Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2023/2024

Report prepared for Greater Wellington by Salt Ecology

Greater Wellington
Te Pane Matua Taiao

SALT ECOLOGY

Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2023/2024

Prepared for

Greater Wellington Regional Council

July 2024

Salt Ecology Report 136

Cover photo: Locating subtidal monitoring plates using a RTK enabled GNSS receiver at Site PS1/Kakaho.

RECOMMENDED CITATION

Stevens LM, Rabel H. 2024. Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2023/2024. Salt Ecology Report 136, prepared for Greater Wellington Regional Council, July 2024. 22p.

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For the People
Mō ngā tāngata

Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2023/2024

Prepared by

Leigh Stevens and

Hayden Rabel

for

Greater Wellington Regional Council

July 2024

leigh@saltecology.co.nz, +64 (0)21 417 936

www.saltecology.co.nz

For the environment
Mō te taiao

GLOSSARY

aRPD	Apparent Redox Potential Discontinuity
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)
TG	Transmission Gully (motorway project)

ACKNOWLEDGEMENTS

Many thanks to Sabine O'Neill-Stevens and Keryn Roberts (Salt Ecology) for assisting in the field, and Megan Melidonis (GWRC) and Keryn Roberts (Salt Ecology) 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. The current report presents the results of the 2023/2024 annual monitoring, undertaken on 14-15 December 2023, and compares findings to previous monitoring results and estuarine health metrics ('condition ratings').

KEY FINDINGS

Sedimentation rates remain elevated in Te Awarua-o-Porirua Harbour. Between January 2023 and December 2023, large increases in mud-elevated sediments were recorded at subtidal sites OS6/Titahi and PS2/Horokiri. In the same period, erosion at sites Duck Creek (PS3), Bradeys Bay (PS4) and Browns Bay (PS5) (range -11mm/yr to -15mm/yr) indicates remobilisation and redistribution of sediment on the southern side of Pāuatahanui Inlet. Accretion recorded at Onepoto intertidal sites Aotea (O2) and Pori B (O3), and Pāuatahanui intertidal sites Paua A (P5) and Duck Creek (P10) was attributed primarily to the movement of marine sands and was of no ecological concern.

The longer term 5-year and 10-year mean annual sedimentation rate results (see adjacent table) show ongoing high deposition in the Pāuatahanui and Onepoto subtidal zones, and moderate to high increases in the intertidal zones. However, there has been an ongoing reduction in the spatial extent of mud-elevated sediments (>25% mud), and an improvement in intertidal sediment condition in Pāuatahanui Inlet since a flood event in December 2020 resulted in the widespread intertidal deposition of soft muds.

Mean annual sedimentation rate (mm/yr)		
Zone	10-y	5-y
Onepoto (intertidal)	+2.8	+2.7
Onepoto (subtidal)*	+3.0	+9.8
Pāuatahanui (intertidal)	+1.4	+1.9
Pāuatahanui (subtidal)	+5.3	+2.8

*Sites OS6 and OS7 only

Very Good	Good	Fair	Poor

Nonetheless, the monitored changes over the past decade, indicate an overall decline in estuary quality with a general trend of increasing or elevated mud content, and high rates of deposition, indicating sediment inputs to the Harbour continue to be excessive.

Under the current situation, the management goals set out in the Te Awarua-o-Porirua Harbour Catchment Sediment Reduction Plan are unlikely to be met. These goals include:

- Interim: Reduce 2012 sediment inputs from tributary streams by 50% by 2021. This goal has not been assessed in the present report, but results suggest this is unlikely to have been met.
- Long-term: Reduce sediment accumulation rate in the Harbour to 1mm per year by 2031 (averaged over whole harbour). Based on sediment plate data, this goal is unlikely to be met if sedimentation patterns continue on the current trajectory.

Turbid water above subtidal mud at Ration Point.

RECOMMENDATIONS

As previously, the December 2023 monitoring results reinforce earlier 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. In addition, it is recommended that GWRC:

- Monitor sediment plates annually, and schedule estuary-wide bathymetric surveys at 5-yearly intervals.
- Undertake a comprehensive assessment of sediment sources, and temporal changes in land use and catchment sediment loads, including assessment of whether any 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). Comprehensive intertidal mapping is undertaken at ~5-yearly intervals, with the extent of mud-elevated sediments in locally impacted areas mapped annually as required.
- 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, 2022).
- Annual monitoring of sedimentation, substrate type and condition at intertidal and subtidal 'sediment plate' sites (e.g., Stevens et al. 2020, 2022, 2023, Roberts et al. 2021).

The current report presents the results for the 2023/2024 annual monitoring at sediment plate sites, carried out on 14-15 December 2023, and compares findings to previous results.

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.

Water 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 salt marsh 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 margin is 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, construction of the Transmission Gully motorway, 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 O1 (Onep A), Onepoto Inlet, December 2023.

2. METHODS

2.1 OVERVIEW

GWRC commenced sedimentation monitoring at four fine scale sites in 2007/2008, with additional sites added over time to a current total of 18, consisting of 9 intertidal and 9 subtidal sites (Fig. 1). In addition, sediment mud content, which can change in the absence of measurable accretion or erosion, has been analysed from the surface 20mm at sediment plate sites since 2012.

In 2016, large increases were observed in the spatial extent of subtidal muddy sediments, particularly in the Pāuatahanui Inlet, with mud-dominated sediments expanding toward the shore from the subtidal plates. Consequently, fixed transects were established between six subtidal sites and the shoreline in 2017 (see Section 2.2.4) to measure changes in the spatial extent of soft muds.

2.2 GENERAL APPROACH

Sampling methods and descriptions of the 18 existing sediment plate 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).

