Auckland East Coast Estuarine Monitoring Programme: Summary of key changes 2015-2018

Judi E Hewitt and K R Carter

May 2020 Technical Report 2020/011

Research and Evaluation Unit RIMU

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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NIWA Reference: ARC19208

Auckland Council
Technical Report 2020/011
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-99-002224-1 (Print)
ISBN 978-1-99-002225-8 (PDF)

This report has been peer reviewed by the Peer Review Panel.
Review completed: 21 May 2020 Reviewed by two reviewers
Approved for Auckland Council publication by: Name: Eva McLaren Position: Manager, Research and Evaluation (RIMU) Name: Megan Carbines Position: Manager, Air, Land and Biodiversity (RIMU)
Date: 21 May 2020

Recommended citation

Hewitt, J. E. and K. R. Carter (2020). Auckland east coast estuarine monitoring programme: summary of key changes 2015-2018. Prepared by NIWA for Auckland Council. Auckland Council technical report, TR 2020/011

Executive summary

Ecological monitoring started in Okura in 2000, in order to better assess the impacts of sediment loads on the health of valued estuarine resources. The abundances of 10 macrofauna taxa, macrofaunal community characteristics and bed sediment characteristics (14 variables) are now monitored in each of eight east coast estuaries – Okura, Puhoi, Waiwera, Orewa, Mangemangeroa, Turanga, Waikopua and Whangateau.

Monitoring focuses on animals living in mud and sand flats (benthic communities), as these animals form an important link between sediment and water column processes. They are important prey items for birds and fish, are sensitive to anthropogenic activities, and are relatively stationary and are therefore representative of local conditions. For these reasons, they are also widely used internationally for monitoring the health of ecosystems.

The purpose of this summary report is to provide an update on key trends observed when data from October 2015 to April 2018 is included in the time series. It documents the degree to which each estuary may be affected by terrestrial sediment inputs as well as their present status.

Scores for sites using the benthic health mud, metals and overall health score range from extremely good to unhealthy, with the majority in the good or moderate category. Using the traits-based indicator of functional health, two sites were ranked as unhealthy with low functional resilience (one in Orewa and one in Waiwera). The majority of the remainder of sites across all estuaries were ranked as having high functional redundancy and resilience with 9 sites ranked as intermediate. Changes in health scores have been variable with scores shifting between groups (both increases and decreases) at six estuaries. Nine sites showed an improvement in health group and five sites a decline in health group.

Trend analysis showed changes in at least one of the 14 monitored variables at all estuaries, and an increase in the number of trends associated with sedimentation at all estuaries except Whangateau since last reported (Hewitt & McCartain 2017). All estuaries had more trends detected that were consistent with increased sedimentation than trends that were not, suggesting that sedimentation is the greatest driver of change. These results suggest that, similar to the last reported, the estuary with the most changes are Okura, followed by Turanga and Waikopua. Whangateau has become the estuary with the least number of changes.

Analyses suggests that all the estuaries, with the possible exception of Whangateau, are at risk with the monitoring detecting trends consistent with increased sediment in each of these estuaries. Thus, continued monitoring of all estuaries is recommended.

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1.0 Introduction

The significant threat of increased terrestrial sediment runoff into estuaries and coastal zones as a result of increased urbanisation was recognised by Auckland Regional Council (ARC) and the National Institute of Water and Atmospheric Research (NIWA) in the 1990s. Sedimentation in estuaries (including experiments in Auckland estuaries) has been shown to have negative effects on the animals living in estuaries from changes in the feeding behaviour and health of individual species to complete eradication of whole macrofaunal communities (Ellis et al., 2002, Hewitt & Pilditch 2004, Lohrer et al., 2004, Norkko et al., 2006, Hewitt & Norkko 2007).

The estuarine monitoring programme provides important information on the health of eight small Auckland east coast estuaries (Figure 2-1) which were identified for their risk profile or strategic location. Data from this monitoring has been used as part of state of the environment reporting and in the development of the Auckland Unitary Plan (including in Environment Court hearings).

Monitoring of Okura Estuary began in 2000 with the intention to capture any changes in the ecology of the estuary associated with planned development. In 2002, Puhoi, Waiwera, Orewa and Mangemangeroa were added to the monitoring programme. Mangemangeroa was added as the urbanisation beginning to occur around its catchment was planned to intensify over time. The other three were added in order to place any potential changes through time in the other estuaries within a broader regional context. However, Mangemangeroa is spatially separated from the others (lying to the south and discharging into the Whitford Embayment). To enable useful comparisons to be made for this estuary, Turanga and Waikopua (also from the Whitford Embayment) were added to the regional monitoring programme in August 2004.

The estuarine monitoring programme was designed to detect long-term effects of sedimentation on macrofaunal (those animals larger than 0.5mm living in the estuary mud and sandflats) community structure, driven by chronic increases in both the turbidity (suspended sediments in water that reduce clarity) and proportion of fine muddy sediments in estuaries. Modifications to land-use that result in increased sediment deposition or suspended sediment concentrations (turbidity) can lead to increases in the percentage of mud or very fine sand content. Many macrofaunal species living within and on the surface of the sediment have been demonstrated to respond to such increases (Anderson 2008, Gibbs and Hewitt 2004, Ellis et al., 2002, Hewitt & Pilditch 2004, Lohrer et al., 2004, Norkko et al., 2006, Hewitt & Norkko 2007). In fact, due to the sensitivity of the organisms, changes in the types and abundances of macrofauna can often be observed before changes in the sediment properties can be detected. This is particularly true on intertidal flats where deposited fine sediment is frequently resuspended by waves and currents. Monitoring also focuses on intertidal macrofauna in mud and sand flats because they: form an important link between sediment and water column quality and processes; are important prey items for birds and fish; are relatively stationary and therefore representative of local conditions; and are widely used internationally for monitoring impacts on and health of ecosystems, allowing comparisons to be made nationally and internationally.

