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Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2017/2018

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Salt Ecology Report 002

ACKNOWLEDGEMENTS

Many thanks to Megan Oliver (GWRC) for her support and feedback on the draft report, Sabine O'Neill-Stevens for help with the field sampling, and Courtney Rayes for help with reporting.

Sampling the Browns Bay subtidal site S5 at sunrise.

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BACKGROUND

Fine sediment is well recognised as one of the primary ecological stressors within NZ estuaries. In order to monitor sediment inputs in Te Awarua-o-Porirua Harbour (Porirua Harbour), Greater Wellington Regional Council (GWRC), within a wider programme of long term estuary monitoring being undertaken in the region, commenced annual monitoring of sediment deposition over buried concrete plates, grain size ("muddiness"), and sediment oxygenation in December 2007.

Over subsequent years, the spatial coverage of monitoring sites has been increased and supported by a variety of related studies to better characterise the nature and extent of fine sediment impacts in the harbour.

In terms of sediment accumulation, comprehensive bathymetric surveys of the harbour have been undertaken by Gibb and Cox (2009) and Cox (2014) to characterise major seabed changes over the entire estuary. Gibb and Cox (2009) reported high annual average sedimentation rates for the 1974-2009 period of 9.1mm/yr in the Pauatahanui Arm, and 5.7mm/yr in the Onepoto Arm, the rates attributed primarily to elevated sediment inputs entering the harbour system from the surrounding catchment during the 1970-1980's, a busy urbanisation period.

The most recent bathymetric results of Cox (2014) indicate that the mean annual average rate of accretion for all harbour areas from 2009-2014 was less than 2mm per year, indicating relatively low accretion compared to the 1974-2009 period. Repeating the comprehensive bathymetric surveys in future will enable sediment deposition from ongoing land disturbance to be assessed throughout the harbour, with sediment plate data providing a direct measure of annual variation at fixed sites.

Supporting this work, broad and fine scale intertidal and subtidal monitoring of the estuary has also been undertaken (e.g. Stevens and Robertson 2013, Robertson and Stevens 2008, 2009, 2010, Milne et al. 2008, Oliver and Conwell 2014, Stevens and Robertson 2014a). Results highlight the occurrence of episodic intertidal mud deposition events (e.g. Stevens 2017), and the very muddy nature of the subtidal basins. The subtidal estuary bed comprises 59% soft muds, with mud contents averaging >60% mud (and often exceeding 80% mud) in the deeper subtidal basins. Such high mud content reflects very poor sediment conditions.

The current report presents the results of annual sedimentation rate measurements undertaken in January 2018 at 18 intertidal and shallow subtidal sedimentation rate sites established in Te Awarua-o-Porirua Harbour(Figure 1).

Sediment grain size and sediment oxygenation were also measured at all sites and ratings, developed as part of the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a,b, Table 1), were used to indicate the risk of adverse ecological impacts on the estuary and guide monitoring and management recommendations.

METHODS

Detailed descriptions of 18 existing sedimentation rate sampling sites and methods are provided in Robertson and Stevens (2008, 2009, 2010) and Stevens and Robertson (2011, 2014b, 2015). Sites were positioned in intertidal areas and subtidal deposition zones to characterise the dominant sediment sources to the estuary - identified as discharges of bed-load and suspended sediment from the various streams entering the estuary, most notably Pauatahanui, Horokiri, and Porirua Streams - see Green et al. (2015), but also including Kakaho Stream and Duck Creek. The sampling methods are briefly summarised below.

Sedimentation Rate

To measure sedimentation rate, 44 concrete plates (19cm x 23cm paving stones at intertidal sites and 30cm diameter circular pavers at subtidal sites) have been buried at a variety of locations throughout the intertidal and subtidal

Table 1. Indicator ratings used to assess the risk of adverse ecological impacts.

INDICATOR	ETI Band* / Risk	A - Very Good / Very Low	B - Good / Low	C - Moderate / Moderate	D - Poor / High
Sedimentation Rate (mm/year)		<1	1-2	>2-5	>5
Sediment Mud Content (% mud)		<5%	5-10%	>10-25%	>25%
Sediment Oxygenation (apparent RPD depth)		>2cm (visual assessment unreliable)		0.5-2cm	<0.5cm

*see Robertson et al. (2016a,b) and Appendix 3 for supporting information on indicator ratings.

reaches of the estuary (Figure 1, Appendix 1). In December 2007, 4 intertidal sites and 1 subtidal site were initially established. In January 2012, 4 additional intertidal sites (16 plates) were installed, followed by 1 intertidal and 8 subtidal plates in January 2013, and 2 intertidal plates in January 2018. Each buried plate was located in stable substrate beneath the sediment surface and its position recorded using a handheld Trimble GeoXH differential GPS (post-processing accuracy ±10cm).

Subtidal plates were positioned approximately 5m from the edge of soft mud deposition zones, located by wading from the shore until firmer sediments transitioned to soft muds. These conditions were generally encountered ~1-1.5m below the mean low water mark. Each plate is relocated without disturbing the overlying soft mud sediments using a differential GPS and a probe. For intertidal sites, a 2m straight edge is then laid across the top of the plate to determine the average sediment level, and the depth to the underlying plate is measured using a probe and ruler.

For subtidal sites, a measuring frame comprising a tube fixed to an aluminium cross piece is aligned over the relocated plate and allowed to settle. A graduated measuring rod, pushed down through the vertical tube, enables the depth of sediment overlying the buried plate to be measured above the water surface.

To account for irregular sediment surfaces, three replicate measures per plate are taken, and averaged in the field to determine the mean annual rate of sedimentation above each plate.

Fixed transect lines at sites S1, S2, S3, S4, S5, and S6 (Table 2, Figure 2, Appendix 1) have also

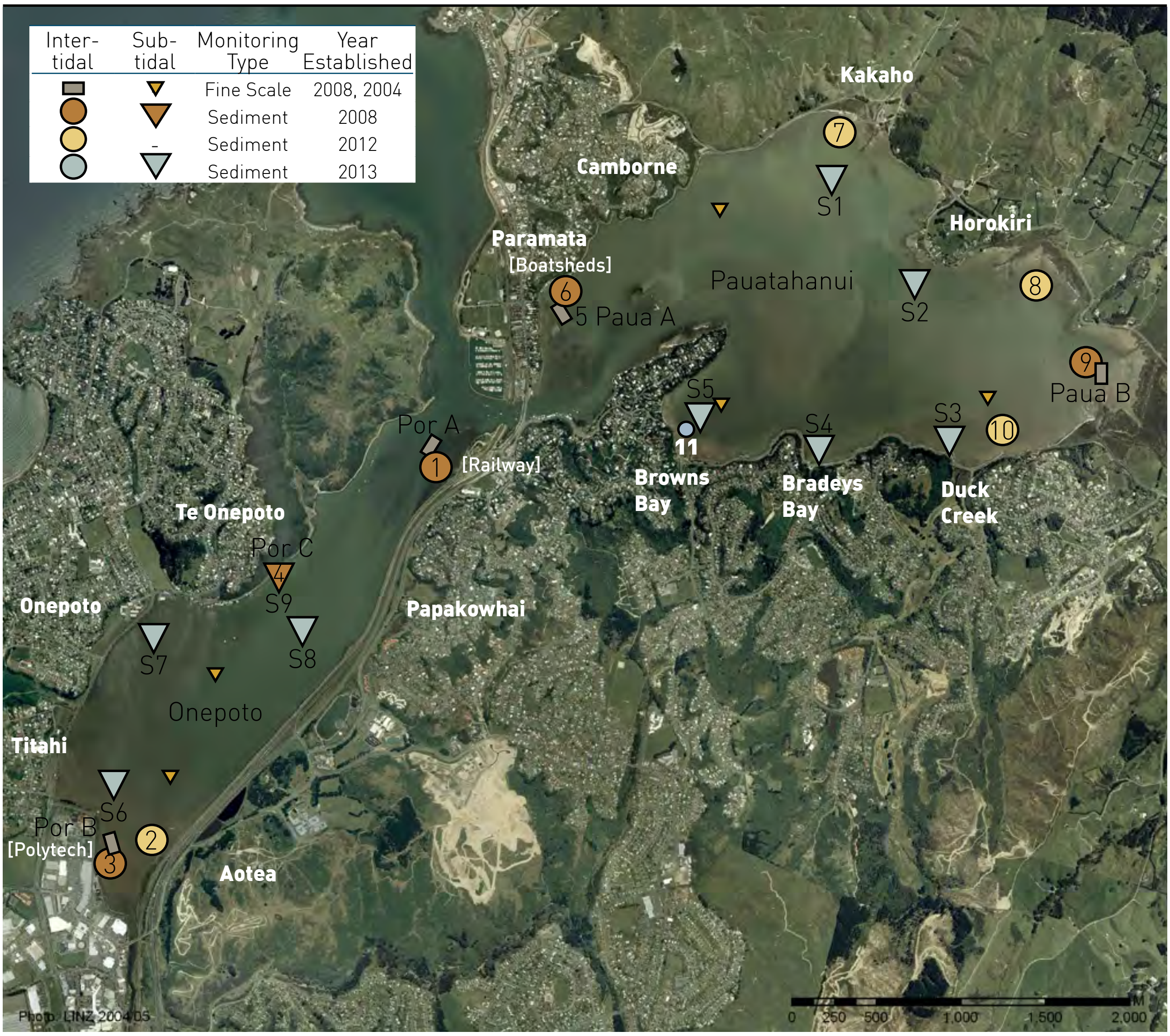


Figure 1. Location of fine scale sites and buried sediment plates established in Te Awarua-o-Porirua Harbour.

