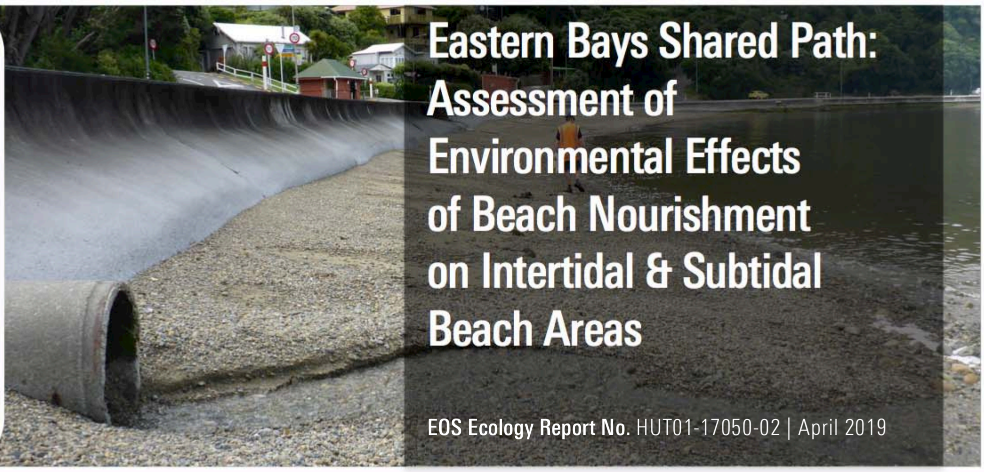

Eastern Bays Shared Path: Assessment of Environmental Effects of Beach Nourishment on Intertidal & Subtidal Beach Areas

EOS Ecology Report No. HUT01-17050-02 | April 2019

SCIENCE + ENGAGEMENT

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Prepared for Hutt City Council

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EXECUTIVE SUMMARY

As part of the Hutt City Council (HCC) transport strategy the HCC is seeking to improve safety for pedestrians and cyclists along part of Marine Drive in the Eastern Bays of Wellington by creating a wider cycle/pedestrian path and replacing a number of seawalls to provide fit-for-purpose structures that are resilient to storm surges and to provide the first step towards adapting to future sea level rise. As the proposed project requires encroachment into the foreshore area for creation of the shared path and upgraded seawall, there will be a loss of beach area in some locations, which will reduce amenity and recreational values of the local area. Consequently beach nourishment has been proposed for Point Howard, Lowry Bay and York Bay beaches to mitigate the loss of beach area. EOS Ecology was commissioned to provide an assessment of environmental effects that the proposed beach nourishment will have on the benthic intertidal and subtidal ecology of these beach areas. This supplements the report undertaken by McMurtrie & Brennan (2019) that assessed the effects of the proposed seawall/shared path upgrades on intertidal benthic ecology.

The area of beach proposed for nourishment is similar to the existing beach area (pre-shared path construction), thereby mitigating beach loss. The total amount of sediment to be added for the nourishment will be 6,000 m^3, but a loss of approximately 1,400 m^3 (20-25%) is expected due to coastal processes (tides, wind and waves). The material proposed to be used for nourishment will be of a similar or coarser grain size and colour to the existing *in situ* beach material, and will have no more than 2-3% of fines, in order to provide similar characteristics and reduce impacts on ecology and amenity.

Broad-scale habitat mapping undertaken in May 2016 and June 2017 showed that the substrate categories ‘firm sand (gravel field)’ along with the small areas of ‘firm sand’ characterise the beach areas. This accounts for 22% of the total intertidal area of the project area, the majority of which exists in Lowry Bay (40% of the total beach habitat defined within the project area). These beach areas are considered to be relatively active and composed of sediments sourced locally from each bays’ catchment.

Ecological surveys of the intertidal and subtidal zones were undertaken on a range of dates in May 2016, June 2017, Dec 2018, and Feb 2019, involving the collection of infauna samples from bays within the project area that are and are not being considered for beach nourishment. A total of 92 invertebrate taxa and 2,199 individuals were identified from the 78 infauna samples collected within the intertidal (31 samples) and subtidal (47 samples) zones of the study area. In general the infauna community was dominated by polychaetes, followed by crustaceans and a lesser proportion of molluscs. The intertidal and subtidal fauna of the beach sediments were considered to be in a healthy condition with dominant species indicative of no adverse nutrient enrichment or chemical contamination. No invertebrate taxa of conservation concern (as listed in the threatened species list of Freeman *et al.*, 2014) were recorded from the project area.

Taxa richness and density were not significantly different between bays but there was a significant difference between tidal zones. Taxa richness and density were significantly higher in the subtidal zone compared to the intertidal zone, with, on average, more than three times the average number of taxa and double the average number of individuals per sample in the subtidal zone.

There were no significant differences in community composition between the different bays within the project area, but there were significant differences in community composition between the subtidal and intertidal zones. The intertidal zone was dominated by the polychaetes *Aonides* sp. and *Prionospio* sp., as well as Gammaridae amphipods, whilst the subtidal zone was dominated by the polychaetes *Magelona*

dakini, Heteromastus filiformis and Sabellidae and the bivalve mollusc *Macomona liliana* (large wedge shell). The subtidal nearshore zone (depth > 1 m) had a greater abundance of *Magelona dakini*_and *Macomona liliana*, whilst the subtidal shallow zone (depth 1-5 m) had a greater abundance of *Heteromastus filiformis*. The polychaete Sabellidae was found throughout the subtidal zone.

When comparing the infauna community from potential impact areas and areas not likely to be affected, there were no significant differences in community composition, taxa density or taxa diversity.

The presence of a number of benthic species of food value within the subtidal zone, and the discarded remains of a range of marine food species as found by McMurtrie & Brennan (2019) is a good indication that food gathering occurs within this area. Horse mussels, pipi, cockles, and some kina appear to be the main species found in the nearshore and shallow subtidal soft sediment zone of the Eastern Bays area. No kelp was observed during the dive surveys undertaken to collect samples from the nearshore and shallow subtidal areas.

The proposed beach nourishment of three beaches (Point Howard, Lowry Bay, York Bay) within the project area has the potential for both short-term (initial introduction of beach material) and medium-term (natural redistribution of beach nourishment material) effects. These include disturbance and possible compaction of habitat during excavation and machinery use (for initial excavations and introduction of beach material), smothering of intertidal habitat/biota during the initial introduction of beach material through to the medium-term movement of beach nourishment material beyond the initial introduction sites, and increased suspendend sediment during the intial phases and possibly during the later redistribution of materials via tide and waves.

Our assessment is that small shifts in community composition may occur at some locations as a response to the shifting beach nourishment material, but it is unlikely to greatly change the overall community composition of the subtidal area due to the similarity of beach nourishment material to the *in situ* material, lack of fines in the introduced material, the localised nature of the sediment movement, the already dynamic nature of the nearshore environment, and the similarity in the subtidal benthic invertebrate community within and between the bays that will allow for recolonisation. A greater level of impact is expected within the intertidal zone where the beach nourishment materials will be introduced, primarily due to the fact that the introduced sediment may be too deep for *in situ* biota to tolerate. Yet this is offset by the lower diversity and density of taxa in the intertidal beach areas and the similarity of the infauna community within the impact areas to the wider intertidal beach area, which will help to facilitate recolonisation after the initial disturbance.

The listed mitigation measures (both currently proposed and additionally recommended here) will help to limit the effects of beach nourishment on the benthic beach environment to a 'minor' or 'less than minor' level of effect in the context of the RMA. However, as sediment migration can vary based on site-specific conditions, and as there is little detail as to the level of redistribution of sediments over time, we would recommend that some monitoring of the movement of beach nourishment materials be undertaken, along with an assessment of the benthic intertidal and subtidal beach fauna at least 12 months after completion of the proposed works.

1 INTRODUCTION

As part of the Hutt City Council (HCC) transport strategy the HCC is seeking to improve safety for pedestrians and cyclists along part of Marine Drive in the Eastern Bays of Wellington by creating a wider cycle/pedestrian path and replacing a number of seawalls to provide fit-for-purpose structures that are resilient to storm surges and to provide the first step towards adapting to future sea level rise. This Eastern Bays Shared Path Project will provide a safe connection for residents in the Eastern Bays to workplaces, schools, shops and public transport facilities in the rest of Hutt City. It will also connect to the planned Wainuiomata Hill and Beltway Shared Paths and, in the future, through to Wellington City by joining up and connecting to new facilities planned by both the New Zealand Transport Agency and Wellington City Council.

The project focuses on Marine Drive, between Point Howard and the northern end of Days Bay, and the southern end of Days Bay (Windy Point) to Eastbourne (Muritai Road / Marine Parade intersection) (Figure 1, Stantec, 2019a). These bays are known collectively as the Eastern Bays and include (from north to south) Point Howard, Sorrento Bay, Lowry Bay, York Bay, Mahina Bay, Sunshine Bay, Days Bay, and Windy Point (in Eastbourne).

The project description for the replacement and creation of seawalls has been previously covered in McMurtrie & Brennan (2019). The overall extent of works is approximately 3.1 km over 4.4 km of lineal shoreline length (Figure 1). Due to the loss of beach area by occupation of the shared path and seawall, beach nourishment has consequently been proposed for three locations: Point Howard beach, Lowry Bay and York Bay (Figure 1). Recreation and amenity are the key reasons for this action, with improved coastal protection a secondary benefit. The approximate total length of beach to be nourished and volume of imported sediment is calculated at 320 m and 6,000 m^3, which is to replace that length and area of beach lost to the shared path and seawall (Reinen-Hamill, 2019).

HCC commissioned EOS Ecology to undertake an assessment of beach nourishment on the ecology of intertidal and subtidal areas of these beaches. This supplements the report undertaken by McMurtrie & Brennan (2019) that assessesed the effects of the proposed seawall/shared path upgrades on intertidal benthic ecology. Note that coastal physical processes are covered in Allis (2019), beach nourishment in Reinen-Hamill (2019), avifauna in Overmars (2019a), seagrass in Overmars (2019b), and freshwater fish passage in James (2019). We have been asked to exclude stormwater due to it being a permitted activity under the Regional Plan.

Figure 1 Proposed areas of seawall works (as shown in Stantec 2018) and proposed locations for beach nourishment.

2 METHODS

Broadscale habitat mapping of the intertidal area was undertaken by McMurtrie & Brennan (2019), and is referred to in this report to characterise the project area. Due to a lack of ecological information regarding the benthic fauna of the intertidal and subtidal beach environments along the Eastern Bays area, field surveys were undertaken to collect benthic samples across various tidal zones. The two main tidal zones within the coastal marine area (CMA) are the intertidal zone between mean high water springs (MHWS) and mean low water springs (MLWS), and the subtidal zone below MLWS (Figure 2). These zones can be further defined relating to their locations and environmental conditions experienced: upper intertidal zone is in the mid-high tide area; lower intertidal zone is in the low-mid tide zone; subtidal (nearshore) is the zone below MLWS but within one metre of water depth; subtidal (shallow) is the slightly deeper zone but shallower than five meters water depth.

The benthic fauna of intertidal beaches of the Eastern Bays were sampled at eight locations as part of the wider intertidal study undertaken by McMurtrie & Brennan (2019) and supplemented by an additional 23 locations on 20 December 2018 as part of this current study. The nearshore and shallow subtidal areas were sampled at 47 locations on 10-11 February and 19 February 2019, which were categorised as shallow subtidal areas less than 5 m deep (32 locations) (defined as Subtidal (shallow)) and nearshore subtidal areas less than 1 m water depth (15 locations) (defined as Subtidal (nearshore)) (Figure 3, Table 1).

The site locations were chosen to ensure coverage of the bays where beach nourishment was proposed as well as comparison bays that were not planned for beach nourishment, and covered the tidal gradient from intertidal through to subtidal to account for any future potential spread of beach nourishment material and/or to provide adjacent comparison samples to potential impact sites.

At each site the benthic community was sampled via the collection of an infauna core. Infauna cores were 130 mm in diameter and were pushed into the sediment to a depth of 150 mm, thereby covering a small portion of surface substrate and a greater volume of subsurface sediment. Infauna samples within the intertidal zone were collected during low tide exposure, while the subtidal samples were collected via boat with the use of divers (Figure 4). Where substrate was sufficiently fine the core was extracted from the *in situ* sediment and upended into a 500 micron mesh bag. Where the substrate consisted of larger material (cobbles and gravel substrate) the collection of the core was assisted via the use of a hand trowel to exacavate material within a comparable diameter and depth. Each infauna sample was washed on site in seawater and fixed in 10% formalin, before being preserved in 70% IPA (isopropyl alcohol) prior to laboratory for processing. In the laboratory each infauna core sample was washed through a 500 micron sieve prior to processing. Processing involved the identification and counting of all invertebrates to the lowest practical level of classification using a full count procedure and stereo microscopes.

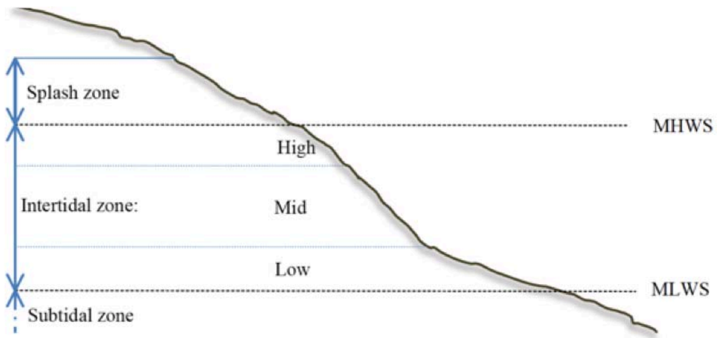

Figure 2 Classification of seashore zones (Smith, 2013).

Figure 3 The survey sites where benthic invertebrate samples were collected in May 2016, June 2017, December 2018 and February 2019 by EOS Ecology. Samples were collected in the intertidal and subtidal areas with the subtidal area characterised as subtidal (nearshore) (<1 m deep), and subtidal (shallow) (<5 m deep).

Figure 3 (cont.) The survey sites where benthic invertebrate samples were collected in May 2016, June 2017, December 2018 and February 2019 by EOS Ecology. Samples were collected in the intertidal and subtidal areas with the subtidal area characterised as subtidal (nearshore) (<1 m deep), and subtidal (shallow) (<5 m deep).

Figure 3 (cont.) The survey sites where benthic invertebrate samples were collected in May 2016, June 2017, December 2018 and February 2019 by EOS Ecology. Samples were collected in the intertidal and subtidal areas with the subtidal area characterised as subtidal (nearshore) (<1 m deep), and subtidal (shallow) (<5 m deep).

Extraction of an infauna core within the intertidal zone.

Transfer of intertidal core into mesh bag.

Collection of a subtidal infauna core.

Subtidal transfer of infauna core into mesh bag.

Figure 4 Examples of survey methodology undertaken by EOS Ecology during the collection of benthic intertidal and subtidal samples in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), Dec 2018 (Sites Int-1 to Int-23) and Feb 2019 (Sites Sub 1 to Sub 47).

Table 1 Breakdown of infauna cores collected within each bay along the project area by EOS Ecology during surveys on the 4-6 May 2016, 8 June 2017, 20 December 2018 and 10-11 and 19 February 2019.

Bay	Proposed beach nourishment within bay	Zone	No. of infauna cores
Point Howard	Yes	Intertidal	3
		Subtidal (nearshore)	2
		Subtidal (shallow)	4
Sorrento Bay	No	Intertidal	3
		Subtidal (nearshore)	1
		Subtidal (shallow)	2
Lowry Bay	Yes	Intertidal	10
		Subtidal (nearshore)	10
		Subtidal (shallow)	14
York Bay	Yes	Intertidal	5
		Subtidal (nearshore)	1
		Subtidal (shallow)	4
Mahina Bay	No	Intertidal	5
		Subtidal (nearshore)	0
		Subtidal (shallow)	4
Sunshine Bay	No	Intertidal	1
		Subtidal (nearshore)	0
		Subtidal (shallow)	0
Days Bay	No	Intertidal	4
		Subtidal (nearshore)	1
		Subtidal (shallow)	4
TOTAL		Intertidal	31
		Subtidal (nearshore)	15
		Subtidal (shallow)	32

2.1 Sediment Contamination

There is some existing information for sediment contamination within the project area, although this is limited to samples from Lowry Bay by Stevens *et al.* (2004). This was used to provide an indication of sediment contaminant levels in the area.

2.2 Data Analysis

Distribution of the infauna community was examined using non-metric multidimensional scaling (NMS). NMS is a non-metric statistical technique that condenses sample data (in this case infauna community data) to a single point in low-dimensional ordination space using some measure of community dissimilarity (Bray-Curtis metric in this instance). Interpretation is straightforward such that points on an x-y plot that are close together represent samples that are more similar in community composition than those further apart (Clarke & Gorley, 2006). Differences in infauna community composition between various groupings (e.g., bay, tidal zone, and control or impact areas) were tested using the analysis of similarities (ANOSIM) procedure, which is a non-parametric procedure applied to the similarity matrix that underlies the NMS ordination. ANOSIM is an approximate analogue of the standard ANOVA (analysis of variance) and compares the similarity between groups using the R test statistic. R=0 where there is no difference in the infauna community between groups, while R=1 where the groups have completely different communities. Where ANOSIM results showed significant or near-significant differences in infauna community compositions, the similarity percentages (SIMPER) procedure was used to determine which taxa where responsible. NMS, ANOSIM, and SIMPER were all carried out in PRIMER v6.1.5 (Clarke & Gorley, 2006).

Analysis of Variance (ANOVA) was used to test for significant differences in taxa richness and density between groupings (bay, tidal zone, and control or impact areas). Data was transformed via square root transformations, where needed, to meet the normality and equal variance assumptions of ANOVA. Where either or both assumptions were not able to be met then the non-parametric Kruskal-Wallis test was used instead. Where significant differences were found then post hoc pairwise multiple comparison procedures (Holm-Sidak method for ANOVA and Dunn's Method for Kruskal-Wallis) were used to determine where these differences occurred.

3 EXISTING STATE OF THE ENVIRONMENT

3.1 Existing Beach Areas and Broadscale Habitat Types

3.1.1 Eastern Bays

The intertidal habitat of the Eastern Bays area (i.e., Point Howard to Windy Point) has been described in McMurtrie & Brennan (2019). In general, the the predominant habitat type (32% of the total area mapped) was defined as a 'cobble field (bedrock)' mix (Table 2; Figure 5), and was present in every bay. Beach areas, in comparison, consist of firm sand or firm sand (gravel field), and account for 22% of the total project area[1], the majority of which exists in Lowry Bay (40% of the total beach habitat defined within the project area) (Table 3; Figure 6).

Firm sand (gravel field), along with the small areas of firm sand, characterise the "beach" areas. They consists of sandy substrate, sometimes below a layer of mobile gravels, or alternatively gravel found beneath a surficial sand layer (Figure 7). These areas are considered to be relatively active and the sediments sourced locally from each bays' catchment (Reinen-Hamill, 2019).

