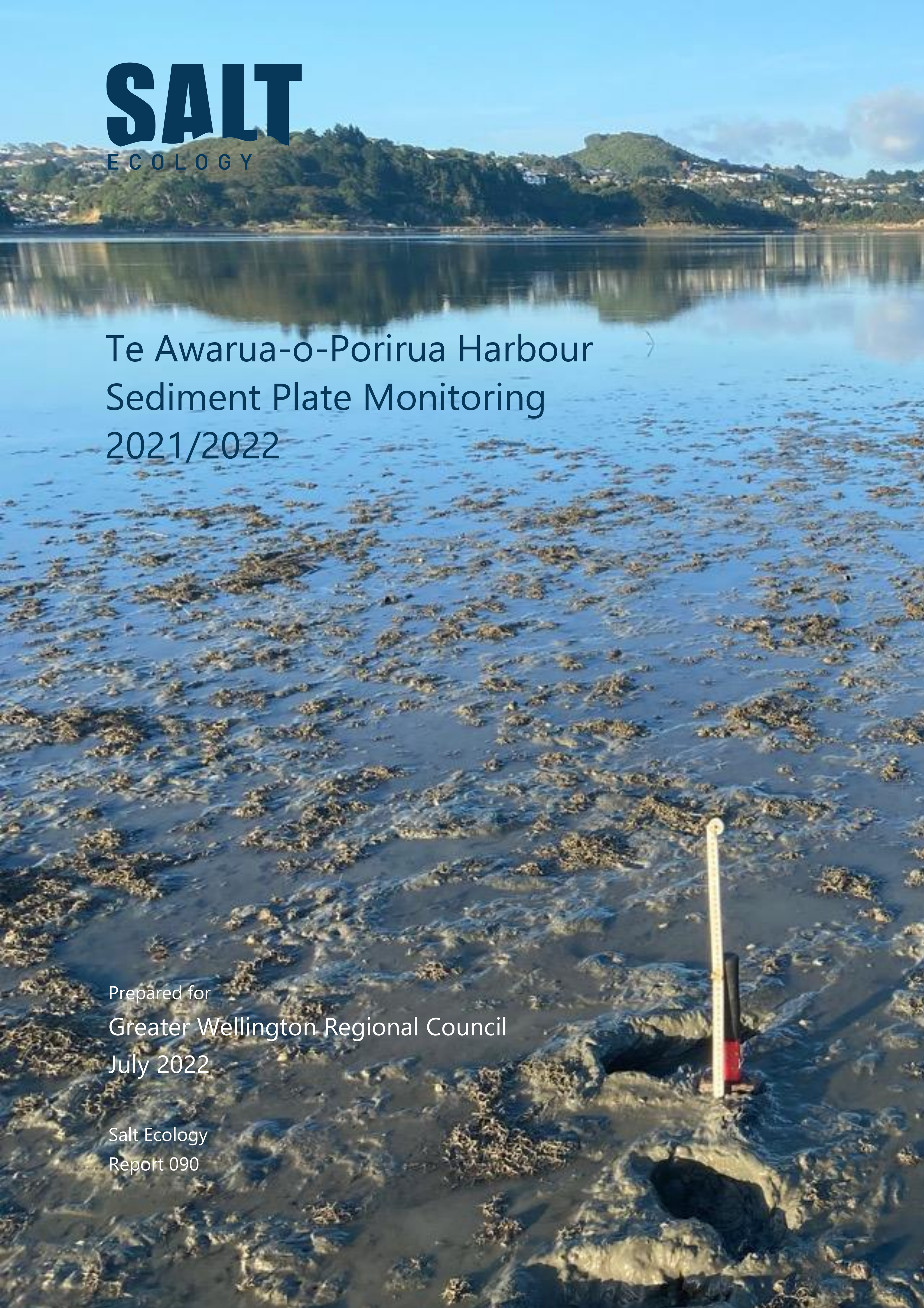

SALT ECOLOGY

Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2021/2022

Prepared for

Greater Wellington Regional Council

July 2022

Salt Ecology

Report 090

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Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2021/2022

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for

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July 2022

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GLOSSARY

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

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Many thanks to Sabine O'Neill-Stevens (Salt Ecology) for assisting in the field, and Keryn Roberts (Salt Ecology), Megan Melidonis and Megan Oliver (GWRC) for reviewing the draft report.

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SUMMARY

As part of ongoing work monitoring and providing scientific advice for 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 are measured on six fixed transects adjacent to subtidal sites. In January 2020, widespread deposition of mud-dominated sediments was recorded in the northern and western Pāuatahanui Inlet. In December 2020, a decrease in the spatial extent of intertidal mud was coincident with an increase in subtidal deposition, suggesting mud mobilised in the intertidal zone was likely deposited in nearby subtidal areas. The current report presents the results of the 2021/2022 annual monitoring, undertaken between 19-22 January 2022. The report compares findings to previous monitoring results and established or provisional estuarine health metrics ('condition ratings').

KEY FINDINGS

Current sediment accrual rates in Te Awarua-o-Porirua Harbour remain elevated, particularly in the Pāuatahanui Inlet. Between December 2020 and January 2022, there was high accretion at Onepoto subtidal sites OS6 and OS7, at Pāuatahanui intertidal sites P8 and P9, and at subtidal sites PS2, PS4 and PS5, all with a 'poor' condition rating. High accretion is commonly associated with high mud contents (>25% mud) and poor sediment oxygenation (<10mm) and is likely causing adverse ecological effects.

The 10-year mean annual sedimentation rate results (see table) show high deposition in the Pāuatahanui and Onepoto subtidal zones, and moderate increases in the intertidal zones. The 5-year results show increased deposition in Onepoto subtidal and Pāuatahanui intertidal zones. The decreased subtidal sedimentation in Pāuatahanui reflects erosion following the substantial deposition between 2016 and 2017. Sediment conditions remain severely degraded.

Mean annual sedimentation rate (mm/y)		
Zone	10-y	5-y
Onepoto (intertidal)	+1.9	+0.4
Onepoto (subtidal)*	+2.3	+12.8
Pāuatahanui (intertidal)	+1.5	+2.8
Pāuatahanui (subtidal)	+6.8	+0.2

*Sites OS6 and OS7 only

Very Good	Good	Fair	Poor

There has been some recovery from the widespread intertidal deposition of soft muds recorded in January 2020 in Pāuatahanui Inlet near Kakaho and Ration Point, but increased deposition was evident at Horokiri (see photo), along with a trend of increasing intertidal sediment mud content.

Mud deposits on the Horokiri intertidal flats, January 2022

Under the current situation, the management goals set out in the Te Awarua-o-Porirua Harbour Catchment Sediment Reduction Plan are not 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 January 2022 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 plate monitoring continues annually, and estuary-wide bathymetric surveys are scheduled at 5-yearly intervals. A comprehensive assessment of sediment 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 plate monitoring; a measure of sediment accrual and erosion in the estuary, in addition to substrate type and condition (e.g. Stevens et al. 2020, Roberts et al. 2021).

1.2 BACKGROUND ON TE AWARUA-O-PORIRUA HARBOUR

Background information on Te Awarua-o-Porirua Harbour, described in previous reports (e.g. Forrest et al. 2020; Stevens & Forrest 2020; Roberts et al. 2021), is summarised below.

The Harbour is a large (807ha, Fig. 1), well-flushed estuary that 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. The Harbour is fed by several small streams including the Kakaho, Horokiri, Pāuatahanui, Duck, and Onepoto.

Residence time in the estuary is less than 3 days, however, compared to many of 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 in 2020 supported extensive areas (48ha) 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 salt marsh 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 to undertake annual sediment monitoring at established sites in Te Awarua-o-Porirua Harbour in the 2021/2022 summer (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 not only the depth of muddy sediments but also their spatial extent, 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.

