in determining the long-term sustainability of disposal activities at Heyward, the Spit and off Shelly Beach.

MetOcean Solutions Ltd (2011) identifies gaps in knowledge of the process environment and changes as a result of the placement of dredge spoil at the disposal sites. Modelling of wave processes across the disposal grounds has provided information about wave shoaling and the surfability of the waves at Aramoana. Modelling of sediment transport potential has identified transport paths along the shore, and on and offshore. These findings are consistent with the rollability analysis undertaken by Bunting *et al.* (2003a) and Single *et al.* (2010). However, while the effects of severe storm events have been modelled in detail, there is a need to model a wider range of events. This would include the net result of sediment transport due to the variable long-term wave environment, with storm events, periods of lower energy, different wind and current conditions over time being examined.

The work of Shears (2009) needs to be assessed with regard to examining sediment bypassing at the harbour inlet, as it may be possible to develop a predictive model of future maintenance dredging demand for the shipping channel.

The amount of retention or dispersal of sediment at the maintenance disposal sites has been estimated from bathymetric surveys, and is understood at a qualitative level. However the quantities of sediment remaining at the sites, or dispersed from the sites to be replaced by naturally moving sediment are not precisely known.

Although it is thought that the placed sediment contributes to the stability and health of the beaches and dunes of Aramoana, Shelly Beach and beaches north of Heyward Point, the quantity of sediment from the disposal sites that nourishes these areas is not known.

7. The direct and indirect effects of the proposal

POL seeks to gain a renewal of its consent that authorises the disposal of up to 450,000 m3 per year of sediment dredged from Otago Harbour for a term of up to three years. The likely effects of the potential disposal on the physical coastal environment have been considered in light of measured and observed effects on the nearshore seabed and beach topography, sediment characteristics over the last 30 years of dredging history, and as a result of model and physical studies that contribute to the understanding of ongoing physical coastal processes acting on the placed sediment.

The historical record shows that the effects of the sediment disposal at Heyward, Aramoana and Shelly Beach have not had an adverse effect on the physical coastal environment. The historical period includes periods of relatively high sediment disposal for prolonged periods, and a range of wave and current conditions.

MetOcean Solutions Ltd present an assessment of the physical sedimentary effects based on numerical modelling of the wave environment and sediment transport as a result of waves and currents. The conclusion is that the effects will be low and are unlikely to be adverse.

This present study of the overall character of physical coastal environment including beach changes over the long-term and as a result of adjustments to variations in wave energy and sediment inputs also indicates that the effects of continued placement of dredged sediment at the existing disposal sites will not result in adverse effects to the environment. Indeed, ongoing disposal of dredged sediment is likely to have beneficial effects in providing sediment to the nearshore and beaches that mitigate erosional effects of storm events.

The sediment character of the nearshore, beaches and wider Blueskin Bay is near homogenous. The dredge disposal sites do not show as anomalies to the adjacent seabed and beaches. Shoaling within the disposal sites has resulted in an improved wave break for surfing at Aramoana, and a reduction in erosion of Shelly Beach. There is no evidence that wave energy is focussed on to the beaches, generating sites of increased erosion during storms. Aramoana and Shelly Beaches appear to respond naturally to storm events and periods of more quiescent wave energy. The beaches adjust naturally to storm events with some erosion of the dunes and movement of sand from the beach to the nearshore, and they accrete again during lower energy swell conditions. Beaches north of Heyward Point also appear to respond naturally to variations in wave energy, and do not show any adverse effect from the presence of the disposal sites.

Renewal of the disposal consent for up to three years should result in no effects that are different to those that have been experienced in the past. However monitoring through annual measurement of the seabed topography in the vicinity of the disposal sites, beach surveys and observations related to the resource use of the beaches will provide a means to further assess the sustainability of the disposal operation. In particular the short-term and longer-term cumulative effects of the dredge spoil placement can be quantified. This provides direct input for the development of an operational management plan applicable to a long-term consent.

8. Recommended studies to provide for a long consent duration

In order to progress a consent application to dispose sediment at, or in the near vicinity of the existing Heyward, Spit and Shelly Beach sites for a long duration (for example 35 years), further work is required. Such work should include:

- Completion of long-term shoreline change analysis from aerial photographs
- Correlation of sediment transport modelling and rollability results with identified areas of seabed elevation changes
- Identification of the components and quantification of a sediment budget for the inner Blueskin Bay area across the outer harbour channel. This would include identifying potential natural volumes of sediment moving north past Taiaroa Head, and the relative distribution of that sediment to the Entrance Channel, the harbour and to the seabed north and west of the channel
- An assessment of measures to achieve adaptive management – use of information from bathymetric surveys, increased beach survey measurement and observation of effects on beach resource through assessing beach and dune health, or the surfability of waves at Aramoana

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Appendix D

Martin Single, Shore Processes and Management Ltd - Beach Morphology

Port Otago maintenance dredging consents - Beach morphology, Otago Harbour entrance to Karitane

Prepared for

Port Otago Ltd

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April 2011

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Contents

List of Figures

List of Tables

Executive Summary

This report presents a description of the beaches and shoreline morphology of Blueskin Bay from the entrance to Otago Harbour north to Karitane. Information on long-term change is presented from earlier studies, while short-term beach change is described from beach profile surveys.

The shore is separated into a series of bayhead beaches within hard rock headlands. There are also three spit beaches. All of the beaches are composed of fine to medium sand, sourced from the nearshore seabed. Dunes back the foreshores. The beaches are subject to adjustment to changes in the wave environment. In response to storm events, the beaches erode, presenting lowered beach surfaces and scarped dunes. During periods of quiescent wave energy, the beaches accrete, dunes reform and sand-binding vegetation colonises the seaward face of the dunes.

The present state of the beaches can be considered as healthy, in that they are able to readily respond to changes in the wave environment with no net retreat of the shoreline. The shoreline position appears stable. Further progradation of the beaches may be limited due to the exposure to greater wave energy beyond the shelter of the headlands. There is no evidence to suggest that the beaches are either under-supplied or oversupplied with sediment.

1. Introduction

This report describes aspects of the physical coastal environment of Blueskin Bay. It has been commissioned in order to provide information for a Port Otago Ltd (POL) application for resource consent to dispose dredged sediment at existing disposal sites between Heyward Point and Otago Harbour. The aim of this report is to describe the morphology of the nearshore and beaches of the area between Otago Harbour and Karitane Peninsula. Where possible, temporal and spatial changes in shoreline position of the beaches of Blueskin Bay are examined. This work updates work carried out for POL in 2002 & 2003 (Bunting *et al.* 2003a). This report should be read in conjunction with Single (2011).

1.1 Field and Analytical Procedures

Three methods were employed to examine the beaches of Blueskin Bay. Firstly, aerial photographs since 1997 were examined and compared with earlier aerial photographs to determine long-term coastal change at a broad scale. Few recent aerial photographs are of sufficient quality and scale from which comparative measures of change can be made. Aerial photographs from 2006, and LiDAR (Light Detection and Ranging scanning) data provide baseline information for future reference and comparison, but cannot be used to accurately quantify changes from earlier dates at this time. The Christchurch earthquake of 22nd February 2011 has halted this work due lack of access to facilities, software and resource materials.

Secondly, photographs were taken of the different morphological features currently present upon the foreshores of the beaches of Blueskin Bay so that the present day (February 2011) state of the foreshores can be compared to photographs of the beach state in July 2002 and descriptions of the beach state presented in the reports by Kirk (1980), Single and Kirk (1994), Single and Stephenson (1998) and Bunting *et al.* 2003a and 2003b).

Thirdly, beach profiles and morphodynamic changes of the beaches of Blueskin Bay were determined from surveys of shore-normal transects at a number of locations between Taiaroa Head and Karitane. The benchmarks used were those established by Otago Regional Council (ORC) in 1990, so direct comparison could be made to profile surveys that have been conducted in previous years. Nine profiles were re-surveyed for this study. Kurt Bowen of Patterson Pitts Partners Ltd carried out the surveys for this study on 7 March 2011. The survey was undertaken at low tide and extended out as far as possible from the backshore and across the upper, mid and lower foreshore. The profiles are linked to benchmarks and have been plotted with surveys from 1987, 1990, 1993, 1996, 1998, 2002, 2005 and 2008 where that data exists.

Figure 1.1 shows the locations of the beaches of Blueskin Bay.

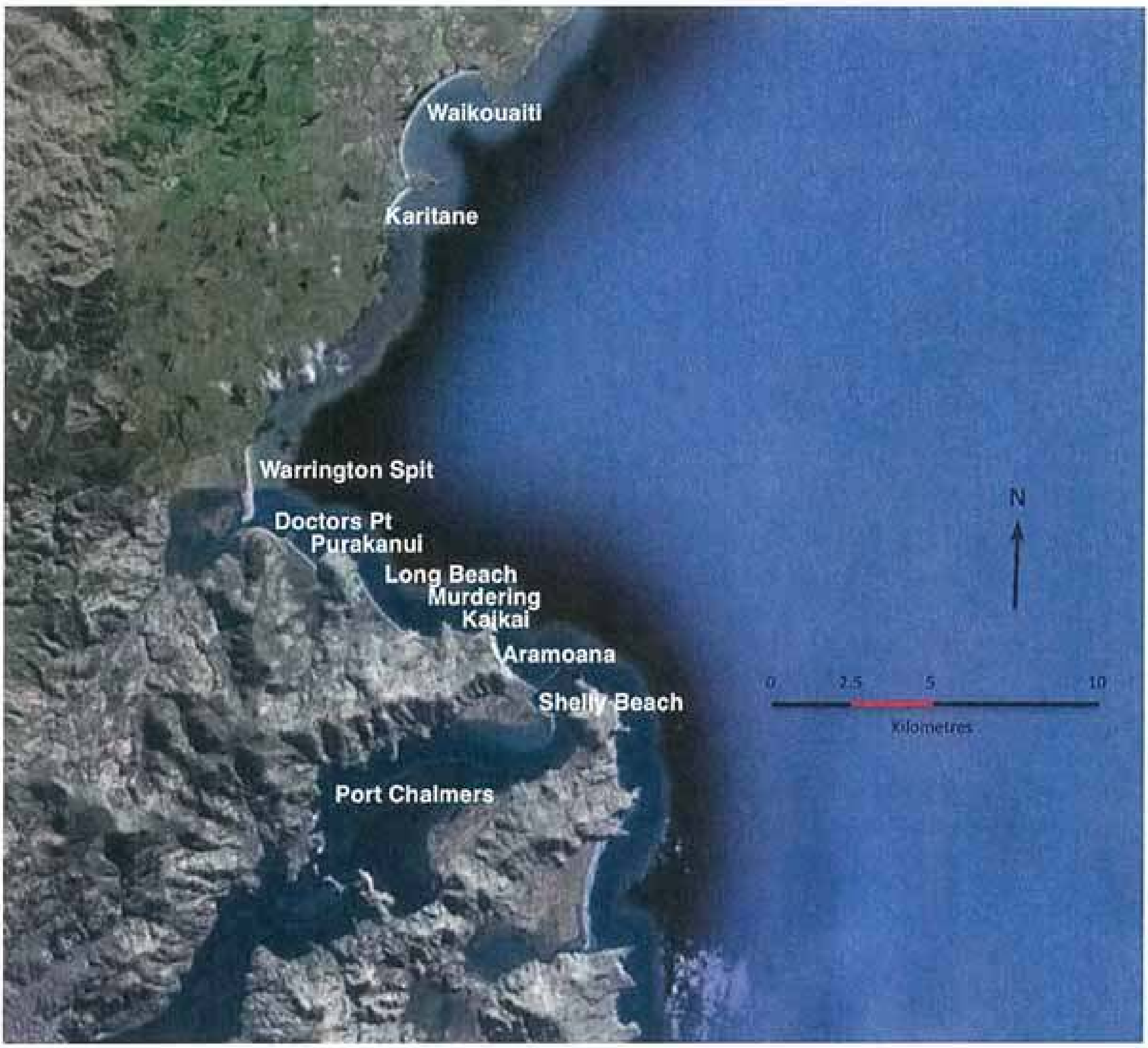

Figure 1.1 Location of beaches discussed in text (base photograph from GoogleEarth)

2. Historic coastal change

A description of the evolution of the beaches of Blueskin Bay is provided by Single (2011). The bay-head beaches and spit complexes are recently formed morphological features with respect to geological time, forming less than 1000 years before present (BP, where present is generally taken to be ~1953). Unconsolidated fine sands form the beaches that front the once exposed volcanic sea-cliffs. Sea-cliffs make up the back beach area of most beaches north of Aramoana. The unconsolidated nature of the fine sand beaches means that they respond readily to changes in wave energy, and to additions and losses of sediment volume in the nearshore and beach zones.

Bunting *et al.* (2003a) carried out an analysis of historical shoreline change. The following sections are based on the findings of that work and additional findings from the assessment of the 2006 aerial photography. This is an area where further work is to be carried out on completion of orthorectification of aerial photographs.

2.1 Aramoana and Shelly Beach

Coastal change that has occurred at the harbour entrance has been the direct response to the construction of physical structures in the late 1800's and early 1900's in order to improve navigational hazards presented at the entrance to Otago Harbour.

Table 2.1 displays data presented by Goldsmith (1995) that shows measurements of shoreline change for Aramoana Beach and Shelly Beach. Goldsmith made these measurements from historical charts and maps of the harbour entrance and from aerial photography.

An offset in the line of the shore between the east and west sides of the Mole has developed since its construction. Aramoana Beach (also known as Spit Beach) has experienced net shoreline advance in the order of 157 metres, whereas Shelly Beach has undergone net retreat of approximately 136 metres. This has produced an offset of 293 metres of the once continuous shore.

The 25 years immediately following the construction of the Mole were characterised by Aramoana Beach advancing seaward by 90 metres at an average rate of 3.6 metres per year. In contrast Shelly Beach retreated by 143 metres for the same period, at an average rate of 5.7 metres per year. This rate of retreat slowed significantly during the period represented by the position of the 1909 and 1985 shoreline, a pattern that can be attributed to the completion of Long Mac. Goldsmith (1995) noted from his examination of maps and charts post-dating 1904 (for example, the chart of Mason dated 1904) that a secondary affect of Long Mac was the build up of Shelly Beach to become a permanent continuous sub-aerial sand spit above the high water mark.

Recent surveys show that change to the Shelly Beach shoreline has been minor, but the dunes have prograded since 1985. Aramoana Beach has also prograded since 1985, with the line of vegetation advancing seaward by about 0.6 m per year since 1996.

Table 2.1 Rate of shoreline change at Aramoana and Shelly Beach (1850-1985)

	Time Period	Measured Change (m)	Rate of Change (m/yr)
Aramoana	1850-1884†	0	0
	1884-1909‡	+90	+3.6
	1909-1985‡‡	+67	+0.88
	Net change 1850-1985	+157	+1.16
Shelly Beach	Time Period	Measured Change (m)	Rate of Change (m/yr)
	1850-1884†	+78	+2.29
	1884-1909‡	-143	-5.70
	1909-1985‡‡	-71	-0.90
	Net change 1884-1985	-214	-2.11
	Net change 1850-1985	-136	-0.15

NB: - denotes shoreline retreat, + denotes shoreline advance, † prior to the completion of the Mole, ‡ after the completion of the Mole but before completion of Long Mac, ‡‡ after the completion of the Mole and Long Mac

2.2 Kaikai Beach

Kaikai Beach is a small bay-head beach located in the lee of Heyward Point. Orientated east west it is bounded by two headlands of volcanic origin. The modern beach is backed by a moderately vegetated transgressive dune system. A stream that drains a lagoon that is situated in the hinterland discharges to the coastal system at the western end of the beach.

Table 2.2 Rate of shoreline change (measured to the former seacliff) at Kaikai Beach 1863 – 1997

Time Period	Measured Change (m)	Rate of Change (m/yr)
Pre 1863	+ 321.2*	
1863-1922	NC*	0
1922-1942	+ 36.03*	+ 7.3*
1942-1951	-54.5*	+ 0.98*
1951-1957	NC*	+ 3.13*
1957-1967	NC*	+ 7.5*
1967-1972	NC*	0*
1972-1975	NC*	0*
1975-1979	NC*	0*
1979-1997	NC	0
Net change 1863-1979	-18.6*	-0.16*
Net change 1863-1997	-18.6	-0.13

NB: * data presented by Nicholson (1979), - denotes shoreline retreat, + denotes shoreline advance, NC denotes no measurable change (value obtain was within the margin of error of this analysis)

Table 2.2 presents results obtained from measurements of shoreline change at Kaikai Beach both by Nicholson (1979) and Bunting *et al.* (2003a). Kaikai Beach appears to be a stable beach system since at least 1863. Only one period of progradation is recorded. This occurred during the period 1922-1942 which was subsequently reversed by a period of erosion that resulted in the shoreline moving landward of its 1863 position. The long-term shoreline trend of Kaikai Beach can be summarised as being stable, while undergoing short-term fluctuations around this mean stable state.

2.3 Murdering Beach

Murdering Beach is a crescent shaped bay-head beach that is bounded by two rocky headlands of volcanic origin. The beach is orientated west – east, and today is backed by a dune system that is well vegetated with marram grass and established macrocarps. Two streams drain the backing hinterland, which consists of lowland swamp and steep pastoral land.

Table 2.3 presents data of long-term coastal change, and the rate of this change for different time periods as calculated by Nicholson (1979) and Bunting *et al.* (2003a).

The general trend of shoreline change noted by Nicholson (1979) for the periods 1863 to 1979 was one of erosion. Murdering Beach experienced long-term retreat, upon which short periods of enhanced retreat occurred. The four-year period between 1975 and 1979 was such a period, when approximately 26.9 meters of shoreline retreat occurred at a rate of 6.72 metres per year. That pattern of retreat continued through to 1997 with approximately 70 metres of erosion occurring during the 18 year time period between 1979 and 1997 at an average rate of 3.92 metres per year.

There was no evidence of continued erosion of this beach from the field inspection in February 2011. A comparison of photographs taken in 2002 and 2011 shows the beach to be in a healthy state, with newly formed embryo dunes and seaward movement of the line of vegetation.

Table 2.3 Rate of shoreline change at Murdering Beach 1863 – 1997

Time Period	Measured Change (m)	Rate of Change (m/yr)
Pre 1863	347.2	
1863-1951	-36.9*	-0.42*
1951-1957	-21.1*	-3.54*
1957-1975	-18.0*	-2.25*
1975-1979	-26.9*	-6.72*
1979-1997	-70.6	-3.92
Net change 1863-1979	-103.1*	-0.89*
Net change 1863-1997	-173.5	-1.29

NB: * data presented by Nicholson (1979), - denotes shoreline retreat, + denotes shoreline advance

2.4 Long Beach

Long Beach is the largest of the bay-head beaches situated within Blueskin Bay, measuring 2.2 kilometres in length. It extends from Pilots Point in the east to Potato Point in the west. This long sweeping beach is orientated northwest – southeast and directly faces the refracted southerly swell. The foreshore is backed by an extensive low dune system that is well vegetated with marram grass. A relatively large stream bisects the beach and drains from a hinterland that consists of pastoral sheep farmland. A second smaller stream is also present at the northern end of the beach.

Table 2.4 Rate of shoreline change at Long Beach 1863 – 1997

Time Period	Measured Change (m)	Rate of Change (m/yr)
Pre 1863	+ 376.8*	
1863-1942	+ 72.2*	+ 0.91*
1942-1951	+ 65.2*	+ 7.3*
1951-1957	+ 4.3*	+ 0.98*
1957-1967	+ 31.3*	+ 3.13*
1967-1972	+ 37.7*	+ 7.5*
1972-1997	NC*	0*
Net change 1863-1979	+ 211.8*	+ 1.83*
Net change 1863-1997	+ 206.25	+ 1.54

NB: * data presented by Nicholson (1979), - denotes shoreline retreat, + denotes shoreline advance, NC denotes no measurable change (value obtain was within the margin of error of this analysis)

Table 2.4 presents measurements of historical shoreline change and rates of change for Long Beach as calculated by Nicholson (1979) and Bunting *et al.* (2003a). Long Beach has undergone net shoreline advance over the 134 years between 1863 and 1997. However, the data shows two distinct patterns of shoreline change over this period. Rapid progradation of the shore occurred from 1863 to 1972. The net shoreline advance as measured from the position of the shore in 1863 was 211.8 metres, which occurred at a rate ranging from 0.91 to 7.5 metres per year. Since 1972, there has been no measurable change. This may indicate that the beach is now 'full' of sediment, and the rate of deposition to this beach is adequate in holding the shoreline in a stable position. Recent surveys show that this beach has prograded slightly at the northern end and eroded slightly in the south.

2.5 Purakanui Beach

This beach is a sand spit that encloses Purakanui Estuary. Orientated northwest – southeast the seaward face of Purakanui beach faces the refracted swell waves from both the northeast and south. The beach is situated north of the inlet to the Purakanui Estuary, where the inlet truncates the southern end. A rocky headland provides a terminus at its northern end. The foreshore is backed by a wide low dune system that is well vegetated with marram grass. Extensive dune ridges are present landward of the foredune.

Table 2.5 Rate of shoreline change at Purakanui Beach 1863 – 1997

Time Period	Measured Change (m)	Rate of Change (m/yr)
1863-1942	+ 304.1*	+ 3.9*
1942-1951	+ 7.9*	+ 0.3*
1951-1957	+ 3.4*	+ 0.6*
1957-1967	+ 39.9*	+ 4.0*
1967-1972	+ 46.5*	9.3*
1972-1975	-40.7*	-13.6*
1975-1979	14.5*	3.6*
1979-1997	NC	0
Net change 1863-1979	+ 370.4*	+ 3.2*
Net change 1863-1997	+ 358.8	+ 2.68

NB: * data presented by Nicholson (1979) - denotes shoreline retreat+ denotes shoreline advance NC denotes no measurable change

Measurement of shoreline change presented at Purakanui for the period 1863 to 1997 are shown in Table 2.5, where it can be seen that this section of shore has undergone net shoreline advance (1863 – 1997). The pattern of long-term change is similar to the trends portrayed in Table 2.4 for Long Beach, where up until 1972 the shoreline experienced continual seaward advance, then experienced alternating periods of erosion and accretion to form a long-term trend of shoreline stability. Episodic periods of erosion may also occur at Purakanui, reflecting a dynamic shorter-term response to the process environment. Erosion scarps along the beach in early 2003 are evidence of this type of change rather than a longer-term situation of beach retreat. By 2011, there is no visible scarp, and dune vegetation was colonising the upper foreshore.

2.6 Warrington Spit

This beach is a sand spit that encloses Blueskin Bay Estuary. Orientated north-northwest – south-southeast the seaward face of the spit is exposed to oblique approach from waves propagating from the northeast but waves from the south refract to become shore-parallel to the Spit. The spit is situated north of the inlet to Blueskin Bay Estuary, where the inlet truncates the southern end. A rocky promontory forms the northern terminus. The foreshore is backed by a low, widespread dune system that is extensively vegetated with marram grass.

Table 2.6 shows the stability of the shore for the period between 1967 and 1997, the period of time that shoreline change has been captured by aerial photography available to Bunting *et al.* (2003a).

Table 2.6 Rate of shoreline change at Warrington Spit (1967-1997)

Time Period	Measured Change (m)	Rate of Change (m/yr)
1967-1975	+125.05	+15.63
1975-1997	-28.05	-1.27
Net change 1967-1997	+ 97.03	+ 3.23

NB: - denotes shoreline retreat+ denotes shoreline advance

From Table 2.6 it can be seen that during the 30-year period from 1967 to 1997 the net charge of Warrington Spit has been 97.03 metres in a seaward direction. This corresponds to the seaward face of the spit advancing at an average rate of 3.23 metres per year. The long-term trend of seaward advance is made up of a period of accretion followed by one of erosion. Such a pattern is reflective of the dynamic nature of sand spits, which rapidly respond to any change in sediment supply and external forces from incident waves, currents, and the position of inlets and rivers.

2.7 Karitane

No aerial photograph assessment has been carried out for Karitane Beach to date.

2.8 Summary of historical shoreline change

Overall, the beaches of Blueskin Bay exhibit a positive sand supply, with most shores prograding over the observed history. Progradation possibly occurred at a faster rate during the period up until the 1970s than since that time, with most of the shores appearing stable to slightly accreting over the last 30 years.

The shoreline change described above is related to observations at snapshots in time, giving long-term differences in beach position. Short-term variations will occur, and may be encapsulated in the long-term analysis to distort any trend of change. Therefore the snapshots may not accurately reflect long-term change, but may reflect the envelope of changes that occur over shorter time-scales related to beach adjustment to changes in wave energy. These short-term variations are examined in the following section with the aid of shore-normal beach profiles spanning periods of 4 to 24 years.

3. Morphology and beach profiles

This section considers the morphology of the beaches of Blueskin Bay. Profiles of the beaches are examined to give a two dimensional analysis that includes the relative height above and below mean sea level and the width of the beach.

The beaches of Blueskin Bay have very similar sediment characteristics and are subject to similar wind and wave conditions. The beaches exhibit spatial similarities in their profiles and beach morphologies. It can also be expected that the beaches of Blueskin Bay will exhibit comparable temporal variability in morphology due to the relatively consistent wave climate around the bay and to changes in the supply of sediment.

3.1 Beach profiles of Blueskin Bay

Infrequent monitoring of the beaches that border Blueskin Bay has been undertaken by ORC since 1990. This monitoring has been limited to three or four surveys for each site undertaken between February 1990 and March 2008. The surveys are plotted on plans N12197 and L13369 and are held by ORC (Dunedin). Figure 3.1 shows the location of the survey lines.

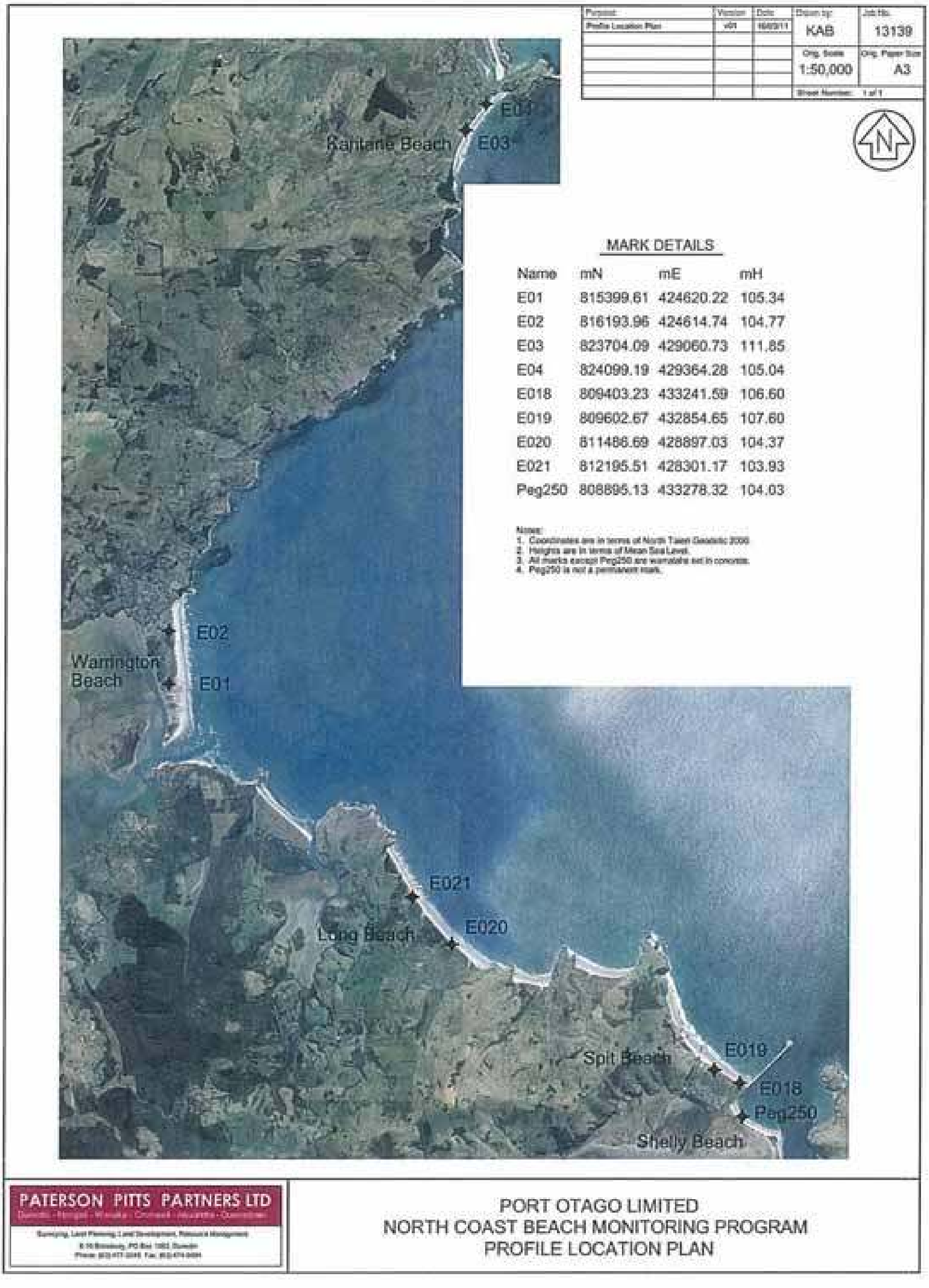

Figure 3.1 Location of beach profiles established by ORC in 1990 and resurveyed for this study 7 March 2011 (prepared by Kurt Bowen, Patterson Pitts Partners Ltd)

All eight profiles established by ORC were resurveyed for this study on 7 March 2011. These include two at Karitane, two at Warrington Spit, two at Long Beach and two at Aramoana. An additional profile was located and surveyed at Shelly Beach (Peg 250). This profile was installed in June 1987 and resurveyed by ORC periodically through to March 2002 (with a total of 10 surveys). Measurements from the profiles surveyed for this study, combined with the data collected by ORC, gives beach change data spanning 21 years (and 24 years for Shelly Beach).

Beach profiles are surveyed from fixed, relocatable markers (benchmarks). Ideally, benchmarks are located on the backshore of the beaches, landward of the maximum run-up of the waves that act on the shore. The survey lines run perpendicular to the shoreline and extend across the upper, mid and lower foreshores, and out to a depth in the nearshore that is limited by safety of the survey team. Points on the profile are surveyed at all major breaks in slope.

The elevations of the benchmarks are known, providing a control datum for each survey line. The surveys are then reduced and the data plotted as overlays on previous surveys of each respective profile. This enables a direct, quantitative comparison of change of the beach profile (the beach height, width, slope, overall shape, and volume) between successive surveys. Over time the initial survey can be used as a baseline upon which long-term comparisons of beach profile change can be made. However, it should be noted that the surveyed profile represents the beach on the day of the survey, and includes adjustments to the beach profile that relate to the most recent wave conditions. Extrapolations of long-term change in beach width and position relate to durable features such as changes in dune position and vegetation, rather than to changes across the foreshore.

Further to these surveys, substantial lengths of the shore were inspected and photographed on 17 February, and detailed field notes were made to supplement the profile surveys.

3.1.1 Aramoana (Spit) Beach (Profiles EO18 and EO19)

Aramoana Beach extends from the Mole north to the volcanic headland that forms the base of Heyward Point. This crescent shaped beach is orientated northwest to southeast and is backed by an extensive, well-vegetated dune system. North of Lion Rock, the dune system comprises blown sand ramped against the rock cliffs.

The average width of the upper beach from the dunes to the high tide mark (indicated by a line of drift wood and sea kelp) is approximately 20 - 25 metres. The sub-aerial beach is made up of well-sorted, fine sand. The upper beach in the lee of the Mole was hard, compacted, wet sand. However, within 150 metres north of the Mole the sand of the upper beach was soft under foot. Winds on this coast are sufficient to pick up and transport the sands inland.

The upper beach is backed by a well-vegetated dune system that has an old large erosion scarp approximately 1 to 2 metres in height. This erosion scarp is most pronounced at the southern end of the beach. Approximately 150 metres north of the Mole (within the vicinity of where the upper beach becomes dry and soft) embryo dunes are forming in front of this scarp. At the site of Profile EO19, the dune is about 3 m in height, and was not present at all in 2002. The dunes are vegetated by marram grass. At the very northern end of the beach, the scarp is no longer visible.

Figures 3.2 and 3.3 present overlay surveys of profiles EO18 and EO19 that represent Aramoana Beach. From these profiles, the typical beach profile of Aramoana can be described as being of low gradient, backed by a relatively steep dune system with a height of approximately 5 metres. The dune system appears to be relatively stable in its position.

With respect to Profile EO18 (Figure 3.2), there is little change to the beach profile since 1990. The backshore scarp has remained in a stable position. The level of the beach surface has lowered indicating a loss of volume and a potential for higher waves breaking across the foreshore onto the dune scarp. However there is no indication that the beach is retreating at this site.

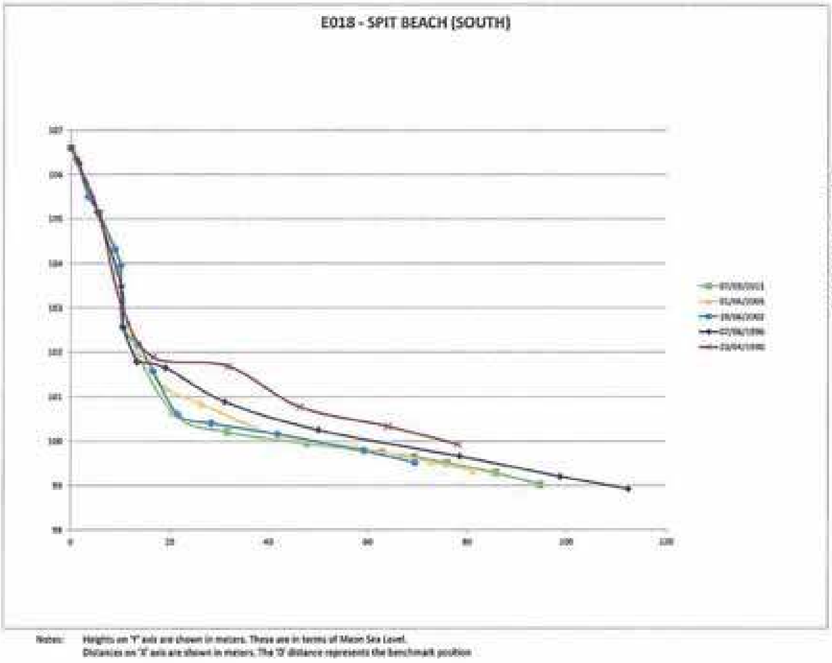

Figure 3.2 Over-lay surveys of Profile EO18 located at the southern end of Aramoana Beach, approximately 50 from the Mole

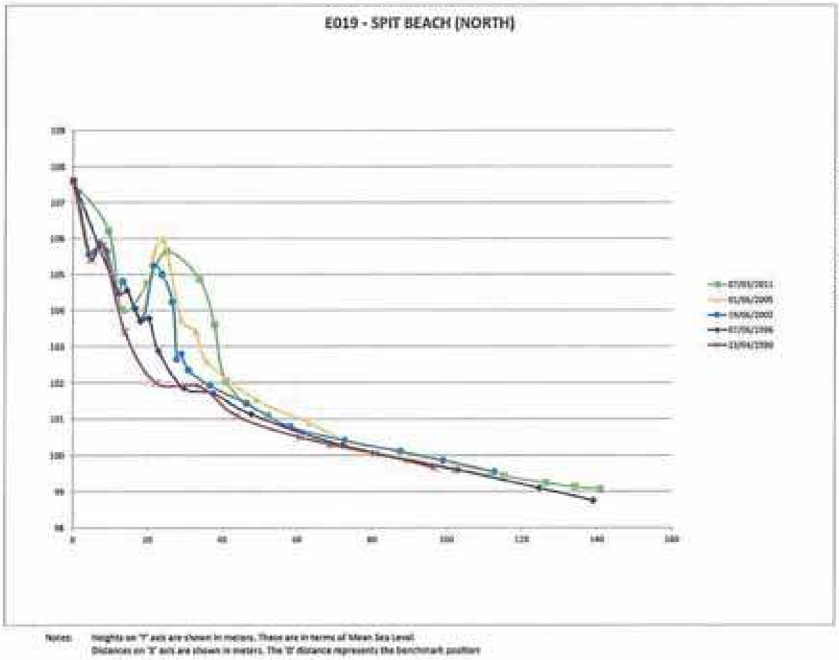

Figure 3.3 Over-lay surveys of Profile EO19 located at the northern end of Aramoana Beach

Profile EO19 (Figure 3.3) illustrates a larger envelope of change. The most apparent change is the build-up of the seaward face of the dunes. This observation indicates that since 2002, the beach system has been in an accretional state. Photos of the site show a comparatively healthy dune system, with embryo dunes forming at the top of the foreshore.

3.1.2 Kaikai Beach

Kaikai Beach is a pocket beach between Heyward Point and Purehurehu Point, both of which are volcanic in origin. The beach is backed by a well-vegetated (marram grass and established macrocarp) hummocky dune system unrestrained to landward. This dune system ranges in height from 1 to 8 metres, being higher in the central part of the bay.

There are no established survey sites in the bay, and access to the bay is by foot across farmland and was not inspected from ground level. The beach appears to be stable to accreting, with no obvious signs of dune blowouts.

3.1.3 Murdering Beach

Murdering Beach is a smaller pocket beach than Kaikai Beach, formed between Purehurehu Point and Pilot Point. The beach is backed by a well-vegetated dune system similar to that present at Aramoana. This dune system ranges in height from 1 to 3 metres, being higher at both extreme ends of the beach. The beach is composed of fine sand, and at time of the inspection was in an accretional state with embryo dunes at the northern end. Dune sands were also blowing up the sidewalls of the northern cliffs. At the southern end of the beach, the dune has a prominent old erosion scarp bisected by a small stream that has incised into recent sand deposits of marine origin.

The ORC survey network does not include Murdering Beach, so there is no quantitative evidence of change in the beach form or position. However from observation it was noted that the sand was soft under foot, with driftwood and wind sculpted formations. The beach was convex in profile, indicative of recent accretion. This is in contrast to the 2002 inspection when the beach was in an erosive state.

A comparison of photographs from 2002 and 2011 shows that the beach form is relatively unchanged, but there is greater development of embryo dunes along all but the southern section of the beach.

3.1.4 Long Beach (Profiles EO20 and EO21)

Long Beach is approximately four times the length of Murdering Beach. The beach is backed by a wetland, and a small community of permanent houses and holiday baches (cribs) are nestled in the middle of the bay. At the time of inspection, the beach sand was in an accretionary state with the sand of the upper foreshore very soft, and freely transported by moderate winds. The dunes are very well vegetated with marram grass. As with Murdering and Aramoana Beaches, the dunes in places have an old erosion scarp with embryo dunes development on the upper foreshore. However the beach overall appears in a healthy condition.

A comparison of photographs form 2002 and 2011 show recent development of the foredune after a possible erosive phase. The stream and overall appearance of the beach is relatively unchanged.

Figures 3.4 and 3.5 show the surveys of profiles EO20 and EO21. From these profiles, the typical beach profile of Long Beach can described as having a dune complex ranging in height from 1 to 1.5 metres. This dune complex is then fronted by a relatively flat, dry upper-foreshore.

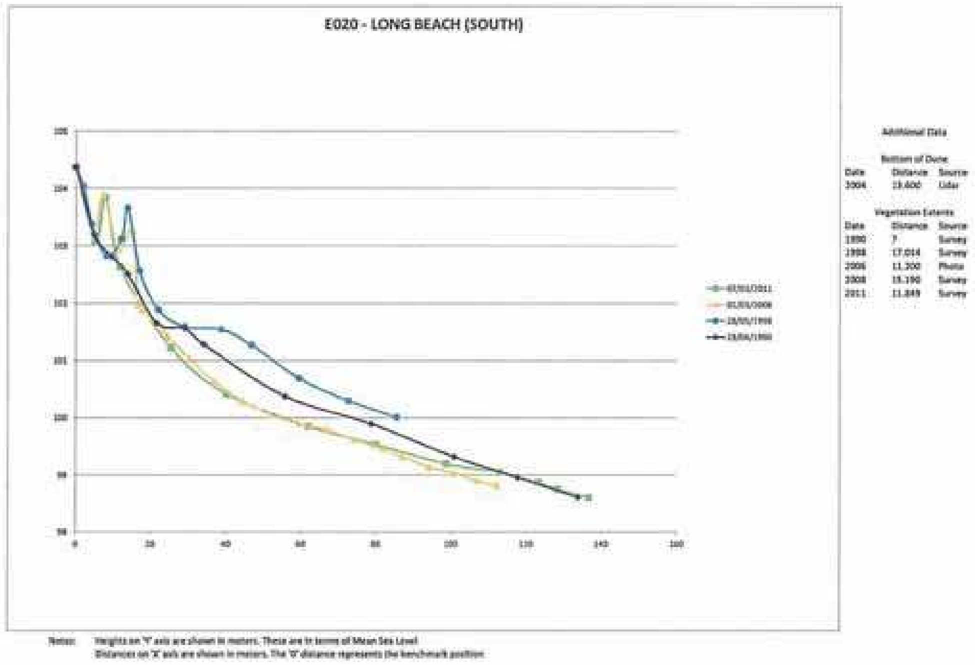

Figure 3.4 Profile of Long Beach as represented by survey line EO20, the southern most profile of Long Beach

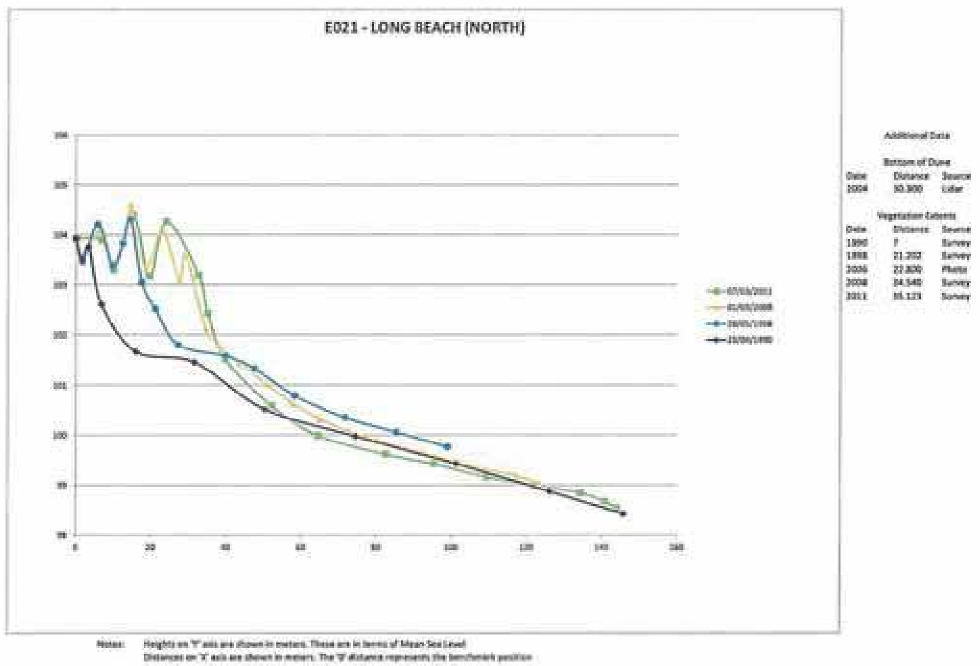

Figure 3.5 Profile of Long Beach as represented by survey line EO21, the northern most profile of Long Beach

From the profiles displayed in Figures 3.4 and 3.5 it is apparent that since the survey in May 1998 the beach surface has lowered. The seaward face of the dunes to the south has retreated by approximately 5 metres. However the dunes to the north have developed significantly, with a new dune formed seaward of that present in 1998. The dune face has prograded approximately 15 metres. It is likely that the long-term state of the beach is slightly accretional, but with a large short-term envelope of change in response to storm events.

3.1.5 Purakanui Beach

Purakanui Beach is situated north of the inlet to the Purakanui Estuary, and is terminated by a rocky headland at its northern end. The upper-foreshore consists of very soft, dry sand and is absent of any shells or driftwood. An extensive low dune system (in the order of 1 metre in height) is densely vegetated with marram grass. At the time of inspection, this dune system appeared to be undergoing a period of growth with numerous embryo dunes forming in front of the main dune system. Marram grass has also become established within the embryo dunes. These observations are confirmed by a comparison of photographs from 2002 with ones taken in 2011.

ORC's survey network does not include Purakanui Beach, so quantitative changes in the beach position and form cannot be described.

3.1.6 Warrington Spit (Profiles EO1 and EO2)

The seaward face of Warrington Spit presents a low flat beach bounded by a rocky headland to the north and the inlet of Blueskin Bay Estuary to the south. The beach is backed by an extensive dune system that is well vegetated with marram grass, and at the time of inspection, appears to be in a good state of health with no signs of 'blow-outs', or erosion scarps on its seaward face. The Warrington Surf Life Saving club, a picnic/play ground, and caravan park are located within this dune system. The beach consists of soft, dry, loose sand that onshore winds can easily transport inland to the dunes.

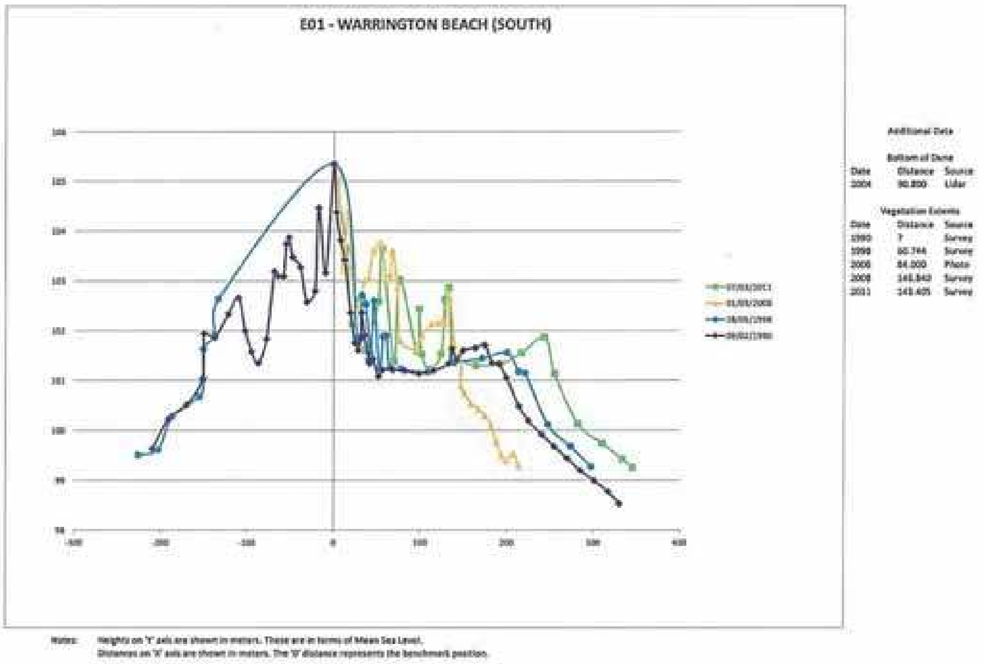

Figure 3.6 Profiles of Warrington Spit Beach as represented by survey line EO1

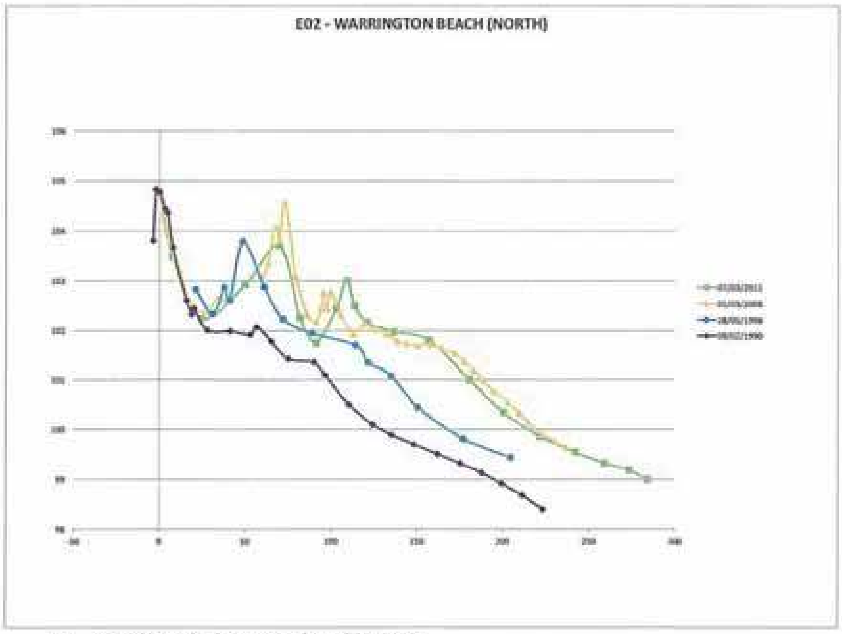

Figure 3.7 Profiles of Warrington Spit Beach as represented by survey line EO2, the northern most profile of the beach

Figures 3.6 and 3.7 show the typical profile of the spit. These profiles show that the width of the beach from HWM to the foot of the dune system is approximately 150 metres. The dune system consists of more than three lines of dunes seaward of the benchmark and three more in a landward direction. It is apparent from past surveys of Profiles EO1 and EO2 that the dunes and beach have built up increasing in height during the 21-year period from 1990 to 2011, with the largest dune having a height of approximately 5 metres above mean sea level, and the foredune ranging in height from 0.5 to 1 metre.

3.1.7 Karitane (Profiles EO3 and E04)

The beach of Karitane fronts a picnic area and the Karitane community. The upper foreshore is very similar to the beaches located further south in that the foreshore is of very gentle slope with a relatively wide inter-tidal area in the order of 30-40 metres.

However, Karitane is different from the rest of the beaches between Taiaroa Head and Karitane, in that a steep clay bank backs the beach at the northern end, and there is no dune system. The clay bank has evidence of failure and slumping in the past, producing a scarp with a height of over 2 metres at the northern end of the beach, and 10 metres at the bluffs located at the southern end. Erosion of the backshore has been managed in the past by the placement of rock fill at the base of the bank, and a concrete seawall in front of the picnic ground.

The concrete wall is no longer visible along the backshore, and sand has built up on the beach. At the time of inspection in 2011, and from a comparison with the 2002 photographs, the beach at Karitane appears to have accreted and built up in height. This is also apparent from the surveyed profiles. However there may have been some human intervention along the backshore.

