SALT ECOLOGY

Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2020/2021

Prepared for

Greater Wellington Regional Council

March 2021

Salt Ecology Report 061

RECOMMENDED CITATION

Roberts KL, Rabel H, Stevens LM 2021. Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2020/2021. Salt Ecology Report 061, prepared for Greater Wellington Regional Council, March 2021. 24p.

Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2020/2021

Prepared by

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for

Greater Wellington Regional Council

March 2021

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For the environment
Mō te taiao

GLOSSARY

aRPD	Apparent Redox Potential Discontinuity
CSR	Current Sedimentation Rate
DGV	Default Guideline Value
ETI	Estuary Trophic Index
GWRC	Greater Wellington Regional Council
LCDB	Land Cover Data Base
NEMP	National Estuary Monitoring Protocol
NSR	Natural Sedimentation Rate
SOE	State of Environment (monitoring)

ACKNOWLEDGEMENTS

Many thanks to Barrie Forrest (Salt Ecology) for assisting in the field. Thanks to Megan Melidonis for reviewing the draft report and her assistance in the field.

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Background

As part of ongoing work monitoring and managing catchment sediment inputs to Te Awarua-o-Porirua Harbour, Greater Wellington Regional Council contracted Salt Ecology to undertake annual sediment monitoring within the Harbour. The monitoring involves measuring sedimentation at nine intertidal and nine subtidal sites, assessing changes in sediment mud content, and visually assessing sediment redox status (oxygenation). In addition, changes in the spatial extent of mud-dominated sediment is measured on six fixed transects adjacent to subtidal sites. In Jan-2020, widespread recent deposition of mud-dominated sediments was recorded in the northern and western Pāuatahanui Inlet. In Dec-2020, these areas were re-mapped to assess net changes over the previous 11 months. This report presents the results of the 2020/2021 annual monitoring, undertaken between 11-15 December 2020. The report compares findings to previous monitoring results and established or provisional estuarine health metrics ('condition ratings').

Key Findings

Except for the Onepoto subtidal zone, the long term 5-year and 10-year mean annual sedimentation rates have been consistently in the 'fair' to 'poor' range (see table below) with subtidal zones the primary deposition areas. The highest levels of sedimentation were associated with a high sediment mud content (>25% mud; 'poor') and low oxygenation (<10mm; 'poor'). Adverse ecological effects are likely to be occurring at these levels.

Zone	10-year mean annual sedimentation rate (mm/y)	5-year mean annual sedimentation rate (mm/y)
Onepoto (intertidal)	+2.5	+1.4
Onepoto (subtidal)	-1.7	+7.3
Pāuatahanui (intertidal)	+1.0	+2.0
Pāuatahanui (subtidal)	+7.9	+8.3

Very Good
Good
Fair
Poor

While there has been some intertidal recovery from the widespread deposition of soft muds recorded in Jan-2020, there has also been degradation in new areas. Of particular concern was a thick slurry of deposited fine sediment covering previously sandy intertidal flats at Kakaho (Site P7), with 21.5mm of intertidal deposition over the previous 11 months, the largest mean annual increase recorded for that site since monitoring began in 2007/2008. At the same time mud content increased from an already very high 63.5% to 67.3% and oxygenation was 'poor'. Decreases in the spatial extent of intertidal mud near Horokiri and Pāuatahanui streams coincided with significant increases in subtidal deposition - Kakaho (Site PS1; 41mm), Horokiri (Site PS2; 30mm) and Duck Creek (Site PS3; 13mm). This indicates that mud mobilised from the intertidal zone is likely deposited in nearby subtidal areas.

The recent data confirm trends in the estuary-wide bathymetric surveys (covering predominantly subtidal areas) and NIWA's estuary sediment load estimator. Under the current situation, it is highly unlikely that the management goals set out in the Te Awarua-o-Porirua Harbour Catchment Sediment Reduction Plan are being met. These goals include:

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

Recommendations

The Dec-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 water clarity in the Harbour. It is recommended that sediment monitoring continue annually, and estuary-wide bathymetric surveys are scheduled at 5-yearly intervals. A comprehensive assessment of sediments sources, land use change data and temporal changes in catchment sediment loads should be carried out. This work should include an assessment of whether current mitigations are sufficient to reduce sediment loads to meet the objectives for Te Awarua-o-Porirua Harbour.

1. INTRODUCTION

1.1 BACKGROUND

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 stressors on estuary health, Greater Wellington Regional Council (GWRC) have maintained a long-term monitoring programme since 2007/2008. The programme includes:

- Intertidal and subtidal broad scale habitat mapping including the spatial extent of different surface substrate types (e.g. Stevens & Robertson 2013, 2014b, Stevens & Forrest 2020). Undertaken at 5-yearly intervals.
- Fine scale monitoring of sediment chemistry and macrofauna (e.g. Milne et al. 2008; Robertson & Stevens 2008, 2009, 2010, 2015; Oliver & Conwell 2014, Forrest et al. 2020). Undertaken at 5-yearly intervals.
- Annual sediment monitoring; a measure of sediment accrual and erosion in the estuary, in addition to substrate type and condition (e.g. Stevens et al., 2020).

1.2 BACKGROUND ON TE AWARUA-O-PORIRUA HARBOUR

Background information on Te Awarua-o-Porirua Harbour described in previous reports is summarised below.

The Harbour is a large (807ha, Fig. 1), well-flushed estuary fed by several small streams. It comprises two Inlets, Onepoto (283ha) and Pāuatahanui (524ha). The Inlets are connected by a narrow channel at Paremata, and the estuary discharges to the sea via a narrow entrance west of Plimmerton.

Residence time in the estuary is less than 3 days, however, compared to many New Zealand's tidal lagoon estuaries which tend to drain almost completely at low tide, the Harbour has a large shallow subtidal component (65%, mean depth of ~1m). Nonetheless, the intertidal area is large (287ha) and supports extensive areas (59ha) of seagrass growing in firm mud/sand, and shellfish beds. The estuary has high ecological values and high recreational use.

The Harbour has been extensively modified, particularly the Onepoto Inlet, where almost all the historical shoreline and saltmarsh have been reclaimed and most of the Inlet is now lined with steep, straight rock walls flanked by road and rail corridors. The Pāuatahanui Inlet is less modified (although most of the Inlet's margins are also encircled by roads), with extensive areas of saltmarsh remaining in the north and east, much of which has been improved through local community enhancement efforts.

Catchment land use in the Onepoto Inlet is dominated by urban (residential and commercial) development (Fig. 1). In the Pāuatahanui Inlet, grazing is the dominant land use, although urban (residential) development is significant in some areas. Various reports have identified sedimentation as a major problem in the estuary, particularly in the Pāuatahanui Inlet, where potential sources include land disturbance associated with residential subdivisions, the Transmission Gully motorway development, and exotic forest harvesting. Elevated nutrient inputs have previously been considered to be causing moderate eutrophication (i.e. poor sediment oxygenation and moderate nuisance macroalgal cover) in the estuary (Robertson & Stevens 2015).

Measuring sedimentation at Site B, Pāuatahanui Inlet

2. METHODS

2.1 OVERVIEW

As part of ongoing work contributing to managing catchment sediment inputs to the Harbour, GWRC contracted Salt Ecology in late 2020 to undertake annual sediment monitoring at established sites in Te Awarua-o-Porirua Harbour (Fig. 1).

GWRC commenced sedimentation monitoring at four sites in 2007/2008, with the number of 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 sedimentation sites since 2012.

Since sedimentation monitoring commenced there has been a significant expansion in the spatial extent of muddy sediments, particularly in the Pāuatahanui Inlet. Hence, at six subtidal sites the spatial extent of soft muds (mud extent) in the direction of the shoreline has been monitored along fixed transects since 2017.

The current report presents the results for the 2020/2021 annual monitoring carried out from 11-15 December 2020 and compares findings to previous work. These results are also considered more broadly in the context of complementary methods for assessing estuarine sedimentation and potential drivers of change.

2.2 GENERAL APPROACH

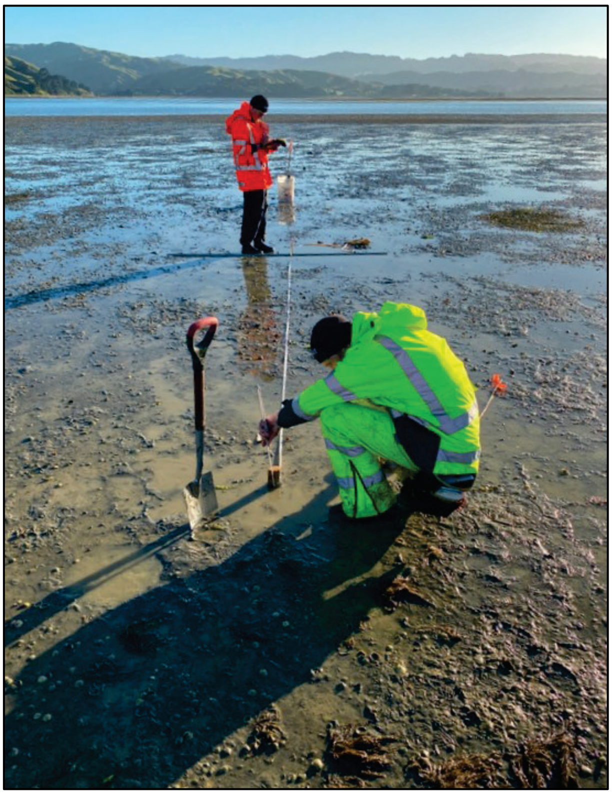
Sampling methods and descriptions of the 18 existing sedimentation rate monitoring sites are provided in Robertson and Stevens (2008), Stevens and Robertson (2011, 2014b, 2015) and Stevens (2017). A synopsis is provided here, and a general method review is presented in Hunt (2019).

