Coastal Water Quality and Ecology monitoring programme

Annual data report, 2016/17

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Contents

1. Introduction

This report summarises the key results of sediment quality, ecological health and habitat monitoring undertaken in the Wellington Region’s near-shore coastal environment for the period 1 July 2016 to 30 June 2017. Note that the suitability of coastal waters for contact recreation purposes is assessed separately under Greater Wellington Regional Council’s (GWRC) recreational water quality monitoring programme (see Brasell & Morar (2017) for the 2016/17 results).

2. Overview of coastal monitoring programme

Coastal monitoring in the Wellington Region began around 25 years ago, with a focus on microbiological water quality – a reflection of the high usage of much of the region's coastline for contact recreation such as swimming and surfing. Periodic assessments of contaminants in shellfish flesh commenced in 1997, with the last assessment undertaken at 20 sites in 2006 (see Milne 2006). In 2004, monitoring expanded into coastal ecology and sediment quality, with a key focus being the effects of urban stormwater on our coastal harbour environments. In addition, between 2004 and 2008 broad scale surveys of the region's coastal habitats were carried out, with detailed sediment and ecological assessments undertaken at representative intertidal locations of selected estuaries and sandy beaches. The information gained from these surveys was combined with ecological vulnerability assessments to identify priorities for a long-term monitoring programme that would enable GWRC to fulfil State of the Environment (SoE) monitoring obligations with respect to coastal ecosystems.

2.1 Monitoring objectives

The aims of GWRC's coastal monitoring programme are to:

1. Assist in the detection of spatial and temporal changes in near-shore coastal waters;
2. Contribute to our understanding of coastal biodiversity in the Wellington Region;
3. Determine the suitability of coastal waters for designated uses;
4. Provide information to assist in targeted investigations where remediation or mitigation of poor water quality or ecosystem health is desired; and
5. Provide information required to determine the effectiveness of regional plans and policies.

2.2 Monitoring sites and frequency

The core coastal ecological monitoring sites are located in Porirua and Wellington harbours, Waikanae, Hutt and Whareama estuaries, and Flat Point on the Wairarapa east coast (Figure 2.1, Appendix 1).

In addition, habitat mapping of key substrate and habitat types is carried out at selected sites approximately every five years. In the past, habitat mapping has been limited to the intertidal areas of estuaries but, in early 2014, habitat mapping was extended to the subtidal areas of Te Awarua-o-Porirua Harbour (Porirua Harbour).

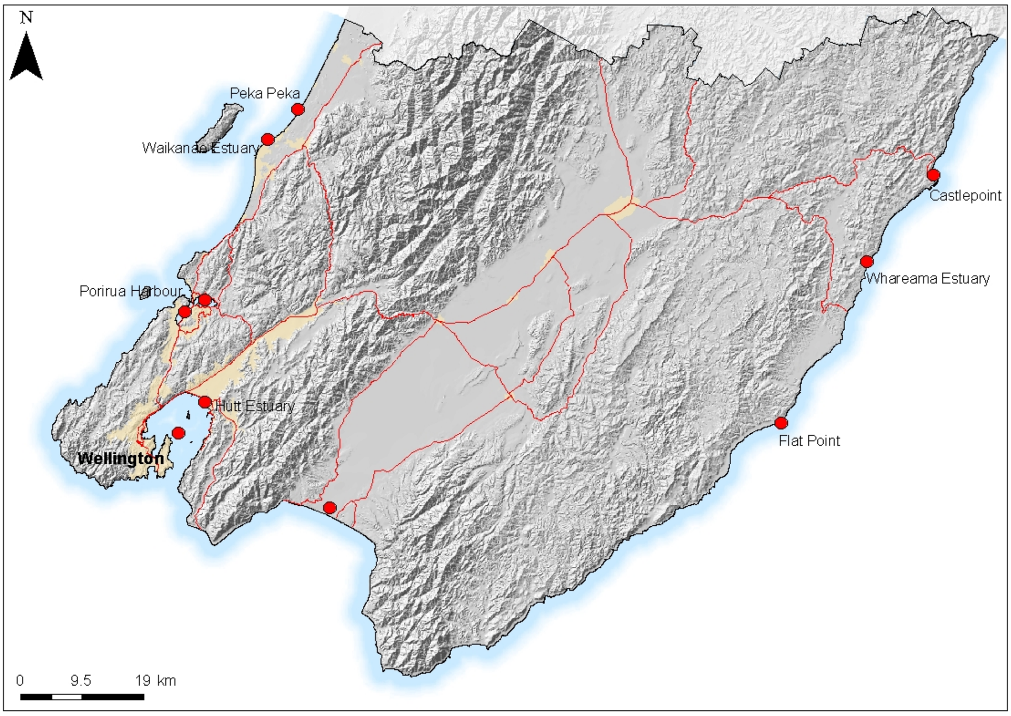

Figure 2.1: Map of the current core estuary, harbour, beach and rocky shore ecological monitoring sites in the Wellington region as at 30 June 2017

Monitoring frequency varies across the sites, depending on the nature of the receiving environment, the purpose of monitoring and what the results indicate. The general approach is to monitor beach, estuary and rocky shore sites annually for three years to establish a baseline, with monitoring then reducing to five-yearly intervals unless specific issues have been identified that warrant more frequent monitoring (eg, persistent macroalgal growth in Hutt Estuary). In contrast, subtidal monitoring in Porirua Harbour and Wellington Harbour is undertaken approximately every five years. See Oliver and Milne (2012) for more information.

2.2.1 Sites monitored during 2016/17

Coastal monitoring undertaken over the period 1 July 2016 to 30 June 2017 included:

- Detailed five yearly ecological monitoring in the Hutt and Waikanae estuaries, including measures of sediment quality and benthic invertebrate communities (Section 3);
- Annual monitoring of macroalgal cover and biomass, and sedimentation rates in Porirua Harbour; Waikanae and Hutt estuaries (Section 3);
- Detailed ecological monitoring of the intertidal rocky shore at Flat Point for the second year of baseline monitoring (Section 4);
- The third survey of subtidal sediment quality and benthic invertebrate communities at 17 sites in Wellington Harbour (Section 5);

- Deployment of a trial water quality instrument mooring in Wellington Harbour to monitor temperature, conductivity, turbidity and chlorophyll-*a* continuously across a range of depths (Section 6); and
- The development of a microbial forecast for Porirua Harbour to predict when water quality conditions are suitable for swimming and shellfish gathering (Section 7)

2.3 Monitoring variables

The basic approach to monitoring coastal microbiological water quality and the ecological condition of the region's estuaries, beaches, rocky shores, and harbours is outlined in detail in Oliver and Milne (2012) and summarised in Appendix 2.

3. Estuary condition

In January 2017, Wriggle Coastal Management carried out surveys of the Waikanae and Hutt estuaries and Porirua Harbour (Onepoto and Pauatahanui Arms). The surveys are documented in full in Robertson and Stevens (2017a,b), Stevens and O'Neill-Stevens (2017 b,c), and Stevens (2017a-c), and the key findings are summarised in Table 3.1

3.1 Annual monitoring indicators

In broad terms the surveys of Porirua Harbour and the Waikanae and Hutt estuaries included measurements of sedimentation over buried plates (Figure 3.1), apparent Redox Potential Discontinuity (aRPD)[1] depth, and mud content. Measures of macroalgal biomass and cover were also carried out in both arms of Porirua Harbour, and the Hutt Estuary, as a proxy for eutrophication risk. These are the fine and broad scale indicators selected for ongoing annual monitoring, following detailed baseline surveys between 2008 and 2012. Table 3.1 presents the results of these assessments. Note that the mean annual sedimentation rates are for the January 2016 to January 2017 period. Further details of the monitoring variables and assessment methods are summarised in Appendix 2.

Figure 3.1: Sedimentation plate monitoring in the Waikanae Estuary, January 2017

It is important to note that the method for assessing the macroalgae condition changed in 2014/15 from simple percentage cover (density) estimates used in previous years, to an Ecological Quality Rating (EQR) for macroalgae. Refer

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[1] The aRPD provides a measure of the depth of oxygenated sediment.

to Stevens & O'Neill-Stevens (2017b) for more detail. This rating is intended to provide an early warning of increasing or excessive algal growth and triggers annual macroalgal monitoring when the EQR is <0.4.

Table 3.1: Sedimentation and eutrophication indicator results for estuaries monitored in early 2017. Porirua Harbour cells shaded in light blue and dark blue equate to intertidal and subtidal sites, respectively

		Sedimentation					Eutrophication	
		Sedimentation rate (Jan 2016 – Jan 2017)	Mean sedimentation rate (mm/yr) for the last 4 years ↑↓ change from previous 4 yr mean[1]	No. of years measured	RPD (cm)	Mean mud content (%)	Ecological Quality Rating (EQR) for macroalgae	Quality status
Waikanae Estuary		-1.8	18.9↓	7	2.9	13.2	Not assessed	
Hutt Estuary		20.0	2.5↑	7	1.3	23.2	0.58	Moderate
Whareama Estuary		Not assessed	-	-	-	-	Not assessed	
Porirua Harbour								
Onepoto Arm	1	-1.5	-1.0↓	9	3	8.0	0.54	Moderate
	2	1.5	2.8↓	5	3	8.7		
	3	5.3	3.6	9	2	8.4		
	S6	32.0	5.3↑	4	1	59.9		
	S7	7.0	-23.3↑	4	2	11.1		
	S8	24.0	-16.8↑	4	>5	12.7		
	S9	-3.0	2.0↑	9	>5	12.2		
Pauatahanui Arm	6	-4.5	-3.3↓	8	2	13.3		
	7	17.8	1.5↑	5	2	37.9		
	8	-7.0	-2.1↓	5	1	10.7		
	9	0.3	-0.7	9	2	4.0		
	10	1.0	3.0↑	5	>5	2.2		
	11	-6.0	-7.8	4	3	8.5		
	S1	64.0	20.2↑	4	2	82.7		
	S2	54.0	27.1↑	4	1	66.1		
	S3	90.0	28.7↑	↑4	2	52.4		
	S4	12.0	3.5↑	4	2	18.8		
	S5	13.0	2.6↑	4	1	65.3		

[1] Note this is a 4-year rolling mean of sedimentation rate rather than the mean sedimentation rate for all years as reported in previous annual data reports

3.2 Five-yearly monitoring indicators

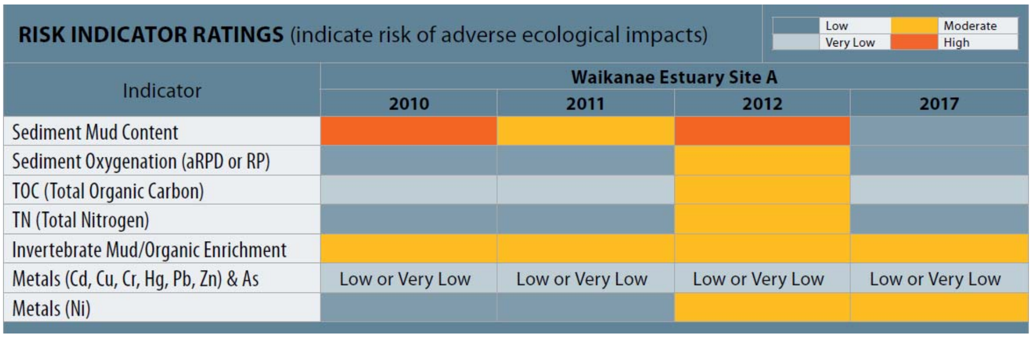
Detailed monitoring of the Waikanae and Hutt estuaries intertidal sediment quality and benthic community health was carried out in January 2017 (Figure 3.2) at long-term sites (Robertson & Stevens 2017a, 2017b). This is the first detailed fine scale survey since the three-year baseline was established in 2012 (Robertson & Stevens 2010a, 2010b). In addition to the annual fine scale indicators outlined in Table 3.1 (eg, sedimentation rates, RPD, mud content), this more detailed five-yearly monitoring considers indicators such as concentrations of nutrient and metals, total organic carbon content and abundance and type of invertebrates living in the sediment.