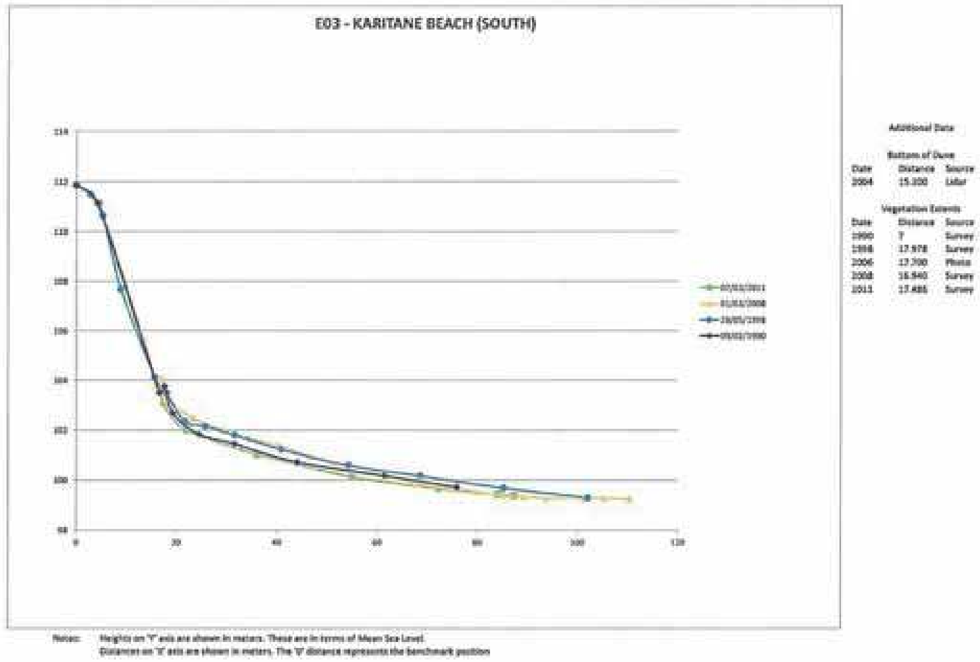

Figure 3.8 Profiles of Karitane Beach as represented by survey line EO3

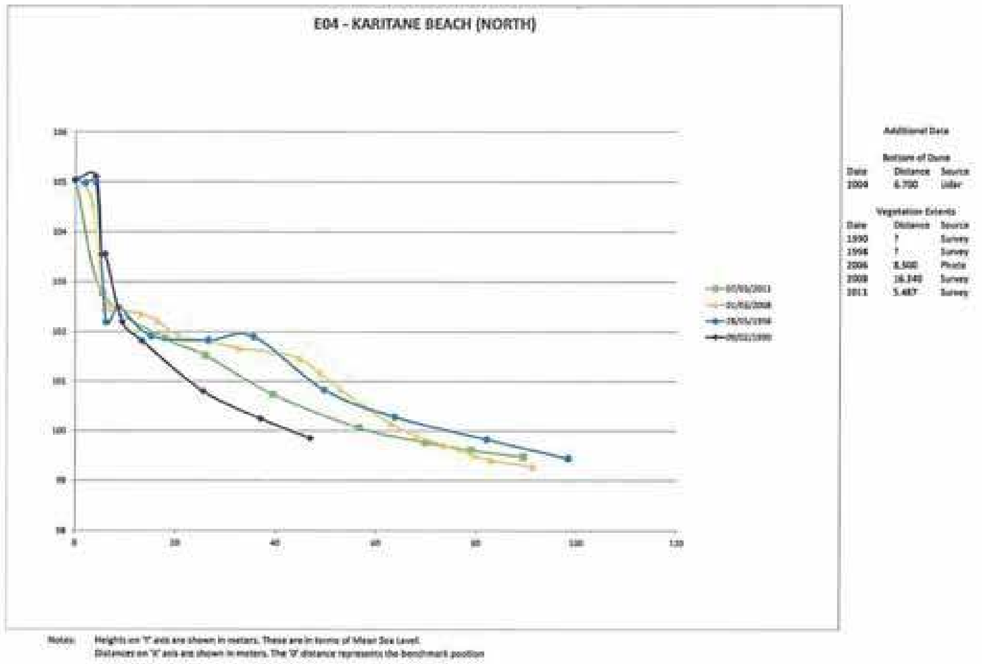

Figure 3.9 Profiles of Karitane Beach as represented by survey line EO4

Profiles E03 and E04 illustrate the typical beach profile of the Karitane foreshore and are shown here as Figures 3.8 and 3.9. It can be seen that the backshore bank is a dominant feature of both profiles, and presents a sharp interface between the hinterland and the beach system. The beach itself is relatively flat. The survey undertaken in 2011 shows no development of berms or dunes. The bank appears to be maintaining the position of the backshore, while the foreshore adjusts in response to episodic periods of erosion and accretion of the foreshore (as indicated by the presence of a berm in 1998).

3.1.8 Shelly Beach (Profile Peg 250)

Shelly Beach is located southeast of Aramoana Beach between the Mole and the Long Mac groyne adjacent to the entrance to Otago Harbour. The contemporary seaward face of Shelly Beach presents a moderately steep beach orientated northwest to southeast. A single line of sparsely vegetated high dunes backs the beach. The dune vegetation is mainly marram grass. At the southern end of Shelly Beach, a number of established pine trees are present and three permanent houses are situated amongst them. Erosion of the dunes through the 1980s and early 1990s resulted in dredged sediment being deposited in the nearshore of the embayment to provide sand to nourish the dunes. The beach is the subject of a number of reports including (Single and Stephenson 1998), Bunting *et al.* (2003b) and Leon (2005).

Comparison of photographs taken in 2002 and 2011 show little change to the foreshore of the beach, and continued instability of the seaward face of the steep, high dunes. The level of the foreshore appears to be similar, but erosion of the backshore of between 1 and 2 metres is evident at the southeastern end of the beach.

Figure 3.10 shows surveys of a profile site near the middle section of the beach. The main changes since 1987 are the retreat of the dune and upper foreshore from 1987 until 2002, and then the relative stabilisation of the dune position between 2002 and 2011. It is possible that the lower foreshore has accreted during the latter inter-survey period.

This beach appears to be sensitive to changes in wave energy, and susceptible to erosion of the foreshore by storm waves, and of the dunes by wind processes. It is likely that nourishment of the nearshore with dredged sediment from the harbour channel has enhanced the stability of the beach since 1987, but dune management is necessary to stabilise the dunes.

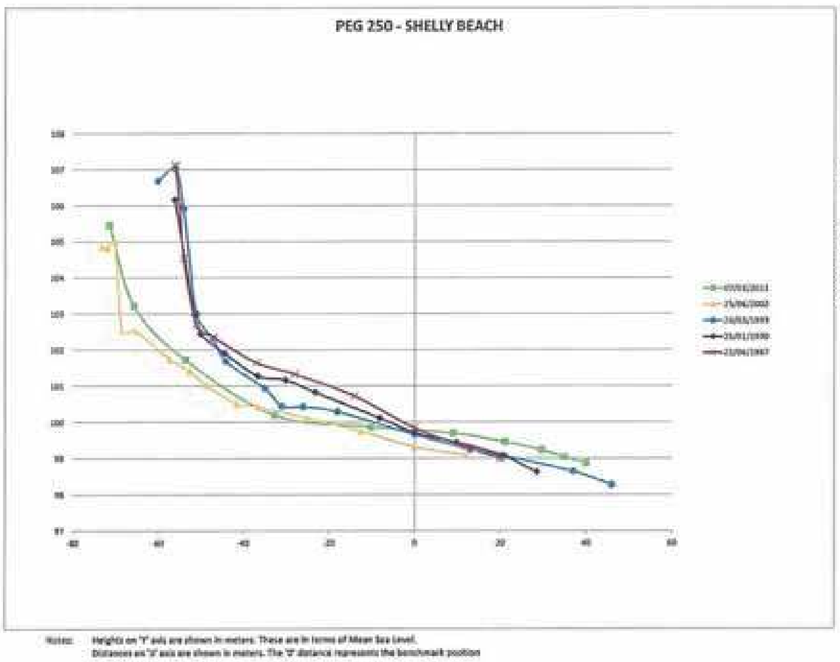

Figure 3.10 Profiles of Shelly Beach as represented by survey line Peg 250

4. Morphological dynamics

Conclusions made in 2003 by Bunting *et al.* (2003a) are applicable to the findings of the 2011 beach inspection and profile surveys. From the analysis of all the shore-normal beach profiles displayed in Section 3, it is evident that the dunes continue to grow, but act as buffers against storm wave attack. This is a normal function of dunes. They erode when attacked by storm waves, and rebuild during periods of quiescent wave conditions. The vegetation readily grows to stabilise the older dunes and to capture sand in foredunes. There are changes to the profiles between 1990 and 2011 that represent the beach response to changes in wave conditions and longer-term changes such as accretion of dunes after significant storm events. Overall, dune and foredune areas of the beach profile have a wide envelope of change, while the foreshore is more stable. This is indicative of beaches in long-term stability or accretion. There is no indication that beach progradation is unusual or specific to any of the beaches, but is part of the ongoing character of the beaches of Blueskin Bay.

5. Conclusions regarding coastal change in Blueskin Bay

Nicholson (1979) and Kirk (1980) described the coastline of Blueskin Bay as being in a state of long-term stability or accretion. Nicholson calculated the rate of change for the shoreline to be between –0.89 metres per year at Murdering Beach to +3.2 metres per year at Purakanui Spit. The surveys undertaken in 2011, and the field inspections do not provide any indications that contradict Nicholson's findings of long-term change. However, it is possible that Murdering Beach has remained stable or accreted slightly over recent years, or that beach change in response to changes in the wave environment are such that there are patterns of change that relate to variability in the process environment, with prolonged periods of erosion, accretion or beach recovery.

Wind transport of sediments is an important process for the beaches of Blueskin Bay. The majority of the dunes backing the sandy beaches are building up and/or advancing seaward, and show active recovery from episodes of storm erosion. There is no evidence that the beaches are over-nourished by sand, and vegetation succession appears to be keeping pace with and promoting dune growth.

Bunting *et al.* (2003a) concluded that "the energy inputs of the beaches of Blueskin Bay that are important to the morphological changes of these beaches are the refracted shoaling waves that approach from the south and north-east, and the onshore winds. Both processes promote on and offshore sediment transport. Therefore it can be concluded that onshore north and north-easterly winds and refracted shoaling waves are the most important geomorphic agents in the study area." These conclusions are still appropriate to the findings of the 2011 work.

In addition, there are no indications from the field inspection or from the survey data, that the beaches of Blueskin Bay, with the exception of Shelly Beach, show any adverse effects of the disposal of dredged sediment at the Heyward or Aramoana disposal sites.

6. References

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Appendix E

Peter McComb, Met Ocean Solutions Ltd – Wave, Current and Sediment Transport Model Studies

PORT OTAGO DREDGING

Preliminary wave, current and sediment transport model studies for dredge disposal investigations

Prepared for Port Otago Ltd

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MetOcean Solutions Ltd: Report 0068-02

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It is the responsibility of the reader to verify the currency of the version number of this report. The report was prepared by S. Weppe, P. McComb, D. Johnson and B. Beamsley.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Port Otago Ltd is seeking a short-term replacement consent to allow for the continued disposal into the sea of up to 450,000m³ per year of dredging spoil. This will replace the current coastal permit, 2000.472, which expires in December 2011. The Port company seeks to continue to disposal of dredging material pursuant to the terms and conditions applying to coastal permit 2000.472.

The spoil is derived from maintenance dredging and incremental improvements to the channel and berth areas in and about the Otago Harbour. It is proposed to be carried out in accordance with the following specific maximum annual discharge quantities at each location:

- Heyward Point, being an area of approximately 38.2ha and to receive up to 200,000m³ of spoil;
- Spit Beach, being an area of approximately 28.3ha and to receive up to 200,000m³ of spoil, and
- South Spit Beach (Shelly Beach), being an area of approximately 14.5ha and to receive up to 50,000m³ of spoil.

A term of three years is being sought for the consent. After this time, it is intended that a 35-year disposal consent will be sought. This will allow for a suitable long-term consent framework and monitoring programme to be developed which takes account of both maintenance dredging disposal and disposal associated with capital dredging sought through the Project Next Generation resource consent which is currently under consideration by Otago Regional Council.

The selection of a site for long term disposal of maintenance dredging volumes requires a detailed understanding of the wave, current and sediment dynamics. The entrance to Otago Harbour is a very complex oceanographic environment, exhibiting considerable spatial gradients in the wave and current fields, plus significant variability over relatively short time scales. An effective method to resolve this complexity is by time-domain simulation of historical events using numerical models of the hydrodynamic and sedimentary processes.

This report provides preliminary results of a model study of the harbour entrance region. The purpose of the work is to examine the dominant processes operating in this area, and to interpret these within the context of the dredge disposal monitoring to date. Ultimately, the model results presented here will be used to guide the subsequent research and model studies to define the optimum locations and associated volumes for the sustainable disposal of dredged sediment for the 35-year consent.

2. WAVE MODELLING

The wave climate in the harbour entrance region has been hindcast over a 12-year period. This is a numerical process that uses computer models to recreate the wave conditions; in this case hour-by-hour over the period from 1998 to 2009. In this section, the technical details on the wave hindcast modelling are presented, along with validation results where the hindcast wave data are compared with measured values from a wave buoy that was moored near the entrance. Analysis of the regional and local wave conditions is also provided.

2.1. Wind fields

A spatially varying wind field was specified from a blended global wind product developed by MetOcean Solutions Ltd. These data are 10 m wind velocity vectors in a 3-hourly gridded format at a resolution of 0.25° of longitude and latitude. The wind field is a combination of 6-hourly Blended Sea Winds data[1] and 3-hourly model wind fields[2] from the National Centers for Environmental Prediction (NCEP) at the United States National Oceanic and Atmospheric Administration (NOAA). The blended data product combines the benefits of measured satellite data with the temporal resolution and continuous coverage of modelled analyses/short range forecasts. These wind data have been validated at coastal and offshore locations around New Zealand.

2.2. Wave hindcast model

SWAN (Simulating Waves Nearshore) was used for all of the wave modelling. SWAN is a third generation ocean wave propagation model, which solves the spectral action density balance equation for wavenumber-direction spectra. This means that the growth, refraction, and decay of each component of the complete sea state, each with a specific frequency and direction, is solved, giving a complete and realistic description of the wave field as it changes in time and space. Physical processes that are simulated include the generation of waves by surface wind, dissipation by white-capping, resonant nonlinear interaction between the wave components, bottom friction and depth limited breaking. A detailed description of the model equations, parameterizations, and numerical schemes can be found in Holthuijsen *et al.* (2007) or the online SWAN documentation[3]. All 3rd generation physics are included. The Collins friction scheme was used for wave dissipation by bottom friction, with a default coefficient of 0.015. The solution of the wavefield is found for the non-stationary (time-stepping) mode. Boundary conditions, wind forcing and resulting solutions are all time dependent, allowing the model to capture the growth, development and decay of the wavefield.

The modelling uses a nested approach that starts with a New Zealand scale domain with spectral open-ocean boundaries obtained from the

---

[1] From the NOAA National Climatic data Center (NCDC), Zhang (2006).
[2] These wind fields are used in the NCEP Wavewatch III global wave hindcast (NWW3), and consist of analyses and 3-hour forecasts from NCEP's operational Global Data Assimilation Scheme (GDAS) and the aviation cycle of its Medium Range Forecast model.
[3] http://swanmodel.sourceforge.net/

MetOcean Solutions global WW3 hindcast[4]. A high-resolution regional Dunedin scale domain at approximately 350 m resolution is then nested within the NZ grid.

2.3. Wave data analysis

The spectral wave parameters were derived as follows. From the modelled directional wave spectrum $S(f,\theta)$, the 1-dimensional spectrum is obtained by integrating over directions:

$$S(f) = \int_0^{2\pi} S(f,\theta) d\theta \tag{2.1}$$

From the computed spectral energy density *S(f)*, the peak frequency f_p and peak energy $S_p = S(f_p)$ of the spectrum are located. Spectral moments

$$M_j = \int_0^{\infty} f^j S(f)\, df \tag{2.2}$$

are computed, allowing further statistics to be defined:

significant height $H_s = 4\sqrt{M_0}$ (2.3)

peak period $T_p = \frac{1}{f_p}$ (2.4)

mean period $T_m = M_0 / M_1$ (2.5)

Directional moments are:

$$M_c = \int_0^{\infty}\int_0^{2\pi} S(f,\theta)\cos\theta\, d\theta\, df \tag{2.6}$$

$$M_s = \int_0^{\infty}\int_0^{2\pi} S(f,\theta)\sin\theta\, d\theta\, df \tag{2.7}$$

The mean direction is $\theta_0 = \arctan\left(\frac{M_s}{M_c}\right)$ (2.8)

and the directional spread is $\Delta = \sqrt{2 - \frac{2\sqrt{M_c^2 + M_s^2}}{M_0}}$. (2.9)

[4] The MetOcean Solutions Ltd (MSL) global WW3 hindcast replicates the NOAA WaveWatch3 (NWW3) hindcast, using the same domain, forcing winds and then assimilating the NWW3 significant wave heights. The MSL WW3 output is effectively identical in terms of spectral parameters, but has the advantage of full spectra being available at arbitrary locations and on nested model boundaries.

2.4. Wave hindcast accuracy measures

The validation process for wave height needs to consider both amplitude and phase, so both qualitative and quantitative techniques are employed. For the qualitative assessment, timeseries plots of the measured and hindcast wave heights are made. Quantitative measures of accuracy are calculated from the measured, x_m and hindcast, x_h , data. These are defined as:

Mean absolute error: $\overline{|x_h - x_m|}$ (2.10)

RMS error: $\sqrt{\overline{(x_h - x_m)^2}}$ (2.11)

Mean relative absolute error: $\overline{\left|\frac{x_h - x_m}{x_m}\right|}$ (2.12)

Bias: $\overline{x_h - x_m}$ (2.13)

where the line indicates an average over all pairs of measured/forecast data. The mean absolute error (MAE) is the most direct representation of what the typical deviation of the hindcast from the measured value. The RMS error exaggerates large differences in measured and hindcast wave heights. The mean relative absolute errors (MRAE) are an expression in ratio terms of the error compared to actual. Bias is a useful indicator of the performance of the hindcast model within discrete wave height ranges.

2.5. Validation

A timeseries validation plot showing measured and hindcast significant wave heights for the period from 7/12/2009 to 11/04/2010 at the wave buoy location (Fig. 2.1) is presented in Figure 2.2. The hindcast timeseries provides a faithfully replication of the periods of high and low energy. The measured and hindcast data have similar statistical means (0.88 m and 0.94 m) and medians (0.78 m and 0.85 m). Further quantitative measures of the accuracy are presented in Table 1.1, showing the hindcast wave heights are on, average, within +/- 25% of the measured values. The bias, which represents a constant 'offset' in the hindcast significant wave heights is 0.06 m. Total significant wave heights are very sensitive to local wind conditions, and the full spatial and temporal variability in the local wind field is not always captured by the Blended Wind product. Also, some of the error in the hindcast wave heights is due to timing of the wave events, as the hindcasting technique has an inherent phase resolution of ~3 hours.

Table 2.1 Joint accuracy measures for hindcast significant wave heights. MAE: mean absolute error, RMSE: RMS error, MRAE: mean relative absolute error, BIAS: bias.

MAE (m)	RMSE (m)	MRAE (%)	BIAS (m)
0.20	0.26	0.25	0.06

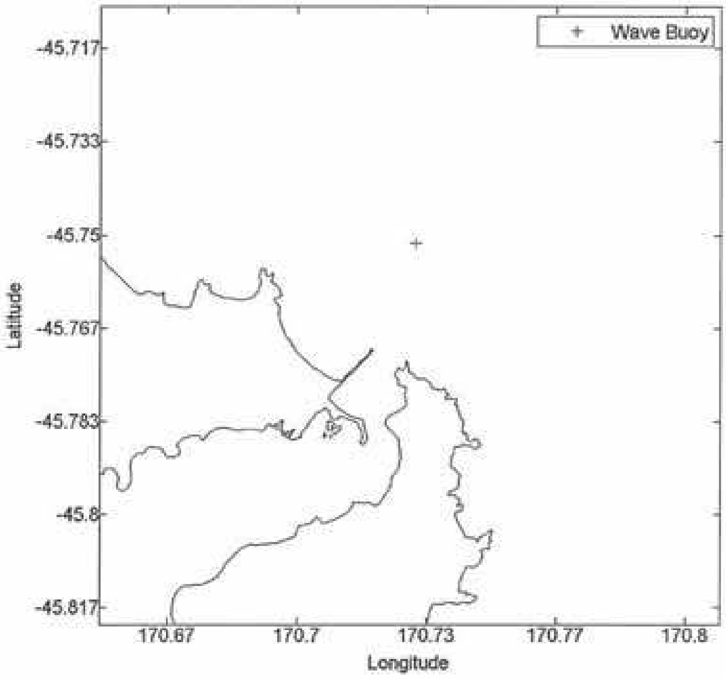


Figure 2.1 Location of the waverider buoy.

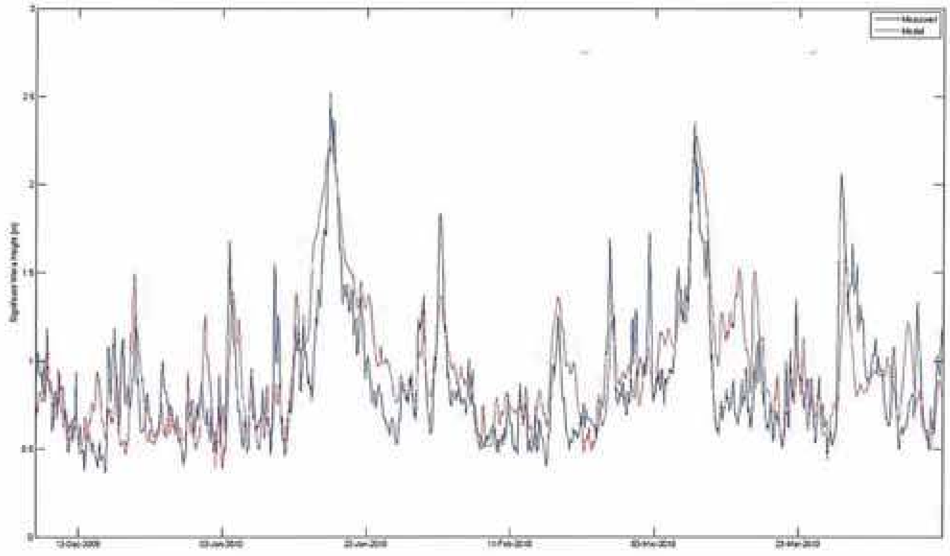


Figure 2.2 Comparison between measured and hindcast significant wave heights near the harbour entrance.

2.6. Regional wave climate

The regional wave hindcast has been used to create summary maps of the wave climate over the wider Dunedin region. The mean significant wave height map is presented in Figure 2.3, showing clear gradients in the wave energy. On average, wave heights increase from the south-western region towards the Cape Saunders. A decrease in mean wave height is then observed towards the Otago harbour region and Aramaona Beach, continuing further north towards Warrington and Karitane. The 99th percentile non-exceedence level exhibits a very similar pattern (Fig.2.3). The maximum hindcast significant wave height (Fig. 2.4) is defined from several storms, and has a similar energy gradient to the mean wave heights, with the largest wave heights occurring along the coastline just south of Cape Saunders. Significant wave heights exceeding 8 m are predicted for the inner shelf regions over the hindcast period. The average peak spectral wave period is presented in Figure 2.5; this remains uniform in along the coastline south of Cape Saunders and decreases west of Tairoa Head. Examples showing wave height patterns during typical wave events from the southwest and northeast are provided in Figures 2.6 and 2.7, illustrating the effects of wave refraction and topographic sheltering.

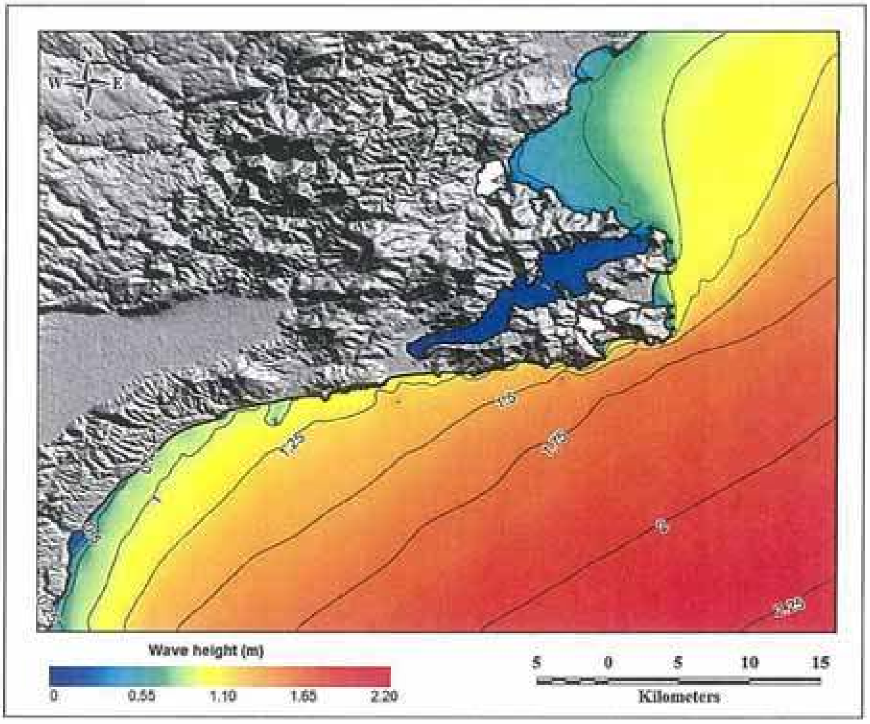


Figure 2.3 Mean significant wave height over the Dunedin region.

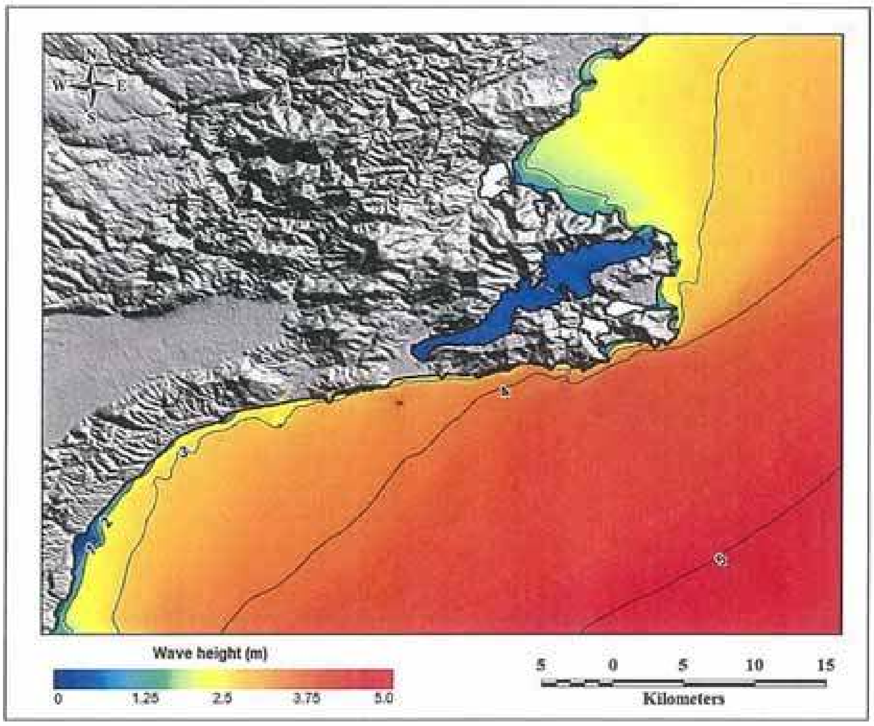


Figure 2.4 99th percentile non-exceedence significant wave height over the Dunedin region.

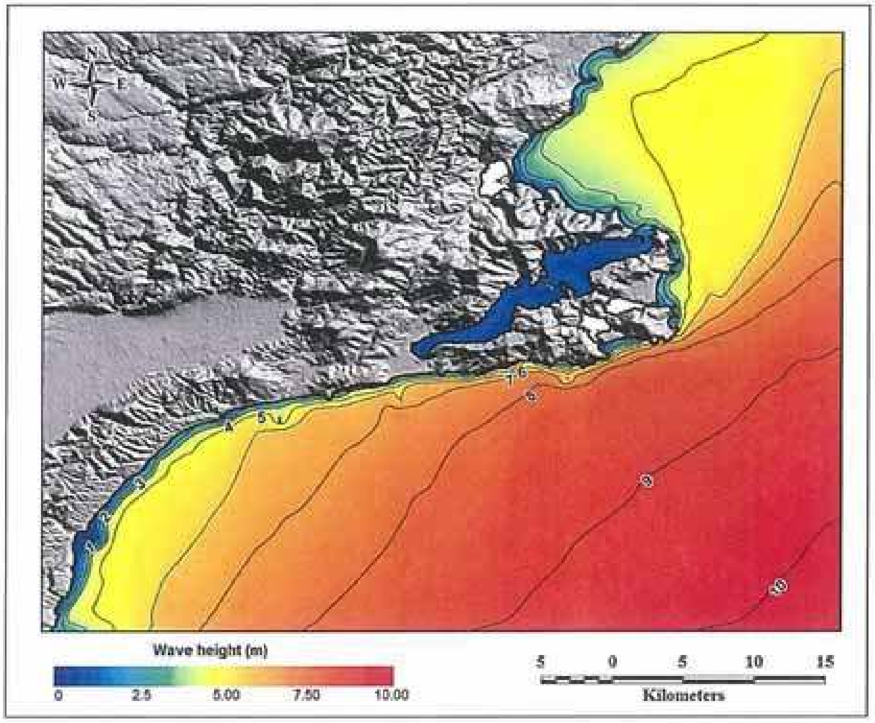


Figure 2.5 Maximum significant wave height over the Dunedin region.

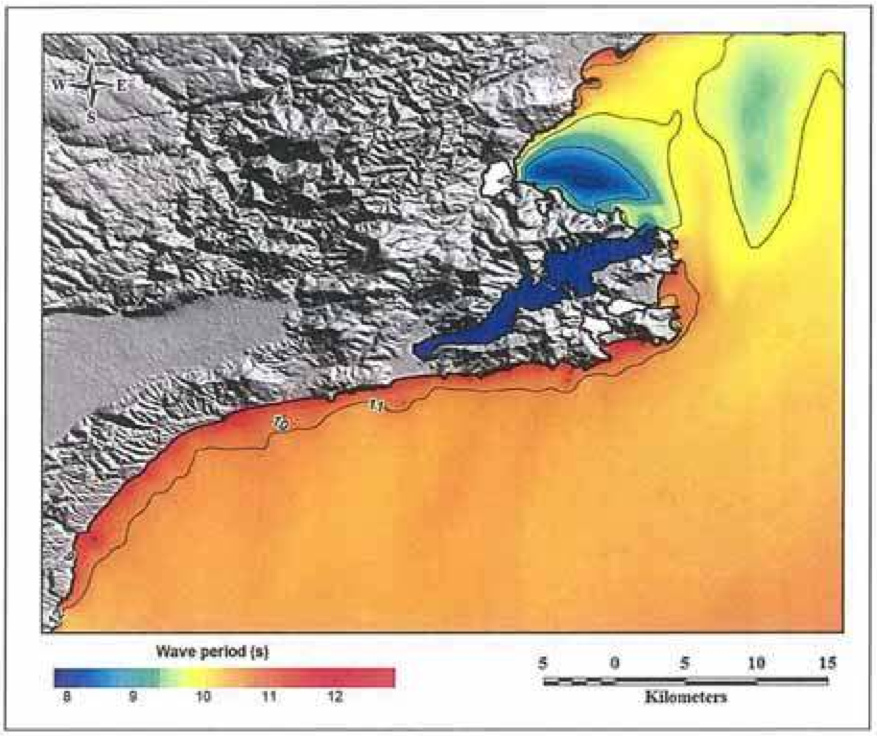


Figure 2.6 Average peak spectral wave period over the Dunedin region.

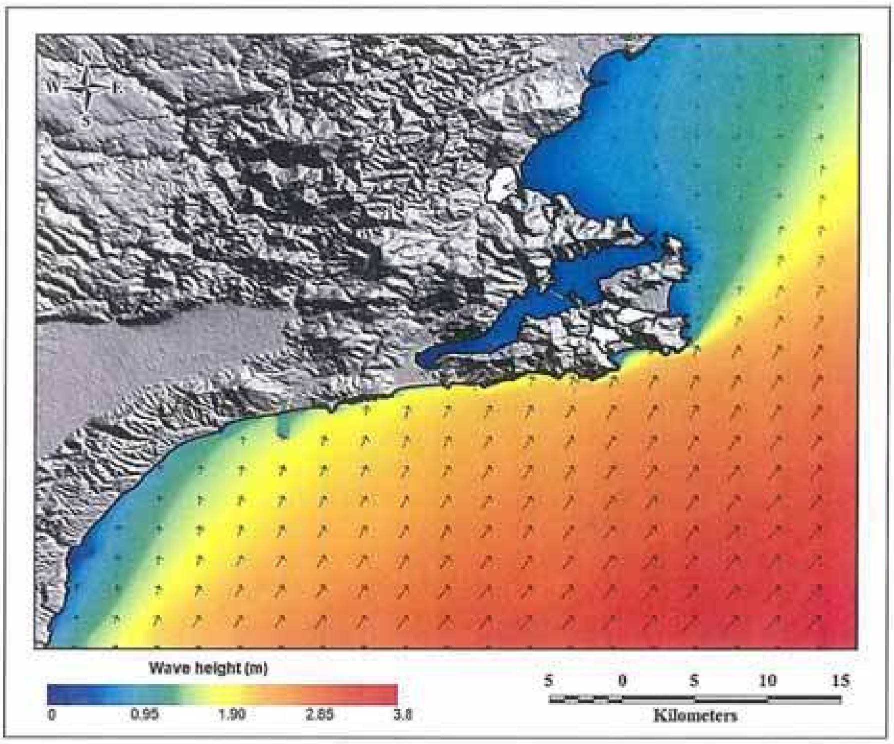


Figure 2.7 Example wave height distributions for a characteristic event from the southwest over the Dunedin region.

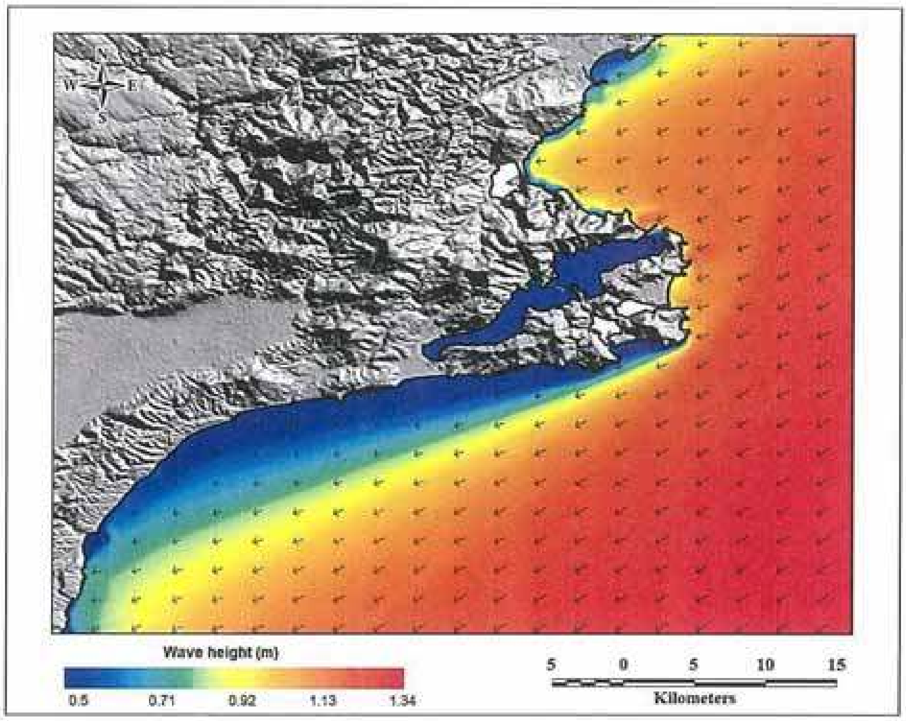


Figure 2.8 Example wave height distributions for a characteristic event from the northeast over the Dunedin region.

2.7. Otago Peninsula wave climate

Summary maps of the wave climate over the harbour entrance region are presented and discussed in this section. The mean significant wave height in Figure 2.9 clearly shows sheltering effect of Cape Saunders on dominant southerly waves, which results in a strong gradient in wave height directly offshore of the harbour entrance. Local onshore deflection of the 0.75 m contour is seen near Aramoana Beach and off Heyward Point, indicating larger waves are observed closer to shore in these zones. This is related to the process of wave focusing along the bathymetric features near the harbour entrance.

The 99th percentile non-exceedence level exhibits a very similar wave height pattern (Fig. 2.10), as does the maximum wave height map (Fig. 2.11). Notably, wave heights up to 4 m were hindcast in the vicinity of Aramoana Beach. The average peak spectral wave period map presented in Figure 2.12 shows distinct gradients, particularly along the north coast. The combined processes of refraction and topographic sheltering act to filter out the higher frequency sea waves from the spectrum, causing a net shift to longer period waves in the resultant sea state.

Local wave height distributions during the typical wave events shown in Figures 2.7 and 2.8 are provided in Figures 5.13 and 5.14, showing the difference in wave energy reaching the harbour entrance and Aramoana Beach under the different incident wave directions.

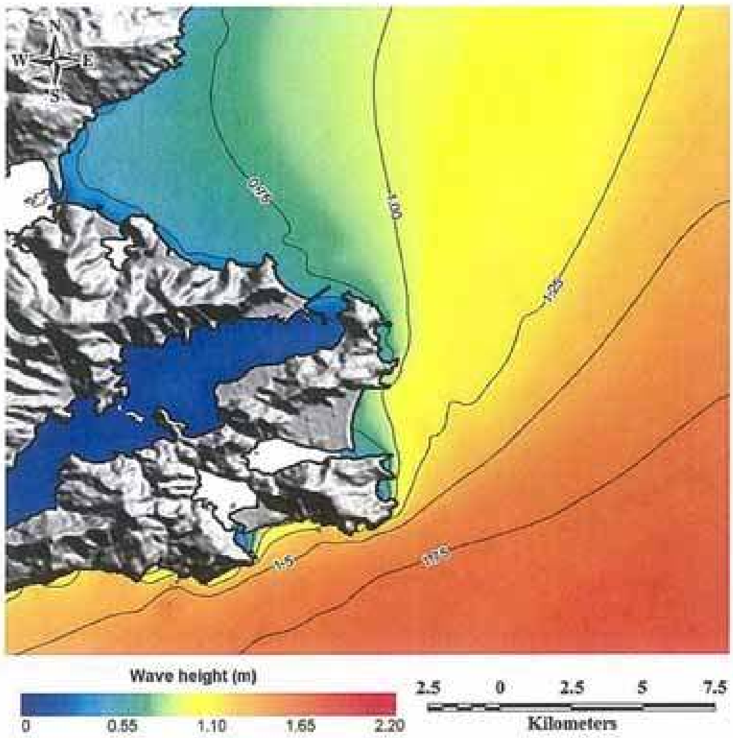


Figure 2.9 Mean significant wave height over the Otago Peninsula region.

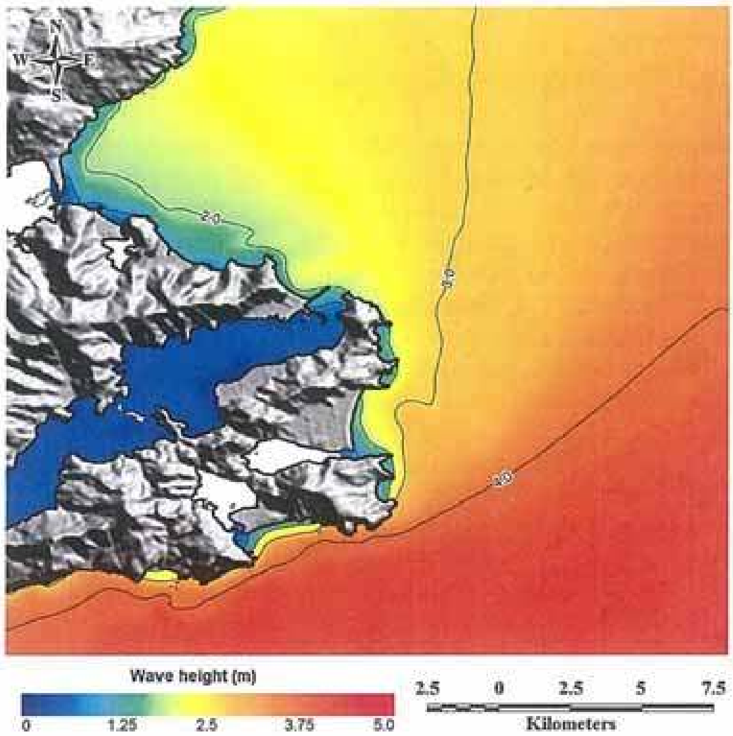


Figure 2.10 99th percentile non-exceedence significant wave height over the Otago Peninsula region.

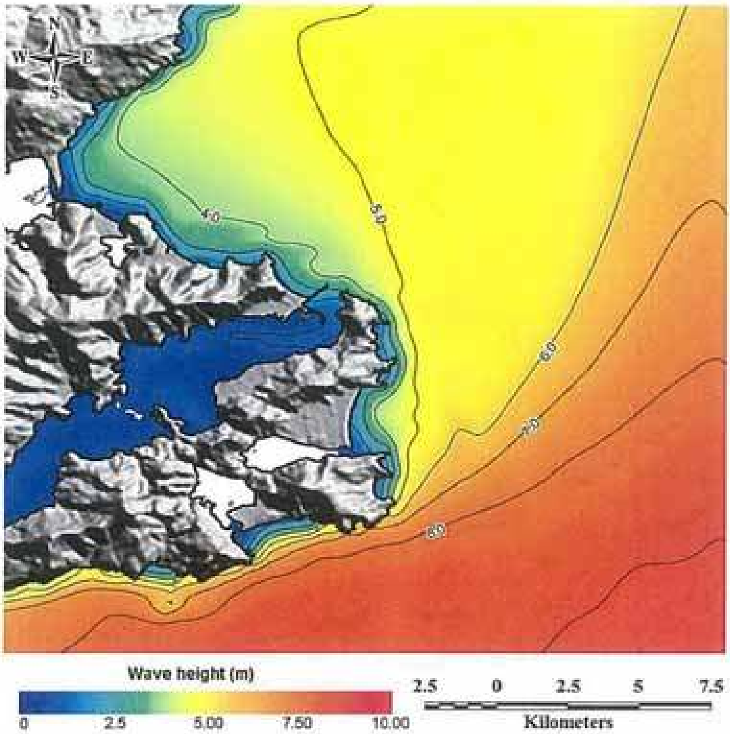


Figure 2.11 Maximum significant wave height over the Otago Peninsula region.

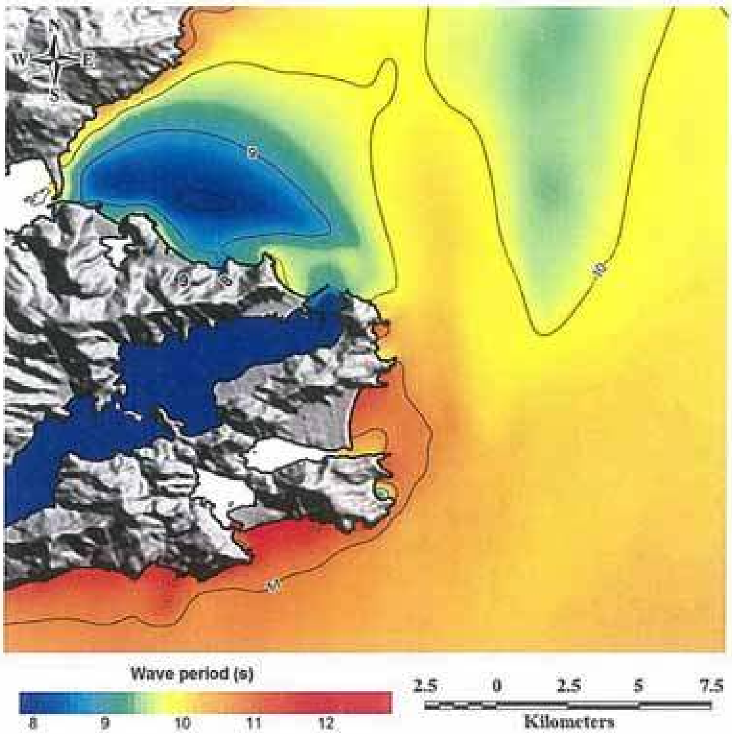


Figure 2.12 Average peak spectral wave period over the Otago Peninsula region.

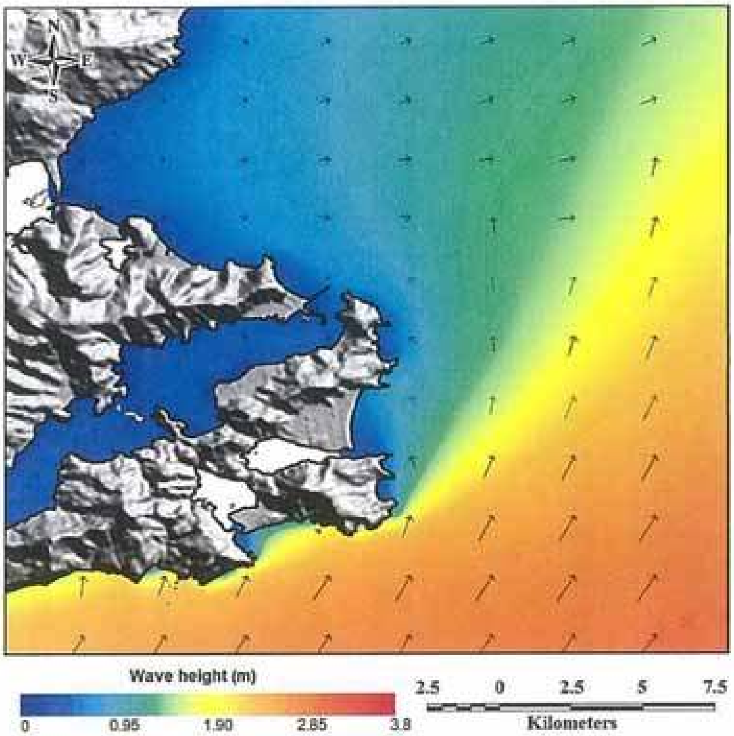


Figure 2.13 Example wave height distributions for a characteristic event from the southwest over the Otago Peninsula region.

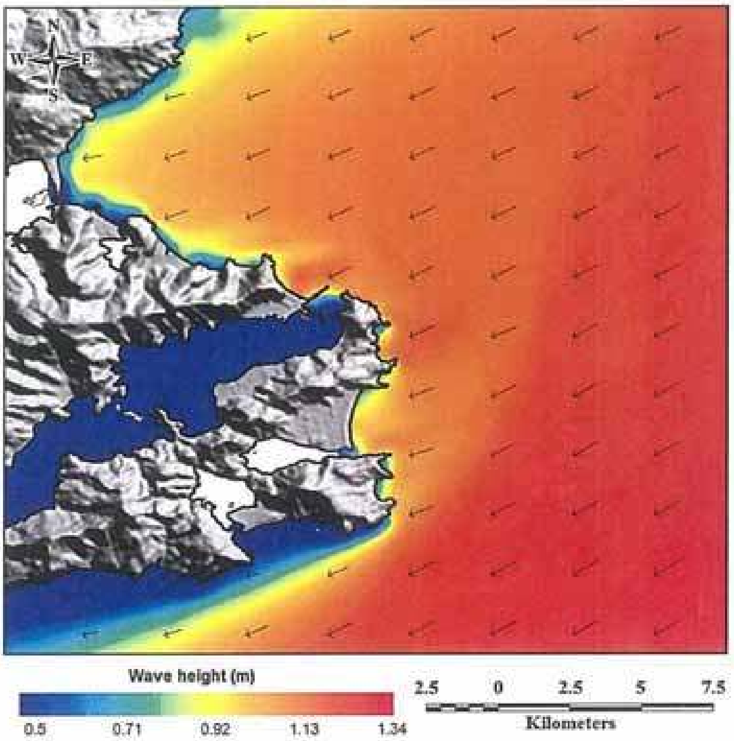


Figure 2.14 Example wave height distributions for a characteristic event from the northeast over the Otago Peninsula region.

2.8. Wave climate at the harbour entrance

Wave climate statistics have been analysed at the wave buoy location near the Landfall Beacon at the harbour entrance (170.7305 ºN, 45.7514 ºS; Fig. 2.1). Monthly and annual significant wave height statistics are provided in Table 2.2, and the exceedence values are reported in Table 2.3.

The wave climate at this location is of relatively moderate energy with a mean annual significant wave height of only 0.89 m. During the winter months of July and August, the mean is 1.1 m, while November is the least energetic month with a mean significant wave height of 0.77 m. The years 2008 and 2009 were slightly more energetic than the rest of the 12-year hindcast, as indicated by the higher mean, P90 and P95 values in Table 2.2.

The joint probability distributions of significant wave height and wave direction are presented for the annual and seasonal conditions in Tables 2.4 – 2.8. The annual table shows that the directional window of incident wave energy is from 270º to 170º (clockwise). The largest waves tend to approach from ENE to SE sectors, while a second group of smaller locally-generated waves approach from the NW-N sector. The seasonal tables show that north-easterly wave events are more frequent during summer months while south-easterly waves are more common during winter.

The joint probability distributions of significant wave height and peak wave period are presented for the annual and seasonal conditions in Tables 2.9 – 2.13. The most energetic wave events typically have peak spectral periods in the range 10-14 seconds. Seasonal decomposition shows a higher percentage of wave events with longer peak periods (T>10 s) occur during the winter months compared with summer. Wave height extrema and associated wave periods at 1 to 100 year return periods are reported in Table 2.14. The omni-directional 100-year return period significant wave height is 7.40 m.

Table 2.2 Significant wave height statistics at the wave buoy location.

Hs (m)	Statistic					
	Mean	**Median**	**p90**	**p95**	**p99**	**Max**
January	0.79	0.69	1.37	1.58	2.43	3.20
February	0.83	0.74	1.46	1.64	2.11	3.08
March	0.83	0.74	1.32	1.58	2.52	4.36
April	0.86	0.77	1.45	1.72	2.39	3.81
May	1.00	0.90	1.70	1.99	2.32	2.73
June	0.92	0.81	1.59	1.86	2.32	2.88
July	1.09	0.91	1.94	2.35	3.35	4.70
August	1.10	0.96	2.00	2.33	2.72	3.19
September	0.88	0.79	1.49	1.73	2.06	3.10
October	0.79	0.73	1.24	1.47	1.88	2.78
November	0.77	0.73	1.20	1.41	1.87	2.52
December	0.81	0.72	1.37	1.52	1.85	2.07
1998	0.81	0.75	1.27	1.44	2.10	2.93
1999	0.87	0.74	1.45	1.70	3.01	3.43
2000	0.85	0.72	1.58	1.80	2.32	2.76
2001	0.86	0.75	1.42	1.85	2.66	3.90
2002	0.88	0.76	1.59	1.88	2.54	3.20
2003	0.89	0.75	1.55	1.96	2.66	4.36
2004	0.90	0.78	1.54	1.79	2.37	3.08
2005	0.82	0.71	1.46	1.76	2.50	3.09
2006	0.85	0.76	1.43	1.70	2.33	3.81
2007	0.82	0.72	1.39	1.69	2.35	4.70
2008	1.08	1.00	1.69	1.93	2.54	3.98
2009	1.05	0.94	1.63	1.90	2.26	2.51
All	0.89	0.78	1.51	1.80	2.46	4.70

Table 2.3 Monthly significant wave height exceedence at the harbour entrance.

Hs (m)	Exceedence (%)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
> 0.25	96.2	97.44	99.19	98.67	98.79	98.63	99.64	99.43	98.63	98.87	97.73	97.85	98.43
> 0.5	74.67	78.61	80.68	81.91	87.85	84.33	88.51	86.82	84.59	82.07	79.4	78.64	82.36
> 0.75	44.11	49.59	49.43	52.66	62.8	58.21	64.2	65.33	54.77	48.49	47.85	47.94	53.82
> 1	26.76	29.18	27.08	29.02	43.81	32.97	42.63	47.64	31.54	21.47	20.06	29.74	31.88
> 1.25	14.26	16.56	13.02	16.13	27.71	19.76	29.89	33.64	17.6	9.99	8.73	16.22	18.67
> 1.5	7.1	9.02	6.47	8.98	15.12	12.15	20.15	22.58	9.92	4.6	3.59	5.41	10.46
> 2	1.98	1.3	1.81	2.41	4.88	3.67	9.07	10.13	1.33	0.76	0.6	0.27	3.21
> 2.5	0.94	0.27	1.06	0.68	0.29	0.41	4.01	2.48	0.41	0.12	0.03	0	0.9
> 3	0.12	0.05	0.17	0.19	0	0	2.36	0.44	0.07	0	0	0	0.29
> 3.5	0	0	0.11	0.08	0	0	0.68	0	0	0	0	0	0.07
> 4	0	0	0.06	0	0	0	0.21	0	0	0	0	0	0.02
> 4.5	0	0	0	0	0	0	0.1	0	0	0	0	0	0.01

Table 2.4 Annual Joint probability distribution (parts per thousand) of the significant wave height and the mean wave direction at peak energy at the harbour entrance.

