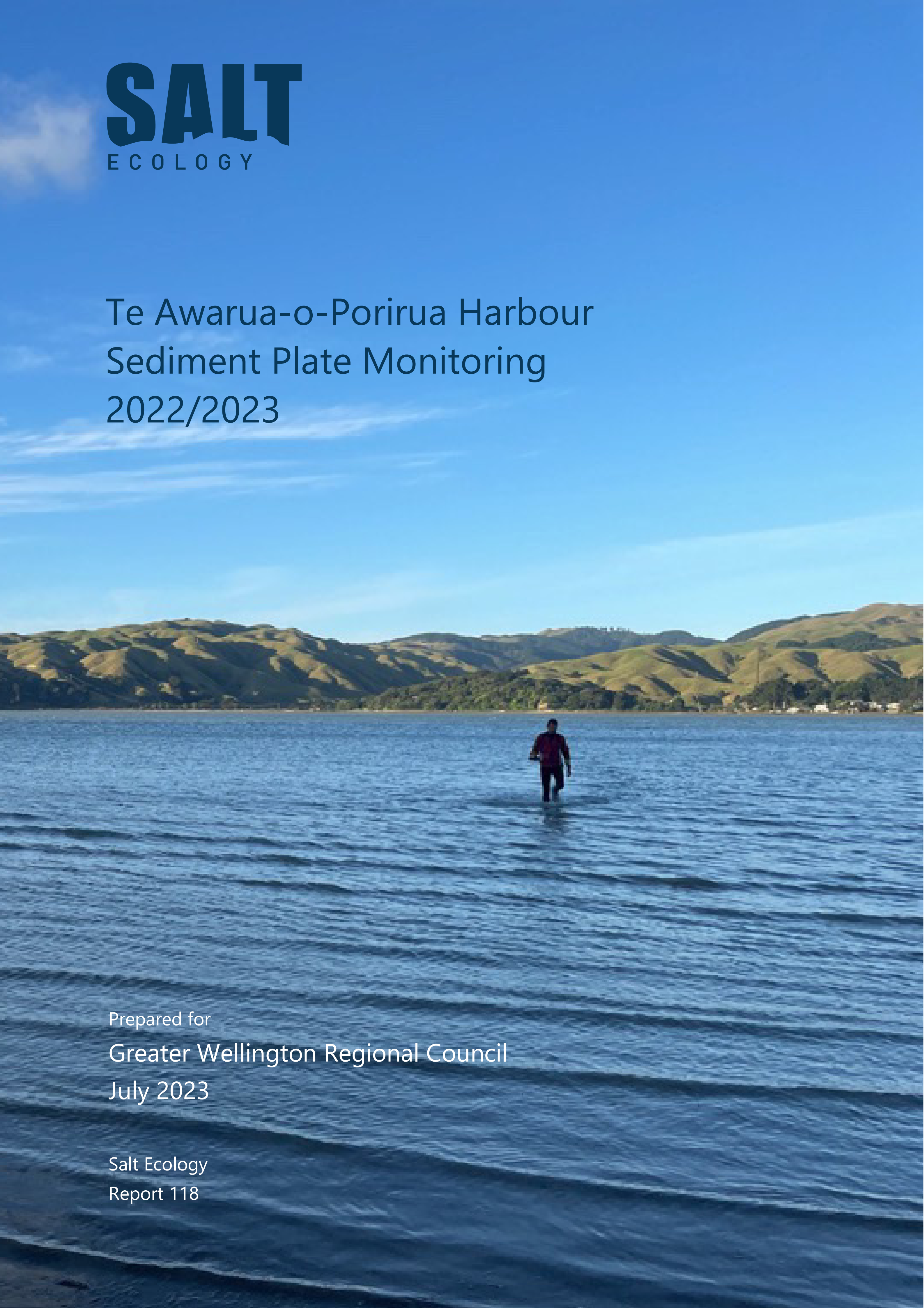

Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2022/2023

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Greater Wellington Regional Council

July 2023

Salt Ecology

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Te Awarua-o-Porirua Harbour Sediment Plate Monitoring 2022/2023

Prepared by

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for

Greater Wellington Regional Council

July 2023

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For the environment
Mō te taiao

GLOSSARY

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

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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 2022/2023 annual monitoring, undertaken on 9-10 January 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 2022 and January 2023, high net accretion of sediment with fine mud was recorded at Onepoto intertidal sites O2 and O3, and at subtidal site OS6. Accretion recorded at the Pāuatahanui intertidal sites was attributable to the movement of marine sands and was of no ecological concern, but subtidal sites PS2, PS3 and PS4 all showed increases in mud elevated sediments. High accretion is commonly associated with high mud contents (>25% mud) and poor sediment oxygenation (<10mm) and is likely causing adverse ecological effects in the Harbour.

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

Mean annual sedimentation rate (mm/y)		
Zone	10-y	5-y
Onepoto (intertidal)	+1.9	+1.7
Onepoto (subtidal)*	+2.7	+9.8
Pāuatahanui (intertidal)	+1.2	+2.4
Pāuatahanui (subtidal)	+7.0	+2.5

*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 excessive sediment inputs to the Harbour.

Mud deposits on the Poriua Stream delta, January 2023.

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 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.

RECOMMENDATIONS

As previously, the January 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. 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 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). 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, 2022).
- Annual monitoring of sedimentation, substrate type and condition at intertidal and subtidal 'sediment plate' sites (e.g., Stevens et al. 2020, Roberts et al. 2021).

The current report presents the results for the 2022/2023 annual monitoring at sediment plate sites, carried out from 9-10 January 2023 and compares findings to previous work. Results are also considered in the context of complementary methods for assessing estuarine sedimentation and potential drivers of change.

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 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, 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 1 (Onep A), Onepoto Inlet.

2. METHODS

2.1 OVERVIEW

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

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 (see Section 2.2.4).

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).