Reinen-Hamill (2019) describes the beach areas as a mix of sand and gravels, with increasing sand content from York Bay north to Point Howard. The nearshore sediment off the beaches in Point Howard, Lowry Bay and York Bay were described in detail from particle size analysis in Reinen-Hamill (2019). Point Howard contains 50% coarse sediment made up of gravels and shells, with 50% fine sand. York Bay has a similar composition to Point Howard, with finer sands trending to the north of the bay. Lowry Bay nearshore sediments were generally fine sand. Stevens *et al.* (2004) describe Lowry Bay sediments as grading with depth from fine sand to coarse sand to silt and mud. Across all the beaches sampled, no fine sediment smaller than 0.09 mm (90 microns) was found, presumably due to the wave processes that occur and wash fine sediment away.

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[1] As the project area excludes the beach area of Days Bay, we have excluded this area in the broad scale-habitat assessment.

The Eastern Bays share a characteristic of many coastal embayments in New Zealand and around the world, the "coastal squeeze", where the intertidal habitat is limited by human land use on the landward side and sea level rise on the seaward side (Pontee, 2013). Beach areas are important for recreation and amenity as well as for ecology. Mitigation for the loss of intertidal beach habitat is an important factor for resilience of ecosystems into the future.

Table 2 Habitat types (in order of dominance) within the intertidal zone of the project area from Point Howard to Windy Point (excluding Days Bay) as mapped by EOS Ecology for the broad scale habitat assessment undertaken 3 May 2016 (Point Howard to Sunshine Bay) and 8 June 2017 (Eastbourne/Windy Point). The areas and percentage of each habitat type is shown, as is the percentage of each habitat type within each bay. Photographs of each of these habitat types is shown in Figure 5 while maps identifying areas of these habitat types are shown in Appendix 2. The habitat types we define as 'beach' habitats are shaded.

				Percentage of habitat type in each bay						
Habitat type (in order of dominance)	Habitat code	Area mapped (m^2)	% of total area mapped	Point Howard	Sorrento Bay	Lowry Bay	York Bay	Mahina Bay	Sunshine Bay	Windy Point
Cobble field (bedrock)	CF/RB	13,134	32	19.5	0.0	30.2	46.0	37.0	38.9	27.4
Firm sand (gravel field)	FS/GF	8,607	21	33.6	17.2	38.9	17.2	13.7	14.3	6.9
Bedrock	RB	5,895	14	23.2	71.0	0.0	8.7	12.4	5.7	28.6
Gravel field	GF	4,335	11	0.0	3.2	9.6	7.5	18.2	15.8	11.6
Cobble field	CF	3,602	9	0.0	0.0	11.1	7.9	6.2	9.1	18.3
Concrete	CT	2,749	7	3.5	8.6	7.9	12.6	8.9	3.3	1.8
Boulder field	BF	2,165	5	20.2	0.0	0.6	0.0	3.6	12.2	2.9
Firm sand	FS	348	1	0.0	0.0	1.7	0.0	0.0	0.7	2.5

Table 3 Approximate length and area of existing beaches (within the project area from Point Howard to Windy Point), according to locations of mapped firm sand or firm sand (gravel field). Habitat types determined during surveys undertaken by EOS Ecology on 3 May 2016 and 8 June 2017.

Bay	Beach length (m)	Beach area (m^2)
Point Howard	120	1,499
Sorrento Bay	40	330
Lowry Bay	400	3,558
York Bay	224	1,101
Mahina Bay	156	928
Sunshine Bay	123	964
Windy Point	125	576
Total	**1,188**	**8,955**

Cobble field (bedrock) (32% of area)

Firm sand (gravel field) (21% of area)

Bedrock (14% of area)

Gravel field (11% of area)

Cobble field (9% of area)

Concrete (7% of area)

Boulder field (5% of area)

Firm sand (1% of area)

Figure 5 Examples of habitat types (and their percentage of total area mapped) as found on the broad scale habitat assessment along the project area on 3-5 May 2016 and 8-9 June 2017, censu McMurtrie & Brennan (2019). Firm sand (gravel field) and firm sand are the substrates that make up the beach areas found in the bays within the project area.

Figure 6 Beach habitat areas (as defined by firm sand (FS) and firm sand (gravel field) (FS/GF) substrate) that currently exist within the project area, as determined during surveys by broad scale habitat mapping undertaken by EOS Ecology on on 3-5 May 2016 and 8-9 June 2017 (Appendix 2). Note that the majority of Days Bay was not surveyed as it is not part of the Project Area.

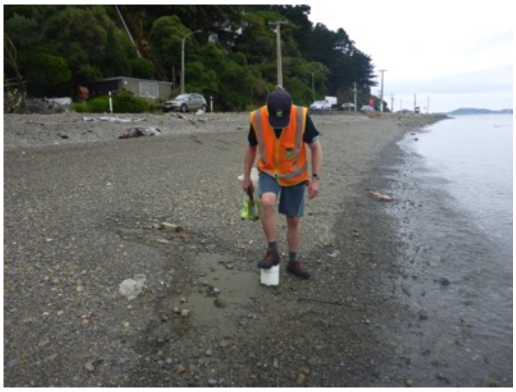
Point Howard, looking south.

Sorrento Bay, looking south.

Lowry Bay, looking south from about midway.

York Bay, looking south.

Mahina Bay, looking south.



Sunshine Bay, looking south.

Days Bay, looking south from the north end of the bay.

Windy Point looking north.

Figure 7 Examples of the beaches (as defined by firm sand or firm sand (gravel field)) within the project area, between Point Howard to Windy Point.

3.2 Comparison to Beach Areas in the Wider Wellington Harbour

According to information on Greater Wellington Regional Council's website, "Wellington Harbour covers an area of 8,900 ha and has 76 km of accessible coastline stretching from Owhiro Bay in the West to Baring Head in the East. The depth averages about 20 metres except for the harbour entrance where it shallows to 11 metres. This is also the narrowest part of the harbour." Sheltered bays and beaches can be found around the harbour with the most popular being Oriental Bay, Petone Beach and Days Bay (Figure 8). Wellington Harbour has a poor supply of natural sand and the beaches are of a gravely nature, limited to areas that have not been modified (Carter & Mitchell, 1985).

A number of sandy/gravel areas, some of which are used for recreational beach activities are located around Wellington Harbour (Figure 8). Petone Beach is made up of sandy habitat with areas of pebbles and boulders, and the western shoreline including Ngauranga and Kaiwharawhara is highly modified with rock and block shoreline protection with small areas of pebbles and boulders (EHEA, 1998). Oriental Bay, including Freyberg Beach, is a very popular inner city beach location, being re-nourished periodically with sand from various sources since 1944. Evans Bay beaches (especially Balaena Bay and Hataitai beaches) are well utilised for sun bathing and swimming during the warmer months, with Balaena Bay receiving nourishment in 1982. The Miramar Peninsula has sections of sandy, pebbly and rocky shore habitats on both the eastern and western sides of the peninsula (EHEA, 1998; Stevens *et al.*, 2004) (Figure 8).

According to the broad-scale mapping of EHEA (1998) and Stevens *et al.* (2004), habitat types south of Days Bay to Pencarrow Head are similar to that within the project area, with pebbles and boulders, sand, gravel, and rocky areas present. There is a northward movement of gravel from Pencarrow Head to Eastbourne with the effects decreasing with distance from the entrance to Wellington Harbour, and with Days Bay currently the northward limit of this gravel transport (Matthews, 1980; Reinen-Hamill, 2016). Beach sediments between Pencarrow Head and Days Bay tend to be a mix of sand and gravels, with an increasing proportion of sand towards Days Bay (Reinen-Hamill, 2016).

Figure 8 Beach locations within Wellington Harbour (main source of information is LINZ).

3.3 Hydrodynamics and Sediment Transport

Wellington Harbour has a maximum tidal range of 1.5 m and an average tidal range of 0.75 m (neap tides) or 1.25 m (spring tides). The tidal zones for beach habitat can be classified as low, mid and high tide and are a significant factor in the determination of biological communities inhabiting intertidal habitats (Lachowicz, 2005). Within the shallow subtidal zone, wave and wind processes can influence the sediments and the fauna living there.

Sediment transport in the coastal zone of Wellington Harbour is primarily driven by waves, with the small tidal currents too weak to transport sediment on the seabed except within the Harbour mouth. The environment of the Eastern Bays is dynamic and the beaches undergo periods of accretion and erosion on a range of timescales from sub-daily (i.e. a tidal cycle) to interannual (Allis, 2019; GHD, 2015; Matthews, 1980), however the long-term trend of shoreline change suggests that the embayments north of Days Bay are relatively stable in terms of total beach volume and shoreline position. Beach erosion is common along the northern ends of the bays during southerly storms, although high tides combined with strong easterly winds also cause bay-wide erosion (Allis, 2019).

Subtidal sediment along the Eastern Bays area of Wellington is generally described as sandy to very sandy due to the supply of marine sands from the Harbour entrance being deposited here during storm events (Figure 9, Booth, 1972; EHEA, 1998). Gravels are also deposited along the Eastern Bays from Cook Strait during large storms as well as from the erosion of adjacent rocky outcrops (EHEA, 1998), however gravel transport decreases from south to north with very little gravel transported north of Days Bay (Reinen-Hamill, 2016). Alluvial sediment is supplied during flood events from the Hutt River and other freshwater streams but does not accumulate on the Eastern Bays foreshore in substantial quantities due to the finer nature of these particles and the relatively exposed nature of the bays. In general, sediments within the Eastern Bays from Sunshine Bay to Point Howard are likely sourced from the bays' own catchment (Reinen-Hamill, 2019).

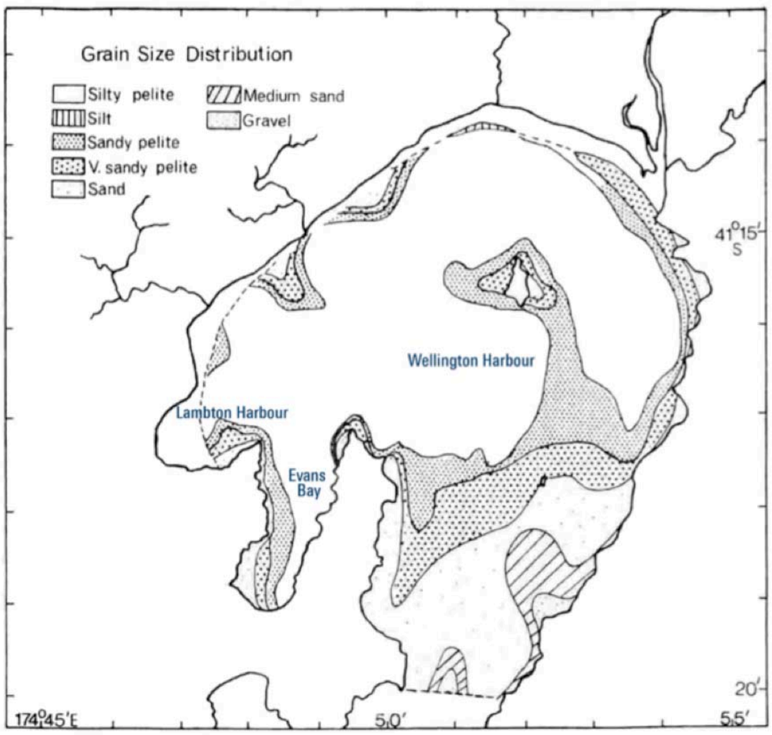


Figure 9 Particle size distribution in Wellington Harbour, as shown in Booth (1972). Note: "pelite" is an older geological term for clay-rick fine-grained sedimentary rock.

3.4 Benthic Invertebrate Ecology

A total of 92 invertebrate taxa and 2,199 individuals were identified from the 78 infauna samples collected within the intertidal (31 samples) and subtidal (47 samples) zones of the study area (Appendix 3, Appendix 4). Of these, five intertidal infauna samples collected had no taxa found.

In general the infauna community was dominated by polychaetes, followed by crustaceans and a lesser proportion of molluscs. Remaining groups (echindoderms, nematodes, nemerteans, other smaller groups) made up a smaller portion of the overall community (Figure 10). This pattern was broadly reflected in the different intertidal and subtidal zones; although the intertidal (mid-high) zone had a greater proportion of nematodes, nemerteans and 'other' groups, and no molluscs; whilst the subtidal (nearshore) zone had a greater proportion of polychaetes and fewer crustaceans than other zones (Figure 10).

There were no significant differences in community composition between the different bays within the project area (ANOSIM Global R=0.192, p=0.004); despite a significant P value, an R value close to zero is indicative of no or very little difference between groups (Figure 11). In comparison there were significant differences in community composition between the subtidal and intertidal zone (ANOSIM Global R=0.751, p=0.01), with an R value closer to 1 (1 indicating distinct communities) (Figure 12). In general the intertidal and subtidal communities were separated along the x-axis, indicating different community compositions. In particular the subtidal community had a greater abundance of the polychaetes *Magelona dakini*, Sabellidae and *Heteromastus filiformis* . When looking at the splits within these tide zones there appeared to be little difference between the two intertidal zones (mid-high and mid-low) in relation to community composition. In contrast, whilst there was greater similarity in community composition of the two subtidal zones (nearshore and shallow) along the x-axis, the clustering of the nearshore subtidal samples within the upper y-axis spread of the shallow subtidal samples indicate the nearshore subtidal samples had a greater similarity/consisted of a subset of the community composition of the shallow subtidal samples (Figure 12). In particular the subtidal (nearshore) zone had a greater abundance of the polychaete *Magelona dakini* and bivalve mollusc *Macomona liliana* (large wedge shell), whilst the subtidal (shallow) zone had a greater abundance of the polychaete *Heteromastus filiformis*.

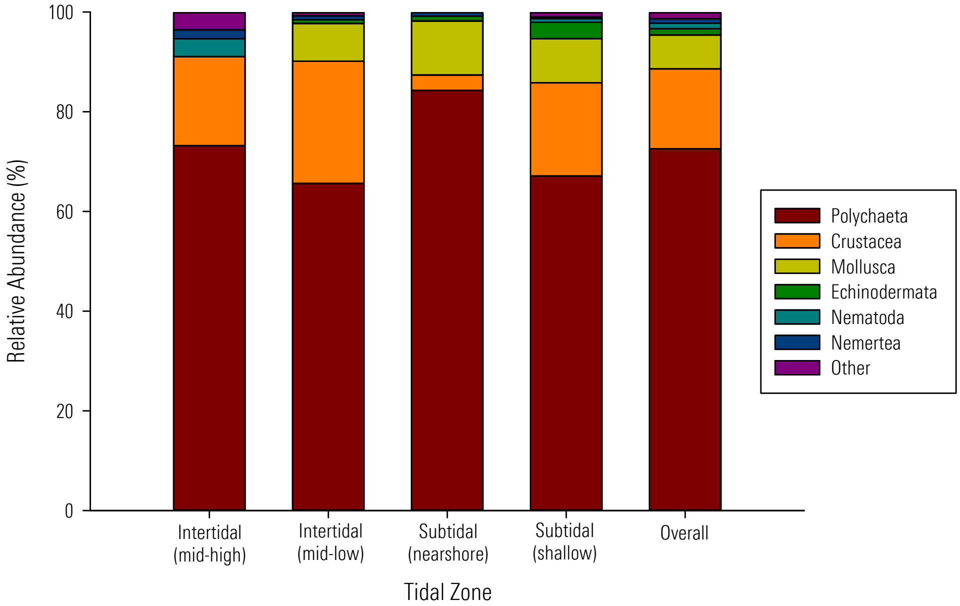


Figure 10 Bar graph showing the relative abundance of faunal groups between the intertidal (mid-low, mid-high) and subtidal (nearshore, shallow) zones, from samples collected by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), Dec 2018 (Sites Int-1 to Int-23) and Feb 2019 (Sites Sub 1 to Sub 47). The "Other" category consists of Chelicerata, Cnidaria, Insecta, Platyhelminthes, and Sipuncula.

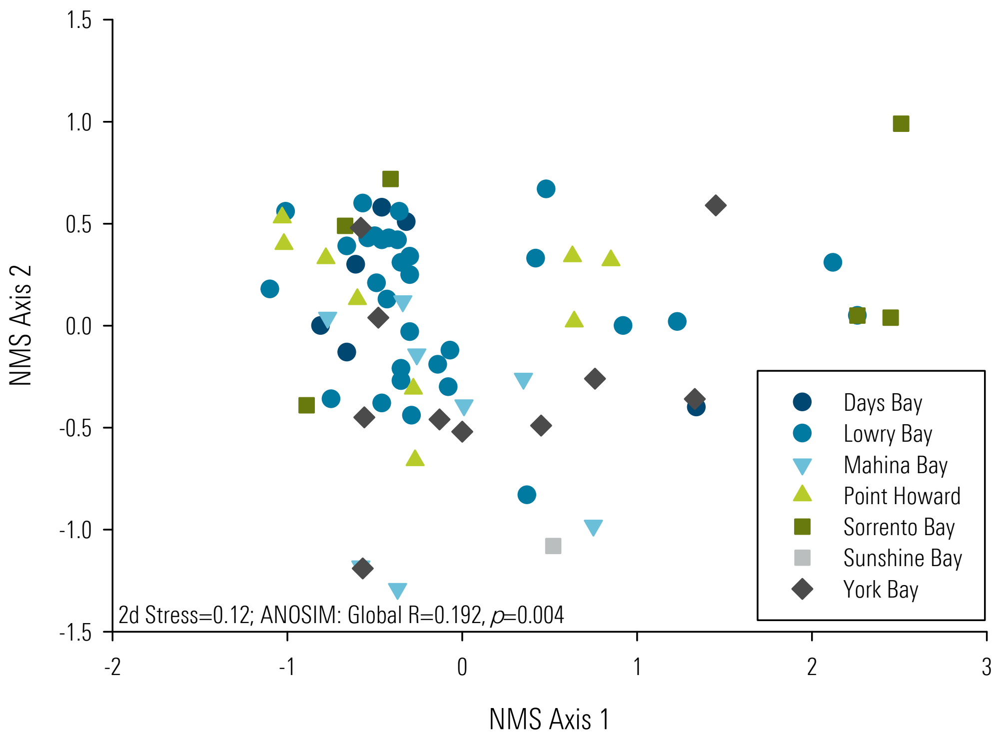


Figure 11 An NMS plot of infauna samples (intertidal and subtidal) collected from the different bays within the project area by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), Dec 2018 (Sites Int-1 to Int-23) and Feb 2019 (Sites Sub 1 to Sub 47).