Hs (m)	Direction (degT)																		
	350 to 10	10 to 30	30 to 50	50 to 70	70 to 90	90 to 110	110 to 130	130 to 150	150 to 170	170 to 190	190 to 210	210 to 230	230 to 250	250 to 270	270 to 290	290 to 310	310 to 330	330 to 350	Total
> 0 <= 0.5	6	4.2	29.4	26.1	3.1	3.5	3.5	79.7	5.7	0	0	0	0	0	3.5	18.2	3.3	1	187.2
> 0.5 <= 1	10.5	9.6	61.9	114.9	25.6	23.8	23.5	141.9	8.3	0	0	0	0	0.2	10.3	59.5	10.5	0.5	501
> 1 <= 1.5	0.5	1.3	10.7	71.5	31.3	22.4	19.1	37.5	1.5	0	0	0	0	0	1.9	11.2	0.4	0	209.3
> 1.5 <= 2	0	0.1	1.5	20	20.9	12.9	8.1	6.7	0.1	0	0	0	0	0	0.1	0.6	0	0	71
> 2 <= 2.5	0	0	0.1	3.5	7.2	8	2.3	1.5	0	0	0	0	0	0	0	0	0	0	22.6
> 2.5 <= 3	0	0	0	1	1.3	2.8	0.6	0.1	0	0	0	0	0	0	0	0	0	0	5.8
> 3 <= 3.5	0	0	0	0.3	0.1	1.5	0.1	0	0	0	0	0	0	0	0	0	0	0	2
> 3.5 <= 4	0	0	0	0	0.2	0.3	0.1	0	0	0	0	0	0	0	0	0	0	0	0.6
> 4 <= 4.5	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0.1
> 4.5 <= 5	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0.1
Total	17	15.2	103.6	237.3	89.7	75.4	57.3	267.4	15.6	0	0	0	0	0.2	15.8	89.5	14.2	1.5	1000

Table 2.5 Summer Joint probability distribution (parts per thousand) of the significant wave height and the mean wave direction at peak energy at the harbour entrance.

Hs (m)	Direction (degT)																	
	350 to 10	**10 to 30**	**30 to 50**	**50 to 70**	**70 to 90**	**90 to 110**	**110 to 130**	**130 to 150**	**150 to 170**	**170 to 190**	**190 to 210**	**210 to 230**	**230 to 250**	**250 to 270**	**270 to 290**	**290 to 310**	**310 to 330**	**330 to 350**	**Total**
> 0 <= 0.5	5.4	3.2	37.7	46.2	5.7	5.7	5.3	85	12.6	0	0	0	0	0	5.7	21.6	4.3	0.8	239.2
> 0.5 <= 1	7.9	10.2	55.5	139.4	34.2	29.5	27.9	77.8	12.6	0	0	0	0	0.3	11.4	65.3	9.2	0.5	481.7
> 1 <= 1.5	0.3	1.3	9.8	93.2	40.4	19.5	14.4	15.4	1.3	0	0	0	0	0.2	2.3	11.6	0.2	0	209.9
> 1.5 <= 2	0	0	1.4	20.5	21.5	3	6.5	4.3	0	0	0	0	0	0	0.1	0.1	0	0	57.4
> 2 <= 2.5	0	0	0.2	1.3	2.3	1.9	0.9	0.9	0	0	0	0	0	0	0	0	0	0	7.5
> 2.5 <= 3	0	0	0	1.3	0.4	1.5	0	0.2	0	0	0	0	0	0	0	0	0	0	3.4
> 3 <= 3.5	0	0	0	0.4	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0.6
> 3.5 <= 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
> 4 <= 4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
> 4.5 <= 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	13.6	14.7	104.6	302.3	104.5	61.1	55	183.8	26.5	0	0	0	0	0.5	19.5	98.6	13.7	1.3	1000

Table 2.6 Autumn Joint probability distribution (parts per thousand) of the significant wave height and the mean wave direction at peak energy at the harbour entrance.

Hs (m)	Direction (degT)																	
	350 to 10	10 to 30	30 to 50	50 to 70	70 to 90	90 to 110	110 to 130	130 to 150	150 to 170	170 to 190	190 to 210	210 to 230	230 to 250	250 to 270	270 to 290	290 to 310	310 to 330	330 to 350	Total
> 0 <= 0.5	3	2.5	29.8	24	2.9	4.2	3.4	85.6	2.3	0	0	0	0	0	2.5	13.3	2.2	0.7	176.4
> 0.5 <= 1	11.4	7.4	64	127.5	26.6	16.3	16.3	155.4	2.9	0	0	0	0	0.2	10.2	48.9	11.2	0.3	498.6
> 1 <= 1.5	1	1.1	13.4	77.6	33.1	16.9	15.1	48.6	1.1	0	0	0	0	0	1.9	14.8	0.9	0	225.5
> 1.5 <= 2	0	0	1.1	15.5	22.9	13.3	6.6	9.7	0.1	0	0	0	0	0	0.2	1	0	0	70.4
> 2 <= 2.5	0	0	0.1	5.4	7	7.7	1.3	1.1	0	0	0	0	0	0	0	0	0	0	22.6
> 2.5 <= 3	0	0	0	0.9	2.7	0.9	0.7	0.2	0	0	0	0	0	0	0	0	0	0	5.4
> 3 <= 3.5	0	0	0	0.2	0.1	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0.6
> 3.5 <= 4	0	0	0	0.1	0.1	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0.5
> 4 <= 4.5	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2
> 4.5 <= 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	15.4	11	108.4	251.2	95.6	59.3	44	300.6	6.4	0	0	0	0	0.2	14.8	78	14.3	1	1000

Table 2.7 Winter Joint probability distribution (parts per thousand) of the significant wave height and the mean wave direction at peak energy at the harbour entrance.

Hs (m)	Direction (degT)																	
	350 to 10	10 to 30	30 to 50	50 to 70	70 to 90	90 to 110	110 to 130	130 to 150	150 to 170	170 to 190	190 to 210	210 to 230	230 to 250	250 to 270	270 to 290	290 to 310	310 to 330	330 to 350	Total
> 0 <= 0.5	5.6	6.3	25.6	15.6	0.9	2.1	1.8	63.1	2.9	0	0	0	0	0	3.4	13.1	1.4	1	142.8
> 0.5 <= 1	7.5	9.5	46.2	83.1	20.3	17.9	22.7	169.3	7.2	0	0	0	0	0	9.9	50.7	7.8	0.2	452.3
> 1 <= 1.5	0.2	1.1	6.6	58.4	30.3	38.1	22.8	51.9	1.6	0	0	0	0	0	2.7	10.6	0.2	0	224.5
> 1.5 <= 2	0	0	2.3	29.3	29.7	23.8	9.7	9.3	0	0	0	0	0	0	0	0.8	0	0	104.9
> 2 <= 2.5	0	0	0.2	4.2	18.9	20.2	5.9	3.8	0	0	0	0	0	0	0	0	0	0	53.2
> 2.5 <= 3	0	0	0	1.2	2.1	8.2	1.3	0.2	0	0	0	0	0	0	0	0	0	0	13
> 3 <= 3.5	0	0	0	0.6	0.4	6	0	0	0	0	0	0	0	0	0	0	0	0	7
> 3.5 <= 4	0	0	0	0	0.6	1	0	0	0	0	0	0	0	0	0	0	0	0	1.6
> 4 <= 4.5	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0.4
> 4.5 <= 5	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0.3
Total	13.3	16.9	80.9	192.4	103.2	118	64.2	297.6	11.7	0	0	0	0	0	16	75.2	9.4	1.2	1000

Table 2.8 Spring Joint probability distribution (parts per thousand) of the significant wave height and the mean wave direction at peak energy at the harbour entrance.

Hs (m)	Direction (degT)																	
	350 to 10	10 to 30	30 to 50	50 to 70	70 to 90	90 to 110	110 to 130	130 to 150	150 to 170	170 to 190	190 to 210	210 to 230	230 to 250	250 to 270	270 to 290	290 to 310	310 to 330	330 to 350	Total
> 0 <= 0.5	9.8	4.7	24.6	18.9	3	2.1	3.6	85.2	5.1	0	0	0	0	0.1	2.4	24.8	5.2	1.6	191.1
> 0.5 <= 1	15.3	11.4	81.9	110	21.3	31.7	27.2	164	10.8	0	0	0	0	0.3	9.9	73.6	14	0.8	572.2
> 1 <= 1.5	0.5	1.8	13	57.2	21.6	14.9	24.3	33.8	2.1	0	0	0	0	0	0.7	7.6	0.3	0.1	177.9
> 1.5 <= 2	0	0.2	1	14.5	9.5	11.3	9.6	3.4	0.1	0	0	0	0	0	0	0.5	0	0	50.1
> 2 <= 2.5	0	0	0	3	0.6	2	1.3	0	0	0	0	0	0	0	0	0	0	0	6.9
> 2.5 <= 3	0	0	0	0.5	0.1	0.6	0.5	0	0	0	0	0	0	0	0	0	0	0	1.7
> 3 <= 3.5	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0.2
> 3.5 <= 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
> 4 <= 4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
> 4.5 <= 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	25.6	18.1	120.5	204.1	56.1	62.6	66.7	286.4	18.1	0	0	0	0	0.4	13	106.5	19.5	2.5	1000

Table 2.9 Annual Joint probability distribution (parts per thousand) of significant wave height and peak wave period at the harbour entrance.

Hs (m)	**Peak spectral wave period (s)**										
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16- 18**	**18- 20**	**Total**
> 0 <= 0.5	0.6	22.4	15	13.1	9.4	54	62.9	8.8	0.8	0.1	187.1
> 0.5 <= 1	0	70.5	43.6	55.4	77.7	94.3	130.1	27.9	1.3	0.1	500.9
> 1 <= 1.5	0	5.9	22.1	22.6	66	53.2	32.1	7.2	0.4	0	209.5
> 1.5 <= 2	0	0	4.1	7.6	15.9	33	8.6	1.5	0.2	0	70.9
> 2 <= 2.5	0	0	0.1	2.8	2.7	10	6.5	0.4	0.1	0	22.6
> 2.5 <= 3	0	0	0	0.5	1.3	1.5	2.5	0.1	0	0	5.9
> 3 <= 3.5	0	0	0	0	0.2	0.5	1.4	0	0	0	2.1
> 3.5 <= 4	0	0	0	0	0.1	0.1	0.3	0	0	0	0.5
> 4 <= 4.5	0	0	0	0	0	0.1	0	0	0	0	0.1
> 4.5 <= 5	0	0	0	0	0	0.1	0	0	0	0	0.1
Total	0.6	98.8	84.9	102	173.3	246.8	244.4	45.9	2.8	0.2	1000

Table 2.10 Summer Joint probability distribution (parts per thousand) of significant wave height and peak wave period at the harbour entrance.

Hs (m)	**Peak spectral wave period (s)**										
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16- 18**	**18- 20**	**Total**
> 0 <= 0.5	0.4	26.9	26.2	21.1	20.5	79.6	57.1	7	0.5	0	239.3
> 0.5 <= 1	0	87.5	54.3	77.4	96.1	91.1	65.7	9.4	0.2	0	481.7
> 1 <= 1.5	0	8.7	24.5	30	83.9	47.4	13	1.9	0.4	0	209.8
> 1.5 <= 2	0	0	3.7	7.3	11.8	31	2.9	0.2	0.6	0	57.5
> 2 <= 2.5	0	0	0	1.5	2	2.8	1.3	0	0	0	7.6
> 2.5 <= 3	0	0	0	0.8	1.5	0.8	0.4	0	0	0	3.5
> 3 <= 3.5	0	0	0	0.1	0.3	0	0.2	0	0	0	0.6
> 3.5 <= 4	0	0	0	0	0	0	0	0	0	0	0
> 4 <= 4.5	0	0	0	0	0	0	0	0	0	0	0
> 4.5 <= 5	0	0	0	0	0	0	0	0	0	0	0
Total	0.4	123.1	108.7	138.2	216.1	252.7	140.6	18.5	1.7	0	1000

Table 2.11 Autumn Joint probability distribution (parts per thousand) of significant wave height and peak wave period at the harbour entrance.

Hs (m)	Peak spectral wave period (s)										
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16- 18**	**18- 20**	**Total**
> 0 <= 0.5	1.4	12.8	12.2	11.5	6.3	50.7	73.1	7.7	0.9	0	176.6
> 0.5 <= 1	0	54	37.8	50.3	71.6	86.1	163.6	34.1	0.9	0	498.4
> 1 <= 1.5	0	6.4	29.2	25.7	64	53.4	39.3	7	0.3	0	225.3
> 1.5 <= 2	0	0	3.3	7.6	9.7	33.3	13.6	3	0	0	70.5
> 2 <= 2.5	0	0	0.1	4	2	7.9	8.5	0.1	0	0	22.6
> 2.5 <= 3	0	0	0	0.4	0.6	0.4	3.4	0.6	0	0	5.4
> 3 <= 3.5	0	0	0	0	0.2	0.4	0	0	0	0	0.6
> 3.5 <= 4	0	0	0	0	0.2	0.3	0	0	0	0	0.5
> 4 <= 4.5	0	0	0	0	0	0.2	0	0	0	0	0.2
> 4.5 <= 5	0	0	0	0	0	0	0	0	0	0	0
Total	1.4	73.2	82.6	99.5	154.6	232.7	301.5	52.5	2.1	0	1000

Table 2.12 Winter Joint probability distribution (parts per thousand) of significant wave height and peak wave period at the harbour entrance.

Hs (m)	Peak spectral wave period (s)										
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16- 18**	**18- 20**	**Total**
> 0 <= 0.5	0	19.4	9.3	7.2	5.1	37.1	56.1	8.4	0.3	0	142.9
> 0.5 <= 1	0	52.5	32	30.9	57	98.4	143.8	35.5	2	0	452.1
> 1 <= 1.5	0	4.6	13.2	17	58.5	77.9	43.5	9.1	0.6	0	224.4
> 1.5 <= 2	0	0	6	8.7	23.3	51.3	13.3	2	0.3	0	104.9
> 2 <= 2.5	0	0	0.2	3.2	6.5	26.3	15.3	1.5	0	0	53
> 2.5 <= 3	0	0	0	0.5	2.8	3.5	6.2	0	0	0	13
> 3 <= 3.5	0	0	0	0	0.5	1.3	5.2	0	0	0	7
> 3.5 <= 4	0	0	0	0	0.1	0.2	1.3	0	0	0	1.6
> 4 <= 4.5	0	0	0	0	0.1	0.2	0.2	0	0	0	0.5
> 4.5 <= 5	0	0	0	0	0	0.3	0	0	0	0	0.3
Total	0	76.5	60.7	67.5	153.9	296.5	284.9	56.5	3.2	0	1000

Table 2.13 Spring Joint probability distribution (parts per thousand) of significant wave height and peak wave period at the harbour entrance.

Hs (m)	Peak spectral wave period (s)										
	0-2	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16- 18**	**18- 20**	**Total**
> 0 <= 0.5	0.5	30.9	12.6	12.6	6	49	65.2	12.3	1.7	0.6	191.4
> 0.5 <= 1	0	88.3	50.6	63.5	86.8	101.9	146.1	32.4	2.3	0.2	572.1
> 1 <= 1.5	0	3.8	21.3	17.8	57.8	33.8	32.3	10.8	0.2	0	177.8
> 1.5 <= 2	0	0	3.3	6.6	18.7	16.1	4.5	0.9	0	0	50.1
> 2 <= 2.5	0	0	0	2.4	0.5	2.7	0.8	0.2	0.2	0	6.8
> 2.5 <= 3	0	0	0	0.2	0.4	1	0	0	0	0	1.6
> 3 <= 3.5	0	0	0	0	0	0.2	0	0	0	0	0.2
> 3.5 <= 4	0	0	0	0	0	0	0	0	0	0	0
> 4 <= 4.5	0	0	0	0	0	0	0	0	0	0	0
> 4.5 <= 5	0	0	0	0	0	0	0	0	0	0	0
Total	0.5	123	87.8	103.1	170.2	204.7	248.9	56.6	4.4	0.8	1000

Table 2.14 Wave height extrema and associated wave periods at the 1-100 year return periods for 25 m water depth near the harbour entrance.

Parameter	**Units**		**Return period in years**					
			1	**5**	**10**	**25**	**50**	**100**
Significant wave height	**Hs**	m	3.03	4.17	4.77	5.69	6.49	7.40
Single maximum wave height	**Hx**	m	5.64	7.76	8.87	10.58	12.07	13.76
Period of Hx (min)	**Tass min**	s	6.28	7.36	7.87	8.60	9.19	9.81
Period of Hx (max)	**Tass max**	s	9.53	11.18	11.96	13.07	13.95	14.90

3. SEDIMENT TRANSPORT AND MORPHOLOGY MODELLING

3.1. Model system

The model system used to undertake the sediment transport and morphology studies consists of three modules:

- Nearshore wave propagation model to simulate the transformation of the incoming wave field.
- Nearshore current model to simulate currents generated by the incident wave field, including the nearbed currents related to vertical variation of the current field. Regional scale tidal and wind-driven currents are also introduced at the model boundaries.
- Sediment transport and bed level update model to simulate the transport of non-cohesive sediment by the action of waves and currents, and calculate resulting changes in bed level.

The modules are fully coupled with varying update intervals, and in this work they are set as follows:

- The wave model has one-hour update cycle. Wave forcing and wave-induced mass fluxes are passed to current module. Near bed RMS orbital velocities are passed to sediment module.
- The current module has a six-minute update cycle. Currents are passed to the wave model.
- The sediment module has a six-minute update cycle and the bed level is updated from a representative sediment flux over the preceding six minutes. New bed level is passed to wave module and current module.

The model can be run in a non-updating mode, in which sediment transport and rate of bed level change is calculated and stored, but the model bathymetry is left unchanged. This is a useful option for long term simulations of general sedimentation transport pathways, without the unrealistic divergence that can occur due to uncorrected non-linear feedbacks between waves, currents and morphology.

3.2. Wave module

A modified version of SWAN (Holthuijsen et al., 2007) is used as the wave model. The code has been changed to allow update of both bed level and currents to be passed into SWAN at each wave model update cycle. The wave forcing as calculated internally by SWAN is also passed back to the current module, and the nearbed orbital velocities are used in the sediment transport calculations. None of the numerics or coding related to the wave physics has been altered.

The wave boundary conditions are fully nested spectral boundaries from the regional wave hindcast described in Section 2 to retain the spatial variability of the incident wave field due to refraction and sheltering effects. The model parameterizations provided in Table 3.1 have been used (described in the SWAN manual). The roughness length of 0.01 for the wave model has been found to be appropriate in several previous wave modelling studies.

Table 3.1 Wave model parameters

Parameter	Value
Friction	Madsen, roughness length 0.01m
Breaking	Depth limited γ=0.73
Quadruplet nonlinear transfer	None
Wind	None
Diffraction	Off
Setup	Direct feedback from current module
Currents	Direct feedback from current module
Triad	Off

3.3. Current module

The current module solves the equations governing the depth averaged nearshore current flow in orthogonal curvilinear coordinates,

$$\frac{\partial \varsigma}{\partial t}+\frac{1}{J}\frac{\partial}{\partial x_\alpha}\left(JV^\alpha h\right)=0$$

$$\frac{\partial V^\alpha h}{\partial t}+\frac{1}{\sqrt{g_0}}\frac{\partial}{\partial x_\beta}\left(V^\alpha V^\beta h\right)+\left(V^\gamma V^\beta h\right)\Gamma^\alpha_{\gamma\beta}=$$

$$-ghg^{\beta\alpha}\frac{\partial \varsigma}{\partial x_\beta}+F^\alpha-\frac{1}{\sqrt{g_0}}\frac{\partial}{\partial x_\beta}T^{\alpha\beta}-T^{\gamma\beta}\Gamma^\alpha_{\gamma\beta}-\frac{1}{\rho}\tau^\alpha_B \qquad (3.1)$$

where V^α is the contravariant depth-averaged velocity vector, ς is the wave-averaged surface elevation, F^α is the forcing due to the incident wavefield, $T^{\alpha\beta}$ is the Reynold's stress tensor, and τ^α_B is the bottom shear stress. g0 is the determinant of the metric tensor in the curvilinear coordinate system, x_α, and $\Gamma^\alpha_{\beta\gamma}$ is the Christoffel symbol of the second kind.

The current module is based on the curvilinear version of SHORECIRC as described in Shi et al. (2003) and Shi et al. (2007). SHORECIRC solves the shallow water equations describing the wave and depth-averaged nearshore current field on a curvilinear grid. The radiation stress gradients in the incident wave field are imposed as forcing terms in the equations, obtained from the wave module. Bottom friction is parameterized with a standard drag coefficient approach:

$$\tau_B^{\alpha} = c_f V^{\alpha} \left| V^{\alpha} \right| \qquad (3.2)$$

In the absence of data for calibration, a uniform drag coefficient of $c_f = 0.005$ is applied throughout. The depth-averaged Reynolds stress tensor is given by,

$$T^{\alpha\beta} = h\nu_t \left(g^{\gamma\beta} u^{\alpha}_{,\gamma} + g^{\gamma\alpha} u^{\beta}_{,\gamma} \right) \qquad (3.3)$$

with the horizontal eddy viscosity, ν_t, approximated by a Smagorinsky type scheme. The numerical solution of equation 3.1 uses the mode-splitting ADI method described in Shi et al. (2007). This method renders the gravity wave mode unconditionally stable. An adaptive timestep has been implemented to keep the vorticity mode Courant number within the stable limit. The actual code used is loosely based on that distributed as part of the NEARCOM project[5].

For this work, both water levels and regional currents are specified along all the seaward boundaries of the model domain. The time and space varying conditions were generated from a regional 12-year current hindcast for the coastal and open-ocean boundaries. The tidal elevation and currents were generated using astronomical constituents obtained from the tidal analysis of the hindcast at half hourly time step and summed with linearly-interpolated half hourly residual elevation and currents. To faithfully replicate the tidal flow in and out of the harbour, the tidal elevation and current conditions along the model boundary within the harbour (see Figure 3.1) were determined from the high resolution model of the Otago Harbour implemented in Bell et al., 2009.

For the cross-shore boundaries a wave-induced increase to the base elevation is estimated by assuming a balance between the cross-shore component of incident wave forcing and setup so that for a coordinate axis x oriented cross-shore:

$$\eta(x) = \eta_0 + \int_0^x \frac{F_x}{gh} dx \qquad (3.4)$$

where η_0 is the tidal elevation at the offshore limit of x = 0.

For velocity, specified current boundaries are introduced at the open boundaries, and use a Flather type condition. An additional wave induced component is also specified at the cross-shore boundaries, with the assumption that locally the friction balances the wave forcing. The alongshore flow normal to the boundary additional to any tidal an wind-driven component , V_n^b , is then prescribed by:

$$V_n^b = \frac{F_n}{c_f \left| V_n^b \right|} \qquad (3.5)$$

[5] http://chinacat.coastal.udel.edu/~kirby/programs/nearcom/

In the numerical scheme, the value of V_n^b in the denominator is applied from the current timestep. Undertow is calculated for use in the sediment module with the near-bed flow given by:

$$u_{bc}^{\alpha} = V^{\alpha} - \frac{Q_w^{\alpha}}{h} - \frac{c_f^{wc}|\hat{u}_w|u_b^{\alpha}h}{3\nu_t} \tag{3.6}$$

where Q_w^{α} is the mass flux of the incoming wavefield, $\hat{u}_w$ is the RMS near-bed orbital wave velocity and ν_t the vertical turbulent eddy viscosity. The mass flux is composed of the Stokes drift component and an additional contribution of the breaking waves.

The breaking wave flux is modelled by a parametric 'roller' approach in which the mass of whitewater travelling with the wave is approximated by a bore. For any individual wave of height H and period T, the total mass flux due to breaking is given by,

$$Q_{br} = \frac{q_b H^2}{T} \tag{3.7}$$

where q_b is a constant ~ 1. The fraction of breaking waves follows the parameterisation of Battjes and Janssen (1978) used for wave energy dissipation in the wave module. This allows the breaking wave mass flux to be related to the breaking dissipation as:

$$Q_{br} = \frac{4 q_b D}{\rho g} \tag{3.8}$$

where the dissipation, D comes directly out of the wave module. The angle of the breaking wave mass flux vector is assumed to be the same as the peak spectral wave direction. Three-dimensional dispersive mixing of the depth-averaged current due to undertow (Svendsen and Putrevu, 1994) is not included.

3.4. Sediment module

The sediment transport module uses a Bagnold type total load transport formulation for the total sediment volume flux vector, $\vec{q}$:

$$\vec{q} = \frac{c_f \varepsilon_b}{\rho(s-1)}\left[\frac{1}{\tan\phi}|\vec{u}_b|^2\vec{u}_b - \frac{\tan\beta}{\tan\phi}|\vec{u}_b|^3\right] + \frac{c_f}{\rho(s-1)}\frac{\varepsilon_s(1-\varepsilon_b)}{\omega}\left[|\vec{u}_b|^3\vec{u}_b - \frac{\varepsilon_s(1-\varepsilon_b)}{\omega}\tan\beta|\vec{u}_b|^5\right] \tag{3.9}$$

where u_b is the instantaneous nearbed velocity, c_f is the bottom friction coefficient, ε_s and ε_b are the suspended and bedload efficiencies. The relative sediment density is s, $\tan\beta$ is the bottom slope, tan ϕ is the sediment friction angle and ω is the representative settling velocity. The upper term represents bedload transport, while the lower term represents the suspended load transport.

Eqn. (3.9) can be rewritten as:

$$\begin{aligned}
\vec{q} &= \vec{q}' - C_z \nabla z \\
\vec{q}' &= \frac{c_f}{\rho(s-1)}\left[\frac{\varepsilon_b}{\tan\phi}|\vec{u}_b|^2\vec{u}_b + \frac{\varepsilon_s(1-\varepsilon_b)}{\tan\phi}|\vec{u}_b|^3\vec{u}_b\right] \\
C_z &= \frac{c_f}{\rho(s-1)}\left[\frac{1}{\tan\phi}|\vec{u}_b|^3 + \frac{\varepsilon_s(1-\varepsilon_b)}{\omega}|\vec{u}_b|^5\right]
\end{aligned} \quad (3.10)$$

which splits the expression into the total transport terms and the bedslope terms, where ∇z is the gradient of the bedslope elevation.

A parametric approach is used to calculate the instantaneous nearbed wave velocity for use in Eqn. (3.9). The time variation of orbital velocities follows the method of Elfrink et al. (2006), with a single representative wave period and height corresponding to the local spectral values of H_s and T_p. A local bed slope is also applied for the calculation of the Irribarren number, which a key parameter in the method. The local spectral U_{rms} value is used as an equivalent orbital velocity and corresponds to $0.5U^*$ in Elfrink et al.'s formulation.

The bed level update solves the equation:

$$\frac{\partial z}{\partial t} + \frac{1}{\sqrt{g_0}}\frac{\partial\sqrt{g_0}\langle q'^{\alpha}\rangle}{\partial x_\alpha} = \frac{1}{\sqrt{g_0}}\frac{\partial}{\partial x_\alpha}\left(\sqrt{g_0}C_z g^{\alpha\beta}\frac{\partial z}{\partial x_\beta}\right) \quad (3.11)$$

where z is the bed level. The terms $\langle q'^{\alpha}\rangle$ is the wave-averaged sediment flux vector, which is calculated by numerical integration over 50 wave phase steps. The WENO scheme described in Long et al. (2007) is used for the advection terms in Eqn. (3.11), which controls the spurious oscillations often experienced with numerical solution of the sediment continuity equation.

3.5. Model domain

The curvilinear model grid is shown in Figure 3.1. It includes the coastline from Rerewahine Point to Murdering Bay and extends ~ 4.5 km offshore. The grid dimensions are 200 by 200 cells with sizes ranging from 15 m to 90 m, with the higher resolution in the shallower nearshore zones.

3.5.1. Initial bathymetry

The initial bathymetry of the model domain was interpolated from a high resolution regional bathymetric grid (~10 by 10 m) used in Bell et al. (2009). This grid was the result of merging of several datasets including Port Otago fairsheets and digital soundings, University of Otago soundings, gridded seabed depth from NIWA ocean bathymetry archives and digitized LINZ nautical charts. Important bathymetric features includes the harbour mouth with the deep entrance channel, the large submerged ebb tidal delta protruding east of the shipping channel, and the disposal mounds at the disposal sites of Spit and Heyward Point (Figure 3.2).

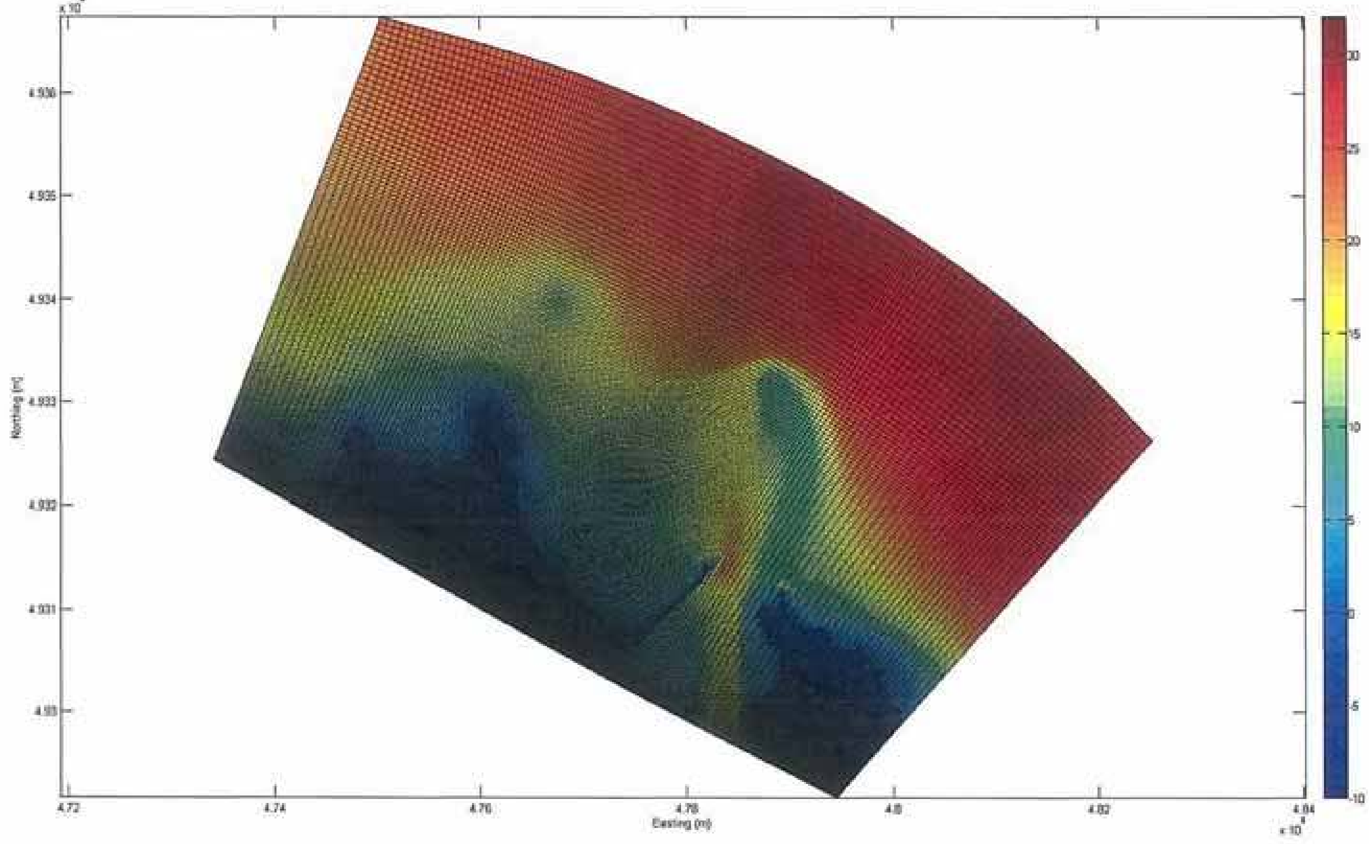


Figure 3.1 Model grid with mean sea level depth.

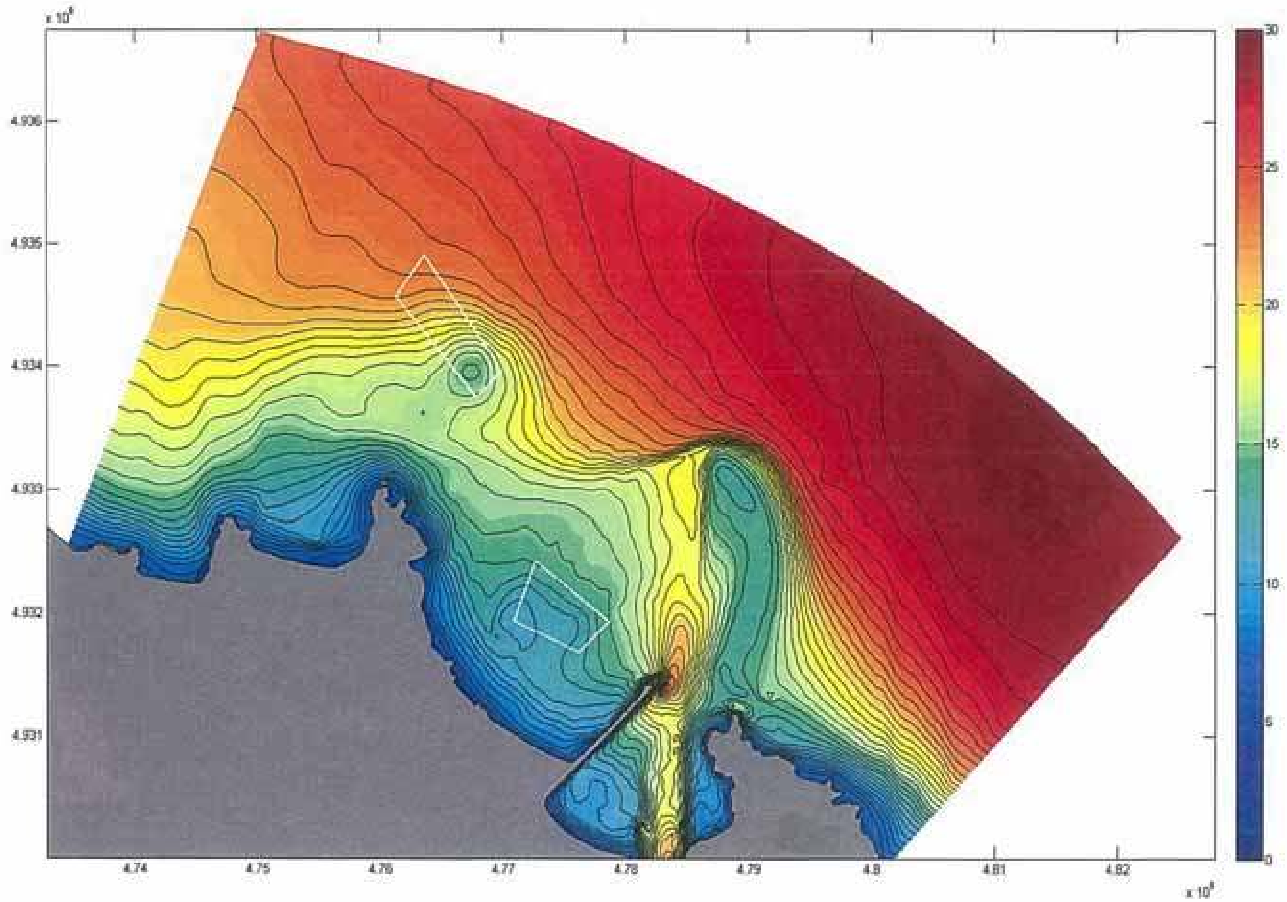


Figure 3.2 Model domain bathymetry with the Spit and Heyward disposal sites shown.

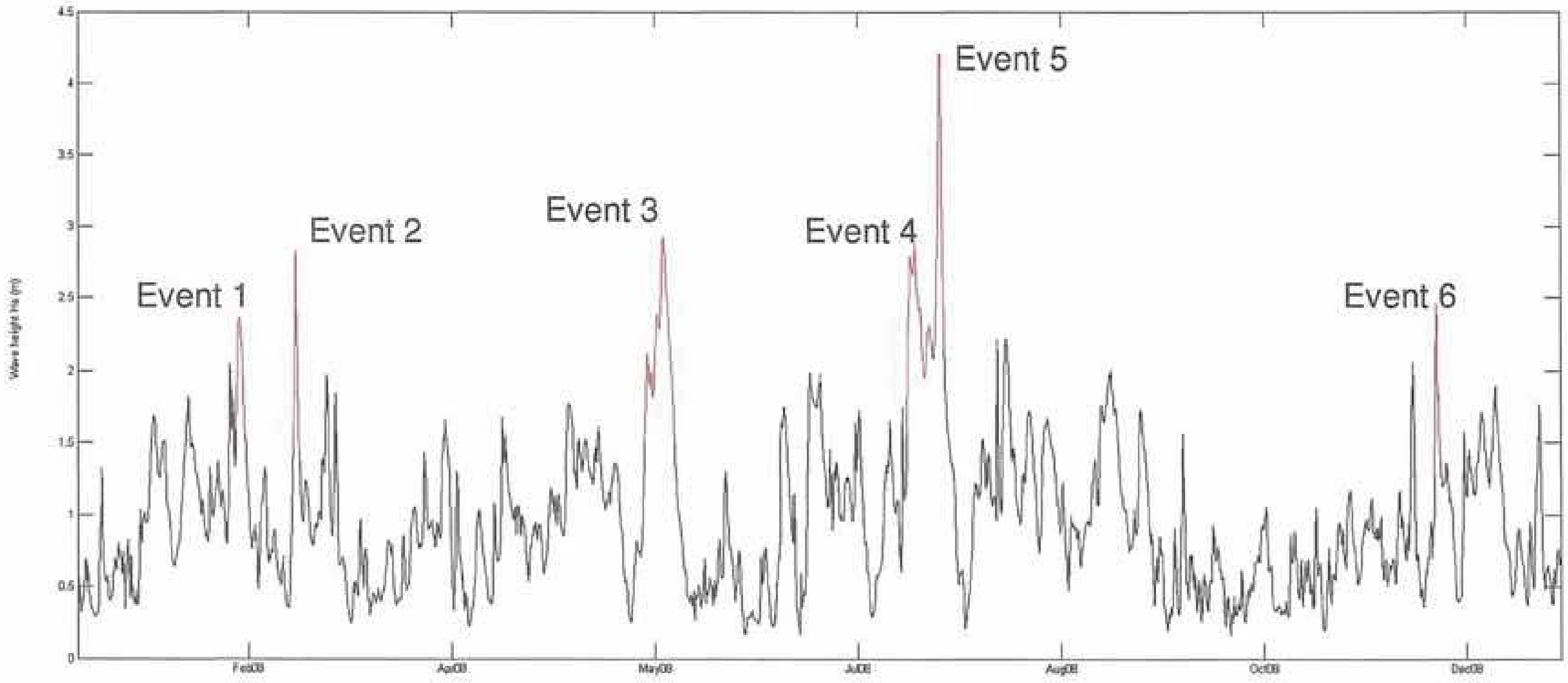


Figure 3.3 The six energetic wave events during 2008.

3.6. Sediment transport and morphology results

3.6.1. Sediment transport scenarios

Sediment transport and morphology simulations have been undertaken for the full calendar year of 2008. The 1-year period was run in non-updating mode for the seabed to identify general sediment transport pathways under ambient and storm conditions. Annual and seasonal periods along with six discrete energetic wave events with a range of incident direction were considered. Summary wave statistics of all these periods for the wave buoy location are given in Table 3.2, while the events are shown on the timeseries plot in Figure 3.3.

This 1-year simulation was supplemented by morphology modelling of the six selected energetic wave events, this time using the model in updating mode for the sea bed level. This allowed qualitative validation of the model ability to reproduce observed changes in the disposal sites region and further investigate erosion/accretion patterns. These simulations all started from the same initial bathymetry as used in the long term run (Fig. 3.2).

Table 3.2 Wave statistics at wave buoy location for each of the modelled events.

Period		Mean Hs (m)	Max Hs (m)	Mean wave direction (degT)
Year	1/1/2008 to 31/12/2008	0.92	3.92	88.99
Summer	1/1/2008 to 31/3/2008	0.88	2.79	81.90
Autumn	1/04/2008 to 31/6/2008	0.88	2.81	98.29
Winter	1/7/2008 to 30/9/2008	1.17	3.92	88.22
Spring	1/10/2008 to 31/12/2008	0.73	2.40	87.74
Event 1	8/2/2008 to 11/2/2008	1.77	2.23	83.39
Event 2	23/2/2008 to 24/2/2008	2.03	2.79	59.88
Event 3	20/5/2008 to 26/5/2008	2.18	2.81	94.45
Event 4	23/7/2008 to 28/7/2008	2.37	2.64	111.21
Event 5	29/7/2008 to 1/8/2008	2.65	3.92	93.91
Event 6	30/11/2008 to 1/12/2008	1.89	2.40	61.55

3.6.2. Model output and post processing

The full set of hydrodynamic variables, including the total depth-averaged sediment fluxes and bathymetry are stored every six hours through the model simulation. Averaged maps of the wave height, depth-averaged currents, and depth-averaged sediment transport fluxes were calculated by vector-averaging the six-hourly outputs through the duration of events considered (see Table 3.2 above). Seabed change maps were obtained subtracting the initial bathymetry from the bathymetry predicted at then end of each modelled event. Note that all event durations are multiples of 12 hours to provide an averaged picture without the tidal effects.

Results are first presented for a series of discrete wave events to illustrate flow patterns and sediment transport pathways experienced during high wave energy conditions. Often such events can dominant the overall sediment transport regime. Yearly and seasonal averaged maps are then presented to illustrate the long-term wave climate and sediment flux patterns.

3.6.3. Wave and circulation patterns

The underlying patterns of wave, wave-driven circulation and sediment fluxes are relatively consistent for the different storm events presented (Fig. 3.4 to 3.9, top plots). The large submerged ebb tide delta northeast of the harbour entrance strongly focuses incident wave heights towards Aramoana Beach and the Spit disposal site, where a zone of increased wave height is clearly evident. A side effect of the focusing process is the generation a wave shadow zone to the immediate west, and a strong wave height gradient along the Aramoana Beach region. The region with maximum wave energy is located mid-beach for a northeast event (e.g. Event 2, Fig. 3.5) and is progressively shifted to the northwest for increasing angles of incidence (i.e. more easterly e.g. Events 3 to 5, Figs. 3.6 to 3.8). In contrast, the south-eastern end of the beach receives relatively low wave energy in these conditions. Similar wave focusing processes are also apparent from the disposal mound (or bathymetric feature) at the Heyward ground.

The disposal mound at the Spit disposal site provides additional shoaling of the incident wave heights, and causes an onshore-directed current flow to develop over the mound. This flow diverges and interacts with wave-driven alongshore flows descending from Heyward Point – creating a strong localised rip current that lies inshore and west of the mound. In the very energetic conditions, this rip flow deviate to the northwest and eventually merges with the strong northwest alongshore flows past Heyward Point (e.g. Event 5, Fig. 3.8). It is notable that this feature prevails in both Events 2 and 4 (Figs. 3.4 and 3.7), which exhibit very different wave incidence angles and alongshore wave height gradients. To the southeast of the mound, the onshore-directed flows are generally deviated alongshore towards the breakwater; progressively losing intensity and adding to a counter-clockwise circulation cell (e.g. Event 5; Fig. 3.8).

Strong alongshore currents are observed in the east of the model domain flowing from Rerewahine Point to Tairoa Head. This flow weakens and is generally deviated offshore at the harbour entrance. During Events 2 and 6, which have the most northerly incidence angle, an underlying large-scale flow is directed southeast – opposing and weakening the wave-driven alongshore flows adjacent to the coast. For Event 2 (Fig. 3.5), a significant flow into the harbour is evident; this event coincided with strong northerly winds and a regional-scale coastal current that was direct to the south. Note that the open boundary conditions at the harbour entrance allows continued flow, whereas in reality an opposing pressure gradient would develop as Otago Harbour filled.

3.6.4. Sediment fluxes

During each of the six Events, the model is predicting strong south-westwards (onshore) sediment flux from the Spit disposal site and disposal mound. The flux vectors are primarily aligned with the wave direction, implying that wave asymmetry dominates the transport over the mound.

Near the shore, there is a weak transport vector to the southeast and toward the breakwater. However, there are very strong transport vectors along the coast immediately south of Heyward Point. These flows bifurcate at a location that varies slightly with the incident wave angle; one flow is directed to the south toward Aramoana Beach, and then veers offshore as a rip flow. The other flow is directed north-northwest toward Heyward Point and then west beyond the Point.

In the vicinity of the bar and channel, the net transport vector is westerly directed, and in most cases sediment is eroded from the bar and deposited in the channel. During the largest event (Event 5), it is notable that sediments are being mobilised over the entire ebb tide delta region, including active sediment transport across the shipping channel.

A summary of the wave and sediment transport patterns under the easterly and northerly extremes of wave incidence angles from the events is provided in Figure 3.10.

3.6.5. Annual and seasonal results

Annual and seasonal maps are presented in Figures 3.11 to 3.15. Wave focusing by the ebb tidal delta and causing a gradient in wave height along Aramoana Beach is a consistent feature. Additional shoaling of wave heights over the Spit mound is clearly evident. Alongshore flows near Heyward Point and the rip feature at the north-western end of Aramoana Beach are prevalent throughout the year.

Note that the annual averaged results in particular do not account for any limitation of sediment supply that might develop, in particular around Heyward Point. In reality, the large transport fluxes directed away from the point in both directions would be restricted by lack of mobile sediment around the rocky headland. However, this effect would not modify the general transport patterns seen over the erodable parts of the domain, including the disposal mounds.

Event 1: 8-11 February 2008

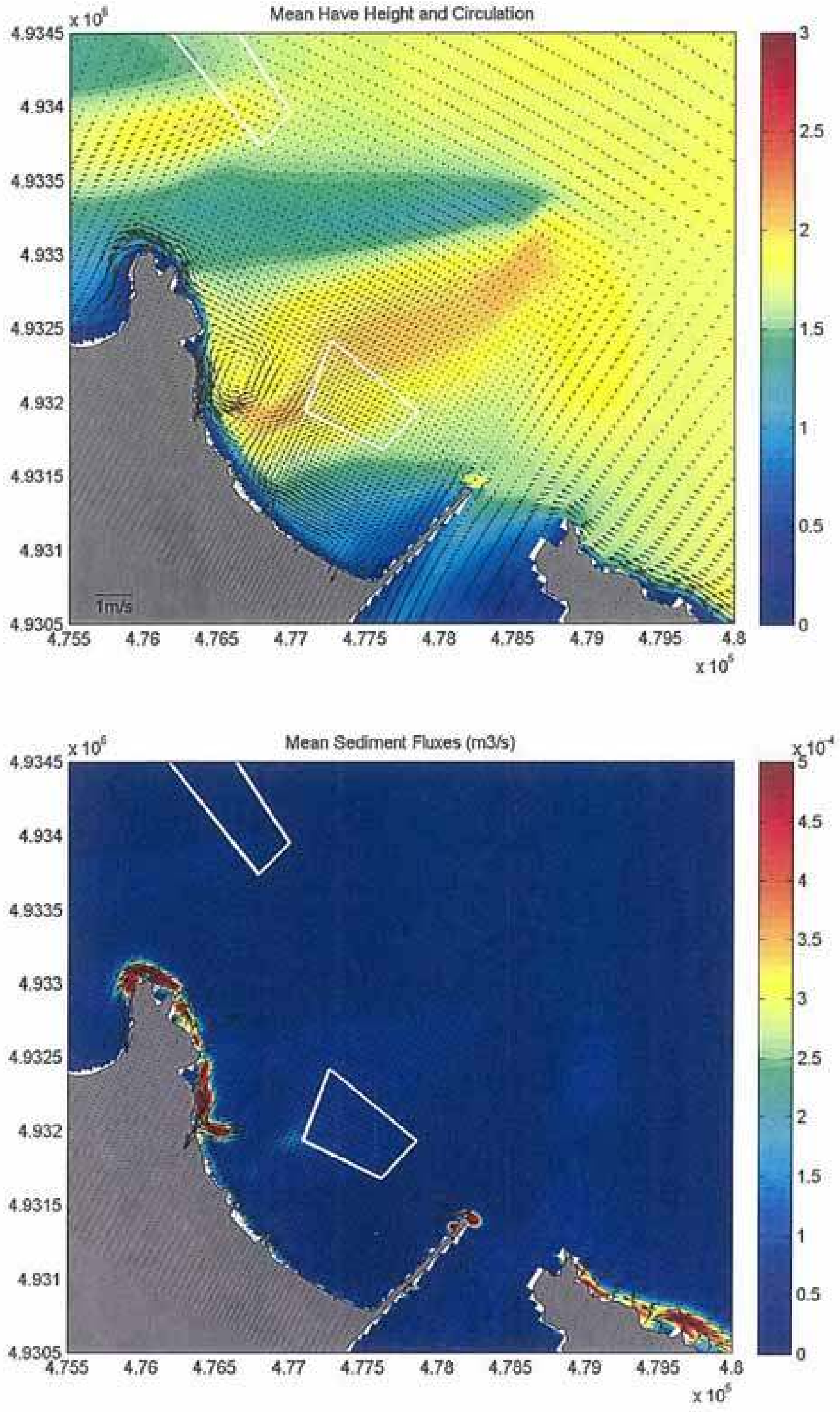


Figure 3.4 Mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom) during Event 1 (mean Hs = 1.77 m, Dir = 83 deg). Disposal sites are shown in white.

Event 2: 23-24 February 2008

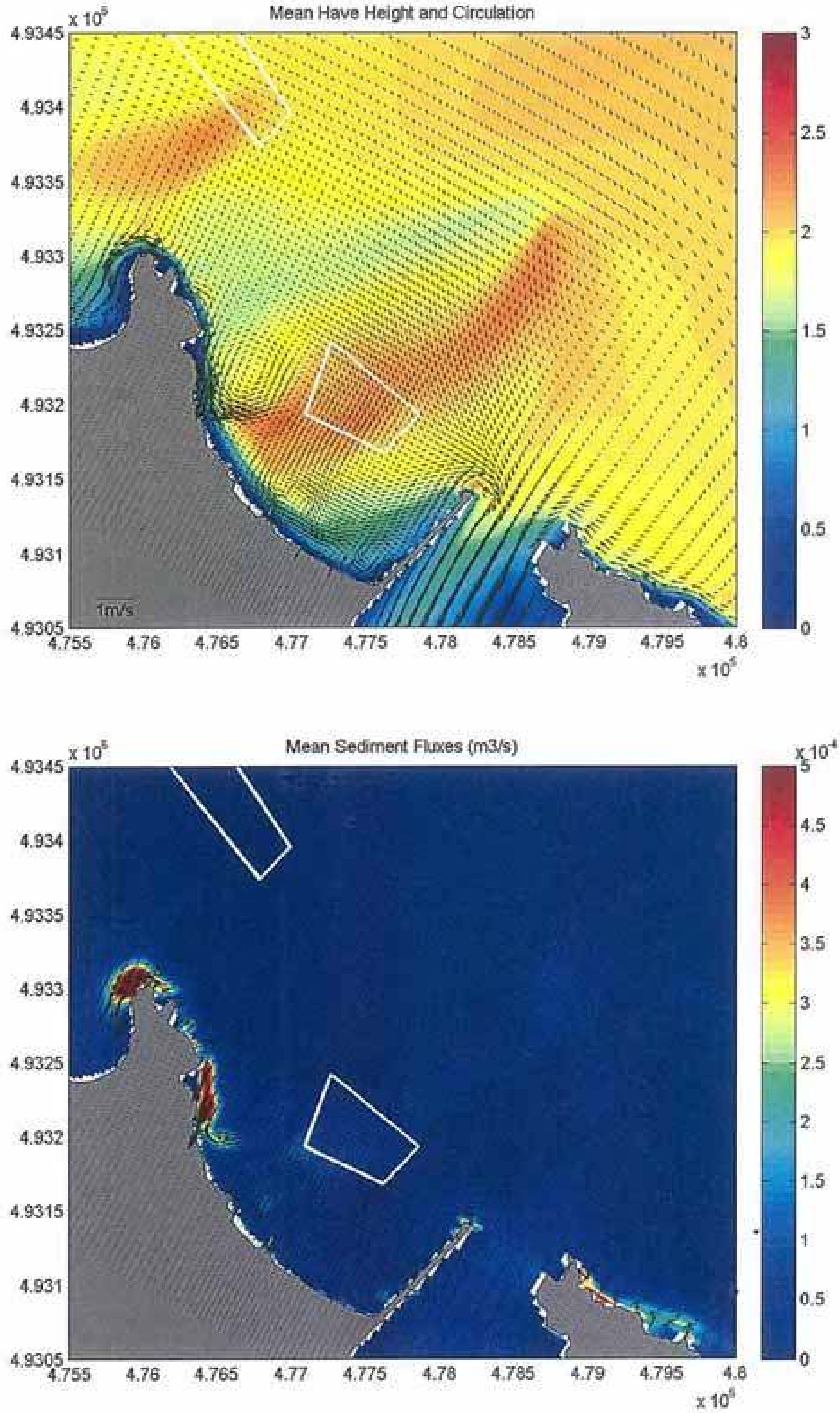


Figure 3.5 Mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom) during Event 2 (mean Hs = 2.03 m, Dir = 60 deg). Disposal sites are shown in white.