Table 2. Coordinates of transect lines used to record the annual movement in the soft mud boundary.

Site	Transect Start (subtidal plate) NZTM EAST	Transect Start (subtidal plate) NZTM NORTH	Subtidal Site No.	Transect End (estuary edge) NZTM EAST	Transect End (estuary edge) NZTM NORTH	Bearing (start to end) Degrees True
Kakaho	1758810.9	5449470.5	S1	1758914.3	5449854.4	15°
Horokiri	1759325.4	5448867.9	S2	1759414.7	5449007.3	33°
Duck Creek	1759529.0	5447896.3	S3	1759525.0	5447834.0	184°
Bradeys Bay	1758763.2	5447865.0	S4	1758714.4	5447750.9	203°
Browns Bay	1758040.6	5448015.1	S5	1757895.4	5447978.1	256°
Titahi	1755704.1	5446797.6	S6	1754480.9	5445709.7	213°

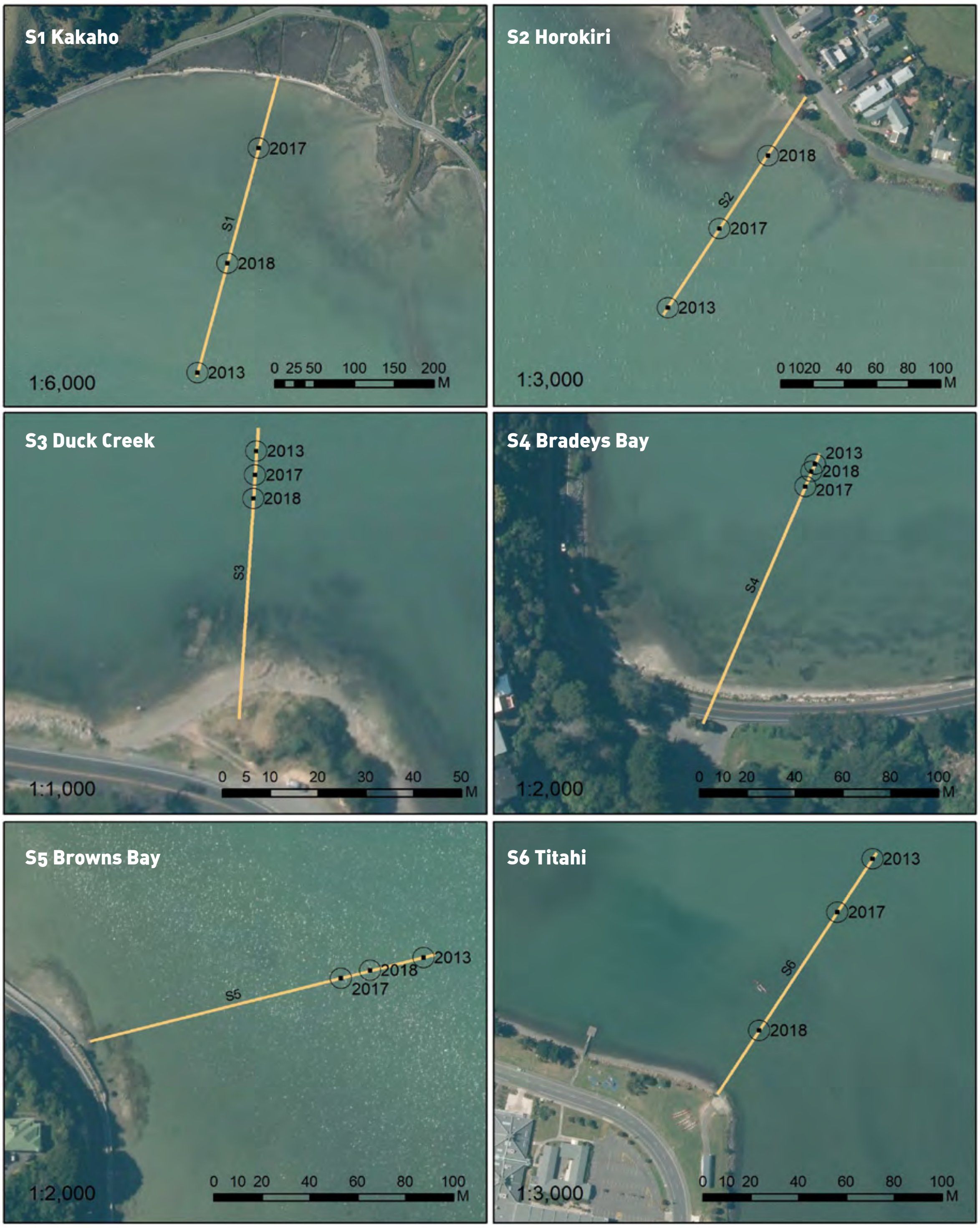


Figure 2. Location of sediment transects used to measure the distance from subtidal plates to the soft mud boundary. The soft mud boundary in 2013, 2017, and 2018 is shown.

been included in the monitoring programme to enable the distance between the front edge of the soft mud and the buried subtidal plates to be consistently recorded.

Grain Size

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. It is recommended that the use of triplicate sampling be considered in conjunction with the next 5 yearly fine scale monitoring (scheduled for 2020) to re-check within-site sample variability.

Apparent Redox Potential Discontinuity (aRPD) depth

To assess sediment oxygenation, the mean depth to the visually apparent RPD (aRPD) layer (the depth where sediments change in colour to grey/black) was determined at each intertidal site by repeatedly digging down from the surface with a hand trowel until the mean aRPD transition depth was located. The same approach was used at subtidal sites, although representative sediment cores were first collected and brought to the surface where the aRPD depth was determined. Because visual changes in oxygenation can sometimes be difficult to readily discern, if there appears to be a significant deterioration in sediment oxygenation it is recommended that a relationship between aRPD and sediment oxygenation measured using a redox probe be established.

Ratings, summarised in Table 1, have been developed to guide the assessment of results to determine the need and priority for more detailed investigations.

RESULTS AND DISCUSSION

Sedimentation Rate

The 42 sedimentation plates buried at 18 sites in Te Awarua-o-Porirua Harbour (Figure 1) were measured on 20-24 January 2018, with results summarised in Table 3 and Figures 3, 4 and

Table 3. Mean change of sediment depth above buried plates (2007-2018), and cumulative mean annual change since baseline in Te Awarua-o-Porirua Harbour.

Site		No	Name	Calendar Year Baseline Commenced	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		
Onepoto Arm	Intertidal	1	Por A Railway (FS)	2008	0.8	2.3	-4.5	-0.3	14.3	-4.3	1.5	0.5	-1.5	12.0	1.0	
		2	Aotea	2012					12.3	-0.3	2.3	7.8	1.5	-0.3	4.7	+3.0
		3	Por B Polytech (FS)	2008	7.0	0.5	2.0	0.3	4.3	1.8	2.3	5.0	5.3	1.3	3.6	
	Subtidal	S6	Titahi	2013						0.0	5.0	-16.0	32.0	43.0	3.3	
		S7	Onepoto	2013						-6.0	-92.0	-2.0	7.0	0	-23.3	-5.1
		S8	Papakowhai	2013						-8.0	-93.0	10.0	24.0	-2	-14.8	
		S9	Te Onepoto	2008	-2.5	-2.5	3.0	-1.0	-14.0	0.0	4.0	7.0	-3.0	1.0	2.0	
Pauatahanui Arm	Intertidal	6	Boatsheds	2008		0.5	-0.8	0.3	3.5	-2.0	-3.0	-3.5	-4.5	6.3	-1.2	
		7	Kakaho	2008					9.3	-4.0	-2.0	-5.8	17.8	-7.0	3.1	
		8	Horokiri	2009					2.0	-2.5	1.3	0.0	-7.0	7.3	-1.3	+0.6
		9	Paua B (FS)	2008	2.3	3.8	0.3	-5.3	-0.8	4.5	-2.5	-5.0	0.3	-1.8	-0.3	
		10	Duck Creek	2012					-3.0	14.8	-5.5	1.8	1.0	4.0	1.8	
		11	Browns Bay	2013						-30.0	4.0	1.0	-6.0	NM*	-	
	Subtidal	S1	Kakaho	2013						6.6	2.0	8.0	64.0	-6.0	20.2	
		S2	Horokiri	2013						26.4	18.0	10.0	54.0	-16.0	27.1	
		S3	Duck Creek	2013						8.0	-12.0	NM	90.0	10.0	21.5	+11.3
		S4	Bradeys Bay	2013						11.0	-4.0	-5.0	12.0	5.0	3.5	
		S5	Browns Bay	2013						9.2	-10.0	-2.0	13.0	-10.0	2.6	

*change attributable to localised sand movement and does not reflect a significant change in sedimentation. Value excluded from calculation of means. NM = Not Measured.