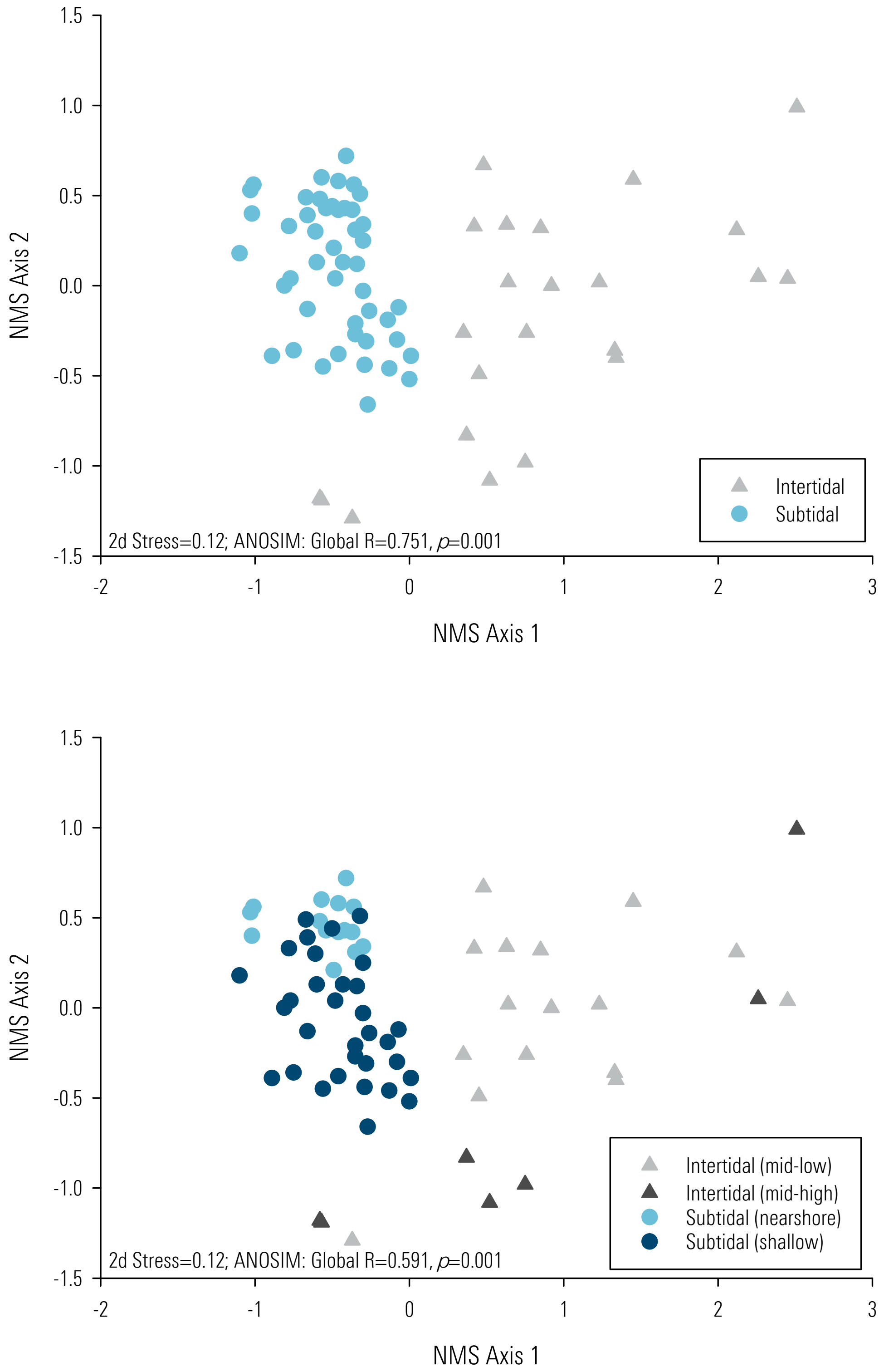


Figure 12 An NMS plot of infauna samples collected from the intertidal zone (mid-low, mid-high) and subtidal zone (nearshore and shallow) within the project area by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), Dec 2018 (Sites Int-1 to Int-23) and Feb 2019 (Sites Sub 1 to Sub 47).

Taxa richness (H=8.237, p = 0.221) and density (F=1.217, p = 0.31) were not significantly different between bays (Figure 13). Whilst there was little pattern evident between bays there was a definite difference between tidal zones for taxa richness and density. Kruskal-Wallis ANOVAs showed that taxa richness (H=38.284, p<0.001) and density (H=32.791, p<0.001) were significantly higher in the subtidal zone compared to the intertidal zone, with (on average) more than three times the number of taxa and double the number of individuals in the subtidal zone (Figure 14). Taxa richness generally increased down the shoreline, from the mid-high intertidal zone through to the shallow subtidal zone (Figure 14), with significantly higher richness in the subtidal (shallow) zone compared to the intertidal (mid-high) zone (F=34.856, p<0.001). Taxa density peaked slightly at the nearshore subtidal zone, although the larger error bars meant that the densities weren't significantly different to the shallow subtidal zone (Figure 14).

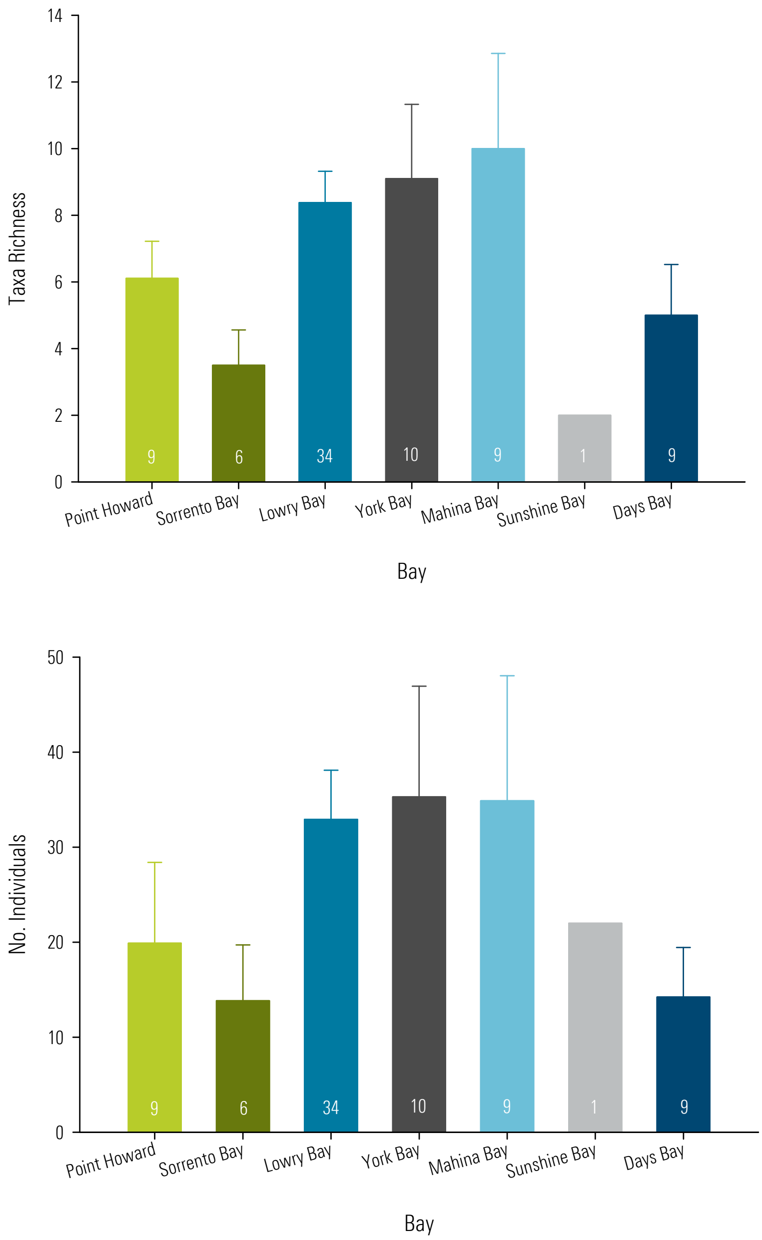


Figure 13 Average (+ 1 SE) taxa richness and density (no. individuals per infauna sample) of infauna samples plotted against bay. Numbers within bars denote the number of samples within that category. Surveys were undertaken by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), Dec 2018 (Sites Int-1 to Int-23) and Feb 2019 (Sites Sub 1 to Sub 47).

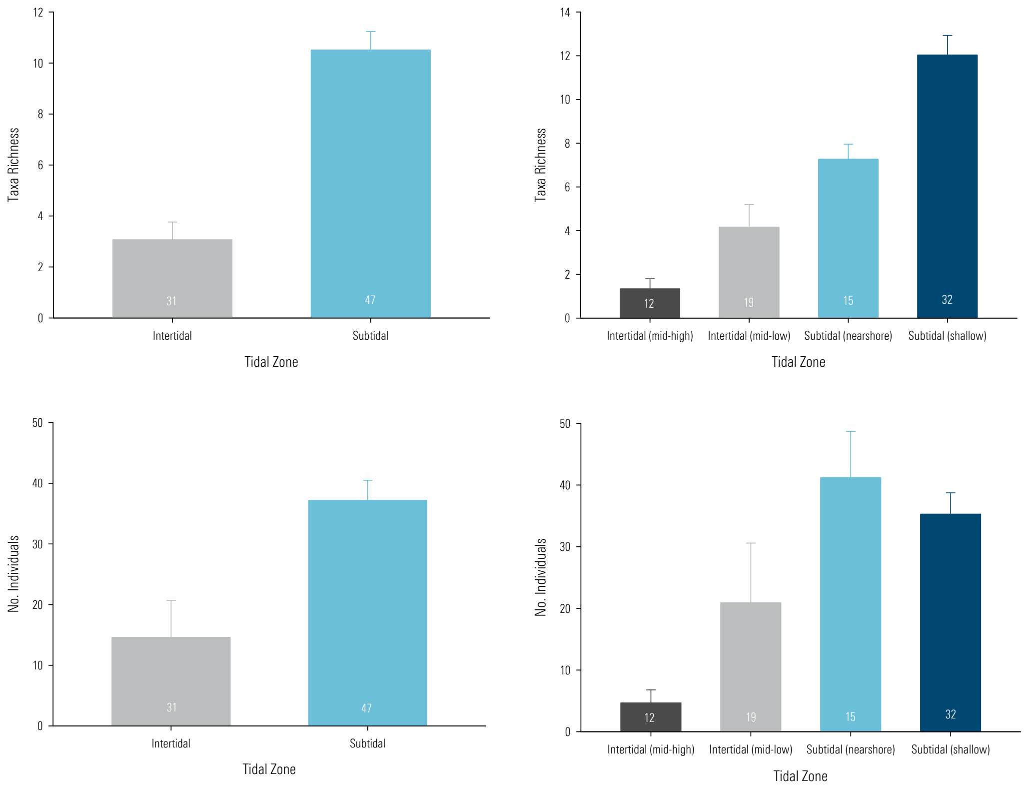


Figure 14 Average (+ 1 SE) taxa richness and density (no. individuals per infauna sample) of infauna samples plotted against tidal zone (intertidal vs substidal, or intertidal mid-high, intertidal mid-low, subtidal-nearsore, subtidal-shallow). Numbers within bars denote the number of samples within that category. Surveys were undertaken by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), Dec 2018 (Sites Int-1 to Int-23) and Feb 2019 (Sites Sub 1 to Sub 47).

3.4.1 Intertidal Zone Taxa

A total of 39 invertebrate taxa and 452 individuals were identified from the 31 samples collected within the intertidal zone of the study area (Appendix 3). Three taxa recorded are actually freshwater insect species - two Diptera larva (*Polypedilum*, Muscidae) and one Megaloptera larva (*Archicauliodes*). These were found at a site adjacent to a stormwater/stream pipe outlet and so it is likely the specimens had been washed out of the stream into the intertidal gravels.

Taxa richness varied from 0-19 taxa per infauna sample, while densities ranged from 0–135 individuals per sample (Appendix 3). Five intertidal samples collected had no taxa found (Int-7, Int-11, Int-14, Int-19, Int-20) (Appendix 3). Three samples (Int-28, Int-29, Int-30) had much higher taxa density (135, 112, and 97 individuals respectively) than all other intertidal samples (which ranged from 0-22 individuals). This was due to high numbers of the polychaetes *Aonides* sp. (Int-28 and Int-29) and *Prionospio* sp. (Int-28) and Gammaridae amphipods (Int-30). Sites Int-29 and Int-30 also had greater taxa richness (11 and 19 respectively) than all other samples which ranged from 0-8 taxa.

The intertidal community was generally dominated by polychaetes, followed by crustaceans (Figure 10). At greater than 10% overall abundance, the most abundant taxa were the polychaetes *Aonides* sp. (23% abundance) and *Prionospio* sp. (17.5%), as well as Gammaridae amphipods (17.3%) (Table 4). The dominance of these three taxa was largely a result of their elevated numbers at a selection of sites (Int-28 and Int-29, Int-30). This was followed by the polychaetes Nereidae (9.1%) and *Capitella* spp (7.3%) that represented more than 5% of overall abundance. The remaining taxa represented less than 5% of overall abundance, with 11 taxa having only one specimen (i.e., 0.2% of overall abundance) (Appendix 3).

Of the 39 recorded taxa, there were no widespread taxa (i.e., being found in more than 50% of samples). Moderately widespread taxa (i.e., found in more than 25% of samples) were the polychaetes Nereidae (found in nine samples) and *Aonides* sp. (found in eight samples) (Table 4). The remaining taxa were found in seven samples (i.e., 23% of samples) or less (Appendix 3).

The polychaetes *Aonides* sp. and *Prionospio* sp. have relatively broad habitat preferences, although *Aonides* is generally found in greater numbers in sandy substrates, and both are intolerant of mud content higher than 70-80% (with an optimum range of 0-5%; Needham *et al.,* 2014). Similarly, gammarid amphipods are generally found in areas with very coarse sediment and low mud content. *Aonides* in particular is a useful indicator of pollution as they are sensitive to copper, which is a contaminant often associated with stormwater discharges. Its abundance and regularity in the intertidal samples implies that the infaunal habitat is in relatively good condition.

Stevens *et al.* (2004) also undertook infauna intertidal surveys at Lowry Bay. As noted by Stevens *et al.* (2004), the Lowry Bay intertidal infauna was dominated by polychaetes, although we found a greater diversity of crustacean and molluscs than recorded in that study; this was likely a result of greater sampling effort. No taxa that are indicative of significant nutrient enrichment or fine sediment input were present in any great abundance within our intertidal infauna samples. This reflects the findings of Stevens *et al.* (2004) who concluded that the intertidal sandy beaches of the Wellington Harbour were generally all in a healthy condition and showed no signs of adverse nutrient enrichment or chemical contamination. No invertebrate taxa of conservation concern (as listed in the threatened species list of Freeman *et al.* 2014) were recorded from the project area.

Table 4 The most abundant and widespread (or moderately widespread) taxa found in the intertidal samples collected by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), Dec 2018 (Sites Int-1 to Int-23). A full species list for the intertidal samples is provided in Appendix 3.

Faunal Group 1	Faunal Group 2	Taxa	Abundant (>5% of total abundance)	Widespread (found in >50% of samples)	Moderately widespread (found in >25% of samples)
				No. samples found in (out of 31)	No. samples found in (out of 31)
Crustacea	Amphipoda	Gammaridae	17.3%		
Polychaeta	Aciculata	Nereidae	9.1%		9
	Canalipalpata	*Aonides* sp.	23.0%		8
		Prionospio sp.	17.5%		
		Capitella spp.	7.3%		
			5 taxa	0 taxa	2 taxa

Future impact and control areas

A comparison was made between those surveyed sites that were in the potential area of effect in relation to beach nourishment. This includes the initial area where beach nourishment material will be added and will spread to in the 'initial adjustment' phase according to Reinen-Hamill (2019) (referred to here as 'Impact 1') (Figure 15). We have also ascribed two other impact zones ('Impact 2' and 'Impact 3') where beach nourishment material may move to within a longer timeframe, depending on wind and tidal movements (Figure 15). These two impact zones are estimates of possible areas that could be affected by longterm movement of beach nourishment, based on the general statement in Reinen-Hamill (2019) that "there may be significant movement of nourished sediment within the embayment following similar sediment transport processes as currently occur" and the indication by Allis (2019) that there is a 'general northward movement of materials' within the project area. It must be noted that in the absence of further detail from these experts, we currently to do not know how far the beach nourishment material will extend into the subtidal zones and along the shore and thus these 'Impact 2' and 'Impact 3' zones may or may not be affected. For example, in a study undertaken by Carter & Mitchell (1985) at Balaena Bay in Wellington Harbour there was very little movement of beach nourishment material into the subtidal area. Based on the assertion by Reinen-Hamil (2019) that there will be little loss of nourishment sediment from the embayed areas, all other bays surveyed that are not proposed for beach nourishment are regarded as 'control' areas, as are samples collected within an embayment undergoing beach nourishment but being further way from the zone of nourishment or possible effect. For intertidal samples there were no intertidal samples that were within the 'Impact 3' zone.

There were no significant differences in community composition between the intertidal control and two intertidal impact areas (ANOSIM Global $R=0.037$, $p=0.263$); the near zero R value indicating a high similarity in community composition between the areas (Figure 16).

Taxa richness was not significantly different between the control and two impact areas within the intertidal zone ($F=0.106$, $p=0.9$), with large error bars indicating a high level of variation among samples within each grouping (Figure 17). Whilst mean densities within the two future impact areas (Impact1, Impact2) were much lower compared to the control area, due to substantial variation within the control grouping (as indicated by the large error bar) there was no statistically significant difference ($H=0.177$, $p=0.915$) (Figure 17).

Figure 15 Map showing possible impact zones where beach nourishment sediment may move to over time. Apart from the 'Impact 1' area, which were based off maps provided in Reinen-Hamill (2019) (and copied here in Appendix 1) as the area where beach nourishment material will be added and will spread to in the 'initial adjustment' phase, the impact areas are estimations of where sediment may or may not move to over time.

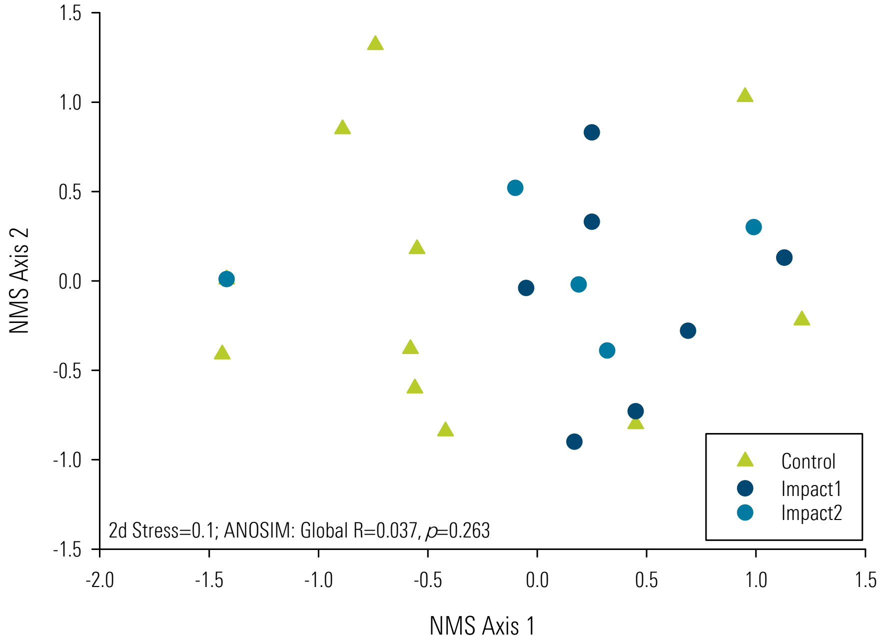


Figure 16 An NMS plot of intertidal infauna samples in future control and impact areas for beach nourishment ('Impact1' = within the initial adjustment footprint for beach nourishment, 'Impact2' = future possible area for movement of beach nourishment sediments). Surveys were undertaken by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), Dec 2018 (Sites Int-1 to Int-23).

