Northland Coastal Water Quality

Results from 2018-2020

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1 Introduction

1.1 Why is coastal water quality important?

The Northland peninsula is lined by 3,200km of stunning coastline which is home to a diverse array of marine plants and animals. The coastline is prized by Northlanders for its beauty, recreational opportunities and as an important source of kai moana.

Maintaining good coastal water quality is essential to supporting healthy marine ecosystems and human activities such as recreation, tourism, aquaculture, and fisheries.

In order to assess the state of our coastal water quality and track changes in water quality over time Northland Regional Council (council) carries out routine state of the environment monitoring of the region's coastal water quality.

1.2 Contaminants of concern

Faecal contamination

Faecal contamination affects the suitability of water for swimming and shellfish consumption. Northland is renowned for its warm climate and beautiful beaches, so it is important that our coastal water and particularly our open coast beaches are safe for swimming. This helps support the wellbeing of our community and our tourism industry.

Collecting shellfish is an important cultural tradition in Northland and the coastline is an important source of high-quality kai to our community. Our coastal environment also supports marine farming for mussels and oysters and a commercial scallop fishery.

Sources of faecal contamination include discharges or overflows from wastewater treatment plants, failing domestic wastewater treatment systems, run-off from agricultural land, and dairy-farm effluent discharges.

Sediment

Good water clarity is important for the healthy functioning of marine ecosystems. High levels of material in the water column can restrict light transmission, which affects the amount of photosynthesis (primary production) of aquatic plants and consequently other species that are dependent on them, such as fish and shellfish. Reduced water clarity can also affect the feeding efficiency of visual predators like fish and sea birds, and sediment particles can clog the feeding structures and gills of fish and suspension feeding animals like hū ai (cockles) and kōkota (pipi) that filter their food from the water column (Australian New Zealand Environment Conservation Council, 2000). Water clarity is also an important attribute for recreation and aesthetic values as poor water clarity makes the water less desirable for swimming and recreational activities.

Nutrients

While nutrients are essential for all forms of life, nutrients that enter the environment from human sources, such as fertiliser, stormwater, treated wastewater, sewage overflows and failing septic systems, may exceed the needs of an ecosystem. Elevated nutrients in the water can cause excessive plant growth leading to algal blooms, which in turn can cause lowered levels of water clarity, and periodically lowered levels of dissolved oxygen. Toxic algal blooms pose a significant human health risk through contact with water and eating contaminated shellfish. Both toxic algal blooms and excessive plant growth due to nutrient supply (eutrophication) can reduce the life-supporting capacity of the water. Excessive plant growth can also look unattractive and can cause an unpleasant odour when it dies and decays.

Dissolved oxygen

Dissolved oxygen is a measure of the quantity of oxygen available to aquatic life in the water column. Oxygen is required by marine organisms (for example, fish, invertebrates and microorganisms) for efficient functioning (Australian New Zealand Environment Conservation Council, 2000) and reduced oxygen levels have been shown to cause lethal and sub-lethal effects (physiological and behavioural) in a variety of organisms, especially in fish (Canadian Council of Ministers of the Environment, 1999). Significant decreases in dissolved oxygen levels can occur when there is an excess of organic material in the system, for example, sewage effluent or dead plant material. Dissolved oxygen levels are reduced by respiration, including microbial respiration during breakdown of organic material. Dissolved oxygen levels can become dangerously low where respiration is not balanced by photosynthesis; for example, at night, and during late summer as organic biomass breaks down in benthic environments.

Chlorophyll-*a*

Chlorophyll-*a* is a green pigment found in plants that is used to absorb sunlight during photosynthesis. Chlorophyll-*a* concentrations are therefore an important indicator of phytoplankton abundance and biomass in coastal waters, which is in turn an indicator of trophic status.

Metal contaminants

Metal contaminants can have lethal and sub-lethal effects on marine organisms. Although plants and animals can usually regulate metal contaminants within a certain range, metals that cannot be excreted remain within the organisms and accumulate over time. As metals accumulate in an organism they can interfere with biological processes. The contaminants can also move progressively up the food chain as organisms are consumed by other animals and humans so this can ultimately pose a risk to human health. Road runoff, storm water discharges, industrial discharges and leachates from landfills are all possible sources of metal contamination.

1.3 Factors that influence coastal water quality

Open coastal versus estuarine environments

Northland's coastal marine area comprises numerous estuaries and open coastal water that extends 12 nautical miles offshore. Human activities, such as ports, marinas, discharges and dredging tend to be focused in and around our estuaries and these are also the immediate receiving environment for the freshwater network so water quality in these environments is typically under more pressure from human activities. In contrast, there are fewer human activities taking place in the open coast and this environment is more remote from human activities on land that may affect water quality.

Shape and size estuaries

The size and shape (geomorphology) of our estuaries also affects water quality as the geomorphology influences the amount of oceanic dilution. Te Puna Inlet in the Bay of Islands, for example is a relatively large deep estuary. In contrast, Aurere Estuary is a small system with a shallow channel bounded by narrow intertidal flats. On an outgoing tide, oceanic water is expelled from the estuary and the water is restricted to a narrow channel, allowing little to no dilution with oceanic water.

Hume *et al.* (2016) have developed a classification system for New Zealand's coastal systems which helps us to categorise the different estuarine systems. In Northland, most estuarine systems have been classified as either tidal lagoons or shallow drowned valleys.

Tidal lagoons are shallow circular to elongate basins with extensive intertidal areas and a narrow entrance to the sea, constricted by a spit or sand barrier. They are normally well flushed as much of the water is expelled on an outgoing tide.

Shallow drowned valley systems have extensive intertidal areas cut by drainage channels with complex shorelines and numerous arms leading off the main channel or central basin. They have a greater mean depth than tidal lagoons which together with their more complex shoreline and network of channels means they are not as well flushed.

We also have a small number of tidal rivers and deep drown valleys. Deep drowned valleys are large, deep, mostly subtidal systems. Both river and tidal inputs over the tidal cycle are small proportions of the tidal basin volume so they tend to be characterised by poor flushing. Tidal Rivers are elongate, narrow and shallow estuaries whose hydrodynamic processes are dominated by river flows.

Differences within estuaries

Even within our estuaries, water quality may vary considerably between different environments. Shallow tidal creek environments in the upper reaches of an estuary are the immediate receiving environment for the freshwater network and will have limited dilution with oceanic water so concentrations of contaminants will typically be higher and more variable than at more open or exposed environments near to the entrance of the estuary with the open coast.

Human activities

Human activities and land use in the upstream catchment will all influence water quality in an estuary. Industrial discharges, stormwater, wastewater treatment plant discharges and farm dairy effluent discharges will all influence water quality. Wastewater treatment plant and farm dairy effluent discharges may include high concentrations of nutrients and micro bacteria while stormwater and industrial discharges may include high concentrations of suspended sediment and metal contaminants.

Diffuse inputs, from different land uses, via runoff and groundwater infiltration will also influence water quality in the freshwater network and ultimately the coastal receiving environment. For example, pasture may contribute nutrients from fertiliser application and micro bacteria contamination from animal excrement. Forestry may contribute sediment, via soil erosion, especially following harvesting when there is limited canopy cover, while runoff from urban land use may include metal contaminants such as zinc from roofing materials and copper from vehicle brake pads.

Activities that take place in the coastal environment can also affect water quality. For example, marinas and mooring areas can be a source of copper due to the leaching of antifouling paint from vessel hulls (Gadd & Cameron 2012).

Most contaminants will have multiple potential sources so it may be difficult to identify the most important contributors. For example, any exposed earth can contribute sediment via runoff during rainfall so forestry, agriculture and earthworks associated with infrastructure and urban development can all contribute sediment to the freshwater network as well as direct discharges from industrial and stormwater discharges.

1.4 Coastal water quality reporting

Council reports the state of its coastal water quality every three years so that we can keep track of the current state of our water quality and identify water quality issues.

This report presents the current state of Northland's coastal water quality using results from monitoring undertaken by council between January 2018 and December 2020 and includes an analysis of temporal trends (2010-2019). It also identifies sites where there are water quality issues and identifies some of the factors that may be causing these water quality issues.

2 Methodology

2.1 Programme design

The coastal water quality programme has evolved over time, but its primary purpose has been to assess coastal water quality and track changes over time. In 2017 a review was undertaken, and the programme was subsequently modified so that sites were more representative of the coastal hydrosystems present in Northland and the four coastal water quality management units in the Proposed Regional Plan for Northland (Northland Regional Council 2019). Changes were also made to the water quality parameters monitored and the frequency and the scheduling of sampling. A more complete history of the programme changes over time is provided in Appendix A.

2.2 Sampling sites

Council currently monitors coastal water quality at 44 sampling sites (Appendix B). Sites are located in the four coastal management units identified in the Proposed Regional Plan for Northland (Northland Regional Council 2019) and in four coastal hydrosystem types identified by Hume *et al.* (2016).

2.2.1 Mangawhai Estuary

Mangawhai is a relatively small estuary on the east coast of the Northland peninsula. It has been classified by Hume et al. (2016) as a tidal lagoon. The estuary comprises two arms and a main estuarine channel. The north-western arm receives freshwater input from Tara Creek and two smaller unnamed tributaries and is separated from the main body of the estuary by a road causeway for Molesworth Drive. The southwestern arm receives freshwater input from Bob's Creek and four unnamed tributaries and is separated from the main body of the estuary by a road causeway Insley Street. There are two sites located in the tidal creek management unit at each of these road causeways and two sites in the estuarine management unit. There is an open coast site at Mangawhai Heads beach Figure 1).

The estuary covers an area of 1.4 km^2 and drains a catchment of approximately 68 km^2. Analysis of land cover in the catchment, based on New Zealand Land Cover Database LCDB v5.0 (New Zealand Land Cover Database v5.0 2020), indicated that 57% of the catchment was covered by high producing exotic grassland and 16% with native forest (Appendix C).

2.2.2 Waipū Estuary

Waipū Estuary is a small estuarine system on the east coast of the Northland peninsula, with two main arms, a deeper river flow dominated northern arm and a shallow southern lagoon. It has been classified as a tidal lagoon by Hume *et al.* (2016). The southern lagoon is partly separated from the northern river arm by a rock groyne and extends approximately 4 km in a south easterly direction, parallel to the shoreline, towards the small settlement of Waipū Cove. There are two coastal water quality sites in the Estuary and an open Coast site at Waipū Cove (Figure 2).

The Waipū Estuary receives freshwater flow from the Waipū River, which drains a catchment of approximately 223.4 km^2. Analysis of land cover in the catchment, indicated that 52% of the catchment was covered by high producing exotic grassland, 29.5% by native forest and regenerating manuka kanuka scrub and 14.8 % with exotic forest (Appendix C).

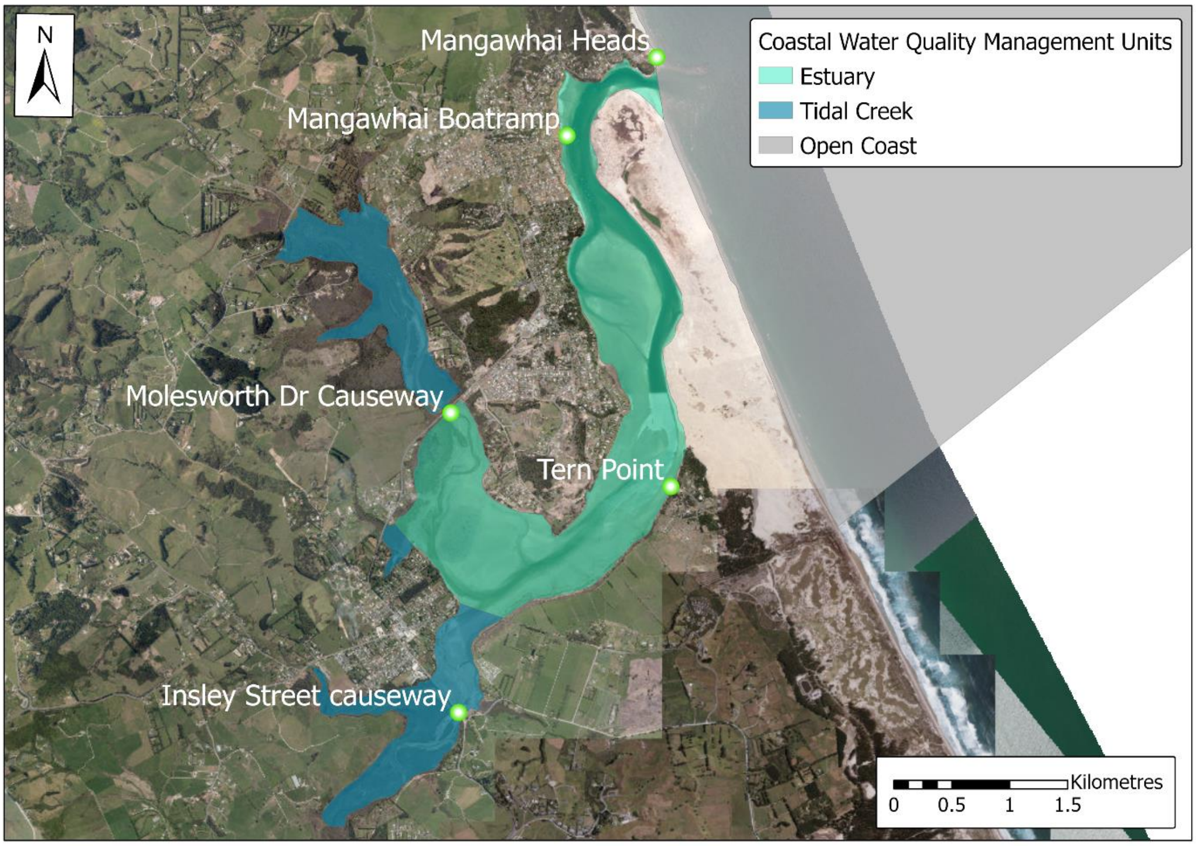

Figure 1. Sampling sites in Mangawhai Estuary.

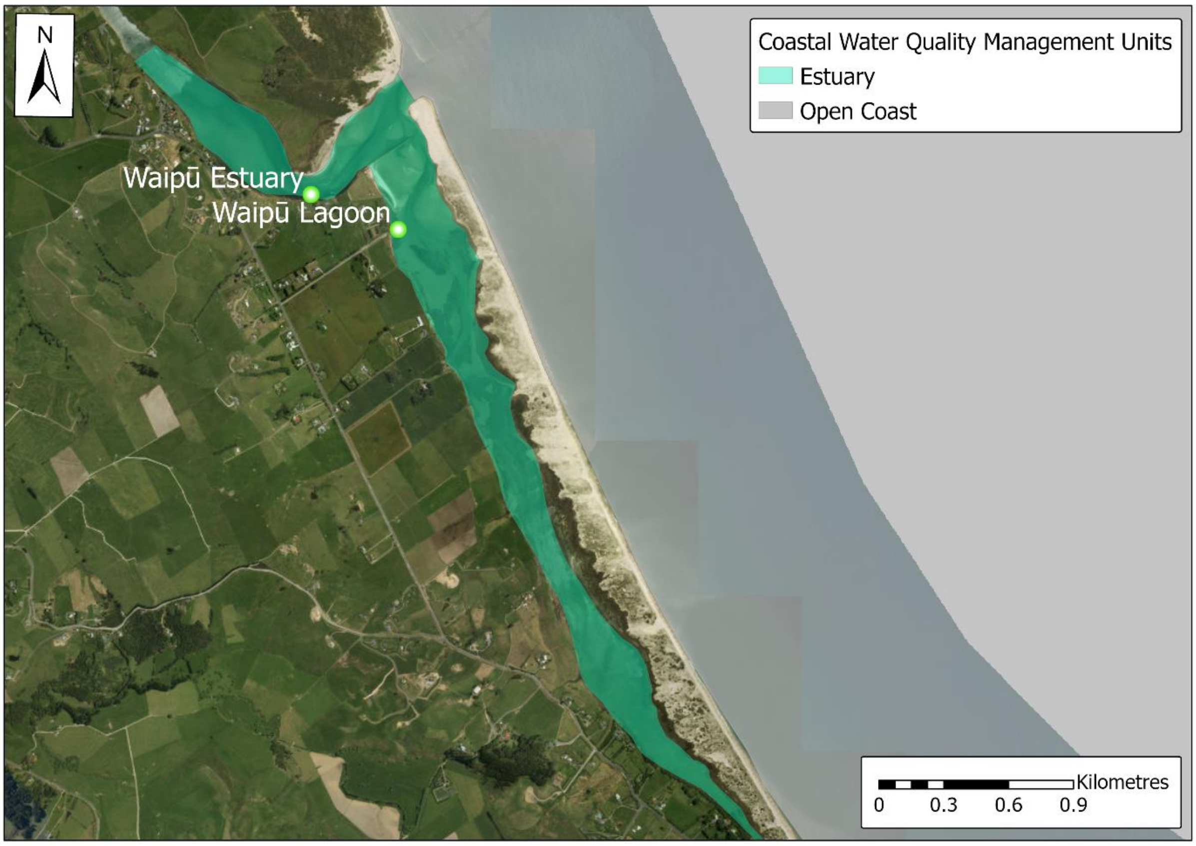

Figure 2. Sampling sites in Waipū Estuary.

2.2.3 Ruakaka Estuary

Ruakaka Estuary is a drowned river valley system located on Northland's east coast, which has been classified by Hume *et al.* (2016) as a tidal lagoon. The Estuary comprises a main river channel, which meanders north to south, an outer lagoon and a southern spur (Figure 3). There is one coastal water quality sites in the estuary, which is located in the estuarine management unit (Figure 3).

The estuary covers an area of 0.5 km^2 and receives freshwater flow from the Ruakaka River, which drains a catchment of 92 km^2. The catchment consists primarily of flat land, covered predominantly with exotic grassland, with two patches of native forest on steeper ground on the northern and southern margins of the catchment. Analysis of land use in the catchment, indicated that 66% of the catchment was covered by high producing exotic grassland and that native forest and manuka kanuka scrub covered a further 27% of the catchment (Appendix C).

2.2.4 Whangārei Harbour

Whangārei Harbour is a drowned river valley system located on the east coast of the Northland peninsula. The harbour is connected to Bream Bay, a large coastal embayment, via an inlet approximately 2.4 km wide, between Marsden Point and Home Point. The main channel extends inland approximately 24 km in a westerly direction and then divides into two arms, the Hātea River in the north and the Mangapai River in the south.

The harbour drains a catchment of 296 km^2 with 47% of the catchment covered by high producing exotic grassland, 20% with indigenous forest, 10% built up (urban), and 8% exotic forest (Appendix C). The city of Whangārei, located on the banks of the Hātea River, is the regional capital of Northland.

There are 11 sites in the Whangārei Harbour (Figure 4). Five sites are located in the Hātea River management unit, two in the tidal creek unit, four in the estuary unit and one site outside of the harbour in the open coast management unit (Figure 4).

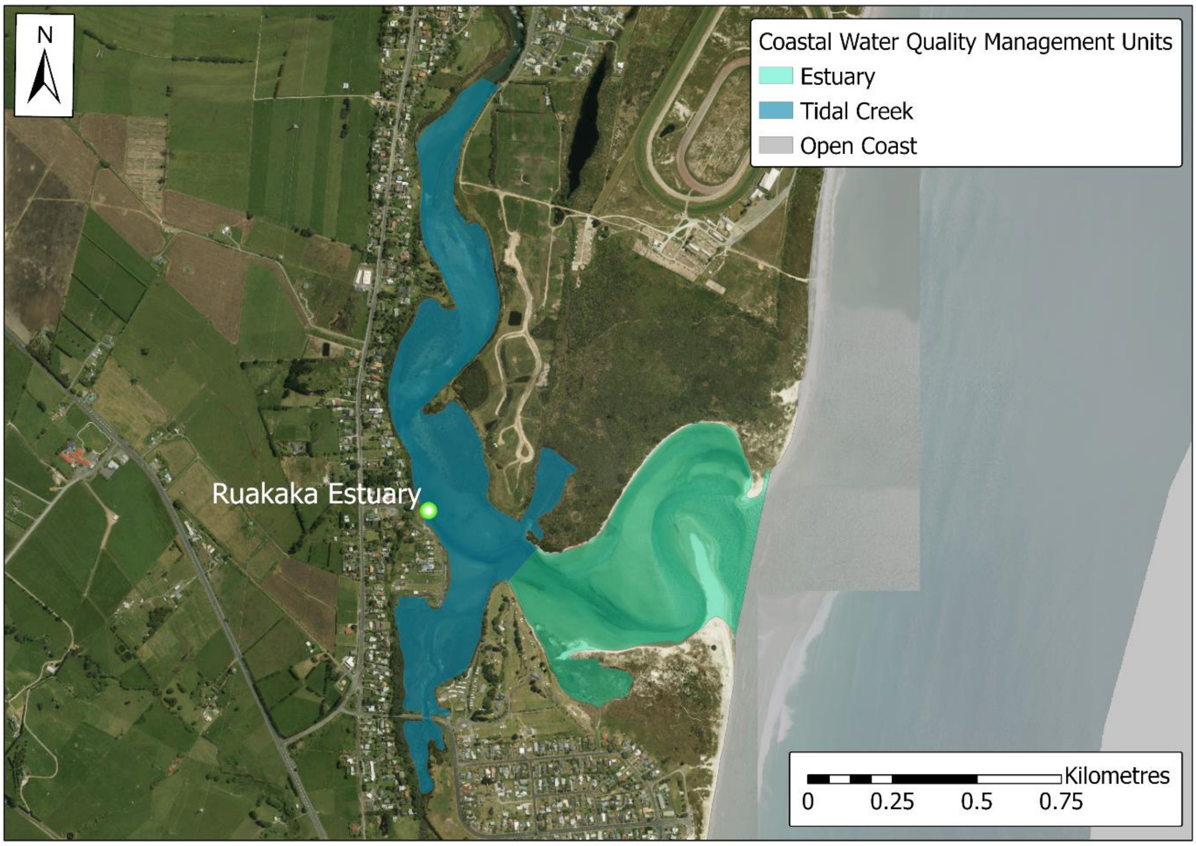

Figure 3. Sampling sites in Ruakaka Estuary.

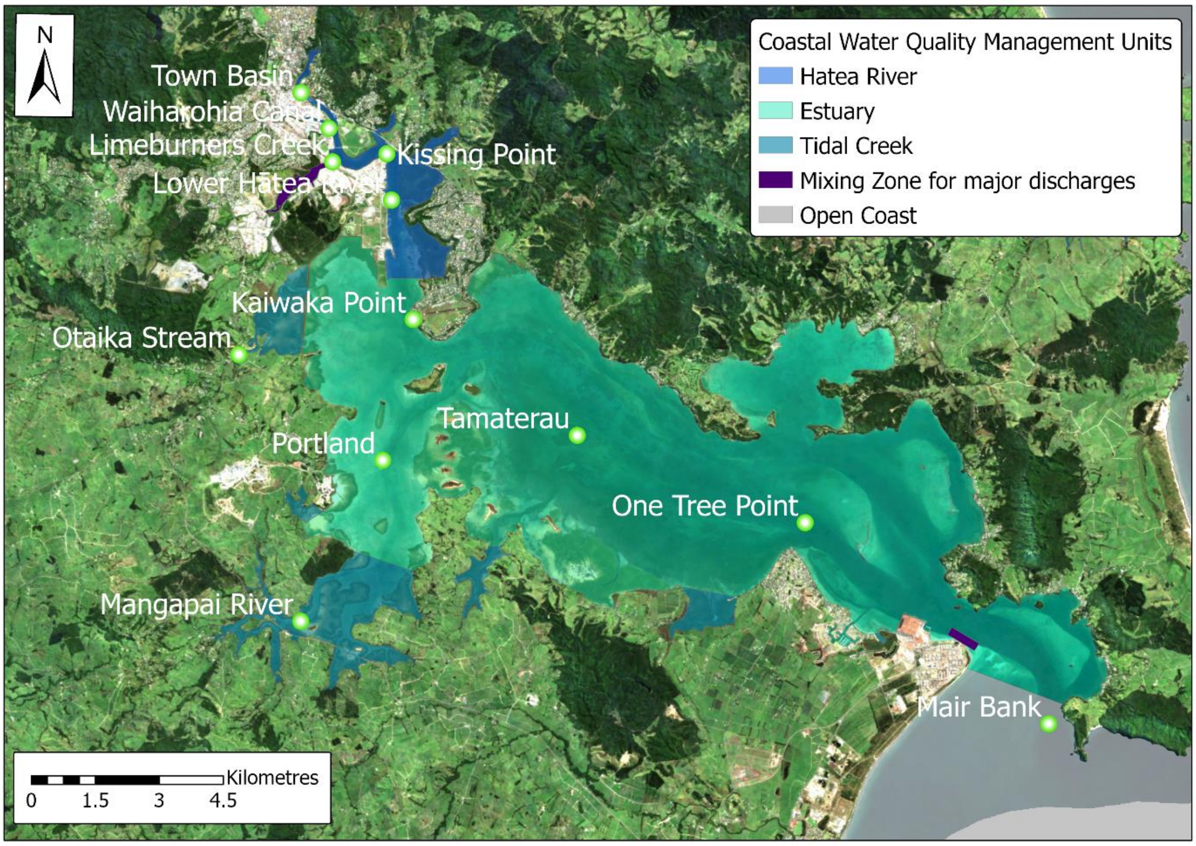

Figure 4. Sampling sites in Whangārei Estuary.

2.2.5 Ōpua Inlet

The Ōpua Inlet has been classified by Hume *et al*. (2016) as a deep drowned valley, although the system actually comprises a number of smaller systems including Waitangi Estuary, that geomorphically is better categorised as a tidal lagoon. The catchment of the Kawakawa River and Waikare Inlet is approximately 614 km^2 and analysis of land use in the catchment, indicated that 33% was covered by high producing exotic grassland, 30% with indigenous forest, 15% with manuka/kanuka scrub (Appendix C). A further 13% of the catchment was covered with exotic forest and 5% by harvested forest. The Waitangi Estuary drains a catchment of 31.6 km^2 and catchment analysis indicated that, 65% of the catchment was covered by high producing exotic grassland, 14% by indigenous forest, 7% by manuka/kanuka and 6% exotic forest. (Appendix C). There are seven sites in Ōpua Inlet system. Six sites are located in the estuarine management unit and one site in the tidal creek management unit (Figure 5). There is also an open coast site at Brampton Reef outside of the Ōpua Inlet system (Figure 5).

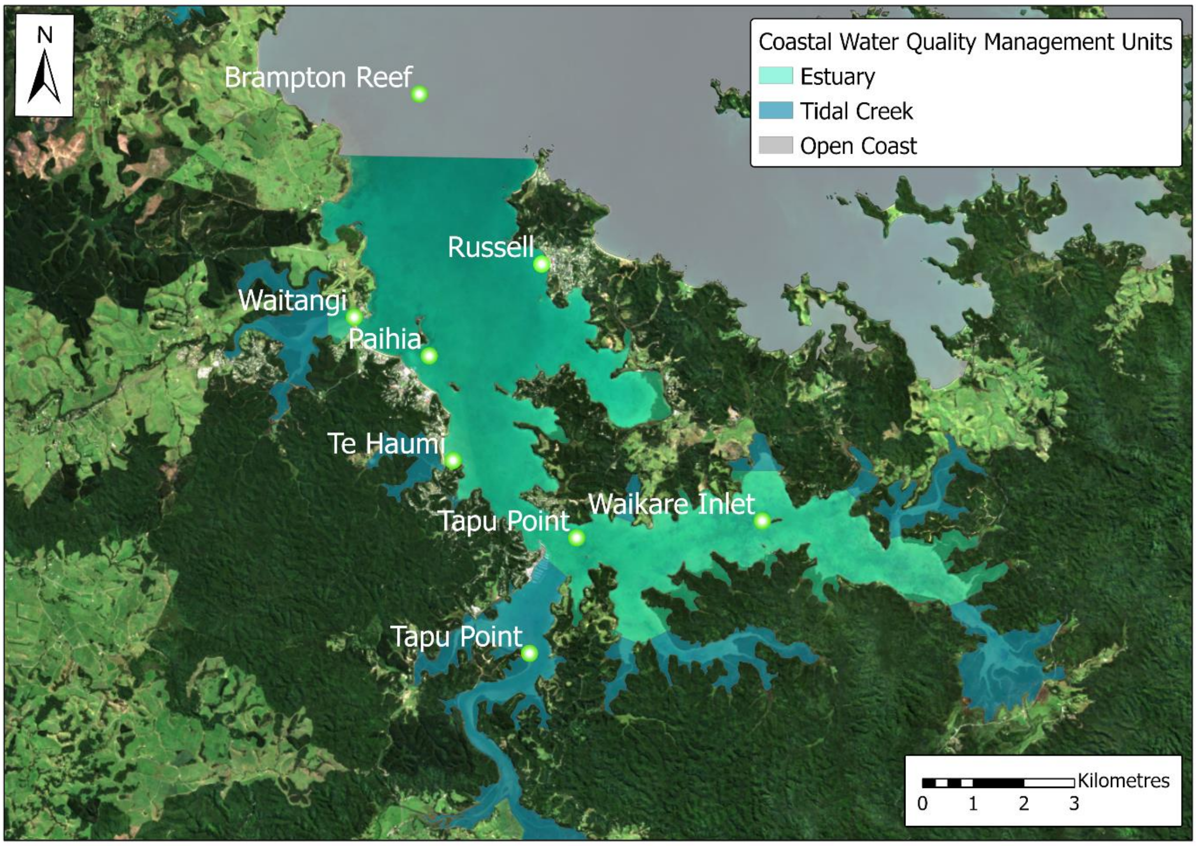

Figure 5. Sampling sites in the Ōpua Inlet.

2.2.5 Kerikeri Inlet

The Kerikeri Inlet drains a catchment of 213 km^2, and analysis of the land cover indicated that 59% of the catchment was covered by high producing exotic grassland, 10% by exotic forest, 8% by horticulture and 5% by native forest (Appendix C). Te Puna Inlet is a deep drowned valley system with a relatively small catchment of just 28 km^2. Analysis of the land cover indicated that 70% of the catchment was covered by high producing exotic grassland with 19% covered by manuka/kanuka and 5% with exotic forest (Appendix C). There are five sites located in the Te Puna/Kerikeri Inlet system (Figure 6). Four of these sites are located in the Kerikeri Inlet, with two sites (Waipapa River and Kerikeri River) in the tidal creek management unit and two sites in the estuarine management unit. One site is located in the Te Puna Inlet (Figure 6).

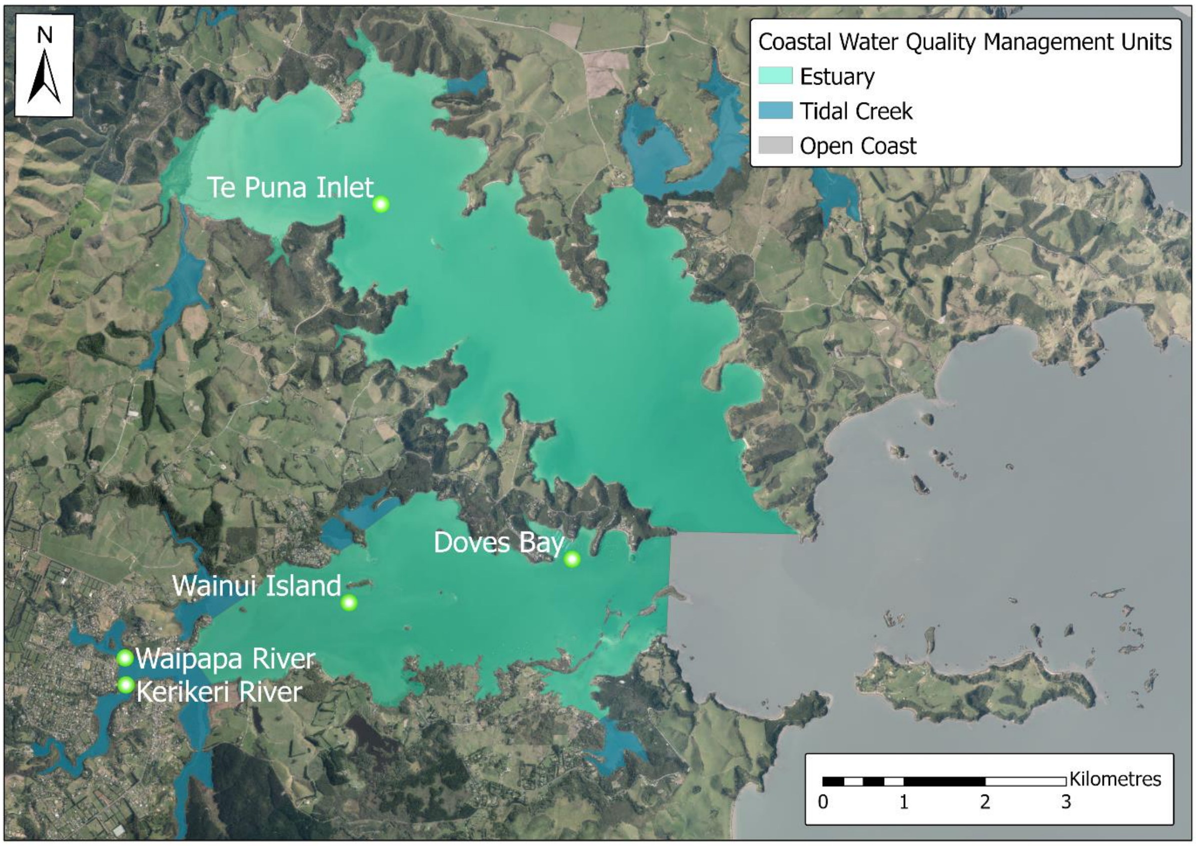

Figure 6. Sampling sites in Te Puna/Kerikeri Inlet system.

