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Porirua Harbour

Sediment Plate Monitoring 2016/17

Prepared for

Greater Wellington Regional Council

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Cover Photo: Sunrise over Browns Bay, Pauatahanui Inlet, Jan. 2017.

Bradeys Bay, Pauatahanui Arm.

Porirua Harbour

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Prepared for
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by

Leigh Stevens

Wriggle Limited, PO Box 1622, Nelson 7040, NZ. Ph 03 545 6315, 021 417 936; 0275 417 935, www.wriggle.co.nz

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1. INTRODUCTION AND METHODS

Greater Wellington Regional Council (GWRC), as part of their wider programme of long term monitoring of key estuaries in the region, have initiated a programme of sediment monitoring in Porirua Harbour to measure changes in sediment deposition rates and grain size ('muddiness") at fixed locations throughout the Onepoto and Pauatahanui arms (Figure 1). Monitoring has been undertaken annually since December 2007 from one subtidal site and four sand-dominated intertidal fine scale sites exposed to moderate but frequent wind-wave disturbance. Baseline fine scale monitoring (Robertson and Stevens 2008, 2009, 2010) recorded elevated mud contents (7-15%) for this type of habitat. To increase the spatial coverage of monitoring within the estuary, four additional intertidal sites were established in February 2012 (3 in the Pauatahanui Arm and 1 in the Onepoto Arm), and an additional nine sites in January 2013 (1 intertidal and 5 subtidal sites in the Pauatahanui Arm and 3 subtidal sites in the Onepoto Arm) - see Figure 1 and Stevens and Robertson (2014a).

Sites were positioned to assess the dominant sediment sources to the estuary - identified as discharges of both bed-load and suspended sediment load from the various streams entering the estuary (most notably Pauatahanui, Horokiri and Porirua Streams - see Green et al. 2015). It is also noted that elevated inputs of nutrients from the same streams are causing symptoms of moderate eutrophication (i.e. poor sediment oxygenation and moderate nuisance macroalgal cover) in the estuary (Stevens and Robertson 2013, Robertson and Stevens 2008, 2009, 2010).

Supporting this work, broad and fine scale subtidal monitoring of the estuary has also been undertaken (e.g. Milne et al. 2008, Oliver and Conwell 2014, Stevens and Robertson 2014b), highlighting the very muddy nature of the subtidal basins. Overall 59% of the subtidal area of the estuary bed comprises very soft muds (mud content >25%), with the deeper subtidal basins having mud contents averaging >60% mud (and often exceeding 80%). Such very high mud contents reflects very poor sediment conditions.

In terms of sediment accumulation, comprehensive bathymetric surveys of the harbour have been undertaken by Gibb and Cox (2009) and Cox (2014) to characterise major seabed changes over the entire estuary. Gibb and Cox (2009) reported high annual average sedimentation rates for the 1974-2009 period of 9.1mm/yr in the Pauatahanui Arm, and 5.7mm/yr in the Onepoto Arm, the rates attributed primarily to elevated sediment inputs entering the harbour system from the surrounding catchment during the 1970-1980's, a busy urbanisation period. Based on these results, Gibb and Cox (2009) predicted the main subtidal basins to rapidly infill and change from tidal estuary to brackish swamps within 145-195 years if rates of deposition over the last ~30 years continued.

The most recent results of Cox (2014) indicate that the mean annual average rate of accretion for all harbour areas over the past 5 years to be less than 2mm per year, indicating accumulation in the estuary between 2009 and 2014 has been relatively low compared to the 1974-2009 period. Repeated comprehensive bathymetric surveys will enable sediment deposition from ongoing land disturbance to be assessed throughout the harbour, with sediment plate data providing a direct measure of annual variation at fixed sites.

The current report presents the results of annual sedimentation rate measurements undertaken in January 2017 at the intertidal and shallow subtidal sites established in Porirua Harbour (Figure 1). Sediment grain size and sediment oxygenation were also measured at all sites, and risk indicator ratings developed for Wellington's estuaries (Section 2) have been used to rate the risk of adverse ecological effects on the estuary, and recommend monitoring and management actions (Section 3).

The report also includes the results of a one-off survey of the established intertidal plate sites undertaken on 1 December 2016 to assess the influence of a significant flood event that occurred on 15 November 2016 and during which extensive deposition of sediment in the harbour was reported (Megan Oliver, GWRC, pers. comm.).

1. Introduction and Methods (Continued)

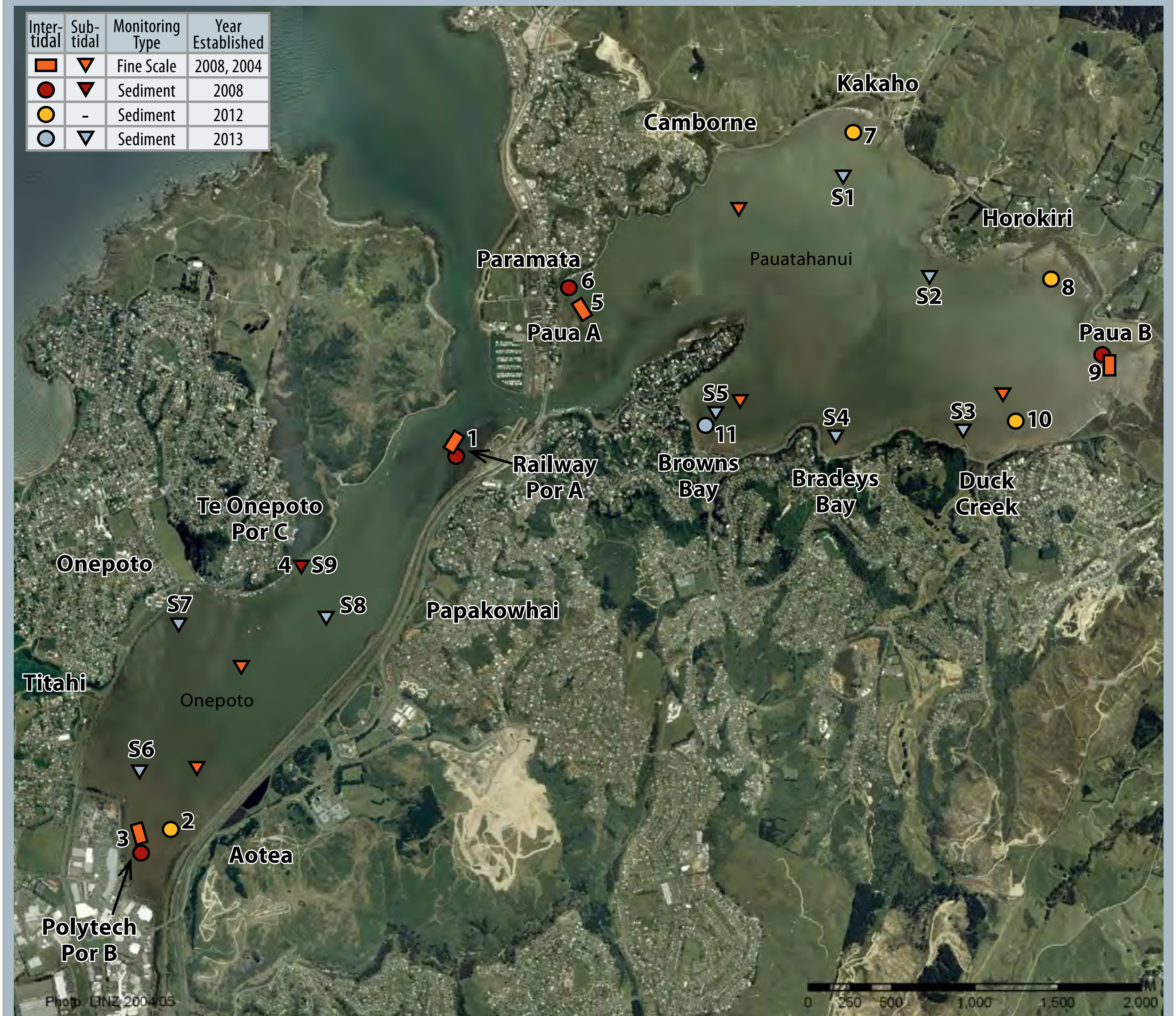


Figure 1. Location of fine scale sites and buried sediment plates established in Porirua Harbour.