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 bedload and suspended sediment from the various streams, most notably Pāuatahanui, Horokiri, Porirua, Kakaho and Duck Creek (see Green et al. 2015).

Each intertidal plate is relocated using marker pegs and a tape measure, while subtidal plates are relocated using a handheld Trimble GeoXH differential GPS (post-processing accuracy ±10cm). Care is taken not to disturb sediment overlying plates when they are located.

In the Pāuatahanui Inlet several changes to plates have been made. In 2018, the intertidal site at Browns Bay (P11) was discontinued because mobile sand and shell deposits were contributing to variable and unrepresentative measures of sediment deposition. In 2021, the 'Boatsheds' site (P6) was discontinued because dense cockles overlying the plates were making it difficult to take accurate measurements. These plates were relocated to the nearby site Paua A. At Paua B, the configuration of the 4 plates was altered to standardise the layout for easier relocation and reduce peg numbers in the estuary.

Immediately following a significant deposition event in Dec-2017, additional sediment plate measurements were made and changes in the mud extent between six subtidal plate sites and the adjacent shoreline were assessed. In addition, in Jan-2020, widespread new deposition of mud-dominated sediments was recorded in the northern and western Pāuatahanui Inlet as part of broad scale habitat mapping (Stevens & Forrest 2020). In Dec-2020, these areas were re-mapped using broad scale assessment methods to assess net changes over the previous 11 months.



Installation of plates at site Paua A, Pāuatahanui Inlet

2.2.1 Sedimentation rate

Intertidal estuary sedimentation was measured using the 'sediment plate' method, as described in Stevens and Forrest (2020). The approach involves measuring the sediment depth from the sediment surface to the top of each buried concrete plate. Small scale irregularities in the sediment surface topography are averaged out using a straight edge. Measurements are averaged across each plate (n=3) and an annual correction (to account for the varied number of days between sampling dates) is applied when calculating the mean annual sedimentation rate for each site. Where there are missing data, the net sedimentation rate is calculated and divided evenly over the monitoring period to represent nominal annual change.

Subtidal plate depths were measured using a custom-built frame (see photos on the following page). The frame was positioned ~5cm above the sediment overlying each relocated plate and allowed to settle onto the surface sediment. A measuring rod was then pushed down through a vertical tube to the underlying plate. Sediment depth is the distance between the base of the frame and the buried plate. The measurement is taken above the water surface using marked increments on the measuring rod. To collect three replicate measures at each plate, the

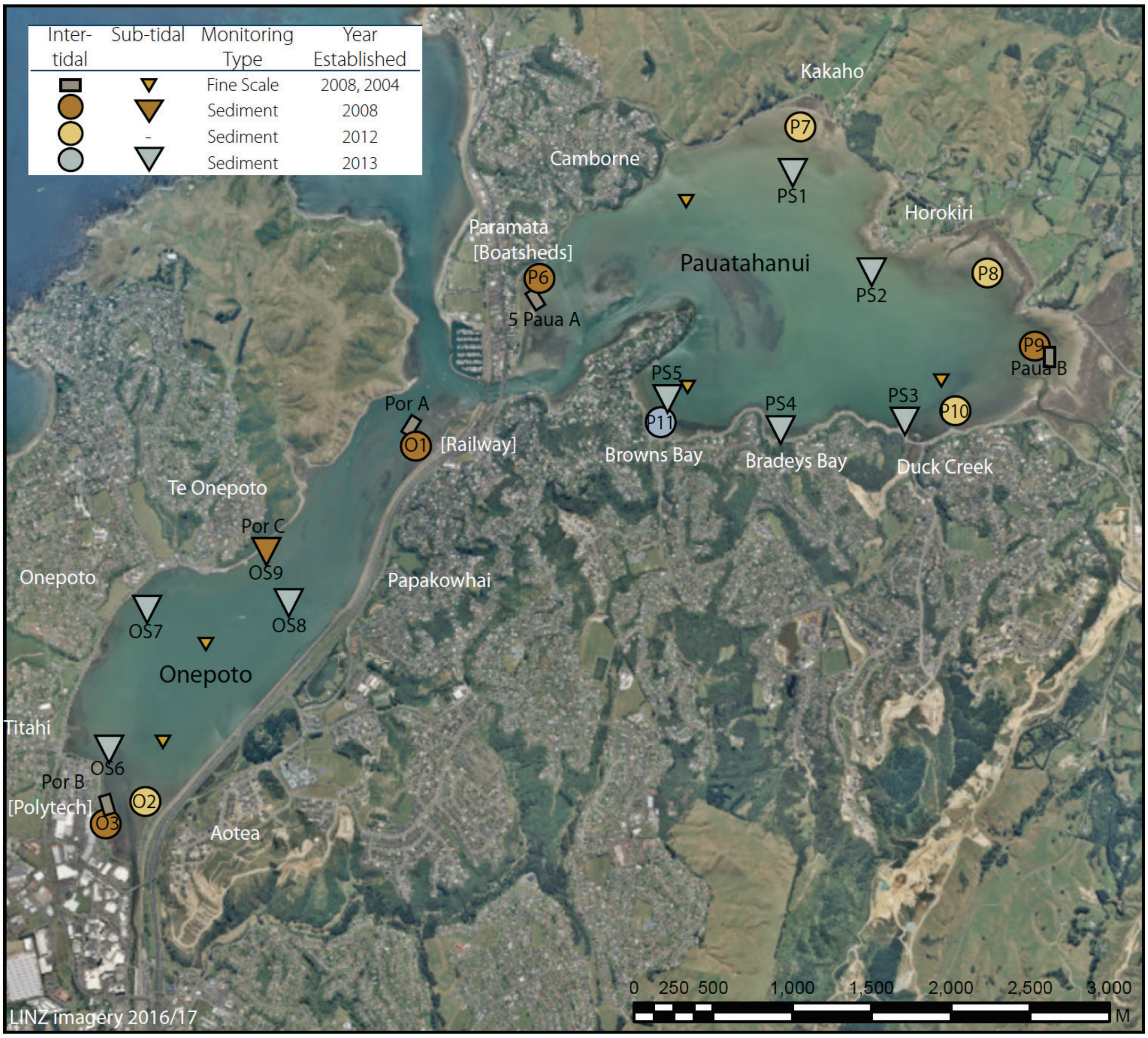


Fig. 1 Location of the 18 buried sediment plate sites (indicated by the alphanumeric sequence on the map) in Te Awarua-o-Porirua Harbour. Also shown are the location of 4 intertidal (rectangles) and 5 subtidal (small triangles) "fine scale" sites at which other monitoring is undertaken at ~5-yearly intervals.

frame was repositioned twice more by carefully lifting, rotating 30° clockwise, and allowing it to resettle.

As year-to-year sedimentation changes can be highly variable, the annual mean sedimentation rate is calculated for 10- and 5-year time periods, from annual change to indicate trends in sedimentation.

Custom-built subtidal measuring frame

2.2.2 Sediment grain size

A sample of the surface 20mm of sediment is collected adjacent to each sediment plate and combined to make one composite sample per sediment plate site. The sample is analysed for particle grain size (wet sieve, RJ Hill Laboratories). This approach allows changes in sediment muddiness to be determined even where there are no changes in sediment depth. Results are compared to condition bands (Table 1) described in section 2.4.

2.2.3 Sediment oxygenation

Sediment oxygenation is visually assessed by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD) depth. Results are compared to condition bands (Table 1) described in section 2.4.

2.2.4 Mud extent and sediment transects

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 mud transitioned to firmer sediments was measured (Fig. 5, Appendix 3).

In Dec-2020 the substrate was mapped in the northern and eastern intertidal flats of the Pāuatahanui Inlet using broad scale habitat mapping methods (see Stevens & Forrest 2020 for method details).

Measuring subtidal plates.

Measuring sediment plates at Paua A in the Pāuatahanui Inlet

2.3 DATA RECORDING, QA/QC AND ANALYSIS

All sediment plate measurements were recorded electronically in templates that were custom-built using software available at www.fulcrumapp.com. Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Fulcrum generates a GPS position for each sampling record. Data analysis, statistics and graphing were carried out in R version 4.0.3.

Sediment samples sent for grainsize analysis at RJ Hill Laboratories were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors.

2.4 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. 2016). 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. (2016);
ii. for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012);
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/yr above natural deposition rates. Where unknown, natural deposition rates are conservatively assumed to be 0mm/yr. The 2mm/yr value has been used as the threshold between the 'fair' 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).

Soft muds at Site P7, Kakaho

Table 1 Summary of condition ratings for sediment plate monitoring

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10
CSR : NSR ratio[4]	ratio	1 to <1.1 x NSR	≥1.1 to <2 x NSR	≥2 to <5 x NSR	≥5 x NSR

Ratings derived or modified from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012), [4]CSR=current sedimentation rate, NSR=natural sedimentation rate (100% native forest cover).

3. RESULTS

3.1 SEDIMENTATION

Sedimentation plate monitoring results are summarised in Table 2 and Figures 2 to 4. Long term 5-year and 10-year mean annual sedimentation rates are consistently in the 'fair' or 'poor' categories, highlighting ongoing and elevated sediment deposition. The 10-year subtidal trend in the Onepoto Inlet is the exception, although this is primarily an artefact of the baseline commencing shortly after a large deposition event. Consequently, there was a rapid period of erosion that indicates a downward (improving) trend, but which does not capture the preceding deposition. If this had been captured, then the net trend would also be sediment deposition.