2.2.6 Aurere Estuary

The Aurere Estuary is a small estuarine system, which has been classified by Hume *et al.* (2016) as a tidal river hydrosystem. The Estuary is fed from two main tributaries, the Aurere Stream that collects water from the western side of the catchment and the Parapara Stream that is fed from the eastern side of the catchment. The catchment is approximately 96 km^2 and analysis of land cover, indicated that 61% of the catchment was covered by high producing exotic grassland, 18% by native forest and 12% by regenerating manuka kanuka scrub (Appendix C). There is one site within the estuary management unit (Figure 7).

2.2.7 Kaipara Harbour

The Kaipara Harbour is a large, drowned river valley system located on the west coast of the Northland peninsula. The Harbour has been classified by Hume *et al*. (2016) as a shallow drowned valley, but the northern section of the harbour is geomorphologically more similar to a deep drowned valley.

The harbour covers an area of approximately 743km^2 and is the largest estuarine system in the southern hemisphere. The harbour is connected to the Pacific Ocean via an entrance 6km wide between Kaipara Head and Papakanui Spit. The northern portion of the harbour consists of four main arms: the Wairoa River arm, the Oruawharo River, the Otamatea River and the Arapaoa River, with numerous smaller creeks and rivers feeding into these arms. The southern Kaipara comprises a large basin with a number of creeks and rivers feeding into it. The northern portion of the catchment is 4500 km^2 and catchment analysis indicated that 61% of the catchment was covered by high producing exotic grassland, 15% with indigenous forest and 13% with exotic forest, and (Appendix C). Seven sites are located in the estuarine management unit and two sites are in the tidal creek management unit (Figure 8).

Figure 7. Sampling site in Aurere Estuary.

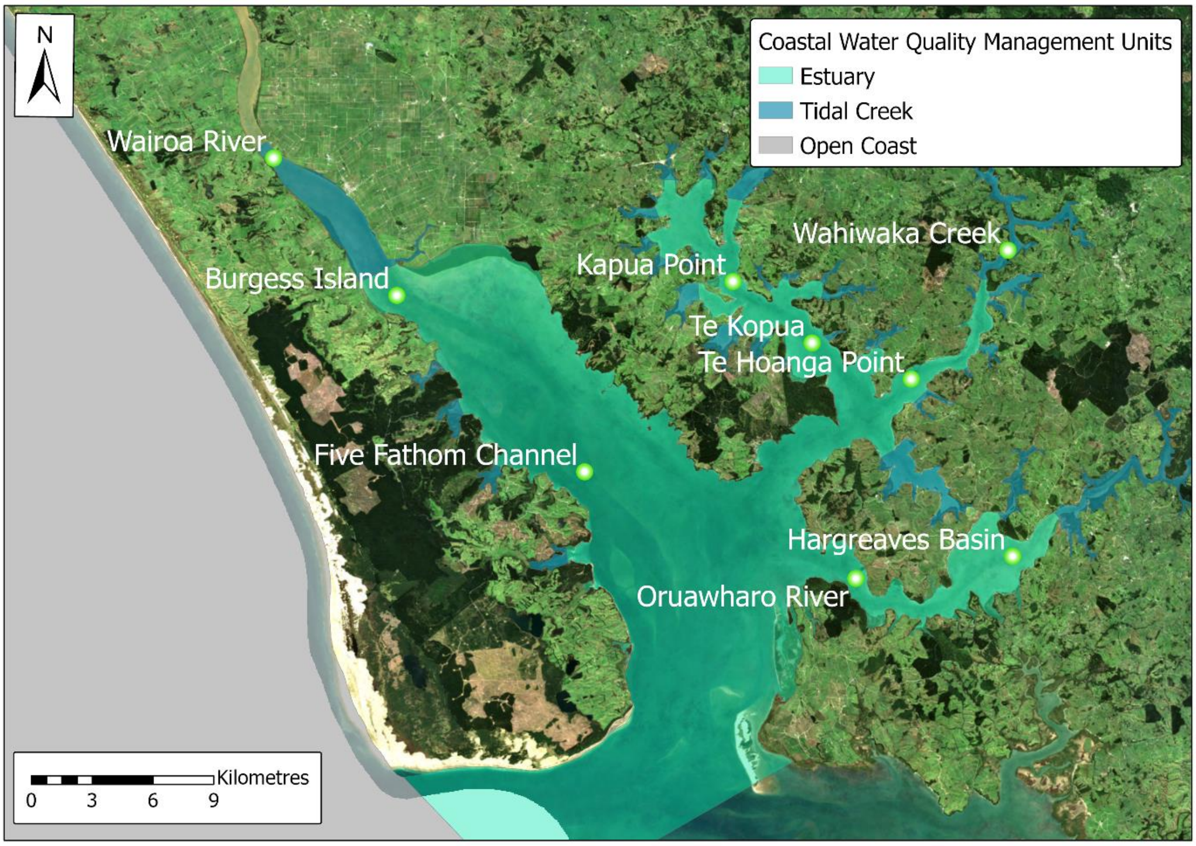

Figure 8. Sampling sites in the Kaipara Harbour.

2.3 Sampling frequency and scheduling

Since August 2017, all coastal water quality sites have been sampled monthly. Sites along Northland's east coast are sampled on a predetermined date with no regard to tidal state. In the Kaipara Harbour, between 2008 and 2019 sampling was conducted at high tide, to coincide with Auckland Council's sampling in the southern Kaipara, with all samples typically collected within three hours of high tide. In 2020, scheduling for the Kaipara Harbour was altered so that sampling was undertaken with no regard to tidal state.

2.4 Sampling parameters

Samples were analysed for a suite of 17 parameters which included indicators of nutrient enrichment, water clarity and faecal indicator bacteria (Table 1).

Table 1: Water quality parameters.

Water quality parameter	Measurement procedure	Unit/Detection limit
Temperature	In situ field measurement handheld YSI meter	°C
Salinity	In situ field measurement handheld YSI meter	ppt
Secchi depth	In situ field measurement with 200mm secchi disc and viewer.	m
Turbidity	Turbidity (infrared light source) by nephelometry ISO 7027-1	0.05 FNU
Total suspended solids	Total suspended solids by gravimetry APHA 2540 D	0.2 mg/L
Enterococci	APHA 9230D	1 MPN/100mL
Faecal coliforms	Faecal coliform (presumptive) APHA section 9222D	<1 cfu/100mL
Dissolved oxygen	In situ field measurement handheld YSI meter	mg/L
Chlorophyll-*a*	Chlorophyll-*a* by aqueous acetone extraction and APHA 10200 H	0.0006 mg/L
Total phosphorus	Total phosphorus by persulphate digestion and discrete analyser APHA 4500-P J	0.004 mg/L
Dissolved reactive phosphorus	Dissolved reactive phosphorus by colorimetry/discrete analyser APHA 4500-P F	0.002 mg/L
Total nitrogen	Total nitrogen by persulphate digestion and flow analysis. APHA 4500-P J, 4500-NO3 I	0.010 mg/L
Total Kjeldahl nitrogen	Total Kjeldahl nitrogen by calculation	0.010 mg/L
Ammonium	Ammoniacal nitrogen by flow analysis APHA 4500-NH3 H	0.005 mg/L
Nitrate-nitrite nitrogen	Total oxidised nitrogen by automated cadmium reduction/flow analysis (0.45 µm filtered) APHA 4500-NO3 I	0.002 mg/L
Copper	APHA 3125 E by ICPMS. Preparation: acid digestion APHA 3030 E (modified, 4:1 nitric:hydrochloric acid)	0.001mg/L
Zinc	APHA 3125 E by ICPMS. Preparation: acid digestion APHA 3030 E (modified, 4:1 nitric:hydrochloric acid)	0.004 mg/L

2.5 Sampling methods

Some water quality parameters (temperature, salinity and dissolved oxygen) are measured in the field with a YSI handheld meter. The YSI meter is lowered into the water within the top 0.5m depth and the measurements recorded.

Secchi depth is measured by lowering a secchi disk (with a 200mm diameter) slowly down into the water. The depth at which the pattern on the disk is no longer visible through a perspective viewer is recorded as the secchi depth. It is not possible to measure secchi depth at 11 sites, which are sampled from the shore.

Faecal indicator bacteria, total suspended solids, turbidity, chlorophyll-*a*, nutrients and metal samples are collected from the top 0.5m of the water column in the appropriate sample bottle, using a gripper pole. The samples are stored on ice in the dark in the field and during transport to the laboratory for analysis.

Rainfall

Rainfall can be a useful explanatory variable because runoff of sediment, nutrients and faecal contaminants from the land, can affect river and coastal water quality. Rainfall data was obtained from Council's rainfall gauges and rainfall over the preceding 24 hours, 48 hours and 72 hours prior to the sampling was calculated.

2.6 Reporting period

State

Results of council's water quality programme have previously been reported for the periods 2013-2017 (Griffiths 2018), 2010-2014 (Griffiths 2015). Harbour-specific reports have been written for Whangārei Harbour 2000-2010 (Tweedle *et al.* 2011) and the Kaipara Harbour using data for 2009 (Hudson 2010).

The reporting period for this report is January 2018 to December 2020 (three full years data). When assessing 'state' there is a trade-off between a sufficient sample size to accurately estimate 'state' and the possibility that temporal trends may influence 'state' over longer periods. McBride (2005) suggests that there are diminishing returns on increasing the confidence of population statistics with sample sizes greater than 30. Monthly sampling over a three-year period (36 samples), would therefore appear to provide a good gauge of current water quality.

Because sites in the Kaipara Harbour were sampled at high tide until January 2020, samples collected in 2018 and 2019 will typically have been more diluted by oceanic waters than samples collected from other sites. To avoid any potential bias, sites in the Kaipara Harbour state has been assessed using only data collected from January 2020 to December 2020 (1 year's data) when sampling was undertaken with no regard to tidal state.

Trend analysis

In their analysis of New Zealand Coastal water quality Dudley *et al.* (2017) performed trend analysis for an 8-year period and an 18-year period. In this report trend analysis was only performed if a minimum of 8 years' data was available for a given site. The trend analysis was performed on data from 2010-2019 (10 full calendar years). Data from 2020 was omitted to avoid any bias caused from the change to the scheduling in the Kaipara Hrabour of sampling in respect to tidal state in 2020

(Section 2.3). There was insufficient data for sites in Ruakaka Estuary, Waipū Estuary, Mangawhai or Aurere Estuary to undertake trend analysis.

2.7 Data analysis

The maximum, minimum, and the median were calculated for each parameter at each site and are presented in summary tables. The data is also presented in box plots, which show the median, interquartile range, range, and outliers for each site (Appendix D).

Censored values

Prior to analysis, results reported as below the laboratory detection limit were replaced by a value equal to half the detection limit (Chapman 1996). For example, a value reported as less than 10 enterococci MPN/100ml by the laboratory would be replaced in the dataset as five enterococci MPN/100ml. Results reported by the laboratory as a greater than value were replaced with the greater than value. For example, a value reported as greater than 30,000 enterococci MPN/100ml by the laboratory would be included in the dataset as 30,000 enterococci MPN/100ml. When more than 50% of the values for a variable at a site were below the detection limit the median was reported as the detection level.

We note that this approach is relatively robust for our non-parametric 'state' statistics (i.e. medians). However, statistical methods to test for trends through time can be influenced by changes in detection limit, such as may result from changes in laboratories or laboratory methods (Helsel 2005). Data from individual sites were checked for changes in detection limit through time, and where appropriate, all values (censored or otherwise) that were less than the highest censored limit, were set as the value of the highest censored limit.

2.7.1 Coastal water quality standards

In the Proposed Regional Plan for Northland (PRP), Northland's coastal marine environment has been classified into four management units: open coast, estuaries, tidal creeks and the Hātea River. This is an acknowledgement that water quality varies significantly in these different zones and there are different resource uses and values in the different zones (Griffiths 2016). For example, tidal creeks are the immediate receiving environment for streams and rivers so nutrient concentrations will be higher and more variable than estuarine and open coast environments. Tidal creeks are also less likely to be used for primary contact recreation (swimming), shellfish gathering and aquaculture compared to estuarine and open coast environments. Three main resources uses and values are covered by the standards: ecosystem health, contact recreation and shellfish consumption. Griffiths (2016) recommended that all four management units be managed for ecosystem health, and that the estuarine and open coast management units be managed for contact recreation and shellfish consumption.

Consequently, there are different coastal standards for each of the management zones (Table 3). The standards for the different management units were developed using: ANZECC 2000 guideline values for metal contaminants; Microbiological Water Quality Guidelines for Marine and Freshwater Areas (Ministry for the Environment 2003) for faecal indicator bacteria; and reference data for secchi depth, turbidity, dissolved oxygen, chlorophyll-*a* and nutrient concentrations (Griffiths 2016).

For the 'open coast' management unit, there are no numerical values in the PRP for turbidity, secchi depth and nutrient concentrations. Instead, the PRP includes a narrative standard for these parameters in the open coast: '*No discernible change*'.

In the PRP, the compliance metric for a number of the parameters is the 'annual median'. Rather than calculating annual medians for each of the three years in the reporting period, the median for all data during the reporting period (2018-2020) has been used to assess compliance. For the Kaipara Harbour only data from 2020 has been used, for the reasons stated in Section 2.6.

2.7.2 Seasonality

Kruskal-Wallis tests were performed for each parameter at each site to identify whether there were seasonal patterns in the data. Monthly data grouped by coastal water quality management unit is also presented in box plots, which show the median, interquartile range, range, and outliers (Appendix E).

2.7.3 Trend analysis

The Kendall (or seasonal Mann-Kendall) was performed for each parameter at each site in order to identify any temporal trends in the data using the Trend and Equivalence Analysis software Version 7.0 (Jowett Consulting). Trend analysis was only performed if the number of censored values in a trend period was less than 15% Dudley *et al*. (2017).

For most water quality parameters an increasing trend indicates that water quality is deteriorating so these trends are represented with orange or red symbology (Table 2). Conversely a decreasing trend typically indicates an improvement in water quality, so these trends are represented with light green or green symbology. In the case of dissolved oxygen, a decrease will typically indicate a deterioration in water quality, so for this parameter the colour of the symbology is reversed.

In 2020, the scheduling of sampling in the Kaipara changed was altered so that samples were no longer collected at high tide, but at random with no regard to tidal state. To avoid any potential bias, caused by this change to the sampling protocol, trend analysis was performed using data from 2009-2019 for the sites in the Kaipara Harbour.

Table 2. Symbology used to describe trend direction and the level of confidence.

Level of confidence	Symbology
Very likely increasing	⇧
Possibly increasing	⇧
As likely to have increased or decreased	⇔
Probably decreasing	⇩
Very likely decreasing	⇩

2.7.4 Correlations

Pearson's correlations were performed on all parameters for each of the 44 sites. Results of all strong correlation coefficients (r +0.8 or higher and r -0.8 or higher) are presented in Appendix F.

Table 3: Coastal water quality standards for Northland waters (Proposed Regional plan for Northland).

Values	Water Quality Parameter	Compliance metric	Hātea River	Tidal creeks	Estuaries	Open coast
Ecosystem Health - Water clarity	Turbidity (NTU)	Annual median	<7.5	<10.8	<6.9	No discernible change
	Secchi depth (m)	Annual median	>0.8	>0.7	>1.0	No discernible change
Ecosystem Health - Trophic state	Dissolved oxygen (mg/L)	Minimum	4.6	4.6	4.6	4.6
	Dissolved oxygen (mg/L)	Annual median	>6.2	>6.3	>6.9	No discernible change
	Chlorophyll-*a* (mg/L)	Annual median	<0.003	<0.004	<0.004	No discernible change
	Total nitrogen (mg/L)	Annual median	<0.860	<0.600	<0.220	No discernible change
	Total ammoniacal nitrogen (mg/L)	Annual median	<0.099	<0.043	<0.023	No discernible change
	Nitrate-nitrite nitrogen (mg/L)	Annual median	<0.580	<0.218	<0.048	No discernible change
	Total phosphorus (mg/L)	Annual median	<0.119	<0.040	<0.030	No discernible change
	Dissolved reactive phosphorus (mg/L)	Annual median	<0.092*	<0.021*	<0.017*	No discernible change
Metal contamination	Total zinc (mg/L)	Maximum	0.015	0.015	0.015	0.0070
	Total copper (mg/L)	Maximum	0.0013	0.0013	0.0013	0.0003
Recreation	Enterococci (per 100mL)	Annual 95th percentile	≤500	≤200	≤200	≤40
Shellfish consumption	Faecal coliforms (MPN per 100mL)	Annual median	Not applicable	Not applicable	≤14	≤43
	Faecal coliforms (MPN per 100mL)	Annual 90th percentile	Not applicable	Not applicable	≤14	≤43

* (From Griffiths 2016)

3. Results

3.1 Salinity

In the open coast management unit, the median salinity for all sites was above 34.40 and there was less variability compared to sites in the other management units (Table 4 & Appendix D-1).

In the estuarine management unit, the median salinity was above 27 at all sites and five sites (Russel, Te Puna, Tamaterau, One Tree Point, Mangawhai Boat Ramp) had median values similar to sites in the open coast management unit (Table 4 & Appendix D-1). High variability was observed at several sites in the estuarine unit, with minimum salinities of zero recorded at Ruakaka Estuary and Aurere Estuary, and 5 at Waipū Estuary. These sites are located in tidal lagoon or tidal river hydrosystems, which are heavily influenced by freshwater inputs on ebb tides.

In the tidal creek management unit, Mangapai River had the highest median salinity (32), and the highest maximum salinity measurement was also recorded at this site. This arm of the Whangārei Harbour has a very small catchment, with limited freshwater inputs and particularly high salinities were recorded in the February and March months when water temperatures also reach their maximum. These high salinities indicate that this arm of the Whangārei Harbour behaves as a reverse estuary during summer months.

Tidal creek sites, had high variability with minimum salinity measurements close to zero recorded at some sites, indicating that at times they are heavily influenced by freshwater inputs. In the tidal creek management unit, the lowest median salinities were recorded at Wairau River and Otaika Creek and their medians were noticeably lower than other sites in the monitoring network. This indicates that these sites are heavily dominated by freshwater inputs from their catchments with less mixing of oceanic waters.

In the Hātea River management unit the median salinity ranged from 18 at the Town Basin to 30 at the Lower Hātea River, reflecting the greater dilution of freshwater inputs with oceanic water down the River towards the estuarine management unit. High variability was observed at all five sites and salinity measurements at or close to zero were recorded at Waiharohia and the Town Basin.

3.2 Temperature

The median temperature was between 16.6°C and 18.4°C at all sites (Table 5 & Appendix D-2). The highest temperature ranges were recorded at sites close to freshwater inputs with lower temperature extremes at open coast sites and estuarine sites in drown river valley systems.

As expected statistically, there was a clear seasonal pattern (Appendix E-2), with highest temperatures recorded in summer and early autumn and lowest temperatures in winter. Trend analysis identified the likelihood of increasing temperatures at 30 of the 32 sites with sufficient data for trend analysis (Table 5).

Table 4. Salinity at open coast, estuarine, tidal creek, and Hātea River sites, 2018-2020.

	n	Min	Max	Median	Seasonality
Open coast management unit					
Mangawhai Heads	35	27.00	36.40	34.80	P = 0.73
Mair Bank	35	31.00	37.0	34.80	P = 0.01
Waipū Cove	35	29.4	36.11	34.59	P = 0.84
Brampton Reef	35	16.2	36.95	34.40	P = 0.63
Estuary management unit					
Mangawhai Ramp	35	19.10	36.35	34.80	P = 0.99
One Tree Point	35	27.30	36.90	34.74	P = 0.01
Tamaterau	35	24.70	36.50	34.41	P = 0.00
Russell	35	25.00	36.41	34.40	P = 0.06
Te Puna Inlet	35	31.74	36.39	34.38	P = 0.18
Waipū Lagoon	35	20.63	35.88	34.30	P = 0.49
Waipū Estuary	35	5.50	36.25	33.92	P = 0.92
Paihia	35	25.10	35.90	33.72	P = 0.12
Te Haumi	35	0.00	35.80	33.59	P = 0.04
Ruakaka Estuary	35	0.30	36.34	33.51	P = 0.69
Doves Bay	35	28.90	35.93	33.40	P = 0.23
Tern Point	35	12.30	35.53	33.33	P = 0.57
Kaiwaka Point	35	19.30	36.70	33.01	P = 0.01
Portland wharf	35	23.80	37.00	33.00	P = 0.00
Waikare Inlet	35	19.60	35.30	32.47	P = 0.02
Tapu Point	35	18.50	35.80	32.10	P = 0.01
Waitangi River	35	14.80	36.04	31.60	P = 0.32
Five Fathom Channel*	11	21.68	34.81	31.45	P = 0.00
Wainui Island	35	22.10	35.50	31.40	P = 0.39
Oruawharo River*	11	24.43	35.13	31.81	P = 0.00
Te Kopua*	11	21.65	35.40	31.46	P = 0.00
Te Hoanga Point*	11	22.67	35.31	30.96	P = 0.00
Hargreaves Basin*	11	20.72	35.35	31.10	P = 0.00
Kapua Point*	11	20.70	35.57	30.64	P = 0.00
Burgess Island*	11	12.13	32.96	27.38	P = 0.00
Aurere Estuary	31	0.00	35.70	27.10	P = 0.09
Tidal creek management unit					
Mangapai River	35	3.90	38.19	32.00	P = 0.00
Wahiwaka Creek*	11	15.77	35.54	29.75	P = 0.00
Kawakawa River	35	0.12	35.70	27.90	P = 0.15
Insley St	35	1.10	35.65	27.70	P = 0.08
Waipapa River	34	3.70	33.50	23.49	P = 0.31
Molesworth Dr	35	0.40	35.20	22.30	P = 0.10
Kerikeri River	34	4.90	31.50	18.09	P = 0.18
Wairoa River*	11	1.87	29.49	13.76	P = 0.36
Otaika Creek	34	0.10	30.10	13.00	P = 0.02
Hātea River management unit					
Lower Hātea River	35	8.50	36.5	30.17	P = 0.01
Kissing Point	35	4.30	36.1	29.84	P = 0.08
Limeburners Creek	35	5.00	35.6	27.30	P = 0.05
Waiharohia	35	0.00	33.6	25.48	P = 0.09
Town Basin	35	1.30	30.4	18.90	P = 0.01

*2020 data only

Table 5. Temperature at open coast, estuarine, tidal creek, and Hātea River sites, 2018-2020.

	n	Min	Max	Median	Seasonality	Trend (2010-19)
Open coast management unit						
Waipū Cove	35	14.0	23.5	18.1	P = 0.02	Insufficient data
Mangawhai Heads	35	14.3	24.6	17.8	P = 0.00	Insufficient data
Brampton Reef	35	13.9	23.6	17.6	P = 0.04	Insufficient data
Mair Bank	35	14.0	23.4	17.3	P = 0.00	⇧0.18%
Estuary management unit						
Waikare Inlet	35	12.7	26.0	18.4	P = 0.00	⇧ 1.01%
Te Haumi	35	11.8	26.5	18.3	P = 0.00	⇧ 0.99%
Aurere Estuary	31	13.4	23.6	18.3	P = 0.07	Insufficient data
Te Puna Inlet	35	13.9	24.5	18.3	P = 0.00	⇧ 0.49%
Tapu Point	35	11.8	25.0	18.2	P = 0.00	⇧ 0.78%
Paihia	35	13.7	23.8	18.2	P = 0.00	⇧ 0.68%
Waipū Lagoon	35	12.1	25.6	18.2	P = 0.01	Insufficient data
Russell	35	14.4	24.1	18.1	P = 0.00	⇧ 0.57%
Tamaterau	35	12.4	26.0	18.0	P = 0.00	⇧ 0.99%
Kaiwaka Point	35	12.4	26.8	17.9	P = 0.00	⇧ 0.84%
Portland wharf	35	12.1	26.4	17.9	P = 0.00	⇧ 0.83%
Wainui Island	35	13.9	25.2	17.9	P = 0.00	⇧ 0.74%
Waipū Estuary	35	11.5	24.3	17.9	P = 0.01	Insufficient data
Doves Bay	35	13.8	24.1	17.8	P = 0.00	⇧ 0.57%
Kapua Point*	11	12.10	25.70	18.00	P = 0.00	⇧ 0.24%
One Tree Point	35	13.2	24.9	17.6	P = 0.00	⇧ 0.57%
Tern Point	35	11.8	26.2	17.6	P = 0.00	Insufficient data
Waitangi River	35	12.9	24.1	17.6	P = 0.00	⇧ 0.58%
Te Hoanga Point*	11	12.20	25.30	17.10	P = 0.00	⇧ 0.25%
Te Kopua*	11	12.20	25.40	17.10	P = 0.00	⇧0.37%
Hargreaves Basin*	11	12.10	25.00	17.40	P = 0.00	⇧0.37%
Mangawhai Ramp	35	12.8	24.9	17.4	P = 0.00	Insufficient data
Burgess Island*	11	11.90	25.10	16.80	P = 0.00	⇔ 0.00%
Five Fathom*	11	12.50	24.40	16.90	P = 0.00	⇧ 0.19%
Oruawharo River*	11	12.20	24.80	17.00	P = 0.00	⇧ 0.37%
Ruakaka Estuary	35	10.6	24.3	16.8	P = 0.00	Insufficient data
Tidal creek management unit						
Wahiwaka Creek*	11	12.00	25.70	18.20	P = 0.00	⇔ 0.14%
Insley St	35	10.6	26.8	17.8	P = 0.00	Insufficient data
Waipapa River	34	12.7	26.8	17.7	P = 0.00	⇧ 0.84%
Kerikeri River	34	12.9	27.5	17.6	P = 0.00	⇧ 0.9%
Mangapai River	35	11.2	26.5	17.5	P = 0.00	⇧ 1.0%
Molesworth Dr	35	10.6	26.7	17.4	P = 0.00	Insufficient data
Wairoa River*	11	11.70	25.40	16.80	P = 0.03	Insufficient data
Kawakawa River	35	11.5	25.5	17.0	P = 0.00	⇧ 0.83%
Otaika Creek	34	10.7	25.7	16.6	P = 0.00	⇧ 1.30%
Hātea River management unit						
Lower Hātea River	35	12.4	26.8	18.0	P = 0.00	⇧ 0.74%
Limeburners Creek	35	11.7	26.4	17.9	P = 0.00	⇧ 0.87%
Kissing Point	35	12.0	26.7	17.8	P = 0.00	⇧ 0.88%
Waiharohia	35	11.9	27.1	17.6	P = 0.00	⇧ 1.26%
Town Basin	35	11.1	26.9	17.1	P = 0.00	⇧ 1.2%

*2020 data only

3.3 Enterococci

Enterococci concentrations at open coast and estuarine site were typically lower than at sites in tidal creeks and the Hātea River. The exception to this was the high concentrations observed at estuarine sites in tidal lagoon (Ruakaka Estuary, Waipū Estuary) and tidal river hydrosystems (Aurere Estuary). All four open coast sites and 23 sites in the estuarine sites achieved the coastal water quality standard (Table 6). The four sites in the estuarine management unit that did not achieve the standard are located in either tidal lagoon or tidal river hydrosystems. Six of the nine tidal creek sites and all five sites in the Hātea River management unit did not achieve the coastal water quality standards (Table 6).

A lot of the enterococci concentrations were reported as below the laboratory detection limit, so trends analysis could only be performed on data from four sites (Table 6). Increasing concentrations were likely at three of these four sites, and this is of concern as concentrations are currently elevated at these sites.

Data from the tidal creek and Hātea River management units, showed a clear seasonal variation, with lower enterococci concentrations in summer and higher concentrations in winter (Appendix E-3). The seasonal variation was less clear in the open coast and estuarine units, with a large number of results below the laboratory detection limits in these units. The higher enterococci concentrations in winter are likely to be due to the seasonal rainfall pattern, with higher precipitation in winter.

Strong positive correlations were found between enterococci concentrations and rainfall over the preceding 24 hours at three sites (Aurere Estuary, Town Basin and Waiharohia), and with rainfall over 48 hours at five sites (Paihia, Waitangi, Town Basin, Doves Bay and Brampton Reef) (Appendix F). A correlation between enterococci and rainfall over the preceding 72 hours was also found at one site (Kerikeri Inlet). These strong correlations point to the influence of rainfall and freshwater inputs on concentrations of faecal indicator bacteria at some sites. The correlation with rainfall over the preceding 48 hours and 72 hours indicates that in some catchments there may be a longer lag time between rain falling in the catchment and the runoff reaching the coast.

3.4 Faecal coliforms

Similar spatial patterns were observed for faecal coliforms as for enterococci, with lower concentrations at open coast and estuarine sites compared to tidal creek and Hātea River sites, and high concentrations again found in estuarine sites in tidal lagoon and tidal river hydrosystems (Table 7). All four sites in the open coast management unit and 17 sites in the estuarine unit achieved the coastal water quality standard. Seven of the nine estuarine sites that did not achieve the coastal water quality standard are in either tidal lagoon or tidal river hydrosystems.

There are no standards for faecal coliforms in either the tidal creek or Hātea River management units, but concentrations were elevated at all 14 sites. When assessed against the microbiological guidelines for shellfish gathering waters (Ministry for the Environment 2003), the water was not suitable for shellfish consumption at any of these 14 sites.

Strong positive correlations were observed between faecal coliforms and rainfall over the preceding 48 hours at four sites (Te Puna, Tapu Point, Paihia and Kerikeri River) (Appendix F) and negative correlations to salinity at Mangawhai Boat Ramp and Burgess Island. These correlations again point to the importance of freshwater inputs on microbiological contamination.

A lot of the enterococci concentrations were reported as below the laboratory detection limit, so trend analysis could only be performed on data from six sites. Increasing trends were likely at three of these sites and a decrease likely at one site (Table 7).