Pauatahanui Arm, intertidal Site 7, Kakaho.

1. Introduction and Methods (Continued)

Measuring frame and probe used to measure shallow subtidal plates.

Detailed descriptions of existing sedimentation rate sampling sites and methods are provided in Robertson and Stevens (2008, 2009, 2010) and Stevens and Robertson (2011). They are briefly summarised below.

Sedimentation Rate

To measure sedimentation rates, 42 concrete plates (20cm x 20cm paving stones at intertidal sites and 30cm diameter circular pavers at subtidal sites) have been buried at a variety of locations throughout the intertidal and subtidal reaches of the estuary (Figure 1, Appendix 1). In December 2007, 4 intertidal sites and 1 subtidal site were established. In January 2012, an additional 4 intertidal sites (16 plates) were added, followed by 1 intertidal and 8 subtidal plates in January 2013. Each buried plate was located in stable substrate beneath the sediment surface and its position recorded using a handheld Trimble GeoXH differential GPS (post-processing accuracy 10-50cm).

Subtidal plates were positioned at least 5m from the edge of soft mud deposition zones located by wading from the shore until firmer sediments transitioned to soft muds. These conditions were generally encountered ~1-1.5m below the mean low water mark.

Each plate is relocated without disturbing the overlying soft mud sediments using a differential GPS and a probe. For intertidal sites, a 2m straight edge is then laid across the top of the plate to determine the average sediment level, and the depth to the underlying plate is measured using a probe and ruler.

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

To account for irregular sediment surfaces, 3 replicate measures per plate are taken, and averaged in the field to determine the mean annual rate of sedimentation above each plate.

Grain Size

To monitor changes in the mud content of sediments, a single composite sample of the top 20mm of sediment is collected from adjacent to each sediment plate site. Samples are analysed for grain size (% mud, sand, gravel). Triplicate sampling in 2013 found no appreciable within-site variance therefore single composite analyses were considered appropriate for ongoing annual monitoring. It is recommended that triplicate sampling be undertaken again in conjunction with the next 5 yearly fine scale monitoring (scheduled for 2020) to re-check within-site sample variability in the future.

Apparent Redox Potential Discontinuity (aRPD) depth

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

2. RISK INDICATOR RATINGS

The National Estuary Monitoring Protocol (NEMP, Robertson et al. 2002), and subsequent additions (e.g. Robertson and Stevens 2006, 2007, 2012), recommend a defensible, cost-effective monitoring design for assessing the long term condition of shallow, intertidally-dominated, NZ estuarine systems. The design is based on the use of indicators that have a documented strong relationship with water or sediment quality. The approach is intended to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity and habitat change). In order to facilitate this process, "risk indicator ratings" have been proposed that assign a relative level of risk of adversely affecting estuary conditions (e.g. very low, low, moderate, high, very high) to each indicator (see examples below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuary condition in relation to key issues. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within a risk category without changing the rating, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results.
- Ratings for many indicators have yet to be established using statistical measures, primarily because of the additional work and cost this requires. In the absence of funding, professional judgment, based on our wide experience from monitoring >300 NZ estuaries, has been used in making initial interpretations. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicators and guide monitoring and management for priority issues.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative) trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

While developed specifically for intertidally dominated estuaries, the indicators and risk ratings presented in Table 1 below, are directly relevant to the Porirua Harbour sediment monitoring programme.

Table 1. Risk indicator ratings for sedimentation rate, sediment mud content, and RPD depth.

RISK INDICATOR RATING	SEDIMENTATION RATE[1]	MUD CONTENT[2]	aRPD DEPTH[3]
Very Low	<1mm/yr	<2%	unreliable at depths >2cm
Low	>1-2mm/yr	2-5%	
Moderate	>2-5mm/yr	>5-15%	0.5-2cm
High	>5-10mm/yr	>15-25%	<0.5cm
Very High	>10mm/yr	>25%	Anoxic at surface

NOTES TO TABLE 1:

[1]**Sedimentation Rate:** Elevated sedimentation rates are likely to lead to major and detrimental ecological changes within estuary areas that could be very difficult to reverse, and indicate where changes in land use management may be needed. Note the very low risk category is based on a typical NZ pre-European average rate of <1mm/year, which may underestimate sedimentation rates in soft rock catchments.

[2]**Sediment Mud Content:** In their natural state, most NZ estuaries would have been dominated by sandy or shelly substrates. Fine sediment is likely to cause detrimental and difficult to reverse changes in community composition (Robertson 2013), can facilitate the establishment of invasive species, increase turbidity (from re-suspension), and reduce amenity values. High or increasing mud content can indicate where changes in land use management may be needed.

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

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

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

3. RESULTS, RATING AND MANAGEMENT

On 15 November 2016, a relatively large (1 in 20 year return period)flood event resulted in widespread sediment deposition in Porirua Harbour, particularly in the Pauatahanui Arm where the intertidal flats were reportedly smothered in fine sediment (Megan Oliver, GWRC, pers. comm.). Because of the significance of this deposition, and because this rainfall event was one of several relatively large storms that had impacted on the estuary in the previous year, GWRC commissioned a one-off interim set of intertidal sediment plate measures (undertaken on 1 December 2016) to assess the magnitude of this event, and the cumulative impact of previous events between Jan. and Dec. 2016.

The results of this survey, undertaken 2 weeks after the 15 November 2016 flood, are summarised in Table 2. Sampling showed that while significant intertidal deposition was present, it appeared that some of the initially reported deposition had already been remobilised and deposited elsewhere. This is reflected in the intertidal plate measurements which showed significant recent deposition in the Pauatahanui arm at the Kakaho, Boatsheds, and Duck Creek sites (+2.5 to +13.5mm). These sites all had observable surface deposits of fine muds, the most extensive at Kakaho where they extended across the entire intertidal flats from high to low tide (Figure 2A).

In contrast, there was no significant deposition recorded over the sediment plates at the Horokiri and Pauatahanui Stream sites, but there were strong indications that the sites had been recently blanketed in muds, but that much of this had been remobilised and deposited elsewhere including among saltmarsh (Figure 2C), or in subtidal zones (Figure 2D).

Table 2. Mean change in intertidal sediment plate depths (mm) between January 2016 and December 2016, Porirua Harbour.

Onepoto Arm	
Por A Railway (FS)	-1.3mm
Aotea	+0.5mm
Por B Polytech (FS)	-0.7mm
Pauatahanui Arm	
Boatsheds	+2.5mm
Kakaho	+13.5mm
Horokiri	-1.3mm
Paua B (FS)	-2.0mm
Duck Creek	+2.5mm
Browns Bay	-5.0mm

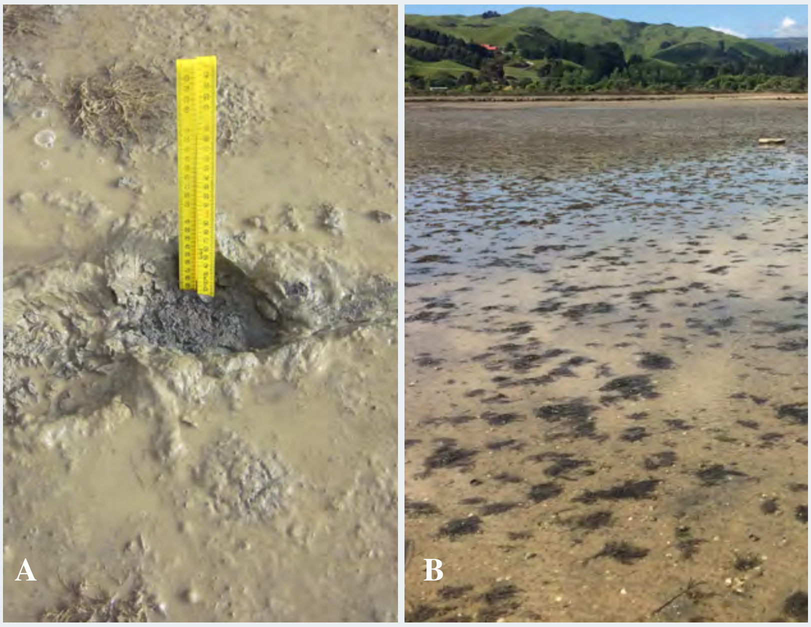


Figure 2. Fine sediment deposits, 1 December 2016, Porirua Harbour. A. Kakaho, B. Ration Point, C. Horokiri, D. shallow subtidal water.