5. Raw data are presented in Appendix 2. Two existing intertidal sites were not measured. Site 11 (Browns Bay) was discontinued as this site is dominated by mobile sand and shell and has proven to be unrepresentative of sediment deposition in this part of the estuary. Site 3 (Por B) plate 1 could not be relocated as the marker pegs had been lost. To ensure ongoing coverage at Site 3 is maintained, two additional plates were installed on the southern edge of the fine scale site (locations in Appendix 1).

The mean annual intertidal sedimentation rate across all sites and over all years of monitoring shows a net increase of intertidal sediment calculated in January 2018 of +0.6mm/yr in the Pauatahanui Arm and +3.0mm/yr in the Onepoto Arm (Table 3), reflecting "very low" and "moderate" risk ratings respectively. Figure 3 shows the steady increase in sediment from the start of the baseline evident at the Onepoto intertidal sites which is attributable largely to coarser deposits on the Porirua Stream delta and sand movement at Por A. There has been little overall change in the Pauatahanui Arm, but within-site variability between years is evident. This variability is shown in detail in Figure 4. The greatest variability is present at sites located on stream deltas where sediment deposition is expected from flood events, and where subsequent sediment remobilisation is predicted to be relatively high due to tide and wave action.

The small net change in intertidal sediment deposition, particularly in the Pauatahanui Arm, does not mean the estuary is free from sediment related impacts. Sediment deposition effects can be significant when they exceed 2mm/yr and can be particularly damaging if sediment deposits are deep or frequent (e.g. Berkenbusch et al. 2002,Hewitt et al. 2003, Thrush et al. 2004, Lohrer et al. 2004, Norkko et al. 2002). The 18mm increase in the mud layer recorded at Kakaho in the Jan 2016 - Jan 2017 period which extended several hundred metres from the upper shoreline to beyond the low tide mark, and for over 1km parallel to the shoreline (Stevens 2017), reflects a significant ecologically damaging sediment deposition event. While there has been reworking and erosion (-7mm) of the intertidal sediment deposited at Kakaho over the past 12 months, the cumulative deposition over the past 2 years remains a very high +11mm and highlights that while long term trends are an

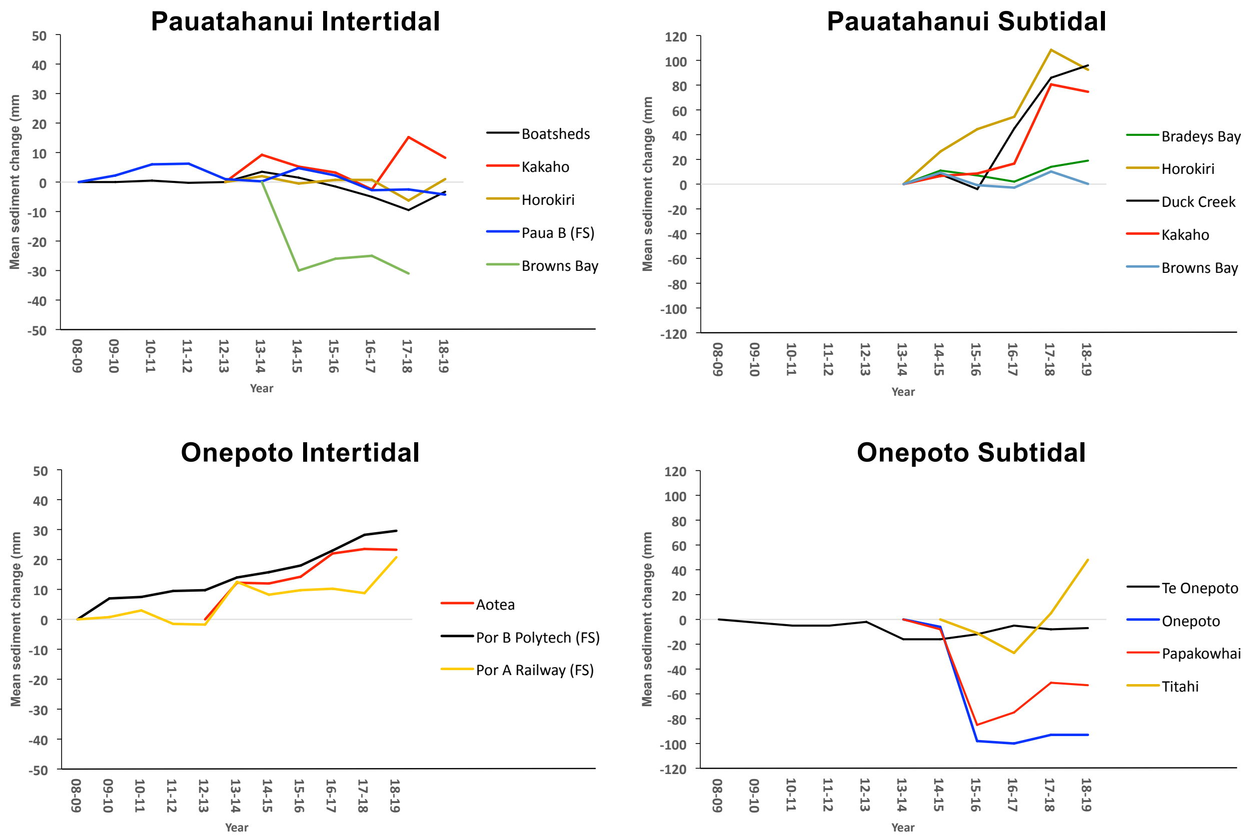
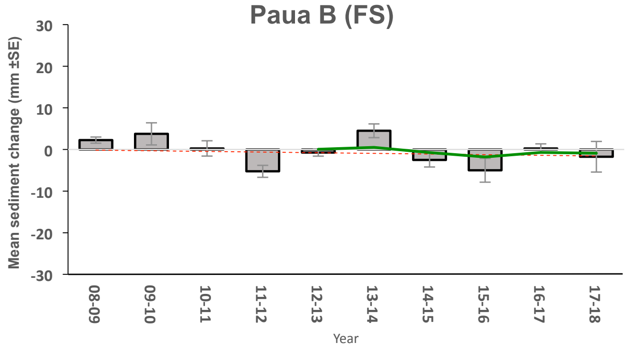
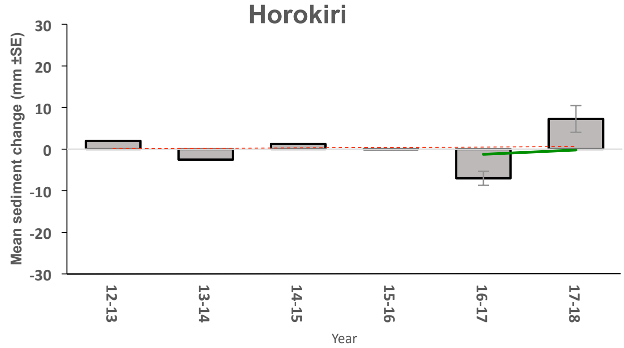
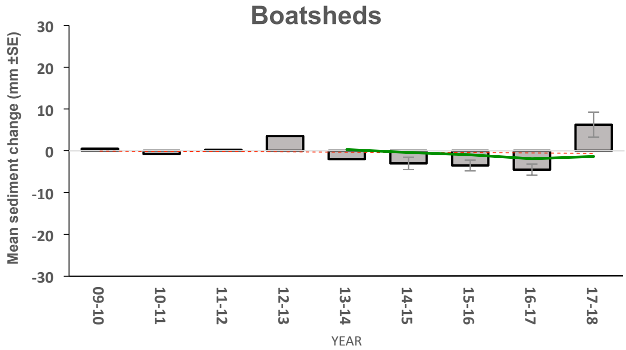


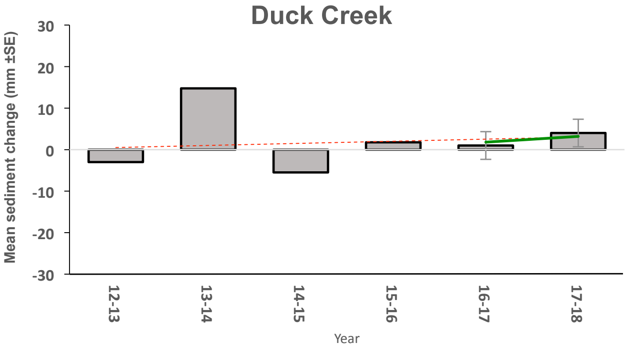
Figure 3. Cumulative change in mean sediment level over buried plates at individual monitoring sites in Te Awarua-o-Porirua Harbour.