Fig. 2 shows net deposition is more consistent at sites Aotea (O2) and Por B (O3) with both sites close to the Porirua stream and stormwater outlets. Whereas annual shifts in erosion and accretion are observed at Por A (O1) in the lower Onepoto Inlet. This is likely attributable to the influence of the Harbour entrance at Por A (O1) and the movement of mobile sands across the site.

Soft muds over shell near Site P7, Kakaho

Table 2 Mean annual change in sediment depth between 2009 – 2021. Mean annual sedimentation rate calculated over 10- and 5- year period and rate per designated zone.

Site	Zone	No	Name	Year#	Change in mean sediment depth (mm/y)													Mean annual sedimentation rate (mm/y)			
					2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	10-year^	Zone (10-y)	5-year	Zone (5-y)
Onepoto Inlet	Intertidal	O1	Por A (FS)	2008	0.7	2.2	-4.5	-0.2	16.1	-4.2	1.5	0.5	-1.5	12.2	-0.7	-3.3	-0.5	+2.0		+1.2	
		O2	Aotea	2012					13.8	-0.2	2.2	7.7	1.5	-0.3	6.5	3.7	-0.5	+3.8	+2.5	+2.2	+1.4
		O3	Por B (FS)	2008	6.4	0.5	2.0	0.2	4.8	1.7	2.2	4.0	4.9	1.4	2.4	-1.8	-2.4	+1.7		+0.9	
	Subtidal	OS6	Titahi	2013						0.0	-10.9	-15.9	31.6	43.8	3.0	16.3	10.9	+9.8		+21.1	
		OS7	Onepoto	2013						-5.9	-91.5	-2.0	6.9	0.0	-1.5*	-1.5	-8.7	-13.0	-1.7	-1.0	+7.3
		OS8	Papakowhai	2013						-7.8	-76.6	9.9	23.7	-2.0	2.0	20.4	4.3	-3.3		+9.7	
		OS9	Te Onepoto	2008	-2.4*	-2.4	0.0	2.7	-15.8	0.0	4.0	6.9	-3.0	1.0	-9.0	-2.0	9.8	-0.5		-0.6	
Pāuatahanui Inlet	Intertidal	P6	Boatsheds	2009		0.5	-0.8	0.2	3.9	-2.0	-3.0	-3.5	-4.4	6.4	4.0	5.8	-8.7	-0.1		+0.6	
		P7	Kakaho	2012					10.4	-3.9	-2.0	-5.7	17.5	-7.1	2.0	13.2	21.5	+5.1		+9.4	
		P8	Horokiri	2012					2.3	-2.5	1.2	0.0	-6.9	7.4	1.3	1.3	-4.3	+0.0	+1.0	-0.3	+2.0
		P9	Paua B (FS)	2008	2.1	3.7	0.3	-4.8	-0.8	4.4	-2.5	-5.0	0.2	-1.8	0.5	2.2	-9.6	-1.7		-1.7	
		P10	Duck Creek	2012					-3.4	14.5	-5.5	1.7	1.0	4.1	2.0	1.0	2.3	+2.0		+2.1	
	Subtidal	PS1	Kakaho	2013						6.5	2.0	7.9	63.1	-6.1	-11.1*	-11.1	41.3	+11.6		+15.2	
		PS2	Horokiri	2013						25.9	17.9	9.9	53.3	-16.3	0.0	-7.1	30.4	+14.2		+12.0	
		PS3	Duck Creek	2013						7.8	-11.9	44.5*	44.5	10.2	-21.2*	-21.2	13.0	+8.2	+7.9	+5.1	+8.3
		PS4	Bradeys Bay	2013						10.8	-4.0	-5.0	11.8	5.1	-1.0	33.6	-3.3	+6.0		+9.3	
		PS5	Browns Bay	2013						9.0	-9.9	-2.0	12.8	-10.2	-1.0	2.0	-4.3	-0.4		-0.1	

Ratings (refer to Table 1 for details)

Very good	Good	Fair	Poor

#Calendar year baseline commenced. *No measurement taken for that year, the change in mean sediment depth has been calculated over a two-year period and standardised to annual change (i.e. mm/y). ^Where 10 years data are not available the mean was calculated for the available time period (i.e. 8- or 9-year mean for some sites). Note: Nominal annual change was reported in previous years. The current report presents annualised change calculated from the specific days between measurements, with the same correction applied to data collected in previous years.

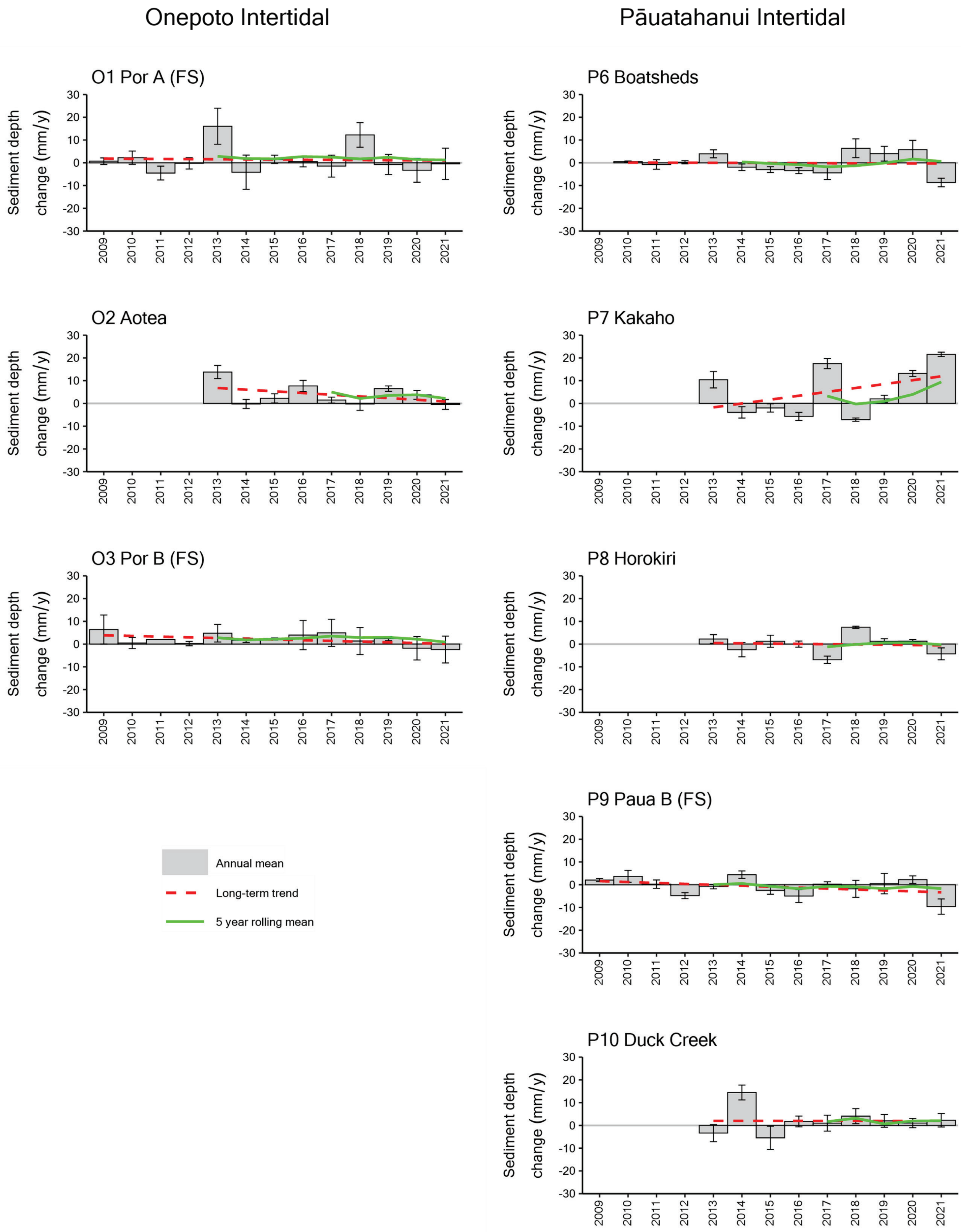


Fig. 2 Mean annual change in sediment depth (mm/y ± SE) at intertidal sites in the Onepoto and Pāuatahanui Inlet of Te Awarua-o-Porirua Harbour. *Note 2021 refers to Dec-2020 monitoring.

