Mauao (Mount Maunganui) across the Port of Tauranga from Harbour Bridge Marina.

BAY OF PLENTY REGIONAL COUNCIL
TOI MOANA

Bay of Plenty Comprehensive Contaminant Report 2020

Bay of Plenty Regional Council
Environmental Publication 2021/07

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ISSN: 1175-9372 (Print)
ISSN: 1179-9471 (Online)

Acknowledgements/He Mihi

This report was the culmination of a large amount of fieldwork and data collection conducted by estuarine ecology students over the years and the Environmental Data Services team. Thank you to Michael Tyler, Jamie Lynds, Mike Stewart, and Daniel Tingey for support with the emerging organic contaminants field sampling. Many thanks to Grant Northcott and Mike Stewart for support planning and identifying key sites and contaminants to target for the emerging organic contaminant survey, and for providing the EOC data report that was inserted into this comprehensive report. Thank you to Claire Conwell for her technical report on the potential ecological impacts of EOCs in Tauranga Harbour.

A huge thank you to Daniel Tingey for his extensive work co-designing and conducting the freshwater contaminant survey, including production of spatial maps, data collation, freshwater results writing, and support in the estuarine water and sediment sampling. Thank you to Erin Bocker for the support on spatial map production.

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Executive summary/ Whakarāpopototanga Matua

The Bay of Plenty Regional Council (BOPRC) undertakes a range of estuarine monitoring which is designed to provide an assessment of the level of sediment contaminants against national environmental guidelines, provide robust spatial data to assess sediment contamination trends over time, and to provide data to help with interpretation of benthic ecology (macrofauna) health. Additional surveys are conducted less frequently to assess the presence of a range of organic chemicals (such as polycyclic aromatic hydrocarbons (PAHs) or pesticides/herbicides) which have previously shown low and/or no detection.

This report presents the sediment, water and shellfish contaminant results (heavy metals, organics and emerging organic contaminants) from the following surveys:

- Annual estuarine monitoring for sediment heavy metals and organics (some sites) at 94 estuarine sites across Tauranga Harbour, Ōhiwa Harbour, Maketū estuary, and Waihī estuary (~1990 to 2020).
- Targeted water heavy metal and pesticides survey (2018/2019 summer) in sub-estuaries of Tauranga Harbour (10 sites) and the lower reaches of Bay of Plenty rivers (22 sites), identified to have significant agricultural/horticultural land use and/or large industrial/residential developments.
- Targeted survey (2018/2019 summer) on emerging organic contaminants (EOCs) in sheltered sub-estuaries of Tauranga Harbour (10 sites) and the lower reaches of Bay of Plenty rivers (2 sites), identified to have significant agricultural/horticultural land use and/or large industrial/residential developments. The survey included sediments, passive sampling devices (time-integrated water conditions, estuary sites only) and shellfish (for a subset of organic contaminants).

Annual Estuary Sediment Monitoring

- All 94 Bay of the Plenty estuary sediment heavy metal sites were below Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018), thus have low risk to estuary ecological health in the current state.
- A number of long term sediment sites are showing a slow increase in heavy metal concentrations, for example increasing arsenic at Te Puna, Waipapa, Waikareao and Welcome Bay.
- Some sites show a reduction in heavy metals, for example decreasing cadmium concentrations at a number of sites in Ōhiwa Harbour.
- There is a clear influence of stormwater on the sediment sites in the highly urbanised Tauranga CBD – including a number of significant increases in heavy metals at Waikareao Estuary.

Estuary Water and Sediment 2018/19 Targeted Contaminant Survey

- There was no detection of trace acid herbicides, multiresidue pesticides, polychlorinated biphenyls (PCBs), metsulfuron, and semivolatile organic compounds (SVOCs: haloethers, phenols, plasticisers, halogenated compounds) in sampled estuary sediments.
- Shellfish were sampled at the EOC monitoring sites where shellfish were present, and were analysed for heavy metals, PAHs, and PCBs. Heavy metals were well below the available food safety guidelines for shellfish. As expected, titiko (mud snails, *Amphibola crenata*) often had higher concentration of heavy metals (cromium, copper, nickel) due to their feeding mode and proximity to streams/stormwater outflows compared to tuangi (cockles - *Austrovenus stuchburyi*) and pipi (*Paphies australis*) found further out in the estuary away from possible sources of heavy metals. All tuangi samples were below detection for PAHs. A number of PAHs were found in Waimapu and Waikareao titiko, and in Waikareao pipi samples. A number of PCBs were detected in Waikareao titiko. There were no relevant food safety guidelines for these contaminants.
- Estuary water heavy metal samples were analysed at 10 sites. Welcome Bay water had elevated concentrations of copper (exceeding the 90% Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) Default Guideline Values (DGV)), lead and zinc compared to other sites. Cadmium, arsenic and nickel were below detection limits at all sites. Zinc and lead were elevated at a number of sites including Welcome Bay, Rangataua Bay and Waikareao. The estuary water heavy metal concentrations for chromium, lead and zinc (when detected) were often higher than river water heavy metal concentrations under low flow conditions, suggesting alternate inputs of heavy metals such as stormwater outlets, or the result of cumulative inputs of freshwater sources.
- Organic pollutants and herbicides/pesticides continue to show a low risk to Tauranga Harbour sediments, although there is some potential risk from the cumulative impacts of aqueous heavy metals.

River Water and Sediment Targeted Contaminant Survey

- A number of river sediment sites were close to exceeding the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) for arsenic in the Lake Rotorua Catchment (Waiowhiro at Bonningtons Farm & Puarenga at FRI). Mercury concentrations exceeded Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) at two Rotorua Lake inflow sites (Puarenga at FRI & Utuhina at Lake Rd), and one site in northern Tauranga Harbour (Matahui at Elmwood Road). A number of the higher heavy metal concentration sites are either located in the geothermal rich area of Rotorua, or are connected to the lake as river outflows, thus geothermal activity likely influences the heavy metal concentrations of this area.
- The river water heavy metal samples were analysed at 22 sites. At many sites no heavy metals were detected. Chromium and copper had some of the higher concentrations recorded, which were graded fair and poor categories for the 90% and 80% DGV respectively. As noted above, many of these sites with higher concentrations of metals are located in areas with geothermal activity.
- There was no detection of herbicides or pesticides in river sediments with the exception of the broadleaf herbicide Triclopyr at at low concentrations at two locations; Waiowhiro at Bonningtons Farm (Rotorua) and Matahui at Elmwood Road (northern Tauranga Harbour).
- Aqueous trace herbicides and pesticides were below detection at all sites except for Waikite at Welcome Bay Road which had a very low concentration of Triclopyr, which is likely to have limited risk based on other reported environmental threshold values.
- Two river sediment sites were tested for PAHs - no detections were made at Koperererua at SH 2, but a number of PAH detections were made at Waimapu at SH 2, which were equal to

the ISQG-high guidelines and may pose an ecological risk in this area. No PCBs, metsulfuron, SVOC, phenols, or plasticisers were detected at either site.

Emerging Organic Contaminant (EOC) Survey

- A total of 15 subtypes of analytes were measured for EOCs in sediment and water in Tauranga Harbour. Five of these subtypes were not detected at any of the sites (flame retardants, polycyclic musk fragrances, steroid estrogens, anticorrosives, and wastewater markers).
- Of the total subtypes of EOCs analysed, seven of the 15 measured analytes were detected in sediments. Plasticisers were detected at all of the sediment sites measured (e.g. DEHP, BBP, BPA), with the highest concentrations of the species di-n-butyl-phthalate and di-ethylhexyl-phthalate (DEHP) recorded. The second most detected analyte was pyrethroid insecticides (bifenthrin), recorded at 11 sediment sites. The next most detected analytes in sediments were preservatives (methyl-paraben) and UV-filters (oxybenzone), detected at 10 sites. Additional EOCs detected in sediment included surfactants, pharmaceuticals, and antifouling agents.
- Of the total subtypes of EOCs analysed, five of the 14 measured analytes were detected in the estuary water passive sampling devices. At the passive sampler water sites there was six detections of preservatives, PFAS, and glyphosate/AMPA. There was one detection of a personal care product at Otumoetai (chloroxylenol; an antiseptic/disinfectant) and one detection of the surfactants (technical nonylphenol equivalents) at Katikati.
- In general the sediment concentrations of EOCs are regarded as low (at or below 10 ng/g, with the exception of plasticisers), and in the range of concentrations reported elsewhere in New Zealand. There were however several exceedances of published risk data (for key plasticisers and for a pyrethroid insecticide).
- Water borne concentrations of EOCs do not pose an immediate risk to Tauranga Harbour, with concentrations well below the published risk values.

Spatial Contaminant Findings

- Spatial patterns show clear accumulation of heavy metals in estuary sediments surrounding highly urbanised areas (such as the Tauranga CBD and Ōmokoroa areas), compared to more rural areas such as the northern Tauranga Harbour. The concentrations of sediment heavy metals were generally higher in more urbanised areas.
- Higher water column concentrations of heavy metals in rivers were also reflected in higher concentrations in estuary water with evidently higher zinc concentrations near the CBD. This was measured during a period of low rainfall and likely represents the lower range of heavy metal inputs to the harbour.
- The higher number of EOCs detected in the passive sampling devices was focused around the southern harbour. The commonly detected contaminants in the southern harbour included PFAS, preservatives and glyphosate. Nothing was detected in the mid harbour, and a few EOCs were detected in the northern harbour, with higher numbers at Katikati compared to Tuapiro.
- Spatial patterns show that EOCs are detectable even outside of the core urbanised areas of Tauranga Harbour, with detectable concentrations in less urbanised/populated catchments. A number of common sediment EOCs were picked up in the northern harbour, including surfactants, insecticides, plasticisers and UV filters. The more urbanised area of Katikati also detected pharmaceuticals and preservatives. In the mid harbour, sediment EOCs included preservatives, pharmaceuticals, plasticiers, and surfactants. The Te Puna site also detected insecticides, whereas Wairoa detected UV-filters. In the southern harbour sediments closer to the river inflows, insecticides, preservatives and plasticisers were commonly detected. Pharmaceuticals were also common in southern harbour sediments, with the exception of Waikareao/Kopurereroa River. UV-filters and surfactants were also common at a number of

sites. Antifouling agents were detected at the two sites measured near boating activity (Otumoetai and Port).

Future monitoring recommendations

- Add routine monitoring of heavy metals into river and estuarine water monitoring to support assessment of receiving environment impacts.
- Investigate natural geothermal inputs of heavy metals to water bodies in the Bay of Plenty.
- Work closely with TCC and Western Bay to investigate the sources of heavy metals and identify solutions to reduce the stormwater concentrations.
- Develop a heavy metal transport model for the lower Tauranga Harbour to support an assessment of the cumulative impact of heavy metal inputs to the harbour.
- Continue to monitor EOCs on a routine 5-yearly basis in line with existing comprehensive contaminant surveys.
- Conduct a ranking of sites based on contamination, and type of contamination, in order to assess the cumulative effects of potential sources of contaminants across different land use types.

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Introduction/Kupu Whakataki

Scope

This report presents the results of annual sediment contamination surveys that occur in harbours and estuaries throughout the Bay of Plenty region as part of the Natural Environment Regional Monitoring Network (NERMN). The NERMN monitoring is designed to provide an assessment of the level of sediment contaminants against national environmental guidelines, provide robust, spatial data to assess sediment contamination trends over time, and to provide data to help with interpretation of benthic ecology (macrofauna) health.

A snapshot survey was also conducted to assess the potential contamination risk of emerging organic contaminants (EOCs) in a representative selection of estuary sediments and water. A number of shellfish samples were also collected from the sites for analysis of heavy metals and organic contaminants. This report also presents results of a spatial survey of heavy metals and pesticides in lower reach river sediments and water across the Bay of Plenty.

The information collected in these surveys will inform the Bay of Plenty Regional Council on the effectiveness of its environmental management through consents, plan rules and provisions, which aim to maintain a healthy and sustainable coastal environment.

Background

Worldwide the rapid growth and expansion of the human population is exerting increased pressure on our coastal receiving environments. The tendency for humans to populate and intensify in coastal regions enhances the pressures faced by coastal ecosystems such as estuaries and harbours. Accumulation and persistence of a contaminants in sediments, water and biota is a global problem. A range of contaminants can have adverse and persistent ecological effects which come from a range of anthropogenic sources including farming, industry, wastewater, landfills, and urbanisation. Such contaminants can include heavy metals, polycyclic aromatic hydrocarbons (PAHs), pesticides, and other organic chemicals. These contaminants can be an increased stressor on top of other pressures facing coastal marine ecosystems such as sedimentation, eutrophication, fisheries, climate change, habitat destruction and invasive species (MfE, 2019).

The Bay of Plenty region is home to 313,318 people (Stats NZ Census, 2018), with two major harbours (Tauranga and Ōhiwa), and three significant smaller estuaries (Waihī, Maketū, Waiōtahe). Annual sediment contaminant monitoring has been carried out across the region since the early 90's, and was last reported on in 2014 (Park, 2014). In the Bay of Plenty, estuarine state of the environment monitoring has focused on heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc) with intermittent surveys for persistent organic pollutants (POPs) – such as legacy organochlorine pesticides, polycyclic aromatic hydrocarbons (PAHs) and legacy polychlorinated biphenyls (PCBs) (Park, 2008, Park, 2014). The past surveys have shown very low levels of these organic pollutants, and generally were reported below detection limits.

More recently, a suite of unregulated chemicals has been emerging in the public eye that may be present in the marine environment, however there is limited understanding of the ecological impacts on marine ecosystems or human health. These contaminants are often termed Emerging Organic Contaminants (or EOCs) and comprise a wide range of possible contaminant groups including industrial chemicals (flame retardants, plasticisers), pesticides, antifouling agents, preservatives, pharmaceuticals and personal care products (discussed in more detail below). A recent guidance document has been produced for regional councils (Stewart *et al.*, 2016) including advice on site selection and a core list of EOCs to act as "markers" that cover a range of EOC sources (sewage, landfall, stormwater, recreation, agriculture/horticulture). A number of surveys for EOCs have been conducted in New Zealands estuarine/harbour ecosystems. A study of

pharmaceuticals in Auckland estuarine sediments quantified 21 of the 46 pharmaceuticals analysed, with paracetamol and naproxen having the highest average sediment concentration (Stewart, 2013). A further study was conducted examining a range of additional EOCs including flame retardants, plasticisers, alkylphenols, steroids and pharmaceuticals (Stewart *et al.*, 2014), with detection of many EOCs in Auckland Harbour.

Contaminant background

Heavy Metals

Heavy metals can be either naturally sourced from rock weathering or anthropogenic sources (Dickinson *et al.*, 1996). The Bay of Plenty is a naturally geothermal rich area, with high sources of some heavy metals based on the geological origin of the catchment, including geothermal seeps. Anthropogenic sources can include wastewater discharges (human and industrial), leachate from solid waste, and stormwater runoff. Heavy metals tend to accumulate in slow, depositional environments such as the upper reaches of estuaries, due to the increasing mud content and organic matter, which preferentially attracts heavy metals (Dickinson *et al.*, 1996, Williamson & Morrisey, 2000, Abrahim & Parker, 2002).

Copper, lead and zinc often accumulate in high concentrations in sediments and water environments (Park, 2008) with relation to vehicles and road usages (combustion by-products, e.g. vehicle emmissions and tyre dust). Up to 60% of lead sources to the environment are through the historical combustion of lead-rich petrol (Fergusson, 1992). Other heavy metal sources include industry and urban housing (zinc from galvanised roofs and lead from old house paints). Lead is also found in batteries, ammunition, and many electronic devices (McMurtie, 2012). Zinc is found in agrichemicals such as fertilisers and pesticides, and in sewage sludge (Abrahim & Parker, 2002). Copper concentrations in New Zealand marine sediments may be sourced from antifouling copper rich paints used on boats (ARC, 1995), copper on roofs and building materials, copper brake pads, and copper in pesticides/herbicides (Kennedy & Sutherland, 2008). Cadmium can be sourced from pigments, protective plating on steel, dry-cell batteries and various alloys (Abrahim & Parker, 2002). In agricultural areas, cadmium is increasing due to the long term application of superphosphate fertilizer on farms (which contains small amounts of cadmium) (Abrahim & Parker, 2002). Mercury occurs naturally in the environment but can also be released to the atmosphere through industrial pollution. Arsenic is also naturally occurring however is increasing in the environment due to mining, geothermal production, treated timber and erosion from intensive land use (McMurtie, 2012).

Zinc, lead, copper, cadmium, mercury and arsenic have been extensively studied by the World Health Organisation and have proven to have adverse health effects on humans (Jarup, 2003). Heavy metal effects on biota have been clearly identified, and in Australia and New Zealand there are heavy metal guidelines set for water and sediment environments to protect ecological health (Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)). Heavy metals have the ability to bioaccumulate in the food chain and have biotoxicity effects on sediment biota. Shellfish in particular are used as indicators of heavy metal stress as they bioaccumulate contaminants through filter feeding. High levels of heavy metals in shellfish can have adverse effects on human health, therefore safe limits for human consumption have been set by the Australia New Zealand Food Standards Code for a number of heavy metals (FSANZ, 2008).

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a large group of compounds made of two or more fused benzene rings, formed by incomplete carbon combustion and during industrial processes. The primary sources include vehicle exhausts and smoke from fires/cigarettes. A number of PAH forms have aquatic biota health concerns and guidelines have been set by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) to protect ecological health.

PFAS

Per- and polyfluoroalkyl substances (PFAS: PFOA, PFOS) are a group of man-made chemicals produced extensively in industries around the globe, from food packaging to commercial household products (non-stick products, polishes, waxes, paints, cleaning products, fire-fighting foams) (EPA, 2018). Many of these products have been phased out of production internationally and in New Zealand due to their environmental persistence and effects on human and ecological health (EPA, 2018; MFE, 2019).

Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a man-made organic chemical containing carbon, hydrogen and chlorine atoms, also commonly referred to as chlorinated hydrocarbons. PCBs were produced in a range of industrial and commercial applications including electrical, heat transfer and hydraulic equipment, plasticisers in paint, plastics and rubber, and pigments, dyes and carbonless copy paper. Production of PCBs was banned in 1979 in the USA due to its persistence in the environment and severe human health impacts (EPA, 2018). In New Zealand, the import of PCB containing products was banned in 1986, and the storage and use prohibited from 1994 (Scobie *et al.*, 1999).

Pesticides/Herbicides/Insecticides

A recent increase in the intensification of agricultural practices in New Zealand has led to increased leaching of pesticides off agricultural land, posing major threats to the water quality of both surface and groundwater (Cameron *et al.*, 2002). Organochlorine pesticides (such as DDT, dieldrin and lindane) were utilised heavily in New Zealand between the mid-1940s to the 1960s before being restricted and finally banned in the 1980s (Scobie *et al.*, 1999). Epidemiological evidence has linked delayed health effects such as cancer, harm to reproductive processes and subtle neurologic sequelae to pesticide exposure (Sharp *et al.*, 1986). Specific agents which have been identified as a ‘primary concern’ for cancer are phenoxy herbicides, arsenicals, dioxins and organochlorines such as dichlorodiphenyltrichloroethane (DDT) (Sharp et al., 1986).

Emerging organic contaminants

Emerging organic contaminants (EOCs) are synthetic or naturally occurring compounds not currently monitored to a large extent in the environment. There are currently no regulatory standards for them but they are considered to likely have adverse environmental and human effects. Major sources of EOCs include sewage, storm water, landfill leachate, antifouling paints, and horticulture/agriculture. These sources are are described in more detail below based on the literature review of Stewart et al. (2016). Sewage can be a source of a large suite of EOCs including pharmaceuticals and metabolites, illicit drugs, personal care product compounds from bathing, food additives, household and industrial chemicals. Many of these compounds are not adequately removed from wastewater treatment plants due to limited technology, therefore sewage outfalls can be the main pathway for EOCs to enter marine receiving environments. Other sewage sources can include sewer overflows, leaky pipes, septic tanks, biosolid recycling on land, and large boats and ships.

Stormwater is another significant source of EOCs, particularly from industrial areas with likely inputs including alklphenols, phthalates, musk fragrances, flame retardants, plasticisers and resin monomers, and pharmaceuticals. Other stormwater sources include building materials and vehicles, wastes disposed of incorrectly down drains, poorly managed industrial sites and sewer overflows/leaking sewers. The disposal of chemicals and used products to landfill can also lead to contamination of the marine environment as the waste products degrade and move offsite with leachate entering stormwater systems. EOCs likely to be present include pharmaceuticals, musk fragrances, insect repellent, flame retardants, UV-filters and perfluorinated compounds.

More direct sources into the marine environment can include personal care products that are used for protection in/near marine environments including sunscreens, insecticides and pharmaceuticals which can be washed off people's skin when undertaking recreational activities such as swimming and diving. Commercial shipping and small boats use antifouling paints to prevent marine organism fouling of hulls. These paints can also be utilised on wharf structures and aquaculture facilities. Some of these paints contain antifouling co-biocides that are classed as EOCs.

Agricultural practises are yet another significant source of EOCs in the environment. The use of chemicals such as veterinary medicines and steroid hormones/antibiotics is common in animal husbandry businesses such as agriculture and aquaculture. Estrogen hormones from the dairy industry in New Zealand have been reported in groundwater and streams of intensively farmed catchments (Gadd *et al.*, 2010), sourced from dairy cow waste applied to pasture. Horticulture and pasture management is a source of insecticides and herbicides through leaching to groundwater or washed into streams by runoff. Glyphosate is a broad-spectrum herbicide used across agriculture, forestry, and urban areas and is also used for aquatic weed control. The major metabolite of glyphosate is aminomethylphosphonic acid (AMPA).

Methodology/Huarahi

Location

The Bay of Plenty region is located on the northeast coast of the North Island, New Zealand. The coastal perimeter of the Bay of Plenty region is 688 km in length, with 259 km of open coast and 369 km of estuaries. Within the Bay of Plenty are two major harbours (Tauranga and Ōhiwa), and a range of smaller estuaries (Waihī, Maketū, Waiōtahe).

Tauranga Harbour

Tauranga Harbour is the largest estuarine water body in the Bay of Plenty region at 201 km^2 with 66% of the total area being intertidal (Figure 1A). Tauranga Harbour is impounded by a large barrier island (Matakana Island) and two barrier tombolos, Mauao (Mount Maunganui) in the south entrance, and Bowentown to the north (Healy and Kirk 1981, in Park 2014).

The Tauranga Moana catchment drains 1300 km^2 including 27 major rivers and 46 minor streams (Lawton & Conroy, 2019). 27% of the total land area is used for agriculture and horticulture, whilst 44% of the land cover is indigenous and exotic forests (Lawton & Conroy, 2019). At the southern end of Tauranga Harbour there is the CBD area. One of the largest contaminant contributors on Tauranga Harbour may be rapid population growth, which is expected to rise to 250,000 people by 2040 (Lawton & Conroy, 2019). In addition, the Port of Tauranga has developed a large area between Mount Maunganui and Sulphur Point, and have plans for future expansion. In Tauranga Harbour 19 sites have been monitored for heavy metal concentrations since the early 2000s, with an additional 50 sites added in sheltered sub-estuaries during the period 2013–2019.

Maketū Estuary

Maketū Estuary is a small (2.3 km^2), shallow estuary with extensive tidal flats (Figure 1B). The estuary is highly modified as the main freshwater input from the Kaituna River was diverted out to the sea at Te Tumu in 1956 resulting in significant changes to the hydrology and ecology. Since 1996 around 100,000 m^3 per tidal cycle was rediverted back to the estuary following reports of adverse ecological and cultural effects of the original river diversion (Hamill, 2014), including accelerated infilling, loss of wetlands, loss of shellfish, loss of flushing and increases in macroalgal blooms (Park, 2018). In early 2020, BOPRC commissioned consent (RC 67958) which now returns around 600,000 m^3 of the Kaituna River flow to the estuary every tidal cycle. One site in Maketū Estuary has been monitored annually for sediment contaminants since the early 2000s, with an additional seven sites being added during the period 2013–2017.

Waihī Estuary

Waihī Estuary is a small (3.34 km^2) estuary which almost fully drains at low tide leaving small shallow and narrow channels (Park, 2018) (Figure 1C). The estuary receives freshwater from a range of streams including the Pongakawa. The catchment of Waihī Estuary has undergone significant changes with the drainage of vast wetlands to make way for agriculture. Prior to this, there was no direct open water channel water flow from the catchment to the estuary. The changes to the hydrology have had severe ecological consequences and there is accumulation of fine sediments in the upper estuary reaches, loss of seagrass beds, in addition to nutrient inputs which have supported the growth of extensive macroalgal beds (*Ulva* and *Gracilaria sp*.), and most recently, the growth of benthic cyanobacteria (*Oscilatoria sp.)*. One site in Waihi Estuary has been monitored annually for sediment contaminants since the early 2000s, with an additional 5 sites being added during the period of 2014 – 2017.

Ōhiwa Harbour

Ōhiwa Harbour is a 26.4 km^2 estuarine lagoon enclosed between the Ōhope and Ōhiwa barrier spits (Figure 1D). The Ōhiwa Harbour drains a 171 km^2 catchment, with a predominant land use of pastoral farming and forestry (Bevan, 2018). At low tide around 83% of the harbour area is exposed. It has a low water volume compared to the spring tidal component and is dominated by tidal currents. Residence time in the harbour is estimated to be 1-2 tidal cycles. Ohiwa Harbour is rapidly changing and infilling with a combination of open coastal sediment supply at the harbour entrance, and land dominated fine sediment inputs in the upper harbour reaches (Bevan, 2018). Ōhiwa Harbour has had four sites monitored annually for sediment heavy metals since the early 2000s, with an additional seven sites being added during the period 2013–2017.

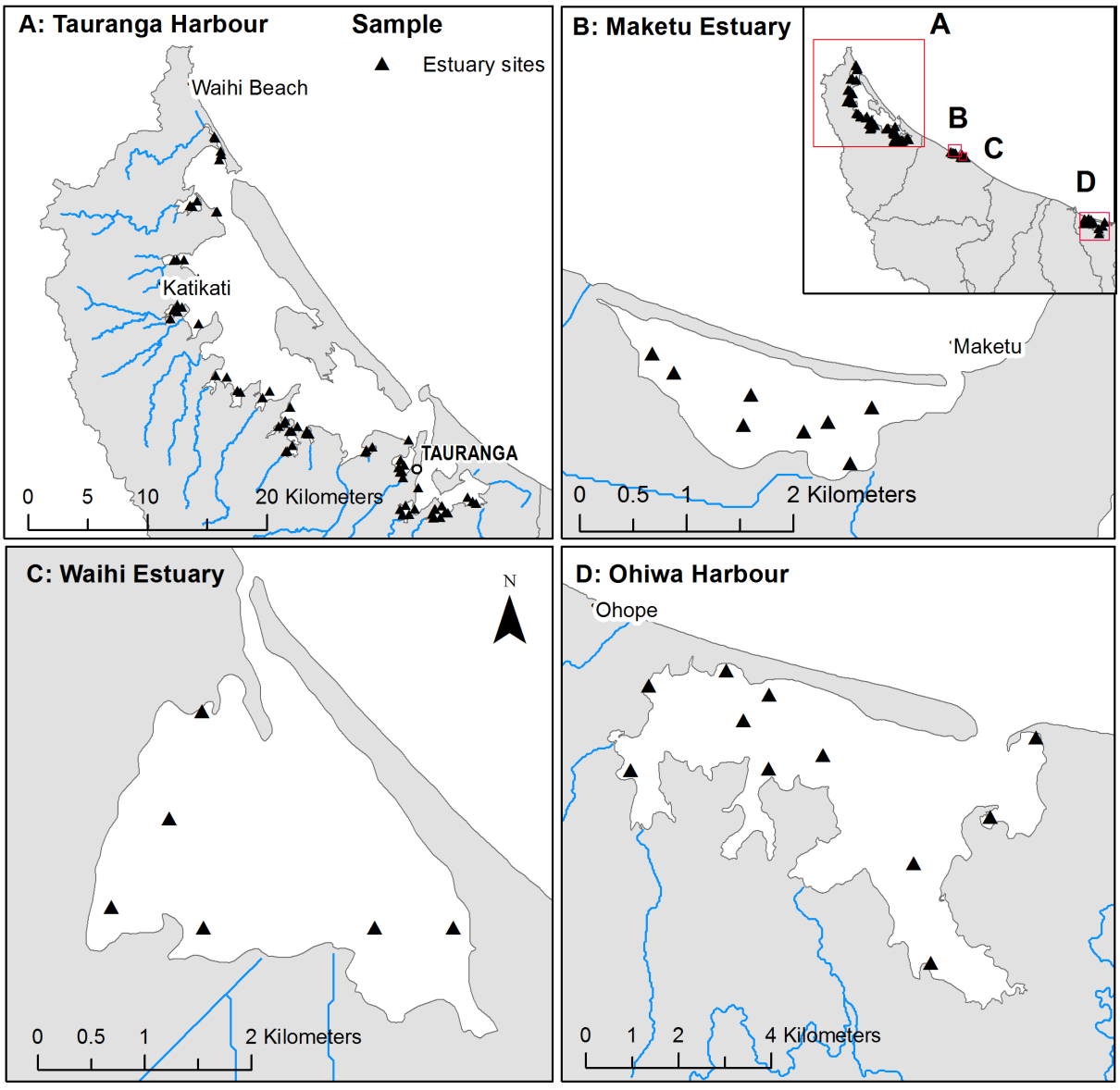

Figure 1 *Location of the annual estuary sediment contaminant monitoring sites (sediment accumulation plates). A: Tauranga Harbour. B: Maketū Estuary. C: Waihī Estuary .D: Ōhiwa Harbour. Inset map shows map scaling across the region.*

Site selection

Baseline yearly sediment monitoring

Previously the contaminant survey programme was conducted every three years (Park, 2008, Park, 2014), however, in 2013/14 the programme was discontinued and instead expanded and incorporated into annual sampling at the NERMN sediment accumulation plate sites. Sediment accumulation rates are now measured at 94 sites in the Bay of Plenty estuaries (Figure 1, Appendix 1). These sites are visited annually over the summer period and a range of sediment and ecological health variables are measured. An overview of Tauranga Moana sediment contaminants was reported in the 2019 Tauranga Moana State of the Environment Report (Lawton & Conroy, 2019).

River snapshot survey

A river snapshot survey was conducted to investigate heavy metal contamination in the lower reaches of Bay of Plenty river water and sediments (Figure 2, Appendix 1). At four sites sediments were collected for measuring emerging organic contaminants linked to high priority estuary sites. Priority river sites were selected based on higher metal contamination in the receiving environment (utilizing previous work by Park (2003, 2008, 2012) and Boffa Miskell, (2018)), the proximity of rivers to waste water treatment plants, and location of existing NERMN river monitoring sites. The sites also aimed to achieve a spread of sites across the Priority Water Management Areas lacking heavy metal data, and a mix of dominant land use (Appendix 1).

Emerging organic contaminants survey

Tauranga Harbour was selected for a survey of emerging organic contaminants due to it being our most urbanised area and therefore having the highest likelihood of showing impacts from EOCs. Sites for analysis of emerging organic contaminants were chosen based on guidance by Stewart *et al.* (2016), which suggests three types of sites for an initial survey of EOCs. These include core sites – that have a high land use component (e.g. sewage effluent, stormwater, landfill); specific sites – that have a high urban land use (e.g. marina, swimming beaches); and reference sites – which are predominantly rural. Some high priority sites identified by Boffa Miskell (2018) for further heavy metal investigations and remediation projects include Waikareao Estuary, the Port industrial area (based on multiple sites of high priority discharging to the area), and Sulphur Point (Figure 3, Table 1). Additional sites were selected in muddy sub-estuaries around the Tauranga CBD and near the wastewater treatment plant and rubbish dump/recycling centre at Rangataua Bay (Figure 3, Table 1). Two agricultural reference sites were chosen from the northern harbour (Tuapiro and Katikati Estuary). Four freshwater river sites were also chosen from the snapshot river heavy metal survey (Kopurererua, Waimapu at SH 29, Waiari at Kaituna influence and Puarenga at FRI). In total 11 sub-estuaries were selected with 16 sites for sediments and 10 sites for passive sampling devices (time integrated water concentrations) (Figure 3). Sites for EOC analysis were aligned with NERMN sediment contaminant sites where possible.