Wading into the shallow subtidal areas revealed fresh deposits of fine muds were present adjacent to all intertidal plate sites in the Pauatahanui Arm, with bottom sediments readily disturbed and remobilised (Figure 2D). A significant increase in the spatial extent of subtidal fine mud deposits was also evident in the Pauatahanui Arm with subtidal soft muds encountered much closer to shore than in previous years. A different picture was present in the Onepoto Arm where there was no significant change recorded at the 3 Onepoto Arm intertidal sites, and little obvious evidence of significant recent intertidal mud deposition. However, as in the Pauatahanui Arm but to a less pronounced extent, fresh deposits of fine muds were evident in the shallow subtidal areas of the central basin.

These findings reinforce current knowledge about catchment flood events causing episodic deposition of fine sediments on intertidal flats, and also highlight the physical processes at play in the estuary which relatively rapidly rework and transport intertidal sediment deposits to adjacent subtidal settlement zones.

The more comprehensive monitoring of sediment plates sites undertaken in January 2017, which assessed sedimentation rate, grain size, and aRPD depth at all sites, showed a very similar situation to that present in December 2016 for the intertidal sites, with the most significant intertidal deposition centred around Kakaho Stream (Figure 3), and very large increases in subtidal deposition in the central basin sites of both arms (Table 3). These changes are discussed below under each of the key indicators.

Table 3. Mean change of sediment depth above buried plates (2007-2017), and cumulative mean annual change since baseline Porirua Harbour.

Site		No	Name	Calendar Year Baseline Commenced	Change in mean sediment depth (mm/yr)									Mean Annual Sedimentation since baseline (mm/yr)	
					2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017		
Onepoto Arm	Intertidal	1	Por A Railway (FS)	2008	0.8	2.3	-4.5	-0.3	14.3	-4.3	1.5	0.5	**-1.5**	1.0	+3.1
		2	Aotea	2012					12.3	-0.3	2.3	7.8	**1.5**	4.7	
		3	Por B Polytech (FS)	2008	7.0	0.5	2.0	0.3	4.3	1.8	2.3	5.0	**5.3**	3.6	
	Subtidal	S6	Titahi	2013						0.0	5.0	-16.0	**32.0**	3.3	-8.2
		S7	Onepoto	2013						-6.0	-92.0	-2.0	**7.0**	-23.3	
		S8	Papakowhai	2013						-8.0	-93.0	10.0	**24.0**	-14.8	
		S9	Te Onepoto	2008	-2.5	-2.5	3.0	-1.0	-14.0	0.0	4.0	7.0	**-3.0**	2.0	
Pauatahanui Arm	Intertidal	6	Boatsheds	2008		0.5	-0.8	0.3	3.5	-2.0	-3.0	-3.5	**-4.5**	-1.2	+0.4
		7	Kakaho	2008					9.3	-4.0	-2.0	-5.8	**17.8**	3.1	
		8	Horokiri	2009					2.0	-2.5	1.3	0.0	**-7.0**	-1.3	
		9	Paua B (FS)	2008	2.3	3.8	0.3	-5.3	-0.8	4.5	-2.5	-5.0	**0.3**	-0.3	
		10	Duck Creek	2012					-3.0	14.8	-5.5	1.8	**1.0**	1.8	
		11	Browns Bay	2013						-30.0	4.0	1.0	**-6.0**	-7.8*	
	Subtidal	S1	Kakaho	2013						6.6	2.0	8.0	**64.0**	20.2	+15.0
		S2	Horokiri	2013						26.4	18.0	10.0	**54.0**	27.1	
		S3	Duck Creek	2013						8.0	-12.0	NM	**90.0**	21.5	
		S4	Bradeys Bay	2013						11.0	-4.0	-5.0	**12.0**	3.5	
		S5	Browns Bay	2013						9.2	-10.0	-2.0	**13.0**	2.6	

*change attributable to localised movement of intertidal sands and does not reflect a significant change in sedimentation. Value excluded from calculation of means.

NM = Not Measured.

Sedimentation Rate. The 42 sedimentation plates buried at 18 sites in Porirua Harbour (Figure 1) were measured on 27-28 January 2017, with results summarised in Table 3 and Figures 4, 5, 6 and 7. Raw data are presented in Appendix 1.

The mean annual intertidal sedimentation rate across all sites and over all years of monitoring shows a net increase of intertidal sediment calculated in January 2017 of +0.4mm/yr in the Pauatahanui Arm and +3.1mm/yr in the Onepoto Arm, reflecting “very low” and “moderate” risk indicator ratings respectively.

3. Results, Rating and Management (Continued)

Figure 3. Fine sediment deposition across the intertidal flats at Kakaho (upper 3 photos,) and adjacent to the Horokiri subtidal site (lower 2 photos), Pauatahanui arm, Jan 2017.

3. Results, Rating and Management (Continued)

While these overall net rates are relatively low, Figures 4 and 5 highlight annual variation within and between sites. The variance is due to different processes at different sites. The Por A and Boatsheds sites are both positioned on flood tide deltas, while the Por B, Aotea, and Paua B sites are on the Porirua and Pauatahanui stream deltas (Figure 1). All these sites are relatively well flushed and, while fine sediments are occasionally deposited, they do not appear to accumulate significantly in these areas. The recorded changes in sediment height at these sites are primarily due to localised sand movement in these parts of the estuary. A similar situation occurs at other Pauatahanui Arm intertidal sites (Browns Bay, Duck Creek, Horokiri and Kakaho) where frequent tidal flushing and wind-driven wave disturbance of intertidal flats appears to rapidly mobilise and redeposit intertidal mud in subtidal settlement areas. As a consequence, long term intertidal accumulation of fine muds appears limited.