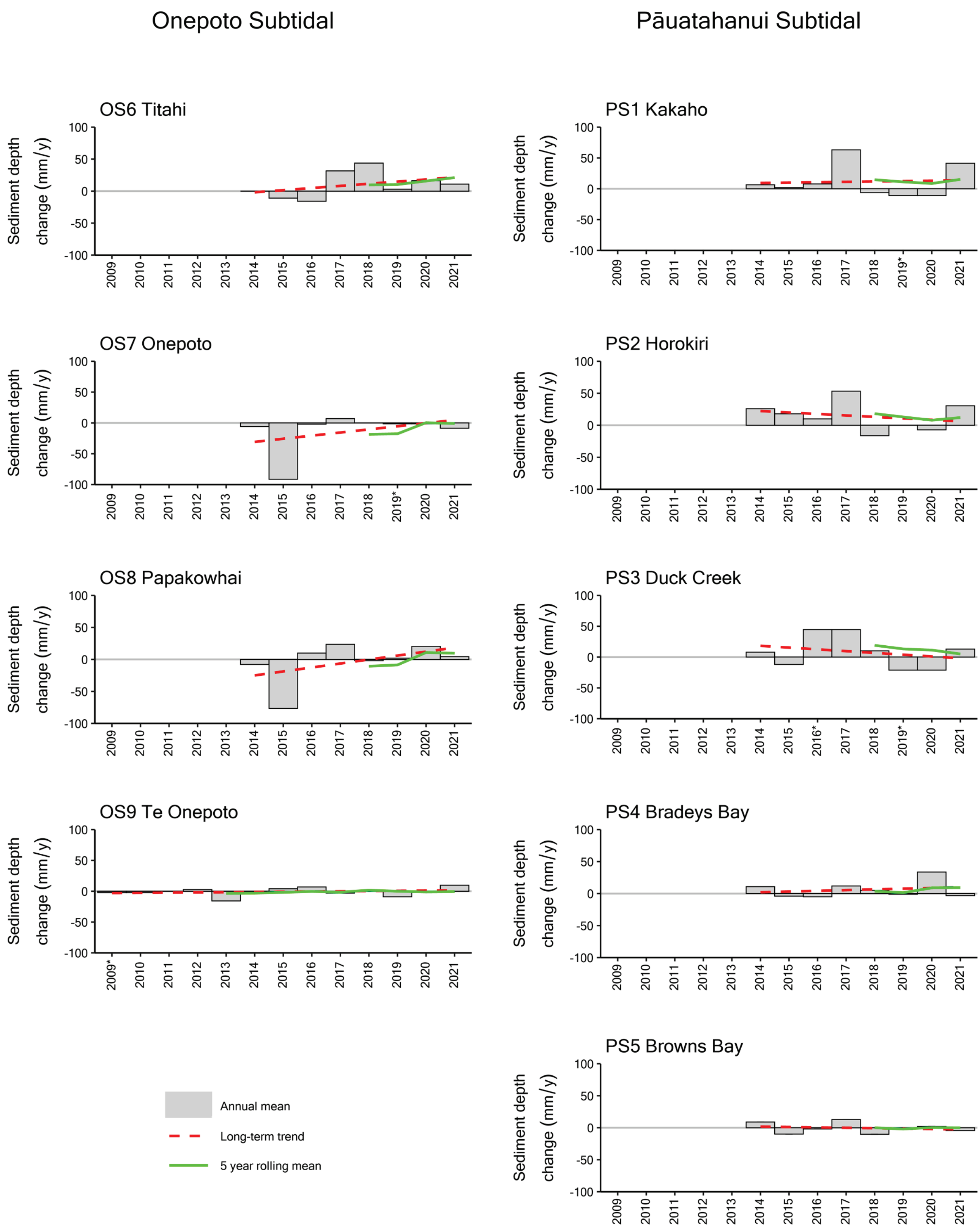


Fig. 3 Mean annual change in sediment depth (mm/y) at subtidal sites in the Onepoto and Pāuatahanui Inlet of Te Awarua-o-Porirua Harbour. Note scale ±100mm/y in comparison to ±30mm/y for the intertidal plates. *Note 2021 refers to Dec-2020 monitoring.

Kakaho (P7) in the Pāuatahanui Inlet has shown significant intertidal accretion, with large deposition events observed in 2017, Jan-2020 and Dec-2020 (Fig 2 and Fig 4). In contrast to other years, net erosion was observed at Boatsheds (P6), Horokiri (P8), and Paua B (P9) in Dec-2020.

Fig 3. shows erosion at the subtidal sites in the Onepoto Inlet from 2013-2015 followed by a trend of increasing deposition. Te Onepoto (OS9), close to the Harbour entrance, is relatively stable compared to the other sites within the Onepoto Inlet.

In the Pāuatahanui Inlet, accretion was observed in Dec-2020 at Kakaho (PS1), Horokiri (PS2) and Duck Creek (PS3) with freshly-deposited fine sediment observed on the surface during field surveys (see photos). Little change was observed at Brown's Bay (PS5).

Kakaho (PS1), Pāuatahanui Inlet

Horokiri (PS2), Pāuatahanui Inlet

Duck Creek (PS3), Pāuatahanui Inlet

3.2 SEDIMENT GRAIN SIZE

While changes in sediment grain size are not always directly reflected in annual sediment erosion and accretion patterns, it is helpful to compare the results. As such, sediment grain size has been presented beside sediment depth over time in Fig. 4.

Except for Kakaho (P7), all intertidal sites in the Pāuatahanui Inlet were rated 'fair' to 'very good', noting that the 'fair' sites were close to the 'fair' to 'good' threshold of 10% mud content (Table 3). Kakaho (P7) had the highest mud content (67.3% mud; a condition rating of 'poor'). This mud content increased significantly from Jan-2019 to Jan-2020 and increased further in Dec-2020 (Table 3). The increase in mud content over the past 2 years is consistent with increased sediment deposition at this site (Fig. 4).

The intertidal flats in the Onepoto Inlet have consistently had low mud content over the monitoring period, and in Dec-2020 mud content at all sites was approximately half that measured in the previous survey, with the condition rating improving from 'fair' to 'good' (Table 3).

In the subtidal zone, mud content has increased in the Pāuatahanui Inlet since monitoring began in 2013, with the most significant increases occurring between 2013 and 2016 at Kakaho (PS1), Horokiri (PS2), Duck Creek (PS3) and Browns Bay (PS5). Elevated mud content has been maintained at these sites over time, with only a marginal decrease observed in Dec-2020 (Fig 4). These sites represent the deeper settlement basins of the estuary. Bradey's Bay (PS4), a sandier site, has had a steadily increasing mud content since monitoring began in 2013, likely owing to localised areas of sediment run-off from development in the catchment.

In Dec-2020, as in previous years, the subtidal sites in the Pāuatahanui Inlet were rated 'poor', with elevated mud contents observed at all sites (Table 3).

The subtidal sites in the Onepoto Inlet were more varied. Papakowhai (OS8) and Te Onepoto (OS9) are close to the Harbour entrance and are dominated by mobile sands with a generally low mud content. The mud content decreased by 53% and 62%, respectively over the previous year, with the condition rating improving from 'fair' to 'good'. Onepoto (OS7), another well-flushed firm sand site, remained stable with a condition rating of 'fair'. In contrast, Titahi (OS6) has shown an overall trend of increasing mud content since 2013, with the Dec-2020 mud content rated 'poor' (Fig. 4 and Table 3). Increasing muddiness at Titahi (OS6) corresponds to an increase in sediment deposition at the site compared to Jan-2020 (Fig. 4).

3.3 SEDIMENT OXYGENATION

In Dec-2020, visually assessed aRPD depths (Table 3) were variable depending on location. In general, high mud contents were associated with shallower aRPD depths (Table 3). This was evident at mud-dominated sites in the Pāuatahanui Inlet, with four out of five subtidal sites rated 'poor' and one (PS2) rated 'fair'.

Some improvement was observed in the intertidal Pāuatahanui Inlet sites compared to Jan-2020 (Stevens & Forrest 2020), with more sites rated 'fair' to 'good' in Dec-2020 (Table 3). The improvement in aRPD depth is consistent with a decrease in mud content at sites P8 to P11 (Fig. 4).

The deepest aRPD depths (>150mm) were recorded from mobile sands at the Onepoto subtidal sites (OS8 and OS9) closest to the Harbour entrance (a rating of 'very good'). The intertidal sites in the Onepoto Inlet ranged from 10mm to 8mm, and were rated 'fair' to 'poor'. The shallow aRPD depths recorded in the Onepoto Inlet are associated with sandy substrate. However organic debris deposited across sites O2 and O3, possibly from nearby stormwater drains, is a contributing factor to the reduced sediment oxygenation at these sites.

Organic debris from drain near site Por B (O3), Onepoto Inlet

Poor water clarity and accumulation of organic debris near a stormwater outfall adjacent to Por B (O3), Onepoto Inlet

Table 3 Measured aRPD depth (mm) and sediment grain size (%), Te Awarua-o-Porirua, Dec-2020.

Site	Zone	No	Name	aRPD depth (mm)	% Gravel (g/100g dw)	% Sand (g/100g dw)	% Mud (g/100g dw)
Onepoto Inlet	Intertidal	O1	Por A (FS)	10	1.6	93.1	5.3
		O2	Aotea	8	7.4	86.4	6.2
		O3	Por B (FS)	15	4.4	87.4	8.1
	Subtidal	OS6	Titahi	15	0.3	43.2	56.5
		OS7	Onepoto	>40	0.6	86.9	12.5
		OS8	Papakowhai	>150	0.7	91.6	7.7
		OS9	Te Onepoto	>150	4.8	88.6	6.7
Pāuatahanui Inlet	Intertidal	P5	Paua A (FS)	10	1.6	88.1	10.2
		P6	Boatsheds	8	4.7	83.4	11.8
		P7	Kakaho	30	14.8	17.9	67.3
		P8	Horokiri	10	3.3	91.1	5.6
		P9	Paua B (FS)	15	2.3	92.5	5.2
		P10	Duck Creek	17	3.0	94.1	2.9
		P11	Browns Bay	40	7.9	84.5	7.6
	Subtidal	PS1	Kakaho	2	0.1	18.0	81.8
		PS2	Horokiri	10	0.2	26.1	73.7
		PS3	Duck Creek	2	2.4	39.3	58.3
		PS4	Bradeys Bay	5	0.8	62.4	36.8
		PS5	Browns Bay	5	1.3	33.0	65.7

Ratings (refer to Table 1 for details):