Table 6. Enterococci (CFU/100mL) at open coast, estuarine, tidal creek, and Hātea River sites, 2018-2020.

	n	Min	Max	Median	95th percentile	Standard achieved	Trend (2010-19)
Open Coast management unit							
Mair Bank	35	<10	31	<10	7	✓	>15% censored data
Brampton Reef	35	<10	130	<10	10	✓	Insufficient data
Mangawhai Heads	35	<10	31	<10	20	✓	Insufficient data
Waipū Cove	35	<10	120	<10	23	✓	Insufficient data
Estuary management unit							
Five Fathom Ch *	11	<10	10	<10	<10	✓	>15% censored data
One Tree Point	34	<10	240	<10	7	✓	>15% censored data
Tamaterau	35	<10	150	<10	7	✓	>15% censored data
Te Puna Inlet	35	<10	20	<10	7	✓	>15% censored data
Oruawharo River *	11	<10	10	<10	8	✓	>15% censored data
Doves Bay	35	<10	470	<10	10	✓	>15% censored data
Kapua Point*	11	<10	130	<10	10	✓	>15% censored data
Te Kopua*	11	<10	31	<10	18	✓	>15% censored data
Hargreaves Basin*	11	<10	52	<10	29	✓	>15% censored data
Burgess Island*	11	<10	41	<10	41	✓	>15% censored data
Paihia	35	<10	1400	<10	41	✓	>15% censored data
Waikare Inlet	35	<10	130	<10	44	✓	>15% censored data
Te Haumi	34	<10	109	<10	51	✓	>15% censored data
Portland Wharf	35	<10	130	<10	52	✓	>15% censored data
Mangawhai Ramp	35	<10	660	<10	58	✓	Insufficient data
Kaiwaka Point	34	<10	550	<10	60	✓	>15% censored data
Russell	34	<10	240	<10	77	✓	>15% censored data
Wainui Island	35	<10	370	<10	78	✓	>15% censored data
Te Hoanga Pt*	11	<10	140	<10	86	✓	>15% censored data
Waipū Lagoon	35	<10	231	<10	104	✓	Insufficient data
Tapu Point	34	<10	310	<10	115	✓	>15% censored data
Tern Point	35	<10	1400	<10	172	✓	Insufficient data
Waitangi River	35	<10	3700	<10	276	×	>15% censored data
Ruakaka Estuary	35	<10	2310	41	659	×	Insufficient data
Waipū Estuary	35	<10	14136	20	1877	×	Insufficient data
Aurere Estuary	30	<10	4600	25	3100	×	Insufficient data
Tidal Creek management unit							
Wairoa River	11	<10	74	15	54	✓	>15% censored data
Mangapai River	34	<10	700	8	121	✓	>15% censored data
Kawakawa River	35	<10	930	10	161	✓	>15% censored data
Kerikeri River	34	<10	520	20	265	×	>15% censored data
Waipapa River	34	<10	441	15	293	×	>15% censored data
Insley St	35	<10	570	52	405	×	Insufficient data
Molesworth Dr	35	<10	770	30	458	×	Insufficient data
Wahiwaka Cr	11	<10	1300	74	945	×	⇧ 117.07%
Otaika Stream	34	<10	1900	147	1048	×	⇧30.76%
Hātea River management unit							
Lower Hātea	35	<10	1400	10	327	×	>15% censored data
Kissing Point	35	<10	1500	10	668	×	>15% censored data
Waiharohia Canal	34	<10	17000	63	1659	×	⇔ 4.07%
Limeburners Creek	35	<10	8700	31	1990	×	>15% censored data
Town Basin	35	<10	24000	85	2780	×	⇧ 5.66%

*2020 data only

Table 7. Faecal coliforms (CFU/100mL) at open coast, estuarine, tidal creek, and Hātea River sites, 2018-2020.

	n	Min	Max	Median	90th percentile	Standard achieved	Trend
Open Coast management unit							
Mangawhai Heads	35	<1.6	31	<5	5	✓	Insufficient data
Mair Bank	35	<1.6	31	<1.6	5	✓	>15% censored data
Brampton Reef	35	<1.6	130	<5	10	✓	Insufficient data
Waipū Cove	35	<5	120	<5	25	✓	Insufficient data
Estuary management unit							
Five Fathom Ch*	11	0.8	11	<1.6	3	✓	Insufficient data
Te Kopua*	11	<1.6	66	<1.6	3	✓	Insufficient data
Kapua Point*	11	<1.6	390	<1.6	5	✓	Insufficient data
One Tree Point	34	<1.6	17	<1.6	5	✓	>15% censored data
Tamaterau	35	<1.6	1200	<1.6	5	✓	>15% censored data
Te Puna Inlet	35	<1.6	140	<1.6	5	✓	>15% censored data
Russell	34	<1.6	990	<1.6	10	✓	>15% censored data
Hargreaves Basin*	11	<1.6	150	3	11	✓	Insufficient data
Oruawharo River*	11	<1.6	18	<1.6	11	✓	Insufficient data
Doves Bay	35	<1.6	9800	2	17	✓	>15% censored data
Te Haumi	34	<1.6	830	3	19	✓	>15% censored data
Portland Wharf	35	<1.6	830	5	23	✓	>15% censored data
Waikare Inlet	35	<1.6	1300	3	30	✓	>15% censored data
Paihia	35	<1.6	4200	5	31	✓	>15% censored data
Kaiwaka Point	34	<1.6	1400	5	41	✓	>15% censored data
Tapu Point	34	<1.6	3200	7	41	✓	>15% censored data
Burgess Island*	11	0.8	110	6.6	46	×	Insufficient data
Mangawhai Ramp	35	<1.6	3100	3	48	×	Insufficient data
Wainui Island	35	<1.6	8900	3	92	×	>15% censored data
Waitangi River	35	<1.6	7700	13	104	×	>15% censored data
Waipū Lagoon	35	<1.6	850	7	130	×	Insufficient data
Tern Point	35	<1.6	4000	8	202	×	Insufficient data
Te Hoanga Pt*	11	<1.6	400	<1.6	203	×	Insufficient data
Waipū Estuary	34	<1.6	9900	18	405	×	Insufficient data
Ruakaka Estuary	35	<1.9	22000	100	1060	×	Insufficient data
Aurere Estuary	31	<10	34000	54	5,100	×	Insufficient data
Tidal Creek management unit							
Mangapai River	34	<1.6	8900	15	56	n/a	>15% censored data
Kawakawa River	35	<1.6	8000	20	166	n/a	>15% censored data
Wairoa River*	11	<1.6	290	39.5	277	n/a	Insufficient data
Insley St	35	<1.6	3600	130	528	n/a	Insufficient data
Waipapa River	34	<2	10000	91	554	n/a	⇧ 6.44%
Molesworth Dr	35	<10	4700	86	616	n/a	Insufficient data
Kerikeri River	34	7	27000	92	711	n/a	⇧ 7.55%
Wahiwaka Cr*	11	2	18000	10	1100	n/a	Insufficient data
Otaika Creek	34	50	6500	315	1649	n/a	⇧ 13.03%
Hātea River management unit							
Lower Hātea	35	2	7300	20	252	n/a	>15% censored data
Kissing Point	35	<1.6	6300	21	292	n/a	>15% censored data
Waiharohia	34	16	15000	205	864	n/a	⇔ 1.06%
Limeburners Creek	35	<2	8400	120	980	n/a	⇩ -7.63%
Town Basin	35	70	15000	320	992	n/a	⇔ 2.85%

*2020 data only

3.5 Turbidity

Turbidity was low at all open coast sites and most estuarine site, except for sites in the Kaipara Harbour, with particularly high turbidity recorded at Hargreaves Basin and Burgess Island (Table 8). Turbidity was generally higher at sites in tidal creeks and the Hātea River, which is to be expected as these areas are the receiving environment for the freshwater network. Sites in the Kaipara Harbour generally had much higher turbidity and six sites in this harbour exceeded the coastal water quality standard (Table 8). Turbidity at Wairoa River and Hargreaves Basin were particularly high and there is clearly a major issue with water clarity at these sites.

Seasonal variation was not statistically significant at any of the sites, although there was some evidence of a seasonal pattern in the site data (Figure 9). At a management unit level there was further evidence of a seasonal pattern for sites in the estuarine, tidal creek and Hātea River management units. Interestingly the pattern showed higher turbidity in spring and summer months (Appendix E-5). This higher turbidity in summer and spring is likely to be driven by increases in algae in the water during these warmer months.

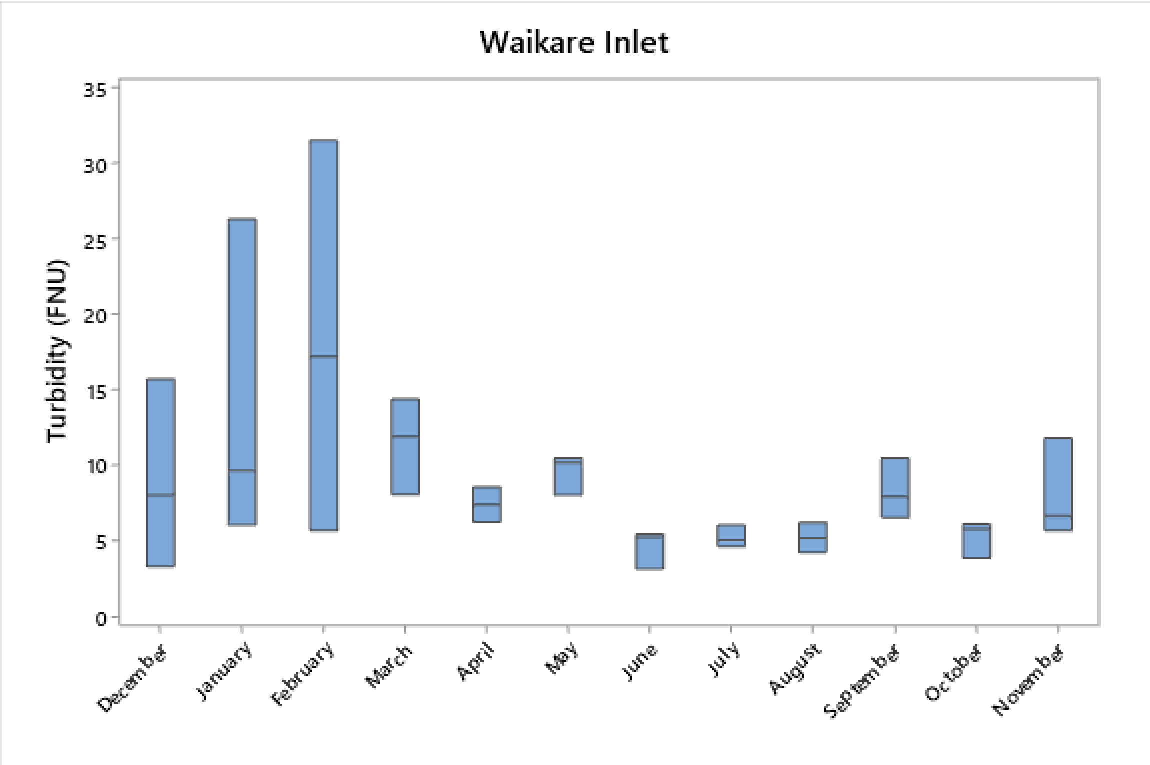

Figure 9. Seasonal variation in Turbidity at Waikare Inlet.

Table 8. Turbidity (FNU) at open coast, estuarine, tidal creek, and Hātea River sites, 2018-2020.

	n	Min	Max	Median	Standard achieved	Seasonality	Trend
	Open Coast management unit						
Mair Bank	35	<0.5	8.86	0.97	n/a	P = 0.19	Insufficient data
Mangawhai Heads	35	0.18	3.36	1.21	n/a	P = 0.63	Insufficient data
Brampton Reef	35	0.52	7.23	2.31	n/a	P = 0.38	Insufficient data
Waipū Cove	35	0.76	11.7	2.76	n/a	P = 0.55	Insufficient data
Estuary management unit							
Mangawhai Ramp	35	<0.5	14.7	1.05	✓	P = 0.45	Insufficient data
One Tree Point	35	<0.5	4.8	1.12	✓	P = 0.31	Insufficient data
Waipū Lagoon	35	0.57	11.2	1.55	✓	P = 0.59	Insufficient data
Waipū Estuary	35	0.58	60.4	2.27	✓	P = 0.49	Insufficient data
Tern Point	35	<0.5	20.2	2.29	✓	P = 0.56	Insufficient data
Ruakaka Estuary	34	0.42	68.8	2.37	✓	P = 0.38	Insufficient data
Russell	35	0.81	5.58	2.69	✓	P = 0.68	Insufficient data
Doves Bay	35	1.32	18.4	2.78	✓	P = 0.23	Insufficient data
Tamaterau	35	0.87	7.26	2.88	✓	P = 0.23	Insufficient data
Five Fathom Ch*	11	1.48	6.33	2.99	✓	P = 0.67	Insufficient data
Paihia	35	1.21	9.93	3.67	✓	P = 0.32	Insufficient data
Te Puna Inlet	35	1.03	11.1	3.7	✓	P = 0.73	Insufficient data
Te Haumi	34	1.36	40.4	3.86	✓	P = 0.13	Insufficient data
Wainui Island	35	2.29	26.4	4.45	✓	P = 0.53	Insufficient data
Kaiwaka Point	35	2.06	13.5	4.86	✓	P = 0.11	Insufficient data
Waitangi River	35	1.43	25.6	5.05	✓	P = 0.17	Insufficient data
Portland Wharf	35	1.81	15.1	5.62	✓	P = 0.27	Insufficient data
Tapu Point	35	2.17	19.9	5.67	✓	P = 0.23	Insufficient data
Oruawharo River*	11	2.57	11.4	6.1	✓	P = 0.60	Insufficient data
Waikare Inlet	35	3.13	31.5	6.55	✓	P = 0.12	Insufficient data
Aurere Estuary	30	1.69	134	6.71	✓	P = 0.27	Insufficient data
Te Kopua*	11	2.62	9.79	6.91	×	P = 0.56	Insufficient data
Te Hoanga Pt*	11	2.32	22.8	7.7	×	P = 0.46	Insufficient data
Kapua Point*	11	2.86	13.2	7.91	×	P = 0.37	Insufficient data
Burgess Island*	11	5.18	26.9	13.4	×	P = 0.37	Insufficient data
Hargreaves Basin*	11	5.19	41.8	25.2	×	P = 0.60	Insufficient data
Tidal Creek management unit							
Molesworth Dr	35	1.30	42.3	4.25	✓	P = 0.98	Insufficient data
Insley St	35	0.82	29.8	4.47	✓	P = 0.90	Insufficient data
Kerikeri River	34	2.32	16.3	4.53	✓	P = 0.39	Insufficient data
Waipapa River	33	2.01	25.6	6.07	✓	P = 0.20	Insufficient data
Kawakawa River	35	3.62	38.4	7.39	✓	P = 0.95	Insufficient data
Otaika Creek	34	1.79	69.1	7.9	✓	P = 0.39	Insufficient data
Mangapai River	35	4.10	24.3	8.62	✓	P = 0.36	Insufficient data
Wahiwaka Cr*	11	4.31	23.7	10.3	✓	P = 0.27	Insufficient data
Wairoa River*	11	7.31	192.0	27.1	×	P = 0.84	Insufficient data
Hātea River management unit							
Town Basin	35	2.41	23.0	4.97	✓	P = 0.31	Insufficient data
Lower Hātea	35	2.05	16.4	5.03	✓	P = 0.19	Insufficient data
Kissing Point	35	3.03	29.3	5.07	✓	P = 0.29	Insufficient data
Waiharohia	35	3.01	59.5	6.63	✓	P = 0.35	Insufficient data
Limeburners Creek	35	3.45	32.0	6.85	✓	P = 0.26	Insufficient data

*2020 data only

3.6 Chlorophyll-*a*

The median chlorophyll-*a* concertation only exceeded the coastal water quality standards at two sites, Burgess Island and Hargreaves Basin, in the Kaipara Harbour (Table 9). Sites in the Kaipara Harbour had higher median concentrations when compared to other sites in the respective management units. In contrast, sites in tidal lagoon and tidal river hydrosystem had lower medians. This is likely a result of the lower residence times in these smaller well flushed systems, which precludes the growth of algae that can occur in shallow and deep drowned valley systems.

A seasonal pattern was observed with higher chlorophyll-*a* concentrations generally recorded in spring and summer, and lower concentrations in winter (Appendix E-6), and fifteen sites had seasonal variation that was statistically significant (Table 9). Although only two sites exceeded the coastal water quality standard, some very high chlorophyll-*a* concentrations were recorded in spring and summer and the median value does not appear to be a particularly useful metric for capturing this large seasonal variability (Figure 10).

Trend analysis identified that chlorophyll-*a* concentrations were likely to be decreasing at nine sites and increasing at two sites (Table 9). The decreasing trend at Hargreaves Basin is particularly welcome as the median concentration at this site exceeds the coastal water quality standard.

3.7 Dissolved oxygen

The median dissolved oxygen concentrations were above the coastal water quality standards at all sites, but concentrations of dissolved oxygen did fall below 4.6 mg/L at six sites, all located in either the tidal creek or Hātea River management units (Table 10). All these measurements below 4.6 mg/L were recorded in either December, February, March, or April, when water temperature is generally high and algae growth likely to be high (Figure 11). Of particular concern is that dissolved oxygen concentrations were below 4.6 mg/L for three consecutive months at the Town Basin and Waiharohia Canal in 2019 (Figure 11).

These is a clear seasonal pattern in the dissolved oxygen data, with higher concentrations in winter, and lower concentrations in summer and early spring (Appendix E-7). This seasonal pattern in dissolved oxygen concentrations matches the seasonal pattern of water temperature, as cold water is able to hold more oxygen than warm water.

Trend analysis found increasing dissolved oxygen concentrations were likely at one site and that decreasing concentrations were likely at eleven sites (Table 10). The decreasing trends identified at Otaika Creek, Wahiwaka Creek, Mangapai River, Waiharohia Canal, Limeburners Creek and Town Basin are of particular concern as concentrations of dissolved oxygen below 4.6 mg/L have been recorded at these sites.

Table 9. Chlorophyll-*a* (mg/L) at open coast, estuarine, tidal creek, and Hātea River sites, 2018-2020.

	n	Min	Max	Median	Standard achieved	Seasonality	Trend (2010-2019)
Open Coast management unit							
Mangawhai Head	35	<0.0006	0.0100	0.0011	n/a	P = 0.48	Insufficient data
Brampton Reef	35	<0.0006	0.0048	0.0013	n/a	P = 0.20	Insufficient data
Mair Bank	35	<0.0006	0.0058	0.0013	n/a	P = 0.44	>15% censored data
Waipū Cove	35	<0.0006	0.0130	0.0023	n/a	P = 0.56	Insufficient data
Estuary management unit							
Waipū Lagoon	35	<0.0006	0.0035	0.0007	✓	P = 0.28	Insufficient data
Aurere Estuary	31	<0.0006	0.0500	0.0008	✓	P = 0.66	Insufficient data
Mangawhai Ramp	35	<0.0006	0.0100	0.0008	✓	P = 0.68	Insufficient data
Waipū Estuary	35	<0.0006	0.0089	0.0008	✓	P = 0.82	Insufficient data
Ruakaka Estuary	35	<0.0006	0.0064	0.0009	✓	P = 0.56	Insufficient data
Tern Point	35	<0.0006	0.0080	0.0012	✓	P = 0.44	Insufficient data
Tamaterau	35	<0.0006	0.0062	0.0013	✓	P = 0.85	>15% censored data
Doves Bay	35	<0.0006	0.0057	0.0014	✓	P = 0.13	>15% censored data
One Tree Point	35	<0.0006	0.0084	0.0014	✓	P = 0.93	⇔ - 2.18%
Russell	35	<0.0006	0.0049	0.0015	✓	P = 0.23	⇩ -12.19%
Te Haumi	34	<0.0006	0.0032	0.0015	✓	P = 0.18	>15% censored data
Paihia	35	<0.0006	0.0029	0.0016	✓	P = 0.09	⇩-6.85
Waitangi River	35	<0.0006	0.0037	0.0016	✓	P = 0.01	⇔ 0.0%
Te Puna Inlet	35	<0.0006	0.0060	0.0018	✓	P = 0.73	⇩ -13.84%
Kaiwaka Point	35	<0.0006	0.0054	0.0021	✓	P = 0.00	>15% censored data
Wainui Island	35	<0.0006	0.0069	0.0021	✓	P = 0.13	⇩ -4.31%
Portland Wharf	35	0.0009	0.0053	0.0022	✓	P = 0.01	⇔ - 0.46%
Te Hoanga Pt*	11	0.0005	0.0071	0.0024	✓	P = 0.00	⇔ -0.87%
Te Kopua*	11	0.0003	0.0064	0.0024	✓	P = 0.00	⇔ -0.42%
Five Fathom Ch*	11	0.0008	0.0077	0.0026	✓	P = 0.00	⇩ 2.15%
Tapu Point	35	0.0007	0.0075	0.0027	✓	P = 0.07	⇔ -1.93%
Kapua Point*	11	0.0004	0.0056	0.0029	✓	P = 0.00	⇔ 0.33%
Waikare Inlet	35	0.0011	0.0220	0.0031	✓	P = 0.26	⇩ -8.13%
Oruawharo Rr*	11	0.0014	0.0089	0.0037	✓	P = 0.40	⇩ -1.91%
Burgess Island*	11	0.0017	0.0086	0.0042	×	P = 0.02	⇔ 0.00%
Hargreaves B*	11	0.0014	0.0150	0.0042	×	P = 0.40	⇩ -1.91%
Tidal Creek management unit							
Molesworth Dr	35	<0.0006	0.0170	0.0016	✓	P = 0.77	Insufficient data
Insley St	35	<0.0006	0.0320	0.0017	✓	P = 0.80	Insufficient data
Mangapai River	35	<0.0006	0.0099	0.0019	✓	P = 0.13	>15% censored data
Waipapa River	33	<0.0006	0.0096	0.0019	✓	P = 0.00	15% censored data
Kerikeri River	34	<0.0006	0.0120	0.0021	✓	P = 0.02	>15% censored data
Otaika Creek	34	<0.0006	0.0300	0.0022	✓	P = 0.74	>15% censored data
Kawakawa River	35	<0.0006	0.0070	0.0029	✓	P = 0.06	⇧ 5.14%
Wairoa River*	11	0.0021	0.0120	0.0034	✓	P = 0.30	Insufficient data
Wahiwaka Cr*	11	0.0012	0.0059	0.0034	✓	P = 0.00	⇩ 3.3%
Hātea River management unit							
Waiharohia	35	<0.0006	0.0110	0.0020	✓	P = 0.01	⇧ 10.19%
Limeburners Cr	35	<0.0006	0.0110	0.0021	✓	P = 0.00	⇔ 0.0%
Kissing Point	35	<0.0006	0.0130	0.0022	✓	P = 0.00	>15% censored data
Lower Hātea	35	<0.0006	0.0110	0.0023	✓	P = 0.00	⇔ 4.28%
Town Basin	35	<0.0006	0.0420	0.0024	✓	P = 0.22	⇔ - 4.53%

*2020 data only

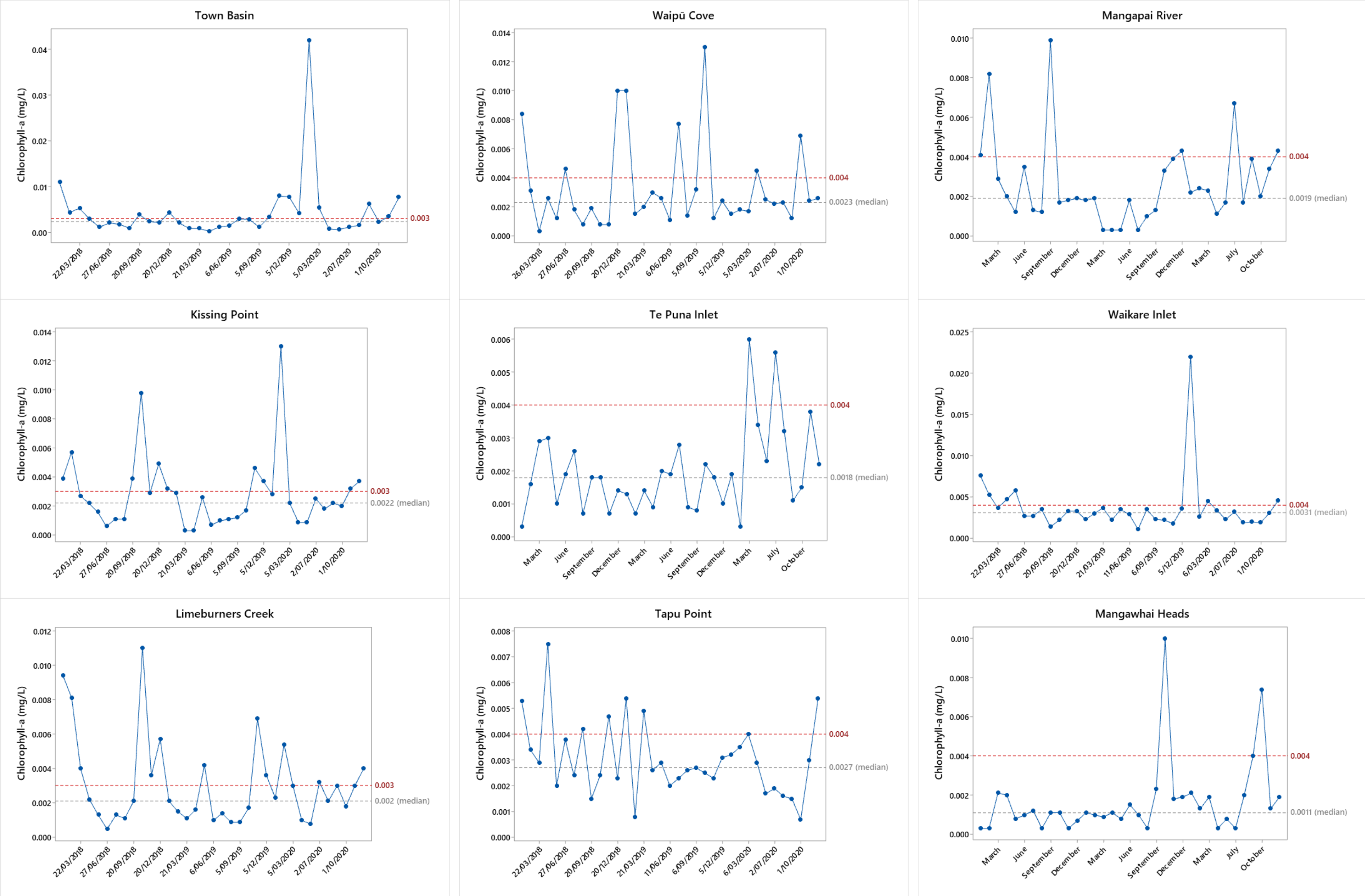

Figure 10. Chlorophyll-*a* concentrations (mg/L) at Town basin, Waipū Cove, Mangapai River, Kissing Point, Te Puna Inlet, Waikare Inlet, Limeburners Creek, Tapu Point and Mangawhai Heads from 2018-2020.

Table 10. Dissolved oxygen (mg/L) at open coast, estuarine, tidal creek, and Hātea River sites, 2018-2020.

	n	Min	Max	Median	Standard achieved	Seasonality	Trend
Open Coast management unit							
Mangawhai Heads	35	7.1	8.8	7.9	✓	P = 0.00	Insufficient data
Waipū Cove	35	7.1	10	7.9	✓	P = 0.03	Insufficient data
Mair Bank	35	7	9.1	7.8	✓	P = 0.00	⬄ 0.0%
Brampton Reef	35	6.4	9.2	7.6	✓	P = 0.07	Insufficient data
Estuary management unit							
Waipū Lagoon	35	6.1	9.9	8.4	✓	P = 0.06	Insufficient data
Five Fathom Ch*	11	6.7	9.5	7.9	✓	P = 0.00	⬄ -0.11%
Tern Point	35	6.6	9.5	7.9	✓	P = 0.00	Insufficient data
Waipū Estuary	35	5.9	9.9	7.9	✓	P = 0.02	Insufficient data
Burgess Island*	11	6.6	9.5	7.8	✓	P = 0.00	⬄ -0.09%
Mangawhai Ramp	35	6.7	9.1	7.8	✓	P = 0.00	Insufficient data
Oruawharo River*	11	6.5	9.3	7.8	✓	P = 0.00	⇩ -0.21%
Te Kopua*	11	6	9.6	7.8	✓	P = 0.00	⬄ 0.00%
One Tree Point	35	6.7	9	7.7	✓	P = 0.00	⬄ -0.07 %
Te Hoanga Pt*	11	6.1	9.4	7.7	✓	P = 0.00	⬄ 0.0%
Aurere Estuary	31	4.9	9	7.6	✓	P = 0.07	Insufficient data
Doves Bay	35	6.4	8.8	7.6	✓	P = 0.00	⬄ 0.27%
Kapua Point*	11	5.9	9.7	7.6	✓	P = 0.00	⬄ 0.0%
Paihia	35	6	8.3	7.6	✓	P = 0.00	⇧ 0.86%
Ruakaka Estuary	35	5.1	10.2	7.6	✓	P = 0.01	Insufficient data
Russell	35	6.6	9.6	7.6	✓	P = 0.00	⬄ 0.17%
Hargreaves Basin*	11	6.2	9.2	7.5	✓	P = 0.00	⇩ -0. 21%
Tamaterau	35	6.6	8.8	7.5	✓	P = 0.00	⬄ 0.00%
Te Puna Inlet	35	5.9	9.4	7.5	✓	P = 0.00	⬄ 0.00%
Tapu Point	35	5.9	8.8	7.4	✓	P = 0.00	⬄ 0.0%
Kaiwaka Point	35	6.2	9.3	7.3	✓	P = 0.00	⬄0.0%
Portland Wharf	35	6	8.6	7.3	✓	P = 0.00	⬄ 0.0%
Te Haumi	34	6.1	8.8	7.3	✓	P = 0.00	⬄ -0.00%
Waikare Inlet	35	5.4	8.9	7.3	✓	P = 0.00	⬄ -0.18%
Wainui Island	35	5.9	8.6	7.3	✓	P = 0.00	⬄ 0.00%
Waitangi River	35	5.3	9.2	7.3	✓	P = 0.00	⬄ -0.26%
Tidal Creek management unit							
Molesworth Dr	35	5.7	10.2	8	✓	P = 0.00	Insufficient data
Wairoa River*	11	6.5	9.5	7.9	✓	P = 0.04	Insufficient data
Insley St	35	5.7	10.4	7.6	✓	P = 0.00	Insufficient data
Kerikeri River	34	4.8	10	7.55	✓	P = 0.00	⬄ 0.0%
Kawakawa River	35	5.4	9	7.3	✓	P = 0.00	⇩ -0.46%
Waipapa River	34	5.2	10.4	7.3	✓	P = 0.00	⇩ -0.76%
Otaika Creek	34	4.4	9.9	7.25	×	P = 0.00	⇩ -2.49%
Wahiwaka Creek*	11	4.3	9.1	7	×	P = 0.00	⇩ -0.75%
Mangapai River	35	4.1	9	6.7	×	P = 0.00	⇩ -1.13%
Hātea River management unit							
Lower Hātea	35	5.5	8.5	7.2	✓	P = 0.00	⬄ 0.0%
Waiharohia	35	4.2	10	7.2	×	P = 0.00	⇩ -1.41%
Kissing Point	35	5.2	8.8	6.9	✓	P = 0.00	⇩-0.68%
Limeburners Creek	35	3.6	8.5	6.9	×	P = 0.00	⇩ - 0.88%
Town Basin	35	3.7	10.5	6.8	×	P = 0.00	⇩ -1.78%

*2020 data only

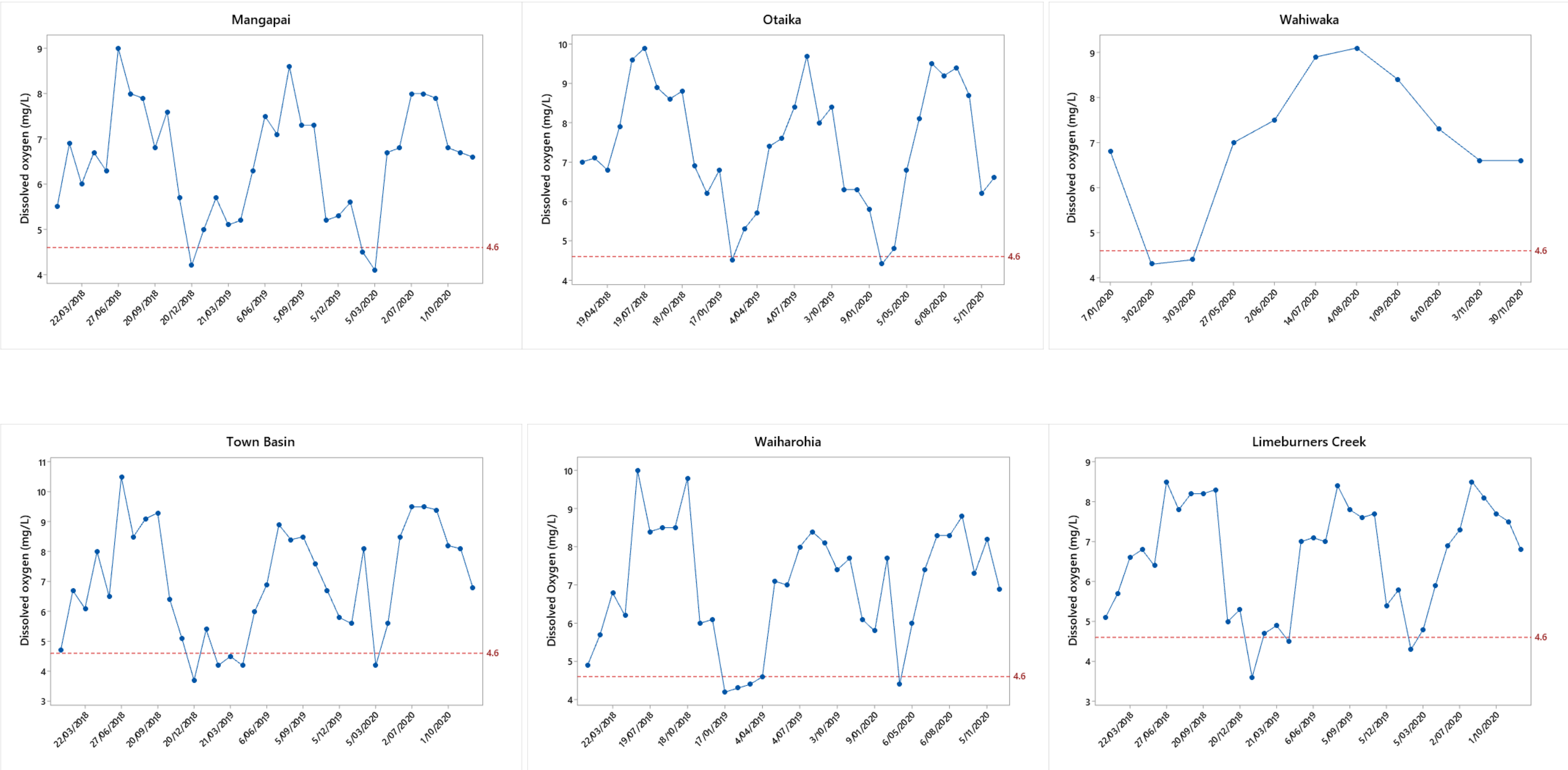

Figure 11. Dissolved oxygen concentrations (mg/L) at Mangapai Creek, Otaika Creek, Wahiwaka Creek, Town Basin, Waiharohia and Limeburners Creek from 2018-2020.