This report summarises any changes in estuarine macrofauna data, sediment data, and health indices since last reported in October 2015. There is a focus on any changes associated with increased sediment at monitored sites and whether there are indications of estuary-wide change. The report has been kept purposefully short and focused on trends in those variables related to sedimentation which previously detailed reporting has shown is the key driver of change in these estuaries (Hewitt & McCartain 2017).The variables for which trends are reported are:

- Sediment characteristics: sediment particles sized <63 mm (mud), sediment particles sized <125 mm (very fine sands plus mud).
- An east coast estuaries specific measure of macrofaunal community response to mud referred to as CAPmud (which decreases with increasing mud content) (see Hewitt & McCartain (2017) for detail and Anderson 2008).
- A measure of biodiversity – total number of taxa found at each site. The number of taxa is expected to decrease with increased sedimentation rates (Lundquist et al., 2003).
- Abundances of seven species that prefer sandy sediment (Anderson 2008); the common anemone, *Anthopleura aureoradiata*; the polychaete, *Aonides trifida*; shellfish, *Austrovenus stutchburyi* (cockle), *Macomona liliana* (wedgeshell) and *Paphies australis* (pipi); and the crustaceans*, Colurostylis* spp. and *Waitangi brevirostris* (amphipod).
- Abundances of three taxa that prefer muddy sediment (Anderson 2008): crabs (*Austrohelice crassa, Hemiplax hirtipes* and *Hemigrapsus crenulatus*); the amphipod family, Corophiidae; and the polychaete family, Nereididae.

Changes in health status are also reported for four health indices used routinely in Auckland Council estuarine monitoring, Benthic Health Model (BHM)metals, BHMmud, Traits Based Indicator (TBI), and the Auckland Council combined health index. The benthic health models are an indication of macrofaunal community health relative to stormwater contaminants (BHMmetals) and sediment (BHMmud). The Traits Based Index (TBI) is a measure of a site’s functional redundancy, centred on the richness of taxa in seven biological trait categories. The TBI, BHMmetals and BHMmud can be combined into a single index of health (Hewitt et al., 2012).

2.0 Methods

Eight small east coast estuaries are monitored: Puhoi, Waiwera, Orewa, Okura, Mangemangeroa, Turanga, Waikopua and Whangateau (Figure 1). These estuaries have been sampled for varying lengths of time: Okura from April 2000; Puhoi, Waiwera, Orewa, and Mangemangeroa from August 2002; Turanga and Waikopua from August 2004; and Whangateau from October 2009. Sampling of sediment organic content began in 2009. Collection of chlorophyll *a* data began in 2012. Originally 10 sites per estuary were monitored, since October 2014, four sites in all of the estuaries have been sampled every six months, with the exception of Okura where 10 sites are sampled. The sites cover upper, mid and lower estuary, and correspond to sites previously sampled for stormwater contaminants and sedimentation rates (by sediment plates). Data in this report includes samples collected in April 2018.

Figure 2-1 Location of the eight monitored estuaries. The location of the sites within each estuary are given in individual figures of each estuary within sections 3.1 to 3.8.

Table 2-1 Sites monitored from October 2014 to present.

Estuary	Sites
Okura	All 10
Whangateau	1,4,5,7
Puhoi	1,4,7,9
Waiwera	1,3,6,8
Orewa	1,3,4,8
Mangemangeroa	3,5,6,9
Turanga	1,4,7,8
Waikopua	1,3,6,9

The methods used to collect, process and analyse the samples are detailed in Hewitt & McCartain (2017), including the calculation of community health indices, sediment and macrofaunal trends.

In short, six replicate macrofaunal cores (130mm in diameter x 150mm deep) are taken from random positions at each site, excluding the area within 5m of a core location for the previous six months. Cores are sieved on a 0.5mm mesh and the material retained preserved in 70% isopropyl alcohol with 0.01% rose bengal. Later the macrofauna are identified to the lowest practical taxonomic level (usually species) and counted. While size information is collected on the three shellfish species, this information is only used to explain observed trends in overall abundances.

Ambient sediment is sampled to determine changes in sediment grain size. Six sediment cores (size) from a single site are combined into a composite sample which is frozen until grain size analysis can occur. Prior to grain size analysis, organic matter is removed using 9% hydrogen peroxide until effervescing ceases. The sample is then wet-sieved on a stack of sieves (2000, 500, 250, 125 and 63µm). Each fraction is dried to a constant weight at 60°C. Sediment per cent weight is then expressed for shell (>2000µm), coarse sand (500-1999µm), medium sand (250-499µm), fine sand (125-249µm), very fine sand (63-124µm) and mud (< 63µm). Due to differences in sediment sampling methods between NIWA and UniServices (depth of sediment sampled and sizes of sieves used) only data from August 2004 onwards are used for subsequent analyses.

For macrofauna, all analyses were performed on the sum of all six cores collected at each site on each sampling occasion. Temporal changes (since 2004) in sediment characteristics, community indices, abundances of selected taxa and bivalve size classes, within the eight estuaries, were determined using the following procedure:

- Visual assessments of plots over time were used to determine whether (a) step changes or (b) multi-year cycles occurred.
- If a step change was indicated, analysis was conducted using a t-test.

- Otherwise, a regression with time was run, using log transformations to include monotonic non-linear responses. Polynomial non-linear responses were not investigated as we were only interested in continuous long-term trends.
- Where a statistically significant trend was observed ($p < 0.05$) residuals were examined for any temporal structure that indicated the presence of cyclic patterns in the data that might drive the detection of trends. Investigation of residuals will become increasingly important with time as the ability to detect small changes increases with the number of sampling times, and these changes are frequently cyclic patterns.

3.0 Are there changes over time associated with increased sedimentation?

Fourteen variables are analysed to provide information on whether there are changes in the estuaries likely to be related to sediment inputs:

- Five of which are predicted to increase with increased sedimentation – sediment mud content, very fine sands plus mud content, and the abundances of crabs, Corophiidae and Nereididae.
- Nine are predicted to decrease with increased sedimentation – CAPmud, total number of taxa, and abundances of *Anthopluera aureoradiata, Aonides trifida; Austrovenus stutchburyi, Macomona liliana, Paphies australis, Colourostylis* spp. and *Waitangi brevirostris.*

For this reason, instead of focussing on increases and decreases, the report talks about whether trends that are detected are consistent (or inconsistent) with increased sedimentation. The report also highlights whether the trends are those previously observed or changes in trends have occurred. For Okura, we also discuss an event that was reported by locals as occurring in April 2018, just before sampling occurred.