Very Good	Good	Fair	Poor

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

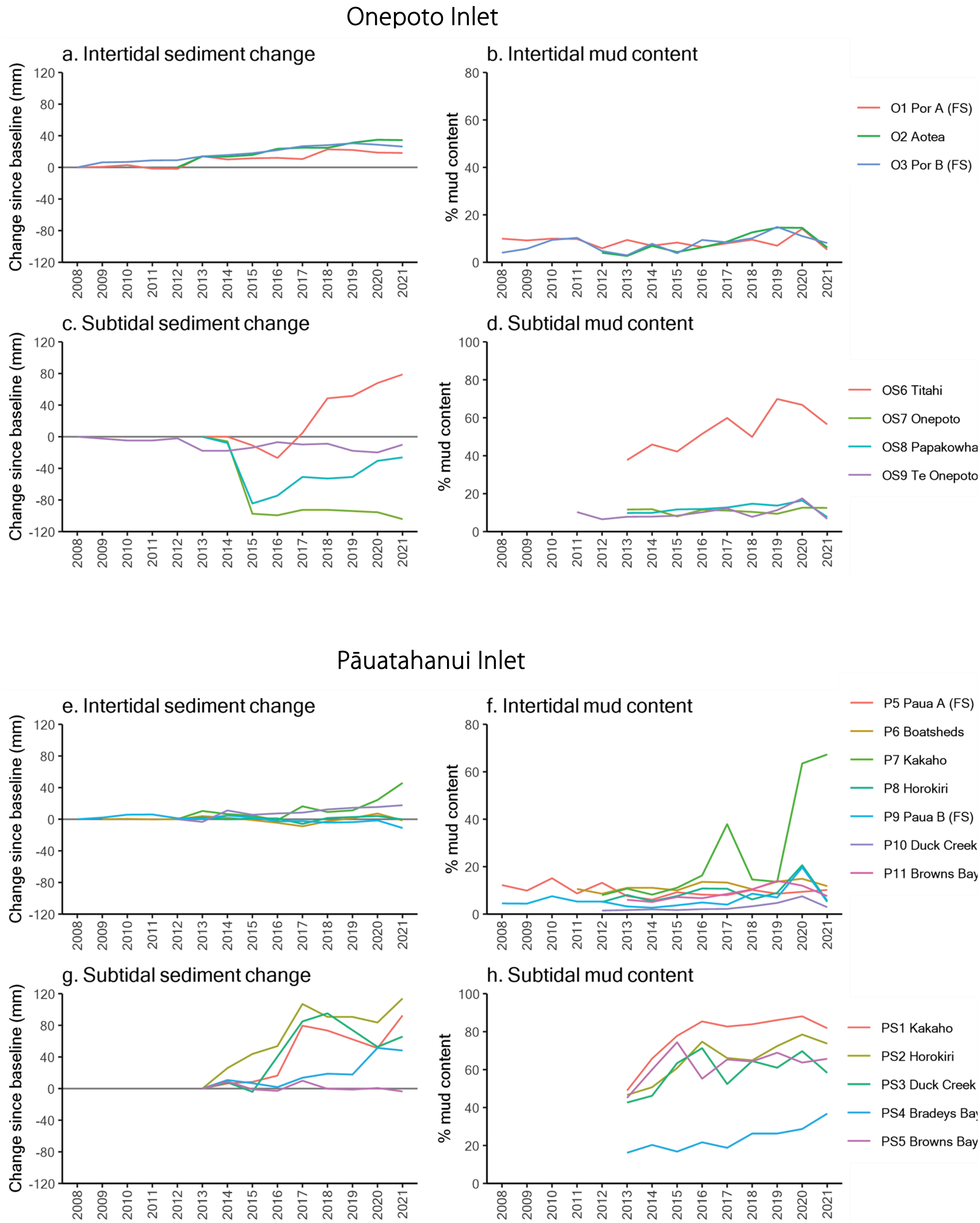


Fig. 4 Sediment depth change from baseline (year installed; mm) and sediment grain size for intertidal and subtidal sites in the Onepoto Inlet and the Pāuatahanui Inlet. *Note 2021 refers to Dec-2020 monitoring

3.4 SEDIMENT TRANSECTS

Table 4 and Fig. 5 show the position along transect lines where soft muds transition to firmer sediments between the 6 subtidal plate sites and the adjacent shore. Soft muds have extended toward the shoreline since monitoring began in 2013. Kakaho (PS1) and Horokiri (PS2), show the largest changes from the starting baseline, of 380m and 75m, respectively (Table 4). From Jan-2020 to Dec-2020, soft mud extended a further 75m toward the shoreline at Kakaho (PS1). This change is consistent with the increased sediment accretion observed at both the subtidal (PS1) and intertidal (P7) Kakaho sites (Figs 2 and 3). There was also an 18m increase in mud extent at Brown's Bay (PS5) between Jan-2020 and Dec-2020, and small decreases at Horokiri (PS2; 10m) and Bradey's Bay (PS4; 5m). Bradey's Bay had undergone a very dramatic change since Jan-2020 with the loss of >90% of the dense intertidal seagrass beds that have been present since at least 2007/2008. The specific cause of the seagrass loss remains unknown.

In the Onepoto Inlet, soft muds at Titahi (OS6) extended a further 21m toward the shoreline between Jan-2020 and Dec-2020, with a 66m increase in soft mud extent observed since 2013. These changes were consistent with muddy surficial sediments that were evident on the sediment surface at OS6 in Dec-2020 (see photo).

Slurry of mud overlying sand near Kakaho

Soft mud deposits to the edge of gravel beds near Ration Point

Sediment sample from Titahi (OS6), soft sandy mud

Horokiri Stream showing discoloured discharge during fine weather. Soft mud covered the stream bottom.

Table 4 Distance from subtidal plates to where soft mud transitions to firmer sediments closer to the shoreline, 2013-2021.

Site	Site No	Distance from subtidal plates to edge of soft mud (m)						Change from baseline (m)
		2013	2017	2018	2019	2020	2021	2013-2021
Kakaho	PS1	5	300	150	55	310	385	380
Horokiri	PS2	5	65	120	80	90	80	75
Duck Creek	PS3	5	10	15	23	20	21	16
Bradeys Bay	PS4	5	15	8	5	15	10	5
Browns Bay	PS5	5	40	28	35	25	43	38
Titahi	OS6	5	45	135	52	50	71	66

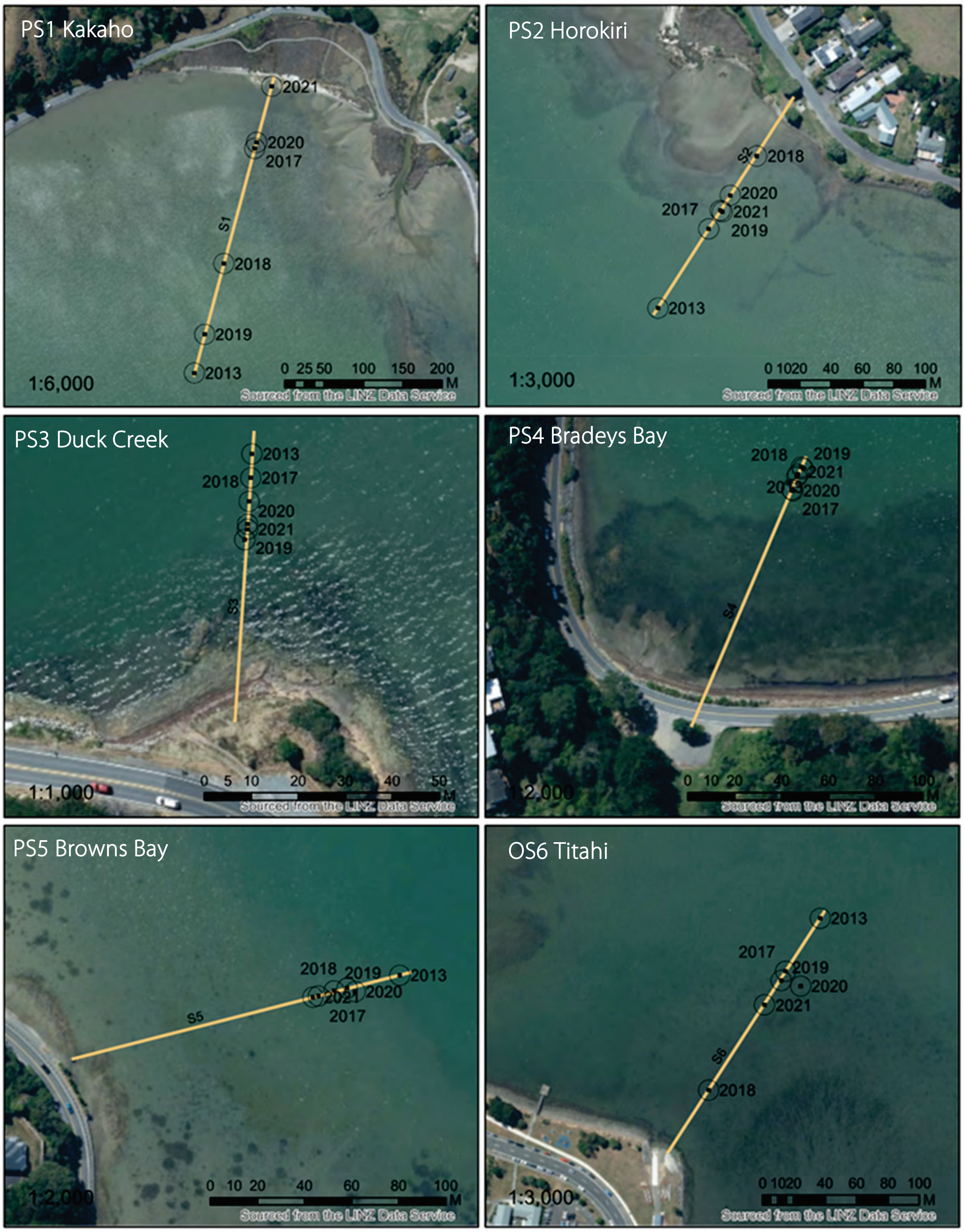


Fig. 5 Transects showing the distance from subtidal plate sites to where soft muds transitions to firmer sediments closer to the shoreline (2013, 2017, 2018, 2019, 2020 and 2021). See Table 4 for measured distances and Appendix 3 for transect coordinates.