Event 3: 20-26 May 2008

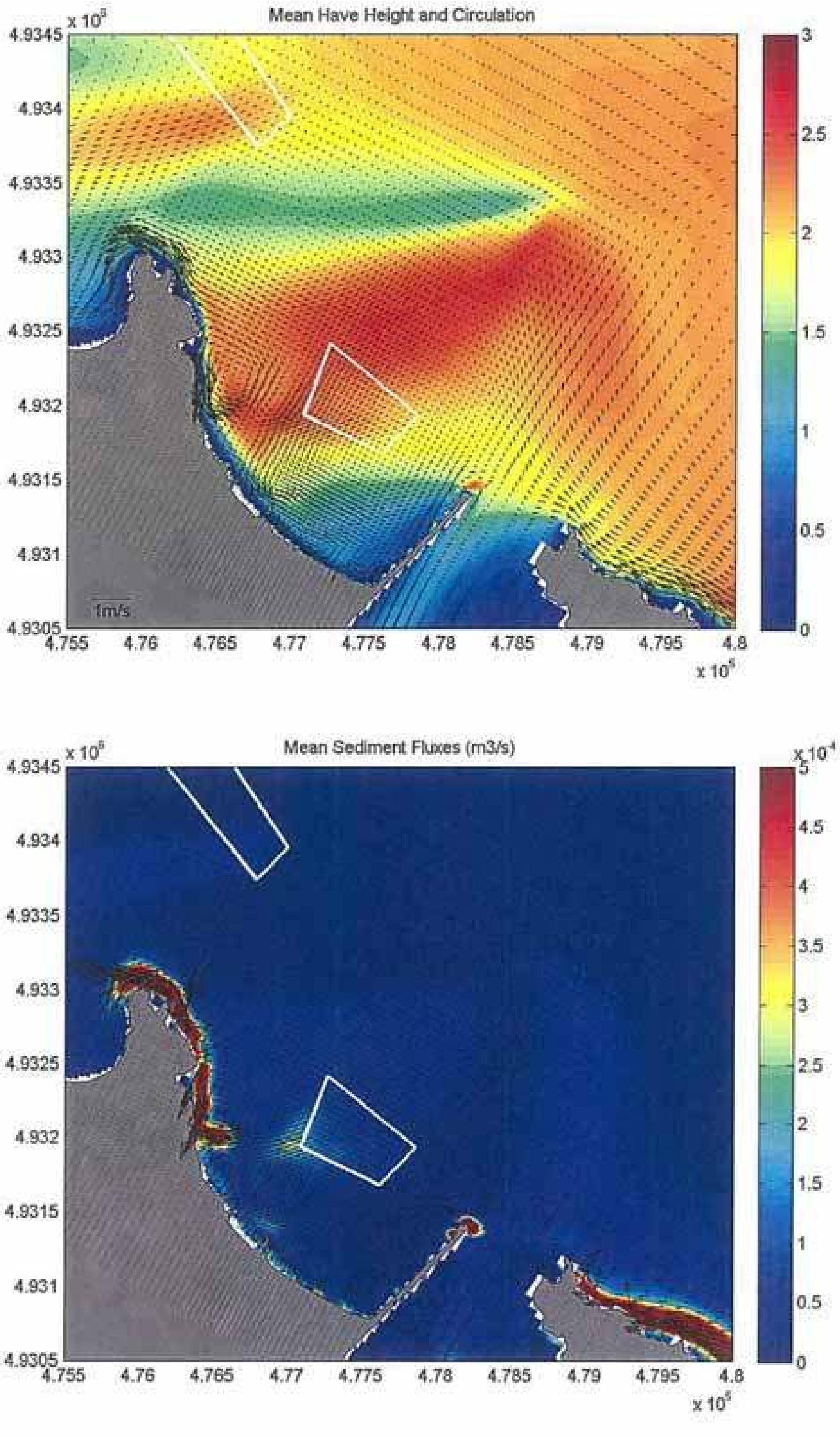


Figure 3.6 Mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom) during Event 3 (mean Hs = 2.18 m, Dir = 94 deg). Disposal sites are shown in white.

Event 4: 23-28 July 2008

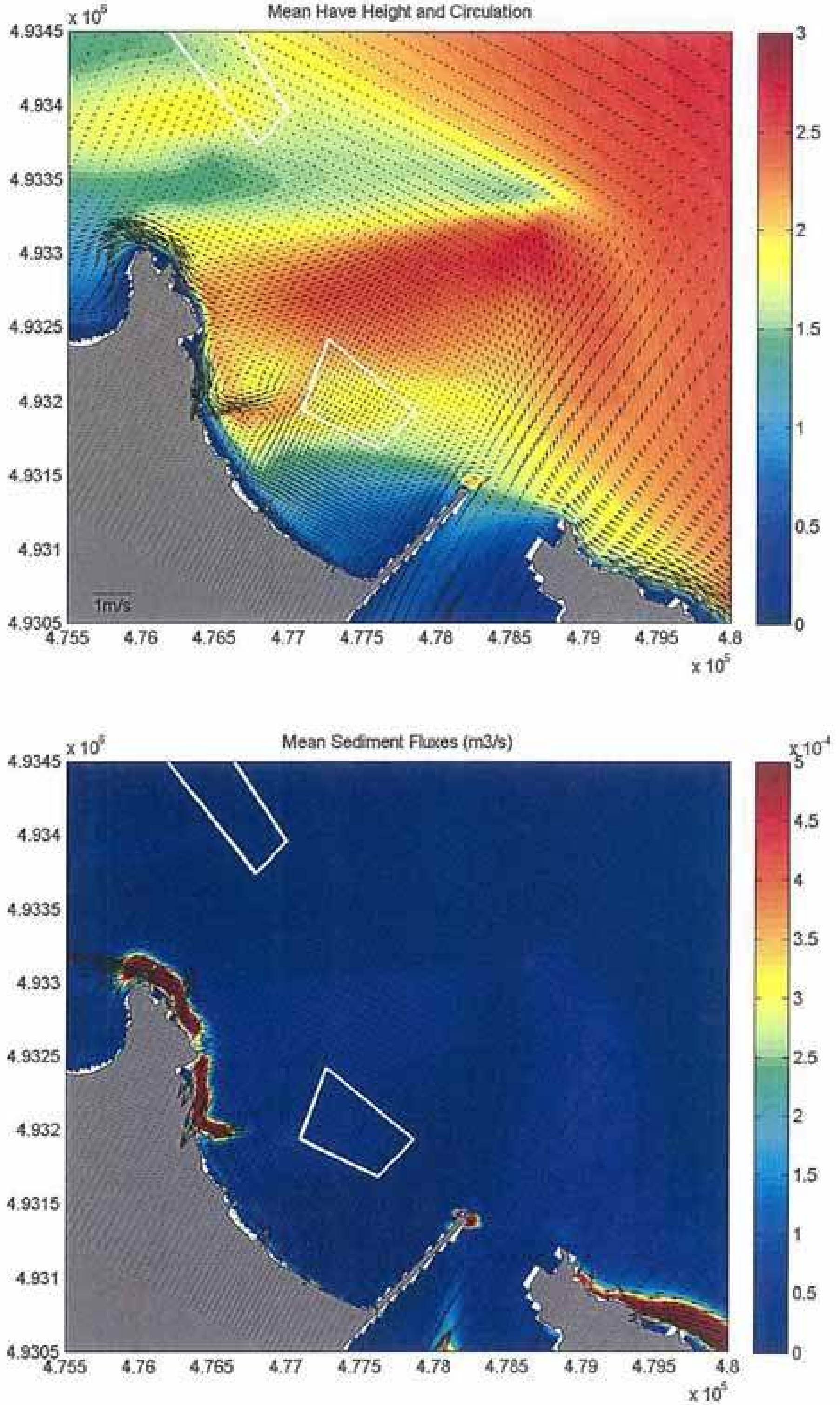
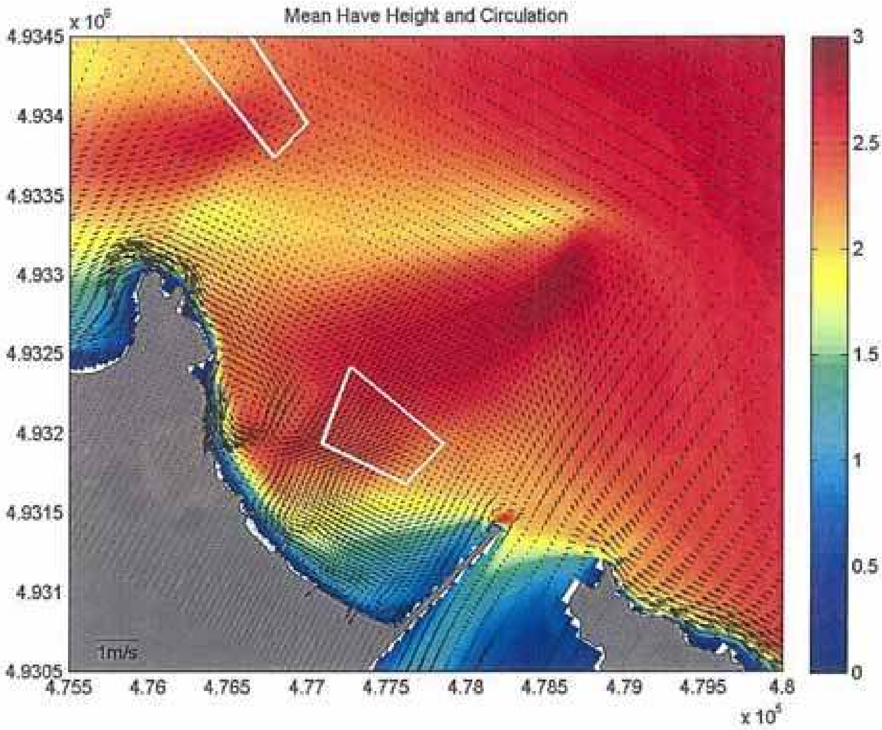


Figure 3.7 Mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom) during Event 4 (mean Hs = 2.37 m, Dir = 111 deg). Disposal sites are shown in white.

Event 5: 28 July - 1 August 2008



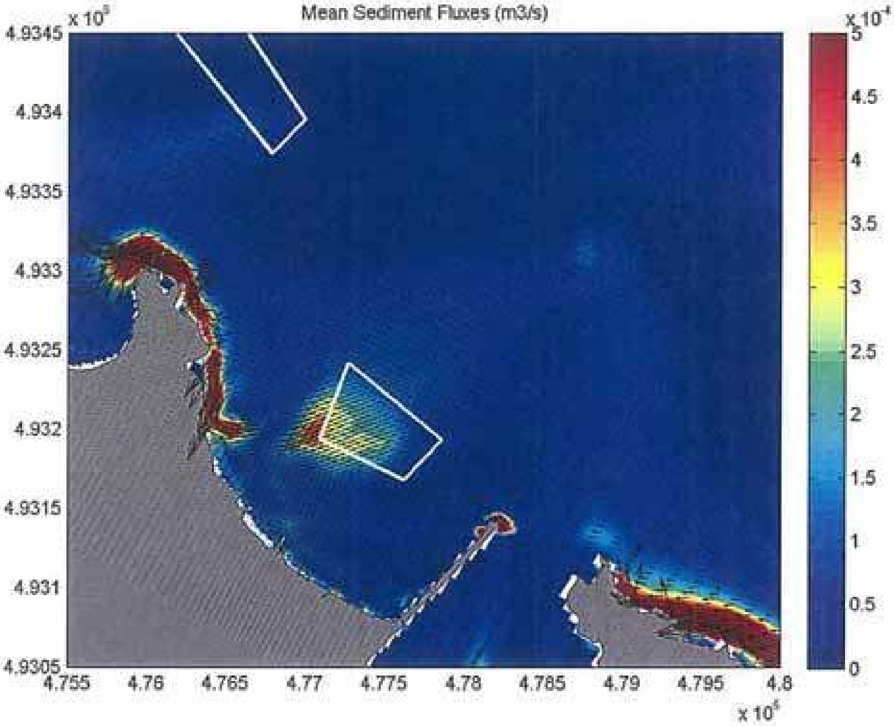
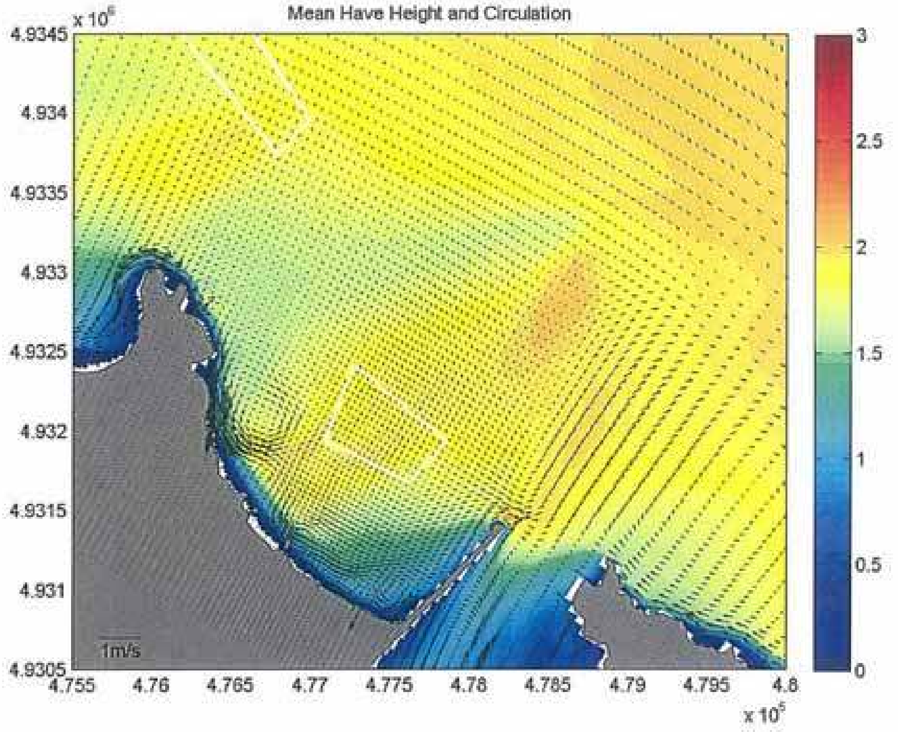


Figure 3.8 Mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom) during Event 5 (mean Hs = 2.65 m, Dir = 94 deg). Disposal sites are shown in white.

Event 6: 30 November – 1 December 2008



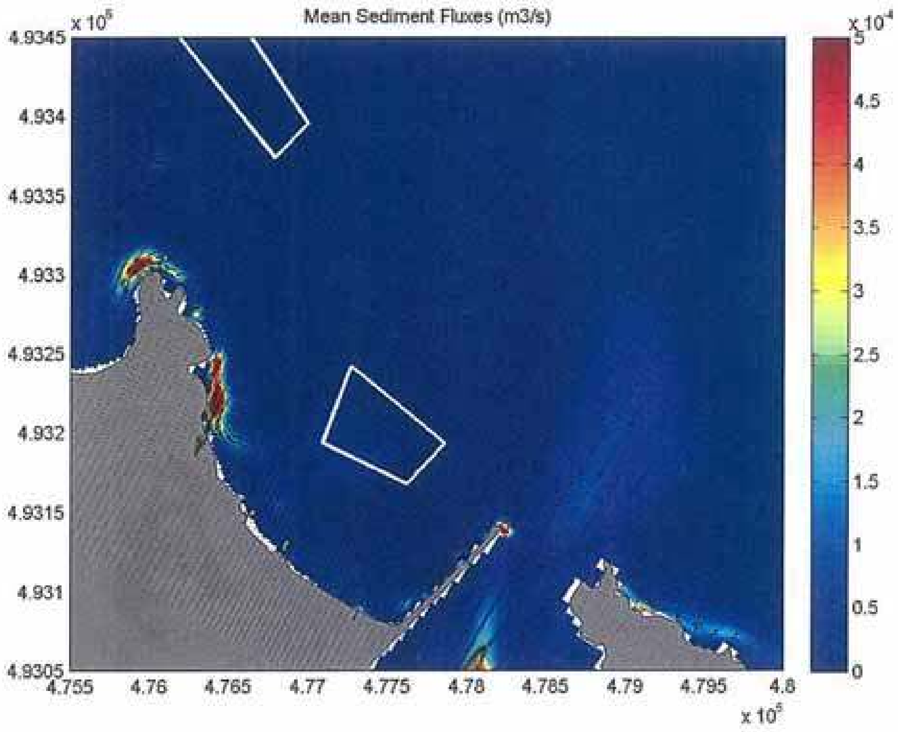


Figure 3.9 Mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom) during Event 6 (mean Hs = 1.89 m, Dir = 62 deg). Disposal sites are shown in white.

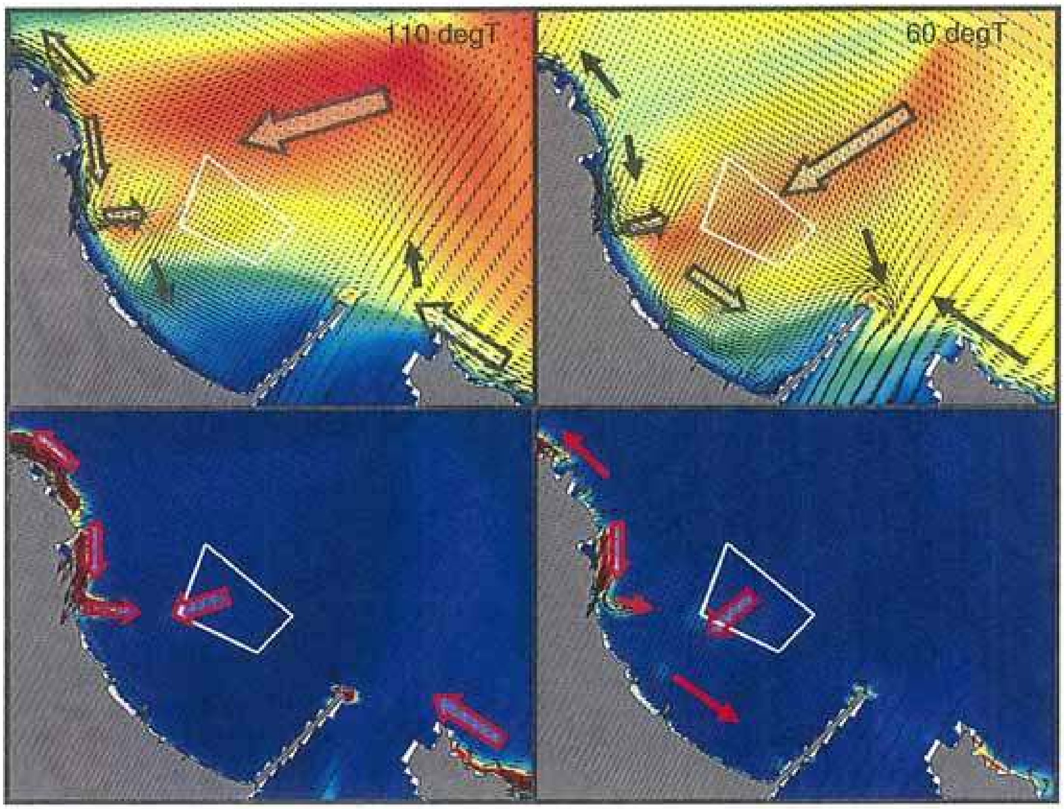


Figure 3.10 Comparison of mean wave height, circulation and sediment fluxes for Events 2 and 4.

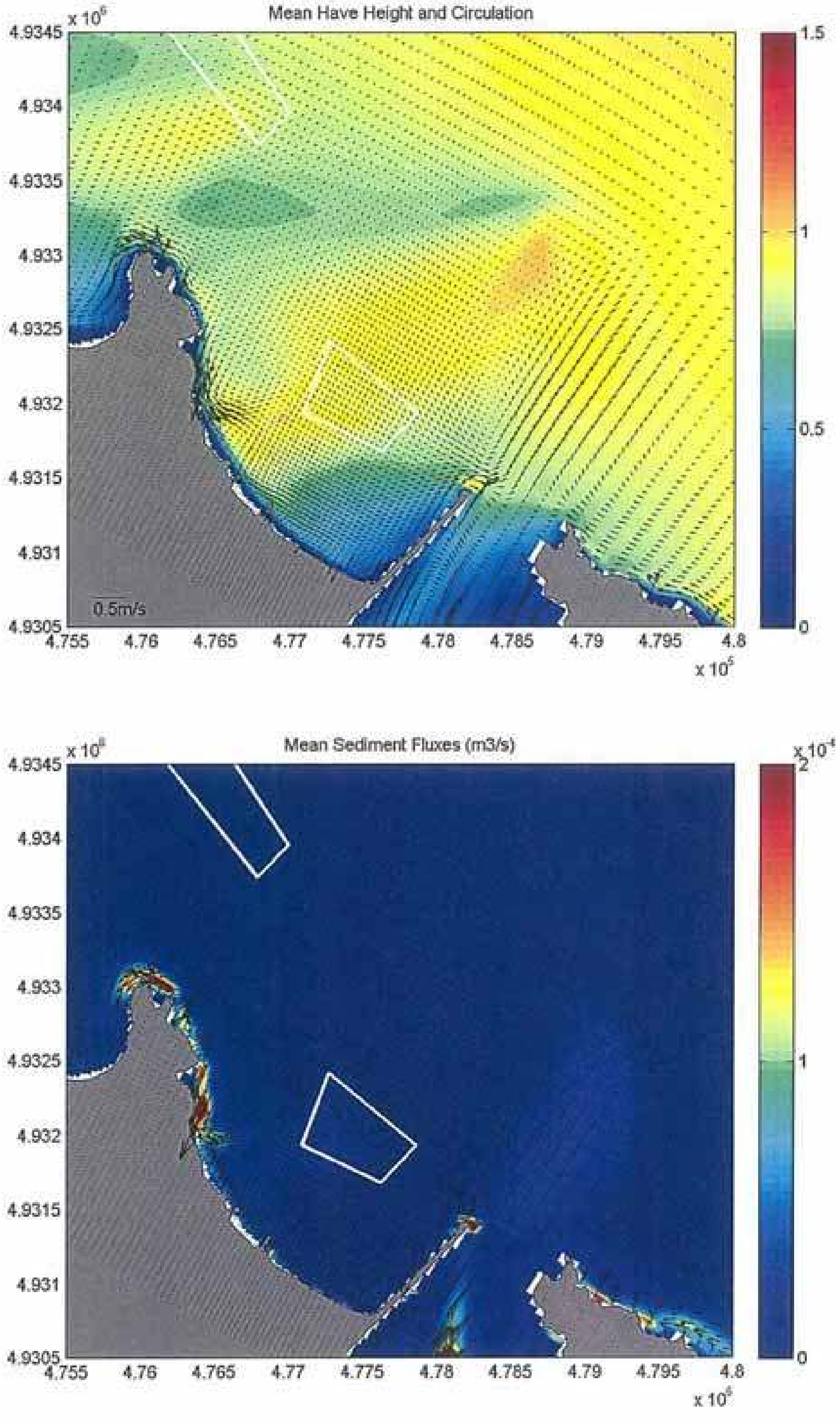


Figure 3.11 Mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom) during 2008. Disposal site locations are shown in white.

January-March

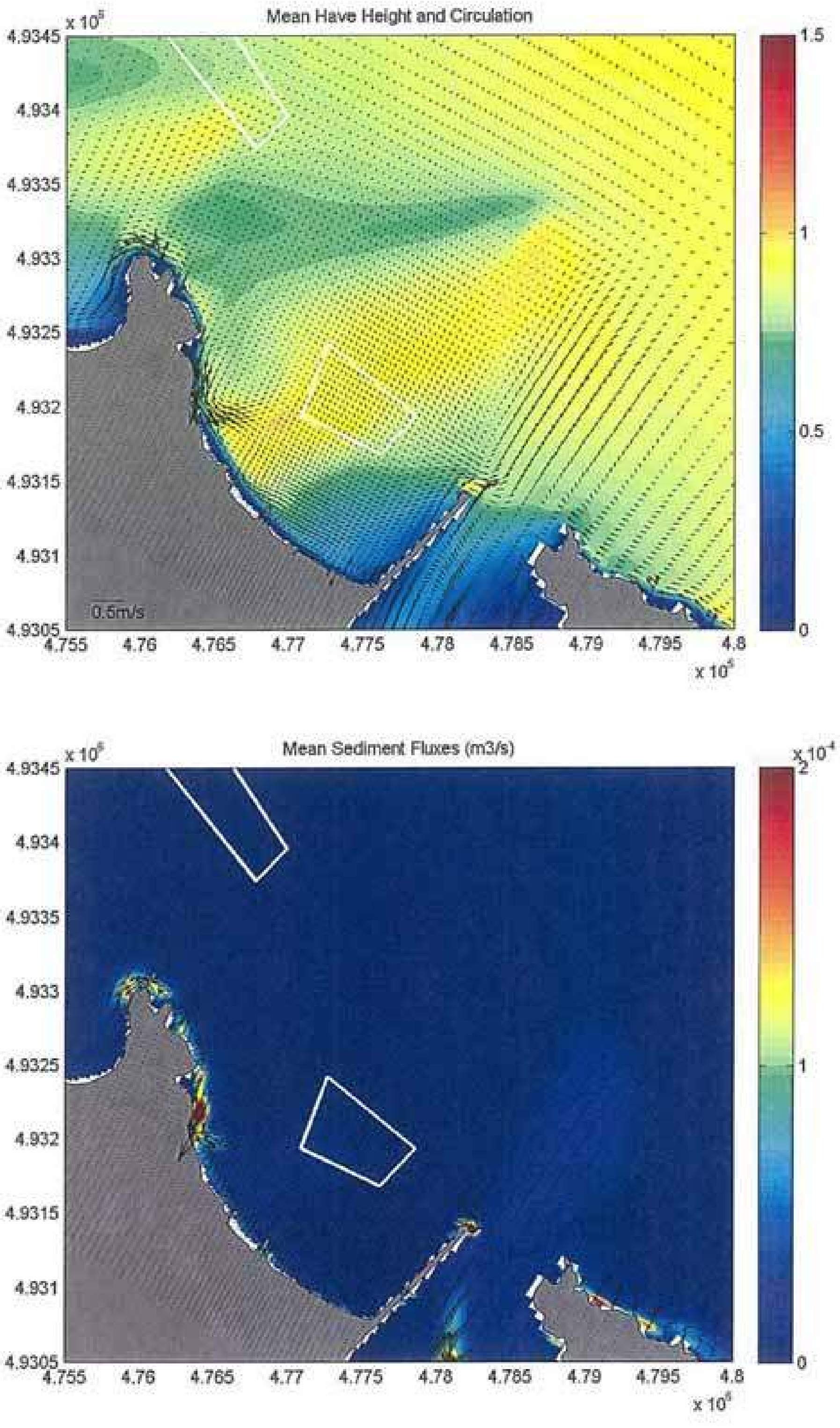


Figure 3.12 January – March 2008 mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom). Disposal site locations are shown in white.

April-June

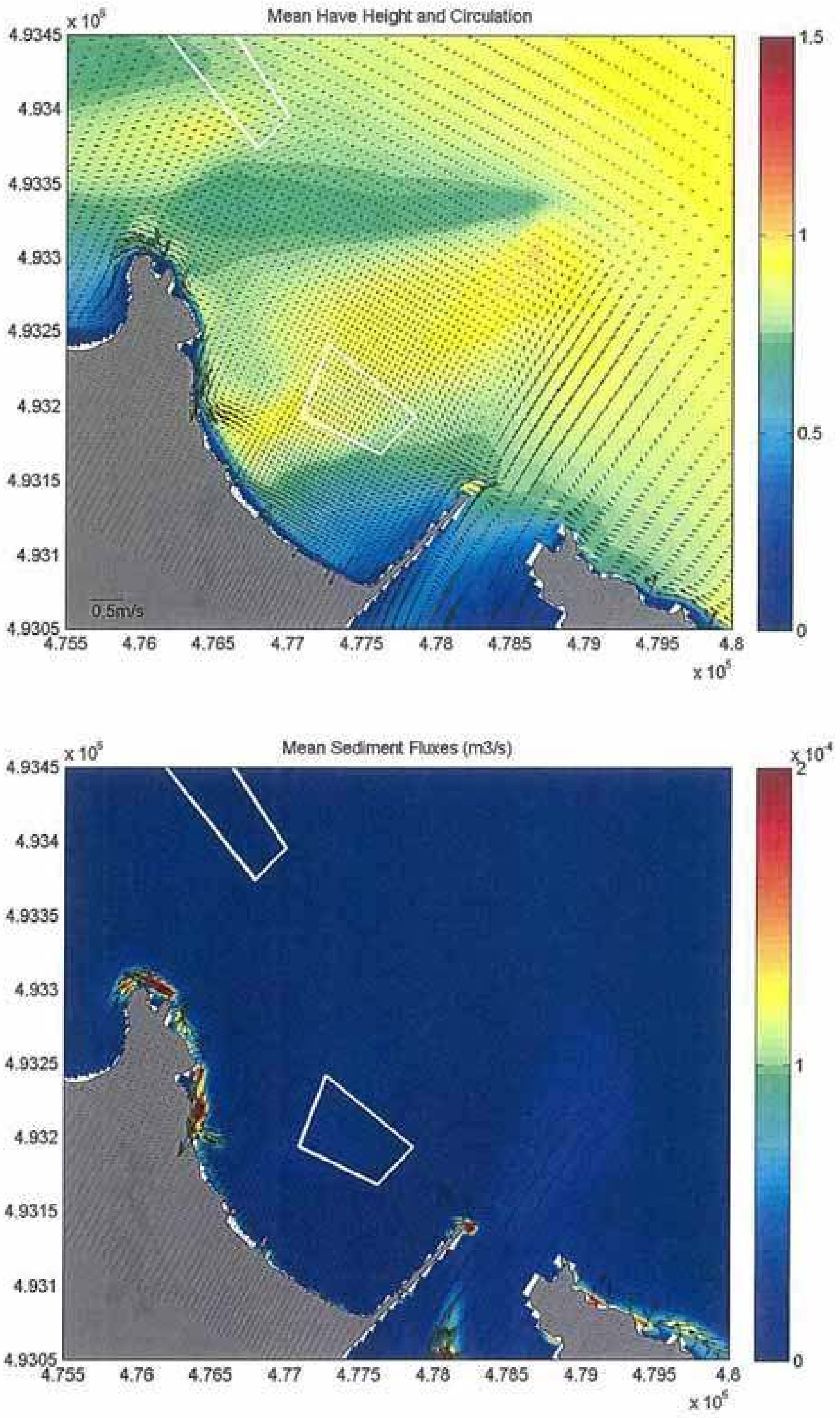
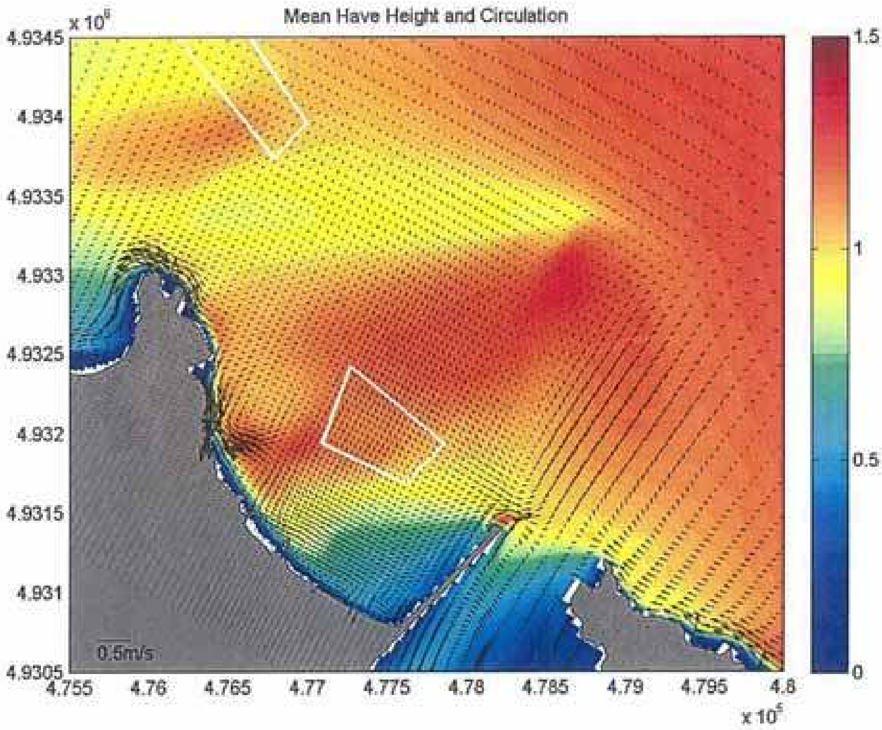


Figure 3.13 April – June mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom). Disposal site locations are shown in white.

July-September



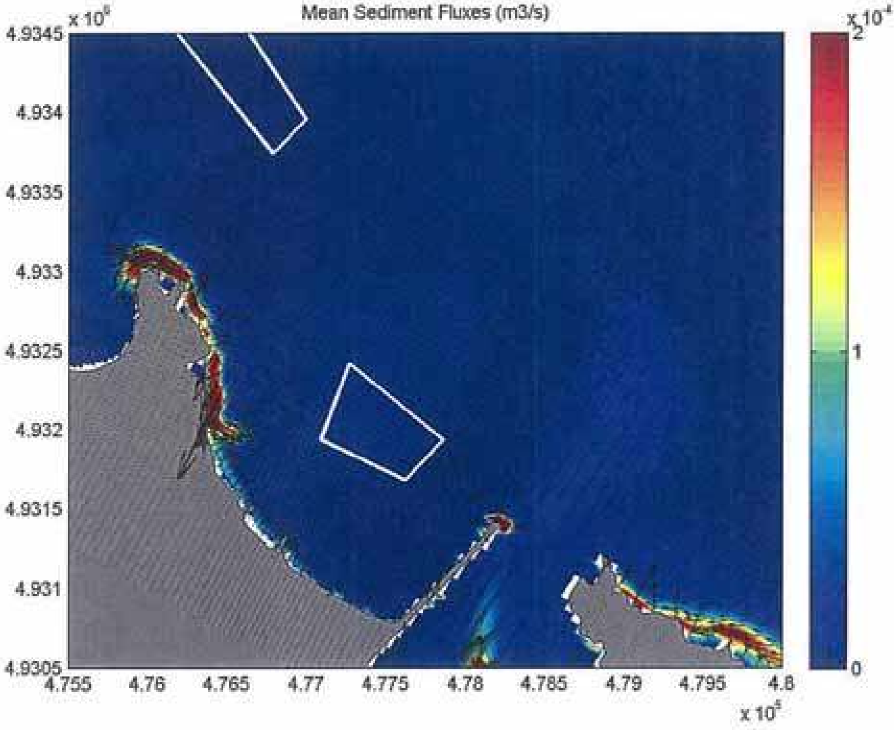


Figure 3.14 July – September mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom). Disposal site locations are shown in white.

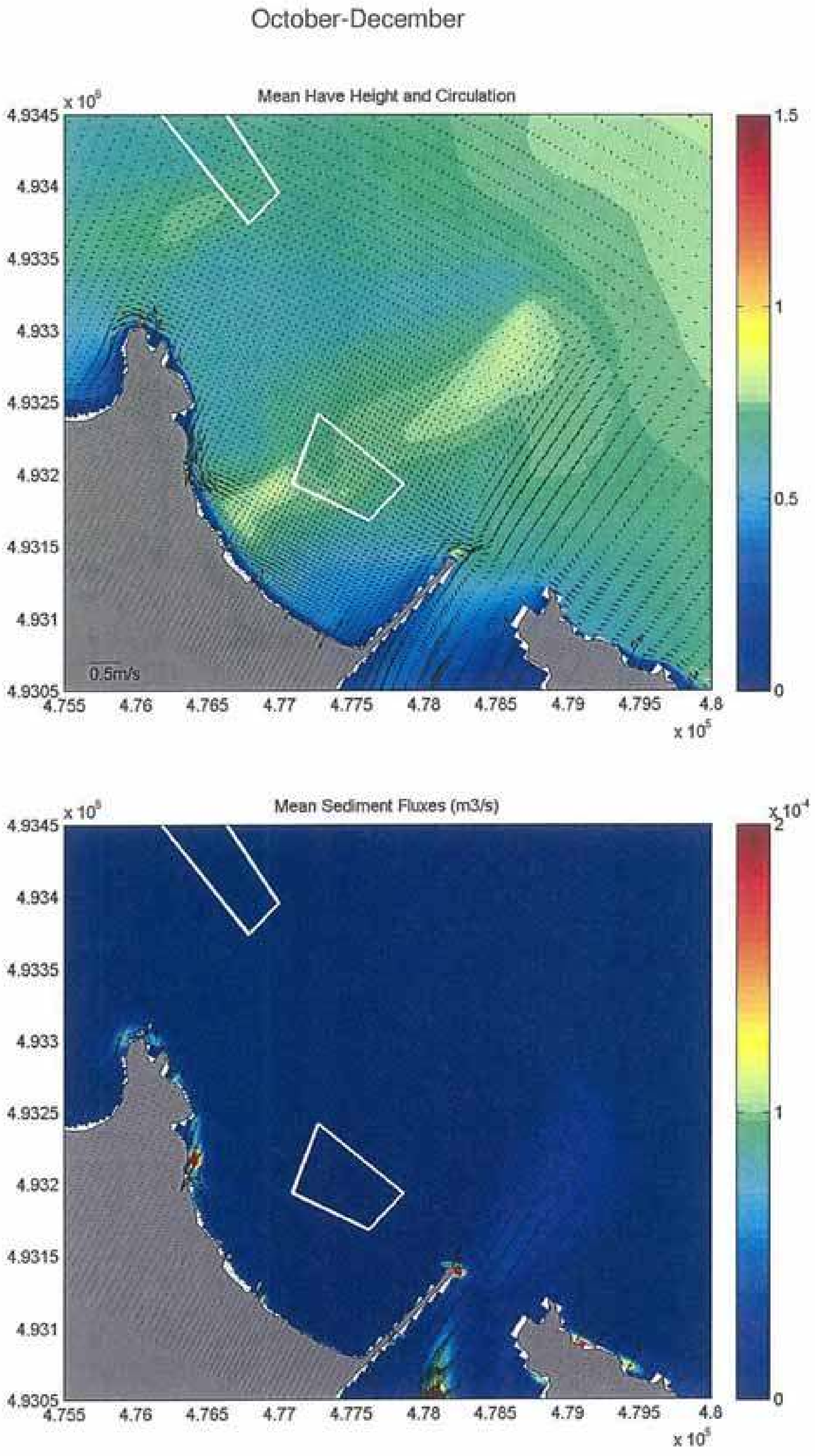


Figure 3.15 October – December mean significant wave height and circulation (top) and mean sediment flux magnitude and direction (bottom). Disposal site locations are shown in white.

3.6.6. Morphological changes

Events 2, 4 and 5 were simulated using the model in updating mode to investigate seabed erosion/ accretion patterns in the vicinity of the Spit disposal site and Aramoana Beach. Event 5 was the most energetic event, while Events 2 and 4 were selected for comparison since they had similar wave energy but different directions (i.e. ~60º and ~110 º respectively; see Table 3.1). The results showing the seabed level changes for the 3 events are provided on Figures 3.16 - 3.18.

Erosion of the Spit mound and accretion directly landward is a consistent prediction by the model for each of these 3 events, despite the fact that mean wave-driven currents are more oblique. The modelled onshore migration trend is consistent with the observed bathymetric changes from 2002 to 2009 (see Fig. 3.19), thereby providing a qualitative validation of the model predictions, and in particular the parameterisation of wave asymmetry. A gradual migration of a disposal mound in the shoreward direction has been observed in other studies (e.g. Douglass, 1996), and has also been attributed to wave-velocity asymmetry. In contrast, McComb and Black (2000) found that suspended sediment transport was the dominant mechanism for mound erosion in a consistently high energy environment.

Further inshore, erosion of the beach face and accretion of the longshore bar are predicted in each of the events. However, it should be noted that the model only parameterises the complex and time-varying sediment transport processes that occur in the surf zone. Accordingly, the results from the surf zone can only be used qualitatively.

The magnitude of seabed level changes near the Heyward disposal site is much smaller than at the Spit location, primarily due to the increased water depth. A zoomed in view of the area after Event 5 is shown in Figure 3.20. The net sediment flux is directed west, which is consistent with observed long-term bathymetric changes shown in Figure 3.19. Another feature of interest is the strong erosion and accretion patterns adjacent to the shore near Heyward Point. It is probable that this area has highly variable sediment levels and frequent scour to exposed rock in the shallow zones.

The model provides a useful tool to examine the short-term morphodynamic response of the shipping channel and ebb tidal delta to individual storm events. Comparison of the erosion/accretion patterns over the channel and bar feature is provided on Figure 3.21. Of interest, the results for Events 2 and 4 show opposing migration trends due to the incident wave direction. The easterly Event 4 acts to erode the bar and deposit material into the eastern side of the channel. During Event 2 however, the deposition is primarily on the eastern side of the bar. The largest event (Event 5) displays the most pronounced patterns, with the largest area of erosion/accretion occurring at the tip of the bar, and a zone of accretion in the channel immediately adjacent to Tairoa Head.

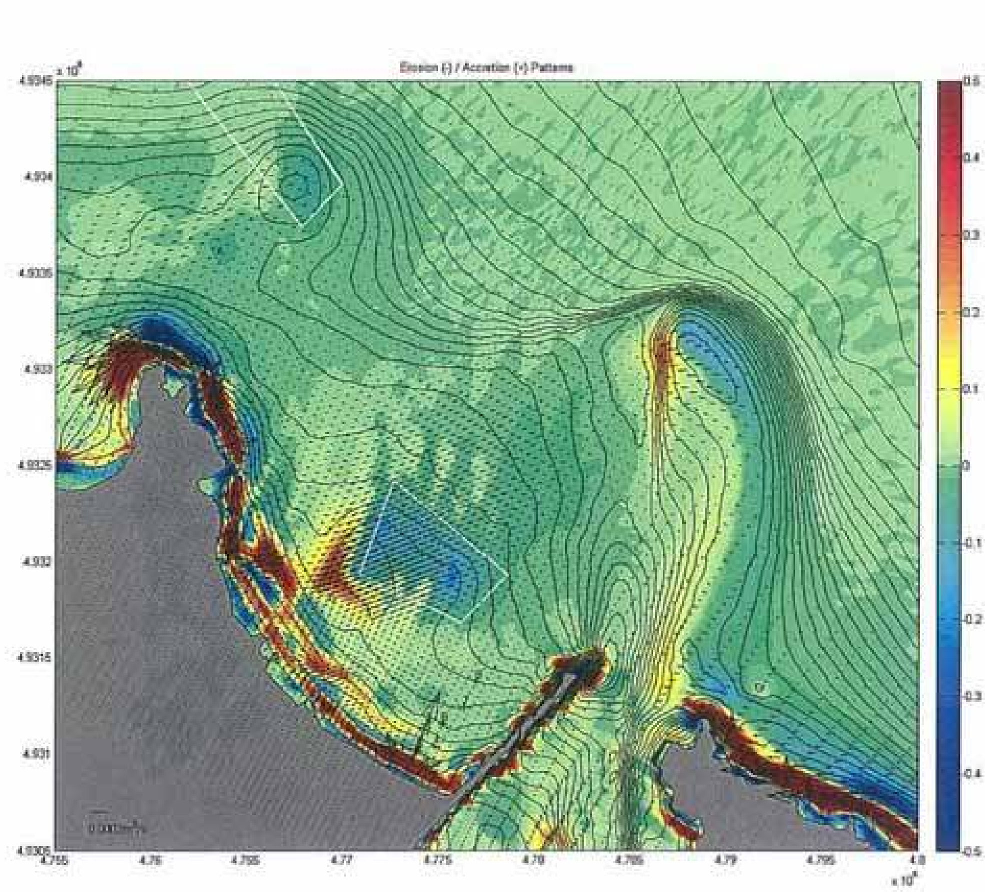


Figure 3.16 Predicted sea-bed level changes and mean sediment flux field over Event 5. Initial depth contours are overlaid.

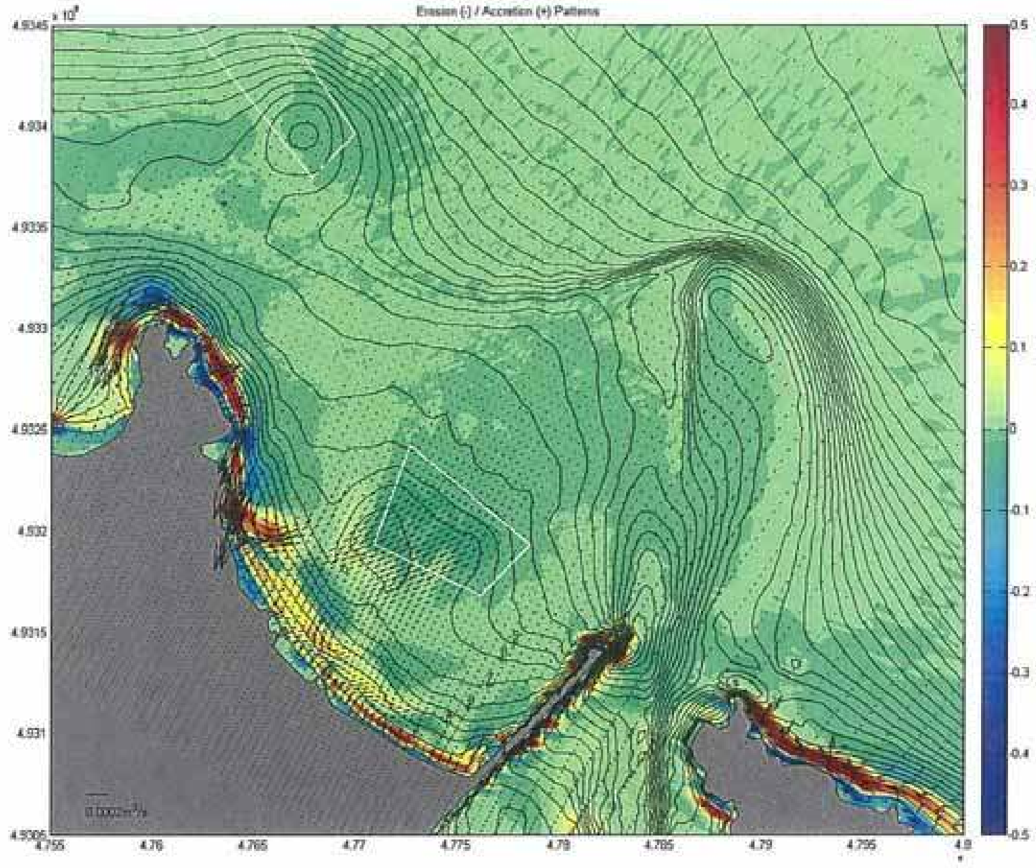


Figure 3.17 Predicted sea-bed level changes and mean sediment flux field over Event 2. Initial depth contours are overlaid.

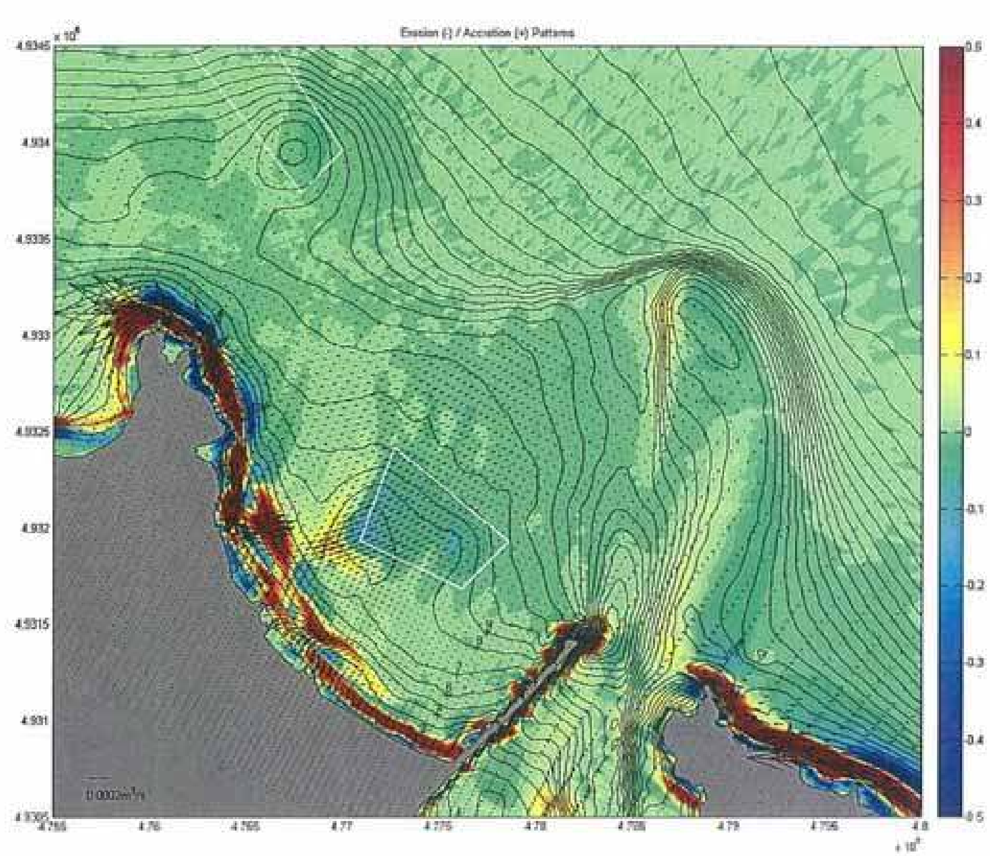


Figure 3.18 Predicted sea-bed level changes and mean sediment flux field over Event 4. Initial depth contours are overlaid.

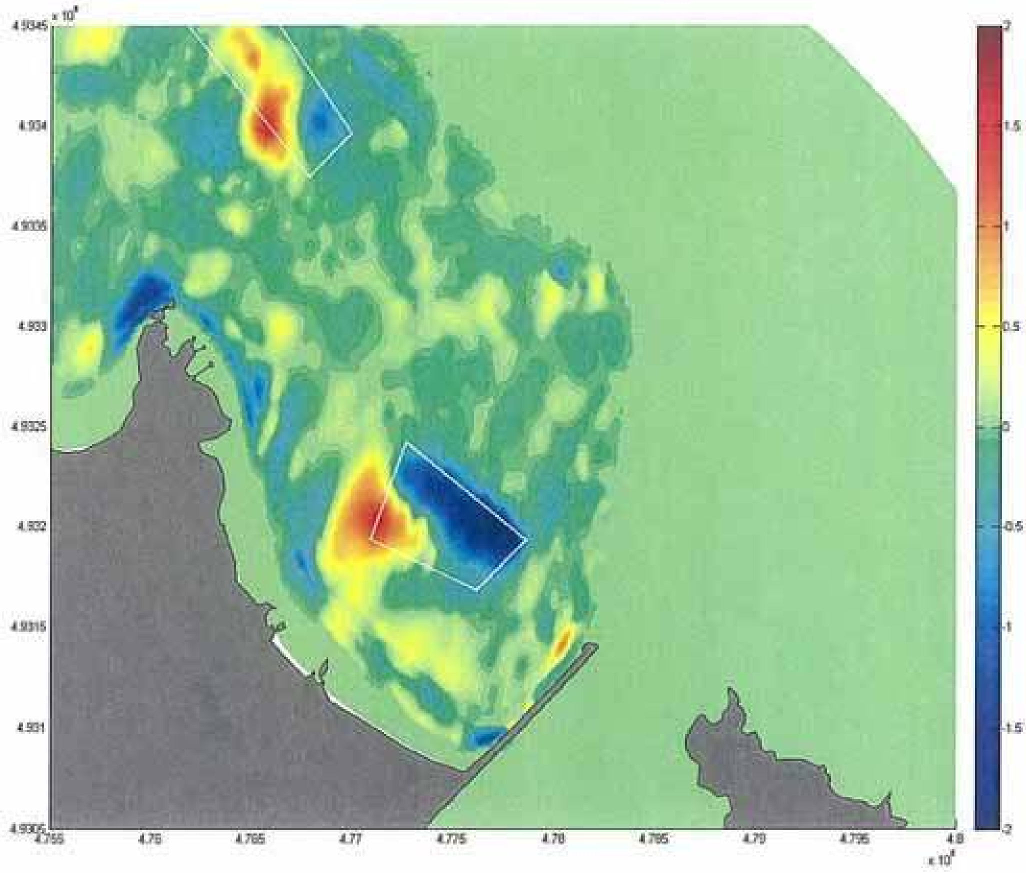


Figure 3.19 Actual sea-bed level changes from 2002 to 2009 determined from historical bathymetric measurements.