Passive sampling devices were deployed at 10 sites at the bottom of each sub-estuary sampled for sediment EOCs. At each site, if possible, a range of indicator shellfish (tuangi, titiko, pipi, hanikura) were collected as close as possible to the passive sampling sites for testing of heavy metals and a number of organic contaminants (Figure 3). The different methods of measuring emerging organic contaminants were aligned where possible to allow comparison of results and identify optimum indicators.

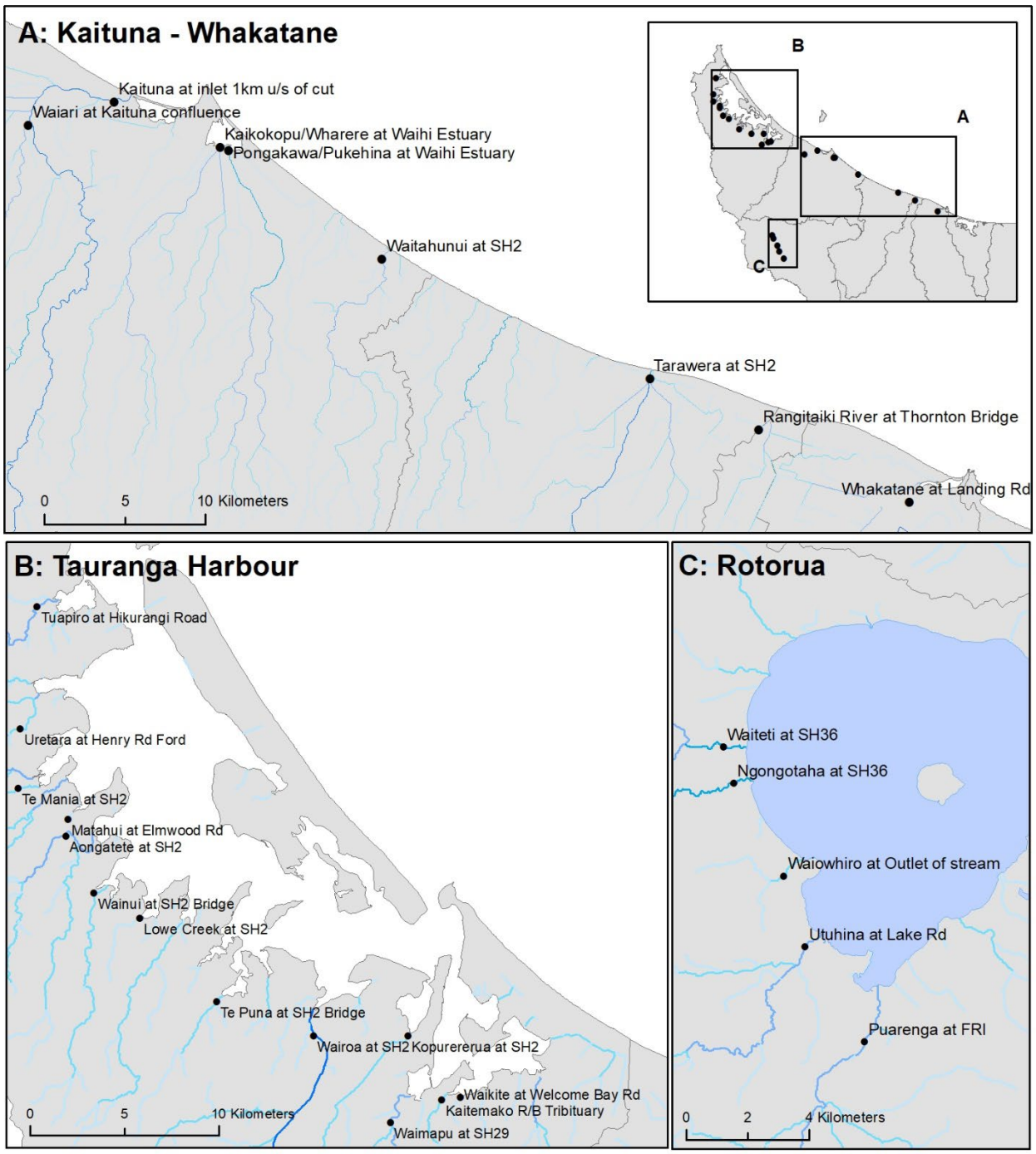

Figure 2 *Location of the river aqueous and sediment sampling sites across the region sampled for heavy metals in 2019. A: Kaituna – Whakatane. B: Tauranga Harbour. C: Rotorua. Inset map shows map scaling across the region*

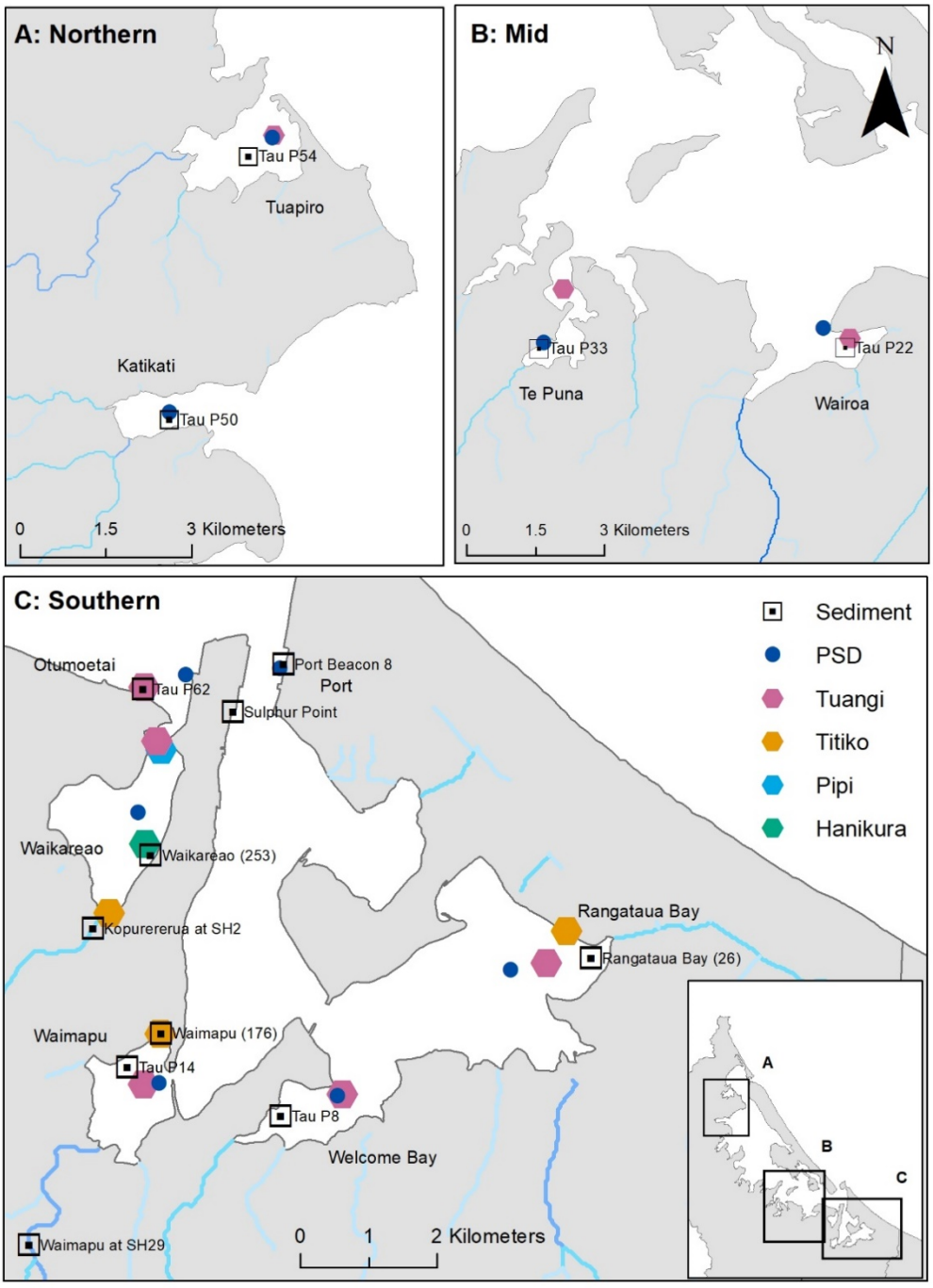

Figure 3 *Location of the sites in Tauranga Harbour sampled for emerging organic contaminants in 2019. A: Northern harbour sites. B: Mid harbour sites. C: Southern harbour sites. Inset map shows map scaling across the harbour. Note two freshwater sites are not displayed on this map: Waiari (Kaituna confluence) and Puarenga (FRI).*

Sampling Protocols

Estuary sampling methodology

Sediments

For the annual NERMN estuary contaminant monitoring programme, 15 small replicate samples from the top 2 cm of sediment were collected using a cut off syringe, stored into a single plastic bag and frozen until analysis. Sediments were analysed for grain size using laser diffraction (University of Waikato), organic content, nutrient contents (total organic carbon, total nitrogen, total phosphorus), PAHs (select sites) and heavy metals (Hills Laboratories).

For the one off EOC sediment sampling, sites were visited at low tide when there was no water on the site. All sediment samples were collected over a one week period at the start of February 2019.

A plastic sediment corer (5 cm diameter) was used to collect the top 2 cm of sediments from each site. The corer was rinsed with 99% ethanol and reverse osmosis water prior to sediment collection at each site. From the centre of each GPS site location, ten 20 m^2 plots were established and 5x replicate core samples were taken and placed into each of the five composite bags (double zip lock bags) from each established plot. Each replicate consists of 10 cores and contained approximately 500g of sediment. Samples were frozen and transported to Plant and Food Research on ice for analysis. For sediment collection at the two subtidal sites (Port and Sulphur Point) a boat and a gravity corer were used to collect sediment samples. Due to the difficulty in collecting the fine sediments, up to 20 sediment cores were collected from each site to pool into the five composite samples. Sample contamination from sediment handling was reduced by avoiding applying sunscreen, insect repellent and perfume prior to sampling. Samplers also used powder-free nitrile gloves during sample collection pre-rinsed in ethanol, and only plastics that do not leach phthalates.

Passive sampler methods

Polar Organic Chemical Integrative Samplers (POCIS) and Molecular Imprinted Polymer (MIP) Passive Sampling Devices (PSDs) were deployed at 10 sites in permanent low tide channels located near the sediment EOC sites. POCIS were used for accumulating the majority of polar (hydrophilic) EOCs. The MIP PSDs were used for accumulating glyphosate/AMPA. Three POCIS were deployed at each site to be analysed for EOCs and perfluorinated chemicals, with one as an archived sample. Two MIPs were deployed that measure glyphosate/AMPA. In addition, one lab and one field blank were utilized for each of the POCIS and MIP samplers.

The PSDs were deployed within a new burley cage to provide protection from sticks and floating objects which may penetrate the sampler surface (Figure 4). At shallow sites the burley cages were deployed between two warratahs by rope to allow some movement in the water currents. The cages were positioned ~ 5 cm above the sediment surface to reduce fouling by re-suspended sediment (Figure 4). At the subtidal sites (Port and Otumoetai), the burley cages were deployed off navigation beacons ~ 10 cm below the mean low water springs mark. The passive samplers were deployed over a 3 week period in April 2019. The PSD sites were visited mid-way through the deployment to remove any built-up algae or floating detritus. Deployment times for each site are reported in Appendix 1.

Estuary water samples

Estuary water samples were collected from the 10 passive sampler sites over a three week period (May 2019; 1 sample per week), to record baseline (low rainfall) levels of heavy metal contamination in the estuary water. All sample jars were provided by Hills Laboratories. Heavy metal (trace As, Cd, Cr, Cu, Ni, Pb, Zn) surface water samples were taken in N100 Nitric acid preservative containers with a plastic sampling pole. Samples were kept chilled in a fridge and sent to Hill Laboratories for analysis.

Figure 4 *Deployment of passive sampling devices inside a burley cage at shallow estuary sites.*

Shellfish collections

Where possible, shellfish were collected from the EOC sampling sites as close as possible to the passive samplers. Tuangi (cockle) samples were gathered from eight sites, titiko (mud snail) from three sites and pipi and hanikura-patu (wedge shells) from one site. A minimum of 30 shellfish individuals were collected at each site and measured for length. Shellfish were sent to Hill Laboratories for analysis of heavy metals and PAHs. One site (Waikareao, representing one of the most urbanised/impacted sub-estuary) had pipi, hanikura and titiko additionally analysed for organochlorine pesticides and polychlorinated biphenyls (PCBs).

River sampling methodology

All river sediment and water samples were taken within two hours either side of low tide. The samples were chilled in cooler bins with ice before being sent to Hill laboratory on the overnight courier for analysis. Heavy metal surface water samples were taken in N100 Nitric acid preservative containers with a plastic sampling pole. Hill Laboratories Org500 jars were used for collection of water samples for herbicides and multiresidue pesticide traces in water. Sample contamination from sediment handling was reduced by avoiding applying sunscreen, insect repellent and perfume prior to sampling. Samplers used powder-free nitrile gloves during sampling collection pre-rinsed in ethanol, and only plastics that do not leach phthalates.

Sediment samples were taken after the water samples at the appropriate sites to ensure no disturbance of contaminants in the sediment to the water column. The limited available sediment at certain sites meant that sampling in transects was not feasible and therefore samples were taken from multiple areas within a collection zone, before being added to a sanitised (ethanol) glass bowl. This allowed for a composite sample to be collected and the sampling jars were used to scoop the sediment to collect the final sample. Samples were sent to Hill Laboratories for analysis of heavy metals, total organic carbon, PAHs, PCBs, metsulfuron, semivolatile organic compounds (SVOC) and acid herbicides and multiresidue pesticides. Emerging organic contaminant samples were collected by the method described for river sediment above, and stored in five zip lock bags with sediment from across the collection area. Samples were frozen and transported to Plant and Food Research on ice for analysis.

Contaminants analysis

A wide range of contaminants were tested from the sediments, water and shellfish. The contaminant analytical suites and laboratories conducting the analyses are reported in Table 1. The suite of emerging organic contaminants was conducted by Northcott Research Consultants (NRC) and AsureQuality in collaboration with Streamlined Environmental (Lab: NRC/AsureQuality). The standard contaminant suites were conducted by Hill Laboratories (Hills). Sediment samples for grain size are measured by laser diffraction at the University of Waikato.

For detailed methodology for the EOC extractions refer to Stewart & Northcott (2020).

Table 1 Contaminant analytical suites and laboratories conducting the analyses. Refer to Stewart & Northcott (2020) for contaminant analytical detection/reporting limits. NRC is Northcott Research Consultants.

Class	Representative EOC	Laboratory
Flame retardants	BDE 47	AsureQuality
	BDE 99	AsureQuality
	BDE 209	AsureQuality
	BDE 28	AsureQuality
	BDE 66	AsureQuality
	BDE 100	AsureQuality
	BDE 85	AsureQuality
	BDE 154	AsureQuality
	BDE 153	AsureQuality
	BDE 183	AsureQuality
	TDCP	NRC
	TPP	NRC
	TCPP	NRC
Plasticisers	Diethylhexyl phthalate (DEHP)	NRC
	Butylbenzyl phthalate (BBP)	NRC
	Bisphenol-A (BPA)	NRC
	Diethyl-phthalate	NRC
	Di-n-butyl-phthalate	NRC
	Di-n-octly phthalate	NRC
	Monobutyl-PAE	NRC
	Mono-ethylhexyl(EH)-PAE	NRC
	Monomethyl-PAE	NRC
Surfactants	4-n-Nonylphenol	NRC
	Technical nonylphenol equivalents	NRC
Perfluorinated compounds (PFAS)	PFOS/PFOA	AsureQuality
Polycyclic musk fragrances	Galaxolide	NRC

Class	Representative EOC	Laboratory
	Tonalide	NRC
Pyrethroid insecticides	Bifenthrin	NRC
	Cis-permethrin	NRC
	Trans-permethrin	NRC
Pesticides	Glyphosate	AsureQuality
Pharmaceuticals	Acetaminophen	NRC
	Carbamazepine	NRC
	Diclofenac	NRC
	Ibuprofen	NRC
	Aspirin (acetyl-salicyclic acid)	NRC
	Clofibric acid	NRC
	Ketoprofen	NRC
	Meclofenamic acid	NRC
	Naproxen	NRC
	Salicyclic acid	NRC
Steroid estrogen	Estrone	NRC
	17α-estradiol	NRC
	17β-estradiol	NRC
	17α-ethinylestradiol	NRC
	Estriol	NRC
Personal care product	Triclosan	NRC
	Methyl-Triclosan	NRC
	Chloroxylenol	NRC
	O-phenylphenol	NRC
Wastewater markers	Caffeine	NRC
	Sucralose (PSDs only)	NRC
Preservative	Methyl-Paraben	NRC
	Propyl-paraben	NRC
Anti-corrosive	Benzotriazole	NRC
Antifouling agents	Diuron	NRC
	Isoproturon	NRC
	Linuron	NRC
UV-filter	Benzophenone-3 (oxybenzone)	NRC
	4-MBC (4-methylbenzylidene camphor)	NRC
	4-hydroxy-benzophenone	NRC
	2,4-dihydroxy-benzophenone	NRC
	Octinoxate	NRC

Class	Representative EOC	Laboratory
Nutrients	TP, TN, TOC	Hills
Heavy metals	As, Cd, Cr, Cu, Pb, Hg, Ni, Zn	Hills
Acid Herbicides	Acid herbicides trace in soil by LCMSMS	Hills
Multiresidue pesticides	Multiresidue pesticides in soil samples by GCMS	Hills
Polycyclic Aromatic Hydrocarbons (PAHs)	Polycyclic aromatic hydrocarbons trace in SVOC soil samples	Hills
Polychlorinated Biphenyls (PCBs)	Polychlorinated biphenyls trace in soil	Hills
Metsulfuron	Metsulfuron in soil samples by LCMS	Hills
Semivolatile Organic Compounds (SVOC)	• Haloethers trace in SVOC soil samples by GCMS • Nitrogen containing compounds trace in SVOC soil samples by GCMS • Organochlorine pesticides trace in SVOC soil samples by GCMS • Phenols trace in SVOC soil samples by GCMS • Plasticisers trace in SVOC soil samples by GCMS • Other halogenated compounds trace in SVOC soil samples by GCMS • Other SVOC trace in SVOC soil samples by GCMS	Hills

Use of environmental guidelines

The results of the contaminant surveys are compared to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018). These guidelines include interim sediment quality guidelines (ISQG) which provide two guideline values (high and low), that are used to guide further decisions and actions rather than provide absolute guidelines (Park, 2014). The low value is a level at which sub-lethal effects may occur for sensitive species, while the high ISQG is a trigger level indicating that there is a need for further investigation and action to remediate the contaminant(s) due to potential toxicity (Park, 2014). In addition to this, recent toxicant default guideline values (DGV) have been derived for water quality management and can be used as a guidance tool for aquatic ecosystem conservation (Australian and New Zealand Environment and Conservation Council, 2000). These trigger values were derived from using statistical distributions, which defined four levels of protection (99%, 95%, 90% and 80% - with the 90% and 80% representing the ISQG low and high thresholds). These protection levels represent the percentage of species that is expected to be protected, and is defined by the condition of the ecosystem at each site. These allow issues to be identified and remedied prior to severe ecological impacts occurring.

Development of environmental health ranking bands

The development of sediment heavy metal condition ratings specific to New Zealand estuaries has been outlined in the Estuarine Vulnerability Assessment developed by Wriggle Coastal Management (as utilised in previous work by Stevens & Robertson (2013), and Robertson & Robertson (2014)). These ratings assign each heavy metal species a grade based on its comparison to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) (Table 2). The heavy metal ISQG banding is shown in Table 3.

For the sediment heavy metal contaminants, the ISQG low and high were used to create four heavy metal health bands. For the aqueous contaminants (river and estuary water), the four Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) protection DGV were used to categorize the heavy metals into five bands. This categorisation (4-5 bands) is used by BOPRC across all scientific reporting to create consistency and comparability across all technical reporting. Similar guideline bands were previously reported in the Tauranga Moana State of the Environment Report (Lawton & Conroy, 2019).

Table 2 *Heavy metal banding system for sediment and aqueous contaminants based on the Wriggle Management Conditions and Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018).*

Sediment heavy metal banding	Aqueous heavy metal banding
Very good =<0.5 x Low ISQG	Very good= <99% DGV
Good=0.5 x Low ISQG to Low ISQG	Good=99%DGV to 95% DGV
Fair=Low ISQG to High ISQG	Fair= 95% DGV to 90% DGV
Poor= >High ISQG	Poor= 90%DGV to 80% DGV
	Very poor= >80%DGV

Table 3 *The heavy metal banding for sediment contaminants based on the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) (reported in mg/kg DW).*

	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Very good	<10.0	<0.75	<40.0	<32.5	<25.0	<0.075	<10.5	<100
Good	10.0	0.75	40	32.5	25	0.075	10.5	100
Fair	20	1.5	80	65	50	0.15	21	200
Poor	> 70	> 10	> 370	> 250	> 220	> 1	> 52	> 410

The estuary water heavy metal concentrations were compared against the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) toxicant default guideline values (DGV) to test the toxicity potential of each heavy metal, which have been converted to a five band grading system (Table 4).

Table 4 *Estuary water heavy metal health rankings based on the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) toxicant default guideline values (DGV). Heavy metal concentrations are in ug/L. Blue= Very good, Green= Good, Yellow = Fair, Orange = Poor, Red = Very poor.*

	As	Cd	Cr	Cu	Pb	Ni	Zn
Very good	NA	<0.7	<7.7	<0.3	<2.2	<7	<7
Good	NA	7	7.7	0.3	4.4	7	7
Fair	NA	5.5	27.4	1.3	6.6	70	15
Poor	NA	14	48.6	3	12	200	23
Very poor	NA	>36	>90.6	>8	>12	>560	>43

The freshwater heavy metal concentrations were assessed against the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) toxicant default guideline values and separated into health bands (Table 5).

Table 5 *Freshwater heavy metal health rankings based on the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) toxicant default guideline values (DGV). Heavy metal concentrations are in ug/L. Blue= Very good, Green= Good, Yellow = Fair, Orange = Poor, Red = Very poor.*

	As	Cd	Cr	Cu	Pb	Ni	Zn
Very good	<27	<0.06	<0.01	<1	<1	<8	<2.4
Good	27	0.06	0.01	1	1	8	2.4
Fair	55	0.2	1.0	1.4	3.4	11	8
Poor	80	0.4	6.0	1.8	5.6	13	15
Very Poor	>150	>0.80	>39	>2.5	>9.4	>17	>31

Emerging organic contaminant guidelines

A review of emerging organic contaminants in the Bay of Plenty was conducted by Conwell (2021). The potential ecological risk of the EOCs concentration data reported in this study was assessed by comparing the concentration against the published toxicity effects data range. Data were compared against available Predicted No Effects Concentration (PNEC[1]) data and/or No Observed Effects Concentration (NOEC[2]) data. These PNEC/NOEC references were cited from existing reports, or sourced where possible from a range of publications including:

- Australia and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018), low reliability default guideline values,
- Topic specific papers published by other government organisations and agencies, internationally (e.g. New Zealand's Ministry for the Environment and Environment Protection Agency (EPA), United States Environmental Protection Agency (USEPA, in particular the ECOTOX database), World Health Organisation (WHO), National Institute for Public Health and the Environment (RIVM, Netherlands), European Union's European Chemicals Agency (ECHA)).

Although these environmental quality guidelines are available, the impact of EOCs are likely to be expressed as non-lethal effects and potentially result in chronic or long-term effects that are not the focus of available and traditional ecotoxicology studies (Conwell, 2021).

Data analysis/Ngā Tātaritanga Raraunga

Sediment samples results are not reported standardised to total organic carbon.

The heavy metal results were categorised into the health rankings outlined above. R Studio (V1.1.463) with base R version 4.0.2 was used for statistical analyses and graph creation. R packages "reshape2" and "plotly" were used for the estuary sediment heavy metal long term trend figures. Linear modelling using "lm" was used to assess long term trends, and plotted on each figure using the "stat_poly_eq" function. Statistical significance was set at $p<0.05$.

[1] The concentration at which a chemical will likely have no toxic effect(s)

[2] The highest tested concentration for which there are no statistical significant difference of effect compared to the control population/test group

Results/Ngā Otinga

Heavy metals

Estuary sediment heavy metals

A range of sediment contaminants are measured annually at estuarine sediment monitoring sites in Tauranga Harbour (n = 69), Ōhiwa Harbour (n = 11), Maketū Estuary (n = 8) and Waihī Estuary (n = 6). The five yearly mean concentrations of the sediment contaminants recorded between 2015 and 2020 are reported in Table 6 below against the heavy metal grading's reported in Table 3.

All heavy metal contaminants were below Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) ISQG-low at all sites based on whole sediment sample analysis (Table 6). The majority of sites were graded as very good for each heavy metal contaminant. The highest arsenic concentrations were recorded in Uretara Estuary closest to the Uretara Stream (10.4 mg/kg DW). Other high concentrations of arsenic occurred at a number of sites in Rereatukahia, Te Puna, Matahui, and Maketū and Ohiwa Estuary. The highest cadmium concentrations were recorded at one site in Waikaraka Estuary (0.21 mg/kg DW). Other high cadmium concentrations occurred at sites in Te Puna and Mangawhai Estuary. The highest chromium concentrations were measured in Rereatukahia (11.9 mg/kg DW), closely followed by sites in Matahui and Ōhiwa. Ōhiwa Harbour had higher copper concentrations on average compared to the other estuaries, with the greatest copper concentrations near the Ōhiwa campsite (6.3 mg/kg DW). The highest copper concentrations in Tauranga Harbour were recorded in Te Puna, Rereatukahia, and Wainui. The highest lead concentrations were recorded in Welcome Bay (9.7 mg/kg DW), with other high readings at Waikareao, Te Puna, Rereatukahia, and Wainui. Mercury concentrations were highest at sites in Matahui (0.112 mg/kg DW), Rereatukahia (0.085 mg/kg DW), and Maketū (0.085 mg/kg DW). Nickel concentrations were greatest in Ōhiwa Harbour, with the greatest concentrations at Ohi P9 (6.6 mg/kg DW). The highest nickel concentrations in Tauranga Harbour were located at Matahui (5.4 mg/kg DW), Rereatukahia (4.2 mg/kg DW) and Uretara (3.5 mg/kg DW). Zinc concentrations were highest at Waikareao Estuary located near the Kopurererua River (108.8 mg/kg DW), which is almost double the next highest value reported further down Waikareao Estuary (55.3 mg/kg DW). Waimapu Estuary sites were also high in zinc with concentrations ~40 mg/kg DW.

Table 6 *Five yearly mean concentrations of mud content (%), total organic carbon (TOC) (g/100g), total nitrogen (TN), total phosphorus (TP), and heavy metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Zn) (mg/kg dry weight) collected from annual sediment monitoring sites in Tauranga Harbour, Ōhiwa Harbour, Maketū Estuary and Waihī Estuary between 2015 – 2020. Coloured highlights indicate the sediment heavy metal banding system described in Table 3 (Blue= very good, Green= Good, Orange = Fair, Red = Poor).*

Tauranga Harbour	Site Name	Mud %	TOC g/100g	TN	TP	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Rangataua Bay	Tau P1	26.3	0.61	725	209	3.7	0.034	3.4	2.1	3.3	0.028	1.2	25.0
Rangataua Bay	Tau P2	17.7	0.31	250	154	3.6	0.024	2.3	1.4	2.6	0.023	0.7	22.3
Rangataua Bay	Tau P3	19.1	0.41	513	158	3.0	0.063	2.2	2.1	2.7	0.032	0.9	16.8
Welcome Bay	Tau P4	16.6	0.44	613	188	3.4	0.105	2.9	2.0	3.1	0.039	1.0	31.0
Welcome Bay	Tau P5	18.9	0.33	313	149	2.6	0.051	2.2	1.6	2.5	0.033	0.7	24.6
Welcome Bay	Tau P6	25.8	0.47	488	168	3.8	0.045	2.6	2.1	3.2	0.029	0.9	30.3
Welcome Bay	Tau P7	44.5	0.95	1000	263	4.4	0.069	5.5	3.6	9.7	0.042	1.5	39.3
Welcome Bay	Tau P8	31.1	0.62	750	243	4.2	0.065	3.5	2.6	4.2	0.030	1.2	40.0
Welcome Bay	Tau P9	22.0	0.41	488	178	3.6	0.069	2.8	1.9	3.4	0.032	0.9	28.8
Welcome Bay	Tau P10	29.5	0.54	700	208	4.3	0.081	3.5	2.4	4.1	0.039	1.1	34.3
Welcome Bay	Tau P65	15.6	0.49	650	208	3.8	0.089	5.1	2.5	4.0	0.033	2.1	28.5
Waimapu	Tau P11	26.0	0.49	513	184	3.3	0.076	2.5	2.0	3.2	0.029	0.8	34.5
Waimapu	Tau P12	37.3	0.71	775	225	3.6	0.069	3.5	2.7	4.6	0.034	1.2	42.3
Waimapu	Tau P13	37.7	0.65	775	238	3.9	0.077	4.2	2.8	4.4	0.026	1.3	43.0
Waimapu	Tau P14	27.1	0.70	700	214	3.7	0.098	3.3	2.5	3.9	0.032	1.2	40.8
Waimapu	Tau P64	22.7	0.61	658	187	3.8	0.081	4.1	2.7	4.2	0.039	1.6	33.3
Waikareao	Tau P15	39.4	0.86	1025	305	4.5	0.105	4.3	3.2	8.3	0.024	1.4	108.8
Waikareao	Tau P16	25.5	0.38	313	154	3.3	0.076	3.3	1.3	3.4	0.031	1.0	39.3
Waikareao	Tau P17	19.8	0.42	625	175	3.5	0.043	3.4	1.3	3.5	0.016	0.9	55.3
Waikareao	Tau P18	22.4	0.43	725	176	3.7	0.043	3.4	1.2	3.3	0.013	0.9	46.0

Tauranga Harbour	Site Name	Mud %	TOC g/100g	TN	TP	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Waikareao	Tau P19	29.6	0.54	650	192	4.0	0.083	3.6	1.6	3.9	0.014	1.1	43.0
Waikareao	Tau P20	5.5	0.29	250	101	1.6	0.057	2.3	0.7	1.6	0.012	0.7	13.5
Waikareao	Tau P21	14.3	0.30	250	109	2.1	0.097	2.7	1.1	2.1	0.017	0.9	19.0
Matua	Tau P22	10.4	0.36	375	97	1.5	0.057	1.9	0.7	1.8	0.008	0.7	11.6
Matua	Tau P23	9.5	0.33	313	111	1.6	0.060	2.1	0.7	1.8	0.008	0.7	11.2
Matua	Tau P24	20.4	0.46	675	154	2.0	0.055	1.9	0.9	2.5	0.009	0.7	18.3
Waikaraka	Tau P25	20.2	0.34	375	126	2.8	0.081	2.3	0.9	2.3	0.018	0.8	14.5
Waikaraka	Tau P26	19.8	0.43	588	165	3.3	0.212	3.0	1.2	2.8	0.039	1.1	25.3
Waikaraka	Tau P27	19.2	0.34	400	133	2.3	0.127	2.4	0.9	1.9	0.018	0.8	15.3
Waikaraka	Tau P28	31.3	0.45	575	155	3.0	0.115	3.1	1.1	2.6	0.025	0.9	19.0
Te Puna	Tau P29	26.0	0.68	883	243	4.5	0.205	6.3	2.0	4.0	0.048	2.6	28.2
Te Puna	Tau P30	34.0	0.77	1025	288	5.7	0.163	5.6	2.3	5.2	0.045	1.9	30.8
Te Puna	Tau P31	16.9	0.35	333	158	2.9	0.083	3.8	1.1	2.8	0.021	1.3	18.0
Te Puna	Tau P32	17.4	0.40	538	139	3.7	0.062	2.6	1.8	3.0	0.022	0.9	14.3
Te Puna	Tau P33	56.2	1.88	2225	498	7.7	0.127	7.5	4.8	8.7	0.058	2.8	41.2
Te Puna	Tau P34	39.8	0.75	850	253	5.9	0.071	5.0	2.4	5.2	0.040	1.7	28.5
Mangawhai	Tau P35	27.5	0.52	700	216	3.5	0.137	4.1	1.5	3.3	0.026	1.4	20.0
Mangawhai	Tau P36	30.5	0.52	700	203	3.7	0.132	3.4	1.5	3.2	0.031	1.2	19.8
Mangawhai	Tau P37	39.7	0.50	563	202	4.3	0.109	4.6	1.6	3.5	0.030	1.5	22.5
Ōmokoroa	Tau P38	14.7	0.34	313	124	2.1	0.081	2.7	0.8	1.9	0.016	0.8	12.0
Waipapa	Tau P39	18.0	0.39	463	158	2.8	0.132	2.6	1.1	2.4	0.024	1.0	15.6
Waipapa	Tau P40	33.6	0.51	625	185	4.0	0.083	3.6	1.5	3.6	0.031	1.3	19.0
Apata	Tau P41	42.5	0.59	588	224	5.0	0.090	6.0	2.0	4.9	0.030	1.9	27.0
Apata	Tau P42	20.6	0.33	400	136	3.3	0.064	4.1	1.2	4.3	0.019	1.0	25.5