3.5 MUD EXTENT

Due to the widespread deposition of soft muds recorded in the north and east of Pāuatahanui Inlet in Jan-2020, intertidal mud extent was re-mapped in those areas in Dec-2020. Table 5 and Fig. 6 show a comparison between Jan-2020 and Dec-2020.

Table 5 Hectares of intertidal mud in the northern Pāuatahanui Inlet of Te Awarua-o-Porirua Harbour.

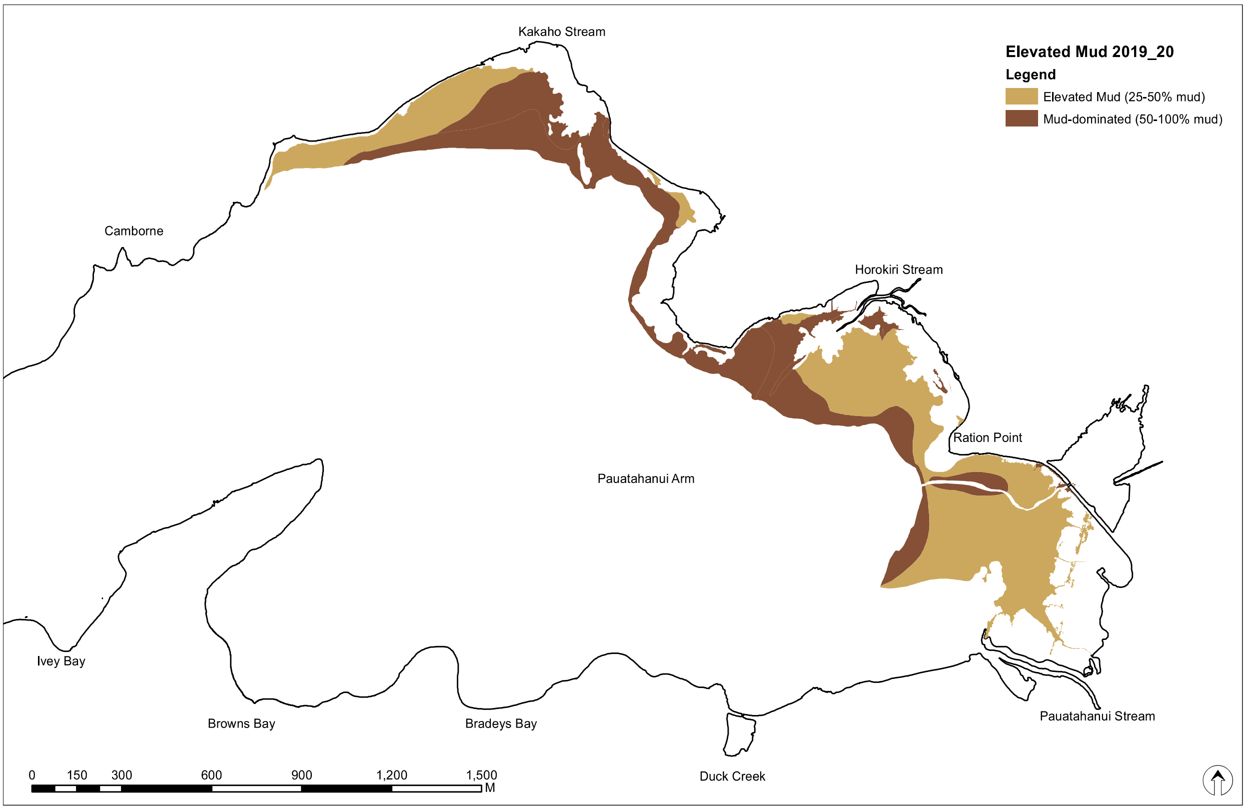
Hectares (ha)	Jan-20	Dec-20
Mud elevated (25-50% mud)	36.0	11.4
Mud-dominated (50-100% mud)	27.9	24.3
Total	63.9	35.7

The largest changes were a 68% (~25ha) decrease in the extent of mud-elevated (25-50% mud) substrate, with most reductions occurring on the intertidal flats near Horokiri and Pāuatahanui streams. It is not known exactly when the large mud deposits recorded in Jan-2020 were remobilised from these areas, however in early Dec-2020 two large rainfall events were recorded (Fig. 7). These two events caused peaks in stream flows and were also accompanied by strong winds. The flow events and associated wind-driven wave-action likely contributed the mobilisation of mud-elevated sediments at the mouth of Horokiri and Pāuatahanui streams.

While mud-elevated (25-50% mud) sediments decreased, there was little change to mud-dominated (50-100% mud) areas with only a 3.6ha decrease overall. However, mud-dominated sediments have been redistributed, with a localised expansion across the intertidal flats of Kakaho (Fig. 6), also reflected in the data from the Kakaho transects and intertidal (P7) and subtidal (PS1) plate measurements (Tables 2 and 4).

Therefore, while there has been some intertidal recovery from the widespread deposition of soft muds recorded in Jan-2020, there has also been degradation in new areas. Further, the changes must be viewed in the context of the whole estuary because any intertidal improvements likely reflect a degradation of subtidal areas. For example, a decrease in intertidal mud near Horokiri and Pāuatahanui streams (Fig. 6) was simultaneous with significant increases in deposition in adjacent subtidal areas: Kakaho (PS1; 41mm), Horokiri (PS2; 30mm) and Duck Creek (PS3; 13mm; Table 2 and Fig. 3). Such results indicate that mud mobilised from the intertidal zone is almost certainly being deposited in the deeper subtidal deposition zones of the estuary. This is supported by the 2019 bathymetric survey of Te Awarua-o-Porirua Harbour that showed accretion in the subtidal areas (Fig 5 and 7 in Waller, 2019).

Boatsheds (P6), Pāuatahanui Inlet



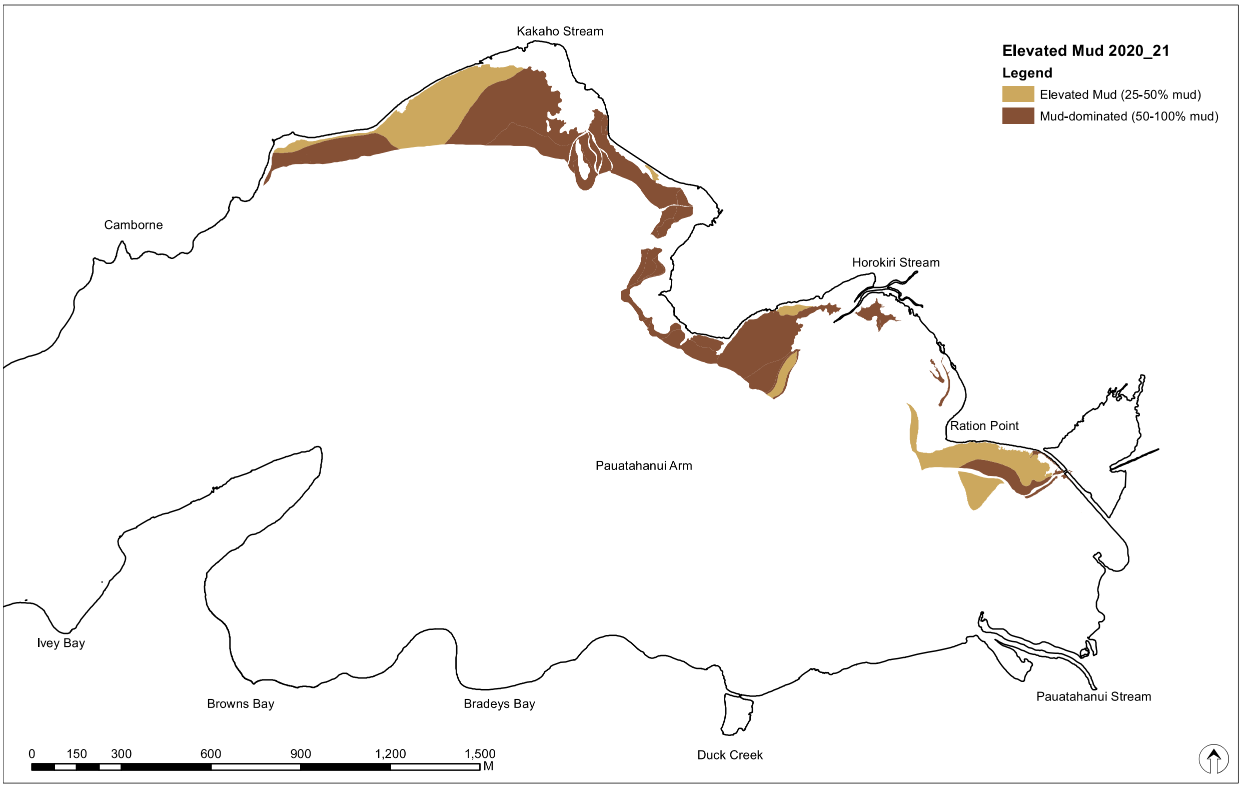


Fig. 6 Maps showing change in mud-elevated (>25-50% mud) and mud-dominated (>50% mud) sediment, Te Awarua-o-Porirua Harbour January 2020 (top) and Dec 2020 (bottom).