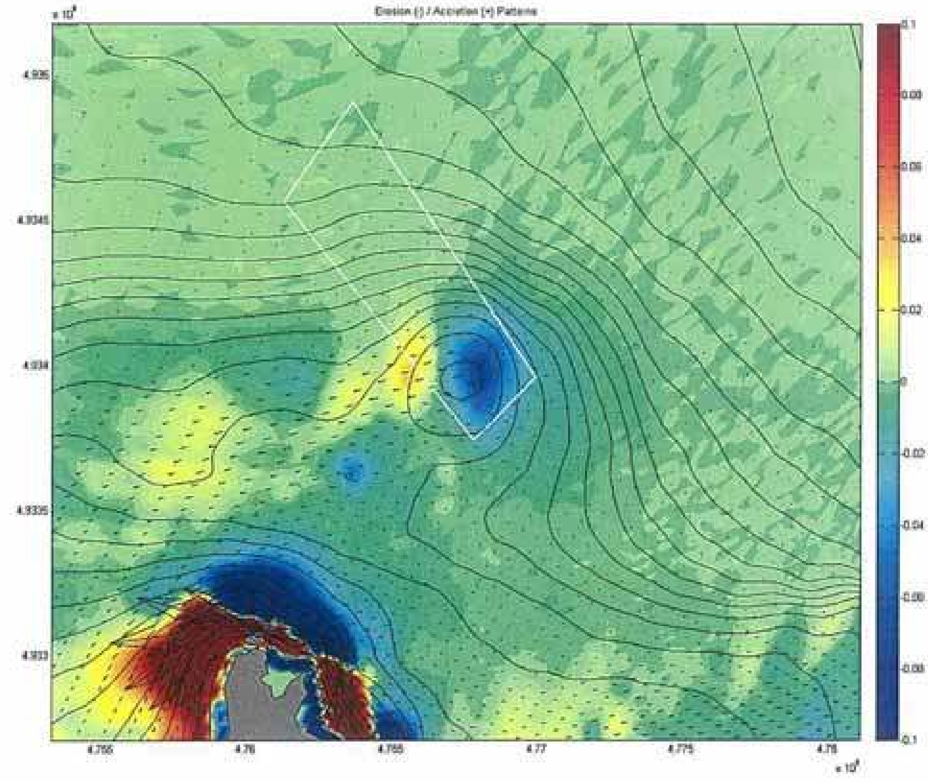


Figure 3.20 Predicted sea-bed level changes and mean sediment flux field in the vicinity of the Heyward disposal site during Event 5.

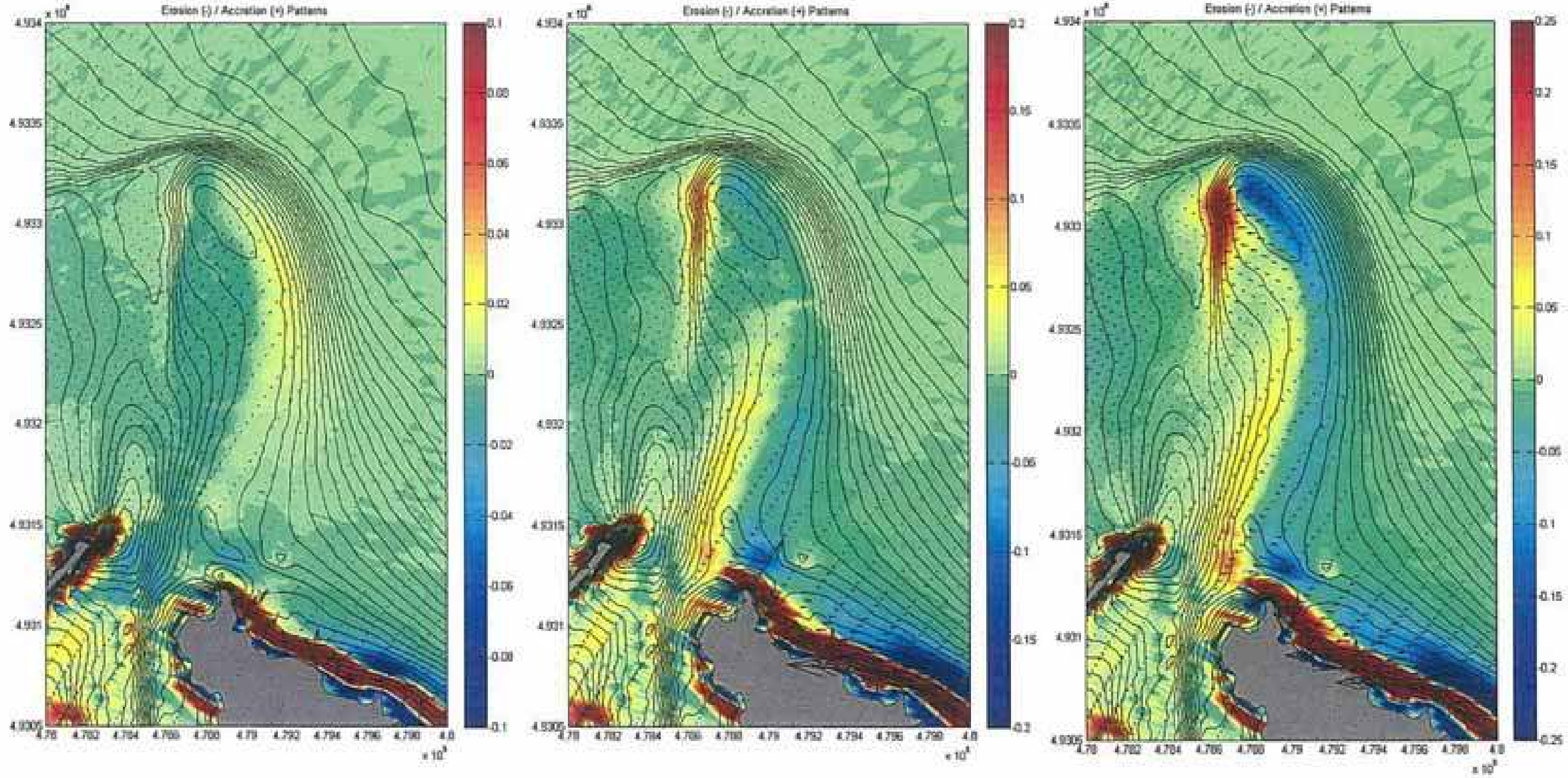


Figure 3.21 Sea-bed level changes over the entrance channel region for Events 2, 4, and 5 (left to right). Note that scales on each plot differ to better show erosion/accretion patterns.

4. SUMMARY

4.1. Existing dynamics

A preliminary modelling study of the wave and sediment dynamics at the Otago harbour entrance has been undertaken. The purpose of the work is to provide improved understanding of this environment, with particular focus on the physical oceanographic and sedimentary process that characterise this area.

The wave climate has been hindcast over a 12-year period; providing an hour-by-hour re-creation of the historical conditions from 1998-2009. From these data, climate statistics and maps of the wave regime have been produced and analysed. On average, the entrance region has a relatively moderate energy wave climate, with a mean annual significant wave height of only 0.89 m. The location of the entrance on the north side of the Otago Peninsula provides a large degree of topographical sheltering from the predominant waves from the south and southeast. However, this coast is exposed to seas and swells that approach from the north, northeast and easterly quarters. Large wave events do occur throughout the year – the 2.5 m significant wave height level is exceeded for approximately 1% of the time on an annual basis. These larger events typically approach from the east-northeast or south-easterly octants, usually with peak spectral periods in the range 10-14 seconds. The ebb tide delta and the entrance bar cause significant modification of the incident wave climate. Combined with sheltering effects, the net result is wave height focussing at locations along Aramoana Beach and the coast toward Heyward Point.

Sediment transport has been modelled over a one year period during 2008. The high-resolution numerical model domain includes the harbour entrance and the adjacent coasts plus the existing disposal grounds. The boundaries to the model are configured with incoming waves and currents, plus the tidal flows through the harbour entrance. Within the model domain wave-driven circulation patterns are resolved and sediment transport scenarios were simulated with and without the seabed morphology updating.

A qualitative interpretation of the results from the sediment transport model is as follows:

1. The modelling system produces similar morphological changes to the seabed and disposal mounds as those observed between successive seabed surveys at the Spit and Heyward disposal grounds.

2. At both locations, there is a net migration of the mound in the direction of wave advance, inferring that i) wave-velocity asymmetry is an important process and ii) bed load sediment transport predominates.

3. During energetic storm events, sediments are mobilised throughout the ebb tide delta region, and active bypassing of the harbour entrance and shipping channel is evident.

4. Characteristic patterns of wave-driven circulation and associated sediment transport pathways in the region west of the entrance are clearly evident. Near Heyward Point there is a strong transport vector directed north-northwest toward the Point and then west beyond the Point. Further south there is an opposing flow directed toward Aramoana Beach, which veers offshore as a rip current near the western end of the beach. Flows are much lower along Aramoana Beach, with a net transport vector directed southeast. East of the harbour entrance, there is a well-defined westward flow adjacent to the coast.

5. The sediment model results do not identify a direct transport pathway from the Spit disposal ground and Aramoana Beach system to the coast west of Heyward Point. It is highly probable that placed sediments at the Spit ground will experience long residence times within this system and historical disposal here has led to general accretion. This is an important factor when considering the long term sustainability of the site in the 35 year consent.

6. The shallow parts of the Heyward ground are mobilised during storms, and net transport to the west is indicated. The deeper parts of the ground appear to be retentive and do not show significant movement.

4.2. Future work

It is envisaged that future work will include:

- Verification of the dominant wave-driven circulation features that have been identified in this preliminary study.
- Incorporation of other sediment transport formulae in the model to improve the confidence in the quantitative results.
- Long term evolution modelling as a further qualitative validation that existing systems in dynamic equilibrium are well modelled.
- Detailed testing of a range of possible disposal sites to ensure long term sustainability while maintaining an adequate sediment supply to the adjacent littoral systems.

4.3. Effect of the three-year consent

The Port Company seeks to continue the disposal of up to 450,000 m^3 per year of dredging spoil into the existing grounds. A term of three years is sought, which is sufficient time to allow the studies identified above to be undertaken and the associated management strategies to be developed. The likely physical sedimentary effects of the continuation of spoil disposal are considered in the following sections.

4.3.1. Heyward

For the Heyward ground, both the historical survey measurements and numerical modelling suggest that sediments within the shallow parts can become mobilised by wave action and tend to migrate westward, while the deeper regions (i.e. greater than about 15 m) are clearly retentive. Accordingly, the effects will depend on the areas used for disposal within the ground. The historical survey data indicate a disposal mound has been slowly accreting in the shallow regions of the ground, which indicates the supply to these areas over recent years has exceeded the natural transportation capacity (i.e. waves and currents). Over the term of the consent there is scope to further manage the disposal volumes within discrete regions of the ground; defining retentive and dispersive quantities.

4.3.2. Spit

For the Spit ground, the model results indicate that the sediment deposited here tends to migrate westwards with the incident wave field. No direct transport vector has been identified from the Aramoana Beach region to the adjacent coastal cells, and so it is likely that the dredged sediments deposited here will have long residence times. Significant transport beyond this immediate area (i.e. the wider Aramoana Beach system) is likely to occur infrequently and only during high storm conditions.

On the basis of the information currently available, it is highly probable that material placed at the Spit ground will slowly migrate shoreward and gradually disperse along the wider Aramoana Beach system. While the region into which this material will disperse is relatively broad, it is considered that a deposition rate of 200,000 m^3 per year is not a sustainable practise over the long term. Note that approximately 750,000 m^3 of material has been deposited at the Spit ground in the last 10 years, and nearly 3.3 Mm^3 in total over the last 26 years. It is considered that the effects from a maximum of 200,000 m^3 per year for the next three years (i.e. 600,000 m^3 in total) will be analogous to the previous 10 years.

Future studies over the next three years will determine the optimum sites and volumes for the deposition of dredged sediments. It is highly likely that considerably less than 200,000 m^3 per year will be specified for the Aramoana Beach system for long term management. Accordingly, a possible consequence arising from the maximum deposition of 600,000 m^3 at the Spit ground may be a delay in future depositions to allow the system to adjust.

In the short term, the presence of the disposal mound will modify the incoming wave field. Wave transformation studies have shown that the historical disposal mound bathymetries produce subtle differences in the wave height gradients along the beach in the surf zone. The mound acts as a secondary focusing feature, redistributing wave energy into zones of slightly increased and decreased wave height. This has a slight effect on the local coastal processes, and does influence the surfing wave quality. Focussing effects that increase the local wave heights along the adjacent beach are likely to confer positive outcomes for surfing. However, the wave focussing process is highly dependent on the mound shape. Therefore as the mound erodes over time and the sediments are distributed shoreward and eventually spread along the beach and nearshore regions, the effects will also change.

4.3.3. Shelly

At the Shelly Beach ground, the effects of the continued disposal of up to 50,000 m^3 per year is not expected to produce outcomes that differ from the past 10 years. Some 237,092 m^3 has been placed in the region, with a relatively low retention rate. The sediment transport has not been modelled for this ground in the present study, However it is highly probable that sediments are actively flushed from this region during periods of elevated wave penetration, with subsequent deposition in the adjacent shipping channel. Accordingly, exercise of the consent for this ground over the three-year period will provide a short term sediment supply to Shelly Beach, but is not expected to produce outcomes that differ from the observations over the past 10 years.

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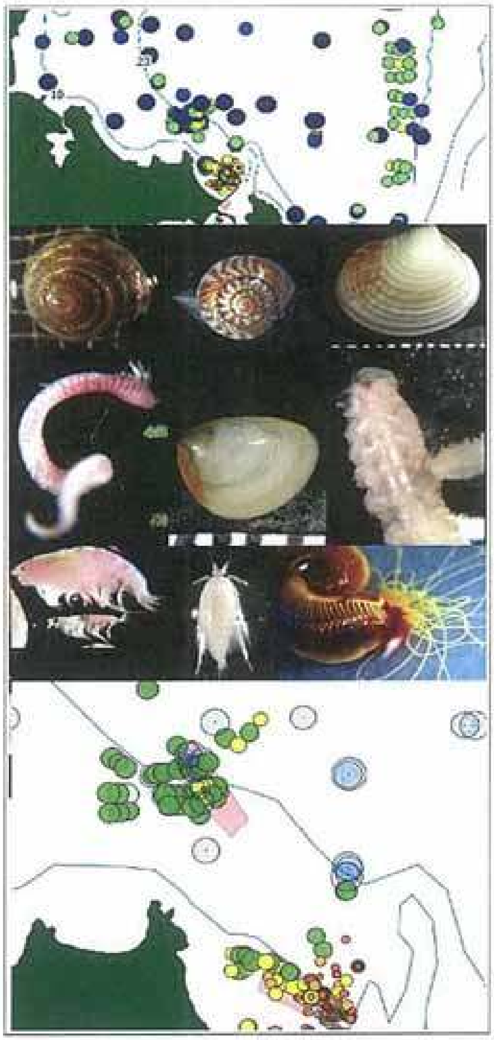
Appendix F

Brian Paavo, Benthic Science Ltd – Benthic Study

Benthic Macrofaunal Assemblages near Maintenance Dredge Spoil Disposal Areas



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Benthic Macrofaunal Assemblages near Maintenance Dredge Spoil Disposal Areas

Final Released Draft - 25 May 2011

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Table of Contents

Executive Summary

Port Otago Limited (POL) is seeking a short-term replacement consent to allow for the continued disposal into the sea of up to 450,000 m³ per year (the current permit volume) of dredge spoil into three existing disposal sites off Heyward Point, Aramoana Beach, and Shelly Beach. This will replace the current coastal permit, 2000.472, which expires in December 2011. Total annual disposal volume has surpassed 250,000 m³ once since 1995. A substantial amount of information on the interaction of disposal practices with coastal ecology and physical processes has been collated since 2000. This report summarises much of the existing information on the coastal ecology of local macrofauna (small, bottom-dwelling animals) with respect to maintenance dredge spoil disposal activities.

The coastal subtidal study area between Taiaroa Head and the northern limits of Blueskin Bay is a dynamic environment where sediments, water depth, and hydraulic energy gradients help shape the animal communities of the benthic (seafloor) habitats (see Fig. 38, page 62). The benthic ecology of the Shelly Beach disposal ground has not been investigated due to the overarching conservation efforts focused on the South Spit shoreline and the Aramoana saltmarsh it shelters. The Aramoana and Heyward Pt. disposal grounds lie inshore of the 12 m and 22 m isobaths, respectively. A mean 510 m³ of dredge spoil per day was discharged at sea in 2010 with disposal occurring during most weeks. The sediments discharged to the sites have generally been medium and fine sand from the Otago Harbour entrance and several lower harbour claims with fine material from ship berths, approaches, and the upper harbour contributing a smaller volume.

Disposal-related mounds were observed at Aramoana and Heyward Pt. Separate studies on coastal water movements (MetOcean Ltd. and others) and sediments (Single *et al.* 2011 and others) complement the available biological information and validate a relationship between these mounds and decreases in benthic macrofaunal abundance and species richness. Some robust species, such as the wheel-shell snail *Zethalia zelandica,* thrive in the energetic areas inshore of the disposal areas while most other taxa are excluded. At Aramoana disposal-related effects are probably limited to the inshore portion of the disposal ground and extend not more than 250 m beyond the disposal ground boundary. The deeper 1/3 of the much larger Heyward Pt. disposal ground does not appear different from 'background' samples and disposal-related effects appear to be restricted to the central portion of the disposal ground and an area 100–500 m west of its shoreward boundary. Both sites are dispersive with respect to silty sediments and

retain sand-sized sediments to different degrees. There is no evidence that disposal has deleterious ecological effects beyond these areas.

A benthic photographic survey identified biogenic features associated with animals living in burrows which were common in waters deeper than 15 m. A one-off investigation revealed that most of these burrows were probably made by a mantis shrimp (*Heterosquilla* cf. *tricarinata*) known to range from Northland to the subantarctic islands. The investigation also identified several commensal species living in the burrows which have not previously been recorded on the Otago coast. These species and burrows are probably common features of shallow subtidal sands along southeastern coasts which have likely not been reported due to a lack of exploration with equipment and methods capable of detecting them rather than scarcity.

Dredge-related effects at Aramoana appear spatially stable in comparisons between 2005 and 2010 and the area retains a 'buffer zone' of animals well-suited to colonise sandy spoil. Dredge-related effects also appear spatially stable at Heyward point in comparisons between 2005 and 2010 though fewer historical data are available. Habitats surrounding the Heyward Pt. disposal ground and large areas *within* the disposal ground support species suited to rapid colonisation of sandy sediments. The position of the Heyward Pt. disposal ground in shallow waters off of a headland which shapes water movements complicates monitoring and management. Even though dredge-related effects are currently localised, informed modification of the disposal area and practices may simplify monitoring and impact an even smaller proportion of a larger habitat than is presently occurring.

Investigations are proposed to take place during a two-year consent period which aim to prepare an effective monitoring and management programme for a subsequent 35-year consent application. The key points of the proposed investigations are:

- Continue POL's improved bathymetric survey regimen and disposal location records
- Use the STFATE model to predict spoil footprints in the Heyward Pt. locale and inform empirical investigations of the patterns and processes of fine sediment transport and macrofaunal recolonisation of spoil in existing and alternate boundaries
- Improve taxonomic resolution of key macrofaunal taxa, especially gammarid amphipods
- Evaluate the ubiquity of infaunal taxa

Successful development of practical and effective monitoring and management procedures requires that further policy benchmarks from the working party and consenting authority be established within the existing national guidelines and in accordance with international best practices for review and implementation.

Introduction

Coastal resource consent application to dispose of dredged material at sea

Port Otago Limited (POL) is seeking a short-term replacement consent to allow for the continued disposal into the sea of up to 450,000 m^3 per year of dredging spoil. This will replace the current coastal permit, 2000.472, which expires in December 2011. Port Otago is seeking to continue to dispose of dredging material pursuant to the terms and conditions applying to coastal permit 2000.472.

The spoil will be derived from maintenance dredging and incremental improvements to the channel and berth areas in and about the Otago Harbour. Disposal is proposed to be carried out in accordance with the following specific maximum annual discharge quantities at each location (Fig. 1, Table 1):

- Heywards Point, being an area of approximately 38.2 ha and to receive up to 200,000 m^3 of spoil;
- Spit Beach, being an area of approximately 28.3 ha and to receive up to 200,000 m^3 of spoil; and
- South Spit Beach (Shelly Beach), being an area of approximately 14.5 ha and to receive up to 50,000 m^3 of spoil.

A term of three years is being sought for the consent. After this time, it is intended that a 35 year disposal consent will be sought. The short-term consent will allow for a suitable long-term consent framework and monitoring programme to be developed which takes into account both maintenance dredging spoil disposal and disposal associated with capital dredging sought through the "Project Next Generation" resource consent which is currently under consideration by Otago Regional Council.

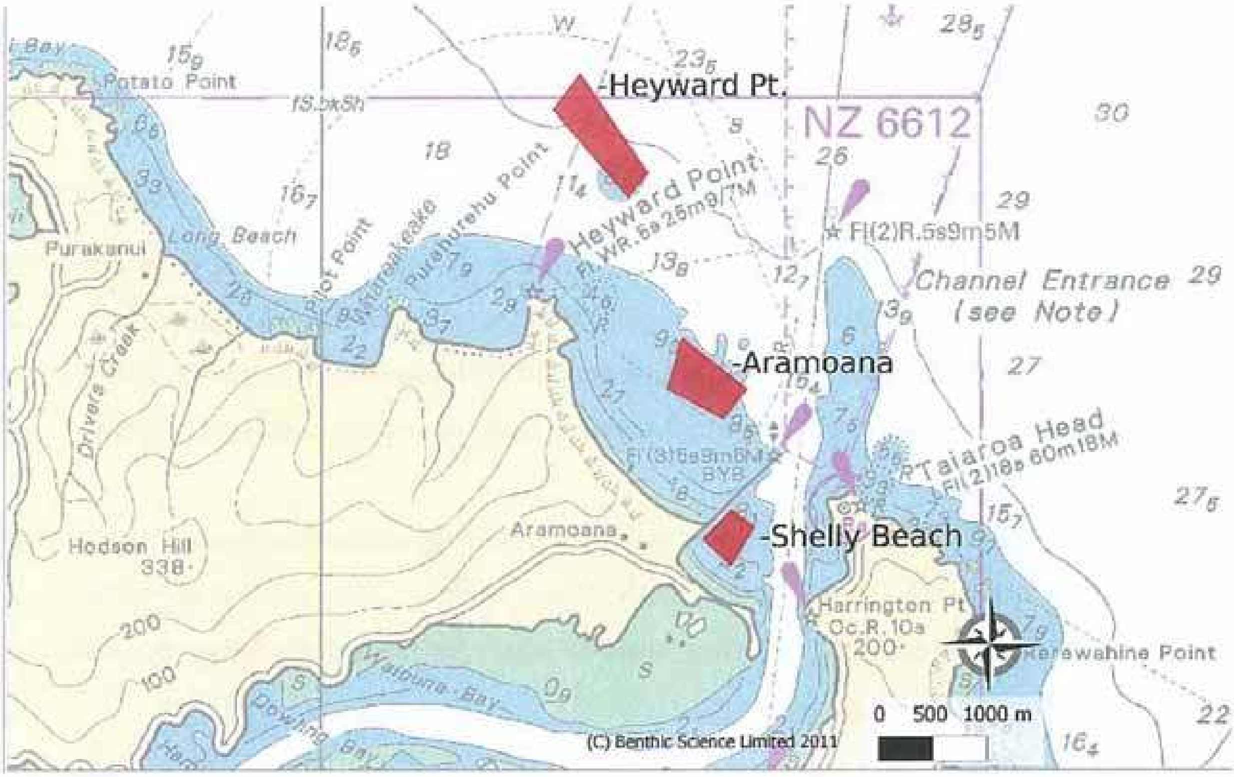


Fig. 1. Existing dredge spoil disposal areas (red polygons). (Background chart NZ661, depths in metres)

Table 1. Geographic coordinates of existing dredge spoil disposal areas.

Site	**Coordinates of corners (WGS84 datum)**
Heyward Point	45° 45.07' S 170° 42.09' E 45° 44.95' S 170° 42.27' E 45° 44.44' S 170° 41.78' E 45° 44.63' S 170° 41.60' E
Spit Beach (Aramoana)	45° 46.18' S 170° 42.74' E 45° 46.05' S 170°42.93' E 45° 45.72' S 170° 42.47' E 45° 46.04' S 170° 42.33' E
South Spit Beach (Shelly Beach)	45° 46.82' S 170° 42.56' E 45° 46.65' S 170° 42.79' E 45° 46.75' S 170° 42.96' E 45° 46.95' S 170° 42.77' E

The Maritime Safety Authority of New Zealand and the Ministry for the Environment have produced guidelines ("the guidelines") for the sea disposal of waste (MSA 1999) to aid regional council decision-making under the RMA (1991) and the Resource Management (Marine Pollution) Regulations (1998) ("the regulations"). The guidelines were modelled on, and intended to be regularly updated in accordance with, the National Ocean Disposal Guidelines for Dredged Material (Environment Australia 2002). The guidelines were created to aid authority and applicant compliance with the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 ("the protocol") with respect to the London Convention[1] ("the convention") administered by the International Maritime Organisation. New Zealand is one of 40 signatory nations to this convention. The guidelines specifically direct that the regional council must have regard for RMA sections 104 and 138A.

Maintenance disposal operations within Otago Harbour is a large (>100,000 m^3) and complex project according to the guidelines which provide a generic assessment framework. The present study provides information on the impact of current disposal operations within the context of the adjacent coastal environment. This is primarily a technical report and no attempt has been made to provide a comprehensive literature review nor synthesise findings beyond those data gathered in the included studies.

The guidelines (Part 1 Section 6) outline the disposal site assessment process. In general they state that the disposal site should be sufficiently removed from ecologically sensitive or incompatible use areas to avoid or minimise adverse environmental effects. The site selection process should be sufficiently flexible to allow for a variety of waste types and quantities and the range of effects that may result from their disposal. The information required on the proposed disposal site is outlined in paragraph 11 of the WAF Annex and clause 6 of Part 1 of Schedule 3 to the regulations, but can be briefly summarised as:

- physical, chemical and biological characteristics of the water column and the seabed
- location of amenities, values and other uses of the sea in the area under consideration
- assessment of the consituent fluxes associated with disposal in relation to existing fluxes of substances in the marine environment
- economic and operational feasibility

This study summarises biological patterns and processes found during recent surveys of the seabed with respect to macrofaunal sampling, photographic, and sonar observations only. Attention has been given to use methods and locations suitable to support future site monitoring if it is required. Monitoring guidelines are set out in Part 1 Section 8 of the guidelines. The guidelines also recognise that each application for discharge into the coastal marine environment requires independent study and that the suitability of a disposal site can only be assessed with respect to matching, sufficiently characterised, spoil (Part 2 of the guidelines) as modified by the dredging process proposed to be used. Though relevant to the proposed disposal site, spoil

1 This is a 'living' document, the latest version can be accessed at: http://www.imo.org/OurWork/Environment/SpecialProgrammesAndInitiatives/Pages/London-Convention-and-Protocol.aspx

characterisation will be addressed by separate reports (*e.g.* Single 2011; Pullar & Hughes 2009) and only briefly mentioned here. For management purposes the Aramoana disposal area falls within class 124 of the New Zealand Marine Environment Classification system (MFE 2005) while the Heyward Pt. disposal area is most similar to class 64 grading to aspects of class 169 .

Why study macrofaunal assemblages?

The term 'macrofaunal assemblages' is used throughout this report. This term is used to refer to relatively large animals (usually over 0.5 mm in their smallest dimension) typically found in densities of dozens to thousands of individuals per square metre living on or in soft-seafloor sediments such as clay, mud, or sand. When a number of individual taxa were found together in any collection they are referred to as an assemblage. The general biological patterns which emerge when enough assemblage information covers broad areas and time scales are then referred to as communities when substantial biological interactions are assumed to exist between observations. Communities form due to both biological and physical patterns and processes in an area.

Any area of the seafloor provides resources of material value called goods (*e.g.* food) and process-based resources like chemical or biological activities called services (*e.g.* livable habitat, storage space, dilution volume, etc.). Goods and services are available to the communities living within the area and adjacent to it (including humans). Predicting the environmental impact of any proposed activity requires an understanding of the goods and services (G&S) provided in an area and an evaluation of the costs and benefits of affecting future G&S through the activity. Since all G&S cannot be monitored or managed, biomonitoring programmes are developed to detect changes in those goods or services most valued by the involved communities.

Macrofaunal communities have intrinsic value, but they also provide information on local G&S which are frequently relevant to regional management scales. Assemblages are usually patchy on the scale of metres and weeks, but community patterns are typically present over broader areas and longer time scales and therefore provide a more synthetic view of conditions. Physical measurements such as temperature, sediment metal content, and such provide detailed information of the environment at the time and point of sampling. Such parameters may or may not be important to the community living there, they may be changed *by* the community, or they may vary over space and time in a way that makes general characterisation impractically expensive or impossible. Because each macrofaunal taxon lives and reproduces within its own synergistic environmental constraint tolerances, community patterns reflect conditions which are ecologically important that may or may not be detected by physical testing. A comparison of physical and ecological patterns in areas, times, or processes can reveal or explain changes in overall G&S.

Macrofauna are useful in G&S impact considerations in this way because of several general biological characteristics. Macrofauna are typically more sedentary than, for example, fish species of direct value and can therefore be studied more easily. Their high density on the seafloor also aids practical study design. While individuals are usually quite small, they typically dominate the collective animal biomass and diversity in benthic habitats and directly provide a large portion of an area's G&S. Their most obvious product is food for other organisms (*e.g.* fish, birds, etc.) while many of the services that they provide are less obvious (*e.g.* habitat construction, sediment binding, etc.). While macrofauna are more sedentary than many larger marine animals, all move in some fashion. Some species move significant distances only through reproduction. In the tropics this often occurs throughout the year, but in temperate Otago waters, most species reproduce once a year or less often. Other species (often including those we don't tend to think of as mobile - like bivalves) may move metres or kilometres as adults and juveniles. Thus macrofaunal reproduction and colonisation can provide information on how frequently conditions are conducive to normal G&S production. Reproduction and colonisation abilities thus dictate the recovery of an area from an impact. Each macrofaunal individual can only die once, therefore, G&S predictions typically look at the maximum degree, spatial extent, and frequency of acute impacts rather than average values and compare them to the ability of the surrounding area to colonise an impacted zone in a given time period. Impacts which do not directly kill or remove species from any area may prohibit reproduction or colonisation, thereby producing the same ecological effect as acute removal depending upon the individual species' biology.

Prior studies

Several authors have provided a general overview of some biological communities and key physical parameters such as water depth and sediments in the study area prior to the studies commissioned by POL. Andrews (1973) produced the most comprehensive assessment of sediment types in the area (Fig. 2). Sediment textural data was primarily based on Agassiz trawl samples at approximately 2.4 km spacings with undefined geospatial precision. Bardsley (1977) used mineral tracers to define a northward-moving sand wedge later described by Carter *et al.*

(1985). Carter & Carter (1986) also described bottom types including a transition from modern sand to relict gravel/palimpsest sand. Smith (1994) updated and summarised prominent coastal processes for the Otago Regional Coastal Plan. Andrews (1973) described the benthic fauna seaward of the disposal sites as a sparsely populated *Antisolarium*-foraminifera assemblage based on the dominance of the snail *Antisolarium egenum*. Probert *et al.* (1979) samples to the south and north of the study area described this same inner sandy-shelf fauna (Fig. 2) as sparsely populated by *A. egenum*, *Ommatocarcinus macgillvrayi*, *Patiriella regularis*, *Nectocarcinus antarcticus*, *Ovalipes catharus*, and *Sclerasterias mollis*. All of these studies highlight the special ecological nature of palimpsests (mixture of relict and modern sediments of different origins) and bryozoan thickets far deeper and southward of the disposal sites. Batson (2000), Batson & Probert (2000), and Jones (2006) only found such sediments deeper than 50 m, but anecdotal reports suggested that some pockets of gravel extended inshore to depths of 40 m.

Several POL-commissioned studies provided information included in the present report. Willis *et al.* (2008) collected grab samples, underwater video, and sidescan sonar returns to characterise the broader area. They found that the continental shelf was dominated by fine and very fine sand with organically enriched (2–3% by loss on ignition method) silty sediments toward the centre of Blueskin Bay. Willis *et al.* (2008) broadly confirmed the earlier findings of other studies (Paavo 2007, Single 2007, Paavo & Probert 2005, Bunting *et al.* 2003), but also suggested that there was a shore-parallel contour near the 30 m isobath which delinated high densities of tube-dwelling polychaetes shoreward which were rare seaward. They also identified previously unreported patches of horse mussels (*Atrina zelandica*) several kilometres seaward of the Heyward Pt. site at depths near 28 m. Horse mussel shells protruding from soft sediments provide ecologically significant benthic structure and are associated with increased faunal diversity and abundance in a complex fashion (Hewitt *et al.* 2002, Cummings *et al.* 2001).

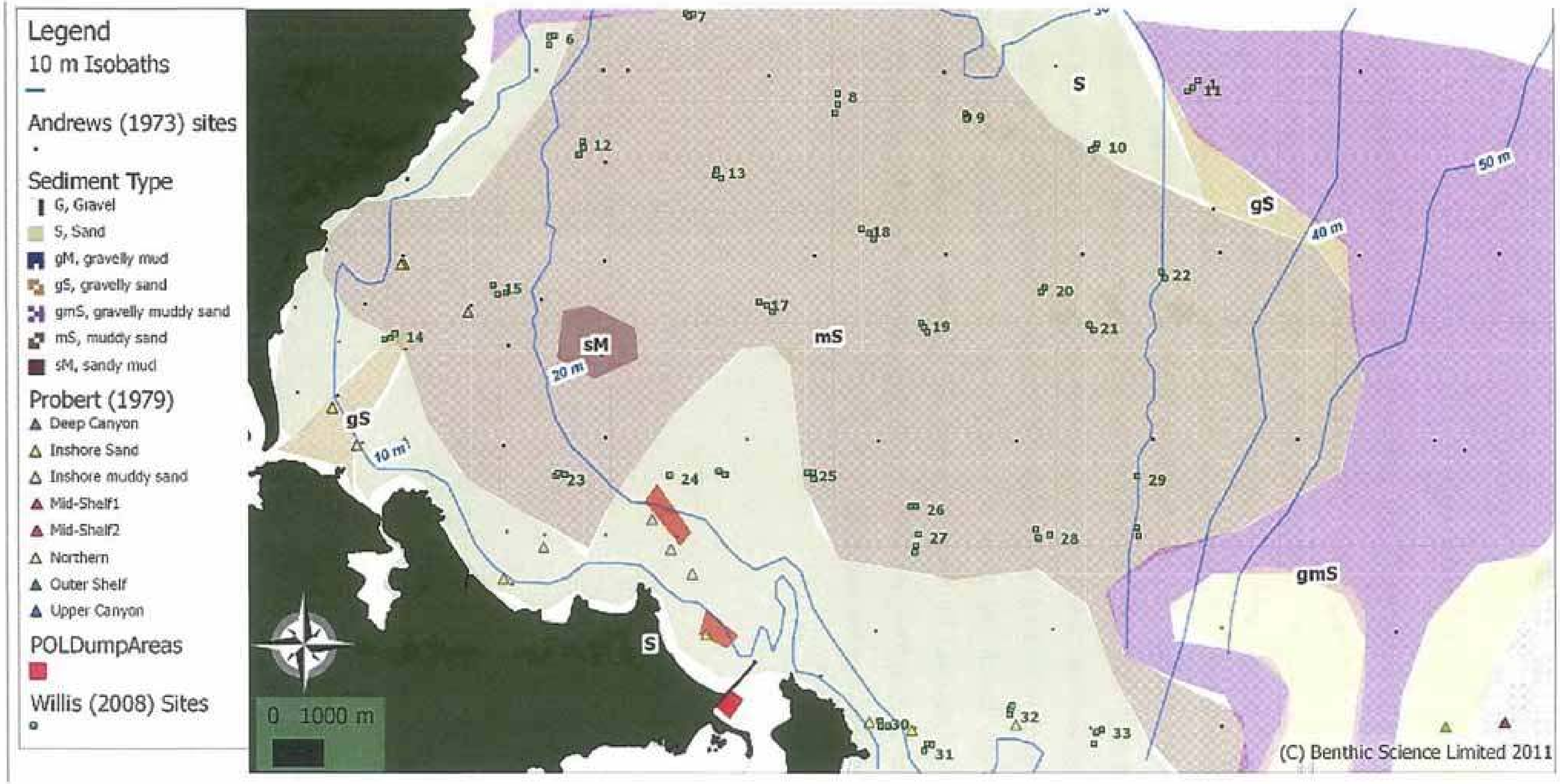


Fig. 2. Sediment types in relation to disposal areas from studies by Andrews (1973), Probert (1979) and Willis *et al.* (2008)(see text).

Study Area and Methods

Disposal Areas and Recent Disposal History

Lusseau (1999) tabulated the historical use of the existing disposal areas while annual reports by POL have characterised disposal activities since then. During the 2010 calendar year there were 282 disposal events from the *M/V New Era*[2] depositing about 36,000 m^3 at Shelly beach, 23,000 m^3 at Aramoana, and 90,000 m^3 at Heywards Pt. Compared to the 2003-2005 ecological investigation period these 2010 totals represent a 2.75 increase in disposal volume at Heyward Pt., a sixfold decrease at Aramoana, and a fractional decrease at Shelly Beach. Disposal frequency at the three sites during the period of 2002-2005 differed from the disposal frequency during the 2010 calendar year (Figs. 3 & 4). Except for three periods of no disposals (totalling about 13 weeks where vessel was not available) there were no weeks in which Heyward Pt. disposal ground did not receive spoil while Aramoana and Shelly Beach had seven or more periods of 40 consecutive days without disposal events each. The Heyward Pt. disposal ground also typically received several disposal events per day (2–5) whereas Aramoana and Shelly Beach disposal areas usually received only one or two disposals on any day that disposal occurred.

2 a small number of additional disposal events were made by barges

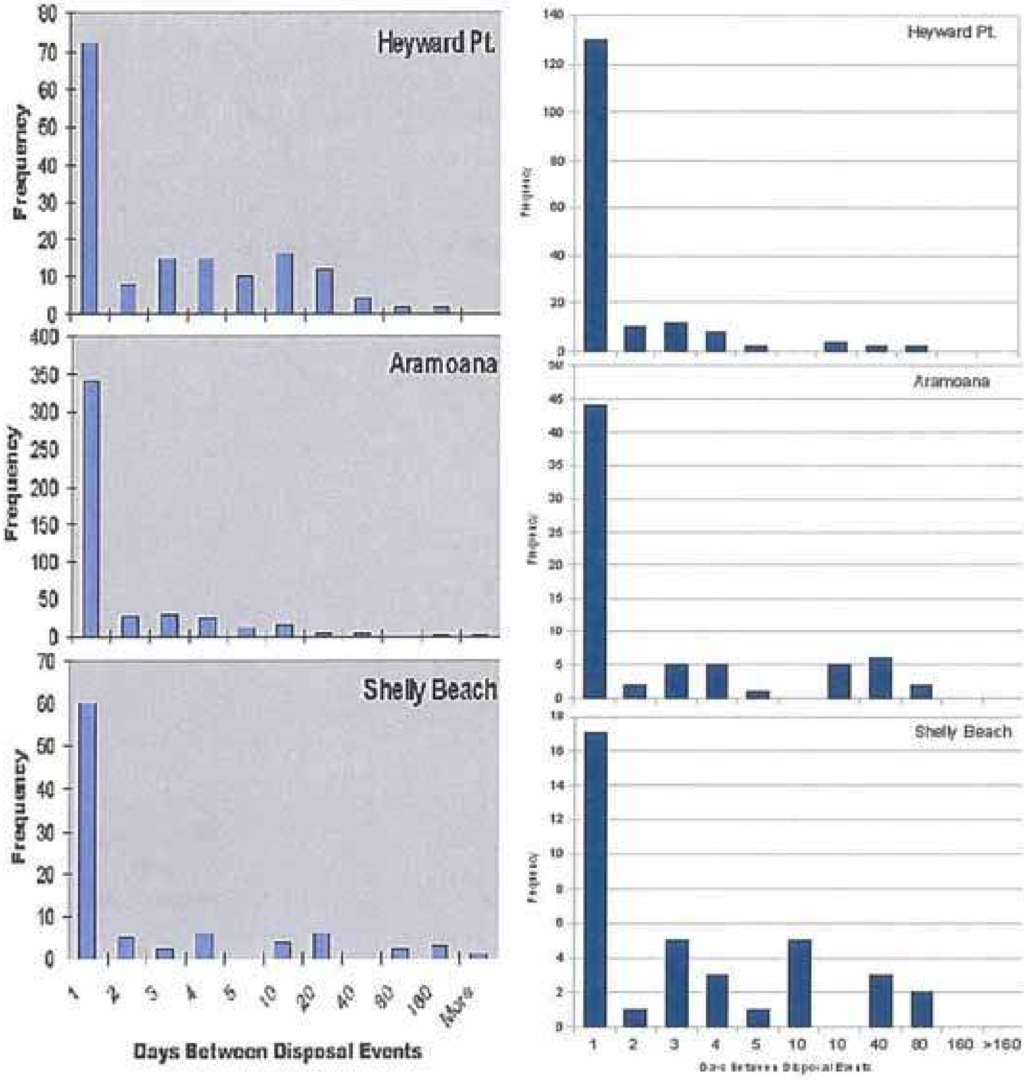


Fig. 3. (Left Panel) Frequency of disposal events between 17 September 2002 and 21 June 2005 (1008 days). The vertical axes indicate the number of times that the corresponding interval occurred (*e.g.* Shelly Beach received spoil with zero or one day's "rest period" 60 times in 1008 days) (Figures from Paavo 1997). (Right Panel) Frequency of disposal events during the calendar year 2010 (based on *M/V New Era* logs provided by POL).

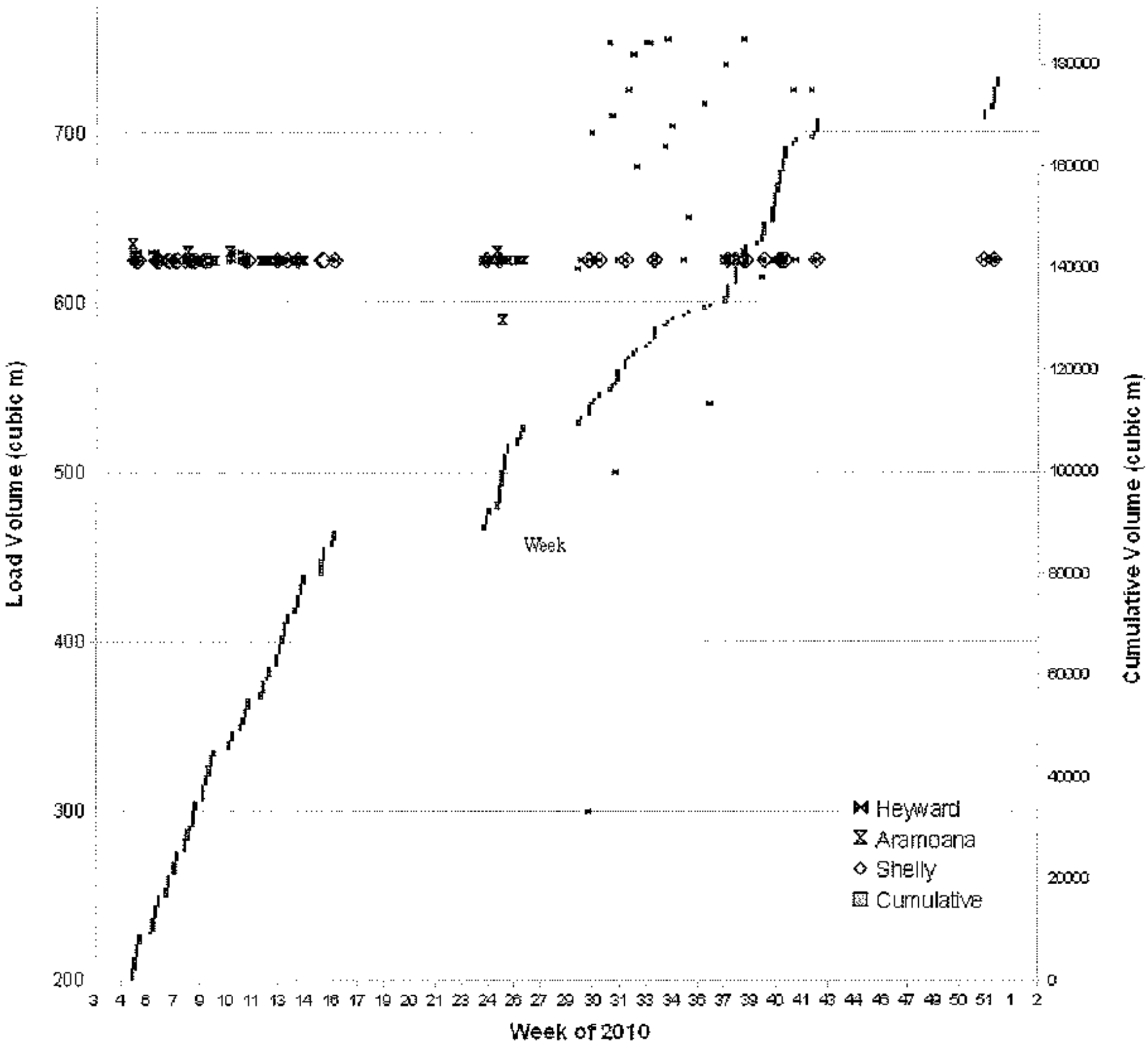


Fig. 4. Frequency of disposal events at each disposal ground throughout the calendar year 2010 (based on *M/V New Era* logs provided by POL). Most *New Era* loads were approximately 625 m^3. The slope of the cumulative volume trend indicates the rate of disposal over the year for year-by-year comparisons. Here the disposal rate was a mean 510 m^3 per day ($R^2 = 0.95$).

Shelly Beach

The Shelly Beach disposal ground (Fig. 1) is also known as South Spit in some publications. It is a shallow disposal ground in 3–8 m of water depth seaward of Shelly Beach. The 750 m wide sandy beach has been in an erosive condition since construction of the adjacent breakwater (c. 1884) blocked southerly transport of sediments. In the late 1980s erosion critically threatened the low dune system, human dwellings, and the Aramoana Salt Marsh, an area of national ecological significance (DOC 2011). Since then, POL has disposed of a quantity (approximately 20,000 m^3 per annum in 1987-2010) of sand from specific, texture-matched, claims into the Shelly Beach disposal ground at the request of regional and national authorities to renourish and stabilise the shoreline. Other than physical studies (*e.g.* Leon 2005; Ramsay 2005; Bunting *et al.* 2003b) POL has not commissioned ecological work in this area given the overriding conservation effort pertaining to shoreline systems. A shallow seaward shelf, extending about 500 m, and surrounding features protect the Shelly beach benthos from the most energetic wave and swell conditions except those coming from a northeasterly direction.

Aramoana

The Aramoana disposal ground is also known as Spit Beach in some publications. The disposal ground lies in waters varying from 6 to 12 m in depth seaward of sandy Aramoana Beach. Between 2002 and 2005 Aramoana received approximately 108,000 m^3 of sediment per annum (Paavo 2007). Leon (2005) described mound accretion at the site. An average of 52,0000 m^3 per annum was released at Aramoana between 2005 and 2010. Recent bathymetry and modelling (MetOcean Ltd. reports) indicates that the spoil mound is a dynamic morphological feature currently shoreward and north of its 2005 position. Aramoana is the most hydrodynamically energetic of the three disposal areas with frequent mobilisation of medium-sized sand grains.

Heyward Point

In the period of 2002-2005, when POL ecological studies began, approximately 40,000 m^3 of spoil was released at the Heyward Pt. site per annum. Between 2005 and 2010, approximately 48,000 m^3 were disposed of per annum with 109,000 released in 2010 alone. The disposal ground lies in waters varying from 9 to 23 m deep off the cliffs and rocky reefs of the Heyward Point headland separating the NE facing Aramoana shore from the more northerly facing southern shores of Blueskin Bay.

Sampling Methods

A variety of sampling and analytical methods have been used to collect biological and physical information in the study area since 2003. Detailed methods are available in each of the cited documents. Only an overview of each is provided here.

Grab Sampling (Macrofauna, Sediment Texture, and Carbon Content)

Most of the biological samples in this report were collected by grab sampling. Grab samples collect the top few centimetres of soft seafloor sediments where many of the epifaunal and shallow-burying macrofaunal taxa live. Because grab jaws must fully close to collect samples, grabs only collect soft sandy or muddy samples from unobstructed areas of the seafloor. Pebbles, rocks, or vegetation may hinder grab collections which are repeated until a successful collection is made. This method quantitatively samples dense assemblages (c. 10s to 1000s of individuals m^{-2}) of small animals well, but a wide variety of gear is required to sample the biodiversity present in any given area (Gray and Elliott 2009). Grab samples were also used collect sediment samples for physical analyses. Grab samples from 2003-2005 (Paavo & Probert 2005) wide-area efforts were collected using a Day grab with a sample area of 0.10 m^2 while the Aramoana manipulation samples were collected by a petite ponar grab with a 0.02 m^2 area. Subsequent grab samples (Willis *et al.* 2008; 2010 samples reported here, Paavo 2011) were collected using a standard ponar grab of 0.09 m^2 (290×300 mm). Because of these sampling differences all macrofaunal counts were transformed to densities (individuals m^{-2}) prior to analysis. Sediment texture samples were processed by the University of Otago Department of Marine Science using standard wet-sieving techniques (*e.g.* Lewis & McConchie 1974). The Total Carbon Content (TCC) of 4–6 mg sediment samples was determined using a Carlo-Erba 1108 CHNS-O analyser (Paavo 2007).

Macrofaunal Sample Processing

Animals were separated from most sediments by a combined elutriation and sieving protocol. This process was intended to provide a standard level of capture efficiency while minimising mechanical stress on the biological material to aid identification and curation. A solution of formalin was added to collections in sufficient quantity, depending upon water content and apparent organic content of the samples, for adequate fixation (typically c. 4% formalin). Samples were held in a cool, dark location for 3–4 days prior to further processing. Several litres of freshwater were added to each sample bag to dilute the fixative and suspend delicate animals. This supernatent was poured into a pre-wetted 1.0×1.0 mm aperture mesh sieve[3] except for samples from the 2004 Aramoana manipulation experiment where a 0.5×0.5. mm aperture mesh was used. A comparison of the taxa recovered from this energetic area indicated that mesh-size effects observed in deeper waters were not present and therefore these data were retained for analysis. In all cases, the sieve residue was then gently rinsed into a 70% ethanol preservative. The sediments were transferred to a shallow pan, agitated to suspend non-calcified animals, and the supernatent poured through the sieve. This elutriation process was repeated at least six times. If macroalgae was present in the sample it was manually extracted, washed over the sieve, and stored separately. For studies occurring after 2005, the entire sample was then also sieved. Where a significant quantity of coarse material (e.g. shell fragments or pebbles) was present an additional mesh was used and the coarse material was separated to minimise damage to specimens.

3 Additional information on macrofauna retained on a 0.5 mm mesh and meiofauna from the 2003-2005 wide-area samples has been reported by Paavo (2007), but those data are not addressed in this report.

Samples were manually sorted to the lowest readily identifiable taxon by experienced technicians in small aliquots using a stereomicroscope. Processing was done blind to sampling location through the use of sample codes (post-2005 samples). Samples were curated to the replicate level for subsequent taxonomic analyses and archiving. Any algal and shell surfaces were examined under a microscope, but sessile and colonial epifauna were uncommon. Abundance values presented in this report represent identifications to the highest practical taxonomic resolution at the time. For polychaetes and molluscs, this usually represented described species, morphospecies, or occasionally genera. Other taxa were recorded at various levels of resolution. The biological material has been stored for more rigorous taxonomic work at a later date if warranted.

