SALT ECOLOGY

Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2019/2020

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For the People
Mō ngā tāngata

SALT ECOLOGY

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Overview

As part of ongoing work monitoring and managing catchment sediment inputs to Te Awarua-o-Porirua Harbour, Greater Wellington Regional Council (GWRC) contracted Salt Ecology in late 2019 to undertake annual sediment monitoring within the harbour.

The monitoring involves measuring the depth from the sediment surface to 44 concrete plates buried at nine intertidal and nine subtidal sites, analysing sediment samples from the surface 20mm at each site to assess changes in sediment mud content, and visually assessing sediment redox status (oxygenation). In addition, on six fixed transects, the position at which soft subtidal mud transitioned to firmer sediments closer to the shoreline was recorded to provide a general guide to changes in the horizontal distance between buried subtidal plates and the landward edge of soft mud substrate.

The current report presents the results of measurements undertaken between 13-16 January 2020, and compares findings to previous monitoring results and to established or provisional estuarine health metrics ('condition ratings'). These results are interpreted in a wider context to consider harbour-wide change as part of a weight of evidence approach using data from four comprehensive bathymetric surveys undertaken to assess changes in depths throughout the harbour, and predictions from the NIWA national estuary sediment load estimator to calculate the ratio between the estimated current sedimentation rate (CSR) and the estimated natural sedimentation rate (NSR). Such predictions provide useful guidance for assessing current inputs and a cross check on the rates of change being directly measured in the estuary.

Results and Discussion

The mean annual sedimentation rate across all intertidal sites and over all years of monitoring (the period being variable due to the staged introduction of sites) shows a net sediment increase of 3.2mm/yr in the Onepoto Arm and 1.2mm/yr in the Pauatahanui Arm. These levels correspond to condition ratings of 'poor' and 'moderate' respectively.

The steady increase in sediment at the Onepoto intertidal sites from the start of the baseline is attributable largely to the deposition of coarse sediment on the Porirua Stream delta and the movement of sand across the tidally swept site O1 near the harbour entrance. From Jan 2019 to Jan 2020, intertidal sediment deposition at Pauatahanui sites increased by an average of 4.6mm, the largest mean annual increase since the baseline commenced in 2008. Associated with this increased sedimentation was a doubling of mean sediment mud content across all Pauatahanui intertidal sites from 10% to 22%. Mud content at Kakaho increased very significantly from 14% to 64% between Jan 2019 and Jan 2020. Intertidal deposition in the Pauatahanui Arm appears more commonly associated with episodic inputs of sediment from catchment sources.

Compared to baseline measurements from 2012/13, there has been an average 263% increase in intertidal mud content across all sites (from 7 to 22%) in the Pauatahanui Arm and 183% (from 5 to 13%) in the Onepoto Arm, both arms shifting overall from a 'good' to a 'moderate' rating band for this indicator.

The combined results for all subtidal sites in the Pauatahanui Arm show a net increase in subtidal sedimentation of 7mm/yr over the past 7 years (a rating of 'poor'), and net subtidal erosion of 2.5mm/yr in the Onepoto Arm (a rating of 'very good'). The latter result however is largely an artefact of the baseline monitoring commencing shortly after a significant deposition event in the Onepoto Arm in 2013.

Subtidal sites in the Pauatahanui Arm have shown large inter-annual variances. There has been little net change at the Browns Bay site (PS5), but all of the other sites have had large overall increases in sediment deposition. In the Onepoto Arm, sites have been highly variable, with a significant loss of mud between Jan 2014 and Jan 2015, followed by large increases in deposition since Jan 2016 at Titahi (OS6) and Papakowhai (OS8).

Compared to baseline measurements from 2013, there has been an average increase in subtidal mud content of 66% (from 40 to 66%) in the Pauatahanui Arm, and an increase of 69% (from 10 to 16%) in the Onepoto Arm, ratings of 'poor' and 'moderate' respectively. The highest mud contents were in the deeper settlement basin areas, with four of the five muddiest subtidal sites in the harbour located in the Pauatahanui Arm.

Measurements of the position along transect lines between buried subtidal plates and the shoreline where soft muds transition to firmer sandier sediments show significant changes between years. In 2013 each subtidal plate was positioned ~5m horizontal distance seaward from where soft mud was first encountered. Since then soft mud has extended shoreward along the transect lines by between 10m and 305m, with a corresponding large increase in the shallow subtidal area covered by mud-dominated sediments. These changes have occurred in both arms of the harbour although the largest changes have been in the Pauatahanui Arm.

Supporting work contracted by GWRC includes estuary-wide bathymetric surveys of the harbour. First undertaken in 1974, these surveys have now been repeated in 2009, 2014, and 2019 allowing net changes to be assessed in discrete time periods. For the 1974-2009 period, annual average sedimentation rates were estimated to be 9.1mm/yr in the Pauatahanui Arm, and 5.7mm/yr in the Onepoto Arm. These high rates were attributed primarily to elevated sediment inputs entering the harbour from the surrounding catchment during the 1970-1980's, which was a busy urbanisation period.

Between 2009 and 2014 the mean annual average rates of accretion were 0.4mm/yr in the Pauatahanui Arm, with 1mm/yr of erosion in the Onepoto Arm, indicating very low sediment accumulation (and some net losses). It is recognised by Porirua City Council that there was less land development during this period, with the global financial crisis (ca.2008) being a possible explanation.

Between 2014 and 2019 the mean annual average rates of accretion were 10.3mm/yr in the Pauatahanui Arm, and 8.8mm/yr in the Onepoto Arm, indicating very high sediment deposition. This period coincides with significantly increased land development including the Duck Creek subdivision and the Transmission Gully motorway project. These recent rates of deposition highlight excessive sediment inputs to the harbour and greatly exceed the recommended ANZECC Default Guideline Value (2mm/yr) indicating an increased likelihood of significant environmental damage.

The presence of excessive sediment inputs is supported by NIWAs sediment load calculator which provides predictions of natural versus current sediment ratios (a measure of how much above natural inputs 'current' inputs are). Current inputs, which are based on LCDB3 (2009) land cover and exclude any point source contributions, are ~5x higher than those under natural land cover (allowing for some trapping of sediment in wetlands). The actual ratio is expected to be significantly higher than that predicted due to increased land disturbance since 2009.

With the high deposition rates measured over the past ~5 years coinciding with significant recent increases in land disturbance, it would appear likely that the measured increase in subtidal muds is a direct consequence of catchment sediment inputs. To better understand this issue, catchment sediment sources would need to be explored through forensic methods such as compound specific stable isotope (CSSI) techniques.

In conclusion, the current sedimentation rates are elevated to a level where adverse ecological effects are likely to be occurring. Furthermore, under the current situation, it is highly unlikely that the management goals for the estuary are being met.

Recommendations

- Continue to annually monitor sediment deposition and erosion, grain size and sediment redox status at the existing intertidal and shallow subtidal sites.
- Install metal markers at each subtidal site to enable future relocation with a metal detector.
- In light of the rapid changes recorded recently, repeat estuary-wide bathymetric surveys 5-yearly.
- Consider investigating catchment sediment sources by undertaking forensic methods such as compound specific stable isotope (CSSI) studies as a complement to the sediment plate method.

1. INTRODUCTION

Fine sediment is recognised as one of the primary ecological stressors within New Zealand estuaries. This has emerged as a particular issue in Te Awarua-o-Porirua Harbour in recent years. To assess the effect of sediment and other influences on estuary health, Greater Wellington Regional Council (GWRC) have a long-term monitoring programme in place. The programme involves intertidal and subtidal broad scale habitat mapping of the spatial extent of different surface substrate types (e.g. Stevens & Robertson 2013, 2014b) and fine scale monitoring of sediment chemistry and macrofauna (e.g. Milne et al. 2008; Robertson & Stevens 2008, 2009, 2010, 2015; Oliver & Conwell 2014). These studies are undertaken ~5-yearly.

To provide a direct measure of sediment accrual and erosion within Te Awarua-o-Porirua Harbour, GWRC also undertakes annual monitoring of sedimentation rates by measuring the depth from the sediment surface to concrete pavers buried at multiple sites (Fig. 1). This work started at four sites in 2007, with the number of monitoring sites increased to a current total of 18; 9 intertidal and 9 subtidal. In addition, sediment mud content, which can change in the absence of measurable accretion or erosion, has been analysed from the surface 20mm at sediment plate sites since 2012 (e.g. Stevens & Robertson 2014a, 2015).

As part of ongoing work for monitoring and managing catchment sediment inputs to the harbour, GWRC contracted Salt Ecology in late 2019 to undertake annual monitoring of the established sediment plate sites in Te Awarua-o-Porirua Harbour (Fig. 1). The current report presents the results of measurements undertaken in January 2020 and compares findings to previous monitoring results. These results are also considered more broadly in the context of complimentary methods for assessing estuarine sedimentation and potential drivers of change.

2. METHODS

2.1 GENERAL APPROACH

Sampling methods and descriptions of the 18 existing sedimentation rate monitoring sites are provided in Robertson and Stevens (2008), Stevens and Robertson (2011, 2014b, 2015) and Stevens (2017). A brief synopsis is provided below, and a method review in Hunt (2019).

To date, 35 concrete plates (19cm x 23cm paving stones) have been buried at 9 intertidal sites, and 9 concrete plates (30cm diameter circular pavers) have been buried at 9 subtidal sites in the estuary (Fig. 1). Each plate has been placed in stable substrate 5-30cm beneath the sediment surface with sites positioned to assess the dominant sediment sources to the estuary. These include discharges of bed-load and suspended sediment from the various streams entering the estuary, most notably Pauatahanui, Horokiri, Porirua and Kakaho Streams and Duck Creek (see Green et al. 2015).