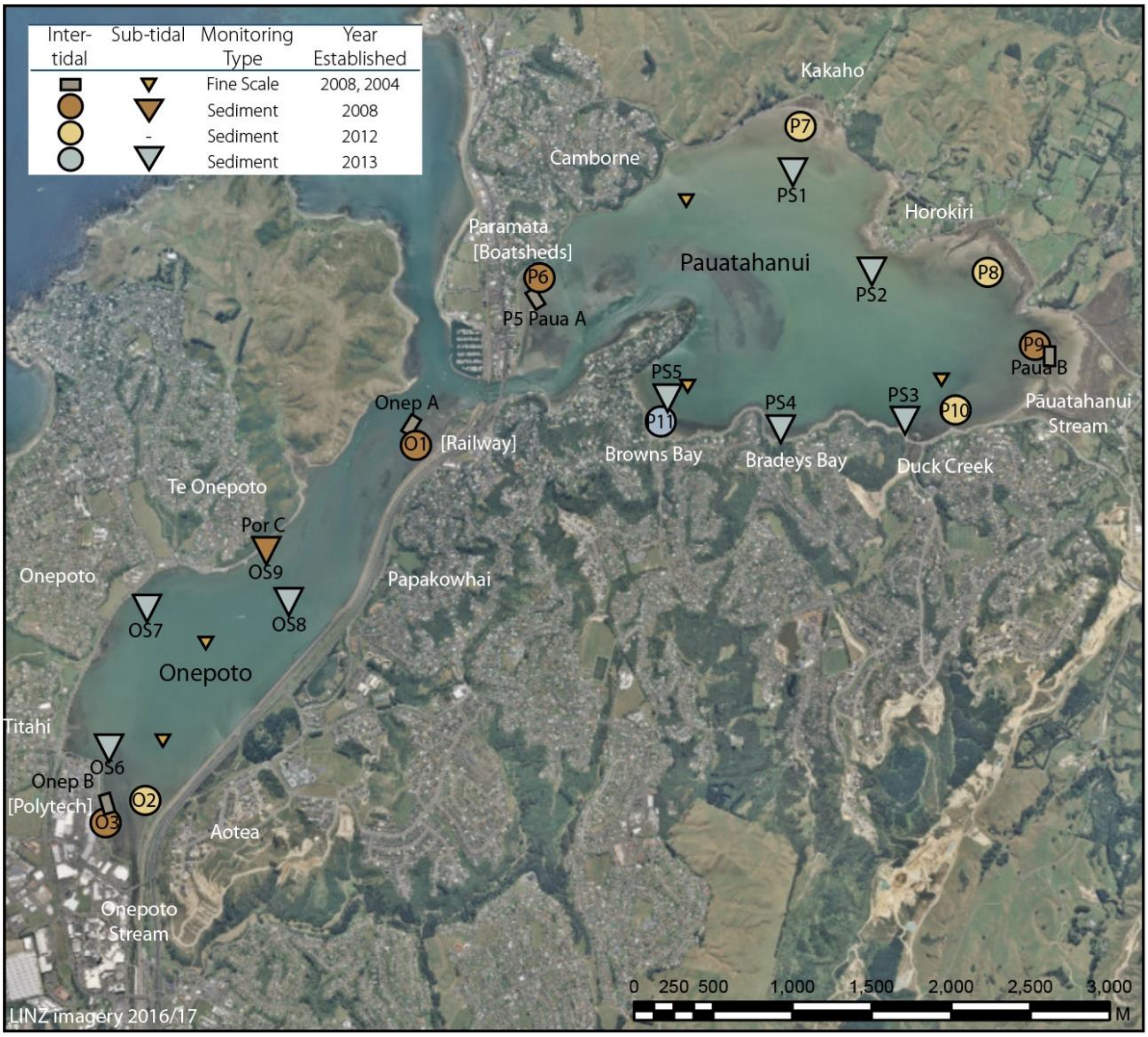


Fig. 1. Location of the 18 buried sediment plate sites (indicated by the alphanumeric sequence on the map) in Te Awarua-o-Porirua Harbour. Also shown are the location of 4 intertidal (rectangles) and 5 subtidal (small triangles) "fine scale" sites at which other monitoring is undertaken at ~5-yearly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

The current report presents the results for the 2021/2022 annual monitoring carried out from 19-22 January 2022 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, also Fig. 1).

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 also altered to standardise the layout for easier relocation and reduce peg numbers in the estuary. In 2022 the plate layout was standardised at the two fine scale sites in the Onepoto Inlet (Onep A and Onep B.

While normally only measured annually, additional sediment plate measurements were made in December 2017 immediately following a significant deposition event, and changes in the mud extent between six subtidal plate sites and the adjacent shoreline were assessed. In addition, in January 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 December 2020, and again in January 2022, these areas were re-mapped using broad scale assessment methods to assess net changes over the previous 12 months.

Installation of plates at site Onep B, Onepoto 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 frame was repositioned twice more by carefully lifting, rotating 30° clockwise, and allowing it to resettle. An inflatable boat ok kayak is used to reach some subtidal sites.

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.

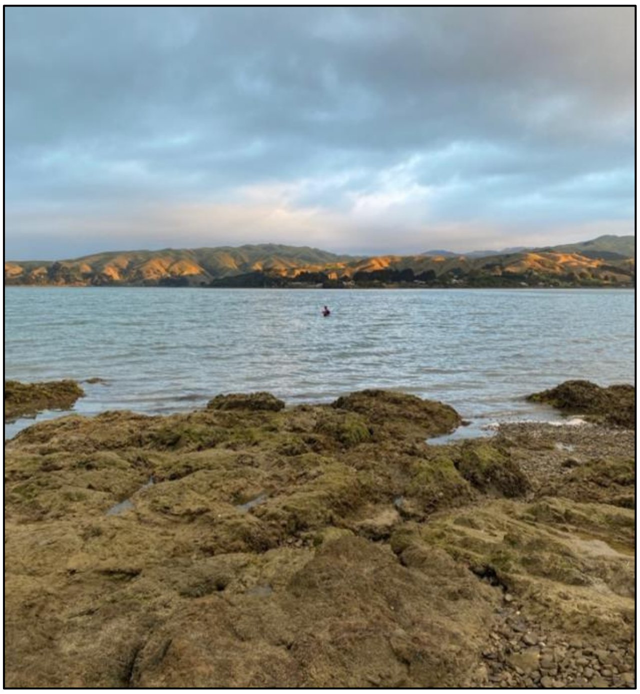
2.2.3 Sediment oxygenation

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 (PS1, PS2, SP3, PS4, PS5 and OS6) and the shoreline, and the distance along the transect where the soft mud transitioned to firmer sediments was measured (Fig. 5, Appendix 3).

In December 2020 and January 2022, 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 in the Onepoto Inlet (site OS7) and at Duck Creek, Pāuatahanui Inlet (Site PS3)

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 4.0.5 (R Core Team 2021).

Sediment samples sent for grainsize analysis (wet sieving) 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:

- for % mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016);
- for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012);
- < 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 overlying gravel and cobble near Site PS2, Motukaraka Point, Pāuatahanui Inlet

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

Condition 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. Between December 2020 and January 2022, fine sediment accretion was high at Onepoto subtidal sites OS6 and OS7, and at Pāuatahanui intertidal sites P8 and P9 and subtidal sites PS2, PS4 and PS5 (see Fig. 1). All sites rated 'poor' for sediment deposition applying the criteria in Table 1. Accretion at Onepoto site O1, near the Harbour entrance, and Pāuatahanui site P10 near Duck Creek was caused by the movement of mobile sand ridges pushed onto the site from nearby areas by wave and current action and does not reflect site degradation.

Sediment erosion was evident at Onepoto intertidal sites O2 and O3. These sites are located close to the Porirua Stream mouth and are subjected to occasional flood scouring. In Pāuatahanui, there was erosion of previously deposited soft muds at Kakaho sites P7 and PS1, and Duck Creek site PS3.

Temporal and spatial variability is reflected in the long term 5-year and 10-year mean annual sedimentation rates. The 10-year results show very high deposition in the Pāuatahanui and Onepoto subtidal zones, and moderate increases in the intertidal zones. The 5-year results show a slightly different pattern with increased subtidal deposition in Onepoto, but relatively little overall change in Pāuatahanui. The latter change largely reflects erosion following the substantial deposition of sediment at Duck Creek, Kakaho and Horokiri between 2016 and 2017. The 5-year results also show an increase in intertidal deposition at the Pāuatahanui intertidal sites.

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.

