SALT ECOLOGY

Otago Region: Intertidal Sedimentation Monitoring Summary 2024/2025

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Cover photo: Staff cross the upper estuary mudflats to monitor Site A in Tautuku Estuary, 2025.

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Otago Region: Intertidal Sedimentation Monitoring Summary 2024/2025

Prepared by

Sorrel O'Connell-Milne

and

Barrie Forrest

for

Otago Regional Council

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sorrel@saltecology.co.nz, +64 (0)27 7282913

www.saltecology.co.nz

GLOSSARY

aRPD	Apparent Redox Potential Discontinuity
CFB	Change From Baseline
NEMP	National Estuary Monitoring Protocol
ORC	Otago Regional Council
SAR	Sediment Accumulation Rate
SOE	State of Environment (monitoring)

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1. INTRODUCTION

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 using New Zealand's National Estuary Monitoring Protocol (NEMP) methods (or extensions of that approach).

As a more recent extension to the NEMP work, SOE sedimentation monitoring within Otago estuaries has also been undertaken. This monitoring has been near-annual, and focused on assessing trends in sediment accumulation rate (SAR) at specific intertidal sites using a 'sediment plate' method. In addition, two related sediment quality variables are measured at sediment plate sites – sediment mud content and oxygenation.

The current report describes the results of annual sediment plate monitoring undertaken in November 2024 in 11 estuaries in Otago. From north to south these are: Shag, Pleasant River (Te Hakapupu), Waikouaiti, Blueskin Bay, Pūrākaunui, Kaikorai, Akatore, Tokomairiro, Catlins (Pounawea), Tautuku, and Waipati River (Chaslands) estuaries (Fig. 1). For each estuary, results are compared across the time series that has been established.

For Akatore Estuary, note that additional work has been conducted outside of the annual monitoring schedule, which involved post-flood sedimentation monitoring and installation of a meso-scale sediment plate network. The purpose of this extra work is to enable ORC to assess potential effects on the estuary from harvest of exotic forestry in the catchment. For the present report, only a summary of the Akatore monitoring is included, with the more in-depth work described in a separate report (see O'Connell-Milne & Roberts 2025).

Background information on each estuary in terms of its key catchment and estuary features is provided in Table 1. This summary shows that the estuaries cover a range of environments, including: estuaries with extensive intertidal flats, such as Blueskin Bay; river-dominated systems with relatively small intertidal areas, such as Tokomairiro; large estuaries with catchments dominated by activities such as farming and forestry that can generate relatively high loads of muddy sediments, such as Pleasant River; and estuaries in relatively unmodified catchments with a high cover of native forest, such as Tautuku and Waipati (Chaslands).

Extensive intertidal flats of Blueskin Bay.

Table 1. Key catchment and estuary features for estuaries where ORC sediment plate monitoring is undertaken.

Estuary	Catchment features[1]				Estuary features[2]				
	Total area (ha)	% Pasture	% Exotic forestry	% Native forest	Mean FW inflow (m^3/s)	Sediment load (T per ha estuary)	Flushing time (d)	Total area (ha)	% Intertidal Area
Shag	54,127	70.2	12.1	0.7	3.8	76.0	0.7	124	66.8
Pleasant River (Te Hakapupu)	12,634	62.4	32.7	0.2	0.8	8.0	4.4	216	86.8
Waikouaiti	42,405	75.0	4.1	0.7	3.4	36.4	2.5	253	76.2
Blueskin Bay	9,444	31.1	23.9	5.4	0.5	7.1	11.5	688	91.0
Pūrākaunui Inlet	939	49.8	12.8	0.1	0.05	1.7	12.1	130	93.4
Kaikorai	5,431	48.6	8.9	1.3	0.5	9.9	7.4	94	84.4
Akatore	6,909	12.1	86.1	0.5	0.7	12.3	1.7	69	87.5
Tokomairiro	39,470	53.8	38.2	0.7	3.7	41.7	2.1	150	64.2
Catlins (Pounawea)	41,017	62.7	5.6	20.4	2.4	16.4	6.2	843	69.9
Tautuku	6,152	2.0	0.0	92.0	1.7	16.0	2.9	94	86.0
Waipati River (Chaslands)	7,213	14.5	9.5	66.8	1.8	38.7	1.3	68	82.8

1. Catchment data from Land Cover Data Base (2018).

2. Estuary area data from Salt Ecology broad-scale mapping, with mean flow and other estuary statistics provided by ORC.

Fig. 1. Otago estuaries with sediment plates monitored in November 2024.

2. METHODS

Sedimentation and sediment quality monitoring is generally undertaken at two to three sites within each estuary (see maps of sediment plate sites for each estuary in Section 3). Table 2 provides a summary of the survey work, including the layout of the sediment plates at each estuary, the date of the baseline survey when sedimentation plates were installed, the duration of the monitoring record, and the date of the most recent survey.

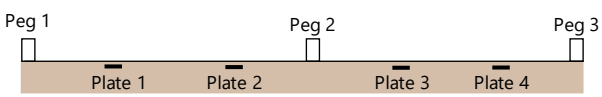
2.1 SEDIMENT PLATE METHOD

The sediment plate method in Otago is based on a method originally developed by Waikato Regional Council (Hunt 2019). The method involves monitoring SAR according to the annual change in sediment depth on top of each of 4 concrete pavers (usually 19cm x 23cm) that are buried (~100mm deep) at each site. The plates at each site are spaced between 2m and 5m apart and arranged along a single transect.

Plates are typically buried ~100mm deep, with transect start, middle and end points marked with wooden pegs to enable relocation. At most estuaries, the transect is aligned along the boundary of sites that are also used for fine-scale monitoring of sediment quality and ecological condition (Stevens et al. 2025). In this way, changes in sediment condition (e.g., mud content, ecology) can potentially be linked to changes in SAR.

At the time of baseline plate installation and on each subsequent sampling occasion, plate depth is measured by placing a straight edge (2-2.5m long) over each plate position to average out small-scale irregularities in surface topography, with the depth to each plate from the base of the straight edge measured by vertically inserting a probe into the sediment. The probe is marked, removed from the sediment and the depth measured with a ruler.

Triplicate depth measurements (to the nearest millimetre) are made for each plate, and averaged. Routine sediment plate measurements are made annually, and sometimes in response to event-related sediment inputs (e.g., after flooding).



Schematic of sediment plate array with four buried concrete pavers marked by two end pegs and an intermediate peg. The length of these arrays ranges from ~8m to 30m, depending on the site.

Measuring depth of sediment over a plate, Blueskin Bay, 2024.

2.2 SEDIMENT QUALITY

At each site, a composite sediment sample (~500g) taken from the surface 20mm was collected adjacent to each sediment plate. Samples are stored on ice and sent to Hill Laboratories for analysis of particle grain size in three categories (%mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm), enabling assessment of sediment muddiness. The laboratory method is based on application of a dispersant to break down particle flocs, wet sieving, and calculation of percent fractions by gravimetry (calculation by dry weight difference).

Sediment oxygenation is visually assessed in the field by measuring the apparent Redox Potential Discontinuity (aRPD) depth. The aRPD depth is the visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). The aRPD provides an easily measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions (Rosenberg et al. 2001; Gerwing et al. 2013).

Measuring aRPD depth, to inform sediment oxygenation, Blueskin Bay, 2024.

Table 2. Otago estuary site information including baseline survey (when sediment plates were installed) and date of last annual survey.