Subtidal plates were first established in soft mud deposition zones in Jan 2013. These subtidal sites were selected by wading from the shore until firmer intertidal sediments transitioned to soft subtidal muds. The sites were positioned ~5m horizontal distance into this soft mud zone which was generally ~1-1.5m below the mean low water mark.

The position of each plate has been recorded using a handheld Trimble GeoXH differential GPS (post-processing accuracy ±10cm). Each intertidal plate is relocated using marker pegs and a tape measure, while subtidal plates are relocated using GPS navigation combined with a probe. Care is taken not to disturb sediment overlying plates when they are located.

In 2018, the intertidal sediment plate at Site 11 (Browns Bay) was discontinued as mobile sand and shell deposits were contributing to variable and unrepresentative measures of sediment deposition.

Sedimentation rate

To measure intertidal sediment depth in 2020, a 2.5m straight edge was placed over each plate position to average out any small-scale irregularities in surface topography. The depth to each buried plate was then measured in triplicate by vertically inserting a measuring probe into the sediment until the plate was located. Depth was measured with a ruler to the nearest mm.

Measuring intertidal plates using a straight edge to average out any small-scale irregularities in surface topography

The height of wooden pegs marking the site location provides an additional check on sediment changes, although due to water current scouring around their base, these measures are not incorporated in calculations of sedimentation rates.

Subtidal plate depths were measured using a custom built frame (see photo). The frame comprises a vertical tube fixed at 90° to a horizontal cross piece. The frame was positioned ~5cm above the relocated plate and allowed to settle onto the surface sediment. A measuring rod was then pushed down through the vertical tube to the underlying plate. Sediment depth is the distance between the base of the frame and the buried plate. This was measured above the water surface using marked increments on the measuring rod and the top of the vertical tube. To collect three replicate measures at each plate, the frame was repositioned twice more by carefully lifting, rotating 30° clockwise, and allowing it to resettle.

Subtidal plate measuring frame

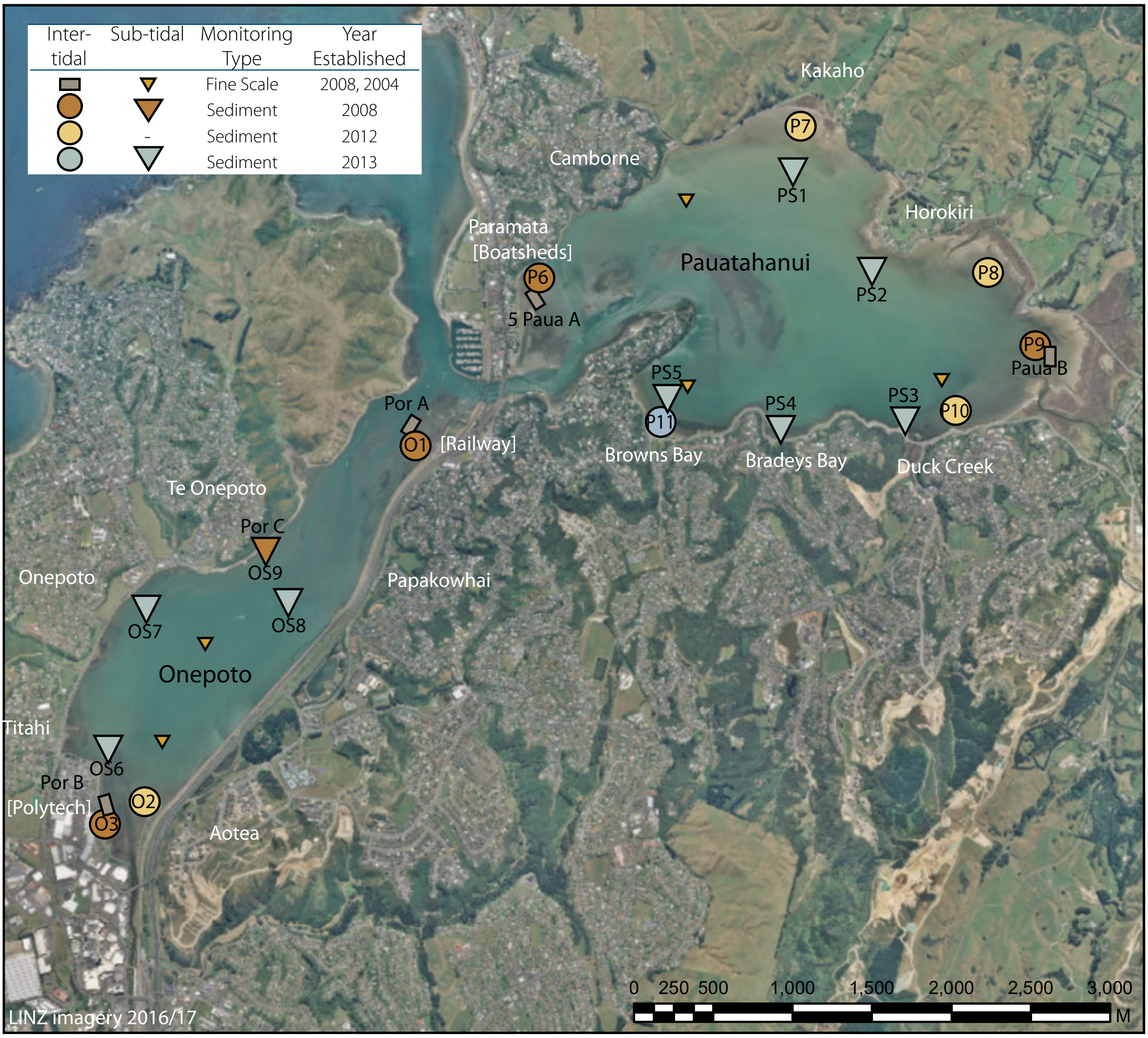


Fig. 1. Location of the 18 buried sediment plate sites (indicated by the alphanumeric sequence on the map) in Te Awarua-o-Porirua Harbour. Also shown are the location of 4 intertidal fine scale sites (rectangles) and 5 subtidal fine scale sites (small triangles) at which monitoring is undertaken ~5-yearly.

Using GPS and probe to locate subtidal site OS7

In 2017, transect lines were established between six of the subtidal plates (S1, S2, S3, S4, S5 and S6) and the shoreline, and the distance along the transect where the soft subtidal mud transitioned to firmer sediments closer to the shoreline was measured (Fig. 1, Appendix 1). This field component was added when it was observed that the subtidal soft mud zone was migrating toward the shore, i.e. the apparent spatial extent of muddy sediment was increasing. Although a subjective measure, it provides a general guide to changes in the horizontal distance between the buried subtidal plates and the landward edge of the soft mud substrate.

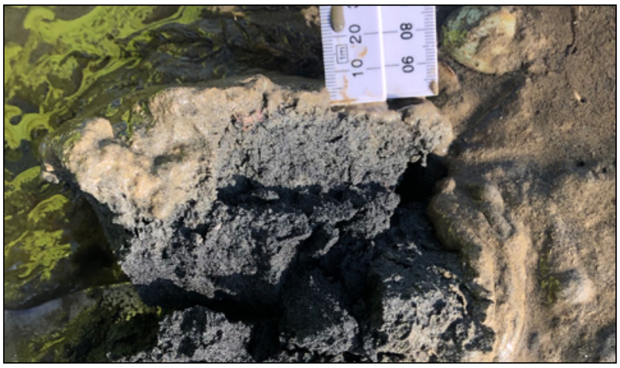
Sediment grain size

Sediment grain size indicates the relative proportion of fine-grained sediments that have accumulated within estuary sediments. In general terms, increasing mud causes a change in sediment animal communities, with sensitive species like pipi preferring low (<10%) mud environments, and communities becoming dominated by mud-tolerant organisms when mud contents exceed ~25%. Increased sediment mud content is also directly related to decreased water clarity, and correlates with reduced sediment oxygenation due to limited diffusion among the tightly packed mud matrix.

To monitor changes in the mud content of sediments, a single composite sample of the top 20mm of sediment was collected adjacent to each sediment plate site. Samples were analysed for grain size (% mud, sand, gravel). Triplicate sampling in 2013 found no appreciable within-site variance therefore single composite analyses were considered appropriate for ongoing annual monitoring.

Sediment oxygenation

The apparent redox potential discontinuity (aRPD) layer is a subjective measure of the enrichment state of sediments according to the depth of visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). It provides an easily measured, time integrated, and relatively stable measure of sediment oxygenation conditions. In the 2020 survey, the aRPD depth was measured to the nearest mm at each plate site by splitting a sediment core or grab vertically with a hand trowel.



Example of a shallow oxygenated surface sediment (aRPD 5mm) overlying poorly oxygenated sands

2.2 DATA RECORDING, QA/QC AND ANALYSIS

All measurements were recorded on waterproof paper in the field and entered electronically in Excel templates with pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) to ensure that the risk of erroneous data recording was minimised. In 2020, all sediment samples were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors.

The focus of the analysis is on changes in sediment plate depth over the last year and since monitoring began. However, because sites are relatively few in number and are deliberately located in areas with variable settlement and retention capacities, it is not straightforward to calculate reliable harbour-wide sedimentation rates. As such, we use some other methods to consider harbour-wide change as part of a weight of evidence approach.

One of these methods was to incorporate the data from comprehensive bathymetric surveys undertaken to assess depths throughout the harbour (Gibb & Cox 2009, Cox 2014, Waller 2019). Bathymetric surveys are a very good method for assessing broad scale temporal and spatial changes. The large number of sample points provide a high overall average accuracy despite method constraints in the vertical accuracy of individual measurements (see above reports for details). As such they provide a reliable way of assessing estuary-wide rates of net sediment accrual or erosion.