Inlet	Zone	Site, Zone, #, Name	Baseline Year#	Change in mean sediment depth (mm/y) 2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean annual sedimentation rate (mm/y) Site (10-y)^	Zone (10-y)•	Site (5-y)	Zone (5-y)•
Onepoto Inlet	Intertidal	O1 Por A (FS)	2008	0.8	2.3	-4.5	-0.2	14.3	-4.2	1.5	0.5	-1.5	12.0	-0.7	-3.2	-0.4	5.8	+2.4		+2.7	
Onepoto Inlet	Intertidal	O2 Aotea	2012					12.3	-0.2	2.3	7.8	1.5	-0.2	6.5	3.7	-0.4	-4.9	+2.8	+1.9	+0.9	+0.4
Onepoto Inlet	Intertidal	O3 Por B (FS)	2008	7.0	0.5	1.0	0.3	4.3	1.8	2.3	4.0	5.0	0.8	2.4	-1.8	-2.2	-11.2	+0.5		-2.4	
Onepoto Inlet	Subtidal	OS6Titahi	2013						0.0	-11.0	-16.0	32.0	43.0	3.0	16.0	10.0	57.0	+14.9	+2.3•	+25.8	+12.8•
Onepoto Inlet	Subtidal	OS7Onepoto	2013						-6.0	-92.0	-2.0	7.0	0.0	-1.5*	-1.5	-8.0	10.0	-10.4		-0.2	
Onepoto Inlet	Subtidal	OS8Papakowhai	2013						-8.0	-77.0	10.0	24.0	-2.0	2.0	20.0	4.0	*	-3.4	-2.2•	+6.0	+2.7•
Onepoto Inlet	Subtidal	OS9Te Onepoto	2008	-2.6*	-2.4	0.0	3.0	-14.0	0.0	4.0	7.0	-3.0	1.0	-9.0	-2.0	9.0	-2.0	-0.9		-0.6	
Pāuatahanui Inlet	Intertidal	P6 Boatsheds	2009		0.5	-0.7	0.3	3.5	-2.0	-3.0	-3.5	-4.5	6.3	4.0	5.7	-8.0	nd	-0.2		+2.0	
Pāuatahanui Inlet	Intertidal	P7 Kakaho	2012					9.3	-4.0	-2.0	-5.7	17.8	-7.0	2.0	12.9	19.8	-10.9	+3.2		+3.4	
Pāuatahanui Inlet	Intertidal	P8 Horokiri	2012					2.0	-2.5	1.3	0.0	-7.0	7.3	1.3	1.3	-3.9	7.5	+0.7	+1.5	+2.7	+2.8
Pāuatahanui Inlet	Intertidal	P9 Paua B (FS)	2008	2.3	3.8	0.3	-5.2	-0.7	4.5	-2.5	-5.0	0.3	-1.7	0.5	2.2	-8.8	19.1	+0.8		+2.2	
Pāuatahanui Inlet	Intertidal	P10 Duck Creek	2012					-3.0	14.8	-5.5	1.8	1.0	4.0	2.0	1.0	2.1	9.7	+2.8		+3.8	
Pāuatahanui Inlet	Subtidal	PS1 Kakaho	2013						6.6	2.0	8.0	64.0	-6.0	-11.1*	-10.9	38.0	-37.0	+6.0		-5.4	
Pāuatahanui Inlet	Subtidal	PS2 Horokiri	2013						26.4	18.0	10.0	54.0	-16.0	0.0	-7.0	28.0	5.0	+13.2		+2.0	
Pāuatahanui Inlet	Subtidal	PS3 Duck Creek	2013						8.0	-12.0	44.9*	45.1	10.0	-21.2*	-20.8	12.0	-4.0	+6.9	+6.8	-4.8	+0.2
Pāuatahanui Inlet	Subtidal	PS4 Bradeys Bay	2013						11.0	-4.0	-5.0	12.0	5.0	-1.0	33.0	-3.0	16.0	+7.1		+10.0	
Pāuatahanui Inlet	Subtidal	PS5 Browns Bay	2013						9.2	-10.0	-2.0	13.0	-10.0	-1.0	2.0	-4.0	10.0	+0.8		-0.6	

Ratings (refer to Table 1 for details)

Very good	Good	Fair	Poor

#Calendar year baseline commenced. •Subtidal Onepoto sites grouped to reflect the central basin sites (OS6 & OS7) and those near the entrance in high current zones (OS8 & OS9) where sediment changes are driven by mobile sand rather than fine mud.

*No measurement taken for that year; change in mean sediment depth calculated over a two-year period 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. 9-year mean for some sites).

Note: The current report presents annualised change calculated from the specific days between measurements, with the same correction applied to data collected in previous years (when nominal annual change was reported). nd = no data, site discontinued

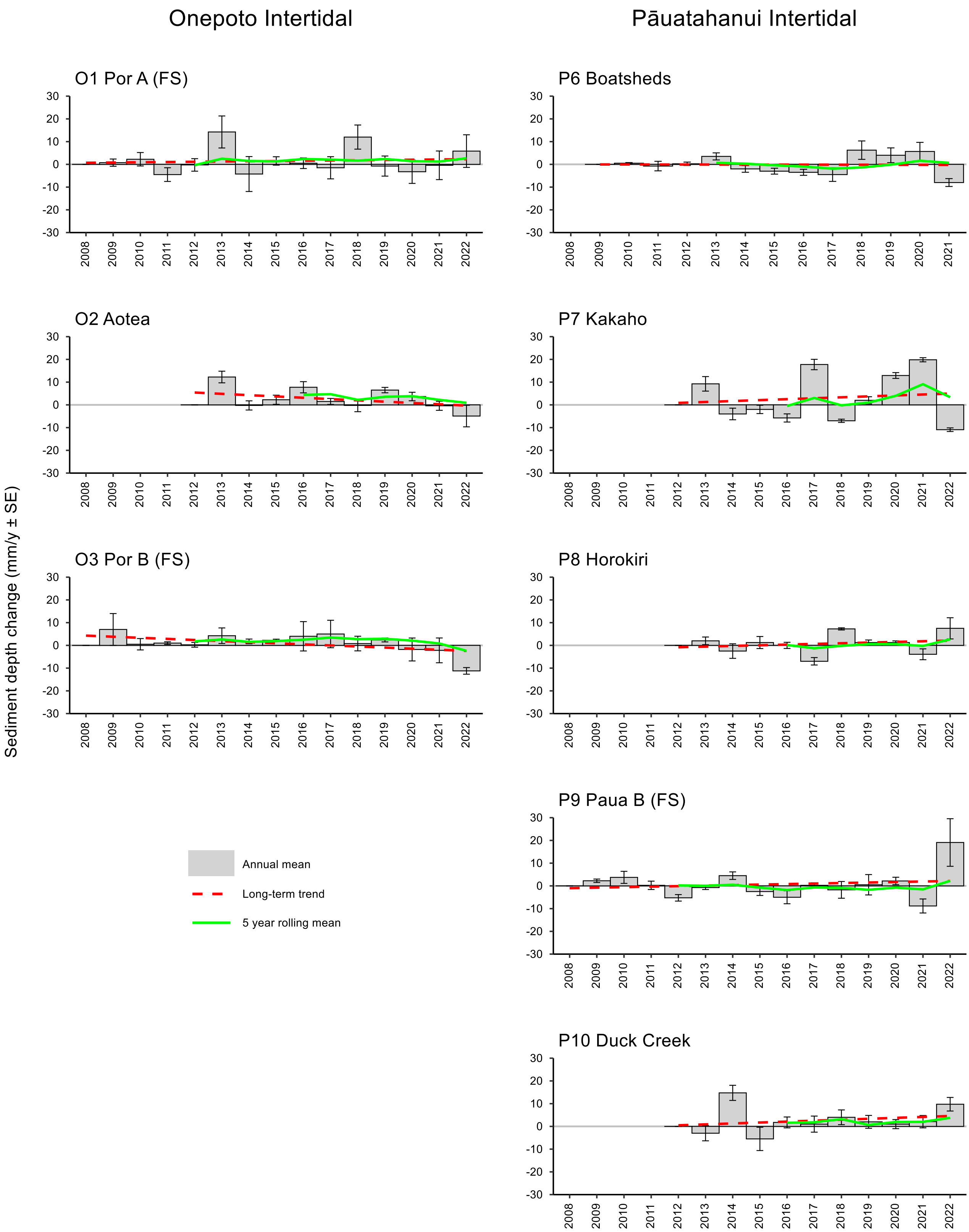


Fig. 2. Mean annual change in sediment depth (mm/y ± SE) at intertidal sites in the Onepoto and Pāuatahanui Inlets of Te Awarua-o-Porirua Harbour.