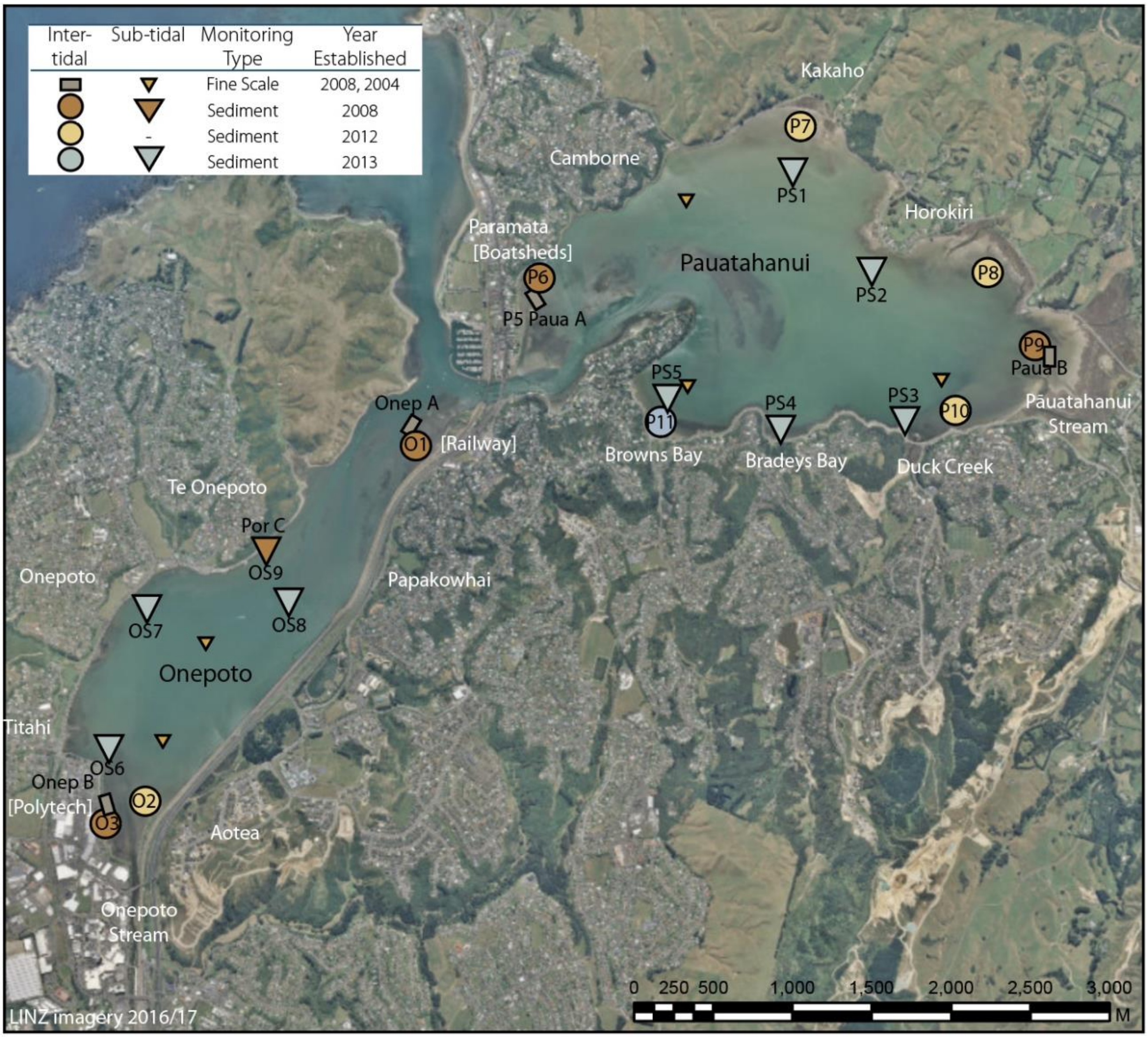


Fig. 1. Location of the 18 sediment plate sites (indicated by the alphanumeric sequence on the map) in Te Awarua-o-Porirua Harbour. Also shown are the location of 4 intertidal (rectangles) and 5 subtidal (small triangles) 'fine scale' sites at which other monitoring is undertaken at ~5-yearly intervals.

To date, 35 concrete 'sediment 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, Kakaho, Duck Creek and Porirua (see Green et al. 2015, also Fig. 1).

Intertidal plates are installed at known distances from wooden marker pegs enabling relocation using a tape measure, while subtidal plates are relocated using a Trimble TDC600 handheld unit and Catalyst DA2 GNSS receiver (post-processing accuracy ±10cm).

In the Inlet several changes to plates have been made. In 2018, the Pāuatahanui intertidal site at Browns Bay (P11) and the Onepoto subtidal site at Papakowhai (OS8) were discontinued because mobile sand and shell deposits were contributing to variable and unrepresentative measures of fine sediment deposition. In 2021, the 'Boatsheds' site (P6) was discontinued because dense cockles overlying the plates made it difficult to take accurate measurements. The P6 plates were relocated to the nearby site Paua A. In addition, the configuration of the intertidal plates at Paua B (P9), Onep A (O1) and Onep B (O3) have been altered to a standardised transect layout to minimise the likelihood of scour across plates and to make the plates easier to relocate.

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 (Stevens & Forrest 2020). Since (December 2020, January 2022, January & December 2023), these areas have been re-mapped using broad scale assessment methods to assess inter-annual changes in the spatial extent of mud-elevated (>25% mud content) intertidal sediments.

2.2.1 Sedimentation rate

The intertidal 'sediment plate' method was 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 2.5m 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 photo below). 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. Where walking access is limited a boat or kayak is used to reach some of the 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 to indicate trends in sedimentation.

Frame used to measure subtidal plates (top) and measuring a subtidal plate at the water surface (bottom).

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. Intertidal samples are collected with a trowel, and subtidal samples are collected with a perspex core (see photos below). The samples are analysed for particle grain size (wet sieve, Hill Labs; Appendix 1). 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.

Collecting sediment samples for laboratory grain size analysis.

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.

The depth to a visually obvious colour change is used to assess oxygenation in sediment.

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 (Appendix 2).

In December 2020, January 2020, January 2022, January 2023 and December 2023, broad scale habitat mapping methods (see Stevens & Forrest 2020 for method details) were used to map the spatial extent of mud-elevated (>25% mud content) sediments in the northern and eastern intertidal flats of 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 4.2.3 (R Core Team 2023).

Sediment samples sent for grain size analysis (wet sieving) at Hill Labs 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 'condition 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) project (Robertson et al. 2016) which includes preliminary site-specific thresholds for mud content (grain size) and aRPD depth. We adopted those thresholds for present purposes, except:

- for % mud the 'Good' to 'Fair' ETI threshold was lowered from 15% to 10% to better reflect where New Zealand data indicate declines in the most sensitive macrofauna species can occur (see Stevens et al. 2024);

- for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012);

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 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).

Mud deposited over cobble and gravel substrate along transect PS2 – Horokiri, December 2023.

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

Condition ratings derived or modified from: [1]Townsend and Lohrer (2015), [2]modified from Robertson et al. (2016), [3]FGDC (2012).

View from Kakaho intertidal site P7 toward subtidal site PS1. Note the plume of resuspended sediment created when wading in shallow water.

3. RESULTS

3.1 SEDIMENTATION

Sediment plate year-to-year monitoring results, along with 10-year and 5-year averages, are summarised in Table 2. The cumulative changes in sediment depth since the baseline (i.e., the year plates were installed) is shown in Figs 2 and 3, along with the associated long-term trend compared to the national DGV of 2mm/yr.

Between January 2023 and December 2023, sediment accretion was high at Onepoto intertidal sites Aotea (O2) and Onep B (O3) near Porirua Stream mouth, and at Pāuatahanui intertidal sites Paua A (P5) near Mana, and Duck Creek (P10) at the eastern end of the inlet. Accretion at these sites appeared to be caused primarily by mobile sand ridges due to wave and current action. Sediment accretion remained elevated at Onepoto subtidal site Titahi (OS6), and was very high at Pāuatahanui subtidal site Horokiri (PS2).

Elsewhere, many sites showed net sediment erosion since January 2023, including Pāuatahanui intertidal sites, Kakaho (P7), Horokiri (P8), Paua B (P9), and subtidal sites, (Duck Creek (PS3), Bradeys Bay (PS4), Browns Bay (PS5).

However, as shown in Table 2, the 10-year and 5-year trends at most sites still show net sediment accretion. When sites are pooled into zones according to their location in the harbour (Pāuatahanui, Onepoto) and tidal elevation (intertidal, subtidal), average sedimentation was in most cases rated 'Fair' or 'Poor' when applying the criteria in Table 1. The exception is the 'Very good' rating for the strongly tidally flushed lower Onepoto subtidal sites Papakowhai (OS8) and Te Onepoto (OS9), while it is reiterated that the natural movement of sands contributes to the ratings for intertidal sites O1, O2, O3 and P10. Natural accretion of sands is of no significant ecological concern.

Table 2. Mean annual change in sediment depth between 2014–2024. Mean annual sedimentation calculated over 10- and 5- year periods, and as a rate per designated zone, and compared to condition ratings.