3.1 Okura

Figure 3-1 Location of sites in Okura Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30% brown, and 30 to 40% red. Core sites (circles) have been sampled on each sampling occasion. Triangles represent sites that have been sampled but are currently rested.

In April 2018, prior to sampling, locals observed dead cockles lying on the surface of the estuary's intertidal flats. Comparison between the density of cockles (sized >15mm) in April 2016, 2017 and 2018 at the sites with high densities of cockles (sites 3 and 6) revealed a sharp decrease in average cockle density per core at site 3 from 43 and 39 in 2016 and 2017 respectively, to 20 cockles. This was nearly a 50% decrease. However, at site 6, while a similar sized decrease was observed, the decrease was more gradual with average densities dropping from 34 in April 2016, to in April 2017, to 17 in April 2018. Sites that generally had lower densities of cockles mainly demonstrated no change, or in the case of site 8 an actual increase.

Nine trends that were detected in data from 2004 to 2015 were no longer detected. These trends had occurred at sites 3 to 7 and were trends inconsistent with increased sediment inputs with the exception of *Aonides* at site 7.

Increasing trends of very fine particles (very fine sands plus mud) were now detected at eight of the 10 sites (all sites except site 1 and 4). A decreasing trend for CAPmud was now detected at six sites (1, 2, 4, 6, 9 and 10), and for the number of taxa at three sites (8, 9 and 10). Site 1, 6 and 8 showed decreasing trends in the abundance of *Aonides*, with individuals rarely found at site 1 for the last 4.5 years and at site 8 for the last seven years and only observed in low numbers at site 6 for the last five years. *Aonides* has had either low abundance or is rarely observed at another three sites since 2013/4. Site 4 data still exhibited an increasing trend in Nereididae but increasing trends were also detected at sites 1, 2, 6 and 7.

Trends consistent with increased sedimentation were also detected for new taxa. Step decreases were detected for: *Macomona* at sites 2 and 9 occurring around 2008; and *Waitangi* at sites 3 and 4 occurring around 2008-2009. Linear decreasing trends in abundance were detected for *Anthopleura* at site 1; *Colurostylis* at site 10; *Macomona* at sites 1 and 8; and *Waitangi* at sites 6 and 9.

An increase in the abundance of Corophiidae was detected at site 1 (i.e., consistent with increased sedimentation) but decreases in the abundances of both Corophiidae and crabs were detected at site 7 (inconsistent with increased sedimentation). Similarly, increases in the abundance of *Austrovenus* were detected at sites 3, 5, 6, 7 and 8, while decreases in mud content were detected for sites 1 and 7.

The majority of trends not consistent with sedimentation were still found at site 7, but this site now had two trends consistent with increased sedimentation. The number of sites at which trends consistent with sedimentation were detected has increased steadily over time (Table 2.1): six out of ten in 2009 (60%); six out of nine in 2011 (78%); six out of seven in 2013 (86%); to ten out of ten sites in 2015 and 2018 (100%). The number of trends consistent with sedimentation has also increased over time from 11 in 2009, to 17 in 2015 and then abruptly to 38 in 2018 (Table 2.1). Magnitudes of the trends detected in 2009 have generally remained consistent, but four step trends occurred in the 2008/9 period (decreases in the abundance of *Macomona* at two sites and decreases in the abundance of *Waitangi* at two other sites).

Table 3-1 Statistically significant trends detected at Okura sites in data collected from October 2004 to April 2018 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 13.5 years of sampling per core. Values with an *, while having p- values <0.05, have residuals that show temporal patterns and are thus potentially part of longer term cycles, rather than consistent trends. Highlighted values are trends consistent with increased sedimentation (TCS), # values are step trends and size of step and date are given. NS – site not sampled in that year.

	1	2	3	4	5	6	7	8	9	10
CAPmud	-0.091	-0.127		-0.123*		-0.092			-0.120*	-0.119*
# taxa				8.8				-8.1	-12.6	-6.6*
Anthopleura aureoradiata	-13.5									
Aonides trifida	-16.3					-2.7		-0.4		
Austrovenus stutchburyi	-20.5		61.5		26.6	29.0	34.8	6.8		
Colurostylis spp.										-0.7
Macomona liliana	-4.9	2008*#-6.3						-5.1	2008#-8.7	
Paphies australis			7.8							
Waitangi brevirostris			2008#-0.53	2008#-1.4		-0.9			-0.1	
Corophiidae	0.45						-5.5		-0.8	
Crabs							-1.8			
Nereididae	0.37	6.4		1.1*		1.2	1.6			
Sediment mud content	-6.7						-8.4			11.7
Sediment very fine sand + mud		33.6	22.8		12.9	27.8	15.6	46.9	54.1	55.3
# TCS 2009	4	1	0	1	0	2	0	0	2	1
# TCS 2011	3	2	1	2	0	NS	0	1	5	2
# TCS 2013	2	2	1	2	NS	NS	NS	1	4	NS
# TCS 2015	2	2	1	2	1	2	1	1	3	2
# TCS2018	7	4	2	3	1	5	2	4	5	5
# Trends total 2018	8	4	4	4	2	6	6	5	6	5

3.2 Whangateau

Figure 3-2 Location of sites in Whangateau Estuary Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30% brown, and 30 to 40% red. Sites with black rings are those presently sampled.

As was expected with the short time period and low frequency of sampling, many of the trends reported in 2016 are no longer present. Importantly, all the trends in CAPmud, consistent with increased sedimentation were no longer detected, although at site 7 CAPmud has still not reached the average value observed from 2009 to 2014. One other trend consistent with increased sedimentation was still detected; a decreasing trend in abundance of *Anthopleura* at site 4 (Table 3-2). Similarly, two of the previously observed trends not consistent with sedimentation are no longer present and another two are likely to be part of multi-year cycles.

Only one new trend was detected; increasing abundances of *Anthopleura* at site 7. As a result, only two sites (4 and 7) exhibited a trend consistent with increased sedimentation.