Figure 3.2: Fine scale sediment sampling in the Waikanae Estuary, January 2017

To provide a defensible, cost-effective means of quickly identifying the key issues affecting an estuary, Wriggle Coastal Management developed risk indicator ratings for each of these indicators (Robertson & Stevens 2016b). A summary of the indicators and interim risk ratings for each are given in Tables 3.2 and 3.3, for the three baseline monitoring years (2010–2012) and the 2017 survey.

Table 3.2: Summary of risk indicator ratings from the baseline fine scale surveys (2010-2012) and post-baseline (2017) survey of Waikanae Estuary

(Source: Robertson & Stevens 2017b)



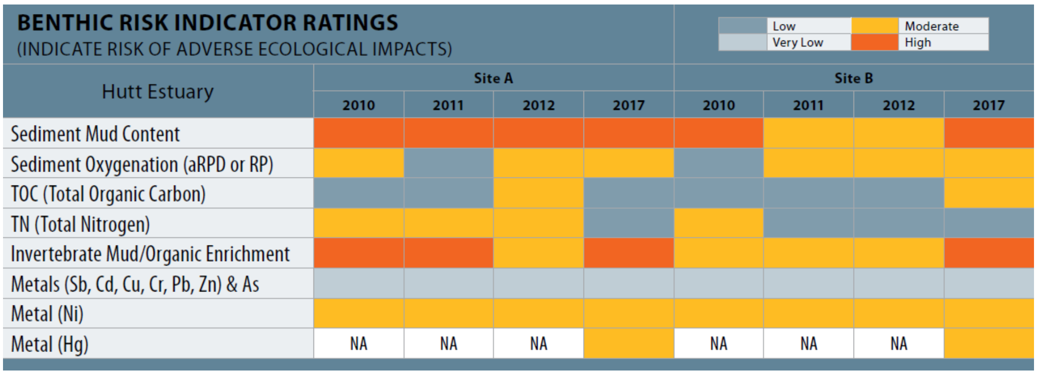
RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

🟦 Low 🟨 Moderate
⬜ Very Low 🟧 High

Indicator	Waikanae Estuary Site A			
	2010	2011	2012	2017
Sediment Mud Content	🟧	🟨	🟧	🟦
Sediment Oxygenation (aRPD or RP)	🟦	🟦	🟨	🟦
TOC (Total Organic Carbon)	⬜	⬜	🟨	⬜
TN (Total Nitrogen)	🟦	🟦	🟨	🟦
Invertebrate Mud/Organic Enrichment	🟨	🟨	🟨	🟨
Metals (Cd, Cu, Cr, Hg, Pb, Zn) & As	Low or Very Low	Low or Very Low	Low or Very Low	Low or Very Low
Metals (Ni)	🟦	🟦	🟨	🟨

Table 3.3: Summary of risk indicator ratings from the baseline fine scale surveys (2010-2012) and post-baseline (2017) survey of Hutt Estuary

(Source: Robertson & Stevens 2017a)



BENTHIC RISK INDICATOR RATINGS
(INDICATE RISK OF ADVERSE ECOLOGICAL IMPACTS)

🟦 Low
⬜ Very Low
🟨 Moderate
🟥 High

Hutt Estuary	Site A				Site B			
	2010	2011	2012	2017	2010	2011	2012	2017
Sediment Mud Content	🟥	🟥	🟥	🟥	🟥	🟨	🟨	🟥
Sediment Oxygenation (aRPD or RP)	🟨	🟦	🟨	🟨	🟦	🟨	🟨	🟨
TOC (Total Organic Carbon)	🟦	🟦	🟨	🟦	🟦	🟦	🟦	🟨
TN (Total Nitrogen)	🟨	🟨	🟨	🟦	🟨	🟦	🟦	🟦
Invertebrate Mud/Organic Enrichment	🟥	🟥	🟨	🟥	🟨	🟨	🟨	🟥
Metals (Sb, Cd, Cu, Cr, Pb, Zn) & As	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
Metal (Ni)	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Metal (Hg)	NA	NA	NA	🟨	NA	NA	NA	🟨

4. Rocky reef condition

In January 2017, Wriggle Coastal Management carried out the second detailed assessment of rocky shore condition at Flat Point on the east coast of the Wairarapa (Stevens & O'Neill-Stevens 2017a). This rocky shore was selected for annual baseline assessments over two to three years as an example of a regionally representative, high diversity rocky shore. Establishing a robust baseline understanding of rocky shore condition is important for monitoring changes related to sea level rise, temperature change, ocean acidification, invasive species and, to a lesser extent, over-collection of living resources.

The key measurements carried out at Flat Point were based on the UK-MarClim project (MNCR 1990) and included assessments of plant and animal diversity and abundance within representative supralittoral and eulittoral zones and within permanent quadrats (Figure 4.1). The percent cover and counts were then rated using SACFOR[2] percentage cover and density scales (see Table 4.1 for an example of how the SACFOR ratings are applied (MNCR 1990)). The risks from pathogens, sedimentation, eutrophication and toxins are considered low so were not assessed. Full details of the monitoring methods can be found in Appendix 2.

Once baseline monitoring is complete, data analyses will be used to characterise the biotic assemblages and changes through time, and to develop condition ratings.

Figure 4.1: Measuring species diversity and abundance within a quadrat in the low eulittoral zone at Flat Point, January 2016

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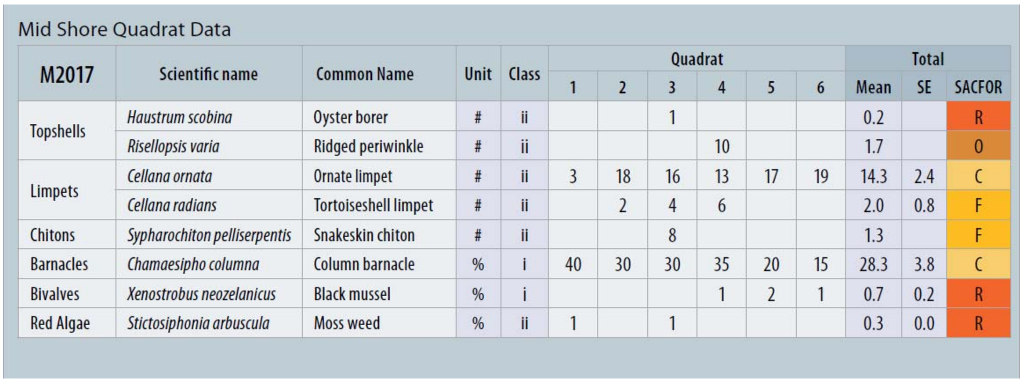
[2] S=Super abundant, A=Abundant, C=Common, F=Frequent, O=Occasional, R=Rare

Table 4.1: Example of the output from rocky shore monitoring summarising raw quadrat counts, mean number or percent cover (±SE), and SACFOR rating of invertebrates and macroalgal present at low shore quadrats, Flat Pt 2017



Mid Shore Quadrat Data

M2017	Scientific name	Common Name	Unit	Class	Quadrat						Total		
					1	2	3	4	5	6	Mean	SE	SACFOR
Topshells	*Haustrum scobina*	Oyster borer	#	ii			1				0.2		R
	Risellopsis varia	Ridged periwinkle	#	ii				10			1.7		O
Limpets	*Cellana ornata*	Ornate limpet	#	ii	3	18	16	13	17	19	14.3	2.4	C
	Cellana radians	Tortoiseshell limpet	#	ii		2	4	6			2.0	0.8	F
Chitons	*Sypharochiton pelliserpentis*	Snakeskin chiton	#	ii			8				1.3		F
Barnacles	*Chamaesipho columna*	Column barnacle	%	i	40	30	30	35	20	15	28.3	3.8	C
Bivalves	*Xenostrobus neozelanicus*	Black mussel	%	i				1	2	1	0.7	0.2	R
Red Algae	*Stictosiphonia arbuscula*	Moss weed	%	ii	1		1				0.3	0.0	R

5. Wellington Harbour subtidal sediment quality monitoring

5.1 Background

Contaminants in urban stormwater discharges have been identified as a potential medium to long-term risk to the health of the marine organisms living in our harbours, largely through the accumulation of these contaminants in the sediments. The Wellington Harbour subtidal sediment quality monitoring programme primarily focuses on urban contaminants (metals, hydrocarbons) as well as select legacy contaminants which tend to bind to the mud fraction of sediments. The harbour sediments are dominated by fine muds and provide a ‘sink’ in which contaminants accumulate. The results of two earlier surveys (2006, 2010) assessed contaminant concentrations in the sediments, together with surveys of the health of benthic fauna present (Stephenson et al. 2008, Milne 2010, Oliver 2014). These sediment surveys allow an ongoing evaluation of urban stormwater management actions directed at maintaining or enhancing the Wellington Harbour receiving environment.

This section briefly summarises the results of the third survey of sediment quality and benthic community health at 17 subtidal sites in Wellington Harbour. The survey was jointly funded by GWRC and Wellington Water Ltd.

5.2 Monitoring sites, variables and methods

Seventeen subtidal sites were sampled in Wellington Harbour between 9 November and 13 December 2016 (Figure 5.1 & Appendix 1). Samples were collected with the use of a boat, GPS and scuba divers, using the same protocols to previous surveys (Figure 5.2) (Stephenson et al. 2008, Oliver 2014). For the collection of sediment samples to be analysed for emerging contaminants, sampling procedures followed methods previously used for sampling in the Auckland Region (Stewart et al. 2009).

5.2.1 Sediments

At each site 25 sediment core samples were collected from a sampling area 20 m in diameter, with the top of each core randomly assigned to one of five replicate groups for composite analysis (Figure 5.3 & 5.4). Samples were homogenised, freeze-dried and tested for:

- particle size distribution (sediment texture);
- total organic carbon (TOC);
- weak acid-extractable and total metals;
- 16 priority polycyclic aromatic hydrocarbons;
- organochlorine pesticides (DDT, DDT, DDE) (composite at 10 sites only); and
- emerging contaminants (composite at 10 sites only).

A summary of analytical methods is listed in Appendix 2.