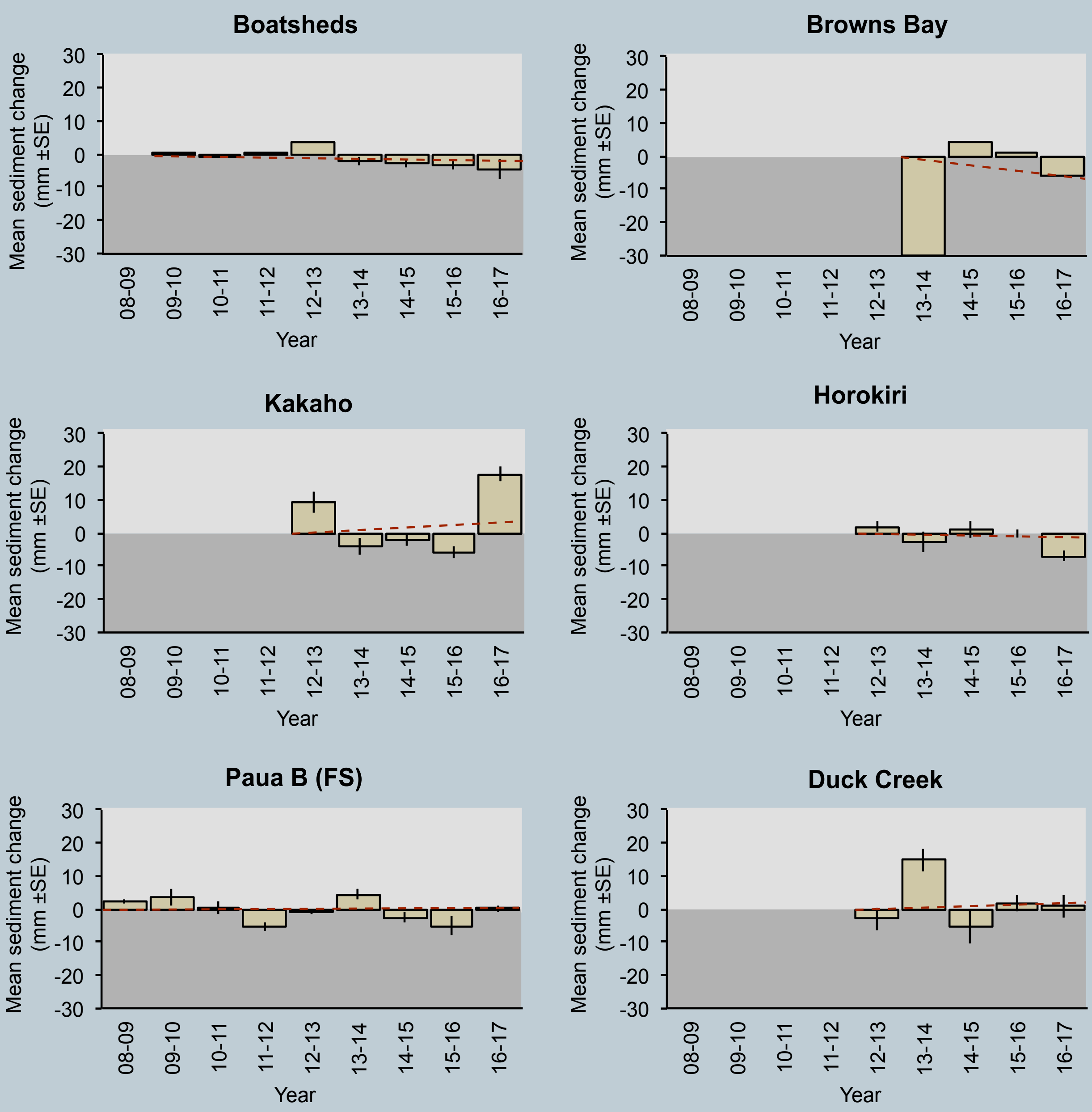


Figure 4. Mean change in intertidal sediment height (mm/yr ±SE) over buried plates at individual monitoring sites in the Pauatahanui arm of Porirua Harbour. Red dotted line shows trend over monitoring period.

3. Results, Rating and Management (Continued)

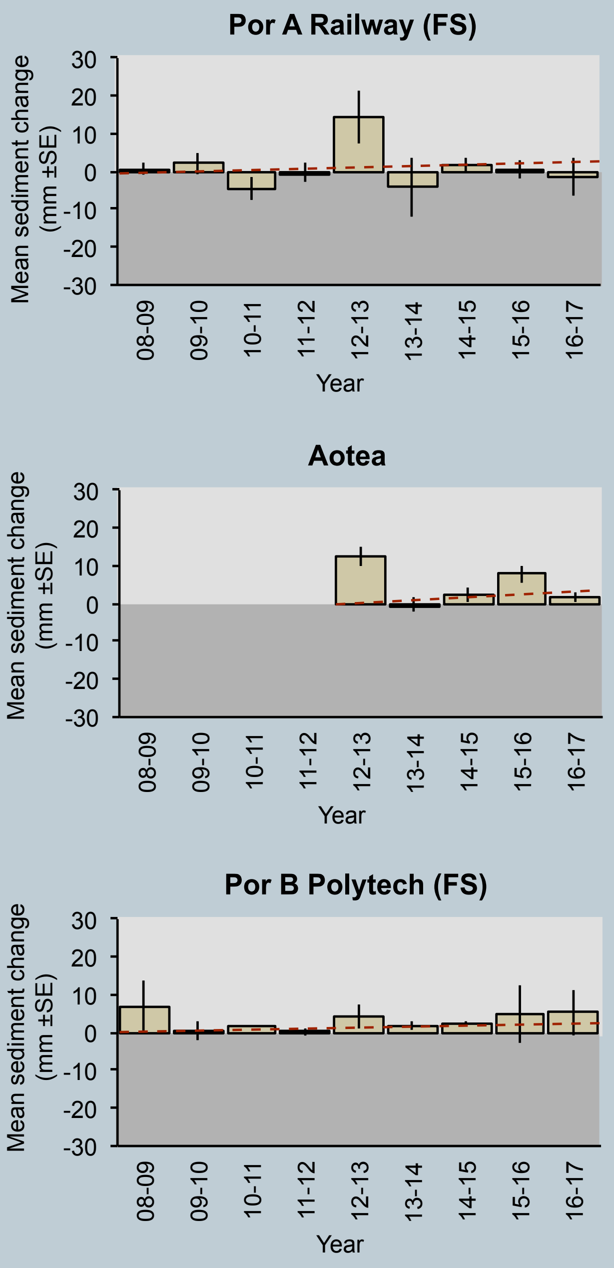


Figure 5. Mean change in intertidal sediment height (mm/yr ±SE) over buried plates at individual monitoring sites in the Onepoto arm of Porirua Harbour. Red dotted line shows trend over monitoring period.

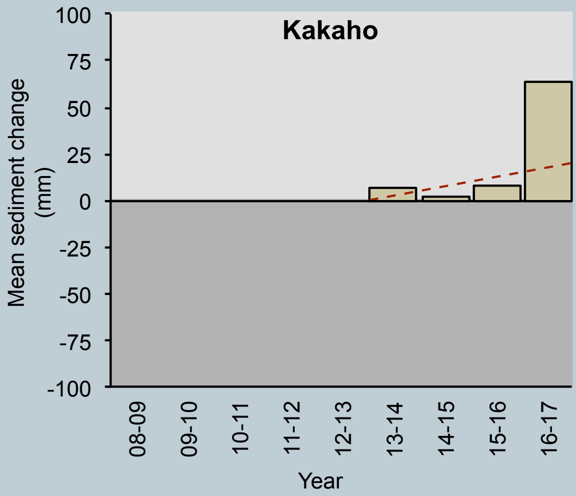
The long term trends that are beginning to be established indicate modest intertidal accretion in the Onepoto Arm attributable largely to coarser deposits on the Porirua Stream delta, while there has been little net change overall in the Pauatahanui Arm.

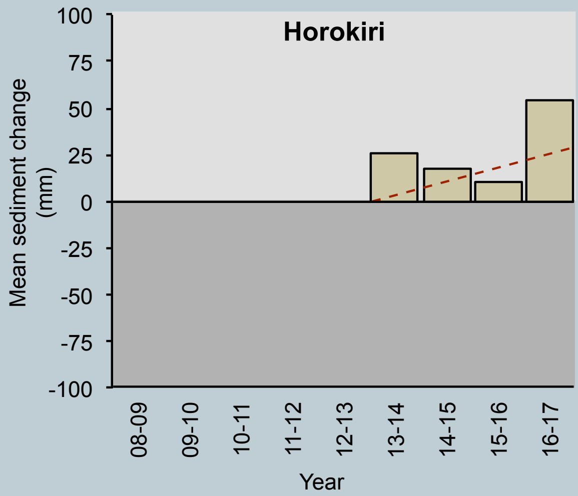
However, over the short term, it is clear that there was significant intertidal change at the Kakaho site in the 2016 -2017 period (Figure 4). An 18mm layer of mud was present over the sediment plate site in January 2017, a slight increase from the 13.5mm measured in December 2016, and which extended with a similar depth cover of fine mud several hundred metres from the upper shoreline down to and beyond the low tide mark and for over 1km parallel to the shoreline. The mud deposits continued unbroken into the subtidal zone at Kakaho, with similar pockets of both intertidal and subtidal deposition evident at Camborne, Horokiri and Ration Point (north of Paua B).