Table 3-2 Statistically significant trends detected at Whangateau sites in data collected from October 2004 to April 2018 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the nine years of sampling per core. Values with an *, while having p- values <0.05, have residuals that show temporal patterns and are thus potentially part of longer term cycles, rather than consistent trends. Highlighted values are those consistent with increased sedimentation.

	1	4	5	7
# taxa		7.8		
Anthopleura aureoradiata		-4.3	4.3*	2.5
Austrovenus stutchburyi	4.6*		7.1	
Macomona liliana			2.8*	
Nereididae				11.6
# Trends consistent with increased sedimentation 2015	2	1	1	1
# Trends consistent with increased sedimentation 2018	0	1	0	1
# Trends total 2018	1	2	3	2

3.3 Puhoi

Figure 3-3 Location of sites in Puhoi Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30% brown, and 30 to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

With three years more data, the trend of decreasing CAPmud at sites 1 and 7, and the increasing trend in number of taxa at site 7, were confirmed as multiyear cycles. Six new trends were detected; two of which were not consistent with increasing sedimentation (the increase of *Austrovenus* at site 9, and *Anthopleura* at site 4), and four which were consistent with sedimentation; the decrease in *Mamomona* at site 1, CAPmud at site 4, and *Colurostylis* at site 7; and the increase of very fine sands plus mud at site 9 (Table 3-3).

As a result, two sites (4 and 9) showed an increase in the number of trends consistent with increased sedimentation, while site 7 showed a decrease.

Table 3-3 Statistically significant trends detected at Puhoi sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 13.5 years of sampling per core. Values with an *, while having p- values <0.05, have residuals that show temporal patterns and are thus potentially part of longer term cycles, rather than consistent trends. Highlighted values are those consistent with increased sedimentation, # values are step trends with date and magnitude given.

	1	4	7	9
CAPmud		-0.089		
Austrovenus stutchburyi		126.2	21.5*	3.2*
Waitangi brevirostris		2013/14- 17.9		
Anthopleura aureoradiata		6.3		
Colurostylis spp.			-5.4*	
Macomona liliana	-1.1			
Sediment very fine sand + mud			31.9	21.5
# Trends consistent with increased sedimentation 2015	1	1	3	0
# Trends consistent with increased sedimentation 2018	1	2	2	1
# Trends total 2018	1	4	3	2

3.4 Waiwera

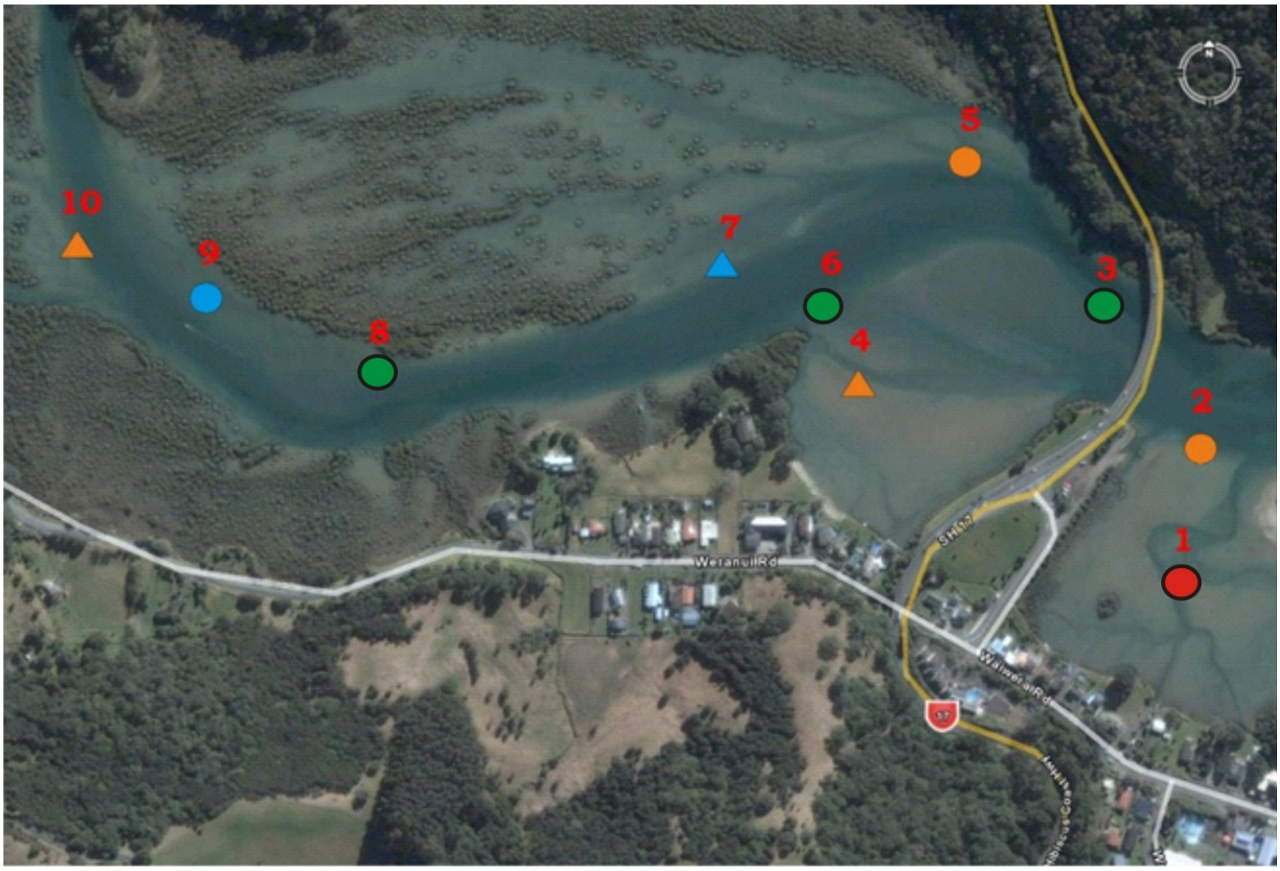

Figure 3-4 Location of sites in Waiwera Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30% brown, and 30 to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

Four of the trends previously detected for this estuary were no longer detected; the increases in number of taxa at site 1 and 8, and the increases in abundance of *Macomona* and *Colurostylis* at site 8. Eight new trends were detected; three consistent with increases in sedimentation (step decreases in the abundances of Waitangi at sites 6 and 8 and linear decreases in the abundance of *Colurostylis* at site 3), and five that were not (increases in the abundance of *Austrovenus* at site 6, decreases in the abundance of Corophiidae at site 3 and decreases in mud content at sites 3, 6 and 8).