Estuary	Site	Plate transect length (m)	Baseline installation	Last survey	Years monitored
Shag	A	10	9/12/2016	14/11/2024	7.9
	B	10	9/12/2016	14/11/2024	7.9
Pleasant River (Te Hakapupu)	A	30	26/11/2021	14/11/2024	3
	B	30	26/11/2021	14/11/2024	3
Waikouaiti	A[1]	30	8/12/2016 & 19/12/2019	13/11/2024	4.9
	B (old)[2]	10	8/12/2016	13/12/2017	1
	B	30	19/12/2019	13/11/2024	4.9
	C	10	8/12/2016	14/11/2024	7.9
Blueskin Bay	A	30	15/01/2021	13/11/2024	3.8
	B	30	15/01/2021	13/11/2024	3.8
Pūrākaunui Inlet	A	30	3/12/2023	12/11/2024	0.9
	B	30	3/12/2023	12/11/2024	0.9
Akatore	A	30	28/11/2022	14/11/2024	2
	B	30	28/11/2022	14/11/2024	2
Kaikorai	A	10	15/12/2017	18/10/2024	6.8
	B	10	15/12/2017	18/10/2024	6.8
	C (old)[3]	10	15/12/2017	18/12/2019	2
	D	30	22/02/2019	18/10/2024	5.7
Tokomairiro	A (old)[4]	30	16/12/2017 & 23/02/2019	20/12/2019	0.8
	B	10	16/12/2017	12/11/2024	6.9
	C	10	16/12/2017	12/11/2024	6.9
Catlins (Pounawea)	A (old)[5]	10	17/12/2016	14/12/2017	1
	A	10	17/12/2019	11/11/2024	4.9
	B	10	17/12/2016	11/11/2024	7.9
Tautuku	A	30	1/12/2021	10/11/2024	2.9
	B	30	1/12/2021	10/11/2024	2.9
Waipati River (Chaslands)	A	30	6/12/2023	11/11/2024	0.9
	B	30	6/12/2023	11/11/2024	0.9

1. At Waikouaiti Site A, plates were initially installed in December 2016 but were never relocated, hence the sedimentation record does not start until after new plates were installed in December 2019.

2. At Waikouaiti B (old) the pegs were lost and plates were exposed due to flooding, and the monitoring record ended after collecting only one sedimentation record. A new Site B was relocated slightly downstream.

3. At Kaikorai C (old) the site became heavily scoured by river flow and monitoring was discontinued after collection of two sedimentation records. The site was deemed unsuitable for sediment plates and new plates were installed at a more stable location (Site D) nearby.

4. At Tokomairiro A (old) the marker pegs and plates installed in December 2017 were lost (assumed buried or washed away) with plates reinstated in February 2019. Only one sedimentation record was collected before the reinstated plates were also lost. Monitoring was therefore discontinued as the site was judged unsuitable for sediment plates.

5. At Catlins A (old) the marker pegs were lost and plates assumed buried, hence the monitoring record ended after collecting only one sedimentation record. New plates were reinstated at the same location.

2.3 DATA ANALYSIS AND PRESENTATION

A one-page summary of findings is provided for each estuary. From the average sediment depth values for each plate, a long-term mean annual SAR for each site is calculated for the monitored period by dividing the average change in sediment depth (across n=4 plates) by the number of years since baseline plate installation.

The SAR data, and results for sediment mud content and aRPD, are compared to condition ratings of ecological state shown in Table 3. These ratings are based on recent work conducted for the Ministry for the Environment (Stevens et al. 2024), with minor differences to ratings used previously for ORC described in footnotes to Table 3.

Note that a minimum 5-year record of annual measurements (ideally at least 10-years; Hunt 2019), is needed for meaningful trends to be established. As such, where the record is <5-years (see Table 2) caution is advised in drawing any strong conclusions.

Table 3. Summary of condition ratings for assessing sediment plate monitoring results.

Indicator	Unit	Very Good	Good	Fair	Poor	Very Poor
Sedimentation[1]	mm/yr	<0.5	≥0.5 to <1	≥1 to <2	≥2 to <10	≥10
Mud content	%	<5	≥5 to <10	≥10 to <25	≥25 to <50	≥50
aRPD depth[2]	mm	>40	≤40 to >25	≤25 to 10	<10 to 5	<5

Ratings taken from Stevens et al. (2024) except where noted below.

1. As per previous Salt Ecology reports, sedimentation ratings benchmarked from the 2mm/yr in Townsend and Lohrer (2015) with additional break points added. An additional 'Very Poor' category has been added based on Stevens et al. (2024).

2. aRPD has been modified from Stevens et al. (2024) by addition of a 'Very Poor' category to discriminate situations of low oxygenation.

3. RESULTS

3.1 OVERVIEW

As noted in Section 1 (see also Table 1), the Otago estuaries monitored encompass a range of environments and potential catchment influences. Within the estuaries, monitoring sites are located across various habitats, ranging from intertidal flats dominated by sand to mud-dominated deposition zones in upper estuary areas. The location of each monitoring site within an estuary is expected to strongly reflect the site's hydrodynamics, sediment composition, and sedimentation regimes. Therefore, the monitored sites do not inherently indicate the condition of the estuary as a whole, and each site needs to be considered independently and alongside location-specific characteristics to inform the interpretation of results.

Table 4 provides a regional summary, showing the change in sediment depth at each site since plates were installed (change from baseline; CFB), and long-term sedimentation results along with their respective condition ratings. Additional results including site-specific sediment mud content and oxygenation, and sedimentation trends, are presented for each estuary in Sections 3.2 – 3.12 below.

In November 2024, most monitored estuary sites in Otago had high rates of sedimentation exceeding the national guideline upper limit of 2mm/yr recommended by Townsend and Lohrer (2015), and corresponding to a condition rating of 'Poor' (Table 4). For each estuary and site, subsequent sections discuss the extent to which these results likely reflect catchment influences due to sediment run-off, versus the redistribution of deposited bed sediments (e.g., due to local hydrodynamics).

Note that some estuaries, such as Akatore and Waipati River (Chaslands) Estuary, have sites which display exceptionally high sediment accretion that far exceeds national guidance. However, due to the short time series (<5 years), it is not yet meaningful to analyse sedimentation trends at these sites. In fact, there are insufficient data to reliably inform trends in sedimentation for six of the 11 estuaries monitored (see footnote Table 4).

Table 4. Sediment depth change from baseline (CFB) and average annual sedimentation rate in Otago estuaries, November 2024. Condition rating colour scheme shown in Table 3.

Estuary	Site	CFB (mm)	Sedimentation (mm/yr)
Shag	A	25.9	3.3
	B	2.7	0.3
Pleasant River (Te Hakapupu)	A*	6.4	2.2
	B*	6.3	2.1
Waikouaiti	A	-3.7	-0.7
	B	6.5	1.3
	C	-20	-2.6
Blueskin Bay	A*	3.6	0.9
	B*	8.3	2.2
Pūrākaunui Inlet	A*	7	7.4
	B*	4.5	4.8
Kaikorai	A	24.6	3.6
	B	31.2	4.6
	D	17.6	3.1
Akatore Estuary[1]	A*	3.4	1.7
	B*	31.8	16.2
Tokomairiro	B	33.8	4.9
	C	-6.2	-0.9
Catlins (Pounawea)	A	32.7	6.7
	B	49.3	6.2
Tautuku	A*	13.1	4.4
	B*	14.4	4.9
Waipati River (Chaslands)	A*	3.8	4
	B*	25.5	27.3

* A longer time series is requred to inform a meaningful trend.
1. Akatore post-flood monitoring in October 2024 was not used to calculate annualised sedimentation rates.

3.2 SHAG ESTUARY

Annual sediment monitoring in Shag Estuary began in December 2016 and is undertaken at two sites (Fig. 2), with the latest survey carried out on 14 November 2024.

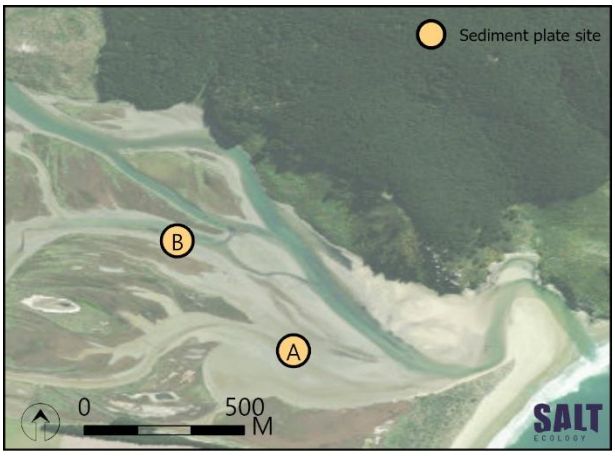


Fig. 2. Location of Shag Estuary sediment plate sites.