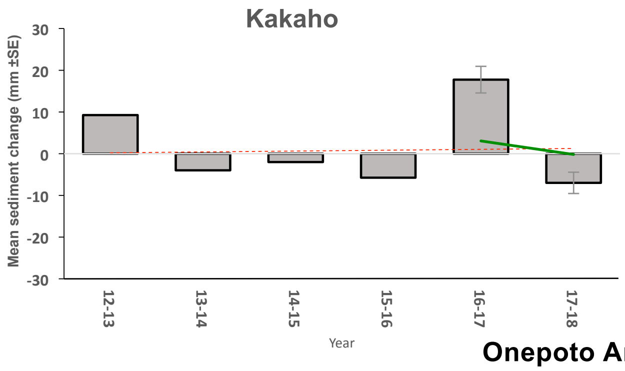
Pauatahanui Arm Intertidal

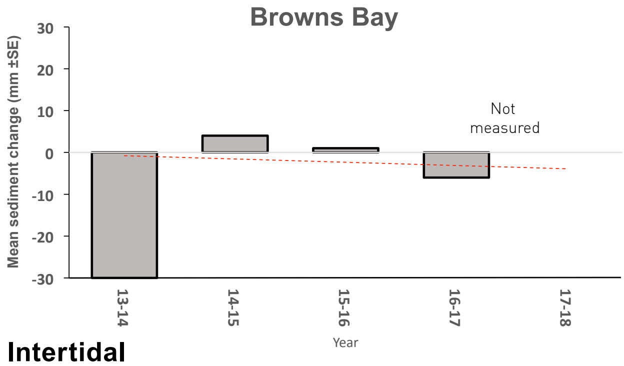




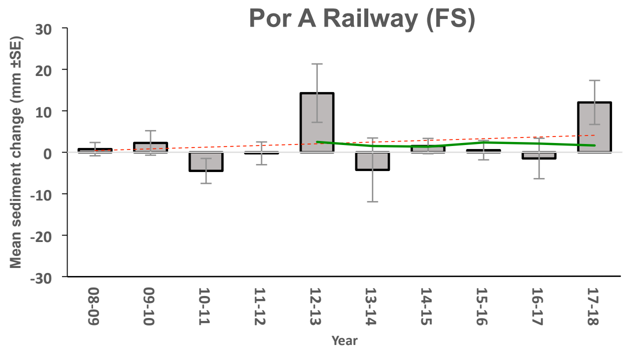


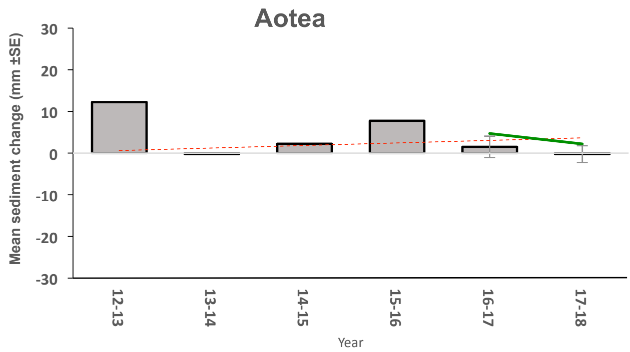






Onepoto Arm Intertidal





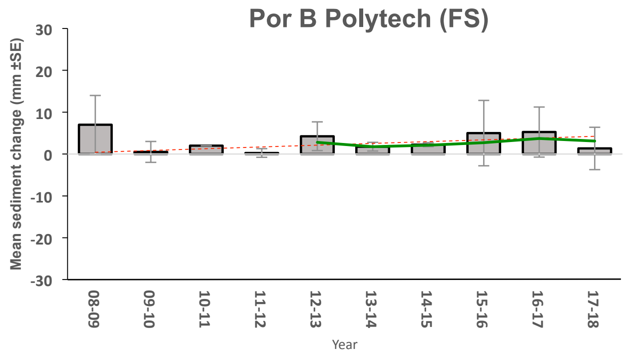
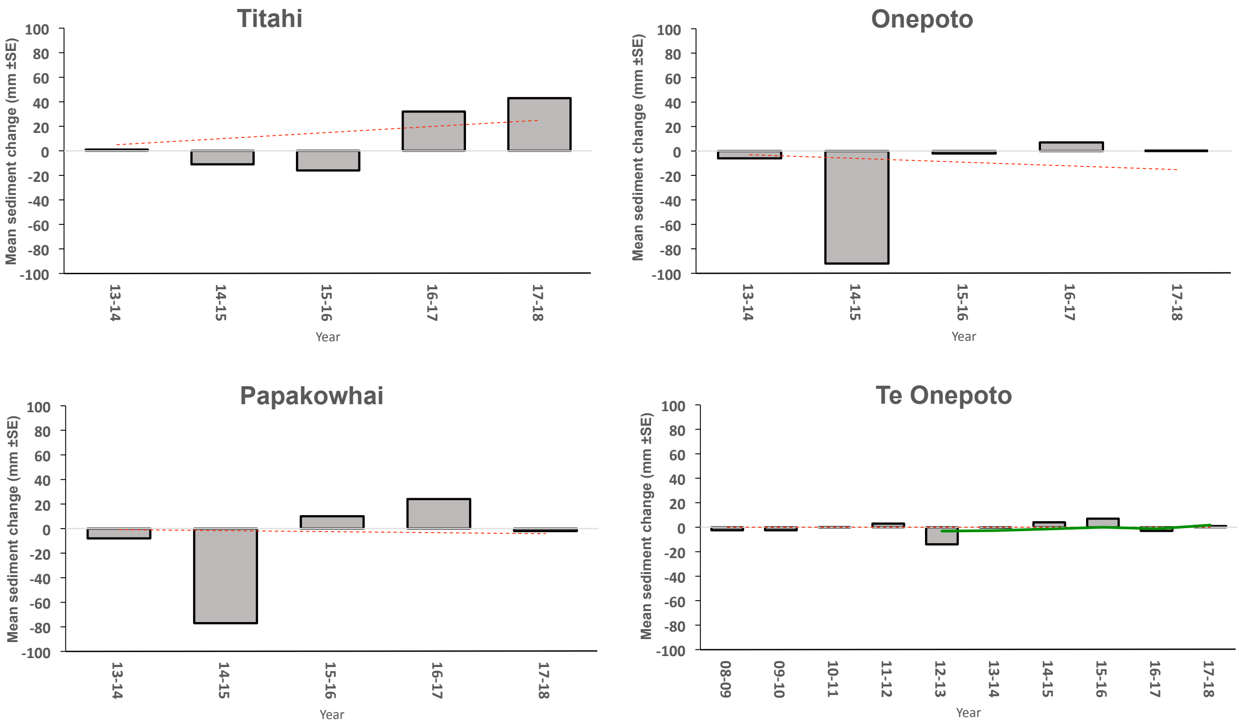


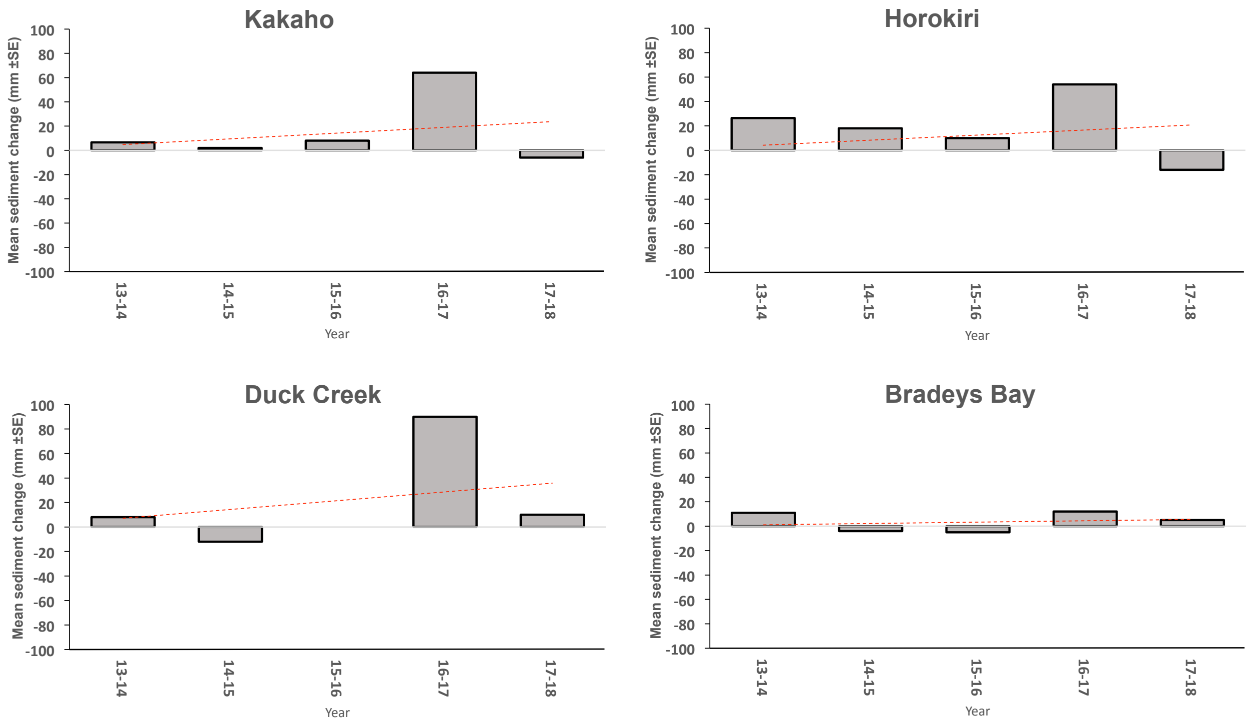
Figure 4. Mean change in intertidal sediment height (mm/yr ±SE) over buried plates at individual monitoring sites in Te Awarua-o-Porirua Harbour.