Tauranga Harbour	Site Name	Mud %	TOC g/100g	TN	TP	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Wainui	Tau P43	66.0	1.35	NA	NA	7.6	0.106	8.0	3.6	7.3	0.030	3.1	31.0
Wainui	Tau P44	64.0	1.08	1175	335	6.0	0.092	7.4	2.7	6.2	0.040	2.6	28.5
Matahui	Tau P45	27.6	0.44	575	245	9.3	0.110	11.7	3.3	4.7	0.112	5.4	33.8
Rereatukahia	Tau P46	39.2	0.67	800	288	5.4	0.075	7.5	2.6	3.9	0.039	2.6	24.0
Rereatukahia	Tau P47	22.1	0.42	313	156	5.6	0.051	9.3	2.4	4.1	0.038	2.9	20.8
Rereatukahia	Tau P48	37.0	0.84	1000	310	5.8	0.117	6.9	2.4	4.4	0.043	2.6	26.3
Rereatukahia	Tau P67	53.8	1.37	1500	395	7.8	0.080	11.9	4.1	7.4	0.065	4.2	35.0
Rereatukahia	Tau P68	21.6	0.42	600	170	4.2	0.066	5.0	1.4	2.8	0.085	1.6	19.0
Rereatukahia	Tau P69	25.7	0.40	500	162	3.8	0.061	4.9	1.3	2.7	0.025	1.4	17.0
Uretara	Tau P49	7.2	0.23	250	87	2.3	0.030	4.2	0.8	1.8	0.016	1.1	9.0
Uretara	Tau P50	36.9	0.83	825	333	10.4	0.096	8.9	3.3	5.9	0.035	3.1	37.2
Uretara	Tau P51	36.9	0.76	750	273	8.4	0.106	7.3	2.8	5.0	0.035	2.6	31.6
Uretara	Tau P52	34.2	1.16	1525	405	7.6	0.114	8.9	3.1	6.3	0.046	3.5	28.5
Ongare	Tau P53	11.7	0.34	338	161	4.7	0.035	6.9	0.8	2.6	0.012	1.6	14.8
Ongare	Tau P66	17.2	0.42	425	191	5.1	0.093	7.2	1.4	3.9	0.030	1.9	24.5
Tuapiro	Tau P54	12.9	0.37	313	147	2.6	0.071	4.3	1.1	2.0	0.016	1.3	11.5
Tuapiro	Tau P55	24.6	0.64	800	238	5.3	0.120	6.0	2.1	3.6	0.033	2.0	21.2
Tuapiro	Tau P56	15.1	0.33	350	145	2.9	0.068	4.3	1.0	2.0	0.017	1.3	11.8
Waiau	Tau P57	6.2	0.20	250	90	1.9	0.037	3.5	0.5	1.3	0.014	0.7	8.0
Waiau	Tau P58	16.3	0.51	675	125	2.7	0.065	3.1	1.2	2.2	0.020	0.9	12.8
Waiau	Tau P59	8.3	0.23	250	80	2.4	0.023	2.6	0.7	1.8	0.011	0.6	9.5
Bowentown	Tau P60	6.2	0.19	250	95	1.8	0.019	5.0	0.5	1.3	0.009	1.0	7.5
Poi's	Tau P61	5.3	0.27	250	112	2.1	0.030	4.2	0.6	1.6	0.010	1.1	9.3
Otumoetai	Tau P62	5.7	0.27	250	129	2.5	0.041	4.1	0.7	1.8	0.015	1.1	11.5

Tauranga Harbour	Site Name	Mud %	TOC g/100g	TN	TP	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Grace Road	Tau P63	17.1	0.45	500	206	3.4	0.069	3.3	2.4	3.6	0.032	1.1	26.3
Ōhiwa Harbour	**Site Name**	**Mud %**	**TOC g/100g**	**TN**	**TP**	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Hg**	**Ni**	**Zn**
Kutarere	Ohi P1	58.1	0.53	625	363	5.6	0.023	8.5	5.5	6.2	0.050	5.4	36.5
Ōhiwa Camp	Ohi P2	74.5	0.55	575	395	5.6	0.028	8.5	6.3	6.3	0.054	5.9	34.8
Waterways	Ohi P3	32.1	0.30	250	243	4.3	0.010	6.3	3.2	3.5	0.027	3.7	20.0
North	Ohi P4	38.4	0.46	640	354	5.8	0.023	9.7	5.3	5.8	0.048	6.4	34.2
Oyster farm	Ohi P5	39.8	0.55	640	286	5.0	0.017	8.5	4.3	5.1	0.034	4.7	28.3
West	Ohi P6	46.8	0.53	650	290	4.1	0.014	7.7	5.2	5.5	0.042	5.0	29.2
East	Ohi P7	38.4	0.28	250	298	5.3	0.015	6.1	4.1	5.2	0.038	4.6	29.2
Ohi 1	Ohi P8	25.8	0.45	542	342	6.0	0.018	10.0	4.7	6.0	0.044	6.5	33.7
Ohi 2	Ohi P9	21.2	0.33	350	267	5.5	0.020	11.4	3.8	4.6	0.040	6.6	27.8
Ohi 3	Ohi P10	18.1	0.36	433	282	5.6	0.022	7.9	3.6	4.5	0.057	5.1	26.0
Ohi 6	Ohi P11	10.2	0.27	250	333	7.2	0.018	8.6	4.4	5.4	0.041	6.0	35.3
Maketū Estuary	**Site Name**	**Mud %**	**TOC g/100g**	**TN**	**TP**	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Hg**	**Ni**	**Zn**
	Mak P1	6.5	0.26	250	179	4.2	0.011	2.9	0.8	2.2	0.016	1.3	16.0
	Mak P2	24.6	0.47	567	239	5.4	0.072	2.6	1.1	1.8	0.033	1.2	19.3
	Mak P3	4.3	0.19	250	146	3.7	0.012	2.3	0.5	1.5	0.017	0.8	12.7
	Mak P4	5.9	0.33	417	159	3.9	0.036	2.9	0.7	1.6	0.023	1.1	15.0
	Mak P5	14.6	0.34	450	168	6.5	0.039	2.8	0.7	1.6	0.025	1.0	15.5
	Mak P6	17.3	0.38	483	163	6.1	0.036	2.5	0.7	1.5	0.030	1.0	14.5
	Mak P7	17.9	0.34	333	207	5.0	0.025	2.4	0.8	1.9	0.025	0.9	18.5
	Mak P8	55.5	1.80	2100	387	9.6	0.131	5.4	3.1	4.5	0.085	2.2	39.5

Waihī Estuary	Site Name	Mud %	TOC g/100g	TN	TP	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
	Wai P1	18.4	0.36	460	180	2.9	0.045	3.3	1.3	2.0	0.019	1.4	18.2
	Wai P2	40.6	0.84	867	403	4.8	0.062	2.1	1.6	2.9	0.023	0.9	26.7
	Wai P3	52.2	0.51	600	283	4.7	0.033	2.9	1.1	2.1	0.023	1.2	28.0
	Wai P4	72.7	1.26	1550	418	5.5	0.112	4.1	3.0	3.9	0.041	1.9	34.5
	Wai P5	27.0	0.69	800	283	4.1	0.028	2.2	1.2	2.3	0.014	0.9	21.3
	Wai P6	21.8	0.30	250	196	2.9	0.024	2.2	0.8	1.4	0.023	1.0	15.7
ISQG-Low						**20**	**1.5**	**80**	**65**	**50**	**0.15**	**21**	**200**
ISQG-High						**70**	**10**	**370**	**250**	**220**	**1**	**52**	**410**

River sediment heavy metals

The results of the one-off river sediment heavy metal survey are reported in Table 7. All metals were below the ISQG guidelines at all sites. Arsenic concentrations were elevated at Waiowhiro at Bonningtons Farm (18.3 mg/kg DW) and Puarenga at FRI (16.5 mg/kg DW) which was close to the ISQG-low concentration of 20 mg/kg DW. Cadmium concentrations were greatest at Waimapu at SH2 (0.179 mg/kg DW) and Matahui at Elmwood Road (0.151 mg/kg DW). The highest chromium concentrations were recorded in the northern Tauranga Harbour area (Aongatete at SH 2, 16.4 mg/kg DW; Matahui at Elmwood Road, 13 mg/kg DW; and Tuapiro at Hikurangi Road, 14.3 mg/kg DW). Copper was highest at Matahui at Elmwood Road (13.2 mg/kg DW) and Aongatete at SH 2 (11.5 mg/kg DW) sites. The greatest lead concentrations were recorded at Matahui at Elmwood Road, which had over double the concentration of all other sites (15 mg/kg DW). Mercury concentrations breached the ISQG-low guidelines (0.15 mg/kg DW) at three sites; two sites were Lake Rotorua inflows (Puarenga at FRI, 0.33 mg/kg DW; and Utuhina at Lake Road, 0.27 mg/kg DW) whilst one was located in the northern Tauranga Harbour (Matahui at Elmwood Road, 0.15 mg/kg DW). Nickel concentrations were greatest at Aongatete at Tuapiro Road (9.9 mg/kg DW) with elevated concentrations also at Tuapiro at Hikurangi Road (7.2 mg/kg DW). Zinc had the greatest concentration at Waimapu at SH 29 (55 mg/kg DW), and higher concentrations also Matahui at Elmwood Road (46 mg/kg DW) and Waikite at Welcome Bay (46 mg/kg DW). Overall, Matahui at Elmwood Road has the greatest concentrations for the majority of the heavy metal species, although this site has the greatest TOC (3.7 g/100g).

Table 7 *Concentrations of sediment total organic carbon (TOC; g/100g) and heavy metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Zn; mg/kg dry weight) collected from a one-off survey of rivers across the Bay of Plenty region. Coloured highlights indicate the sediment heavy metal banding system described in Table 3 (Blue= very good, Green= Good, Orange = Fair, Red = Poor).*

	TOC g/100g	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Waiteti at SH 36	0.42	4.5	0.03	1.7	1.3	3.3	< 0.02	0.5	23
Ngongotaha at SH 36	0.08	3.4	0.019	1.1	0.5	2.8	< 0.02	0.3	20
Waiowhiro at Bonningtons Farm	1.08	18.3	0.044	1.8	2.6	5.6	0.07	0.7	27
Utuhina at Lake Road	0.15	5.6	0.025	1.5	1.5	4.4	0.27	0.9	19.6
Puarenga at FRI	0.12	16.5	0.011	0.9	1.3	2	0.33	0.2	7.8
Matahui at Elmwood Road	3.7	5.4	0.151	13	13.2	15	0.15	5.8	46
Aongatete at SH 2	0.2	1.9	0.026	16.4	11.5	5.9	0.03	9.9	35
Lowe Creek at SH 2	0.46	2.8	0.029	2.3	2.4	5.5	0.03	1.1	26
Tuapiro at Hikurangi Road	0.36	3.1	0.05	14.3	5	7.3	0.06	7.2	43
Uretara at Henry Road Ford	0.51	1.7	0.042	12.2	4.7	6.9	0.04	4.7	35
Te Mania at SH 2	0.17	1.4	0.022	12.4	2.6	5.5	0.1	5.6	18.5
Kopurererua at SH 2	0.06	0.9	< 0.010	0.7	0.5	3	< 0.02	0.2	13.7
Waikite at Welcome Bay Road	0.43	2.7	0.02	2.3	2.5	4	0.02	0.7	46
Kaitemako R/B Tributary at D/S Welcome Bay Road	0.12	0.9	0.027	2	1.2	2.8	0.02	0.6	17.7
Waimapu at SH 29	3.7	3.1	0.179	3.9	6.2	10.9	0.07	1.4	55
ISQG Low		20	1.5	80	65	50	0.15	21	200
ISQG High		70	10	370	250	220	1	52	410

Estuary water heavy metals

Water samples were collected from the 10 passive sampler device monitoring sites over a three week period in May 2019 at low tide for average heavy metal concentrations. It is noted that these average water column metal concentrations represent a period of time with little rainfall occurring (Figure 5).

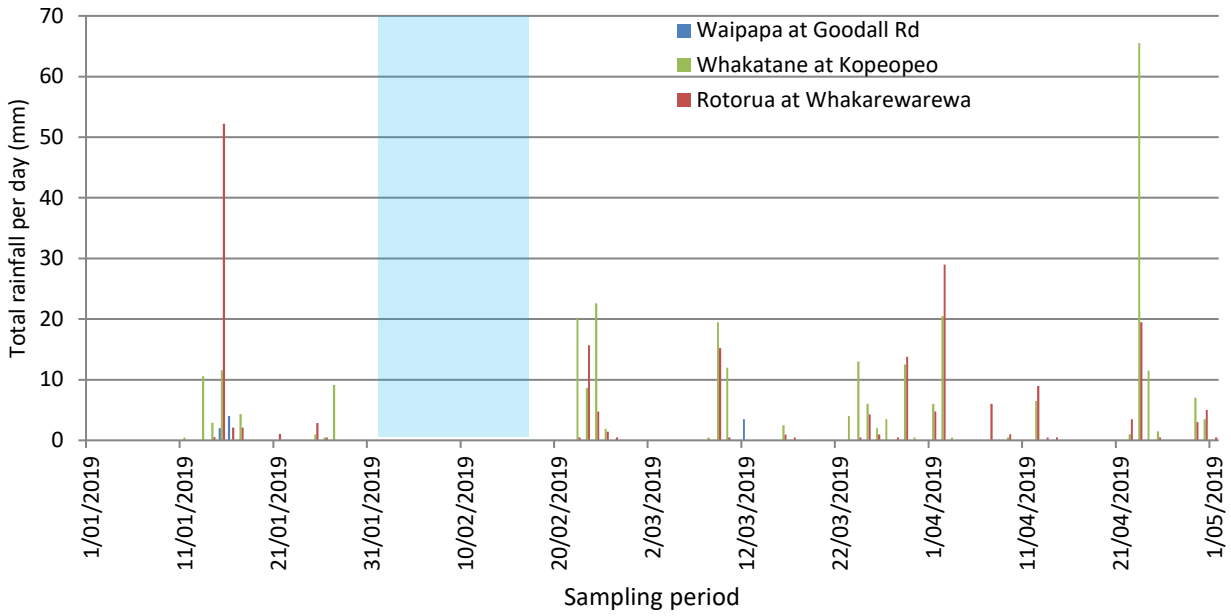

Figure 5 *Total rainfall per day (mm) ranging from 1 January – 1 May 2019 at BOPRC continuous rainfall monitoring sites (Waipapa at Goodall Road, Whakatāne at Kopeopeo and Rotorua at Whakarewarewa). Period of blue background represents the time period of freshwater sampling (2 February-13 February) across all sites in the Bay of Plenty region.*

Table 8 shows the results from the estuary water heavy metal monitoring sites. At all sites arsenic, cadmium and nickel were below detection limits and DGV across all sampling periods. Chromium was above detection limits at all sites, although the concentrations were below the 99% DGV of 7.7 ug/L. The highest average chromium concentration was recorded at Welcome Bay (3.5 ug/L). Copper was below detection at the majority of sites with the exception of Welcome Bay and Rangataua Bay. The detection limit for copper (1.1 ug/L) is higher than the 99% DGV so we are unable to assess potential impacts of copper above the 99% DGV. Rangataua Bay breached the 95% DGV with an average water concentration of 1.7 ug/L. Welcome Bay breached the 90% DGV with an average water concentration of 3.2 ug/L. Lead concentrations were below detection limits at the majority of sites with the exception of Welcome Bay, Rangataua Bay and Waikareao. Rangataua Bay and Waikareao were below the 99% DGV for lead (2.2 ug/L), however, Welcome Bay breached the 99% DGV with a lead concentration of 3.7 ug/L. Zinc concentrations were below detection limits at the majority of sites with exception of Welcome Bay, Rangataua Bay and Waikareao. Rangataua Bay and Waikareao were below the 99% DGV for zinc (5.5 and 6.8 ug/L respectively). Zinc concentrations at Welcome Bay breached the 95% DGV with an average concentration of 17.7 ug/L.

Table 8 *Average estuary heavy metal concentrations (ug/L) from three weekly water samples. Note samples showing above detection limits are in bold. Samples that exceed one or more of the toxicant default guideline values (DGV) are highlighted in colours relevant to their banding.*

	As	Cd	Cr	Cu	Pb	Ni	Zn
Te Puna	<4.2	<0.2	**1.8**	<1.1	<1.1	<7	<4.2
Tuapiro	<4.2	<0.2	**1.7**	<1.1	<1.1	<7	<4.2
Katikati	<4.2	<0.2	**2.1**	<1.1	<1.1	<7	<4.2
Welcome Bay	<4.2	<0.2	**3.5**	**3.2**	**3.7**	<7	**17.7**
Rangataua Bay	<4.2	<0.2	**1.5**	**1.7**	**1.5**	<7	**5.5**
Bridge Marina	<4.2	<0.2	**1.5**	<1.1	<1.1	<7	<4.2
Waikareao	<4.2	<0.2	**1.9**	<1.1	**1.2**	<7	**6.8**
Wairoa	<4.2	<0.2	**1.2**	<1.1	<1.1	<7	<4.2
Otumoetai	<4.2	<0.2	**1.3**	<1.1	<1.1	<7	<4.2
Waimapu	<4.2	<0.2	**1.9**	<1.1	<1.1	<7	<4.2
99% DGV	NA	0.7	7.7	0.3	2.2	7	7
95% DGV	NA	5.5	27.4	1.3	4.4	70	15
90% DGV	NA	14	48.6	3	6.6	200	23
80% DGV	NA	36	90.6	8	12	560	43

River water heavy metals

A one-off survey of river water heavy metals was conducted during summer 2018/19 and represents a snapshot of the state of the environment during low rainfall conditions (Figure 5). At all river water sites the heavy metals cadmium and nickel were below detection limits (Table 9). For arsenic, 12 of the 22 sites were above detection limits. The highest arsenic concentrations were recorded at Tarawera at SH 2 (36 ug/L), followed by Puarenga at FRI and Waikite at Welcome Bay Road (33 ug/L). These three sites were graded at 95% DGV good category, whilst the rest were at lower concentrations below the 99% DGV very good category. For chromium, nine of the 22 sites were above detection limits. The highest concentrations of chromium were recorded at Waiowhiro at Bonningtons Farm (5.4 ug/L) followed by Tarawera at SH 2 (4.3 ug/L), which were both graded in the 90% DGV fair category. Another two sites were graded in the 90% DGV, and five sites in the 95% DGV good category. For copper, eight of the 22 sites were above detection limits. The highest concentrations were recorded at Tarawera at SH 2 (3.2 ug/L), which was graded in the poor category (80% DGV). The next highest copper concentrations were Kaituna at inlet 1 km u/s of cut (1.76 ug/L), Waimapu at SH 29 (1.66 ug/L) and Puarenga at FRI (1.57 ug/L). These three sites were all graded in the fair 90% DGV grading's for copper. For lead, eight of the 22 sites were above detection limits. The highest concentrations of lead were recorded at Kaitemako R/B Tributary at D/S Welcome Bay Road (0.42 ug/L). All lead concentrations were in the very good 99% DGV grading. Zinc was the most commonly detected heavy metal species, with 14 of the 22 sites above detection limits. The highest concentrations of zinc were reported at Tarawera at SH 2 (6.1 ug/L), followed by Waikite at Welcome Bay Road (5.5 ug/L). Nine sites were in the 95% DGV good category for zinc concentrations.

Table 9 *One-off river heavy metal concentrations (ug/L) from sites across the Bay of Plenty. Samples above detection limits are in bold. Colours show grading based on Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) toxicant default guideline values (DGV). Blue= Very good, Green= Good, Yellow = Fair, Orange = Poor.*

	As	Cd	Cr	Cu	Pb	Ni	Zn
Waiteti at SH 36	**1.2**	< 0.053	< 0.53	< 0.53	< 0.11	< 0.53	**3**
Ngongotaha at SH 36	**1.5**	< 0.053	**0.76**	< 0.53	< 0.11	< 0.53	**2.3**
Waiowhiro at Bonningtons Farm	**1.4**	< 0.053	**5.4**	< 0.53	< 0.11	< 0.53	**3.7**
Utuhina at Lake Road	**5**	< 0.053	**0.72**	**1.05**	**0.12**	< 0.53	**3**
Puarenga at FRI	**33**	< 0.053	**1.36**	**1.57**	**0.25**	< 0.53	**4**
Whakatāne at Landing Road	< 11	< 0.53	< 5.3	< 5.3	< 1.1	< 5.3	< 11
Rangitāiki River at Thornton Bridge	< 1.1	< 0.053	< 0.53	< 0.53	< 0.11	< 0.53	< 1.1
Matahui at Elmwood Road	< 2.1	< 0.11	< 1.1	< 1.1	< 0.21	< 1.1	< 2.1
Aongatete at SH 2	< 1.1	< 0.053	**1**	**0.74**	< 0.11	< 0.53	**2.4**
Wainui at SH 2 Bridge	< 11	< 0.53	< 5.3	<5.3	< 1.1	< 5.3	< 11
Lowe Creek at SH 2	< 21	< 1.1	< 11	< 11	< 2.1	< 11	< 21
Te Puna at SH 2 Bridge	< 1.1	< 0.53	< 5.3	< 5.3	< 1.1	< 5.3	< 11
Kaituna at inlet 1 km u/s of cut	**4.8**	< 0.053	**0.94**	**1.76**	**0.16**	< 0.53	**3.5**
Tarawera at SH 2	**36**	< 0.053	**4.3**	**3.2**	**0.19**	< 0.53	**6.1**
Wairoa at SH 2	< 5.3	< 0.27	< 2.7	< 2.7	< 0.53	< 2.7	< 5.3
Tuapiro at Hikurangi Road	**1.2**	< 0.053	**0.58**	< 0.53	< 0.11	< 0.53	**1.2**
Uretara at Henry Road Ford	**1.5**	< 0.053	< 0.53	< 0.53	< 0.11	< 0.53	< 1.1
Te Mania at SH 2	**1.4**	< 0.053	< 0.53	< 0.53	< 0.11	< 0.53	**1.2**
Kopurererua at SH 2	**5**	< 0.053	< 0.53	< 0.53	**0.19**	< 0.53	**2.1**
Waikite at Welcome Bay Road	**33**	< 0.053	< 0.53	**0.57**	**0.16**	< 0.53	**5.5**
Kaitemako R/B Tributary at D/S Welcome Bay Road	< 11	< 0.053	< 0.53	**0.64**	**0.42**	< 0.53	**3.4**
Waimapu at SH 29	< 1.1	< 0.053	**0.88**	**1.66**	**0.19**	< 0.53	**2.8**
99% DGV	27	0.06	0.01	1	1	8	2.4
95% DGV	55	0.2	1	1.4	3.4	11	8
90% DGV	80	0.4	6	1.8	5.6	13	15
80% DGV	150	0.8	39	2.5	9.4	17	31

Shellfish heavy metals

Shellfish were collected where possible from the estuary sites, where passive samplers were deployed to indicate the comparative bioavailability of sediment and water column contaminants to the estuary biology. Tuangi (*Austrovenus stuchburyi*; cockle) were collected from eight sites, titiko (*Amphibola crenata*; mud snail) from three sites, and pipi (*Paphies australis*) and hanikura (*Macomona liliana*; wedge shell) from one site. Generally the tuangi sites were located further downstream from the sediment collection sites as the conditions were too muddy for tuangi in the upper estuary reaches. Tuangi size (site average) showed a decrease with the increasing total organic carbon (Figure 6) (which has been shown to be closely linked with % mud content, not reported in this survey). Sites with no tuangi present were located in highly muddy, organic rich regions (Katikati; 0.86 g/100g DW and Waimapu C176; 0.64 g/100g DW). For Te Puna, tuangi were collected outside of the main estuary arm on the edge of the outflowing channel in sandy sediments.

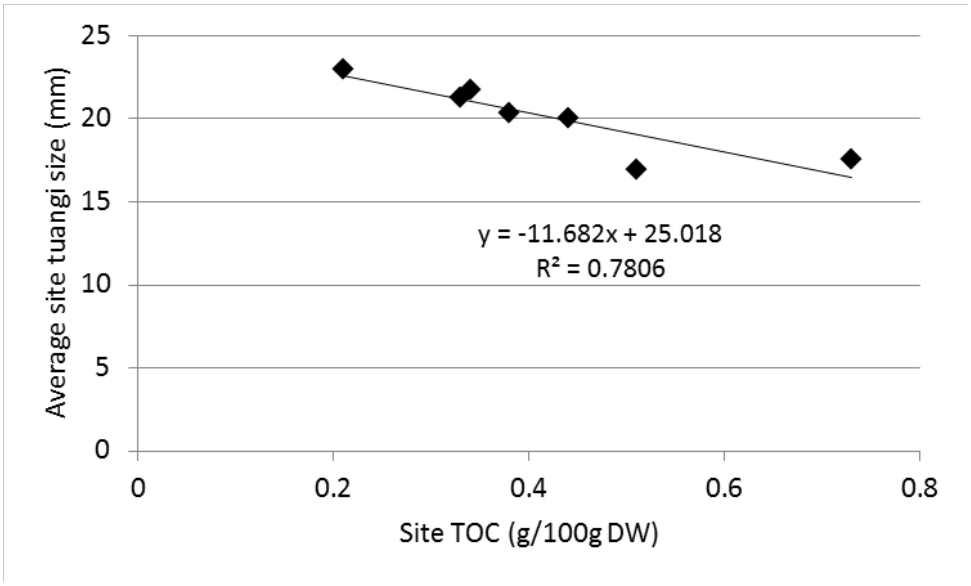

Figure 6 *Average site tuangi size against the site sediment total organic carbon (TOC).*

The Food Safety Australia New Zealand (FSANZ) Code publishes food safety standards for shellfish. The report has heavy metal limits only for cadmium (2 mg/kg wet weight), lead (2 mg/kg wet weight), and mercury (0.5 mg/kg wet weight). The US Federal Drug Agency estimate shellfish safety for arsenic to be above 86 mg/kg wet weight (1 mg/kg inorganic arsenic (FSANZ)). The heavy metal concentrations in the shellfish were compared against these guidelines as an indication of food consumption safety. The shellfish collected from Tauranga Harbour were well within safe eating standards (Table 10).

As tuangi are filter feeders, they represent “bioavailable” contamination sourced predominantly from the water column or suspended particulate sediments (Stewart *et al.*, 2016). Shellfish heavy metal concentrations are individually displayed in Figure 7. Chromium and copper concentrations were higher in the titiko than the tuangi.

Table 10 Concentration of heavy metals (mg/kg wet weight) in shellfish in Tauranga Harbour.

Site	Shellfish	Average size (mm)	As	Cd	Cr	Cu	Pb	Ni	Zn
Tuapiro	Tuangi	20.05	2.7	0.021	0.36	1.58	0.02	1.24	7.3
Te Puna	Tuangi	19.08	3	0.021	0.3	3.1	0.029	1.27	5.3
Wairoa	Tuangi	21.73	1.6	0.015	0.14	0.75	0.066	0.9	7.1
Otumoetai	Tuangi	22.96	2.8	0.028	0.3	1.35	0.016	1.38	6.2
Welcome Bay	Tuangi	17.53	1.24	0.014	0.19	1.34	0.028	0.93	6
Waimapu	Tuangi	16.94	0.66	0.01	0.08	1.39	0.014	0.52	4.6
Waimapu	Titiko	16.94	1.34	0.0187	2.4	19.6	0.69	1.2	9.7
Rangataua Bay	Tuangi	21.24	1.1	0.016	0.14	1.11	0.029	0.64	6.7
Rangataua Bay	Titiko	24.43	1.43	0.04	3	19.6	0.31	1.42	7.7
Waikareao	Tuangi	20.34	2.5	0.021	0.33	1.39	0.027	1.17	6.2
Waikareao	Titiko	26.26	0.94	0.014	0.63	10.3	0.24	0.28	6.7
Waikareao	Pipi	46.25	3.1	0.04	1.88	23	1.28	1.08	23
Waikareao	Hanikura	29.60	2.5	0.053	0.2	1.41	0.055	0.16	10
FSANZ Limit (mg/kg wet weight)	-	-	86*	2	NA	NA	2	NA	NA

* 1 mg/kg inorganic arsenic

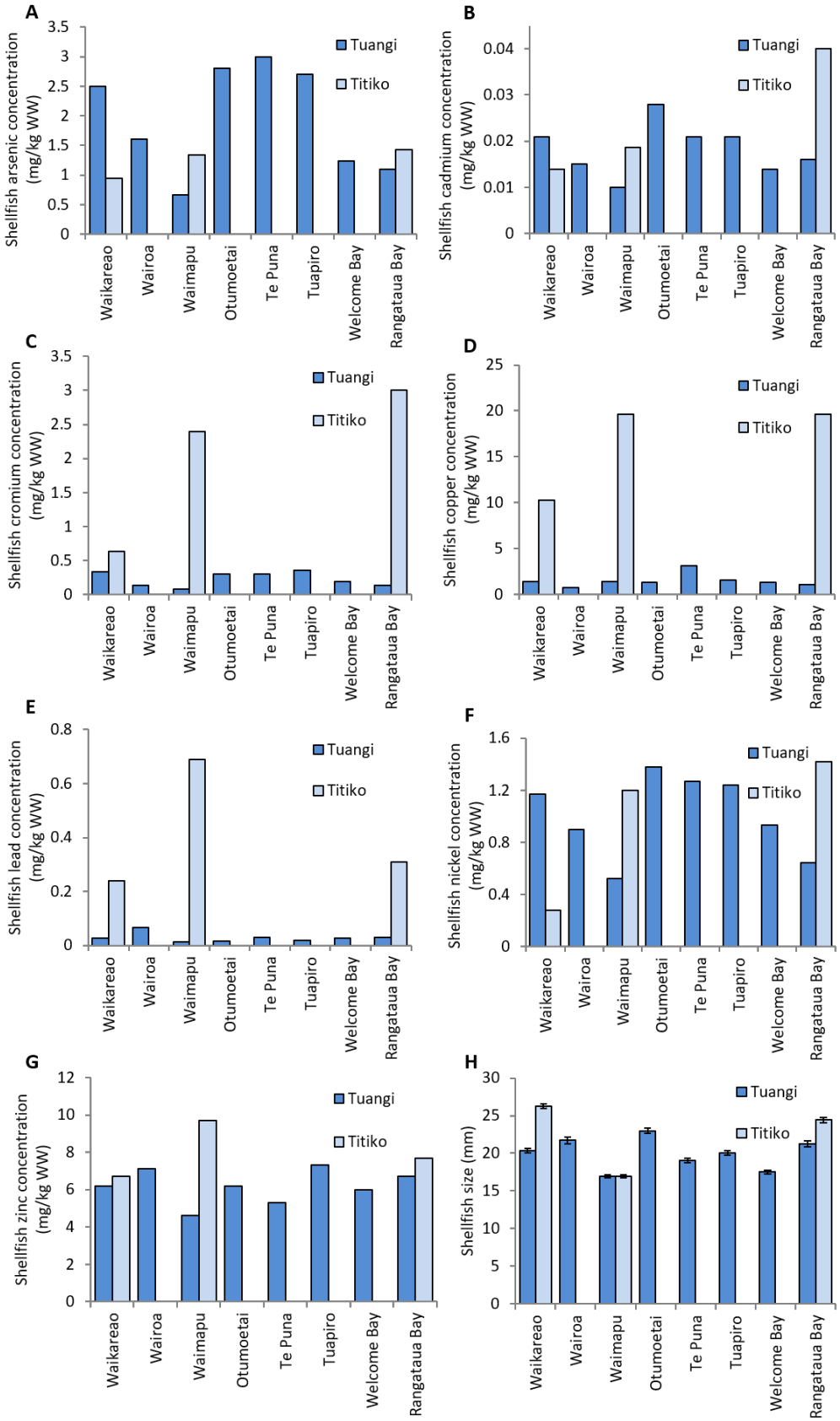

Figure 7 *Shellfish heavy metal concentrations (mg/kg wet weight) in tuangi flesh (dark blue) and titiko flesh (light blue) across the sites where the shellfish species were present. A = arsenic, B = cadmium, C = cromium, D = copper, E = lead, F = nickel, G = zinc, H = shellfish size.*

Long term estuary sediment heavy metal trends

A number of estuarine sites have had annual monitoring since the early 1990s, with another subset having at least 10 years of monitoring back to the early 2000s. These sites have been extracted from the data set to investigate long term trends in sediment contaminants. This resulted in one site from both Maketū Estuary and Waihī Estuary respectively, four sites from Ōhiwa Harbour, and 19 sites from Tauranga Harbour. The annual sediment sample results were each plotted against year sampled, with the colour across all plots coded to the concentration of the contaminant (red = higher, blue = lower). Linear regression was used to identify significant change over time.