In addition to these direct measurement approaches, NIWA have developed a national estuary sediment load estimator (Hicks et al. 2019) which provides predictions of catchment sediment input and sediment retention within most New Zealand estuaries. These predictions can be used to calculate a theoretical net annual estuary-wide sediment deposition rate (mm/yr), as well as to calculate the ratio between the estimated current sedimentation rate (CSR) and the estimated natural sedimentation rate (NSR). Such predictions provide useful thresholds for assessing current inputs and a cross check on the rates of change being directly measured in the estuary.

2.3 ASSESSMENT OF ESTUARY CONDITION

In addition to our expert interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas. These metrics assign different indicators to one of four 'health status' bands, colour-coded as shown in Table 1. The thresholds used in the current report were derived primarily from the New Zealand Estuary Trophic Index (ETI) (Robertson et al. 2016b).The ETI includes site-specific thresholds for mud content (grain size), the ratio between the current sedimentation rate (CSR) and the estimated natural sedimentation rate (NSR), and aRPD depth. We adopted those thresholds for present purposes, except: (i) for %mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016b); (ii) for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012); and (iii) < and ≥ values were applied to CSR and NSR criteria in the ETI.

In addition to these, Townsend and Lohrer (2015) propose a recommended ANZECC Default Guideline Value (DGV) for estuary sedimentation of 2mm/year above natural deposition rates, background rates, conservatively assumed to be 0mm/yr where unknown. The 2mm/yr value has been used as the threshold between the 'moderate' and 'poor' bands in Table 1 on the basis that exceeding the DGV is expected to result in an increased likelihood of adverse ecological effects.

As the scoring categories in Table 1 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the health categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

Table 1. Condition ratings used to characterise estuarine health for key indicators.

Indicator	Unit	Very Good	Good	Moderate	Poor
Sedimentation Rate[1]	mm/yr	<0.5	0.5-1	>1-2	>2
Mud content	%	≤ 5	5 to ≤ 10	10 to ≤ 25	≥ 25
aRPD	mm	≥ 50	20 to ≤ 50	10 to ≤ 20	≤ 10
CSR : NSR ratio[2]	ratio	1 to <1.1 x NSR	≥1.1 to <2 x NSR	≥2 to <5 x NSR	≥5 x NSR

[1]Above natural deposition rate, assumed to be 0mm/yr where unknown

[2]CSR=current sedimentation rate, NSR=natural sedimentation rate (100% native forest cover)

Measuring sediment depth at site OS9

3. RESULTS

3.1 SEDIMENTATION

The sedimentation plates in Te Awarua-o-Porirua Harbour were measured between 13-16 January 2020 with results summarised in Table 2 and Figs 2, 3 and 4. Raw data are presented in Appendix 2.

The mean annual intertidal sedimentation rate across all intertidal sites and over all years of monitoring (the period being variable due to the staged introduction of sites) shows a net sediment increase of 3.2mm/yr in the Onepoto Arm and 1.2mm/yr in the Pauatahanui Arm (Table 2). These levels correspond to condition ratings of 'poor' and 'moderate' respectively.

Fig. 2a shows a steady increase in sediment at the Onepoto intertidal sites since 2007, which is likely attributable to the deposition of coarse sediment on the Porirua Stream delta and the movement of sand across the tidally swept O1 site near the harbour entrance. In the Pauatahanui Arm there has been a small net increase in intertidal deposition over all sites (Table 2), but significant deposition events recorded at Kakaho (P7) in 2016/17 and 2019/20 (Fig. 2b).

In contrast with the intertidal pattern, the combined results for all subtidal sites show a net decrease in subtidal sedimentation of 2.5mm/yr in the Onepoto Arm (a rating of 'very good') and a net increase in subtidal sedimentation in the Pauatahanui Arm of 7mm/yr over the past 7 years (a rating of 'poor') (Table 2).

The Onepoto Arm subtidal plates have also been highly variable, with a significant loss of mud at two sites (OS6, OS8) from Jan 2014 and Jan 2015 (Fig. 2c), followed by large increases in deposition.

Fig. 2d shows most subtidal sites in the Pauatahanui Arm have shown large inter-annual variances and large overall increases in sediment deposition, although there has been little net change at the Browns Bay site (PS5).

Figs 3 & 4 present site-specific data of annual changes over sediment plates. Intertidal sites with multiple plates are presented as means ±SE. Although the data record is still relatively short for this type of monitoring, a trendline has been added to each plot as a tentative guide to the overall pattern of change. Where more than 5 years of data have been collected, a rolling 5-year mean is also shown to indicate the trend over the past five year period. The plots illustrate substantial within-site variability between years. The greatest intertidal variability was apparent at sites located on the stream deltas or areas of strong tidal flow (Por A, Aotea, Duck Creek, Kakaho)

Table 2. Mean change of sediment depth from previous year above buried plates (2008-2020), and cumulative mean annual change since baseline in Te Awarua-o-Porirua Harbour.

Site		No	Name	Year#	Change in mean sediment depth (mm/yr)												Mean Annual Sedimentation since baseline (mm/yr)	
					2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020		
Onepoto Arm	Intertidal	O1	Por A (FS)	2008	0.8	2.3	-4.5	-0.3	14.3	-4.3	1.5	0.5	-1.5	12.0	-0.8	-3.3	2.5	+3.2
		O2	Aotea	2012					12.3	-0.3	2.3	7.8	1.5	-0.3	6.5	3.7	4.2	
		O3	Por B (FS)	2008	7.0	0.5	2.0	0.3	4.3	1.8	2.3	5.0	5.3	1.3	2.4	-1.7	2.9	
	Subtidal	OS6	Titahi	2013						0.0	-11.0	-16.0	32.0	43.0	3.0	16.0	9.6	-2.5
		OS7	Onepoto	2013						-6.0	-92.0	-2.0	7.0	0	NM	-4.0*	-13.7	
		OS8	Papakowhai	2013						-8.0	-77.0	10.0	24.0	-2.0	2.0	20.0	-4.4	
		OS9	Te Onepoto	2008	-2.5	-2.5	0	3.0	-14.0	0.0	4.0	7.0	-3.0	1.0	-9.0	-2.0	-1.5	
Pauatahanui Arm	Intertidal	P6	Boatsheds	2008		0.5	-0.8	0.3	3.5	-2.0	-3.0	-3.5	-4.5	6.3	4.0	5.7	0.7	+1.2
		P7	Kakaho	2008					9.3	-4.0	-2.0	-5.8	17.8	-7.0	2.0	12.9	2.9	
		P8	Horokiri	2009					2.0	-2.5	1.3	0	-7.0	7.3	1.3	1.3	0.4	
		P9	Paua B (FS)	2008	2.3	3.8	0.3	-5.3	-0.8	4.5	-2.5	-5.0	0.3	-1.8	0.5	2.2	-0.1	
		P10	Duck Creek	2012					-3.0	14.8	-5.5	1.8	1.0	4.0	2.0	1.0	2.0	
	Subtidal	PS1	Kakaho	2013						6.6	2.0	8.0	64.0	-6.0	NM	-22.0*	7.5	+7.0
		PS2	Horokiri	2013						26.4	18.0	10.0	54.0	-16.0	0	-7.0	12.2	
		PS3	Duck Creek	2013						8.0	-12.0	NM	90.0	10.0	NM	-42.0*	7.7	
		PS4	Bradeys Bay	2013						11.0	-4.0	-5.0	12.0	5.0	-1.0	33.0	7.3	
		PS5	Browns Bay	2013						9.2	-10.0	-2.0	13.0	-10.0	-1.0	20	0.2	

#Calendar Year Baseline Commenced. *Change from 2018-20 (plate unable to be relocated in 2019). NM= Not Measured