As a result there were increases in the number of trends consistent with increased sedimentation at sites 3 and 6, no changes at site 8 and a decrease at site 1 (Table 3-4).

Table 3-4 Statistically significant trends detected at Waiwera sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 13.5 years of sampling per core. Values with an *, while having p- values <0.05, have residuals that show temporal patterns and are thus potentially part of longer term cycles, rather than consistent trends. Highlighted values are those consistent with increased sedimentation, # values are step trends with date and magnitude given.

	1	3	6	8
CAPmud	-0.049		-0.065	-0.045
Anthopleura aureoradiata			1.5*	2.8
Austrovenus stutchburyi			23.5	15.7*
Colurostylis spp.		-8.0		
Waitangi brevirostris		-8.5	2015#-11.3	2014#-19.9
Corophiidae		-0.1		
Nereididae			1.9	3.8
Sediment mud content	6.8	-4.8	-5.2	-1.9*
Sediment very fine sand + mud	14.1			
# Trends consistent with increased sedimentation 2015	4	1	2	3
# Trends consistent with increased sedimentation 2018	3	2	3	3
# Trends total 2018	3	4	6	6

3.5 Orewa

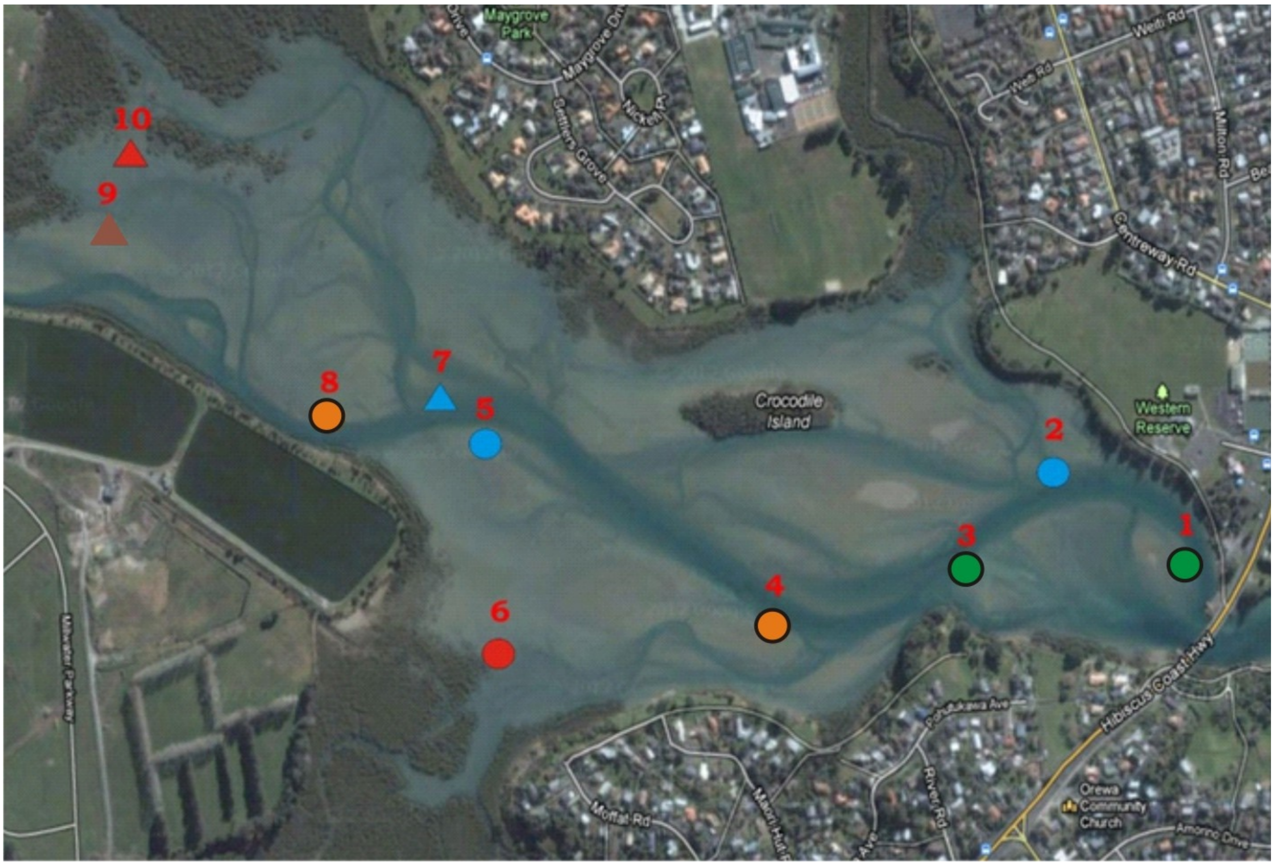

Figure 3-5 Location of sites in Orewa Estuary. Sites are colour coded to show average sediment mud content (<63µm): <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30% brown, and 30 to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

Only two trends observed in the previous report were not detected: decreasing CAPmud at site 1 and increasing abundance of *Anthopleura* at site 8. However, three new trends were detected; increasing abundances of Nereididae at site 4 and decreasing abundances of *Austrovenus* at sites 1 and 3.

As a result, sites 3 and 4 exhibited an increasing number of trends consistent with increased sedimentation (Table 3-5).

Table 3-5 Statistically significant trends detected at Orewa sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 13.5 years of sampling per core. Values with an *, while having p- values <0.05, have residuals that show temporal patterns and are thus potentially part of longer term cycles, rather than consistent trends. Highlighted values are those consistent with increased sedimentation, # values are step trends with date and magnitude given.