Trend over monitored period
5 year rolling mean

Onepoto Arm Subtidal



Pauatahanui Arm Subtidal



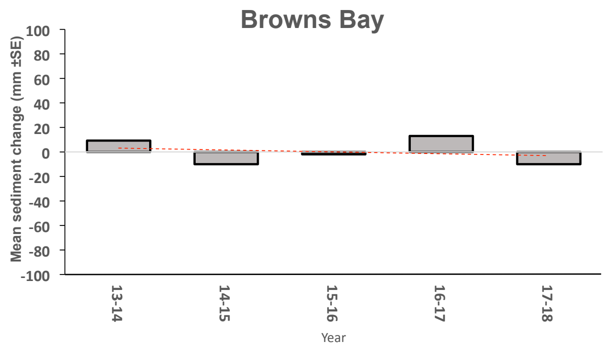


Figure 5. Mean change in subtidal sediment height (mm/yr ±SE) over buried plates at individual monitoring sites in Te Awarua-o-Porirua Harbour.

Trend over monitored period
5 year rolling mean

important measure of sediment changes, localised inputs and site specific changes need to be carefully assessed.

The subtidal sediment plate monitoring, while covering a shorter monitoring interval, shows much greater rates of sediment deposition than is evident at intertidal sites (Figure 3).

In the Pauatahanui Arm there has been overall mean deposition of +11.3mm/yr over the past 5 years (Table 3) with 20-27mm/yr increases at the Kakaho, Horokiri and Duck Creek sites (S1, S2 and S3). The trend of increasing deposition (Figure 3) reflects a "very high" risk rating. Field observations indicate this increase appears to be driven by both direct catchment inputs as well as intertidal sediment deposited following rainfall events being remobilised into shallow subtidal areas.

The Onepoto Arm subtidal results show a net decrease in subtidal sediment of -5.1mm/yr for the arm over the past 5 years (Table 3). While a positive trend, this result is driven almost exclusively by extensive sediment erosion at the Onepoto and Papakowhai sites in 2014-15 (Figures 3 and 5). For S7 (Onepoto) in the central basin, this reflects the loss of fine muds from the estuary following a significant deposition event and highlights how the time baseline monitoring commences can significantly influence the subsequent temporal trends.

For S8 (Papakowhai), the sediment loss reflects the erosion of sandy sediments on the edge of the flood tide delta.

Measurements along fixed transect lines of the distance between the front edge of the soft mud and the buried subtidal plates show significant changes between years. Since 2013 there has been a large increase in the shallow subtidal area covered by soft muds along the transect lines (Table 4, Figure 2). These changes have occurred in both arms of the harbour with the largest changes in the Pauatahanui Arm.

When established in 2013, each subtidal site was located approximately 5m subtidally of where soft muds were first encountered when wading from the shoreline. In 2017 subtidal soft muds had extended shorewards by 10-300m, and in 2018 the change from baseline was 3-145m.

The large expansion of subtidal soft mud towards the intertidal boundary, the high cumulative increase in sediment deposition, and the often very high measured annual deposition particularly at subtidal sites S1, S2, S3 and S6 (Kakaho, Horokiri, Duck Creek and Titahi) highlight that the subtidal basins (the primary deposition zones in the estuary) are currently undergoing a very rapid rate of infilling.

The results are consistent with the expected response to the pulsed input and subsequent erosion or redistribution of catchment derived sediments, and highlights that variable patterns in deposition occur in different parts of the harbour due to different processes affecting them. For example, the flood tide deltas in the lower reaches of each arm are strongly tidally flushed and reflect a mix of catchment and marine sourced sediments. In contrast, deeper central subtidal basins have less marine deposition and are more strongly influenced by wind-wave and flood disturbance than tidal flows. Intertidal flats in each arm are strongly influenced by local scale wind-driven wave action that remobilises intertidal sediment deposits and redistributes sediment to subtidal areas, noting subtidal sediments can also be remobilised and deposited intertidally.

As such, interpreting the long term patterns of deposition evident at individual sites needs to consider the length of the monitoring record, the frequency and intensity of storm events, and ideally be complimented by regular bathymetric surveys characterising major seabed changes

Table 4. Distance from subtidal plates to the soft mud boundary at sites S1-S6 in 2013, 2017, and 2018.

Site	Subtidal Site No.	Distance from subtidal plate to edge of soft mud (m) 2013	2017	2018	Change from baseline (m) 2012-2018
Kakaho	S1	5	300	150	+145
Horokiri	S2	5	65	120	+115
Duck Creek	S3	5	10	15	+10
Bradeys Bay	S4	5	15	8	+3
Browns Bay	S5	5	40	28	+23
Titahi	S6	5	45	135	+130

over the entire estuary e.g. Gibb and Cox (2009) and Cox (2014). The use of hydrodynamic/sediment modelling to assess both the amount of terrestrial fine sediment imported and exported from the estuary to the sea, and the relative extent and importance of fine sediment remobilisation and relocation within the estuary, would also be beneficial. Results of such work will directly aid understanding of the overall estuary sediment budget and the setting of management priorities on a catchment specific basis, and help in the establishment of defensible catchment load limits for the estuary.

Because sediment plate monitoring provides an important check on annual changes occurring between the less frequent bathymetric monitoring (5+ years), it is recommended that plates continue to be monitored annually to assess the impacts of predicted land disturbance from impending forest harvesting, urban development (Duck Creek subdivision), and road construction (in particular ongoing Transmission Gully works) in the catchment. Comprehensive reporting of results, including plots of sedimentation trends, is recommended 5 yearly (e.g. next scheduled for 2023), or annually if there is major land disturbance or unexpected results occur.

Grain Size

Grain size (% mud, sand, gravel) is a key indicator of sediment changes as well as eutrophication. Increasing mud content signals a deterioration in estuary condition and can exacerbate eutrophication symptoms.

Grain size monitoring results (Table 5) show that in 2018 sands continue to dominate intertidal sediments (80%-97%) with most mud contents in the "low" or "moderate" ecological risk rating categories. The muddiest intertidal site was Kakaho (14.6%), with the mud content decreasing significantly at this site from 37.9% over the previous 12 months (Figure 6). Subtidal sites were generally much muddier, 26%-84% in the Pauatahanui Arm and 8%-50% in the Onepoto Arm. The lowest subtidal mud contents were recorded from the relatively well flushed sites at Papakowhai, Te Onepoto, and Onepoto, and the highest in the deeper settlement basin areas (Figure 7, Table 5).

Previous results (Figures 6 and 7) and field observations highlight that inter-annual variability is evident and this most likely reflects event related deposition (e.g. pulsed deposits from stream inputs during storms), with fine sediments being relatively quickly re-mobilised by wind generated waves and tidal streams. Despite this, sediment grain size has been relatively consistent within individual sites but overall there has been an increase in the combined mean mud content of intertidal and subtidal sites in both arms of the estuary since the commencement of grain size measures (Figure 8). While a relatively short time series, it strongly suggests inputs of fine muds have been ongoing and that the estuary is continuing to get muddier. Recommended hydrodynamic modelling of the estuary will greatly assist in understanding sediment movement and fate (including retention) within both arms and the likely response of the estuary to ongoing sediment inputs.

Because of the strong trend in increasing mud content across sites, it is recommended that annual monitoring of sediment grain size continue.

Redox Potential Discontinuity (RPD)

The depth to the RPD boundary is a critical estuary condition indicator in that it provides a direct measure of sediment oxygenation. This commonly shows whether nutrient driven organic enrichment in the estuary exceeds levels causing nuisance anoxic conditions in the surface sediments, and also reflects the capacity of tidal flows to maintain and replenish sediment oxygen levels, a capacity which reduces as grain size decreases. In well flushed sandy intertidal sediments, tidal flows typically oxygenate the top 5-10cm of sediment. However, when fine muds fill the interstitial pore spaces, less re-oxygenation occurs and the RPD moves closer to the surface.