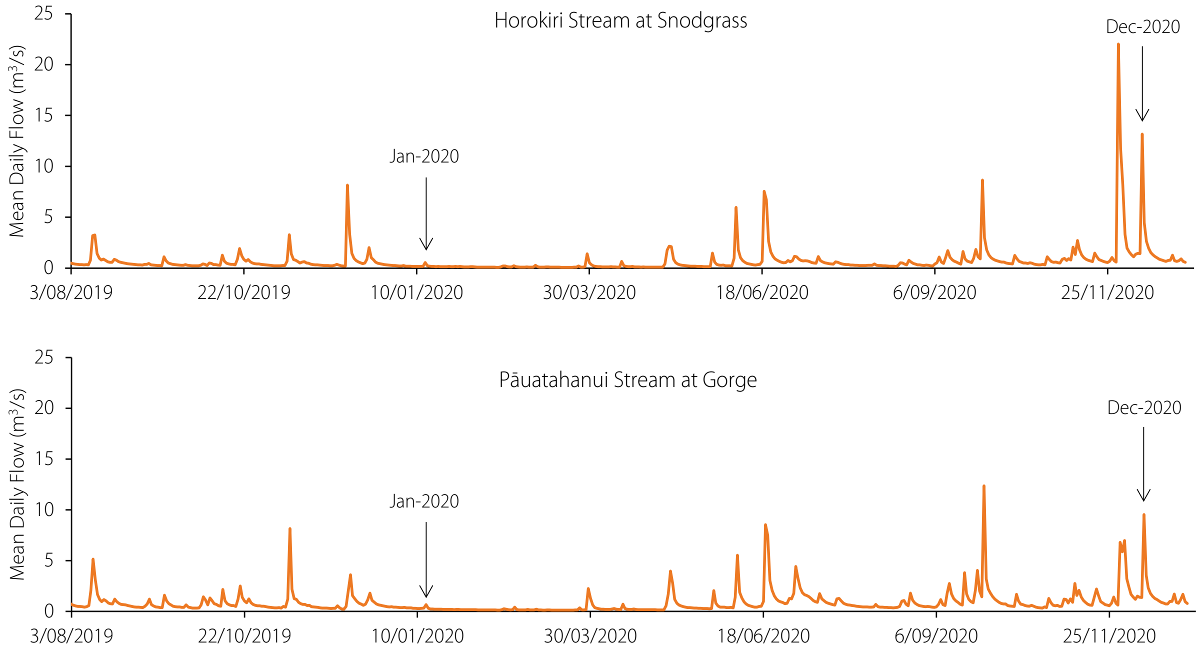


Fig. 7 Provisional mean daily flow at Horokiri Stream at Snodgrass and Pāuatahanui Stream at Gorge. Data from Greater Wellington Regional Council (https://graphs.gw.govt.nz/).

Kakaho (P7), Pāuatahanui Inlet

4. SYNTHESIS OF MONITORING DATA

While there have been some recent changes in sedimentation in the intertidal zone, the long term 5-year and 10-year mean annual sedimentation rates have been consistently in the 'fair' to 'poor' range exceeding the 1mm/y target set in the Te Awarua-o-Porirua Harbour Catchment Sediment Reduction Plan.

Of particular concern was the thick slurry of deposited fine sediment covering previously sandy intertidal flats at Kakaho (P7) (see photos). At this site sediment accrual had increased for the third consecutive year, with the 21.5mm of deposition between Jan-2020 and Dec-2020 the largest mean annual increase recorded for that site. At the same time, mud content increased from an already very high 63.5% to 67.3% and oxygenation was 'poor'.

There was strong anecdotal evidence that at least some of this material was recently deposited from the Kakaho Stream, presumably following a large rainfall event immediately prior to sampling (Fig. 7). This supports previous results and field observations indicating that event-related deposition (e.g. pulsed deposits from stream inputs during storms) is relatively common in Te Awarua-o-Porirua Harbour.

Such episodic sedimentation events caused by rainstorms or wind driven re-suspension can have lethal impacts on sediment dwelling animals because they cannot access food, oxygen, and nutrients (Townsend and Lohrer, 2015).

Local sediment conditions are also changed with increased mud content and poor oxygenation, which can have longer term impacts on the benthic community.

Elsewhere, Dec-2020 results showed erosion of mud-elevated intertidal sediments near the outlet of Horokiri and Pāuatahanui streams which coincided with a decrease in mean annual intertidal sedimentation rate and measured mud content over the preceding 11 months (Table 3 and Fig. 4).

Freshly deposited fine sediments and macroalgae (*Gracilaria*)

Widespread deposits of mud, Kakaho (P7), Pāuatahanui Inlet

View towards Kakaho (PS1), Pāuatahanui Inlet highlighting suspended sediment present in shallow water and wind driven re-suspension of fine sediments in the subtidal zone.

Previous monitoring has shown that subtidal areas in Te Awarua-o-Porirua Harbour are the primary deposition zones in the estuary. Longer term 5-year and 10-year mean annual sedimentation rates have been consistently 'poor'. The 10-year subtidal trend in the Onepoto Inlet is the exception but, as discussed earlier, is primarily an artefact of the baseline commencing shortly after a large deposition event. At the subtidal sites where deposition is prominent, sediments were characterised by a mud content well above the 'poor' threshold of >25% (Table 1), and low oxygenation (Table 3).

While the combined results described above summarise general trends, it is important to note that averaging data across sites carries a risk of obscuring the mechanisms causing accretion and erosion at the site-scale. For example, whereas sediment accrual depths at the Onepoto Inlet sites Titahi (OS6) and Te Onepoto (OS9) appear similar (Fig. 3 and 4c), the mechanisms causing these changes are different.

Titahi (OS6) is located within the relatively deep central basin of the estuary where mud-dominated sediments tend to readily settle and accumulate. Accretion (+10.9mm/y) was recorded in Dec-2020, with a mud content of 56.5% (aRPD 15mm), which represents significant degradation of the Harbour substrate. In contrast, Te Onepoto (OS9) is located closer to the Harbour entrance and is subject to strong tidal currents and dominated by mobile sands. Accretion of +9.8mm/y in Dec-2020 and a mud content of 6.7% (aRPD >150mm), reflects natural migration of sands and is likely to result in significantly fewer adverse ecological impacts than those associated with the high deposition of muds.

Wind driven resuspension Horokiri (P8), Pāuatahanui Inlet

In Jan-2020, widespread deposition of mud-dominated sediments was recorded in the northern and western Pāuatahanui Inlet. When re-mapped in Dec-2020, these areas indicated a decrease in mud extent in the intertidal zone of the Pāuatahanui Inlet near Horokiri and Pāuatahanui streams (Fig. 4 and 6). These intertidal areas were likely flushed clean as a consequence of recent high flow events in these streams (Fig. 7) in conjunction with resuspension of sediment by wind driven wave-action. However, at the same time, there was a significant increase in the deposition of soft muds at the subtidal sites adjacent to these areas (Kakaho, Horokiri and Duck Creek) indicating that fine sediments are readily remobilised from the intertidal zone and deposited in the subtidal zone.

Remobilisation of fine sediments and wind driven mixing in the Pāuatahanui Inlet

Stevens & Forrest (2020) summarised previous bathymetric surveys of the Harbour in 1974, 2009, 2014 and 2019, that estimate estuary-wide sedimentation rates and indicate ongoing and relatively rapid infilling of the subtidal Pāuatahanui Inlet. The results of these surveys are summarised in Table 6.

Table 6 Summary of sedimentation rates derived from bathymetric surveys (Stevens and Forrest, 2020). Coloured condition ratings are presented in Table 1.

Time period	Sedimentation rate (mm/y)	
	Pāuatahanui Inlet	Onepoto Inlet
1974 – 2009	9.1	5.7
2009 – 2014	0.4	1.0
2014 – 2019	10.3	8.8

The changes in sedimentation over the three time periods reflect;

- <u>1974-2009:</u> high accretion rates likely as the by-product of rapid urbanisation between 1970's to 1980's (Gibb & Cox, 2009).
- <u>2009-2014:</u> low accretion corresponding to less land development following the global financial crisis (ca 2008; Porirua City Council).
- <u>2014-2019:</u> high accretion rates likely owing to significantly increased land development including urban subdivision, the Transmission Gully motorway project, and forest harvesting in the catchment.

The general trend of increasing sedimentation across the Harbour has also been detected at the sediment plate sites (5-year mean; Table 2), with more recent increases in sedimentation likely due to significant land development in the catchment.

Both the most recent bathymetric survey (2019; Table 6) and the measured mean sedimentation rates greatly exceed the 'poor' threshold and the recommended ANZECC Default Guideline Value (2mm/yr) and highlight rapid and excessive sediment inputs to the Harbour.

The results are also consistent with NIWAs sediment load estimator which indicates the Current Sedimentation Rate is conservatively at least 5 times the Natural Sedimentation Rate expected for the estuary (Stevens & Forrest 2020).

High rates of measured deposition in Te Awarua-o-Porirua Harbour coincide with significant recent increases in land disturbance. It would appear that the measured increase in subtidal muds and the expansion of mud-dominated sediments across the intertidal flats is a direct consequence of catchment sediment inputs.

Sediment sources to Te Awarua-o-Porirua Harbour, while varied over time, are linked to land development in the catchment. Subdivisions for urban development, earthworks, run-off from pastural lands and exotic forest clearing in the catchment also contribute to the total sediment load.

More recently, the Transmission Gully motorway project, a known source of sediment to Te Awarua-o-Porirua Harbour has likely contributed to further sedimentation in the estuary. The project has recorded several trigger events (elevated turbidity in streams) in Horokiri stream, Ration Stream, Pāuatahanui steam and Duck Creek since the beginning of the project. These trigger events follow high rainfall that causes failures in sediment controls. Post-event inspections have identified sediment inputs from pond discharges, slips and scouring of drains (e.g. Strange 2020a; 2020b). Increased deposition of fine sediments has been detected in the Transmission Gully consent monitoring of the estuary, with significant increases in silt and clay (compared to the 2013 baseline) recorded at sites in the Pāuatahanui Inlet in both the intertidal and subtidal zones (Strange 2020a). The likely volume of sediment inputs from these sources, and potential impacts on the estuary, do not appear to have been assessed.