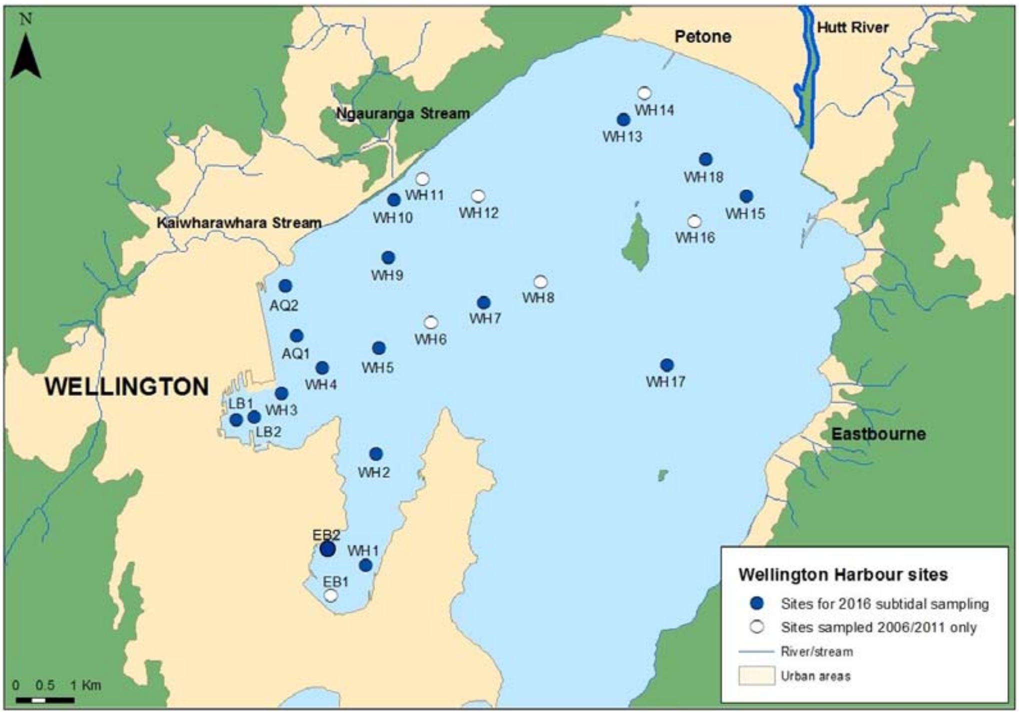


Figure 5.1: Map of Wellington Harbour showing the subtidal locations sampled in 2016. Sample collection and analyses at sites EB2, WH1–5, LB1–2, AQ1–2 and WH10 were funded by Wellington City Council

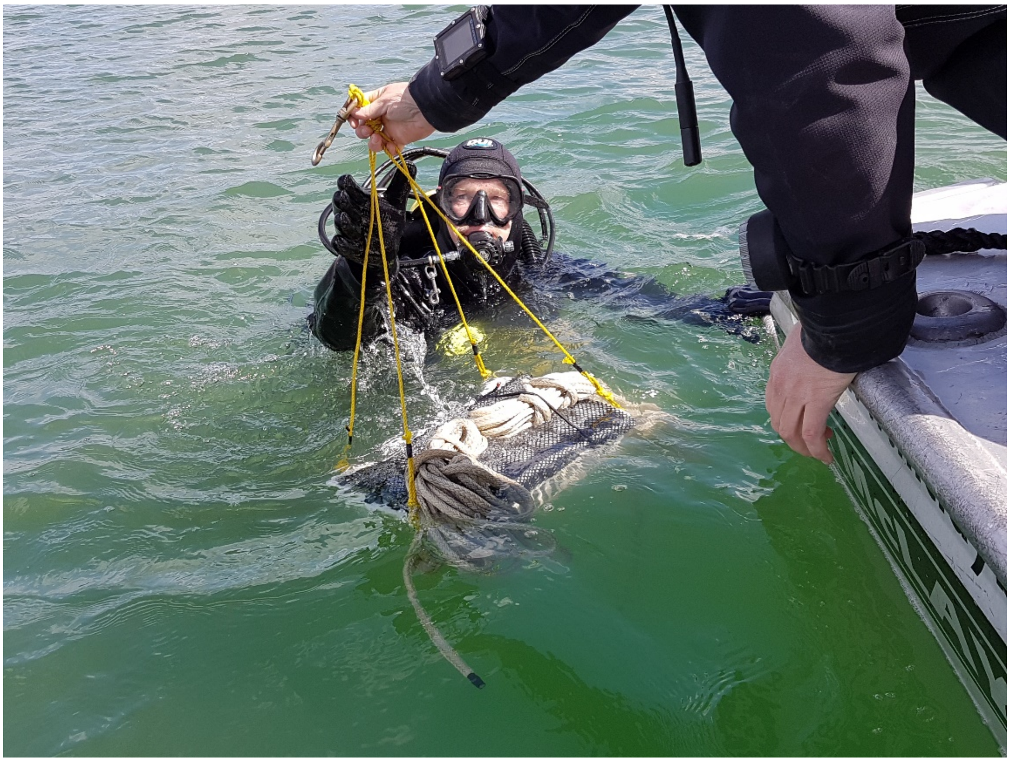


Figure 5.2: Divers handing over a tray of sediment cores collected during the 2016 Wellington Harbour subtidal sediment survey

Figure 5.3: NIWA laboratory technician siphoning off water from a sediment sample core bottle collected during the 2016 Wellington Harbour subtidal sediment survey

Figure 5.4: NIWA laboratory technician sieving benthic sediment core samples to remove the bulk of fine sediment and mud for samples collected during the 2016 Wellington Harbour subtidal sediment survey

5.3 Key findings

Full laboratory results and analytical methods are reported in Olsen et al. (2017) and Olsen (2017). A selection of the metal and organic contaminants found in harbour sediment samples are presented in Table 5.1. The key findings of the 2016 survey are:

- Concentrations of total copper and lead exceeded nationally recognised ‘early warning’ (ie, ARC (2004) ERC[3]-amber or ANZECC[4] (2000) ISQG-Low) sediment quality guidelines at several sites throughout Wellington Harbour;
- Total mercury remains a wide spread legacy metal contaminant, with concentrations exceeding ‘early warning’ sediment quality guidelines at all but one site in the harbour;
- Concentrations of high molecular weight polycyclic aromatic hydrocarbons (HMW PAHs) exceeded ARC ERC-red and ANZECC ISQG-Low sediment quality guidelines at the inner harbour site, and Evans Bay sampling sites (EB2, WH1). Concentrations of HMWPAH exceeded the ARC ERC-amber threshold at the remaining inner harbour sites and along Aotea Quay;
- The insecticide DDT remains a ubiquitous legacy contaminant throughout the harbour with total DDT concentrations being highest at the inner harbour sites where they exceeded the ARC ERC-red threshold;
- Evidence of a contaminant gradient extending offshore is consistent with previous surveys, with some of the highest concentrations of copper, lead, mercury, HMWPAH and DDT found at the inner harbour sites adjacent to Wellington city;
- The concentrations of emerging contaminants in the surficial subtidal sediments from Wellington Harbour were all low compared with concentrations reported at other sites in New Zealand or other countries; and
- A total of 100 invertebrate taxa and 2896 individual organisms were identified in the 2016 survey, with bivalves, echinoderms, polychaete worms, and crustaceans, being the most abundant invertebrates present.

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[3] Auckland Council (ARC) Environmental Response Criteria (ERC) (ARC 2004).

[4] Australia and New Zealand Environment and Conservation Council (ANZECC) Interim Sediment Quality Guidelines (ISQG) (ANZECC 2000).

Table 5.1: Percentage of mud particles (<63 µm, n=5), summary of concentrations (mg/kg dry weight) and variability (percentage co-efficient of variation, c.v. %) of selected total recoverable metals (n=3), and organic contaminants (PAH n=5, DDT n=1 composite) in sediments of 17 sites sampled in Wellington Harbour in 2016 (<500 µm fraction). Cells highlighted in orange exceed the ARC (2004) ERC amber threshold and cells in red exceed the ARC (2004) ERC red threshold and/or ANZECC (2000) ISQG-Low trigger value.

Site	% mud	Copper	Mercury	Lead	Zinc	HMW PAH @ 1% TOC^2	DDT @ 1% TOC^2
EB2	5.8 (9.9)	11.4 (10.6)	0.5 (1.2)	42.7 (8.2)	74.0 (6.2)	2.5 (5.5)	-
WH1	49.3 (8.1)	24.0 (0)	0.9 (4.6)	77.3 (0.7)	118.3 (0.5)	2.2 (6.4)	2.7
WH2	67.7 (7.4)	16.5 (2.1)	0.6 (4.9)	52.7 (2.2)	94.7 (1.6)	1.2 (14.9)	1.8
LB1	19.8 (7.8)	45.3 (2.5)	0.7 (3.7)	75.0 (4.8)	118.0 (2.2)	2.3 (13.9)	11.3
LB2	23.0 (8.4)	36.3 (3.2)	0.6 (8.1)	71.3 (1.6)	117.3 (1)	0.9 (32.8)	--
WH3	45.6 (6.7)	29.0 (3.4)	0.7 (25.8)	66.7 (3.1)	115.7 (2.6)	0.7 (13.9)	7.3
WH4	64.9 (7.4)	18.1 (3.1)	0.4 (4.8)	50.7 (2.3)	97.7 (2.6)	0.8 (30.5)	2.2
AQ1	54.8 (3.8)	19.2 (0.5)	0.5 (7.2)	51.0 (0)	98.7 (1.2)	1.5 (6.2)	5.7
AQ2	24.0 (8.4)	18.1 (2.2)	0.4 (3.7)	62.7 (17.1)	97.3 (3.9)	1.4 (3.6)	4.2
WH5	82.8 (3)	13.6 (0.4)	0.3 (21.9)	37.3 (1.5)	85.3 (0.7)	0.6 (32.3)	-
WH7	82.3 (1.9)	12.4 (2.1)	0.2 (17.2)	32.3 (1.8)	80.0 (2.2)	0.2 (52.8)	1
WH9	92.2 (1.9)	14.4 (1.7)	0.3 (5.8)	40.3 (5.2)	92.0 (1.9)	0.1 (49)	-
WH10	86.4 (2.2)	17.7 (1.7)	0.3 (3.1)	51.3 (2.2)	103.7 (1.1)	0.8 (28.2)	2.1
WH13	86.0 (3.4)	16.3 (3.4)	0.2 (5)	40.7 (6.2)	93.7 (3.1)	0.3 (3.4)	-
WH18	87.7 (0.7)	15.1 (3.5)	0.2 (5.4)	33.3 (1.7)	86.7 (0.7)	0.2 (4.8)	-
WH15	66.9 (3.3	14.4 (0)	0.1 (5.8)	25.7 (2.2)	78.0 (1.3)	0.1 (9.4)	1.8
WH17	49.5 (3)	11.3 (1.5)	0.1 (2.2)	28.0 (0)	76.7 (2.0)	0.4 (4.2)	-

DDT and related compounds have been summarised as 'Total DDT', which is the sum of concentrations of 2,4'-DDE, 2,4'-DDD, 2,4'-DDT, 4,4'-DDE, 4,4'-DDD and 4,4-DDT. Analysed as a single composite at 10 selected sites only.