In 2018, the visually assessed aRPD depths (Table 5) were relatively shallow (1cm) across most muddy subtidal sites, a "moderate" risk indicator rating, and 1 to >5cm across the intertidal sites, "moderate"or "low" risk indicator ratings. The absence of surface anoxia indicates that there are no sites in the "high" risk indicator rating for aRPD.

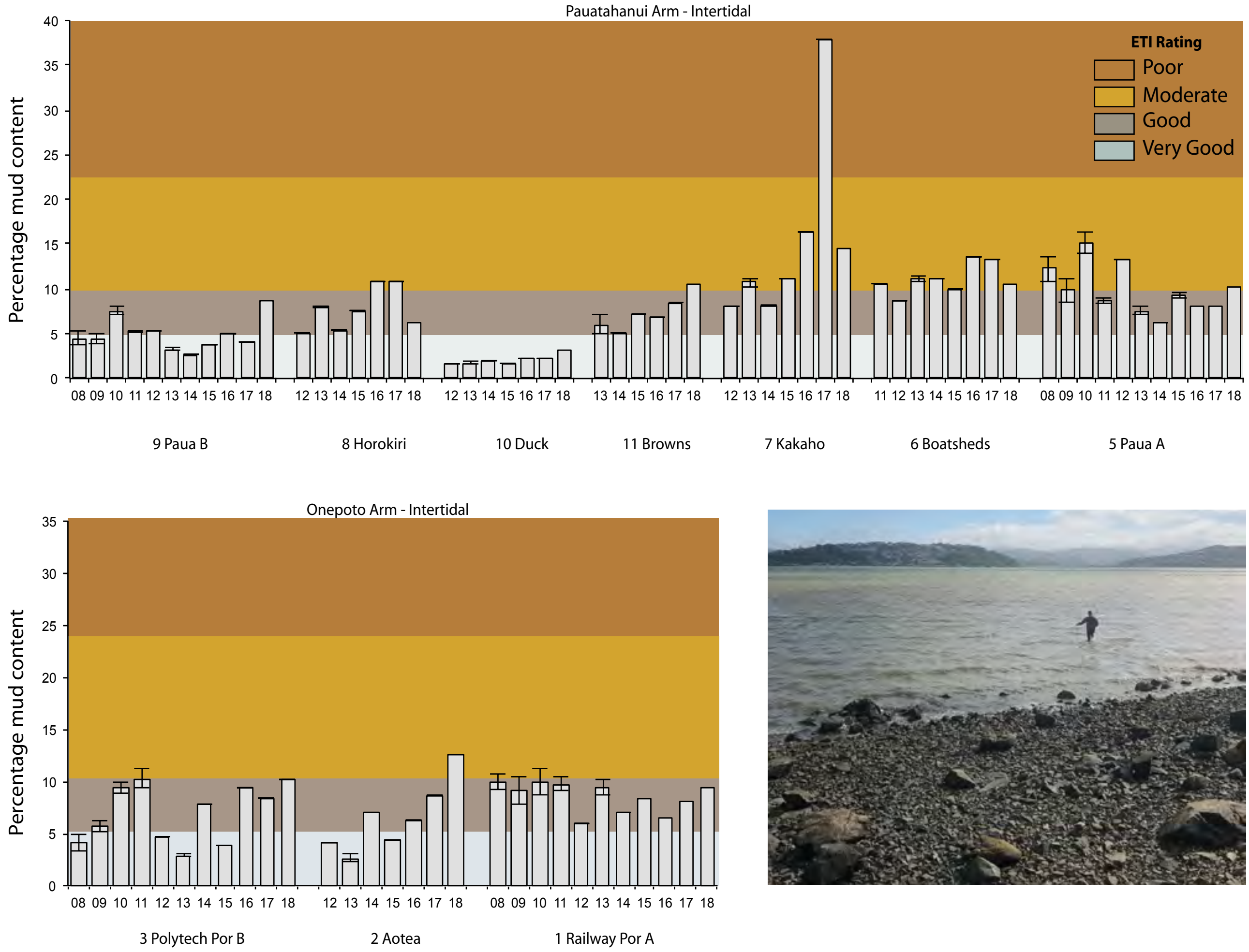


Figure 6. Mean sediment mud content (+/-SE) at individual Te Awarua-o-Porirua Harbour intertidal sites (2008-2018).

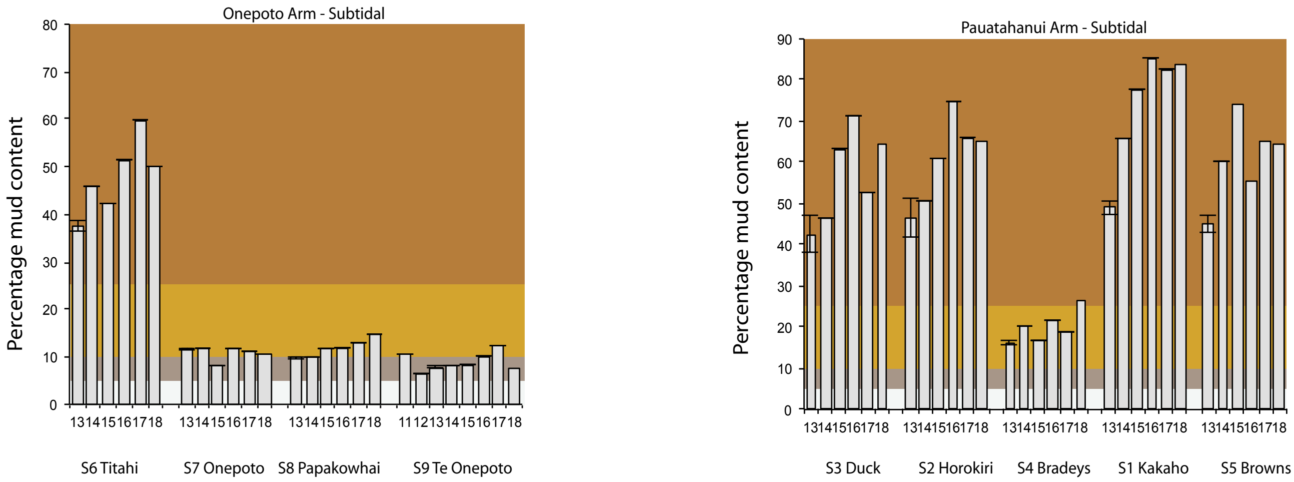


Figure 7. Mean sediment mud content (+/-SE) at individual Te Awarua-o-Porirua Harbour subtidal sites (2013-2018).

Table 5. Sediment grain size and RPD depth results, Te Awarua-o-Porirua Harbour, January 2018.

Site		No	Name	aRPD depth (cm)	Site Mean % Gravel g/100g dry weight	% Sand g/100g dry weight	% Mud g/100g dry weight
Onepoto Arm	Intertidal	1	Por A Railway (FS)	3-5	0.9	89.6	9.5
		2	Aotea	3	7.9	79.5	12.6
		3	Por B Polytech (FS)	2	4.6	85.4	10.1
	Subtidal	S6	Titahi	0.5	0.4	49.7	49.9
		S7	Onepoto	3	2.2	87.4	10.4
		S8	Papakowhai	5	<0.1	85.2	14.7
		S9	Te Onepoto	3	0.9	91.3	7.8
Pauatahanui Arm	Intertidal	5	Paua A (FS)	3	4.2	85.6	10.2
		6	Boatsheds	3	1.6	87.8	10.5
		7	Kakaho	2	1.3	84.1	14.6
		8	Horokiri	1	3.4	90.4	6.2
		9	Paua B (FS)	1	3.3	88.1	8.6
		10	Duck Creek	2	<0.1	96.6	3.3
		11	Browns Bay	3	3.5	86.0	10.4
	Subtidal	S1	Kakaho	1	0.2	15.8	83.9
		S2	Horokiri	1	0.2	34.9	64.9
		S3	Duck Creek	1	0.2	35.4	64.5
		S4	Bradeys Bay	1	0.9	72.9	26.3
		S5	Browns Bay	1	2.5	33.2	64.3

Note: Grain size results are based on a single composite sample comprising 4 sub-samples collected from each site. Mean RPD depth is derived from 4 replicate measures.