Sediment total organic carbon trends

For total organic carbon (Figure 8), there was a lot of variability between sites. Significant increases in TOC were evident at Tau P15 (Waikareao, $p<0.05$, $R^2 = 0.48$), Tau P33 (Te Puna, $p<0.05$, $R^2 = 0.59$), and Tau P8 (Welcome Bay, $p<0.05$, $R^2 = 0.51$). Decreases in TOC were recorded at Ohi P10 ($p<0.01$, $R^2 = 0.39$), Ohi P11 ($p<0.05$, $R^2 = 0.23$), Ohi P9 ($p<0.01$, $R^2 = 0.35$), Tau P22 (Matua, $p<0.05$, $R^2 = 0.53$), Tau P23 (Matua, $p<0.01$, $R^2 = 0.73$), Tau P5 (Welcome Bay, $p<0.05$, $R^2 = 0.50$), Tau P50 (Katikati, $p<0.01$, $R^2 = 0.58$), Tau P51 (Uretara, $p<0.05$, $R^2 = 0.61$), and Wai P1 ($p<0.01$, $R^2 = 0.33$).

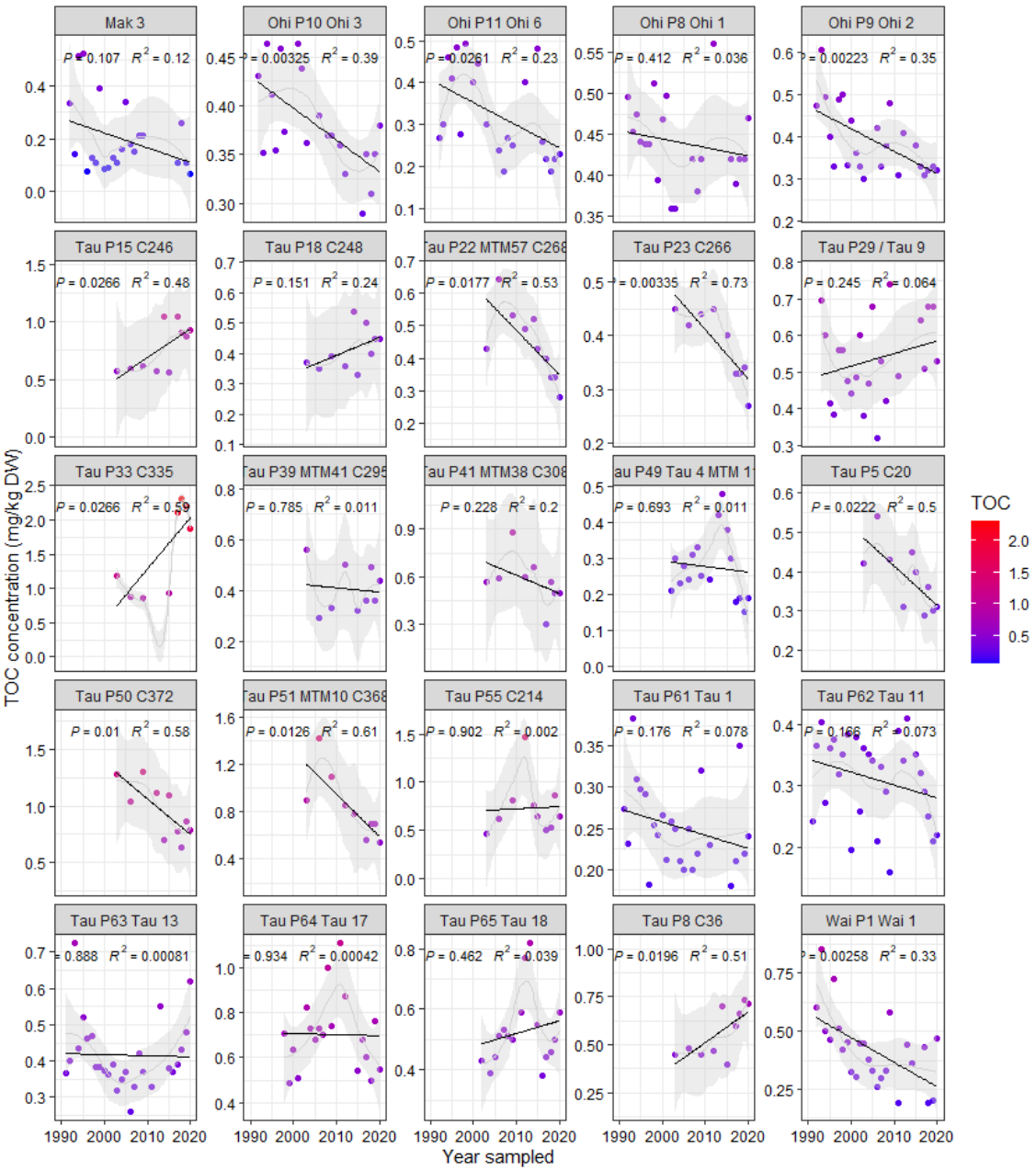

Figure 8 *Total organic carbon concentration (TOC, g/100g DW) against year sampled at 25 sites with monitoring data dating back a minimum of 10 years. A loess regression line (locally weighted least squares regression) is fitted (grey), and a linear trend line (black). The points are colour coded to the concentration of TOC. Significance of trend was assessed with linear regression (p and R^2).*

Sediment arsenic trends

Arsenic concentrations across the estuaries were also quite variable (Figure 9), however, there was a number of significant increases of arsenic at some sites in Tauranga Harbour (Figure 9). Increases in arsenic concentrations are evident at Tau P33 (Te Puna $p<0.05$, $R^2 = 0.48$), Tau P39 (Waipapa $p<0.05$, $R^2 = 0.48$), Tau P51 (Uretara $p<0.05$, $R^2 = 0.51$), and Tau P63 (Grace Rd $p<0.05$, $R^2 = 0.31$), with stronger correlations at Tau P15 (Waikareao $p<0.01$, $R^2 = 0.63$) and Tau P8 (Welcome Bay $p<0.01$, $R^2 = 0.66$). At site Tau P22 arsenic concentrations appear to be steadily decreasing (Matua $p<0.01$, $R^2 = 0.75$).

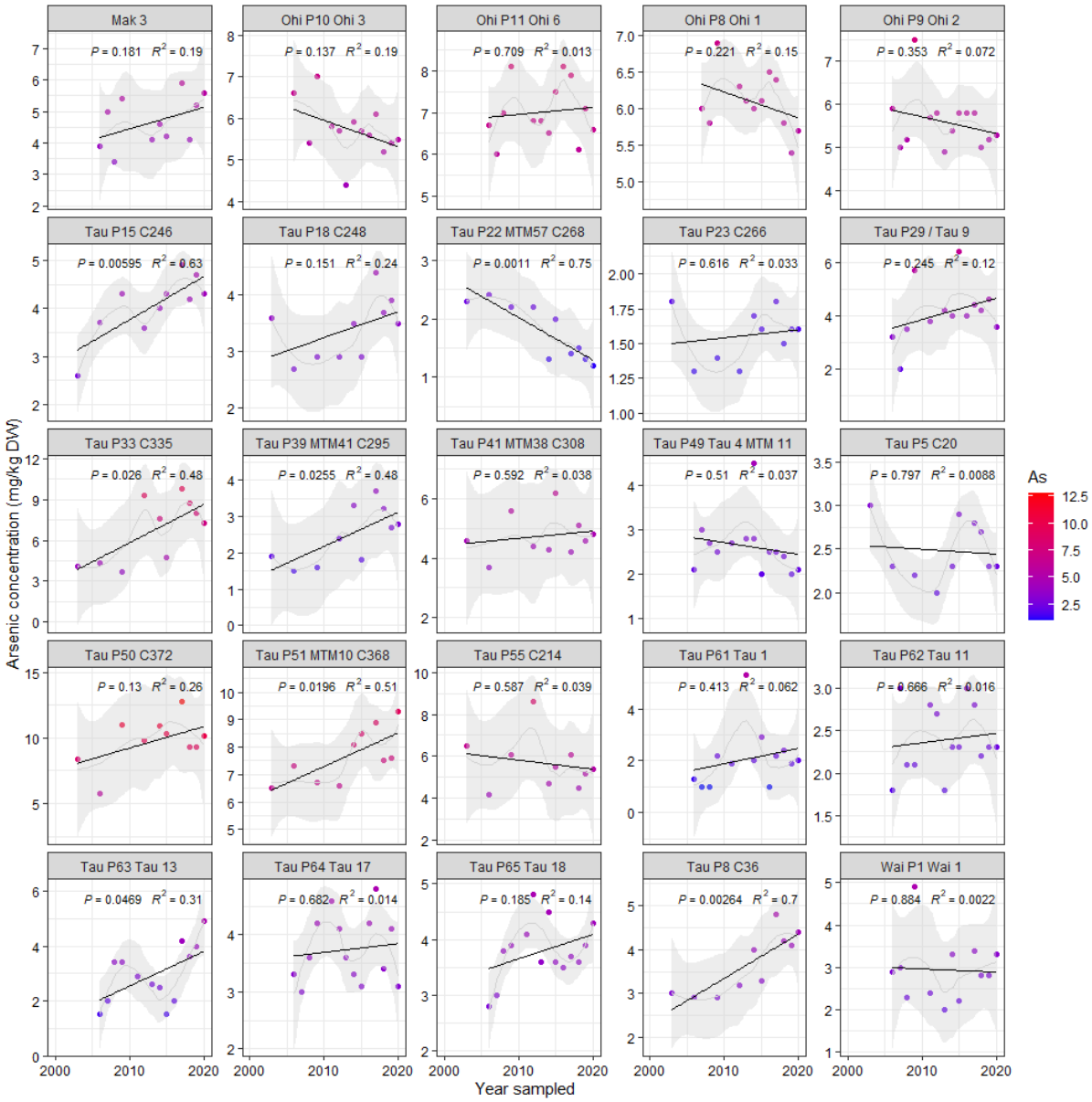

Figure 9 *Sediment arsenic concentration (mg/kg DW) against year sampled at 25 sites with monitoring data dating back a minimum of 10 years. A loess regression line (locally weighted least squares regression) is fitted (grey), and a linear trend line (black). The points are colour coded to the concentration of arsenic. Significance of trend was assessed with linear regression (p and R^2).*

Sediment cadmium trends

Cadmium concentrations in Ōhiwa Harbour have been decreasing slightly at all sites (Figure 10) (Ohi P10 $p<0.05$, $R^2 = 0.42$; Ohi P11 $p<0.05$, $R^2 = 0.41$; Ohi P8 $p<0.001$, $R^2 = 0.69$; Ohi P9 $p<0.05$, $R^2 = 0.39$). However, the regression relationships are weighted strongly to two high points in the early 2000s that then drop back down again. In Tauranga Harbour one site is decreasing in cadmium concentrations (Katikati Tau P51 $p<0.05$, $R^2 = 0.58$). Six sites in Tauranga Harbour are increasing in cadmium concentrations (Tau P23 Matua $p<0.05$, $R^2 = 0.51$; Tau P33 Te Puna $p<0.05$, $R^2 = 0.51$; Tau P15 Waikareao $p<0.01$, $R^2 = 0.61$; Tau P29 Te Puna $p<0.01$, $R^2 = 0.62$; Tau P39 Waipapa $p<0.01$, $R^2 = 0.59$; Tau P41 Apata $p<0.05$, $R^2 = 0.46$).

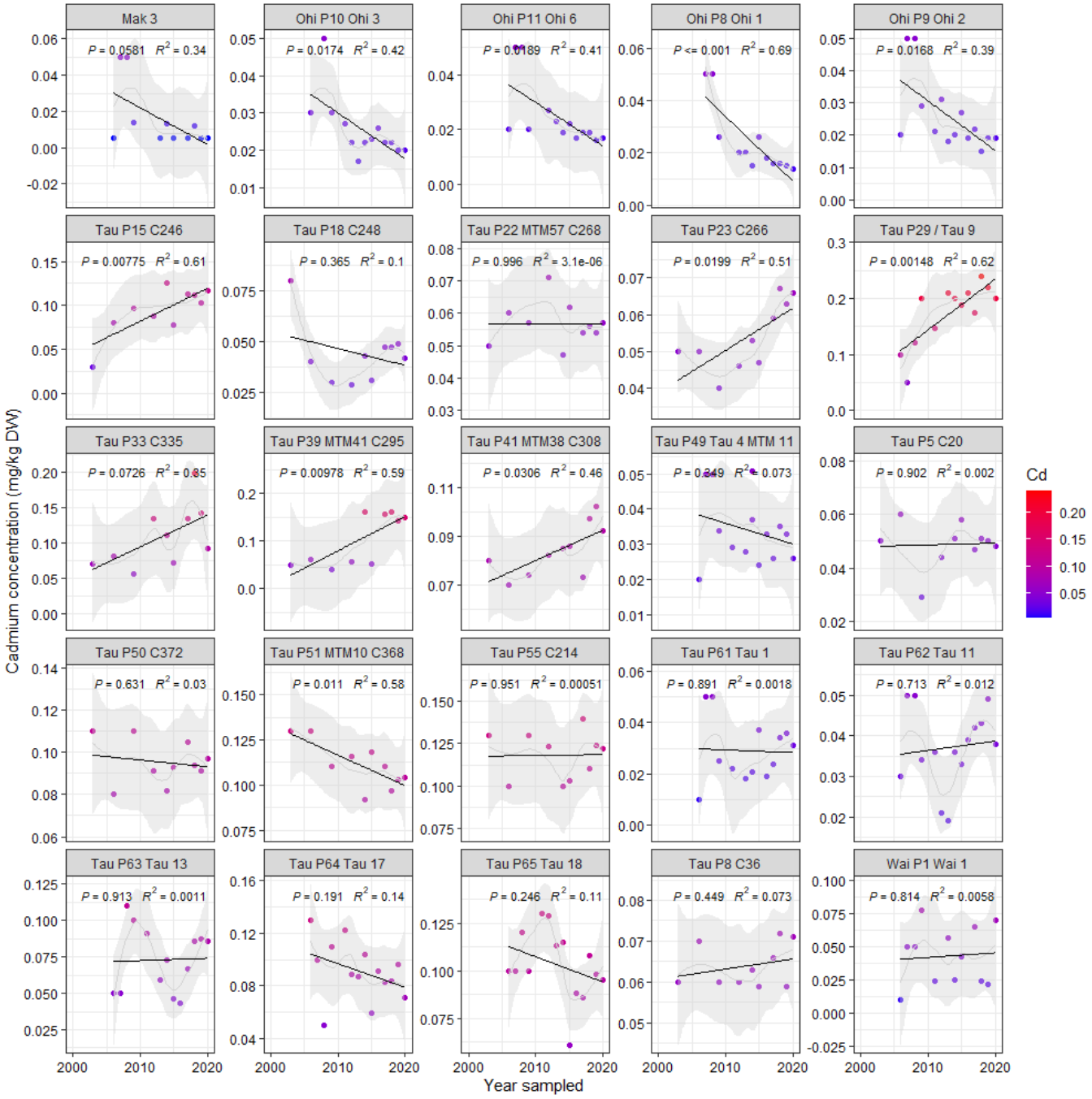

Figure 10 *Sediment cadmium concentration (mg/kg DW) against year sampled at 25 sites with monitoring data dating back a minimum of 10 years. A loess regression line (locally weighted least squares regression) is fitted (grey), and a linear trend line (black). The points are colour coded to the concentration of cadmium. Significance of trend was assessed with linear regression (p and R^2).*

Sediment chromium trends

Sediment chromium concentrations show significant increases at one site in Tauranga Harbour (Figure 11), Tau P15 (Waikareao $p<0.01$, $R^2 = 0.61$). Slight sediment chromium decreases are evident at site Tau P64 (Waimapu $p<0.05$, $R^2 = 0.31$).

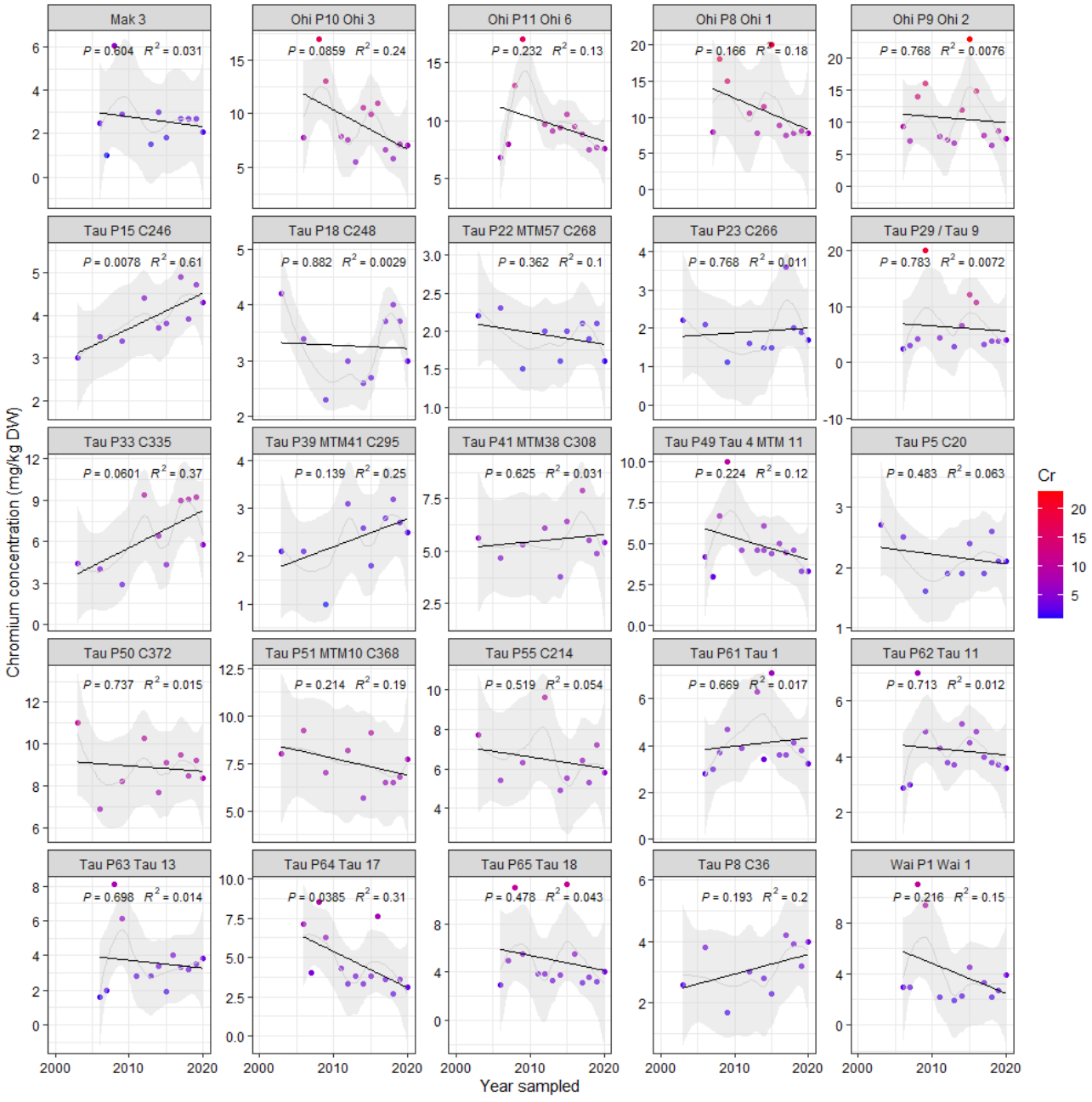

Figure 11 *Sediment chromium concentration (mg/kg DW) against year sampled at 25 sites with monitoring data dating back a minimum of 10 years. A loess regression line (locally weighted least squares regression) is fitted (grey), and a linear trend line (black). The points are colour coded to the concentration of chromium. Significance of trend was assessed with linear regression (p and R^2).*

Sediment copper trends

Copper concentrations across the sites were quite variable (Figure 12). In Ōhiwa Harbour, all sites appear to have a slight decrease in copper, however, this was only significant at Ohi P8 ($p<0.05$, $R^2 = 0.35$) and Ohi P9 ($p<0.05$, $R^2 = 0.32$). Two sites in Tauranga Harbour (Waikareao & Welcome Bay) are showing an increase in copper over time (Tau P15 $P<0.001$, $R^2 = 0.83$; Tau P8 $p<0.05$, R2 = 0.39). Five sites in Tauranga Harbour are showing decreasing concentrations in copper (Tau P22 Matua $p<0.01$, $R^2 = 0.70$; Tau P23 Matua $p<0.05$, $R^2 = 0.55$; Tau P41 Apata $p<0.05$, $R^2 = 0.50$; Tau P5 Welcome Bay $p<0.01$, $R^2 = 0.66$; Tau P64 Waimapu $p<0.05$, $R^2 = 0.30$).

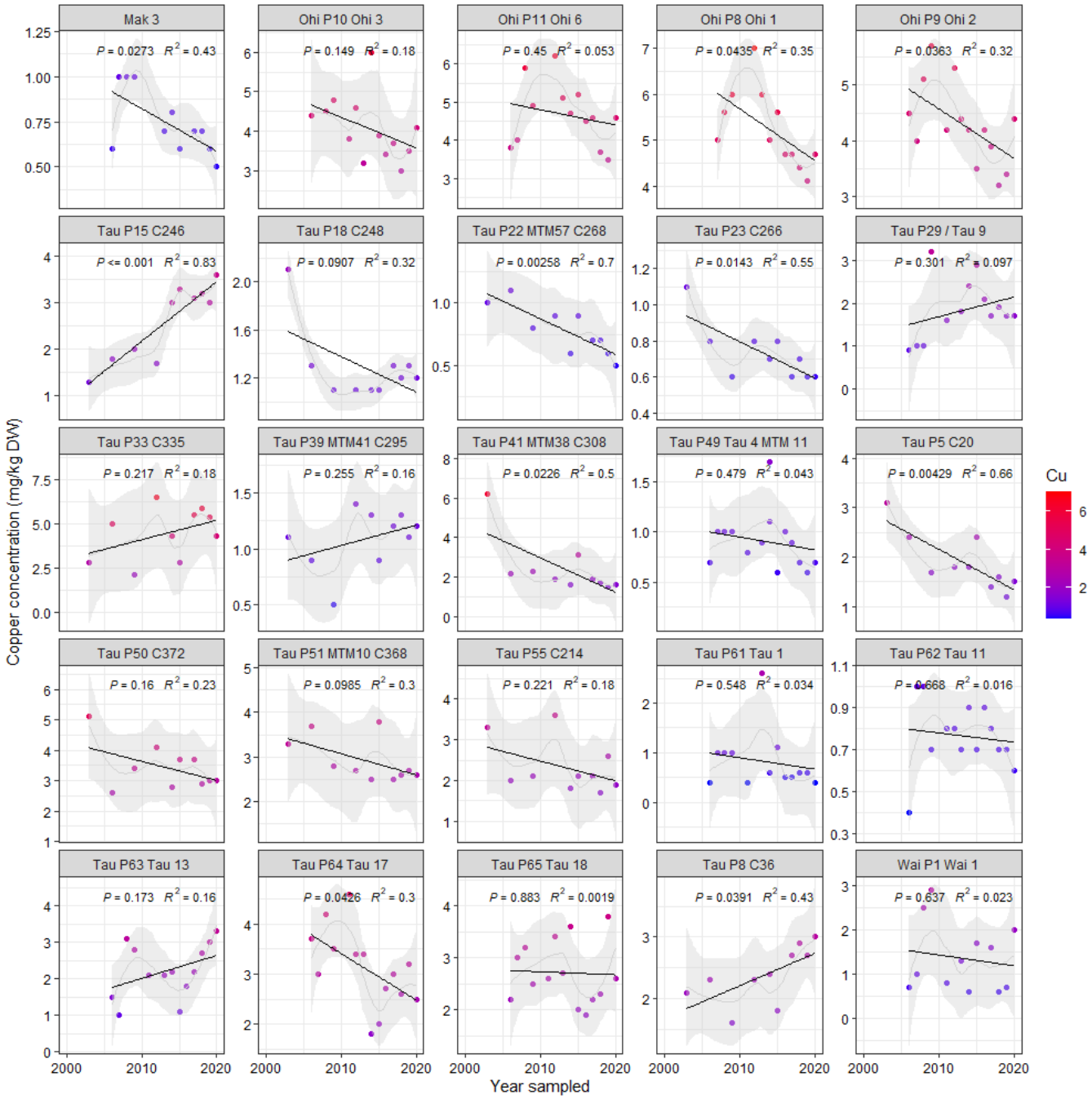

Figure 12 *Sediment copper concentration (mg/kg DW) against year sampled at 25 sites with monitoring data dating back a minimum of 10 years. A loess regression line (locally weighted least squares regression) is fitted (grey), and a linear trend line (black). The points are colour coded to the concentration of copper. Significance of trend was assessed with linear regression (p and R^2).*

Sediment lead trends

In Ōhiwa, similarly to the copper concentrations, lead also showed a decreasing trend across a number of the sites (Figure 13), however this was only significant at Ohi P9 ($p<0.05$, $R^2 = 0.33$). One site in Tauranga Harbour (Waikareao) is showing an increase in lead over time (Tau P15 $P<0.01$, $R^2 = 0.70$). Three sites in Tauranga Harbour are showing decreasing concentrations in lead (Tau P22 Matua $p<0.01$, $R^2 = 0.68$; Tau P23 Matua $p<0.05$, $R^2 = 0.45$; Tau P5 Welcome Bay $p<0.01$, $R^2 = 0.59$).

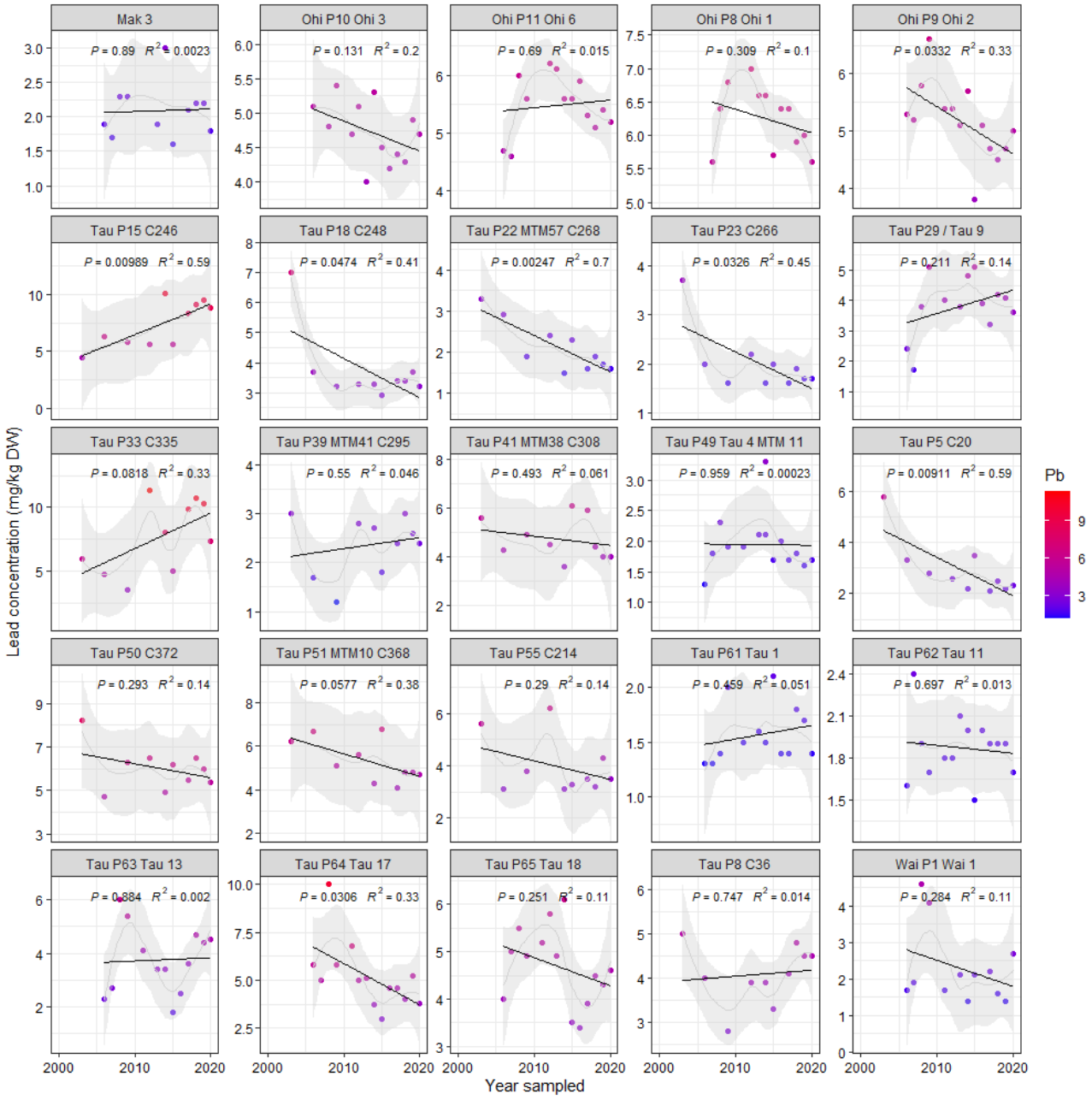

Figure 13 *Sediment lead concentration (mg/kg DW) against year sampled at 25 sites with monitoring data dating back a minimum of 10 years. A loess regression line (locally weighted least squares regression) is fitted (grey), and a linear trend line (black). The points are colour coded to the concentration of lead. Significance of trend was assessed with linear regression (p and R^2).*

Sediment mercury trends

Concentrations of mercury are very low across the region (Figure 14), with most sites near the detection limit (<0.02 mg/kg DW). A number of sites showed very slight decreases in mercury concentrations (Tau P22 Matua p<0.05 R^2 = 0.54; Tau P5 Welcome Bay p<0.05 R^2 = 0.61; Tau P50 p<0.05, R2 = 0.46; Tau P64 p<0.05, R^2 = 0.29; Ohi P8 p<0.05, R^2 = 0.37).