	1	3	4	8
# taxa			16.7	
Anthopleura aureoradiata			9.4$^{\#4.2}$	
Austrovenus stutchburyi	-6.7	-20.2	28.3	
Macomona liliana			6.6	
Paphies australis			-14.0	
Waitangi brevirostris	2013$^{\#-19.2}$	2013$^{\#-13.6}$	2011$^{\#-21}$	
Nereididae			0.3	
Sediment mud content			-18.0	-19.0
Sediment very fine sand + mud			28.3	41.2
# Trends consistent with increased sedimentation 2015	2	1	3	1
# Trends consistent with increased sedimentation 2018	2	2	4	1
# Trends total 2018	2	2	9	2

3.6 Mangemangeroa

Figure 3-6 Location of sites in Mangemangeroa Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30% brown, and 30 to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

Only one trend previously detected was no longer detected; the abundance of Nereididae at site 6 was no longer decreasing. However, five new trends were detected, all consistent with increased sedimentation: decreases in number of taxa at sites 6 and 9, decreases in abundances of *Macomona* at sites 5 and 6; and an increase in mud content at site 5. As a result, there were increases in the numbers of trends consistent with increased sedimentation at sites 5, 6 and 9 (Table 3-6).

Table 3-6 Statistically significant linear trends detected at Mangemangeroa sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 13.5 years of sampling per core. Values with an *, while having p- values <0.05, have residuals that show temporal patterns and are thus potentially part of longer term cycles, rather than consistent trends. Highlighted values are those consistent with increased sedimentation, # values are step trends with date and magnitude given.

	3	5	6	9
CAPmud		-0.11	-0.15	-0.081*
# taxa		-8.7*	-11.4*	-6.7*
Aonides trifida	2014#-6.4			
Macomona liliana		-0.67	-2.2	
Sediment mud		22.7		
Sediment very fine sand + mud		2012#29.9	2009#34.8	47.2*
# Trends consistent with increased sedimentation 2015	1	3	2	2
# Trends consistent with increased sedimentation 2018	1	5	4	3
# Trends total 2018	1	5	4	3

3.7 Turanga

Figure 3-7 Location of sites in Turanga Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30% brown, and 30 to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

One trend previously detected was no longer detected; the decrease in CAPmud at site 8 likely related to increased sedimentation. However, a number of new trends were detected, most of them unlikely to be related to increased sediment (increases in abundance of *Austrovenus* at sites 1 and 7, and the decreases in Corophiidae at site 8, Nereididae at sites 7 and 8, and the decrease of sediment mud content at site 1). New trends detected that were consistent with increased sediment were decreases in abundances of *Macomona* at sites 7 and 8, and of *Colurostylis* at site 7.

As a result, there were increases in the numbers of trends consistent with increased sedimentation at site 7 only (Table 3-7).

Table 3-7 Statistically significant trends detected at Turanga sites in data collected from October 2004 to October 2015 for community composition, number of taxa and the abundance of the selected species. Values given are the predicted change over the 13.5 years of sampling per core. Values with an *, while having p- values <0.05, have residuals that show temporal patterns and are thus potentially part of longer term cycles, rather than consistent trends. Highlighted values are those consistent with increased sedimentation, # values are step trends with date and magnitude given.

	1	4	7	8
CAPmud		-0.17	-0.12	
# taxa				2009#-7.5
Anthopleura aureoradiata	5.7*		15.2*	
Austrovenus stutchburyi	2014#6.0		20.0*	
Colurostylis spp.			-1.6	
Macomona liliana			-2.0	-0.5
Corophiidae				2013#-2.6
Nereididae			-2.2	-2.2
Sediment mud content	-5.1			
Sediment very fine sand + mud	48.1	2010 46.7	35.2	42.3
# Trends consistent with increased sedimentation 2015	1	2	2	3
# Trends consistent with increased sedimentation 2018	1	2	4	3
# Trends total 2018	4	2	7	5

3.8 Waikopua

Figure 3-8 Location of sites in Waikopua Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30% brown, and 30 to 40% red Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

Two trends previously detected were no longer detected, both of which were not consistent with increased sediment: increased abundance of *Anthopleura* and decreased mud content at site 3. While seven more trends were detected, only two were unlikely to be related to increased sediment; the increased abundances of *Austrovenus* at site 1 and the decreased abundances of Nereididae at site 9 (Table 3-8). New trends detected that were consistent with increased sedimentation were increases in abundance of Nereididae at site 1 and decreases in CAPmud, number of taxa and abundances of *Aonides* and *Macomona* at site 6.

As a result, there were increases in the numbers of trends consistent with increased sedimentation at sites 1 (one new trend), and 6 (four new trends).

Table 3-8 Statistically significant trends detected at Waikopua sites in data collected from October 2004 to October 2015 for community composition, number of taxa and the abundance of the selected species. Values given are the predicted change over the 13.5 years of sampling per core. Values with an *, while having p- values <0.05, have residuals that show temporal patterns and are thus potentially part of longer term cycles, rather than consistent trends. Highlighted values are those consistent with increased sedimentation.

	1	3	6	9
CAPmud			-0.091	-0.11
# taxa		-9.5	-4.4*	
Aonides trifida			-4.0*	
Austrovenus stutchburyi	3.6*		3.3	
Macomona liliana			-1.4*	
Neriedidae	2.4			-0.7
Sediment very fine sand + mud	23.0	37.6	40.6	42.8
# Trends consistent with increased sedimentation 2015	1	2	1	2
# Trends consistent with increased sedimentation 2018	2	2	5	2
# Trends total 2018	3	2	6	3

4.0 Are there any changes in health indicators at the monitored sites?

The benthic health models are an indication of macrofaunal community health relative to stormwater contaminants (BHMmetals) and sediment (BHMmud). Scores range approximately from 0.20 to -0.20 with lower values indicative of better health. These continuous scores can also be converted into categories of health (1-5) using cut-off values (Anderson et al., 2006). The Traits Based Index (TBI) is a measure of a site's functional redundancy, centred on the richness of taxa in seven biological trait categories. Values close to 0 indicate low levels of functional redundancy and are indicative of highly degraded sites, whereas values closer to 1 indicate healthier sites. The TBI, BHMmetals and BHMmud can be combined into a single index of health. For the combined index, lower scores (≤0.2) are better and an indication of good health, whereas scores approaching 1 are indicative of unhealthy areas with low resilience. Since October 2015, there have been some change in these health indices which are described below.