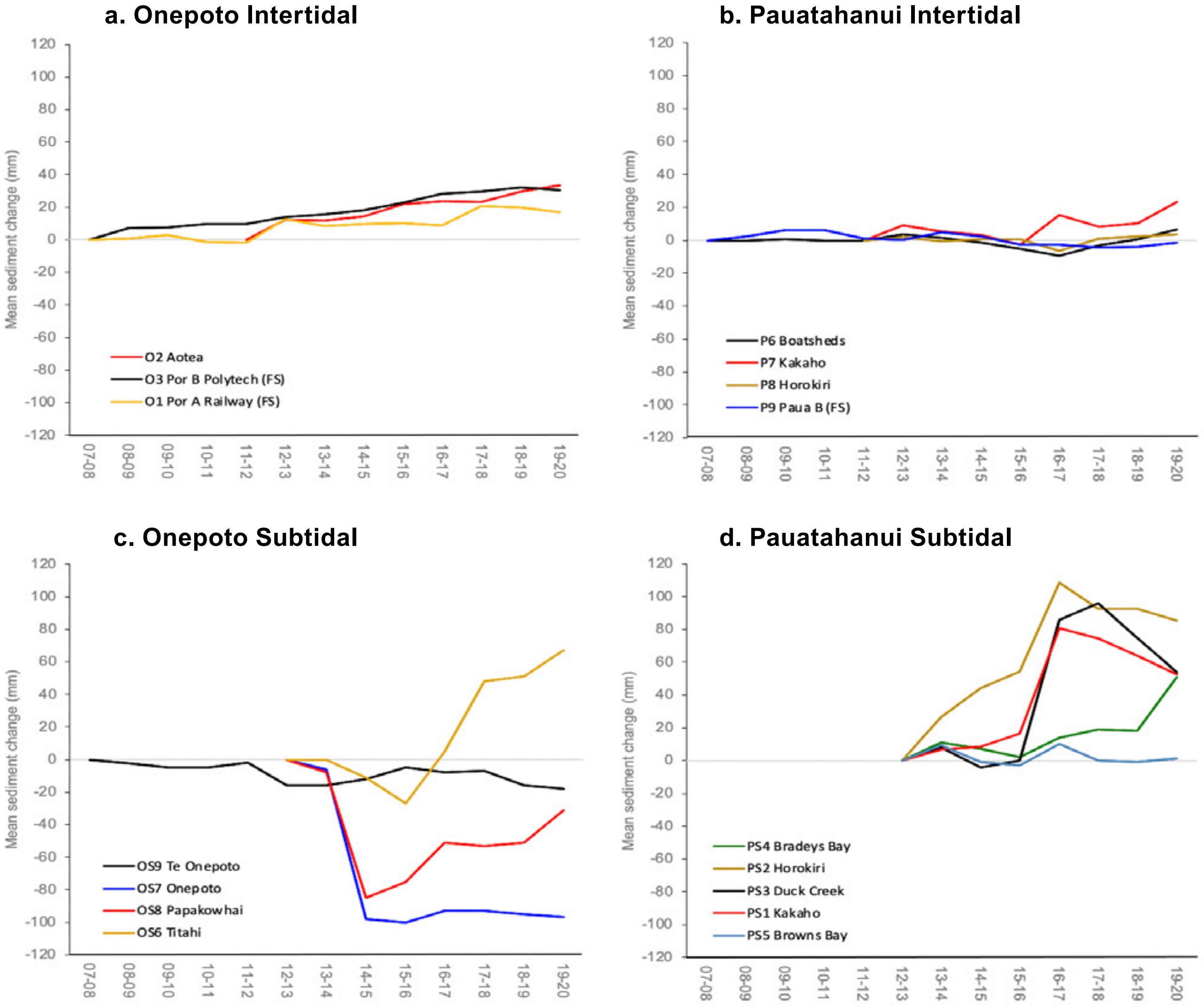


Fig. 2. Cumulative change in mean sediment level over buried plates at individual monitoring sites in Te Awarua-o-Porirua Harbour.

Table 3. Distance from subtidal plates to where soft subtidal mud transitioned to firmer sediments closer to the shoreline, 2013-2020.

Site	Subtidal Site No.	Distance from subtidal plates to edge of soft mud (m) 2013	2017	2018	2019	2020	Change from baseline (m) 2013-2020
Kakaho	PS1	5	300	150	55	310	305
Horokiri	PS2	5	65	120	80	90	85
Duck Creek	PS3	5	10	15	23	20	15
Bradeys Bay	PS4	5	15	8	5	15	10
Browns Bay	PS5	5	40	28	35	25	20
Titahi	OS6	5	45	135	52	50	45

where sediment deposition from flood events or tidal scouring has been observed. The greatest subtidal variation was evident at sites adjacent to where intertidal deposition events have been observed (e.g. Titahi, Onepoto, Kakaho, Horokiri).

Table 3 and Fig. 5 show the position along transect lines between buried subtidal plates and the shoreline where soft muds transition to firmer sandier sediments. Measurements show significant changes between years. In 2013 each subtidal plate was positioned ~5m seaward from where soft mud was first encountered. Since then soft mud has extended shoreward along the transect lines by between 10m and 305m, with a corresponding large increase in the shallow subtidal area covered by mud-dominated sediments. These changes have occurred in both arms of the harbour although the largest changes have been in the Pauatahanui Arm.

Between January 2019 and January 2020 the mud extent increased significantly (255m) at Kakaho, with small increases at Horokiri (10m) and Bradeys Bay (10m), and small decreases at Duck Creek (3m) and Browns Bay (10m). In the Onepoto Arm at Titahi, there was a very small decrease in mud extent (2m). In intertidal areas, these changes were characterised by the presence of soft mud overlying firm sand-dominated sediments (see accompanying photos).

Soft mud slurry overlying poorly oxygenated sands at Kakaho, Jan 2020

3.2 SEDIMENT GRAIN SIZE

Grain size monitoring results (Table 4, Figs 6 and 7) show that in 2020, as in previous years, most intertidal sediments had moderate mud contents (10-25%) (Fig. 6). Over the previous 12 months, all intertidal sites in the Pauatahanui Arm, and in particular Kakaho, recorded an increase in mud content. Mud content at Kakaho increased significantly from 14% to 64% between Jan 2019 and Jan 2020 (Fig 6b).

Compared to the baseline measurements from 2012/13 there has been an average increase in intertidal mud content of 263% (from 7 to 22%) in the Pauatahanui Arm and an increase of 183% (from 5 to 13%) in the Onepoto Arm (both arms shifting overall from a 'good' to a 'moderate' rating band).

Fig. 7 shows subtidal sites are either dominated by sands or dominated by muds. The lowest subtidal mud contents were recorded from the relatively well-flushed sites at Papakowhai, Te Onepoto, and Onepoto. Bradeys Bay also had a relatively low mud content. The highest mud contents were in the deeper settlement basin areas, with four of the five muddiest subtidal sites in the harbour located in the Pauatahanui Arm.

Compared to the baseline measurements from 2013 there has been an average increase in subtidal mud content of 66% (from 40 to 66%) in the Pauatahanui Arm, and an increase of 69% (from 10 to 16%) in the Onepoto Arm (ratings of 'poor' and 'moderate' respectively). There is a clear trend of increasing mud content at all sites since the start of the baseline (Figs 6 and 7).

A cockle ploughing through recently deposited surface muds at Horokiri, Jan 2020. Note the presence of the nuisance macroalgae *Gracilaria* in the top of the photo. *Gracilaria* is very tolerant of muddy and poorly oxygenated sediments and, when it becomes established in sediments, it is also very efficient at trapping muds which can facilitate rapid sediment accumulation.

3.3 SEDIMENT OXYGENATION

In 2020, the visually assessed aRPD depths (Table 4) were variable but a relationship between mud content and aRPD depth was evident, aRPD being shallower than 10mm at all sites where mud content exceeded 60% (a rating of 'poor'). The deepest aRPD depths (>50mm) were recorded from mobile sands at the two subtidal sites (OS8 and OS9) closest to the harbour entrance (a rating of 'very good'). At intertidal sites, aRPD depth ranged from 5mm to 30mm ('poor' to 'good' - Table 4).

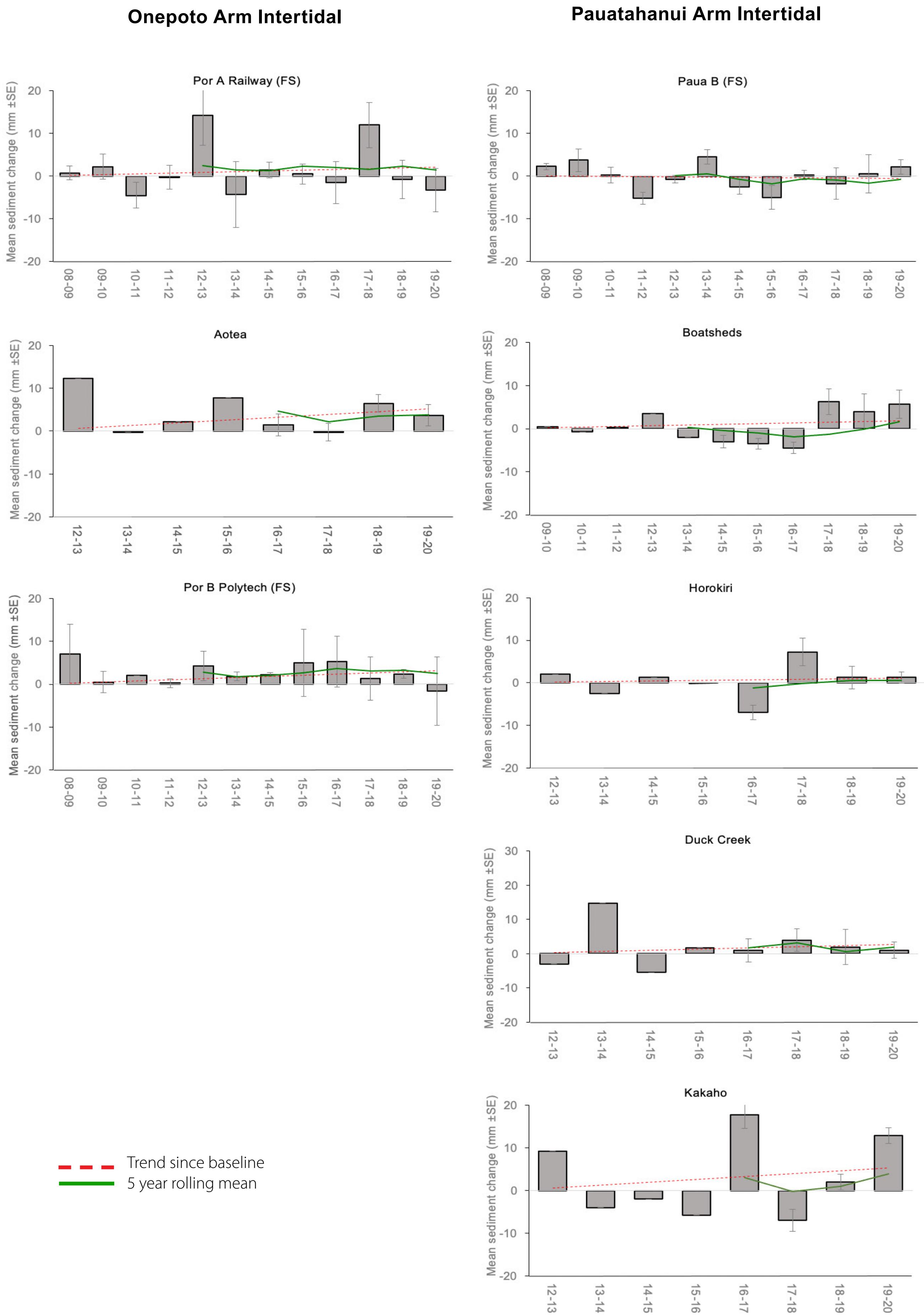


Fig. 3. Mean change compared to previous year in intertidal sediment height (mm/yr ±SE) over buried plates at individual monitoring sites in Te Awarua-o-Porirua Harbour.