Total High MW PAH are the sum of the 10 HMWPAH as a subset of the 16 USEPA priority PAHs analysed for this survey. Note, the ANZECC (2000) guidelines only use 6 of the priority PAH as the benchmark for guideline assessment.

6. Wellington Harbour water quality monitoring programme

6.1 Background

The use of real-time telemetered water quality instruments is one tool for monitoring biophysical properties of water. Coupled with discrete water quality sampling, this information can be used to build a baseline picture of water quality, as well as validate existing models for a range of purposes.

A collaborative project was developed with NIWA, to deploy a high-spec real-time coastal monitoring buoy in Wellington Harbour. This represents the first steps by both agencies to address the gaps in understanding about biophysical properties of the harbour, and to measure the influence the Hutt River has on water quality in the marine receiving environment.

Prior to the deployment of the real-time buoy, a smaller 'interim' buoy (logged data only) was deployed on 31 August 2016. The interim mooring was set up as a 'proof of concept' deployment to gauge the feasibility of deploying a larger high-spec real-time monitoring buoy. The telemetered buoy, WRIBO (Wellington Region Integrated Buoy Observations) was deployed on 10 July 2017 with discrete monthly water quality sampling commencing in August 2017. Results will be presented in the 2017/2018 annual coastal data report.

6.2 Deployment and monitoring

The interim buoy (seabed frame and mooring) was deployed approximately 1.5 km east of Matiu/Sommes Island (Figure 6.1, Appendix 1). A schematic of the seabed frame and moored instruments is shown in Figure 6.2, with instrumentation summarised in Table 6.1.

Figure 6.1: Location of the interim coastal water quality monitoring buoy and position of discrete water column sampling in Wellington Harbour; yellow lines indicate navigation channels

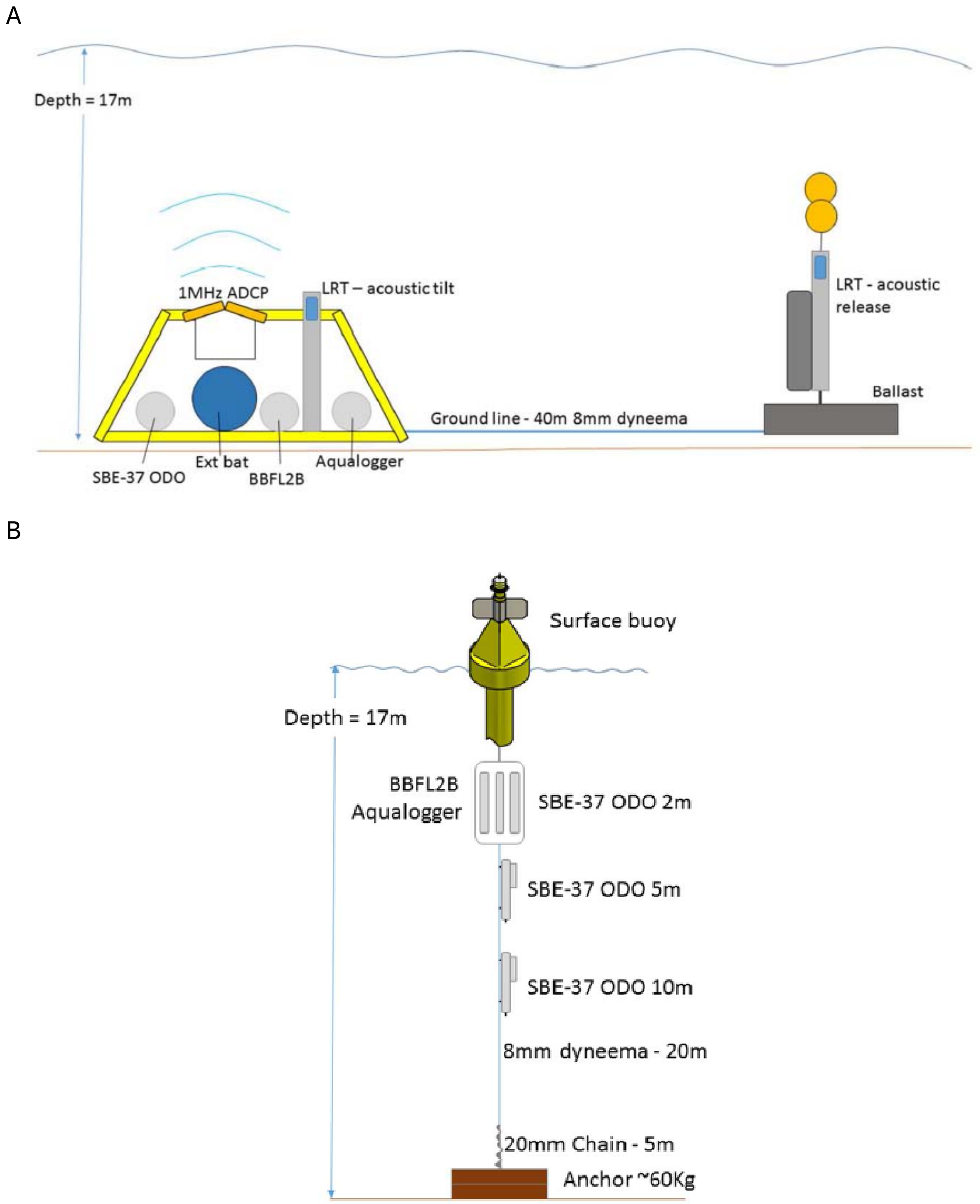

Figure 6.2: Schematic of the interim buoy mooring at the (A) seabed frame and (B) inline mooring (Elliot 2016)

Table 6.1: Summary of instrumentation and parameters for the seabed frame and inline mooring (Elliot 2016)

Instrument	Parameter
Wetlabs BBFl2B (ECOtriplet)	Chlorohyll-*a* CDOM Backscatter at 660 nm
Aquatech Aqualogger	Turbidity
Seabird SBE27 SMPODO (microcat)	Conductivity Temperature Pressure Dissolved oxygen
Nortek 1MHz AWAC ADCP	Currents Waves

A discrete water sampling programme to support the calibration and performance of instruments commenced in September 2016, following the deployment of the interim buoy. The sampling schedule for the interim buoy for 2016/17 was limited to four sample runs only, with monthly runs commencing following the deployment of the telemetered buoy.

Water sampling was done using a hand held van Dorn grab (3L) deployed to selected depths corresponding to the depth of moored instrument packages. Water samples were decanted into standard laboratory supplied bottles. As far as possible, all sample handling was in accordance with protocols set out in Part 4 of the draft National Environmental Monitoring Standards for Water Quality (NEMS 2017). The suite of physico-chemical variables and analytical methods are listed in Appendix 2.

6.3 Key findings

NIWA summarised the performance of the interim buoy in a preliminary report covering the deployment period from 31 August 2016 – 8 November 2016; full details are in Elliot (2016). This found that after 69 days in the water there was minimal biofouling of the sensors, and there was full data retrieval of all instruments except for the upper ECOtriplet which halted sampling 28 days earlier on 11 October 2016 (Figure 6.4).

Preliminary analysis indicated that significant weather events and the influence of the Hutt River are being picked up by the instrument arrays. For example, very low surface salinity was evident during September 2016 which lasted for six to seven days (Figure 6.3), and peaks in coloured dissolved organic matter (CDOM) at the surface were coincident with that freshwater event. Around 23 September 2016 high chlorophyll-*a* values were matched by supersaturated oxygen concentrations indicating a short-lived algal bloom in the surface waters. Lowest near-bed dissolved oxygen concentrations were 70% and averaged 85%.

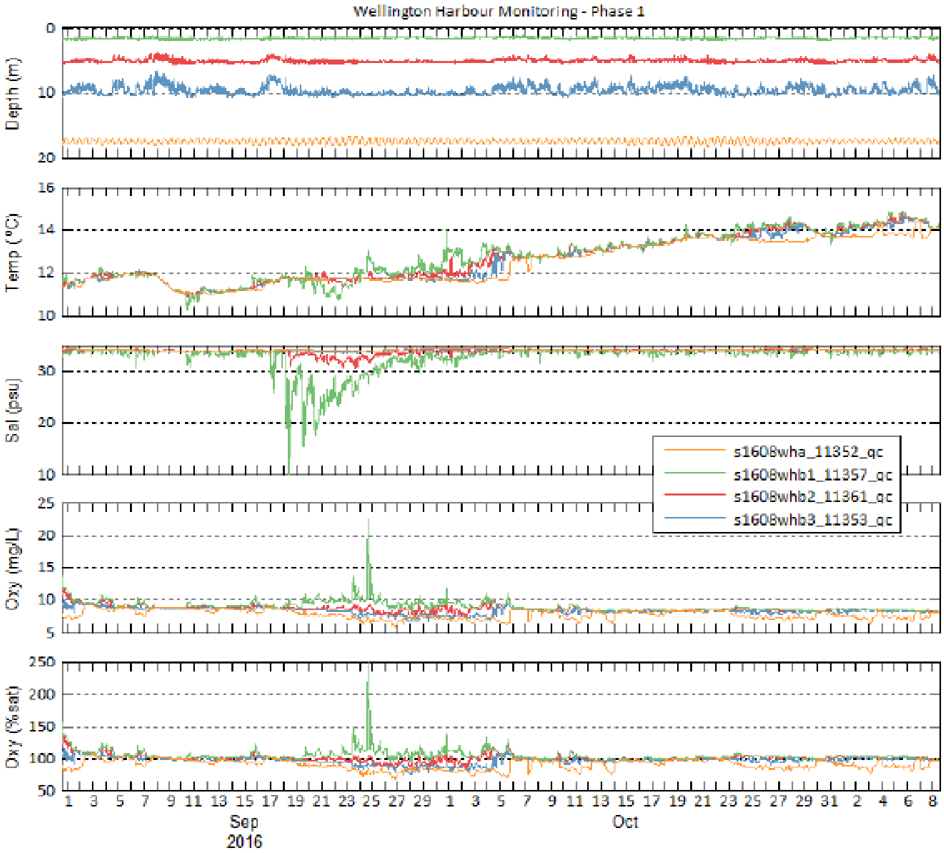

Figure 6.3: Data set logs from the Seabird SBE-37 sensors deployed on the interim buoy in Wellington Harbour 2016 (Elliot 2016)