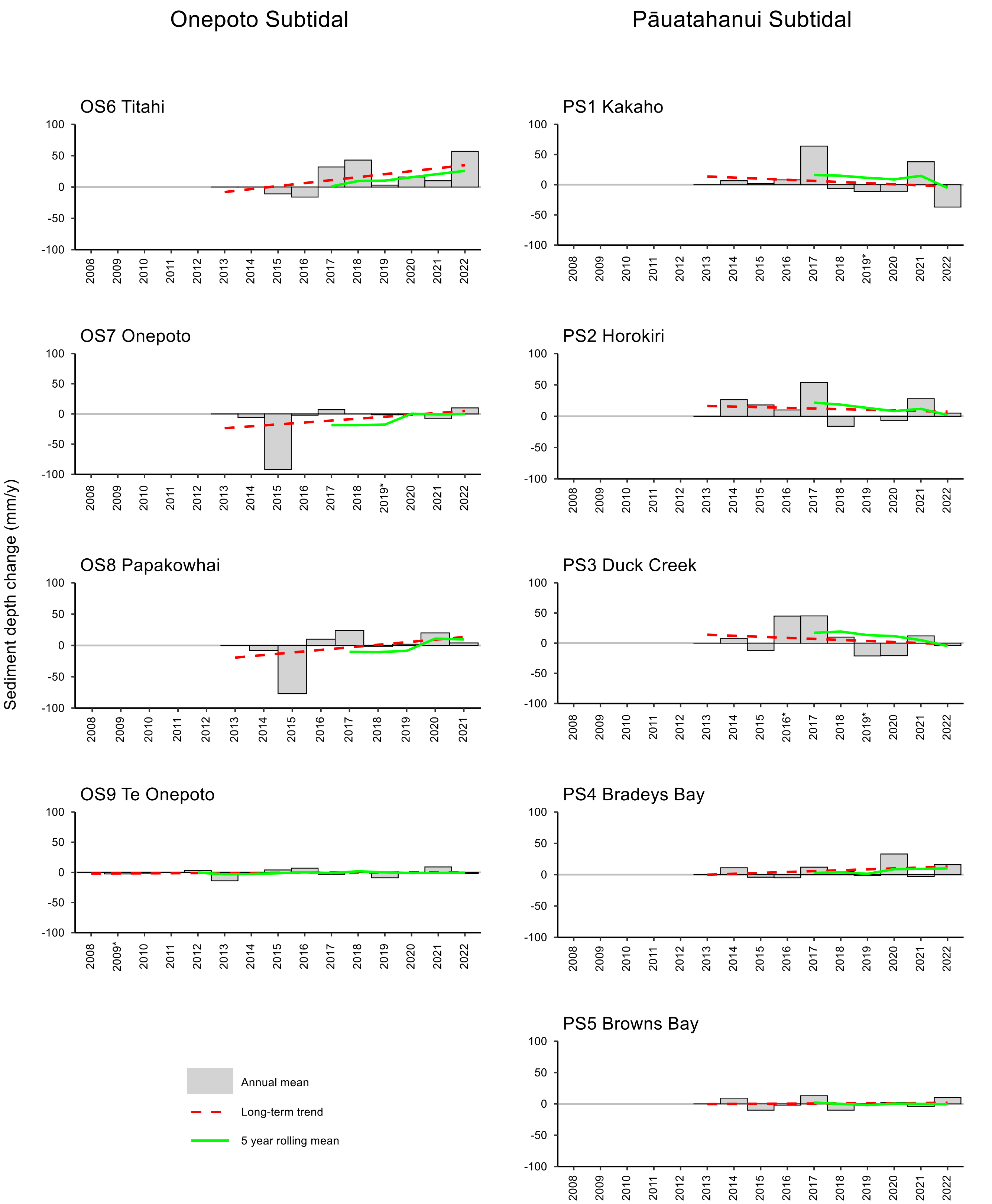


Fig. 3. Mean annual change in sediment depth (mm/y) at subtidal sites in the Onepoto and Pāuatahanui Inlets of Te Awarua-o-Porirua Harbour. Note scale ±100mm/y in comparison to ±30mm/y for the intertidal plates.

Despite recent erosion, the intertidal flats and shallow subtidal zone at Kakaho (P7 and PS1) in the Pāuatahanui Inlet remain heavily impacted by soft muds (see photos below) deposited following intensive rain events in 2017, January 2020 and December 2020 (Fig. 2 and Fig. 4).

Soft muds in the intertidal flats near Kakaho (PS1), Pāuatahanui Inlet

Soft muds were readily re-suspended in shallow water near Kakaho (PS1), Pāuatahanui Inlet

Paua B (P9), Pāuatahanui Inlet

Erosion recorded in December 2020 at Horokiri (P8) and Paua B (P9) has not continued, with 6-17mm of accretion recorded in January 2022. At both sites it appeared that subtidal muds may have been remobilised onto the intertidal flats as there was no direct indication of catchment inputs at the time of sampling, e.g. input streams were not laden with fine sediment.

Fig. 3 shows erosion at the subtidal sites in the Onepoto Inlet from 2013 to 2015, followed by a trend of increasing deposition. In January 2022, there was further deposition of fine muds at Titahi (OS6) and Onepoto (OS7) in the central basin of the inlet. In contrast, the more strongly tidally flushed Te Onepoto (OS9) close to the Harbour entrance, continued to show little change compared to other sites within Onepoto Inlet. No measurement was made at Papakowhai (OS8) due to the presence of a large mobile sand ridge over the sediment plate. As regular sediment changes at this site are unrelated to fine sediment impacts, which are the focus of the monitoring programme, it is recommended that this site be excluded from ongoing monitoring.

In the Pāuatahanui Inlet, subtidal accretion was recorded in January 2022 at Horokiri (PS2), Bradeys Bay (PS4) and Brown's Bay (PS5). There was minor erosion at Duck Creek (PS3) and a relatively large reduction in sediment (34mm) at Kakaho (PS1). At all sites, sediments comprised fine soft muds which appear to be widespread throughout the subtidal reaches of the inlet.

50mm deep deposits of soft mud on the intertidal flats at Horokiri, with the nuisance macroalgae *Agarophyton* spp. beginning to establish

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.

With respect to mud content, all intertidal sites in the Pāuatahanui Inlet were rated 'fair' to 'good' (Table 3) and had become muddier since December 2020 (Fig. 4f) The exception was Kakaho (P7) which had the highest mud content (29.2% mud; a condition rating of 'poor'), although this had decreased from 67.3% in December 2020, consistent with a large reduction in sediment at the site (Table 2, Fig. 2). The intertidal flats in the Onepoto Inlet have consistently had low mud content, with the condition rating in 2022 rated 'good' at all three sites, and slightly improved from December 2020 (Fig. 4b).

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 consistent at these sites over time, with all sites rated 'poor' (Table 3; Fig. 4h). 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. There has been a large reduction in seagrass cover at this site over the past two years (authors observation, Roberts et al. 2021). Although it is not possible to determine whether seagrass losses have been directly caused by the measured increases in sediment mud content; a recent study in the estuary (Zabarte-Maeztu et al. 2020) suggests that sediment mud content is a strong controlling factor in seagrass health, with seagrass absent from sites with a mud content >23%. At Bradey's Bay, coincident with the observed seagrass losses, mud content increased from 16% in 2013 to 41% in 2022.

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. Both sites have a condition rating of 'good' (Table 3). Onepoto (OS7), another well-flushed firm-sand site, remained stable with a condition rating of 'fair' (Table 3). In contrast, Titahi (OS6) has shown an overall trend of increasing mud content since 2013, with the January 2022 mud content rated 'poor' (Table 3; Fig. 4d). Increasing muddiness at Titahi (OS6) (up from 57% to 84%) corresponds to a very large increase (57mm) in sediment deposition at the site compared to December 2020 (Table 2, Fig. 4c).

Table 3. Measured aRPD depth (mm) and sediment grain size (%), Te Awarua-o-Porirua, January 2022.

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)	20	1.1	89.5	9.3
		O2	Aotea	15	3	87.6	9.4
		O3	Por B (FS)	18	1.2	90.3	8.5
	Subtidal	OS6	Titahi	1	0.5	15.1	84.3
		OS7	Onepoto	5	0.7	87.3	12.0
		OS8	Papakowhai	>150	0.4	82.7	16.9
		OS9	Te Onepoto	Indet.	0.9	89	10.1
Pāuatahanui Inlet	Intertidal	P5	Paua A (FS)	15	5.3	81.7	13.0
		P7	Kakaho	25	2.2	68.6	29.2
		P8	Horokiri	8	2.2	79.3	18.5
		P9	Paua B (FS)	10	1	88.5	10.4
		P10	Duck Creek	15	< 0.1	94.5	5.4
		P11	Browns Bay	15	3	80.3	16.7
	Subtidal	PS1	Kakaho	1	< 0.1	9.4	90.5
		PS2	Horokiri	10	< 0.1	15.4	84.6
		PS3	Duck Creek	2	1.7	43	55.3
		PS4	Bradeys Bay	3	0.2	58.8	40.9
		PS5	Browns Bay	5	5.6	31.4	63.0

Ratings (refer to Table 1 for details):

Very Good	Good	Fair	Poor

dw=dry weight

Note: Grain size and aRPD are based on a single composite sample comprising 3-4 sub-samples collected from each site. Indet. = indeterminant