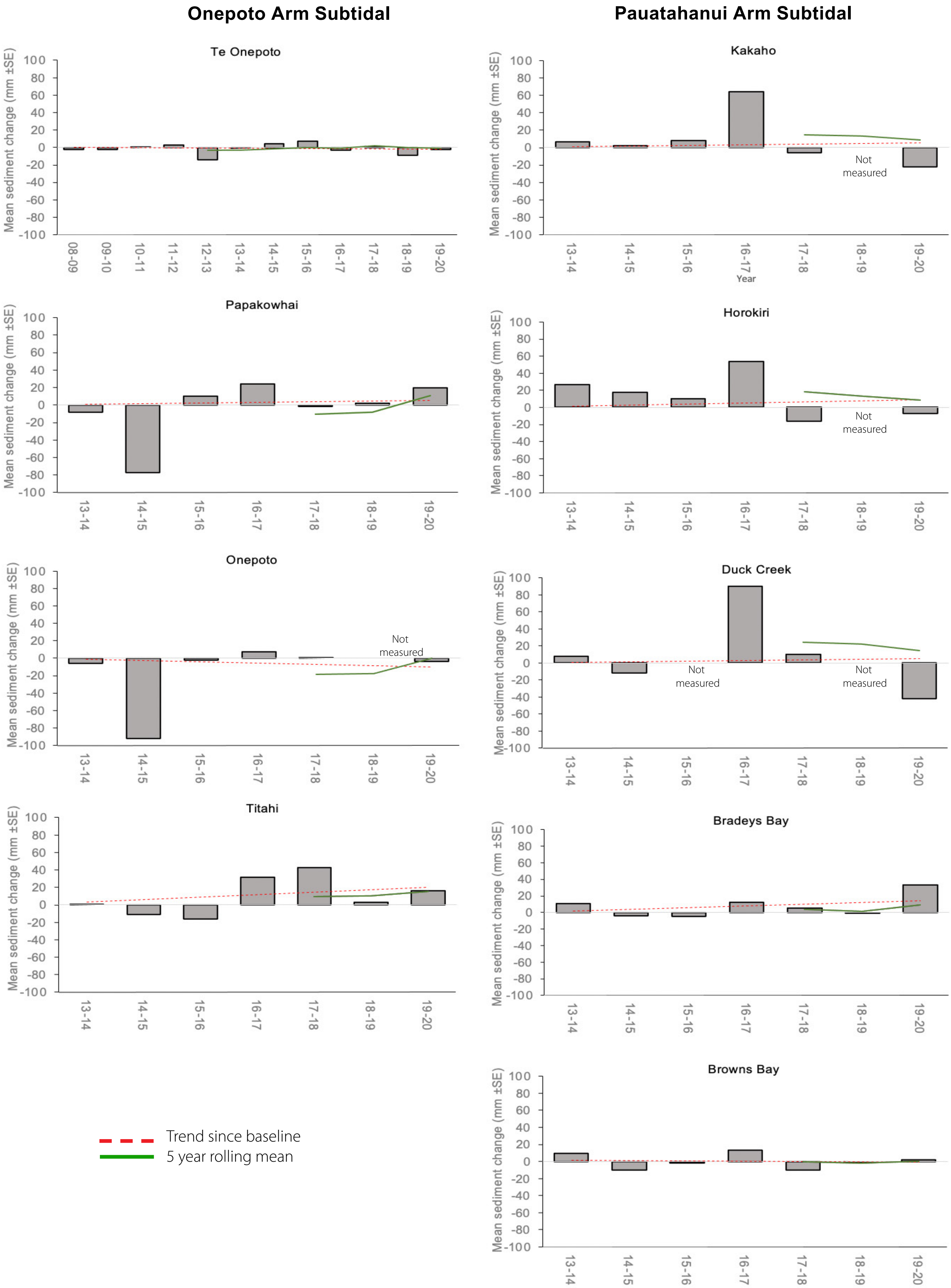


Fig. 4. Mean change compared to previous year in subtidal sediment height (mm/yr) over buried plates at individual monitoring sites in Te Awarua-o-Porirua Harbour.

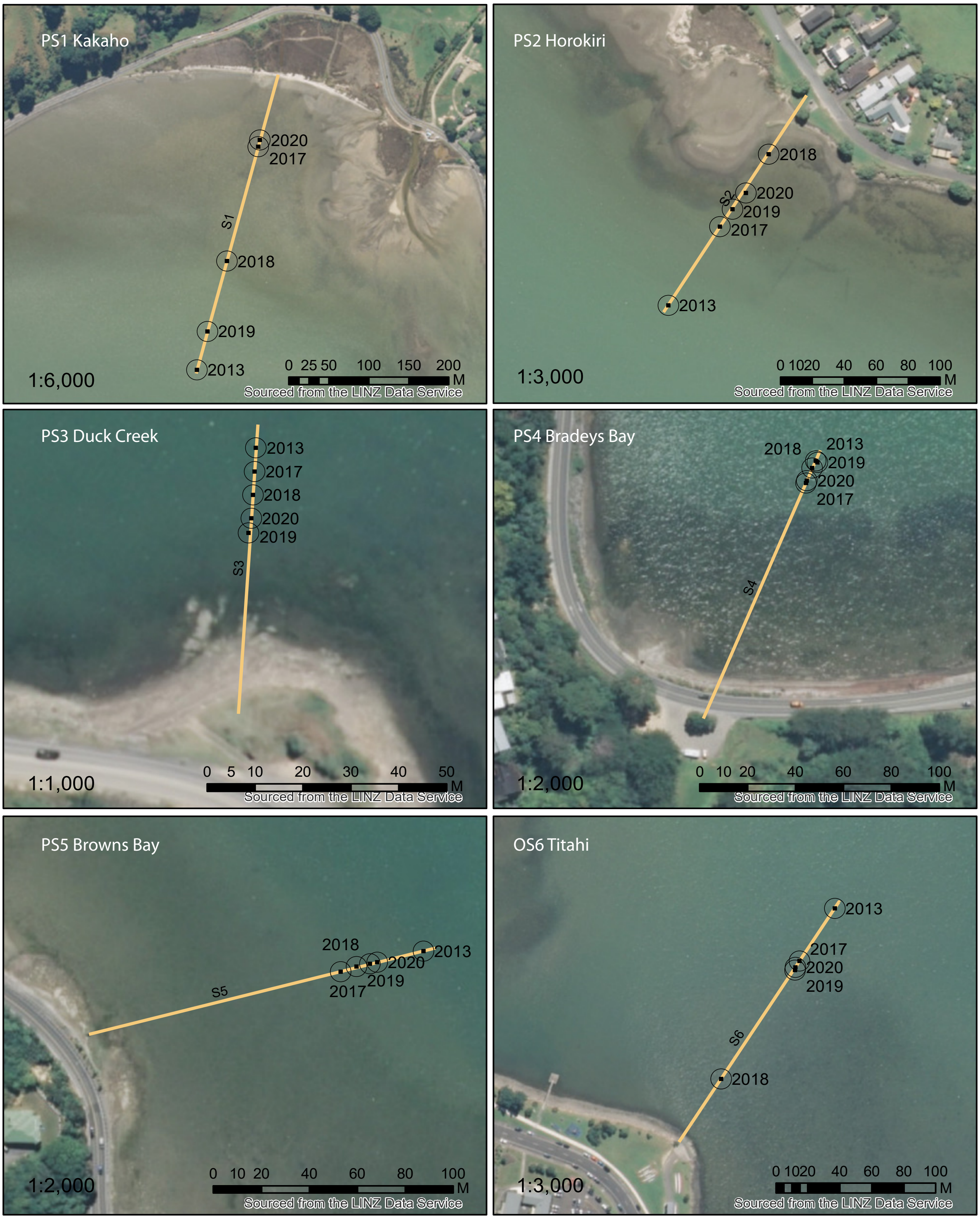


Fig. 5. Transects showing the distance from subtidal plates to where soft subtidal mud transitioned to firmer sediments closer to the shoreline (2013, 2017, 2018, 2019 and 2020).

See Table 3 for specific measures and Appendix 1 for site coordinates. Base imagery sourced from LINZ (2016/17).

Table 4. Sediment grain size and aRPD depth results, Te Awarua-o-Porirua Harbour, January 2020.

Site		No	Name	aRPD depth (mm)	Site Mean % Gravel g/100g dry weight	Site Mean % Sand g/100g dry weight	Site Mean % Mud g/100g dry weight
Onepoto Arm	Intertidal	O1	Por A Railway (FS)	8	0.9	88.1	11.0
		O2	Aotea	25	1.2	84.4	14.5
		O3	Por B Polytech (FS)	11	2.3	83.6	14.1
	Subtidal	OS6	Titahi	5	4	29.2	66.8
		OS7	Onepoto	15	0.4	86.9	12.6
		OS8	Papakowhai	>50	< 0.1	83.5	16.4
		OS9	Te Onepoto	>50	1.7	80.8	17.5
Pauatahanui Arm	Intertidal	P5	Paua A (FS)	15	2.5	84.8	12.7
		P6	Boatsheds	9	8.3	76.8	14.9
		P7	Kakaho	7	1.1	35.3	63.5
		P8	Horokiri	5	3.6	75.7	20.6
		P9	Paua B (FS)	5	1.3	79.0	19.7
		P10	Duck Creek	30	< 0.1	92.5	7.5
		P11	Browns Bay	10	1.3	86.7	12.0
	Subtidal	PS1	Kakaho	5	< 0.1	11.9	88.1
		PS2	Horokiri	4	0.2	21.3	78.5
		PS3	Duck Creek	2	0.5	29.8	69.7
		PS4	Bradeys Bay	10	0.6	70.8	28.7
		PS5	Browns Bay	10	0.9	35.4	63.7

Note: Grain size and aRPD are based on a single composite sample comprising 4 sub-samples collected from each site.