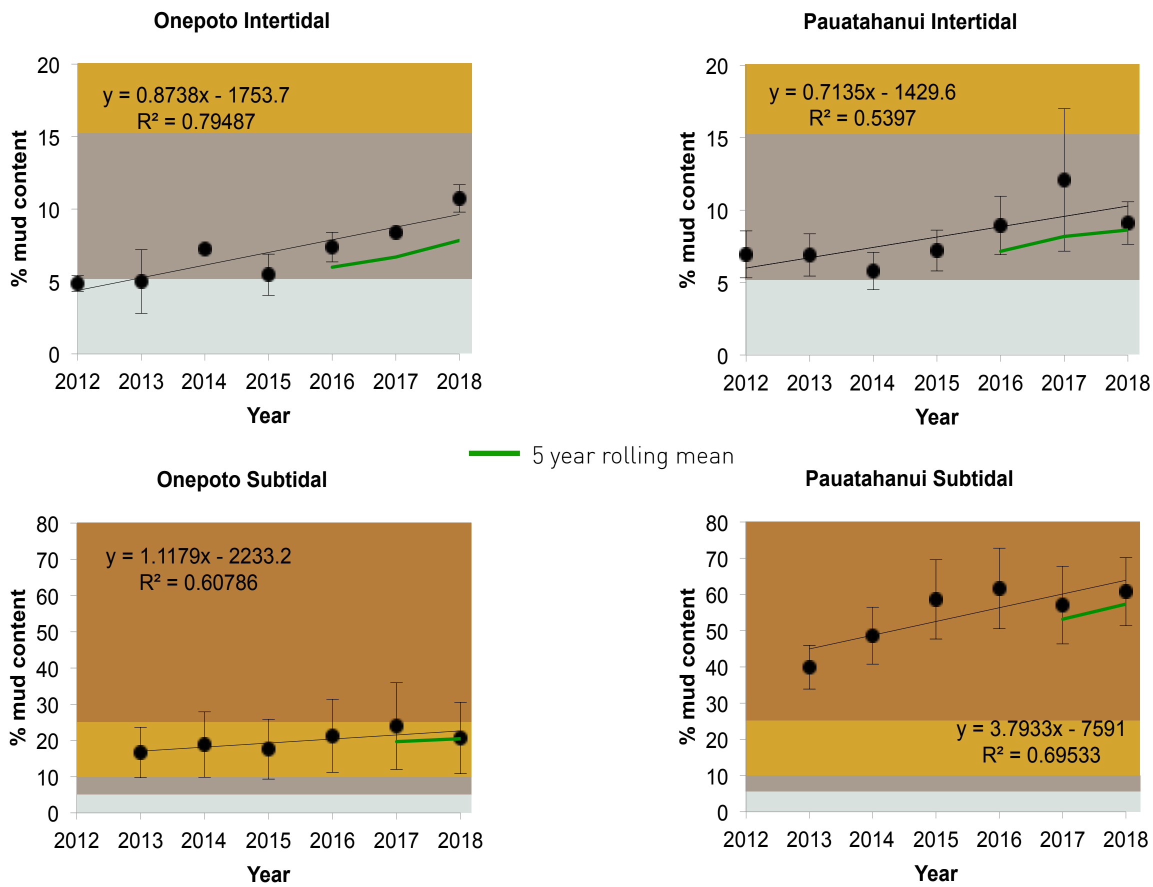


Figure 8. Change and trend in mean sediment mud content (±SE) for all intertidal sites combined (top) and all subtidal sites combined (bottom) in each arm of Te Awarua-o-Porirua Harbour.

SUMMARY AND RECOMMENDATIONS

Sediment plate monitoring, first established in 2007/08 at strategic intertidal sites within Te Awarua-o-Porirua Harbour, indicates a mean annual intertidal sedimentation rate across all sites of +0.6mm/yr in the Pauatahanui Arm and +3.0mm/yr in the Onepoto Arm, reflecting "very low" and "moderate" risk indicator ratings respectively. Sediment plates established within the subtidal basins of both estuary arms, where the greatest rates of sedimentation are predicted, show a mean annual subtidal sedimentation rate of +11.3mm/yr over the past 5 years with 20-27mm/yr increases at the Kakaho, Horokiri and Duck Creek sites.

A trend of increasing deposition reflects a "very high" risk rating, noting that the subtidal results remain strongly influenced by the short monitoring record at these sites and need to be interpreted with caution. Despite this caution, a consistent trend of increasing mean sediment mud content at intertidal and subtidal sites in both arms highlights ongoing fine sediment issues in the estuary.

The sediment indicators monitored in 2018 reinforce the 2008 to 2010 fine scale monitoring recommendations to manage fine sediment inputs to the estuary, in particular limiting catchment sediment inputs to more natural levels that will not cause excessive estuary infilling and will improve harbour water clarity. To achieve this, interim and long term targets have been 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 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).

GWRC is currently modelling the biophysical processes of the entire Te Awarua-o-Porirua and catchment as part of the sub-regional whaitua planning process to set limits for water quality and quantity. The outputs of this modelling will include estimates of present-day sediment inputs to the harbour from the surrounding catchment and subsequent sediment deposition throughout the intertidal and subtidal areas. The modelling will also estimate sediment inputs under future land development scenarios.

It is recommended that monitoring continue as outlined below:

Annual Sediment Monitoring (both intertidal and subtidal)

To assess sediment derived changes in the estuary, annually monitor sedimentation rate, aRPD depth and grain size at the existing intertidal and shallow subtidal sites. To optimise reporting, it is recommended that results be fully reported every 5 years (next review due in 2023 after 10 years of annual subtidal monitoring), with interim yearly results presented by way of a summary report card.

Fine Scale Monitoring (both intertidal and subtidal)

To assess intertidal estuary condition it is recommended that a detailed fine scale monitoring assessment based on the National Estuary Monitoring Protocol (Robertson et at. 2002) be undertaken at 5 yearly intervals (next scheduled for Jan-Feb 2020). As recommended in the 2014 broad scale subtidal survey (Stevens and Robertson 2014a), fine scale intertidal and subtidal monitoring should ideally be combined and integrated as part of a "whole of estuary" monitoring approach.

Broad Scale Habitat Mapping (both intertidal and subtidal)

It is recommended that broad scale intertidal and subtidal habitat mapping be integrated, and repeated every 5-10 years. Broad scale intertidal habitat mapping was last undertaken in 2013, and subtidal habitat mapping in 2014.

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APPENDICES

1. SITE LOCATIONS AND DETAILED RESULTS
2. LABORATORY RESULTS
3. ADDITIONAL NOTES SUPPORTING INDICATOR RATINGS (TABLE 1)

1. SITE LOCATIONS AND DETAILED RESULTS

Te Awarua-o-Porirua Sediment Plate Locations (NZGD 2000).

	No.	Site	PLATE	NZTM EAST	NZTM NORTH
Intertidal	1	Por A Railway (fine scale site)	1	1756505.7	5447788.6
			2	1756477.9	5447784.8
			3	1756478.8	5447762.7
			4	1756508.1	5447755.8
	2	Aotea	1	1754771.8	5445520.0
			2	1754770.5	5445521.2
			3	1754768.3	5445523.1
			4	1754767.3	5445523.9
	3	Por B Polytech (fine scale site)	1	1754561.9	5445430.3
			2	1754577.9	5445403.8
			3	1754561.6	5445529.5
			4	1754559.9	5445528.6
			5	1754564.0	5445479.0
			6	1754566.0	5445479.0
Subtidal	S6	Titahi	1	1755704.1	5446797.6
	S7	Onepoto	1	1754811.3	5446762.9
	S8	Papakowhai	1	1754580.9	5445864.0
	S9	Te Onepoto	1	1755551.8	5447105.3
Intertidal	5	Paua A (fine scale)	-	1757243.0	5448644.0
	6	Boatsheds	1	1757267.5	5448785.8
			2	1757265.6	5448785.2
			3	1757263.6	5448784.7
			4	1757262.0	5448784.1
	7	Kakaho	1	1758885.4	5449747.8
			2	1758884.9	5449746.0
			3	1758884.4	5449744.2
			4	1758884.0	5449742.3
	8	Horokiri	1	1760040.2	5448827.6
			2	1760039.8	5448825.5
			3	1760039.6	5448823.5
			4	1760039.1	5448821.5
	9	Paua B (fine scale site)	1	1760333.9	5448378.8
			2	1760349.2	5448355.8
			3	1760375.1	5448366.9
			4	1760362.3	5448391.9
	10	Duck Creek	1	1759829.3	5447944.8
			2	1759828.7	5447946.7
			3	1759828.1	5447948.7
			4	1759827.6	5447950.6
	11	Browns Bay	1	1757971.4	5447956.8
Subtidal	S1	Kakaho	1	1758810.9	5449470.5
	S2	Horokiri	1	1759325.4	5448867.9
	S3	Duck Creek	1	1759529.0	5447896.3
	S4	Bradeys Bay	1	1758763.2	5447865.0
	S5	Browns Bay	1	1758040.6	5448015.1

Sediment Plate Depths, Te Awarua-o-Porirua (2007-2018).