Site, Zone, No., Name & Baseline Year#				Change in mean sediment depth between surveys (mm)											Mean annual sedimentation (mm/y)			
				2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Site (10-y)	Zone (10-y)•	Site (5-y)	Zone (5-y)•
Onepoto Inlet	Intertidal	O1 Por A (FS)	2008	-4.2	1.5	0.5	-1.5	12.0	-0.7	-3.2	-0.5	6.0	2.6	1.1	+1.8		+1.2	
		O2 Aotea	2012	-0.2	2.3	7.8	1.5	-0.2	6.5	3.5	-0.5	-4.7	17.4	14.7	+4.8	+2.8 (Poor)	+6.1	+2.7 (Poor)
		O3 Por B (FS)	2008	1.8	2.3	4.0	5.0	0.8	2.4	-1.8	-2.2	-11.0	12.0	7.1	+1.9		+0.8	
	Subtidal	OS6 Titahi	2013	0.0	-11.0	-16.0	32.0	43.0	3.0	16.0	10.0	57.0	14.0	2.0	+15.0	+3.0 (Poor)	+19.8	+9.8 (Poor)
		OS7 Onepoto	2013	-6.0	-92.0	-2.0	7.0	0.0	-1.5*	-1.5	-8.0	10.0	-1.0	-1.0	-9.0		-0.3	
		OS8 Papakowhai	2013	-8.0	-77.0	10.0	24.0	-2.0	2.0	20.0	4.0	sd	sd	sd	-2.7	-0.8 (Very good)	+12.0	+7.2 (Poor)
		OS9 Te Onepoto	2008	0.0	4.0	7.0	-3.0	1.0	-9.0	-2.0	9.0	-2.0	12.0	-5.0	+1.2		+2.4	
Pāuatahanui Inlet	Intertidal	P5 Paua A (FS)	2021									3.5	-0.5	8.6	+3.9		+3.9	
		P6 Boatsheds	2009	-2.0	-3.0	-3.5	-4.5	6.3	4.0	5.8	-8.2	sd	sd	sd	-0.5		-1.2	
		P7 Kakaho	2012	-4.0	-2.0	-5.7	17.8	-7.0	2.0	12.8	20.0	-11.2	-4.4	-4.7	+1.7	+1.4 (Fair)	+2.5	+1.9 (Fair)
		P8 Horokiri	2012	-2.5	1.3	0.0	-7.0	7.3	1.3	1.3	-4.0	7.5	-9.3	-0.1	-0.2		-0.9	
		P9 Paua B (FS)	2008	4.5	-2.5	-5.0	0.3	-1.7	0.5	2.0	-9.0	19.3	2.3	-0.8	+0.5		+2.8	
		P10 Duck Creek	2012	14.8	-5.5	1.8	1.0	4.0	2.0	1.0	2.3	9.8	8.8	1.1	+2.6		+4.6	
	Subtidal	PS1 Kakaho	2013	7.0	2.0	8.0	64.0	-6.0	-11.0*	-11.0	38.0	-37.0	0.0*	0.0	+5.2		-2.5	
		PS2 Horokiri	2013	26.0	18.0	10.0	54.0	-16.0	0.0	-7.0	28.0	5.0	3.0	17.0	+11.2		+9.2	
		PS3 Duck Creek	2013	8.0	-12.0	45.0*	45.0	10.0	-21.0*	-21.0	12.0	-4.0	28.0	-11.0	+7.1	+5.3 (Poor)	+0.8	+2.8 (Poor)
		PS4 Bradeys Bay	2013	11.0	-4.0	-5.0	12.0	5.0	-1.0	33.0	-3.0	16.0	21.0	-15.0	+5.9		+10.4	
		PS5 Browns Bay	2013	9.0	-10.0	-2.0	13.0	-10.0	-1.0	2.0	-4.0	10.0	-15.0	-12.0	-2.9		-3.8	

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; change in mean sediment depth calculated over a two-year period standardised to annual change (i.e., mm/yr).

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, sd = site discontinued.

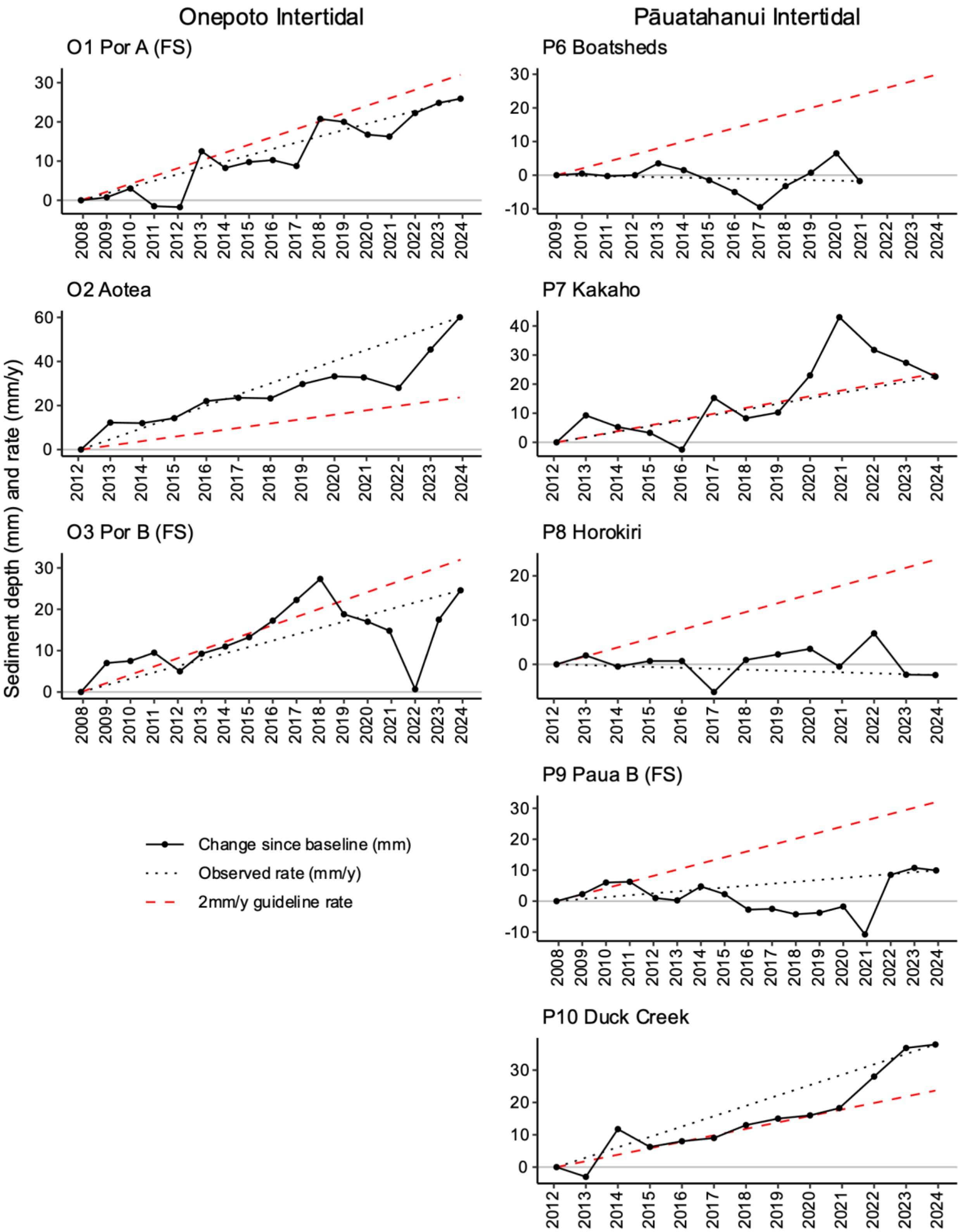


Fig. 2. Sediment depth change (mm) from baseline (year plates installed) at intertidal sites in the Onepoto and Pāuatahanui Inlets of Te Awarua-o-Porirua Harbour. The black dotted trendline shows linear accrual at the observed average annual rate, and the red dashed trendline corresponds to the ANZG (2018) guideline rate of 2mm/yr.