Ratings (refer Table 1 for details):

Very Good	Good	Moderate	Poor

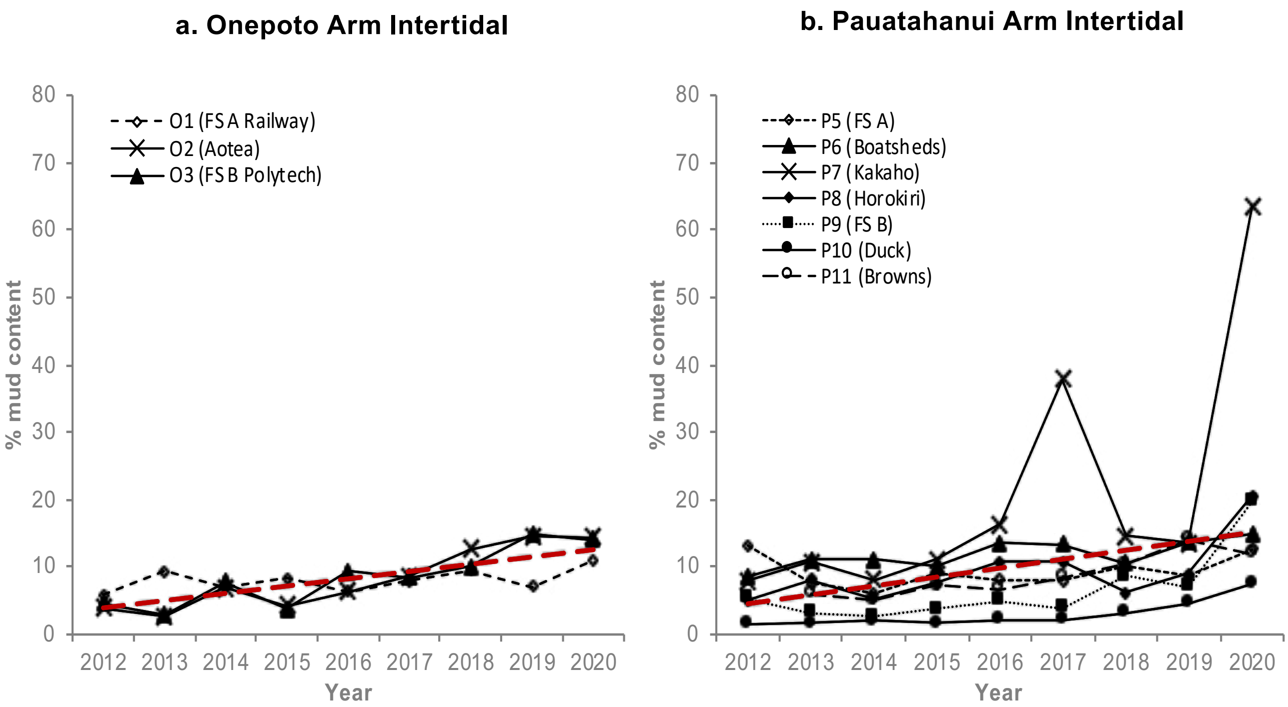


Fig. 6. Change and trend in mean sediment mud content for intertidal sites in the Pauatahanui and Onepoto arms of Te Awarua-o-Porirua Harbour.

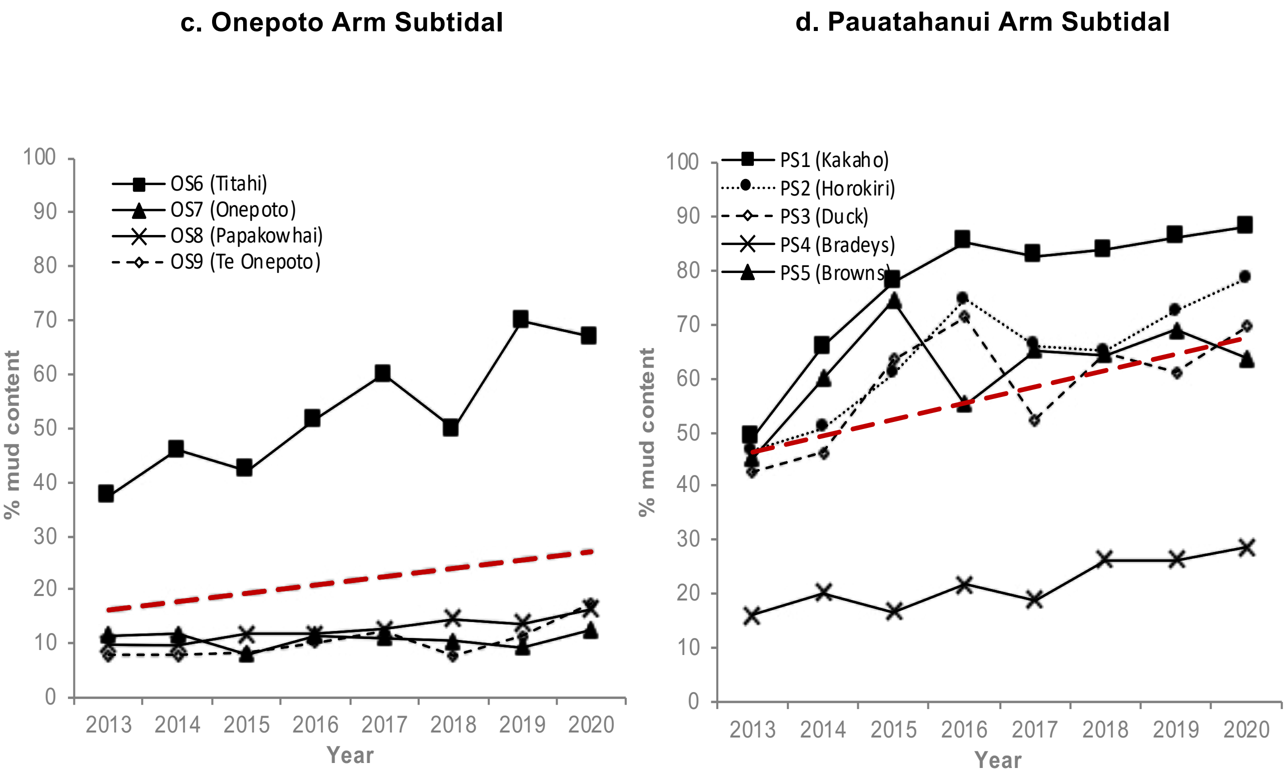


Fig. 7. Change and trend in mean sediment mud content for subtidal sites in the Pauatahanui and Onepoto arms of Te Awarua-o-Porirua Harbour.

4. SYNTHESIS AND RECOMMENDATIONS

4.1. SYNTHESIS

Monitoring from Jan 2019 to Jan 2020 showed a significant increase in sediment deposition and mud content over the previous 12 months. In the Pauatahanui Arm, sediment deposition at intertidal sites increased by an average of 4.6mm (a rating of 'poor'), the largest mean annual increase since the baseline commenced in 2008. Associated with this increased sedimentation was a doubling of mean sediment mud content across all Pauatahanui intertidal sites from 10% to 22%.

The largest specific change was evident at Kakaho (P7) where 13mm of sediment deposition was recorded over the plates, and mud content increased from 14 to 64%. Similar changes, albeit less pronounced, were evident near the Pauatahanui Stream mouth site. These measured changes were consistent with our field observations of a slurry of mud (~10-20mm thick) that was widespread on the intertidal flats in these locations in Jan 2020 (see photo below, and on page 7).

Previous results and field observations highlight that event-related deposition (e.g. pulsed deposits from stream inputs during storms) is relatively common in Te Awarua-o-Porirua Harbour, with fine sediments being re-mobilised by wind generated waves and tidal streams, and washed from intertidal areas into subtidal zones. At the time the Jan 2020 measurements were made, sediment deposits had partially eroded thus measurements will not fully reflect the overall significance of the initial inputs.

5-10mm deep deposits of partially eroded muds on cockle beds near Pauatahanui Stream, Jan 2020

Although not directly assessed, the degree of intertidal sediment accrual following significant episodic events such as these is likely to smother and kill many of the sediment dwelling animals present, and create localised conditions with high sediment mud contents and poor oxygenation.

Sediment accrual also appeared to have increased in the subtidal zones in Pauatahanui from Jan 2019 to Jan 2020. Deposition rates could not be calculated at two sites, Kakaho (PS1) and Duck (PS3) as plates were unable to be relocated in 2019, but an average increase in deposition of 9mm was recorded from the other subtidal sites from 2019 to 2020 (a rating of 'poor'). The mean sediment mud content (for all sites) increased slightly from 63 to 66% from 2019 to 2020, remaining well above the >25% threshold rating for 'poor'. These sediment plate results and field observations are consistent with transect data that show a significant shoreward expansion of subtidal soft mud in the Pauatahanui Arm over the past 12 months.

In contrast, the Onepoto Arm showed little recent change in intertidal sediment deposition; 0.4mm of sediment erosion (a rating of 'very good'), or mud content; up from 12 to 13% (a rating of 'moderate'). Larger changes were evident at subtidal Onepoto sites; 7mm average deposition (a rating of 'poor'), and mud content; up from 26 to 28% (a rating of 'moderate').

Looking at longer term trends, the mean annual sedimentation rate across all sites and over all years of monitoring shows a net increase of intertidal sediment of 3.2mm/yr in the Onepoto Arm and 1.2mm/yr in the Pauatahanui Arm. The combined results for all subtidal sites show a net increase in subtidal sedimentation of 7mm/yr in the Pauatahanui Arm and a net decrease of 2.5mm/yr in the Onepoto Arm.