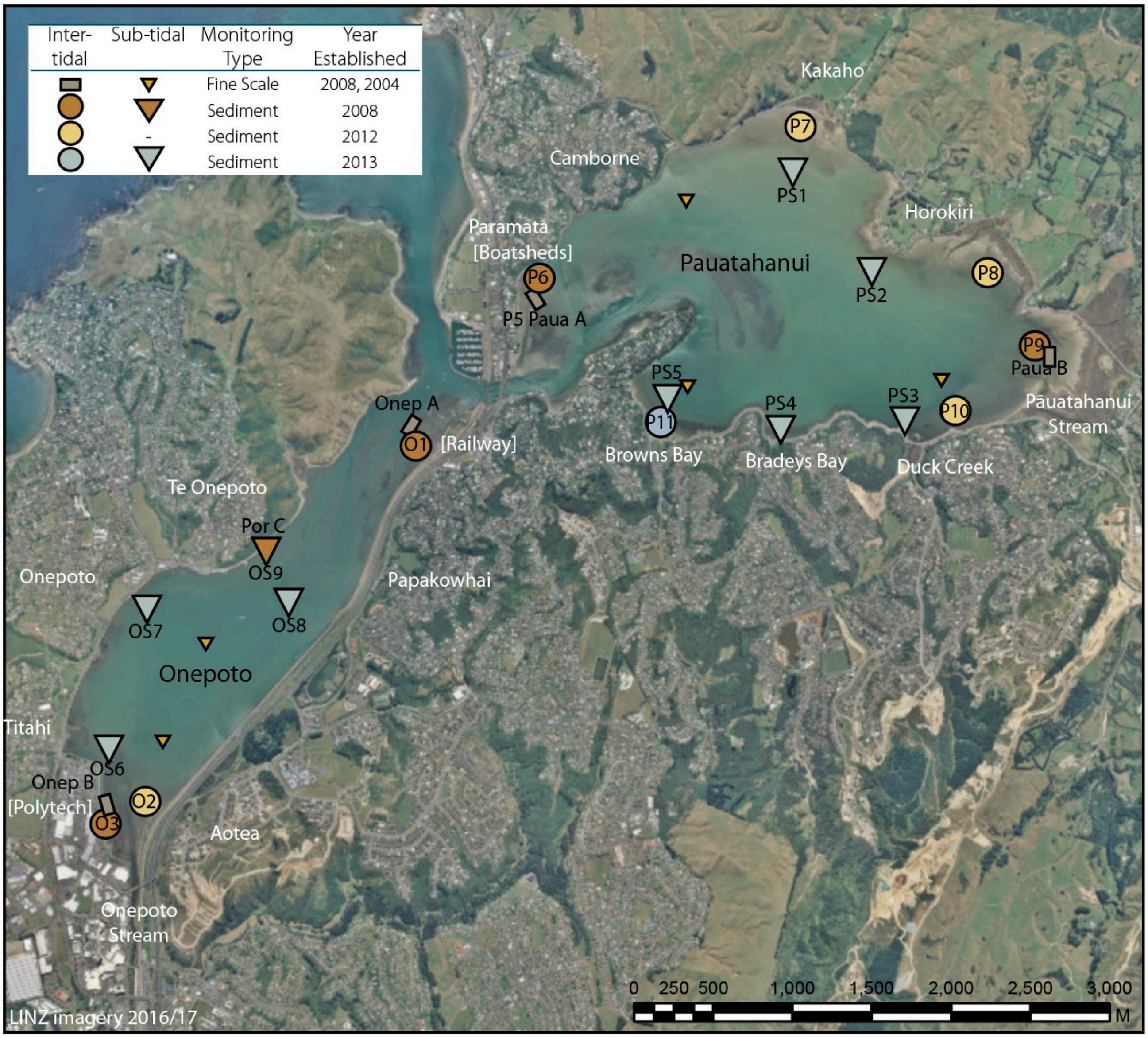


Fig. 1. Location of the 18 sediment plate sites (indicated by the alphanumeric sequence on the map) in Te Awarua-o-Porirua Harbour. Also shown are the location of 4 intertidal (rectangles) and 5 subtidal (small triangles) "fine scale" sites at which other monitoring is undertaken at ~5-yearly intervals.

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, 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).

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. The P6 plates were relocated to the nearby site Paua A. In addition, the configuration of the plates at Paua B, Onep A and Onep B has been altered to standardise the layout and make the plates easier to relocate.

Installation of plates at site Onep B, Onepoto Inlet.

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). In December 2020, January 2022 and again in January 2023, these areas were mapped using broad scale assessment methods to assess inter-annual changes.

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.

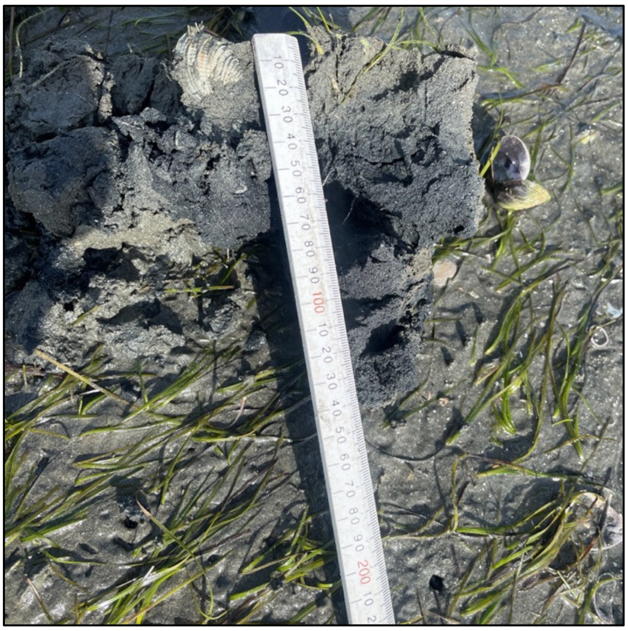
Subtidal plate depths were measured using a custom-built frame (see photos on the following page). The frame was positioned ~5cm above the sediment overlying each relocated plate and allowed to settle onto the surface sediment. A measuring rod was then pushed down through a vertical tube to the underlying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

Frame used to measure subtidal plates at the water surface.

Measuring subtidal plates in the Pāuatahanui Inlet (Site PS3 – Browns Bay) and at Onepoto Inlet (Site OS9).

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 or 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 to indicate trends in sedimentation.



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

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, 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.

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 (Appendix 2).

In December 2020, January 2022 and January 2023, 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).

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 grainsize 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 '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) project (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).

Collecting sediment samples for laboratory analysis, Browns Bay intertidal Site P11, 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

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 at each site) is shown in Figures 2 and 3, along with the associated long-term trend compared to the national DGV of 2mm/y. Note that subtidal site PS1 was unable to be relocated in January 2023 due to a GPS issue.

Between January 2022 and January 2023, fine sediment accretion was high at the three Onepoto intertidal sites, and at Pāuatahanui intertidal sites P9 and P10 at the eastern end of the inlet. Sediment accretion was also high at Onepoto subtidal sites OS6 and OS9 (Titahi and Te Onepoto), and Pāuatahanui subtidal sites PS2, PS3 and PS4 (Horokiri, Duck Creek, Bradeys Bay).

Accretion at the three Onepoto intertidal sites, and Pāuatahanui site P10 (Duck Creek), appeared to be caused primarily by the movement of mobile sand ridges due to wave and current action, and does not reflect fine sediment (mud) deposition.

Not all sites showed accretion of sediment between 2022 and 2023, with sediment erosion evident at Pāuatahanui intertidal sites P7 and P8 (Kakaho and Horokiri), and at subtidal site PS5 (Browns Bay).

However, as shown in Table 2, the 10-year and 5-year trends at most sites showed 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. Long-term overall trends in relation to the DGV are illustrated in Figures 2 and 3.

Table 2. Mean annual change in sediment depth between 2014 – 2023. 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	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	+1.2		+0.8	
		O2 Aotea	2012	-0.2	2.3	7.8	1.5	-0.2	6.5	3.5	-0.5	-4.7	17.4	+3.3	+1.9	+4.4	+1.7
		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	+1.3		-0.1	
	Subtidal	OS6 Titahi	2013	0.0	-11.0	-16.0	32.0	43.0	3.0	16.0	10.0	57.0	14.0	+14.8	+2.7•	+20.0	+9.8•
		OS7 Onepoto	2013	-6.0	-92.0	-2.0	7.0	0.0	-2.0*	-1.0	-8.0	10.0	-1.0	-9.5		-0.4	
		OS8 Papakowhai	2013	-8.0	-77.0	10.0	24.0	-2.0	2.0	20.0	4.0	nd	nd	-3.4	-0.9•	+8.7	+5.2•
		OS9 Te Onepoto	2008	0.0	4.0	7.0	-3.0	1.0	-9.0	-2.0	9.0	-2.0	12.0	+1.7		+1.6	
Pāuatahanui Inlet	Intertidal	P5 Paua A (FS)	2021									3.2	-0.5	-		-	
		P6 Boatsheds	2009	-2.0	-3.0	-3.5	-4.5	6.3	4.0	5.8	-8.2	sd	sd	-0.7		+0.5	
		P7 Kakaho	2012	-4.0	-2.0	-5.7	17.8	-7.0	2.0	12.8	20.0	-11.2	-4.4	+1.8		+3.8	
		P8 Horokiri	2012	-2.5	1.3	0.0	-7.0	7.3	1.3	1.3	-4.0	7.5	-9.3	-0.4	+1.2	-0.7	+2.4
		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	+1.1		+3.0	
		P10 Duck Creek	2012	14.8	-5.5	1.8	1.0	4.0	2.0	1.0	2.3	9.8	8.8	+4.0		+4.8	
	Subtidal	PS1 Kakaho	2013	7.0	2.0	8.0	64.0	-6.0	-11.0*	-11.0	38.0	-37.0	nd	+6.0		-5.2	
		PS2 Horokiri	2013	26.0	18.0	10.0	54.0	-16.0	0.0	-7.0	28.0	5.0	3.0	+12.1		+5.8	
		PS3 Duck Creek	2013	8.0	-12.0	45.0*	45.0	10.0	-21.0*	-21.0	12.0	-4.0	28.0	+9.0	+7.0	-1.2	+2.5
		PS4 Bradeys Bay	2013	11.0	-4.0	-5.0	12.0	5.0	-1.0	33.0	-3.0	16.0	21.0	+8.5		+13.2	
		PS5 Browns Bay	2013	9.0	-10.0	-2.0	13.0	-10.0	-1.0	2.0	-4.0	10.0	-15.0	-0.8		-1.6	