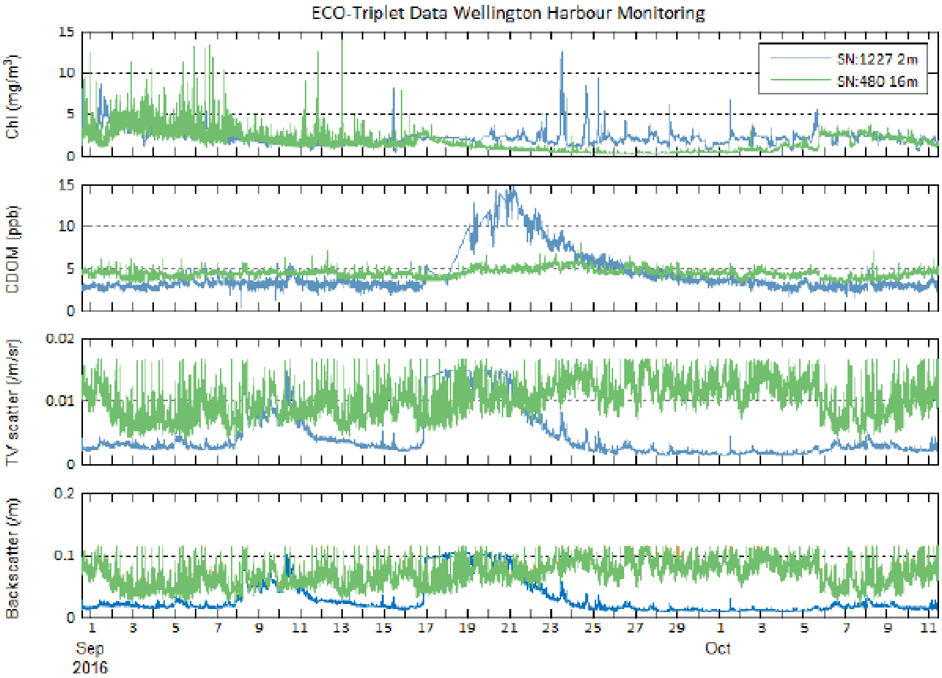

Figure 6.4: Data set logs from the ECO-triplet sensors deployed on the interim buoy in Wellington Harbour 2016. The blue line represents the upper unit SN1227 at 2m depth, the green line represents the lower unit SN 480 at 18 m depth (Elliot 2016)

A summary of the discrete water quality sampling is listed in Table 6.2.

Table 6.2: Range of discrete water quality sampling undertaken at depth at the interim buoy between September 2016 and February 2017 (4 sample occasions)

Parameter	Unit	Depth			
		1.5 m	5m	10m	18m
Chlorophyll-*a*	g/m^3	< 0.003 - 0.003	< 0.003	< 0.003 - 0.003	< 0.003
Turbidity	NTU	0.82 - 7.6	0.86 - 2.8	0.86 - 2	1.49 - 4.3
Salinity		21-34	32 - 34	33 - 34	34
Nitrate-N	g/m^3	< 0.002 - 0.065	0.003 - 0.011	< 0.002 - 0.01	< 0.002 - 0.021
SSC	g/m^3	< 11 - 93	44 - 127	< 11 - 95	12 - 154
EC	mS/m	3440 - 5230	4980 - 5240	5160 - 5250	5200 - 5260
VSS	g/m^3	< 11	< 11 - 17	< 10 - 22	< 11 - 47
Total Nitrogen (trial)	g/m^3	0.125 - 0.28	0.149 - 0.175	0.126 - 0.174	0.165 - 0.188
Total Ammoniacal-N	g/m^3	0.006 - 0.013	0.01 - 0.017	0.01 - 0.02	0.012 - 0.043
Nitrite-N	g/m^3	< 0.0010 - 0.0011	< 0.0010	< 0.0010	< 0.0010 - 0.0017
Nitrate-N + Nitrite-N	g/m^3	< 0.002 - 0.066	< 0.002 - 0.011	< 0.002 - 0.01	< 0.002 - 0.022
DRP	g/m^3	0.004 - 0.008	0.005 - 0.008	0.007 - 0.012	0.011 - 0.017
TKN	g/m^3	< 0.2	< 0.2 - 0.2	< 0.2	< 0.2 - 0.2
TP	g/m^3	0.008 - 0.024	0.011 - 0.019	0.013 - 0.019	0.018 - 0.025
Absorbance at 340 nm	AU cm-1	< 0.002 - 0.019	< 0.002 - 0.005	< 0.002 - 0.006	< 0.002 - 0.004
Absorbance at 440 nm	AU cm-1	< 0.002 - 0.003	< 0.002	< 0.002 - 0.002	< 0.002
Absorbance at 740 nm	AU cm-1	< 0.002	< 0.002	< 0.002	< 0.002

On the basis of 4 sample rounds it is difficult to draw clear links between the influence of the Hutt River, weather events and output of the logged data. This data, however, indicates broadly the range of values to expect over the course of sampling. A fuller understanding of statistical ranges will be built over the course of the 2017/18 sampling season. Following the first season of the deployment of WRIBO (around July 2018) a full interpretation of telemetered data and discrete data will be undertaken.

7. Porirua Harbour microbial forecast model

7.1 Background

In 2015 a water quality forecast with a focus on enterococci contamination was developed for Porirua Harbour. The forecast follows successive years of poor recreational water quality in the harbour and builds on previous investigations of hydrodynamics and faecal contamination in the harbour. The development of the three day forecast is intended to address the limitations of the traditional approach to monitoring recreational water quality (for full discussion refer to Milne et al. 2017). A screen display of the seven sites for which the forecast is available is shown in Figure 7.1.

Figure 7.1: Representative map display of seven water quality forecast sites in Porirua Harbour

The forecast has been running since January 2016, and the full details of the assumptions, updates and performance of the forecast in the second year are available in the technical annual quality status report (Tuckey 2017). Briefly three different model set-ups, each with different sources of wind data were compared with observed (routine and event-based) data to assess their performance:

- Set Up 1 – Global Forecast System (GFS) wind data
- Set Up 2 – Set Up 1 with updates using Baring Head wind data
- Set Up 3 – Set Up 2 with scaled GFS wind data

7.2 Field sampling and model validation

Data for model validation was sourced from the routine recreational water quality surveillance sampling programme conducted between 1 December 2016 and 31 March 2017. This data was supplemented by targeted event-based sampling, which was carried out at 10 marine and freshwater sites around the harbour.

For routine sampling, the sample procedures were undertaken according to standard protocols outlined in MfE/MoH (2003) guidelines, and Brasell and Morar (2017). For event-based sampling, the 10 marine and freshwater sites were sampled following overnight rain, and for the following two days, where possible. Locations of marine and freshwater sites for event based targeted sampling are listed in Appendix 1. Laboratory methods for freshwater and marine samples are listed in Appendix 2.

The performance of the three model set ups is based on the comparison of the observed data against the predictions. For simplicity and comparison against scenarios, only the frequency of exceedance of the red/action trigger of 280 cfu/100 mL (MfE/MoH 2003) was compared as follows:

		Predicted	
		No alert	Alert
Observed	No alert	Match	False negative
	Alert	False Positive	Match

The aim is to have 100% agreement between the two green squares (ie, matching observed versus predicted). A false positive is undesirable, and indicates an observed alert (>280 cfu/100 mL) has not been predicted by the forecast. Some false negatives (alert is predicted where none was observed) can be considered acceptable (i.e. overly precautionary).

A summary of the results of the annual quality status report are presented in Tables 7.1 and 7.2

Table 7.1: Model performance compared with routine observations. Comparison (as % of total observations) of alert mode (>280 cfu/100mL) for observed and model forecast concentrations of enterococci at routine recreational monitoring sites in Porirua Harbour 2016/17

			Predicted					
			Set Up 1 (GFS wind Model)		Set Up 2 (Baring Head Model)		Set Up 3 (Scaled GFS Wind Model)	
			No Alert	Alert	No Alert	Alert	No Alert	Alert
Observed	Rowing Club	No Alert	79	0	64	15	61	18
		Alert	15	6	18	3	12	9
	Waka Ama	No Alert	64	7	50	21	36	36
		Alert	21	7	0	29	7	21
	Sth Beach	No Alert	88	0	82	6	82	6
		Alert	12	0	9	3	9	3
	Water Ski	No Alert	100	0	95	5	95	5
		Alert	0	0	0	0	0	0

For the event-based data, the current model set up (Set Up 1) significantly under predicted the enterococci contamination risks that occurred within the Onepoto Arm (Rowing Club, Waka Ama) as well as at South Beach. The performance improved under the modified model sets ups (Set Up 2, 3).

Table 7.2: Model performance compared with rain event collected observations. Comparison (as % of total observations) of alert mode (>280 cfu/100mL) for observed and model forecast concentrations of enterococci at selected monitoring sites in Porirua Harbour 2016/17

			Predicted					
			Current Model		Baring Head Model		GFS Wind Model	
			No Alert	Alert	No Alert	Alert	No Alert	Alert
Observed	Rowing Club	No Alert	10	0	10	0	10	0
		Alert	80	10	20	70	30	60
	Waka Ama	No Alert	20	0	10	10	10	10
		Alert	60	20	20	60	40	40
	Sth Beach	No Alert	75	0	62.5	12.5	75	0
		Alert	25	0	25	0	25	0
	Water Ski	No Alert	70	0	70	0	70	0
		Alert	30	0	30	0	30	0

The forecast will continue to run for the 2017/18 season following the recommendations of Tuckey (2017). A closed public trial of the forecast will be conducted with targeted groups in order to gauge how well the web-based information can be accessed, used, and communicated.

Acknowledgements

Dr Barry Robertson, Leigh Stevens and Ben Robertson of Wriggle Coastal Management Ltd undertake the estuarine, rocky reef and habitat mapping fieldwork and reporting.

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Ben Tuckey (DHI) is undertaking the modelling for development of the Porirua Harbour microbial water quality forecast tool.

Dr Joanne O’Callaghan, Mike Brewer and Fiona Elliot undertook the deployment of the Wellington Harbour interim buoy, as well as summary of the sensor performance of the buoy.