Table 5 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 3.

Table 5. Shag Estuary annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
A	2016-Dec	3.5	77.4	19.1	30
	2017-Dec	1.0	80.0	19.0	-
	2019-Feb	2.8	78.6	18.6	38
	2019-Dec	3.0	79.5	17.5	45
	2021-Jan	0.7	44.0	55.3	45
	2021-Nov	0.9	71.5	27.6	30
	2022-Nov	0.9	69.8	29.3	45
	2023-Nov	1.1	69.5	29.4	30
	2024-Nov	0.3	45.2	54.5	39
B	2016-Dec	25.1	51.9	23.0	30
	2017-Dec	6.3	77.2	16.5	-
	2019-Feb	13.3	63.0	23.7	35
	2019-Dec	9.2	69.8	21.0	35
	2021-Jan	6.4	70.2	23.4	45
	2021-Nov	2.9	71.5	25.7	30
	2022-Nov	7.0	64.1	28.9	50
	2023-Nov	3.7	66.4	29.8	27
	2024-Nov	4.5	62.2	33.3	30

Sediment mud content and oxygenation

Since 2021, at both sites, sediment mud-content has exceeded the biologically relevant threshold of 25%, corresponding to a condition rating of 'Very Poor' at Site A and 'Poor' at Site B (Table 5). These elevated fine sediments likely arise from a large proportion of catchment being in land uses which generate sediment release (e.g., 71% pasture and 11% forestry; O'Connell-Milne et al. 2024a).

Despite the sediment muddiness, both sites generally show aRPD depths greater than 30mm, a condition rating of 'Good' (Table 5). Previous studies (Forrest 2023) have identified high abundances of tube-building macrofauna such as *Paracorophium excavatum* that draw oxygen deeper into the sediment and may explain the high oxygenation observed.

Sedimentation rate

Estuary sedimentation has been highly variable at both sites since monitoring began, however, there has been slightly more sediment accretion than erosion.

The long-term sedimentation rate of 3.3mm/yr at Site A is rated 'Poor' and exceeds the national guideline upper limit of 2mm/yr. While average sedimentation at Site B is 0.3mm/yr, a condition rating of 'Good' (Table 4, Fig. 3). Sedimentation rates at Site A suggest sediment is readily deposited in the lower estuary. The same level of accumulation has not been observed at Site B, likely owing to its proximity to the channel and scour during flooding in October 2024. The temporal variability likely reflects the river dominated hydrological setting and episodic inputs from the developed catchment (O'Connell-Milne et al. 2024a).

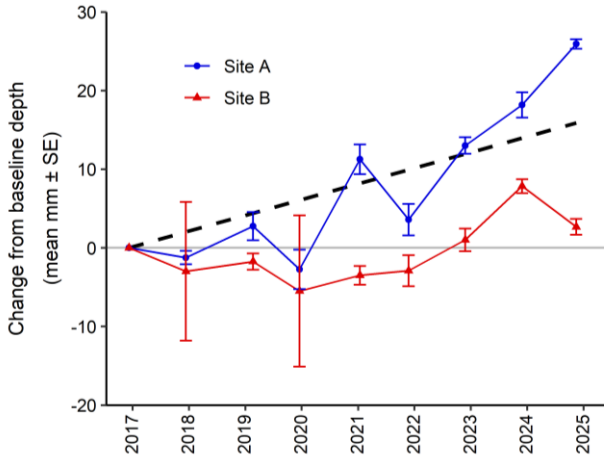


Fig. 3. Shag Estuary change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed line shows sediment accrual at the national guideline upper limit of 2mm/yr.

3.3 PLEASANT RIVER (TE HAKAPUPU) ESTUARY

Annual sediment monitoring in Pleasant River Estuary began in November 2021 and is undertaken at two sites (Fig. 4), with the latest survey carried out on 14 November 2024.

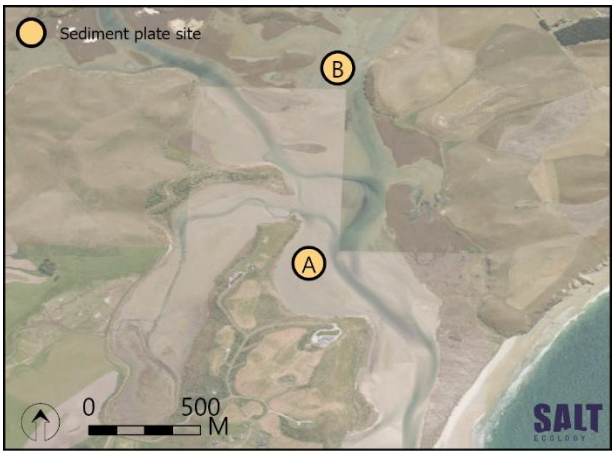


Fig. 4. Location of Pleasant River Estuary sediment plate sites.

Table 6 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 5.

Sediment mud content and oxygenation

Sediment mud-content exceeded the biologically relevant threshold of 25% for the fourth year running at both sites, rated 'Very Poor' and 'Poor' (Table 6). These elevated fine sediments likely arise from land uses in the Pleasant River catchment that are known to generate high sediment loads (61.9% pasture, 31.7% exotic forest; Roberts et al. 2022).

Table 6. Pleasant River Estuary annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
A	2021-Nov	<0.1	57.4	42.6	4
	2022-Nov	<0.1	59.4	40.5	12
	2023-Dec	0.1	46.8	53.1	5
	2024-Nov	<0.1	47.4	52.6	9
B	2021-Nov	2.3	51.6	46.1	2
	2022-Nov	1.2	52.9	45.9	3
	2023-Dec	2.8	46.8	50.4	1
	2024-Nov	0.9	58.8	40.3	12

< All values below lab detection limit.

In November 2024, the aRPD depth at Site A received a condition rating of 'Poor', while Site B was rated 'Fair', but in some years aRPD has been 'Very Poor' at both sites (Table 6). The shallow oxygenation depth in most surveys likely reflects the muddy nature of the sediments, and the associated assemblage of small-bodied macrofauna (see Forrest et al. 2022a), which are less efficient than larger organisms at turning over sediment and allowing oxygen to reach deeper layers.

Muddy, yet relatively firm, sediments at Site A, November 2024.

Sedimentation rate

In November 2024, sedimentation rates at Site A and B were 2.1mm/yr and 2.2mm/yr, respectively, slightly above the national guideline upper limit of 2mm/yr, a condition rating of 'Poor' (Table 4). However, sediment accrual at both sites in November 2024 may reflect sediment deposition following a large flood in October 2024. Given the year-to-year variability observed, and the short time series (3-years of sedimentation data) it is too early to gauge trends.

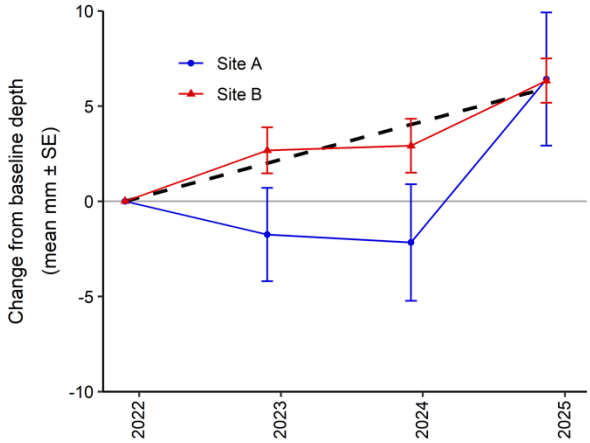


Fig. 5. Pleasant River Estuary change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed line shows sediment accrual at the national guideline upper limit of 2mm/yr.

3.4 WAIKOUAITI ESTUARY

Annual sediment monitoring in Waikouaiti Estuary began in December 2016 and is undertaken at three sites (Fig. 6). In December 2019, Site B was reinstated at a new location after the original site was washed away (see Table 2). The latest survey was carried out on 13 November 2024.

Table 7 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 7.

Fig. 6. Location of Waikouaiti Estuary sediment plate sites.