Epibenthic Dredges

Benthic animals living on the seabed's surface which are at least several centimetres in size and neither affixed to the seabed nor able to swim away were surveyed using a towed dredge. This method samples taxa which occur at densities too low to be captured by grabs (less than 10 individuals m^{-2}). Variable efficiency makes this method semi-quantitative. The dredge used in this study had an opening of 680×240 mm with a 5×5 mm mesh cod end which was towed at 1.5–3 kts for 3–5 minutes on each deployment. Vessel position fixes (1 per second), recorded during positive ground contact, were used to quantify over-ground sampling distance. A submersible camera was attached to the dredge in later collections (Paavo 2011) to verify that it operated efficiently. Once on deck, the dredge was emptied, animals were photographed, and then identified to the lowest practical taxon. Several voucher specimens were collected, fixed in formalin, and stored in 70% ethanol but most animals were discarded after enumeration.

Benthic Imagery (Still and Video)

Photographs of the seafloor have provided both qualitative and quantitative information about the study area (Willis *et al.* 2008; Paavo 2011; present study). Formal analysis of physical features provided information on the density of large animals affixed to the seabed (such as sea tulips) and signs of animals (trails, mounds, and burrows) which burrow too deeply to be sampled by the methods mentioned above. Still and video images also provided qualitative information on sediment type, patch size, movement, and short-term (minutes to weeks) hydraulic energy indicators like sand ripples. Still cameras were deployed to the seafloor in a steel frame from a surface vessel. The vessel was allowed to drift over a ground distance of approximately 50 m at each photo site. While drifting, the system was set down on the seafloor five to ten times to capture plan-area views each encompassing 0.09 m^2 (280×310 mm). One or more video cameras mounted on the same frame allowed operators to compile notes on the area or record the deployment.

A number of parameters were estimated or enumerated from still and video images to characterise the substratum type, small-scale bedforms (see Amos & Friend 2005; Allen 1968), epifauna, and biological features indicating the presence of animals not sampled by other study methods (Table 2). No siphons of deeply burrowing bivalves were observed though use of the system within the Otago Harbour indicated that they were likely to be detected if they were present (Paavo & Probert 2008; Paavo 2009). Regularly shaped, presumably biogenic, holes observed fell into three apparently discrete size classes (Fig. 5). The smallest holes were typically 1–3 mm in diameter and were consistent in construction and distribution with polychaete and macrofaunal crustacean tubes. The origin and occupants of the mid-sized (<5 mm in diameter) and big holes (c. 10–20 mm in diameter) could not be conclusively proven in any one particular case, but a subset were sampled using an air-lift (see below).

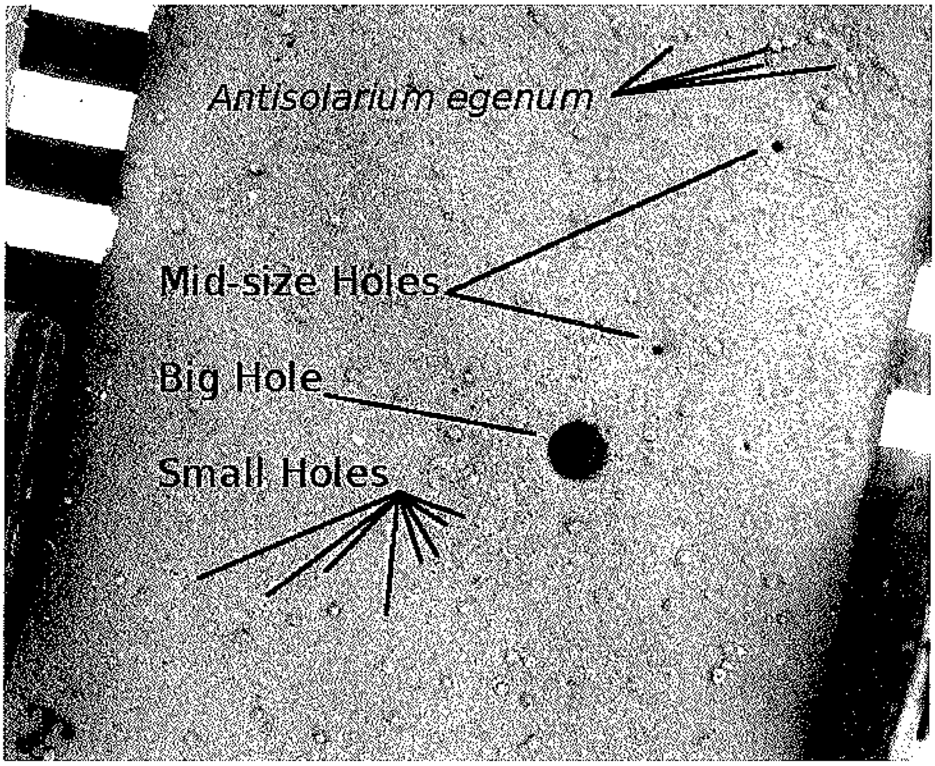


Fig. 5. Portion of a benthic image showing the three size classes of biogenic burrows, a high density of the snail *Antisolarium egenum*, and a ripple wavelength of about 12 cm. Each white and black band is 20 mm wide.

Table 2. Parameters enumerated or estimated from benthic still images.

Parameter	**Description**
Sediment fabric	(G)ranular or (C)ohesive apparent biological or physical binding of grains to each other
Texture	Apparent bulk sediment texture among the following classes: (B)oulder, (Cob)bles, (G)ravel, (CS) Coarse Sand, (MS) Medium Sand, (FS) Fine Sand, (MudS) Muddy sand, (S)ilt, and (P)acked clay or silt
Dominant bedform	Dominant bedforms among the following classes : (P)arallel ripples, (S)inusoidal ripples, (C)atenary ripples, (L)unate ripples, or (M)ounds and pits.
Wavelength (cm)	Wavelength (mean crest-to-crest distance) of ripples when present and <300 mm (lowe measurement limit)
Small holes	Presence or absence of holes approximately 1–3 mm in diameter, thought to be made by tube-building polychaetes and crustaceans. Indicate sediment binding and colonisation
Medium holes	Number of apparently biogenic holes c. 5 mm in diameter. Indicate that deeper-dwelling infauna have colonised area
Big holes	Number of apparently biogenic holes > 10 mm in diameter. Indicate that deeply burrowing infauna, unlikely to be sampled by grabs or trawls, have colonised the area
Biogenic pits	Feeding pits formed by burrowing animals or demersal fish
Biogenic mounds	Mounds apparently formed by burrowing animals
Fecal casts	Coils of sediment and organic matter extruded from the burrows of many types of worms and echinoderms
Floculent layer	Presence or absence of mobile floculent material in the benthic boundary layer
Algae	Presence or absence of macrothallus algae
Zethalia zelandica	Number of the wheel shell snails observed
Antisolarium egenum	Number of individuals of this snail species observed.
Notes	Observations not categorised above

Air-lift Sampling

Many deeply-burrowing species may leave little or no visual sign of their presence on the sediment surface, but the presence of large, well-maintained burrows in photographs indicates the presence of infaunal species unlikely to be sampled using the methods mentioned above. Rhoads and Germano (1982) used such features to infer the ecologically dominant successional stage present and the associated disturbance frequency (Fig. 6). An airlift sampler similar in construction to that described by Barnett and Hardy (1967) was used (without the bore cylinder) by divers to suction-collect sediments and animals from several holes in the study area. Sediments were winnowed by the sampler and animals were retained in a collection mesh bag with apertures of approximately 2 mm diameter. These samples provided qualitative information on animals found in and near burrows.

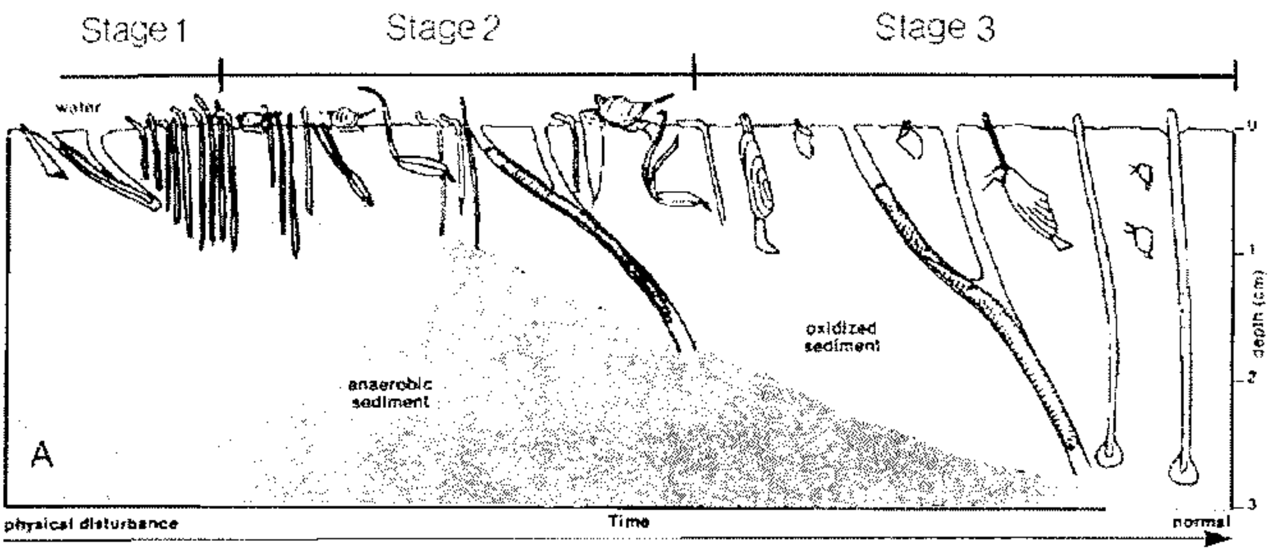


Fig. 6. Ecological successional stages as indicated by soft-sediment infaunal burrowing activities. (From Rhoads and Germano 1982)

Sidescan Sonar Survey

Sidescan sonar (SSS) uses a pair of sonar transducers towed near the seafloor behind a vessel. Sound transmitted to either side of the vessel track provides information on the topography of the seabed, such as ripple patterns and mounds, and composition (acoustically reflective or absorbtive surfaces). Most features observed during SSS surveys must be 'groundtruthed' using visual or physical sampling methods. SSS allows comparatively large areas (100s to 1000s of m^2) of the seafloor to be examined in moderate detail relatively quickly. Once SSS data are processed and geospatially resolved (*e.g.* methods described by Blondel 2009) thematic maps of seabed features can be produced. Low frequency SSS (c. 100 kHz) provide low-resolution information over great distances (100s of m) while higher frequency SSS (c. 600 kHz) provide higher resolution imagery over shorter distances (<50 m). As an example, Fig. 7 shows a calibration run near medium sand, rock, gravel, shell hash, and larger features around the Harbour entrance using a 450 kHz SSS. The Aramoana disposal area was similarly examined using a digital 675 kHz SSS in 2004 while the Heyward Pt. disposal ground was coarsely examined with an analog 100 kHz SSS in 2002.

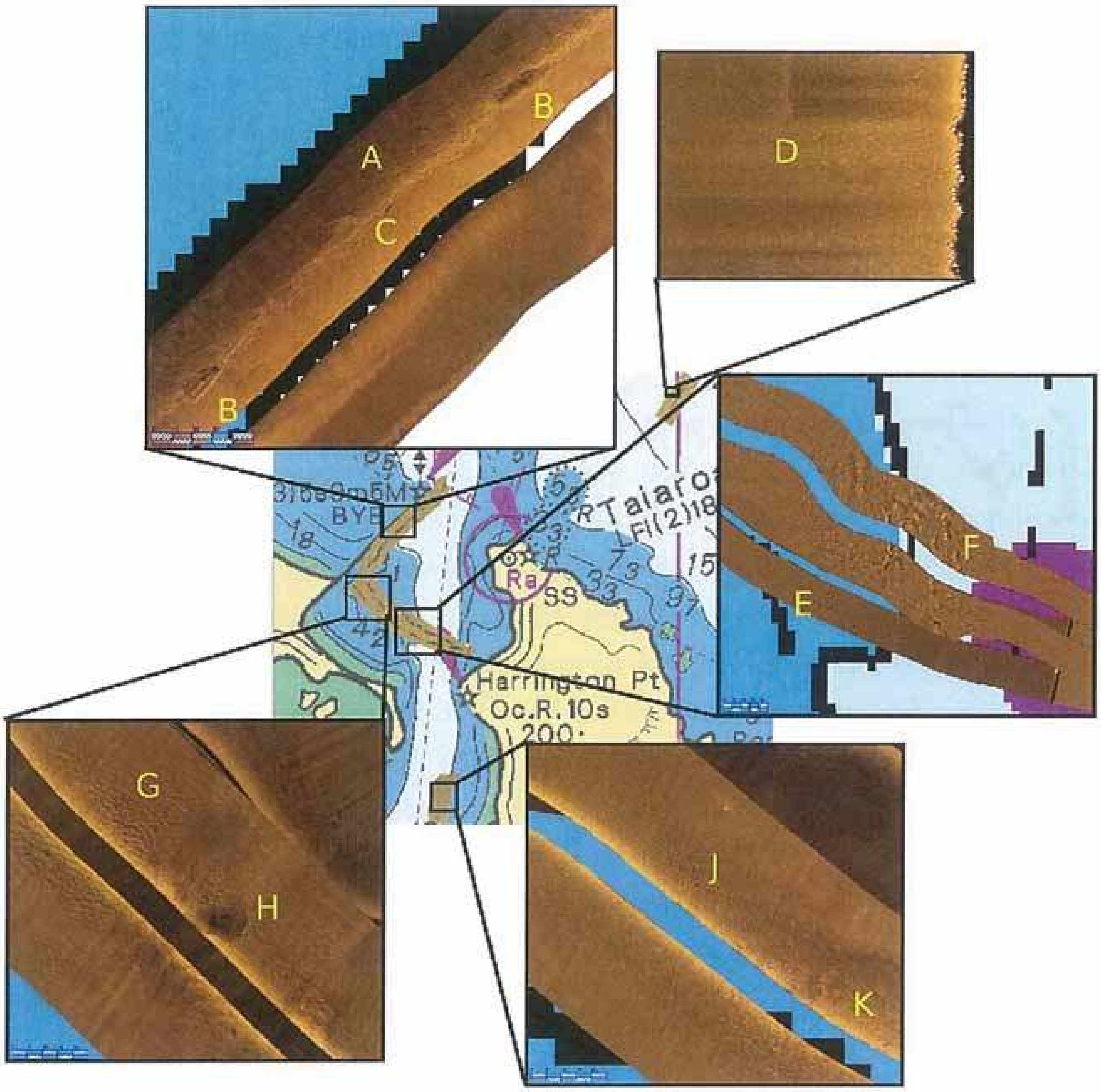


Fig. 7. Sample sidescan sonar mosaics from known benthic features collected near the Otago Harbour Entrance (overlaid on NZ Chart 661). A= Mole rock structure with overlying algae, B=shipwrecks, C=large rocks, D= flat medium sandy bottom sampled during 1.5 m swell conditions, E= short wavelength ripples and patches of drift algae with increasing shell content toward channel, F= shell and mudstone pavement in channel, G= longer wavelength ripples over medium and coarse sand, H= spoil disposal mound proud of bottom, J= three-pile channel marker, K= gravel and shell (mostly cockle) bed.

Data Analysis

All macrofaunal samples examined for this report were processed using the same methods, however each study identified macrofauna to different taxonomic resolutions for pragmatic reasons. In order to analyse broad patterns in analyses crossing years and studies, undescribed morphospecies were resolved to common taxa, usually by lumping them to family level. Examination of broad spatial patterns is the focus of these cross-study comparisons. Extreme caution should be exercised when using these cross-study data for any other purpose. Agglomerative effects are necessarily more pronounced for uncommon taxa.

Taxon richness (S_{obs}) values cannot easily be extrapolated from studies which used different sample collection areas (m^2, survey grain) and different spacings between samples (survey lag) so values represent the number of taxa recovered in any single grab event. Caution must be employed when comparing values between different studies. For large, annually reproducing species, diversity can vary as young may be captured or excluded depending up sample timing. The taxonomic resolution of any one study greatly affects the utility of cross-study comparisons.

Macrofaunal analyses were conducted partially blind with all taxa converted to anonymous codes prior to statistical analyses. Data were extracted from a PostgreSQL database for simple manipulation, calculation, and graph generation using spreadsheet applications. Univariate tests and plots were performed using R (R Development Core Team, 2010) or MiniTab (MiniTab Corp.) software applications. The Anderson-Darling statistic was used to test for data normality prior to calculation of confidence-intervals. Confidence intervals (CI) are at α=95% unless otherwise stated. Multivariate statistical comparisons and plots were performed using the PRIMER v.6.0 (or earlier) suite of applications (Clarke and Gorley 2006) described by Clarke (1993). Unless otherwise indicated, all analyses were conducted on macrofaunal densities (individuals m^{-2}) from whole grabs.

Soft-sediment macrofaunal diversity was evaluated using a number of methods. The most basic measure of diversity, the number of taxa observed (reported as richness or S_{obs}) was used most frequently. The dimensionless Shannon diversity measure (H') includes information on the number of taxa and the distribution of individuals among those taxa for comparison with other studies (Shannon & Weaver 1963). Values of H' typically range from 1 (low diversity) to 4 (high diversity). Pielou's Evenness is also a dimensionless metric (J') which describes how individuals were distributed among taxa (Pielou 1966). A J' value of 1 indicates that an equal number of individuals were found in every taxon, while a value closer to zero indicates that one or more taxa contained most individuals. Simultaneous review of H' and J' values allow comparison of site assemblages which may be impoverished or dominated by a few taxa.

The macrofaunal biodiversity of the study area as a whole, and sampling effectiveness, were examined using a taxon accumulation curve where 999 permutations of sampling order were used to assess the diminishing number of species encountered (S_{obs}) as more samples were collected. The Chao2 procedure produces a similar metric, but also includes information on the probability of collecting any given taxon in another sample. The Chao2 procedure has been shown to more accurately represent the number of taxa actually present in an area than the simple S_{obs} accumulation curve (Hortal 2006). It is important to note that all of these diversity measures estimate the number of taxa likely to be found with more sampling using only the same methods, sampling the same community (*e.g.* macrofauna only in space not time), at the same level of taxonomic detail. Many more species are present in the study area than are represented in this work.

Abundance data were fourth-root transformed prior to multivariate analysis to provide more statistical weight to less-frequently occurring taxa while down-weighting abundant taxa. The macrofaunal assemblages among grabs were compared, using abundance and composition information with Bray-Curtis similarity ranking (dendrograms were produced using group-average branch linking). The contribution of any single taxon to the overall 'distinctness' of a given sample group was determined using the SIMPER protocol in PRIMER. ANOSIM subroutines were also used to evaluate the significance of differences between *a priori* sample groups (e.g. disposal areas vs. near-field controls). This procedure is a multivariate counterpart to the MANOVA-family of analyses and tests the null hypothesis of no assemblage difference (in terms of sample taxon abundance and composition). ANOSIM was also used to facilitate comparisons between sites with no *a priori* design rationale where hypothesis testing is not appropriate. However, using this *post-hoc* classification as a factor in analysis, the ANOSIM procedure quantified the numeric robustness of cluster separation observed between samples where this couldn't be determined by other means.

Non-metric multidimensional scaling ordinations (nMDS) were constructed to aid interpretation of assemblage similarity values. In each nMDS plot any two samples close to each other in the two-dimensional plot were more similar to each other in taxonomic composition **and** abundance than any two samples plotted further apart. Because similarity was measured in many dimensions, some information was lost when multi-dimensional results were reduced to a two-dimensional plot. A convention has arisen where a 'stress-value' indicates the level of distortion due to this dimensional reduction. Stress values of 0–0.1 imply that the sample point separations on the plot accurately reflect differences in sample assemblages as described by the Bray-Curtis similarity statistic. Stress values of 0.1–0.18 indicate that the spacing is increasingly distorted from the true multi-dimensional spacing of sample centroids, but are still informative. Stress values from 0.2–0.3 suggest that plots should be interpreted with caution, while values greater than 0.3 indicate that almost no stable relationship exists between the plot and true statistical values.

Spatial analyses were conducted using the Q-GIS (Quantum GIS Core Team 2010) with PostGIS installed, and GRASS (e.g. Neteler & Mitasova 2008) geographic information systems (GIS). Field point observations were collected using the WGS84 geographic datum, but data were frequently transformed to convenient projections for presentation (*e.g.* NZ Transverse Mercator

2000). Bathymetric depths are presented as metres from Otago Harbour chart datum, while field observations were not tide-corrected.

Collections

2003

POL began its current programme of coastal ecological analysis in 2003 with a wide-area study reported by Paavo & Probert (2005) and Paavo (2007). Collections were made (Fig. 8) in March and October to examine the animals present, identify coarse bathymetric patterns, longshore-distributions, and whether 1.0 mm aperture meshes provided adequate information compared to the more time-intensive 0.5 mm mesh collections. Simple meiofaunal analyses (animals passing through a 0.5 mm mesh, but retained on a 0.063 mm mesh) were also conducted. Only 1.0 mm aperture mesh data are presented here to allow comparison with subsequent studies.

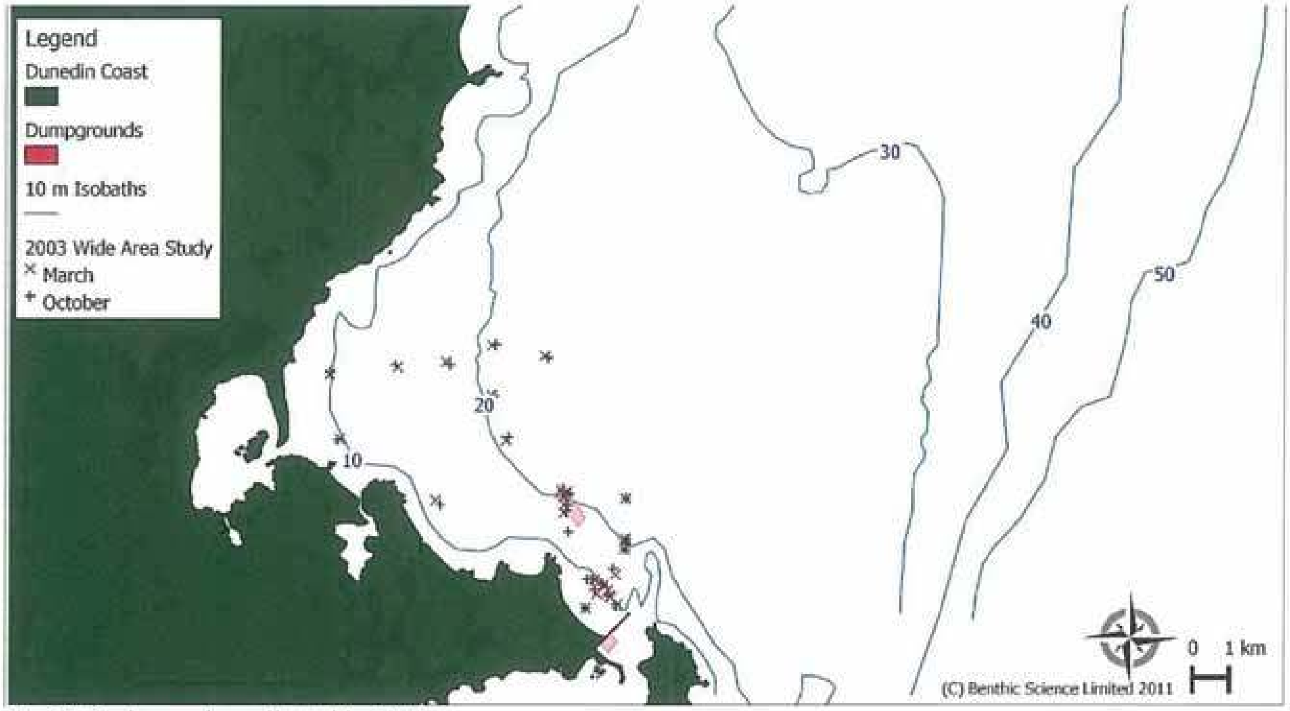


Fig. 8. Grab samples collected in 2003.

2004-2005

In 2004-05 POL conducted a field manipulation (Paavo 2007) at Aramoana to validate a model for the initial size of individual disposal events on the seafloor (mud and sand), recolonisation rates in the energetic Aramoana environment, and the faunal-transplanting potential of sand disposal operations in a coastally-responsible fashion. An area of the Aramoana disposal ground was reserved for a period of at least 180 days, then sampled by grab and SSS. One sand and one mud load were released in the area, and those areas were then sampled incrementally over a period of 119 days (Fig. 9).

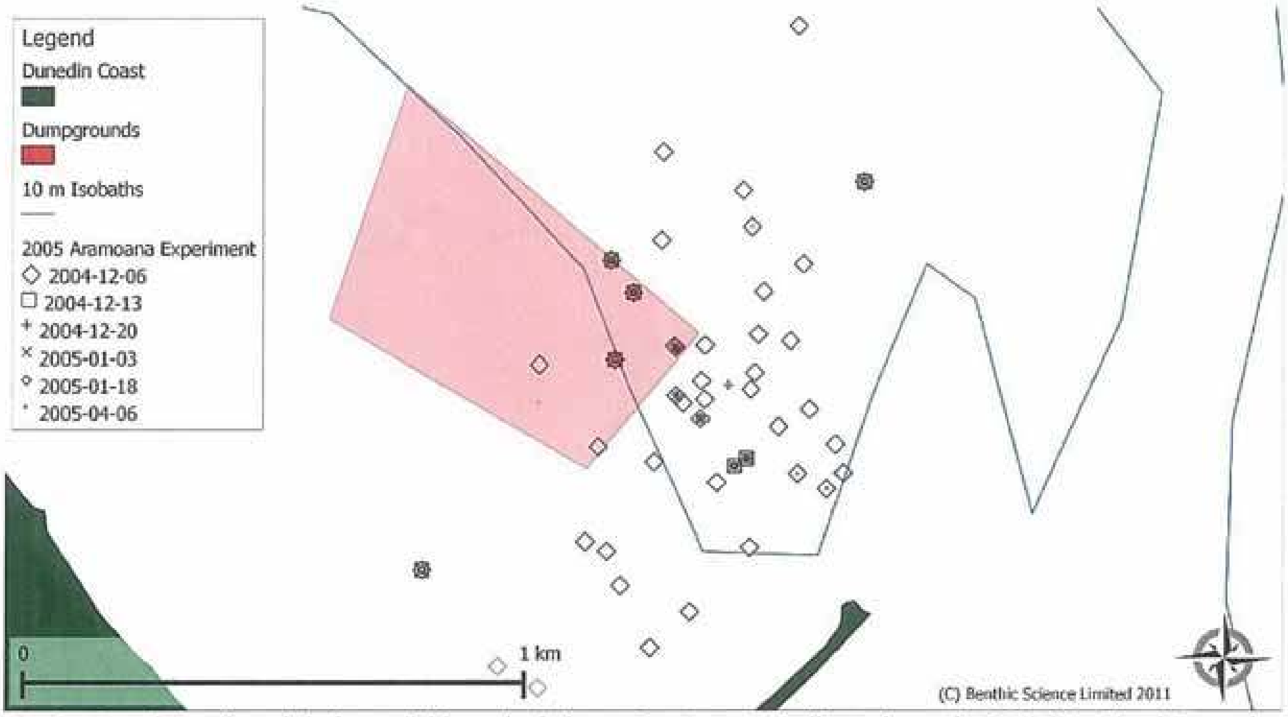


Fig. 9. Samples collected during a field manipulation at the Aramoana disposal area in 2004-05. The 6 December samples were taken along the bathymetric gradient and sampled only once prior to experimental disposal. Subsequent samples were at the indicated subset of those locations representing impacted, near-field, and far-field conditions relative to the sand and mud disposal events.

2008

In 2008 Willis *et al.* (2008) used a grid-based approach to grab sample (with replicates) the broader coastal environment surrounding the disposal areas and Blueskin Bay (Fig. 10) to provide impact context. Sidescan sonar, sediment analyses, and drop-video transects were also conducted.

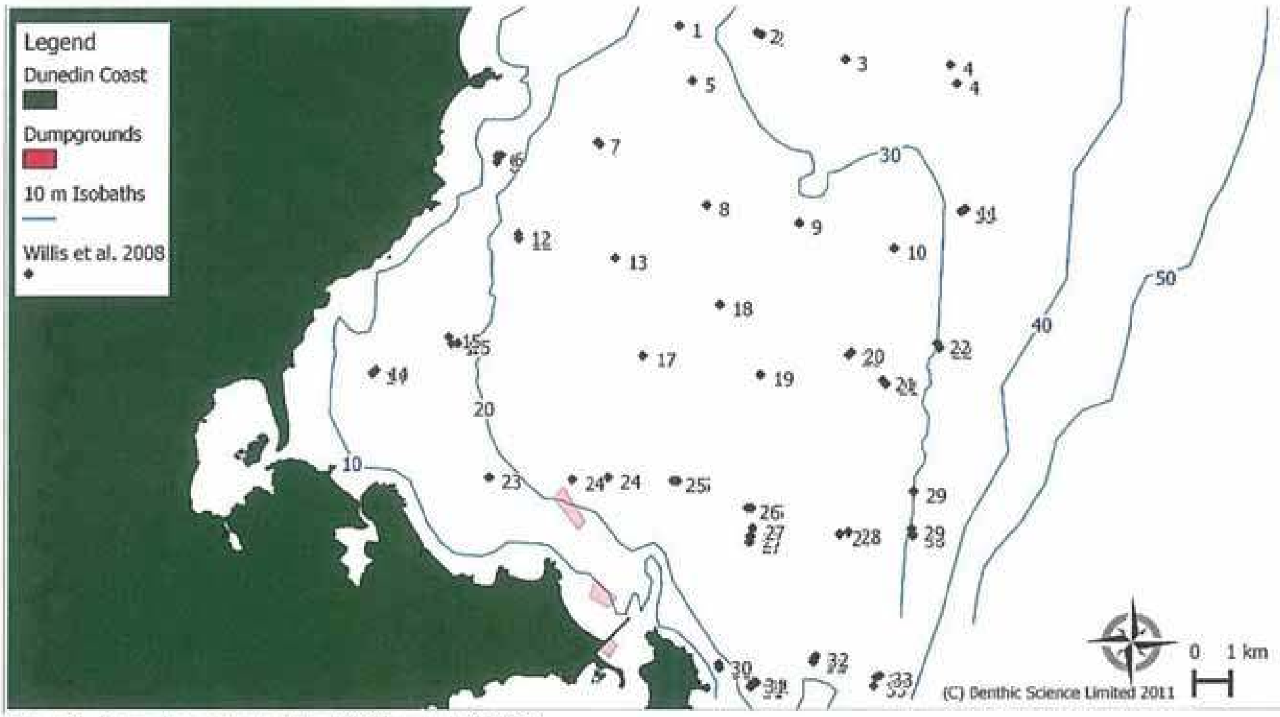


Fig. 10. Samples collected by Willis *et al.* (2008).

2010 A0 Mapping

In 2010 POL examined the macrofauna closer to the seaward edge of the sandy shelf facies (Paavo 2011). SSS returns, dredge vollections, and benthic images were gathered in addition to grab samples (Fig. 11). These collections provided further context for the study area with respect to the predominantly northward-moving water masses.

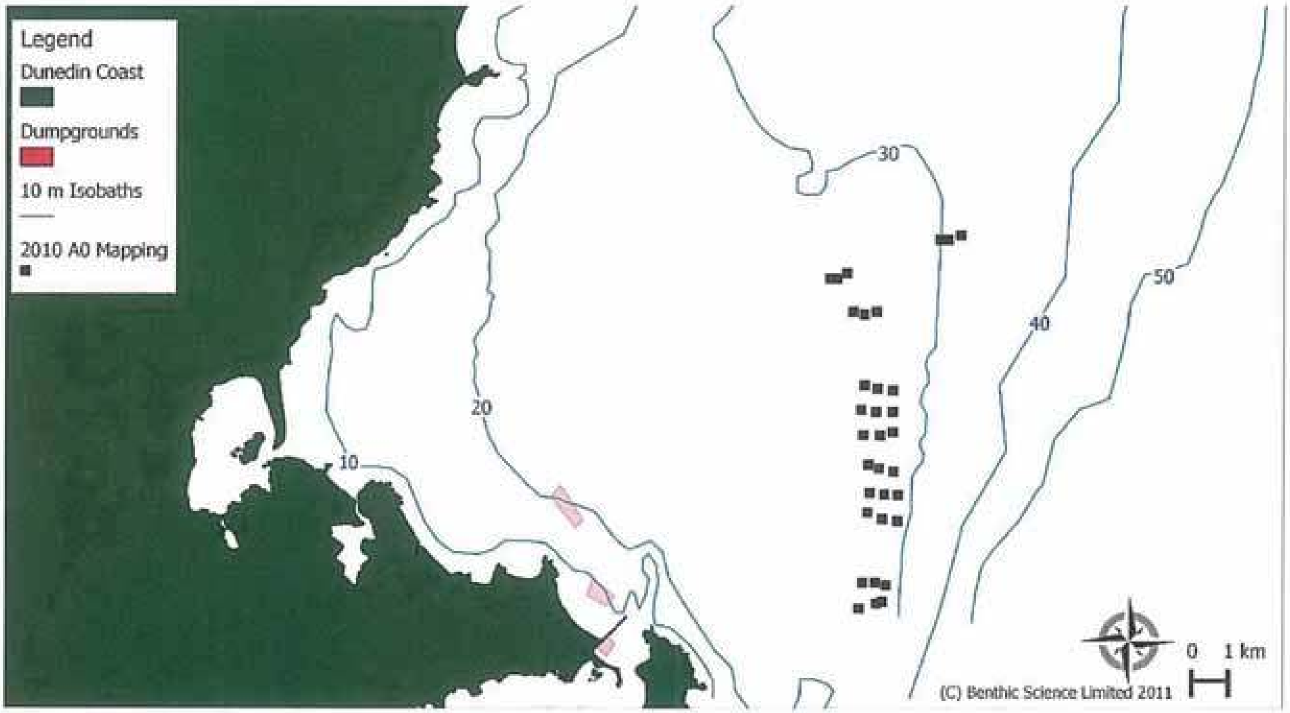


Fig. 11. Samples collected by by POL for the A0 Mapping project (2010).

2010-2011 Maintenance Seasonal Sampling

In September 2010 POL collected samples around the Heyward and Aramoana disposal areas to complement the 2005 wide-area study and to provide higher spatial resolution of assemblages around the existing disposal areas. A subset of those sample sites were sampled again in late December 2010 and will continue to be sampled quarterly until September 2011 to provide information on the seasonal fluctuations in abundance, diversity, and potential indicator species to help develop an efficient disposal ground monitoring programme for the future (Fig. 12).

Fig. 12. Sample sites for 2010-2011 collections for seasonal effects analysis near the disposal areas.

Results

Original data and detailed analyses are available in each of the cited documents. The results presented here represent a synthesis of findings. Similar methods, equipment, and personel were used for each report. While such a synthesis provides a valuable, generic, analysis of patterns in the study area, extreme caution must be used when comparing the absolute magnitude of observations taken in different locations or times (Fig. 13).

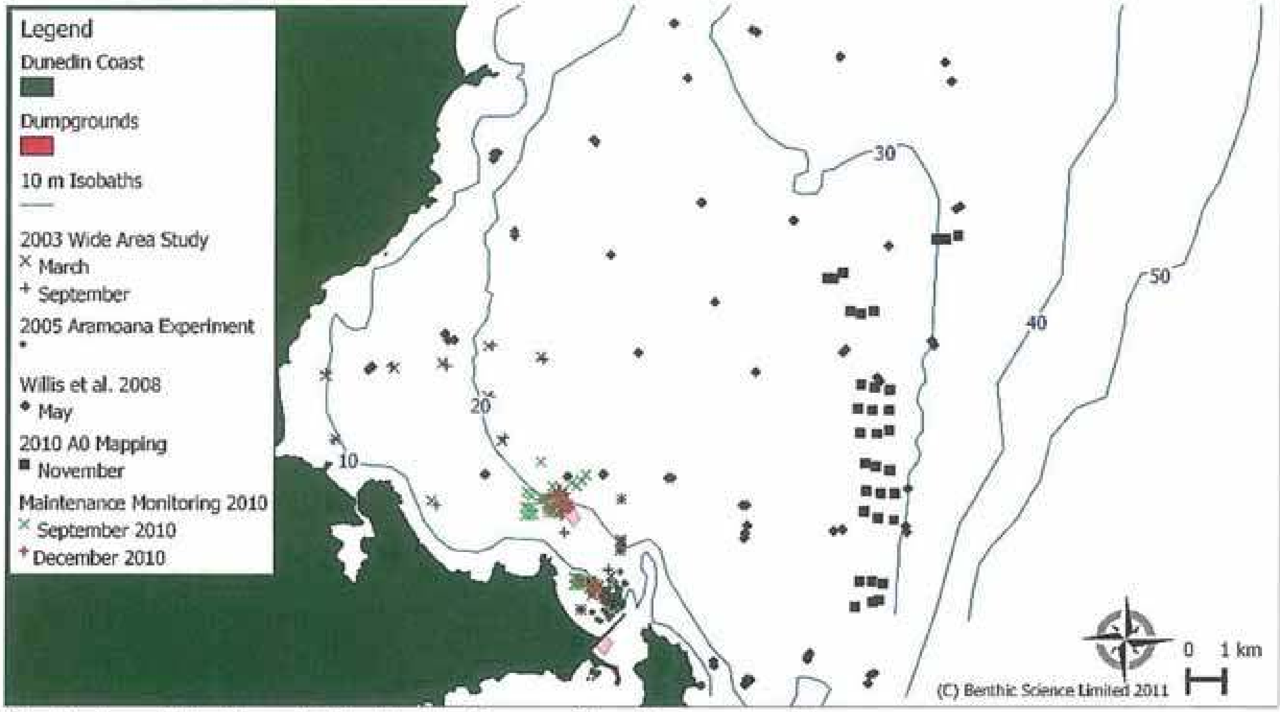


Fig. 13. Sample locations of **all** grab collections considered in present analyses.

Sediment texture

Recent sediment texture analyses (Willis *et al.* 2008; Paavo 2011; Paavo 2007; Paavo & Probert 2005; Bunting *et al.* 2003a; Smith 1994) are broadly consistent with those described by Andrews (1973) and have been independently verified. A fine sand wedge extends from about the 20 m isobath to past the 40 m isobath throughout the study area. Inshore of that wedge is a slightly coarser sand which grades from about 2.0 Φ near the harbour entrance to a finer 3.5 phi median grain size in the the centre of Blueskin Bay near the 21 m isobath (Fig. 14). There are isolated patches of rubble and rocky reef adjacent to the shore, but such features are rare offshore. Coring sections (Paavo 2007) found the same texture pattern at the seabed surface (0–20 mm), at sediment depths of 20–40mm, and 40~55 mm with negligible seasonal differences. The finer grains contain an increasing amount of carbon ranging from 0–3% (by loss on ignition methods which does not guarantee that it is biologically available)(Fig. 15). Water depth, sediment texture, and carbon content are expected to be the primary natural variables shaping soft-sediment ecological patterns in coastal temperate waters such as these (Gray and Elliott 2009).

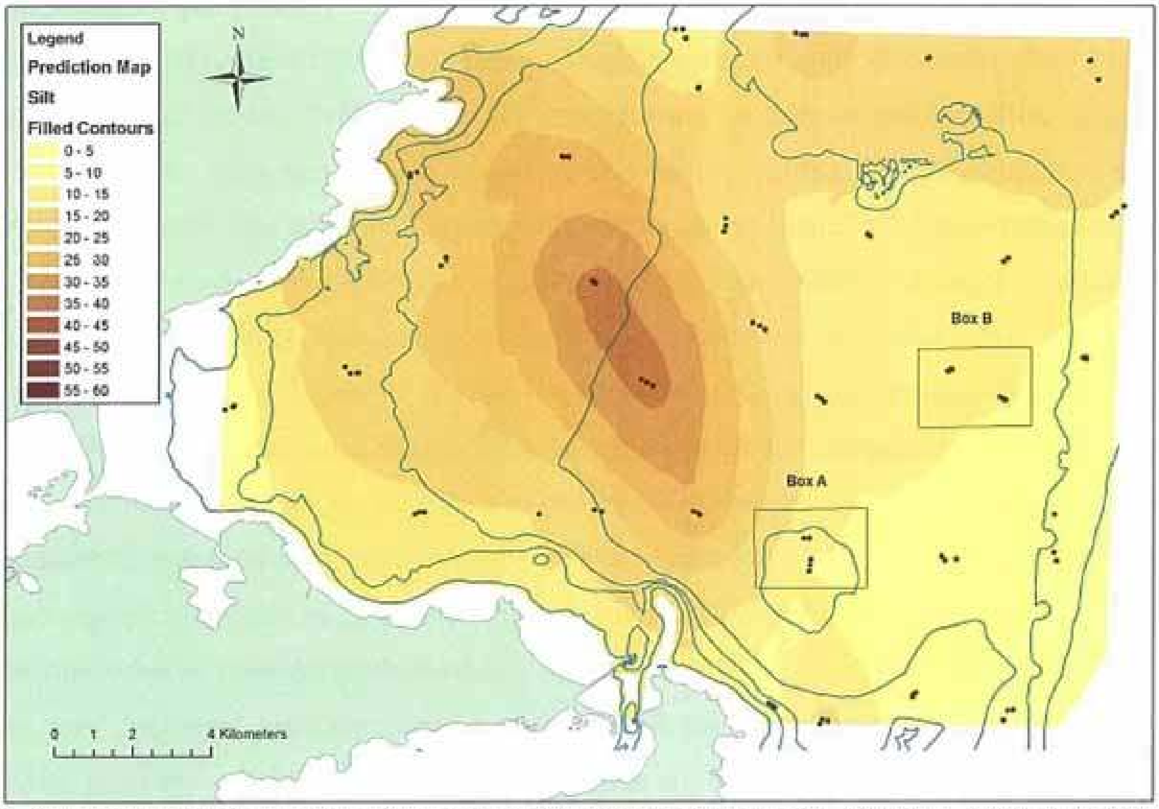


Fig. 14. Silt content of sediments illustrating texture gradient across the study area. (Figure 11, Willis *et al.* 2008).

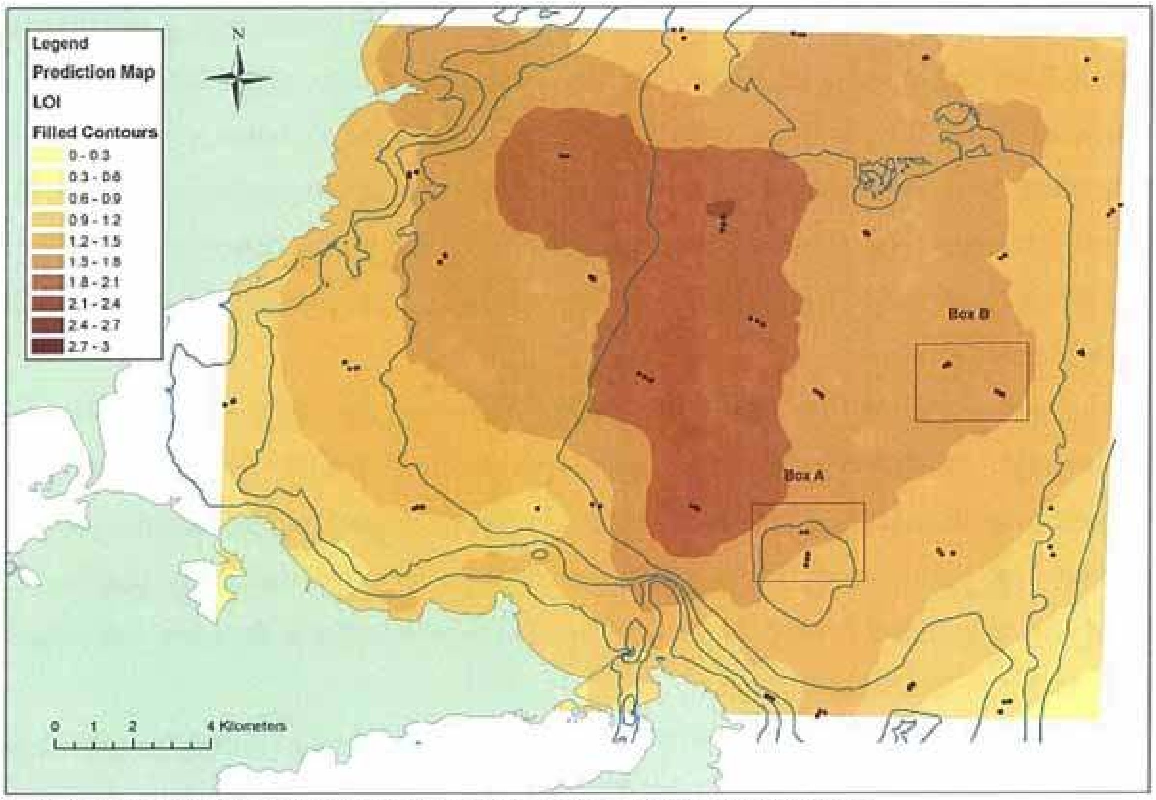


Fig. 15. Carbon content (by LOI) across the study area. (Figure 10, Willis *et al.* 2008).

Sidescan sonar surveys and deposition footprints

The primary purpose of the SSS surveys was to delineate mud, sand, or gravel dominated sediments in the study area. Given this objective, no attempt was made to groundtruth individual acoustic reflectors other than calibration targets and spoil mounds and effort was preferentially applied to truth areas corresponding to discrete acoustic return textures. Shelf swaths inshore of the 30 m isobath were dominated by strong acoustic returns from a rippled fine sand bottom confirmed by video ground-truthing. Reflective structures proud of the seafloor were rare. Occasionally observed 'point' returns without shadows were likely molluscs or echinoderms given video and dredge observations in the area, but one-to-one correlations of such small structures are impractical to resolve. Small aggregations (c. 1–3 m) of such points represented shells accumulating in the troughs of larger sand ripples. Acoustic returns consistent with algae having large blades and gas bladders (such as *Macrocystis* or *Durvillaea* among others) were occasionally observed. No gravel or substantial shell patches were observed. SSS swaths at the northern boundary of Blueskin Bay near Waikouaiti Bay grew increasingly softer with less developed or no ripples though depth also increased along the track. Drop-videos used for ground-truthing showed near-bottom turbidity suggesting that the acoustic energy was being reflected by a consistent boundary layer of water transporting very fine sediments likely due to tidal flows (surface conditions were calm, Beaufort 2-3, with swell <1m).

The Heyward Pt. disposal ground was only examined with coarse analog 100 kHz sidescan capable of little post-processing refinement. The resulting mosaic (Fig. 16) showed a greater patchwork of bottom types than were present offshore, near Aramoana, or Blueskin Bay. Groundtruthing by grabs indicated that the textural mosaic represented patches of medium sand and cobbles with tunicates (mostly sea tulips) and occasional shell hash patches on the 10s of metres scale on the southern half of the disposal areas while the deeper, northwestern half was consistently covered by rippled sand.

The high resolution (675 kHz) of the digital Aramoana SSS survey in 2005 allowed better post-processing. A thematic map was created to describe benthic features likely to bound macrofaunal assemblages (Fig. 17). Elongate ovoid 'spindles' contained asymmetic, unidirectional flow features around a central mound while the seaward face had oscillatory ripples. Coarser sediments graded to gravel toward the sub-surface *Macrocystis* bed near the Mole and mega-ripples were present NE of the disposal ground.

SSS observations validated the STFATE computational model of initial sediment deposition from typical 625 m^3 loads as released by the *M/V New Era*. Despite vessel motion during disposal over shallow water, sand disposals (characteristic of Entrance, Howlett's, and Harrington Bend claims) were consistent with model predictions 300 seconds after disposal. Sand mounds were approximately 86 m in diameter with only slight elongation along the disposal track. The initial deposition mound was, at most, 0.4 m proud of the seafloor in the centre (Fig. 18). Dewatered silty sediments (characteristic of Dunedin basin and wharf approach claims) impacted the sandy seafloor with greater force (less water entrainment) and temporarily cratered the seafloor in a fashion that was not modelled, but overall deposition boundaries again validated the STFATE model 300 seconds after disposal (Fig. 19). The mud spoil footprint was approximately ovoid with a long axis of about 135 m and a short axis of approximately 90 m with the mound <0.6 m proud of the seafloor in a small area (9 m^2) due to the cratering.

A recent run of an updated version of the STFATE model (available via the US Army Corps of Engineers) was also used to predict individual spoil footprints in 22 m deep waters (flat bottom) using the same vessel and physics parameters used in 2005. A sand disposal had a maximum height of 0.24 m proud of the bottom with an along-vessel track of c. 120 m and spread of c. 122 m. A release of dewatered spoil comprised of 80% silt and 20% fine sand had a modelled footprint of about 124 m diameter with a maximum central peak of 0.43 proud of the bottom. Investigations with adult snails *Zethalia zelandica*, one of the most numerous and likely robust macrofaunal species in the disposal areas, indicated that rapid burial with sand to 200 mm depth had a mortality rate of approximately 70%. The same mortality rate was reached with rapid mud burial of about 30 mm, and 100 mm burial had a near 100% mortality rate.

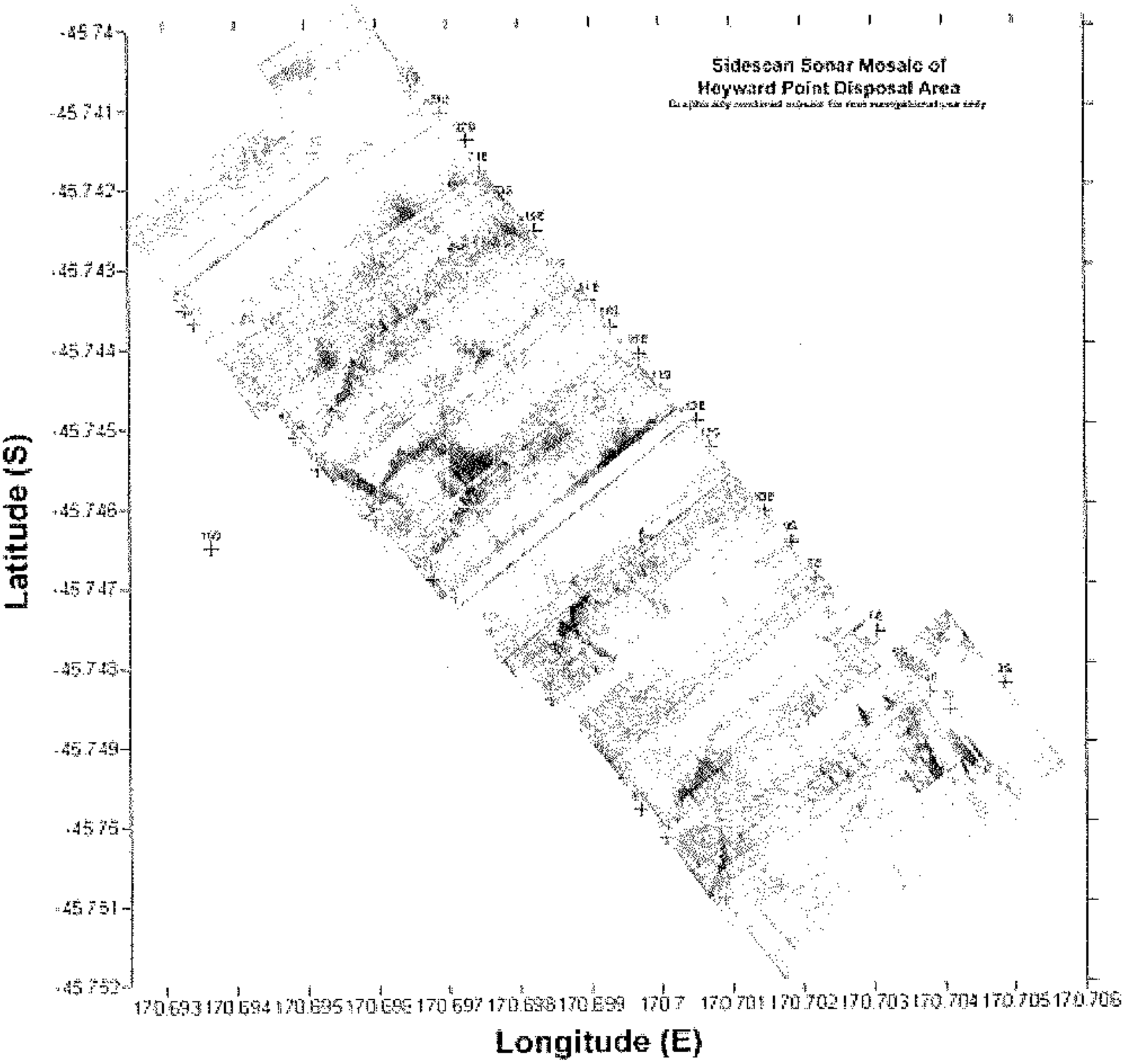


Fig. 16. Manually constructed mosaic of a sidescan sonar survey of the Heyward Point disposal ground (2002).