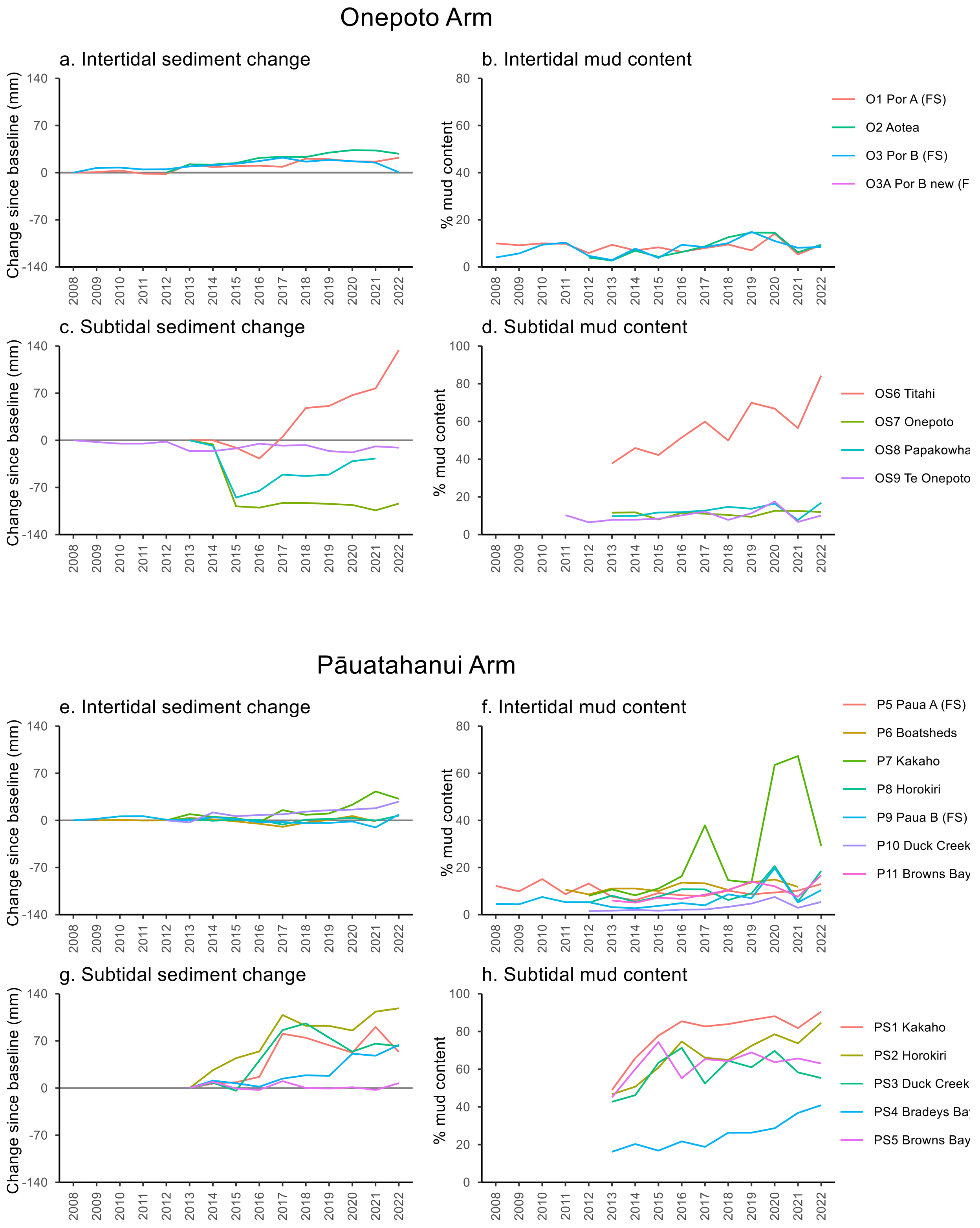


Fig. 4. Sediment depth change from baseline (year installed; mm) and sediment grain size for intertidal and subtidal sites in the Onepoto Inlet and the Pāuatahanui Inlet.

3.3 SEDIMENT OXYGENATION

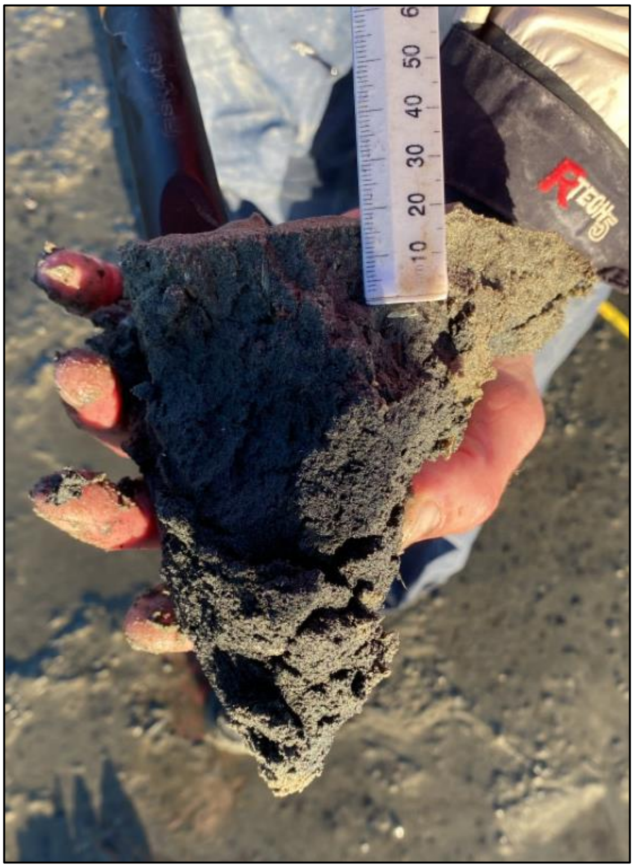
In January 2022, visually assessed aRPD depths (Table 3) were variable depending on location. In general, high mud contents were associated with shallower aRPD depths. This was evident at mud-dominated sites in the Pāuatahanui Inlet, with four out of five subtidal sites rated 'poor' and one (PS2) rated 'fair' for sediment oxygenation. However, relatively shallow aRPD depths were also present in sandier sediments (P5, P9, P10, P11, O2, O3) which were all rated 'fair'. This may, in part, be a residual impact of extensive mats of drift macroalgae *Chaetomorpha ligustica* observed in the estuary in 2020, as well as from organic debris deposited across sites O2 and O3 from nearby stormwater drains, and the Porirua Stream (see photo below).As the organic matter breaks down, oxygen is depleted causing the oxygenation of the sediments to reduce and the aRPD layer to move closer to the surface.

The deepest aRPD depths (>150mm) were recorded from mobile sands at the Onepoto subtidal sites closest to the Harbour entrance (OS8 and OS9), the latter having no discernible colour change in the sediment.

The most anomalous result was OS7 which had an aRPD of 5mm and a mud content of only 12%. However, this site, in the centre of the Onepoto Basin, had a layer of organic material under a fresh layer of mobile sand cover which likely explains the shallower aRPD.

Organic debris on the tidal flats near Por B (O3), Onepoto Inlet in December 2020

Organically enriched sediment Paua B (P9), Pauatahanui Inlet



Oxygenated sand above organically enriched sediment Por B (O3), Onepoto Inlet

3.4 SEDIMENT TRANSECTS

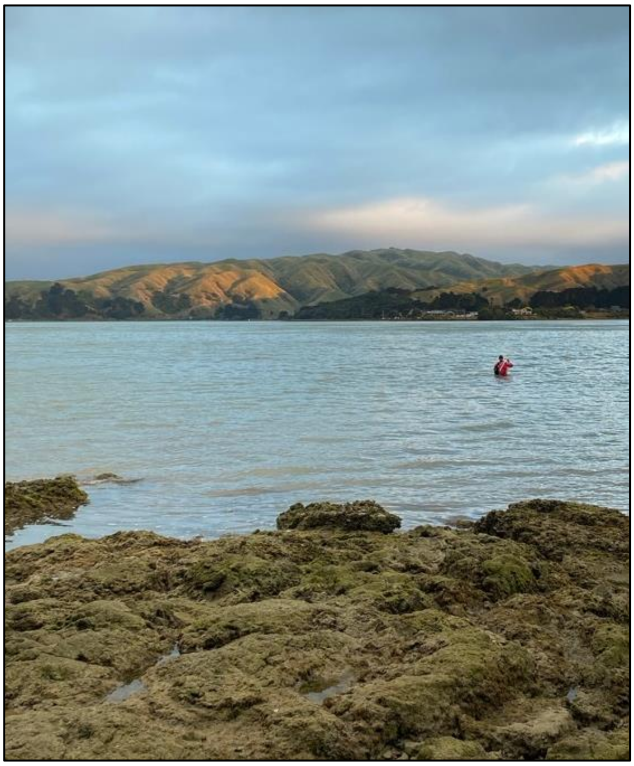
Table 4 and Fig. 5 show the position along transect lines where soft muds transition to firmer sediments between the six subtidal plate sites and the adjacent shore. Soft muds have extended toward the shoreline since monitoring began in 2013. Kakaho (PS1), Horokiri (PS2) and Titahi (OS6) show the largest increases from the starting baseline, of 120m, 94m and 83m, respectively (Table 4). From December 2020 to January 2022, soft mud retreated 260m toward the subtidal zone at Kakaho (PS1).