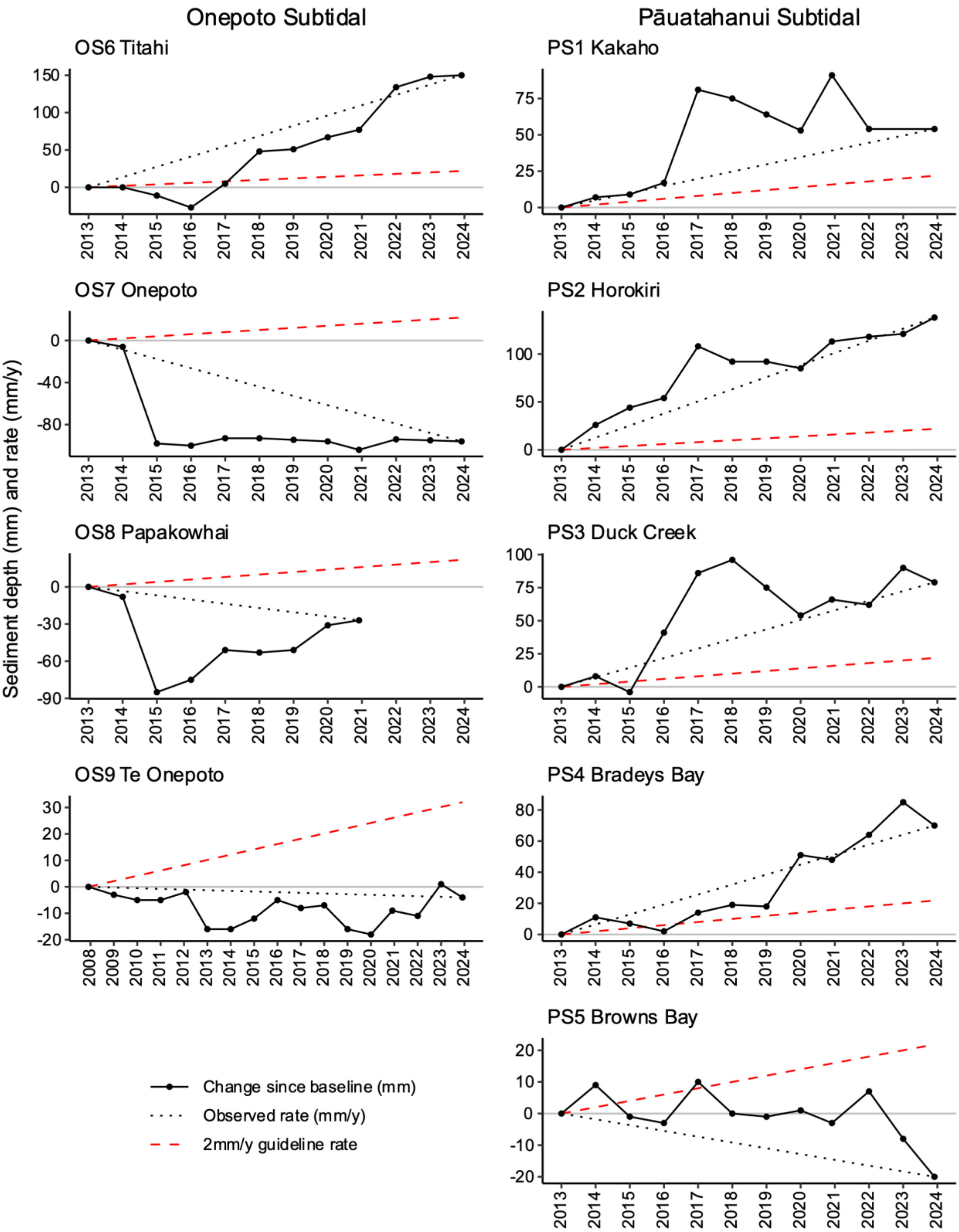


Fig. 3. Sediment depth change (mm) from baseline (year plates installed) at subtidal sites in the Onepoto and Pāuatahanui Inlets of Te Awarua-o-Porirua Harbour. The black dotted trendline shows linear accrual at the observed average annual rate, and the red dashed trendline corresponds to the ANZG (2018) guideline rate of 2mm/yr.

Table 2, and Figs 2 and 3, show high temporal and spatial variability between surveys and sites, reflecting episodic deposition and erosion events. The 10-year averages show high overall mean deposition in the Pāuatahanui subtidal zone and Onepoto intertidal and subtidal zones, and moderate increases in the Pāuatahanui intertidal zone. Compared to the 10-year average, results from the past 5 years indicate higher recent subtidal accretion rates in Onepoto, and reduced accretion in Pāuatahanui. The latter change includes moderate erosion at Browns Bay and Kakaho, offset by high deposition at Horokiri and Bradeys Bay.

3.2 SEDIMENT GRAIN SIZE

Fig. 4 presents sediment grain size alongside sediment depth over time, noting changes in sediment grain size are not always directly reflected in sedimentation patterns. With respect to mud content, intertidal sites in the Pāuatahanui Inlet ranged from 'Very good' to 'Fair' (Table 3), with mud contents decreasing slightly across most sites since January 2023 (Fig. 4f). Kakaho (P7) continued to recover from a peak mud content of 67.3% recorded in December 2020, consistent with the recent ongoing reduction in sedimentation at that site (Table 2, Fig. 2). The intertidal flats in the Onepoto Inlet have had consistently low mud content (rated 'Very good' to 'Fair'), with Site O2 showing a ~50% decrease in mud content in December 2023 (Table 3, Fig. 4b). This was associated with the deposition of sands across the site.

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). Mud contents have remained consistently high at these sites over time, with all sites rated 'Poor' (Table 3; Fig. 4h). These sites represent the deeper settlement basins of the Inlet. The biggest change evident in December 2023 was the reduction in mud content at Browns Bay (PS5) from 71% in January 2023 to 41% in December 2023. This coincided with erosion of muds to below the depth of the 2013 baseline. The subtidal sites in the Onepoto Inlet were more varied. Te Onepoto (OS9), a well-flushed sand-dominated site where muddy sediments are unlikely to accumulate, was rated 'Good' (Table 3). Titahi (OS6) has shown an overall trend of increasing mud content since 2013, with the December 2023 mud content rated 'Poor' (Table 3; Fig. 4d) and consecutive annual increases in deposition recorded since 2017 (Table 2, Fig. 4c).

Onepoto (OS7) had a slight increase in mud content compared to January 2023 (up from 9% to 12%), but little change in sedimentation (Fig. 4c).

Table 3. Measured aRPD depth (mm) and sediment grain size (%), Te Awarua-o-Porirua, December 2024, relative to condition ratings.

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	7.7	89.4	2.9
		O2	Aotea	22	5.1	82.2	12.7
		O3	Por B (FS)	20	3.0	84.8	12.3
	Subtidal	OS6	Titahi	5	0.2	20.3	79.5
		OS7	Onepoto	Indet.	0.6	87.1	12.3
		OS9	Te Onepoto	50	0.9	92.7	6.4
Pāuatahanui Inlet	Intertidal	P5	Paua A (FS)	15	1.6	85.1	13.3
		P7	Kakaho	20	1.9	84.0	14.1
		P8	Horokiri	8	17.2	74.4	8.4
		P9	Paua B (FS)	30	12.8	79.4	7.8
		P10	Duck Creek	35	2.8	94.2	3.0
		P11	Browns Bay	3	5.5	84.9	9.6
	Subtidal	PS1	Kakaho	15	0.0	11.0	89.0
		PS2	Horokiri	10	0.1	15.2	84.7
		PS3	Duck Creek	8	0.7	29.4	69.9
		PS4	Bradeys Bay	5	0.8	58.9	40.3
		PS5	Browns Bay	Indet.	0.6	58.0	41.4