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/y).
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.

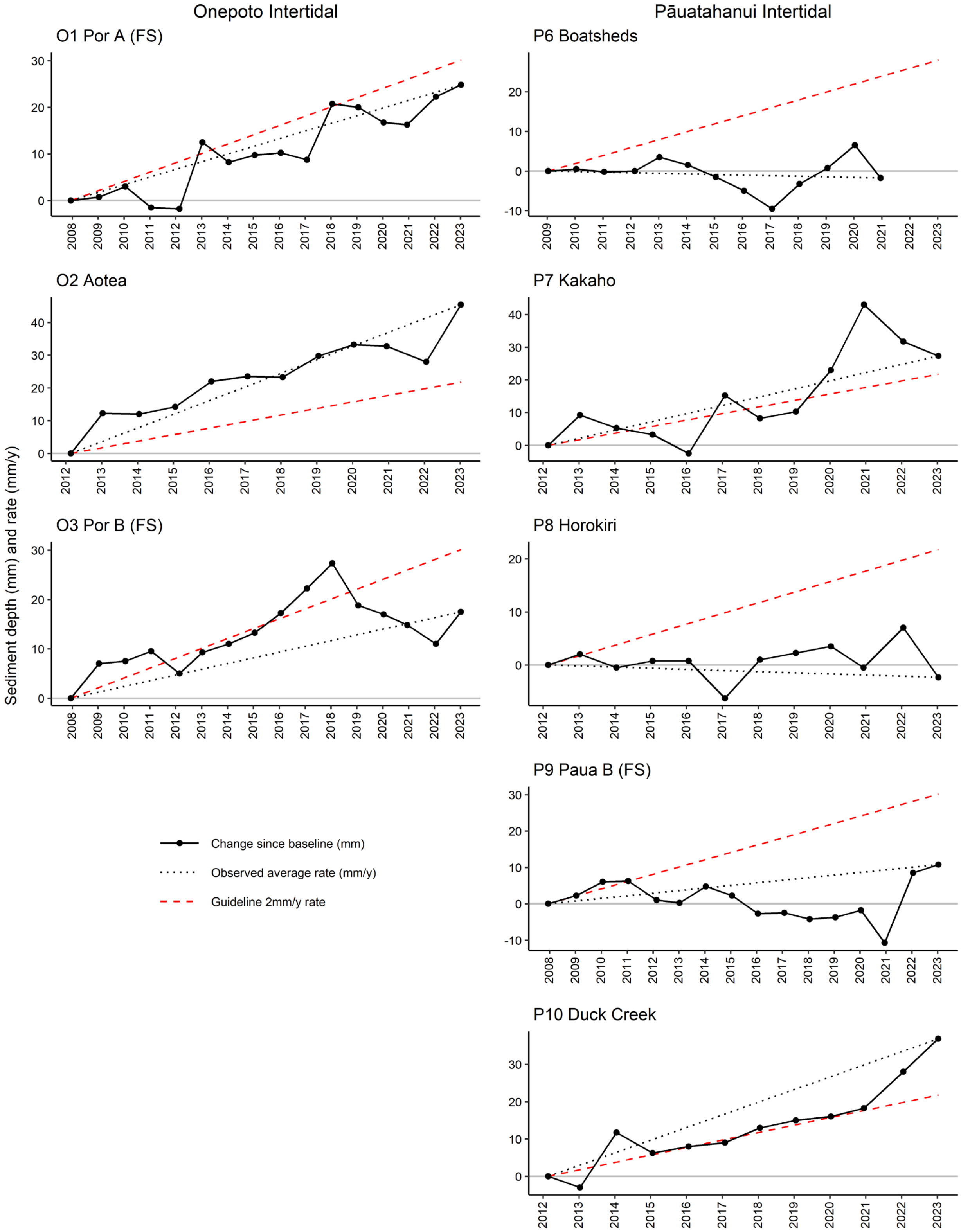


Fig. 2. Sediment depth change (mm) from baseline (year plates installed) at intertidal sites in the Onepoto and Pāuatahanui Inlets of Te Awarua-o-Porirua Harbour. The black dotted trendline shows linear accrual at the observed average annual rate, and the red dashed trendline corresponds to the ANZG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