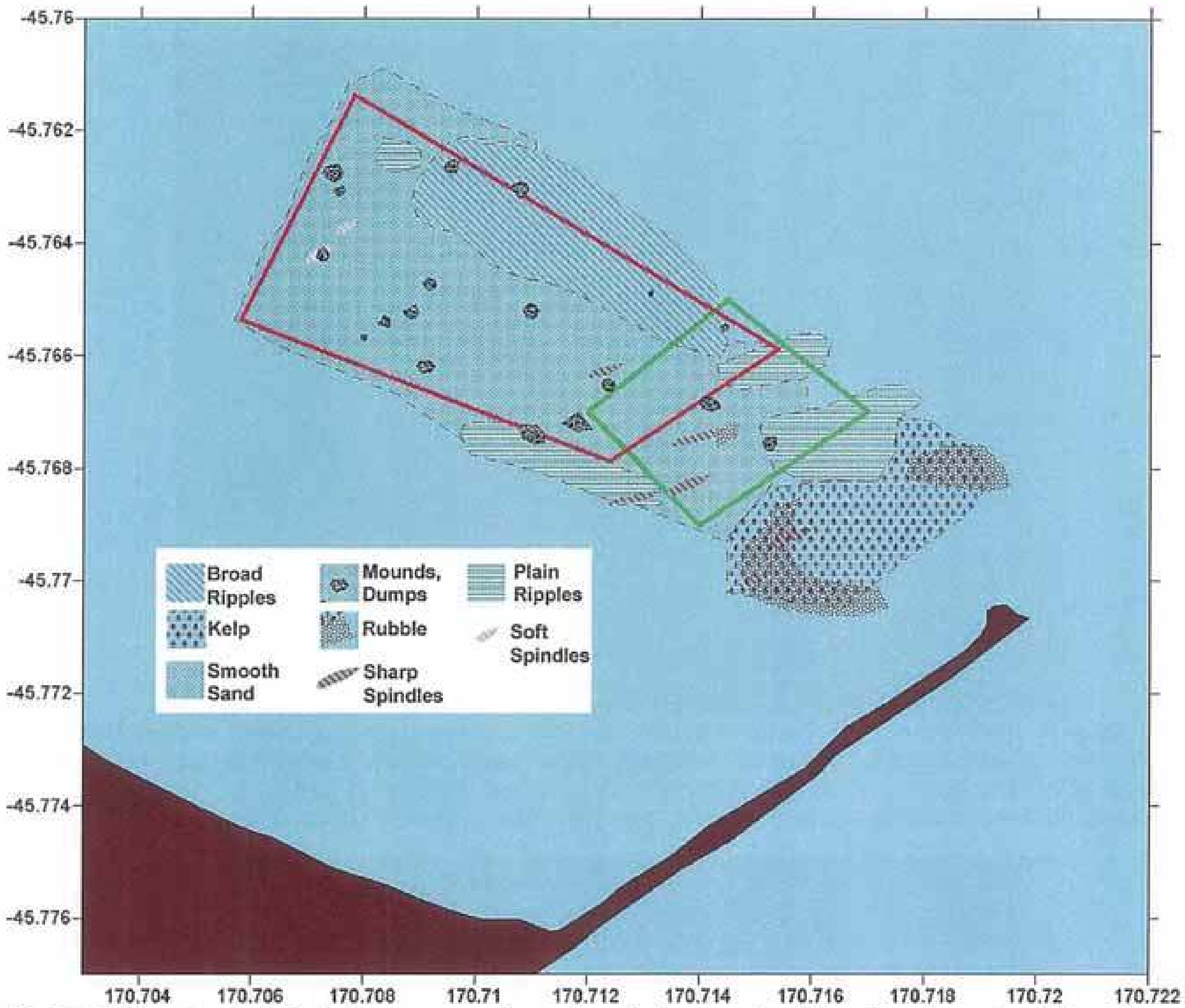


Fig. 17. Bottom characteristics in the Aramoana disposal area (red polygon) and the adjacent experimental area (green polygon) derived from a high-resolution sidescan sonar survey (2005). (Figure 5.10 from Paavo 2007)

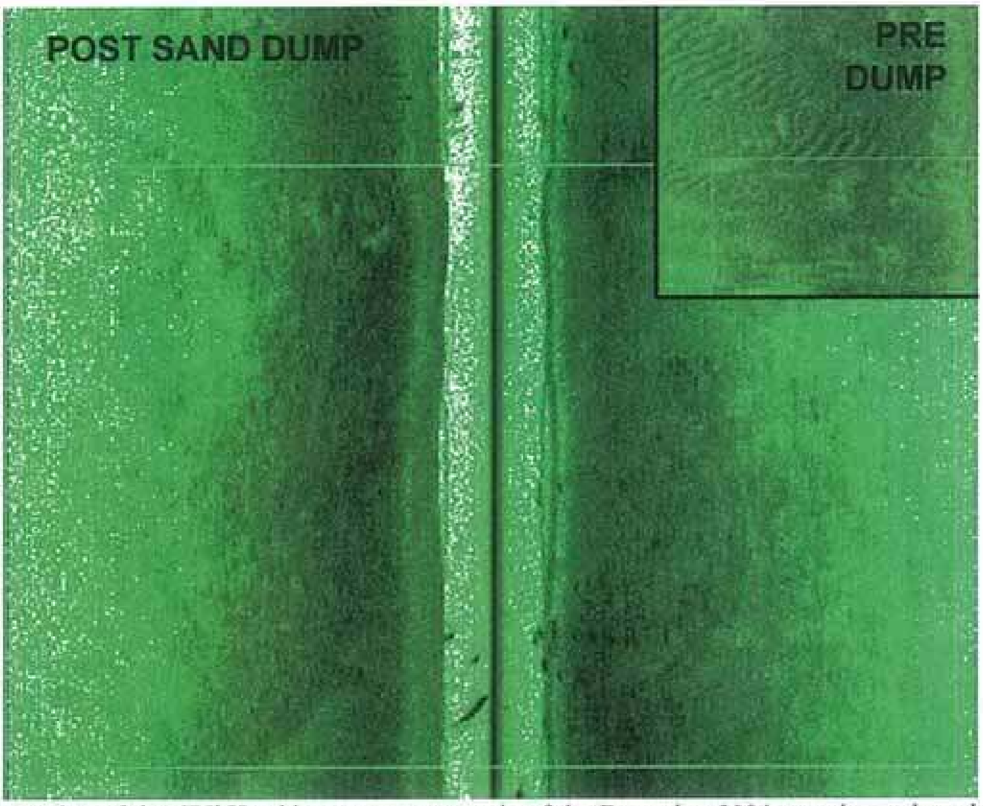


Fig. 18. A portion of the 675kHz side-scan sonar mosaic of the December 2004 experimental sandy spoil area. The inset shows the same area prior to disposal. The spoil margins are not as distinct as the mud spoil, but there is an absence of bottom ripples when surveyed in the same track heading. Kelp can be seen in the water column (centre) portion of this image which was not removed during post-processing. (Figure 5.13 Paavo 2007)

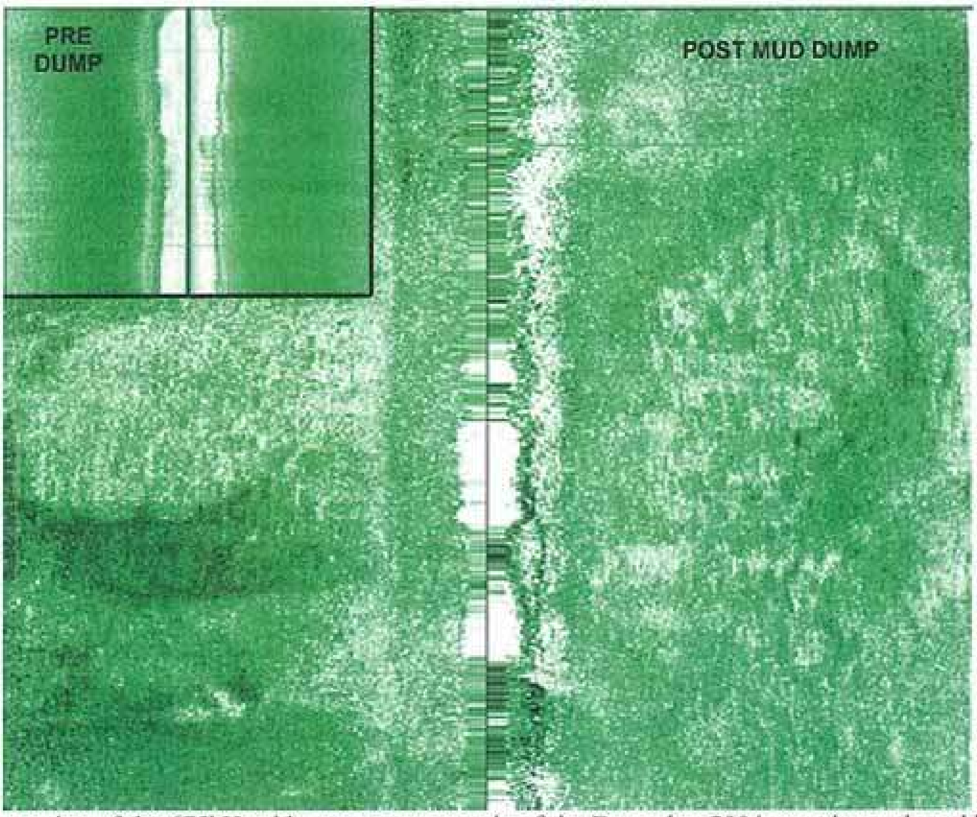


Fig. 19. A portion of the 675kHz side-scan sonar mosaic of the December 2004 experimental muddy spoil site. The inset shows the same area prior to disposal. The crater-like mound on the right-hand side of the image is the primary impact site and collapse surrounded by spreading spoil while the left-hand track shows the trailing mound of less compacted mud as the M/V *New Era* moved on. (Figure 5.12 Paavo 2007)

Benthic still imagery

Benthic images were collected at Aramoana and Heyward Pt. disposal areas in 2010 (Fig. 20). Imagery showed rubble present at Aramoana sites 2 and 11 among otherwise strongly rippled clean, medium sand. Sites 4–6 had slightly more broken shell than other Aramoana locations. Bedforms at Heyward Pt. indicated stronger seabed water motion at the SE sites (13–16) declining toward the NW with increasing depth. Dark fine particles (floc, silt, or debris unlikely to be identified in textural analyses) was present at sites 17–19 which contrasted with other flocs (sites 29–32). Floc was most frequently observed in the centre of the Heyward Pt. disposal ground where, anecdotally, most disposal events probably occurred. Surface sediments at these sites did not appear to vary in dominant texture or fabric from adjacent floc-free areas. Pebbles and cobbles were found among sand patches at sites 23, 24, and 56.

Biogenic features were almost entirely absent at Aramoana where only a few medium-sized infaunal burrows were present (Fig. 21). Other photo sites shallower than the 15 m isobath were devoid of obvious biogenic or depositional features. Feeding pits, likely formed by demersal fish, were the most common biogenic feature. Faecal casts made by deposit-feeding infauna were also common below the 15 m isobath, but were mostly absent from nearfield sites. In general, at sites beyond the 15 m contour where one biogenic feature such as a burrow was present, several others created by different processes were present as well with the exception of the centre of the Heyward Pt. disposal ground (though limited data outside of the disposal ground hinders an evaluation). The northwestern quarter of the Heyward Pt. disposal area presented indications of burrowing and multiple modes of deposit feeding infauna similar to areas outside the disposal ground. There were fewer signs of advanced successional stage activities in the remainder of the disposal ground. Signs of deposit feeders were absent at locations of the highest floc occurence.

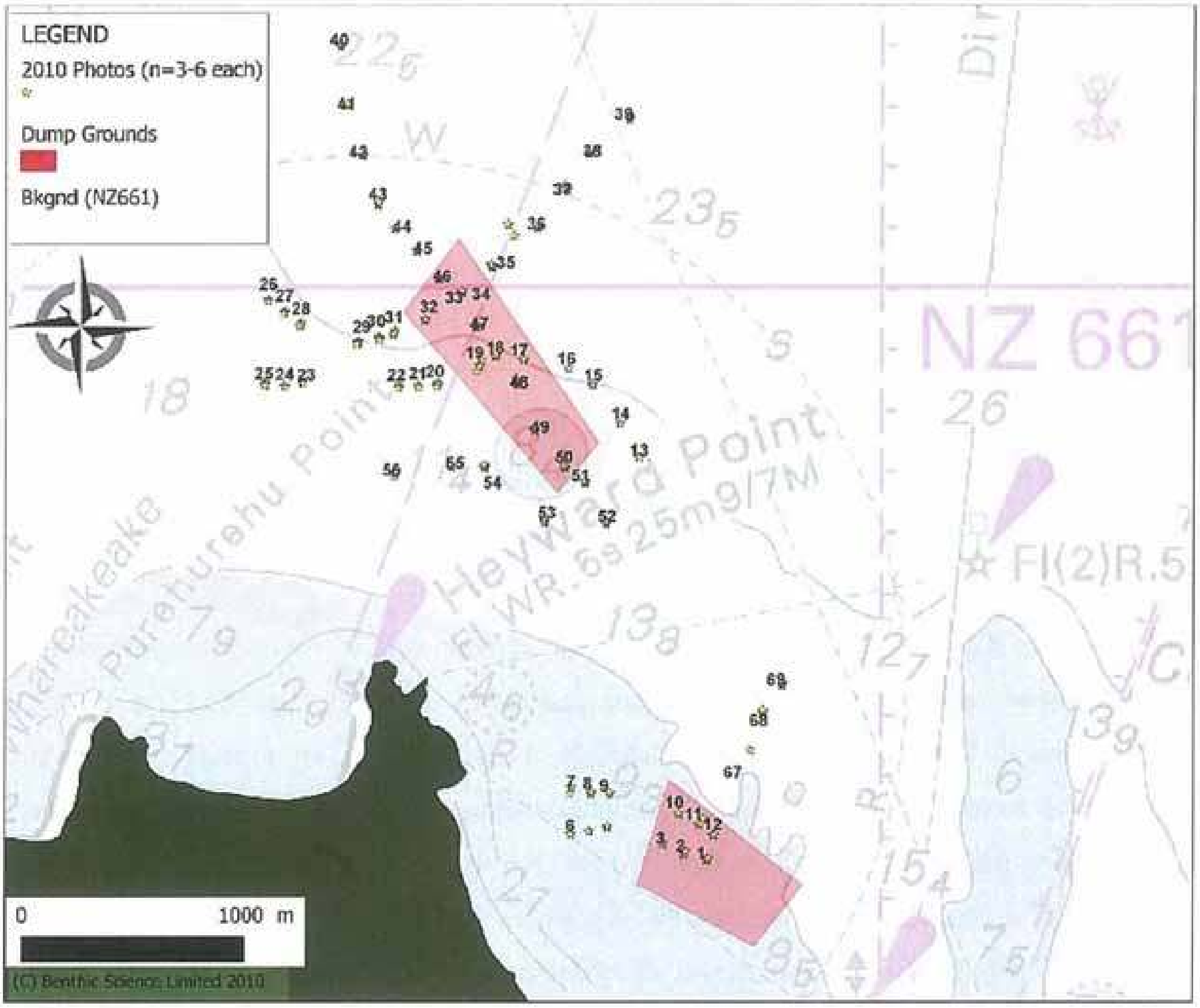


Fig. 20. Location of benthic still photos collected between August and November 2010. Three to six photos were collected over 50 m of bottom drift at each site.

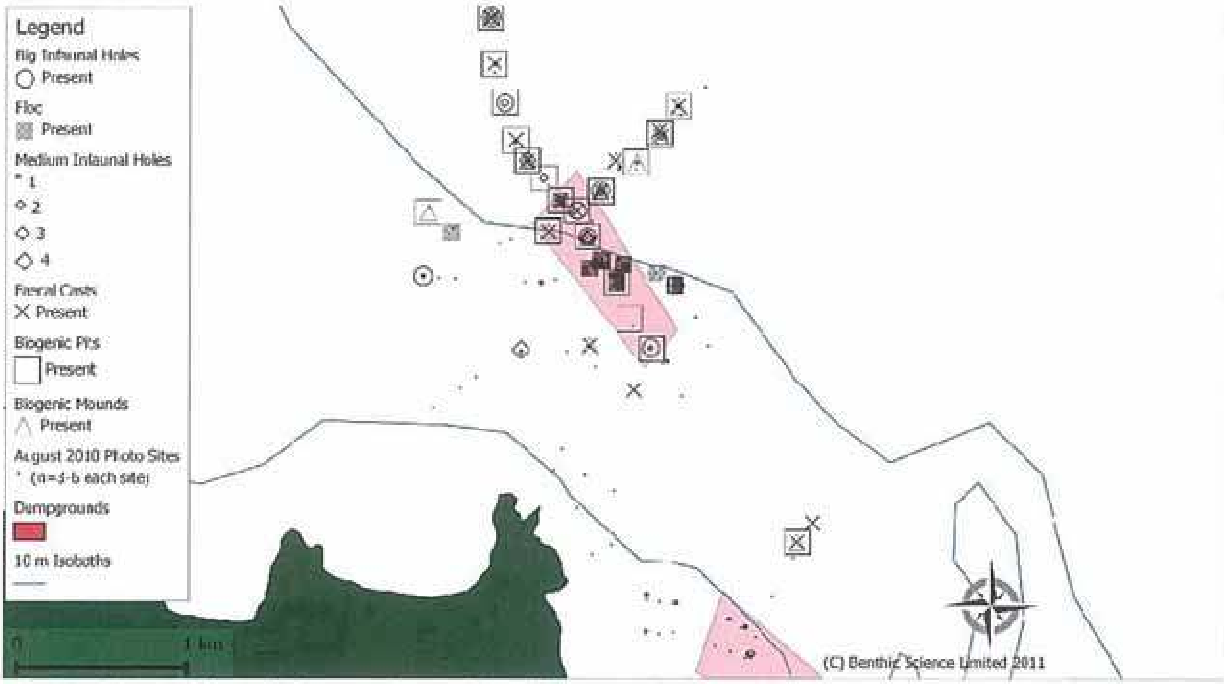


Fig. 21. Primary biogenic features observed in still imagery (2010).

Macrofaunal observations

Air-lift sample

Approximately 18 apparently maintained burrows were sampled by air-lift on 9 March 2011 at approximately 22 m depths. A total of 174 individuals from 24 taxa were recovered. Three specimens of the predatory mantis shrimp *Heterosquilla* cf. *tricarinata*[4] were found; each weighed approximately 10 g (wet wt.). This species was the likely creator of most of the large-infaunal burrows observed in the photo analysis. Medium-sized holes were probably created by a burrowing ghost-shrimp similar to *Callianassa filholi* (specialist confirmation pending) also recovered by airlift. Six other taxa found in the airlift sample have not previously been observed in grab samples and are therefore likely to be commensal with the burrowers. The most notable of these was a small bivalve, *Divariscintilla maoria*, known to attach themselves to shrimp burrow walls in the North Island (Judd 1971). A large (c. 10 mm) ampeliscid amphipod species was recovered only from burrows as well as three polychaete worm taxa (Flabelligeridae sp. A, Scalibregmatidae sp. A, and *Paradiopatra* sp.) and the unusual sand-dwelling bryozoan *Otionellina* sp. The characteristic spines of the heart urchin *Echinocardium cordatum* were also collected. Entire heart urchin specimens have only been observed locally at A0 sites recently.

Fig. 22. *Heterosquilla* cf. *tricarinata* (left) and *Divariscintilla maoria* (5 mm across, right) recovered from the air-lift sample.

Dredge samples

Dredge collections of over 11,000 animals were made inside (*n*=3) and outside (*n*=3) of the Aramoana disposal ground in March and September of 2003. Taxon richness was similar inside (S_{obs} = 11 in Mar, S_{obs} = 10 in Sep) compared to outside (S_{obs} = 11 in Mar, S_{obs} = 9 in Sep) with eight

4 *H. tricarinata* (*sensu stricto*) is a smaller intertidal species common in nearby inlets. Specimens collected in this survey most likely belong to a separate, undescribed, species known from sandy subtidal areas at multiple locations in the North Island and the subantarctic islands (Shane Ahyong pers comm.). Identification has been confirmed by a specialist and the taxon is likely to be referred to *Heterosquilla laevis* in an upcoming revision of NZ stomatopods.

and five taxa shared respectively. Macrofauna were significantly more abundant (H=5.03, $p<0.025$) outside of the disposal ground as inside at the same depth. This difference was due to the most abundant taxon, *Zethalia zelandica* (10,676 individuals) which occurred at a mean density of <1 individual per m^2 inside the disposal ground boundary and a mean of 5 individuals per m^2 outside. The abundance of non-*Z. zelandica* individuals was not significantly different inside and outside of the disposal ground (Kruskal-Wallis Test n=12, H=0.01, $p<0.936$) nor between seasons (Kruskal-Wallis Test n=12, H=0.10, $p<0.749$). Several taxa were more commonly collected outside the disposal ground than inside including the swimming crab (*Ovalipes catharus)*, sea tulips (*Pyura pachydermatina*), a shrimp (*Periclimenes* sp.), and the sunrise clam (*Tawera spissa),* but the number of samples was low for this type of analysis.

Dredge collections were also made at sites corresponding to grab collections during the A0 Mapping study in 2010. A total of 442 individuals among 39 taxa were collected in 13 tows (Table 3). The most common and abundant animal was the carnivorous snail *Austrofusus glans*. Dredge collections are likely to be gross underestimates of this shallow burrowing species in comparison to the surface dwelling scavenger hermit crabs (*Pagurus novizealandiae*), and the predatory apricot sea star *Sclerasterias mollis.* The greatest non-shell biomass probably belonged to the burrowing and deposit feeding ostrich foot shell (*Struthiolaria papulosa*) (Crump 1968; Morton 1954) which was also likely to be underestimated. These taxa were rarely collected or observed (video and still imagery) at depths near 20 m but were commonly collected at depths inshore of 30 m despite similar bottom features and sediment types. Their presence indicates a substantial late-successional stage infaunal biomass probably laying seaward of the existing disposal areas which were unlikely to be sampled by typical grab collections, but the inshore limits of this assemblage have not been identified.

Table 3. Density of epifauna collected during dredge tows (November 2010) as corrected for overground distance covered by dredges (inferred from vessel track and bottom time). The density of shaded taxa are likely to be grossly underestimated by this sampling method due to size, structure, mobility, or habits as indicated in the 'Comment' column.

			Overground corrected density (ind. per 100 sq. m)													Actual	Stnd.	
		Dredge Track Number >	1	2	3	4	5	6	7	8	9	10	11	12	13	Sum	Sum	Comment
Group	Family	Resolved Taxon																
Gastropoda	Buccinidae	*Austrofusus glans*	0.0	0.6	1.5	12.5	22.9	5.3	10.1	3.9	2.5	5.4	5.4	12.6	9.0	122	91.81	
Anomura		*Pagurus novizealandiae*	1.1	1.2	9.1	14.7	21.2	6.5	5.5	6.9	8.2		0.5	6.3	4.5	116	85.69	
Asteroidea		*Sclerasterias mollis*	0.5	3.5		1.5	0.8	1.2	1.8	2.9	2.5			2.1	3.4	26	20.24	
Gastropoda	Trochidae	*Antisolarium egenum*						0.6	3.7	1.0	1.6	2.2	2.2	0.7	7.9	24	19.86	went through mesh
Gastropoda	Calliostomatidae	*Calliostoma selectum*				0.7	1.6	1.2	2.8		3.3	0.5	1.6	4.9	1.1	24	17.78	
Brachyura	Portunidae	*Ovalipes catharus*			1.0	2.2		0.6	0.9	1.0		0.5	1.1	0.7	4.5	16	12.57	
Bivalvia	Veneridae	*Tawera spissa*		0.6	1.0	1.5	0.8	0.6	3.7			0.5			3.4	15	12.09	went through mesh, or burrowed
Gastropoda	Struthiolariidae	*Struthiolaria papulosa*		0.6	2.0	12.5	27.0	6.5	10.1	4.9	4.9	6.0	6.0	13.3	9.0	15	10.99	most buried too deeply
Gastropoda	Volutidae	*Alcithoe arabica swainsoni*			0.5				0.9		0.8		1.6	3.5	1.1	12	8.51	
Asteroidea	Asterinidae	*Patiriella regularis*					0.8	0.6			1.6	3.3		0.7	1.1	12	8.14	
Spatangoidea	Loveniidae	*Echinocardium cordatum*									0.8			2.1	1.1	5	4.05	burrow too deeply
Holothuroidea		Holothuroidea			0.5		0.8				1.6		1.1			6	4.05	most went through mesh
Cephalopoda	Octopodidae	*Octopus huttoni*					0.8	0.6	0.9	1.0		0.5				5	3.85	
Gastropoda	Calyptraeidae	*Maoricrypta sodalis*						1.2							2.3	4	3.44	cryptic in other snail shells
Brachyura		*Ommatocarcinus macgillivrayi*		1.2	0.5							0.5		0.7		5	2.93	in burrows
Nudibranchia	Discodorididae	*Hoplodoris* sp.		1.2			0.8		0.9							4	2.91	
Anthozoa		Anthozoa									0.8	0.5			1.1	3	2.49	
Pisces	Leptoscopidae	*Crapatalus* sp.											0.5		1.1	2	1.68	could likely outswim
Bivalvia	Corbulidae	*Corbula zelandica*		0.6						1.0						2	1.57	went through mesh
Gastropoda	Naticidae	*Tanea zelandica*				0.7					0.8					2	1.55	
Gastropoda	Conidae	*Phenatoma rosea*				0.7	0.8									2	1.55	
Polychaeta	Onuphidae	Onuphidae sp. 1						0.6	0.9							2	1.51	went through mesh
Scaphopoda		Scaphopoda													1.1	1	1.13	went through mesh
		Tunicate													1.1	1	1.13	
Polychaeta	Phyllodocidae	*Nereiphylla* sp.							0.9							1	0.92	went through mesh
Gastropoda	Muricidae	*Xymene ambiguus*							0.9							1	0.92	
Bivalvia	Pinnidae	*Atrina zelandica*					0.8									1	0.82	
Porifera	Callyspongiidae	*?Dactylia palmata*					0.8									1	0.82	
Pisces	Sygnathidae	*Hippocampus abdominalis*									0.8					1	0.82	
Gastropoda	Trochidae	*Zethalia zelandica*				0.7										1	0.74	went through mesh
		Pycnogonid				0.7										1	0.74	went through mesh
Polychaeta	Aphroditidae	Aphroditidae sp.				0.7										1	0.74	
Bivalvia	Veneridae	*Circomphalus yatei*												0.7		1	0.7	burrow deeply
Polychaeta	Nephtyidae	*Aglaophamus* sp.		0.6												1	0.59	most went through mesh
Cirripedia		Sessilia						0.6								1	0.59	
Cnidaria	Hydrozoa	Hydrozoa colony											0.5			1	0.54	too fragile for collection
Pisces	Bothidae	*Arnoglossus scapha*											0.5			1	0.54	could likely outswim
Pisces	Psychrolutidae	*Neophrynicthys latus*											0.5			1	0.54	
Ophiuroidea		*Amphiura* sp.			0.5											1	0.51	too fragile for collection
		Actual Sum	3	16	30	50	70	35	37	19	35	27	30	51	39	441		
		Standard Sum	2	10	17	49	80	26	44	23	30	20	22	48	53		332	
		Taxon Richness	2	9	9	12	13	13	14	8	13	10	12	12	16			

Overall Abundance (grab samples)

Approximately 31,607 specimens (among selected taxa) from 457 grabs were reduced to 175 taxa over the 2003-2010 study period. General abundance patterns on the shelf (Fig. 23) indicate widespread macrofaunal densities of 3,000 to 12,000 individuals m^{-2}, with the difference between geographically similar Willis *et al.* (2008) and A0 Mapping (Paavo 2011) values representing the magnitude of seasonal differences (May *vs.* November respectively) as predicted by Paavo & Probert (2005). Lower densities of 100–600 individuals m^{-2} were common near the Aramoana disposal area which increased to the northwest. Low densities of 200–1000 individuals m^{-2} were more frequently recovered from individual samples in the central area of the Heyward Pt. disposal ground while the majority of values were similar to those observed outside the disposal area at simliar depths. This abundance pattern may be associated with the mound present in the disposal ground (Fig. 24). Given the size of the Heyward Pt. disposal area relative to the presumed boundaries of the actual disposal events near the centre of the site, the placement of such samples have an undue influence on simple statistical comparisons of disposal effects inside and outside of the disposal ground (Fig. 25).

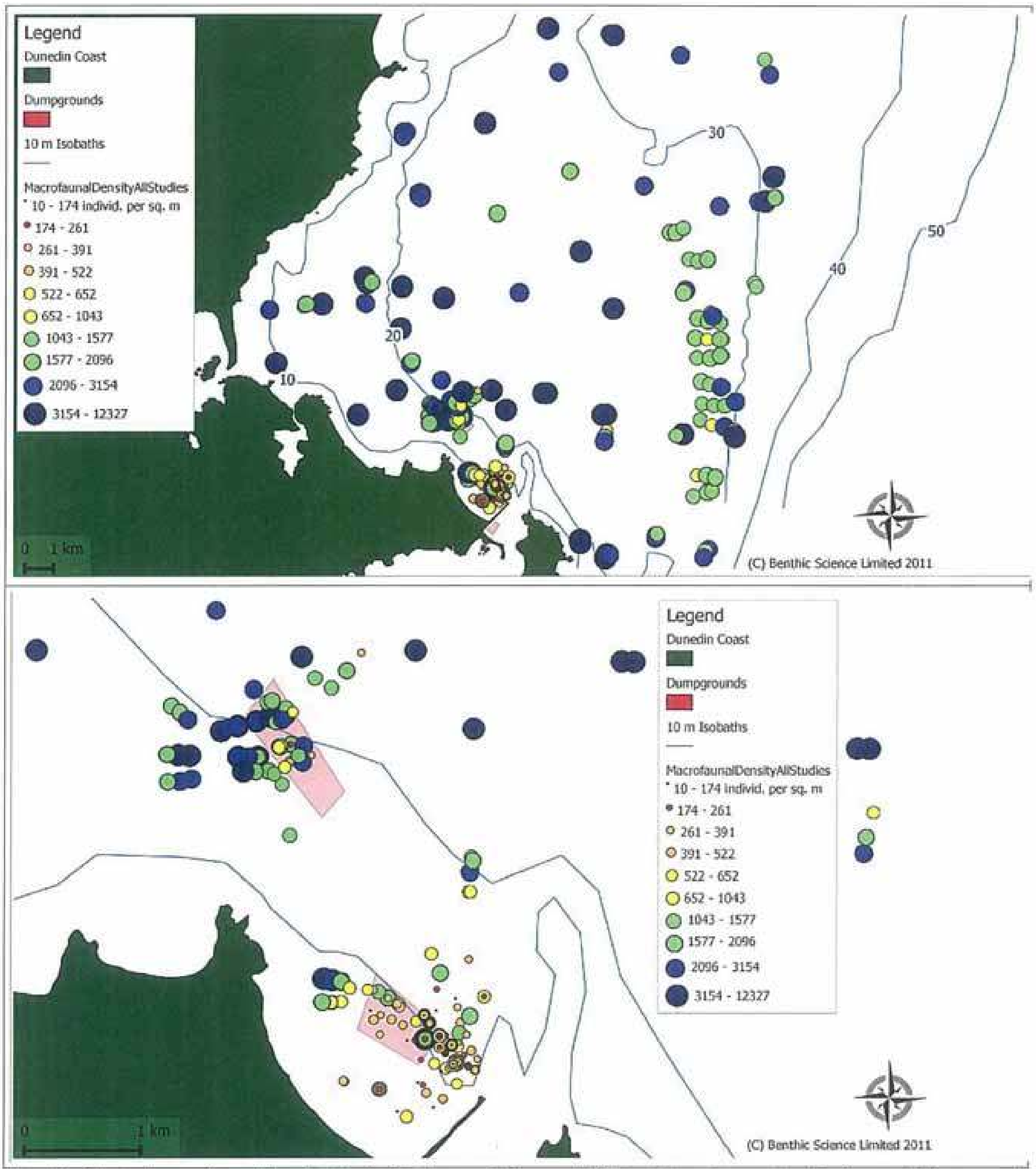


Fig. 23. Coastal macrofaunal density (individuals per m²) from all POL study grab samples (during multiple seasons) between 2003–2010.

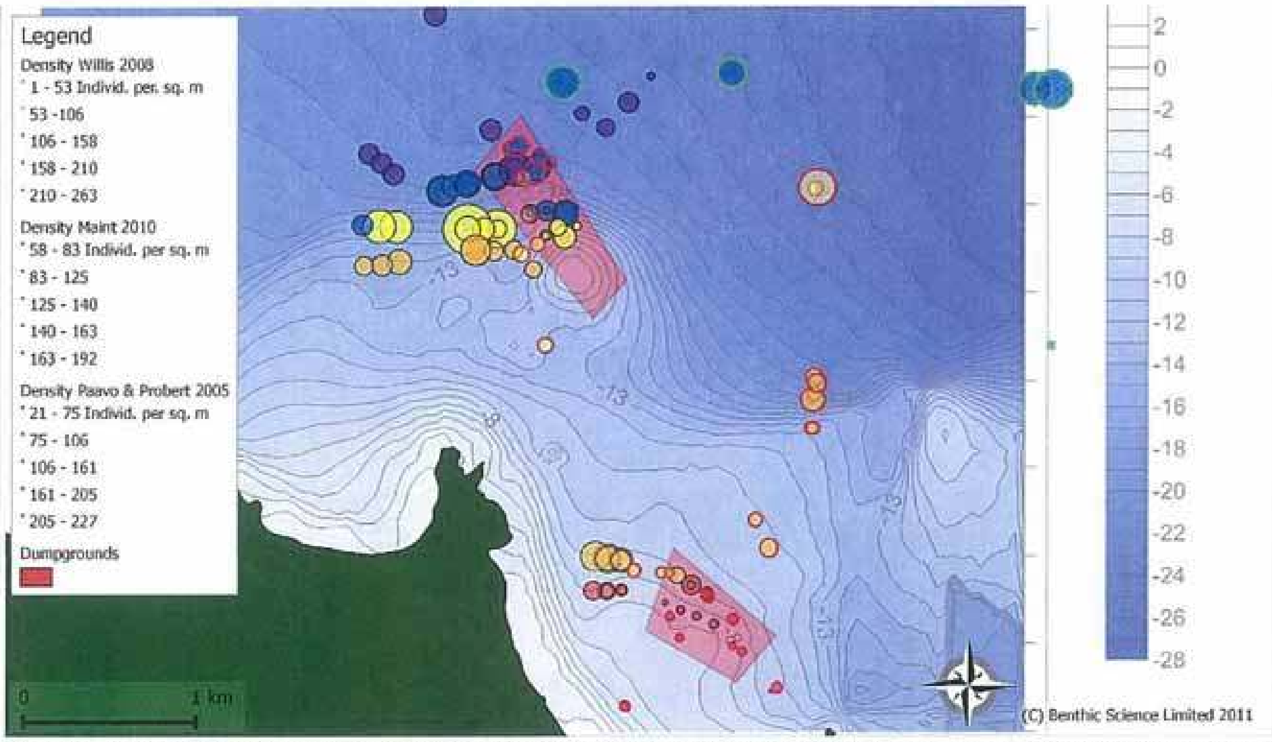


Fig. 24. Coastal macrofaunal density (individuals per m^2) nearest the disposal areas from the indicated studies in comparison with bathymetric features (isobaths are in m from chart datum). Different fill colours denote density quantiles for easy reference. The size (area) of any circle directly represents the density of animals collected. Circle border colours indicate study (black = POL Maint 2010, red = 2005, green = Willis (2008)).

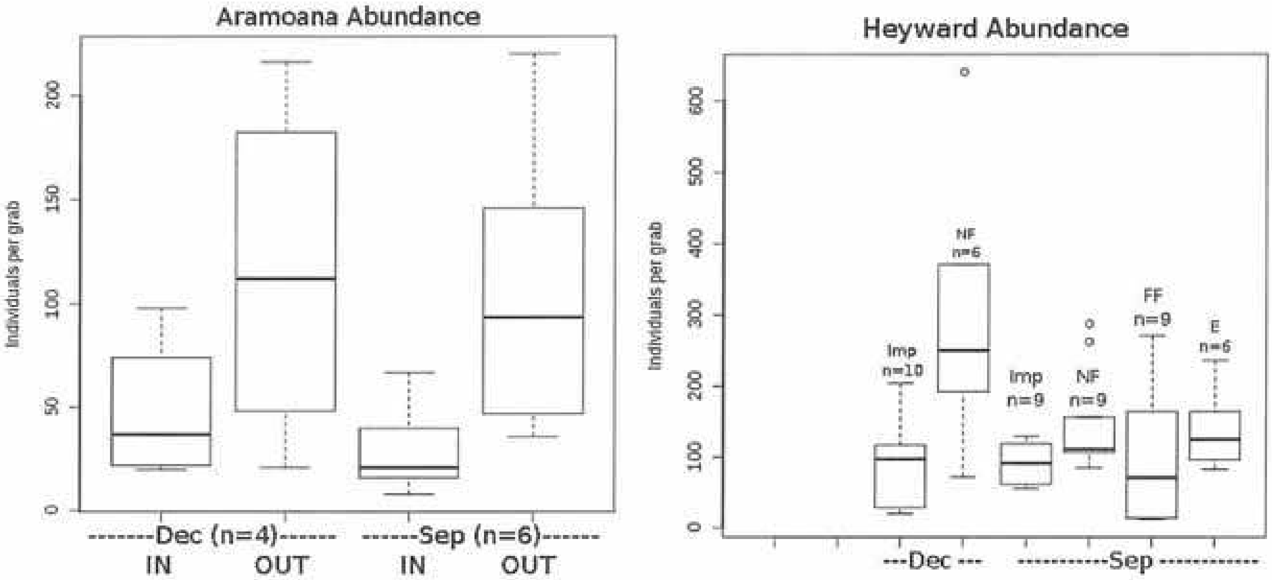


Fig. 25. Macrofaunal abundance from September and December 2010 grabs taken inside disposal ground boundaries (IN) and from near-field sites of matching depths (NF, OUT). The Heyward Pt. disposal ground also had far-field (FF) and external (E) sites sampled in September 2010. Boxes denote the interquartile range while whiskers show upper and lower value ranges and the heavy horizontal bars represent mean values. Circles represent statistical outliers.

Distribution of selected taxa (grab samples)

The numerically dominant 20 taxa represented approximately 80% of all individuals collected (Table 4). The top two dominants, *Antisolarium egenum* and *Zethalia zelandica*, had an almost mutually exclusive distribution (Fig. 26) with *A. egenum* dominating the shelf while *Z. zelandica* was present in shallow, high hydraulic-energy areas. Grab collections supported independent dredge and photosurvey data indicating significantly higher *Z. zelandica* abundances outside the Aramoana disposal ground than inside.

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%**

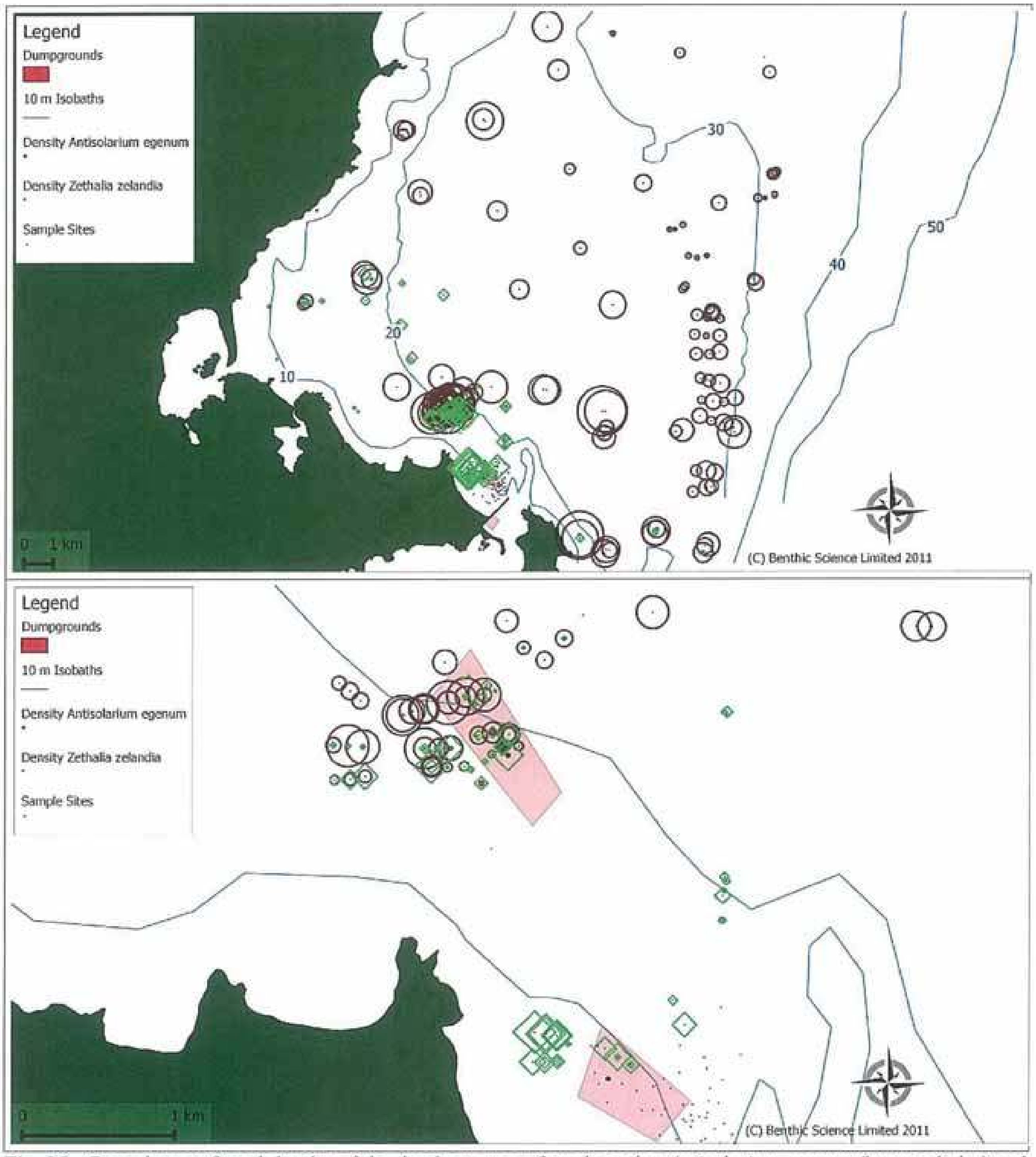


Fig. 26. Coastal macrofaunal density of the dominant macrofaunal species *Antisolarium egenum* (brown circles) and *Zethalia zelandica* (green diamonds) (individuals per m^2), both snails, in the study area from all POL study grab samples (during multiple seasons) between 2003–2010. The size (area) of any symbol directly represents the density of animals collected.

Three of the numerically dominant taxa had broad and fairly uniform distributions in the study area across all years. These included a nephtyid polychaete worm taxon which may contain a small number of other species, but was overwhelmingly dominated by *Aglaophamus macroura,* commonly called catworms. These species roam the surface of sandy sediments and shallowly burrow to prey on other animals. Specimens >40 mm in length were frequently encountered so low abundances may actually represent substantial biomass at a high trophic level. They occured at a mean density of 121 individuals m^{-2} when they were present at all (SD=83, *n*=341). Their density was lowest, as with most taxa, in the shallowest and most energetic areas (Fig. 27). Another polychaete worm, *Spiophanes* cf. *bombyx*, is a sedentary, tube building species. When present they occurred at a mean density of 138 m^{-2} (SD=165, *n*=205). Highest densities occured on the northern boundary of the silty area in Blueskin Bay and between Aramoana disposal area and the Mole (Fig. 27). *Spiophanes* tubes are known to provide shelter for other macrofaunal taxa. Another numerically dominant species with a wide distribution was the small bivalve *Nucula nitidula* (typically 2-7 mm shell width). These animals were abundant and common at depths >15 m. They had a mean density of 209 m^{-2} (SD=156, *n*=158) where they occurred at all. They were marginally less abundant within Heyward Pt. disposal area than surrounding depths, but not anomalously so given the patchiness of their distribution within the available data limits (Fig. 28).

The sedentary worm taxon (family Terebellidae) was found at a mean density of 163 m^{-2} (SD=380, *n*=63) when they were found at all (Fig. 28). This soft-bodied taxon is well known for building tubes in soft, often silty sediments against small rocks or shells and feeding on organic surface deposits nearby. They grow relatively slowly and are largely intolerant of frequent disturbance.

Two of the numerically abundant taxa had distributions antithetical to the abundance patterns of most taxa (Fig. 29). *Armandia maculata* is a polychaete worm with a robust body able to swim (almost like a small fish) and quickly burrow in sandy sediments. They are thought to primarily feed on organic particulates. This taxon was found in 268 grabs at a mean density of 96 individuals m^{-2} (SD=105). Higher densities (Max = 810 individuals m^{-2}) were found adjacent to the Aramoana disposal ground where few other taxa were found. This density pattern was the same for another organic particulate feeding taxon, *Prionospio* spp. Species within this genus were difficult to reconcile between studies, but appear to have been dominated by *Prionospio kirrae*. They were found at a mean density of 130 individual m^{-2} (SD=142, *n*=259) where they occurred at all. One other polychaete taxon (family Cirratulidae) was common between Aramoana and the Mole, but the Willis *et al.* (2008) data indicated that most cirratulids were found beyond the 25 m isobath. This disjunct distribution was an artifact of the taxon-agglomeration procedure. Individual cirratulid taxa could not be reliably reconciled between studies. One or more taxa dominated the shallow protected areas adjacent to the kelp patch near the Mole while another taxon dominated sediments deeper on the shelf.

The sunrise clam (*Tawera* spp. - mostly *Tawera spissa*) was found widely in the study area across all studies, but a larger-than-typical number of small individuals (maximum of >6,000 individuals per m^{-2}) were collected west of the Heyward Pt. disposal ground in September and December 2010 (Fig. 30). High densities (500–600 individuals per m^{-2}) were found in 2003 in sandy sediments near 15 m water depths in Blueskin Bay compared to more common densities of 20–60 individuals per m^{-2}. Localised high densities may indicate important areas where water and sediment conditions support reproduction or colonisation. Too little is known about *Tawera* dispersal to evaluate the ecological importance of this patchy distribution.

Three numerically dominant taxa represent higher taxonomic groupings of amphipod crustaceans. These are predominantly mobile, shallow-burrowing taxa which likely represent a biomass readily accessible to many coastal predators. Collectively, the surface-dwelling phoxocephalid taxa represented about 3% of all macrofauna as did digging haustoriids while the robust lyssiananssids represented 1%. The phoxocephalid taxon was dominated by two species, *Torridoharpinia hurleyi* and *Waitangi brevirostris,* but several other unresolved taxa were present. Lysianassid and haustorid amphipods were not identified any further, but were differentiated from other common amphipod taxa such as aorids, eusirids, corophiids, and caprellids. Besides their overall abundance (Fig. 31), ecologically meaningful information cannot be further analysed using this coarse taxonomic information. Gammarid amphipod abundance was consistently lower across studies and seasons at Heyward Pt. locations between 18 and 22 m isobaths when compared to other areas of similar depth. Collectively these numerically dominant taxa (Table 4, Fig. 32) probably provide most of the macrofaunal biomass in the study area.

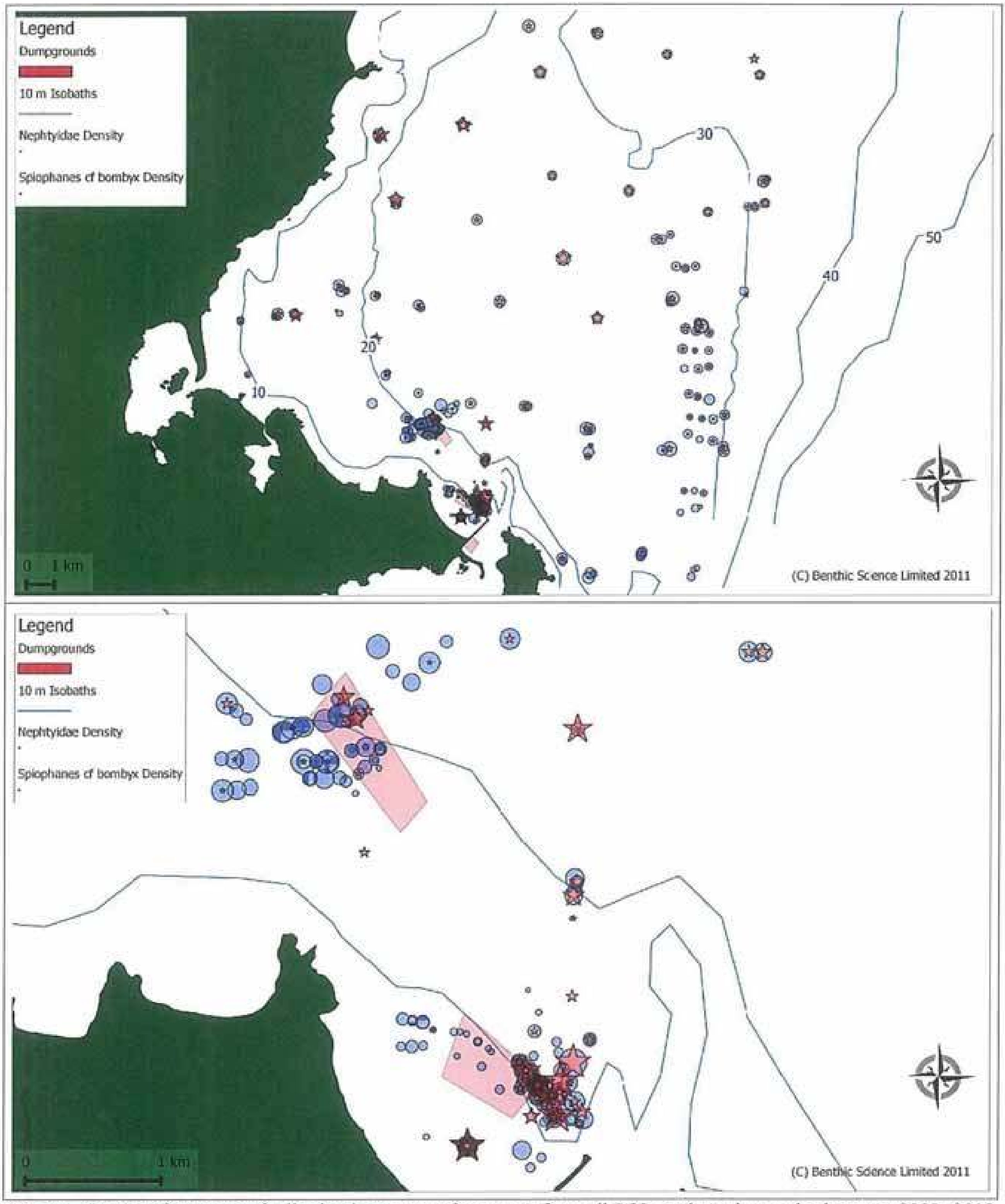


Fig. 27. Density of two numerically dominant macrofauna taxa from all POL study grab samples between 2003–2010 (Nephtyidae = purple circles, *Spiophanes* cf *bombyx* = red stars). The area of any symbol directly represents the density of animals collected.