Very Good	Good	Fair	Poor

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

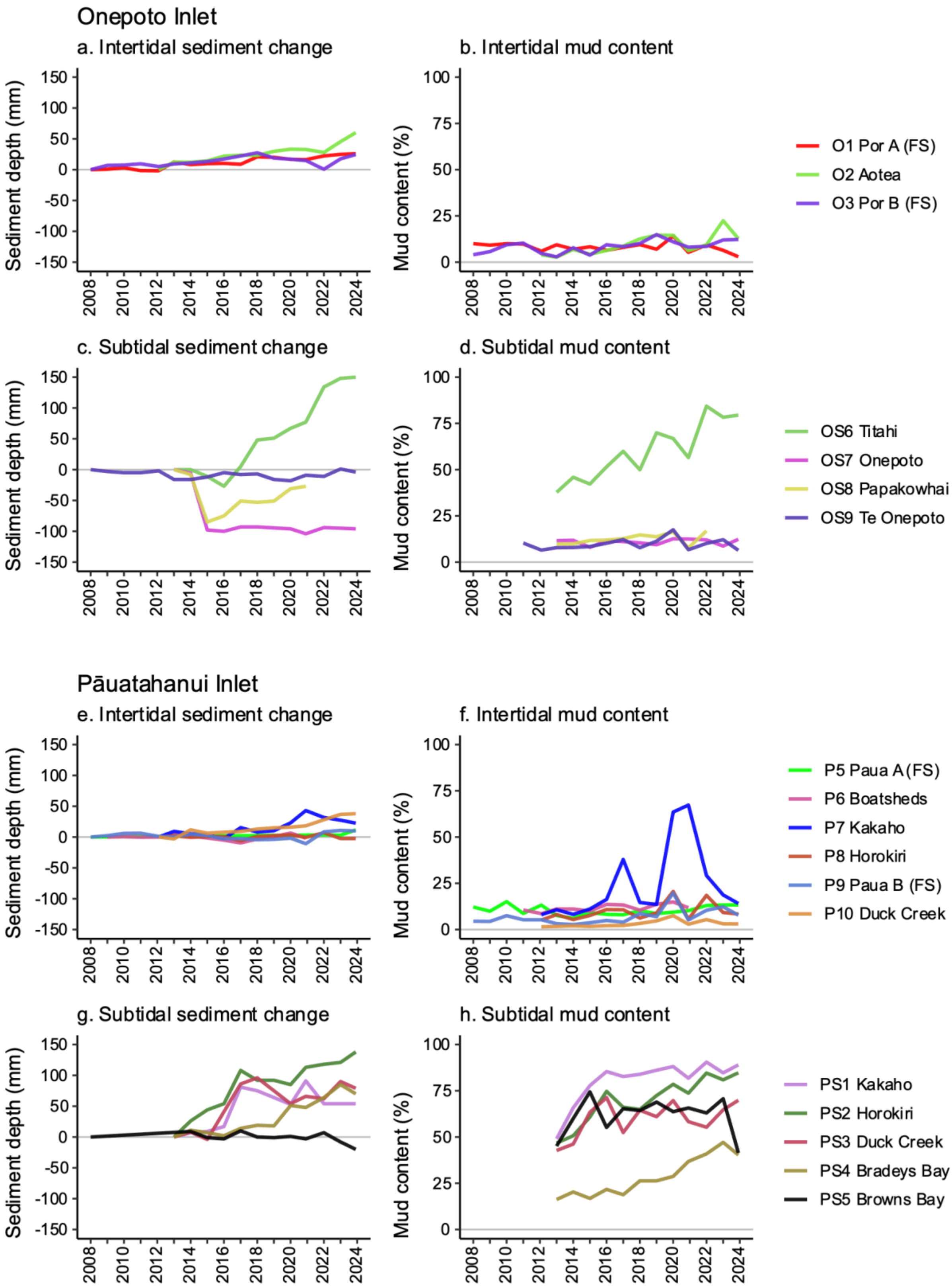


Fig. 4. Sediment depth change (mm) from baseline (year plates installed) and corresponding change in sediment mud content (%) for intertidal and subtidal sites in the Onepoto Inlet and the Pāuatahanui Inlet.

3.3 SEDIMENT OXYGENATION

In December 2023, visually assessed aRPD depths (Table 3) were variable depending on location. As in previous years, high mud contents were generally associated with shallower aRPD depths: sites with >25% mud being rated as 'Poor' (OS6, PS3, PS4) or 'Fair' (PS1, PS2) for sediment oxygenation. At Browns Bay (PS5), an aRPD could not be determined. The intertidal sites Horokiri (P8) and Browns Bay (P11) had sandy substrate (<10% mud) but were also rated as 'Poor' for sediment oxygenation. It is unclear why the aRPD is shallow at Horokiri (P8) but may reflect the combined presence of gravel and shell material and the breakdown of organic material where macroalgal cover was anecdotally observed to have increased over the previous 11 months, while at Browns Bay (P11), it is likely attributable to the presence of organic enrichment associated with seagrass beds. Other sites with mud contents less than 25% generally had an aRPD rated as 'Very good' to 'Fair' (Table 3).

The intertidal sites in both arms tended to have higher sediment oxygenation than adjacent subtidal sites, with intertidal aRPD depths ranging between 3 and 35mm and most subtidal aRPD depths between 5 and 15mm. The deepest aRPD (>50mm) was recorded from subtidal site Te Onepoto (OS9), and is a substantial improvement on the 5mm recorded the previous year when a layer of organic material was buried beneath a layer of mobile sand.

25mm of oxygenated sand above organically enriched sediment Onep B (O3), Onepoto Inlet.

10mm layer of oxygenated sand at site PS3, Pāuatahanui 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. The transects at Kakaho, Horokiri and Titahi continue to show the largest net increases in extent from the starting baseline (66m, 77m and 70m respectively - Table 4).

Soft mud has retreated toward the subtidal zone at four sites over the past year (Horokiri, Duck Creek, Browns Bay and Titahi), the extent of retreat ranging from 4-19m.

In contrast, increases from the starting baseline were recorded at two sites (Kakaho and Bradeys Bay) over the same period – range 9-11m. The variable results likely reflect widespread mobilisation and redistribution of subtidal sediments in this part of the estuary.

Overall, while there appears to have been localised improvements in mud extent at some sites, none have returned to the state they were in when monitoring commenced in 2013.

Table 4. Distance from subtidal plates to where soft mud transitions to firmer sediments closer to the shoreline, 2013 to 2024.

Site	Site No	Distance from subtidal plates to edge of soft mud (m)#									Change from baseline (m) 2013-2024
		2012/13	2016/17	2017/18	2018/19	2019/20	2020/21	2020/22	2022/23	2023/24	
Kakaho	PS1	5	300	150	55	310	385	125	60	71	66
Horokiri	PS2	5	65	120	80	90	80	99	89	82	77
Duck Creek	PS3	5	10	15	23	20	21	21	25	21	16
Bradeys Bay	PS4	5	15	8	5	15	10	9	11	20	15
Browns Bay	PS5	5	40	28	35	25	43	36	54	35	30
Titahi	OS6	5	45	135	52	50	71	88	80	75	70

Reflects the distance continuous soft muds extend toward the shore from the subtidal plate.