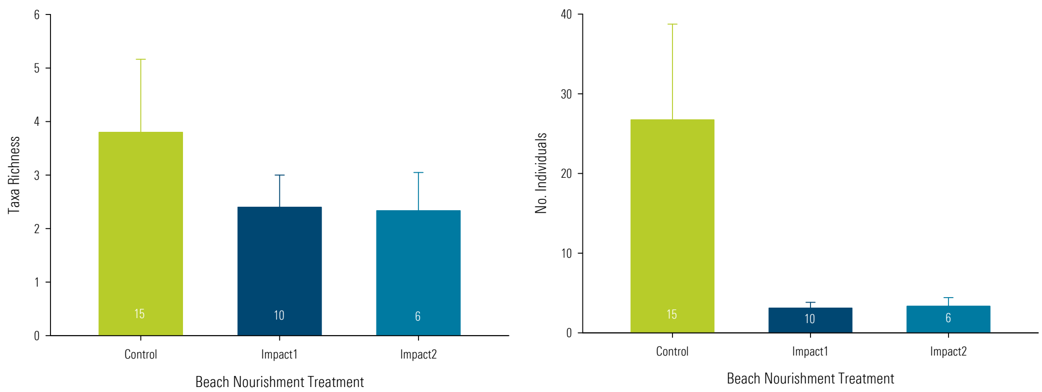


Figure 17 Average (+ 1 SE) taxa richness and density (no. individuals per infauna sample) of intertidal infauna samples plotted against future control and impact areas for beach nourishment ('Impact1' = within the initial adjustment footprint for beach nourishment, 'Impact2' = future possible area for movement of beach nourishment sediments). Numbers within bars denote the number of samples within that category. Surveys were undertaken by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), Dec 2018 (Sites Int-1 to Int-23).

3.4.2 Subtidal Zone Taxa

A total of 66 invertebrate taxa and 1,747 individuals were identified from the 47 infauna samples collected within the subtidal zone of the study area (Appenidix 4).

Taxa richness varied from 3-24 taxa per infauna sample, while densities ranged from 6–103 individuals per sample (Appendix 4). The subtidal (nearshore) community was generally dominated by polychaetes followed by molluscs, and the subtidal (shallow) community by polychaetes followed by crustaceans (Figure 10). The subtidal community was dominated by the polychaete *Magelona dakini* with 32% abundance, followed by the polychaetes *Heteromastus filiformis* at 15.7% abundance and Sabellidae at 7.7% (Appendix 4). Based on NMS analysis *Magelona dakini* was more abundant in the subtidal (nearshore) zone whilst *Heteromastus filiformis* was more abundant in the subtidal (shallow) zone. Whilst only at 4.5% overall abundance, the bivalve mollusc *Macomona liliana* (large wedge shell) was a defining/abundant species of the subtidal (nearshore) zone based on the NMS ordination between tidal zones (Figure 12). The remaining taxa represented less than 5% of overall abundance, with 21 taxa having only 1-2 specimens (i.e., 0.1-0.2% of overall abundance) (Appendix 4).

Of the 66 recorded taxa, five taxa were regarded as widespread (i.e., being found in more than 50% of samples). These were the polychaetes *Magelona dakini* (35 samples), Sabellidae (32 samples), Glyceridae (29 samples), and *Heteromastus filiformis* (25 samples), as well as the bivalve mollusc *Macomona liliana* (26 samples) (Table 5). Ten taxa were considered to be moderately widespread (i.e., found in more than 25% of samples), made up of mainly polychaetes with three crustaceans and an echindoderm (Table 5). The remaining taxa were found in ten samples (i.e., 21% of samples) or less.

The polychaetes *Magelona dakini* and Sabellidae (which were both abundant and widespread) are generally indicative of sandier (rather than muddy) sediments. The shovel-head worm *Magelona dakini* (the dominant and most widespread taxa, and a defining species of the subtidal (nearshore) zone) is regarded as a good indicator species, whose numbers will reduce with excessive fine sediment or lead contamination (Hewitt *et al.,* 2009 censu Hailes & Hewitt, 2012), although populations are also known to fluctuate on multi year cycles corresponding to El Nino years (Hailes & Hewitt, 2012). The type of Sabellidae that were found are a sedentary fan worm (with remnants of their sand tubes still evident in the samples), which are generally found in more sandy sediments,. The polychaete *Heteromastus filiformis* (which was most abundant in the subtidal (shallow) zone) is a mobile burrowing detritivore that inhabits muddy to sandy substrate in sheltered areas. As a head-down deposit feeder they are adapted to low oxygen environments (Abele *et al.*, 1998). Thrush *et al.* (2008) found that they had a negative response to mud and lead in one of their models for multiple stressors.

The bivalve mollusc *Macomona liliana* (which was widespread and a defining taxon of the subtidal (nearshore) zone) is both a deposit feeder and suspension feeder, and is sensitive to terrestrial sedimentation (Norkko *et al.*, 2002) and increases in suspended sediment and stormwater contaminants such as copper (Thrush *et al.* 2008). They are often found with cockles although they are less tolerant of fine sediment and can be excluded from areas with high cockle numbers via feeding competition.

The community was not dominated by taxa that are indicative of significant nutrient enrichment or fine sediment input. No invertebrate taxa of conservation concern (as listed in the threatened species list of Freeman *et al.* 2014) were recorded from the project area.

Table 5 The most abundant and widespread (or moderately widespread) taxa found in the subtidal samples collected by EOS Ecology in Feb 2019. Those taxa that were both abundant and widespread are highlighted in bold. A full species list for the subtidal samples is provided in Appendix 4.

Faunal Group 1	Faunal Group 2	Taxa	Abundant (>5% of total abundance)	Widespread (found in >50% of samples)	Moderately widespread (found in >25% of samples)
				No. samples found in (out of 47)	No. samples found in (out of 47)
Crustacea	Amphipoda	Corophiidae			13
		Cumacea			20
		Gammaridae			18
Echindodermata	Asteroidea	*Patiriella* sp.			21
Mollusca	Bivalva	*Macomona liliana*	(4.5%)	26	
Polychaeta	Aciculata	*Glycera americana*			12
		Glyceridae		29	
	Canalipalpata	*Boccardia* spp.			14
		Magelona dakini	32.3	35	
		Oweniidae			17
		Prionospio sp.			21
		Sabellidae	7.7	32	
	Errantia	Lumbrineridae			13
	Scolecida	***Heteromastus filiformis***	15.7	25	
		Opheliidae			14
			3 (4) taxa	5 taxa	10 taxa

Future impact and control areas

A comparison was made between those surveyed sites that were the potential area of effect in relation to beach nourishment. This includes the initial area where beach nourishment material will be added and will spread to in the 'initial adjustment' phase according to Reinen-Hamill (2019) (referred to here as 'Impact 1', and constrained to the intertidal zone) (Figure 15). We have also ascribed two other impact zones ('Impact 2' and 'Impact 3') where beach nourishment material may move to within a longer timeframe, depending on wind and tidal movements (Figure 15). These two impact zones are estimates of possible areas that could be affected by longterm movement of beach nourishment, based on the general statement in Reinen-Hamill (2019) that "there may be significant movement of nourished sediment within the embayment following similar sediment transport processes as currently occur" and the indication by Allis (2019) that there is a 'general northward movement of materials' within the project area. It must be noted that in the absence of further detail from these experts, we currently to do not know how far the beach nourishment material will extend into the subtidal zones and thus these 'Impact 2' and 'Impact 3' zones may or may not be affected. For example, in a study undertaken by Carter & Mitchell (1985) at Balaena Bay in Wellington Harbour there was very little movement of beach nourishment material into the subtidal area. Based on the assertion by Reinen-Hamil (2019) that there will be little loss of nourishment sediment from the embayed areas, all other bays surveyed that are not proposed for beach nourishment are regarded as 'control' areas, as are samples collected within an embayment undergoing beach nourishment but being further way from the zone of nourishment or possible effect.

There were no significant differences in community composition between the subtidal control and two subtidal impact zones (ANOSIM Global R=0.048, p=0.205); the near zero R value indicating a high similarity in community composition between the zones (Figure 18). Similarly there was no significant difference in taxa richness[2] or density (H=2.313, p=0.315) between the control and two impact areas (Impact2, Impact3) within the subtidal zone, with large error bars indicating a high level of variation among samples (Figure 19).

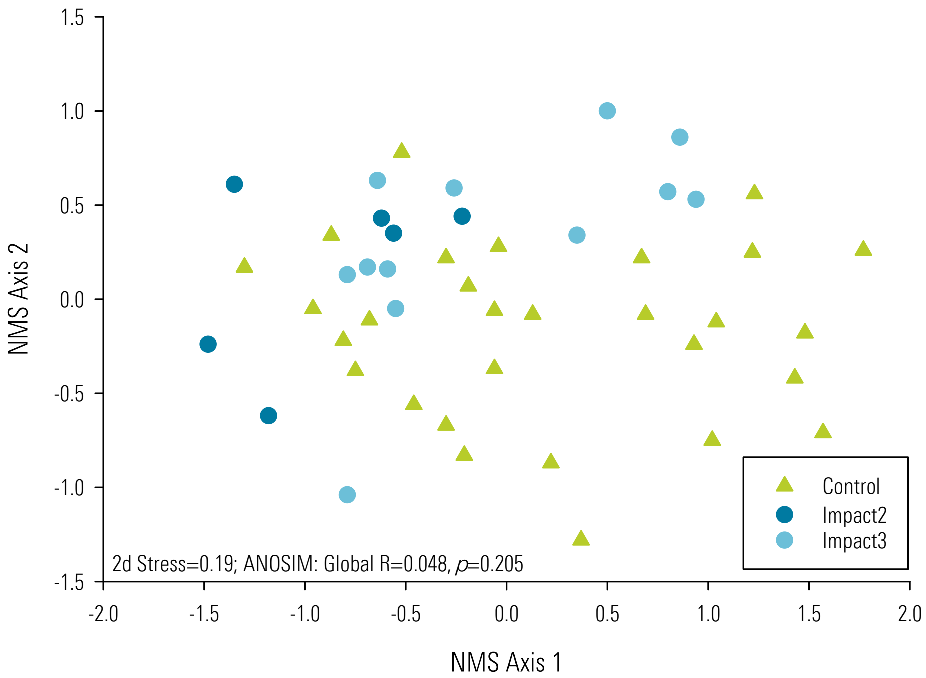


Figure 18 An NMS plot of subtidal infauna samples in future control and impact areas for beach nourishment ('Impact2' and 'Impact3'= future possible areas for movement of beach nourishment sediments of increasing distance from the initial nourishment site). Surveys were undertaken by EOS Ecology in Feb 2019 (Sites sub-1-47).

[2] Whilst there was a significant result (F=3.548, p=0.037) the differences were too weak to be significantly different in the post-hoc tests.

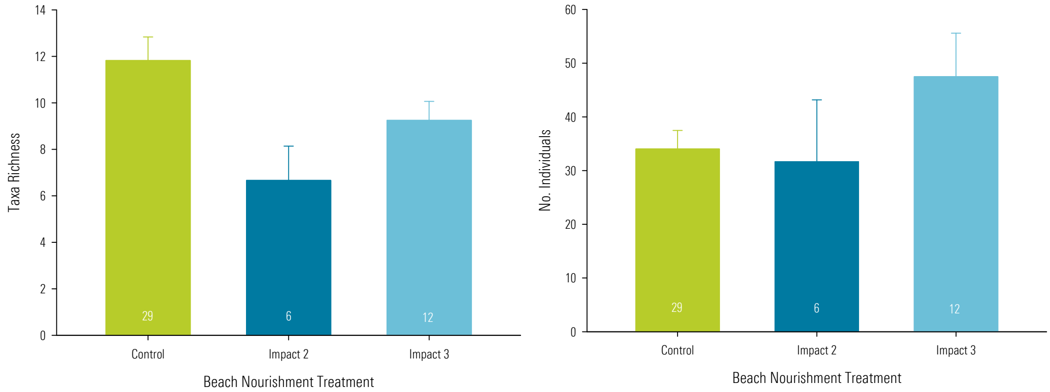


Figure 19 Average (+ 1 SE) taxa richness and density (no. individuals per infauna sample) of intertidal infauna samples plotted against future control and impact areas for beach nourishment ('Impact1' = within the initial adjustment footprint for beach nourishment, 'Impact2' = future possible area for movement of beach nourishment sediments). Numbers within bars denote the number of samples within that category. Surveys were undertaken by EOS Ecology in Feb 2019 (Sites sub-1-47).

3.4.3 Mahinga Kai Benthic Species

A number of shellfish of potential value as mahinga kai were observed or sampled during the intertidal and subtidal beach surveys. Horse mussels (*Atrina*) were observed in Lowry Bay (at Site Sub-13 and Sub-17), and large numbers of kina (*Evechinus chloroticus*) in Mahina Bay (Site Sub-27) during the subtidal surveys but (with the exception of one kina specimen) were not recorded in the infauna samples. EHEA (1998) notes that significant pipi and cockle beds are known from the western end of Petone Beach to Lowry Bay. In this study we found pipi (*Paphies australis*) in both intertidal and subtidal samples from Point Howard (intertidal), Lowry Bay, York Bay and Mahina Bay (intertidal, subtidal) and cockles (*Austrovenus stutchburyi*) in samples from Lowry Bay (intertidal, subtidal), York Bay, and Mahina Bay (subtidal). During site visits and field surveys, people were also observed collecting cockles in the subtidal (nearshore) environment of Lowry Bay, particularly around the seagrass bed out from the bus stop, and there are anecdotal accounts of divers collecting or observing scallops in 5-15 m deep water out from many of the bays and points around the Eastern Bays area (Derek Wilshere, pers. comm.).

McMurtrie & Brennan (2019) also observed blue mussel (*Mytilus galloprovincialis*), black mussel (*Xenostrobus neozelanicus*), greenshell mussel (*Perna canaliculus*), pipi (*Paphies australis*), tuangi cockle (*Austrovenus stutchburyi*), as well as the discarded remains of paua (*Haliotis iris* and *Haliotis australis*), rock oyster (*Saccostrea glomerata*), kina (*Evechinus chloroticus*), catseye (*Lunella smaragda*), turban shell (*Cookia sulcata*), and scallop (*Pecten novaezelandiae*) during their surveys of the wider intertidal area. In general the mussels were observed on bedrock outcrops and larger substrate as opposed to the finer material of the beach areas, whilst paua, rock oyster, catseye and turban shell are known to predominantly inhabit more rocky areas rather than sand/gravel beach zones.

The presence of a number of species of food value, and the discarded remains of a range of marine food species as found by McMurtrie & Brennan (2019) is a good indication that food gathering occurs within this area. While some of the discarded species may have been dumped at these locations by people returning from further afield, it is likely that at least some of these would have come from food gathering from the closer subtidal and intertidal Eastern Bays area. Greenaway & Associates (2019) reports on management for recreational fishing and shellfish gathering within the Wellington Harbour and notes that Sorrento Bay has been non-compliant for recreational shellfish gathering water quality guidelines for *E. coli* levels during 2017. Of the species listed above, it is reasonable to expect (based on our observed sitings as well as known habitat preference of those species whose remains were found) that horse mussels, pipi, cockles, and some kina are in the nearshore subtidal soft sediment zone of the Eastern Bays area.

3.4.4 Macroalgae

Macroalgae were generally absent from the surveyed intertidal beach areas, and were more located more within areas of intertidal rocky shore or larger substrate. McMurtrie & Brennan (2019) provides more information on macroalge across those habitat types. Green algae (*Ulva*, *Enteromorpha*), and red algae (*Gracilaria*) were observed growing on larger substrate scattered within the wider sandy area at the southern end of Lowry Bay (i.e., from site Int-10 south). The seaweed Neptune's necklace (*Hormosira banksii*) was also observed in high abundance on cobble substrate in the nearshore subtidal zone of York Bay. Within the subtidal area divers observed common flapjack (*Carpophyllum maschalocarpum*) usually attached to cobbles or bedrock during the subtidal surveys. Refer to Overmars (2019a) and (2019b) for information on seagrass (as a vascular plant).

Wellington Harbour is also known for its significant *Macrocystis* (kelp) beds (EHEA, 1998, MacDiarmid *et al.*, 2012, GWRC, 2015). No kelp was observed during the dive surveys undertaken to collect samples from the nearshore and shallow subtidal area of Point Howard beach, Sorrento Bay, Lowry Bay, York Bay, Mahina Bay and the northern and southern end of Days Bay as part of this study. A shallow subtidal (up to 0.6-0.8 m deep at low tide) survey by Overmars (2019) for seagrass also confirmed the absence of kelp in Point Howard beach, mid-south Lowry Bay and York Bay.

3.4.5 Comparison of Intertidal and Subtidal Beaches Within the Wider Wellington Harbour

Two reports have sampled the intertidal and/or subtidal fauna of nearby beaches. Both Stevens *et al.* (2004) and Stevens (2018) surveyed the intertidal beach area at Petone, whilst Stevens *et al.* (2004) also sampled the intertidal zone of Lowry Bay and Stevens (2018) also collected two samples within the subtidal zone at Petone. In general the larger Petone beach supports a greater number of bivalves (particularly pipis) within its intertidal zone, likely a result of the finer substrate of that beach (firm sand) compared to Lowry Bay (firm sand(gravel field)). The subtidal infauna (although only based on two samples) of Petone is also numerically dominated by bivalves (Stevens, 2018). Our data from 24 subtidal samples in Lowry Bay show that whilst not numerically dominant over polychaetes, molluscs and bivalves are diverse and reasonably abundant, with seven bivalves recorded, including cockles, pipis and large wedge shells (*Macomona liliana*).

Booth (1972) studied bivalves (larvae and adults) within Wellington Harbour and concluded that the eastern and southern portion of the Harbour supported faunistically rich (5-10 species) bivalve communities compared to the central, northern and western portions of the harbour. This was reflected in our intertidal and subtidal data, with York Bay, Lowry Bay, and Mahina Bay having 6, 7 and 9 species of bivalve recorded in samples, respectively.

A number of studies have investigated the subtidal ecology of soft sediment areas within the wider Wellington Harbour; Bolton-Ritchie (2003) investigated the nearshore benthic community of inner Wellington Harbour (Lambton Harbour and Evans Bay) in relation to stormwater outlets; Gardner & Wear (2006) studied the recovery of subtidal communities (including a site in Days Bay) following a large-scale natural die-off; Boffa Miskell (2015) reported on a survey of intertidal and subtidal soft substrate benthos between Lower Hutt and Ngauranga as part of the Wellington to Hutt Valley shared path consent application; and Oliver & Milne (2012) reported on the findings of monitoring of subtidal fauna and sediment quality in the northern and eastern portions of Wellington Harbour.

In general the species lists from our study of the Eastern Bays subtidal areas were broadly dissimilar to that of the subtidal infauna communities recorded by Boffa Miskell (2015) along the northern Harbour shoreline, with the key differences in species composition related to the presence of taxa more tolerant of/suited to finer sediments in the northern harbour edge. For example, the non-indigenous polychaete *Barantolla lepte* that numerically dominated the samples collected by Boffa Miskell (2015) is found predominantly in estuarine sublittoral mud and weed beds (Inglis *et al.* 2006).