Table 7. Waikouaiti Estuary annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
A	2019-Dec	11.8	80.4	7.8	75
	2021-Jan	24.9	69.4	5.7	30
	2021-Nov	15.4	78.0	6.6	50
	2022-Nov	7.3	83.9	8.7	60
	2023-Dec	17.7	73.7	8.6	30
	2024-Nov	9.6	75.9	14.5	19
B	2019-Dec	25.3	67.7	7.0	10
	2021-Jan	27.8	66.8	5.4	8
	2021-Nov	18.7	76.7	4.6	8
	2022-Nov	4.1	92.1	3.8	50
	2023-Dec	10.5	82.6	6.9	8
	2024-Nov	13.0	78.5	8.5	10
C	2016-Dec	0.3	68.9	30.9	0
	2017-Dec	0.2	69.5	30.3	-
	2019-Feb	0.4	71.4	28.3	20
	2019-Dec	0.2	70.8	29.1	18
	2021-Jan	0.3	71.3	28.4	25
	2021-Nov	0.2	73.3	26.5	12
	2022-Nov	<0.1	67.0	33.0	10
	2023-Dec	0.6	69.8	29.6	20
	2024-Nov	0.8	64.8	34.4	14

< All values below lab detection limit.

Sediment mud content and oxygenation

Sediment mud content has remained relatively stable at each site over the monitoring period (Table 7). Sites A and B have been predominantly rated 'Good', with mostly gravel and sand-dominated sediments. However, in November 2024, the mud content at Site A increased slightly and was rated 'Fair'. Sediment mud content at Site C has consistently exceeded the biologically relevant threshold of 25% (rated 'Poor').

Site A has well oxygenated sediments, however, in November 2024, the aRPD was slightly shallower (Table 7). The aRPD is often shallower in muddy rather than sandy sediments due to mud limiting oxygen diffusion into deeper sediment layers. However, sandy sediments at Site B generally have the shallowest aRPD despite muddier conditions at Site C. The results at Site B may reflect sediment enrichment with river-derived detritus (O'Connell-Milne et al. 2024b). Note that the unusually deep aRPD at Site B in 2022 was due to deposition of clean sand across the site (Table 7). Also note that the aRPD of zero ('Very Poor') at Site C in 2016 likely reflects a provider difference in aRPD interpretation.

Sedimentation rate

Sedimentation at Sites A and B has been highly variable (Fig. 7), with periods of erosion and accretion likely influenced by their proximity to the main river channel. They were rated 'Very Good' (-0.7mm/y) and 'Good' (1.3mm/y), respectively. Site C, in a depositional zone of the upper estuary, has experienced erosion (Fig. 7), possibly due to ongoing sediment loss from decaying *Spartina* spp. beds poisoned in the early 2000s (O'Connell-Milne et al. 2024b).

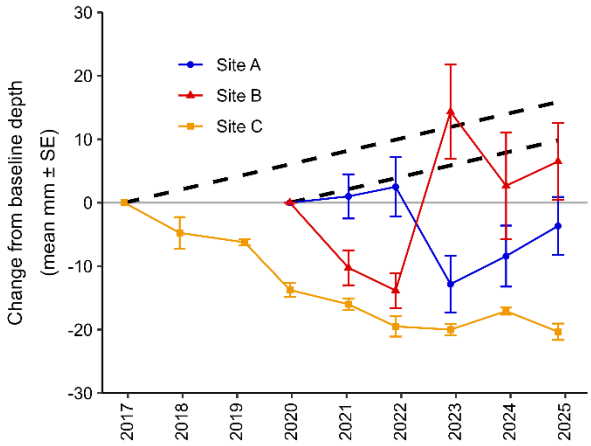


Fig. 7. Waikouaiti Estuary change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed lines show sediment accrual at the national guideline upper limit of 2mm/yr.

3.5 BLUESKIN BAY

Annual sediment monitoring in Blueskin Bay Estuary began in January 2021 and is undertaken at two sites (Fig. 8), with the latest survey carried out on 13 November 2024.

Fig. 8. Location of Blueskin Bay sediment plate sites.

Table 8 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 9.

Sediment mud content and oxygenation

Both Site A and B are located within sand-dominated and low mud-content sediment, receiving a condition rating of 'Very Good' and 'Good' (Table 8).

Average aRPD depths at Site A and B generally reflect well oxygenated sediment, rated 'Good' and 'Very Good' respectively (Table 8), which is typical of porous sandy sediments.

Table 8. Blueskin Bay annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
A	2021-Jan	0.6	94.5	5.0	45
	2021-Nov	<0.1	96.0	4.0	20
	2022-Nov	<0.1	94.0	6.0	15
	2023-Dec	0.1	95.1	4.9	35
	2024-Nov	<0.1	96.6	3.4	31
B	2021-Jan	1.1	93.2	5.7	35
	2021-Nov	0.1	93.3	6.6	30
	2022-Nov	0.4	92.7	6.9	30
	2023-Dec	0.3	92.2	7.6	35
	2024-Nov	1.8	90.4	7.8	50

< All values below lab detection limit.

Sedimentation rate

Sedimentation rates have been variable in Blueskin Bay over the four years of monitoring (Fig. 9), hence, meaningful characterisation of trends will require an additional year of data at minimum. Initial results indicate low rates of sedimentation at Site A of 0.9mm/yr, a condition rating of 'Good'. Although sedimentation at Site B has shown a variable pattern of erosion and accrual, the average sedimentation rate of 2.2mm/yr falls just above the 2mm/yr national guideline upper limit, a condition rating of 'Poor' (Table 4). Although the catchment is currently well vegetated with 37% native forest, an additional 21% of the catchment comprises exotic forestry which may result in sediment release to the estuary when harvested (Roberts et al. 2021).

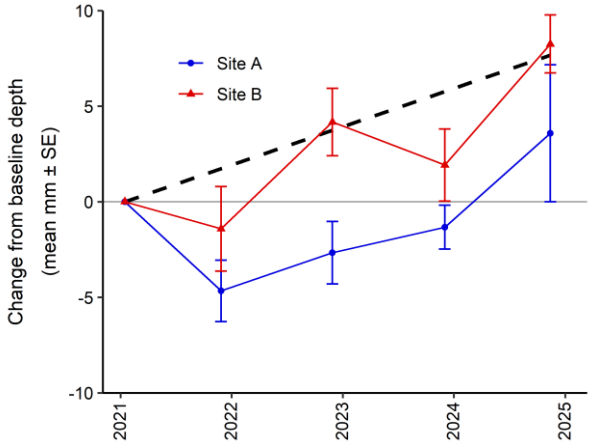
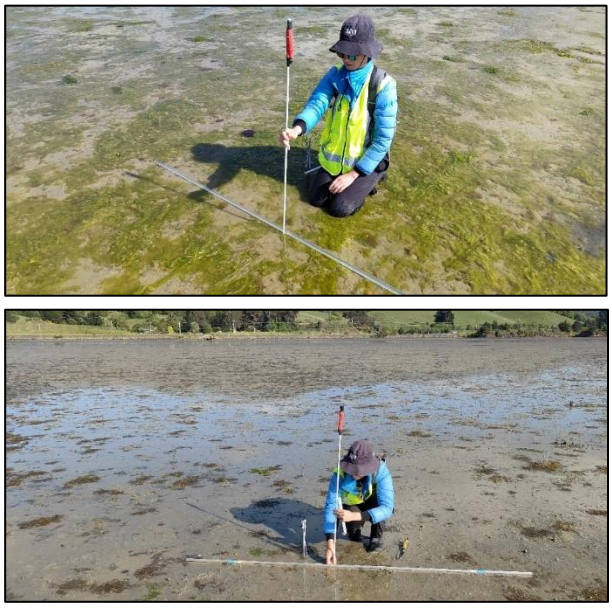


Fig. 9. Blueskin Bay change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed line shows sediment accrual at the national guideline upper limit of 2mm/yr.



Firm sandy sediment at Site A with bloom of opportunistic macroalgae *Ulva* sp. (top), and Site B (bottom), November 2024.