3.8 Total nitrogen

Total nitrogen was low at all open coast sites and most estuarine site, except at sites in the Kaipara Harbour, Aurere Estuary and at Kaiwaka Point in Whangārei Harbour (Table 11). Sites in the tidal creek management unit generally had higher median concentrations reflecting their proximity to freshwater inputs, with particularly high concentrations recorded at Otaika Creek and Wairoa River. In total eight sites had medians that exceeded the relevant coastal water quality standards with five of these sites in the Kaipara Harbour (Table 11).

In the Hātea River management unit, although the median concentrations at all sites were below the relevant coastal water quality standard, this needs to be viewed in the context of the much higher standard that applies in this unit. Particularly high concentrations were recorded at Limeburners Creek, Town Basin and Waiharohia, and the medians at these sites are elevated in comparison to most other tidal creek sites and would have been above the standard for the tidal creek management unit.

Trend analysis could only be performed on data from eight sites in the Kaipara Harbour, because there was insufficient data at all other sites. Analysis found that concentrations were likely to be increasing at seven of these sites including at Kapua Point, Te Honga, Hargreaves Basin and Burgess Island, where total nitrogen concentrations currently exceed the coastal water quality standard (Table 11). The increasing trends at Oruawharo River and Te Koupa are also of concern, as these sites have medians that are close to the coastal water quality standard.

3.9 Ammoniacal nitrogen

Total ammoniacal nitrogen concentrations were low at all open coast sites and most estuarine site, with higher concentrations recorded at sites in tidal lagoons and tidal river hydrosystems (Ruakaka Estuary, Waipū Estuary and Aurere Estuary) and at sites in the Kaipara Harbour. Particularly large ranges were observed at Ruakaka Estuary, Waipū Estuary and Aurere Estuary with very high concentrations recorded after rainfall or when salinity was low with lower concentrations when high salinity was recorded. Median ammoniacal nitrogen concentrations exceeded the coastal water quality standards at seven sites with four exceedances in the Kaipara Harbour (Table 12).

Concentrations in the Hātea River unit were elevated compared to sites in the tidal creek management unit and although only one site exceeded the relevant coastal water quality standard, all medians would have been above the tidal creek standard. Large ranges were observed at all sites in this management unit with particularly high maximum concentrations recorded at Limeburners Creek (Table 12).

Because of the large number of samples below the laboratory detection limit trend analysis could only be performed at nine sites, with an increasing trend identified at one site (Kerikeri River).

3.10 Nitrate-nitrite nitrogen

Nitrate-nitrite nitrogen concentrations were low at all open coast sites and most estuarine site with the exception of Burgess Island, in the Kaipara Harbour (Table 13). In the tidal creek management unit, particularly high medians were recorded at Otaika Creek and Wairoa River and both these sites exceeded the coastal water quality standard.

Although all five sites in the Hātea River had medians below the standard for the Hātea River management unit, the medians at Limeburners Creek, Town Basin and Waiharohia are elevated and above the standard for the tidal creek management unit. Large ranges were again observed at sites in this management unit with particularly high maximum concentrations recorded at Limeburners Creek.

Because of the large number of samples below the laboratory detection limit, trend analysis could only be performed on data from 18 sites, with an increasing trend identified at one site and decreasing trends at three sites (Table 13). The decreasing concentration of nitrate-nitrite nitrogen at Waiharohia Canal in Whangārei Harbour is welcome as this site had the highest median nitrate-nitrite nitrogen concentration.

There appeared to a seasonal pattern in nitrate-nitrite concentrations in all four management units with the highest concentrations observed in winter and lower concentrations during summer (Figure E-10), and 28 sites had a seasonal variation that was statistically significant (Table 13). This seasonal pattern may reflect greater freshwater and oceanic inputs of nutrients during winter and uptake of nutrients by phytoplankton and macroalgae in summer.

3.11 Total phosphorus

Median total phosphorus concentrations were low at open coast sites and most estuarine sites. High concentrations were recorded at sites in the Kaipara Harbour, Aurere Estuary, and the Hātea River management unit (Table 14). Seven sites, including six of the nine sites in the Kaipara Harbour, exceeded the relevant coastal water quality standards. In addition, although the five sites in the Hātea River achieved the standard for that management unit, the medians were elevated relative to most other tidal creek sites and were all above the standard for the tidal creek management unit.

Trend analysis identified that concentrations of total phosphorus were likely decreasing at 17 sites and increasing at two sites (Table 14). The decreases at Wahiwaka Creek and Hargreaves Basin are particularly welcome as the coastal water quality standards are exceeded at these sites. Equally, decreases at four of the sites in the Hātea River is welcome as concentrations at all of these sites are elevated.

3.12 Dissolved reactive phosphorus

Median dissolved phosphorus concentrations were low at open coast sites and most estuarine sites. High concentrations were recorded at sites in the Kaipara Harbour, Aurere Estuary, Ruakaka Estuary and the Hātea River management unit (Table 15). Ten sites, including seven of the nine sites in the Kaipara Harbour, exceeded the relevant coastal water quality standards. In addition, although the five sites in the Hātea River achieved the standard for that management unit, the medians were elevated relative to most other tidal creek sites and were all above the standard for the tidal creek management unit. The ranges recorded in the Hātea River were large with some exceptionally high concentrations recorded at Kissing Point, Town Basin, Limeburners Creek and Waiharohia (Table 15).

Trend analysis identified a likelihood that concentrations of dissolved reactive phosphorus were decreasing at three sites and increasing at twelve sites (Table 15). Increasing concentrations found at Te Honga, Te Kopua, Kapua Point and Wahiwaka Creek in the Kaipara Harbour are of concern as the medians at these sites currently exceed the relevant coastal water quality standards. In contrast, decreasing concentrations at Kaiwaka Point, in Whangārei Harbour is good news as the median at this site is currently above the coastal water quality standard.

Table 11. Total nitrogen (mg/L) at open coast, estuarine, tidal creek, and Hātea River sites, 2018-2020.

	n	Min	Max	Median	Standard achieved	Seasonality	Trend
Open Coast management unit							
Mangawhai Heads	35	0.01	0.17	0.09	n/a	P = 0.23	Insufficient data
Mair Bank	34	0.04	23.00	0.10	n/a	P = 0.68	Insufficient data
Waipū Cove	35	0.07	0.37	0.11	n/a	P = 0.12	Insufficient data
Brampton Reef	35	0.06	5.20	0.12	n/a	P = 0.27	Insufficient data
Estuary management unit							
One Tree Point	35	0.01	0.26	0.11	✓	P = 0.54	Insufficient data
Te Puna Inlet	35	0.04	0.25	0.11	✓	P = 0.35	Insufficient data
Mangawhai Ramp	35	0.01	1.30	0.12	✓	P = 0.87	Insufficient data
Russell	35	0.06	2.20	0.12	✓	P = 0.23	Insufficient data
Tamaterau	35	0.05	0.36	0.13	✓	P = 0.95	Insufficient data
Waipū Lagoon	35	0.05	0.38	0.13	✓	P = 0.76	Insufficient data
Five Fathom Ch*	11	0.099	0.63	0.14	✓	P = 0.00	⇧ 13.1%
Paihia	35	0.06	2.60	0.15	✓	P = 0.58	Insufficient data
Waipū Estuary	35	0.03	2.10	0.15	✓	P = 0.91	Insufficient data
Te Haumi	34	0.08	0.64	0.16	✓	P = 0.26	Insufficient data
Doves Bay	35	0.05	4.10	0.17	✓	P = 0.79	Insufficient data
Tapu Point	35	0.09	1.30	0.17	✓	P = 0.82	Insufficient data
Tern Point	35	0.07	1.10	0.17	✓	P = 0.45	Insufficient data
Ruakaka Estuary	35	0.01	2.00	0.18	✓	P = 0.83	Insufficient data
Waikare Inlet	35	0.09	1.50	0.18	✓	P = 0.71	Insufficient data
Oruawharo Rr*	11	0.10	0.48	0.19	✓	P = 0.30	⇧ 8.57%
Wainui Island	35	0.10	7.20	0.19	✓	P = 0.44	Insufficient data
Waitangi River	35	0.06	4.60	0.19	✓	P = 0.06	Insufficient data
Portland Wharf	35	0.01	0.40	0.20	✓	P = 0.26	Insufficient data
Te Kopua*	11	0.11	0.41	0.21	✓	P = 0.14	⇧ 8.32%
Kaiwaka Point	35	0.05	11.00	0.22	×	P = 0.31	Insufficient data
Kapua Point*	11	0.14	0.56	0.22	×	P = 0.49	⇧ 6.18%
Te Hoanga Pt*	11	0.11	0.51	0.23	×	P = 0.38	⇧ 7.81%
Aurere Estuary	31	0.1	1.60	0.28	×	P = 0.08	Insufficient data
Hargreaves Basin*	11	0.11	0.59	0.32	×	P = 0.30	⇧ 8.57%
Burgess Island*	11	0.11	1.00	0.34	×	P = 0.00	⇧ 5.00%
Tidal Creek management unit							
Kawakawa River	35	0.12	2.30	0.22	✓	P = 0.40	Insufficient data
Mangapai River	35	0.085	1.60	0.25	✓	P = 0.13	Insufficient data
Insley St	35	0.12	1.10	0.26	✓	P = 1.00	Insufficient data
Molesworth Dr	35	0.15	1.10	0.30	✓	P = 0.97	Insufficient data
Waipapa River	34	0.11	3.00	0.36	✓	P = 0.14	Insufficient data
Kerikeri River	34	0.20	0.99	0.42	✓	P = 0.10	Insufficient data
Wahiwaka Creek*	11	0.22	1.60	0.46	✓	P =0.37	⇧ 8.97%
Otaika Creek	34	0.27	2.10	0.71	×	P = 0.24	Insufficient data
Wairoa River*	11	0.17	1.40	0.84	×	P = 0.26	Insufficient data
Hātea River management unit							
Lower Hātea	35	0.18	3.20	0.35	✓	P = 0.43	Insufficient data
Kissing Point	35	0.18	2.20	0.42	✓	P = 0.60	Insufficient data
Limeburners Creek	35	0.27	13.00	0.70	✓	P = 0.44	Insufficient data
Town Basin	35	0.44	1.30	0.79	✓	P = 0.06	Insufficient data
Waiharohia	35	0.59	1.50	0.82	✓	P = 0.78	Insufficient data

*2020 data only

Table 12. Ammoniacal nitrogen (mg/L) at open coast, estuarine, tidal creek, and Hātea River sites.

	n	Min	Max	Median	Standard achieved	Seasonality	Trend
Open Coast management unit							
Mangawhai Heads	30	<0.005	0.075	<0.005	n/a	P = 0.27	Insufficient data
Mair Bank	35	<0.005	0.100	<0.005	n/a	P = 0.46	>15% censored data
Brampton Reef	35	<0.005	0.056	0.007	n/a	P = 0.66	Insufficient data
Waipū Cove	30	<0.005	0.084	0.007	n/a	P = 0.82	Insufficient data
Estuary management unit							
One Tree Point	35	<0.005	0.100	0.005	✓	P = 0.32	>15% censored data
Russell	35	<0.005	0.081	0.005	✓	P = 0.25	>15% censored data
Te Puna Inlet	35	<0.005	0.066	0.006	✓	P = 1.00	>15% censored data
Tapu Point	35	<0.005	0.071	0.009	✓	P = 0.24	>15% censored data
Doves Bay	35	<0.005	0.110	0.010	✓	P = 0.13	>15% censored data
Tamaterau	35	<0.005	0.097	0.010	✓	P = 0.39	>15% censored data
Waikare Inlet	35	<0.005	0.087	0.010	✓	P = 0.36	>15% censored data
Mangawhai Ramp	30	<0.005	0.034	0.013	✓	P = 0.11	Insufficient data
Paihia	35	<0.005	0.087	0.014	✓	P = 0.67	>15% censored data
Waipū Lagoon	30	<0.005	0.096	0.014	✓	P = 0.56	Insufficient data
Tern Point	30	<0.005	0.064	0.015	✓	P = 0.84	Insufficient data
Waitangi River	35	<0.005	0.094	0.015	✓	P = 0.18	>15% censored data
Te Kopua*	11	<0.005	0.045	0.017	✓	P = 0.03	>15% censored data
Wainui Island	35	<0.005	0.11	0.017	✓	P = 0.16	>15% censored data
Portland Wharf	35	<0.005	0.087	0.018	✓	P = 0.14	>15% censored data
Five Fathom Ch*	11	<0.005	0.041	0.020	✓	P = 0.15	>15% censored data
Kapua Point*	11	<0.005	0.064	0.021	✓	P = 0.03	>15% censored data
Te Haumi	34	<0.005	0.055	0.021	✓	P = 0.53	>15% censored data
Te Hoanga Pt*	11	<0.005	0.060	0.021	✓	P = 0.08	>15% censored data
Oruawharo River*	11	<0.005	0.047	0.022	✓	P = 0.00	>15% censored data
Ruakaka Estuary	30	<0.005	0.210	0.022	✓	P = 0.71	Insufficient data
Hargreaves Basin*	11	<0.005	0.077	0.023	×	P = 0.04	>15% censored data
Kaiwaka Point	35	<0.005	0.120	0.025	×	P = 0.03	>15% censored data
Waipū Estuary	30	<0.005	0.130	0.025	×	P = 0.46	Insufficient data
Burgess Island*	11	<0.005	0.078	0.035	×	P = 0.00	>15% censored data
Aurere Estuary	31	0.014	0.210	0.059	×	P = 0.20	Insufficient data
Tidal Creek management unit							
Insley St	30	<0.005	0.094	0.018	✓	P = 0.50	Insufficient data
Mangapai River	35	<0.005	0.073	0.019	✓	P = 0.13	>15% censored data
Kawakawa River	35	<0.005	0.063	0.020	✓	P = 0.23	>15% censored data
Molesworth Dr	30	<0.005	0.078	0.024	✓	P = 0.87	Insufficient data
Kerikeri River	34	<0.005	0.120	0.029	✓	P = 0.28	⇧ 1.37%
Waipapa River	34	<0.005	0.082	0.030	✓	P = 0.24	⬄ -1.13%
Otaika Creek	34	<0.005	0.200	0.039	✓	P = 0.13	⬄ -1.5%
Wahiwaka Creek*	11	<0.005	0.130	0.039	✓	P = 0.04	⬄ -1.71%
Wairoa River*	11	0.011	0.093	0.053	×	P = 0.18	Insufficient data
Hātea River management unit							
Lower Hātea	35	0.006	0.340	0.046	✓	P = 0.16	⬄ 1.33%
Kissing Point	35	0.005	0.440	0.060	✓	P = 0.42	⬄ -2.12%
Town Basin	35	0.013	0.210	0.077	✓	P = 0.31	⬄ -0.89%
Limeburners Cr	35	0.018	1.400	0.089	✓	P = 0.96	⬄ -2.75%
Waiharohia	35	<0.005	0.470	0.100	×	P = 0.92	⬄ -1.51%

*2020 data only

Table 13. Nitrate-nitrite nitrogen (mg/L) at open coast, estuarine, tidal creek, and Hātea River sites.

	n	Min	Max	Median	Standard achieved	Seasonality	Trend period
Open Coast management unit							
Mangawhai Head	35	<0.002	0.066	0.005	n/a	P = 0.24	Insufficient data
Waipū Cove	35	<0.002	0.060	0.005	n/a	P = 0.11	Insufficient data
Mair Bank	35	<0.002	0.078	0.007	n/a	P = 0.00	>15% censored data
Brampton Reef	35	<0.002	0.085	0.018	n/a	P = 0.17	Insufficient data
Estuary management unit							
Te Puna Inlet	35	<0.002	0.062	0.002	✓	P = 0.59	>15% censored data
Oruawharo Rr*	11	<0.002	0.26	0.003	✓	P = 0.00	>15% censored data
Hargreaves *	11	<0.002	0.29	0.005	✓	P = 0.00	>15% censored data
Waipū Lagoon	35	<0.002	0.17	0.006	✓	P = 0.03	Insufficient data
Mangawhai Ramp	35	<0.002	0.05	0.007	✓	P = 0.13	Insufficient data
One Tree Point	35	<0.002	0.08	0.007	✓	P = 0.00	>15% censored data
Te Kopua*	11	<0.002	0.21	0.007	✓	P = 0.00	Insufficient data
Tern Point	35	<0.002	0.1	0.007	✓	P = 0.02	Insufficient data
Waikare Inlet	35	<0.002	0.069	0.007	✓	P = 0.01	⇔ 0.0%
Tamaterau	35	<0.002	0.12	0.008	✓	P = 0.00	>15% censored data
Five Fathom Ch*	11	<0.002	0.42	0.009	✓	P = 0.00	>15% censored data
Russell	35	<0.002	0.068	0.009	✓	P = 0.00	>15% censored data
Tapu Point	35	<0.002	0.12	0.011	✓	P = 0.00	>15% censored data
Te Haumi	34	<0.002	0.086	0.011	✓	P = 0.00	>15% censored data
Portland Wharf	35	<0.002	0.3	0.012	✓	P = 0.00	>15% censored data
Waipū Estuary	35	<0.002	0.59	0.012	✓	P = 0.31	Insufficient data
Ruakaka Estuary	35	<0.002	1.2	0.015	✓	P = 0.19	Insufficient data
Waitangi River	35	<0.002	0.28	0.017	✓	P = 0.00	⇔ -2.4%
Te Hoanga Pt*	11	<0.002	0.24	0.019	✓	P = 0.00	⇔ -4.93%
Doves Bay	35	<0.002	0.21	0.021	✓	P = 0.00	>15% censored data
Paihia	35	<0.002	0.13	0.021	✓	P = 0.00	>15% censored data
Kaiwaka Point	35	<0.002	0.3	0.029	✓	P = 0.00	⇔ -4.42%
Wainui Island	35	<0.002	0.29	0.029	✓	P = 0.00	⇔ -0.58%
Aurere Estuary	31	0.002	0.21	0.030	✓	P = 0.08	Insufficient data
Kapua Point*	11	<0.002	0.22	0.034	✓	P = 0.00	⇩ -7.44%
Burgess Island*	11	<0.002	0.7	0.110	×	P = 0.00	⇩ -7.38%
Tidal Creek management unit							
Insley St	35	<0.002	0.21	0.008	✓	P = 0.04	Insufficient data
Mangapai River	35	<0.002	0.12	0.0097	✓	P = 0.18	⇔0.23 %
Molesworth Dr	35	<0.002	0.22	0.011	✓	P = 0.07	Insufficient data
Kawakawa River	35	0.002	0.18	0.026	✓	P = 0.00	⇔ -2.17%
Wahiwaka Cr*	11	0.024	0.93	0.081	✓	P = 0.00	⇧7.42%
Waipapa River	33	<0.002	0.4	0.140	✓	P = 0.00	⇔ 0.81 %
Kerikeri River	34	<0.002	0.57	0.19	✓	P = 0.00	⇔ 0.60 %
Otaika Creek	34	0.0077	0.97	0.35	×	P = 0.06	⇔ 1.97 %
Wairoa River*	11	0.0059	0.88	0.43	×	P = 0.23	Insufficient data
Hātea River management unit							
Lower Hātea	35	0.015	0.53	0.100	✓	P = 0.19	⇔ -0.95%
Kissing Point	35	0.035	0.78	0.210	✓	P = 0.26	⇔ 0.00%
Limeburners Cr	35	0.059	2.3	0.370	✓	P = 0.88	⇔ 0.00%
Town Basin	35	0.12	1.1	0.470	✓	P = 0.00	⇔ -0.56%
Waiharohia	35	0.22	1.2	0.500	✓	P = 0.50	⇩ -2.34%

*2020 data

Table 14. Total phosphorus (mg/L) at open coast, estuarine, tidal creek, and Hātea River sites.

	n	Min	Max	Median	Standard achieved	Seasonality	Trend
Open Coast management unit							
Mangawhai Heads	35	0.004	0.02	0.011	n/a	P = 0.72	Insufficient data
Mair Bank	35	0.004	0.021	0.011	n/a	P = 0.07	⇔ 0.00%
Brampton Reef	35	0.007	0.025	0.013	n/a	P = 0.46	Insufficient data
Waipū Cove	35	0.006	0.083	0.016	n/a	P = 0.39	Insufficient data
Estuary management unit							
One Tree Point	35	0.005	0.021	0.012	✓	P = 0.87	⇩ - 1.81%
Mangawhai Ramp	35	0.006	0.077	0.013	✓	P = 0.17	Insufficient data
Russell	35	0.008	0.029	0.013	✓	P = 0.41	⇩-1.24%
Doves Bay	35	0.009	0.058	0.014	✓	P = 0.58	⇩ -1.37%
Waipū Lagoon	35	0.008	0.060	0.014	✓	P = 0.98	Insufficient data
Paihia	35	0.006	0.035	0.016	✓	P = 0.65	⇔ -0.69%
Tamaterau	35	0.008	0.042	0.016	✓	P = 0.76	⇩-4.15%
Waipū Estuary	35	0.009	0.150	0.016	✓	P = 0.79	Insufficient data
Te Puna Inlet	35	0.009	0.029	0.017	✓	P = 0.36	⇩ -2.52%
Five Fathom Ch*	11	0.012	0.024	0.018	✓	P = 0.45	⇩ -1.46%
Te Haumi	34	0.011	0.057	0.018	✓	P = 0.23	⇩ -1.1%
Waitangi River	35	0.010	0.063	0.018	✓	P = 0.82	⇔ 0.0%
Wainui Island	35	0.010	0.070	0.019	✓	P = 0.33	⇩ -1.9%
Tapu Point	35	0.011	0.043	0.020	✓	P = 0.38	⇩-1.83%
Tern Point	35	0.009	0.071	0.020	✓	P = 0.67	Insufficient data
Ruakaka Estuary	35	0.007	0.310	0.021	✓	P = 0.52	Insufficient data
Waikare Inlet	35	0.012	0.042	0.022	✓	P = 0.01	⇩ -1.08%
Oruawharo River*	11	0.015	0.035	0.024	✓	P = 0.07	⇩ -1.95%
Portland Wharf	35	0.013	0.032	0.024	✓	P = 0.01	⇩ -5.57%
Kaiwaka Point	35	0.012	0.056	0.027	✓	P = 0.01	⇩-4.45%
Te Kopua*	11	0.021	0.040	0.028	✓	P = 0.01	⇧ 1.85%
Te Hoanga Pt*	11	0.014	0.051	0.030	×	P = 0.00	⇔ 0.21%
Kapua Point*	11	0.022	0.051	0.033	×	P = 0.00	⇔ 0.00%
Burgess Island*	11	0.016	0.056	0.036	×	P = 0.79	⇔ -1.08%
Aurere Estuary	31	0.016	0.250	0.041	×	P = 0.07	Insufficient data
Hargreaves Basin*	11	0.029	0.091	0.049	×	P = 0.07	⇩ -1.95%
Tidal Creek management unit							
Kerikeri River	34	0.008	0.180	0.019	✓	P = 0.67	⇔ 0.00%
Waipapa River	34	0.009	0.062	0.021	✓	P = 0.73	⇔ 0.61%
Molesworth Dr	35	0.013	0.120	0.027	✓	P = 0.94	Insufficient data
Mangapai River	35	0.01	0.150	0.028	✓	P = 0.00	⇩-3.42%
Kawakawa River	35	0.016	0.067	0.029	✓	P = 0.13	⇔ 0.00%
Insley St	35	0.009	0.230	0.029	✓	P = 0.97	Insufficient data
Otaika Creek	34	0.011	0.120	0.032	✓	P = 0.57	⇔1.86%
Wairoa River*	11	0.04	0.240	0.059	×	P = 0.59	Insufficient data
Wahiwaka Cr*	11	0.034	0.100	0.061	×	P = 0.01	⇧ 1.55%
Hātea River management unit							
Lower Hātea	35	0.024	0.110	0.044	✓	P = 0.09	⇩ -2.67%
Kissing Point	35	0.029	0.150	0.058	✓	P = 0.24	⇩ -2.19%
Town Basin	35	0.015	0.230	0.074	✓	P = 0.04	⇩-2.78%
Limeburners Creek	35	0.022	0.550	0.100	✓	P = 0.71	⇔ -1.78%
Waiharohia	35	0.039	0.310	0.110	✓	P = 0.00	⇩ -2.34%

*2020 data only

Table 15. Dissolve reactive phosphorus (mg/L) at open coast, estuarine, tidal creek, and Hātea River sites.

	n	Min	Max	Median	Standard achieved	Seasonality	Trend
Open Coast management unit							
Mair Bank	35	0.004	0.015	0.007	n/a	P = 0.00	⇔ 0.0%
Mangawhai Heads	35	0.004	0.017	0.008	n/a	P = 0.15	Insufficient data
Waipū Cove	35	0.003	0.045	0.009	n/a	P = 0.13	Insufficient data
Brampton Reef	35	0.001	0.017	0.010	n/a	P = 0.25	Insufficient data
Estuary management unit							
Russell	35	<0.005	0.017	0.008	✓	P = 0.01	⇔ 0.0%
Doves Bay	35	<0.005	0.025	0.009	✓	P = 0.00	⇔ 1.58%
One Tree Point	35	<0.005	0.017	0.009	✓	P = 0.14	⇔ 0.0%
Te Puna Inlet	35	0.003	0.020	0.009	✓	P = 0.05	⇧ 1.33%
Mangawhai Ramp	35	0.004	0.025	0.010	✓	P = 0.14	Insufficient data
Paihia	35	<0.005	0.017	0.010	✓	P = 0.33	⇧ 1.24%
Wainui Island	35	<0.005	0.024	0.010	✓	P = 0.07	⇔ 0.00%
Tamaterau	35	<0.005	0.022	0.011	✓	P = 0.14	⇩ -1.38%
Tapu Point	35	0.006	0.022	0.011	✓	P = 0.08	⇧ 1.29%
Tern Point	35	0.007	0.029	0.011	✓	P = 0.87	Insufficient data
Waipū Lagoon	35	0.006	0.022	0.011	✓	P = 0.64	Insufficient data
Waitangi River	35	<0.005	0.020	0.011	✓	P = 0.41	⇧ 2.92%
Five Fathom Ch*	11	0.005	0.015	0.012	✓	P = 0.01	⇔ 0.0%
Waikare Inlet	35	0.006	0.017	0.012	✓	P = 0.05	⇔ 0.0%
Te Haumi	34	0.007	0.018	0.013	✓	P = 0.02	⇔ 0.00%
Waipū Estuary	35	0.002	0.036	0.013	✓	P = 0.78	Insufficient data
Portland Wharf	35	0.006	0.021	0.014	✓	P = 0.00	⇩ -4.28%
Oruawharo River*	11	0.008	0.022	0.015	✓	P = 0.60	⇔ 0.0%
Ruakaka Estuary	35	0.005	0.150	0.017	×	P = 0.70	Insufficient data
Te Hoanga Pt*	11	0.008	0.038	0.018	×	P = 0.00	⇧ 1.87%
Te Kopua*	11	0.010	0.029	0.018	×	P = 0.00	⇧ 3.52%
Kaiwaka Point	35	0.010	0.037	0.019	×	P = 0.03	⇩-2.49%
Burgess Island*	11	0.011	0.032	0.022	×	P = 0.00	⇔ 0.0%
Kapua Point*	11	0.014	0.034	0.022	×	P = 0.00	⇧ 1.61%
Aurere Estuary	31	0.006	0.077	0.025	×	P = 0.16	Insufficient data
Hargreaves Basin*	11	0.017	0.044	0.027	×	P = 0.60	⇔ 0.0%
Tidal Creek management unit							
Kerikeri River	34	<0.005	0.030	0.008	✓	P = 0.00	⇧ 5.71%
Waipapa River	33	<0.005	0.015	0.009	✓	P = 0.01	⇧ 5.56%
Insley St	35	0.006	0.060	0.013	✓	P = 0.62	Insufficient data
Mangapai River	35	0.008	0.030	0.014	✓	P = 0.01	⇔ 0.0%
Molesworth Dr	35	0.005	0.030	0.014	✓	P = 0.90	Insufficient data
Otaika Creek	34	0.004	0.030	0.014	✓	P = 0.09	⇧ 7.51%
Kawakawa River	35	0.007	0.023	0.015	✓	P = 0.13	⇧ 2.28%
Wairoa River*	11	0.013	0.046	0.029	×	P = 0.40	Insufficient data
Wahiwaka Cr*	11	0.028	0.083	0.043	×	P = 0.06	⇧ 3.48
Hātea River management unit							
Lower Hātea	35	0.019	0.077	0.032	✓	P = 0.56	⇔ -1.57%
Kissing Point	35	0.022	0.150	0.046	✓	P = 0.59	⇔ -0.75%
Town Basin	35	0.011	0.160	0.056	✓	P = 0.06	⇔ 0.0%
Limeburners Creek	35	0.018	0.480	0.070	✓	P = 0.92	⇔ -0.66%
Waiharohia	35	0.018	0.290	0.086	✓	P = 0.04	⇔ -1.41%

*2020 data only

3.13 Copper

Concentrations of total copper were typically below the laboratory detection limits at most sites, except for sites in the Hātea River management unit and five sites in the Kaipara Harbour. Seven sites achieved the coastal water quality standard (Table 16).