Arm	Zone	No.	Site	PLATE	Dec07	Jan09	Jan10	Jan11	Jan12	Jan13	Jan14	Jan15	Jan16	Dec 16	Jan 17	Jan 18
Onepoto Arm	Intertidal	1	Por A Railway (fine scale site)	1	168	164	159	155	160	183	181	181	187	182	181	208
				2	150	152	158	156	151	150	160	159	158	157	166	168
				3	152	155	163	150	145	174	148	155	150	148	137	147
				4	93	95	95	96	100	106	107	107	109	112	114	123
		2	Aotea	1					138	145	140	148	151	148	156	157
				2					108	126	128	127	139	137	141	137
				3					103	118	116	118	122	130	122	129
				4					100	109	113	113	125	124	124	119
		3	Por B Polytech (fine scale site)	1	237	237	240	242	245	243	243	246	-	242	248	lost
				2	230	244	242	244	244	256	256	258	245	251	268	281
				3				110	110	109	112	115	130	122	128	123
				4				75	73	81	85	86	99	99	97	93
																58
																50
	Subtidal	S6	Titahi	1						191	191	180	164	-	196	239
		S7	Onepoto	1						194	188	96	94	-	101	101
		S8	Papakowhai	1						183	175	98	108	-	132	130
		S9	Te Onepoto	1	120	-	115	115	118	104	104	108	115	-	112	113
Pauatahanui Arm	Intertidal	5	Paua A (fine scale)	-												
		6	Boatsheds	1		171	172	165	166	172	166	160	159	160	152	166
				2		213	213	215	216	221	222	220	216	223	205	217
				3		232	232	233	234	233	232	228	226	230	229	231
				4		234	235	236	234	238	236	236	229	227	226	223
		7	Kakaho	1					73	89	85	79	78	91	89	82
				2					100	106	104	100	95	116	116	111
				3					90	103	92	92	84	100	104	96
				4					92	94	95	97	88	92	107	99
		8	Horokiri	1					106	104	104	103	107	104	100	108
				2					108	111	113	113	112	109	101	109
				3					118	124	124	121	119	118	112	119
				4					98	99	87	96	95	97	92	98
		9	Paua B (fine scale site)	1	181	182	186	186	181	180	187	184	171	169	169	175
				2	215	218	228	233	228	225	229	230	230	230	233	224
				3	182	186	183	183	181	182	182	181	179	174	180	173
				4	176	177	181	177	168	168	175	168	163	162	162	165
		10	Duck Creek	1					134	121	136	140	146	145	140	142
				2					108	108	117	115	119	120	116	123
				3					122	122	146	126	128	131	138	134
				4					88	89	100	96	91	98	94	105
		11	Browns Bay	1						220	190	194	195	190	189	NA
	Subtidal	S1	Kakaho	1						165	172	174	182		246	240
		S2	Horokiri	1						176	202	220	230		284	268
		S3	Duck Creek	1						194	202	190	-		280	290
		S4	Bradeys Bay	1						124	135	131	126		138	143
		S5	Browns Bay	1						179	188	178	176		189	179

Sediment Transects, Te Awarua-o-Porirua

Site	Transect Start (subtidal plate) NZTM EAST	NZTM NORTH	Subtidal Site No.	Transect End (estuary edge) NZTM EAST	NZTM NORTH	Bearing (start to end) Degrees True (reciprocal)
Kakaho	1758810.9	5449470.5	S1	1758914.3	5449854.4	15 (195)
Horokiri	1759325.4	5448867.9	S2	1759414.7	5449007.3	33 (213)
Duck Creek	1759529.0	5447896.3	S3	1759525.0	5447834.0	184 (4)
Bradeys Bay	1758763.2	5447865.0	S4	1758714.4	5447750.9	203 (23)
Browns Bay	1758040.6	5448015.1	S5	1757895.4	5447978.1	256 (76)
Titahi	1755704.1	5446797.6	S6	1754480.9	5445709.7	213 (33)

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Certificate of Analysis

Page 1 of 3

Client:	Salt Ecology Limited	**Lab No:**	1916026 SPv2
Contact:	Leigh Stevens C/- Salt Ecology Limited 21 Mount Vernon Place Washington Valley Nelson 7010	**Date Received:**	30-Jan-2018
		Date Reported:	26-Mar-2018 **(Amended)**
		Quote No:	90062
		Order No:	
		Client Reference:	GWRC 2018
		Submitted By:	Leigh Stevens

Sample Type: Sediment

Sample Name:					POR 01 Railway 20-Jan-2018	POR 02 Aotea 20-Jan-2018
Lab Number:					1916026.4	1916026.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd				74	79
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt				0.9	7.9
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt				89.6	79.5
Fraction < 63 µm*	g/100g dry wt				9.5	12.6

Sample Name:		POR 03 FS B Polytech 20-Jan-2018	POR S6 Titahi 24-Jan-2018	POR S7 Onepoto 24-Jan-2018	POR S8 Papakowhai 21-Jan-2018	POR S9 Te Onepoto 21-Jan-2018
Lab Number:		1916026.6	1916026.7	1916026.8	1916026.9	1916026.10
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	76	61	80	73	80
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	4.6	0.4	2.2	< 0.1	0.9
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	85.4	49.7	87.4	85.2	91.3
Fraction < 63 µm*	g/100g dry wt	10.1	49.9	10.4	14.7	7.8

Sample Name:		PAUA 05 FS A 20-Jan-2018	PAUA 06 Boatsheds 20-Jan-2018	PAUA 07 Kakaho 24-Jan-2018	PAUA 08 Horokiri 21-Jan-2018	PAUA 09 FS B 21-Jan-2018
Lab Number:		1916026.11	1916026.12	1916026.13	1916026.14	1916026.15
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	75	76	79	80	80
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	4.2	1.6	1.3	3.4	3.3
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	85.6	87.8	84.1	90.4	88.1
Fraction < 63 µm*	g/100g dry wt	10.2	10.5	14.6	6.2	8.6

Sample Name:		PAUA 10 Duck 21-Jan-2018	PAUA 11 Browns Bay 21-Jan-2018	PAUA S1 Kakaho 27-Jan-2018	PAUA S2 Horokiri 27-Jan-2018	PAUA S3 Duck 21-Jan-2018
Lab Number:		1916026.16	1916026.17	1916026.18	1916026.19	1916026.20
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	78	81	67	65	69
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	3.5	0.2	0.2	0.2
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	96.6	86.0	15.8	34.9	35.4
Fraction < 63 µm*	g/100g dry wt	3.3	10.4	83.9	64.9	64.5

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:		PAUA S4 Bradeys 21-Jan-2018	PAUA S5 Browns 21-Jan-2018
Lab Number:		1916026.21	1916026.22
Individual Tests			
Dry Matter of Sieved Sample	g/100g as rcvd	76	68
3 Grain Sizes Profile			
Fraction >/= 2 mm*	g/100g dry wt	0.9	2.5
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	72.9	33.2
Fraction < 63 µm*	g/100g dry wt	26.3	64.3

Analyst's Comments

#1 It should be noted that a significant portion of the sample was comprised of stones which will significantly alter the portion of >2mm and <2mm fractions. This should be kept in mind when interpreting these results.

#2 It should be noted that a significant portion of the sample was comprised ofwillalter the portion of >2mm and <2mm fractions.This should be kept in mind when interpreting these results.

Amended Report: This certificate of analysis replaces an earlier certificate issued on 23 Mar 2018 at 4:42 pm
Reason for amendment: The >2mm fraction is now reported.

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 clean 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.

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
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%.	-	49-50
Dry Matter for Grainsize samples	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-47, 49-50
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	49-50
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	49-50
3 Grain Sizes Profile*		0.1 g/100g dry wt	1-47, 49-50
3 Grain Sizes Profile			
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-47, 49-50
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-47, 49-50

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

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

Note: The above laboratory printout has been edited to only show results from Te Awarua-o-Porirua referenced in the current report.

3. ADDITIONAL NOTES SUPPORTING INDICATOR RATINGS (TABLE 1)

Soft Mud Percent Cover

Soft mud (greater than 25% mud content) has been shown to result in a degraded macroinvertebrate community (Robertson et al. 2015, 2016), and excessive mud decreases water clarity, lowers biodiversity and affects aesthetics and access. Because estuaries are a sink for sediments, the presence of large areas of soft mud is likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, its presence indicates where changes in land management may be needed. If an estuary is suspected of being an outlier (e.g. has greater than 25% mud content but substrate remains firm to walk on), it is recommended that the initial broad scale assessment be followed by particle grain size analyses of relevant areas to determine the extent of the estuary with sediment mud contents greater than 25%.

Sedimentation Mud Content

When the mud content is less than 20-30%, sediments are relatively incohesive and firm to walk on. Above this, they become sticky and cohesive and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon concentrations, which typically increase with mud content, as do the concentrations of sediment bound nutrients and heavy metals. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, and on intertidal flats of estuaries can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready resuspension of fine muds, impacting on seagrass, birds, fish and aesthetic values.

Apparent Redox Potential Discontinuity (aRPD)

aRPD depth, the transition between oxygenated sediments near the surface and deeper anoxic sediments, is a primary estuary condition indicator as it is a direct measure of whether nutrient and organic enrichment exceeds levels causing nuisance (anoxic) conditions. Knowing if the aRPD is close to the surface is important for two main reasons:

1. As the aRPD layer gets close to the surface, a "tipping point" is reached where the pool of sediment nutrients (which can be large), suddenly becomes available to fuel algal blooms and to worsen sediment conditions.
2. Anoxic sediments contain toxic sulphides and support very little aquatic life.

In sandy porous sediments, the aRPD layer is usually relatively deep (greater than 3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to less than 1cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. The tendency for sediments to become anoxic is much greater if the sediments are muddy.

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