3.6 PŪRĀKAUNUI INLET

Annual sediment monitoring in Pūrākaunui Inlet began in November 2023 and is undertaken at two sites (Fig. 10), with the latest survey carried out on 12 November 2024.

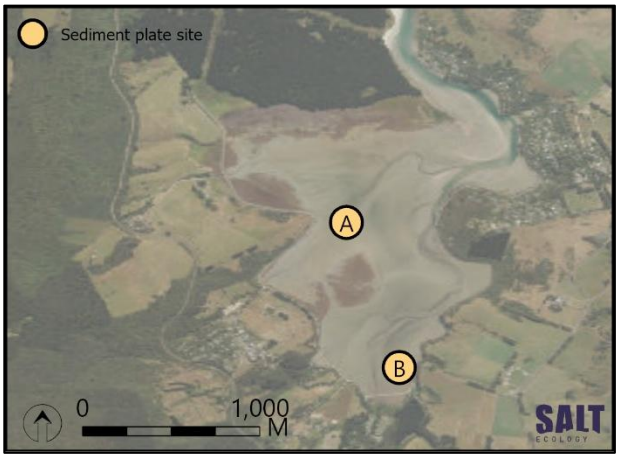


Fig. 10. Location of Pūrākaunui Inlet sediment plate sites.

Table 9 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 11.

Sediment mud content and oxygenation

The two years of sampling indicate Site A is predominantly sandy (~4% mud), a condition rating of 'Very Good'. While Site B is also sand dominated, mud content has been more variable, increasing from 9% to 13% in November 2024, a reduction in condition rating from 'Good' to 'Fair' (Table 9). Further data are required to inform meaningful site trends.

Average aRPD depths at both sites indicate a moderate oxygenation of the sediment (condition ratings of 'Fair'), which is slightly lower than expected with porous sands (Table 9).

Table 9. Pūrākaunui Inlet annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
A	2023-Dec	0.1	96.2	3.8	18
	2024-Nov	0.1	96.2	3.7	14
B	2023-Dec	0.1	90.5	9.5	15
	2024-Nov	< 0.1	86.8	13.2	13

< All values below lab detection limit.

Sedimentation rate

Sedimentation data from one year of monitoring in Pūrākaunui Inlet (Fig. 11, Table 4) provides very limited information, and more data are required before any meaningful trends can be assessed. However, in the first year of monitoring, average sedimentation at Site A was 7.4mm/yr while Site B was 4.8mm/yr. Both sites far exceed the national guideline upper limit of 2mm/yr, a condition rating of 'Poor'. These results are unexpected given the highly vegetated catchment (Stevens et al. 2023), however given the limited time series it remains uncertain whether this represents a trend of deposition from catchment inputs or reworking of sediments within the estuary due to waves and currents.

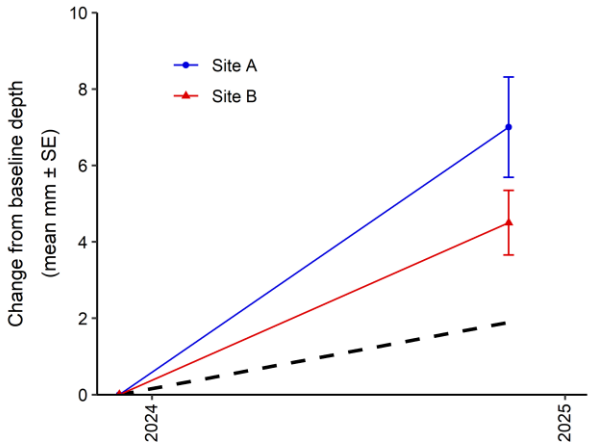


Fig. 11. Pūrākaunui Inlet change in mean sediment depth over buried plates (±SE) in November 2024 relative to the November 2023 baseline. The dashed line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Sand-dominated substrate at Site A (top), and muddy-sand substrate at Site B (bottom), November 2024.

3.7 KAIKORAI ESTUARY

Sediment monitoring in Kaikorai Estuary began in December 2017 and is undertaken at three sites (Fig. 12). In February 2019, Site C (not shown in Fig. 12) was discontinued due to river erosion and was replaced by Site D (see Table 2). The latest survey was carried out on 18 October 2024. Site A was removed in November 2024 as its proximity to the mobile channel made it ineffective for sedimentation monitoring. Sites were not monitored in 2022 as they remained submerged and inaccessible at low tide due to the closed estuary mouth.

Table 10 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 13.

Fig. 12. Location of Kaikorai Estuary sediment plate sites.

Sediment mud content and oxygenation

The monitoring sites in Kaikorai Estuary describe three distinct regions of sediment mud-content. Site A in the well-flushed lower estuary is in mobile sand (condition rating 'Very Good'; Table 10). Site B in the mid-estuary is in very soft mud-dominated sediment with 83% mud-content (rated 'Very Poor'). Site D in the upper estuary has become less muddy in recent years improving to 22.5% mud-content (rated 'Fair').

Sediment oxygenation has been shallow at all sites over previous years, however, improved somewhat in the latest survey (Table 10). This may in part be linked to the estuary mouth being open, improving water movement, or observer differences. However, low sediment oxygenation recorded at these sites in previous years likely reflects the high mud content, which limits oxygen diffusion into the sediment. In November 2024, the sites did not show symptoms of strong enrichment (e.g., black colour & sulfide odour).

Table 10. Kaikorai Estuary annual grain size and aRPD results with condition ratings*.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
A	2017-Dec	0.1	85.7	14.3	30
	2019-Feb	0.1	93.0	7.0	70
	2019-Dec	0.1	91.8	8.2	38
	2021-Jan	<0.1	87.0	13.0	35
	2021-Nov	<0.1	89.7	10.3	10
	2023-Dec	0.1	88.4	11.6	11
	2024-Oct	<0.1	97.2	2.8	40
B	2017-Dec	0.2	34.8	65.0	0
	2019-Feb	0.3	27.8	72.0	5
	2019-Dec	0.2	21.9	78.0	3
	2021-Jan	0.4	13.2	86.4	2
	2021-Nov	5.3	11.9	82.8	5
	2023-Dec	0.1	15.0	85.0	5
	2024-Oct	0.2	16.5	83.3	10
D	2019-Feb	0.9	57.4	41.7	20
	2019-Dec	0.6	62.7	36.7	3
	2021-Jan	0.6	41.5	57.9	2
	2021-Nov	0.4	73.4	26.2	15
	2023-Dec	0.8	71.2	28.0	8
	2024-Oct	0.3	77.3	22.5	20

* Sites not monitored in 2022, < All values below lab detection limit.

Sedimentation rate

Sedimentation has been variable in Kaikorai Estuary, however, long-term trends indicate sediment accrual at Site A, B, and D at a rate of 3.6mm/yr, 4.6mm/yr, and 3.1mm/yr, respectively; all rated 'Poor' (Fig. 13; Table 4). These results may reflect that the estuary mouth is often closed to the coast, resulting in retention and deposition of sediment.

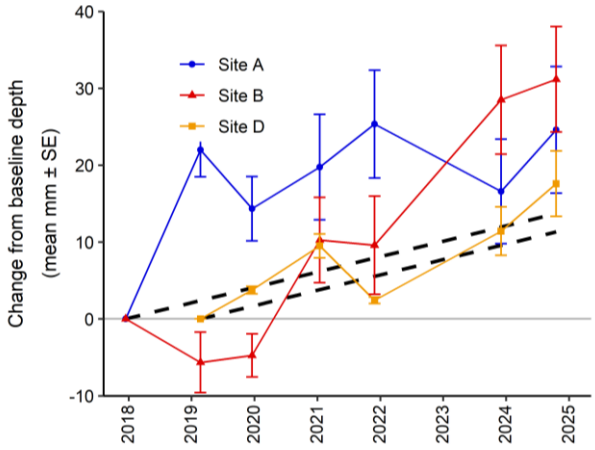


Fig. 13. Kaikorai Estuary change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed lines show sediment accrual at the national guideline upper limit of 2mm/yr.