The standard was achieved at two sites in the open coast management unit and at five sites in the estuary management unit. At most sites the standard was exceeded in fewer than 10% of samples, but at sites in the Kaipara Harbour and at Kaiwaka Point and Aurere Estuary the standard was exceeded more regularly.

In the tidal creek management unit, the standard was exceeded at all nine sites. At both Wairoa River and Wahiwaka Creek, in the Kaipara Harbour, 73% of samples exceeded the standard. In the Hātea River unit, all sites exceeded the limit with more than 50% of samples exceeding the limit at Limeburners Creek, Town Basin and Waiharohia.

Trend assessment and seasonality tests were not undertaken for concentrations, due to the combination of the low number of measurements above detection limits and the limited data record for these parameters.

3.14 Zinc

Concentrations of total zinc were typically below the laboratory detection limits at most sites, except at the Town Basin, Waiarohia Canal and Wairoa River (Table 17). Concentrations of zinc were below the water quality standards at twenty-three sites.

In the open coast unit, three of the four sites had concentrations below the standard and all but two samples collected at Mair Bank were below the laboratory detection limit. In the estuary management unit, 16 sites achieved the standard. At the 10 sites that exceeded the standard, less than 10% of samples exceeded the standard.

In the tidal creek management unit only two sites achieved the standard and in the Hātea River unit, four of the five sites exceeded the standard at least once. The highest number of exceedances were at Limeburners Creek (20%) and Waiarohia (32%), in the Hātea River management unit and at Insley Street (29%) and Wairoa River (18%), in the tidal Creek unit.

Table 16. Total copper concentrations (mg/L), 2018-2020.

Site	N	Max	Censored	% above standard	Standard achieved
Open coast management unit					
Brampton Reef	35	<0.001	35	0 (0%)	✓
Mangawhai Heads	35	0.0011	34	0 (0%)	✓
Waipū Cove	35	0.0024	34	1 (3%)	×
Mair Bank	35	0.0025	33	1 (3%)	×
Estuarine management unit					
Aurere Estuary	31	0.0047	26	4 (13%)	×
Paihia	35	0.0064	33	2 (6%)	×
Burgess Island	11	0.0086	3	6 (55%)	×
Five Fathom Ch	11	0.0021	9	2 (18%)	×
Hargreaves Basin	11	0.0041	3	7 (64%)	×
Kapua Point	11	0.0016	6	4 (36%)	×
Oruawharo River	11	0.0018	7	3 (27%)	×
Te Hoanga Point	11	0.0017	5	3 (27%)	×
Te Kopua	11	0.0018	6	5 (45%)	×
Tapu Point	35	0.0011	33	0 (0%)	✓
Doves Bay	35	0.0037	29	4 (12%)	×
Wainui Island	35	0.0015	33	1 (3%)	×
Mangawhai ramp	35	<0.001	35	0 (0%)	✓
Tern Point	35	0.0097	34	1 (3%)	×
Te Haumi	34	0.0047	30	3 (9%)	×
Ruakaka Estuary	35	0.0170	31	3 (9%)	×
Russell	35	0.0010	35	0 (0%)	✓
Te Puna Inlet	35	0.0079	34	1 (3%)	×
Waikare Inlet	35	0.0130	33	1 (3%)	×
Waipū Estuary	35	0.0025	31	3 (9%)	×
Waipū Lagoon	35	0.0011	34	0 (0%)	✓
Waitangi River	35	0.0013	33	1 (3%)	×
Kaiwaka Point	35	0.0038	26	5 (14%)	×
One Tree Point	35	0.0012	34	0 (0%)	✓
Portland	35	0.0027	28	3 (9%)	×
Tamaterau	35	0.0290	30	1 (3%)	×
Tidal creek management unit					
Molesworth Dr	35	0.0024	32	2 (6%)	×
Insley St	35	0.0024	31	3 (9%)	×
Kawakawa River	35	0.0022	31	2 (6%)	×
Kerikeri River	34	0.0041	29	4 (12%)	×
Waipapa River	34	0.0100	29	5 (15%)	×
Wahiwaka Creek	11	0.0027	3	8 (73%)	×
Wairoa River	11	0.0072	1	8 (73%)	×
Mangapai River	35	0.0022	28	5 (14%)	×
Otaika Creek	34	0.0055	26	6 (18%)	×
Hātea River management unit					
Kissing Point	35	0.0032	16	17 (49%)	×
Limeburners Creek	35	0.0037	16	18 (51%)	×
Lower Hātea River	35	0.0035	21	13 (37%)	×
Town Basin	35	0.0083	17	13 (66%)	×
Waiharohia	34	0.0040	16	18 (53%)	×

Table 17. Total zinc concentrations (mg/L), 2018-2020.

	N	Max	Censored	% above standard	Standard achieved
Open coast management unit					
Brampton Reef	35	0.0086	33	0 (0%)	✓
Mangawhai Heads	35	0.0140	33	0 (0%)	✓
Waipū Cove	35	0.0094	33	0 (0%)	✓
Mair Bank	35	0.0480	33	2 (6%)	×
Estuarine management unit					
Aurere Estuary	31	0.015	23	1 (3%)	×
Paihia	35	0.180	30	2 (6%)	×
Burgess Island	11	0.012	7	0 (0%)	✓
Five Fathom Ch	11	0.004	10	0 (0%)	✓
Hargreaves Basin	11	0.029	9	1 (9%)	×
Kapua Point	11	0.011	7	0 (0%)	✓
Oruawharo River	11	<0.01	11	0 (0%)	✓
Te Hoanga Point	11	0.021	8	1 (9%)	✓
Te Kopua	11	0.100	8	0 (0%)	×
Tapu Point	35	0.009	33	0 (0%)	✓
Doves Bay	35	0.012	33	0 (0%)	✓
Wainui Island	35	0.005	34	0 (0%)	✓
Mangawhai ramp	35	0.100	31	1 (3%)	×
Tern Point	35	0.044	34	2 (6%)	×
Te Haumi	35	0.230	27	1 (3%)	×
Ruakaka Estuary	35	0.055	31	1 (3%)	×
Russell	35	0.005	33	0 (0%)	✓
Te Puna Inlet	35	0.005	33	0 (0%)	✓
Waikare Inlet	35	0.005	34	0 (0%)	✓
Waipū Estuary	35	0.010	29	0 (0%)	✓
Waipū Lagoon	35	0.026	32	1 (3%)	×
Waitangi River	35	0.007	32	0 (0%)	✓
Kaiwaka Point	35	0.009	30	0 (0%)	✓
One Tree Point	35	0.010	32	0 (0%)	✓
Portland	35	0.013	30	0 (0%)	✓
Tamaterau	35	0.021	32	1 (3%)	×
Tidal creek management unit					
Molesworth Dr	35	0.023	31	2 (6%)	×
Insley St	35	0.041	27	5 (29%)	×
Kawakawa River	35	0.043	32	1 (3%)	×
Kerikeri River	34	0.010	30	0 (0%)	✓
Waipapa River	34	0.025	31	1 (3%)	×
Wahiwaka Creek	11	0.400	10	1 (9%)	×
Wairoa River	11	0.024	4	2 (18%)	×
Mangapai River	35	0.010	33	0 (0%)	✓
Otaika Creek	32	0.027	24	2 (6%)	×
Hātea River management unit					
Kissing Point	35	0.014	26	0 (0%)	✓
Limeburners Creek	35	0.046	17	7 (20%)	×
Lower Hātea River	35	0.088	22	4 (11%)	×
Town Basin	35	0.018	17	4 (11%)	×
Waiharohia	34	0.280	12	11 (32%)	×

4. Synthesis

4.1 Salinity

Salinity was generally higher and less variable at open coast and estuarine sites compared to tidal creeks and the Hātea River sites. However, the data also showed that estuarine sites like Waipū Estuary, Ruakaka Estuary and Aurere Estuary, located in tidal lagoon and tidal river hydrosystems had more variability than estuarine sites in drowned river valley systems, reflecting the greater influence of freshwater inputs and tidal state at sites in these hydrosystems. At low tide, these systems essentially behave like an extension of the river network with little or no dilution with oceanic water, while at high tide they are flooded with oceanic water. The influence of salinity on water quality at these sites was apparent in the water quality results and correlation analysis, with the highest turbidity, faecal indicator bacteria and nutrient concentrations generally recorded when salinity was low.

A seasonal pattern was also evident, with lower salinity and more variability in winter compared to summer, which is likely to reflect the seasonal variation in rainfall, with more precipitation during winter.

4.2 Temperature

Water temperature is an important water quality variable which will help to influence the ecological communities present and the patterns of primary production. Water temperature also affects biochemical reactions and importantly the concentration of dissolved oxygen, with cold water able to hold more oxygen than warm water.

Open coast sites and estuarine sites in drowned river systems had relatively stable temperature regimes, with oceanic water likely helping to regulate temperature at these sites. In contract, sites with more freshwater influence tended to have greater temperature extremes.

The water is getting warmer

Trend analysis has indicated the likelihood of increasing temperatures at 30 sites, which is consistent with warming reported elsewhere in Northland and New Zealand (Chiswell & Grant 2018, Gadd *et al.* 2020). Increasing water temperature may affect the distribution of flora and fauna and assist with the introduction and spread of invasive species (Willis *et al.* 2007).

From a water quality perspective, increasing water temperature are likely to alter patterns of primary production, concentrations of nutrients, and dissolved oxygen concentrations. Temperature can act as a control on algae growth, so increasing water temperature may increase primary production or alter the seasonal pattern, by for example allowing more algae growth in winter. Changes in algal growth and biomass driven by warming temperatures can, in turn, temporarily reduce water column nutrient concentrations as more nutrients are taken up to support algal growth (Gadd *et al*. 2020). Dissolved oxygen concentrations are negatively correlated to temperature and show a strong seasonal pattern at most sites, with low concentrations during summer and early autumn. Increasing temperatures may therefore exacerbate or extend periods of low dissolved oxygen concentrations.

4.3 Faecal indicator bacteria

Is the water suitable for contact recreation?

All four sites in the open coast and 23 sites in the estuary management unit achieved the coastal water quality standard. When assessed against the microbiological assessment category definitions for marine waters, all open coast sites and nine estuarine sites would be graded in category A, using the three-year 95th percentile. The estimated risk for marine water within this category is of < 1% gastrointestinal illness (GI) risk and of < 0.3% acute febrile respiratory illness (AFRI). This relates to an excess illness of less than one incidence in every 100 exposures.

The four sites in the estuarine management unit that did not achieve the coastal water quality standard are located in either tidal lagoon or tidal river hydrosystems (Waitangi, Ruakaka, Waipū Estuary and Aurere Estuary). When assessed against the microbiological assessment category definitions for marine waters, Waitangi Estuary would be graded in category C and Ruakaka River, Waipū River and Aurere Estuary would be graded in category D. Category C corresponds to a 5-10% risk of GI illness and 1.9-3.95 risk of AFRI, while category D corresponds to a >10% risk of GI risk and a >3.95% risk of AFRI. The salinity ranges at these four sites indicates that at times these systems are heavily influenced by freshwater inputs, with salinity close to zero recorded at Aurere Estuary, Ruakaka Estuary and Waipū Estuary and elevated enterococci concentrations were generally recorded after heavy rainfall. The actual risk will therefore generally be less if a person does not swim following rain events.

This grading has used data collected over three calendar years, rather than data collected during the summer recreational bathing season, that is used by Council and the Land Air Water Aotearoa (LAWA website) and as a seasonal pattern was found in the data, gradings are likely to be different. For example, the recreational bathing site at Ruakaka has been graded 'Good' using 5-year data collected over the summer bathing season.

Of these four sites that did not achieve the standard, the high concentrations at Ruakaka are of most concern as there is a campground on the shoreline of the estuary and this is a very popular estuary for swimming and recreation. Waitangi Estuary is not as popular for swimming but is used for secondary contact recreation such as paddle boarding, kayaking and Waka Ama (author's observations). At Waitangi, swimming tends to occur closer to entrance to the estuary at the bridge or at Te Ti beach, outside of the estuary and concentrations of enterococci at the nearby Paihia sampling site were lower.

Only three sites of the nine sites in the tidal creek management unit achieved the coastal water quality standard and none of the five sites in the Hātea River management unit achieved the standard. The high enterococci recorded at sites in the tidal creek management units is not unexpected as these sites are the immediate receiving environments for the freshwater network. Tidal creeks environments like Otaika Creek are not typically used for contact recreation as they are less accessible and appealing compared to estuarine and open coast locations (Plate 1). However, these environments are sometimes used for secondary contact recreation, with areas of the Kerikeri River, Waipapa River and the Hātea River used for paddle boarding, kayaking, rowing and waka ama (authors observations). Kerikeri River, Waipapa River and the Lower Hātea River site would be graded in category C when assessed against the Microbiological Assessment Category, with the other sites in the Hātea River graded in category D.

Plate 1. Otaika Creek, in Whangārei Harbour.

Is the water suitable for shellfish collection?

All four sites in the open coast management and 16 sites in the estuary management achieved the coastal water quality standard for faecal coliforms so the data suggests that in these areas the water is suitable for shellfish gathering.

Based on the data for three-year sampling period, there is a risk for shellfish gathering at nine estuarine sites. Seven of the nine estuarine sites that did not achieve the coastal water quality standard are located in tidal lagoons or tidal river hydrosystems, and on ebb tides these systems are heavily influenced by freshwater inputs with very little dilution with saltwater. The biggest concern is the faecal coliform concentrations at Aurere Estuary, Ruakaka Estuary, Waipū Estuary, Mangawhai Estuary and Waitangi Estuary, as these estuaries all support shellfish beds.

There are no standards for the tidal creek and Hātea River management units as these environments are not typically used for shellfish gathering but if the water was assessed against the microbial guidelines for shellfish-gather waters, it would not be suitable for shellfish consumption.

Is it improving?

Because of the high number of samples that were below the laboratory detection limit, trend analysis could not be undertaken at most sites. At sites with sufficient data for trend analysis, a likelihood of increasing concentrations of macrobacteria were found at five sites. Concentrations of faecal indicator bacteria is high at all of these sites so increasing trends are of concern. A decreasing trend was found for faecal coliforms at Limeburners Creek, which is welcome as concentrations are elevated at this site.

What's causing the problem?

Sources of faecal contamination include point source discharges such as wastewater treatment plants and farm dairy effluent discharges, and diffuse run off from agricultural land, but can also include birds, dogs and ecosystems reservoirs.

The site in Limeburners Creek is the immediate receiving environment for Whangārei wastewater treatment plant and would at first glance appear a prime suspect for the high concentrations of enterococci and faecal coliforms in the Hātea River. However, on closer inspection of the data, concentrations of these bacteria were often higher at other sites in the Hātea River such as the Town Basin and Waiharohia, and concentrations at Otaika Creek which is completely separate sub-catchment were also very high.

The seasonal variation observed at sites in the Hātea River management unit and at Otaika Creek, with higher concentrations in autumn and winter, when rainfall is typically higher, suggests that inputs from the freshwater network are at least partly responsible for the high enterococci concentrations. Strong correlations were also found between enterococci and rainfall over the preceding 24 hours at Town Basin and Waiharohia.

The Hātea River catchment has a relatively high proportion of urban land use and relatively little agricultural land use, so sources of contamination are likely to include unauthorised connections to the stormwater, stock access to waterways on lifestyle plots, septic systems, dogs and birds. Microbial source tracking conducted in 2020/2021 at freshwater recreational bathing sites at Raumanga Valley and the Hātea River, in the catchment detected ruminant markers at both these sites (Northland Regional Council 2021).

Land cover in the Otaika catchment is dominated by exotic grassland for pasture and there are several farm dairy effluent discharges so agricultural sources are more likely to be responsible for the high enterococci and faecal coliform concentrations in this catchment.

The high concentrations at Ruakaka Estuary, Waitangi Estuary and Waipū Estuary are likely to be from agricultural sources. There are no wastewater treatment plants in the Waitangi catchment and both the Waipū and Ruakaka wastewater treatment plants discharge to land. All three catchments have a high proportion of exotic grassland for pasture and point source discharges of farm dairy effluent. Microbial source tracking conducted in 2019/2020 at the freshwater recreational bathing site in the Waitangi River detected ruminant markers at this site (Northland Regional 2020).

The Aurere Estuary has a high proportion of agricultural land in catchment, but also receives point source discharges from the Taipa wastewater treatment plant and farm dairy effluent discharges. The Wahiwaka Creek, in the Kaipara Harbour receives inputs from both the Maungaturoto and Kaiwaka wastewater treatment plants and a community wastewater scheme in Maungaturoto. There is also a high proportion of agriculture in the catchment and several farm dairy effluent discharges.

4.4 Water clarity

Sites in the Kaipara Harbour generally had much higher turbidity and six sites in this harbour exceeded the coastal water quality standard. Turbidity at Wairoa River and Hargreaves Basin was particularly high and there is clearly a major issue with water clarity at these sites.

What's the cause of low turbidity?

Water clarity can be reduced by human activities that increase levels of suspended solids entering the coastal environment, such as soil erosion from agricultural land and forestry, sediment loss from earthworks sites, stormwater runoff and point source discharges.

The highest turbidity measurements were generally recorded after heavy rainfall events and catchment sources of sediment are undoubted responsible for some of the elevated turbidity results. This is particularly true of sites located in tidal creaks and estuarine sites located in either tidal lagoon or tidal river hydrosystems, such as Ruakaka Estuary, Waipū Estuary and Aurere Estuary. At the Wairoa River site, in the Kaipara Harbour, turbidity is particularly poor and is clearly caused by sediment laden inputs from the vast northern Wairoa catchment. On ebb tides sediment laden water can be seen advancing down the channel and tidal state is critical to how poor water clarity is at the time of sampling (Plate 2).

Plate 2. Photograph taken near the sampling site at the Wairoa River in the Kaipara Harbour.

There is a strong seasonal pattern

However, at some sites elevated turbidity concentrations were recorded when there had been little or no rainfall and a positive correlation between turbidity and rainfall was only observed at one site, indicating that other factors may also be important. For example, the highest turbidity at Tamaterau (7.26 FNU) was recorded after no rainfall had fallen over preceding 72 hours and the highest turbidity observed at One Tree Point (4.8FNU) was measured after only 2mm had fallen in the previous 72 hours.

Water clarity can also be affected by algae in the water column, and it is often obvious when collecting samples that the poor water clarity is caused by algae in the water (Plate 3). Although none of the sites had a seasonal pattern that was statistically significant, it was apparent at some sites that the highest turbidity was recorded in summer, when there is typically less rainfall but more algal growth, and that the lower turbidity was recorded in winter, when rainfall is typically higher but algae growth low.

Plate 3. Poor water clarity caused by algae growth in the water column, in Whangārei Harbour.

Another factor that can affect turbidity and water clarity is the resuspension of seabed sediment. This is most apparent at the two open coast sites which are sampled from the shore. The median at these two sites were higher than the open coast sites sampled via a vessel, and it is likely that results are impacted by the resuspension of sand from wave action. This may also be a factor at other shallow sites, particularly when there are strong winds and tidal flows, when sampling is undertaken.

4.5 Chlorophyll-*a*

The median chlorophyll-*a* concertation only exceeded the coastal water quality standards at two sites (Burgess Island and Hargreaves Basin, in the Kaipara Harbour). However, some very high chlorophyll-*a* concentrations were recorded during the summer and extended periods of elevated concentrations were observed at several sites, which had medians below the standard (Figure 10). It may be that an annual median is not the most appropriate metric to measure the trophic state of coastal waters or identify issues with nuisance algal growth as lower chlorophyll-*a* concentrations during the winter serve to depress the annual median. A seasonal metric that accounts for the significantly higher chlorophyll-*a* concentrations during the summer or one that captures the peak may be more appropriate and help us to better identify issues with the trophic state of our estuaries.

Chlorophyll-*a* concentrations are decreasing

Trend analysis has shown the likelihood of decreasing concentrations of chlorophyll-*a* at nine sites and increases at just two sites. The decreases at Oruawharo River and Hargreaves Basin are particularly significant as concentrations at these sites are currently either close to or above the coastal water quality standard.

4.6 Dissolved oxygen

Oxygen enters estuaries and marine waters from streams and rivers, groundwater, diffusion from the atmosphere and as a waste product of photosynthesis. Plants and animals use oxygen during respiration and bacteria can consume oxygen during the decay of organic matter. Because primary producers are both producers of oxygen during photosynthesis and (directly or indirectly) consumers of oxygen through respiration, excessive nutrient enrichment and plant growth can cause dissolved oxygen levels to fluctuate greatly at daily and seasonal timescales.

Median dissolved oxygen concentrations were all above the coastal standards, but six sites had dissolved oxygen concentrations below the minimum standard. As with chlorophyll-*a* the median value may not be the most appropriate metric to measure the impact of dissolved oxygen in coastal waters. There was a strong seasonal pattern at all sites with higher dissolved oxygen concentration in winter, when the water is cooler. These higher concentrations in winter will therefore be uplifting the median values and potentially masking problems associated with low dissolved oxygen during the summer, when the water is warmer. The minimum measurements were all made during summer and at several sites extended periods of dissolved oxygen were observed (Figure 11). Of most concern is that in 2019, dissolved oxygen dropped below 4.6 mg/L for three consecutive months at both the Town Basin and Waiharohia, in Whangārei Harbour. Extended periods of low dissolved oxygen are more important to the flora and fauna than the annual median so monitoring of the minimum concentrations is critical.

Another concern is that sampling of dissolved oxygen takes place during the day when dissolved oxygen concentrations are likely to be highest. Dissolved oxygen has a strong diurnal cycle with oxygen concentrations falling at night when primary producers stop photosynthesising. Sampling is also restricted to surface waters, were aeration and oxygen enrichment through atmospheric exchange occurs. Concentrations near the seabed may be lower, especially in deeper water where stratification may occur.

Dissolved oxygen concentrations are decreasing

Decreasing concentrations of dissolved oxygen were identified at 11 sites and six of these sites (Otaika Creek, Wahiwaka Creek, Mangapai River, Waiarohia canal, Limeburners and Town Basin) currently do not comply with the coastal water quality standard so decreasing trends are particularly worrying.

What is causing the decrease in dissolved oxygen concentrations?

Decreases in dissolved oxygen can be caused by algae blooms stimulated by excess nutrient loads. As the algae die, bacteria that consume this dead organic matter increase and consume dissolved oxygen. In extreme cases this can cause oxygen depletion and result in anoxic sediments and waters, changes in sediment chemistry and ecosystem shifts to animals tolerant of anoxic conditions. However, the concentration of dissolved oxygen is also affected by the water temperature. Cold water can hold more dissolved oxygen that warm water so there is typically a seasonal cycle. In the winter when water is colder, it can hold more dissolved oxygen and in summer when water is warmer it holds less. Trend analysis has showed the likelihood of warming water at most sites so decreasing dissolved oxygen concentrations may be a response to increased water temperatures. At the eleven sites where dissolved oxygen was decreasing, temperature was also increasing at ten of these sites, whereas chlorophyl-*a* concentrations were only increasing at two sites (Table 18).

Table 18. Dissolved oxygen, chlorophyll-*a* and temperature trends at 11 sites, where decreasing dissolved oxygen was recorded.

	Dissolved oxygen	Chlorophyll-*a*	Temperature
Oruawharo River	⇩ -0.21%	⇩ -1.91%	⇧ 0.37%
Hargreaves Basin	⇩ -0.21%	⇔1.09%	⇧ 0.37%
Waipapa River	⇩-0.76%	⇩ -1.91%	⇧ 0.84%
Kawakawa River	⇩ -0.46%	⇧ 5.14%	⇧ 0.83%
Otaika Creek	⇩ -2.49%	>15% censored	⇧ 1.30%
Wahiwaka Creek	⇩ -0.75%	⇩ 3.3%	⇔ 0.14%
Mangapai River	⇩ -1.13%	>15% censored	⇧ 1.0%
Waiharohia	⇩ -1.36%	⇧ 10.19%	⇧ 1.26%
Kissing Point	⇩-0.53%	>15% censored	⇧ 0.88%
Limeburners Creek	⇩ - 0.96%	⇔ 0.0%	⇧ 0.87%
Town Basin	⇩ -1.15%	⇔ - 4.53%	⇧ 1.2%

4.7 Nutrient concentrations

Concentrations of nutrients were typically lower at open coast and estuarine sites compared to sites in tidal creeks and the Hātea River. However, large differences were also observed between estuarine systems, with higher nutrient concentrations typically found at sites in the Kaipara harbour and Aurere Estuary. Elevated concentrations were also observed at Kaiwaka Point, but this is to be expected as this site is just beyond the Hātea river management unit, where elevated nutrient concentrations have previously been reported (Griffiths 2016, Griffiths 2018). Aurere Estuary and a number of sites in the Kaipara harbour had medians that exceeded the relevant coastal water quality standards.

Concentrations in the Hātea River were particularly high and although they were generally below the coastal water quality standard for the Hātea River management unit, they were typically above concentrations for the tidal creek management unit.

Are nutrient concentrations increasing?

Trend analysis produced some contradictory results, with nutrient concentrations moving in different directions at sites that are relatively close to each other. For example, an increase in dissolved reactive phosphorus was found at Kawakawa River while downstream at Tapu Point concentrations were decreasing.

However, some consistent trends were identified that appear to indicate more widespread changes in nutrient concentrations. In the Kaipara Harbour, increases in total nitrogen concentrations were found at eight sites, providing good evidence that total nitrogen is increasing in the Harbour.

Decreasing trends in total phosphorus were recorded at 17 sites in Whangārei harbour, Bay of Islands and the Kaipara Harbour, providing evidence that widespread decreases have occurred. In contrast decreasing trends in dissolved reactive phosphorus were only found at three sites, with increasing trends found at twelve sites.

Interestingly, at two sites (Te Puna Inlet and Tapu Point) decreasing trends were found for total phosphorus but increasing trends for dissolved reactive phosphorus. In contrast, at Kaiwaka Point total phosphorus was increasing and dissolved reactive phosphorus decreasing.

Some sites are getting worse

Unfortunately, at a couple of sites in the Kaipara Harbour, increases were observed across a number of parameters. At Wahiwaka Creek, increasing concentrations of total phosphorus, total nitrogen, dissolved reactive phosphorus and nitrate-nitrite nitrogen were found. Likewise at Te Kopua, total phosphorus, total nitrogen and dissolved reactive phosphorus were increasing. The increasing trends at Wahiwaka Creek is particularly concerning as concentrations of nutrients at this site are already elevated.

4.8 Metals

Metal concentrations were generally low, with the majority of concentrations below the laboratory detection limits. The coastal water quality standards set a maximum concentration that all samples must not exceed. Twenty-one sites had at least one sample that exceeded the standard for zinc and 37 sites had at least one sample that exceeded the standard for copper. Most sites recorded a relatively small number of exceedances, in absolute and percentage terms. However more than 50% of copper concentrations at Hargreaves Basin, Wahiwaka Creek, Wairoa River, Burgess Island, Kissing Point, Limeburners Creek, Town Basin and Waiarohia were above the standard. At Wairoa River, Limeburners Creek and Waiarohia more than 20% of samples also exceeded the standard for zinc. This data indicates there is the potential for toxic affects at some sites in the Kaipara Harbour and the Hātea River.

4.9 Where are the water quality issues?

4.9.1 Aurere Estuary

A number of parameters, including faecal indicator bacteria, nutrient concentrations and metal contaminants exceeded the coastal water quality standards at Aurere Estuary (Table 19). Both faecal coliforms and enterococci exceeded the coastal water quality standard indicating that the estuary is not suitable for contact recreation or shellfish consumption. Total nitrogen, ammoniacal nitrogen, total phosphorus and dissolved reactive phosphorus also exceeded the coastal water quality standards and some exceptional high concentrations were recorded after rain events. There is a risk these elevated nutrient concentrations contributes to excessive growth of phytoplankton or macroalgae in the estuary. The nutrient concentrations in the estuary will also contribute to nutrient enrichment in Doubtless Bay and large quantities of macroalgae have been observed near the entrance of the Estuary (Plate 4).

Table 19. Turbidity, faecal indicator bacteria and nutrient concentrations collected from Aurere Estuary, 2018-2020.

	n	Min	Max	Median	Standard	Standard achieved
Enterococci (CFU/100mL)	30	<10	4600	25	*90th %ile	×
Faecal coliforms	31	<10	34000	54	≤14	×
Turbidity (FNU)	30	1.69	134	6.71	<6.9	✓
Total nitrogen (mg/L)	31	0.10	1.60	0.28	<0.22	×
NH4 (mg/L)	31	0.014	0.210	0.059	<0.023	×
NNN (mg/L)	31	0.002	0.210	0.030	<0.048	✓
Total phosphorus (mg/L)	31	0.016	0.250	0.041	<0.030	×
Dissolved reactive phosphorus	31	0.006	0.077	0.025	<0.017	×

Plate 4. Algae observed outside the mouth of Aurere Estuary in Doubtless Bay, April 2021.

What's the cause of the problem?

Aurere Estuary has been classified by Hume *et al.* (2006) as a tidal river. Tidal rivers are elongate, narrow, shallow basins where river flow delivered during a tidal cycle is a significant proportion of the basins volume and greater than the tidal volume entering. Salinity at Aurere Estuary ranged from zero to 35.70, highlighting that on ebb tide the system is effectively and extension of the Aurere Stream with no dilution occurring. Conversely on a flood tide, oceanic water fills the estuary and water quality was generally very good, with the lowest concentrations of contaminants recorded when salinity was above 34.

However, water quality is not always bad on ebb tides, with rainfall an important factor impacting water quality. This is demonstrated by the water quality results collected for the two lowest salinities. In February 2020, no rainfall had fallen in preceding 72 hours while in October 2020, 45mm had fallen in 72 hours. In February most parameters were below the relevant water quality standards while in October all parameters were above the relevant standards (Table 20). Correlation analysis also highlighted the influence of rainfall, for some parameters, with enterococci, faecal coliforms and turbidity all strongly correlated to rainfall (Appendix F).

Table 20. Water quality at Aurere Estuary for the two lowest salinities.

Date	Salinity	Rainfall	FC	Turb	TN	NH_4	TP	DRP	Cu	Zn
12/02/2020	0.00	0mm	42	6.54	0.17	0.014	0.023	0.025	<0.001	<0.002
14/10/2020	0.65	35mm	32000	134	1.2	0.08	0.18	0.031	0.0047	0.015

The land cover in the catchment is predominantly exotic grassland for agriculture and there are several point sources discharges in the catchment, including farm dairy effluent discahrges and the Taipa wastewater treatment plant (Figure 12). The Taipa wastewater treatment plant has a consent authorising the discharge of treated municipal wastewater to an unnamed tributary of Te Wai o Te Parapara Stream and there have been ongoing water quality issues relating to the discharge.