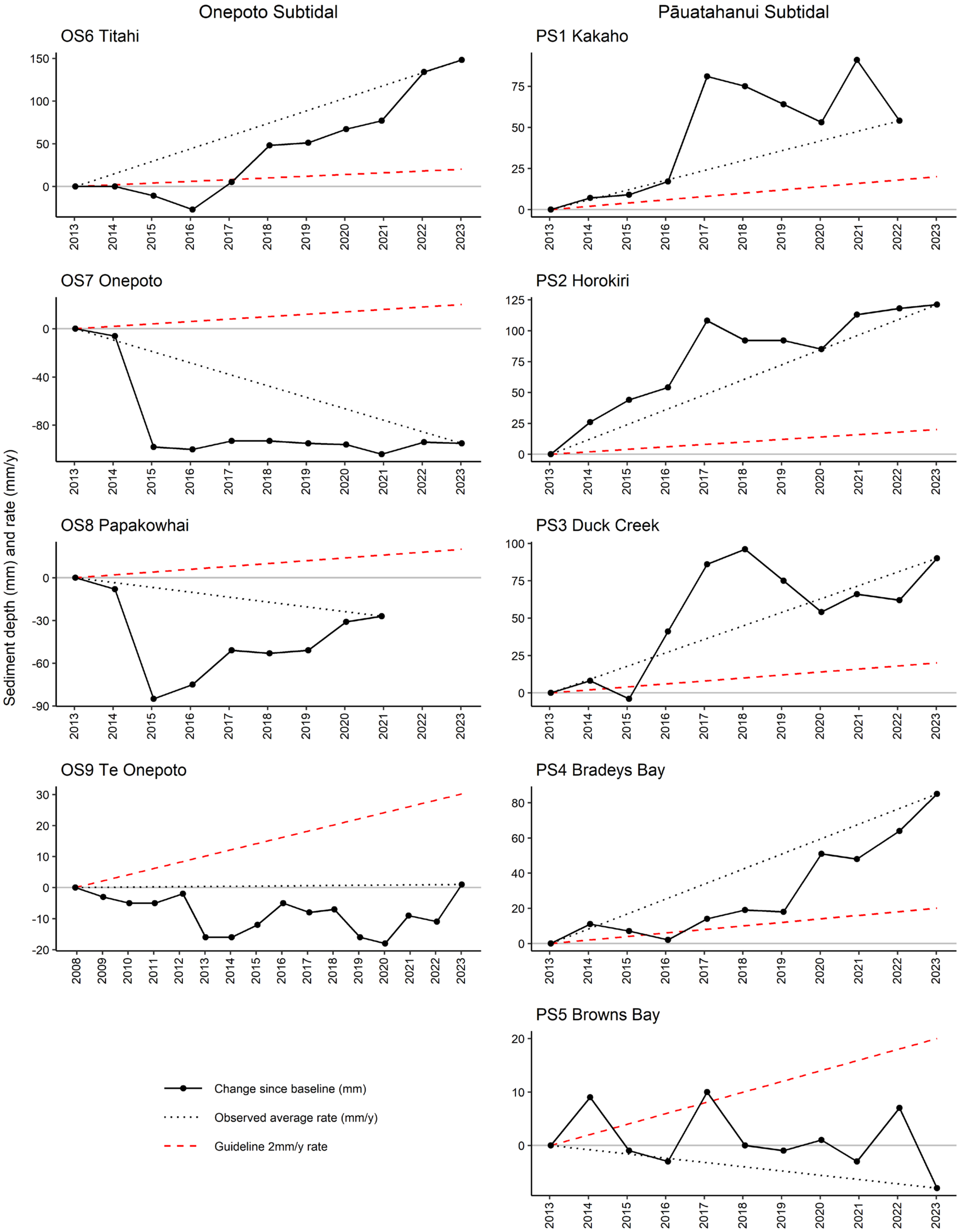


Fig. 3. Sediment depth change (mm) from baseline (year plates installed) at subtidal sites in the Onepoto and Pāuatahanui Inlets of Te Awarua-o-Porirua Harbour. The black dotted trendline shows linear accrual at the observed average annual rate, and the red dashed trendline corresponds to the ANZG (2018)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

Table 2, and Figures 2 and 3, show high temporal and spatial variability between surveys and sites, reflecting episodic deposition and erosion events. Overall, the 10-year averages in Table 2 show high mean deposition in the Pāuatahanui and Onepoto subtidal zones, and moderate increases in the intertidal zones. Compared to the 10-year average, the results from the past 5 years indicate higher recent subtidal accretion rates in Onepoto, and reduced accretion in Pāuatahanui. The latter change largely reflects net sediment erosion at the Browns Bay site, offset by high deposition at Duck Creek and Bradeys Bay.

Despite 5-year results showing a net increase in intertidal deposition at the Pāuatahanui intertidal sites, as mentioned above, sediment erosion was evident at intertidal sites P7 and P8 (Kakaho and Horokiri). This was reflected in a continuing decline in the extensive layer of mud that had been deposited at these sites following intensive rain events in 2017, January 2020 and December 2020 (see next section). The deep, soft deposits that occurred following these rain events (see photos opposite) have now been largely remobilised and the sites are becoming firmer and sandier (see lower photo opposite).

The muddiest and deepest deposits of intertidal fine sediments remaining in the harbour were located near Ration Point where ankle deep muds were overlying gravel beds in many areas near the low tide line (see photo below).

Soft muds overlying gravelbeds on the intertidal flats near Horokiri (PS2), Pāuatahanui Inlet, January 2023.

On the Porirua Stream delta, cockle beds were covered by muds that appeared to have been recently deposited. Over the previous 12 months, sediment depths in this part of the Onepoto Inlet had increased by 17.2mm at site O2 (see photo below), and 12mm at O3.

Muds deposited on cockle beds at the mouth of the Porirua Stream (O2), Onepoto Inlet, January 2023.

Kakaho intertidal site P7 in December 2020 (top) and in January 2023 (bottom), highlighting the significant deposition and subsequent erosion of muds at the site.

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, intertidal sites in the Pāuatahanui Inlet ranged from 'very good' to 'fair' (Table 3), with mud contents decreasing slightly across most sites since January 2022 (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 the site (Table 2, Fig. 2). The intertidal flats in the Onepoto Inlet have had a relatively consistently low mud content (rated 'good' at all three sites in 2022), although sites O2 and O3 both showed increased mud in 2023, with sites shifting to a rating of 'fair' (Table 3, 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). 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 estuary. Bradeys 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 Bradeys Bay, coincident with the observed seagrass losses, mud content increased from 16% in 2013 to 41% in 2022, and was 47% in 2023.

The subtidal sites in the Onepoto Inlet were more varied. Te Onepoto (OS9) and Onepoto (OS7) are both well-flushed sand-dominated sites and were rated 'good' or 'fair' (Table 3). Titahi (OS6) has shown an overall trend of increasing mud content since 2013, with the January 2023 mud content rated 'poor' (Table 3; Fig. 4d) and consecutive annual increases in deposition recorded since 2017 (Table 2, Fig. 4c).

Table 3. Measured aRPD depth (mm) and sediment grain size (%), Te Awarua-o-Porirua, January 2023, 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)	35	0.8	92.8	6.4
		O2	Aotea	35	0.9	76.7	22.4
		O3	Por B (FS)	25	0.6	87.4	12.0
	Subtidal	OS6	Titahi	5	0.8	21.0	78.3
		OS7	Onepoto	>50	0.5	90.8	8.7
		OS9	Te Onepoto	23	1.4	86.5	12.1
Pāuatahanui Inlet	Intertidal	P5	Paua A (FS)	35	3.3	83.5	13.3
		P7	Kakaho	25	0.5	80.8	18.7
		P8	Horokiri	30	2.2	88.6	9.2
		P9	Paua B (FS)	30	0.4	87.3	12.3
		P10	Duck Creek	40	1.5	95.4	3.1
		P11	Browns Bay	15	3.1	84.2	12.7
	Subtidal	PS1	Kakaho	10	0.1	15.2	84.7
		PS2	Horokiri	15	0.1	19.0	80.9
		PS3	Duck Creek	10	0.4	34.9	64.7
		PS4	Bradeys Bay	5	0.1	52.8	47.1
		PS5	Browns Bay	5	0.7	28.6	70.7

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.