3.8 AKATORE ESTUARY

Annual sediment monitoring in Akatore Estuary began in November 2022, initially at two sites (Fig. 14), with the latest survey carried out on 14 November 2024. Interim monitoring following a flood event was conducted in October 2024, and a wider sediment plate monitoring network was put in place in November 2024. This additional work is reported separately (O'Connell-Milne & Roberts 2025).

Fig. 14. Location of Akatore Estuary sediment plate sites.

Table 11 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 15.

Sediment mud content and oxygenation

Sediment mud content across both sites and the two surveys has been close to 70%, hence greatly exceeding the biologically relevant threshold of 25% ('Very Poor', Table 11). Both sites are in upper tidal reaches of Akatore Estuary where slow flushing times likely increase fine sediment retention (Roberts et al. 2022). Interestingly, sediment mud content did not increase following the flood event (O'Connell-Milne & Roberts 2025).

Table 11. Akatore Estuary annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
A	2022-Nov	0.3	29.5	70.2	10
	2023-Dec	0.1	30.5	69.4	20
	2024-Nov	0.1	27.3	72.6	19
B	2022-Nov	0.5	27.7	71.7	10
	2023-Dec	0.4	32.4	67.3	20
	2024-Nov	0.1	35.1	64.8	25

Despite the high mud-content, sediment at both sites appears to be reasonably well oxygenated, rated 'Fair'. Sediment oxygenation is likely maintained by the presence of sufficient porous sandy sediment (approx. 30% at both sites), as well as organisms such as crabs, which turn over surface sediments and transfer oxygen to underlying layers.

Sedimentation rate

Sediment accretion was observed at both sites after the first full year of monitoring, with a spike in sedimentation at Site B in October 2024 following the flood. There was notable erosion at both sites between October and November 2024. Over the two years of monitoring the average annual sedimentation has been 1.7mm/yr ('Fair') and 16.2mm/yr ('Very Poor') at Site A and Site B, respectively (Table 4). Although the flood effect was obvious at Site B, a longer time series will be required to establish a meaningful trend and determine whether the accumulated sediment is retained within the estuary.

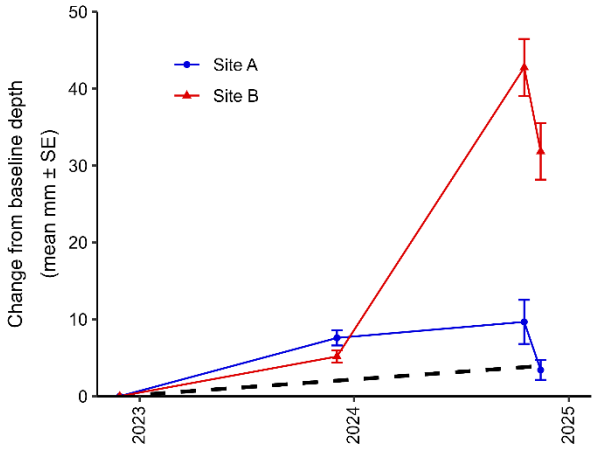


Fig. 15. Akatore Estuary change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Akatore Site B.

3.9 TOKOMAIRIRO ESTUARY

Annual sediment monitoring in Tokomairiro Estuary began in December 2017 and, although initially undertaken at three sites, Site A was discontinued in December 2019 (see Table 2), with ongoing monitoring at Sites B and C only (Fig. 16). The latest survey was carried out on 12 November 2024.

Fig. 16. Location of Tokomairiro Estuary sediment plate sites.

Table 12 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 17.

Table 12. Tokomairiro Estuary annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
B	2017-Dec	0.6	34.9	64.6	10
	2019-Feb	0.6	31.0	68.4	5
	2019-Dec	0.9	38.5	60.6	5
	2021-Jan	0.4	31.7	67.9	7
	2021-Nov	0.1	36.7	63.2	17
	2022-Nov	0.7	29.6	69.7	15
	2024-Jan	0.3	28.2	71.6	10
	2024-Nov	1.1	43.5	55.3	18
C	2017-Dec	3.0	40.7	56.3	10
	2019-Feb	2.2	40.2	57.6	3
	2019-Dec	6.0	35.8	58.2	4
	2021-Jan	4.1	47.9	47.9	5
	2021-Nov	3.2	39.8	57.0	8
	2022-Nov	1.8	42.7	55.5	8
	2024-Jan	1.9	46.8	51.2	5
	2024-Nov	3.3	45.9	50.9	13

Sediment mud content and oxygenation

Sediment mud content at both sites exceeds the biologically relevant threshold of 25%, a condition rating of 'Very Poor' (Table 12). Tokomairiro Estuary drains a large catchment whose land uses are predominantly agriculture (54%) and forestry (35%), which are known sources of muddy sediment (Forrest et al. 2020).

In November 2024, measurements of aRPD at Site B were largely consistent with earlier surveys, while Site C showed improvements (both rated 'Fair'; Table 12). This improvement may be linked to the estuary mouth being open to the coast, allowing for better water movement and less stagnation than during mouth closure or observer interpretation. Although sediment oxygenation at Site C has typically been 'Very Poor' or 'Poor', likely attributed to the high mud content, there have been localised exceptions where oxygenated sediment has extended to 10mm or deeper.

Sedimentation rate

Following several years of erosion, sediment deposition was recorded at both sites in November 2024 (Fig. 17). Site B had very high sediment accretion, likely driven by a flood event in October 2024, with an average long-term sedimentation rate of 4.9mm/yr exceeding the national guideline upper limit of 2mm/yr; a condition rating of 'Poor' (Table 4). Despite the recent accretion at Site C, the long-term sedimentation trend remains one of erosion with a rate of -0.9mm/yr, a condition rating of 'Very Good'.

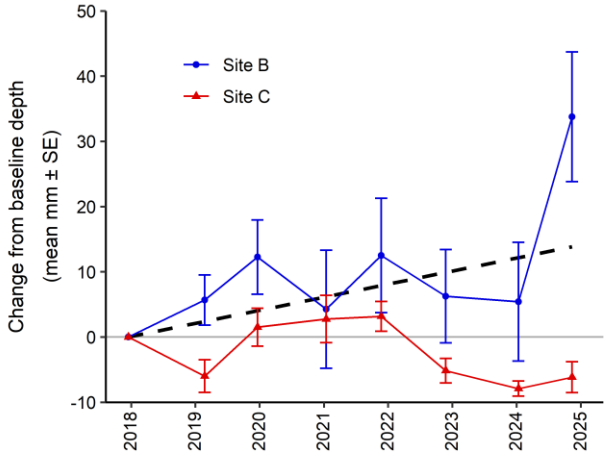


Fig. 17. Tokomairiro Estuary change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed line shows sediment accrual at the national guideline upper limit of 2mm/yr.

3.10 CATLINS (POUNAWEA) ESTUARY

Annual sediment monitoring in Catlins (Pounawea) Estuary began in December 2016 and is undertaken at two sites (Fig. 18). Site A was washed away and reinstated in the same general location in December 2019 (see Table 2). The latest survey was carried out on 11 November 2024.

Fig. 18. Location of Catlins Estuary sediment plate sites.

Table 13 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 19.

Sediment mud content and oxygenation

The locations of each monitoring site influence their sediment composition. Site A is located close to the main river channel where sands are relatively mobile and generally have a very low mud-content of around 3%. In November 2024, mud content increased to 8%, resulting in a decline in condition rating from 'Very Good' to 'Good' (Table 13). Site B, in the upper estuary, is within a deposition zone and consistently exceeds the biologically relevant threshold of 25% mud-content (rated 'Poor').

Sediment oxygenation has been generally rated as 'Fair' to 'Good' (aRPD >20mm; Table 13) at both sites and does not appear to be impacted by shifts in sediment grain size. In general, elevated mud-content can restrict oxygen penetration into the sediment. However, at Site B high abundances of bioturbating macrofauna (see Morrisey & Forrest 2023) likely draw oxygen deeper into the sediment leading to good sediment oxygenation.