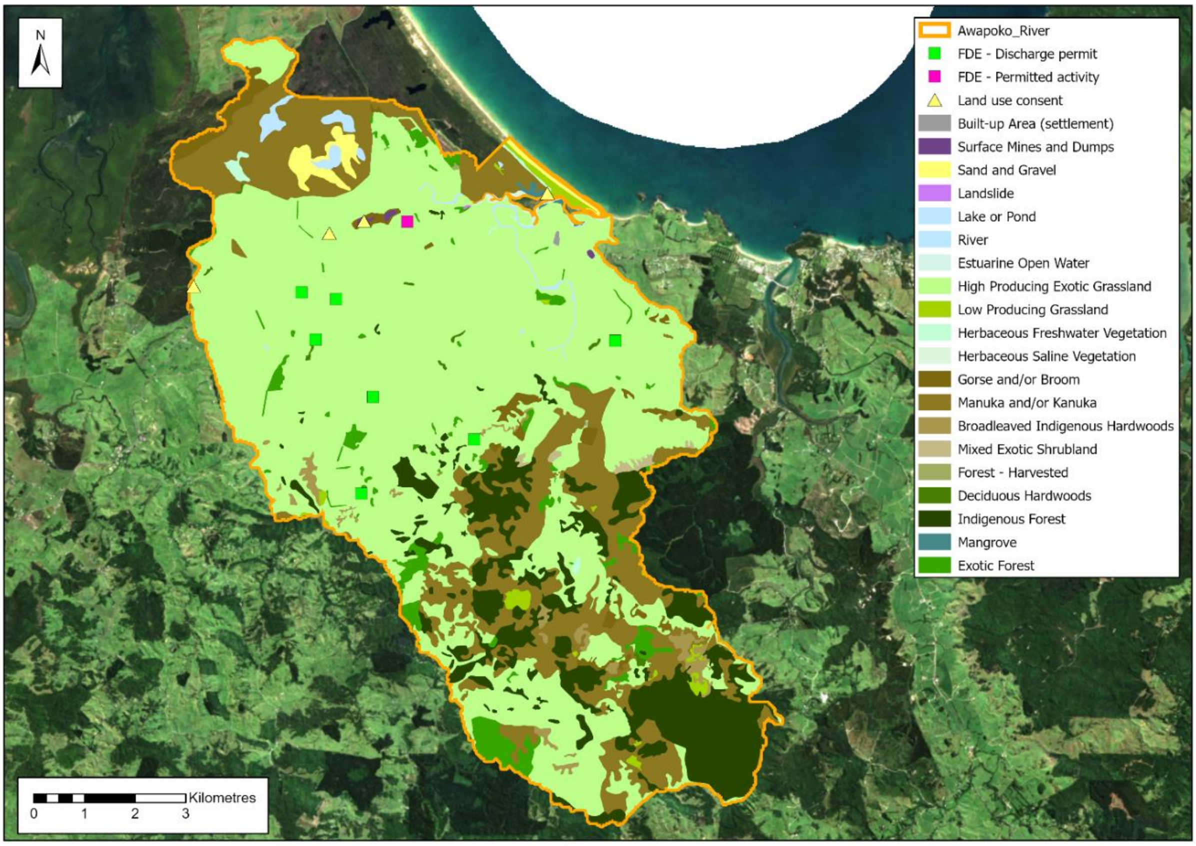

Figure 12. Land cover in the Aurere catchment and discharge permits.

4.9.2 Hātea River

Water quality at all five sites in the Hātea River management unit was particularly poor. Concentrations of faecal indicator bacteria were particularly high and enterococci concentrations exceeded the Hātea River standard of 500 CFU/100mL at all five sites. Although the River is not used for swimming it is popular for secondary recreation, including rowing, paddle boarding and waka ama.

Nutrient concentrations were high relative to other coastal water bodies in the Northland Region and although the water quality standards were achieved for some parameters, this needs to be viewed in the context of the much lower standards applied in this management unit. The Hātea River is a tidal creek but was classified as its own management unit in the Proposed Regional Plan, after it was identified as a Condition 3 (highly disturbed) ecosystem. Condition 3 ecosystems are ecosystems that are measurably degraded ecosystems of lower ecological value, as per the ANZECC 2000 classification for ecosystem condition. If the water quality results were assessed against the tidal creek standards, most parameters would exceed the standards at all five sites (Table 21).

Table 21. Median nutrient concentrations in the Hātea River, assessed against the tidal creek coastal water quality standard.

	Total nitrogen (mg/L)	Total ammoniacal nitrogen (mg/L)	Nitrate-nitrite nitrogen (mg/L)	Total phosphorus (mg/L)	Dissolved reactive phosphorus (mg/L)
Tidal creek standard	<0.600	<0.043	<0.218	<0.040	<0.021*
Town Basin	0.79	0.077	0.470	0.074	0.056
Waiarohia	0.82	0.100	0.500	0.110	0.086
Limeburners	0.70	0.089	0.370	0.100	0.070
Kissing Point	0.42	0.060	0.210	0.058	0.046
Lower Hātea River	0.35	0.046	0.100	0.044	0.032

*From Griffiths (2016)

Dissolved oxygen concentrations also dropped below the minimum standard at the Town Basin, Waiharohia and Limeburners Creek, and of particular concern are the extended periods of low dissolved oxygen concentrations measured during summer months. These extended periods of low dissolved oxygen are likely to be physiologically stressful and potentially lethal to some aquatic organisms (Vaquer-Sunyer & Duarte 2008). Concentrations of metal contaminants also exceeded the coastal standards and there is the potential for toxic effects in the Hātea River.

What's the cause of the problem?

The Hātea River is a tidal creek which flows through the city of Whangārei (Plate 5). Land cover in the catchment, has a relatively high proportion of urban use (19%) covering the catchment, with high producing grassland covering 29% and indigenous forest covering a further 26% (Figure 13). It receives road run-off and stormwater from Whangārei city and is the receiving environment for the Whangārei wastewater treatment plant and a number of industrial discharges. There is also a relatively high number of domestic on-site systems in the catchment (38). Much of the saltmarsh and mangrove habitat that would have flanked the river has been drained and reclaimed for urban and industrial land use and the shoreline has been significantly modified. There is also a marina at the Town Basin, a large mooring area at Kissing point and several boat maintenance facilities in the Hātea River.

Plate 5. Confluence of the Waiarohia Canal and Hātea River, Whangārei (the Town Basin marina and mooring area is visible to the right of photograph).

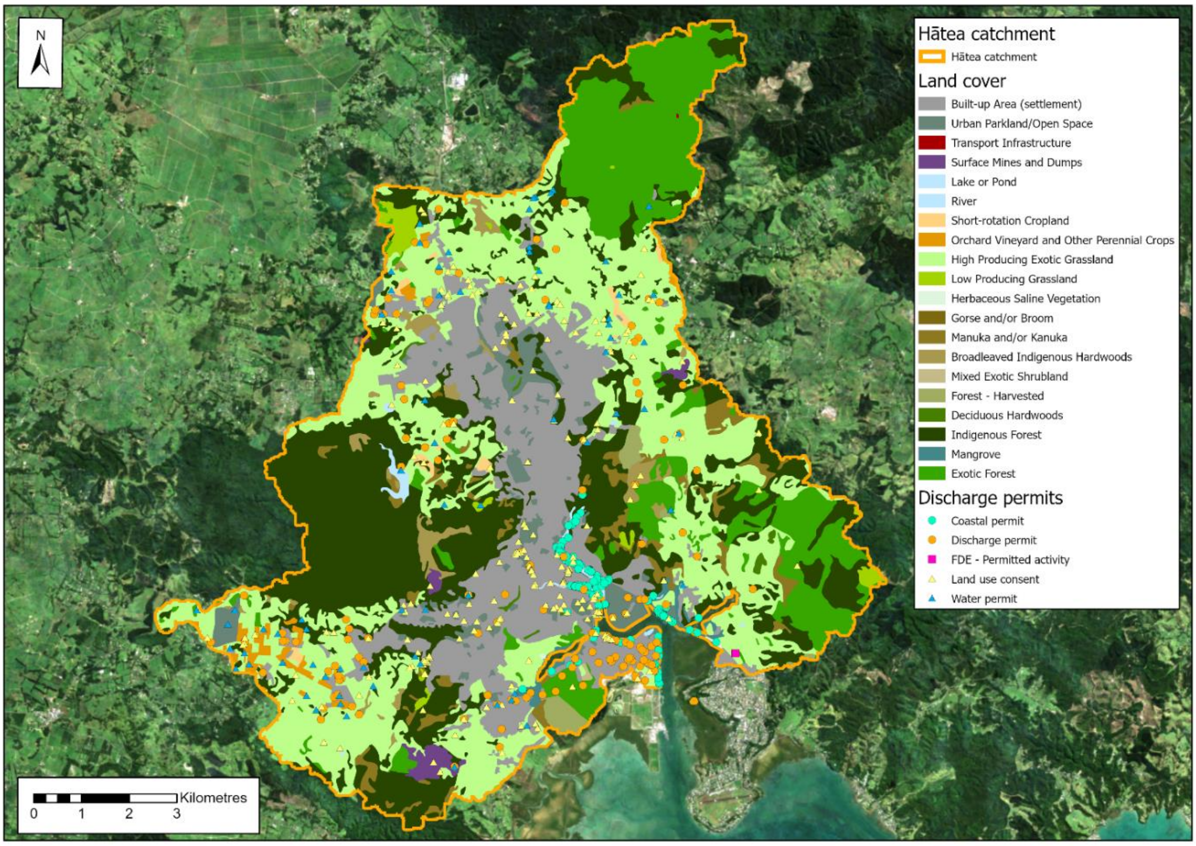

Figure 13. Land cover in the Hātea catchment and discharge permits.

Water quality improves rapidly beyond the Hātea River

Despite the poor water quality in the Hātea River it is noticeable that water quality clearly improves as you move down the Hātea River management unit towards the 'boundary' with the estuarine management of the harbour. Median concentrations of contaminants at the Lower Hātea River site are typically 50% lower that concentrations recorded at Town Basin, Waiharohia and Limeburners, indicating that significant dilution occurs within the management unit.

Despite the poor water quality in the Hātea River unit, water quality at other sites in the Whangārei Harbour is generally good. Water quality at Kaiwaka Point, in the estuarine management unit, immediately downstream of the 'boundary' with the Hātea River is not noticeably worse than other estuarine sites, and enterococci, faecal coliforms, dissolved oxygen, turbidity, total phosphorus, nitrate-nitrite nitrogen, and total zinc all achieved the coastal water quality standards at this site. Towards the entrance of the estuary, water quality at Tamaterau and One tree point is very good. The presence of extensive intertidal and subtidal seagrass beds and dense shellfish beds in the outer harbour also indicates that water quality is good (Griffiths and Eyre, 2014).

4.9.3 Kaipara Harbour

Turbidity and concentrations of nutrients were elevated at sites in the Kaipara Harbour compared to sites in other drowned valley systems such as Whangārei Harbour, Te Puna Inlet and the Ōpua inlet system. Significantly, the only sites that did not achieve the coastal water quality standard for turbidity were in the Kaipara Harbour. The median turbidity at Wairoa River of 27 FNU is almost three times the turbidity standard for tidal creeks (10.8 FNU) and the median turbidity at Hargreaves basin (25.2 FNU) is almost four times the coastal water quality standard for the estuary management unit. In the Wairoa River there is a significant issue caused by sediment laden water from the vast northern Wairoa catchment (Plate 6). At Hargreaves Basin, and other sites within the Kaipara Harbour sediment laden water from the catchment is still a contributing factor but algae also contribute to high turbidity. Chlorophyll-*a* and nutrient concentrations are also elevated in the Kaipara Harbour and noticeably higher than at sites in similar estuarine systems like Whangārei Harbour and the Bay of Islands.

Plate 6. Sediment laden water from the Kaihu River and Northern Wairoa River at Dargaville.

Wairoa River

Water quality at the Wairoa River is particularly poor with water quality standards exceeded for almost all parameters (Table 22). Water clarity is also a significant issue with sediment laden water clearly visible at this site (Plate 2).

Table 22. Turbidity and nutrient concentrations collected from Wairoa River in 2020.

	n	Minimum	Maximum	Median	Standard achieved
Turbidity (FNU)	11	7.31	192	27.1	×
Total nitrogen (mg/L)	11	0.17	1.40	0.84	×
Ammoniacal nitrogen (mg/L)	11	0.011	0.093	0.053	×
Nitrate-nitrite nitrogen (mg/L)	11	0.0059	0.88	0.43	×
Total phosphorus (mg/L)	11	0.04	0.240	0.059	×
Dissolved reactive phosphorus (mg/L)	11	0.013	0.046	0.029	×

What's the cause of the problem?

This site is located in the Wairoa River, between Raupo and Tikinui, where the channel is still relatively narrow (700m). The channel starts to widen downstream of the site and is approximately 2km wide when it reaches Burgess Island and the main body of the Harbour. The site has a median salinity of just 13.76 and is heavily influenced by freshwater inputs from the vast northern Wairoa River catchment. The land use in the catchment is predominantly exotic grass land for agriculture and there are a number of point source discharges in the catchment, predominantly from farm dairy effluent. There is a wastewater treatment plant at Dargaville, where wastewater is irrigated to land adjacent to the river; and under normal operations there should not be any direct discharges to the Wairoa River however this remains a potentially significant source of nutrients to the site.

Wahiwaka Creek

The Wahiwaka Creek is another site where water quality is of concern. Water quality standards were exceeded for enterococci, total phosphorus, dissolved reactive phosphorus, dissolved oxygen, copper and zinc. Trend analyses also indicate that water quality is deteriorating rapidly at this site (Table 23).

Table 23. Faecal indicator bacteria and nutrient concentrations collected from Wahiwaka Creek in 2020.

	n	Min	Max	Median	Standard achieved	Trend
Enterococci (CFU/100mL)	11	<10	1300	74*	✗	⇧ 11%
Total nitrogen (mg/L)	11	0.220	1.600	0.460	✓	⇧ 8.97%
Ammoniacal nitrogen (mg/L)	11	<0.005	0.130	0.039	✓	⬄ -1.71%
Nitrate-nitrite nitrogen (mg/L)	11	0.024	0.930	0.081	✓	⇧ 7.42%
Total phosphorus (mg/L)	11	0.034	0.100	0.061	✗	⇧ 1.55%
Dissolved reactive phosphorus (mg/L)	11	0.028	0.083	0.043	✗	⇧ 3.48%
Dissolved oxygen (mg/L)	11	4.3	9.1	7.0	✗	⇩ 1.13%

* Compliance metric is the 95th percentile. The 95th percentile at Wahiwaka Creek was 945 per 100mL.

What's the cause of the problem?

Wahiwaka Creek is located in the upper reaches of the Otamatea channel, just below the confluence of the Wairau River and Kaiwaka River. Land cover in the Otamatea catchment is predominantly exotic grassland for agriculture (77%) and there are a number of point source discharges in the catchment, including farm dairy effluent discharges, two wastewater treatment plants, discharges associated with a milk process factory and discharges of stormwater and treated concrete process wastewater (Figure 14).

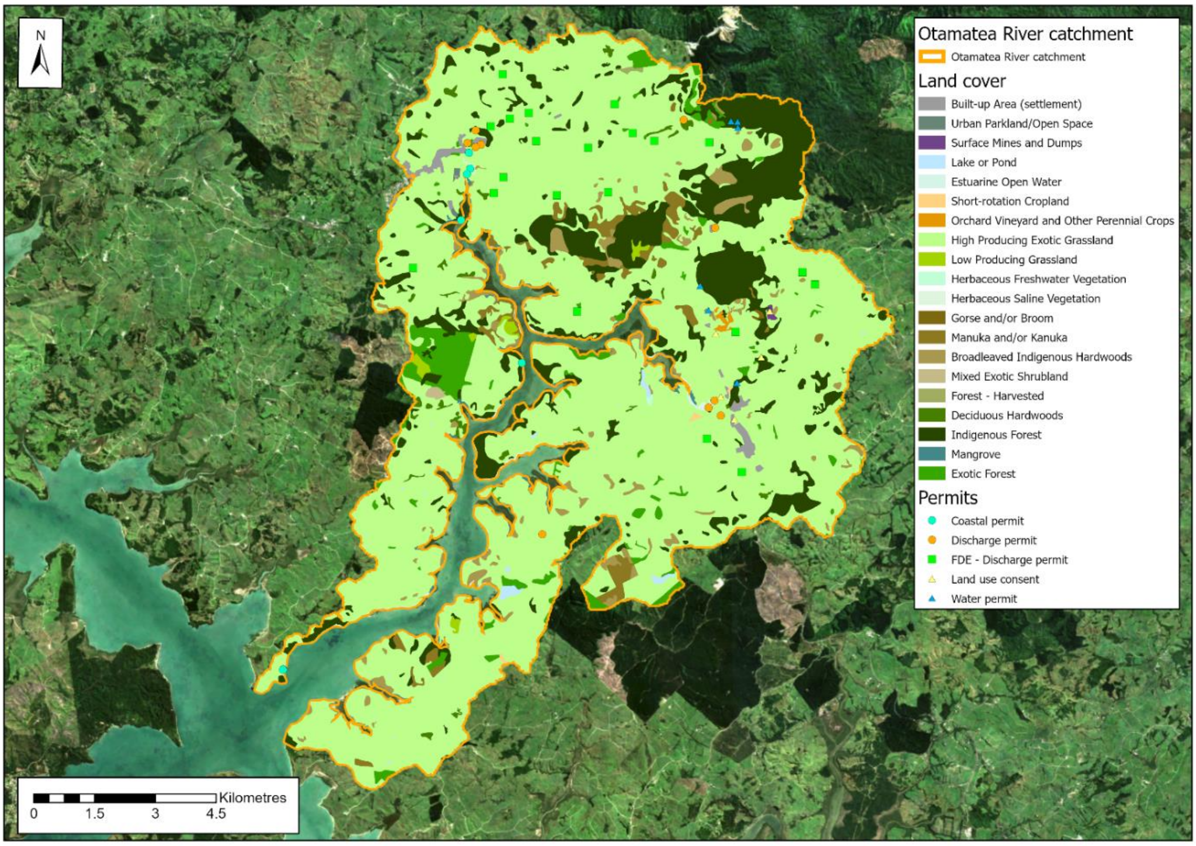

Figure 14. Land cover and permits in the Otamatea catchment.

Hargreaves Basin

Water quality at Hargreaves Basin is also poor. Although water quality standards were achieved for faecal indicator bacteria, indicating that the water is suitable for contact recreation, the standards for turbidity, chlorophyll-*a,* some nutrients, copper and zinc were exceeded. Trend analyses also indicates that total nitrogen concentrations are increasing, and that dissolved oxygen is decreasing (Table 24).

Table 24. Faecal indicator bacteria and nutrient concentrations collected from Hargreaves Basin in 2020.

	n	Min	Max	Median	Standard achieved	Trend
Enterococci (CFU/100mL)	11	<10	52	<10*	✓	**
Turbidity (FNU)	11	5.19	41.8	25.2	×	**
Chlorophyll-*a* (mg/L)	11	0.0014	0.0150	0.0042	×	⇩ -1.91%
Total nitrogen (mg/L)	11	0.11	0.59	0.32	×	⇧ 8.57%
Ammoniacal nitrogen (mg/L)	11	<0.005	0.077	0.023	×	**
Nitrate-nitrite nitrogen (mg/L)	11	<0.002	0.29	0.005	✓	**
Total phosphorus (mg/L)	11	0.029	0.091	0.049	×	⇩ -1.95%
Dissolved reactive phosphorus (mg/L)	11	0.017	0.044	0.027	×	⇔ 0.0%
Dissolved oxygen (mg/L)	11	6.2	9.2	7.5	✓	⇩ -0.21%

* Compliance metric is the 95th percentile. The 95th percentile at Hargreaves Basin was 29 per 100mL.
** Insufficient data or >15% censored data

What's the cause of the problem?

The Hargreaves Basin site is located in the middle reaches of the Oruawharo River. The boundary of the Northland Region runs down the middle of the river and the southern portion of the catchment falls within the Auckland Council Region. In the portion of the catchment that falls within the Northland Region, 68% of the catchment is covered by high producing exotic grassland for pasture, 13% by plantation forestry and 9% by indigenous forest. There are ten farm dairy effluent discharges, a discharge from a landfill site, discharges associated with a timber conditioning facility, and an onsite wastewater disposal system for a resort facility in the portion of the catchment within Northland.

4.9.4 Ruakaka Estuary and Waipū Estuary

Waipū Estuary and Ruakaka Estuary have been classified by Hume *et al*. (2016) as tidal Lagoons. Tidal Lagoons are shallow basins with simple shorelines, extensive intertidal areas and narrow entrances to the sea. There are strong reversing tidal current flows through the entrance and despite the narrow entrances there is good flushing as most of the water leaves the estuary on an outgoing tide.   The influence of freshwater inputs on ebb tides and oceanic water on flood tides was clear in the salinity data for these sites. Both sites had significantly larger salinity ranges than other estuarine sites with salinity as low as 0.3 recorded at Ruakaka Estuary and 5.5 at Waipū Estuary.

At both Ruakaka Estuary and Waipū Estuary, freshwater inputs clearly dominate these systems on ebb tides with a number of parameters negatively correlated to salinity (Figure 15-17, Appendix F). As a result, water quality was noticeably more variable than at other estuarine sites.

Enterococci and faecal coliforms concentrations both exceeded the standard at both sites and indicate that the water is not suitable for contact recreation of shellfish gathering. High nutrient concentrations were also recorded on ebb tides and dissolved reactive phosphorus concentrations exceeded the standard at Ruakaka Estuary and ammoniacal nitrogen exceeded the standard at Waipū Estuary.

There is a risk that these elevated nutrient concentrations contribute to excessive growth of phytoplankton or macroalgae in the estuaries and nuisance quantities of macroalgae have been reported in both estuaries. In March 2021, a particularly large quantity of nuisance algae was reported in Waipū Cove and as the algae started to die, microbial decomposition appears to have caused a rapid decrease in oxygen, which caused mortality to other plants and animals (Plate 7).

The nutrient concentrations in both estuaries will also contribute to nutrient concentrations in Bream Bay and there have been several large depositional events of macroalgae (Plate 8) in recent years that have resulted in a number of negative impacts including curtailing access to the beach and water for recreation, and producing unpleasant odours (Nelson, 2018).

Plate 7. Nuisance macroalgae in Waipū Estuary, March 2021.

Plate 8. Nuisance algae at Waipū Cove, 2010.

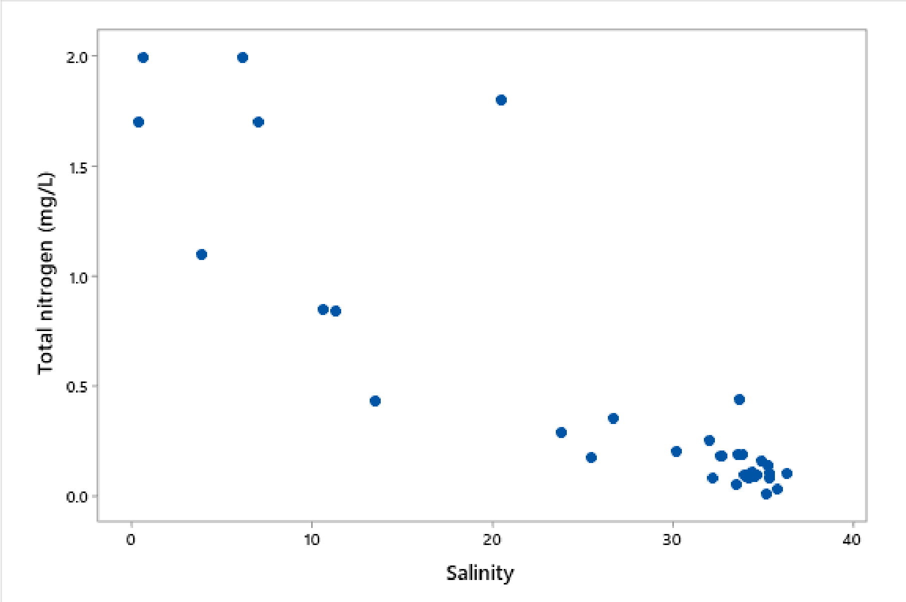

Figure 15. Salinity and total nitrogen concentrations at Ruakaka Estuary, 2018-2020.

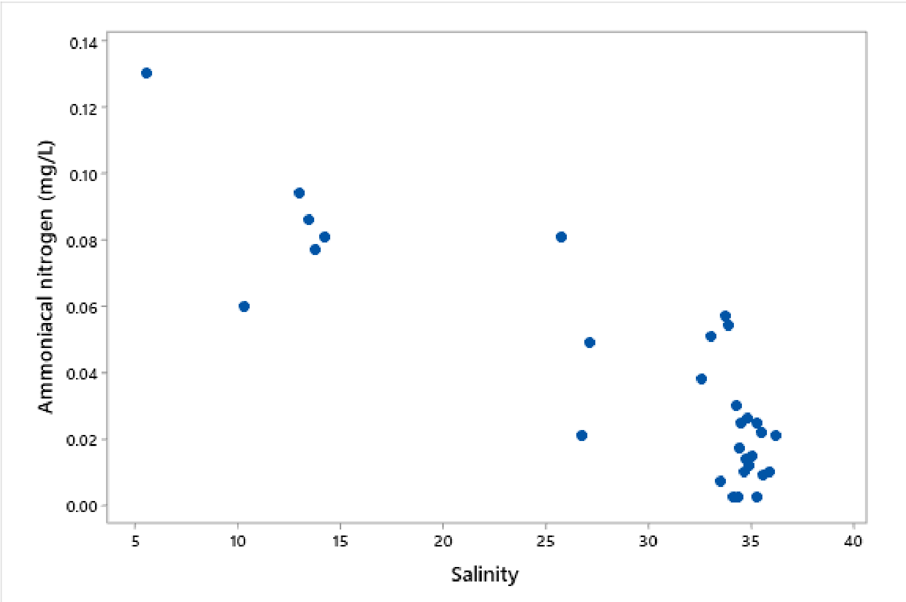

Figure 16. Salinity and ammoniacal nitrogen at Waipū Estuary, 2018-2020.

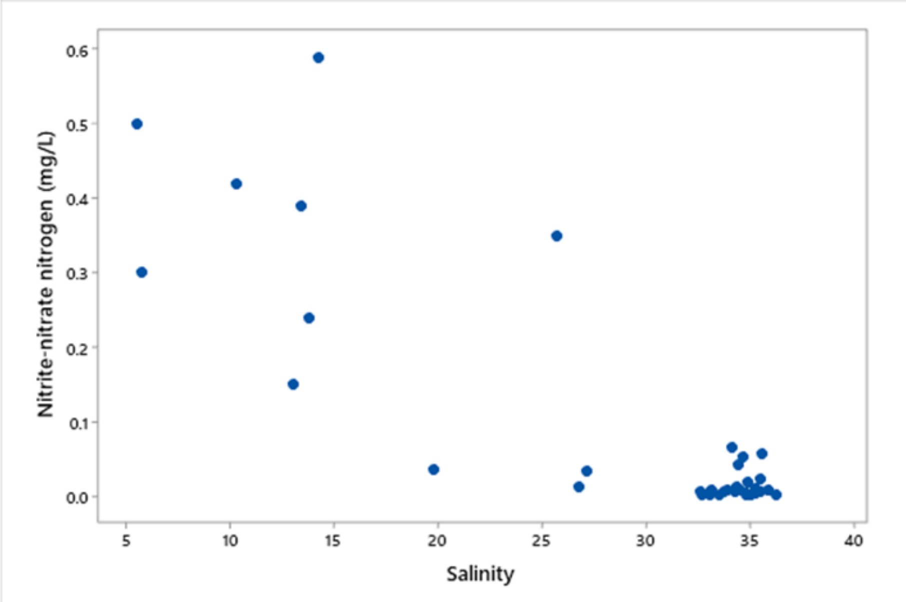

Figure 17. Salinity and nitrate-nitrite nitrogen at Waipū Estuary, 2018-2020.

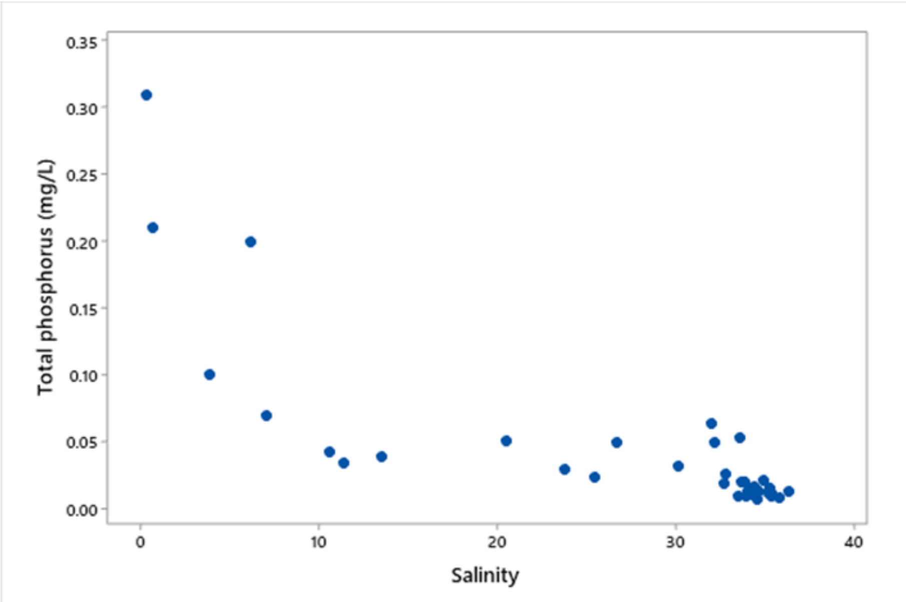

Figure 18. Salinity and total phosphorus at Ruakaka Estuary, 2018-2020.

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6. Acknowledgments

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7. Appendices

Appendix A. Coastal water quality sample sites.

Sample site	Coastal Management Unit	Coastal Hydrosystem	Sample method	Commenced
Brampton Reef	Open coast	n/a	Boat	January 2018
Mangawhai Heads	Open coast	n/a	Shore	May 2017
Waipū Cove	Open coast	n/a	Shore	November 2017
Mair Bank	Open coast	n/a	Boat	March 2008
Aurere Estuary	Estuary	Tidal river	Shore	January 2018
Burgess Island	Estuary	Shallow drowned valley	Boat	May 2009
Doves Bay	Estuary	Shallow drowned valley	Boat	May 2008
Five Fathom Ch	Estuary	Shallow drowned valley	Boat	May 2009
Hargreaves Basin	Estuary	Shallow drowned valley	Boat	May 2009
Kaiwaka Point	Estuary	Shallow drowned valley	Boat	March 2008
Kapua Point	Estuary	Shallow drowned valley	Boat	May 2009
Mangawhai Ramp	Estuary	Tidal lagoon	Shore	October 2016
One Tree Point	Estuary	Shallow drowned valley	Boat	March 2008
Oruawharo River	Estuary	Shallow drowned valley	Boat	May 2009
Paihia	Estuary	Deep drowned valley	Boat	May 2008
Portland Wharf	Estuary	Shallow drowned valley	Boat	March 2008
Ruakaka Estuary	Estuary	Shallow drowned valley	Shore	May 2017
Russell	Estuary	Deep drowned valley	Boat	May 2008
Tamaterau	Estuary	Shallow drowned valley	Boat	March 2008
Tapu Point	Estuary	Deep drowned valley	Boat	May 2008
Te Haumi	Estuary	Deep drowned valley	Boat	May 2008
Te Hoanga Pt	Estuary	Shallow drowned valley	Boat	May 2009
Te Kopua	Estuary	Shallow drowned valley	Boat	May 2009
Te Puna Inlet	Estuary	Deep drowned valley	Boat	May 2008
Tern Point	Estuary	Tidal lagoon	Shore	May 2017
Waikare Inlet	Estuary	Deep drowned valley	Boat	May 2008
Wainui Island	Estuary	Shallow drowned valley*	Boat	May 2008
Waipū Estuary	Estuary	Tidal lagoon	Shore	May 2017
Waipū Lagoon	Estuary	Tidal lagoon	Shore	May 2017
Waitangi River	Estuary	Tidal lagoon*	Boat	May 2008
Insley St	Tidal Creek	Tidal lagoon	Shore	October 2016
Kawakawa River	Tidal Creek	Shallow drowned valley	Boat	May 2008
Kerikeri River	Tidal Creek	Shallow drowned valley*	Boat	May 2008
Mangapai River	Tidal Creek	Shallow drowned valley	Boat	March 2008
Molesworth Dr	Tidal Creek	Tidal lagoon	Shore	October 2016
Otaika Creek	Tidal Creek	Shallow drowned valley	Shore	January 2013
Wahiwaka Cr	Tidal Creek	Shallow drowned valley	Boat	May 2009
Waipapa River	Tidal Creek	Shallow drowned valley*	Boat	May 2008
Wairoa River	Tidal Creek	Shallow drowned valley	Boat	February 2018
Kissing Point	Hātea River	Shallow drowned valley	Boat	March 2008
Limeburners Creek	Hātea River	Shallow drowned valley	Boat	March 2008
Lower Hātea	Hātea River	Shallow drowned valley	Boat	March 2008
Town Basin	Hātea River	Shallow drowned valley	Boat	March 2008
Waiharohia	Hātea River	Shallow drowned valley	Boat	March 2008

Appendix B. Coastal water monitoring programme changes.