This change at Kakaho is consistent with reductions in sediment depth measured at both the intertidal and subtidal sites, and general observations of reduced mud depth in this part of the estuary. However, the sediments still have an elevated mud content (Table 3; Section 3.5) that is indicative of degraded ecological health.

Elsewhere, the results reflect the effective trapping of fine sediments in subtidal areas. There appears to have been little improvement in the areas affected since monitoring commenced in 2013.

Soft mud deposits on firm sands on the Horokiri flats

Slurry of mud overlying cobble near Ration Point



Calf-deep soft muds are present just offshore of rocky reef habitat at Duck Creek

Table 4. Distance from subtidal plates to where soft mud transitions to firmer sediments closer to the shoreline, 2013 to 2022.

Site	Site No	Distance from subtidal plates to edge of soft mud (m)#							Change from baseline (m)
		2013	2017	2018	2019	2020	2021	2022	2013-2022
Kakaho	PS1	5	300	150	55	310	385	125	120
Horokiri	PS2	5	65	120	80	90	80	99	94
Duck Creek	PS3	5	10	15	23	20	21	21	16
Bradeys Bay	PS4	5	15	8	5	15	10	9	4
Browns Bay	PS5	5	40	28	35	25	43	36	31
Titahi	OS6	5	45	135	52	50	71	88	83

this reflects the distance continuous soft muds extent toward the shore from the subtidal plate

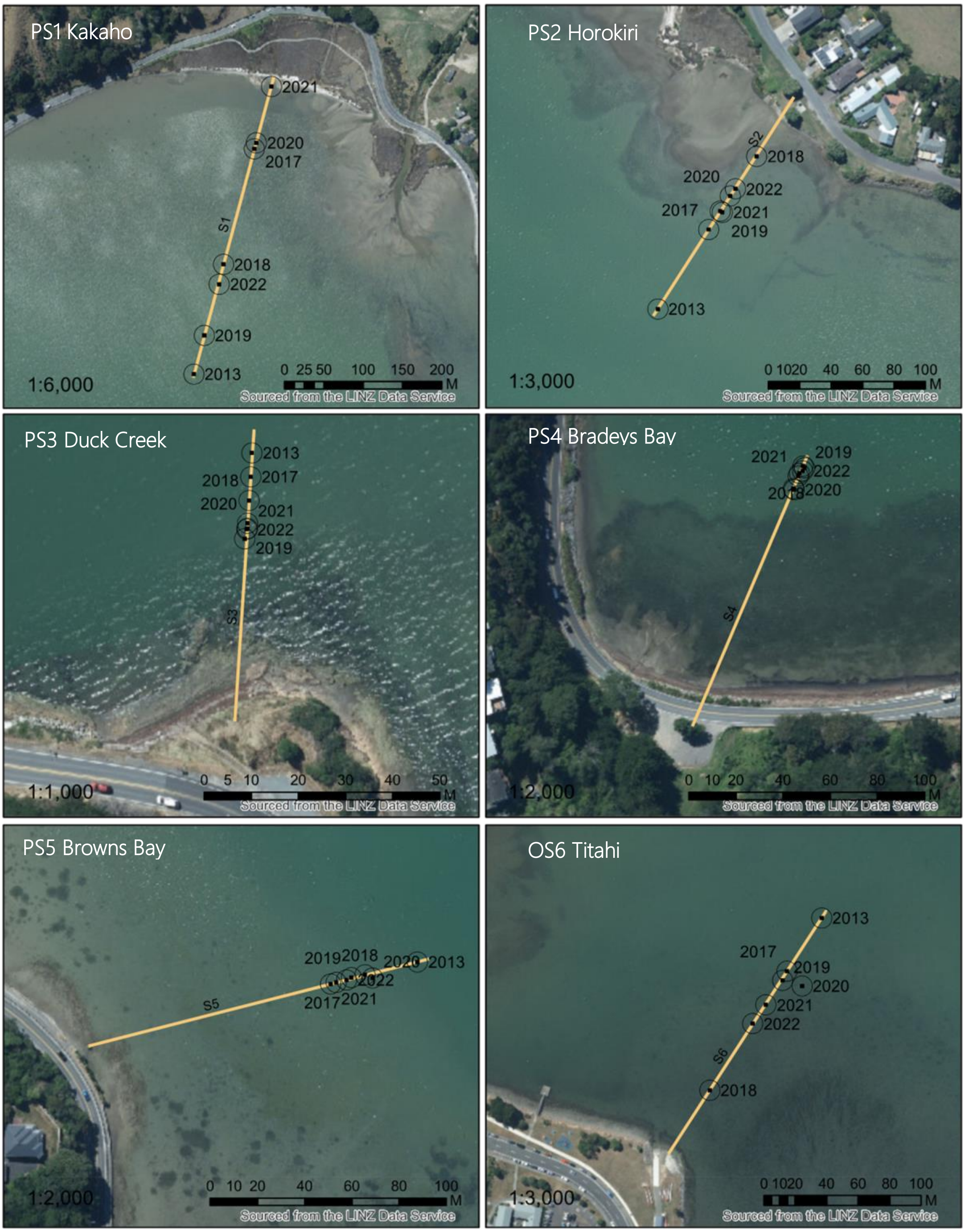


Fig. 5. Transects showing the distance from subtidal plate sites to where soft muds transitions to firmer sediments closer to the shoreline (2013, 2017-2022). See Table 4 for measured distances and Appendix 2 for transect coordinates. The sediment plates are located at the seaward end of each transect line.

3.5 MUD EXTENT

Due to the widespread deposition of soft muds recorded in the north and east of Pāuatahanui Inlet in January 2020 as part of broad scale habitat mapping, the intertidal mud extent between Camborne and Duck Creek was re-mapped in December 2020 and January 2022. Table 5 and Fig. 6 show a comparison of results.

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

Hectares (ha)	Jan-20	Dec-20	Jan-22
Mud elevated (>25-50% mud)	36.0	11.4	11.4
Mud-dominated (>50% mud)	27.9	24.3	15.3
Total	**63.9**	**35.7**	**26.7**

The extent of mud-elevated (>25-50% mud) substrate decreased by 25ha from January 2020 to December 2020 but showed no further change to January 2022. However, there was a relatively large reduction in mud-dominated (>50% mud) substrate which reduced by 9ha between December 2020 and January 2022.

While there was no overall change in the area of mud-elevated (25-50% mud) substrate, Fig. 6 shows changes in its location, reducing near Ration Point and increasing on the Horokiri flats and at Kakaho. At Kakaho, this generally reflects a transition from mud-dominated (>50% mud) to mud-elevated (>25-50%) substrate, consistent with observations of a reduced depth and cover of muds, and as reflected in the data from the Kakaho transects and intertidal (P7) and subtidal (PS1) plate measurements (Tables 2 and 4, Fig. 4).

As suggested in previous assessments (e.g. Roberts et al. 2021), wind-driven wave-action appears to be the most likely mechanism for the mobilisation and redistribution of mud-elevated intertidal sediments. While this local improvement is encouraging, increases in sediment mud content in the eastern part of Pāuatahanui Inlet suggests that a residual effect may be an increase in fine particulates being trapped and integrated into the underlying intertidal sediments. Increases in sediment muddiness are known to have an adverse ecological effect on the sediment community, leading to losses of sensitive species (e.g. Forrest et al. 2020, Townsend and Lohrer 2015).

Further, the changes must be viewed in the context of the whole estuary because any intertidal improvements likely reflect a degradation of subtidal areas. Bathymetric surveys of Te Awarua-o-Porirua Harbour have showed substantial accretion over time (Gibb & Cox 2009, Cox 2015, Waller 2019 - Figs 5 and 7) highlighting that sediment inputs to the harbour are being retained in subtidal areas. Such results, and the 10-year trend at subtidal sedimentation sites (Table 2), indicate that mud mobilised from the intertidal zone is almost certainly being deposited in the deeper subtidal deposition zones of the estuary.

A thin layer of soft mud overlying firm sands (P8), Horokiri, Pāuatahanui Inlet. Sediment mud content was 5.1% in 2013, and 18.5% in 2022.