Sedimentation rate

Since plate installation, sedimentation rates have average 6.7mm/yr at Site A and 6.2mm/yr at Site B, exceeding the 2mm/yr guidelines ('Poor', Table 4; Fig. 19). Sedimentation is variable across Site A, likely due to its proximity to the main channel and deposition of mobile sand. In contrast, sedimentation at Site B is likely driven by fine sediment inputs from the pasture dominated (62%) catchment (Roberts et al. 2024).

Table 13. Catlins Estuary annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel	Sand	Mud	aRPD
		%	%	%	mm
A	2019-Dec	0.1	96.9	3.1	200*
	2021-Jan	<0.1	97.7	2.3	70
	2021-Dec	0.3	96.7	3.0	20
	2022-Nov	<0.1	96.6	3.4	21
	2023-Dec	0.1	96.5	3.5	25
	2024-Nov	<0.1	91.7	8.3	18
B	2016-Dec	0.1	75.2	24.7	20
	2017-Dec	0.1	69.6	30.4	-
	2019-Feb	0.1	57.1	42.9	10
	2019-Dec	0.1	59.0	41.0	35
	2021-Jan	<0.1	67.6	32.4	25
	2021-Dec	<0.1	65.4	34.6	30
	2022-Nov	<0.1	70.6	29.4	20
	2023-Dec	0.1	71.9	28.1	25
	2024-Nov	0.3	58.5	41.2	34

* Aberrant aRPD at Site A in 2019 due to observer interpretation, < All values below lab detection limit.

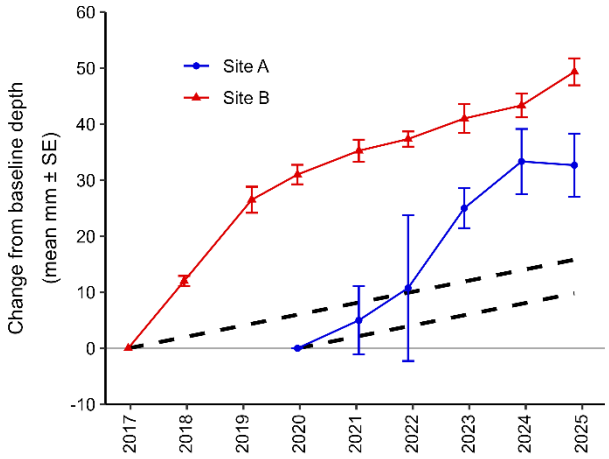


Fig. 19. Catlins Estuary change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed lines show sediment accrual at the national guideline upper limit of 2mm/yr.

3.11 TAUTUKU ESTUARY

Annual sediment monitoring in Tautuku Estuary began in December 2021 and is undertaken at two sites (Fig. 20), with the latest survey carried out on 10 November 2024. Tautuku is of particular interest as a relatively unmodified 'reference' estuary for other river-dominated estuaries in the region (Forrest et al. 2022b).

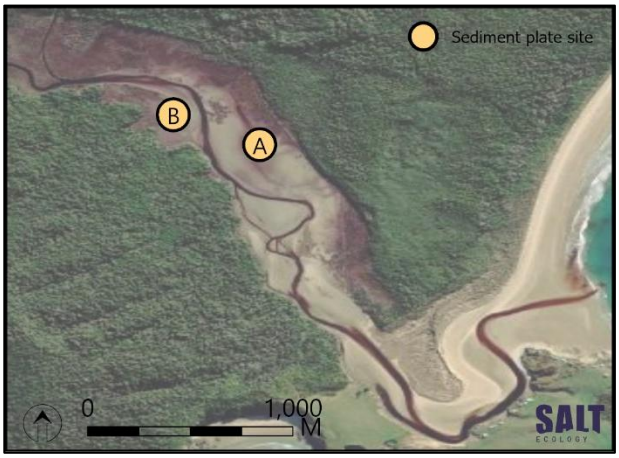


Fig. 20. Location of Tautuku Estuary sediment plate sites.

Table 14 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 21.

Sediment mud content and oxygenation

Sites A and B generally have 'Fair' and 'Very Poor' sediment mud-content ratings, respectively (Table 14). For Site B, these sediment mud-contents are in exceedance of the biologically relevant threshold of 25%, which is likely due to this site being in a depositional area that is less well-flushed than Site A (which is located on more exposed flats). Site B appears to be more affected by the Tautuku River, with deposition of mud and detritus apparent.

Initial monitoring suggested that sediment oxygenation was linked to sediment grain-size, with the coarser sediments of Site A allowing more oxygen to penetrate through sediment layers. However, recent surveys indicate both sites are generally well oxygenated and receive condition ratings of 'Good' despite high mud content as Site B (Table 14). This result may be due to bioturbation of sediments by organisms such as worms, crabs and cockles, which are present across both sites.

Sedimentation rate

Interestingly, sediment accretion has been observed at Site A and B across all monitoring years (Fig. 21), with an average sedimentation rate of 4.4mm/yr and 4.9mm/yr, respectively (Table 4). These rates exceed the national guideline of 2mm/yr, resulting in a condition rating of 'Poor' (Table 4). The flood event observed across many estuaries in Otago may have resulted in elevated sediment deposition in 2024, however, more data are required before any meaningful trends can be assessed.

Table 14. Tautuku Estuary annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
A	2021-Dec	<0.1	83.9	16.1	50
	2022-Dec	<0.1	79.7	20.3	45
	2023-Dec	0.1	82.7	17.3	35
	2024-Nov	<0.1	83.5	16.5	36
B	2021-Dec	0.1	46.4	53.5	20
	2022-Dec	0.2	51.5	48.3	12
	2023-Dec	0.2	44.6	55.3	31
	2024-Nov	0.1	40.9	58.9	36

< All values below lab detection limit.

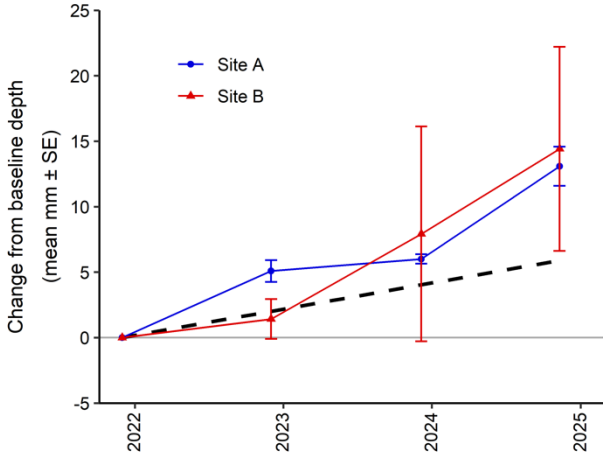


Fig. 21. Tautuku Estuary change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Mud-dominated sediment at Site B, November 2024.

3.12 WAIPATI RIVER (CHASLANDS) ESTUARY

Annual sediment monitoring in Waipati River (Chaslands) Estuary began in December 2023 at two sites (Fig. 22), with the latest survey carried out on 11 November 2024. In addition to Tautuku, Waipati River Estuary provides a second relatively unmodified 'reference' estuary for Otago's estuary monitoring network (Forrest et al. 2023).

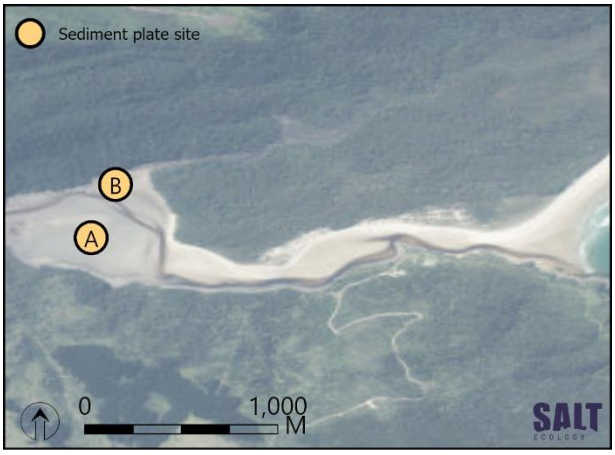


Fig. 22. Location of Waipati River Estuary sediment plate sites.