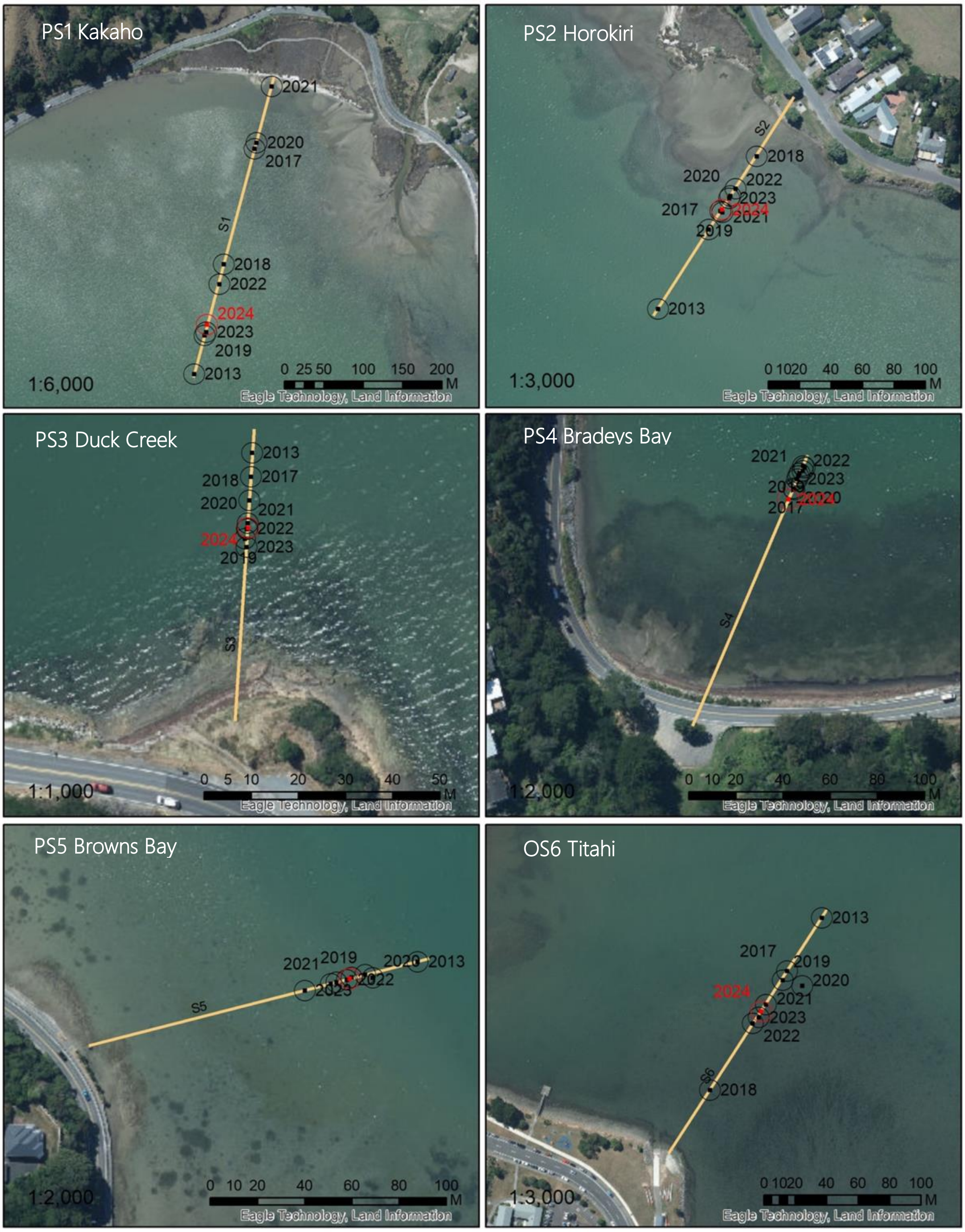


Fig. 5. Transects showing the distance from subtidal plate sites to where soft muds transition to firmer sediments closer to the shoreline. 2013 represents the mud/sand boundary recorded in the baseline year. Records further toward the shoreline than the 2013 baseline indicate mud extent has expanded. 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 MAPPING OF MUD AREA

Widespread intertidal deposition of mud-elevated (>25-50% mud) and mud-dominated (>50% mud) substrate was recorded in the north and east of Pāuatahanui Inlet between Camborne and Duck Creek during broad scale habitat mapping in January 2020. Subsequently, changes in the spatial extent of these habitat types were re-mapped in December 2020, January 2022, January 2023, and repeated in December 2023. Table 5 summarises results, and Figs 6 and 7 show key broad temporal changes in the location of mud-elevated and mud-dominated sediments over the past five years.

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

Hectares (ha)	Jan-20	Dec-20	Jan-22	Jan-23	Dec-23
Mud-elevated (>25-50% mud)	36.0	11.4	11.4	8.8	4.5
Mud-dominated (>50% mud)	27.9	24.3	15.3	3.3	0.3
Total	63.9	35.7	26.7	12.1	4.8

Since January 2020, broad scale mapping has shown a consistent reduction in the spatial extent of intertidal mud-elevated (>25-50% mud) and mud-dominated (>50% mud) substrate, the extent reducing by 31.5ha and 27.6ha in December 2023 for each substrate type respectively. The results reflect a relatively rapid and significant reduction in the areal extent of muddy sediments, which is consistent with intertidal sediment plate measurements from this part of the Inlet.

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 muddy intertidal sediments. While this reduction in intertidal mud cover is encouraging, the changes must be viewed in the context of the whole estuary because any intertidal improvements are likely to reflect a degradation of subtidal areas. Bathymetric surveys of Te Awarua-o-Porirua Harbour (Gibb & Cox 2009, Cox 2015, Waller 2019 have showed substantial accretion over time (Table 6) highlighting the retention of sediment inputs within subtidal harbour 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 and retained in the deeper subtidal deposition zones of the estuary.

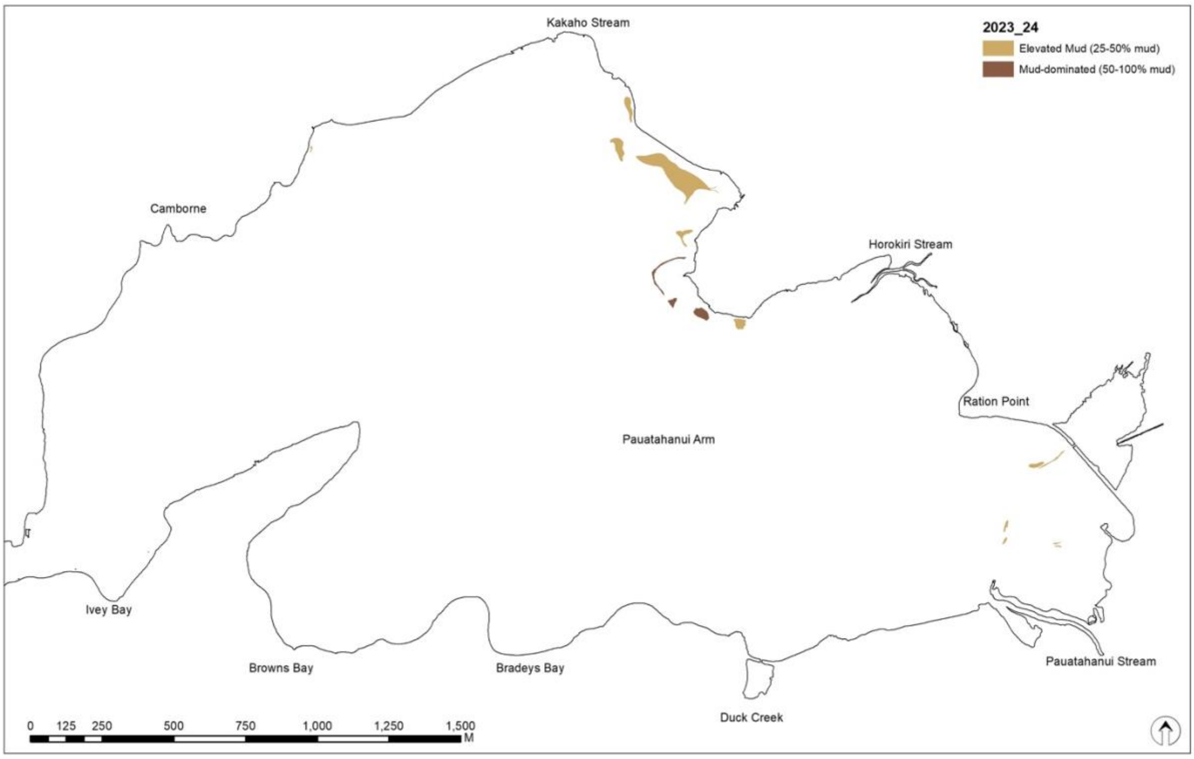
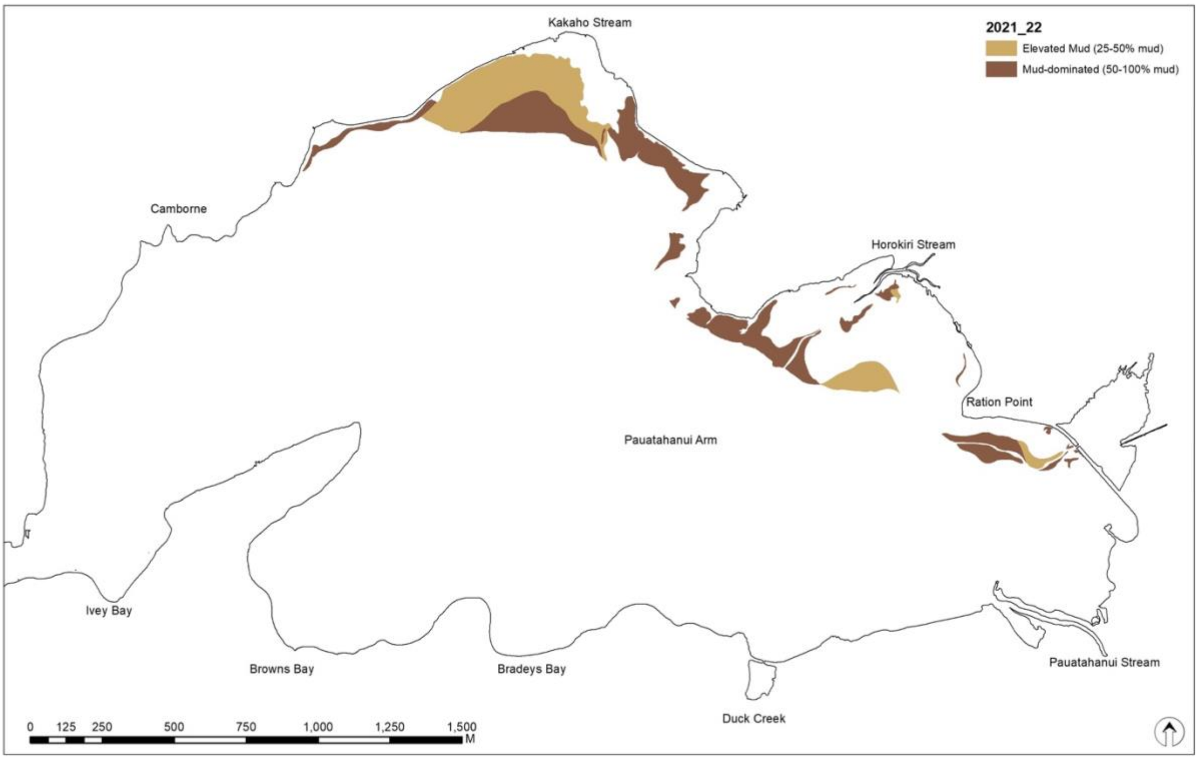


Fig. 6. Map showing extent of mud-elevated (>25-50% mud) and mud-dominated (>50% mud) sediment, Te Awarua-o-Porirua Harbour, December 2023.