Whangārei Harbour

The council has conducted routine water quality monitoring under various programmes in the Whangārei Harbour since 1986. The programmes were reconfigured in 2008 into a Whangārei Harbour water quality programme consisting of 16 sites. In the inner harbour, six sites were located in the channel draining the Hātea River and two sites located in the channel that drains the Mangapai River. A further seven sites were located along the main channel of the harbour. An additional site was added in January 2013, at Otaika Creek, in order to monitor the water quality from this important sub-catchment. Following a review of the coastal network in 2017, five sites were discontinued (Upper Hātea River, Onerahi, Blacksmith Creek, Snake Bank and Marsden Point).

Bay of Islands

In May 2008, council began a routine water quality monitoring programme in the Bay of Islands. Sixteen sites were initially monitored in the Bay of Islands. Five sites were located in and around the Kawakawa River and the Waikare Inlet and five sites are in the Kerikeri Inlet. Sites were also located in the Waitangi Estuary, Te Haumi Estuary and Te Puna Inlet. The remaining sites were located in more exposed outer estuarine locations around Paihia and Russel.

Following a review of the coastal network in 2017, four sites (Ōpua Basin, Windsor Landing, Paihia Southern headland and Paihia Northwest headland) were discontinued, and a new open coast (Brampton Reef) site added to the network.

Kaipara Harbour

In June 2009, council initiated a routine water quality monitoring programme in the Kaipara Harbour in conjunction with Auckland Council. Initially nine sites were sampled in the northern Kaipara, with samples from three sites (Otamatea Channel, Oruawharo River and Hargreaves Basin) collected by Auckland Council via a helicopter. In June 2014 one site near the harbour entrance (Otamatea Channel) was discontinued and from July 2017 sampling of Oruawharo River and Hargreaves Basin was undertaken by Northland Regional Council using a vessel. Following a review of the coastal network in 2017 an additional site was added in the Wairoa River.

Mangawhai Harbour, Waipū Estuary and Ruakaka Estuary

In October 2016, council initiated a water quality programme In Mangawhai Harbour. In May 2017, two sampling sites were added in Waipū Estuary and one in Ruakaka Estuary. Following a review of the coastal water quality network in 2017, two sites (Entrance Beach and Bullet Point Beach) in Mangawhai Harbour were discontinued and a new open coast site created at Waipū Cove Beach.

Aurere Estuary

During the review of the coastal network in 2017 it was identified that there were no coastal water quality sites located in tidal river hydrosystems. A new site was subsequently added to the network in Aurere Estuary as this estuary had previously been sampled for 12 months in 2011 and was more accessible than the other two tidal river systems.

Appendix C. Analysis of catchment land cover.

Table C-1. Land cover in the Mangawhai catchment, from the New Zealand Land Cover Database v5.0 2020. Land cover <1% of total catchment not presented.

Land cover	Area (hectare)	Percentage
High Producing exotic grassland	3884.1	57.2
Indigenous forest	1092.3	16.1
Manuka and/or Kanuka	443.4	6.5
Built-up area (settlement)	353.1	5.2
Exotic forest	188.4	2.8
Sand or gravel	149.2	2.2
Orchard, vineyard or other perennial crop	145.6	2.1
Broadleaved indigenous hardwoods	121.9	1.8
Urban parkland/open space	87.7	1.3
Herbaceous saline vegetation	84.1	1.2
Total	6785.3	

Table C-2. Land cover in the Waipū catchment, from the New Zealand Land Cover Database v5.0 2020. Land cover <1% of total catchment not presented.

Land cover	Area (hectare)	Percentage
High producing exotic grassland	11601.3	51.9
Indigenous forest	5109.8	22.9
Exotic forest	3215.0	14.4
Manuka and/or Kanuka	1045.3	4.7
Broadleaved indigenous hardwoods	430.5	1.9
Forest - harvested	316.9	1.4
Total	22338.5	

Table C-3. Land cover in the Ruakaka catchment, from the New Zealand Land Cover Database v5.0 2020. Land cover <1% of total catchment not presented.

Land cover	Area (hectare)	Percentage
High producing exotic grassland	6036.1	65.8
Indigenous forest	1980.9	21.6
Manuka and/or Kanuka	455.5	5.0
Exotic forest	190.1	2.1
Low producing grassland	127.5	1.4
Built-up area (settlement)	122.4	1.3
Total	9174.4	

Table C-4. Land cover in the Whangārei catchment, from the New Zealand Land Cover Database v5.0 2020. Land cover <1% of total catchment not presented.

Land cover	Area (hectare)	Percentage
High producing exotic grassland	13930.6	47.1
Indigenous forest	6035.5	20.4
Built-up area	3051.3	10.3
Exotic forest	2410.5	8.2
Manuka and/or Kanuka	1645.8	5.6
Urban parkland/open space	524.5	1.8
Broadleaved indigenous hardwoods	465.0	1.6
Orchard, vineyard or other perennial crop	290.9	1.0
Total	29565.7	

Table C-5. Distribution of land use classes in the Kerikeri catchment, from the New Zealand Land Cover Database v5.0 (2020).

Land cover	Area (hectare)	Percentage
High Producing Exotic Grassland	12596.0	59.1
Exotic Forest	2169.0	10.2
Orchard, Vineyard or Other Perennial Crop	1679.5	7.9
Indigenous Forest	1135.7	5.3
Manuka and/or Kanuka	1055.1	4.9
Built-up Area (settlement)	796.2	3.7
Broadleaved Indigenous Hardwoods	599.4	2.8
Herbaceous Freshwater Vegetation	252.0	1.2
Lake or Pond	234.5	1.1
Forest - Harvested	188.7	0.9
Total	21319.8	

Table C-6. Distribution of land use classes in the Te Puna catchment, from the New Zealand Land Cover Database v5.0 (2020). Land cover <5% of total catchment not presented.

Land cover	Area (hectare)	Percentage
High producing exotic grassland	3341.8	70.1
Manuka and/or Kanuka	881.3	18.5
Exotic forest	238.8	5.0
Total	4778.6	

Table C-7. Distribution of land use classes in the Aurere catchment, from the New Zealand Land Cover Database v5.0 (2020).

Land cover	Area (hectare)	Percentage
High Producing Exotic Grassland	5885.7	61.1
Manuka and/or Kanuka	1765.8	18.3
Indigenous Forest	1131.4	11.7
Total	9639.8	

Table C-8. Distribution of land use classes in the Kaipara catchment, from the New Zealand Land Cover Database v5.0 (2020). Land cover <1,500ha not presented.

Land cover	Area (hectare)	Percentage
High Producing Exotic Grassland	274427.0	60.8
Indigenous Forest	66979.7	14.8
Exotic Forest	58270.6	12.9
Manuka and/or Kanuka	13546.9	3.0
Forest - Harvested	10629.2	2.4
Broadleaved Indigenous Hardwoods	6196.4	1.4
Low Producing Grassland	4994.8	1.1
Short-rotation Cropland	3151.0	0.7
Herbaceous Freshwater Vegetation	2327.6	0.5
Orchard, Vineyard or Other Perennial Crop	1511.7	0.3
Total	451204.5	

Appendix D. Box plots of water quality data for each water quality site.

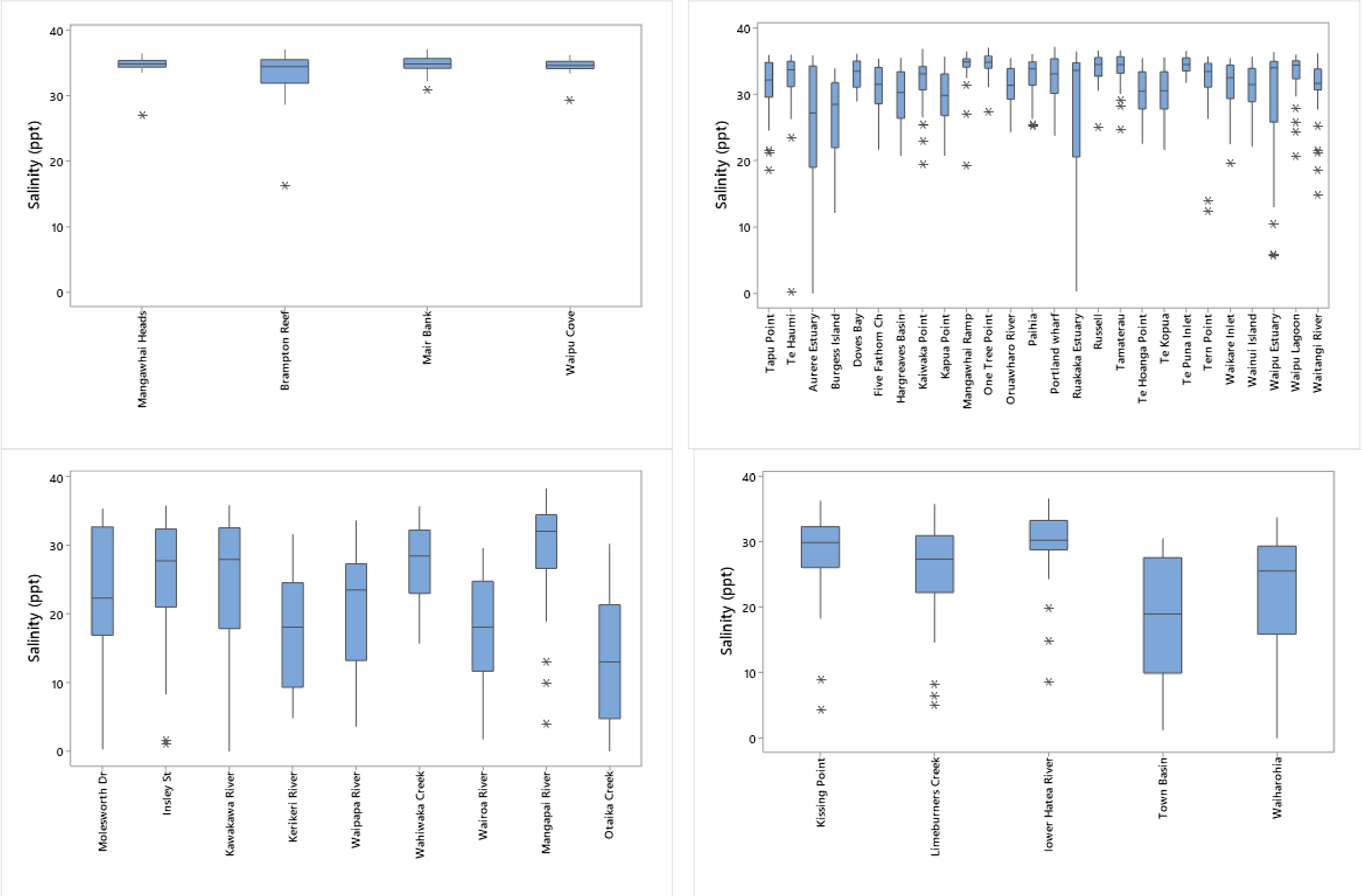

Figure D-1. Salinity of sites open coast, estuarine, tidal creek, & Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

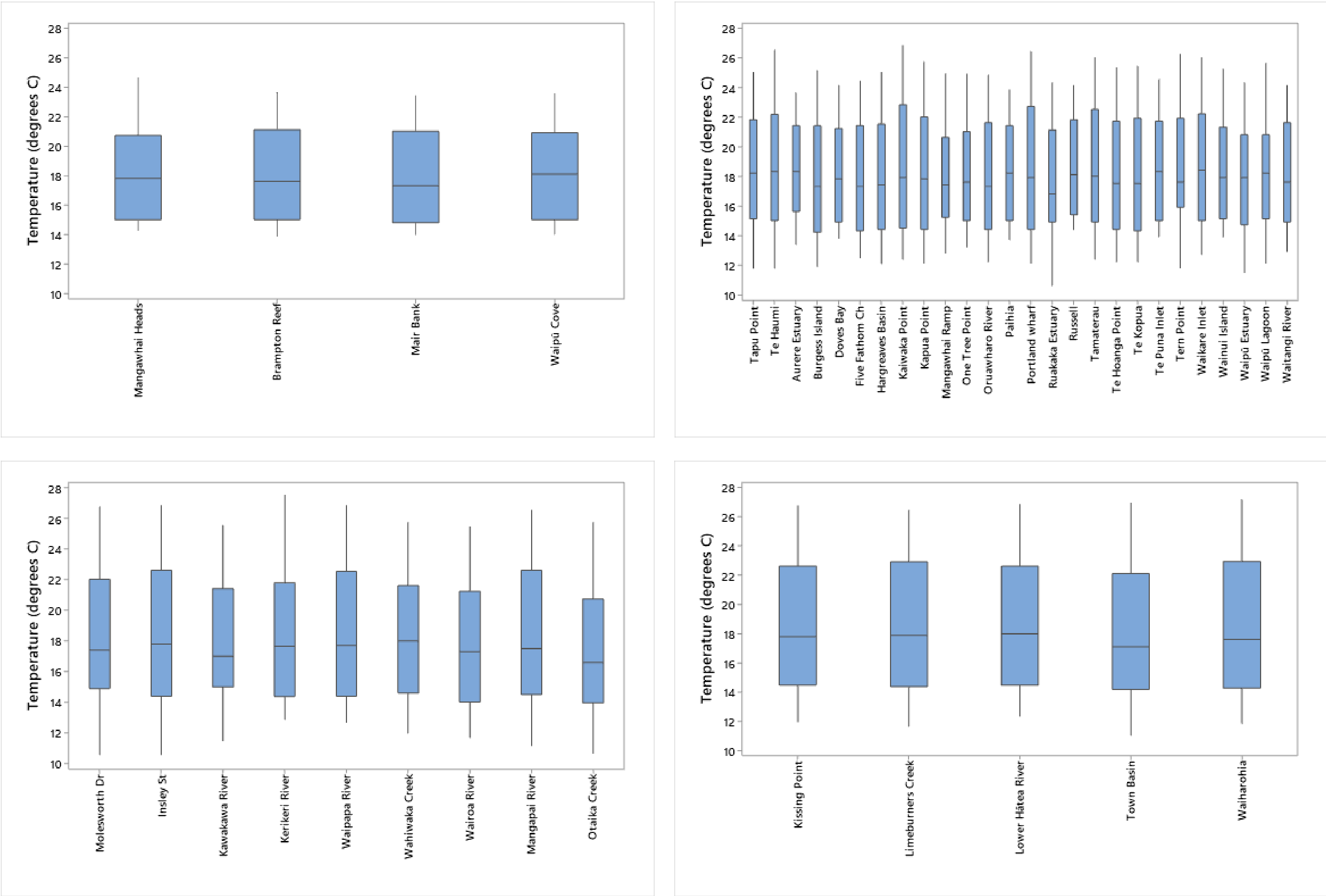

Figure D-2. Temperature at open coast, estuarine, tidal creek, and Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

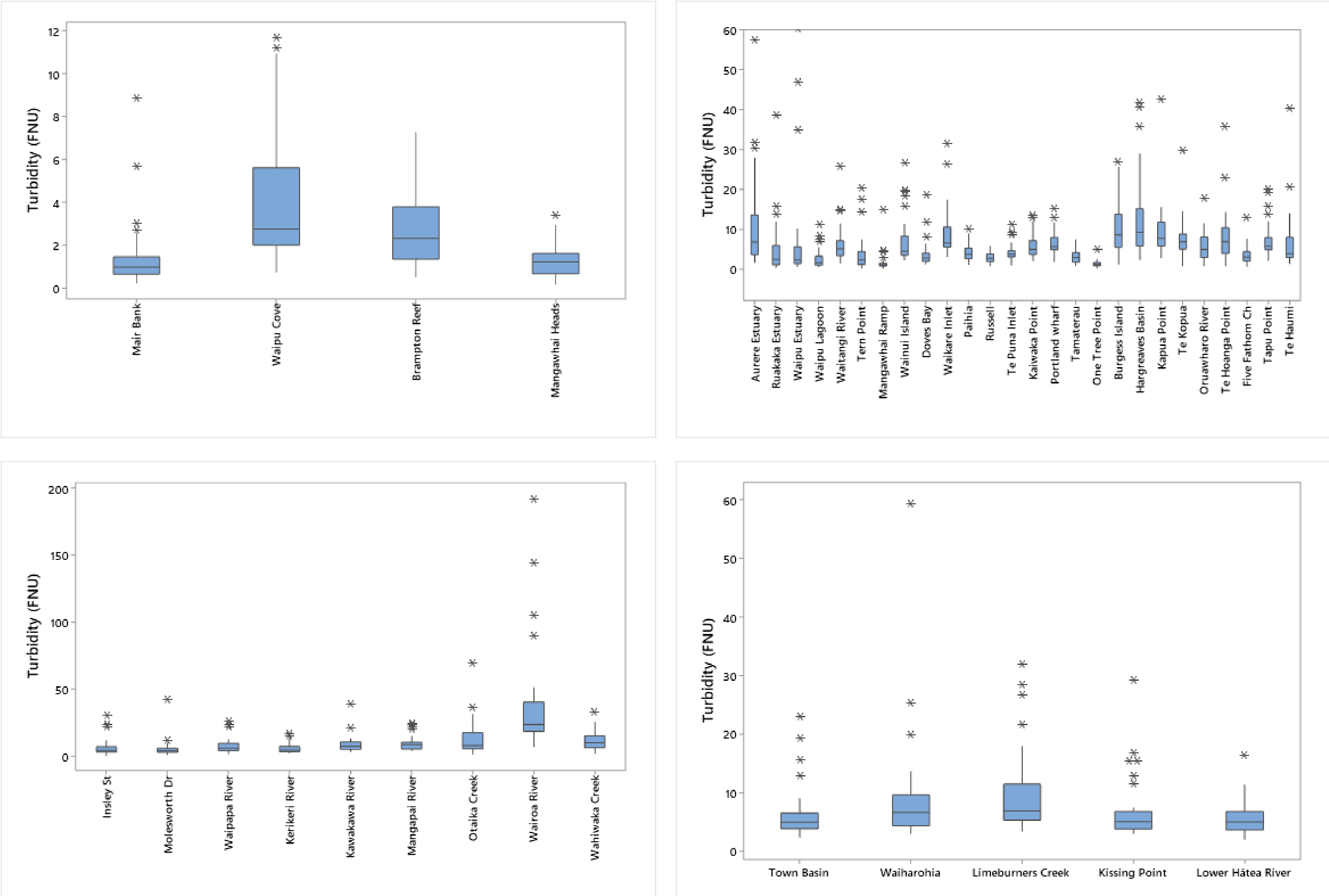

Figure D-3. Turbidity at open coast, estuarine, tidal creek, and Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

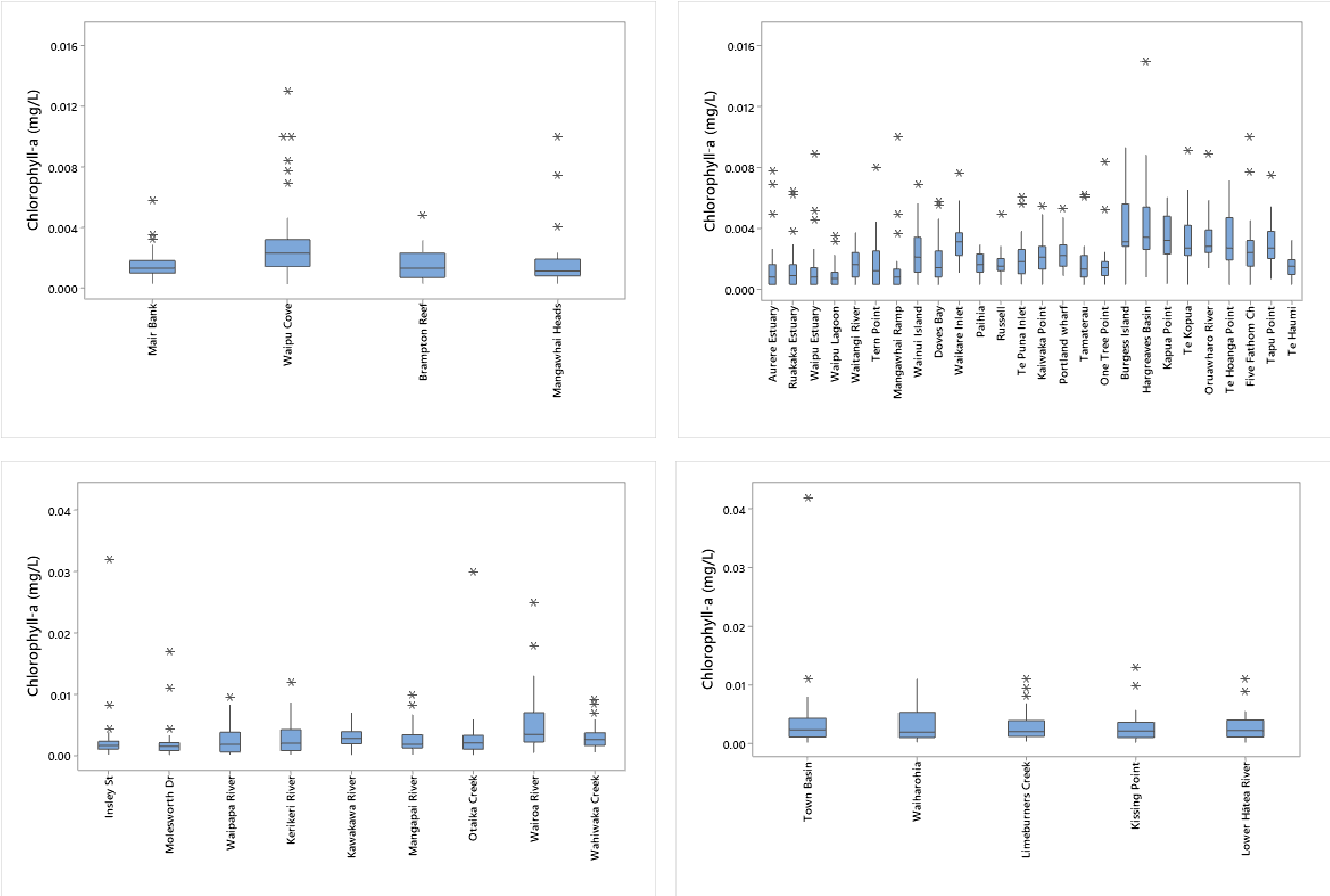

Figure D-4. Chlorophyll-*a* for open coast, estuarine, tidal creek and Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

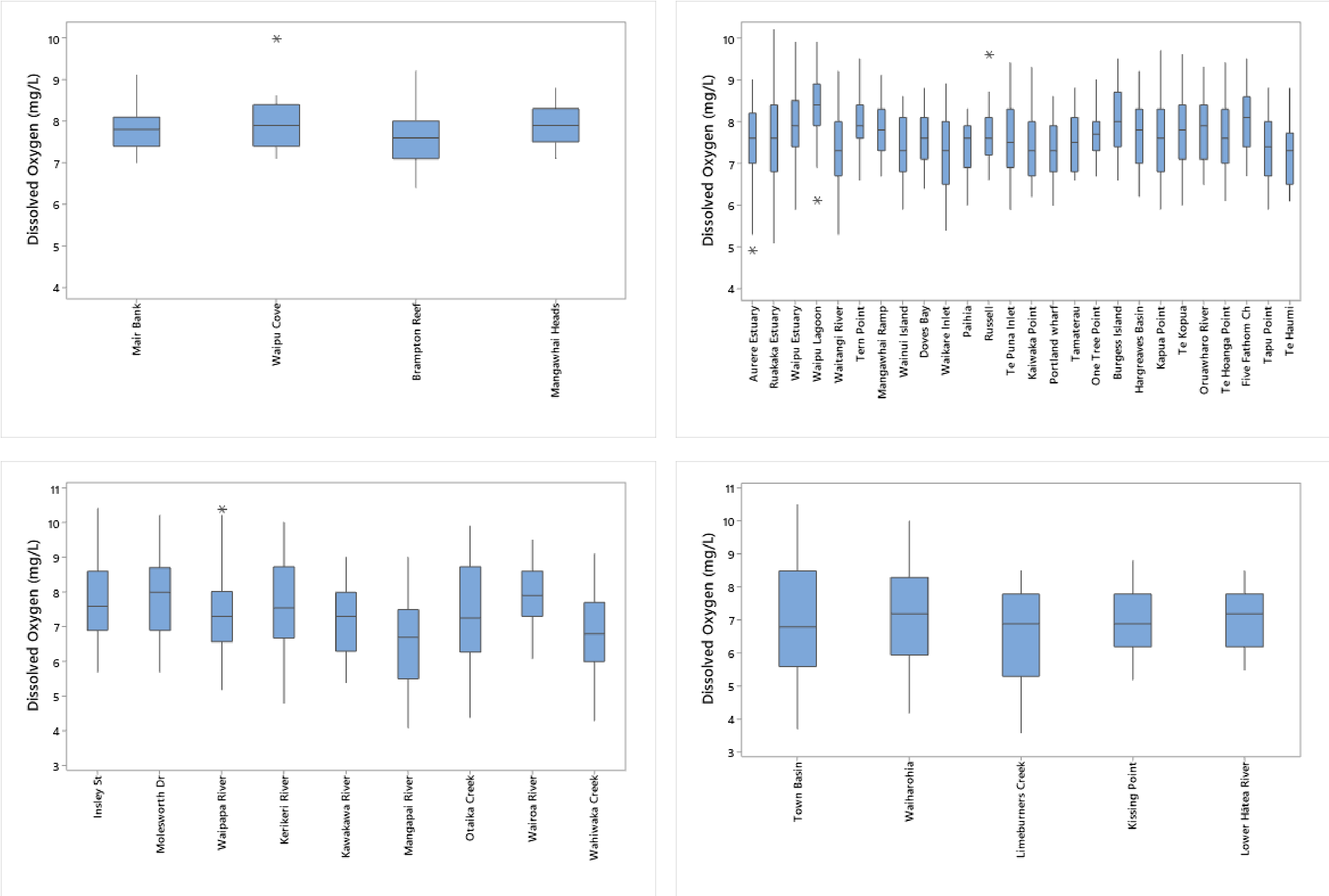

Figure D-5. Dissolved oxygen for open coast, estuarine, tidal creek and Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

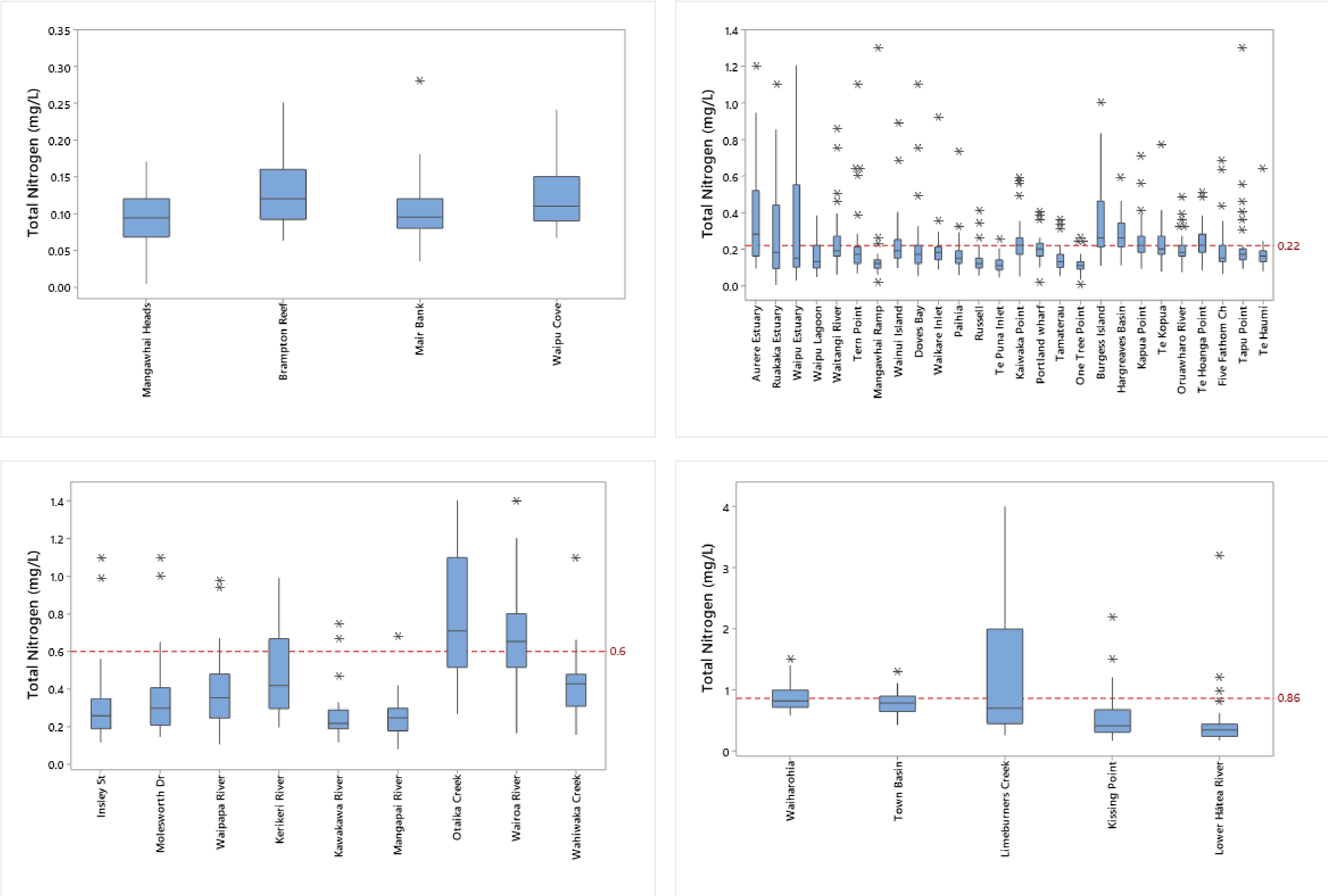

Figure D-6. Total nitrogen for open coast, estuarine, tidal creek and Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

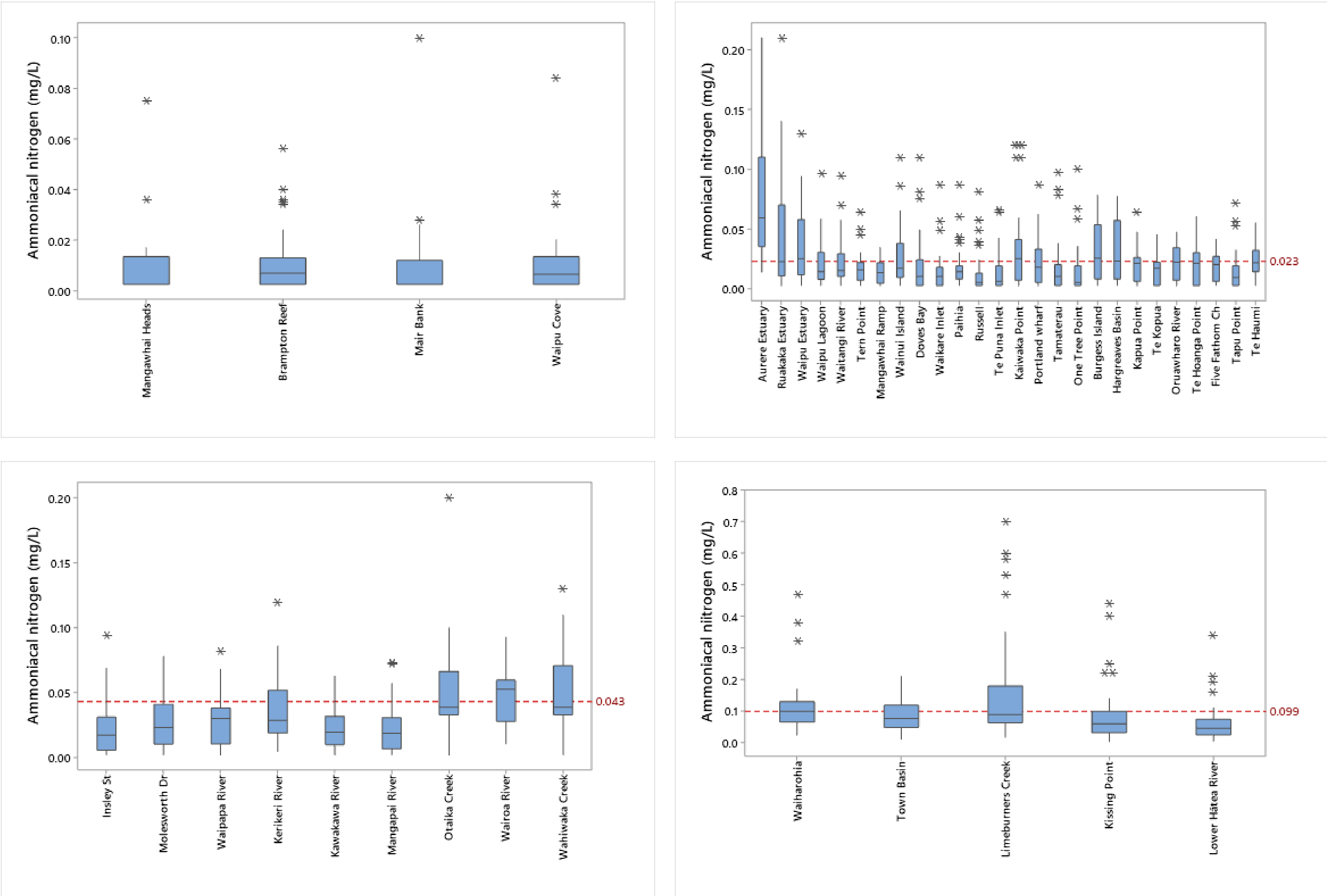

Figure D-7. Ammoniacal nitrogen at open coast, estuarine, tidal creek and Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