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Appendix 1: Monitoring sites

Table A1.1: Waikanae Estuary intertidal sampling locations

Sampling site	NZTM co-ordinates	
	Easting	Northing
Waikanae A	1769248 (Plot 01) 1769261 (Plot 10)	5473364 (Plot 01) 5473355 (Plot 10)

Table A1.2: Hutt Estuary sampling locations

Sampling site	NZTM co-ordinates	
	Easting	Northing
Hutt A (South)	1759174 (Peg 1) 1759174 (Peg 2)	5433638 (Peg 1) 5433618 (Peg 2)
Hutt B (North)	1759369 (Peg 1) 1759369 (Peg 2)	5434135 (Peg 1) 5434116 (Peg 2)

Table A1.3: Whareama Estuary intertidal sampling locations

Sampling site	NZTM co-ordinates	
	Easting	Northing
Whareama A (North)	1860703 (Plot 01) 1860684 (Plot 10)	5455343 (Plot 01) 5455338 (Plot 10)
Whareama B (South)	1860084 (Plot 01) 1860067 (Plot 10)	5455318 (Plot 01) 5455294 (Plot 10)

Table A1.4: Porirua Harbour sediment plate locations

Sampling site	Location	NZTM co-ordinates	
		Easting	Northing
1	Porirua A Railway	1756505	5447788
2	Aotea	1754771	5445520
3	Por B Polytech	1754561	5445430
S6	Titahi (subtidal)	1755704	5446797
S7	Onepoto (subtidal)	1754811	5446762
S8	Papkowhai (subtidal)	1754580	5445864
S9	Te Onepoto (subtidal)	1755551	5447105
6	Boatsheds	1757267	5448785
7	Kakaho	1758885	5449747
8	Horokiri	1760040	5448827
9	Paua B	1760333	5448378
10	Duck Creek	1759829	5447944
11	Browns Bay	1757971	5447956
S1	Kakaho (subtidal)	1758810	5449470
S2	Horokiri (subtidal)	1759325	5448867
S3	Duck Creek (subtidal)	1759529	5447896
S4	Bradeys Bay (subtidal)	1758763	5447865
S5	Browns Bay (subtidal)	1758040	5448015

Table A1.5: Porirua Harbour subtidal sediment quality monitoring sites

Sampling site	Location	NZTM co-ordinates	
		Easting	Northing
PAH1	Pauatahanui Arm off Browns Bay	1758157	5448052
PAH1B		1758136	5448074
PAH2	Pauatahanui Arm off Duck Creek	1759727	5448139
PAH2B		1759759	5448116
PAH3	Pauatahanui Arm off Camborne	1758151	5449206
PAH3B		1758154	5449222
POR1	Onepoto Arm South	1754864	5445871
POR1B		1754834	5445890
POR2	Onepoto Arm North	1755179	5446506
POR2B		1755158	5446538

B = Benthic fauna collection area

Table A1.6: Flat Point rocky reef quadrat locations

Quadrat	Location	NZTM co-ordinates	
		Easting	Northing
1	High eulittoral	1847960	5429657
2	High eulittoral	1847960	5429657
3	High eulittoral	1847958	5429655
4	High eulittoral	1847951	5429653
5	High eulittoral	1847950	5429651
6	High eulittoral	1847949	5429648
1	Mid eulittoral	1847960	5429657
2	Mid eulittoral	1847558	5429655
3	Mid eulittoral	1847957	5429654
4	Mid eulittoral	1847951	5429655
5	Mid eulittoral	1847950	5429651
6	Mid eulittoral	1847948	5429649
1	Low eulittoral	1847948	5429663
2	Low eulittoral	1847949	5429661
3	Low eulittoral	1847946	5429662
4	Low eulittoral	1847947	5429659
5	Low eulittoral	1847948	5429657
6	Low eulittoral	1847946	5429657

Table A1.7: Wellington Harbour subtidal sediment quality monitoring sites

Site	Location/Sample collection	NZTM co-ordinates	
		Easting	Northing
WH1	Southern Evans Bay	1751530	5425348
WH1B	R, EC	1751492	5425333
WH2	Northern Evans Bay	1751710	5427288
WH2B	R, EC	1751744	5427271
WH3	Lambton Basin entrance	1750056	5428340
WH3B	R, EC, BR	1750055	5428303
WH4	~ 0.7 km NW of Point Jerningham	1750763	5428789
WH4B	R, EC	1750775	5428760
WH5	~ 1.2 km NNE of Point Jerningham	1751748	5429138
WH5B	R	1751743	5429104
WH7	≈ 1.5 km N of Point Halswell	1753581	5429932
WH7B	R, EC	1753604	5429907
WH9	~ 1.5 km SSE of Ngauranga Stream mouth	1751921	5430708
WH9B		1751975	5430747
WH10	~ 0.5 km SSE of Ngauranga Stream mouth	1752012	5431724
WH10B	R, EC	1752008	5431740
WH13	~ 1.25 km S of Petone Wharf	1756023	5433121
WH13B	R	1756061	5433126
WH15	~ 1.1 km SW of Seaview (Hutt River mouth)	1758160	5431778
WH15B	R, EC	1758176	5431750
WH17	~ 1.6 km NNW of Makaro/Ward Island	1756770	5428847
WH17B	R, BR	1756793	5428858
WH18	~1.75 km WSW of Seaview (Hutt River mouth)	1757450	5432426
WH18B	R	1757460	5432435
EB2	Evans Bay , Western side	1750896	5425520
EB2B	R	1751283	5425517
LB1	Lambton Harbour ~ 250 m from shore (FK Park)	1749263	5427887
LB1B	R, EC	1749262	5427872
LB2	Lambton Harbour ~ 500 m from shore (FK Park)	1749576	5427939
LB2B	R	1749541	5427940
AQ1	~ 0.5 km ENE of Aotea Quay east	1750317	5429346
AQ1B	R, EC	1750331	5429374
AQ2	~ 0.5 km ENE of Aotea Quay west	1750125	5430214
AQ2B	R, EC	1750133	5430254

R: routine sediment chemistry, B: benthic fauna collection area, EC: emerging contaminant sediment collection, BR: bulk reference sediment sample collection

Table A1.8: Wellington Harbour interim and real-time buoy mooring sites

Site	NZTM	
	Easting	Northing
Interim buoy SW of the Hutt River mouth (18 m depth)	1758074	5431236
WRIBO, SE of Matiu-Sommes (20 m)	1757265	5429427.95

Table A1.9: Porirua Harbour microbial water quality forecast sites

Site	NZTM	
	Easting	Northing
South Beach at Plimmerton*	1756810	5449874
Pauatahanui Inlet at Water Ski Club*	1758074	5449593
Pauatahanui Inlet at Browns Bay	1757989	5447780
Pauatahanui Inlet at Ivey Bay	1757356	5447977
Pauatahanui Inlet at Shellfish Collection Site	1756697	5447910
Porirua Harbour at Rowing Club*	1754891	5446947
Porirua Harbour at Waka Ama (Wi Neera Drive)*	1754485	5445706

* Sites monitored under the Recreational Water Quality Monitoring Programme

Table A1.10: Porirua Harbour microbial water quality targeted event sampling sites

Site	Type	NZTM	
		Eastings	Northing
Porirua at Town Centre	Fresh	1754674	5443939
Kenepuru at Mepham Place	Fresh	1754924	5444467
Porirua Harbour at Waka Ama (Wi Neera Drive)	Marine	1754492	5445712
Takapuwahia Stream	Fresh	1754225	5445803
Onepoto Stream	Fresh	1754879	5447115
Porirua Harbour at Rowing Club	Marine	1754936	5446933
Browns creek	Fresh	1757999	5447731
Porirua Harbour at Browns Bay	Marine	1757989	5447780
Taupo Stream	Fresh	1756919	5450139
Porirua Harbour at South Beach	Marine	1756810	5449874

Appendix 2: Monitoring variables and methods

Microbiological water quality for Porirua Harbour microbial water quality field sampling.

Field sampling was undertaken for the purpose of providing samples to validate Porirua Harbour microbial water quality model assumptions. All sampling was undertaken in accordance with the 2003[5] Ministry for the Environment (MfE) and the Ministry of Health (MoH) microbiological water quality guidelines for marine and freshwater recreational areas. For routine water samples collected from coastal waters, these were generally sampled weekly during the summer bathing season (1 December to 31 March inclusive) and fortnightly at selected sites. The recommended indicator for coastal water is enterococci (with faecal coliforms the preferred indicator for shellfish gathering waters). Refer to Brassel et al. (2017) for full details of GWRC's microbiological water quality monitoring methods, site details, and results of the routine bathing water monitoring.

For event based sampling (freshwater and marine) at selected sites outside the routine weekly bathing sampling, all sampling protocols followed the MfE/MoH (2003) protocols. For freshwater samples, laboratory methods 9222D (2012) and 9222G (2012) were used for the analysis of faecal coliforms and E. coli, respectively. Marine water sample analysis for enterococci was according to standard marine methods also used under the bathing programme (USEPA 1600 (2009), see Brasell and Morar 2017).

Estuary condition

The broad and fine scale surveys undertaken in the region's estuaries to date have been based on the National Estuary Monitoring Protocol (Robertson et al. 2002) and recent extensions to these developed by Wriggle Coastal Management (eg, Robertson & Stevens 2008, 2015b; Stevens & Robertson 2008, 2015e). The fine scale surveys target the dominant intertidal habitat and three of the five core indicators of estuarine ecosystem health: sedimentation, eutrophication (nutrient enrichment) and toxic contamination (Table A2.1). The remaining two indicators are habitat loss and disease risk, which are assessed through periodic broad scale surveys and GWRC's recreational water quality programme, respectively. As outlined below, broad scale surveys also provide information relevant to assessing sedimentation and nutrient enrichment.

Fine scale monitoring generally takes place at one or two locations (sites) within an estuary that are selected to be representative of the dominant (generally intertidal) habitat present. Each site is assessed for a suite of environmental characteristics that are indicative of estuary condition and will provide a means for detecting future change (Table A2.1) (Robertson et al. 2002; Robertson & Stevens 2015b).

Broad scale monitoring involves defining the dominant habitats and features of an area and developing baseline maps with a combination of photography, ground-truthing and digital mapping using GIS technology. The area boundaries are first defined at a scale appropriate for baseline monitoring before vegetation (eg, saltmarsh, seagrass, macroalgae) and substrate types (eg, gravel, coarse sand, mud) are mapped (Robertson et al. 2002; Stevens & Robertson 2015e).

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[5] The guidelines were published in June 2002 and updated in June 2003.

In 2014/15, the annual broad scale assessment of macroalgal density was updated to an Ecological Quality Rating (EQR) for macroalgae. The EQR approach replaces the previous Low Density Macroalgal Coefficient developed by Wriggle because it incorporates a more comprehensive assessment of key parameters, particularly macroalgal biomass and entrainment. It is intended to provide an early warning of increasing or widespread low density growth, as well as warning of excessive dense growth within those parts of an estuary when macroalgae can potentially establish (Stevens & Robertson 2015e).

Along with annual estuary-scale mapping of macroalgae cover and condition to complement the fine scale assessments of estuary condition, sedimentation monitoring plates are used to measure sedimentation rates at specific locations within each estuary. Such plates have been deployed at several locations across five of the region's estuaries to date.