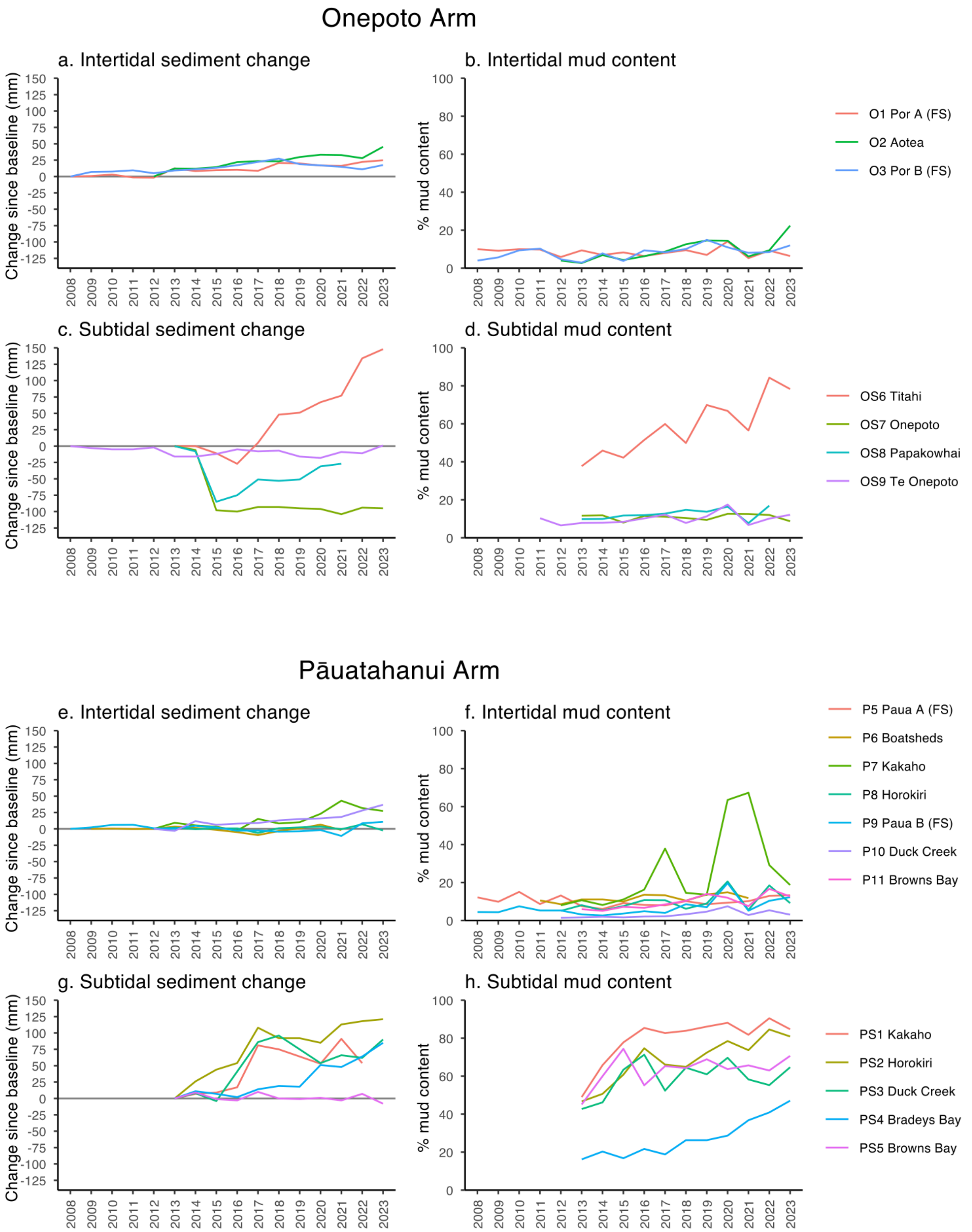


Fig. 4. Sediment depth change (mm) from baseline (year plates installed) and corresponding change in sediment mud content (%) for intertidal and subtidal sites in the Onepoto Inlet and the Pāuatahanui Inlet.

3.3 SEDIMENT OXYGENATION

In January 2023, visually assessed aRPD depths (Table 3) were variable depending on location. In general, high mud contents were associated with shallower aRPD depths, with three of the six mud-dominated sites rated as 'poor' (OS6, PS4, PS5) and three (PS1, PS2, PS3) rated 'fair' for sediment oxygenation. All the other sites had mud contents less than 25% and an aRPD rated as 'very good' to 'fair' (Table 3).

The intertidal sites in both arms had higher sediment oxygenation than adjacent subtidal sites, with intertidal aRPD depths between 15 and 35mm and most subtidal aRPD depths between 5 and 15mm. The deepest aRPD (>50mm) was recorded from subtidal site OS7, and is a substantial improvement on the 5mm recorded in the previous year when a layer of organic material was present beneath a fresh layer of mobile sand.

25mm of oxygenated sand above organically enriched sediment Por 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. Kakaho, Horokiri and Titahi continue to show the largest net increases in extent from the starting baseline (55m, 84m and 75m respectively - Table 4), although soft mud has retreated toward the subtidal zone at all three sites over the past year.

In contrast, increases from the starting baseline were recorded at Duck Creek, Bradeys Bay and Browns Bay over the previous 12 months. All three sites are located on the southern side of the Pāuatahanui Inlet, and this result may indicate that widespread mobilisation and redistribution of subtidal sediments has occurred in this part of the estuary recently.

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 2023.

Site	Site No	Distance from subtidal plates to edge of soft mud (m)#								Change from baseline (m) 2013-2023
		2013	2017	2018	2019	2020	2021	2022	2023	
Kakaho	PS1	5	300	150	55	310	385	125	60	55
Horokiri	PS2	5	65	120	80	90	80	99	89	84
Duck Creek	PS3	5	10	15	23	20	21	21	25	20
Bradeys Bay	PS4	5	15	8	5	15	10	9	11	6
Browns Bay	PS5	5	40	28	35	25	43	36	54	49
Titahi	OS6	5	45	135	52	50	71	88	80	75