Table 15 shows a summary of annual sediment sampling results and condition ratings for all surveys, with annual changes in sediment depth over plates shown in Fig. 23.

Sediment mud content and oxygenation

In November 2024, sediment at Site A was muddier and softer than in 2023, with a mud content of 29% exceeding the biologically relevant threshold of 25% mud, a condition rating of 'Poor'. Conversely, Site B became sandier and had a condition rating of 'Good'. Field observations suggest that the changes at Site B appear to be from high river flow across the site resulting in deposition of coarse material.

At Site A the aRPD depth was similar across the two surveys, a condition rating of 'Good', despite increased mud content which can negatively impact substrate oxygenation (Table 15). At Site B, the aRPD was deeper in 2024, a condition rating of 'Very Good', consistent with the increased sand content of the substrate.

Sedimentation rate

Sedimentation data from one year of monitoring in Waipati River Estuary provides very limited information and more data are required before assessing meaningful trends. However, in the first year of monitoring, sedimentation at Site A was 4mm/yr while Site B was 27.3mm/yr (Table 4, Fig. 23), far exceeding the national guideline upper limit of 2mm/yr and resulting in a condition rating of 'Poor' and 'Very Poor', respectively (Table 4). A flood event in October 2024 may have driven the changes observed, with woody flood debris from the catchment (as well as soft sediments) observed approximately 30cm deep on the true right bank of the main channel. This sediment has potentially been dispersed onto the main tidal flats (i.e., Site A).

Table 15. Waipati River Estuary annual grain size and aRPD results with condition ratings.

Site	Survey	Gravel %	Sand %	Mud %	aRPD mm
A	2023-Dec	0.1	81.6	18.3	40
	2024-Nov	<0.1	70.9	29.0	36
B	2023-Dec	0.1	82.0	17.9	30
	2024-Nov	<0.1	92.8	7.2	62

< All values below lab detection limit.

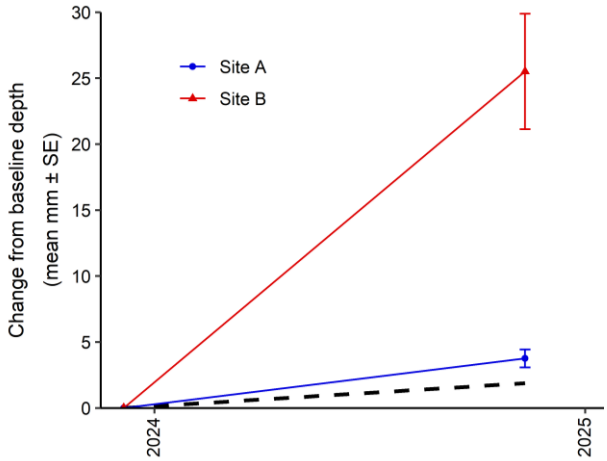


Fig. 23. Waipati River Estuary change in mean sediment depth over buried plates (±SE) in November 2024 relative to the November 2023 baseline. The dashed line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Elevated sedimentation and increased mud content of substrate at Site A, November 2024.

4. CONCLUSIONS

This report has provided a data summary of annual sediment plate monitoring results for 11 estuaries in ORC's SOE monitoring programme.

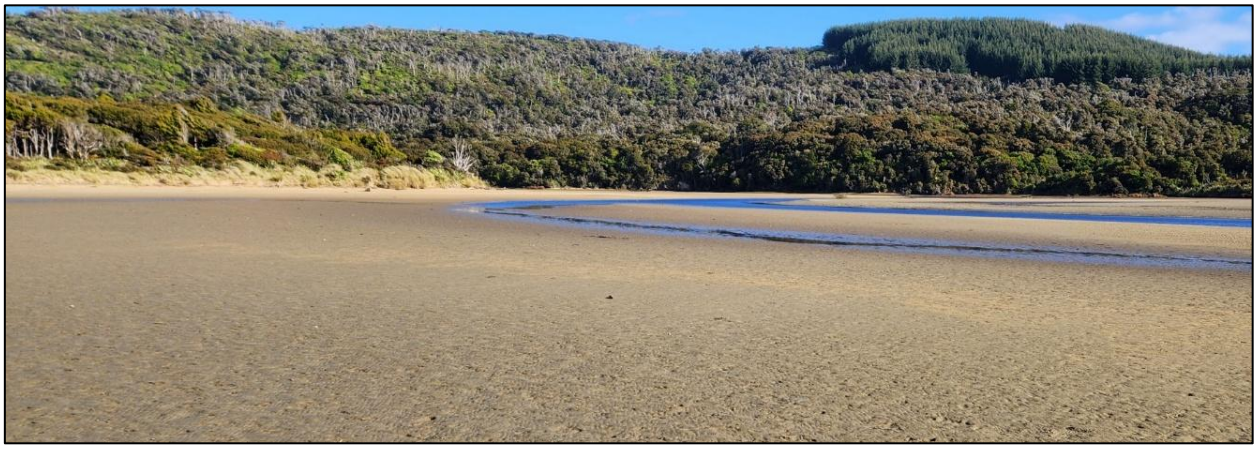
The results highlight that most estuaries are experiencing sedimentation levels at the monitored sites that exceed the national guideline upper limit of 2mm/yr. That said, for six of the 11 estuaries (i.e., Pleasant River, Blueskin Bay, Pūrākaunui Inlet, Akatore, Tautuku, Waipati River) the monitoring duration is too short for meaningful trends to be established. The initial results are nonetheless still useful in indicating sites at risk of high sediment accretion.

Due to the selection of locations for sediment plates within depositional areas, more than half of the monitored sites are either mud-dominated (>50% mud), or have a sediment mud content that exceeds the biologically-relevant threshold of 25%. This means that almost half of the sites (i.e., those <25% mud) may be vulnerable to long-term increases in muddy sediment deposition. At this stage, there are instances such as Shag Estuary where mud content appears to be slowly increasing over time. In general, however, sediment mud content appears to vary over time with no strong directional trends. Again, a longer-time series will help to understand these patterns.

Levels of oxygenation, measured as aRPD depth fluctuate widely over time and among sites. In general, substrate oxygen penetration increases with substrate grainsize when no enrichment symptoms are present. However, aRPD variability can also reflect a range of factors, including the subjective nature of the method (i.e., leading to observer differences), and bioturbation of sediments by organisms such as worms, crabs and cockles. For example, low levels of sediment mud-content, as seen in Blueskin Bay, often provide a habitat for larger macrofauna species such as crabs and shellfish that turn over surface sediments and transfer oxygen to underlying layers. By contrast, muddy substrates, as seen in Pleasant River Estuary, often support infaunal communities with smaller body sizes which are less efficient at turning over sediment and allowing oxygen to reach deeper layers. Although some sites displayed very shallow substrate oxygenation in some years, none of the Otago sites assessed showed symptoms of gross enrichment (e.g., intense black sediment colour and strong sulfide odour).

ORC's sediment plate monitoring and SOE monitoring, including broad-scale habitat mapping and fine-scale surveys, show that many of Otago's estuaries (or parts of them) are under pressure from muddy-sediment inputs. This is often due to the impact of highly modified catchments on downstream estuarine environments, as seen in Shag, Tokomairiro, Akatore and Catlins (Site B). Estuaries with well-oxygenated sand-dominated sediments, such as Blueskin Bay, are still considered vulnerable to future increases in sediment loads due to anticipated catchment activities, such as sediment release following harvest of exotic forest plantations. These forests comprise almost a quarter of the Blueskin Bay catchment land use (O'Connell-Milne & Forrest 2023). These results reinforce previous recommendations to monitor and manage catchment sediment sources.

It is beyond the scope of this data summary to consider the detail of the monitoring that is needed going forward. However, parallel work is underway that is reviewing ORC's estuary SOE programme, which will be completed before the end of 2025. Among other things, that review is undertaking a closer evaluation of the sediment plate monitoring data to evaluate temporal trends, and investigate the factors (e.g., catchment land use) that may be driving the differences among sites and estuaries. That review will build on the summary provided here, and make specific recommendations for future monitoring.



Native forest catchment and estuary margin fringing Waipati River Estuary.

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