Results from Oliver & Milne (2012) for subtidal monitoring of infauna in the northern and eastern parts of Wellington Harbour described the fauna as being predominantly composed of polychaete worms, crustaceans, bivalve molluscs, and nemertean worms, and were considered to be variants of an inner harbour fine sediment community occurring at water depths of >10 m. Whilst the general faunal groups of polychaetes, crustaceans and molluscs is akin to that found in the Eastern Bays subtidal area, the species composition differed between these different subtidal depths, with the heart urchin *Echinocardium cordatum*, the bivalve *Dosinia zelandica*, the ragworm *Onuphis aucklandensis*, and the bamboo worm *Asychis trifilosa* most often dominanting the biomass. Of these taxa only small species of *Dosinia* were found within the Eastern Bays samples. Oliver & Milne (2012) noted that the subtidal community of the eastern and northern areas of Wellington Harbour were influenced by elevated concentrations of stormwater-associated contaminants. Bolton-Ritchie (2003) similarly concluded that Lambton Harbour and Evans Bay, two sheltered embayments in the southern basins of Wellington Harbour, were organically enriched and contained high concentrations of heavy metals.

The subtidal community was found to support and be dominated by different species to those recorded by subtidal surveys of the deeper harbour, western bays and northern nearshore subtidal area. These differences are most likely attributable to depth and substrate differences (including possible sediment contamination effects). Booth (1972) described sediment type as the single most important factor in bivalve occurrence in Wellington Harbour, within a suitable hydrological environment.

Stevens *et al.* (2004) concluded that the intertidal sandy beaches of the Wellington Harbour were generally all in a healthy condition and showed no signs of adverse nutrient enrichment or chemical contamination; an assertion that we feel also holds for the subtidal infauna of the beach areas surveyed here based on the habitat preferences and environmental sensitivity of the most abundant and widespread species recorded and the absence of more pollution/mud tolerant species found in other parts of the harbour.

3.5 Sediment Contamination

Due to the input of urban and industrial stormwater runoff into Wellington Harbour, both historically and currently, contamination of sediments by heavy metals has been found to exceed a number of sediment quality guidelines, in particular in Evans Bay and Lambton Harbour (Stoffers *et al.,* 1986; Dickinson *et al.,* 1996; Pilotto *et al.,* 1998, Bolton-Ritchie, 2003; Stephenson *et al.*, 2008; Oliver, 2013). Compared with sites in the main basin of Wellington Harbour, the studies have found surface sediments of these areas to contain elevated levels of heavy metals, particularly copper, lead and zinc. MWH (2003) and Bolton-Ritchie (2003) determined that there is a negative correlation between sediment heavy metal concentration and distance from a stormwater outlet.

There have been limited studies looking at sediment contamination of the intertidal area of the Eastern Bays. Stevens *et al.,* (2004) collected sediment samples from two intertidal sites (with three replicates per site) within Lowry Bay, and found them to be relatively free of contaminants (Table 6). They found that while there was a slight trend for both nutrients and heavy metals to be slightly enriched in the lower beach samples versus the high beach samples, the levels overall were not high. Levels of heavy metals (cadmium, chromium, copper, lead, nickel, and zinc) were all well below the ADAWR (2019) Defaut Guideline Values (DGV) (which have replaced the ANZECC (2000) ISQG-low trigger levels), as well as the Auckland Council's more conservative Environmental Response Criteria for copper (<19 mg/kg), lead (<30 mg/kg) and zinc (<124 mg/kg) (ARC, 2004) (Table 6). They concluded that there was no sign of sediment contamination or sediment enrichment.

Heavy metals are typically bound to fine sediment particles and accumulate in sheltered areas. The intertidal zone of the Eastern Bays is relatively exposed for Wellington Harbour and experiences a dynamic and sometimes high energy hydrologic regime. During the site walkover and the site surveys we did not come across any depositional zones for fine sediment, with any fine sediment (mainly fine sand) limited to patches between substrate. These factors, combined with the fact that there is limited urban development in the area that discharge into these Eastern Bays, mean that it is probable that the bays within the Eastern Bays area have low sediment contaminant levels.

In comparison, testing of sediment contamination in two intertidal samples along the Hutt Road bordering the north-west side of Wellington Harbour by Boffa Miskell (2015) showed higher levels of copper (13.9-17.5 mg/kg) and lead (15-15.3 mg/kg) and similar levels of zinc (59-86 mg/kg) when compared to those found by Stevens *et al.* (2004) in the Eastern Bays area (Table 6). The higher concentrations (particularly for copper and lead) recorded for the intertidal area along Hutt Road is likely reflective of the larger urbanised catchment that discharges to the coastal environment in that area.

Table 6 Results from Stevens *et al.* (2004) for particle size (% wet weight), heavy metal (mg/kg) and nutrient (mg/kg dry) contamination in sediment samples collected from two sites within Lowry Bay. The ADAWR (2019) DGV and GV-high values (which replace the ANZECC (2000) ISQG low/high values) and the Auckland Council's Environmental Response Criteria lowest 'green' (AC ERC) values have been added for comparison.

Variable	ADAWR DGV(/DG-high trigger	AC ERC	Rep 1	Rep 2	Rep 3	Mean	1 SD	Rep 1	Rep 2	Rep 3	Mean	1 SD
Ash free dry weight			0.9	0.7	0.9	0.8	0.1	1.2	1.3	1.3	1.3	0.1
Mud <63 μm			1.0	0.4	1.1	0.8	0.4	1.1	0.7	1.1	1.1	0.2
Sand <2mm			99.0	99.0	98.9	99.0	0.1	98.3	68.4	98.9	98.9	17.4
Gravel >2mm			<0.1	0.6	<0.1	0.2	0.3	0.7	30.9	<0.1	<0.1	17.6
Cadmium	1.5/10		<0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2	<0.2	-
Chromium	80/370		5.8	5.0	5.4	5.4	0.4	7.1	6.2	6.0	6.4	0.6
Copper	65/270	<19	2.5	2.5	2.6	2.5	0.1	3.1	3.4	2.7	3.1	0.4
Lead	50/220	<30	15	7.9	7.9	10.3	4.1	9	12	9.5	10.2	1.6
Nickel	21/52		4.4	3.8	4.2	4.1	0.3	5.3	4.5	4.5	4.8	0.5
Zinc	200/410	<124	60	56	61	59.0	2.6	69	64	66	66.3	2.5
Total Nitrogen			190	140	170	166.7	25.2	230	140	190	186.7	45.1
Total Phosphorus			193	155	184	177.3	19.9	227	197	198	207.3	17.0

4 OVERVIEW OF DESIGN AND METHODOLOGY FOR BEACH NOURISHMENT

4.1 Beach Nourishment Approach

The Eastern Bays Shared Path Project requires encroachment into the foreshore area for creation of the shared path and upgraded seawall. This will cause a loss of beach area which, in some locations, will reduce amenity and recreational values of the local area. Beach nourishment is proposed for Point Howard, Lowry Bay, and York Bay beaches to mitigate the loss of beach area. These locations all have beach areas at high tide and are important recreational areas for the community. Table 7 and Figure 20 provide a comparison of beach area for the three bays pre-construction of the shared path; post-shared path construction without beach nourishment; and post-shared path construction with beach nourishment. Without beach nourishment approximately half of the high tide beach areas in the three bays will be lost (Table 7, Figure 20). With beach nourishment the area of high tide beach will increase by roughly half in Point Howard, and will be roughly similar in Lowry Bay and York Bay (Table 7, Figure 20), thereby mitigating beach loss.

Following an initial assessment by Allis (2019), Reinen-Hamill (2019) prepared the beach nourishment design and effects assessment report, which we base our assessment of effects on. Reinen-Hamill (2019) states that the purpose of the beach nourishment in these areas is to:

» Augment the existing beach areas to provide the same area of beach that is expected to be occupied by the seawall works where they extend beyond the existing seawall toe.

» As far as possible to be within the existing beach footprint and not to increase the beach areas beyond the existing areas (except for temporarily during construction or to offset increased sediment loss rates after construction) so as to avoid unnecessary adverse effects on intertidal and subtidal ecology and avifauna.

» It is noted that nourishment may also be used in the future to enhance "resilience" of Marine Drive and implemented as an adaptive management option throughout the medium to long-term (i.e. the purpose is to maintain existing beach area/amenity and not to create new beach area/amenity).

Table 7 Comparison of beach areas at high tide at Point Howard, Lowry Bay and York Bay, before and after completion of the seawall/shared path, with and without the proposed beach nourishment. Negative values (also highlighted in red) denote losses. Areas are shown in Figure 20.

Beach to be nourished	Area of existing high tide beach (above MHWS) (m^2) [A]	Area of high tide beach after construction of seawall/shared path (above MHWS) (m^2) [B]	Area of high tide beach after nourishment (m^2) [C]	Loss or gain after seawall/shared path construction		Loss or gain after seawall/shared path construction AND beach nourishment	
				Area of high tide beach lost/gained (m^2)	% of high tide beach lost/gained (%)	Area of high tide beach lost/gained (m^2)	% of high tide beach lost/gained (%)
Point Howard	240	115	382	-125	-52%	142	59%
Lowry Bay	1,373	753	994	-620	-45%	-379	-28%[D]
York Bay	276	149	309	-127	-46%	33	12%

[A] Calculated from the beach delineation by Allis (2019) and the MHWS mark using ArcMap GIS.
[B] Calculated from the beach delineation by Allis (2019), Revision J shared path and seawall toe (Stantec, 2018) and the MHWS mark using ArcMap GIS.
[C] Calculated from the beach nourishment plans in Reinen-Hamill (2019), using the initial adjusted profile for the beach berm (the anticipated high tide beach after the initial adjustment period of days to weeks in Appendix C of that report) and ArcMap GIS to calculate area.
[D] Note that this reduction may be an artefact of the post-nourishment beach berm drawn by Reinen-Hamill not taking into account the remainder of the high tide beach area to the north of the nourishment zone (refer to Figure 20).

Figure 20 Locations of existing high tide beach areas (blue shaded area and that under the hashed area) within Point Howard, Lowry Bay and York Bay, overlaid with the high tide beach area post seawall/shared path construction without beach nourishment (i.e, the hashed area) and with beach nourishment (orange shaded area).

Figure 20 (cont.) Locations of existing high tide beach areas (blue shaded area and that under the hashed area) within Point Howard, Lowry Bay and York Bay, overlaid with the high tide beach area post seawall/shared path construction without beach nourishment (i.e, the hashed area) and with beach nourishment (orange shaded area).

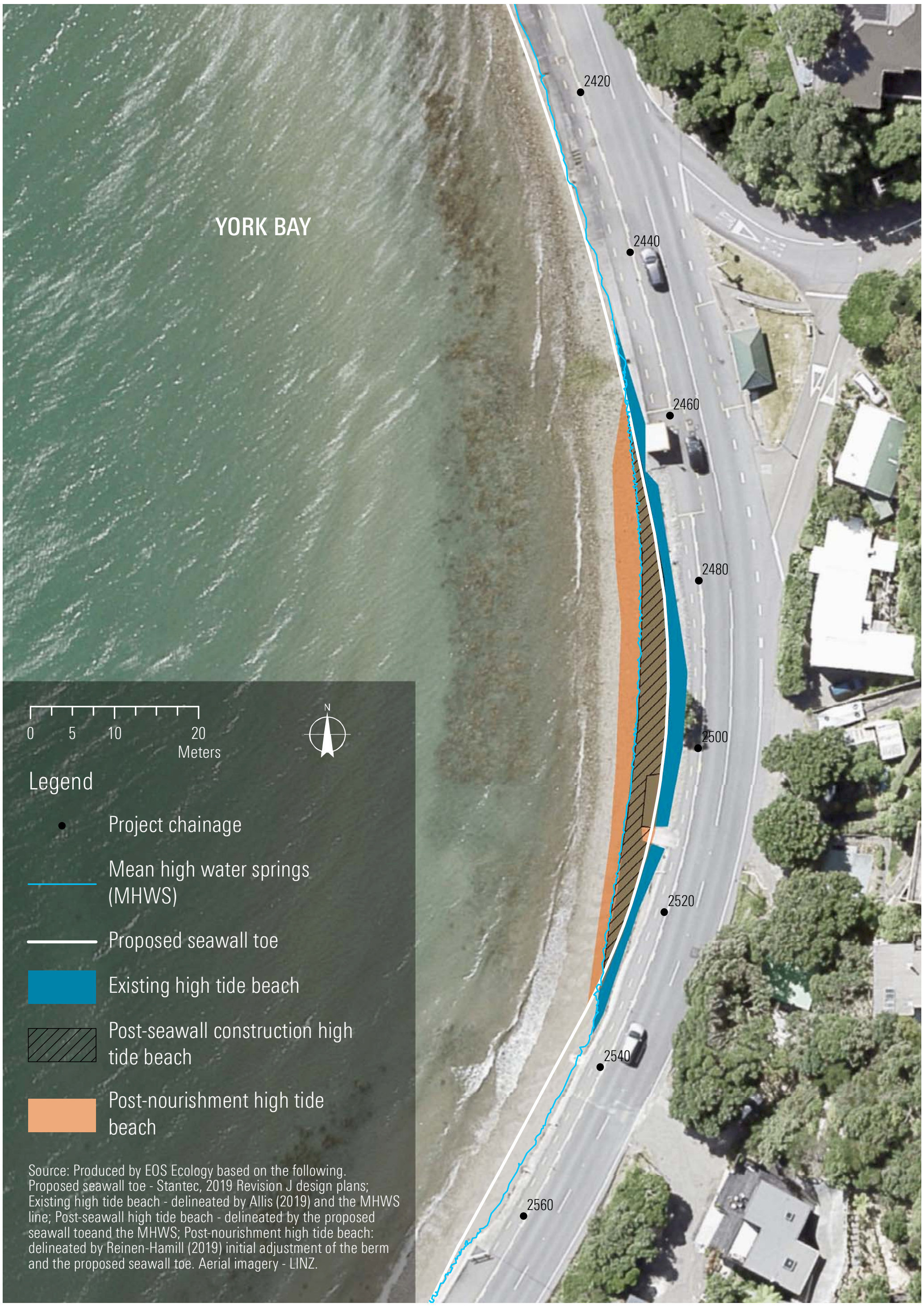


Figure 20 (cont.) Locations of existing high tide beach areas (blue shaded area and that under the hashed area) within Point Howard, Lowry Bay and York Bay, overlaid with the high tide beach area post seawall/shared path construction without beach nourishment (i.e, the hashed area) and with beach nourishment (orange shaded area).

4.2 Overview of Methodology

There is a requirement for the nourishment sediment to be of a similar or coarser grain size and colour and have no more than 2-3% of fines in order to provide similar characteristics and reduce impacts on ecology and amenity. Preferred sources of sediment are from the accumulated source of gravels south of Eastbourne or the existing extraction source from the lower Hutt River. Other potential areas are dredged from Wellington Harbour or externally sourced. Regardless of source location, processing will be required to sort the sediments into appropriate grain sizes and for the removal of fines.

The total amount of sediment to be added for the nourishment will be 6,000 m^3, but a loss of approximately 1,400 m^3 (20-25%) is expected due to coastal processes (tides, wind and waves). The initial loss of sediment is likely to occur over the first days to weeks.

Preparation of the beach will be to form a level bench from the toe of the seawall to the MHWS mark, to provide a working area and protect the construction zone from tidal intrusion. To do this, existing beach sediments will be pushed seaward to form a flat bench using a hydraulic excavator working from the crest of the seawall or along the upper part of the beach, and will be undertaken during construction of the seawall itself. The bench will sit above the high tide limit.

Transport of the beach nourishment material will be by truck or barge, with truck transport the preferred method. We have based our assessment on the preferred method of landward transport of sediment by trucks. Trucks will either unload the sediment into one location for it to be distributed or the truck will work its way along the beach, end tipping sediment at multiple locations. Hydraulic excavators may be used to shape the beach. The sediment will be placed at the widest part of the beach on the landward side of the high tide bench and only the amount of sediment that can be placed within that day will be delivered. The location of the initial placement will also avoid stormwater outlets (no closer than 10 m) and be as far away as possible to the seagrass bed in Lowry Bay.

An alternative treatment has been proposed that would deliver the beach nourishment material in smaller volumes over two or three treatments, which could improve stability of the sediments by allowing them to settle. The time between treatments has not been defined.

Beach nourishment material will be distributed along the beach length during low tide to form a berm 0.6 m above MHWS. The beach will then slope seaward at around 1V:4H (steeper than the existing beach) out to 6 m for Point Howard and Lowry Bay, and 4.6 m for York Bay. Nourishment will take place across a shorter length than where it is expected to settle due to coastal processes spreading it along the shore in the initial phase.

5 ASSESSMENT OF ENVIRONMENTAL EFFECTS

The Eastern Bays share a characteristic of many coastal embayments in New Zealand and around the world, the "coastal squeeze", where the intertidal habitat is limited by human land use on the landward side and sea level rise on the seaward side (Pontee, 2013). Beach areas are important for recreation and amenity and, while they support invertebrate fauna that inhabit the sediment, they are less diverse than the adjacent bedrock and cobble habitats (McMurtrie & Brennan, 2019). Beach habitats provide an important function within coastal ecosystems and mitigation for the loss of intertidal beach habitat is an important factor for resilience of ecosystems into the future.

The current proposed beach nourishment of three beaches (Point Howard, Lowry Bay, York Bay) within the project area has the potential for both short-term (initial introduction of beach material) and medium-term (natural redistribution of beach nourishment material) effects. These include disturbance and possible compaction of habitat during excavation and machinery use (for initial excavations and introduction of beach material), smothering of intertidal habitat/biota during the initial introduction of beach material through to the medium-term movement of beach nourishment material beyond the initial introduction sites, and increased suspendend sediment during the intial phases and possibly during the later redistribution of materials via tide and waves.

5.1 Initial Excavation and Use of Machinery in the Intertidal Beach Area

Formation of the high tide bench requires mechanical digging of the existing beach above the high tide level. This activity will cause a direct loss of the infauna within this zone. If excavators are working along the beach they also have the potential to cause loss of species by crushing and compaction of habitat. Preparation of the beach for nourishment will disturb a proportion of the landward edge of the beach along the entire length undergoing nourishment in order to create the high tide berm, followed by sediment addition.

Much of the initial excavation for the seawall and initial high tide bench will occur above the MHWS, and as such will minimise the effect on the intertidal benthic community. Intertidal areas that will be affected by the excavation occur on each end of the beach nourishment sections, where a small portion of the mid-high intertidal zone intersects with the existing seawalls. However, the benthic community found in the upper intertidal area (i.e., intertidal (mid-high)) was not significantly different to that found within the lower intertidal zone (i.e., intertidal (mid-low)) and had significantly fewer taxa (less than two taxa per infauna core) and lower densities (less than five individuals per infauna core). Taxa in both the intertidal and subtidal zones were dominated by polychaetes (Figure 10). Polychaetes, spionid worms in particular, are known as being either opportunistic or able to recover from distubances quickly and colonise recently disturbed areas (Leewis *et al.*, 2012; Lundquist *et al.*, 2013). In a study by Leewis *et al.* (2012), a spionid polychaete and a gammarid amphipod responded positively following beach nourishment, with the spionid polychaete "over-recolonising" after beach nourishing. While their study investigated different species, they correspond with the same families as three of the most abundant taxa found in the intertidal zone in our study: *Aonides*, *Prionospio* and Gammaridae amphipods. Taxa found in the impact areas within the intertidal zones were also similar to the taxa in the control areas within the same zone, suggesting that there is a nearby source of invertebrates for recolonisation following completion of the construction activities.