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

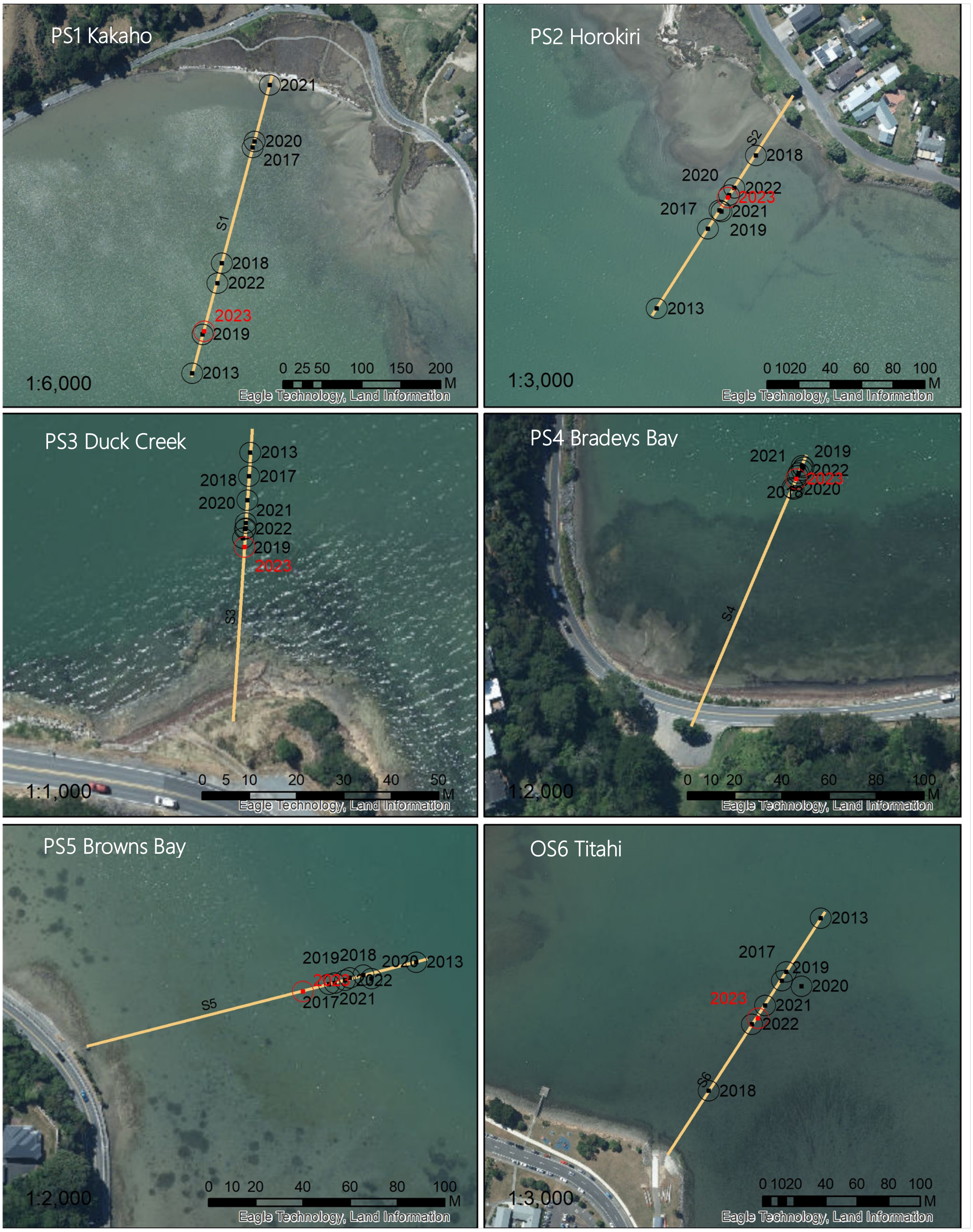


Fig. 5. Transects showing the distance from subtidal plate sites to where soft muds transitions to firmer sediments closer to the shoreline (2013, 2017-2023). See Table 4 for measured distances and Appendix 2 for transect coordinates. The sediment plates are located at the seaward end of each transect line.

3.5 MAPPING OF MUD AREA

Due to the widespread deposition of soft muds recorded in the north and east of Pāuatahanui Inlet during broad scale habitat mapping in January 2020, the area of intertidal mud between Camborne and Duck Creek was re-mapped in December 2020 and January 2022, and repeated again in January 2023. Table 5 summarises results, and Fig. 6 and Fig. 7 show broad temporal changes in the location of mud-elevated and mud-dominated sediments over the past four years.

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

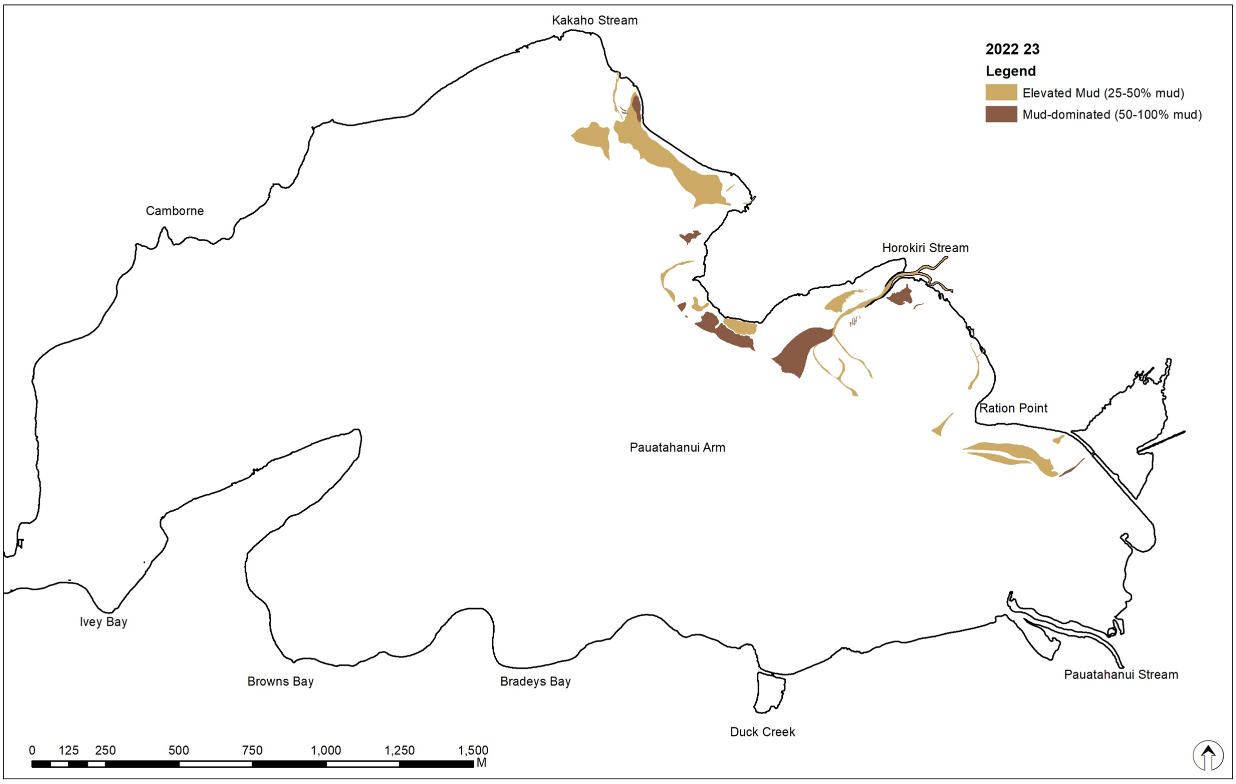
Hectares (ha)	Jan-20	Dec-20	Jan-22	Jan-23
Mud elevated (>25-50% mud)	36.0	11.4	11.4	8.8
Mud-dominated (>50% mud)	27.9	24.3	15.3	3.3
Total	**63.9**	**35.7**	**26.7**	**12.1**

Between January 2020 and January 2023, the extent of intertidal mud-elevated (>25-50% mud) substrate has decreased by 27ha, and mud-dominated (>50% mud) substrate has reduced by 25ha. While the remaining 12ha extent is still significant, the results reflect a relatively rapid and significant reduction in the area extent of muddy sediments, which is consistent with sediment plate measurements at P7 and P8 (Kakaho and Horokiri) in the main depositional area. As mentioned earlier, sediment accretion recorded at Duck Creek was attributed to the movement of mobile sand and does not reflect fine sediment (mud) deposition.

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 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 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 in the deeper subtidal deposition zones of the estuary.

Mud-elevated sediments overlying sandier sediment.

Fine muds in the shallow subtidal margins are readily re-suspended by even small waves, resulting in decreased water clarity and facilitating the redistribution of sediment throughout the harbour.