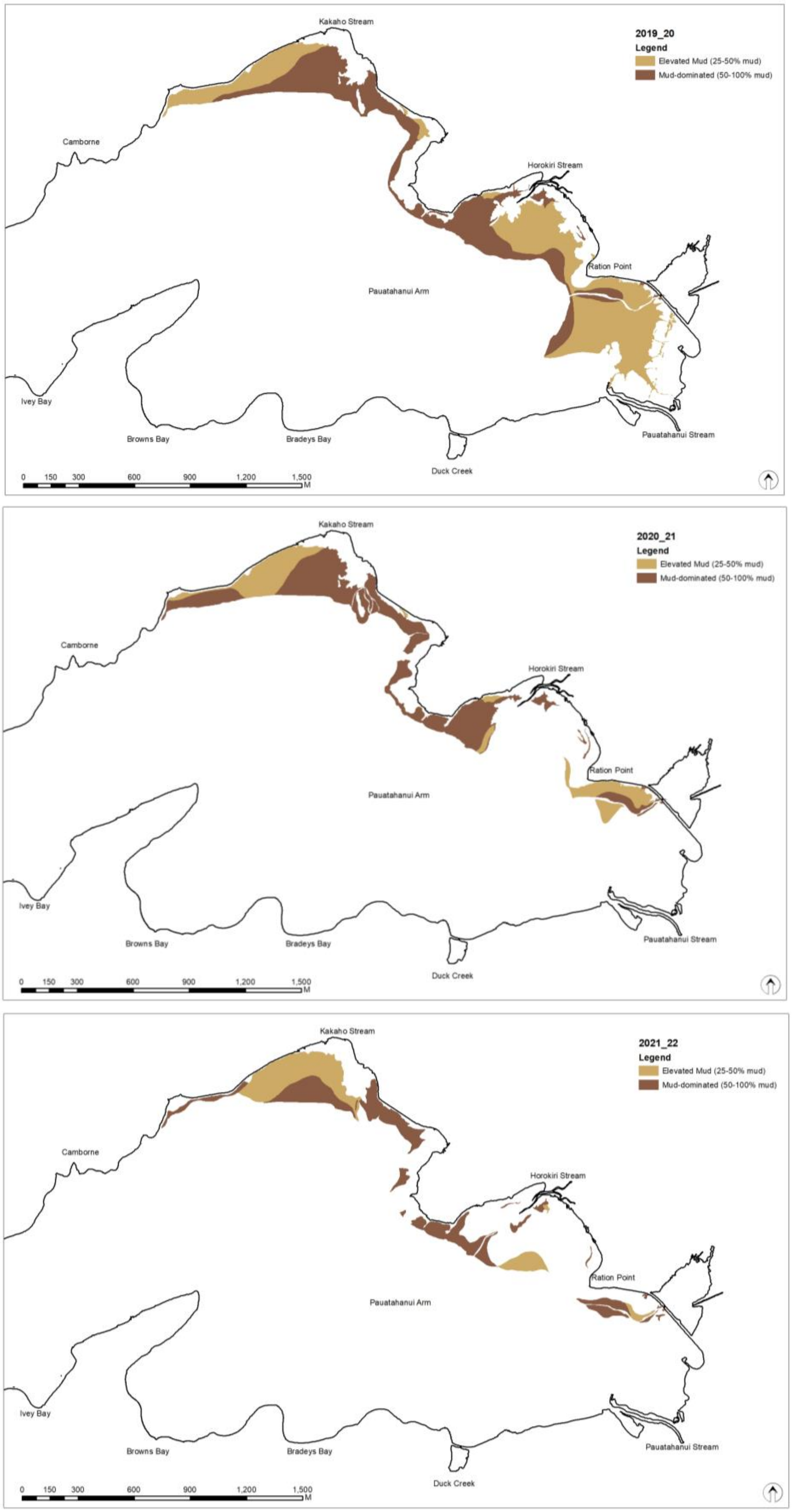


Fig. 6. Maps showing change in mud-elevated (>25-50% mud) and mud-dominated (>50% mud) sediment, Te Awarua-o-Porirua Harbour January 2020 (top), December 2020 (middle), and January 2022 (bottom).

4. SYNTHESIS OF MONITORING DATA

Bathymetric surveys of the Harbour have been undertaken in 1974, 2009, 2014 and 2019. Results, which estimate estuary-wide sedimentation rates, are summarised in Stevens and Forrest (2020) and Table 6. They indicate ongoing and relatively rapid infilling of the subtidal reaches of both Onepoto and Pāuatahanui Inlets well in excess of the 1mm/y target set in the Te Awarua-o-Porirua Harbour Catchment Sediment Reduction Plan. The changes in sedimentation over the three time periods reflect;

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

Table 6. Summary of sedimentation rates derived from bathymetric subtidal surveys (from Stevens & Forrest, 2020).

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

Refer to Table 1 for details on coloured condition ratings

Subtidal sediment plate monitoring results over the past 10 years reflect the most recent (2014-2019) bathymetric changes and show an average increase in the Pāuatahanui Inlet of +6.8mm/y, and an increase of +2.3m/y in the Onepoto Inlet (Table 2). Intertidal sedimentation rates (areas not captured by the bathymetric surveys) are much lower, +1.5 and +1.9mm/y, for Pāuatahanui and Onepoto Inlets, respectively (Table 2).

The mean annual sedimentation rates over the past 5-year period (2018-2022) show a slightly different pattern, with increased subtidal deposition in Onepoto (+12.8mm/yr), but decreased to +0.2mm/yr in Pāuatahanui (Table 2). The recent change in subtidal deposition in Pāuatahanui (rated 'very good') does not however equate to an overall improvement in estuary quality. Rather it reflects a reduction to the substantial deposits of fine sediment at Duck Creek, Kakaho and Horokiri that accrued between 2016 and 2017. Extensive deposits of soft muds remain throughout the subtidal basin and, despite erosion of some material over the past 5 years, the sites remain severely degraded with very high mud contents and low oxygenation (Table 3).

In the intertidal areas of the estuary, the most significant recent impacts have been due to the deposition of a thick slurry of fine sediment covering previously sandy intertidal flats at Kakaho (P7; Roberts et al. 2021). Following three consecutive years of sediment increases, a 10.4mm decrease was recorded from December 2020 to January 2022. As above, the change reflects a reduction in the fine sediment deposited, and sediment mud content (down from 67.3% to 29.2%), but not a significant change in impact with the site remaining very muddy compared to its condition in 2015. However, sediment oxygenation was rated 'good' (~25mm deep), and appeared to be a result of high rates of resuspension combined with bioturbation from larger macrofauna e.g. cockles and mud snails. Elsewhere, January 2022 results showed a general increase in intertidal sediment mud content (Fig. 4) and increased sediment deposition on the intertidal flats near Horokiri (Fig. 6) suggesting little overall improvement in estuary condition.

While the combined results described above summarise general trends, it is important to note that averaging data across a limited number of sites or years carries a risk of obscuring the mechanisms causing accretion and erosion at the site-scale. For example, the subtidal site at Kakaho (PS1) showed erosion of 37mm/y between December 2020 and January 2022. While at face value this is a significant improvement, the mud content was 90.5% and sediment oxygenation was poor (aRPD 1mm; Tables 2 and 3). So, despite a loss of sediment (nominally an improvement), the site remains highly degraded which is likely a legacy of previous deposition events.

In Onepoto Inlet, the two subtidal sites located within the relatively deep central basin of the estuary - Titahi (OS6) and Onepoto (OS7) - show variable results. Whereas OS6 has shown consistent accumulation since 2017, and a large increase (+57mm/y) over the last year, OS7 has shown 3 years of accretion and 3 years of erosion, with a +10mm increase over the last year. OS6 had a mud content of 84.3% (aRPD 1mm) which has risen relatively steadily since 2013, whereas OS7 had a mud content of 12.0% (aRPD 5mm) which has remained relatively stable since 2013. At OS7, the relatively low mud content and variable deposition and erosion of fine sediments (e.g. -92mm of erosion was recorded between 2014 and 2015) suggests high sediment losses can occur in this part of the estuary. As above, erosion of fine sediment reflects a nominal improvement, but long-term improvements will not accrue unless sediment inputs are reduced.

The other two subtidal Onepoto sites (near the entrance) are well-flushed, with site OS8 additionally influenced by mobile ridges of sand moving across the site. Fine sediments are not expected to accumulate at either site, with increases at OS8 attributable to sand. As such, it is recommended that monitoring at this site be suspended.

Overall, the monitored changes, particularly those in the Pāuatahanui Inlet, indicate estuary quality has declined over time, and worsened over the past 5 years. The general trend of increasing mud content, the continued presence of mud-elevated intertidal sediments at Kakaho, Horokiri and Pāuatahanui sites, and a net trend of increasing deposition, all indicate excessive sediment inputs to the estuary.