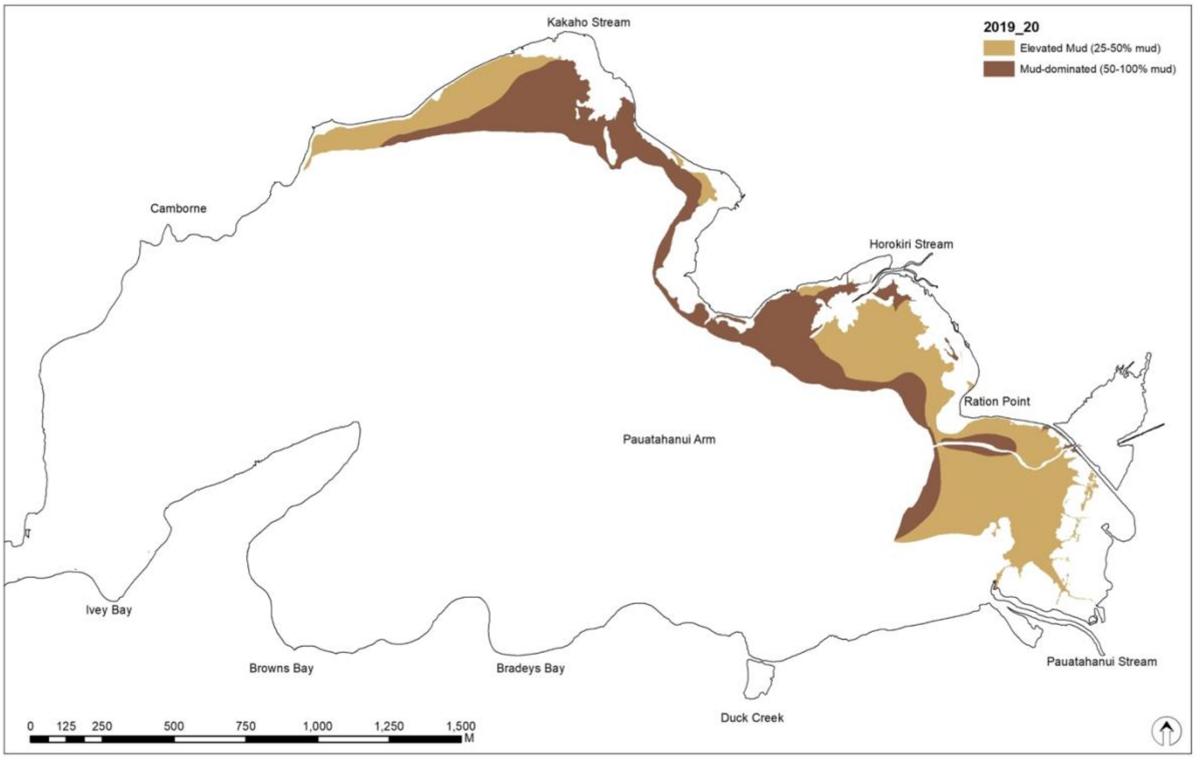


Fig. 7. Maps showing change in mud-elevated (>25-50% mud) and mud-dominated (>50% mud) sediment, Te Awarua-o-Porirua Harbour, January 2022 (top) and January 2020 (bottom).

4. SYNTHESIS OF FINDINGS

Subtidal sediment plate monitoring results over the past 10 years show an average increase of +5.3mm/yr in the Pāuatahanui Inlet, and +3.0mm/yr in the two subtidal sites located within the relatively deep central basin of Onepoto Inlet. Compared to the 10-year mean annual sedimentation rate, the past 5-year period (2020-2024) shows an increased mean rate of subtidal deposition in Onepoto (+9.8mm/yr), and a lower (but still elevated) rate in Pāuatahanui (+2.8mm/yr). In all cases subtidal sedimentation was rated 'Poor' (Table 2).

Intertidal sedimentation rates over the past 10 years show an average deposition rate of +1.4 and +2.8mm/yr for Pāuatahanui and Onepoto Inlets respectively (rated 'Fair' and 'Poor'; Table 2). Compared to the 10-year mean annual sedimentation rate, the most recent 5-year period (2020-2024) shows an increased mean rate of deposition in Pāuatahanui Inlet (+1.9mm/yr; rated 'Fair'), and a similar rate in the Onepoto Inlet (2.7mm/yr; rated 'Poor'). The net rate of change in Pāuatahanui is driven primarily by the erosion of mud deposits at Kakaho (P7) and Horokiri (P8), offset by deposition of sands at Paua A (P5) and Duck Creek (P10).

The continued sediment erosion and decrease in mud content recorded at intertidal sites Kakaho (P7) and Horokiri (P8, in December 2023 represent ongoing improvements at these sites (see photos below) which were significantly impacted by the deposition of a thick slurry of fine sediment following several intensive rain events between 2017 and 2020 (Roberts et al. 2021).

For example, at P7/Kakaho, three consecutive years of sediment deposition from 2019-2021, were followed by three consecutive years of sediment erosion (annual reductions of 11.2mm, 4.4mm and 4.7mm). The most recent reductions in the depth of fine sediment are also reflected in the sediment mud content which has reduced from 67.3% to 29.2% to 18.7% to 14.1% over the last four monitoring surveys.

Broad scale mapping of the location of intertidal mud-elevated and mud-dominated sediments mud between Camborne and Duck Creek over the past five years show a relatively rapid reduction in the spatial extent of intertidal mud-elevated (>25% mud content) sediment, which is consistent with sediment plate measurements in this part of the Inlet.

Despite recovery from deposition events, the overall changes measured over the past decade indicate a general decline in estuary quality, with a trend of increasing or elevated mud content, and high rates of deposition, indicating excessive sediment inputs to the Harbour, particularly to subtidal areas.

In the subtidal basins of both inlets, mean sedimentation rates exceed the 'Poor' threshold and the recommended ANZECC Default Guideline Value (2mm/yr). These results are consistent with both the most recent (2019) bathymetric survey (Table 6), and NIWA's 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).

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

Time period	Sedimentation rate (mm/yr)	
	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.

Photos showing the change in muds smothering Pāuatahanui site Kakaho (P7) in December 2020 (left) and Decmbber 2023 (right).

Mean rates of intertidal deposition within both inlets are, in part, elevated due to deposition of marine sands at several of the sites (which does not represent a significant ecological concern), as well as erosion of recent mud deposits (which reflects an ecological improvement). However, the reduction in intertidal mud deposits is likely to be contributing to the subtidal accretion recorded, due to predicted high sediment retention (97%) in the estuary (Hicks et al. 2019).

Fine sediment inputs are almost certainly a direct consequence of catchment land disturbance, with sources likely linked to urban subdivisions, earthworks, run-off from pastoral lands, exotic forest harvesting and, in recent times, the Transmission Gully (TG) motorway project. The TG project resulted in several trigger events (elevated turbidity) in Horokiri Stream, Ration Stream, Pāuatahanui Stream and Duck Creek following failures in sediment controls after high rainfall. Post-event inspections identified sediment inputs from pond discharges, slips and scouring of drains (e.g., Strange 2020a; 2020b). Increased deposition of fine sediments has also been detected in the TG 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 subtidal zones of Pāuatahanui Inlet. 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 levels.