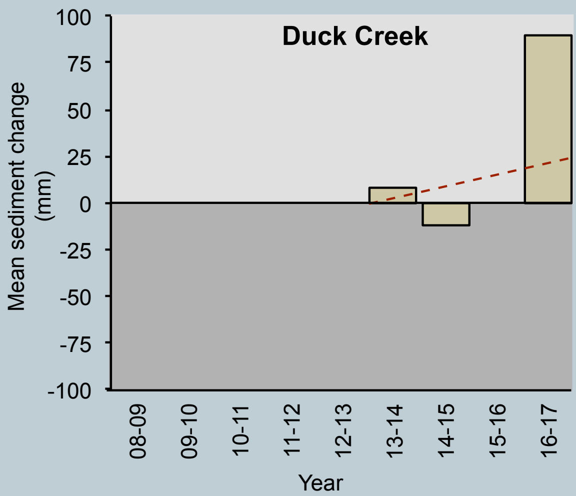
Adjacent to these sites, subtidal sediment plate monitoring which, while still preliminary due to the short monitoring interval, shows much greater rates of sediment deposition. In the Pauatahanui Arm there has been overall mean deposition of +15mm/yr over the past 4 years with a constant trend of increasing deposition at all sites reflecting a "very high" risk rating. Over the past year there has been deposition of 12-90mm (Figure 6) with a corresponding increase in the spatial extent of soft muds. When established in 2013, each subtidal site was located approximately 5m subtidally of where soft muds were first encountered when wading from the shoreline. In 2017 subtidal soft muds had extended shorewards by the following distances:

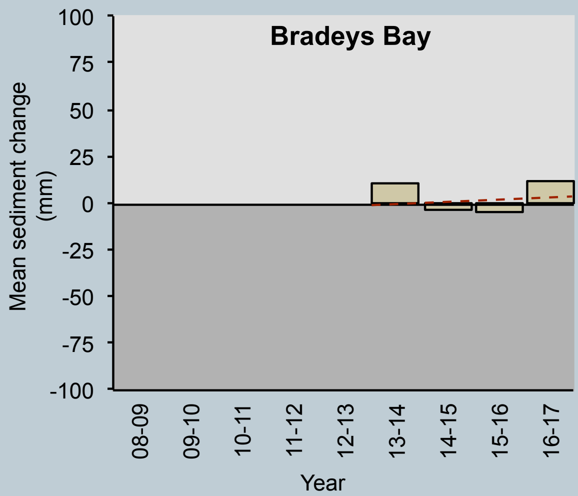
Kakaho +300m
Horokiri +65m
Duck Creek +10m
Bradeys Bay +15m
Browns Bay +40m

The large expansion of subtidal soft mud towards the intertidal boundary, the very high measured deposition in Jan. 2017, and the trend of increasing deposition across all Pauatahanui subtidal sites highlight that the Pauatahanui subtidal basins (the primary deposition zones in the estuary) are currently undergoing a very rapid rate of infilling.









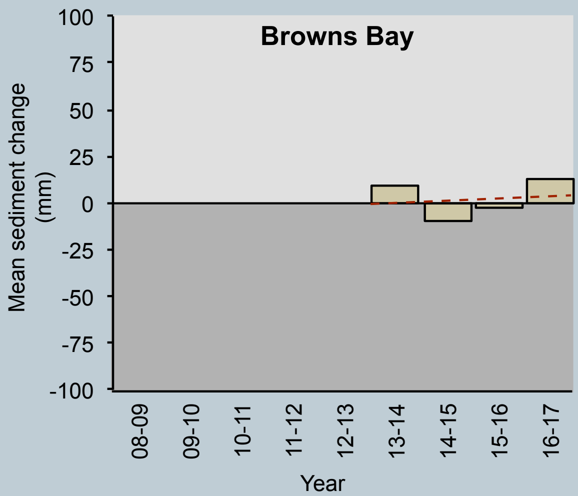


Figure 6. Mean change in subtidal sediment height (mm/yr ±SE) over buried plates at individual monitoring sites in the Pauatahanui arm of Porirua Harbour. Red dotted line shows trend over monitoring period.

The 2017 Onepoto Arm subtidal results show trends that need to be carefully interpreted. While there has been a net decrease in subtidal sediment of -8.2mm/yr for the arm over the past 4 years, this result is driven almost exclusively by extensive sediment erosion at the Onepoto and Papakowhai sites in 2014-15. For the Onepoto site in the central basin, this reflects the loss of fine muds from the estuary following a significant deposition event. For the Papakowhai site, it reflects the erosion of sandy sediments on the edge of the flood tide delta.

This is consistent with the expected response to the pulsed input and subsequent erosion or redistribution of catchment derived sediments, and highlights that very different trends will be apparent over a short monitoring period if it commences either before or after a large deposition event. Further, it highlights variable patterns in deposition occur in different parts of the harbour due to different processes affecting them. For example, the flood tide deltas in the lower reaches of each arm are strongly tidally flushed and reflect a mix of catchment and marine sourced sediments. In contrast, deeper central subtidal basins have less marine deposition and are more strongly influenced by wind-wave and flood disturbance than tidal flows. Intertidal flats in each arm are strongly influenced by local scale wind-driven wave action that predominantly see intertidal deposits remobilised and deposited subtidally, noting subtidal sediments can also be remobilised and deposited intertidally.

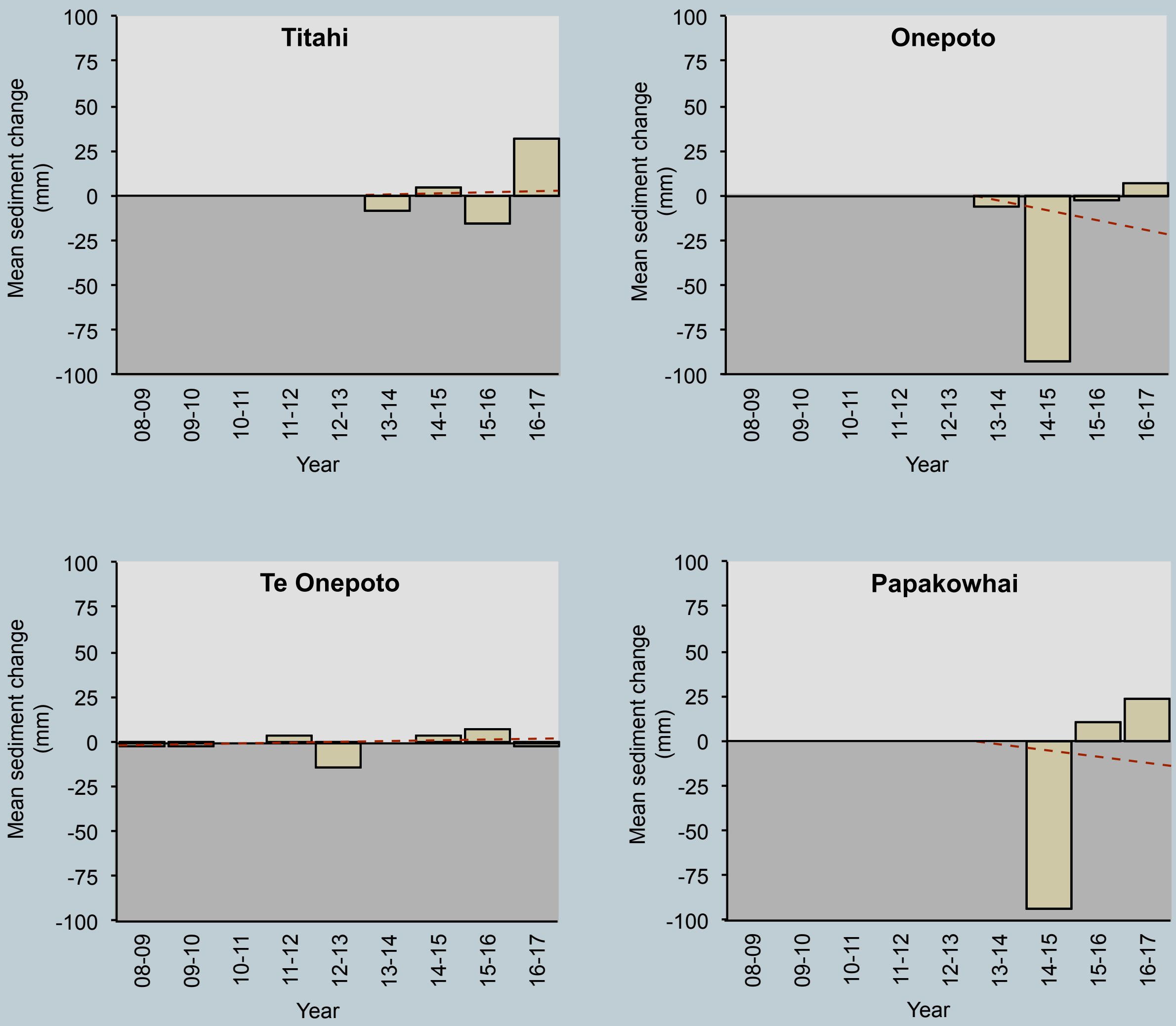


Figure 7. Mean change in subtidal sediment height (mm/yr ±SE) over buried plates at individual monitoring sites in the Onepoto arm of Porirua Harbour. Red dotted line shows trend over monitoring period.