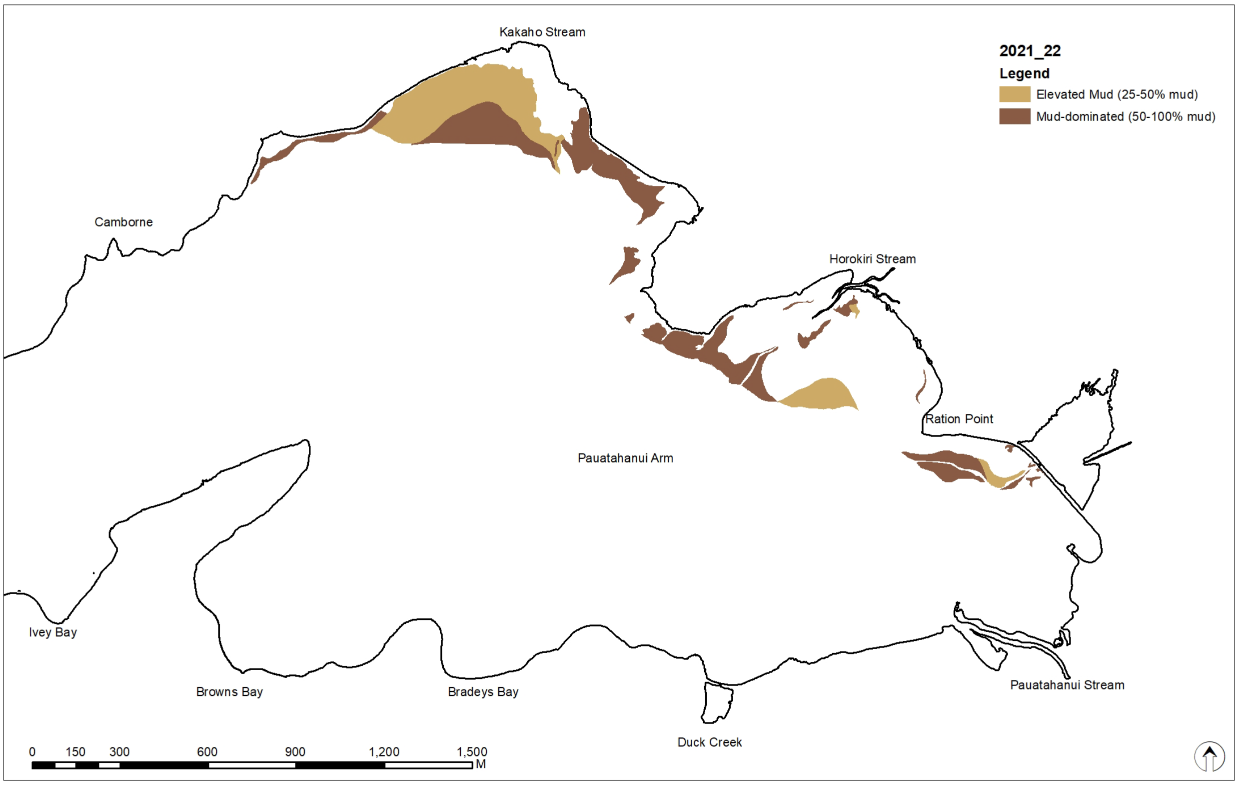
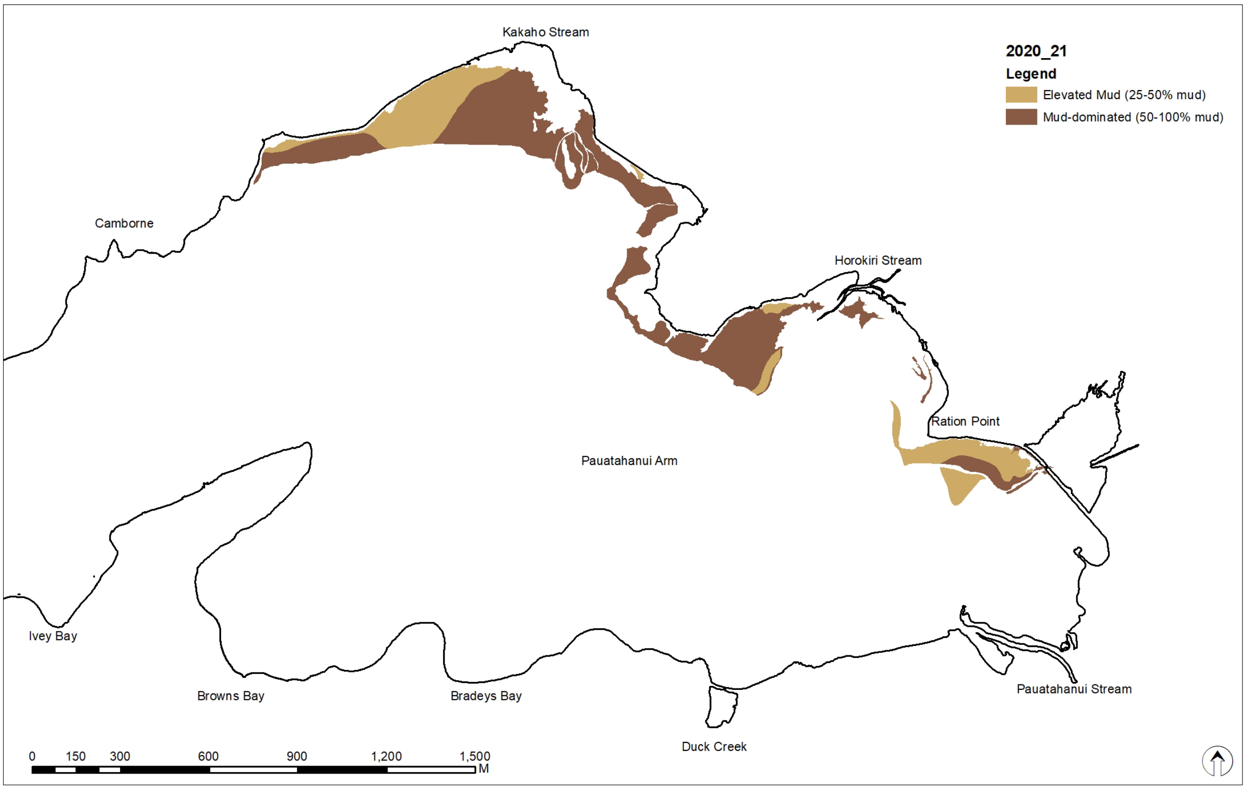


Fig. 6. Maps showing change in mud-elevated (>25-50% mud) and mud-dominated (>50% mud) sediment, Te Awarua-o-Porirua Harbour, January 2023 (top) and January 2022 (bottom).



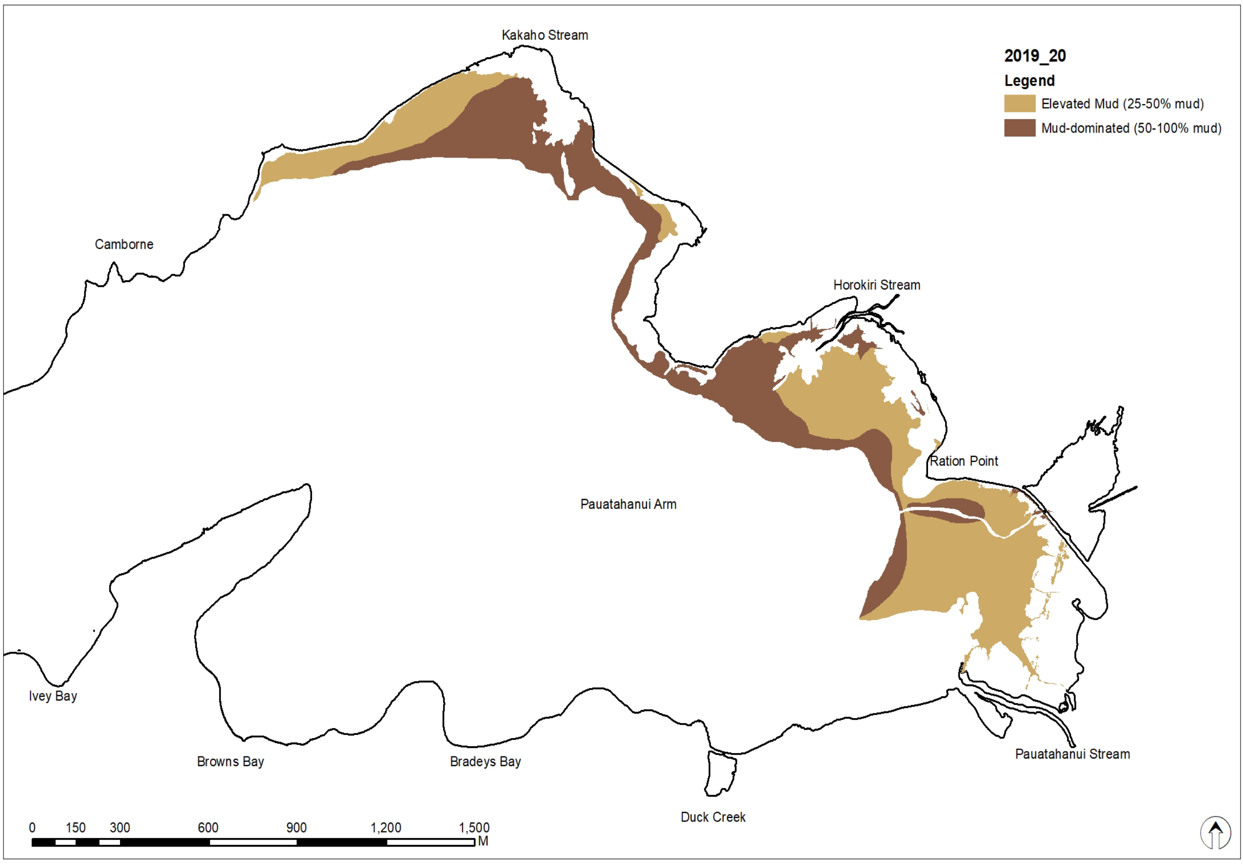


Fig. 7. Maps showing change in mud-elevated (>25-50% mud) and mud-dominated (>50% mud) sediment, Te Awarua-o-Porirua Harbour, January 2020 (top) and December 2020 (bottom).