Under the current situation, the management goals for Te Awarua-o-Porirua Harbour are unlikely to be 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. These goals are as follows:

- Interim: Reduce 2012 sediment inputs from tributary streams by 50% by 2021. This goal has not been assessed in the present report, but results suggest this is unlikely to have been met.
- Long-term: Reduce sediment accumulation rate in the Harbour to 1mm per year by 2031 (averaged over whole harbour). Based on sediment plate data, this goal is unlikely to be met if sedimentation patterns continue on the current trajectory.

6. RECOMMENDATIONS

The December 2023 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. 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 any current mitigations are sufficient to reduce sediment loads enough to meet the management goals for Te Awarua-o-Porirua.

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APPENDIX 1. SEDIMENT ANALYTICAL METHODS AND RESULTS

Hill Labs

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

0508 HILL LAB (44 555 22)
+64 7 858 2000
mail@hill-labs.co.nz
www.**hill-labs**.co.nz

Certificate of Analysis

Page 1 of 2

Client:	Greater Wellington Regional Council	**Lab No:**	3432342 SUPv1
Contact:	Megan Melidonis C/- Greater Wellington Regional Council PO Box 11646 Manners Street Wellington 6142	**Date Received:**	19-Dec-2023
		Date Reported:	08-Feb-2024
		Quote No:	127931
		Order No:	PN00018330
		Client Reference:	Particle grain size
		Submitted By:	Megan Melidonis

Sample Type: Sediment

Sample Name:		Onep-Well-1 Por A (FS) 15-Dec-2023 5:30 pm	Onep-Well-2 Aotea 15-Dec-2023 6:00 pm	Onep-Well-3 Por B (FS) 15-Dec-2023 6:30 pm	Paua-Well-5 Paua A (FS) 15-Dec-2023 5:00 pm
Lab Number:		3432342.1	3432342.2	3432342.3	3432342.4
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	74	78	74	74
3 Grain Sizes Profile as received					
Fraction >/= 2 mm	g/100g dry wt	7.7	5.1	3.0	1.6
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	89.4	82.2	84.8	85.1
Fraction < 63 µm	g/100g dry wt	2.9	12.7	12.3	13.3

Sample Name:		Paua-Well-7 Kakaho 14-Dec-2023 4:30 pm	Paua-Well-8 Horokiri 14-Dec-2023 5:00 pm	Paua-Well-9A Paua B (FS) 14-Dec-2023 6:00 pm	Paua-Well-10 Duck Creek 14-Dec-2023 6:30 pm
Lab Number:		3432342.5	3432342.6	3432342.7	3432342.8
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	79	81	80	77
3 Grain Sizes Profile as received					
Fraction >/= 2 mm	g/100g dry wt	1.9	17.2	12.8	2.8
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	84.0	74.4	79.4	94.2
Fraction < 63 µm	g/100g dry wt	14.1	8.4	7.8	3.0

Sample Name:		Paua-Well-11 Browns Bay 14-Dec-2023 6:40 pm	Paua-Well-S1 Kakaho 14-Dec-2023 4:15 pm	Paua-Well-S2 Horokiri 14-Dec-2023 4:45 pm	Paua-Well-S3 Duck Creek 14-Dec-2023 5:30 pm
Lab Number:		3432342.9	3432342.10	3432342.11	3432342.12
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	79	62	60	66
3 Grain Sizes Profile as received					
Fraction >/= 2 mm	g/100g dry wt	5.5	< 0.1	< 0.1	0.7
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	84.9	11.0	15.2	29.4
Fraction < 63 µm	g/100g dry wt	9.6	89.0	84.7	69.9

Sample Name:		Paua-Well-S4 Bradeys Bay 14-Dec-2023 6:00 pm	Paua-Well-S5 Browns Bay 14-Dec-2023 6:30 pm	Onep-Well-S6 Titahi 15-Dec-2023 6:15 pm	Onep-Well-S7 Onepoto 15-Dec-2023 6:45 pm
Lab Number:		3432342.13	3432342.14	3432342.15	3432342.16
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	68	64	57	79
3 Grain Sizes Profile as received					
Fraction >/= 2 mm	g/100g dry wt	0.8	0.6	0.2	0.6
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	58.9	58.0	20.3	87.1
Fraction < 63 µm	g/100g dry wt	40.3	41.4	79.5	12.3

Sample Name:	Onep-Well-S9 Te Onepoto 15-Dec-2023 7:10 pm	Waik-A Waikanae 15-Dec-2023 7:00 am	Waik-B Waikanae 15-Dec-2023 8:00 am	Waik-C Waikanae 15-Dec-2023 7:30 am
Lab Number:	3432342.17	3432342.18	3432342.19	3432342.20

Sample Type: Sediment					
	Sample Name:	Onep-Well-S9 Te Onepoto 15-Dec-2023 7:10 pm	Waik-A Waikanae 15-Dec-2023 7:00 am	Waik-B Waikanae 15-Dec-2023 8:00 am	Waik-C Waikanae 15-Dec-2023 7:30 am
	Lab Number:	3432342.17	3432342.18	3432342.19	3432342.20
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	79	74	78	79
3 Grain Sizes Profile as received					
Fraction >/= 2 mm	g/100g dry wt	0.9	4.0	2.2	12.1
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	92.7	70.2	84.9	59.5
Fraction < 63 µm	g/100g dry wt	6.4	25.8	12.9	28.4

	Sample Name:	Hutt-A Hutt 15-Dec-2023 1:45 pm
	Lab Number:	3432342.21
Individual Tests		
Dry Matter of Sieved Sample	g/100g as rcvd	83
3 Grain Sizes Profile as received		
Fraction >/= 2 mm	g/100g dry wt	13.0
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	72.5
Fraction < 63 µm	g/100g dry wt	14.5

The reported uncertainty is an expanded uncertainty with a level of confidence of approximately 95 percent (i.e. two standard deviations, calculated using a coverage factor of 2). Reported uncertainties are calculated from the performance of typical matrices, and do not include variation due to sampling.

For further information on uncertainty of measurement at Hill Laboratories, refer to the technical note on our website: www.hill-laboratories.com/files/Intro_To_UOM.pdf, or contact the laboratory.

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 Labs, 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	1-21
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	1-21
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	1-21
Fraction < 63 µm	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-21

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

Testing was completed between 26-Jan-2024 and 08-Feb-2024. 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.

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

APPENDIX 3. ADDITIONAL OBSERVATIONS

While undertaking the field survey in December 2023, observations were noted on two features in the estuary that are likely to be of interest to GWRC. The first is related to the recovery of seagrass reported in January 2023 as having declined by ~90% at Bradeys Bay in response to impacts attributed to high sediment deposition. Much of this seagrass has now re-established in areas where it was previously growing, although it is still showing signs of extensive epiphytic growth and smothering by filamentous algae (see photos below).

The second observation relates to mats of *Chaetomorpha ligustica* that anecdotally have become more conspicuous in recent years (Stevens and Forrest 2020), and appear to be the same species described as being present in Te Awarua-o-Porirua Harbour since the 1950's (Adams 1994). The extensive drift (unattached) mats observed on the Paremata railway flats in January 2023 (top photo below) were not observed in December 2023 (lower photo below), indicating an improvement in condition. However, patches of dead cockles and seagrass, and areas with anoxic sediments at the surface indicated that there had been localised recent impacts from smothering algae.

Recovering seagrass in Bradeys Bay, December 2023.

Mats of *Chaetomorpha ligustica*, Paremata railway flats, January 2023.

Epiphytic growth on seagrass at Bradeys Bay, December 2023.

Very little *Chaetomorpha ligustica* was observed on the Paremata railway flats, December 2023.

SALT
ECOLOGY
www.saltecology.co.nz

Greater Wellington Regional Council:

Wellington office
PO Box 11646
Manners Street
Wellington 6142

T 04 384 5708
F 04 385 6960

Upper Hutt office
PO Box 40847
Upper Hutt 5018

T 04 526 4133
F 04 526 4171

Masterton office
PO Box 41
Masterton 5840

T 06 378 2484
F 06 378 2146

Follow the Wellington
Regional Council

info@gw.govt.nz
www.gw.govt.nz

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