4.1 Benthic Health Model: Metals (BHMmetals)

Based on the metal scores, Orewa had the healthiest sites, varying between extremely good to good health. All the other estuaries exhibited a larger range of scores, with sites varying from extremely good to moderate health. No estuary had sites that scored as poor or unhealthy in relation to metals.

Statistically significant trends indicating an improvement in health in relation to sediment metal content were observed at five of the eight monitored east coast estuaries (Whangateau site 4, Puhoi site 9, Waiwera site 8, Orewa site 4 and Mangemangeroa sites 3 and 5). There have also been some changes that have resulted in the health scores shifting between groups (both increases and decreases) at all estuaries except Whangateau (Table 4-1). A total of three sites across these estuaries have moved to a less healthy group, and six sites have moved to a healthier group.

4.2 Benthic Health Model: Mud (BHMmud)

Based on the mud scores, Orewa had the healthiest sites, varying from extremely good to good health. Turanga and Waiwera ranged from poor to extremely good. Okura, Mangemangeroa, Puhoi and Waikopua ranged from poor to good health. Whangateau ranged from moderate to good health.

At Okura site 6 and Turanga site 4, statistically significant trends indicating a decrease in health in relation to sediment mud content were observed, while at Orewa site 4 an improvement in health was indicated. Changes in BHMmud scores since 2015 have also led to health scores shifting between groups (both increases and decreases) at five estuaries (Table 4-1). A total of six sites across these estuaries have moved to a less healthy group, and four sites have moved to a healthier group.

4.3 Traits Based Index (TBI)

Statistically significant trends indicating an improvement in health were detected for Waiwera site 1, Orewa site 4, and Mangemangeroa sites 3, 5 and 9. No trends indicating a decline in health were observed in TBI values. Changes in TBI scores since 2015 have also led to scores shifting between groups (both increases and decreases) at five estuaries; 3 sites moving to a less healthy TBI group and 7 sites showing an improvement in TBI score. (Table 4-1). Only Orewa and Waiwera contained sites with low functional resilience.

4.4 mCombined Health Score

Combining these indices into the single health score resulted in sites in estuaries varying from poor to extremely good. Sites in Waiwera were ranked as good or extremely healthy. All sites in Okura and Whangateau were ranked as good or moderate. Puhoi, Turanga Mangemangeroa, Orewa and Waikopua estuaries all had at least one site with a poor health rating. Okura, Mangemangeroa, Waikopua, Whangateau had no sites rated as “extremely good”.

As a result of the trends commented on above, there have been changes in combined scores since 2015 leading to scores shifting between groups (both increases and decreases) at six estuaries, 14 changes in total; nine sites showing an improvement in health group and five sites having a decline in health group (Table 3-1). As the combined health score is a combination of other indicators it is not appropriate to test for trends.

Table 4-1 Benthic Health Model scores for storm water contaminants (BHMmetals) and mud content (BHMmud), Trait Based Index (TBI) and the Combined Health scores for all sites in October 2017 and any changes in health group observed since October 2015. For BHMmetals, BHMmud and the Combined Score, blue = extremely good health (Group 1); Green = good health (Group 2); yellow = moderate health (Group 3); orange = poor health (Group 4). Group 5 (unhealthy, red) is not represented. For the TBI, blue = good health and high functional redundancy/resilience (Group 1); yellow = intermediate (Group 2); red = unhealthy and low functional redundancy/resilience (Group 3).

	BHMmetals		BHMmud		TBI		Combined Score	
Estuary	Oct-17	Change	Oct-17	Change	Oct-17	Change	Oct-17	Change
Okura								
1	-0.1366	↓1-2	-0.1131	↓1-2	0.6558		0.3767	↓1-2
2	-0.0646		-0.0031		0.6729		0.5100	
3	-0.1529		-0.1101		0.4448		0.3767	
4	-0.1543		-0.1076		0.7756		0.3767	
5	-0.1422		-0.0709		0.4220		0.3767	
6	-0.1292		-0.0916		0.6615		0.3767	
7	-0.1528		-0.1055	↓1-2	0.5760		0.3767	
8	-0.0740		-0.0224		0.4904		0.4433	
9	-0.0384		0.0240	↓3-4	0.4505		0.5767	
10	-0.0133		0.0739		0.4049		0.5767	

	BHMmetals		BHMmud		TBI		Combined Score	
Estuary	Oct-17	Change	Oct-17	Change	Oct-17	Change	Oct-17	Change
Whangateau								
1	-0.1129		-0.1059		0.4277		0.3767	
4	-0.1164		-0.0930		0.5418		0.3767	
5	-0.0486		-0.0044		0.4277		0.5100	
7	-0.0903		-0.0736		0.4904		0.3767	
Puhoi								
1	-0.1990	↑2-1	-0.1292	↑2-1	0.3422	↑3-2	0.2000	↑4-1
4	-0.1383	↓1-2	-0.1080	↑1-2	0.5874		0.3767	↓1-2
7	-0.1232		-0.0829		0.6159	↑2-1	0.3767	↑3-2
9	-0.0578		0.0059	↑4-3	0.3764	↓1-2	0.6233	↓3-4
Waiwera								
1	-0.0437		0.0231		0.5475	↑2-1	0.5767	↑4-3
3	-0.1394		-0.0869		0.2737		0.6000	↑4-3
6	-0.1899	↑2-1	-0.1359		0.4904		0.2000	↑2-1
8	-0.1709		-0.1209		0.3308	↓1-2	0.2000	
Orewa								
1	-0.1795		-0.1144		0.1882		0.5333	
3	-0.1617	↓1-2	-0.1248		0.4505	↑2-1	0.3000	↓1-2
4	-0.1803		-0.1357		0.3764	↓1-2	0.2000	
8	-0.1507		-0.0555	↑3-2	0.3251		0.4900	
Mangemangeroa								
3	-0.0972		-0.0612		0.6216		0.3767	
5	-0.0828	↑3-2	0.0054	↑4-3	0.5874		0.4433	
6	-0.0451		0.0224		0.5874		0.5767	
9	0.0016		0.0908		0.3878		0.6900	
Turanga								
1	-0.1668	↑2-1	-0.1407		0.5133		0.2000	↑2-1
4	0.0036		0.0667		0.3650	↑3-2	0.6900	↑5-4
7	-0.0950		-0.0290		0.6501		0.4433	
8	-0.0095	↑4-3	0.0498		0.3080	↑3-2	0.6900	↑5-4
Waikopua								
1	-0.1066		-0.0611		0.7813		0.3767	
3	-0.0798		-0.0485	↓2-3	0.5532		0.4433	↓2-3
6	-0.0582		-0.0103	↓2-3	0.4106		0.5100	
9	0.0174	↑4-3	0.0766		0.3593	↑3-2	0.6900	↑5-4