4. SYNTHESIS OF FINDINGS

Subtidal sediment plate monitoring results over the past 10 years show an average increase of +7.0mm/y in the Pāuatahanui Inlet, and +2.7mm/y 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 (2019-2023) shows an increased mean rate of subtidal deposition in Onepoto (+9.8mm/y), and a decreased (but still elevated) rate in Pāuatahanui (+2.5mm/y). In all cases subtidal sedimentation was rated 'poor' (Table 2).

Intertidal sedimentation rates over the past 10 years show an average increase of +1.2 and +1.9mm/y, for Pāuatahanui and Onepoto Inlets, respectively (both areas rated 'fair'; Table 2). Compared to the 10-year mean annual sedimentation rate, the past 5-year period (2019-2023) shows an increased rate of deposition in Pāuatahanui Inlet (+2.4mm/y; rated 'poor'), and a slightly reduced rate in the Onepoto Inlet (1.7mm/y; rated 'fair'). However, the intertidal increase in Pāuatahanui Inlet is driven primarily by deposition of marine sand at Duck Creek (3% mud content) and, to a lesser extent, at P9/Paua B (12% mud content).

More notably, the sediment erosion and decrease in mud content recorded at sites P7/Kakaho and P8/Horokiri in January 2023 represent a visually obvious improvement in intertidal condition. Both these sites, but particularly P7/Kakaho, were significantly impacted by the deposition of a thick slurry of fine sediment covering previously sandy intertidal flats, following several intensive rain events between 2017-2020 (Roberts et al. 2021). For example, at P7/Kakaho, after three consecutive years of sediment deposition from 2019-2021, there was an 11.2mm decrease recorded from December 2020 to January 2022, followed by a further 4.4mm decrease from January 2022 to January 2023. The change reflects an ongoing reduction in the depth of fine sediment deposited at the site, which is also reflected in the sediment mud content which has reduced from 67.3% to 29.2% to 18.7% over the last three 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 four years show a relatively rapid and significant reduction in the areal extent of mud, which is consistent with sediment plate measurements in the main depositional area. 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 in subtidal areas. In the subtidal basins of both inlets, mean sedimentation rates exceed the 'poor' threshold and the recommended ANZECC Default Guideline Value (2mm/y). 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/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.

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 continued 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. ADDITIONAL OBSERVATIONS

While undertaking the field survey in 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 reduction in seagrass previously reported at Bradeys Bay. Although the extent of the loss has not been quantified, it is estimated to be at ~90%. The photo below illustrates that the extensive beds of seagrass that previously had a near complete cover, are now patchy and in decline. Of the remaining seagrass, much of it had thick cover of epiphytic growth in January 2023, which is potentially adversely impacting seagrass condition.

Patchy seagrass remaining in Bradeys Bay, January 2023.

Epiphytic growth on seagrass at Bradeys Bay, January 2023.

The second observation relates to the presence in 2023 of extensive mats of *Chaetomorpha ligustica* on the Paremata railway flats. Observed previously in 2020, these mats have anecdotally become more conspicuous in recent years (Stevens and Forrest 2020), and appear to be formed by the same species described as being present in Te Awarua-o-Porirua Harbour since the 1950's (Adams 1994). The *Chaetomorpha* mats present in 2023 appeared to mainly be drift (unattached) material, but had smothered cockle beds or killed patches of seagrass beneath them in many localised places.

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

Dead cockles and seagrass caused by mats of *Chaetomorpha ligustica* on the Paremata railway flats, January 2023.

6. 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 high 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 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.

7. RECOMMENDATIONS

The January 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 Laboratories
TRIED, TESTED AND TRUSTED

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Certificate of Analysis

Client:	Salt Ecology Limited	**Lab No:**	3150115 SPv1
Contact:	Leigh Stevens	**Date Received:**	12-Jan-2023
	C/- Salt Ecology Limited	**Date Reported:**	31-Jan-2023
	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 10-Jan-2023 7:00 am	Onep-Well-2 09-Jan-2023 6:30 pm	Onep-Well-3 09-Jan-2023 6:00 pm	Paua-Well-5 10-Jan-2023 5:30 am	Paua-Well-7 10-Jan-2023 6:30 pm
Lab Number:		3150115.1	3150115.2	3150115.3	3150115.4	3150115.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	70	74	75	71	74
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	0.8	0.9	0.6	3.3	0.5
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	92.8	76.7	87.4	83.5	80.8
Fraction < 63 µm	g/100g dry wt	6.4	22.4	12.0	13.3	18.7

Sample Name:		Paua-Well-8 10-Jan-2023 6:30 am	Paua-Well-9A 10-Jan-2023 6:00 am	Paua-Well-10 09-Jan-2023 8:30 pm	Paua-Well-11 09-Jan-2023 7:15 pm	Paua-Well-S1 10-Jan-2023 7:00 pm
Lab Number:		3150115.6	3150115.7	3150115.8	3150115.9	3150115.10
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	76	71	73	75	63
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	2.2	0.4	1.5	3.1	0.1
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	88.6	87.3	95.4	84.2	15.2
Fraction < 63 µm	g/100g dry wt	9.2	12.3	3.1	12.7	84.7

Sample Name:		Paua-Well-S2 10-Jan-2023 8:00 pm	Paua-Well-S3 09-Jan-2023 8:00 pm	Paua-Well-S4 09-Jan-2023 7:30 pm	Paua-Well-S5 09-Jan-2023 7:00 pm	Onep-Well-S6 09-Jan-2023 5:30 pm
Lab Number:		3150115.11	3150115.12	3150115.13	3150115.14	3150115.15
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	57	63	62	63	58
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	0.1	0.4	0.1	0.7	0.8
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	19.0	34.9	52.8	28.6	21.0
Fraction < 63 µm	g/100g dry wt	80.9	64.7	47.1	70.7	78.3

Sample Name:		Onep-Well-S7 09-Jan-2023 5:00 pm	Onep-Well-S9 09-Jan-2023 4:30 pm
Lab Number:		3150115.16	3150115.17
Individual Tests			
Dry Matter of Sieved Sample	g/100g as rcvd	79	78
3 Grain Sizes Profile as received			
Fraction >/= 2 mm	g/100g dry wt	0.5	1.4
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	90.8	86.5
Fraction < 63 µm	g/100g dry wt	8.7	12.1

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	1-17
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	1-17
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	1-17
Fraction < 63 µm	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-17

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

Testing was completed on 31-Jan-2023. 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.

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

Ara Heron BSc (Tech)
Client Services Manager - Environmental

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°

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