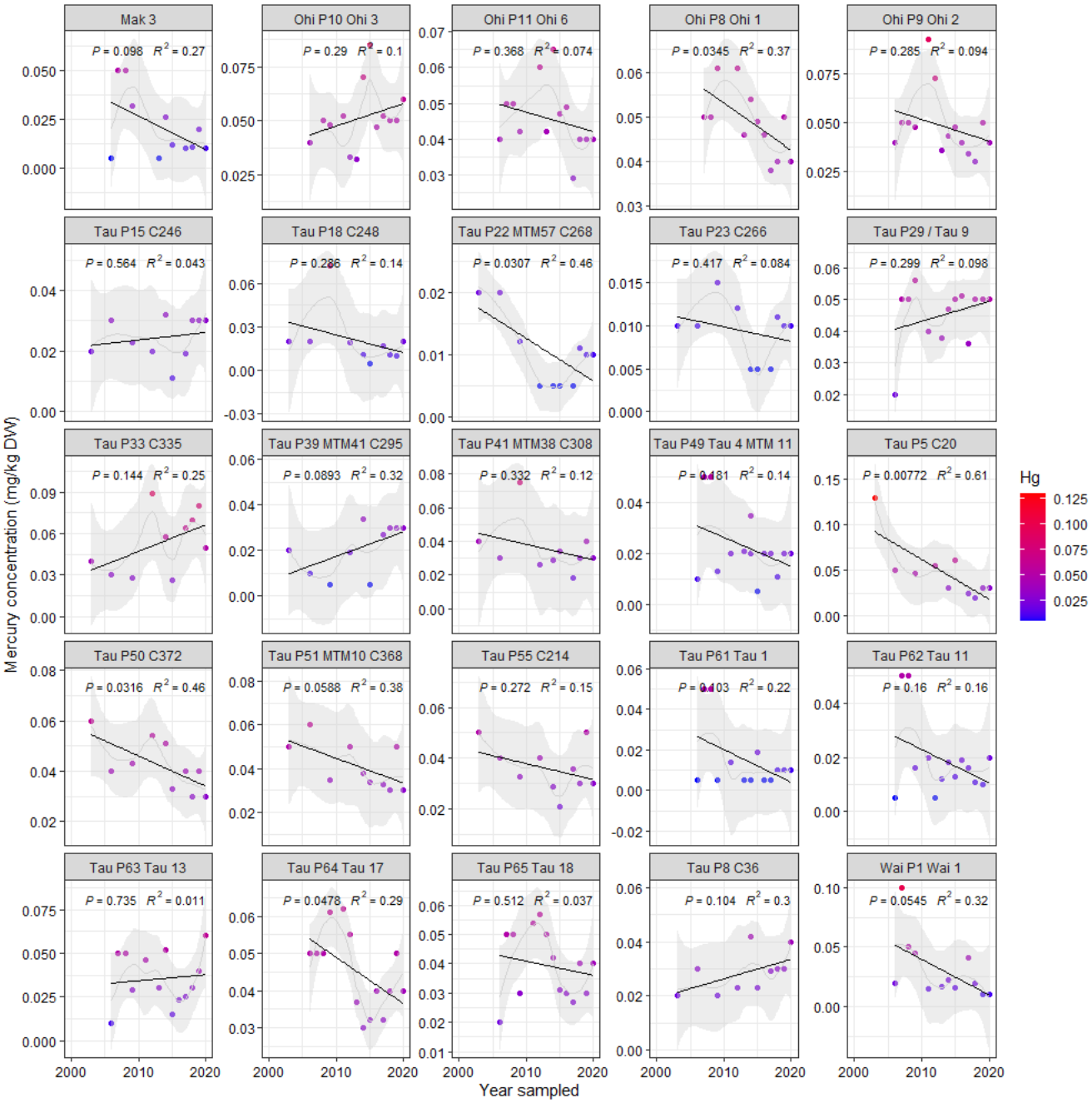

Figure 14 *Sediment mercury concentration (mg/kg DW) against year sampled at 25 sites with monitoring data dating back a minimum of 10 years. A loess regression line (locally weighted least squares regression) is fitted (grey), and a linear trend line (black). The points are colour coded to the concentration of mercury. Significance of trend was assessed with linear regression (p and R^2).*

Sediment nickel trends

Sediment nickel concentrations were on average much greater in Ōhiwa Harbour than the other sites (Figure 15). In Tauranga Harbour one site (Waikareao) showed a significant increase in nickel concentrations (Tau P15 $p<0.01$ $R^2 = 0.62$).

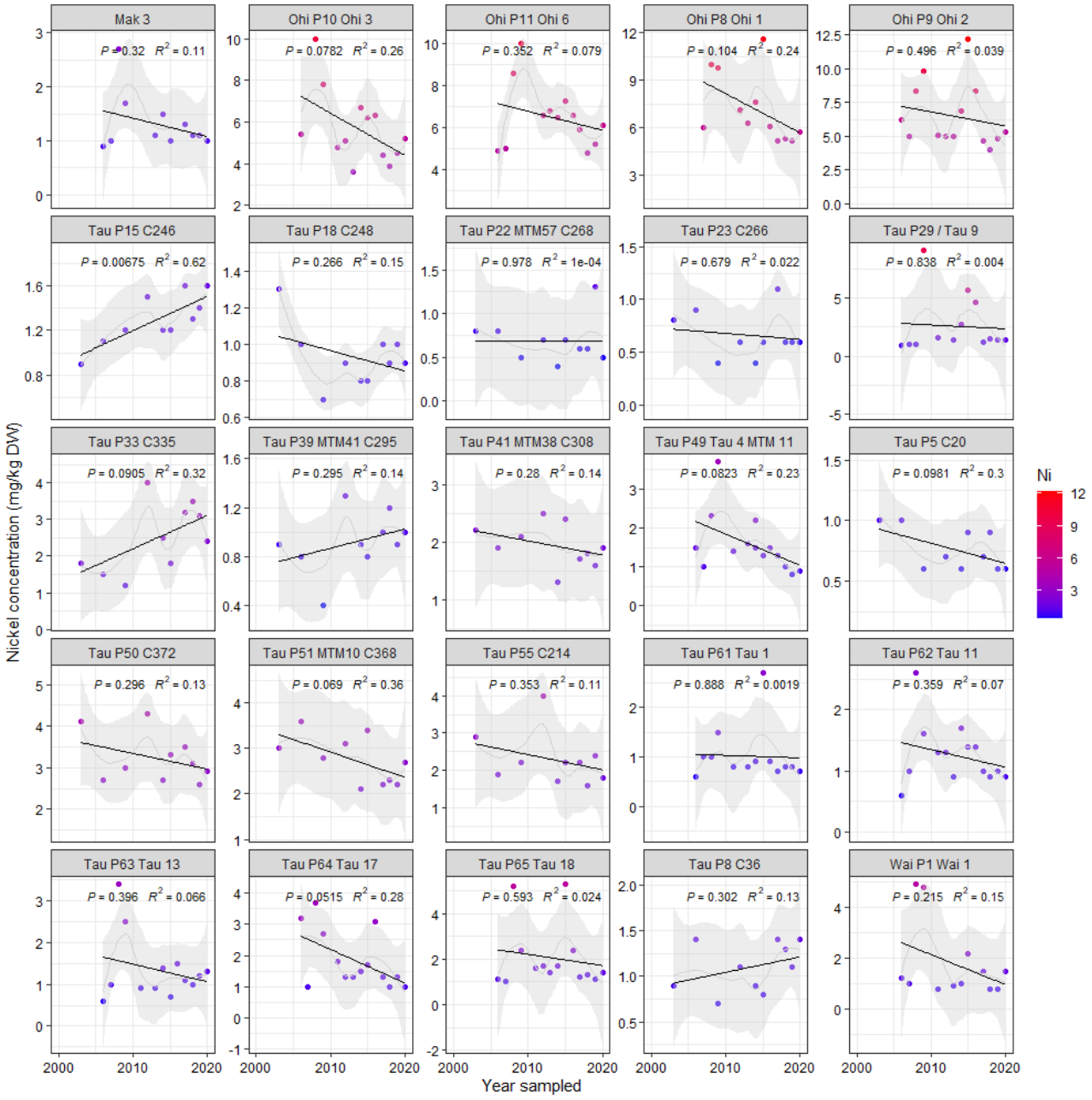

Figure 15 *Sediment nickel concentration (mg/kg DW) against year sampled at 25 sites with monitoring data dating back a minimum of 10 years. A loess regression line (locally weighted least squares regression) is fitted (grey), and a linear trend line (black). The points are colour coded to the concentration of nickel. Significance of trend was assessed with linear regression (p and R^2).*

Sediment zinc trends

Sediment zinc trends are displayed in Figure 16. A decrease in zinc was evident at Tauranga P22 (Matua) ($p<0.01$ $R^2 = 0.7$). Increases in zinc are seen at Tau P15 (Waikareao $p<0.001$, $R^2 = 0.79$), Tau P33 (Te Puna $p<0.05$ $R^2 = 0.51$), Tau P29 (Te Puna $p<0.05$, $R^2 = 0.33$), Tau P8 (Welcome Bay $p<0.05$, $R^2 = 0.39$) and Tau P39 (Waipapa $p<0.05$ $R^2 = 0.57$).

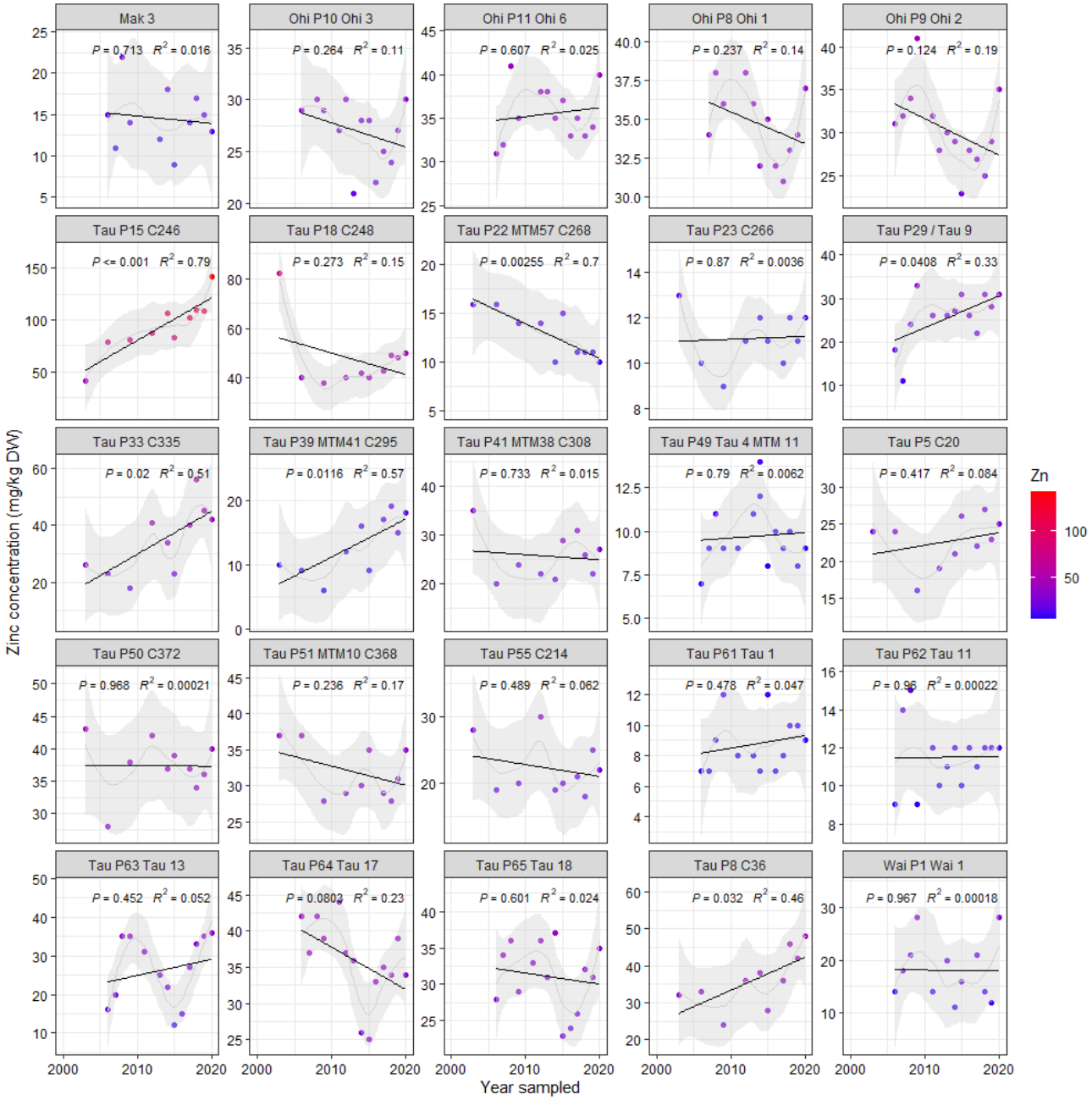

Figure 16 *Sediment zinc concentration (mg/kg DW) against year sampled at 25 sites with monitoring data dating back a minimum of 10 years. A loess regression line (locally weighted least squares regression) is fitted (grey), and a linear trend line (black). The points are colour coded to the concentration of zinc. Significance of trend was assessed with linear regression (p and R^2).*

Estuary sediment heavy metal trend summary

The results of the trend analysis has been summarised in Table 11. The table shows an overview of the trends (improving, worsening, and no significant change). 48% of the sites showed an improving trend in one or more contaminants. 28% of sites showed no significant change in contaminants, whilst 28% of sites showed a worsening trend in one or more contaminants. Arsenic, cadmium and zinc were the most common heavy metals to show a worsening trend. Cadmium, copper, and lead were the most common heavy metals to show an improving trend. Sites at Te Puna, Waikareao, Welcome Bay and Waipapa were identified to have worsening trends for a number of heavy metal species.

Table 11 *Linear regression trend analysis for the sediment contaminants. A worsening trend is indicated by an upwards orange arrow. An improving trend is indicated by a downwards blue arrow. No trend detected is indicated by a dash).*

Site Name	Estuary	TOC	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Mak 3	Maketū	—	—	—	—	—	—	—	—	—
Ohi P10	Ohiwa	↓	—	↓	—	—	—	—	—	—
Ohi P11	Ohiwa	↓	—	↓	—	—	—	—	—	—
Ohi P8	Ohiwa	—	—	↓	↓	—	—	↓	—	—
Ohi P9	Ohiwa	↓	—	↓	—	↓	↓	—	—	—
Tau P15	Waikareao	↑	↑	↑	↑	↑	↑	—	↑	↑
Tau P18	Waikareao	—	—	—	—	—	—	—	—	—
Tau P22	Matua	↓	↓	—	—	↓	↓	↓	—	↓
Tau P23	Matua	↓	—	↓	—	↓	↓	—	—	—
Tau P29	Te Puna	—	—	↑	—	—	—	—	—	↑
Tau P33	Te Puna	↑	↑	—	—	—	—	—	—	↑
Tau P39	Waipapa	—	↑	↑	—	—	—	—	—	↑
Tau P41	Apata	—	—	↑	—	↓	—	—	—	—
Tau P49	Uretara	—	—	—	—	—	—	—	—	—
Tau P5	Welcome Bay	↓	—	—	—	↓	↓	↓	—	—
Tau P50	Uretara	↓	—	—	—	—	—	↓	—	—
Tau P51	Uretara	↓	↓	↓	—	—	—	—	—	—
Tau P55	Tuapiro	—	—	—	—	—	—	—	—	—
Tau P61	Bowentown	—	—	—	—	—	—	—	—	—
Tau P62	Otumoetai	—	—	—	—	—	—	—	—	—
Tau P63	Town Reach	—	↑	—	—	—	—	—	—	—
Tau P64	Waimapu	—	—	—	↓	↓	↓	—	—	—
Tau P65	Waimapu	—	—	—	—	—	—	—	—	—
Tau P8	Welcome Bay	↑	↑	—	—	↑	—	—	—	↑
Wai P1	Waihī Estuary	↓	—	—	—	—	—	—	—	—

Spatial heavy metal trends

Although the concentrations of heavy metals in Tauranga Harbour are generally low compared to Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018), spatially some patterns have emerged when comparing across the sediment, water, and shellfish in estuarine/freshwater environments. The heavy metal datasets for estuary and river sediment and water were compiled to look at spatial trends across Tauranga Harbour, and spatially displayed to allow easy comparison between concentrations of river and estuary heavy metals in both the water and sediment.

For arsenic, the estuary water was all below the detection limit of 4.2 ug/L (Figure 17). A number of higher concentrations of arsenic were recorded in the river water, in particular at one of the Welcome Bay inflows where concentrations were 33 ug/L. Concentrations of arsenic in the river and estuary sediments showed moderate variation and in general were lower in the northern Tauranga Harbour, and higher in the southern (Figure 17). Higher arsenic in the river sediments did not appear to correspond to higher arsenic in the estuary sediments.

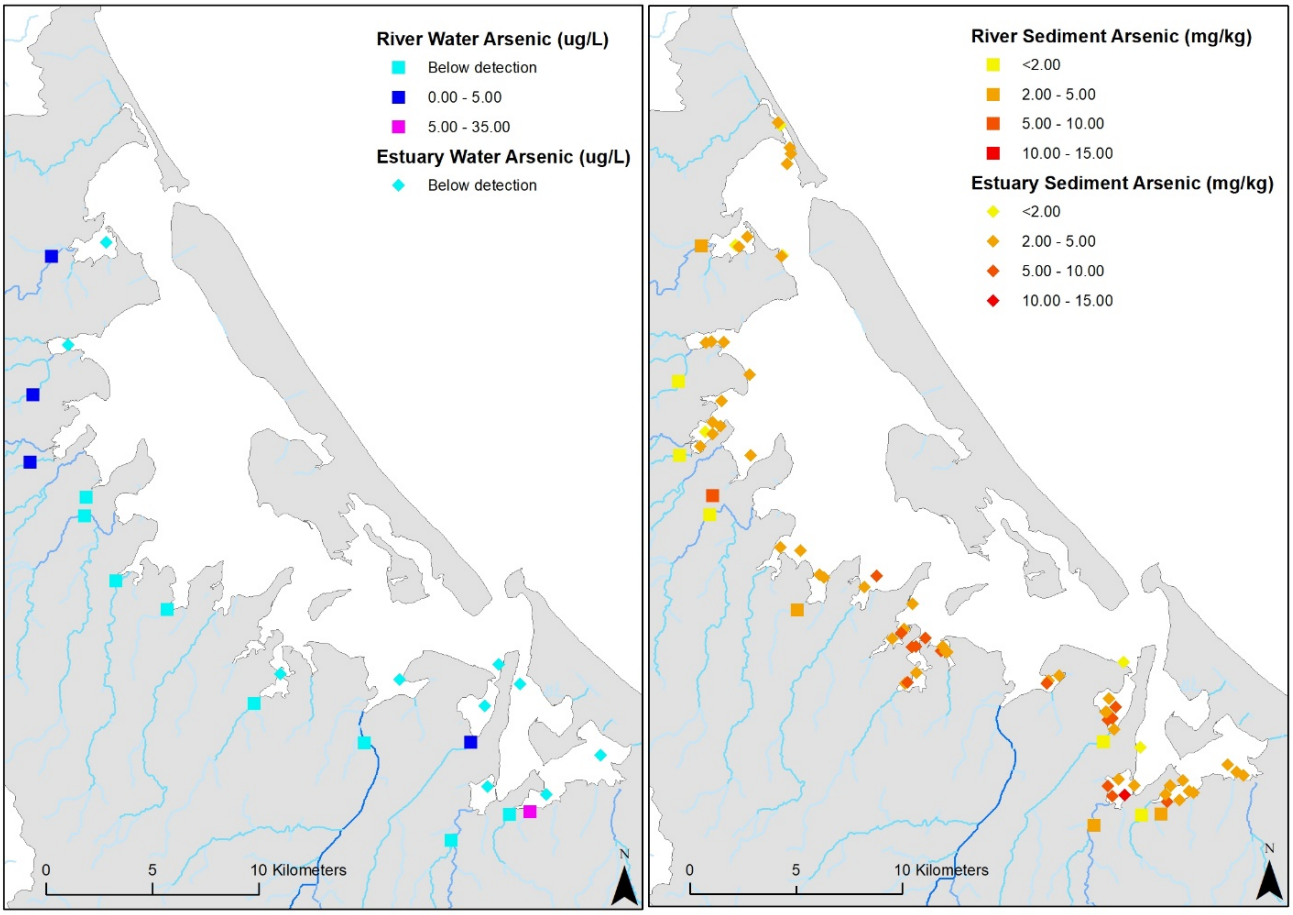

Figure 17 *Arsenic concentrations in river and estuary water (ug/l) and arsenic concentrations in river and estuary sediments (mg/kg) in Tauranga Harbour.*

Cadmium concentrations were below detection limits in both the river (<0.053 ug/L) and estuary (<0.2 ug/L) water samples (Figure 18). The higher estuary and river sediment cadmium concentrations were recorded around the central and southern part of Tauranga Harbour (Figure 18). The estuary sediment cadmium concentrations were generally a magnitude higher than the river sediments.

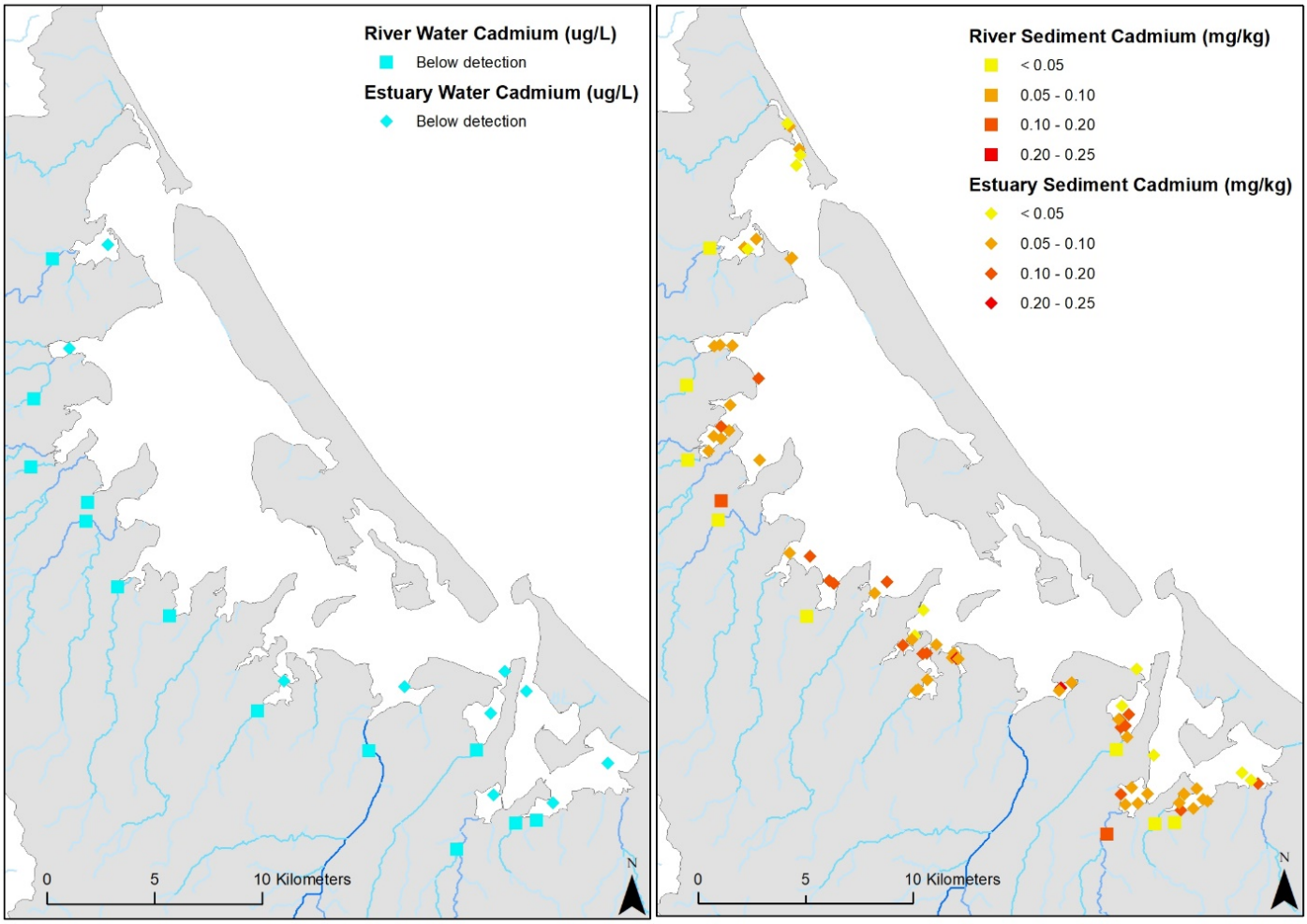

Figure 18 *Cadmium concentrations in river and estuary water (ug/l) and cadmium concentrations in river and estuary sediments (mg/kg) in Tauranga Harbour.*

The concentrations of chromium in estuary water was generally higher than recorded in the river water (Figure 19). Concentrations of chromium in the river sediments appeared higher in the northern end of Tauranga Harbour, whereas estuary sediment concentrations were varied across the harbour, but the higher concentrations were recorded closer to the southern end of Tauranga Harbour (Figure 19).

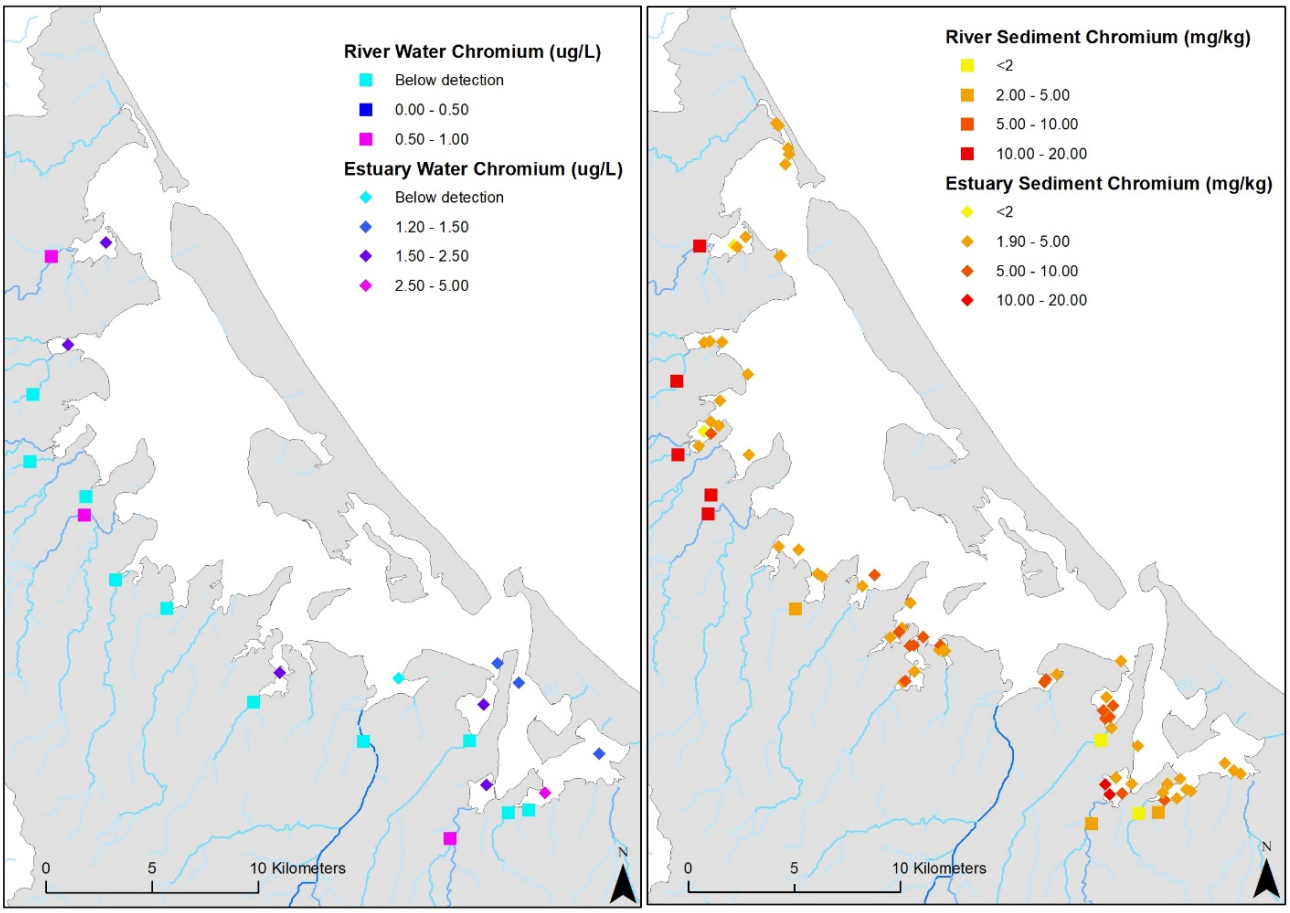

Figure 19 *Chromium concentrations in river and estuary water (ug/l) and chromium concentrations in river and estuary sediments (mg/kg) in Tauranga Harbour.*

Copper concentrations in the river water was generally below detection limits, however, a cluster of higher concentrations were recorded around the southern harbour (Figure 20). The area around Rangataua Bay and Welcome Bay was also where estuary water copper concentrations were higher. Copper concentrations in river sediments varied across the region, however estuary sediment concentrations of copper showed a strong spatial pattern of higher concentrations in the southern harbour, decreasing towards the northern end. The pattern of river sediment copper concentrations were the opposite of estuaries, with higher river sediment copper concentrations in the northern harbour area.

At many sites, both the river and sediment water concentrations of lead were below detection limits (Figure 21). The higher lead concentrations in the estuary and river water were concentrated near the southern end of the harbour. Again, estuary concentrations were often higher than river water concentrations where they were above detection limits. Lead concentrations in the river sediments were all relatively high across the harbour, however, the higher estuary lead concentrations were focussed around the southern harbour (Figure 21).

Mercury was not measured in water samples. Mercury concentrations in river sediments varied across the harbour, however, estuary sediment mercury concentrations were higher in the mid-southern harbour (Figure 22).