5.1.1 Release of Contaminants During Excavation

The potential for the release of *in situ* contaminants as a result of the initial excavations for the seawall toe has been covered in McMurtrie & Brennan (2019). There is the risk that other contaminants associated with the machinery to be used in the intertidal area (i.e., petroleum-based products) might also be released. However, it is expected that the use of the excavator on the beach would be minimised, and all machinery would use biodegradable hydraulic fluids and be stored and refuelled away from the beach. These considerations are also covered in McMurtrie & Brennan (2019).

5.2 Initial Addition and Redistribution of Beach Nourishment Material

The initial placement of beach nourishment material will consist of a two-part process (Appendix 1):

- The initial placement of excavated beach material (from the construction of the seawall itself) to be shifted seaward to create a bench above the high tide line. This will occur during the construction of the seawall within the beach nourishment section. The formation of a bench at the high tide level is needed to prepare the site and protect it from coastal processes.
- The placement of beach nourishment material from the seawall edge (i.e., outside of the CMA) out to just at or just below the low tide mark. The amount of material placed will be no more than can be distributed along the beach in the working day to mitigate losses of sediment, whilst an alternative proposed method to place smaller volumes of material over two or three treatments will allow the material to settle between treatments and improve the likelihood of infauna escaping the burial. The material will be initially placed at the top of the beach (i.e., outside of the CMA) through to the intertidal mid tide mark (to an approximate height of 0.6 m above the high tide mark and a slope of 1V:4H) but the material will reform with a toe that will extend to (or just below) the low tide mark.

Beach nourishment will alter the habitat in the immediate and less immediate impact areas by the addition of non-native sediment and changing the beach profile. While the proposed plan is for the beach area to remain the same as existing, the height of the beach will change with the toe of the beach moving seaward. This alteration of beach morphology will have an effect on the benthic communities in the intertidal zone and the nearshore subtidal zone, with a lesser effect on the subtidal zone further seaward. The extent to which the beach morphology and sediment type changes will determine the level of impact on the benthic community, as it is these factors coupled with hydraulic condition within an environment that affect community structure (Leewis *et al.* 2012).

The sediment type chosen for the nourishment is a key factor for mitigating detrimental effects to the ecology of the beaches. The sediments provide specific habitat qualities with regards to moisture retention, oxygen availability and burrowing effort and ability, with finer sediments such as silt more compact with less oxygen than coarse sediments. Booth (1972) described sediment type as the single most important factor in bivalve occurrence in Wellington Harbour, within a suitable hydrological environment. Fine sediment (silt or clay) has been shown to have a strong negative effect on benthic invertebrates both as habitat and increased tendency to become suspended and increase turbidity. Beach sediment within Point Howard, Lowry Bay and York Bay does not contain fine sediment types and would therefore be negatively affected if fine sediment was used to nourish the beaches. The material proposed to be used for nourishment will be similar in grain size or slightly coarser than the existing beach material with no more than 2-3% fines (Reinen-Hamill, 2019).

Following the addition of the beach nourishment material there will be an initial adjustment period of days to weeks where coastal processes will distribute the sediments, with the beach toe in the nourished area expected to shift seaward six meters for Point Howard and Lowry Bay, and 4.6 m for York Bay. A loss of approximately 20-25% of the placed volume is anticipated in this initial period (Reinen-Hamill, 2019) but no indication have been given for longer timeframes. The sediment is expected to end up in the adjacent areas on the shore from cross-shore transport, as well as in the subtidal zone from seaward movement. There is currently no clear indication as to where or how far this sediment will move, with the exception of Reinen-Hamill (2019) stating that "there may be significant movement of nourished sediment within the embayment following similar sediment transport processes as currently occur" and the indication by Allis (2019) that there is a 'general northward movement of materials' within the project area. We have estimated where this movement could occur in Figure 15. Based on the assertion by Reinen-Hamil (2019) that there will be little loss of nourishment sediment from the embayed areas themselves, it is expected that any sediment will remain within each bay where it was introduced.

The potential effects on intertidal and subtidal ecology from initial introduction of beach nourishment material and the redistribution of this material pertains to increased turbidity - via resuspension of introduced material - and, sedimentation - via initial introduction of material (i.e., burial) and subsequent movement and redeposition of introduced material.

5.2.1 Sedimentation and Burial

The biggest factors influencing the effects of burial of infauna by beach nourishment is the deposition amount and rate, and sediment type (Kjeilen-Eilertsen *et al.*, 2004; Angonesi et al, 2006; Leewis *et al.*, 2012). Benthic communities can be relatively resilient to burial of sediment, some species faring better than others. Survival from burying depends on the physiology of a particular species and the local conditions it is adapted to (Lundquist *et al*, 2013). The greatest impact of burial of the beach will be in the intertidal zone, withthe nearshore subtidal zone affected to a lesser degree. It is expected that loss of taxa will occur in the intertidal zone as a result of the burial, but having the nourishment material applied at smaller volumes over two or three treatments will improve the likelihood of some taxa escaping burial.

Higher mortality of benthic fauna will occur if the thickness of sediment applied at one time cannot be penetrated by the infauna (Turk & Risk, 1981; Kjeilen-Eilertsen *et al.*, 2004). Most species are unlikely to survive burial in more than one meter of sediment (Leewis *et al.*, 2012). The intertidal zone is dominated by polychaetes, which are species of limited mobility and unlikely to survive burial but recover quickly from disturbances, and crustaceans, which are highly mobile and actively move away from unfavourable conditions (Thrush *et al.* 2008).

A study on the response of an amphipod crustacean (Corophiidae, as found widespread in our study) and a bivalve mollusc (same family as the large wedge shell *Macomona liliana* found widespread in our study) to sediment accumulation was undertaken by Turk & Risk (1981). The accumulation of 1.0-3.5 cm of sediment at a rate of 1.9 cm/month showed a strong negative response to densities of the amphipod crustacean but no effect to densities of the mollusc (Turk & Risk, 1981). Corophiid amphipods are classified in Thrush *et al.* (2008) as highly motile organisms that actively move through the sediment. Gibbs & Hewitt (2004) show that small duration, thin sediment deposit events were able to be adapted to by many of the species studied. Most macrofauna studied (including polychaete worms, bivalves and shrimps) were able to move vertically through a terrigenous layer less than 3 mm thick, but with negative impacts observed at thicker deposition.

Benthic infauna can tolerate more sediment of the same or coarser grain size than if it is a different size. Matching the sediment type as best as possible to the sediment (especially grain size) of the existing beaches is a critical requirement for mitigating loss of infauna due to burial and compaction (Kjeilen-Eilertsen *et al.*, 2004).

Bivalves can be categorised into their relative ability to survive burial based on their feeding mechanisms (Kranz, 1974 censu Kjeilen-Eilertsen et al, 2004). When the burial sediment type matches the native sediment type, larger depths of burial can be withstood and can range from 10 cm to 57 cm. As well as matching grain size, colour of the imported sediment should also match as best as possible to the existing sediment type. Darker coloured sediment than what is currently found at a beach could have the potential to increase the temperature of the environment where it is placed, having a negative effect on the infauna (Speybroeck *et al.*, 2006).

The beach nourishment proposal is to introduce material of a similar sediment type to that currently present at each of the three beaches. Imported material used for nourishment will contain no more than 2-3% fine sediment and be of similar grain size, if not coarser than the existing sediment, and will be of similar colour to the *in situ* material (Reinen-Hamill, 2019). Thus the effect of the beach nourishment material *per se* is likely to have less of an impact than the depth of sediment being initially deposited. Reinen-Hamill (2019) indicates that the initial depth of added material (i.e., the intial placed berm) may be 0.6 m deep above the high-tide mark. This represents a reasonable depth of sediment and it is therefore expected that few taxa would be able to survive this initial burial. The addition of this material is, however, introduced into a zone that has low diversity and density of taxa, and there will remain intertidal zone within the bays where the material is not added, which can act as recolonisation sources. A reasonable portion of the area to be initially buried during intial introduction of beach nourishment material is also outside the CMA and therefore will have the least impact on intertidal benthic infauna.

The design report describes an alternate method of beach nourishment where the volume required is delivered over two or three treatments, allowing for a smaller volume per treatment and a period of time between the treatments to allow benthic invertebrates to adjust. This method is preferred to increase the potential for survival of intertidal beach infauna as it should allow time for them to adjust to the addition of smaller amounts of material.

The recovery of benthic invertebrates that occupy the impact areas of the beach nourishment in the intertidal and subtidal zones is influenced by recruitment, which is species-specific and determined by suitable habitat, food and environmental conditions. Recruitment of invertebrates to the disturbed areas is generally by planktonic larval dispersal and settlement, rather than adult migration, and the life history traits of these species determine their recovery (such as reproduction strategy and dispersal capabilities) (Menn *et al.,* 2003; Kjeilen-Eilertsen *et al.,* 2004; Gardner & Wear, 2006; Speybroeck *et al.*, 2006; Leewis *et al*., 2012). A study of the recovery of the macroinvertebrate community structure following a toxic algal bloom in Wellington Harbour by Gardner & Wear (2006) determined that recovery of the benthic community proceeded rapidly with the impact of the bloom only just detectable 12 months following the event. If habitat is available, recruitment of species will be dependent on the larval influx from adjacent intertidal areas and from pelagic influences (Schiel, 2004). Within the Eastern Bays area, benthic community composition was similar across all bays (Figure 11) and was similar within the intertidal and subtidal zones (Figure 12), thereby providing a potential source of larval recruitment for areas affected by nourishment. Given the beach materials being introduced are similar to those beach materials of the bays, the substrate type should remain similar to that which currently exists, meaning that the habitat will be suitable for recolonisation by the same taxa that are currently present.

Following the initial burial, opportunistic taxa (typically polychaetes, and mobile deposit feeders and small scavengers such as amphipods and small crustaceans) are early colonisers following a disturbance and respond favourably to disturbance, sometimes by 'over-recolonising'. This applies especially to spionid polychates (e.g. *Aonides*, *Boccardia* and *Prionospio*) and other polychaetes (Angonesi *et al.* 2006; Leewis *et al.,* 2012; Lundquist *et al.,* 2013). Gardner & Wear (2006) also found polychates to be the first to recolonise a disturbed area, this case in Wellington Harbour. Recovery times of species will take longer if the sediment grain size of the nourishment does not match the existing sediment, especially if they contain silts or clays (Greene, 2002). Response to inputs of terrigenous sediment over 1 cm in estuaries by bivalves (*Paphies australis* and *Macomona liliana*) typically show a slow recovery of species, especially the response by juveniles (Cummings & Thrush, 2004). However it has also been shown that these bivalves have the ability to move if conditions become 'unfavourable' (Cummings & Thrush, 2004; Taylor & Keeley, 2009). Given the similarity of grain size, lack of fines, and a marine source of material proposed for the beach nourishment, such effects would be substantially lessened.

Sedimentation (i.e., redeposition of introduced material)

In addition to the initial introduction of beach nourishment material into the intertidal zone, there is the potential for sedimentation effects to occur within the wider intertidal and subtidal zone as the introduced material is redistributed by tide and waves over time. Increased sedimentation can negatively impact benthic environments by smothering habitats (Gibbs & Hewitt, 2004). Shoaling, embeddedness and other physical modification of habitat can result from sudden changes in sediment supply. The level of impact from sedimentation is determined by the ecosystem community composition, the thickness and rate of the deposition and the ambient environmental conditions experienced, as discussed in Section 5.2.1.

Functional groups representing substrate destabilisers (e.g., surface burrowers like *Echinocardium* spp.) are likely to respond negatively to sedimentation due to their sensitivity and slow recovery time (Lundquist et al, 2013). The amount of sediment movement will drop off with increasing distance from shore and as such there will be less material moving into the nearshore (shallow) zone. This will mitigate the effect on these large, biogenic species.

The proposed areas for beach nourishment are adjacent to rocky outcrops, areas that are known to support the greatest biodiveristy of any coastal habitat (Smith, 2013). Effects of increased sedimentation and turbidity in these areas would be detrimental. The sediment grain size used for the nourishment will be of a similar, if not coarser, size to the existing sediments which will prevent transport to adjacent areas. Reinen-Hamill (2019) has assumed little settlement of the nourishment sediments on the rocky platforms and reefs due to the limited transport anticipated and that the rocky outcrops will experience a higher exposure to wind and wave energy and creating their own turbulence among the formations, thereby preventing the long-term settlement of sediment.

On the basis that the introduced beach nourishment material will become redistributed in the subtidal zone via natural processes, and because the nature of the material being introduced is similar to the *in situ* material, we do not expect the redistribution to be significantly dissimilar to the natural redistruction of marine sediments within the embayments.

5.2.2 Increased Turbidity

Increased turbidity may be experienced during the initial introduction of beach nourishment material into the intertidal zone. Over a period of weeks to months following this introduction, the sediments will also undergo a stabilisation period where changes to the beach state and profile will occur (Reinen-Hamill, 2019) and which may also result in some increase in turbidity if sediments become resuspended. The main process of sediment transport is expected to be cross-shore, but seaward movement of sediment is also expected to some (albeit undetermined) degree. The stability of the beach nourishment at Balaena Bay in Wellington Harbour in 1982 was monitored monthly for one year and reassessed after two years (Carter & Mitchell, 1985). Sediment movement was determined by the hydraulic regime of tides, currents and waves and there was very little nourishment sediment found in the subtidal zone, and only traces at the landward edge. Understanding that the effect is site-specific, Balaena Bay has similarities to the project area in the hydraulic conditions they both experience and in the native sediments.

The impact of inputs of land-derived (terrigenous) fine sediment has been documented in a number of New Zealand studies (Lohrer *et al.*, 2003; Thrush *et al.,* 2003a; Thrush *et al.,* 2003b; Cummings & Thrush, 2004; Gibbs & Hewitt, 2004; Taylor & Keeley, 2009). Terrigenous sediment can be detrimental to the survival of intertidal and subtidal invertebrate biota as it reduces light penetration into the water column, impacting primary production of pelagic phytoplankton and benthic macrophytes (algae that live in or on the sediments) and thus reducing a key food component to suspension feeders, herbivorous benthic grazers and deposit feeders (Gibbs & Hewitt, 2004). Suspended sediments can also interrupt feeding and respiration by clogging gill structures of filter feeders, can impact larval recruitment and settlement and can cause reduced oxygen levels as oxygen in the water column is consumed by microbes that break down the organic content in the sediment.

Turbidity can affect early life stages of benthic organisms and larval settlement (Schiel 2004). While the nourishment sediment is not expected to contain fine sediments, increased turbidity is likely to occur to some degree given the addition of sediment to the area. Sediment generation and transport is a naturally occurring process in the Eastern Bays portion of Wellington Harbour (Booth, 1975; Lachowicz, 2005, Matthews, 1980). During storm (rainfall and wind-wave) events, longshore drift, terrigenous supply and wave action will temporarily suspend fine particulate matter in the water column (Booth, 1975; Lachowicz, 2005). Such natural events cause brief periods of high turbidity and increased sediment flux to near-shore environments. In general, sedimentation and turbidity beyond what is typically experienced within the local environment is detrimental not only to the individual taxa, but to the ecosystem as a whole.

Soft sediment dwelling benthic organisms are adapted to sediment mobilisation and short-term disturbances; the extent to which species are adapted is site and species specific. Large bivalve species and echinoderms identified in the project area's subtidal zone include horse mussels (*Atrina zelandica*), pipi (*Paphies australis*), cockle (*Austrovenus stutchburyi*), large wedge shell (*Macomona liliana*), seven-armed sea star (*Astrostole scabra*), and kina (*Evechinus chloroticus*) and these are at risk of becoming stressed if suspended sediment concentration and duration is experienced outside the normal variation of the area. Having less than 2-3% of fine sediment in the nourishment sediment will significantly mitigate this risk. The Eastern Bays of Wellington Harbour support *Macrocystis* (kelp) beds/forests growing at depths 3–15 m, which are representative habitats at the northern extent of this habitat type in New Zealand (EHEA, 1998). Kelp beds have a high biodiversity value with major threats including sedimentation, increases in turbidity and increases in storminess (MacDiarmid *et al.* 2012). While unlikely given the small area of the beach nourishment additions, harbour-wide sediment plumes over an extended time (a number of days) can potentially have a detrimental impact on these beds. It should be noted that these areas would already be exposed at times to low light conditions during storm events where Wellington Harbour experiences significantly higher turbidity from its catchments (James *et al.* 2015). *Macrocystis* beds are reported to occur along the eastern bays area (between Point Howard and Hinds Point) (GWRC, 2015), however no kelp beds were found in the nearshore or shallow subtidal areas of the locations sampled (within Point Howard, Sorrento Bay, Lowry Bay, York Bay, Mahina Bay or Days

Bay) (Figure 3). Overmars (2019b) has identified shallow subtidal and intertidal seagrass beds in central and Southern Lowry Bay[3], thus refer to Overmars (2019a, 2019b) for consideration of effects on seagrass.

Based on the grain size of the nourishment material it is unlikely that the particles will stay in suspension for long or for any distance. Reinen-Hamill (2019) suggests that it is unlikely that any nourishment material will disperse out of the embayment and the processes of sediment movement will be within natural variation. This reflects the findings of Carter & Mitchell (1985) who found that beach nourishment sediments in Balaena Bay did not disperse into the subtidal zone. Thus it is our assertion that any effects of turbidity will be minimised as a result of the large grain size, marine source of material and lack of fines in the material.

5.2.3 Release of Contaminants from Introduced Material

There is the potential for the introduced materials (both from the locally excavated beach material as well as the greater portion of introduced beach nourishment material) to introduce contaminants to the receiving environment during their initial introduction and during the medium-term redistribution of materials.

Based on some testing of *in situ* intertidal beach sediments from Lowry Bay Stevens *et al.* (2004) concluded that there was no sign of sediment contamination or sediment enrichment, with levels below the ADAWR (2019) Defaut Guideline Values (DGV) (which have replaced the ANZECC (2000) ISQG-low trigger levels), as well as the Auckland Council's more conservative Environmental Response Criteria for heavy metals. Preferred options for the source of nourishment sediments are the foreshore south of Eastbourne which is an area of naturally accumulated brown sand and lighter gravels, or dark grey sand from the lower Hutt River where consents are already in place for dredging of the sand. The materials will be free of fines, which is what most contaminants bind to, implying that the level of contamination of introduced material should be low. On this basis there should be no addition of contaminated materials and thus no effect of contaminants on the receiving environment. However, to be certain of this, the material being introduced should be checked for contaminants prior to the approval of such materials for use in any beach nourishment.

5.3 Mitigation Measures

Beach nourishment is recognised across the globe for having an effect on the ecology in the area which it relates, however there are varying studies about the degree of this effect and the duration of impact. A number of studies have found little long-term effect to the benthic community and habitat as a result of beach nourishment, due to rapid recovery rates (Menn *et al.*, 2003; Leewis *et al.,* 2012; Culter & Mahadevan 1982). Our assessment is that small shifts in community composition may occur at some locations as a response to the shifting beach nourishment material, but it is unlikely to greatly change the overall community composition of the subtidal area due to the similarity of beach nourishment material to the *in situ* material, lack of fines in the introduced material, the localised nature of the sediment movement, the already dynamic nature of the nearshore environment, and the similarity in the subtidal

[3] As vascular plants, seagrass has been dealt with in the Avifauna and Vegetation technical report by Overmars (2019a, 2019b).

benthic invertebrate community within and between the bays that will allow for recolonisation. A greater level of impact is expected within the intertidal zone where the beach nourishment materials will be introduced, primarily due to the fact that the depth of introduced sediment may be too deep for *in situ* biota to tolerate. Yet this is offset by the lower diversity and density of taxa in the intertidal beach areas and the similarity of the infauna community within the impact areas to the wider intertidal beach area, which will help to facilitate recolonisation after the initial disturbance.