Mean sedimentation rates exceed the 'poor' threshold and the recommended ANZECC Default Guideline Value (2mm/yr) in the subtidal Onepoto Inlet and intertidal Pāuatahanui Inlet, results consistent with both the most recent (2019) bathymetric survey (Table 6), and 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).

Fine sediment inputs are almost certainly a direct consequence of catchment land disturbance with sources likely linked to land development subdivisions for urban development, earthworks, run-off from pastural lands, exotic forest harvesting and, more recently, the Transmission Gully motorway project. Since the beginning of the Transmission Gully motorway project there have been several trigger events (elevated turbidity) in Horokiri Stream, Ration Stream, Pāuatahanui Stream and Duck Creek. These trigger events follow high rainfall that cause 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.

5. SUMMARY

Current sedimentation accrual rates in Te Awarua-o-Porirua Harbour remain elevated, particularly in the Pāuatahanui Inlet in both the intertidal and subtidal zones. The highest rates are commonly associated with high mud contents (>25% mud) and poor sediment oxygenation (<10mm). Adverse ecological effects, e.g. loss of sensitive species, are likely to occur at these high levels.

Under the current situation, the management goals for the estuary have not been 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).

6. RECOMMENDATIONS

The January 2022 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 follows:

- Continue to monitor existing intertidal and subtidal sediment plates annually to assess deposition and erosion, along with aRPD depth and grain size.
- 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.
- Undertake a comprehensive investigation of sediments sources, land use change data and temporal changes in catchment sediment loads. 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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APPENDIX 1. SEDIMENT ANALYTICAL METHODS AND RESULTS

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Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	2836245
Contact:	Leigh Stevens	**Date Received:**	22-Jan-2022
	C/- Salt Ecology Limited	**Date Reported:**	25-Mar-2022
	21 Mount Vernon Place	**Quote No:**	115833
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Porirua Harbour - Sediment Plates
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		Onep-Well-1 20-Jan-2022 8:00 am	Onep-Well-2 20-Jan-2022 7:00 am	Onep-Well-3 20-Jan-2022 7:15 am	Paua-Well-5 19-Jan-2022 5:45 pm	Paua-Well-7 19-Jan-2022 7:00 am
Lab Number:		2836245.1	2836245.2	2836245.3	2836245.4	2836245.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	66	71	72	67	68
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	1.1	3.0	1.2	5.3	2.2
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	89.5	87.6	90.3	81.7	68.6
Fraction < 63 µm	g/100g dry wt	9.3	9.4	8.5	13.0	29.2

Sample Name:		Paua-Well-8 19-Jan-2022 5:30 pm	Paua-Well-9A 19-Jan-2022 5:15 pm	Paua-Well-10 19-Jan-2022 5:00 pm	Paua-Well-11 20-Jan-2022 12:54 am	Paua-Well-S1 20-Jan-2022 6:45 am
Lab Number:		2836245.6	2836245.7	2836245.8	2836245.9	2836245.10
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	72	72	75	71	57
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	2.2	1.0	< 0.1	3.0	< 0.1
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	79.3	88.5	94.5	80.3	9.4
Fraction < 63 µm	g/100g dry wt	18.5	10.4	5.4	16.7	90.5

Sample Name:		Paua-Well-S2 20-Jan-2022 6:30 am	Paua-Well-S3 19-Jan-2022 6:15 am	Paua-Well-S4 19-Jan-2022 6:00 am	Paua-Well-S5 19-Jan-2022 5:55 am	Onep-Well-S6 19-Jan-2022 8:00 am
Lab Number:		2836245.11	2836245.12	2836245.13	2836245.14	2836245.15
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	53	61	64	63	52
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	< 0.1	1.7	0.2	5.6	0.5
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	15.4	43.0	58.8	31.4	15.1
Fraction < 63 µm	g/100g dry wt	84.6	55.3	40.9	63.0	84.3

Sample Name:		Onep-Well-S7 19-Jan-2022 8:15 am	Onep-Well-S8 19-Jan-2022 8:30 am	Onep-Well-S9 19-Jan-2022 8:45 am		
Lab Number:		2836245.16	2836245.17	2836245.18		
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	73	65	73	-	-
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	0.7	0.4	0.9	-	-
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	87.3	82.7	89.0	-	-
Fraction < 63 µm	g/100g dry wt	12.0	16.9	10.1	-	-

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	1-18
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	1-18
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	1-18
Fraction < 63 µm	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-18

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

Testing was completed between 22-Mar-2022 and 25-Mar-2022. For completion dates of individual analyses please contact the laboratory.

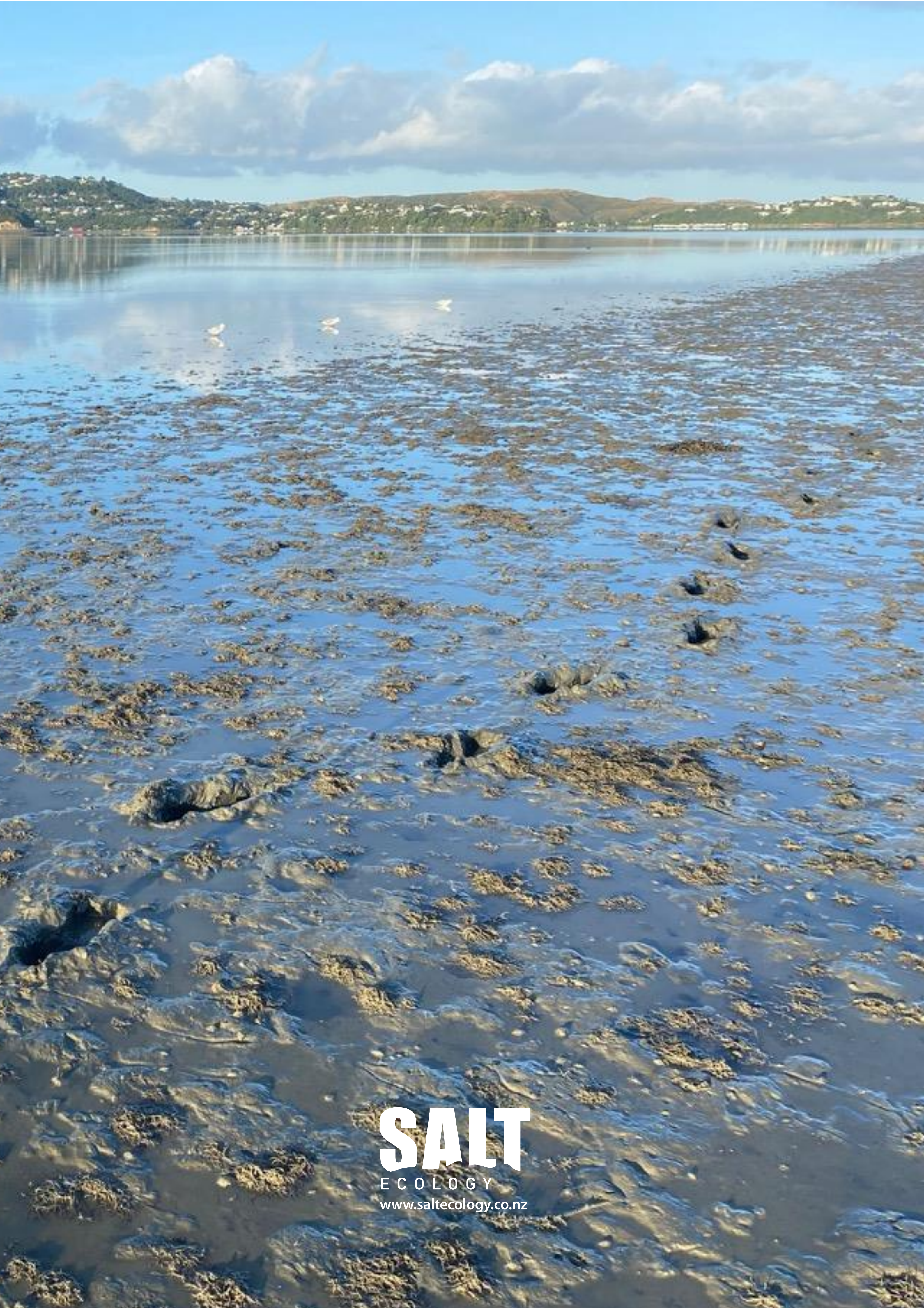
Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the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

Martin Cowell - BSc
Client Services Manager - Environmental

APPENDIX 2. TRANSECT COORDINATES

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	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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