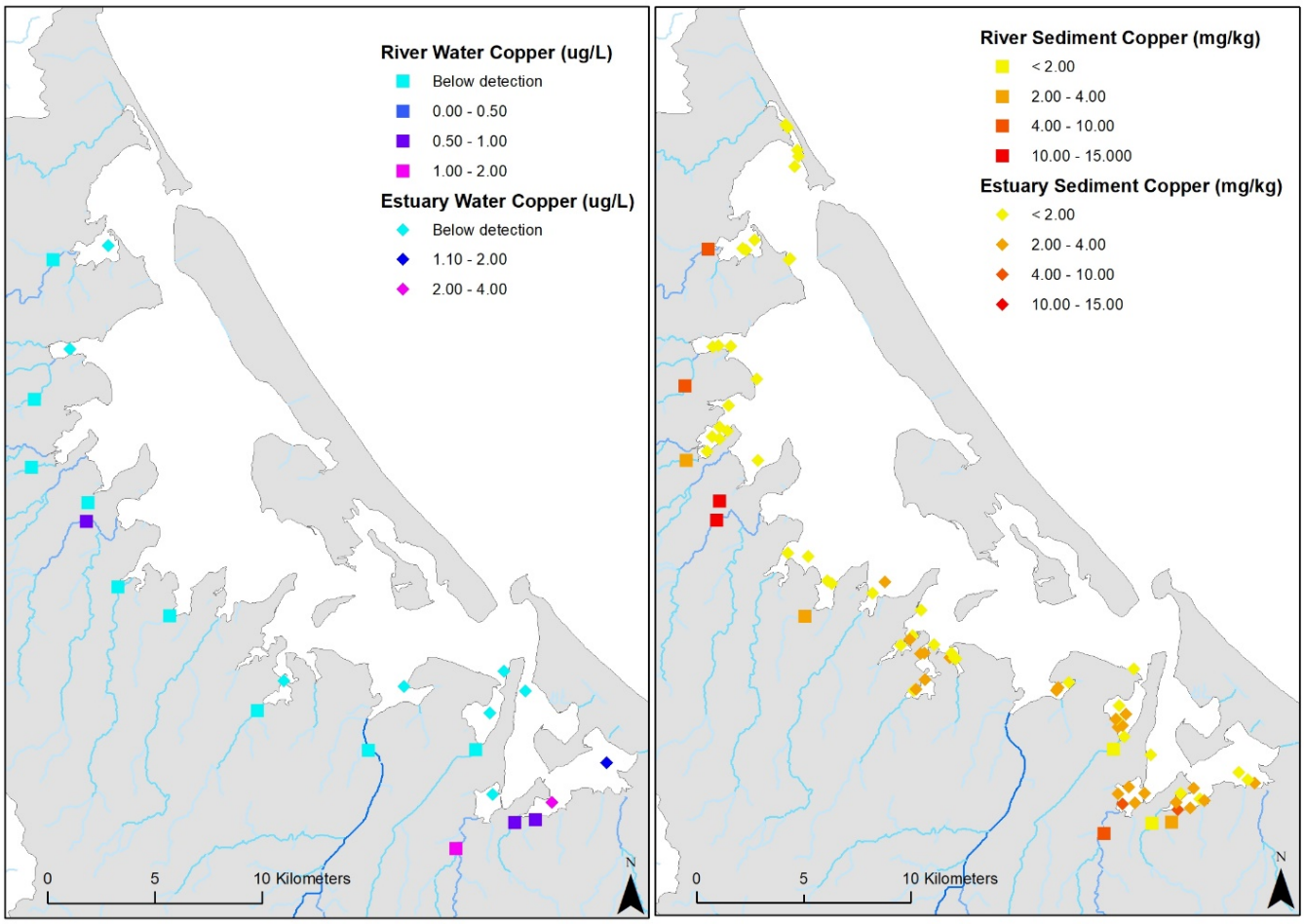

Figure 20 *Copper concentrations in river and estuary water (ug/l) and copper concentrations in river and estuary sediments (mg/kg) in Tauranga Harbour.*

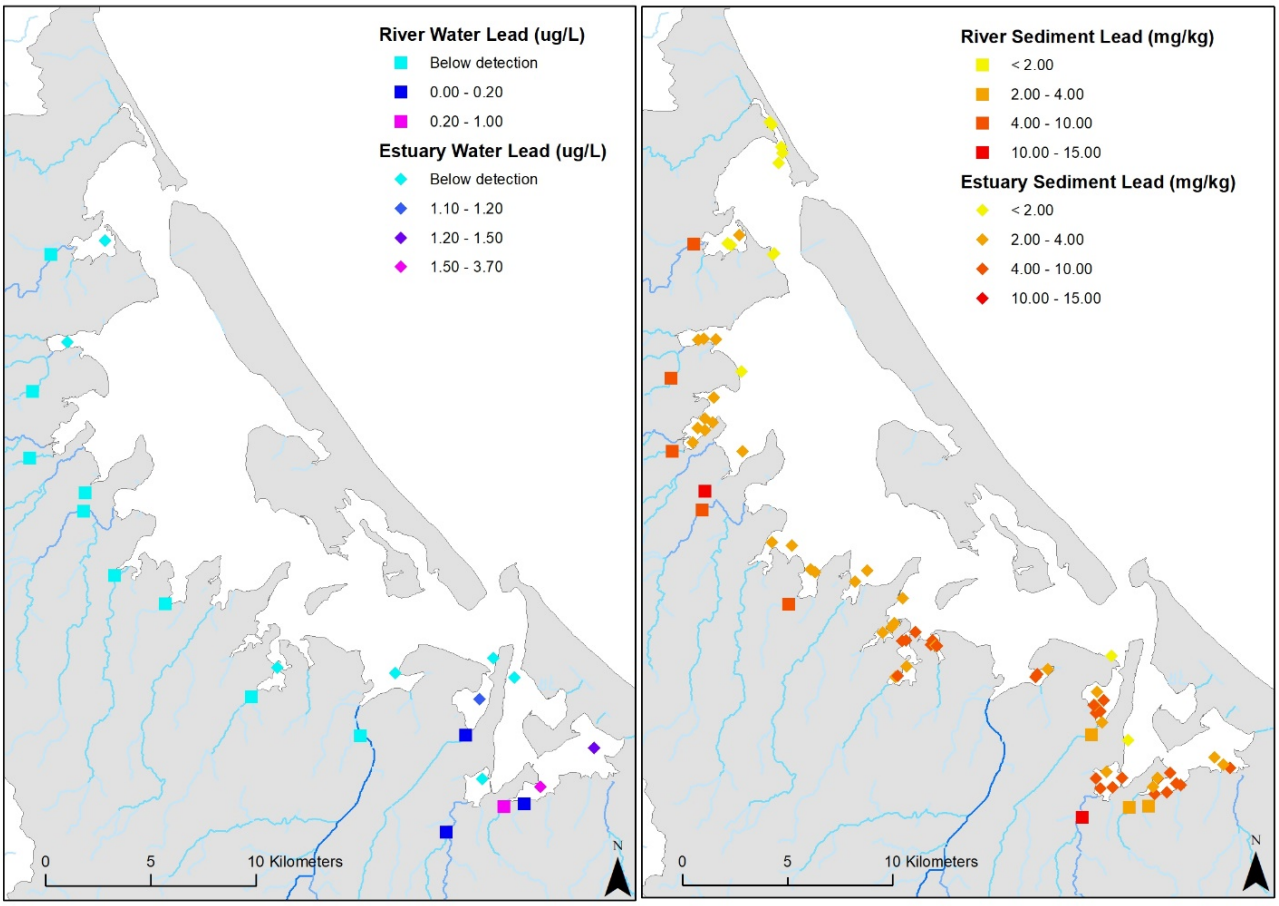

Figure 21 *Lead concentrations in river and estuary water (ug/l) and lead concentrations in river and estuary sediments (mg/kg) in Tauranga Harbour.*

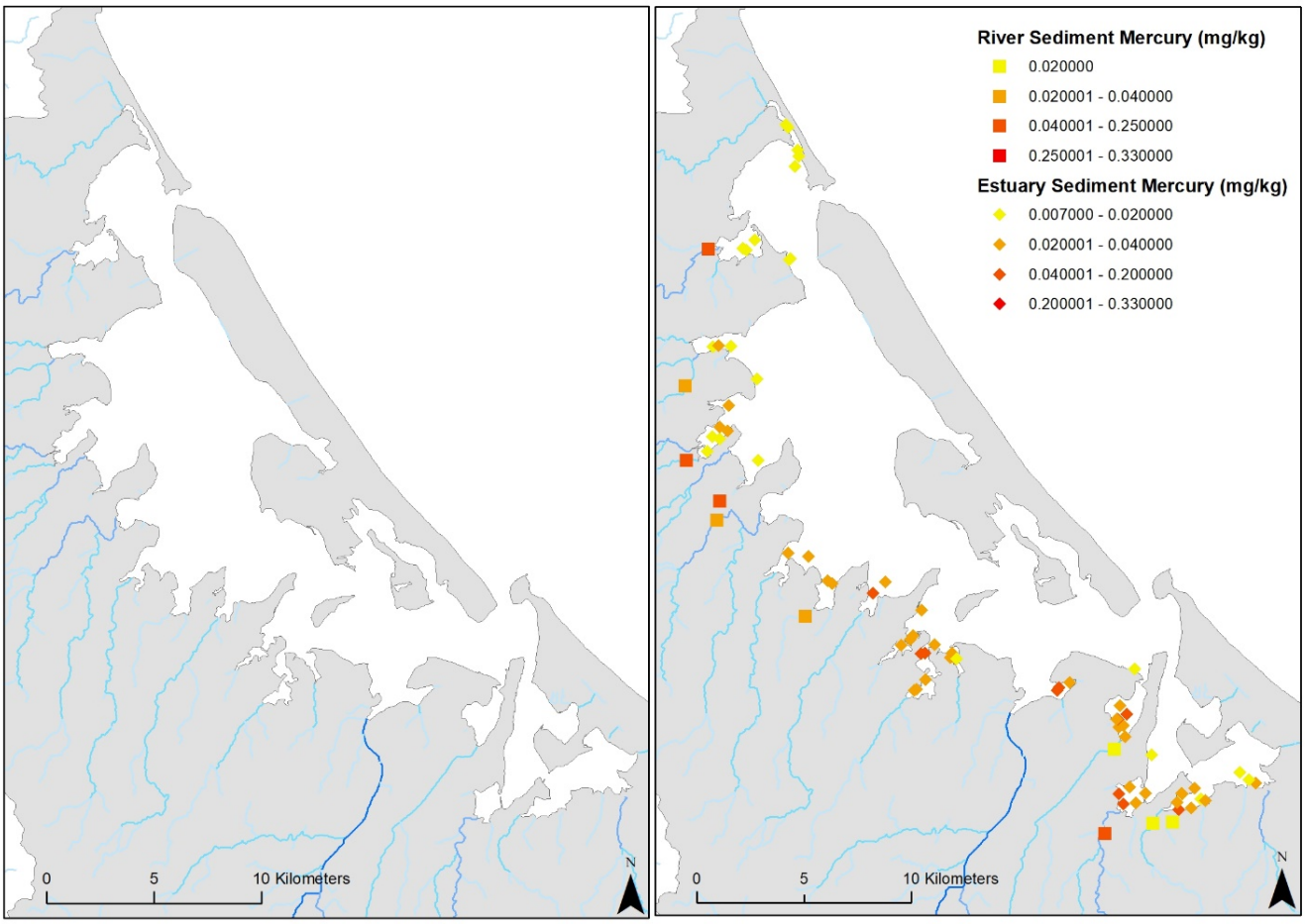

Figure 22 *Mercury concentrations in river and estuary sediments (mg/kg) in Tauranga Harbour. Mercury was not measured in water samples.*

Nickel concentrations were below detection in both the river (<0.53 ug/L) and estuary (<7 ug/L) water samples (Figure 23). River sediment nickel concentrations were higher in the northern harbour, and the estuary sediment nickel concentrations were higher in isolated patches around the mid-southern harbour.

Zinc concentrations were below detection at a number of the river and estuary water sites (Figure 24), however higher concentrations in both the river and estuary water was concentrated in the southern harbour. Some river water zinc concentrations were higher also in the northern harbour. River sediment zinc concentrations varied across the harbour, however estuary sediments were much higher in the southern harbour compared to the northern harbour.

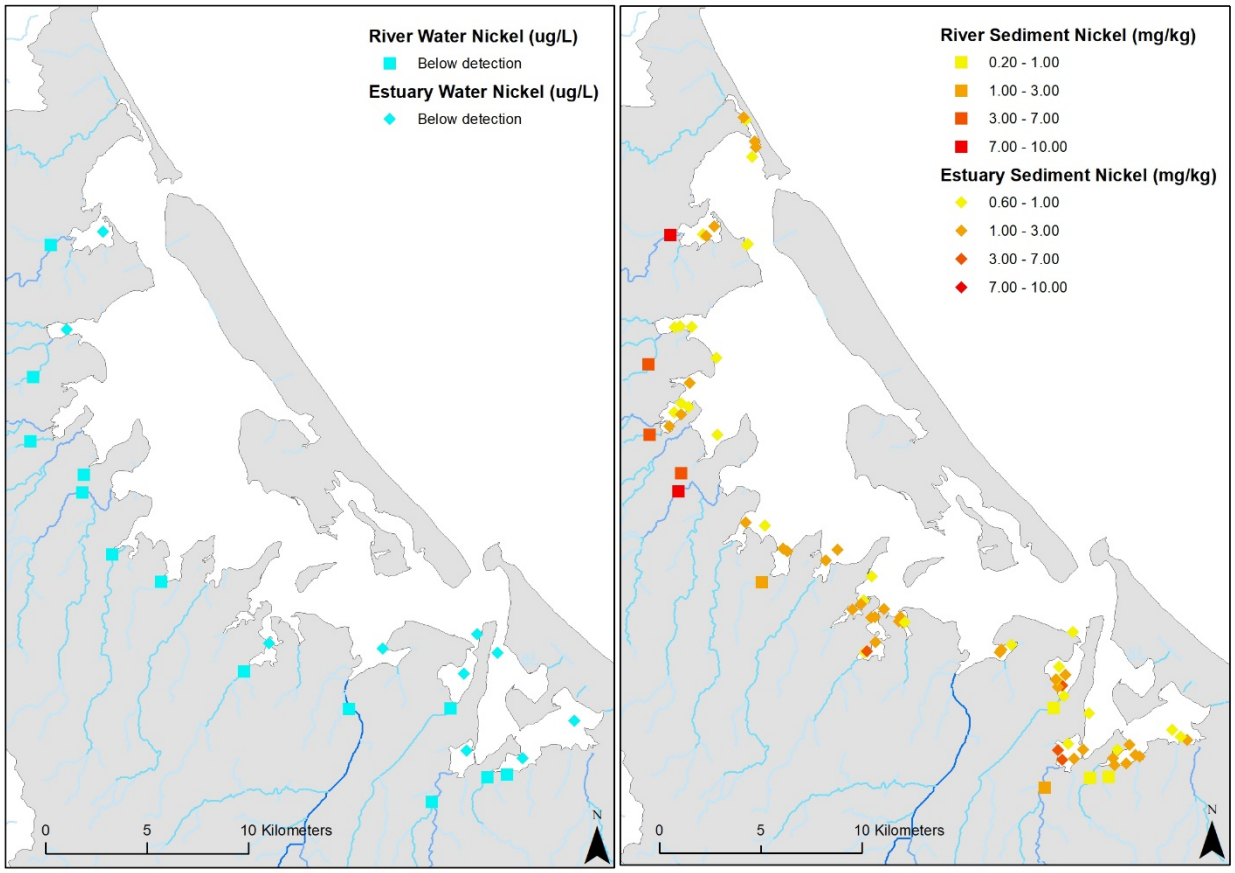

Figure 23 *Nickel concentrations in river and estuary water (ug/l) and nickel concentrations in river and estuary sediments (mg/kg) in Tauranga Harbour.*

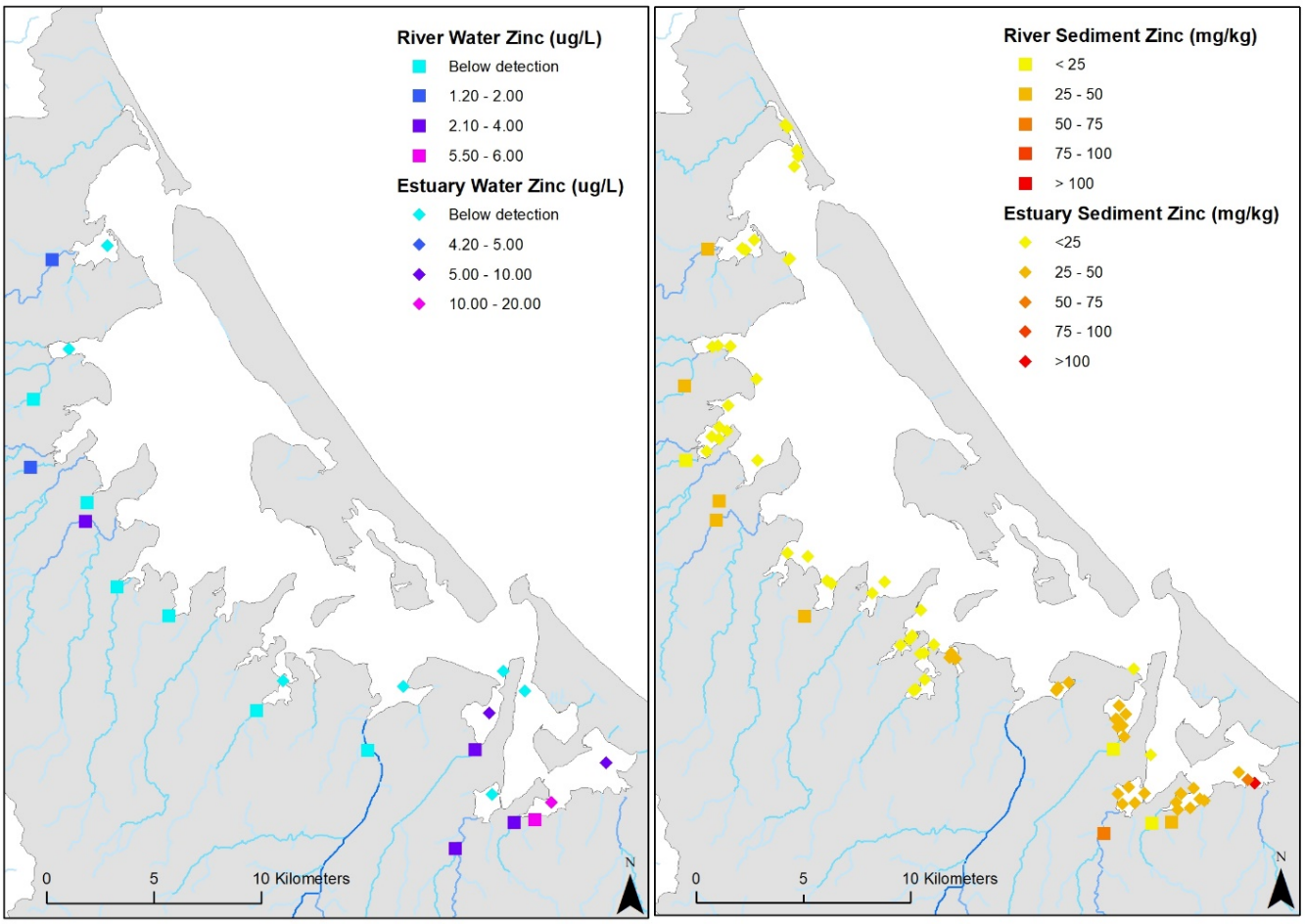

Figure 24 *Zinc concentrations in river and estuary water (ug/l) and zinc concentrations in river and estuary sediments (mg/kg) in Tauranga Harbour.*

Organic contaminants

Estuary sediment organic contaminants

Twelve estuarine and four freshwater sites were selected to test an extensive suite of organic contaminants, including a range of emerging organic contaminants (Figure 3). Sites were chosen in predominantly high urban intensity sub-estuaries and additional agricultural reference sites.

Results for the estuary sediment acid herbicides, multiresidue pesticides, polychlorinated biphenyls (PCBs), metsulfuron, and semivolatile organic compounds (SVOCs: haloethers, phenols, plasticisers, halogenated compounds) were below detection at all sites.

PAH sediment samples were collected at a subset of sites, which were all well below the ISQG-low guidelines. Wairoa (P23), Otumoetai (P62) and Sulphur Point had no detectable PAHs recorded (Figure 3). The highest sum of PAHs was recorded at the Port site (0.087 mg/kg DW), with readings above detection for, chrysene, fluoranthene, indenopyrene, perylene, and phenanthrene. The next three highest sum PAH concentration sites were Welcome Bay (P8; 0.026 mg/kg DW), Waimapu (P14; 0.016 mg/kg DW) and Katikati (P62; 0.009 mg/kg DW).

River sediment organic contaminants

Herbicide, pesticide and PAH samples were also taken at many of the river sampling locations. The results from these samples had indicated that there was no detection of herbicides or pesticides in the sediment samples across the region, with the exception of Triclopyr (broadleaf herbicide) which was detected at two locations (Figure 2). Waiowhiro at Bonningtons Farm was only just above detection for Triclopyr (0.00006 mg/kg) however Matahui at Elmwood Road was much greater than the detection limit (0.0001 mg/kg).

Two river sediment sites were sampled for PAHs (Kopurerua at SH 2 and Waimapu at SH 29). There was no detection of PAHs for Kopurerua at SH 2. A large range of PAH species were above detection limits at Waimapu at SH 2, with a total reported PAH in soil of 0.4 mg/kg, which is at the ISQG-low trigger value. No PCBs, metsulfuron, SVOC, phenols, or plasticisers were detected at either site.

River water organic contaminants

Twenty two river sites were tested for aqueous trace herbicides and pesticides. All were below detection, with the exception of one site for a very low concentration of the herbicide Triclopyr (0.0001 g/m^3) at Waikite at Welcome Bay Road. This is below a reported proposed guideline value of 1.6 ug/L for 99% species protection (King et al. 2017).

Shellfish organic contaminants

Polycyclic aromatic hydrocarbons (PAHs) were tested at the same sites as heavy metals (Figure 3). All the tuangi samples collected were below detection for the suite of PAHs, along with the Rangataua Bay titiko. The Waimapu titiko had concentrations fluoranthene (0.028 mg/kg WW) and phenanthrene (0.0024 mg/kg WW) well above the detection limits. Fluorene was just above detection limits in the Waikareao titiko (0.0002 mg/kg WW). In the Waikareao pipi and titiko samples there was a range of PAHs above the detection limits, with a sum concentration of PAHs of 0.0098 mg/kg WW in pipi, and 0.0158 mg/kg WW in titiko.

Organochlorine pesticides were below detection limits in the pipi and hanikura, however 4,4'-DDD and 4,4'-DDE (breakdown products of DDT) were above detection limits (0.0012 & 0.0054 mg/kg WW respectively). Polychlorinated biphenyls (PCBs) were also examined, and similarly to the pesticides, there was no detections in the pipi or hanikura (detection limit 0.0005 mg/kg WW)). A number of PCBs however were detected in the titiko, including PCB-138 (0.0008 mg/kg WW), PCB-149, PCB-153 and PCB-180 (0.0006 mg/kg WW). However, note that these are only just above the detection limit.

Emerging organic contaminants

A wide suite of emerging organic contaminants were tested in estuary and river sediments (see Table 1 for contaminant suite), based on previous work in New Zealand estuaries by Stewart *et al.* (2016). The full data report is available on request from BOPRC (Objective ID: A3625626).

PFAS (per- and poly-fluoroalkyl substances)

Sediment PFAS

Sediment concentrations of PFAS were below limits of reporting (LOR) at all sites (ranging from 0.001 to 0.005 mg/kg dry weight, 1-5 ppb) (Stewart & Northcott, 2020).

POCIS PFAS extract concentrations

Selected PFAS water extract concentrations that had at least one site above the limits of reporting are summarised in Table 12. Six sites in the southern harbour recorded at least one PFAS above limits of reporting. The highest sum concentration of water concentrations of PFHxS+PFOS was recorded at Waimapu (0.093 ug/L). Time-weighted concentrations were calculated for a number of PFOS species and are reported in Table 13.

Table 12 Concentration of selected PFAS measured in POCIS (ug/L). Samples above limits of reporting are shown in bold.

Site	L-PFHxS	Total PFHxS	L-PFOS	Total PFOS	Sum PFHxS+PFOS	PFHpA	PFOA1	6:2 FTS1
Tuapiro	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Katikati	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Te Puna	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Wairoa	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Otumoetai	<0.010	<0.010	<0.010	**0.01**	**0.01**	<0.010	<0.010	<0.010
Waikareao	**0.011**	**0.011**	<0.010	**0.022**	**0.033**	**0.014**	**0.021**	<0.010
Waimapu	**0.029**	**0.029**	**0.024**	**0.04**	**0.093**	**0.017**	**0.016**	**0.005**
Port	**0.014**	**0.014**	<0.010	**0.02**	**0.034**	<0.010	<0.010	<0.010
Welcome Bay	**0.02**	**0.02**	**0.017**	**0.031**	**0.068**	<0.010	**0.001**	**0.009**
Rangataua Bay	**0.02**	**0.02**	**0.018**	**0.027**	**0.065**	**0.011**	**0.009**	<0.010

Table 13 Time weighted average water concentrations (pg/L) for selected PFAS calculated from POCIS. Samples above limits of reporting are shown in bold.

Site	mono-PFOS	Total PFOS	Sum PFHxS+PFOS	PFOA
Tuapiro	<0.19	<0.36	<0.54	<0.25
Katikati	<0.19	<0.36	<0.54	<0.25
Te Puna	<0.19	<0.36	<0.54	<0.25
Wairoa	<0.19	<0.37	<0.56	<0.26
Otumoetai	<0.17	**0.33**	**0.33**	<0.23

Site	mono-PFOS	Total PFOS	Sum PFHxS+PFOS	PFOA
Waikareao	**0.21**	**0.81**	**1.03**	**0.54**
Waimapu	**0.5**	**2.1**	**2.59**	**0.36**
Port	**0.24**	**0.66**	**0.9**	<0.23
Welcome Bay	**0.39**	**1.78**	**2.16**	**0.03**
Rangataua Bay	**0.39**	**1.66**	**2.05**	**0.23**

Glyphosate/AMPA

Sediment glyphosate/AMPA

Sediment concentrations of sediment glyphosate and AMPA were below the limits of reporting (LOR) at all sites (0.025 mg/kg dry weight, 20 ppb) (Stewart & Northcott, 2020).

POCIS glyphosate/AMPA extract concentrations

Six of the ten sites had concentrations of glyphosate or AMPA above limits of reporting (Table 14). The highest concentrations of AMPA were recorded at Waimapu and Rangataua Bay, with some detection at Katikati, Port and Welcome Bay. The highest concentrations of glyphosate were recorded at Waimapu, followed by Port, Rangataua Bay and Waikareao. Time weighted average water concentrations are reported for both AMPA and glyphosate.

Table 14 *Concentration (mg/kg) and time-weighted average water concentrations (pg/L) of AMPA and glyphosate measured in MIP POCIS. Samples above limits of reporting are shown in bold.*

	Concentration		Time-weighted average water concentration	
Site	**AMPA (mg/kg)**	**Glyphosate (mg/kg)**	**AMPA (pg/L)**	**Glyphosate (pg/L)**
Tuapiro	<0.0010	<0.0010	<49.3	<44.8
Katikati	**0.001**	<0.0010	**49.3**	<44.8
Te Puna	<0.0010	<0.0010	<49.3	<44.8
Wairoa	<0.0010	<0.0010	<51.3	<46.7
Otumoetai	<0.0010	<0.0010	<45.4	<41.3
Waikareao	<0.0010	**0.0011**	<51.3	**51.3**
Waimapu	**0.0019**	**0.0015**	**86.3**	**62**
Port	**0.0013**	**0.0013**	**59.1**	**53.7**
Welcome Bay	**0.0011**	<0.0010	**56.4**	<46.7
Rangataua Bay	**0.0019**	**0.0012**	**97.5**	**56**

Flame retardants

Sediment flame retardants

All sediment concentrations of the brominated diphenyl ether (BDE) flame retardants (BDE28, BDE66, BDE47, BDE85, BDE99, BDE100, BDE153, BDE183, and BDE209) were below limits of reporting at all sites (1 ng/g dry weight for all BDEs except BDE209, which had a LOR of 50 ng/g dry weight) (Stewart & Northcott, 2020). Sediment concentrations of the phosphate flame retardants (TDCP, TCPP, TPP) were also below limits of reporting at all sites (0.25 ng/g dry weight for TDCP and TCPP, and 0.50 ng/g dry weight for TPP).

POCIS flame retardants extract concentrations

Brominated diphenyl ether (BDE) flame retardants were not measured in POCIS as their hydrophobic properties preclude their accumulation. Phosphorus flame retardants (TCPP, TPP, and TDCP) were below LOR at all sites (TCPP: 93 ng/sampler, TPP: 1 ng/sampler, and TDCP: 6 ng/sampler) (Stewart & Northcott, 2020).

Plasticisers

Sediment plasticisers

A range of phthalate plasticisers (di-ethylhexyl-phthalate (DEHP), benzylbutyl-phthalate (BBP), bisphenol A (BPA), and di-n-butyl-phthalate) were recorded at a large number of the sediment sites (Table 15). The highest concentrations of DEHP were recorded at Waimapu (176) with 519 ng/g recorded in the sediments. This was followed by the next closest of Port and Waikareao with 193 and 154 ng/g reported respectively. The highest BBP sediment concentration was recorded at Waimapu (176) with a concentration of 208 ng/g, which is nearly a magnitude higher than the next reported concentration of 40.5 ng/g at Waikareao. The highest concentrations of BPA were recorded at Te Puna (1.8 ng/g), Wairoa (1.34 ng/g) and Waikareao (1.32 ng/g). Di-n-butyl-phthalate was recorded at all sites, with a maximum concentration recorded in the Kopurereroa Stream (3200 ng/g) followed by the receiving environment Waikareao Estuary (1893 ng/g). High concentrations were recorded in sediments at Waimapu River at SH 29 (1213 ng/g), however high concentrations were not reported in Waimapu Estuary. Other high sediment concentrations of di-n-butyl-phthalate include Sulphur Point (879 ng/g), Welcome Bay (720 ng/g), Tuapiro (677 ng/g) and Te Puna (675 ng/g).

Two additional phthalate plasticisers were detected at a few sites (di-methyl-phthalate, diethyl-phthalate). Di-n-octyl-phthalate was below limits of reporting at all sites.

Table 15 Sediment concentrations (ng/g dry weight) of phthalate plasticisers in sediment. Samples above limits of reporting are shown in bold.

Site	Di-ethylhexyl-phthalate (DEHP)	Benzylbutyl-phthalate (BBP)	Bisphenol A (BPA)	Di-n-butyl-phthalate	dimethyl-phthalate	Diethyl-phthalate
Port	**193**	**2.67**	**0.2**	**400**	**6.53**	<5.0
Sulphur Point	**36.6**	**1.16**	<0.10	**879**	<0.50	<5.0
Waimapu (176)	**519**	**208**	**0.94**	**50.6**	<0.50	<5.0
Katikati	<25	**2.14**	<.010	**43.6**	<0.50	<5.0
Tuapiro	**8.61**	<1	<.010	**677**	<0.50	<5.0
Te Puna	**27.3**	**2.12**	**1.8**	**675**	<0.50	<5.0
Otumoetai	<25	<1	**0.22**	**185**	<0.50	<5.0

Site	Di-ethylhexyl-phthalate (DEHP)	Benzylbutyl-phthalate (BBP)	Bisphenol A (BPA)	Di-n-butyl-phthalate	dimethyl-phthalate	Diethyl-phthalate
Wairoa	<25	<1	**1.34**	**569**	<0.50	<5.0
Waikareao	**154**	**40.5**	**1.32**	**1893**	<0.50	<5.0
Puarenga (FRI)	**51**	<1	**0.14**	**172**	<0.50	<5.0
Welcome Bay	**38.6**	**9.88**	**0.96**	**720**	<0.50	<5.0
Rangataua	<25	**3.28**	**0.15**	**225**	<0.50	<5.0
Waimapu (P14)	**62.9**	**5.29**	**0.52**	**77.6**	<0.50	<5.0
Kopurererua	<25	**5.04**	**0.46**	**3200**	**1.88**	**6.61**
Waimapu (SH 29)	<25	<1	**0.64**	**1213**	**1.25**	**10.5**
Waiari (Kaituna confluence)	<25	<1	**0.26**	**144**	<0.50	<5.0

Three primary metabolites or transformation products of parent phthalate acid ester (PAE) plasticisers were recorded in the sediments (Table 16).

Table 16 Sediment concentration (ng/g dry weight) of phthalate mono-acid ester plasticisers. Samples above limits of reporting are shown in bold.

Site	Monobutyl-PAE	Mono-ethylhexyl(EH)-PAE	Monomethyl-PAE
Port	<0.25	<0.25	**3**
Sulphur Point	<0.25	<0.25	<0.25
Waimapu (176)	<0.25	<0.25	**6.29**
Katikati	<0.25	<0.25	**6.59**
Tuapiro	**1.94**	<0.25	<0.25
Te Puna	**10.9**	<0.25	**22.9**
Otumoetai	<0.25	<0.25	<0.25
Wairoa	<0.25	<0.25	<0.25
Waikareao	**16.7**	**0.45**	**7.75**
Puarenga (FRI)	<0.25	<0.25	<0.25
Welcome Bay	<0.25	<0.25	**10.3**
Rangataua	<0.25	<0.25	**2.4**
Waimapu (P14)	<0.25	<0.25	**2.78**
Kopurererua	<0.25	<0.25	**3.23**
Waimapu (SH 29)	<0.25	<0.25	**4.57**
Waiari (Kaituna confluence)	<0.25	<0.25	<0.25

POCIS plasticisers extract concentrations

No phthalate plasticiser was applicable for POCIS as they were too hydrophobic and/or had no literature values for calculation of uptake rates. Bisphenol-A was below the limit of reporting for all sites (2.5 ng/sampler) (Stewart & Northcott, 2020).