3. Results, Rating and Management (Continued)

As such, the patterns of deposition at individual sites need to consider the length of the monitoring record, and ideally be complimented by regular bathymetric surveys characterising major seabed changes over the entire estuary over time e.g. Gibb and Cox (2009) and Cox (2014), as well as hydrodynamic/sediment modelling to assess both the amount of fine sediment exported from the estuary to the sea, and the relative extent and importance of fine sediment remobilisation and relocation within the estuary. Results of such work will directly aid understanding of the overall estuary sediment budget, and help in the establishment of defensible catchment load limits for the estuary.

Because sediment plate monitoring provides an important check on specific annual changes which 5 yearly bathymetric monitoring doesn't, it is recommended that plates continue to be monitored annually to assess the impacts of predicted land disturbance from impending forest harvesting, urban development (Duck Creek subdivision), and road construction (in particular Transmission Gully) in the catchment. Comprehensive reporting of results, including plots of sedimentation trends, is recommended 5 yearly (e.g. next scheduled for 2018), or annually if there is major land disturbance or unexpected results occur. As part of ongoing monitoring it is proposed that metal markers be installed at each plate to facilitate more rapid plate relocation using a metal detector and to protect against the loss or burial of existing wooden marker pegs.

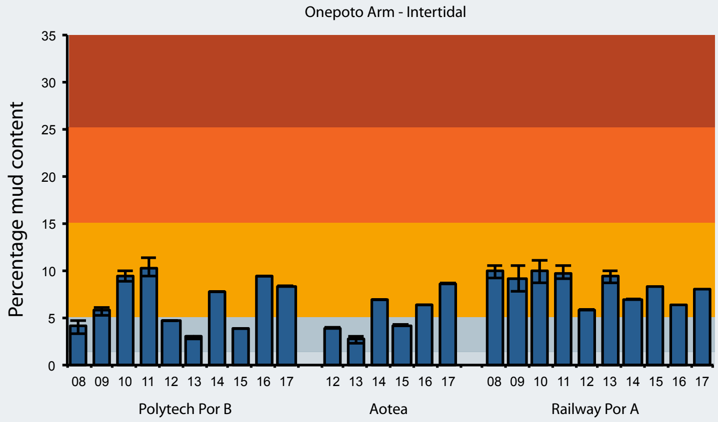
Grain Size. Grain size (% mud, sand, gravel) is a key indicator of both eutrophication and sediment changes. Increasing mud content signals a deterioration in estuary condition and can exacerbate eutrophication symptoms.

Grain size monitoring results (Table 4) show that in 2017 sands continue to dominate intertidal sediments (61-98%), with most mud contents in the "moderate" ecological risk rating category, the exceptions being Duck Creek and Paua B in the "low" category, and Kakaho in the "very high" category. The latter result is due to a large increase in mud (from 16% to 38%) apparent following the 15 November 2016 flood event (Figure 8). Subtidal sites were generally much muddier, the lowest mud contents (11%-13%, "moderate" risk category) recorded at relatively well flushed sites at Papakowhai, Te Onepoto, and Onepoto, and higher mud contents (19% to 83%, "high" to "very high" risk categories) in deeper settlement basin areas, (Figure 9, Table 4).

Figure 10 shows that there has been an increase in the combined mean mud content of intertidal and subtidal sites in both arms of the estuary since the commencement of grain size measures in 2012 and 2013 respectively. While a relatively short time series, it strongly suggests inputs of fine muds have been ongoing and that the estuary is getting significantly muddier.

The previous results and field observations highlight that inter-annual variability is evident and this most likely reflects event related deposition (e.g. pulsed deposits from stream inputs during storms), with fine sediments being relatively quickly re-mobilised by wind generated waves and tidal streams. It is recommended that GWRC rainfall and flood records be used to investigate the relationship between such events and measured sediment rate results and mud content results as part of recommended 5 yearly detailed reporting. The recommended hydrodynamic modelling of the estuary will greatly assist in understanding sediment movement and fate (including retention) within both arms.

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



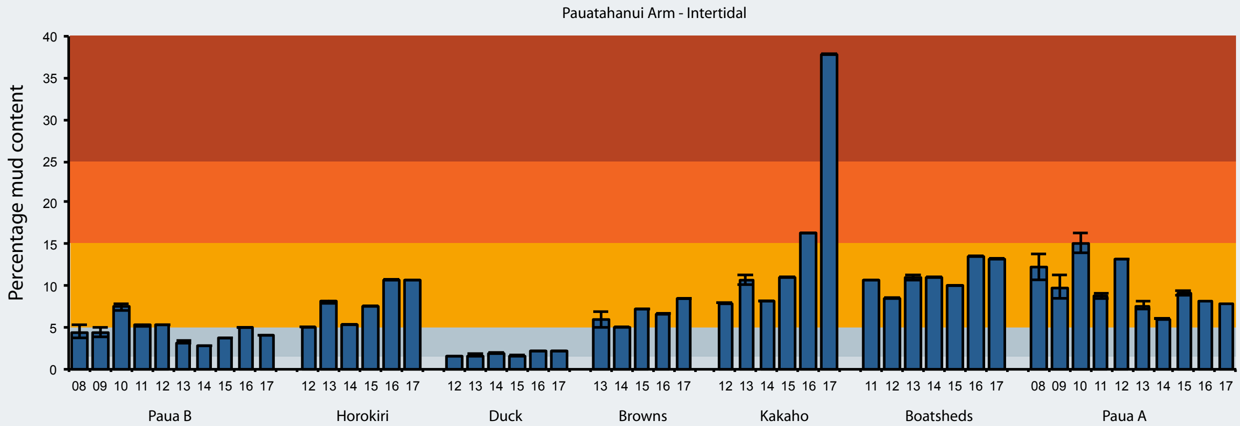
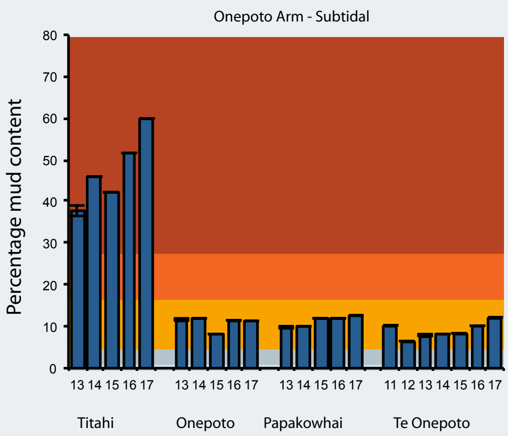


Figure 8. Mean sediment mud content (+/-SE) at individual Porirua Harbour intertidal sites, (2008-2017).



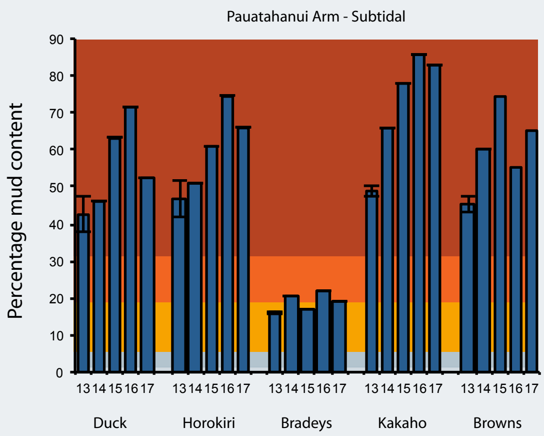


Figure 9. Mean sediment mud content (+/-SE) at individual Porirua Harbour subtidal sites, (2013-2017).