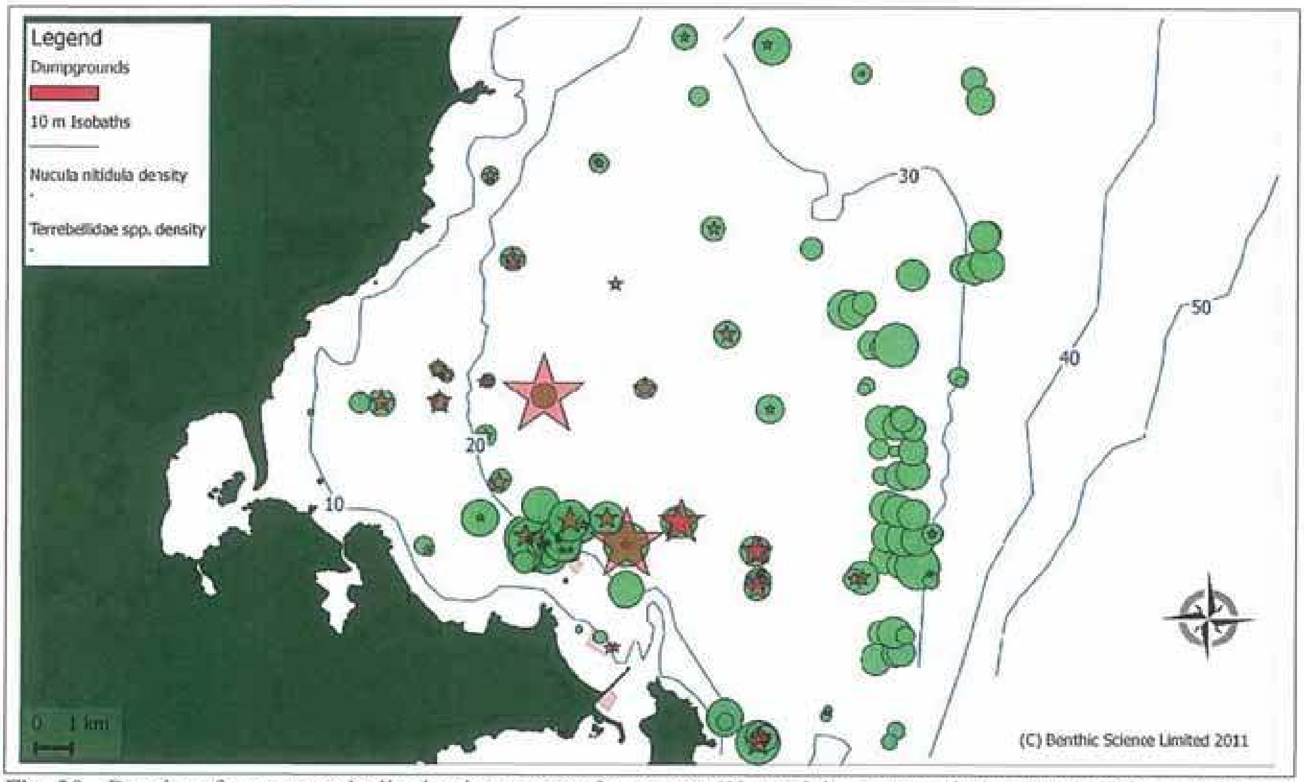


Fig. 28. Density of two numerically dominant macrofauna taxa (*N. nitidula* = green circles, Terebellidae = red stars) from all POL study grab samples between 2003–2010. The area of any symbol directly represents the density of animals collected.

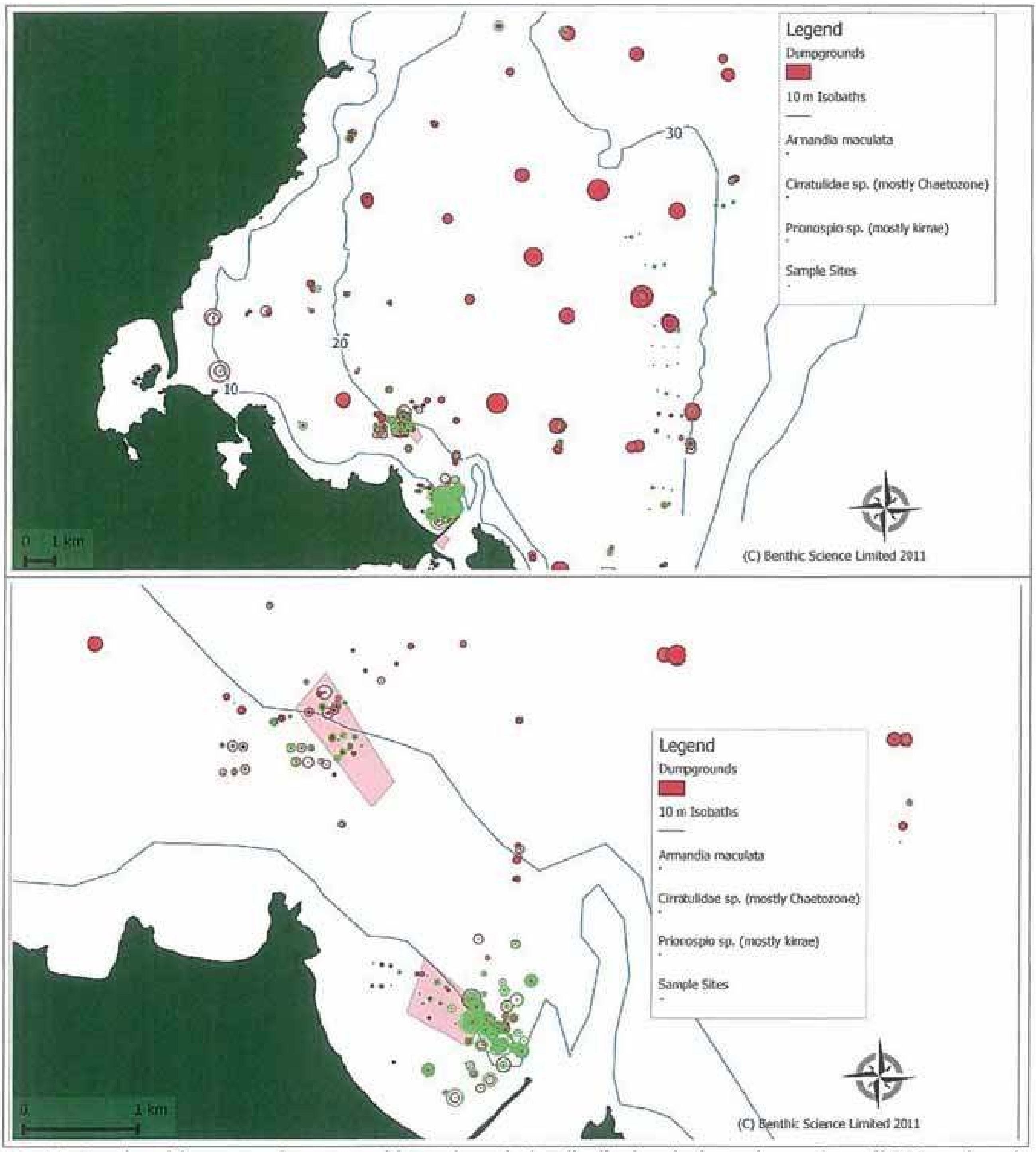


Fig. 29. Density of three macrofauna taxa with mostly exclusive distributions in the study area from all POL study grab samples between 2003–2010 (closed red circles = Cirratulidae, open red circles = *Armandia maculata*, green circles=*Prionospio* spp.). The area of any circle directly represents the density of animals collected.

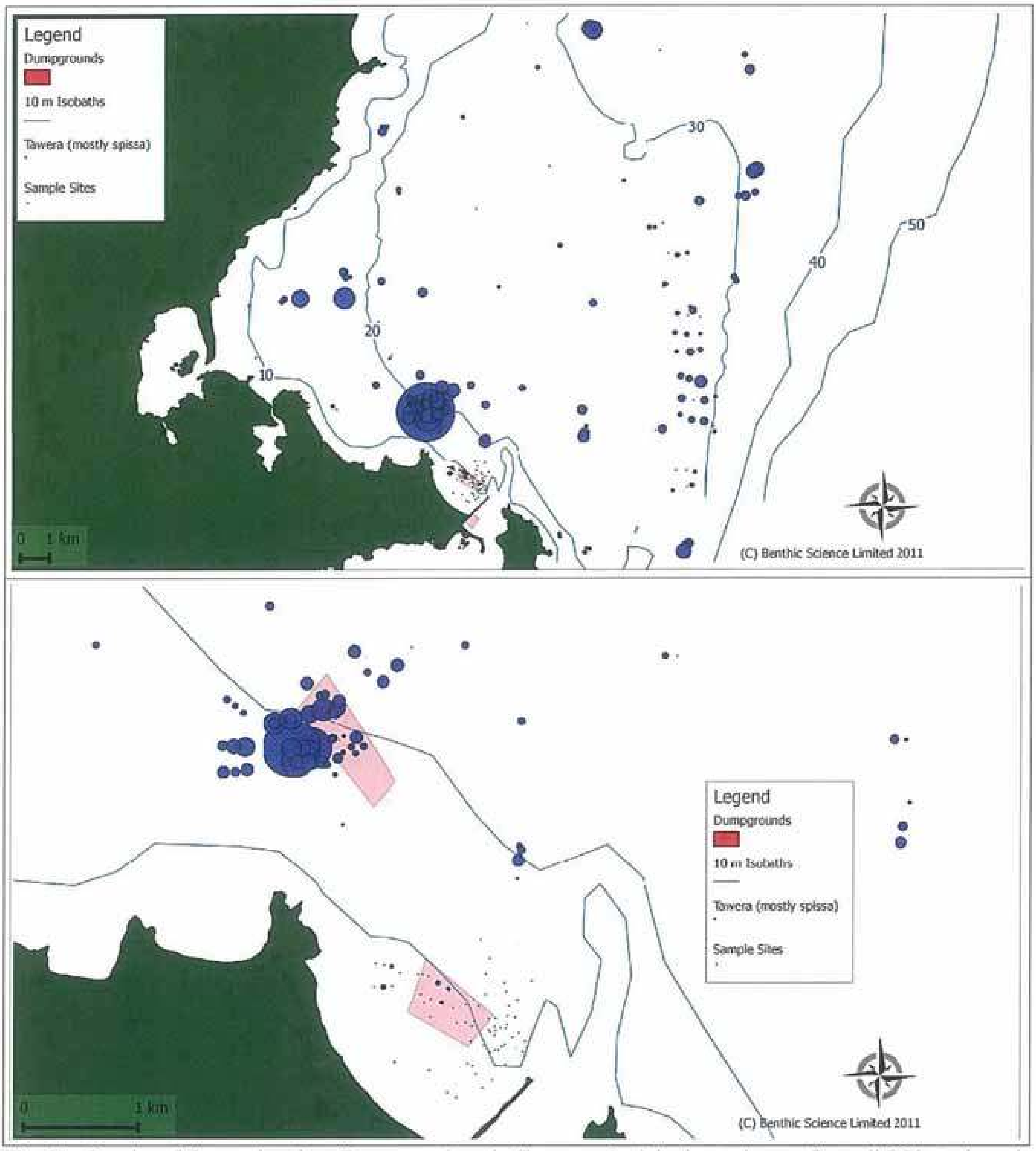


Fig. 30. Density of the sunrise clam *Tawera* sp. (mostly *Tawera spissa*) in the study area from all POL study grab samples between 2003–2010. The area of any circle directly represents the density of animals collected.

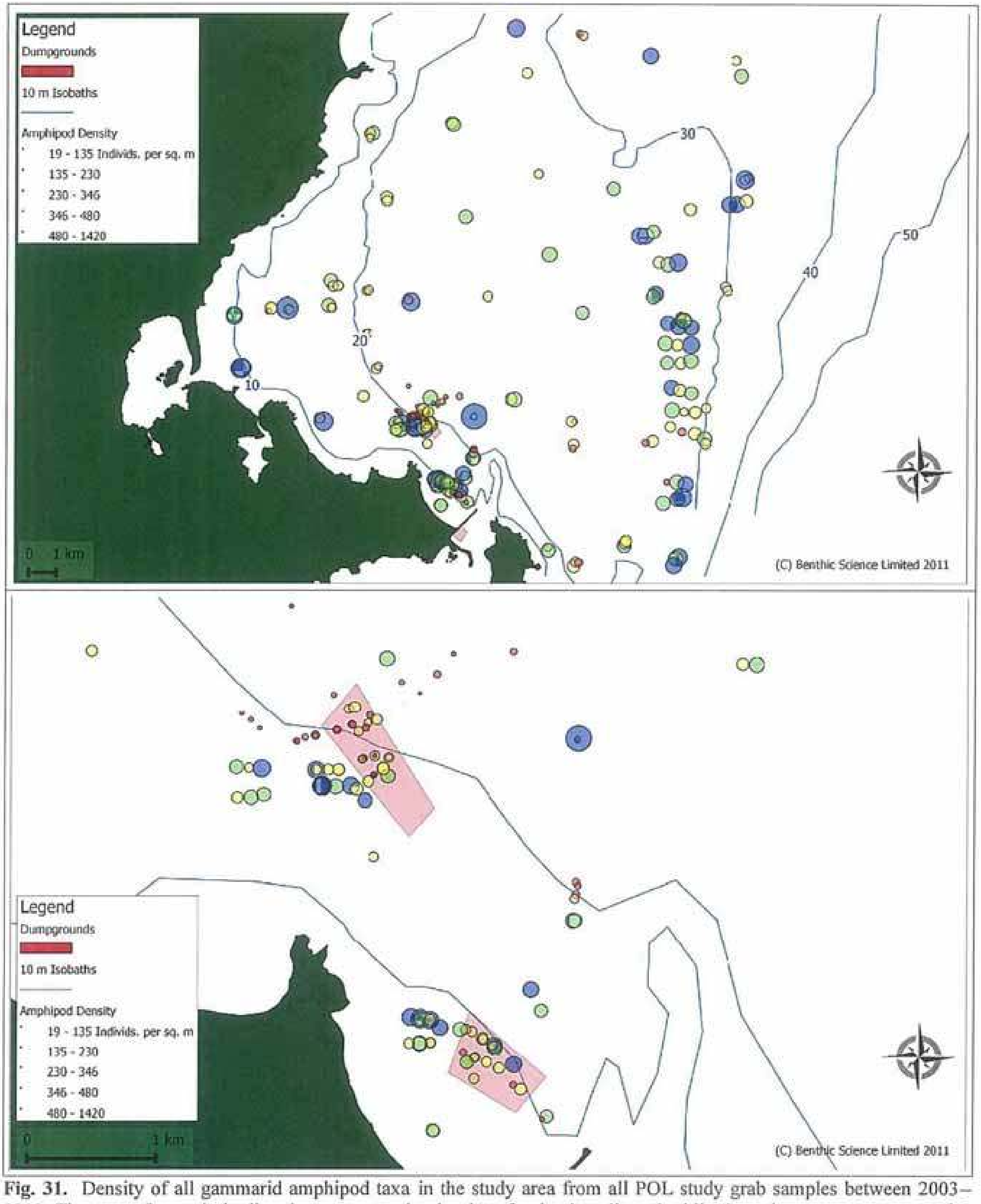


Fig. 31. Density of all gammarid amphipod taxa in the study area from all POL study grab samples between 2003–2010. The area of any circle directly represents the density of animals collected while the colour represents one of 5 density quantiles.

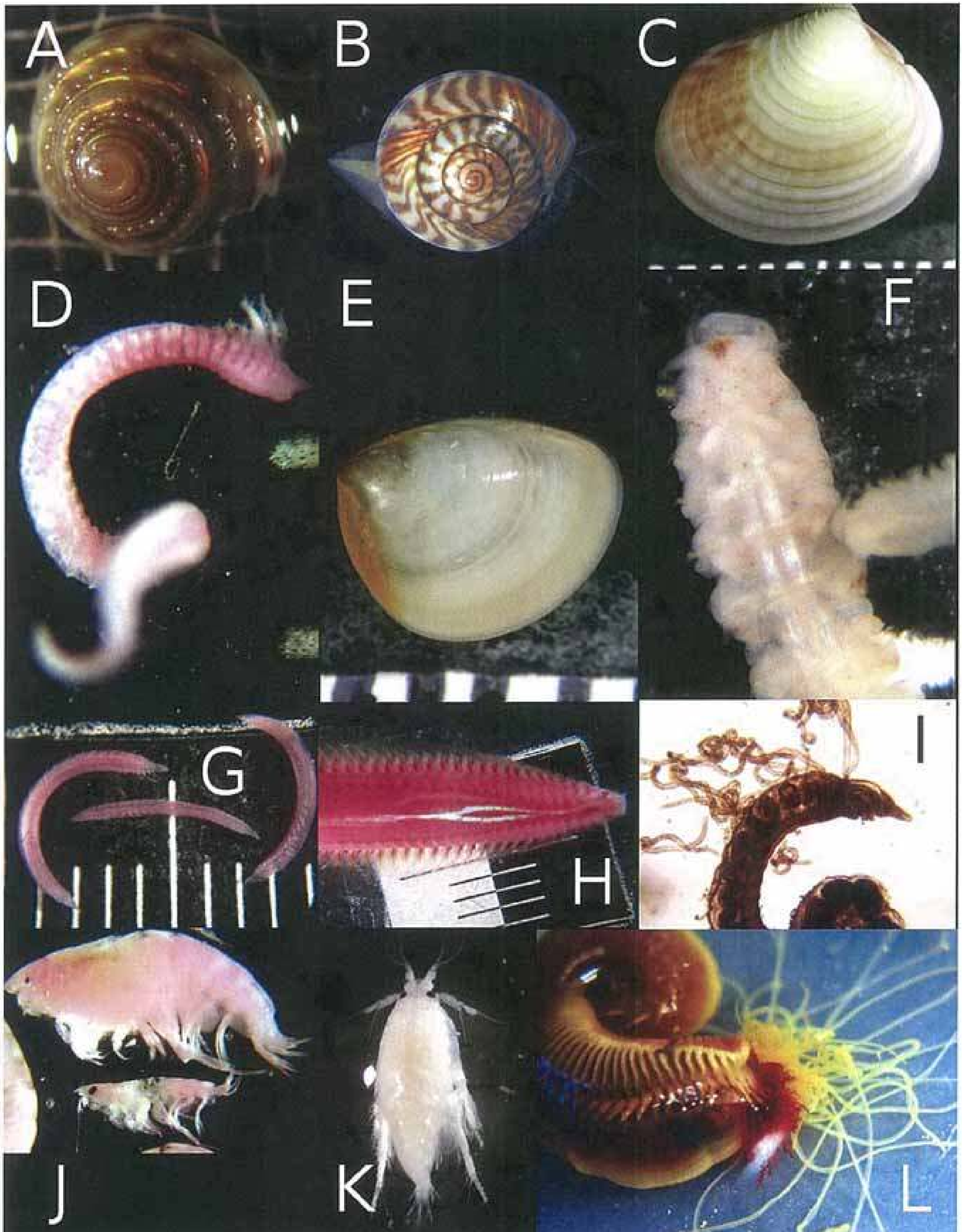


Fig. 32. Twelve numerically dominant taxa in the study area. A) *Antisolarium egenum*, B) *Zethalia zelandica*, C) *Tawera spissa*, D) *Prionospio* sp., E) *Nucula nitidula*, F) *Spiophanes* cf. *bombyx*, G) *Armandia maculata*, H) *Aglaophamus macroura*, I) Cirratulidae sp., J) Phoxocephalidae sp., K) *Urothoe* sp., L) *Streblosoma toddae* (Terebellidae). Scale = 1 mm divisions where present.

Biodiversity (grab samples)

The asymptotic species accumulation curve from the September 2010 data (Fig. 33) indicated that collection to have observed most taxa detectable using these grab methods and taxonomic resolution. The Chao procedures incorporate intersample probability of new taxa and predict slightly more than 100 macrofaunal taxa were actually present.

Density and taxon richness were generally directly related in all studies (density=richness $\times 102.94 - 13$, $R^2=0.55$, $n=453$). In general, Blueskin Bay area samples produced between 13 and 30 taxa each (Fig. 34). Marginal fine sand sediments tended to produce more taxa than the silty central area. Typically 1–13 taxa were found in each sample collected from the Aramoana area with more taxa on the seaward boundary of the central mound location in any given study year and fewer taxa present on the shoreward side of the mound and toward the Mole. Macrofaunal taxon richness was similarly low in isolated samples from the central portion of the Heyward disposal ground and just beyond the westward boundary within any one study, but the overall patchiness of richness was similar to sediments of similar depths outside the disposal ground. Impoverished samples generally corresponded with an apparent difference in fine grain content observed during processing (Fig. 35). These differences were probably due to serendipitous sampling of discrete disposal events. Sample number and position therefore have a large influence on overall taxon richness values when comparing samples taken inside and outside the disposal ground boundaries (Fig. 36). Even with such patchiness the two disposal areas produce assemblages that are different in composition and abundance from each other and somewhat distinct from samples outside the disposal ground (Fig. 37). SIMPER analysis indicated that the discriminating taxa were primarily *Armandia maculata*, *Aglaophamus macroura*, Scalibregmatidae, *Antisolarium egenum*, *Zethalia zelandica*, and *Tawera spissa* as indicated by individual taxon distribution patterns mentioned above. Impoverished central Heyward Pt. samples had larger evenness values (J') than depth-matched near-field and far-field samples, but diversity (H') values were within the range of NF and FF samples.

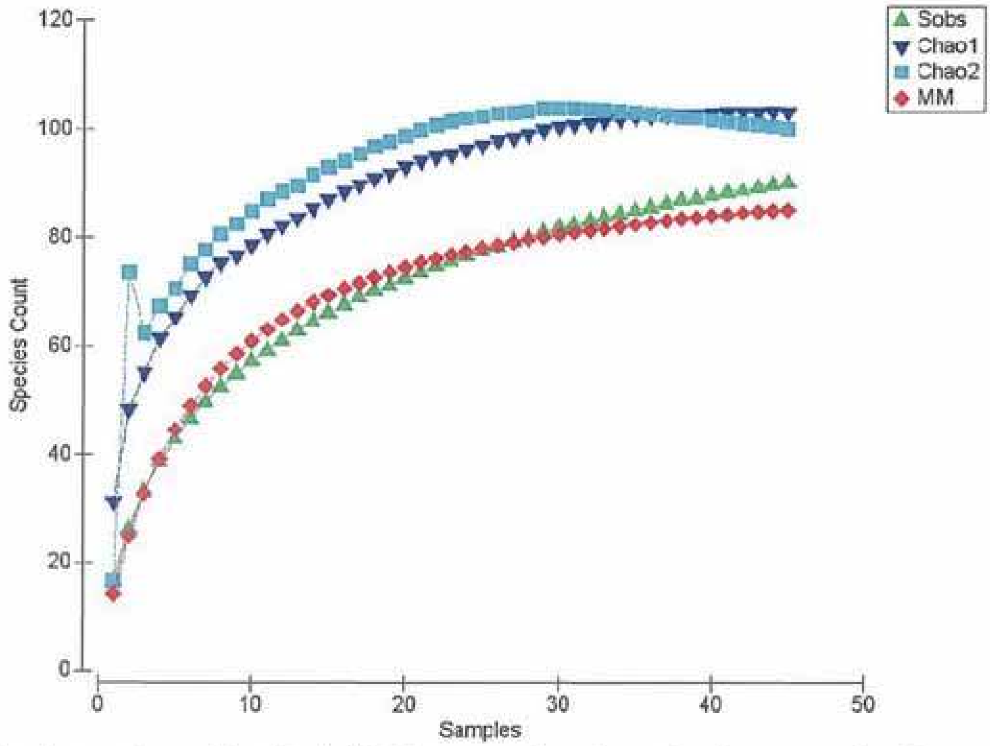


Fig. 33. Actual taxon observations (S_{obs}) with 999 permutations of sample order compared to Chao predictions of taxon richness from September 2010 grab data.

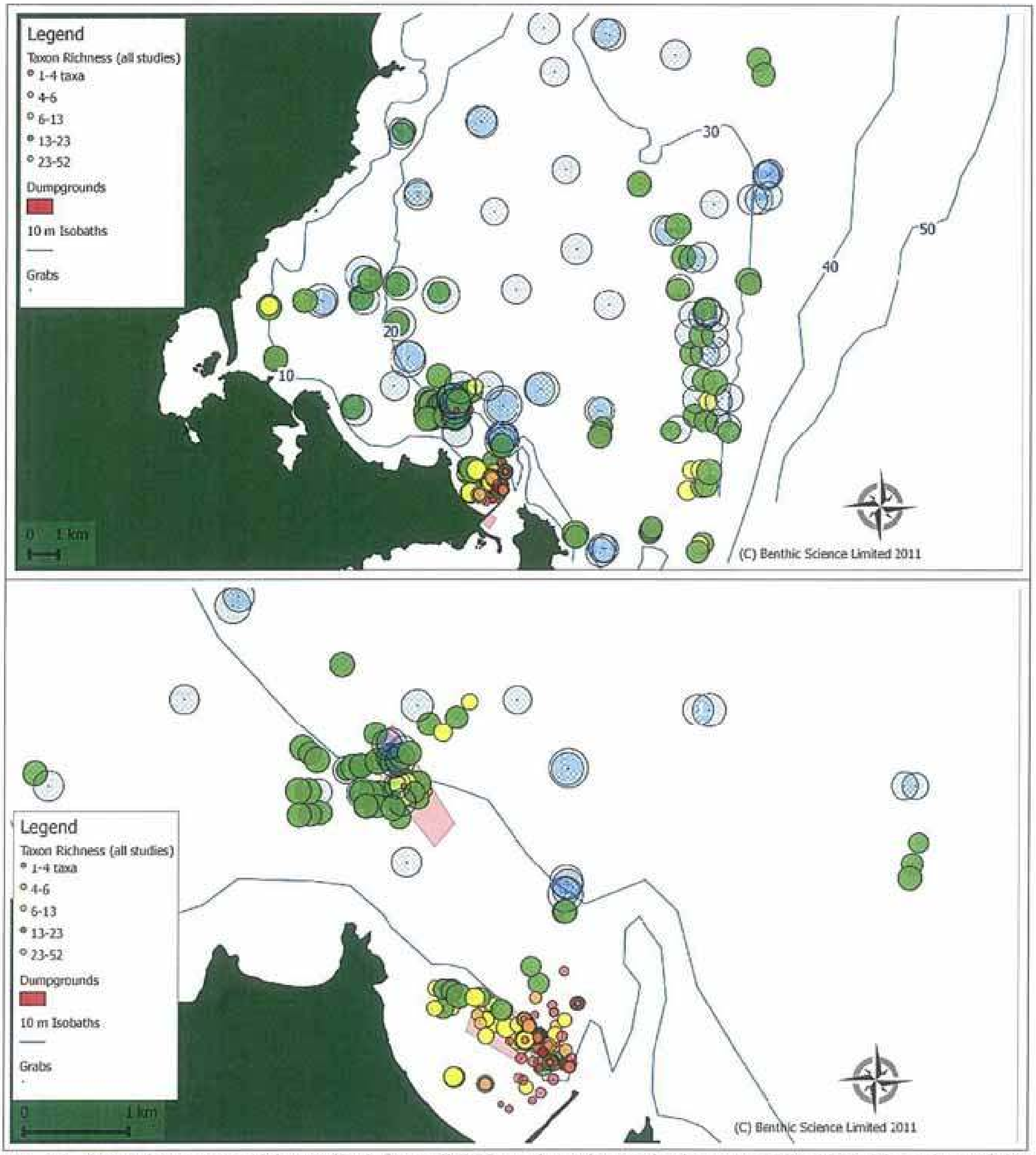


Fig. 34. Macrofauna taxon richness (S_{obs}) from all POL study grab samples between 2003–2010. The colour of the symbols represents the taxon richness quantile. The area of each circle directly relates to the number of taxa found. (Please note, taxon richness cannot be simply extrapolated from different grab sample areas (m^2) as has been done for abundance, employ caution when comparing between studies).

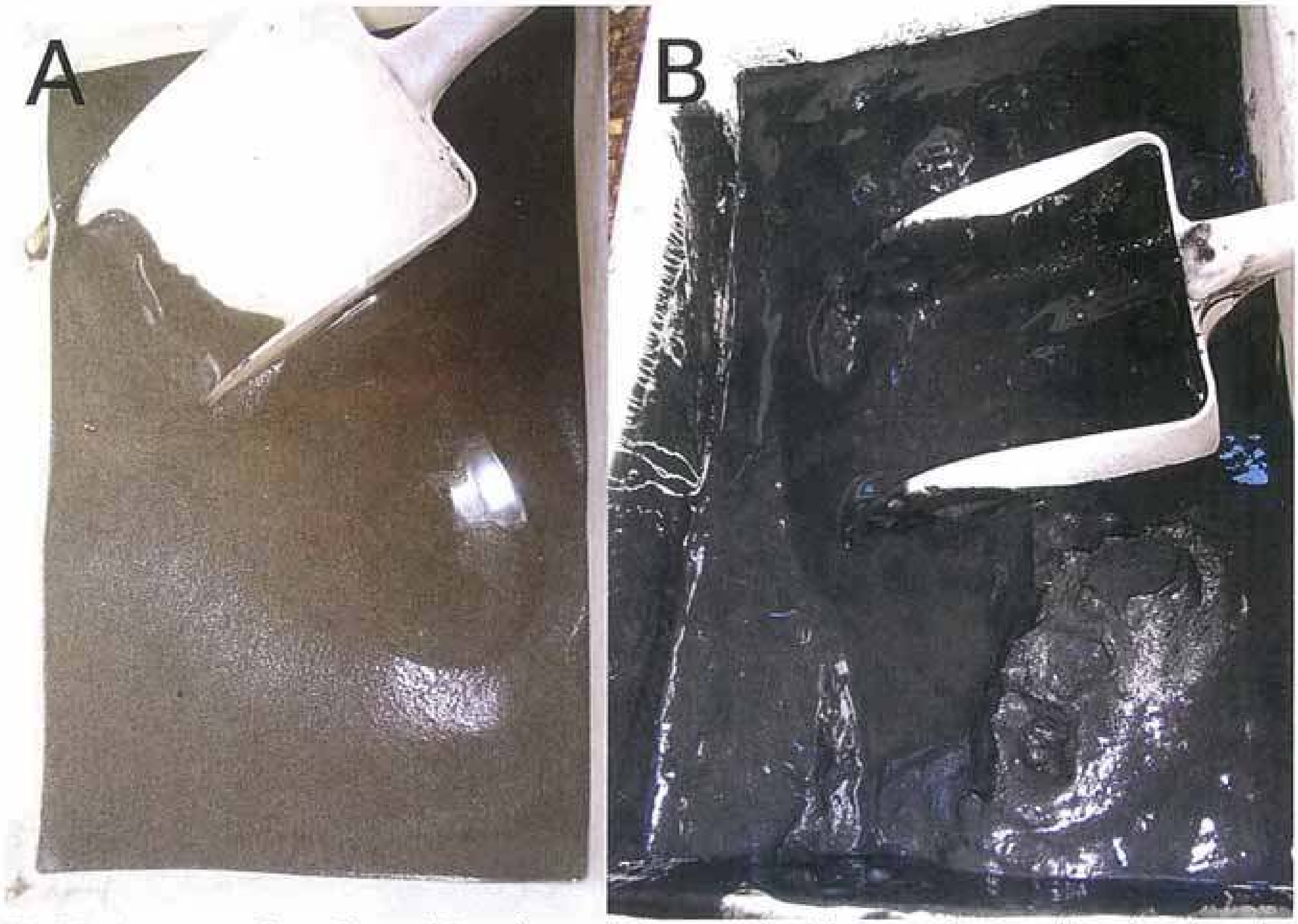
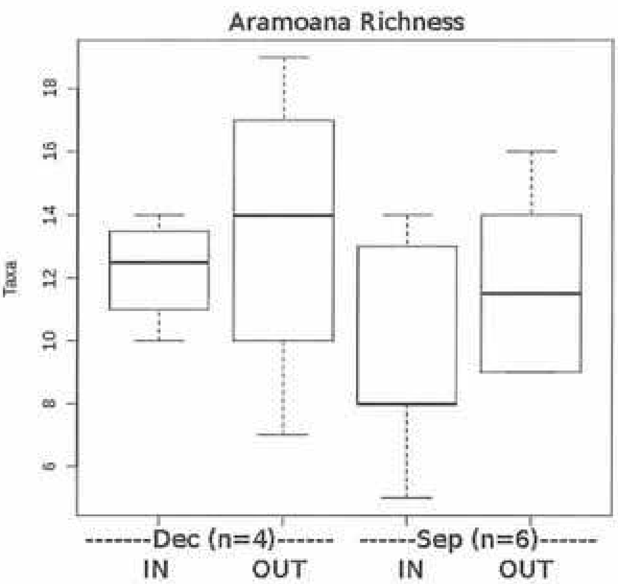


Fig. 35. Appearance of most Heyward Pt. sediments during processing (A) compared to a small number of samples with increased fine grain content generally associated with low abundances and richness (B).



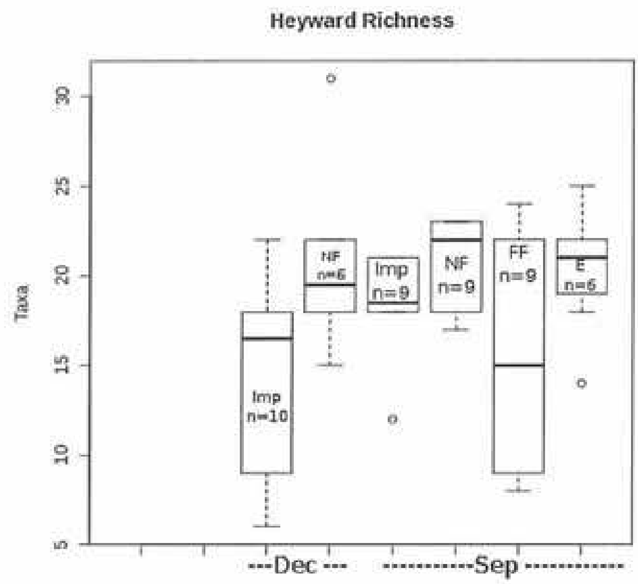


Fig. 36. Macrofaunal taxon richness from September and December 2010 grabs taken inside disposal ground boundaries (IN, Imp) and from near-field sites of matching depths (NF, OUT). The Heyward Pt. disposal ground also had far-field (FF) and external (E) sites sampled in September 2010. Boxes denote the interquartile range while whiskers show the range and the heavy horizontal bars represent mean values. Circles represent statistical outliers.

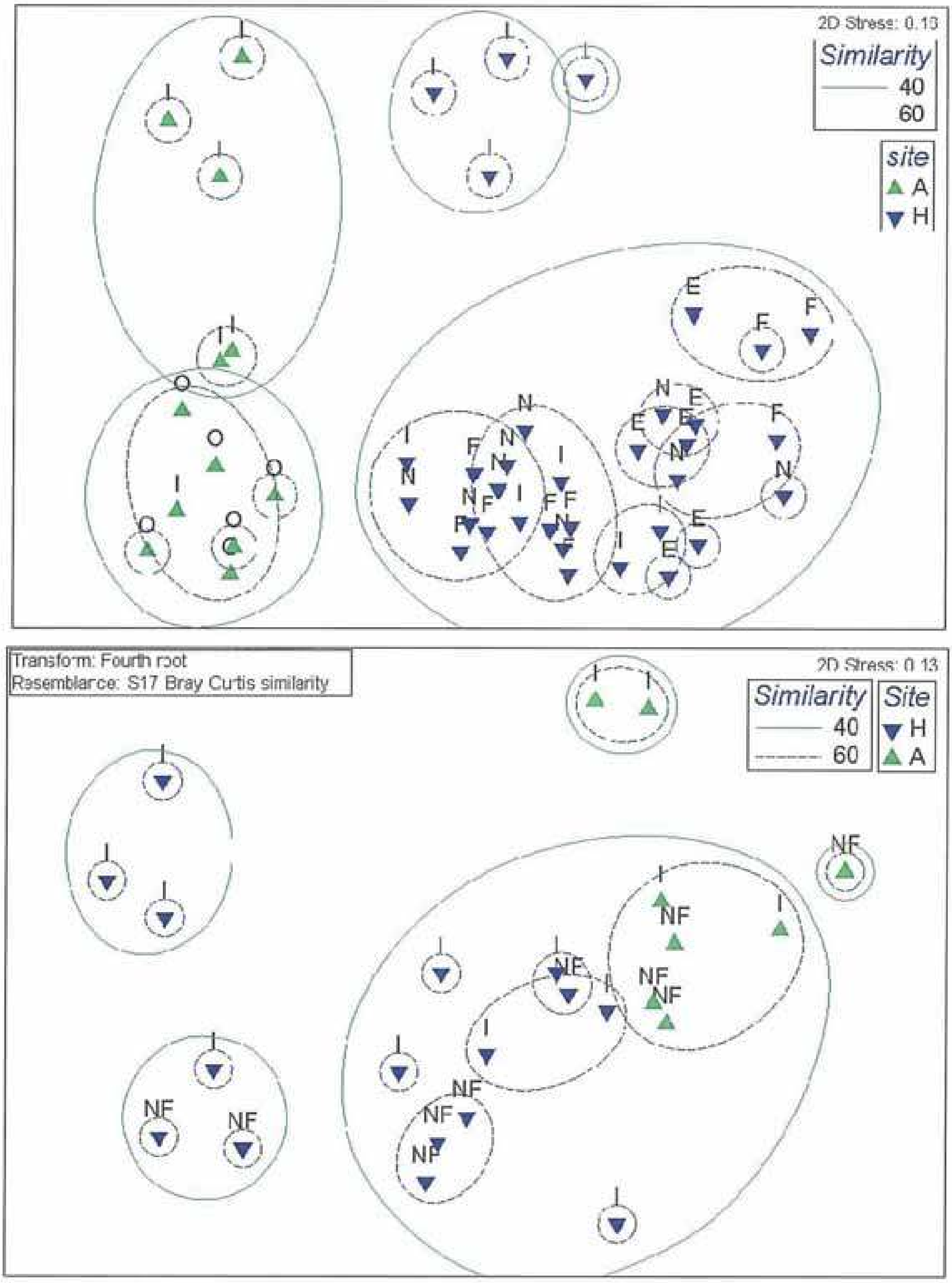


Fig. 37. nMDS ordinations of macrofaunal abundances (fourth-rot transformation) at Aramoana (A, green triangles) and Heyward Pt. (H, blue triangles) grouped by Bray-Curtis similarity levels in September (top panel) and December (bottom panel) 2010. O=outside disposal ground, I=inside, N=near-field, F=far-field, E=external Heyward Pt. sites along depth contours seaward of the existing site.

Discussion

Assemblages relative to hydrodynamic energy

Final hydrodynamic model results will be presented in a separate report (MetOceans Solutions Ltd.), but preliminary models indicated that the study area is primarily exposed to seas and swells from northern to southeastern directions which exceed 2.5 m significant wave heights approximately 1% of the time on at least an annual basis. For macrofauna with limited adult dispersal capabilities and taxon-specific physical disturbance tolerances, Paavo et al. (2011) provided evidence that these events shaped benthic communities which were first constrained by the covarying depth and sediment texture gradients previously described (Single 2007). The mechanism is probably physical disruption due to increased benthic shear forces associated with focusing by bathymetric features as observed in mean wave height and circulation modelling whether or not significant sediment is moved via bedload transport processes (observed in modelled sediment volume changes). Benthic shear forces have taxon-specific effects, but feeding efficiency and sediment binding influences have been most frequently documented.

While the causal mechanism connecting local macrofauna to hydraulic energy has not been explicitly tested, the biological characteristics of observed taxa support this link and provide the basis for a conceptual model of the study area (Fig. 38). Shallow subtidal areas were inhabited by few tubicolous animals and dominated by robust mobile species. Deeper than the 15 m contour there was an increase in the number of features associated with ghost-shrimp which did not appear frequently below 20 m. The 15–18 m contours also marked the appearance of head-down feeders such as lugworms, species inhabiting emergent tubes, taxa with weak-integuments, and substantial burrow systems which generally became more common with increasing depth, but collectively represented an inner shelf community. Somewhere between the 20 and 25 m contours large epifaunal taxa such as hermit crabs, policeman crabs, sea stars, and large snail species became more common as well as indications of additional infaunal taxa including heart urchins. Beyond the 50 m contour sandy sediments gave way to gravelly or palimpsest bottoms with a sharp ecological shift to the well characterised outer shelf community with spatially discrete bryozoan thickets extending to the shelf break. The Aramoana disposal ground is wholly contained within the energetic nearshore band occupied by taxa intolerant to mud or silt sediments. The Heyward Pt. disposal ground is a physically and biologically complex area spanning significant, 'natural' assemblage boundaries.

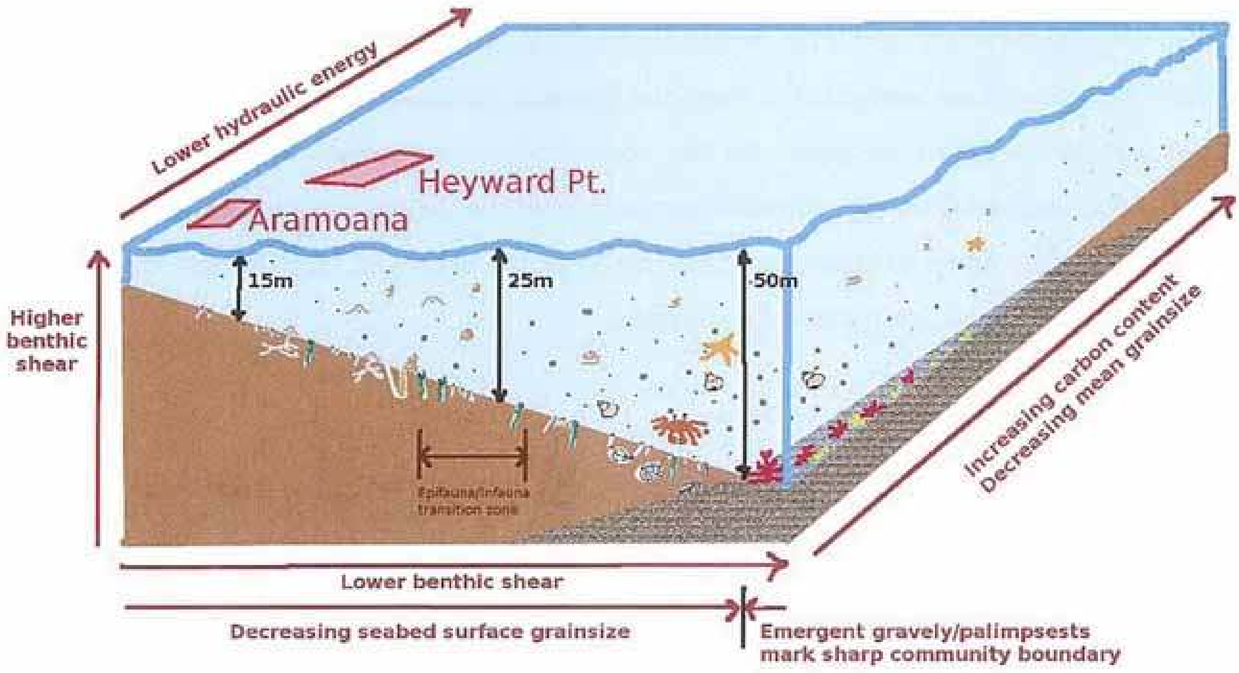


Fig. 38. Developing conceptual model of the study area and the location of the Aramoana and Heyward Pt. disposal areas within a coastal ecology context.

Patterns relative to disposal activities

Macrofaunal abundances were generally lower in areas associated with mounds at both Aramoana and Heyward Pt. disposal areas. At Aramoana there was an increase in abundance with increasing distance from the disposal area at bathymetrically matched sites. The same increase was observed near the Aramoana mound as well. Taxon richness was correspondingly lower in these areas, as a consequence of lowered abundance. This likely signifies an assemblage-wide effect of disposal rather than taxon-specific effects with the exception of *Zethalia zelandica* and a few other taxa. Although 2003-2005 data did not provide high spatial resolution around the disposal areas, the samples fit into the general bathymetric and impact patterns observed in 2008 and 2010. It is not plausible that disposal activities have substantially altered the entire area covered by the present synthetic analyses, so the patterns observed indicate that disposal impacts appear to be localised around the existing disposal sites.

Data are currently being gathered on the actual spatial utilisation of the Heyward Pt. disposal ground in response to these analyses, but occasional field observations and anecdotal evidence suggest that recent disposals have been more common in the central area just NW of the existing submarine mound than elsewhere. If this is true, then the abundance and taxon distributions suggest that the impacts of disposal activities rarely extend into the northern third of the site boundary, but probably does extend beyond the western boundary to some degree from

250–500 m. Given the arbitrary origins of the disposal ground boundaries, it is not unexpected for the disposal effects to not match the actual disposal limits. The small-scale heterogeneity of the Heyward Pt. macrofauna supports the view that disposal effects at the current rates, volume, and composition are localised in space (on the scale of 10s of m from each disposal) and that recolonisation from surrounding sediments has been rapid (on the scale of months rather than years) with no substantial taxon extinctions. This demonstrated ability to identify disposal impacts is beneficial to future impact mitigation management.

Looking Forward

Data and analyses represented in this report provide a synthetic understanding of key ecological patterns in the study area. POL has extended its bathymetric survey area thus providing a vital link in understanding the system. POL has also begun monitoring actual disposal locations to further link day-to-day practices with benthic observations. Benthic photographic surveys and SSS work have provided fundamental information on the animals and habitat surrounding disposal activities. This iterative procedure of study and changes in disposal practices has led to an adaptive management approach that would be useful in guiding future mitigation management decisions.

Focused Research on Processes (the next three years)

Our current understanding highlights the importance of integrating physical and biological information to map the impacts of disposal activities. The association of impacts and spoil mounds is apparent, but current information cannot, as yet, differentiate between the effects of disposal due to the physical presence of the mound focussing hydraulic energy, the dispersal pathway of fine material from the mound, nor the composition of the spoil material. The lack of obvious downstream effects suggests that physical processes dominate and dilution of any contaminants that may be present is sufficient for normal ecological processes at the frequency and volume scales observed.

Successful longterm management (*ie.* 35 years) would benefit from modelling physical and biological processes at the Heyward Pt. locale with a focus on dispersal of fine grains and recolonisation by macrofauna using the key species highlighted in this report. Fine grains (mostly bedload transportable) and very fine grains (mostly transported in suspension) are likely to have different fates depending upon the location of deposition (relative to the 16–18 m contours) (MetOcean 2011). The Heyward Pt. site is dispersive with respect to fines as evidenced by the presence of floc and the lack of substantial muddy areas. It seems likely that fines are transported into central Blueskin Bay along the existing grainsize gradient where they remain for an extended period of time (decades or more) and can be colonised by a fauna adapted to muddy sediments which are absent from Heyward Pt. The consistency of the Blueskin Bay macrofauna in 2008 suggests that few or no deleterious effects were observed in a straight line from the Heyward Pt. boundary to the centre of Blueskin Bay under pre-2008 disposal frequency and volume practices. Physical information may indicate if a coastal transport pathway exists, but existing biological information cannot distinguish these assemblages from a 'natural' state. Using the simple and freely available STFATE model may help define areas suitable for empirical testing of discrete disposal events at Heyward Pt. This simple exercise, especially when coupled with approximate macrofaunal tolerances, is likely to improve long-term management data.

The Heyward Pt. mound is a partially anthropogenic feature which adds complexity to an already heterogeneous benthic environment in an ecological transition zone. Monitoring, modelling, and management may benefit from relocating disposal events to one or more areas in only slightly deeper water (19–25 m). The area would need to be large enough and the disposal practices placed so as to avoid formation of another mound joining the existing one (which will probably degrade with time). Further information on practical disposal precision is forthcoming, but it may be that one or more deeper disposal 'target areas' within a defined 'impact boundary' of sufficient size to accommodate projected volumes (but in a different orientation) would make the current strategy even more effective in reducing disposal effects. This approach would also be in keeping with typical best practices developed in Europe and North America.

Monitoring and management for ecological impact mitigation are linked through the identification of important species. Regional management rests on an understanding of the G&S provided by those species. Several of the dominant species in the study area have been identified by this work, most notably polychaetes and molluscs, but gammarid amphipods remain unresolved. As mobile and abundant organisms consumed by many other animals they likely provide important links between benthic production and water column consumers (*e.g.* juvenile or adult fish). Further taxonomic resolution of the most numerous amphipod morphospecies and a few polychaete taxa (*e.g.* Cirratulidae), in the near-future would help determine whether future monitoring should include these taxa or eliminate them from consideration entirely[5].

Beyond 2014

Historical coastal data clearly identifies changes in the shoreline at Aramoana and South Spit since the construction of the Mole over a century ago. Disposal activities have taken place more or less

5 Although infrequent qualitative inspections would remain useful to raise flags for any species introductions or local extinctions.

constantly since that time and coastal sediment transport loads may have altered in response to input and transport conditions from the Clutha River source to the south. Little quantitative ecological information near the disposal areas was available prior to the 2003 data gathered by POL. As a consequence of these facts we can have no comparison to the 'pre-disposal' ecology of the area so assessments and predictions are logically constrained to the ecological *status quo*. No ecological data are available for the Shelly Beach site as seafloor ecology does not currently enter into management considerations in deference to South Spit and Aramoana saltmarsh conservation efforts.

The Aramoana disposal area contains an impoverished macrofaunal community compared to depth-matched sites beyond. Like Heyward Pt., the impact of disposal is probably a result of the anthropogenic mound and impacts probably extend <500 m beyond the disposal area boundary. The Aramoana area is occupied by taxa well-suited to colonise spoil of matching texture dredged from the harbour entrance and many lower-harbour claims as shown by the field manipulation. The site is dispersive with respect to fine sediments which are likely inimical to the Aramoana fauna. Ecological impact mitigation at Aramoana should therefore aim to maintain an unimpacted boundary 'buffer zone' to support a sufficient source population of key taxa (including *Z. zelandica*, *Armandia maculata*, and possibly *Spiophanes* cf *bombyx* among others) able to colonise the volume of sand introduced as spoil. Disposal volumes, rates, and compositions prior to 2005 and between 2005 and 2010 indicate a fairly steady state of impact. A decrease in sand disposal volumes and frequency will likely decrease the impact zone from the current state through recolonisation from the surrounding area. Some unknown increase in sand disposal volume and frequency will compromise the ability of the surrounding area to recolonise sandy spoil and the impact area will expand from the *status quo*. The volumes and disposal frequency required to cause this effect are not known, but are likely proportional to the growth of the mound (which can be physically modelled). Disposal of fine sediments is likely to expand impacts from the *status quo* disproportionate to its volume when sediment transport is through bedload or boundary layer processes. Therefore if disposal continues at Aramoana active management is likely to be most effective at mitigating impacts if it concentrates on physical modelling and the composition of introduced spoil.

At pre-2010 disposal volumes, rates, and spoil composition the effects of disposal at Heyward Pt. appear limited to the central area of the disposal ground and 100–500 m beyond the western boundary. If additional spoil in the Heyward Pt. disposal ground has the effect of increasing the mound then negative effects could be expected to expand relative to current conditions. The lack of impacts in the northern third of the disposal ground relative to surrounding sediments indicates that pre-2010 practices do not negatively impact biota in a down-slope direction. Benthic habitats inside the disposal ground remain predominantly rippled medium to fine sands with occasional small rock or temporary mud patches of 10s to 100s of m^2 in extent. The surrounding communities appear to be rapidly recolonising retained spoil and tolerating dispersed sediments in an ecologically desirable fashion. Disposal of fine sediments at some point beyond recent volumes and rates is likely to expand impacts from the *status quo* disproportionate to its volume when sediment transport is through bedload or boundary layer processes. The volume, frequency, and composition of fines disposal required to overwhelm current recolonisation capacity is not known, therefore if disposal continues at Heyward Pt. active management is likely to be more effective at mitigating impacts if it concentrates on reducing or relocating mound formation and modifying practices in response to recolonisation rates observed for introduced spoil and fine sediment transport pathways. Careful consideration of the altered bathymetry of the Heyward Pt. disposal area is important as the mound position and shape is likely to strongly influence communities in the area and hence effects of disposal.

Disposal relative to the coastal plan and guidelines

Any use of the seabed contributes positive and negative effects to the G&S provided by the biota and physical processes in that space. Unlike many other regional authorities, the Otago Regional Council currently "relies on resource consent monitoring to fulfil it's [sic] responsibilities under the Resource Management Act (1991), the Regional Policy Statement and the Regional Plan: Coast." (ORC 2005). As such, there are currently no clear policy statements against which to measure or project acceptable impacts. For long-term management and monitoring this further complicates responsible mitigation compliance in consideration of inevitable compound effects. The national guidelines provide best practices for the express purpose of aiding regional council policy formation. POL has proposed an intensive and integrative three-year study period to make use of recent research to support a future application for long-term disposal consent permission. Development of a practical ecological monitoring programme and an effective impact mitigation management plan requires a policy statement from the working party (which has a representative from the consenting authority) guiding baseline conditions or locations[6]. With such a policy in place, management and monitoring strategies can be developed and evaluated which target the G&S most valued by the working party and regional authority. It is also good scientific practice, with

6 Additional information and one example can be found at: http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/sitemonitor.cfm

ample domestic precedent, to provide for independent review of technical data and management strategies by qualified reviewers who did not participate in any of the work (*e.g.* the current review of proposed Great Barrier Island disposal site by MaritimeNZ).

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