Surfactants

Sediment surfactants

Sediment concentrations of the endocrine disrupting surfactant metabolite 4-n-nonylphenol was below limits of reporting at all sites (<0.20 ng/g dry weight), however the sum of technical nonylphenols was reported at eight of the sixteen sites (Table 17). The highest concentration of sum of technical nonylphenols was reported at Te Puna (28.3 ng/g) followed by Tuapiro (24.6 ng/g), Port (20.7 ng/g) and Waimapu River (SH29) (20.5 ng/g).

Table 17 Sediment concentration (ng/g dry weight) of nonylphenol surfactants. Samples above limits of reporting are shown in bold.

Site	Sum of technical nonylphenols
Port	**20.7**
Sulphur Point	<10.0
Waimapu (176)	**14.6**
Katikati	**15.2**
Tuapiro	**24.6**
Te Puna	**28.3**
Otumoetai	**11.1**
Wairoa	**18.1**
Waikareao	<10.0
Puarenga (FRI)	<10.0
Welcome Bay	<10.0
Rangataua	<10.0
Waimapu (P14)	<10.0
Kopurererua	<10.0
Waimapu (SH 29)	**20.5**
Waiari (Kaituna confluence)	<10.0

POCIS surfactants extract concentrations

4-n-nonylphenol POCIS extract concentrations were below limits of reporting at all sites (1 ng/sampler). Technical nonylphenol equivalents were below limits of reporting (20 ng/sampler) at all sites except Katikati with a total sampler concentration of 827 ng/sampler (Table 18).

Table 18 POCIS extract water concentrations (ng/sampler) for technical nonylphenol equivalents calculated from POCIS. Samples above limits of reporting are shown in bold.

Site	Technical nonylphenol equivalents
Tuapiro	<636
Katikati	**827**
Te Puna	<636
Wairoa	<662
Otumoetai	<586

Site	Technical nonylphenol equivalents
Waikareao	<662
Waimapu	<586
Port	<586
Welcome Bay	<662
Rangataua Bay	<662

Polycyclic musk fragrances

Sediment polycyclic musk fragrances

The sediment concentrations of polycyclic musk fragrances galaxolide and tonalide were below limits of reporting (0.50 ng/g dry weight) (Stewart & Northcott, 2020).

POCIS polycyclic musk fragrances extract concentrations

The polycyclic musk fragrances were below limits of reporting in the passive sampling devices (galaxolide: 16 ng/sampler, tonalide: 6 ng/sampler) (Stewart & Northcott, 2020).

Pharmaceuticals

Sediment pharmaceuticals

The majority of sediment pharmaceuticals were below limits of reporting at all sites, including acetaminophen, diclofenac, ibuprofen, carbamazepine, aspirin, clofibric acid (<0.20 ng/g dry weight). Ketoprofen was reported at seven of the sixteen sites, with the maximum concentration reported at Wairoa (11.1 ng/g) (Table 19). Meclofenamic acid was reported at two sites (Katikati and Te Puna, 0.9 and 0.29 ng/g respectively), naproxen at one site (Katikati, 0.33 ng/g), and salicyclic acid reported at five sites (maximum concentration at Waiari river, 30.2 ng/g (Kaituna confluence)).

Table 19 Sediment concentration (ng/g dry weight) of pharmaceuticals. Samples above limits of reporting are shown in bold.

Site	Ketoprofen	Meclofenamic acid	Naproxen	Salicylic acid
Port	<0.20	<0.20	<0.20	<0.20
Sulphur Point	<0.20	<0.20	<0.20	**2**
Waimapu (176)	<0.20	<0.20	<0.20	<0.20
Katikati	**2.09**	**0.9**	**0.33**	<0.20
Tuapiro	<0.20	<0.20	<0.20	<0.20
Te Puna	**0.69**	**0.29**	<0.20	**2.33**
Otumoetai	**3.93**	<0.20	<0.20	<0.20
Wairoa	**11.1**	<0.20	<0.20	<0.20
Waikareao	<0.20	<0.20	<0.20	**4.25**
Puarenga (FRI)	<0.20	<0.20	<0.20	<0.20
Welcome Bay	**3.64**	<0.20	<0.20	<0.20
Rangataua	**3.22**	<0.20	<0.20	<0.20

Site	Ketoprofen	Meclofenamic acid	Naproxen	Salicylic acid
Waimapu (P14)	**3.49**	<0.20	<0.20	<0.20
Kopurererua	<0.20	<0.20	<0.20	**12.2**
Waimapu (SH 29)	<0.20	<0.20	<0.20	<0.20
Waiari (Kaituna confluence)	<0.20	<0.20	<0.20	**30.2**

POCIS pharmaceutical extract concentrations

All of the measured pharmaceuticals (acetaminophen, diclofenac, ibuprofen, carbamazepine, aspirin (acetyl-salicylic acid), clofibric acid, ketoprofen, meclofenamic acid, naproxen and salicylic acid) were below limits of reporting in the passive sampling devices (Stewart & Northcott, 2020).

Steroid estrogens

Sediment steroid estrogens

All sediment steroid estrogens (estrone, 17α-estradiol; 17β-estradiol; 17α -ethinylestradiol and estriol) were below limits of reporting at all sites (0.25 ng/g dry weight) (Stewart & Northcott, 2020).

POCIS steroid estrogen extract concentrations

All POCIS concentrations of steroid estrogens (estrone, 17α-estradiol; 17β-estradiol; 17α -ethinylestradiol and estriol) were below limits of reporting at all sites (1 ng/sampler for all except 17α –ethinylestradiol which was 2.5 ng/sampler) (Stewart & Northcott, 2020).

Personal care products

Sediment personal care products

Sediment concentrations of personal care products were below limits of reporting at all sites (triclosan: 0.50 ng/g dry weight, methyl-triclosan: 0.10 ng/g dry weight, chloroxylenol: 0.25 ng/g dry weight, and o-phenylphenol: 0.10 ng/g dry weight) (Stewart & Northcott, 2020).

POCIS personal care products extract concentrations

POCIS concentrations of triclosan, methyl-triclosan and phenylphenol were below limits of reporting at all sites (1 ng/sampler for triclosan and methyl-triclosan, 2.5 ng/sampler for phenylphenol) (Stewart & Northcott, 2020). Chloroxylenol (an antiseptic/disinfectant) was recorded at one site (Otumoetai) with a concentration of 23 ng/sampler (limits of reporting 2.5 ng/g dry weight).

Preservatives

Sediment preservatives

The preservative methyl paraben was reported at 10 sites, with the highest concentrations reported at Waimapu (2.13 ng/g) (Table 20). Propyl paraben was below limits of reporting at all sites (<0.10 ng/g dry weight).

Table 20. Sediment concentration of preservatives (ng/g dry weight). Samples above limits of reporting are shown in bold.

Site	Methyl paraben
Port	<0.10
Sulphur Point	<0.10
Waimapu (176)	**0.19**
Katikati	**0.37**
Tuapiro	<0.10
Te Puna	**0.75**
Otumoetai	**0.53**
Wairoa	**0.55**
Waikareao	**0.28**
Puarenga (FRI)	**0.38**
Welcome Bay	**0.93**
Rangataua	<0.10
Waimapu (P14)	<0.10
Kopurererua	**0.12**
Waimapu (SH 29)	**2.13**
Waiari (Kaituna confluence)	<0.10

POCIS preservatives extract concentrations

Methyl paraben was reported at six sites in the POCIS samplers (Table 21) and propyl paraben was reported at one site (Tuapiro, 7.7 ng/sampler). The highest POCIS concentrations of methyl paraben were at Katikati with a concentration of 77.1 ng/sample, followed by Tuapiro (34 ng/sampler) and Port (28.7 ng/sampler).

Table 21 POCIS concentration of preservatives (ng/sampler). Samples above limits of reporting are shown in bold.

	Concentration of preservative (ng/sampler)	
Site	Methyl paraben	Propyl paraben
Tuapiro	**34**	**7.7**
Katikati	**77.1**	<2.5
Te Puna	**23.3**	<2.5
Wairoa	<2.5	<2.5
Otumoetai	<2.5	<2.5

	Concentration of preservative (ng/sampler)	
Site	**Methyl paraben**	**Propyl paraben**
Waikareao	**12.2**	<2.5
Waimapu	**17.2**	<2.5
Port	**28.7**	<2.5
Welcome Bay	<2.5	<2.5
Rangataua Bay	<2.5	<2.5

Anti-corrosive

Sediment anti-corrosive

The sediment concentrations of benzotriazole were below limits of reporting at all sites (1 ng/g dry weight) (Stewart & Northcott, 2020).

POCIS anti-corrosive extract concentration

The POCIS concentrations of benzotriazole were below limits of reporting at all sites (1 ng/sampler) (Stewart & Northcott, 2020).

Pyrethroid insecticides

Sediment pyrethroid insecticides

The insecticide bienthrin was reported at 11 sites, with the highest sediment concentration of 2.59 ng/g at Te Puna. The pyrethroid insecticide cis- and trans- permethrin were reported at three (Welcome Bay, Waimapu (P14) and Katikati) and one sites (Welcome Bay) respectively (Table 22).

Table 22 Sediment concentration of pyrethroid insecticides (ng/g dry weight). Samples above limits of reporting are shown in bold.

Site	Bifenthrin	cis-permethrin	trans-permethrin
Port	<0.10	<0.25	<0.25
Sulphur Point	<0.10	<0.25	<0.25
Waimapu (176)	**0.46**	<0.25	<0.25
Katikati	**1.04**	**3.65**	<0.25
Tuapiro	**1.03**	<0.25	<0.25
Te Puna	**2.59**	<0.25	<0.25
Otumoetai	<0.10	<0.25	<0.25
Wairoa	<0.10	<0.25	<0.25
Waikareao	**0.17**	<0.25	<0.25
Puarenga (FRI)	**0.16**	<0.25	<0.25
Welcome Bay	**1.31**	**5.01**	**5.35**
Rangataua	**0.25**	<0.25	<0.25
Waimapu (P14)	**1.02**	**2.66**	<0.25
Kopurererua	**0.14**	<0.25	<0.25

Site	Bifenthrin	cis-permethrin	trans-permethrin
Waimapu (SH 29)	**0.44**	<0.25	<0.25
Waiari (Kaituna confluence)	<0.10	<0.25	<0.25

POCIS pyrethroid insecticides

Pyrethroid insecticides were not measured in POCIS because they are too hydrophobic.

Antifouling agents

Sediment antifouling agents

Antifouling agents were only analysed for the Port and Otumoetai sampling sites. Diuron was detected at both sites (Table 23), whilst isoproturon and linuron were below limits of reporting at both sites (<0.01 ng/g dry weight).

Table 23 Sediment concentration of antifouling agents (ng/g dry weight). Samples above limits of reporting are shown in bold.

Site	Diuron
Port	**0.035**
Otumoetai	**0.013**

POCIS antifouling extract concentrations

All antifouling agents (diuron, isoproturon, linuron) measured at the two sites were below limits of reporting (0.005 ng/sampler).

UV filters

Sediment UV filters

The main UV filter oxybenzone (or benzophenone-3) was reported at ten sites with the highest sediment concentration at Waimapu (SH 29) (2.57 ng/g) (Table 24). Four other measured UV filters (4-MBC (4-methylbenzylidene camphor), 4-hydroxy-benzophenone, 2,4-dihydroxy-benzophenone, and octinoxate) were all below limits of reporting (<0.50 ng/g dry weight for 4-MBC and oxtinoxate, <0.25 ng/g dry weight for 4- and 2,4- hydroxybenzophenone).

Table 24 Sediment concentration of UV filters (ng/g dry weight). Samples above limits of reporting are shown in bold.

Site	Oxybenzone
Port	<0.10
Sulphur Point	**0.42**
Waimapu (176)	**1.54**
Katikati	**0.44**
Tuapiro	**0.48**
Te Puna	<0.10
Otumoetai	**0.19**

Site	Oxybenzone
Wairoa	**1.21**
Waikareao	<0.10
Puarenga (FRI)	**0.41**
Welcome Bay	<0.10
Rangataua	<0.10
Waimapu (P14)	<0.10
Kopurererua	**0.42**
Waimapu (SH 29)	**2.57**
Waiari (Kaituna confluence)	**0.14**

POCIS UV filter extract concentrations

All UV filters in POCIS were below limits of reporting (oxybenzone: 2.5 ng/sampler, 4-MBC: 5 ng/sampler, 4-hydroxy-benzophenone: 1 ng/sampler, 2, 4-dihydroxy-benzophenone: 2.5 ng/sampler, and octinoxate: 2.5 ng/sampler).

Wastewater markers

Sediment wastewater markers

Caffeine sediment concentrations were below the limits of reporting at all sites (10 ng/g dry weight). The artificial sweetener sucralose was only measured in the POCIS water samples.

POCIS wastewater extract concentrations

Caffeine and sucralose POCIS concentrations were below limits of reporting (caffeine: 20 ng/sampler, sucralose: 5 ng/sampler).

Summary of EOC results

Of the total subtypes of EOCs analysed, seven of the 15 analytes were detected in sediments (Table 25). Plasticisers were detected at all of the sediment sites measured, with the highest concentrations of the species di-n-butyl-phthalate and di-ethylhexyl-phthalate (DEHP) recorded. The second most detected analyte was pyrethroid insecticides, recorded at 11 sediment sites. The next most detected analytes in sediments were preservatives (methyl-paraben) and UV-filters (oxybenzone), detected at 10 sites.

There was an absence of several main classes of compounds in the sediment samples, which includes industrial polybrominated diphenyl ether flame retardants, phosphate flame retardants, polyfluorinated alkyl substances (PFAS), polycyclic musk fragrances, the herbicide glyphosate and its metabolite AMPA, steroid estrogens, personal care products, core pharmaceuticals, anticorrosive compounds, and caffeine.

At the passive sampler water sites there was six detections of preservatives, PFAS, and glyphosate/AMPA (Table 27). There was one detection of a personal care product at Otumoetai (chloroxylenol) and one detection of the surfactants (technical nonylphenol equivalents) at Katikati. The most commonly detected EOCs were those belonging to the synthetic organofluorine chemical compounds (PHxS, PFOS, PFOA).

Table 25 Sediment concentration (ng/g) of EOCs detected above the LOR at one or more sample sites in the Bay of Plenty Region, 2020. Numbers in blue are the reported concentrations, non-detects (below the LOR) are shaded grey. Values highlighted in red correspond to the potential exceedances of the risk values set out in Table 26. Table taken from Conwell (2021).

Site		Port	Sulphur Point	Waimapu 176	Katikati	Tuapiro	Te Puna	Otumoetai	Wairoa	Waikareao	Puarenga (FRI)	Welcome Bay	Rangataua Bay	Waimapu (P14)	Kopurereroa	Waimapu (SH 29)	Waiari (Kaituna confulence)	LOR[A] (ng/kg)	No. detects/EOC
Receiving environment[1]		M	E	E	E	E	E	M	E	E	F	E	E	E	F	F	F		
Class	**Representative EOC**																		
Plasticisers	DEHPAE[G]	193	36.6	519	ND	8.61	27.3	ND	ND	154	51	38.6	ND	62.9	ND	ND	ND	20	9
Phthalates (core)	BBPAE[H]	2.67	1.16	208	2.14	ND	2.12	ND	ND	40.5	ND	9.88	3.28	5.29	5.04	ND	ND	10	10
	Bisphenol-A	0.2	ND	0.94	ND	ND	1.8	0.22	1.34	1.32	0.14	0.96	0.15	0.52	0.46	0.64	0.26	0.5	13
	Dimethyl phthalate	6.53	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.88	1.25	ND		3
Additional phthalate plasticisers	Diethyl phthalate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.61	10.5	ND		2
	Di-n-butyl phthalate	400	879	50.6	43.6	677	675	185	569	1893	172	720	225	77.6	3200	1213	144		16
Additional Phthalate acid esters	Monobutyl-PAE	ND	ND	ND	ND	1.94	10.9	ND	ND	16.7	ND	ND	ND	ND	ND	ND	ND		3
	Mono-EH-PAE	ND	ND	ND	ND	ND	ND	ND	ND	0.45	ND	ND	ND	ND	ND	ND	ND		1
	Monomethyl-PAE	3	ND	6.29	6.59	ND	22.9	ND	ND	7.75	ND	10.3	2.4	2.78	3.23	4.57	ND		10
	Tech-NP EQs[I]	20.7	ND	14.6	15.2	24.6	28.3	11.1	18.1	ND	ND	ND	ND	ND	ND	20.5	ND	10	8
Core pyrethroid insecticide	Bifenthrin	ND	ND	1.02	1.04	1.03	2.59	ND	ND	0.17	0.16	1.31	0.25	0.46	0.14	0.44	ND	0.1	11
Additional pyrethroid insecticide	cis-permethrin	ND	ND	2.66	3.65	ND	ND	ND	ND	ND	5.01	ND	ND	ND	ND	ND	ND	0.25	3
	transpermethrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.35	ND	ND	ND	ND	ND	ND	0.25	1
Additional pharmaceuticals	Ketoprofen	ND	ND	ND	2.09	ND	0.69	3.93	11.1	ND	ND	3.64	3.22	3.49	ND	ND	ND	0.2	7
	Meclofenamic acid	ND	ND	ND	0.9	ND	0.29	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2	2
	Naproxen	ND	ND	ND	0.33	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2	1
	Salicyclic acid	ND	2	ND	ND	ND	2.33	ND	ND	4.25	ND	ND	ND	ND	12.2	ND	30.2	0.2	5
Core preservative	Methyl-Paraben	ND	ND	0.19	0.37	ND	0.75	0.53	0.55	0.28	0.38	0.93	ND	ND	0.12	2.13	ND	0.1	10
Core antifouling agent	Diuron	0.035						0.013										0.01	2
Core UV filter	Oxybenzone	ND	0.42	1.54	0.44	0.48	ND	0.19	1.21	ND	0.41	ND	ND	ND	0.42	2.57	0.14	0.1	10
	No. detects/ site	8	5	10	11	6	12	7	6	10	6	10	6	7	10	9	4		
	No. highest detects/site	2		2	2		5		1			2			1	2			

[1] Receiving environment type: M = marina, E = estuary, F = freshwater.

Ecological risk of EOCs

A technical report was commissioned to investigate the potential ecological risk of EOCs to the sediment and aquatic environment (Conwell, 2021). The section below is summarised from the full technical report (available on request from BOPRC Objective ID: A3879986).

Sediment

The concentrations of EOCs that exceeded a corresponding risk concentration are shown in Table 26. Risk has been defined as the concentration at which there is likely no adverse effects that can be detected in the biota/ecological systems. This report has not looked at human exposure effects, however biota would have adverse effects at lower concentrations. Out of the 19 EOCs listed in Table 26 which recorded a concentration above the Limit of Reporting (LOR) at at least one site, four results exceeded available/published PNEC data for that EOC.

Three exceedances of the plasticisers exceeded their PNEC risk concentrations by 3% (BBPAE, freshwater sediment Kopurereroa), 20% (Di-n-butyl phthalate, estuarine sediment Waimapu 176), and 40% (dimethyl phthalate, freshwater sediment Kopurereroa).

The pyrethroid insecticide cis-permethrin exceeded the PNEC at the three sites it was detected, from 260-500% of the published PNEC (Waimapu 176, Katikati, Welcome Bay).

The concentrations of EOCs that included the antifoulants, preservatives, surfactants, and several remaining plasticisers were at least one magnitude lower than their respective EQGC value, indicating a low risk of these compounds to resident aquatic biota.

Table 26. Concentration of core and non-core EOCs analysed in Bay of Plenty estuarine and freshwater sediments (ng/g dry weight) that were recorded above limit of reporting (LOR) detection limits with available ecological risk guideline data. Red text shows where field result exceeds the PNEC reference. Table taken from Conwell (2021).

Class	Representative EOC	LOR[A] (ng/g)	Field range (ng/g)	PNEC of NOEC (ng/g)	Reference (sediment PNEC/NOEC)
Plasticisers	DEHPAE[D]	20	NDB - 519 (6)C	100000	ECB, 2008a
	BBPAE[E]	10	ND - **208** (8)	172	ECB, 2007
	Bisphenol-A	0.5	ND - 1.8 (10)	24	EU, 2008b
	Dimethyl phthalate		ND - 6.53 (m,1) ND- **1.88*** (f, 2)	1.3(f) 130(m)	ECHA (online, sediment freshwater (f) marine (m) PNEC)
	Diethyl phthalate		ND - 10.5 (2)	137 (f) 13.7(m)	ECHA (online, sediment freshwater (f) marine (m) PNEC)
	Di-n-butyl phthalate		ND - **3200** (13)	3100**	ECB, 2004
	Monobutyl-PAE[F]		ND - 10.9 (2)		Data not listed on ECHA
	Monomethyl-PAE		ND - 22.9 (8)		Data not listed on ECHA
Surfactants	Tech-NP EQs[G]	10	ND - 28.3 (8)	1000	Environment Canada, 2002

Class	Representative EOC	LOR[A] (ng/g)	Field range (ng/g)	PNEC of NOEC (ng/g)	Reference (sediment PNEC/NOEC)
Pyrethroid insecticides	Bifenthrin	0.1	ND - 2.59 (8)		Data not listed on ECHA
	cis-permethrin	0.25	ND – **5.01** (3)	1	EU 2014
Pharmaceuticals	Clofibric acid	0.2	ND		Not listed on ECHA
	Ketoprofen	0.2	ND - 11.1 (6)		Data not listed on ECHA
	Meclofenamic acid	0.2	ND - 0.9 (2)		Data not listed on ECHA
	Naproxen	0.2	ND - 0.33 (1)		Data not listed on ECHA
	Salicyclic acid	0.2	ND - 30.2 (4)		Not listed on ECHA
Preservative	Methyl-Paraben	0.1	ND - 2.13 (7)	63.2(f), 6.32(m)	ECHA (online, sediment freshwater (f) marine (m) PNEC)
Anti-foulant	Diuron	0.01	0.013 - 0.035 (2)	5	ECHA (online, PNEC is for sediment in marine waters)
UV filter	Oxybenzone	0.1	ND - 2.57 (9)	7	ECHA (online, PNEC is for sediment in marine waters)

A LOR = Limit of reporting, B ND = not detected above the LOR, C number of samples detected in brackets, D DEHPAE Diethylhexylphthalate acid ester, E BBPAE Butylbenzylphthalate acid ester, F PAE Phthalate ester plasticizer, G Sum of the eleven highest response peaks in a technical mixture of branched nonylphenol isomer, * PNEC is for biota in freshwater sediments only, **Data reported by the ECHA assessment indicated this was based on equilibrium partitioning, rather than the multi-species study due to data quality concerns, thus the PNEC for DBP is tentative only.

Water

There were no EOCs that exceeded the reported risk effects range data (as PNEC or NOEC)(Table 27). The PNEC data is expressed in nanograms per litre, which is a factor of 1000 greater than the calculated average concentration data, which is expressed in pictograms per litre. The comparison of the PNEC data indicates all of the EOCs were well below the ecological risk limits. For some of the EOCs, the calculated in-stream concentrations were lower than the ecological risk concentrations by several orders of magnitude.

Table 27 Concentration range of calculated time weighted concentrations of EOCs compared against ecological risk data (as PNEC or NOEC, where available). Note units for concentration are expressed as pg/L, units for risk effects concentrations are expressed as ng/L. Blue text indicates where sites were above the limits of reporting. Table taken from Conwell (2021).

Class	Representative EOC	TWA range (pg/L)	No. sites	Number of detects >LOR*	PNEC or NOEC (ng/L)	Reference
PFHxS/PFOS/PFOA	PFHxS	0.21 - 0.5	10	5		
	PFOS	0.33 - 2.1	10	6	0.23	99% Draft DGV (FW)
	PFOA	0.03 - 0.54	10	4	19000	99% Draft DGV (FW)
Phosphate flame retardants	TDCP[D]	<243	10	0	1300	Env Canada 2016
	TPP[E]	<50	10	0	740	Verbruggen 2006
	TCPP[F]	<32,585	10	0	160000	Verbruggen 2007
Plasticisers/Phthalates (core)	Bisphenol-A	<165	10	0	60	Wright-Walters 2011
Surfactants	4-n-Nonylphenol	<33	10	0	24000	Comber et al. 1993. Chemosphere
	Tech-NP EQs[1]	827	10	1	330	European Union 2002
Herbicide	Glyphosate	51.3 - 62	10	4	370000	ANZG 99%ile Low reliability DGV
	AMPA	49.3 - 97.5	10	5	15 x 10^6	Levine et al 2015.
Pharmaceuticals (core)	Acetaminophen	<316	10	0	5.72 x 10^6	Lim et al. 2012
	Carbamazepine	<321	10	0	9000	Zhao et al. 2017
	Diclofenac	<678	10	0	9800	Zhao et al. 2018
	Ibuprofen	<335	10	0	13875	Ortez de Garcia 2014
Steroid estrogen	Estrone	<280	10	0	6	Caldwell et al. 2012
Personal care product	Triclosan	<46	10	0	100	WFD-UKTAG 2009
Anti-corrosive	Benzotriazole	<314	10	0	19000	ECHA online
Antifouling agent (core)	Diuron	<2.2	2	0	200	ANZG 99% Low reliability DGV
	Isoproturon	<0.9	2	0	300	Durak et al 2020
Wastewater marker	Caffeine	<6727	10	0	87000	ECHA online

*Note: The number of detects >LOR are for the analyses of the EOC extracted from the PSD, prior to calculation of the TWA. The TWA represents the average concentration, following the time integrated calculations and relevant coefficient factors. Only TWA for EOC where the rate of sampling (Rs) coefficient was available could be calculated, even if the analyses of the EOC in the PSD was >LOR.

Spatial EOC trends

The higher number of EOCs detected in the passive sampling devices was focused around the southern harbour (Figure 25). The commonly detected contaminants in the southern harbour included PFAS, preservatives and glyphosate. Nothing was detected in the mid harbour, and a few EOCs were detected in the northern harbour, with higher numbers at Katikati compared to Tuapiro.

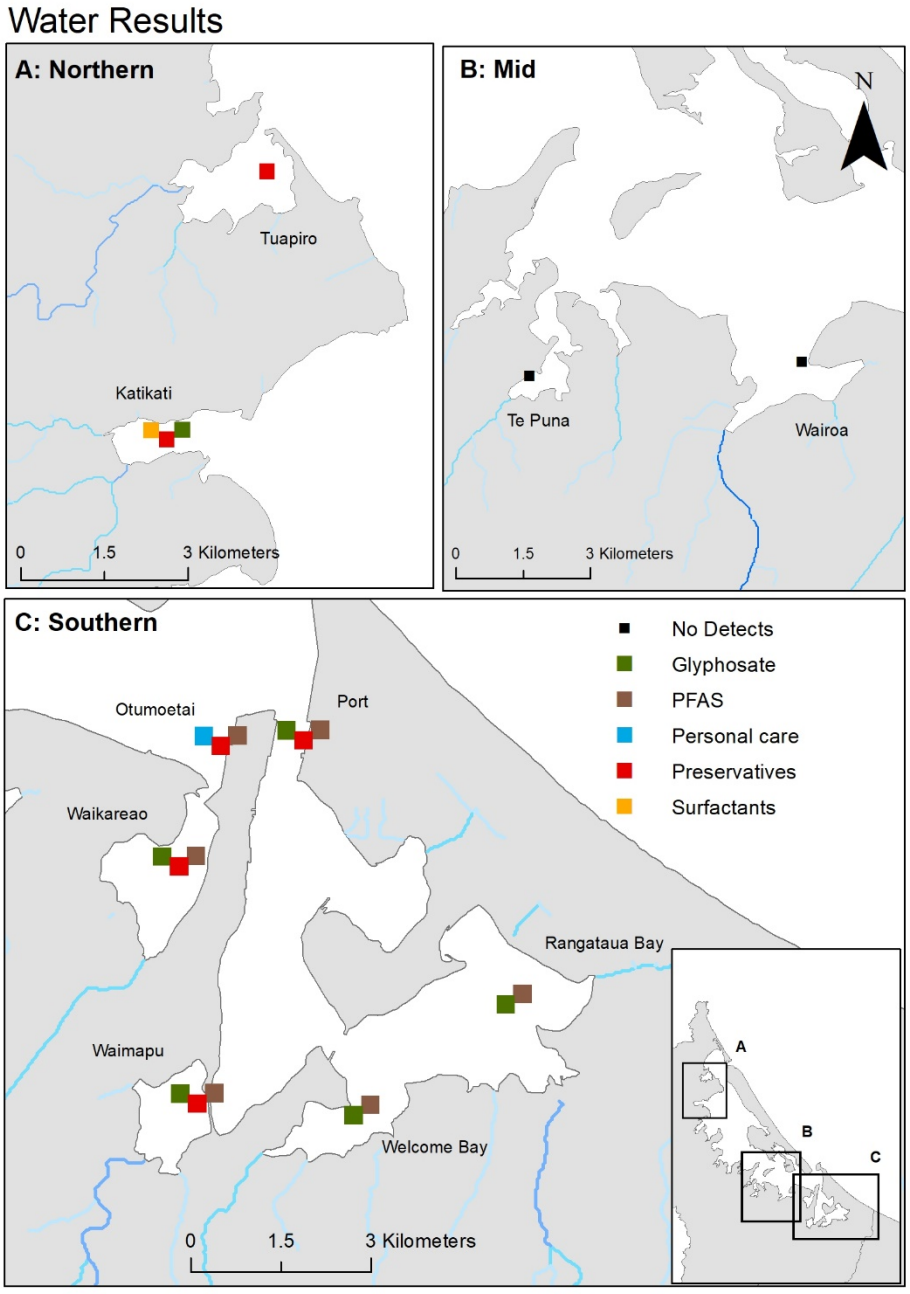

Figure 25 Spatial emerging organic contaminant results for the water passive sampling devices.

A number of common sediment EOCs were picked up in the northern harbour, including surfactants, insecticides, plasticisers and UV filters. The more urbanised area of Katikati also detected pharmaceuticals and preservatives. In the mid harbour, sediment EOCs included preservatives, pharmaceuticals, plasticiers, surfactants. The Te Puna site also detected insecticides, whereas Wairoa detected UV-filters. In the southern harbour sediments closer to the river inflows, insecticides, preservatives and plasticisers were commonly detected. Pharmaceuticals were also common in southern harbour sediments, with the exception of Waikareao/Kopurereroa River. UV-filters and surfactants were also common at a number of sites.

Antifouling agents were detected at the two sites near boating activity it was measured at (Otumoetai and Port).

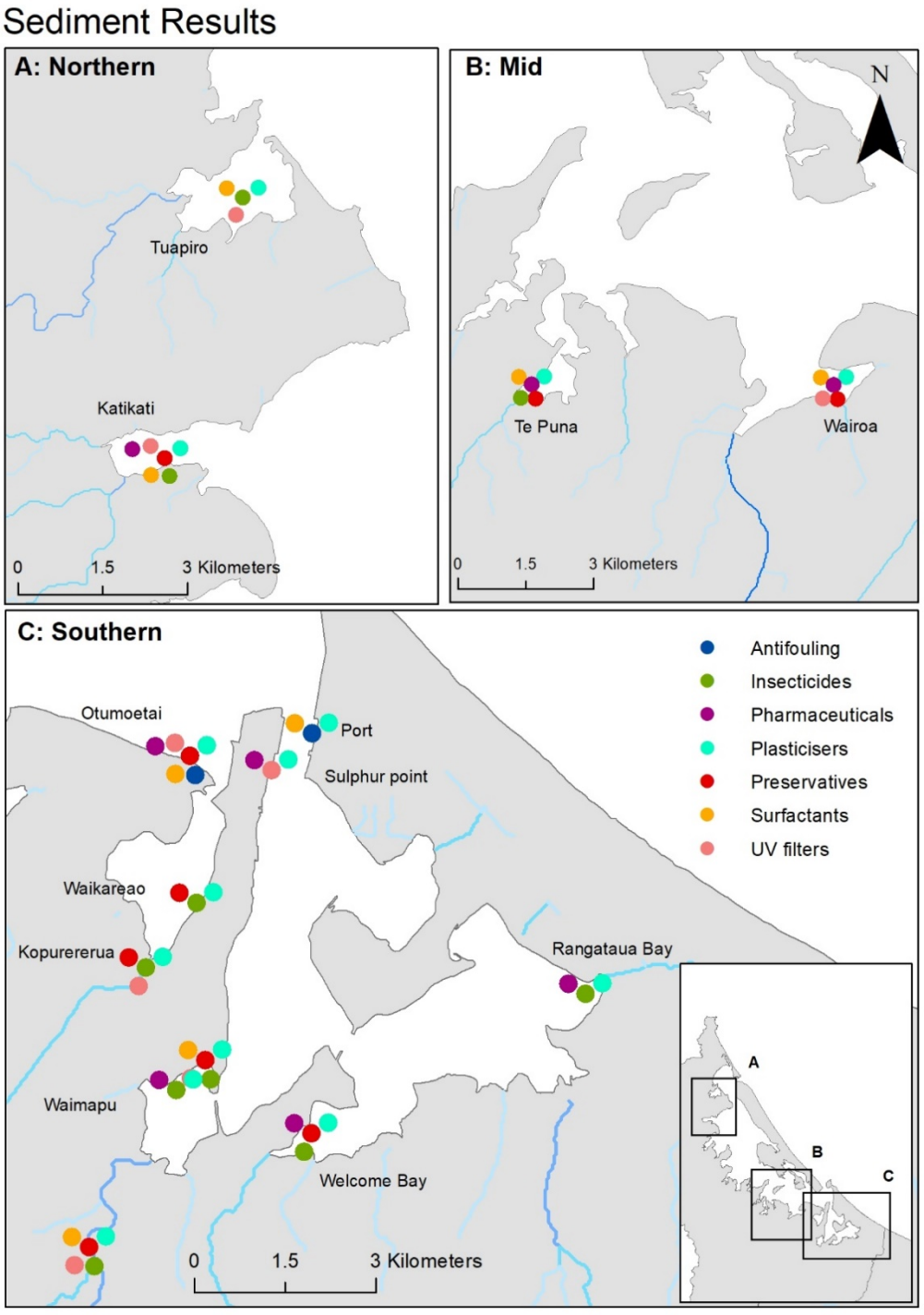

Figure 26 Spatial emerging organic contaminant results for the sediment samples.