The high mean annual deposition measured since the baseline commenced at subtidal sites PS1, PS2, PS3, PS4 and OS6 (Kakaho, Horokiri, Duck Creek, Bradeys and Titahi) highlight that the subtidal basins (the primary deposition zones in the estuary) have been infilling relatively rapidly. Combined with a harbour-wide trend of increasing sediment mud content (Figs 6 and 7), and with sediment oxygenation limited to the surface 10mm of sediments when mud content exceeded 60%, these results highlight a progressive decline in sediment quality since the baseline was established.

It is also important to note that the long term net subtidal erosion rate currently evident in the Onepoto Arm is largely an artefact of the 2013 baseline monitoring commencing shortly after a significant deposition event. Had sediment plates been installed a year earlier, a large increase (in the order of

100mm) would have been measured over the first year of monitoring highlighting significant degradation of the harbour. Instead, erosion of the material shows a trend of significant improvement over the monitored period, in particular the large loss of mud from the estuary between Jan 2014 and Jan 2015. Although net erosion and export of mud from this arm is a positive trend and highlights that the estuary has the capacity to cleanse itself if sediment sources are managed effectively, the more recent data show significant sediment accrual is ongoing.

While the combined results described above summarise general trends, it is important to note that averaging data across sites carries a risk of obscuring important results that may be evident with a more nuanced analysis. This is clearly the case in the Onepoto Arm where the patterns of increase at sites OS6 and OS8 are very similar (see Fig. 2c), but the mechanisms of change are different at each site. Site OS6 is located within the relatively deep central basin of the estuary where mud-dominated sediments tend to readily settle and accumulate. There has been a 94mm increase in measured deposition since 2016, and the mud content is very high (67%). This reflects significant degradation of the harbour. In contrast, OS8 is located in the lower Onepoto Arm in an area subjected to strong tidal currents and dominated by mobile sandy sediments. The 44mm increase in sediment deposition since 2016 is attributable primarily to the movement of mobile sands across the site, and the mud content is relatively low (16%). This reflects natural sediment migration and is likely to result in significantly fewer adverse ecological impacts than associated with the high deposition of muds at OS6.

Overall, the monitored changes, particularly those in the Pautahanui Arm, indicate estuary quality has declined over time. The trend of increasing mud content, an expanding spatial boundary of soft mud compared to baseline measurements, and a net trend of increasing deposition, serve a clear message that there are excessive sediment inputs to the estuary.

These findings are also evident in estuary-wide bathymetric surveys of the harbour that GWRC have commissioned. First undertaken in 1974, repeat surveys have now been undertaken in 2009, 2014, and 2019 allowing net changes to be assessed in discrete temporal blocks. For the 1974-2009 period, annual average sedimentation rates were estimated to be 9.1mm/yr in the Pauatahanui Arm, and 5.7mm/yr in the Onepoto Arm. These high rates were attributed primarily to elevated sediment inputs entering the harbour from the surrounding catchment during the 1970-1980's, which was a busy urbanisation period (Gibb & Cox, 2009).

Between 2009 and 2014 the mean annual average rates of accretion were 0.4mm/yr in the Pauatahanui Arm, and 1mm/yr of erosion in the Onepoto Arm (calculated from data in Waller 2019), indicating very low sediment accumulation (and some net losses). It is recognised by Porirua City Council that there was less land development during this period, with the global financial crisis (ca.2008) being a possible explanation.

Between 2014 and 2019 the mean annual average rates of accretion were 10.3mm/yr in the Pauatahanui Arm, and 8.8mm/yr in the Onepoto Arm (calculated from data in Waller 2019), indicating very high accretion. This period coincides with significantly increased land development including the Duck Creek subdivision and the Transmission Gully motorway project. These recent rates of deposition greatly exceed the recommended ANZECC Default Guideline Value (2mm/yr) and highlight rapid and excessive sediment inputs to the harbour.

Although there are multiple caveats on the accuracy of sediment rate estimates (see Hicks et al. 2019), the current sediment rate predicted by NIWA's sediment load calculator for the estuary (under LCDB3 (2009) land use) is a relatively low 1.8mm/yr. This is similar to the measured values between the period of reduced catchment land disturbance from 2009 to 2014.

With the current high rates of measured deposition coinciding with significant recent increases in land disturbance, it would appear likely that the measured increase in subtidal muds is a direct consequence of catchment sediment inputs. To better understand this issue, catchment sediment sources would need to be explored through forensic methods such as compound specific stable isotope (CSSI) techniques, e.g. Gibbs and Woodward (2018).

With regard to predicted natural versus current sediment ratios, application of NIWAs sediment load calculator provides a CSR/NSR ratio of 2.5 (a rating of 'moderate'), which probably underestimates the true extent of current sedimentation. This is because the estimates:

- are based on LCDB3 (2009) land cover,
- exclude any point source contributions from recent land disturbance, and
- do not make any allowance for likely sediment trapping in wetland and salt marsh areas under a natural state.

As the latter were historically extensive in the catchment and are very efficient at trapping fine sediment, it is reasonable to apply a wetland attenuation value of 50% to the predicted natural sediment inputs. This increases the CSR/NSR ratio to ~5.0, giving a rating on the threshold between 'moderate' and 'poor'.

In conclusion, the current sedimentation rates are elevated to a level where adverse ecological effects are likely to be occurring. Furthermore, under the current situation, it is highly unlikely that the management goals for the estuary are being met. These goals include interim and long term targets prepared and approved by the joint councils (Porirua City Council, Wellington City Council and Greater Wellington Regional Council), Te Runanga Toa Rangatira and other key agencies with interests in Te Awarua-o-Porirua and catchment, as follows:

- Interim – Reduce 2012 sediment inputs from tributary streams by 50% by 2021.
- Long-term – Reduce sediment accumulation rate in the harbour to 1mm per year by 2031 (averaged over whole harbour).

Clearly there is a need for more effective catchment management than is currently evident.

4.2 RECOMMENDATIONS

The 2020 monitoring results reinforce previous recommendations to manage fine sediment inputs to the estuary, in particular limiting catchment sediment inputs to more natural levels to minimise excessive estuary infilling and improve harbour water clarity. It is recommended that monitoring continue as outlined below:

- Because sediment plate monitoring provides an important check on annual changes occurring between the less frequent and relatively expensive bathymetric surveys (5+ years), it is recommended that plates continue to be monitored annually to assess sediment deposition and erosion, with aRPD depth and grain size also measured at the existing intertidal and shallow subtidal sites.

- Over the past three years of monitoring it has become increasingly difficult to relocate subtidal plates using the current methods. This is due in part to the increased deposition of muds at the sites, as well as the increased spread of muds in general. It is therefore recommended that metal markers be installed at each site to enable relocation with a metal detector.

- In light of the rapid changes recorded recently, repeat estuary-wide bathymetric surveys 5-yearly.

- Consider investigating catchment sediment sources by undertaking forensic methods such as compound specific stable isotope (CSSI) sediment studies as a complement to the sediment plate method.

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APPENDIX 1. SUBTIDAL TRANSECT LOCATIONS AND COORDINATES

Coordinates of transect lines used to record the annual movement in the soft mud boundary.

Site	Transect Start (subtidal plate)		Subtidal	Transect End (estuary edge)		Bearing (start to end)
	NZTM EAST	NZTM NORTH	Site No.	NZTM EAST	NZTM NORTH	Degrees True
Kakaho	1758810.9	5449470.5	PS1	1758914.3	5449854.4	15°
Horokiri	1759325.4	5448867.9	PS2	1759414.7	5449007.3	33°
Duck Creek	1759529.0	5447896.3	PS3	1759525.0	5447834.0	184°
Bradeys Bay	1758763.2	5447865.0	PS4	1758714.4	5447750.9	203°
Browns Bay	1758040.6	5448015.1	PS5	1757895.4	5447978.1	256°
Titahi	1755704.1	5446797.6	OS6	1754480.9	5445709.7	213°

APPENDIX 2. ANALYTICAL METHODS AND RESULTS FOR SEDIMENTS

Hill Laboratories
TRIED, TESTED AND TRUSTED

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Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	2306313
Contact:	Leigh Stevens	**Date Received:**	17-Jan-2020
	C/- Salt Ecology Limited	**Date Reported:**	28-Feb-2020
	21 Mount Vernon Place	**Quote No:**	96904
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	GWRC- Porirua Harbour
		Submitted By:	Leigh Stevens

Sample Type: Sediment

Sample Name:		ONEP-WELL AX 14-Jan-2020	ONEP-WELL AY 14-Jan-2020	ONEP-WELL AZ 14-Jan-2020	ONEP-WELL BX 15-Jan-2020	ONEP-WELL BY 15-Jan-2020
Lab Number:		2306313.1	2306313.2	2306313.3	2306313.4	2306313.5
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	68	68	67	74	74
Total Recoverable Phosphorus	mg/kg dry wt	410	420	390	240	270
Total Nitrogen*	g/100g dry wt	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Total Organic Carbon*	g/100g dry wt	0.34	0.28	0.29	0.42	0.33
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	5.7	5.7	5.2	3.4	3.5
Total Recoverable Cadmium	mg/kg dry wt	0.029	0.033	0.025	0.062	0.057
Total Recoverable Chromium	mg/kg dry wt	11.3	10.9	10.3	7.6	8.6
Total Recoverable Copper	mg/kg dry wt	4.7	4.3	4.4	7.3	7.4
Total Recoverable Lead	mg/kg dry wt	5.8	5.4	5.4	13.4	13.4
Total Recoverable Mercury	mg/kg dry wt	< 0.02	< 0.02	< 0.02	< 0.02	0.02
Total Recoverable Nickel	mg/kg dry wt	8.8	8.3	8.3	6.3	17.9
Total Recoverable Zinc	mg/kg dry wt	48	47	44	132	134
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.6	0.7	1.3	1.3	1.6
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	87.5	87.8	89.1	85.3	83.9
Fraction < 63 µm*	g/100g dry wt	11.9	11.5	9.7	13.4	14.5