Table 4. Sediment grain size and RPD depth results, Porirua Harbour (January 2017).

Site		No	Name	Site Mean: % Mud (g/100g dry wt)	% Sand (g/100g dry wt)	% Gravel (g/100g dry wt)	aRPD depth (cm)	2017 %Mud Risk Indicator Rating	2017 aRPD Risk Indicator Rating
Onepoto Arm	Intertidal	1	Por A Railway (FS)	8.0	89.6	2.4	3	Moderate	Low
		2	Aotea	8.7	91.2	<0.1	3	Moderate	Low
		3	Por B Polytech (FS)	8.4	88.0	3.6	2	Moderate	Moderate
	Subtidal	S6	Titahi	59.9	39.8	0.3	1	Very High	Moderate
		S7	Onepoto	11.1	87.3	1.6	2	Moderate	Moderate
		S8	Papakowhai	12.7	87.3	<0.1	>5	Moderate	Low
		S9	Te Onepoto	12.2	86.6	1.2	>5	Moderate	Low
Pauatahanui Arm	Intertidal	5	Paua A (FS)	8.0	86.4	5.6	3	Moderate	Low
		6	Boatsheds	13.3	82.9	3.8	2	Moderate	Moderate
		7	Kakaho	37.9	61.0	1.1	2	Very High	Moderate
		8	Horokiri	10.7	87.1	2.2	1	Moderate	Moderate
		9	Paua B (FS)	4.0	94.1	1.9	2	Low	Moderate
		10	Duck Creek	2.2	97.8	<0.1	>5	Low	Low
		11	Browns Bay	8.5	85.7	5.8	3	Moderate	Low
	Subtidal	S1	Kakaho	82.7	16.9	0.3	2	Very High	Moderate
		S2	Horokiri	66.1	33.8	0.1	1	Very High	Moderate
		S3	Duck Creek	52.4	47.1	0.5	2	Very High	Moderate
		S4	Bradeys Bay	18.8	80.3	1.0	2	High	Moderate
		S5	Browns Bay	65.3	33.9	0.8	1	Very High	Moderate

Note grain size results are based on a single composite sample comprising 5 sub-samples collected from each site. aRPD depth is based on 3 replicate measures at each site.

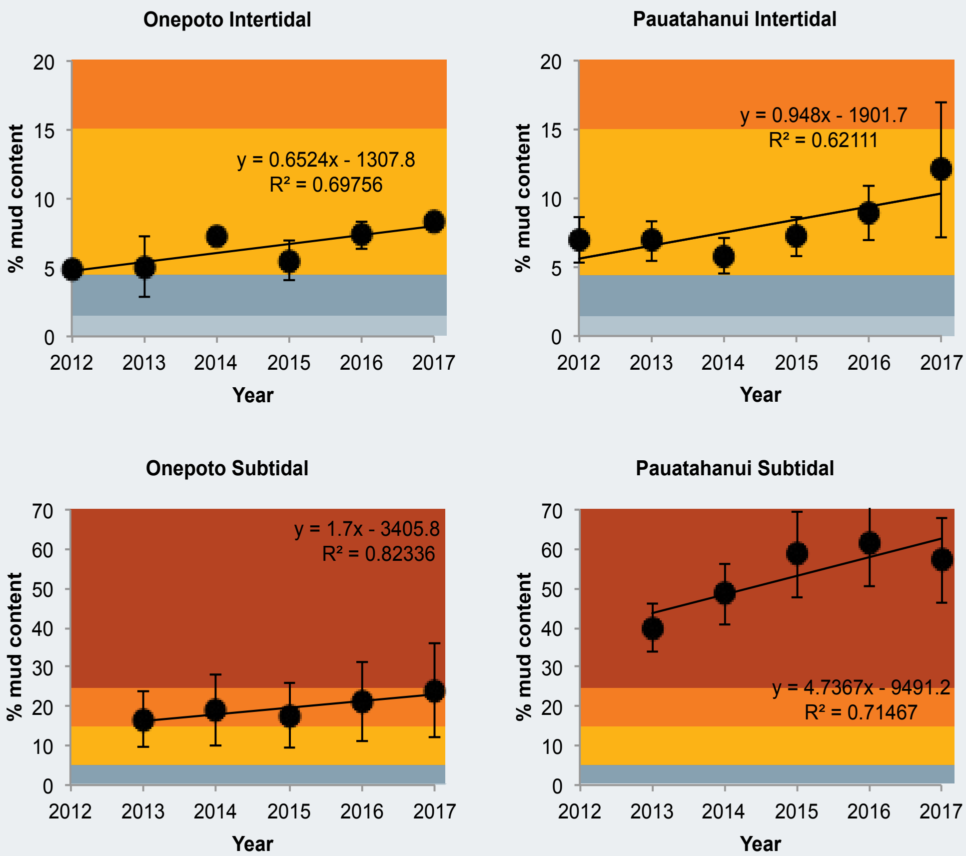


Figure 10. Change and trend in mean sediment mud content (±SE) for all intertidal sites combined (top) and all subtidal sites combined (bottom) in each arm of Porirua Harbour.

Redox Potential Discontinuity (RPD). The depth to the RPD boundary is a critical estuary condition indicator in that it provides a direct measure of sediment oxygenation. This commonly shows whether nutrient enrichment in the estuary exceeds levels causing nuisance anoxic conditions in the surface sediments, and also reflects the capacity of tidal flows to maintain and replenish sediment oxygen levels.

In well flushed sandy intertidal sediments, tidal flows typically oxygenate the top 5-10cm of sediment. However, when fine muds fill the interstitial pore spaces, less re-oxygenation occurs and the RPD moves closer to the surface.

In 2017, the visually assessed aRPD depths (Table 4) were relatively shallow (1-2cm) across most subtidal sites, a “moderate” risk indicator rating, and 1 to >5cm across the intertidal sites, “moderate”or “low” risk indicator ratings. The absence of surface anoxia indicates that there are no sites in the “high” risk indicator rating for aRPD. In the future, it is recommended that redox potential (mV) be measured in order to more accurately assess the depth at which “poor” oxygenation (i.e. <150mV) occurs.

SUMMARY

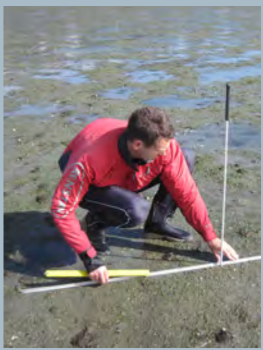
Sediment plate monitoring, first established in 2007/08 at strategic intertidal sites within the Porirua Harbour, indicates a mean annual intertidal sedimentation rate across all sites of +0.4mm/yr in the Pauatahanui Arm, and +3.1mm/yr in the Onepoto Arm, reflecting “very low” and “moderate” risk indicator ratings respectively. Sediment plates established within the subtidal basins of both estuary arms, where the greatest rates of sedimentation are predicted, show a mean annual subtidal sedimentation rate across all sites over the past 4 years of +15.0mm/yr in the Pauatahanui Arm, and -8.2mm/yr in the Onepoto Arm, reflecting “very high” and “very low” ecological risk indicator ratings respectively. The subtidal results are strongly influenced by the short monitoring record at these sites and need to be interpreted with caution.

A consistent trend in increasing mean sediment mud content at intertidal and subtidal sites in both arms highlights ongoing fine sediment issues in the estuary.

Pauatahanui Arm, intertidal Site 7, Kakaho.

3. Results, Rating and Management (Continued)

RECOMMENDED MONITORING



It is recommended that monitoring continue as outlined below:

Annual Sediment Monitoring (both intertidal and subtidal). To assess sediment derived changes in the estuary, annually monitor sedimentation rate, aRPD depth and grain size at the existing intertidal and shallow subtidal sites. Next due in Jan. 2018.