5.0 Conclusions

This monitoring programme was designed to detect changes resulting from increased terrestrial sediment inputs. While it has been expanded to include a health indicator related to stormwater heavy metals and an overall health indicator, these have only been measured since 2009. Similarly, since 2009, organic content, an indicator of nutrient enrichment has been monitored. No increases in organic content were observed at any of the sites in any of the estuaries. The regional health index related to mud content did show decreasing health trends at two sites, even though it has only been measured since 2009. We would expect it to be a less sensitive measure than the community index specifically developed for the monitoring programme.

As a result, the report focuses only on changes of concern related to terrestrial sediment inputs, raised by the trend analyses of sediment mud and very fine sands plus mud, community indices developed specifically for these estuaries (CAPmud, total number of taxa) and abundances of the 10 taxa. It is important to see the trends observed in these variables against the context of the location of the sites that are being monitored in each estuary. Four sites only are monitored from the estuaries, with the exception of Okura. These sites are located along the estuarine gradient of likely sediment deposition, although none are located at the uppermost end, on the assumption that this area is the most likely to already have undergone change.

There was an increase in the number of trends consistent with terrestrial sediment inputs at all estuaries except Whangateau, with Okura having the largest numbers of increases (even accounting for the larger number of monitored sites in this estuary), followed by Waikopua (Table 4-1). Whangateau actually had fewer trends consistent with terrestrial sediment input detected in 2018 than 2015. This is not unexpected as with a time series of less than 10 years multi-year patterns are often detected as trends. It is interesting that now nearly all sites in all estuaries, with the exception of Whangateau, have increasing trends in the amount of very fine particles. It is unfortunate that there is yet no robust method of measuring gross sediment accumulation rates, as this would have been a useful contributor to the weight of evidence.

As trends may be driven by multiple factors, and some sites may be naturally variable, we calculated the difference between the number of trends consistent with sedimentation and the number of trends not consistent for each site. These were then averaged across each estuary to remove the effect of different numbers of sites being sampled. Numbers close to zero indicate that trends in the estuary are driven by a number of factors and numbers less than zero indicate the terrestrial sediment is not a particularly important factor. However, all estuaries except Whangateau had more trends that were consistent with terrestrial sediment detected than trends that were not, suggesting that ongoing change related to terrestrial sediment inputs is occurring. The estuary with the largest difference was Okura, followed by Turanga and Waikopua. Other indicators of concern are the proportion of sites monitored that have trends in the very fine sands plus mud content or in community indices. The highest proportions of trends in the very fine sands plus mud content occurred at Waikopua, Turanga and Okura. The highest proportions of trends in community indices occurred at Turanga and Okura.

Table 5-1 Summary of trends consistent with increased terrestrial sediment across the estuaries. Increase = average increase in number of trends per site. Difference = average difference between number of trends consistent and inconsistent with sedimentation per site. Sediment = proportion of sites with increasing trends in very fine sands plus mud content. Community = proportion of sites with decreasing trends in community level indices (CAPmud and number of taxa). These numbers are all given either as per site, or a proportion of the number of sites sampled so that direct comparisons can be made across estuaries differing in the number of sites sampled.

Estuary	Increase	Difference	Sediment	Community
Okura	2	2.5	0.8	0.7
Waikopua	1.25	2	1.0	0.5
Mangemangeroa	0.75	0.5	0.75	0.5
Turanga	0.5	2.25	1.0	0.75
Orewa	0.5	0.75	0.5	0
Waiwera	0.25	0.75	0.5	0.75
Puhoi	0.25	0.5	0.5	0.25
Whangateau	-0.75	-1	0	0

These results suggest that, similar to the last report, the estuary with the most changes is Okura, followed by Turanga. At Okura, the number of sites at which trends consistent with sedimentation were detected has increased steadily over time from 6 out of 10 in 2009 to all 10 sites by 2015. The number of trends consistent with sedimentation has also increased over time from 11 in 2009, to 17 in 2015 and then abruptly to 38 in 2018. While the trends detected in Okura are generally linear, four step trends occurred in the 2008/9 period and one species sensitive to terrestrial sedimentation has only occurred in low abundances at 3 sites since 2013/4. Cumulative effects and lags in responses have been increasingly been identified and highlighted as leading to snowballing effects (O'Meara et al., 2017, Thrush et al., 2008, Thrush et al., 2014). These are likely to play an important role in changes observed in Okura Estuary but have not been specifically addressed in this report. Indeed, separating the role of different activities in driving change is not only difficult but often not useful when cumulative effects are driving responses (Hewitt and Thrush 2019, Thrush et al., 2016).

Unlike the last report, Waikopua is also showing changes related to sedimentation and Whangateau has become the estuary with the least trends. The estuary with the next lowest level of change is Puhoi.

6.0 Recommendations for ongoing monitoring

The estuarine monitoring programme has provided important information on the health of these estuaries which has informed state of the environment reporting and been used in Environment Court hearings. The results of this year's analysis suggest that all the estuaries, with the possible exception of Whangateau, are at risk with the monitoring detecting trends consistent with increased sediment in each of these estuaries. However, Whangateau has been monitored for less than 10 years and the catchment is continuing to change. Thus, we recommend continuing monitoring of all estuaries.

At this stage, we do not suggest changing the number of sites monitored at Turanga and Waikopua, despite the changes observed in these estuaries. However, if there are proposed developments in specific locations in their catchments, reactivating sites nearest to those locations is recommended.

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