Sample Name:		ONEP-WELL BZ 15-Jan-2020	PAUA-WELL AX 13-Jan-2020	PAUA-WELL AY 13-Jan-2020	PAUA-WELL AZ 13-Jan-2020	PAUA-WELL BX 14-Jan-2020
Lab Number:		2306313.6	2306313.7	2306313.8	2306313.9	2306313.10
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	74	69	71	70	66
Total Recoverable Phosphorus	mg/kg dry wt	290	470	430	460	210
Total Nitrogen*	g/100g dry wt	< 0.05	< 0.05	< 0.05	< 0.05	0.05
Total Organic Carbon*	g/100g dry wt	0.34	0.32	0.27	0.34	0.57
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	3.8	6.9	7.1	7.5	3.0
Total Recoverable Cadmium	mg/kg dry wt	0.055	0.023	0.022	0.025	0.029
Total Recoverable Chromium	mg/kg dry wt	9.3	10.6	10.6	10.7	5.9
Total Recoverable Copper	mg/kg dry wt	7.9	5.0	4.6	4.8	4.1
Total Recoverable Lead	mg/kg dry wt	13.8	6.4	5.7	6.1	6.5
Total Recoverable Mercury	mg/kg dry wt	0.03	0.02	< 0.02	< 0.02	0.03
Total Recoverable Nickel	mg/kg dry wt	7.0	7.7	7.7	7.7	4.5
Total Recoverable Zinc	mg/kg dry wt	141	44	40	41	33

IANZ ACCREDITED LABORATORY

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked *, which are not accredited.

Sample Type: Sediment						
Sample Name:		ONEP-WELL BZ 15-Jan-2020	PAUA-WELL AX 13-Jan-2020	PAUA-WELL AY 13-Jan-2020	PAUA-WELL AZ 13-Jan-2020	PAUA-WELL BX 14-Jan-2020
Lab Number:		2306313.6	2306313.7	2306313.8	2306313.9	2306313.10
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	3.9	2.3	3.1	2.2	1.6
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	81.7	84.0	85.3	85.2	78.8
Fraction < 63 µm*	g/100g dry wt	14.4	13.8	11.6	12.6	19.6

Sample Name:		PAUA-WELL BY 14-Jan-2020	PAUA-WELL BZ 14-Jan-2020	ONEP-WELL 2 AOTEA 15-Jan-2020	PAUA-WELL 6 BOATSHEDS 13-Jan-2020	PAUA-WELL 7 KAKAHO 13-Jan-2020
Lab Number:		2306313.11	2306313.12	2306313.13	2306313.14	2306313.15
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	68	68	78	75	56
Total Recoverable Phosphorus	mg/kg dry wt	210	185	-	-	-
Total Nitrogen*	g/100g dry wt	0.05	< 0.05	-	-	-
Total Organic Carbon*	g/100g dry wt	0.50	0.47	-	-	-
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	2.9	2.8	-	-	-
Total Recoverable Cadmium	mg/kg dry wt	0.030	0.028	-	-	-
Total Recoverable Chromium	mg/kg dry wt	5.9	5.5	-	-	-
Total Recoverable Copper	mg/kg dry wt	3.7	3.6	-	-	-
Total Recoverable Lead	mg/kg dry wt	6.2	5.9	-	-	-
Total Recoverable Mercury	mg/kg dry wt	0.03	0.02	-	-	-
Total Recoverable Nickel	mg/kg dry wt	4.5	4.2	-	-	-
Total Recoverable Zinc	mg/kg dry wt	31	29	-	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	1.3	1.0	1.2	8.3	1.1
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	77.7	80.5	84.4	76.8	35.3
Fraction < 63 µm*	g/100g dry wt	21.0	18.5	14.5	14.9	63.5

Sample Name:		PAUA-WELL 8 HOROKIRI 14-Jan-2020	PAUA-WELL 10 DUCK 13-Jan-2020	PAUA-WELL 11 BROWNS 13-Jan-2020	PAUA-WELL S1 KAKAHO 13-Jan-2020	PAUA-WELL S2 HOROKIRI 13-Jan-2020
Lab Number:		2306313.16	2306313.17	2306313.18	2306313.19	2306313.20
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	70	80	83	59	57
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	3.6	< 0.1	1.3	< 0.1	0.2
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	75.7	92.5	86.7	11.9	21.3
Fraction < 63 µm*	g/100g dry wt	20.6	7.5	12.0	88.1	78.5

Sample Name:		PAUA-WELL S3 DUCK 13-Jan-2020	PAUA-WELL S4 BRADEYS 13-Jan-2020	PAUA-WELL S5 BROWNS 13-Jan-2020	ONEP-WELL S6 TITAHI 14-Jan-2020	ONEP-WELL S7 ONEPOTO 14-Jan-2020
Lab Number:		2306313.21	2306313.22	2306313.23	2306313.24	2306313.25
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	65	71	69	63	81
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.5	0.6	0.9	4.0	0.4
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	29.8	70.8	35.4	29.2	86.9
Fraction < 63 µm*	g/100g dry wt	69.7	28.7	63.7	66.8	12.6

Sample Name:		ONEP-WELL S8 PAPAKOWHAI 14-Jan-2020	ONEP-WELL S9 TE ONEPOTO 14-Jan-2020			
Lab Number:		2306313.26	2306313.27			
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	72	76	-	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	1.7	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	83.5	80.8	-	-	-
Fraction < 63 µm*	g/100g dry wt	16.4	17.5	-	-	-

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request.
Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

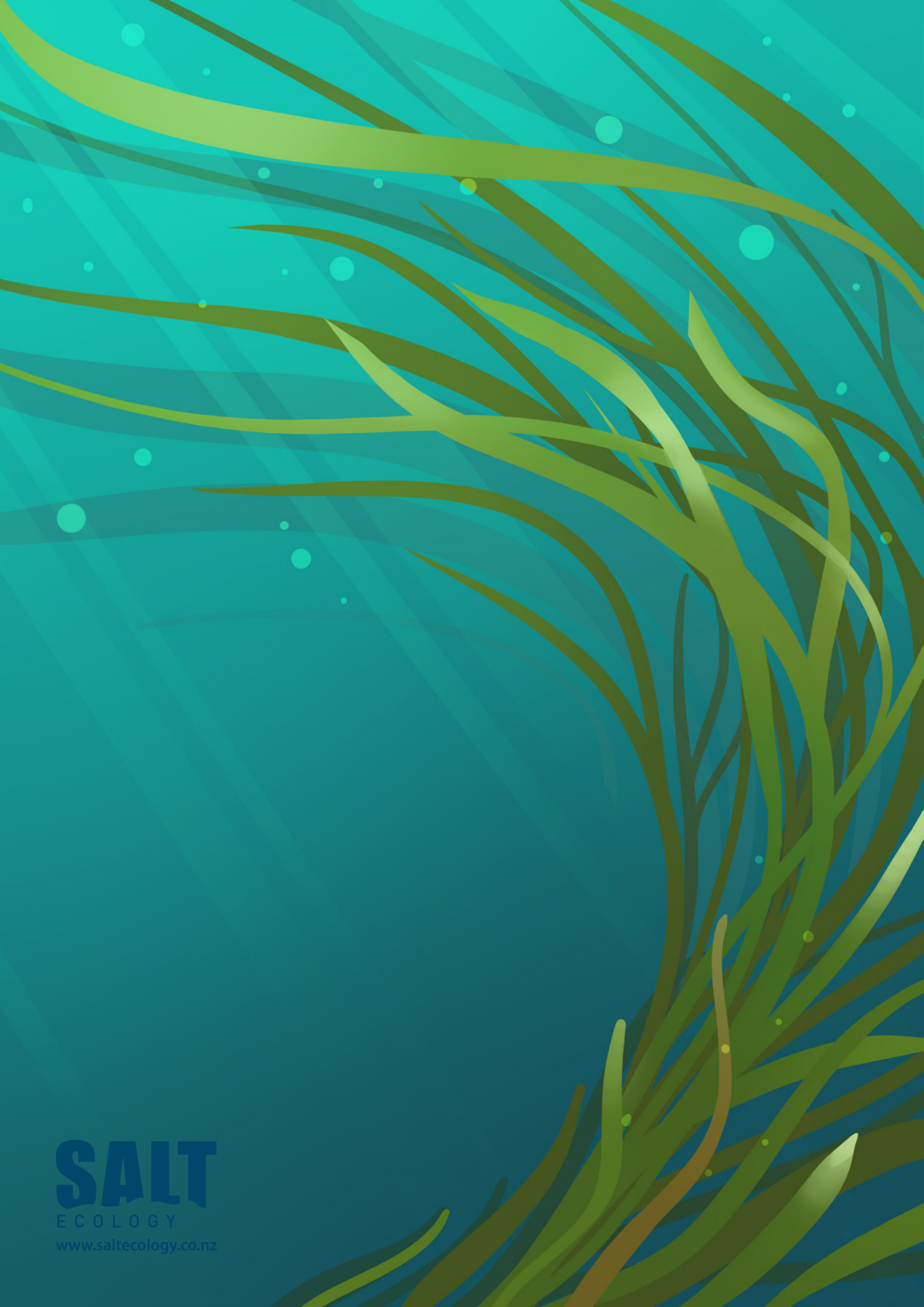
Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-12
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-12
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-27
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-12
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-12
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt	1-12
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-27
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Dates of testing are available on request. Please contact the laboratory for more information.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

Ara Heron BSc (Tech)
Client Services Manager - Environmental



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