The following are mitigation measures either currently proposed or what we would additionally recommend to ensure that the effects of beach nourishment are limited to a 'minor' or 'less than minor' level of effect in RMA terms.

- » Recommendations in McMurtrie & Brennan (2019) for mitigation relating to construction of the seawall be followed.
- » The recommendations in Overmars (2019a, 2019b) for mitigation relating to seagrass beds be followed.
- » All machinery used for the redistribution of excavated beach material (from the construction of the seawall itself) to create a bench above the high tide line remain above MHWS, and all bench material is not to extend below the MHWS line.
- » Adding beach nourishment material in smaller volumes over two or three treatments instead of in one treatment. This provides a greater ability for infauna to survive the more shallow burial and also provides an opportunity for an adaptive management approach where the programme is improved based on experience.
- » The beach nourishment material must have similar grain size and properties of the beach sediments, and must not contain more than 2-3% of fine material in the nourishment sediment.
- » Testing beach nourishment material for contaminants prior to the approval of such materials for use in any beach nourishment. Contaminant levels must be below the ADAWR (2019) Defaut Guideline Values, as well as the Auckland Council's more conservative Environmental Response Criteria for heavy metals (ARC, 2004).
- » The initial placement of beach nourishment material will be at the widest part of the beach at/around low tide, in calm weather conditions, and will be placed such that the intial toe does not extend beyond (or much beyond) the MLWS.
- » Timing the addition of beach nourishment to as closely follow the completion of the seawall construction within the Bay as possible, so that the duration of disturbance is minimised.
- » Delineating a strict construction works site to minimise the working area and mobilisation of sediment.
- » Retain any woody debris in the wrack line of the beaches and return this to the same position up the shoreline following completion of the beach nourishment.
- » Avoid intial placement of beach nourishment material at the southern extreme of Lowry Bay where there are emergent larger rocky substrates within the finer beach materials.

With the mitigation measures above, it is anticipated that the effects of sedimentation in the subtidal zone will be short-lived and within a range that is experienced within the ambient environment naturally. However, as sediment migration can vary based on site-specific conditions, and as there is little detail as to the level of redistribution of sediments over time, we would recommend that some monitoring of the redistribution of beach nourishment materials be undertaken, along with an assessment of the benthic intertidal and subtidal beach fauna at least 12 months after completion of the proposed works. The results of this monitoring will help to inform any future additional beach nourishment measures.

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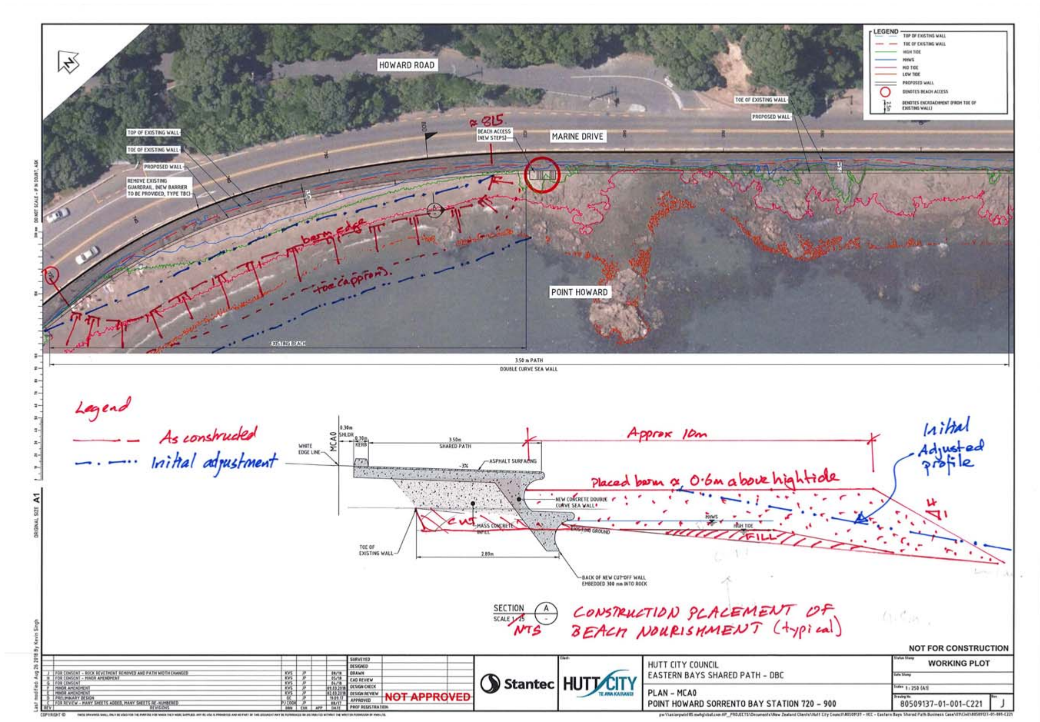
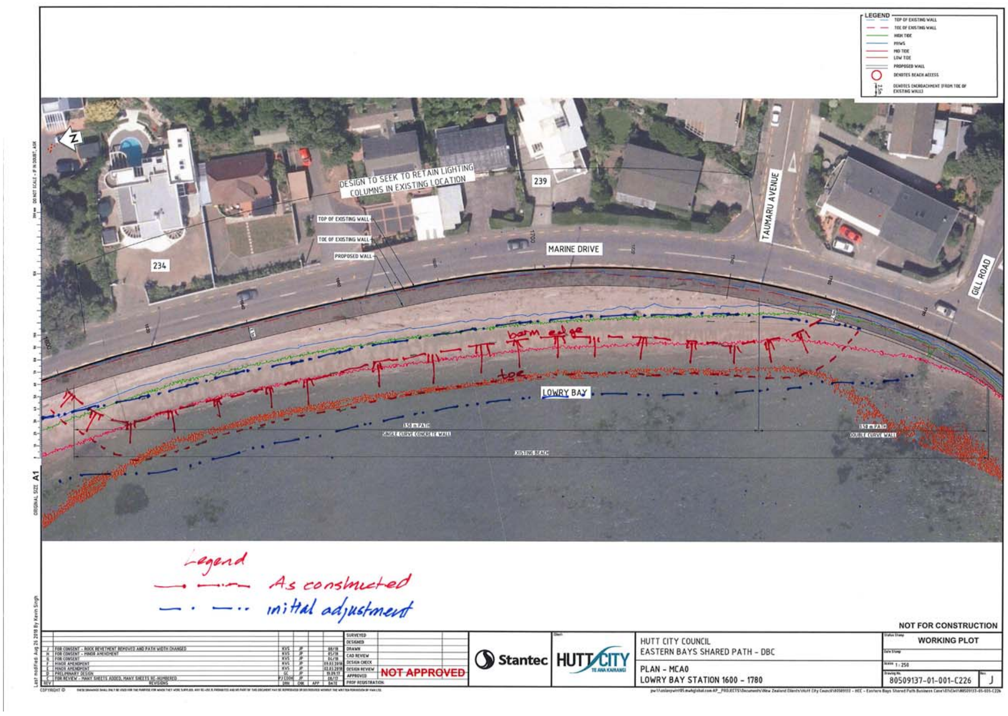
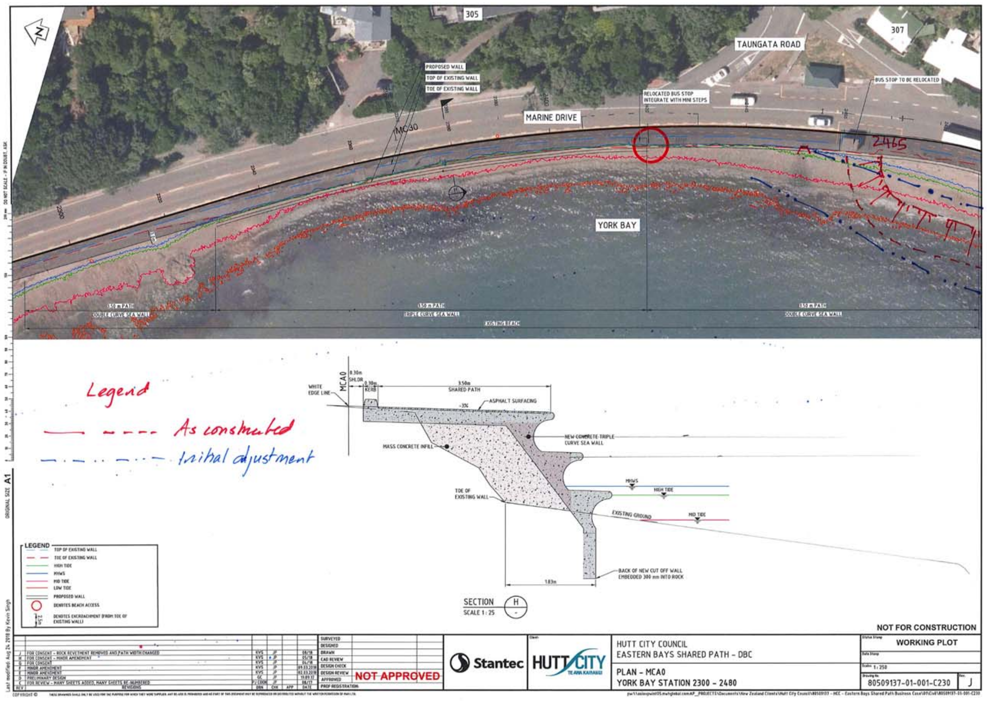
8 APPENDICES

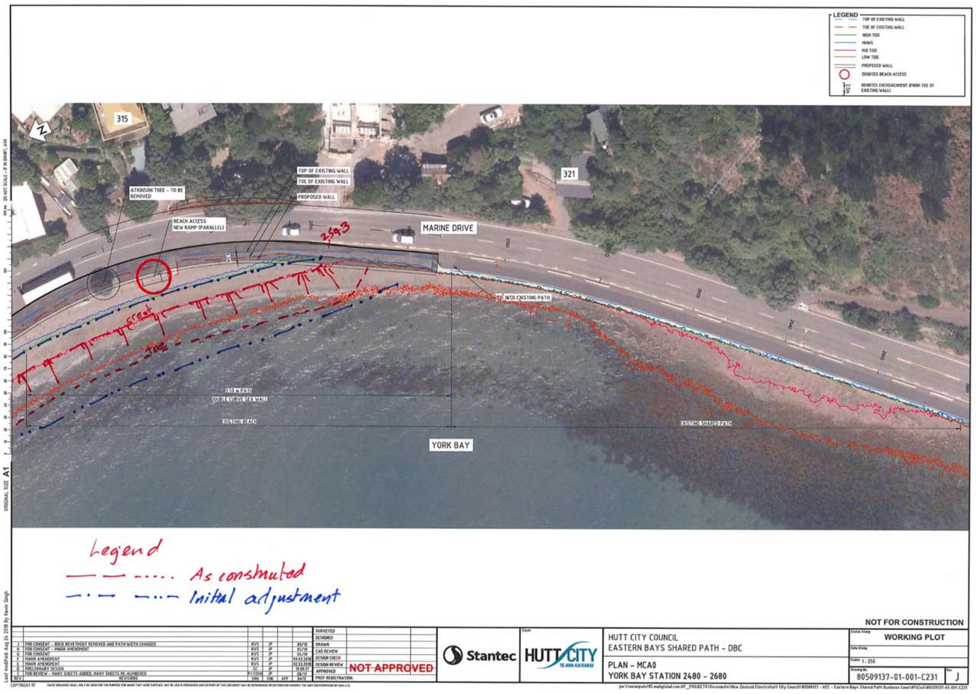
8.1 Appendix 1 – Detailed Map of Proposed Beach Nourishment Areas

The proposed beach nourishment areas, as provided in Reinen-Hamill (2016).






305
307
TAUNGATA ROAD
PROPOSED WALL
TOP OF EXISTING WALL
TOE OF EXISTING WALL
RELOCATED BUS STOP INTEGRATE WITH MINI STEPS
BUS STOP TO BE RELOCATED
MARINE DRIVE
YORK BAY
Legend
As constructed
Initial adjustment
SHARED PATH
ASPHALT SURFACING
NEW CONCRETE TRIPLE CURVE SEA WALL
MASS CONCRETE INFILL
TOE OF EXISTING WALL
MHWS
HIGH TIDE
MID TIDE
EXISTING GROUND
BACK OF NEW CUT OFF WALL EMBEDDED 300 mm INTO ROCK
SECTION H
SCALE 1 : 25
LEGEND
TOP OF EXISTING WALL
TOE OF EXISTING WALL
HIGH TIDE
MHWS
MID TIDE
LOW TIDE
PROPOSED WALL
DENOTES BEACH ACCESS
NOT FOR CONSTRUCTION
NOT APPROVED
Stantec
HUTT CITY
HUTT CITY COUNCIL
EASTERN BAYS SHARED PATH - DBC
PLAN - MCA0
YORK BAY STATION 2300 - 2480
WORKING PLOT
80509137-01-001-C230
J

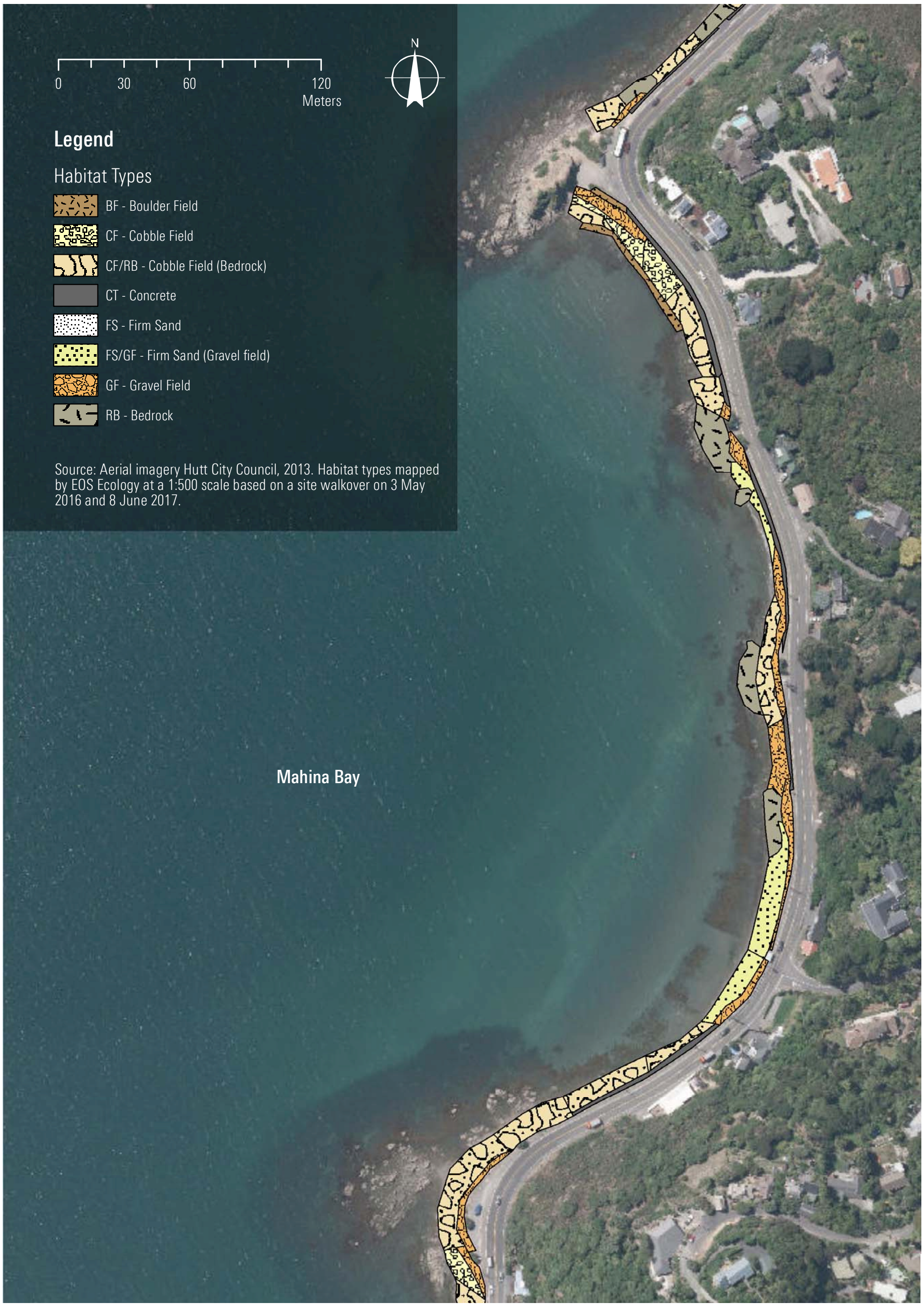

LEGEND
TOP OF EXISTING WALL
TOE OF EXISTING WALL
HIGH TIDE
MHWS
MID TIDE
LOW TIDE
PROPOSED WALL
DENOTES BEACH ACCESS
315
321
TOP OF EXISTING WALL
TOE OF EXISTING WALL
PROPOSED WALL
BEACH ACCESS NEW RAMP (PARALLEL)
MARINE DRIVE
YORK BAY
Legend
As constructed
Initial adjustment
NOT FOR CONSTRUCTION
NOT APPROVED
Stantec
HUTT CITY
HUTT CITY COUNCIL
EASTERN BAYS SHARED PATH - DBC
PLAN - MCA0
YORK BAY STATION 2480 - 2680
WORKING PLOT
80509137-01-001-C231
J

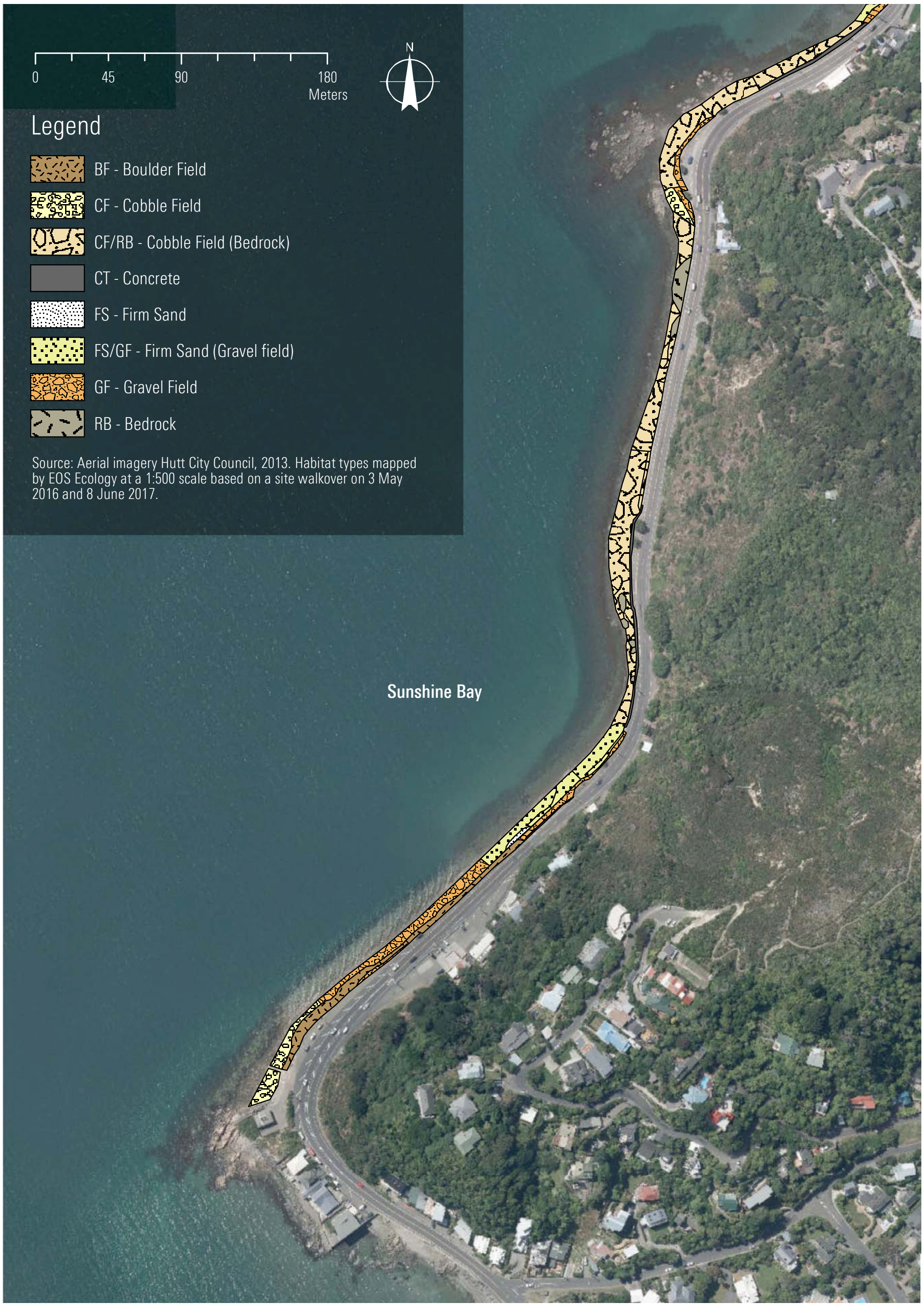
8.2 Appendix 2 – Habitat Maps – Broad Scale Assessment

The broad scale assessment of habitat types undertaken as part of McMurtrie & Brennan (2019), and included here for completeness. The maps provide habitat types adapted from Stevens *et al.* (2004) at a 1:500 scale. Note that Days Bay was excluded from the habitat mapping as it falls outside of the project area. Existing beach areas are characterised by FS/GF (firm sand (gravel field), and FS (firm sand).