Table A2.1: Key broad scale (BS) and fine scale (FS) indicators used to assess estuarine condition in the Wellington Region. Many of the indicators in the table are also applicable to assessing beach condition

(Source: Adapted from Robertson & Stevens 2015b)

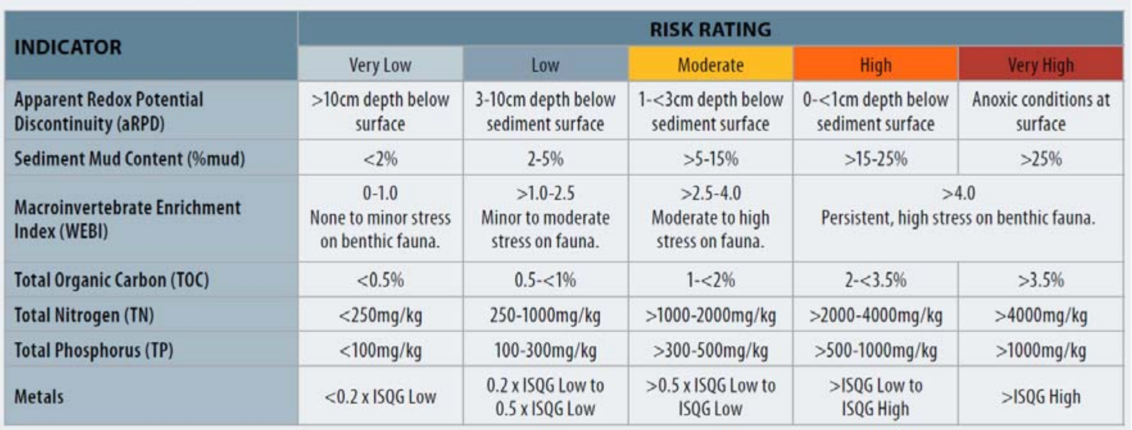
Issue	Indicator	Indicator type	Rationale
Sedimentation	Soft mud area	BS	Estuaries are a natural sink for catchment-derived sediment but if sediment inputs are excessive, estuaries infill quickly with muds, reducing biodiversity and human values and uses. In particular: - muddy sediments have a higher tendency to become anoxic and anoxic sediments contain toxic sulphides and very little aquatic life. - elevated sedimentation rates are likely to lead to major and detrimental ecological changes within estuary areas that could be very difficult to reverse.
	Sediment composition (% mud)	FS	
	Sedimentation rate	FS	
	Diversity of benthic fauna	FS	Soft sediment macrofauna can be used to represent benthic community health in relation to the extent of mud tolerant organisms compared with those that prefer sands.
Eutrophication (nutrient enrichment)	Ecological Quality Rating (EQR) for Macroalgae	BS	Mass blooms of green and red macroalgae, mainly of the genera *Enteromorpha, Cladophora, Ulva,* and *Gracilaria,* can present a significant nuisance problem, especially when loose mats accumulate and decompose. Algal blooms also have major ecological impacts on water and sediment quality, such as reduced clarity, physical smothering and lack of oxygen, and can displace estuarine animals.
	Organic content	FS	High sediment organic content can result in anoxic sediments and bottom water, release of excessive nutrients, and adverse impacts on biota.
	Sediment nutrient concentrations: • Nitrogen • Phosphorus	FS	In shallow estuaries the sediment compartment is often the largest nutrient pool in the system, and nutrient exchange between the water column and sediments can play a large role in determining trophic status and stimulating the production and abundance of fast-growing algae, such as phytoplankton and short-lived macroalgae (eg, sea lettuce).
	Sediment oxygenation (RPD depth)	FS	Surface sediments need to be well oxygenated to support healthy invertebrate communities (anoxic sediments contain toxic sulphides and very little aquatic life).
	Diversity of benthic fauna	FS	Soft sediment macrofauna can be used to represent benthic community health and classify estuary condition.

Issue	Indicator	Indicator type	Rationale
Contamination	Sediment contamination – eg, concentrations of: • heavy metals • PAHs • pesticides	FS	Many chemicals discharged to estuaries via urban and rural runoff can be toxic, even at very low concentrations. These chemicals can accumulate in sediments and bioaccumulate in fish and shellfish, causing health risks to people and marine life.
	Diversity of benthic fauna	FS	Soft sediment macrofauna can be used to represent benthic community health and classify estuary condition.
Habitat loss	Saltmarsh area	BS	Estuaries function best with a large area of rooted vegetation (ie, saltmarsh and seagrass), as well as a healthy vegetated terrestrial margin. Loss of this habitat reduces ecological, fishery and aesthetic values, and adversely impacts on an estuary's role in flood and erosion protection, contaminant mitigation, sediment stabilisation and nutrient cycling.
	Seagrass area	BS	
	Vegetated terrestrial buffer	BS	

A series of interim fine and broad scale estuary 'condition ratings' (reproduced as Tables A2.2–A2.4 from reports prepared for GWRC by Wriggle Coastal Management) are proposed for Porirua Harbour, and Waikanae, Hutt and Whareama estuaries. These ratings are based on data collected within the Wellington Region over the last 8 years and the observed correlation between each indicator and the presence of degraded estuary conditions from a range of tidal lagoon estuaries throughout New Zealand. They are designed to be used in combination with each other (usually involving expert input) when evaluating overall estuary condition and deciding on appropriate management. The ratings will continue to be refined and updated as data become available.

Table A2.2: Summary of fine scale estuary condition ratings used in the Wellington Region

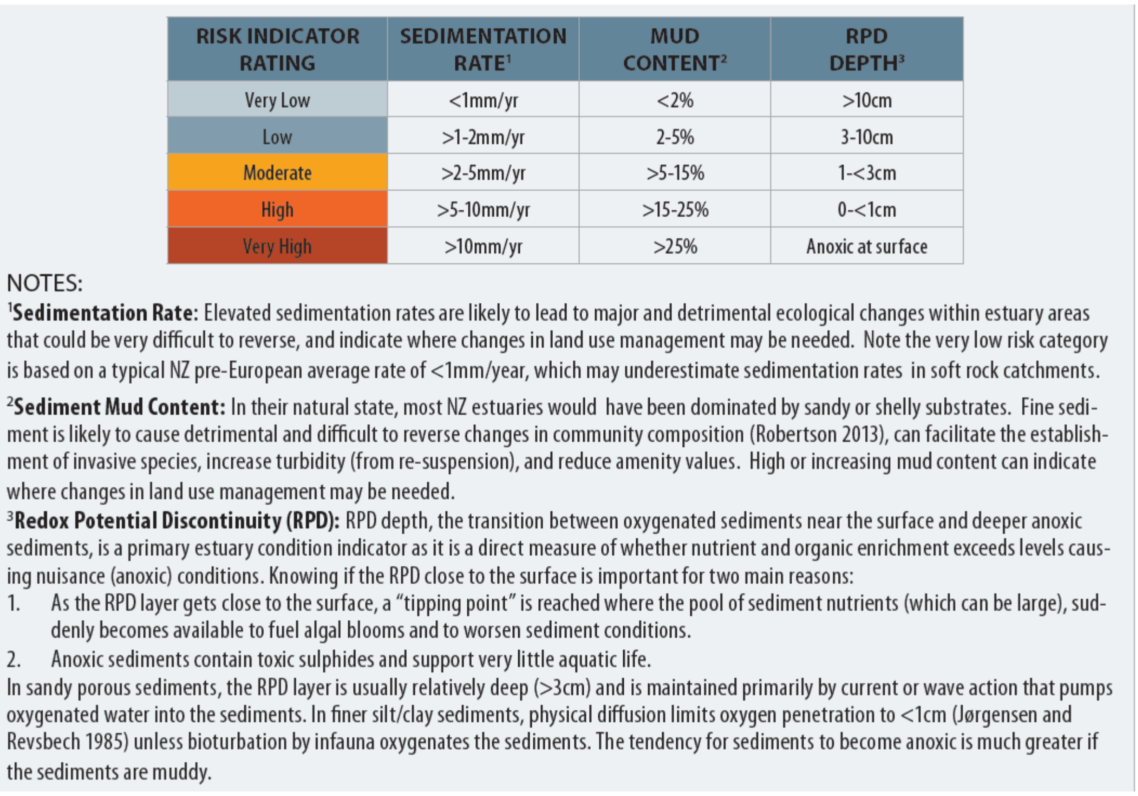
(Source: Robertson & Stevens 2015b)



INDICATOR	RISK RATING				
	Very Low	Low	Moderate	High	Very High
Apparent Redox Potential Discontinuity (aRPD)	>10cm depth below surface	3-10cm depth below sediment surface	1-<3cm depth below sediment surface	0-<1cm depth below sediment surface	Anoxic conditions at surface
Sediment Mud Content (%mud)	<2%	2-5%	>5-15%	>15-25%	>25%
Macroinvertebrate Enrichment Index (WEBI)	0-1.0 None to minor stress on benthic fauna.	>1.0-2.5 Minor to moderate stress on fauna.	>2.5-4.0 Moderate to high stress on fauna.	>4.0 Persistent, high stress on benthic fauna.	
Total Organic Carbon (TOC)	<0.5%	0.5-<1%	1-<2%	2-<3.5%	>3.5%
Total Nitrogen (TN)	<250mg/kg	250-1000mg/kg	>1000-2000mg/kg	>2000-4000mg/kg	>4000mg/kg
Total Phosphorus (TP)	<100mg/kg	100-300mg/kg	>300-500mg/kg	>500-1000mg/kg	>1000mg/kg
Metals	<0.2 x ISQG Low	0.2 x ISQG Low to 0.5 x ISQG Low	>0.5 x ISQG Low to ISQG Low	>ISQG Low to ISQG High	>ISQG High

Table A2.3: Risk indicator ratings for sedimentation rate in estuaries in the Wellington Region

(Source: Stevens & Robertson 2015d)



RISK INDICATOR RATING	SEDIMENTATION RATE[1]	MUD CONTENT[2]	RPD DEPTH[3]
Very Low	<1mm/yr	<2%	>10cm
Low	>1-2mm/yr	2-5%	3-10cm
Moderate	>2-5mm/yr	>5-15%	1-<3cm
High	>5-10mm/yr	>15-25%	0-<1cm
Very High	>10mm/yr	>25%	Anoxic at surface

NOTES:

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

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

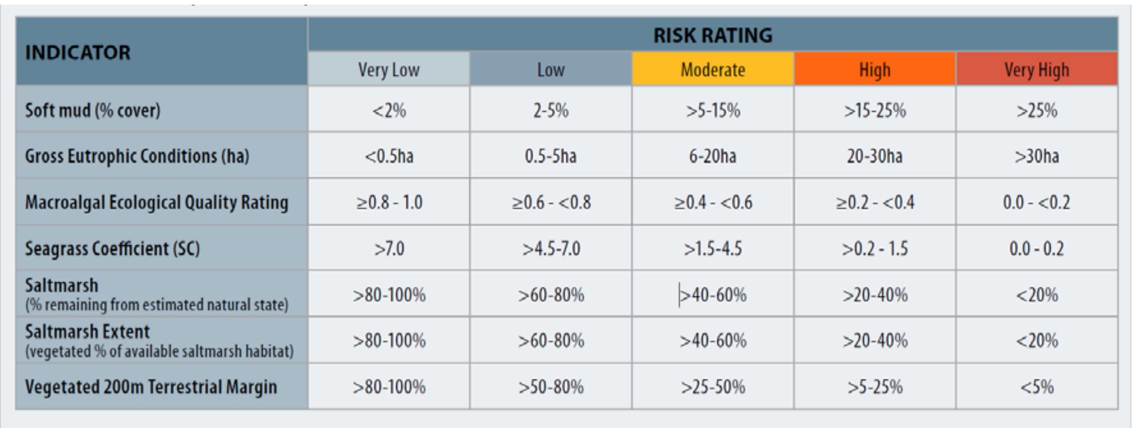
[3] **Redox Potential Discontinuity (RPD):** RPD depth, the transition between oxygenated sediments near the surface and deeper anoxic sediments, is a primary estuary condition indicator as it is a direct measure of whether nutrient and organic enrichment exceeds levels causing nuisance (anoxic) conditions.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

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

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

Table A2.4: Summary of broad scale estuary condition ratings used in the Wellington Region

(Source: Stevens & Robertson 2015e)