Overall, the monitored changes, particularly those in the Pāuatahanui Inlet, indicate estuary quality has declined over time, and significantly worsened over the past 5 years. The trend of increasing mud content, an expanding spatial boundary of soft mud in the Kakaho, and a net trend of increasing deposition, particularly in the subtidal zone, serve a clear message that there are excessive sediment inputs to the estuary.

Fine sediments smothering the intertidal zone at Kakaho (P7)

5. SUMMARY

Current sedimentation rates remain elevated in the Te Awarua-o-Porirua, particularly in the Pāuatahanui Inlet in both the intertidal and subtidal zones. The highest rates, particularly in the subtidal zones, are commonly associated with high mud content (>25% mud) and poor sediment oxygenation (<10mm). Adverse ecological effects are likely occurring at these high levels.

Under the current situation, the management goals for the estuary are not 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 Rūnanga Toa Rangatira and other key agencies with interests in Te Awarua-o-Porirua Harbour and the 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.

Fine sediment at Horokiri

6. RECOMMENDATIONS

The Dec-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 water clarity in the Harbour. It is recommended that monitoring continue as outlined below:

- 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.
- Considering the rapid changes recorded recently from sediment plate work, schedule estuary-wide bathymetric surveys at 5-yearly intervals to determine the extent of harbour shallowing.
- Considering the significant recent mud deposition, and because there is a clear cause and effect relationship between land disturbance and sediment-related impacts in estuaries, a comprehensive investigation of sediments sources, land use change data and temporal changes in catchment sediment loads should be carried out. This work should include an assessment of whether current mitigations are sufficient to reduce sediment loads enough to meet the objectives for Te Awarua-o-Porirua.

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APPENDICES

APPENDIX 1. SEDIMENT ANALYTICAL METHODS AND RESULTS

Hill Laboratories
TRIED, TESTED **AND TRUSTED**

R J Hill Laboratories Limited
28 Duke Street Frankton 3204
Private Bag 3205
Hamilton 3240 New Zealand

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T +64 7 858 2000
E mail@hill-labs.co.nz
W www.hill-laboratories.com

Certificate of Analysis

Client:	Salt Ecology Limited	**Lab No:**	2496173 SPv1
Contact:	Leigh Stevens	**Date Received:**	17-Dec-2020
	C/- Salt Ecology Limited	**Date Reported:**	12-Jan-2021
	21 Mount Vernon Place	**Quote No:**	96904
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	GRWC- Porirua Harbour
		Submitted By:	Leigh Stevens

Sample Type: Sediment

Sample Name:		ONEP-WELL-1 11-Dec-2020 6:30 pm	ONEP-WELL-2 13-Dec-2020 7:00 pm	ONEP-WELL-3 14-Dec-2020 7:00 am	ONEP-WELL-S6 13-Dec-2020 6:00 pm	ONEP-WELL-S7 13-Dec-2020 6:30 pm
Lab Number:		2496173.1	2496173.2	2496173.3	2496173.4	2496173.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	72	72	72	59	79
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	1.6	7.4	4.4	0.3	0.6
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	93.1	86.4	87.4	43.2	86.9
Fraction < 63 µm	g/100g dry wt	5.3	6.2	8.1	56.5	12.5

Sample Name:		ONEP-WELL-S8 13-Dec-2020 6:45 pm	ONEP-WELL-S9 13-Dec-2020 7:00 pm	PAUA-WELL-5 13-Dec-2020	PAUA-WELL-6 13-Dec-2020 6:00 pm	PAUA-WELL-7 13-Dec-2020 3:00 pm
Lab Number:		2496173.6	2496173.7	2496173.8	2496173.9	2496173.10
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	69	75	73	73	53
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	0.7	4.8	1.6	4.7	14.8
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	91.6	88.6	88.1	83.4	17.9
Fraction < 63 µm	g/100g dry wt	7.7	6.7	10.2	11.8	67.3

Sample Name:		PAUA-WELL-8 13-Dec-2020 6:00 pm	PAUA-WELL-9 13-Dec-2020 3:30 pm	PAUA-WELL-10 13-Dec-2020 4:00 pm	PAUA-WELL-11 13-Dec-2020 4:30 pm	PAUA-WELL-S1 13-Dec-2020 2:30 pm
Lab Number:		2496173.11	2496173.12	2496173.13	2496173.14	2496173.15
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	78	77	77	78	60
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	3.3	2.3	3.0	7.9	0.1
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	91.1	92.5	94.1	84.5	18.0
Fraction < 63 µm	g/100g dry wt	5.6	5.2	2.9	7.6	81.8

Sample Name:		PAUA-WELL-S2 13-Dec-2020 3:00 pm	PAUA-WELL-S3 13-Dec-2020 3:30 pm	PAUA-WELL-S4 13-Dec-2020 4:00 pm	PAUA-WELL-S5 13-Dec-2020 4:30 pm	
Lab Number:		2496173.16	2496173.17	2496173.18	2496173.19	
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	59	64	65	62	-
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	0.2	2.4	0.8	1.3	-
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	26.1	39.3	62.4	33.0	-
Fraction < 63 µm	g/100g dry wt	73.7	58.3	36.8	65.7	-

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			
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	1-19
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	1-19
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	1-19
Fraction < 63 µm	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-19

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

Testing was completed between 08-Jan-2021 and 12-Jan-2021. For completion dates of individual analyses please contact the laboratory.

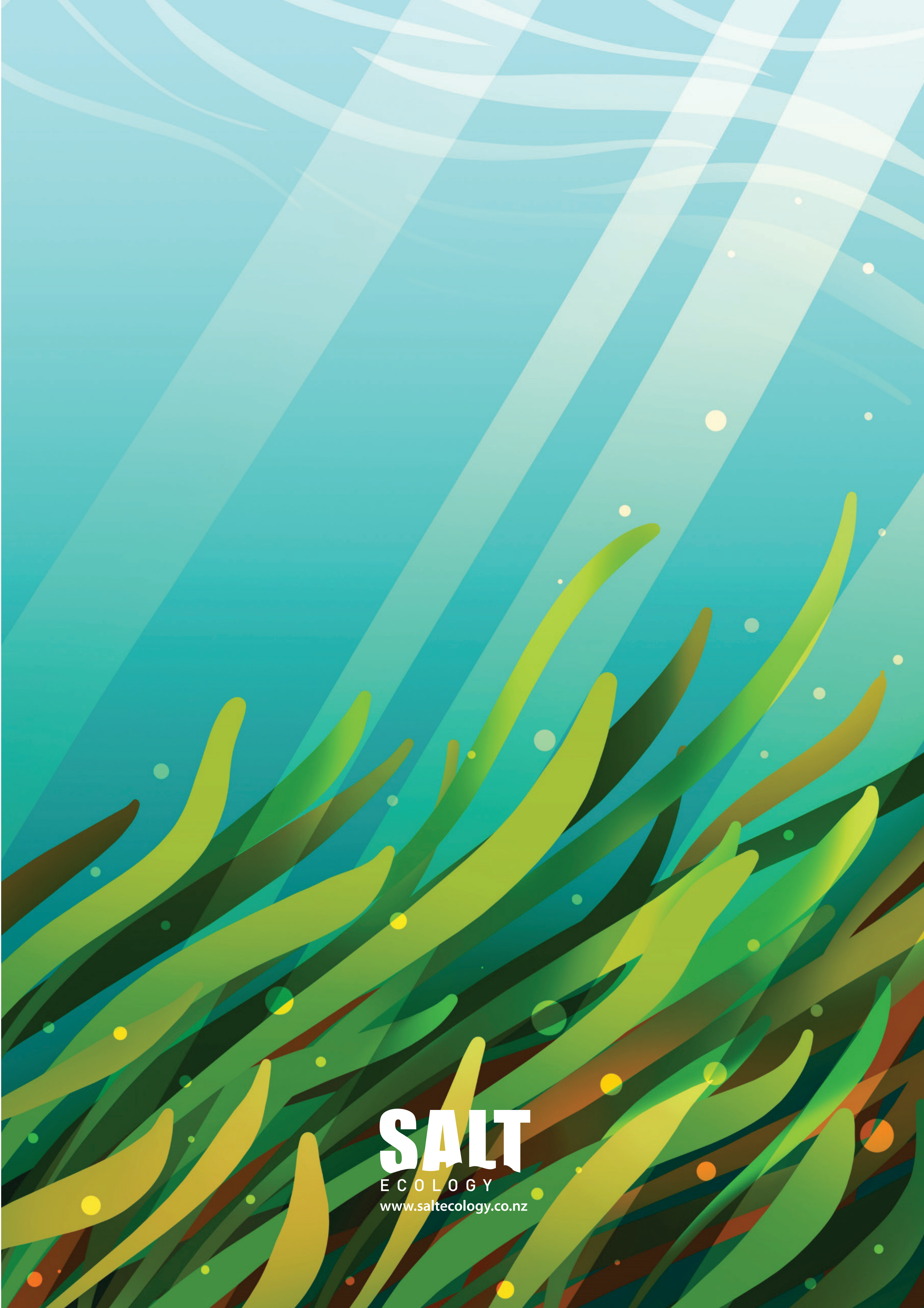
Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the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

Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 2. TRANSECT COORDINATES

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

	Transect Start (subtidal plate)		Subtidal	Transect End (estuary edge)		Bearing (start to end)
Site	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°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