Lowry Bay
0 40 80 160
Meters
N
Legend
Habitat Types
BF - Boulder Field
CF - Cobble Field
CF/RB - Cobble Field (Bedrock)
CT - Concrete
FS - Firm Sand
FS/GF - Firm Sand (Gravel field)
GF - Gravel Field
RB - Bedrock
Source: Aerial imagery Hutt City Council, 2013. Habitat types mapped by EOS Ecology at a 1:500 scale based on a site walkover on 3 May 2016 and 8 June 2017.


0
40
80
160
Meters
N
Legend
Habitat Types
BF - Boulder Field
CF - Cobble Field
CF/RB - Cobble Field (Bedrock)
CT - Concrete
FS - Firm Sand
FS/GF - Firm Sand (Gravel field)
GF - Gravel Field
RB - Bedrock
Source: Aerial imagery Hutt City Council, 2013. Habitat types mapped by EOS Ecology at a 1:500 scale based on a site walkover on 3 May 2016 and 8 June 2017.
York Bay


0
30
60
120
Meters
N
Legend
Habitat Types
BF - Boulder Field
CF - Cobble Field
CF/RB - Cobble Field (Bedrock)
CT - Concrete
FS - Firm Sand
FS/GF - Firm Sand (Gravel field)
GF - Gravel Field
RB - Bedrock
Source: Aerial imagery Hutt City Council, 2013. Habitat types mapped by EOS Ecology at a 1:500 scale based on a site walkover on 3 May 2016 and 8 June 2017.
Mahina Bay


0
45
90
180
Meters
N
Legend
BF - Boulder Field
CF - Cobble Field
CF/RB - Cobble Field (Bedrock)
CT - Concrete
FS - Firm Sand
FS/GF - Firm Sand (Gravel field)
GF - Gravel Field
RB - Bedrock
Source: Aerial imagery Hutt City Council, 2013. Habitat types mapped by EOS Ecology at a 1:500 scale based on a site walkover on 3 May 2016 and 8 June 2017.
Sunshine Bay


0
30
60
120
Meters
N
Legend
BF - Boulder Field
CF - Cobble Field
CF/RB - Cobble Field (Bedrock)
CT - Concrete
FS - Firm Sand
FS/GF - Firm Sand (Gravel field)
GF - Gravel Field
RB - Bedrock
Source: Aerial imagery Hutt City Council, 2013. Habitat types mapped by EOS Ecology at a 1:500 scale based on a site walkover on 3 May 2016 and 8 June 2017.
Days Bay
Windy Point
Eastbourne

8.3 Appendix 3 – Summary Data for Intertidal Infauna Samples

Table 8 The average density (number per sample), total number (sum), % abundance, and number of samples taxa were found in for infauna samples collected within the intertidal zone by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), and Dec 2018 (Sites Int-1 to Int-23). The taxa that were most abundant (>5% abundance) and moderately widespread (found in >25% of samples) are highlighted in bold.

Faunal Group 1	Faunal Group 2	Taxa	Ave Density (no/sample)	Total No.	% abundance	No samples found in (out of 31)
Chelicerata	Arachnida	Acarina	0.03	1	0.2%	1
Crustacea	Amphipoda	**Gammaridae**	2.52	78	**17.3%**	7
		Paracalliope sp.	0.03	1	0.2%	1
	Copepoda	Copepoda	0.03	1	0.2%	1
	Decapoda	Austrohelice crassa	0.13	4	0.9%	1
		Heterozius rotundifrons	0.06	2	0.4%	2
		Petrolisthes elongatus	0.16	5	1.1%	2
	Isopoda	Flabellifera	0.39	12	2.7%	7
	Ostracoda	Ostracoda	0.13	4	0.9%	1
Echinodermata	Echinodermata	Echinodermata	0.10	3	0.7%	1
Insecta	Diptera	Muscidae	0.03	1	0.2%	1
		Polypedilum	0.03	1	0.2%	1
	Megaloptera	Archichauliodes	0.03	1	0.2%	1
Mollusca	Bivalvia	Arthritica sp.	0.03	1	0.2%	1
		Austrovenus stutchburyi	0.10	3	0.7%	2
		Mytilidae	0.03	1	0.2%	1
		Paphies australis	0.23	7	1.5%	5
		Tawera spissa	0.06	2	0.4%	1
	Gastropoda	Cellana radians	0.16	5	1.1%	2
		Diloma aethiops	0.13	4	0.9%	1
		Diloma nigerrimum	0.03	1	0.2%	1
		Potamopyrgus sp.	0.10	3	0.7%	1
		Zeacumantus subcarinatus	0.10	3	0.7%	2
Nematoda	Nematoda	Nematoda	0.06	2	0.4%	2
Nemertea	Nemertea	Nemertea	0.13	4	0.9%	2
Platyhelminthes	Platyhelminthes	Notoplana australis	0.03	1	0.2%	1
Polychaeta	Aciculata	Glycera americana	0.23	7	1.5%	1
		Glyceridae	0.16	5	1.1%	3
		Nereidae	1.32	41	**9.1%**	**9**
		Perinereis camiguinoides	0.03	1	0.2%	1
		Perinereis sp.	0.23	7	1.5%	4
		Perinereis vallata	0.19	6	1.3%	3
	Canalipalpata	**Aonides sp.**	3.35	104	**23.0%**	**8**
		Oweniidae	0.13	4	0.9%	1
		Prionospio sp.	2.55	79	**17.5%**	4
	Scolecida	Capitella capitata	0.19	6	1.3%	2
		Capitella spp.	1.06	33	**7.3%**	5
		Heteromastus filiformis	0.16	5	1.1%	2
		Orbinia papillosa	0.10	3	0.7%	3
TOTAL		39 taxa		**452**		

Table 9 Taxa density (numper per sample) and taxa richness recorded for each intertidal sample by EOS Ecology in May 2016 (Sites Int-24 to Int-30), June 2017 (Site Int-31), and Dec 2018 (Sites Int-1 to Int-23).

Site No.	Bay	Tide zone	Taxa density (no/sample)	Taxa richness
Int-1	Point Howard	Intertidal (mid-low)	6	5
Int-2	Point Howard	Intertidal (mid-low)	5	4
Int-3	Point Howard	Intertidal (mid-low)	3	3
Int-4	Lowry Bay	Intertidal (mid-upper)	18	6
Int-5	Lowry Bay	Intertidal (mid-low)	8	5
Int-6	Lowry Bay	Intertidal (mid-low)	4	2
Int-7	Lowry Bay	Intertidal (mid-upper)	0	0
Int-8	Lowry Bay	Intertidal (mid-low)	6	3
Int-9	Lowry Bay	Intertidal (mid-low)	2	1
Int-10	Lowry Bay	Intertidal (mid-low)	4	4
Int-11	Lowry Bay	Intertidal (mid-upper)	0	0
Int-12	York Bay	Intertidal (mid-low)	2	2
Int-13	York Bay	Intertidal (mid-low)	1	1
Int-14	Mahina Bay	Intertidal (mid-low)	0	0
Int-15	Mahina Bay	Intertidal (mid-low)	3	3
Int-16	Mahina Bay	Intertidal (mid-upper)	3	2
Int-17	Days Bay	Intertidal (mid-low)	1	1
Int-18	Days Bay	Intertidal (mid-upper)	1	1
Int-19	Days Bay	Intertidal (mid-upper)	0	0
Int-20	Days Bay	Intertidal (mid-low)	0	0
Int-21	Sunshine Bay	Intertidal (mid-upper)	22	2
Int-22	Sorrento Bay	Intertidal (mid-low)	2	2
Int-23	Sorrento Bay	Intertidal (mid-upper)	3	1
Int-24	York Bay	Intertidal (mid-low)	5	5
Int-25	York Bay	Intertidal (mid-upper)	2	1
Int-26	Sorrento Bay	Intertidal (mid-upper)	2	1
Int-27	Lowry Bay	Intertidal (mid-upper)	1	1
Int-28	Lowry Bay	Intertidal (mid-low)	135	8
Int-29	Mahina Bay	Intertidal (mid-low)	112	19
Int-30	York Bay	Intertidal (mid-low)	97	11
Int-31	Mahina Bay	Intertidal (mid-upper)	4	1
Total			452 individuals	39 taxa

8.4 Appendix 4 - Summary Data for Subtidal Infauna Samples

Table 10 The average density (number per sample), total number, % abundance, and number of samples taxa were found in for infauna samples collected within the subtidal zone by EOS Ecology in Feb 2019. The taxa that were most abundant (>5% abundance) and widespread (found in >50% of samples) are highlighted in bold.

Faunal Group 1	Faunal Group 2	Taxa	Ave Density (no/sample)	Total No.	% abundance	No. samples found in (out of 47)
Cnidaria	Anthozoa	Actinaria sp.	0.04	2	0.1%	2
		Edwardsia leucomelos	0.02	1	0.1%	1
Crustacea	Amphipoda	Amphipoda	0.02	1	0.1%	1
		Corophiidae	0.83	39	2.2%	13
		Cumacea	0.64	30	1.7%	20
		Gammaridae	0.89	42	2.4%	18
	Cirripedia	Chamaesipho sp.	0.96	45	2.6%	1
	Decapoda	Biffarius filholi	0.13	6	0.3%	5
		Halicarcinus	0.04	2	0.1%	2
		Hemiplax hirtipes	0.11	5	0.3%	4
		Ogyrididae	0.02	1	0.1%	1
		Pagurus sp.	0.34	16	0.9%	10
		Unidentified decapoda megalopa	0.04	2	0.1%	2
	Isopoda	Anthuridae	0.02	1	0.1%	1
		Valvifera	0.04	2	0.1%	2
	Leptostraca	Nebalia sp.	0.02	1	0.1%	1
	Ostracoda	Ostracoda	0.51	24	1.4%	10
	Tanaidacea	Tanaidacea	0.28	13	0.7%	4
Echinodermata	Asteroidea	Astrostole scabra	0.02	1	0.1%	1
		Patiriella sp.	0.87	41	2.3%	21
	Camarodonta	Evechinus chloroticus	0.02	1	0.1%	1
Mollusca	Bivalvia	Asaphis sp.	0.15	7	0.4%	3
		Austrovenus stutchburyi	0.28	13	0.7%	7
		Cyclomactra ovata	0.17	8	0.5%	5
		Dosinia sp.	0.43	20	1.1%	10
		Linucula hartvigiana	0.02	1	0.1%	1
		Macomona liliana	1.66	78	4.5%	**26**
		Paphies australis	0.15	7	0.4%	5
		Venerupis sp.	0.11	5	0.3%	5
	Chitonida	Chiton glaucus	0.02	1	0.1%	1
		Juvenile chiton	0.11	5	0.3%	3
	Gastropoda	Buccinulum linea	0.02	1	0.1%	1
		Cellana sp.	0.09	4	0.2%	4
		Cominella maculosa	0.06	3	0.2%	2
		Cominella sp.	0.02	1	0.1%	1
		Ellobiidae	0.02	1	0.1%	1
		Lunella smaragda	0.26	12	0.7%	9
Nematoda	Nematoda	Nematoda	0.17	8	0.5%	3
Nemertea	Nemertea	Nemertea	0.19	9	0.5%	7
Polychaeta	Aciculata	Aglaophamus macroura	0.02	1	0.1%	1
		Glycera americana	0.32	15	0.9%	12

Faunal Group 1	Faunal Group 2	Taxa	Ave Density (no/sample)	Total No.	% abundance	No. samples found in (out of 47)
		Glyceridae	0.91	43	2.5%	**29**
		Nephytidae	0.09	4	0.2%	4
		Nereidae	0.09	4	0.2%	3
		Phyllodocidae	0.02	1	0.1%	1
		Sigalionidae	0.11	5	0.3%	3
		Syllidae	0.32	15	0.9%	7
	Canalipalpata	Boccardia spp.	1.11	52	3.0%	14
		Cirratulidae	0.02	1	0.1%	1
		Magelona dakini	12.00	564	**32.3%**	**35**
		Oweniidae	0.62	29	1.7%	17
		Pectinaria australis	0.13	6	0.3%	5
		Prionospio sp.	0.64	30	1.7%	21
		Sabellidae	2.87	135	**7.7%**	**32**
		Scolecolepides sp.	0.19	9	0.5%	4
		Serpulinae	0.02	1	0.1%	1
		Spionidae	0.09	4	0.2%	4
		Terebellidae	0.09	4	0.2%	3
	Errantia	Eunicida	0.15	7	0.4%	6
		Lumbrineridae	0.36	17	1.0%	13
	Scolecida	Capitella spp.	0.26	12	0.7%	5
		Heteromastus filiformis	5.85	275	**15.7%**	**25**
		Maldanidae	0.21	10	0.6%	5
		Opheliidae	0.53	25	1.4%	14
		Orbinia papillosa	0.19	9	0.5%	6
		Paraonidae	0.02	1	0.1%	1
Sipuncula	Sipuncula	Sipuncula	0.17	8	0.5%	7
Grand Total				1747		

Table 11 Taxa density (number per sample) and taxa richness recorded for each subtidal sample by EOS Ecology in Feb 2019.

Site No.	Bay	Tide zone	Taxa density (no/sample)	Taxa richness
Sub-1	Point Howard	Subtidal (shallow)	50	12
Sub-2	Point Howard	Subtidal (shallow)	76	10
Sub-3	Point Howard	Subtidal (shallow)	8	4
Sub-4	Point Howard	Subtidal (shallow)	16	9
Sub-5	Sorrento Bay	Subtidal (shallow)	34	4
Sub-6	Sorrento Bay	Subtidal (shallow)	13	7
Sub-7	Lowry Bay	Subtidal (shallow)	42	19
Sub-8	Lowry Bay	Subtidal (shallow)	31	14
Sub-9	Lowry Bay	Subtidal (shallow)	24	14
Sub-10	Lowry Bay	Subtidal (shallow)	30	12
Sub-11	Lowry Bay	Subtidal (shallow)	16	9
Sub-12	Lowry Bay	Subtidal (shallow)	19	6
Sub-13	Lowry Bay	Subtidal (shallow)	32	11
Sub-14	Lowry Bay	Subtidal (shallow)	48	11
Sub-15	Lowry Bay	Subtidal (shallow)	37	12
Sub-16	Lowry Bay	Subtidal (shallow)	38	16
Sub-17	Lowry Bay	Subtidal (shallow)	49	14
Sub-18	Lowry Bay	Subtidal (shallow)	60	24
Sub-19	Lowry Bay	Subtidal (shallow)	38	5
Sub-20	Lowry Bay	Subtidal (shallow)	19	5
Sub-21	York Bay	Subtidal (shallow)	27	13
Sub-22	York Bay	Subtidal (shallow)	41	15
Sub-23	York Bay	Subtidal (shallow)	87	22
Sub-24	York Bay	Subtidal (shallow)	22	14
Sub-25	Mahina Bay	Subtidal (shallow)	40	12
Sub-26	Mahina Bay	Subtidal (shallow)	76	22
Sub-27	Mahina Bay	Subtidal (shallow)	21	14
Sub-28	Mahina Bay	Subtidal (shallow)	55	17
Sub-29	Days Bay	Subtidal (shallow)	18	10
Sub-30	Days Bay	Subtidal (shallow)	25	8
Sub-31	Days Bay	Subtidal (shallow)	22	11
Sub-32	Days Bay	Subtidal (shallow)	15	9
Sub-33	Point Howard	Subtidal (nearshore)	8	3
Sub-34	Point Howard	Subtidal (nearshore)	7	5
Sub-35	Sorrento Bay	Subtidal (nearshore)	29	6
Sub-36	Lowry Bay	Subtidal (nearshore)	22	5
Sub-37	Lowry Bay	Subtidal (nearshore)	28	10
Sub-38	Lowry Bay	Subtidal (nearshore)	16	8
Sub-39	Lowry Bay	Subtidal (nearshore)	37	9
Sub-40	Lowry Bay	Subtidal (nearshore)	6	3
Sub-41	Lowry Bay	Subtidal (nearshore)	42	8
Sub-42	Lowry Bay	Subtidal (nearshore)	61	9
Sub-43	Lowry Bay	Subtidal (nearshore)	66	12
Sub-44	Lowry Bay	Subtidal (nearshore)	103	10
Sub-45	Lowry Bay	Subtidal (nearshore)	78	9
Sub-46	York Bay	Subtidal (nearshore)	69	7
Sub-47	Days Bay	Subtidal (nearshore)	46	5
Total			**1747 individuals**	**66 taxa**