INDICATOR	RISK RATING				
	Very Low	Low	Moderate	High	Very High
Soft mud (% cover)	<2%	2-5%	>5-15%	>15-25%	>25%
Gross Eutrophic Conditions (ha)	<0.5ha	0.5-5ha	6-20ha	20-30ha	>30ha
Macroalgal Ecological Quality Rating	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
Seagrass Coefficient (SC)	>7.0	>4.5-7.0	>1.5-4.5	>0.2 - 1.5	0.0 - 0.2
Saltmarsh (% remaining from estimated natural state)	>80-100%	>60-80%	>40-60%	>20-40%	<20%
Saltmarsh Extent (vegetated % of available saltmarsh habitat)	>80-100%	>60-80%	>40-60%	>20-40%	<20%
Vegetated 200m Terrestrial Margin	>80-100%	>50-80%	>25-50%	>5-25%	<5%

Rocky shore condition

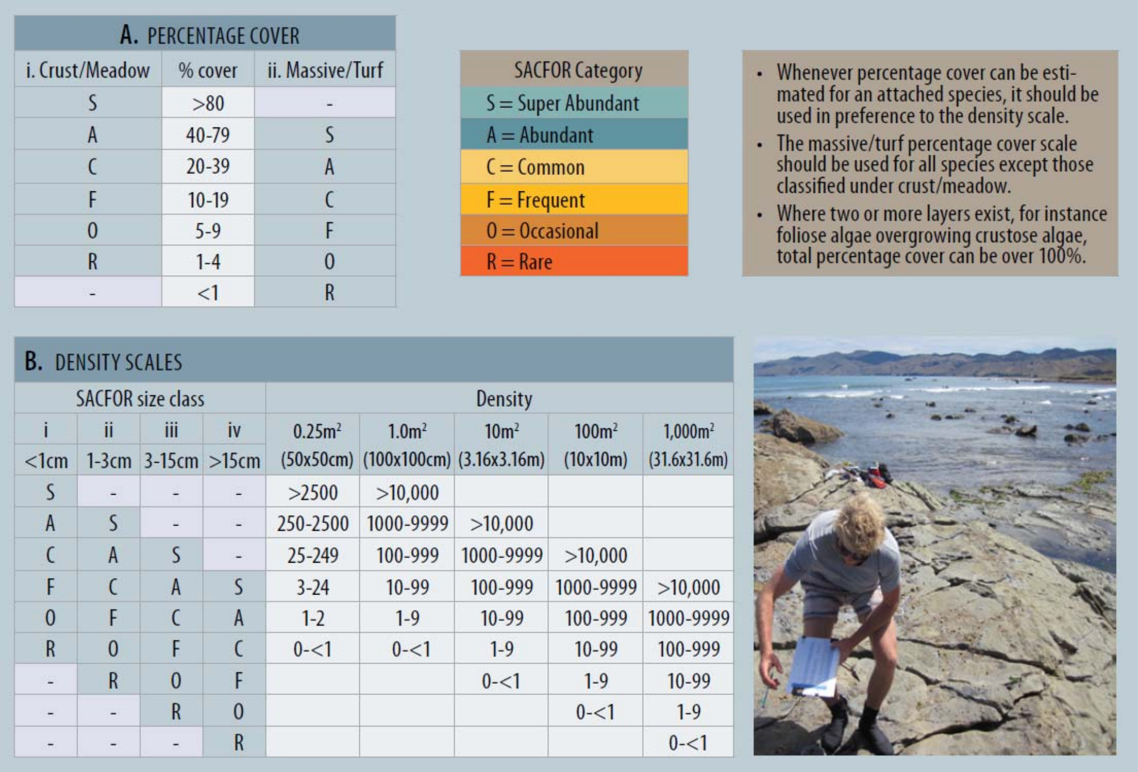
There are five main environmental issues that affect NZ rocky shores; climate change, sea level rise, over-collection of living resources, introduction of invasive species, and pollution. All of these issues can lead to a decline in the dominant algal canopy species, on which many other species depend for food or habitat.

There is currently no nationally recognised protocol for ecological monitoring of rocky shores. Therefore, to provide baseline information on rocky shore ecology, the assessment methodology is based on that used in the UK MarClim Marine Biodiversity and Climate Change project (MNCR 1990). This consists of two parts: a semiquantitative assessment to develop a checklist of species present and record their relative abundance across a representative sampling area, and recording the abundance and diversity of plants and animals in 0.25 m^3 fixed quadrats positioned in the spatially largest strata at the site, and stratified within three eulittoral tide levels (high, mid and low).

The abundance of each species was rated using SACFOR categories described in Table A2.5. The SACFOR assessment preferentially uses percentage cover of two growth types of attached organisms, Crust/Meadow or Massive/Turf. All other individual organisms >5mm in size were counted, with the largest individual organism size used to determine the relevant SACFOR size class rating for each species as detailed in Table A2.5B. See Robertson & Stevens (2016a) for further information.

Table A2.5: SACFOR Percentage cover and density scales (after Marine Nature Conservation Review – MNCR)

(Source: Robertson & Stevens 2016a)



A. PERCENTAGE COVER

i. Crust/Meadow	% cover	ii. Massive/Turf
S	>80	-
A	40-79	S
C	20-39	A
F	10-19	C
O	5-9	F
R	1-4	O
-	<1	R

SACFOR Category
S = Super Abundant
A = Abundant
C = Common
F = Frequent
O = Occasional
R = Rare

- Whenever percentage cover can be estimated for an attached species, it should be used in preference to the density scale.
- The massive/turf percentage cover scale should be used for all species except those classified under crust/meadow.
- Where two or more layers exist, for instance foliose algae overgrowing crustose algae, total percentage cover can be over 100%.

B. DENSITY SCALES

SACFOR size class				Density				
i	ii	iii	iv	$0.25m^2$	$1.0m^2$	$10m^2$	$100m^2$	$1,000m^2$
<1cm	1-3cm	3-15cm	>15cm	(50x50cm)	(100x100cm)	(3.16x3.16m)	(10x10m)	(31.6x31.6m)
S	-	-	-	>2500	>10,000			
A	S	-	-	250-2500	1000-9999	>10,000		
C	A	S	-	25-249	100-999	1000-9999	>10,000	
F	C	A	S	3-24	10-99	100-999	1000-9999	>10,000
O	F	C	A	1-2	1-9	10-99	100-999	1000-9999
R	O	F	C	0-<1	0-<1	1-9	10-99	100-999
-	R	O	F			0-<1	1-9	10-99
-	-	R	O				0-<1	1-9
-	-	-	R					0-<1

Table A2.6: Sediment quality analytical methods for estuarine, beach and subtidal sediments

Determinant	Method	Detection limit
Sediment grain size (2 mm, 63 µm–2mm & <63 µm fractions)	Air dried at 35°C and sieving using 2 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt
Sediment grain size	NIWA Hamilton Eyetech Particle size analyser "B" lens. Freeze-dried subsamples are sieved through a 500 micron screen, ultrasonically dispersed for 4 minutes before analysis. Typically 10^5-10^6 particles are counted per sample.	
Total organic carbon (TOC)	Acid pretreatment to remove carbonates if present, Elementar Combustion Analyser.	0.05 g/100g dry wt
Total recoverable phosphorus	Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt
Total nitrogen	Catalytic Combustion (900°C, O_2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt
Total sulphur	LECO SC32 Sulphur Determinator, high temperature furnace,infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239. (contracted to SGS Waihi)	0.005 g/100g dry wt
Total recoverable cadmium	Nitric/Hydrochloric acid digestion, <2 mm fraction, ICP-MS, trace level. US EPA 200.2.	0.01 mg/kg dry wt
Total recoverable chromium	Nitric/Hydrochloric acid digestion, <2 mm fraction, ICP-MS, trace level. US EPA 200.2.	0.2 mg/kg dry wt
Total recoverable copper	Nitric/Hydrochloric acid digestion, <2 mm fraction, ICP-MS, trace level. US EPA 200.2.	0.2 mg/kg dry wt
Total recoverable lead	Nitric/Hydrochloric acid digestion, <2 mm fraction, ICP-MS, trace level. US EPA 200.2.	0.04 mg/kg dry wt
Total recoverable nickel	Nitric/Hydrochloric acid digestion, <2 mm fraction, ICP-MS, trace level. US EPA 200.2.	0.2 mg/kg dry wt
Total recoverable zinc	Nitric/Hydrochloric acid digestion, <2 mm fraction, ICP-MS, trace level. US EPA 200.2.	0.4 mg/kg dry wt
Extractable copper	2M HCl extraction (<63µm fraction), ICP-MS. ARC Tech	2M HCl extraction (<63µm fraction), ICP-MS. ARC Tech
Extractable lead	2M HCl extraction (<63µm fraction), ICP-MS. ARC Tech	2M HCl extraction (<63µm fraction), ICP-MS. ARC Tech
Extractable zinc	2M HCl extraction (<63µm fraction), ICP-MS. ARC Tech	2M HCl extraction (<63µm fraction), ICP-MS. ARC Tech
Total petroleum hydrocarbons (TPH)	Gas chromatography, flame ionisation detection (GC-FID) method, USEPA 8015/NZ	
Organochlorine pesticides	Sonication extraction, SPE cleanup, GPC cleanup (if req.), 4, 8 dual column GC-ECD analysis, trace level.	0.001 mg/kg dry wt
Polycyclic aromatic hydrocarbon (PAHs)	Sonication extraction, SPE cleanup, GC-MS SIM analysis, US EPA 8270C, trace level. Tested on as received sample.	0.001 mg/kg dry wt

Table A2.7: Summary of discrete water quality sampling physico-chemical measured

Variable	Unit	Detection Limit	Method	Source
Field measurements				
Dissolved oxygen	ppm	0.1	CTD	Field
Dissolved oxygen saturation	% sat	0.01	CTD	Field
Temperature	^oC	0.1	CTD	Field
Conductivity	mS/m	0.1	CTD	Field
Laboratory measurements				
Salinity	-	0.01	APHA (2012) 2520 B	Lab
pH	pH units	0.01	APHA 4500-H^+	Lab
Suspended sediment conc.	mg/L	10.0	ASTM D3977-97 (modified)	Lab
Turbidity	NTU	0.1	APHA (2012) 2130 B (modified)	Lab
VSS	mg/L	3.0	APHA 2540 E GF/C 1.2 µm	Lab
Chlorophyll-*a*	mg/L	0.0006	APHA (2012) 10200 H (modified)	Lab
Nitrate nitrogen (NO3)	mg/L	0.002	Calculation (NNN - NO2)	Lab
Nitrite nitrogen (NO2)	mg/L	0.002	APHA (2012) 4500-NO2 B (modified)	Lab
Ammoniacal nitrogen (NH4-N)	mg/L	0.005	APHA (2012) 4500-NH3 G (modified)	Lab
Total kjeldahl nitrogen (TKN)	mg N /L	0.02	APHA (2012) 4500-org A, D Modified	Lab
Total nitrogen (TN)	mg N /L	0.02	APHA (2012) 4500-P J, 4500-NO3 F (modified)	Lab
Soluble reactive phosphorus	mg/L	0.0006	APHA (2012) 4500-P B, F Mod	Lab
Total phosphorus	mg/L	0.005	APHA (2012) 4500-P B,J (modified)	Lab