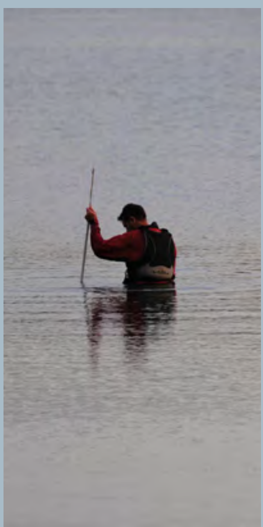
Establish fixed transects extending from intertidal to subtidal areas to annually monitor the boundary between dominant sediment types (e.g. firm muddy sand, soft mud, and very soft mud habitats). Suggested initial locations are adjacent to existing subtidal sites S1 and S7.

To optimise reporting, it is recommended that results be fully reported every 5 years (first 5 year review due in 2018 after 5 years of annual subtidal monitoring).

Fine Scale Monitoring (both intertidal and subtidal). To assess intertidal estuary condition it is recommended that a "complete" fine scale monitoring assessment be undertaken at 5 yearly intervals (next scheduled for Jan-Feb 2020). To assess subtidal estuary condition it is recommended that subtidal fine scale monitoring be undertaken as part of a "whole of estuary" monitoring approach as recommended in the 2014 broad scale subtidal survey (Stevens and Robertson 2014).

Broad Scale Habitat Mapping (both intertidal and subtidal). It is recommended that broad scale intertidal and subtidal habitat mapping be integrated, and repeated every 5 years (next monitoring due in January 2018).

RECOMMENDED MANAGEMENT



The sediment indicators monitored in 2017 reinforce the 2008 to 2010 fine scale monitoring results about the need to manage fine sediment inputs to the estuary.

In particular, limiting catchment sediment inputs to more natural levels that will not cause excessive estuary infilling and will improve harbour water clarity. To achieve this, interim and long term targets have been prepared and approved by the joint councils (Porirua City Council, Wellington City Council and Greater Wellington Regional Council), Te Runanga Toa Rangatira and other key agencies with interests in Porirua Harbour and catchment, as follows:

- Interim – Reduce sediment inputs from tributary streams by 50% by 2021
- Long-term – Reduce sediment accumulation rate in the harbour to 1mm per year by 2031 (averaged over whole harbour)

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

3. Results, Rating and Management (Continued)

ACKNOWLEDGEMENTS

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APPENDIX 1

ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Grain Size	R.J Hill	Wet sieving (2mm and 63µm sieves), gravimetry (calculation by difference).	0.1 g/100g dry wgt

DETAILED RESULTS

Porirua Harbour Sediment Plate Locations.

No.	Site	PLATE	NZTM EAST	NZTM NORTH
Onepoto Arm - Intertidal				
1	Por A Railway (fine scale site)	1	1756505.7	5447788.6
		2	1756477.9	5447784.8
		3	1756478.8	5447762.7
		4	1756508.1	5447755.8
2	Aotea	1	1754771.8	5445520.0
		2	1754770.5	5445521.2
		3	1754768.3	5445523.1
		4	1754767.3	5445523.9
3	Por B Polytech (fine scale site)	1	1754561.9	5445430.3
		2	1754577.9	5445403.8
		3	1754561.6	5445529.5
		4	1754559.9	5445528.6
Onepoto Arm - Subtidal				
S6	Titahi	1	1755704.1	5446797.6
S7	Onepoto	1	1754811.3	5446762.9
S8	Papakowhai	1	1754580.9	5445864.0
S9	Te Onepoto	1	1755551.8	5447105.3

No.	Site	PLATE	NZTM EAST	NZTM NORTH
Pauatahanui Arm - Intertidal				
5	Paua A (fine scale)	-	1757243.0	5448644.0
6	Boatsheds	1	1757267.5	5448785.8
		2	1757265.6	5448785.2
		3	1757263.6	5448784.7
		4	1757262.0	5448784.1
7	Kakaho	1	1758885.4	5449747.8
		2	1758884.9	5449746.0
		3	1758884.4	5449744.2
		4	1758884.0	5449742.3
8	Horokiri	1	1760040.2	5448827.6
		2	1760039.8	5448825.5
		3	1760039.6	5448823.5
		4	1760039.1	5448821.5
9	Paua B (fine scale site)	1	1760333.9	5448378.8
		2	1760349.2	5448355.8
		3	1760375.1	5448366.9
		4	1760362.3	5448391.9
10	Duck Creek	1	1759829.3	5447944.8
		2	1759828.7	5447946.7
		3	1759828.1	5447948.7
		4	1759827.6	5447950.6
11	Browns Bay	1	1757971.4	5447956.8
Pauatahanui Arm - Subtidal				
S1	Kakaho	1	1758810.9	5449470.5
S2	Horokiri	1	1759325.4	5448867.9
S3	Duck Creek	1	1759529.0	5447896.3
S4	Bradeys Bay	1	1758763.2	5447865.0
S5	Browns Bay	1	1758040.6	5448015.1

APPENDIX 1

DETAILED RESULTS

Sediment Plate Depths, Pauatahanui Arm, Porirua Harbour (2007-2017).

	No.	Site	PLATE	Dec07	Jan09	Jan10	Jan11	Jan12	Jan13	Jan14	Jan15	Jan16	Dec 16	Jan 17
Pauatahanui Arm - Intertidal	5	Paua A (fine scale)	-											
	6	Boatsheds	1		171	172	165	166	172	166	160	159	160	152
			2		213	213	215	216	221	222	220	216	223	205
			3		232	232	233	234	233	232	228	226	230	229
			4		234	235	236	234	238	236	236	229	227	226
	7	Kakaho	1					73	89	85	79	78	91	89
			2					100	106	104	100	95	116	116
			3					90	103	92	92	84	100	104
			4					92	94	95	97	88	92	107
	8	Horokiri	1					106	104	104	103	107	104	100
			2					108	111	113	113	112	109	101
			3					118	124	124	121	119	118	112
			4					98	99	87	96	95	97	92
	9	Paua B (fine scale site)	1	181	182	186	186	181	180	187	184	171	169	169
			2	215	218	228	233	228	225	229	230	230	230	233
			3	182	186	183	183	181	182	182	181	179	174	180
			4	176	177	181	177	168	168	175	168	163	162	162
	10	Duck Creek	1					134	121	136	140	146	145	140
			2					108	108	117	115	119	120	116
			3					122	122	146	126	128	131	138
			4					88	89	100	96	91	98	94
	11	Browns Bay	1						220	190	194	195	190	189
Subtidal	S1	Kakaho	1						165	172	174	182		246
	S2	Horokiri	1						176	202	220	230		284
	S3	Duck Creek	1						194	202	190	-		280
	S4	Bradeys Bay	1						124	135	131	126		138
	S5	Browns Bay	1						179	188	178	176		189

APPENDIX 1

DETAILED RESULTS

Sediment Plate Depths, Onepoto Arm, Porirua Harbour (2007-2017).

	No.	Site	PLATE	Dec07	Jan09	Jan10	Jan11	Jan12	Jan13	Jan14	Jan15	Jan16	Dec 16	Jan 17
Onepoto Arm - Intertidal	1	Por A Railway (fine scale site)	1	168	164	159	155	160	183	181	181	187	182	181
			2	150	152	158	156	151	150	160	159	158	157	166
			3	152	155	163	150	145	174	148	155	150	148	137
			4	93	95	95	96	100	106	107	107	109	112	114
	2	Aotea	1					138	145	140	148	151	148	156
			2					108	126	128	127	139	137	141
			3					103	118	116	118	122	130	122
			4					100	109	113	113	125	124	124
	3	Por B Polytech (fine scale site)	1	237	237	240	242	245	243	243	246	-	242	248
			2	230	244	242	244	244	256	256	258	245	251	268
			3				110	110	109	112	115	130	122	128
			4				75	73	81	85	86	99	99	97
Subtidal	S6	Titahi	1						191	191	180	164		196
	S7	Onepoto	1						194	188	96	94		101
	S8	Papakowhai	1						183	175	98	108		132
	S9	Te Onepoto	1	120	-	115	115	118	104	104	108	115		112