Report Discussion/Matapakitanga

NERMN Contaminants monitoring trends

This is the first time BOPRC has reported on heavy metal trends in sediments for the Bay of Plenty as a minimum of 10 years data was available from a range of sites for the first time. Increasing trends in heavy metals were found in many subestuary sites around the Bay of Plenty. Waikareao Estuary at Tau 15 shows significant increases in a suite of heavy metals, including arsenic, cadmium, chromium, copper, lead, nickel and zinc. It has also increased greatly in mud content, which helps bind heavy metals and supports their accumulation. Te Puna Estuary (Tau P33) also shows increases in a number of heavy metals including arsenic, cadmium, chromium and zinc, however, no significant increases in mud. This area is already a highly muddy environment (58%) thus supporting the binding of heavy metals to the sediment. Two sites in Tauranga Harbour that have seagrass beds have also shown an increase in some heavy metals (Waipapa & Te Puna), likely increased by muddying sediments and reduced hydrodynamics in/around the seagrass bed, supporting metal deposition and/or metal uptake by seagrass plants (Nienhuis, 1986, Haiying *et al.*, 2016, Farias *et al.*, 2018). In Welcome Bay at a mangrove seedling site (Tau 8), arsenic concentrations have been increasing likely due to the same mechanisms as described for the seagrass beds, in addition previous NZ studies have shown increasing arsenic due to binding with carbonate rich sediments (Bastakoti *et al.*, 2018). Many metals such as arsenic are present naturally in certain sediment types, thus increased accumulations may also be due to rock weathering and deposition in the catchment. In Ōhiwa Harbour, cadmium concentrations have been declining at four sites since around 2008-09. Cadmium can be introduced to the environment through phosphate fertilizers, sewage sludge and various industrial products such as batteries, platings and plastics. The decrease in cadmium may be an indicator of successful land management intervention reducing the inputs to Ōhiwa Harbour.

There were also a number of sites showing clear decreases in heavy metals such as in Welcome Bay at Tau P5. Mud content has been decreasing at this particular site, along with concentrations of copper, lead and mercury. This is in contrast to Tau 8 in the same estuary where increases in metals are occurring, in an area dominated by mangrove seedlings. This shows the importance of monitoring a number of sites within an estuary covering a range of sediment types and habitats. A general trend for sites in the Matua Estuary is evident, where heavy metals are decreasing at two sites. Removal of adult mangrove by mulching occurred in 2010, and small decreases in some heavy metals have been evident since that time.

Spatial trends

The results clearly show the sheltered, urbanised areas are hotspots for heavy metal contaminants, particularly shown by the heavy metal spatial maps in Figures 15-22. The large number of stormwater discharges are likely having a cumulative impact increasing zinc concentrations in the Waikareao Estuary water. Zinc has been flagged by the latest TCC Comprehensive Stormwater reporting as the most common contaminant to exceed ISQG-high guidelines, followed by copper (Boffa Miskell, 2018). Although the heavy metals are not exceeding contaminants in the estuary sediments, high concentrations are being recorded in the estuary water, and the cumulative impacts of the CBD stormwater inputs are evident. Copper and zinc are both heavy metals of concern in the estuarine water. Copper concentrations exceeded the 95% DGV guidelines at Rangataua Bay, and the 90% DGV at Welcome Bay. Many other sites may be exceeding the 99% DGV due to the high detection limits in estuarine water. The zinc and lead 95% DGV were also breached at Welcome Bay, indicating a number of contaminants of concern in the area. The default value guidelines are based on a small number of ecological test subjects, and the full impact on the harbour ecology is not fully known.

Organics survey

A number of organic based pesticides and herbicides were tested for across the Bay of Plenty in both rivers and estuary sediments, and river water. In the estuary sediments all organic contaminants were below detection limits (acid herbicides, multiresidue pesticides, PCBs, metsulfuron, and semivolatile SVOCs). In the last estuary contaminant survey (Park, 2014), all organic contaminants were also below detection with the exception of a breakdown product of DDT (4,4'-DDE) at one site in Apata estuary. In the river sediments, all herbicides and pesticides were below detection in sediments with the exception of Triclopyr (broadleaf herbicide) which was just above detection at two river locations (Waiowhiro and Matahui) and one river water site (Waikite at Welcome Bay Road). PAHs were detected at a number of estuary sediment sites, generally in urbanised areas, and were well below ISQG low levels. A large suite of PAHs were detected in Waimapu at SH29 which was at the ISQG-high guideline, suggesting a high industrial influence and input, or sourced from roads, including tyre abrasion, pavement abrasion, oil leaks and exhaust particles. This was also evident in the titiko samples at Waimapu, with high concentrations of fluoranthene and pyrene detected. The tuangi samples however did not show signs of bioaccumulation and were below detection for all PAHs, however they were collected from further out in the channel unlike the titiko that are directly beside a stormwater inflow. The pipi and titiko collected from Waikareao Estuary had a number of PAHs detected, however, the sum of PAHs were relatively low compared to the Waimapu titiko. A number of PCBs were detected in the Waikareao titiko. It is currently unknown what impact this may have further up the food web, however current work is underway at the University of Waikato to elucidate the heavy metal burden on a number of higher trophic level consumers (stingrays, sharks).

Due to the large suite of pesticides and herbicides being tested, detection limits are quite high. The majority of pesticides and herbicides were below detection, however, there is the potential for ecological effects at or below detection limits. There are toxicant default guidelines values (DGV) for a number of pesticides and herbicides. Many of the 99% species protection limits are at or lower than the detection limit for many of the measured pesticides, thus not providing a clear view of lower level impacts on ecological life. The freshwater sites were selected to cover a wide range of highly agricultural and horticultural sites, thus providing a good estimation of worst case scenario for our rivers and estuaries at a snapshot in time during a low rainfall period.

Emerging organic contaminants

The most common emerging organic contaminants measured in the sediments were a range of plasticisers, surfactants, preservatives, insecticides, UV filters and pharmaceuticals. The emerging contaminants measured in the water by the POCIS samplers were PFAS, glyphosate/AMPA, preservatives, personal care products, and surfactants.

Greater Wellington Regional Council reported the most prevalent EOCs detected in subtidal sediments of Wellington Harbour included the flame retardant (TCPP), plasticisers (butylbenzyl phthalate, bisphenol-A), a surfactant (technical nonylphenol), the pyrethroid insecticide bifenthrin, estrone, personal care products (triclosan, methyl-paraben) and the anticorrosive benzotriazole (Oliver & Conwell, 2019). In Wellington Harbour sediments the highest concentrations of EOCs were the phosphate flame retardants (TPP, TCPP), bisphenol-A, surfactants (Tech-NP EQs) and estrone. The pyrethroid insecticides (bifenthrin, cis-permethrin) and plasticisers (DEHPAE, BBPAE) were detected at higher concentrations in Bay of Plenty sediments, compared to Wellington Harbour. For a comprehensive comparison table see Conwell (2021).

Auckland Council reported an assessment of EOCs in marine intertidal sediments in 2009 (Stewart *et al.*, 2009, Stewart *et al.*, 2014). For Auckland estuarine sediments, EOCs including surfactants (Tech-NP EQ), brominated phosphate flame retardants, and plasticisers were well above (by orders of magnitude) the sediment concentrations reported in Bay of Plenty sediments. However the concentration of the insecticide cis-permethrin was higher in the Bay of Plenty than reported for Auckland sediments. For a comprehensive comparison table see Conwell (2021).

A 2019 survey across several sites in Dunedin revealed a low occurrence of detected EOCs (PCPPs) in sediments, and all those detected represent concentrations that are a low ecological risk (Bernot *et al.*, 2018).

The prevalence of plasticisers was noted by Northcott (2018) in the analyses of the Wellington Harbour subtidal sediments, and similarly there is a high prevalence in Bay of Plenty samples. These compounds are considered as 'high production volume' chemicals that are common components in a wide range of domestic and industrial products and household products (Northcott, 2018). Estrone was not reported in the Bay of Plenty samples, in contrast to both Wellington and Auckland. Northcott 2018 summarises that estrone is an estrogenic steroid hormone, naturally excreted by all mammals, as well as being present in hormone based pharmaceutical products. It is generally considered to be a ubiquitous pollutant in New Zealand aquatic ecosystems, and its primary source is excretion by dairy cows and from wastewater treatment plants.

There are few studies that analyse the in-stream concentration of EOCs in receiving environments waters in New Zealand. In 2019 a suite of EOCs in freshwater streams in Dunedin focused on the concentration before and after the student influx at the start of the University term (Bernot *et al.*, 2018). The study reported concentrations of carbamazepine (9.7-26 ng/L) and caffeine (74-77 ng/L) concentrations both much higher than the limits of the time weighted averaged concentrations calculated for this study. Stewart et al. 2016 conducted passive sampling devices for EOCs in Waitemata Harbour. Concentrations of paracetamol (acetaminophen) were reported in the range of 0.25-1.18 ng/L, compared to this study which were below the limits of reporting of <0.32 ng/L. Caffeine was reported in the range of 2-6 ng/L, compared to this study which had none above the limits of reporting (<6.7 ng/L).

A recent nationwide survey of EOCs and pesticides in groundwater found bisphenol-A (BPA) and UV filter compounds to be the most commonly detected EOCs (Close & Humphries, 2019). Concentrations of the plasticiser BPA ranged from 1.28 to 423 ng/L. The UV filter oxybenzone ranged from 2.47–25.4 ng/L. In the Bay of Plenty 13 of the 25 sampled bores recorded detection of EOCs. These included bisphenol-A, methyl- and propyl-paraben, caffeine, octinoxate, and 2, 4-dihydroxybenzophenone. The results of the study indicated that EOCs are likely sourced from either animal or human effluents/ activities, and are making their way into shallow groundwater systems. The authors also acknowledged that there is a lack of information of the fate and effect of EOCs and whether the detected concentrations are likely to have an impact on ecological systems. Bisphenol A was not detected in the passive sampler devices, however, it was a common detect across all of the sediment sites.

At a high level, the frequency of the EOC detections in sediments and concentration gradient across the Tauranga sites reflected the proximity of the sites to more urbanised/commercial areas of the Tauranga city centre. The spatial extent of the sediment results above detection limits also demonstrates that for even less urbanised/populated catchments, EOCs are at detectable concentrations in the estuarine receiving environment (i.e. Welcome Bay, Te Puna, Tuapiro, and Katikati). Understanding the source of the contamination is crucial to create mitigation options to protect the receiving environment. It is likely that land-based agricultural activities in semi-rural catchments are an active source of pyrethroid insecticide contamination. In addition, plasticisers are ubiquitous contaminants across all catchment types.

Study limitations

This report is an accrual of a number of contaminant programmes and investigations, with a strong focus on Tauranga Harbour. The large number of sites monitored for contaminants under the NERMN programme allows for robust analyses and trend detection to occur. The freshwater data reported in this study was a one-off spatial survey for a number of contaminants. Due to the large suite of contaminants selected for analysis, and the large number of sites, the replication was low at one sample per site. This provided a good spatial overview, but little understanding of variability and seasonal changes in the water based contaminants. The sampling for this project occurred over a warm summer with low rainfall. All sampling for water contaminants occurred during a month of low rainfall, thus these results represent low flow conditions at the end of summer. The majority of heavy metals enter estuaries during moderate-high rainfall events (such as reported in TCC Stormwater Report), hence this large potential input has not been quantified in this survey. Many crop applications of herbicides and pesticides occur coming into spring and summer when peak growth is occurring and may present a better time to target in future surveys. The sediment samples however do provide a long term view of the accumulation of contaminants over time, and will also pose the greatest stress to benthic invertebrate communities. High water column concentrations of heavy metals may pose short term acute stress on marine life.

Future work recommendations

Given some of the high concentrations of heavy metals that have been recorded in the spatial estuary and river water sampling, further sampling should occur in this area with a focus on expanding our temporal knowledge of the receiving estuarine environments of the stormwater outfalls. The use of passive samplers should be considered for heavy metals to provide a time integrated concentration of heavy metals (Stewart *et al.*, 2016), in addition to spot samples during high rainfall events. These are currently being trialled by BOPRC in a number of streams around the Bay of Plenty (Suren pers. Comms). Consideration should also be given to adding heavy metal water sampling to the monthly NERMN estuary monitoring programme.

The Bay of Plenty Regional Council Regional Coastal Plan became operative on the 3 December 2020, with various issues identified relating to stormwater and the potential to transport contaminants into the estuary such as heavy metals and hydrocarbons. Method 6 has identified a piece of work modelling catchments in Tauranga Harbour where stormwater is discharged to the coastal environment, to support the management of cumulative effects and loading of contaminants from stormwater discharges. This piece of work should be prioritised and work closely with Tangata Whenua and relevant territorial agencies (TCC, Western Bay) to share and collect data to support model development. In addition, a new investigative project is being developed in collaboration with TCC to identify some key sources and inputs of heavy metals to the stormwater network, to then develop programs for mitigation and remediation.

The Land Management team has developed the “Focus Catchments” programme to align its work with the highest priorities identified through BOPRC implementation of the National Policy Statement for Freshwater Management (NPS-FM). The programme currently includes Focus Catchments in parts of Tauranga Harbour, Ōhiwa Harbour, Maketū Estuary, and Waihī Estuary, where specific improvements in water quality attributes are being identified through the NPS-FM National Objectives Framework process. Catchment action planning and land management work is now underway to address issues in these catchments. The next review period of the Focus Catchments programme in 2022 could give consideration to some of the new contaminant issues identified in this report, especially where they align with priorities of the NPS-FM. In the interim, the Land Management team could assist with promoting awareness of the emerging issues through their ongoing engagement work with community, and contribute towards further technical understanding and contaminant mitigation work in Focus Catchments.

The NERMN sediment monitoring network provides good spatial coverage and identification of problem areas, and has detected some increasing heavy metal concentrations over time. The EOC sampling has detected a range of EOCs present in Tauranga Harbour, some of which (pyrethroid

insecticide, plasticisers) exceed available published risk data. These results are considered indicative, and a conservative assessment only, due to the low availability of published risk data, and with the majority based from overseas studies. Given the low current detections of EOCs, it is suggested this work continues on a 5-yearly intensive contaminant monitoring scheme, or in line with current New Zealand recommendations around the monitoring of emerging organic contaminants.

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Appendices

Appendix 1

Site Locations

Table 1. Estuary contaminant site GPS locations and identifier.

Easting	Northing	Site Name	Tauranga Harbour	Site Identifier
1884242	5821235	Tau P1	Rangataua Bay	EP424123
1883931	5821400	Tau P2	Rangataua Bay	EP393140
1883506	5821739	Tau P3	Rangataua Bay	EP350173
1881672	5820490	Tau P4	Welcome Bay	EP167049
1881886	5820412	Tau P5	Welcome Bay	EP188041
1881239	5820062	Tau P6	Welcome Bay	EP123006
1880652	5819988	Tau P7	Welcome Bay	EO065999
1880571	5820329	Tau P8	Welcome Bay	EP057032
1880808	5820738	Tau P9	Welcome Bay	EP080073
1880768	5820756	Tau P10	Welcome Bay	EP076075
1881385	5821000	Tau P65	Welcome Bay	EP139102
1878635	5820296	Tau P11	Waimapu	DP863029
1878074	5820244	Tau P12	Waimapu	DP807024
1877856	5820740	Tau P13	Waimapu	DP785074
1878341	5821044	Tau P14	Waimapu	DP834104
1879080	5820750	Tau P64	Waimapu	DP908079
1878137	5823383	Tau P15	Waikareao	DP813338
1878054	5823913	Tau P16	Waikareao	DP805391
1877860	5823857	Tau P17	Waikareao	DP786385
1877791	5824213	Tau P18	Waikareao	DP779421
1877750	5824216	Tau P19	Waikareao	DP775421
1878215	5824448	Tau P20	Waikareao	DP821444
1877916	5824840	Tau P21	Waikareao	DP791484
1875046	5825697	Tau P22	Matua	DP504569
1874961	5825553	Tau P23	Matua	DP496555
1875561	5825937	Tau P24	Matua	DP556593
1869982	5827082	Tau P25	Waikaraka	CP998708
1870072	5827297	Tau P26	Waikaraka	DP007729
1870183	5827068	Tau P27	Waikaraka	DP018706
1870273	5827050	Tau P28	Waikaraka	DP027705
1868601	5827266	Tau P29	Te Puna	CP856728
1868802	5827303	Tau P30	Te Puna	CP880730
1869251	5827693	Tau P31	Te Puna	CP925769

Easting	Northing	Site Name	Tauranga Harbour	Site Identifier
1868821	5826072	Tau P32	Te Puna	CP882607
1868286	5825573	Tau P33	Te Puna	CP828557
1868407	5825618	Tau P34	Te Puna	CP840561
1868241	5828130	Tau P35	Mangawhai	CP824813
1868109	5827940	Tau P36	Mangawhai	CP810794
1867686	5827666	Tau P37	Mangawhai	CP768766
1868651	5829310	Tau P38	Ōmokoroa	CP865931
1866956	5830640	Tau P39	Waipapa	CQ695064
1866357	5830113	Tau P40	Waipapa	CQ635011
1864245	5830677	Tau P41	Apata	CQ424067
1864469	5830553	Tau P42	Apata	CQ446055
1863363	5831812	Tau P43	Wainui	CQ447055
1862416	5831965	Tau P44	Wainui	CQ241196
1860998	5836300	Tau P45	Matahui	CQ099630
1858880	5837422	Tau P46	Rereatukahia	BQ888742
1859212	5837312	Tau P47	Rereatukahia	BQ921731
1859646	5838863	Tau P48	Rereatukahia	BQ964886
1858640	5836725	Tau P67	Rereatukahia	BQ864672
1859588	5837671	Tau P68	Rereatukahia	BQ958767
1859223	5837860	Tau P69	Rereatukahia	BQ922786
1860953	5840102	Tau P49	Uretara	CR095017
1858903	5841602	Tau P50	Uretara	BR890160
1859161	5841666	Tau P51	Uretara	BR916166
1859746	5841640	Tau P52	Uretara	BR974164
1862527	5845714	Tau P53	Ongare	CR252571
1862450	5845670	Tau P66	Ongare	CR245567
1860285	5846213	Tau P54	Tuapiro	CR028621
1860458	5846124	Tau P55	Tuapiro	CR045612
1860851	5846591	Tau P56	Tuapiro	CR085659
1862847	5850792	Tau P57	Waiau	CS284079
1862398	5851854	Tau P58	Waiau	CS239185
1862303	5851980	Tau P59	Waiau	CS230198
1862727	5850040	Tau P60	Bowentown	CS272004
1862905	5850500	Tau P61	Poi's	CS292058
1878590	5826550	Tau P62	Otumoetai	DP847700
1879380	5822540	Tau P63	Grace Rd	DP928239
1963082	5782161	Ohi P1	Kutarere	ML308216
1965356	5787028	Ohi P2	Ōhiwa Camp	ML536703
1958667	5788485	Ohi P3	Waterways	LL867848

Easting	Northing	Site Name	Tauranga Harbour	Site Identifier
1959589	5787961	Ohi P4	North	LL959795
1956983	5788151	Ohi P5	Oyster farm	LL697814
1956592	5786329	Ohi P6	West	LL659633
1964364	5785310	Ohi P7	East	ML436531
1959035	5787401	Ohi P8	Ohi 1	LL903740
1959574	5786357	Ohi P9	Ohi 2	LL957636
1960754	5786649	Ohi P10	Ohi 3	ML075665
1963082	5782161	Ohi P11	Ohi 6	ML308216
1903580	5815515	Mak P1	Mak P1 CEE Mak 5	GO358551
1903377	5814991	Mak P2	Mak P2 Sed 53	GO337499
1903167	5815377	Mak P3	Mak P3 Sed 51	GO316537
1902940	5815287	Mak P4	Mak P4 Sed 48	GO294528
1902444	5815633	Mak P5	Mak P5 Sed 41	GO244563
1902375	5815351	Mak P6	Mak P6 Sed 40	GO237535
1901726	5815839	Mak P7	Mak P7 Sed 35B	GO172583
1901520	5816020	Mak P8	Mak P8 Sed 33	GO152602
1906190	5814927	Wai P1	Wai P1 Wai 1	GO619493
1906200	5813660	Wai P2	Wai P2 sed 8	GO620366
1907660	5813660	Wai P3	Wai P3 sed 13	GO766366
1905660	5813780	Wai P4	Wai P4 sed 9b	GO566378
1907200	5813660	Wai P5	Wai P5 sed 10b	GO720366
1906000	5814300	Wai P6	Wai P6 sed 5	GO600430

Table 2. River contaminant site GPS locations and common name from BOPRC existing sites.

River EOC sites			
Easting	**Northing**	**BOPRC Site Name**	**Site Identifier**
1894513	5814716	Waiari at Kaituna confluence	FO450471
1885980	5771792	Puarenga at FRI	EK598179
1877839	5823064	Kopurererua at SH 2	DP784306
1876903	5818452	Waimapu at SH 29	DO690845

River Sites			
Easting	**Northing**	**BOPRC Site Name**	
1858128	5845877	Tuapiro at Hikurangi Road	BR809582
1857235	5839393	Uretara at Henry Road Ford	BQ723939
1857111	5836225	Te Mania at SH 2	BQ711622
1859753	5834575	Matahui at Elmwood Road	
1859660	5833690	Aongatete at SH2	BQ966369
1861149	5830645	Wainui at SH 2 Bridge	CQ105067
1863571	5829311	Lowe Creek at SH 2	CP356927
1867653	5824884	Te Puna at SH 2 Bridge	CP756608
1872818	5823049	Wairoa at SH 2	DP281304
1879635	5819668	Kaitemako R/B Tributuary at D/S Welcome Bay Road	DO963966
1880616	5819797	Waikite at Welcome Bay Road	New Site 2 (NS2)
1894513	5814716	Waiari at Kaituna confluence	FO450471
1899859	5816162	Kaituna at inlet 1km u/s of cut	FO985616
1906399	5813345	Kaikokopu/Wharere at Waihi Estuary	New Site 3(NS3)
1906940	5813175	Pongakawa/Pukehina at Waihi Estuary	GO694343 (NS4)
1916435	5806447	Waitahunui at SH 2	HN643644
1933033	5799004	Tarawera at SH 2	JM303899
1939781	5795874	Rangitāiki River at Thornton Bridge	JM977587
1949094	5791381	Whakatāne at Landing Rd	KM909138
1949980	5781507	Whakatane at Pekatahi Bridge	KL998150
1881743	5780173	Ngongotaha at SH 36	EL174017
1883351	5777173	Waiowhiro at Outlet of stream	EK387782
1884052	5774873	Utuhina at Lake Road	EK405487
1881396	5781349	Waiteti at SH 36	EL139134
1885980	5771792	Puarenga at FRI	EK598179

Table 3. Emerging organic contaminant sampling sites for sediments and passive sampling devices.

Easting	Northing	Location	EOC Type	Site Name	Site Identifier
1878677	5824131.2	Waikareao	Sediment	Tauranga Harbour at 253	DP867412
1878496	5824761	Waikareao	Passive sampler		
1874970	5825594	Wairoa	Sediment	Tauranga Harbour at Plate 22	DP504569
1874494	5826016	Wairoa	Passive sampler		
1878567	5826556	Otūmoetai	Sediment	Tauranga Harbour at Plate 62	DP847700

Easting	Northing	Location	EOC Type	Site Name	Site Identifier
1879189	5826763	Otūmoetai	Passive sampler		
1868286	5825573	Te Puna	Sediment	Tauranga Harbour at Plate 33	CP828557
1868390	5825702	Te Puna	Passive sampler		
1860285	5846213	Tuapiro	Sediment	Tauranga Harbour at Plate 54	CR028621
1860701	5846531	Tuapiro	Passive sampler		
1858903	5841602	Katikati	Sediment	Tauranga Harbour at Plate 50	BR890160
1858903	5841724	Katikati	Passive sampler		
1880571	5820329	Welcome Bay	Sediment	Tauranga Harbour at Plate 8	EP057032
1881398	5820626	Welcome Bay	Passive sampler		
1878825	5821538	Waimapu	Sediment	Tauranga Harbour at 176	DP882153
1878341	5821044	Waimapu	Sediment	Tauranga Harbour at Plate 14	DP834104
1878799	5820818	Waimapu	Passive sampler		
1885095	5822631.8	Rangataua Bay	Sediment	Tauranga Harbour at Rangataua Bay 26	EP509262
1883926	5822468	Rangataua Bay	Passive sampler		
1879875	5826220	Sulfur Point	Sediment		
1880617	5826920	Port Beacon 8	Sediment		
1880564	5826858	Port Beacon 8	Passive sampler		

Rationale for river site selection

Priority sites identified from previous data

The following sites were found to have irregular or heightened contamination levels which emphasised the importance for monitoring these sites. Magnesium at the Matahui site had reached the lower trigger ISQG value in 2003 and 2012 and Waimapu was close to exceeding the lower trigger for cadmium in 2012. Uretara has displayed moderate- high levels of arsenic with the concentrations being persistent over multiple sampling periods. The Te Puna stream showed a trend of degradation in multiple parameters from 2003-2012. Waikareao Estuary has been highlighted as an area with high zinc and PAH concentrations through all three of the sampling years. Further sites such as Wairoa and Aongatete have large catchments with urban, horticultural and agriculture land use areas which should be further monitored to help understand the change over time. The Kopurererua Stream has had substantial development in the upper reaches with The Lakes subdivision and is the receiving tributary for the Judea Industrial area, therefore becoming a site of high priority. Certain sites were unable to be moved to Aquarius sites and a new site had to be selected, these are as follows: Matahui at Elmwood Rd (no sites in this area although this is high priority), Waikite at Welcome Bay Rd (No sites low enough in the catchment), and the two Waihī Estuary inflow sites (the existing sites were above the junction in the river and would have required four sampling sites to sample this catchment).

Once sites had been determined through desktop analysis, all sites were visited to identify the feasibility of achieving both water and sediment samples. All sites were appropriate for the water sampling methodology as outlined in the RSCMP Sampling Protocol (2018), although the limiting factors which eliminated certain sites for sediment sampling were river depth, width, access as well as the composition of the benthic layer.

Table 4. River site selection based on agricultural influence (agricultural, horticultural, urban)

Easting	Northing	Site	Reasons for site selection	Ag %	Hort %	Urb %
1858128	5845877	Tuapiro at Hikurangi Road	Agriculture >15% Horticultural >5% - NERMN Site - Corresponding estuary sites	**15%**	**6%**	**1%**
1857235	5839393	Uretara at Henry Road Ford	Agriculture >15% Horticulture >5% - NERMN site -Elevated As - Corresponding estuary site	**17%**	**12%**	**5%**
1857111	5836225	Te Mania at SH 2	Agriculture >15% Horticulture >5% Elevated Copper	**42%**	**12%**	**5%**
1859753	5834575	Matahui at Elmwood Road	Agriculture > 15% Horticulture >5%Above lower trigger Hg	**27%**	**48%**	**6%**
1859660	5833690	Aongatete at SH 2	Agriculture >15% Horticultural >5% - NERMN Site	**16%**	**6%**	**1%**
1861149	5830645	Wainui at SH 2 Bridge	Agriculture >15% Horticultural >5%	**19%**	**7%**	**2%**
1863571	5829311	Lowe Creek at SH 2	Agriculture >15% Horticultural >5% -	**34%**	**17%**	**7%**

Easting	Northing	Site	Reasons for site selection	Ag %	Hort %	Urb %
			Corresponding estuary site			
1867653	5824884	Te Puna at SH 2 Bridge	Agriculture >15% Horticultural >5% - Corresponding estuary sites	**28%**	**13%**	**7%**
1872818	5823049	Wairoa at SH 2	Agriculture >15% Horticultural >5% - NERMN Site - Corresponding estuary sites	**29%**	**7%**	**8%**
1877839	5823064	Kopurererua at SH 2	Agriculture >15% Horticultural >5% Urban >10% - NERMN Site- Corresponding estuary sites	**19%**	**6%**	**20%**
1876903	5818452	Waimapu at SH 29	Agriculture >15% Urban>10% - NERMN Site - Corresponding estuary site	**31%**	**4%**	**12%**
1879635	5819668	Kaitemako R/B Tributary at D/S Welcome Bay Road	Agriculture >15% Urban >10% - Corresponding estuary site	**38%**	**2%**	**25%**
1880616	5819797	Waikite at Welcome Bay Road	Agriculture >15% Horticultural >5% Urban >10% Corresponding estuary site	**13%**	**8%**	**33%**
1894513	5814716	Waiari at Kaituna confluence	Agriculture >15% Horticultural >5% Urban >10% - Downstream of WWTP	**35%**	**7%**	**2%**
1899859	5816162	Kaituna at inlet 1km u/s of cut	Agriculture >15% Horticultural >5% - Large catchment	**34%**	**9%**	**4%**
1906399	5813345	Kaikokopu/Wharere at Waihi Estuary	Agriculture >15% Horticultural >5%	**54%**	**6%**	**2%**
1906940	5813175	Pongakawa/Pukehina at Waihi Estuary	Agriculture > 15% - Degraded estuary (dairy on reclaimed flood plains)	**50%**	**4%**	**2%**
1916435	5806447	Waitahunui at SH 2	Agriculture >15% - Degraded estuary (dairy on reclaimed flood plains)	**28%**	**1%**	**1%**
1933033	5799004	Tarawera at SH 2	Agriculture >15% - NERMN Site	**22%**	**0%**	**2%**
1939781	5795874	Rangitāiki River at Thornton Bridge	Receiving environment for large catchment	**13%**	**0%**	**1%**
1949094	5791381	Whakatāne at Landing Road	Receiving environment for large catchment	**12%**	**0%**	**1%**
1881743	5780173	Ngongotaha at SH 36	Agriculture >15% - NERMN Site	**44%**	**0%**	**0%**

Easting	Northing	Site	Reasons for site selection	Ag %	Hort %	Urb %
1883351	5777173	Waiowhiro at Outlet of stream	Agriculture >15% Urban>10%	**15%**	**0%**	**40%**
1884052	5774873	Utuhina at Lake Road	Agriculture >15% Urban>10%	**18%**	**0%**	**22%**
1881396	5781349	Waiteti at SH 36	Agriculture >15%	**59%**	**0%**	**3%**
1885980	5771792	Puarenga at FRI	Agriculture >15% - NERMN Site	**34%**	**0%**	**6%**