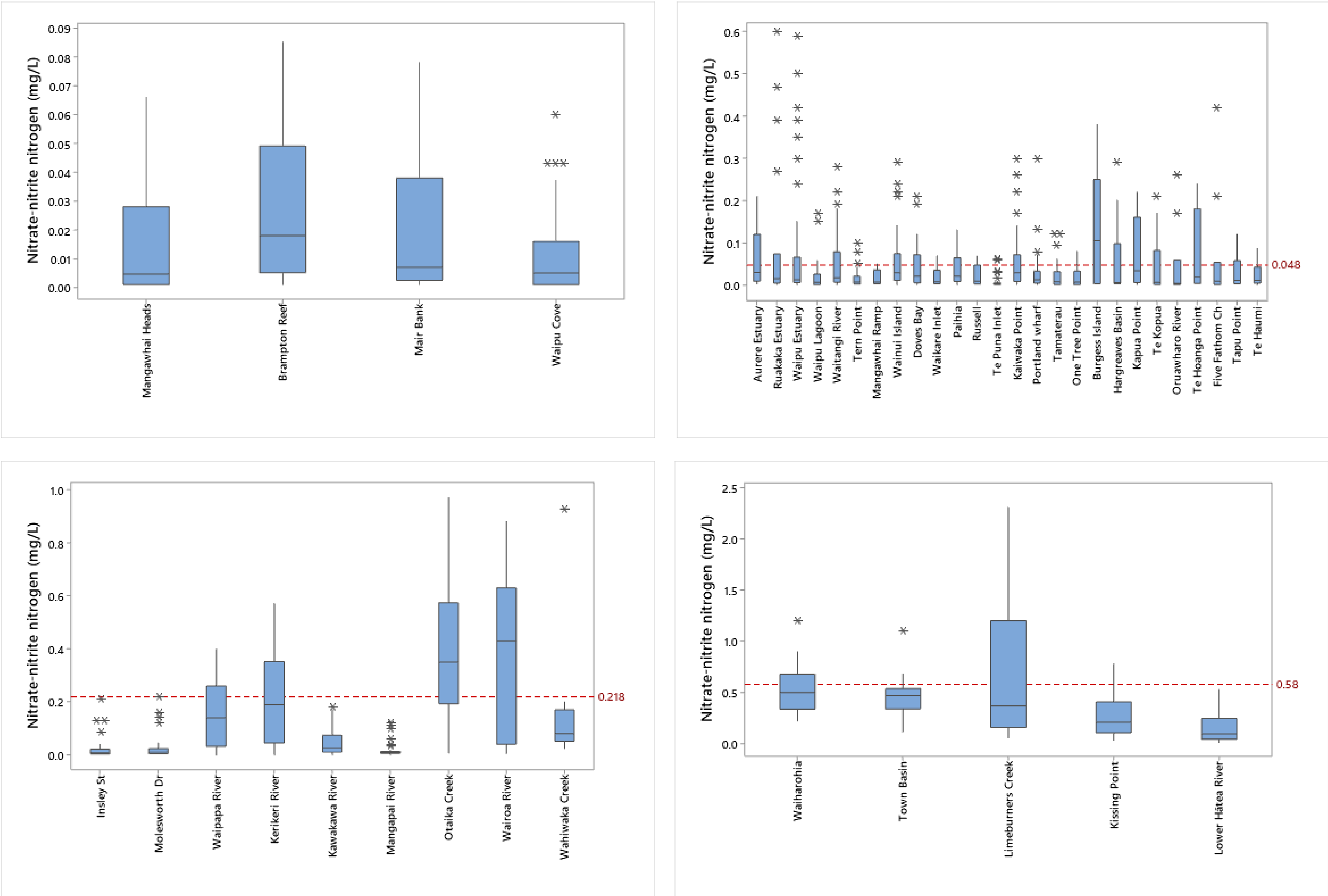

Figure D-8. Nitrate-nitrite nitrogen for sites open coast, estuarine, tidal creek and Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

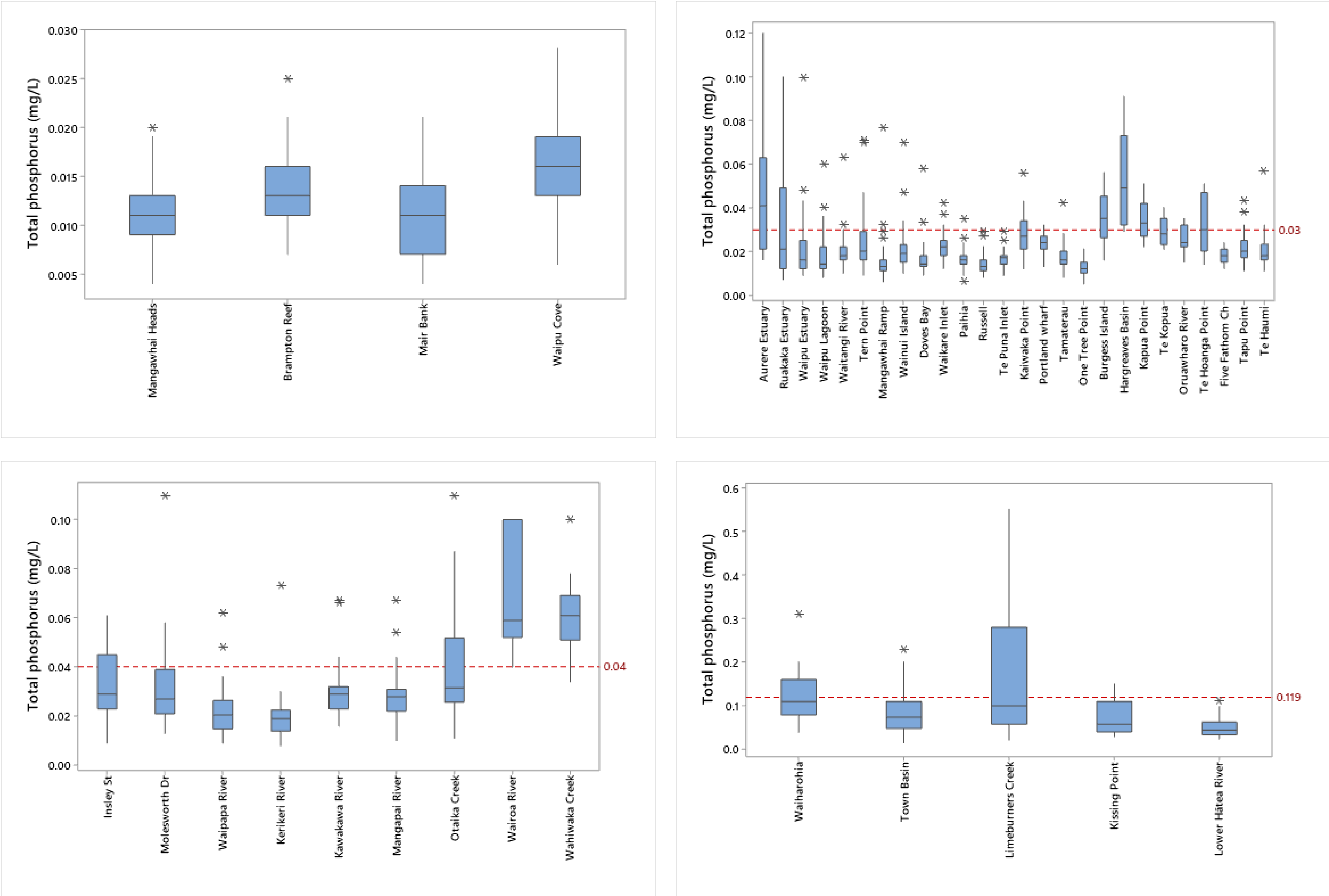

Figure D-9. Total phosphorus concentrations for open coast, estuarine, tidal creek and Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

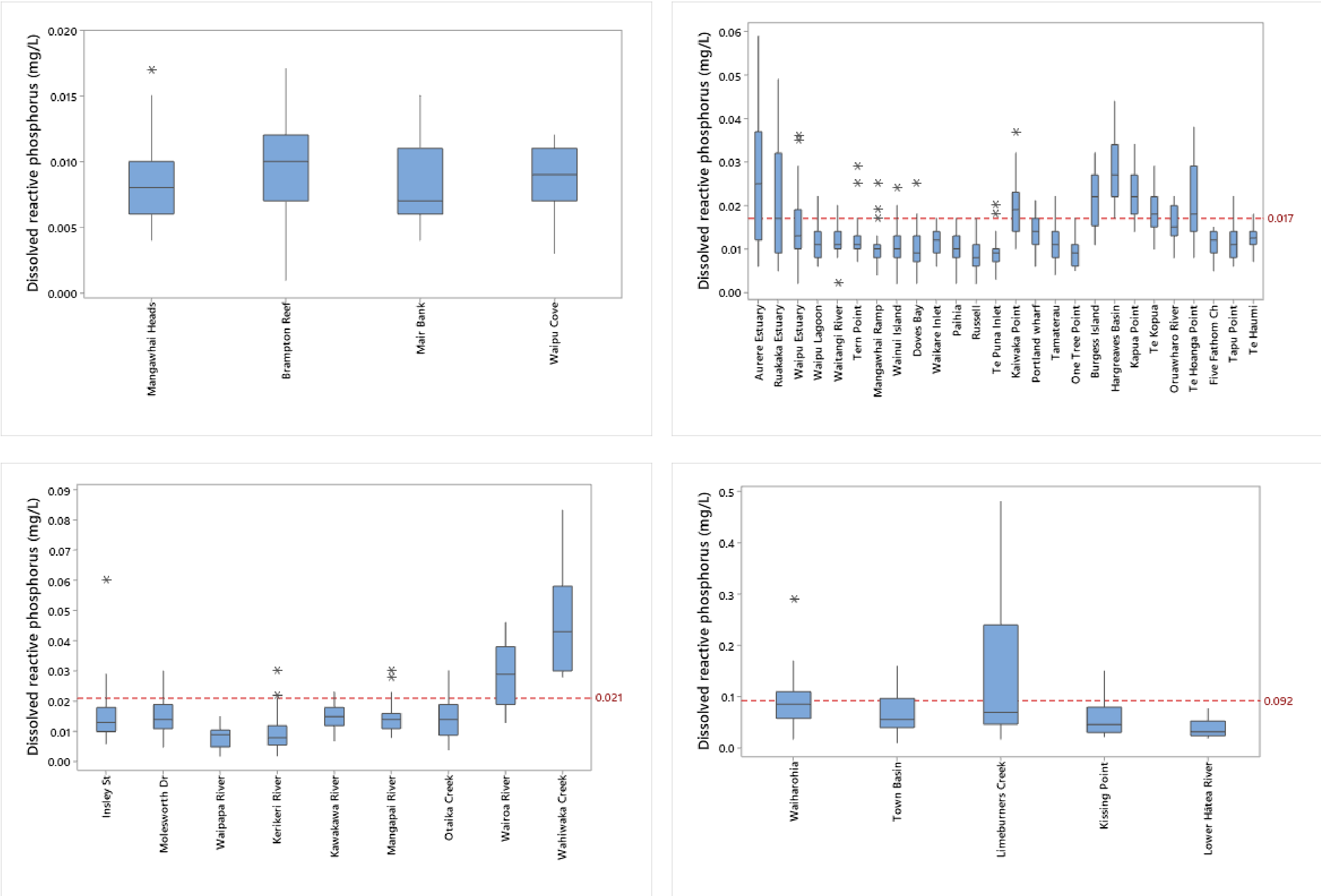

Figure D-10. Dissolved reactive phosphorus concentrations for open coast, estuarine, tidal creek and Hātea River sites. Box plots show distributions for 2018-20, except for sites in the Kaipara (2020).

Appendix E. Box plots of monthly water quality data, grouped by water quality management unit.

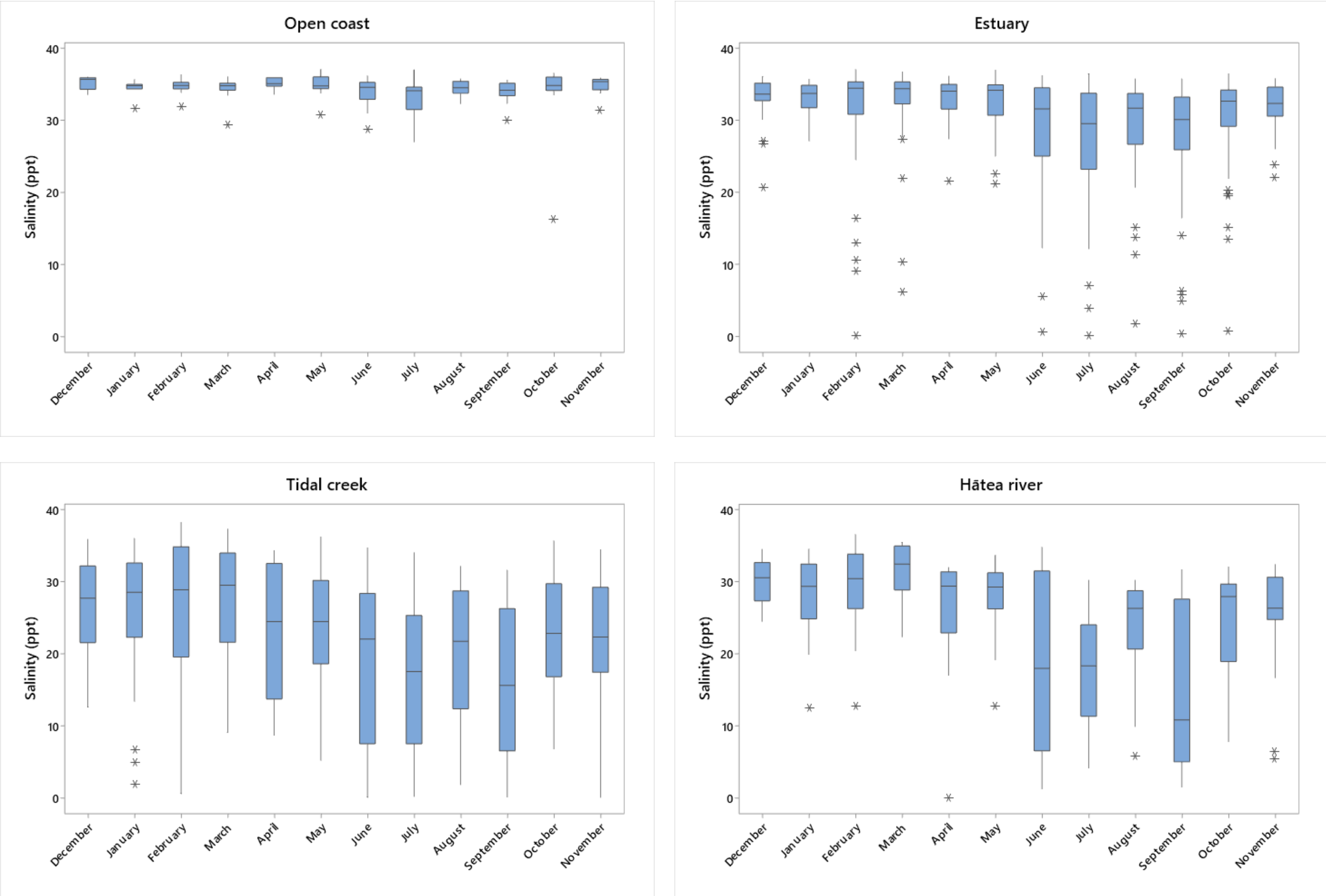

Figure E-1. Seasonal variation in salinity for sites in the open coast, estuarine, tidal creek and Hātea River management unit.

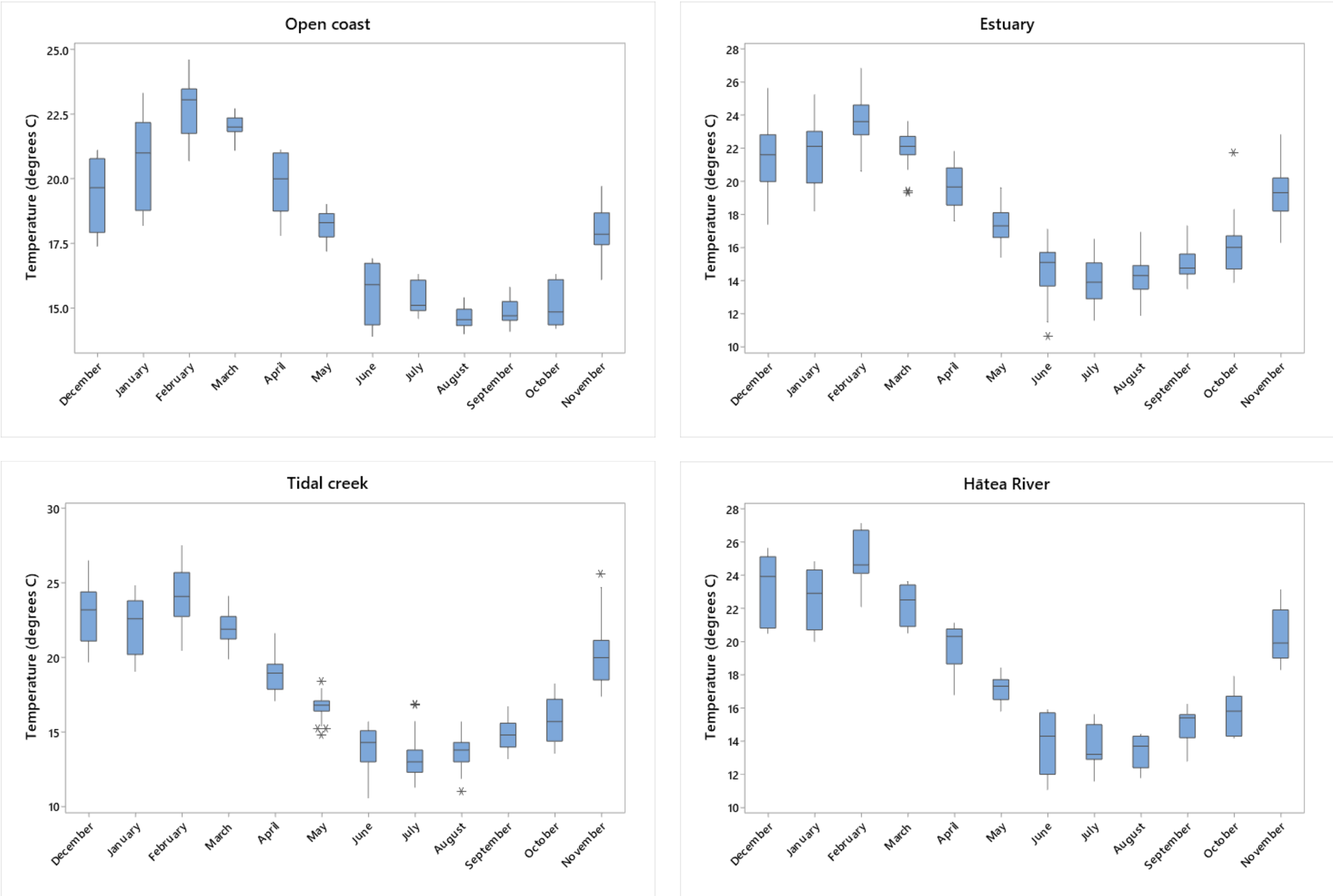

Figure E-2. Seasonal variation in temperature for sites in the open coast, estuarine, tidal creek and Hātea River management unit.

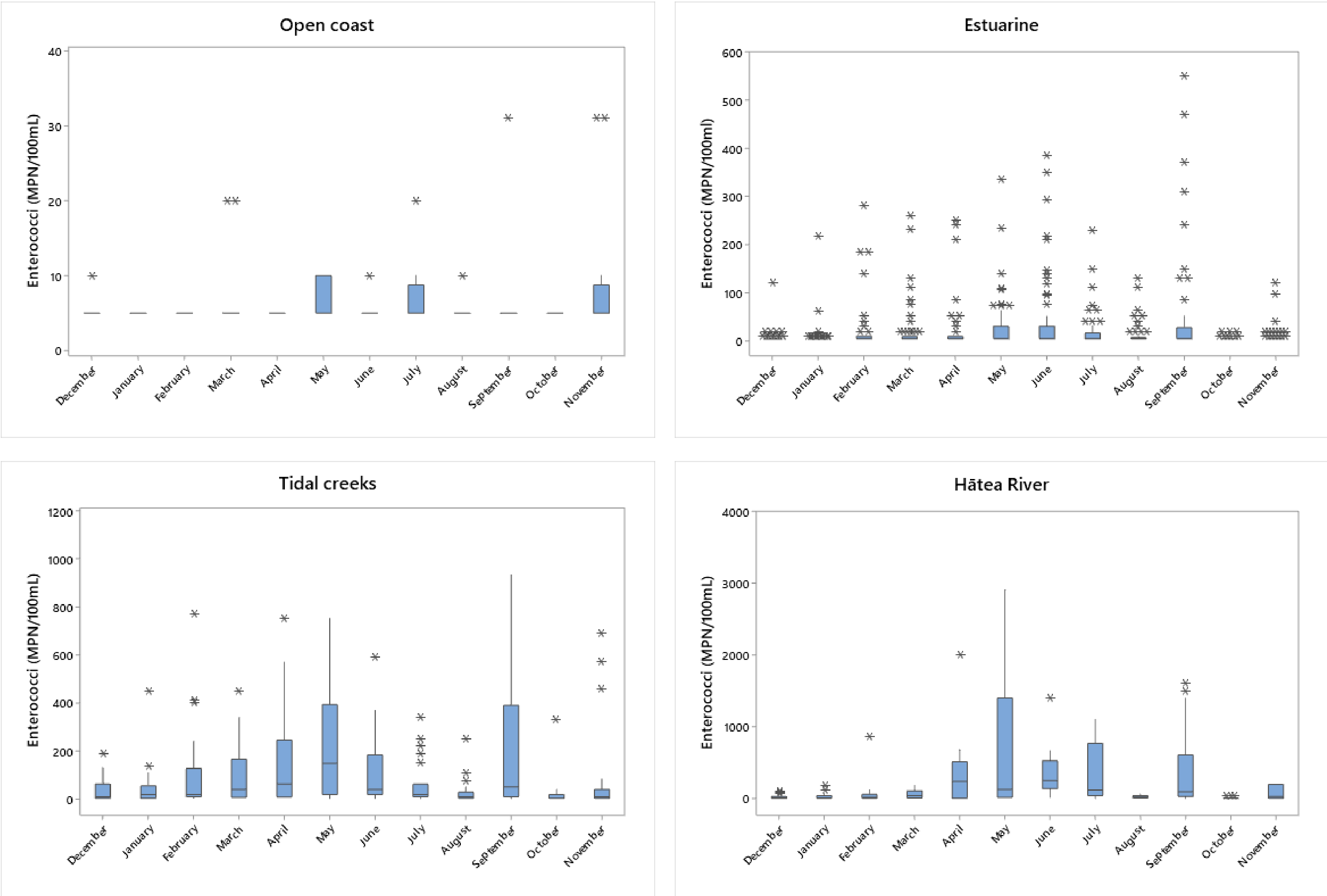

Figure E-3. Seasonal variation in enterococci concentrations for open coast, estuarine, tidal creek and Hātea River sites.

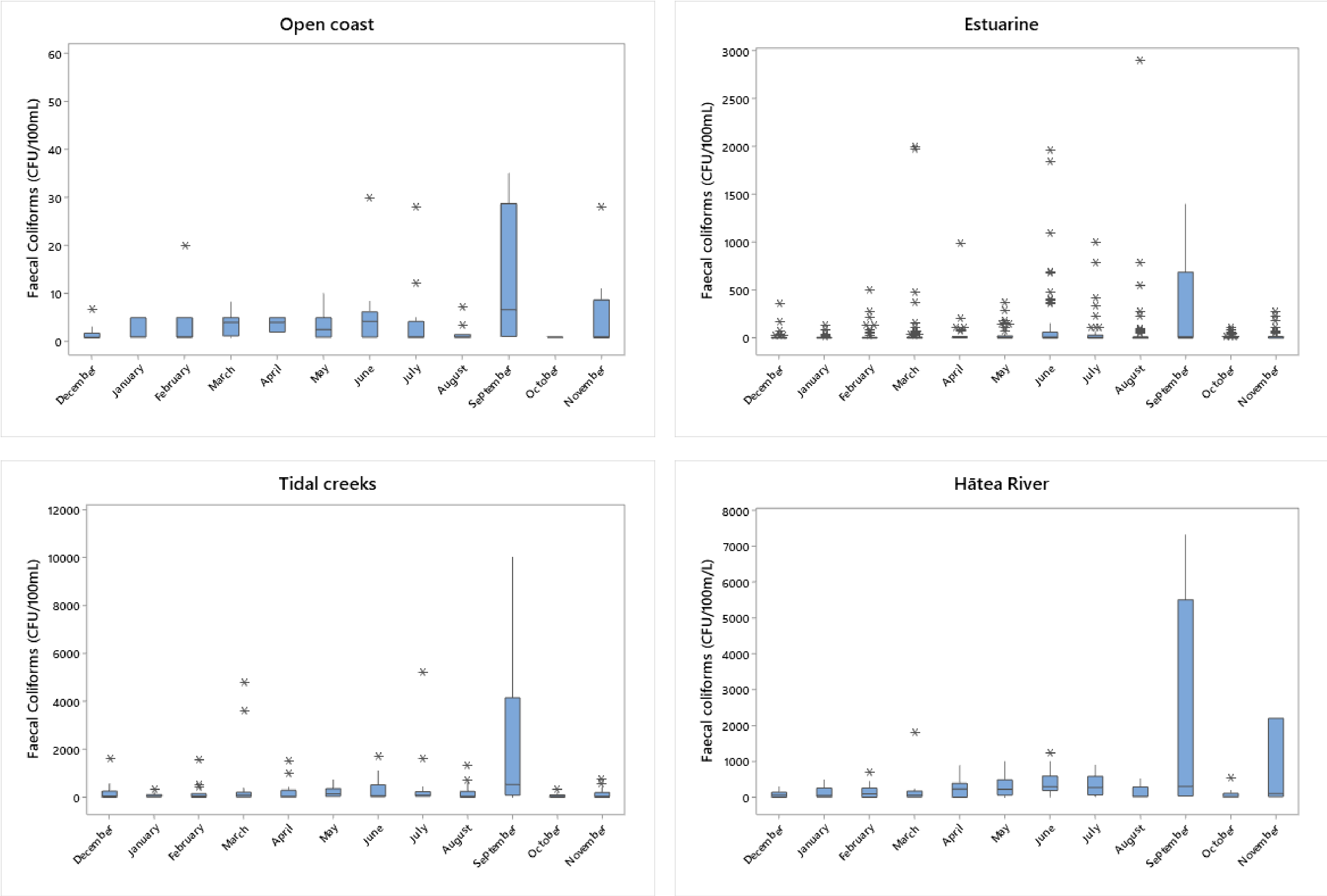

Figure E-4. Seasonal variation in faecal coliforms concentrations for open coast, estuarine, tidal creek and Hātea River units.

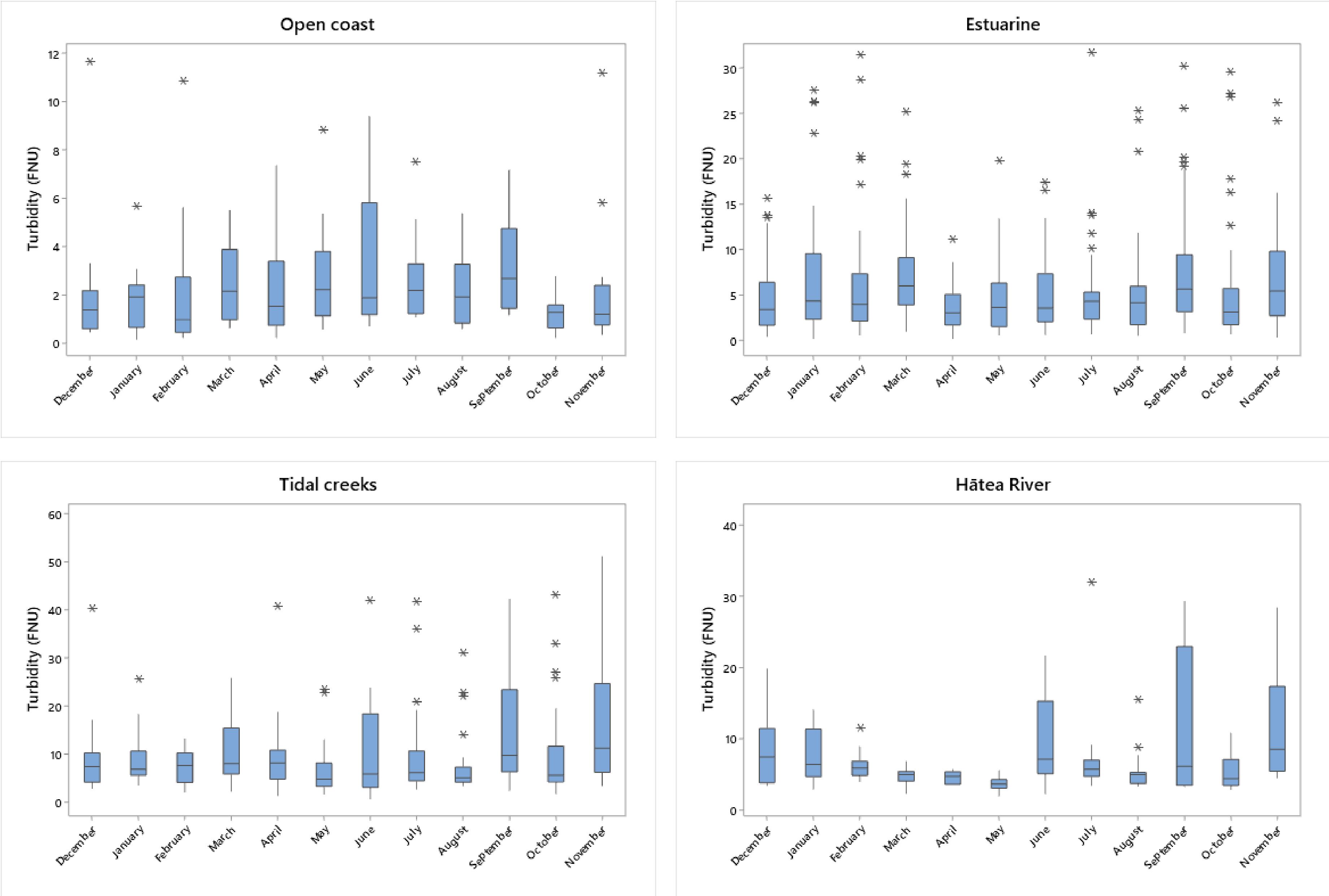

Figure E-5. Seasonal variation in turbidity in the open coast, estuarine, tidal creek and Hātea River management units.

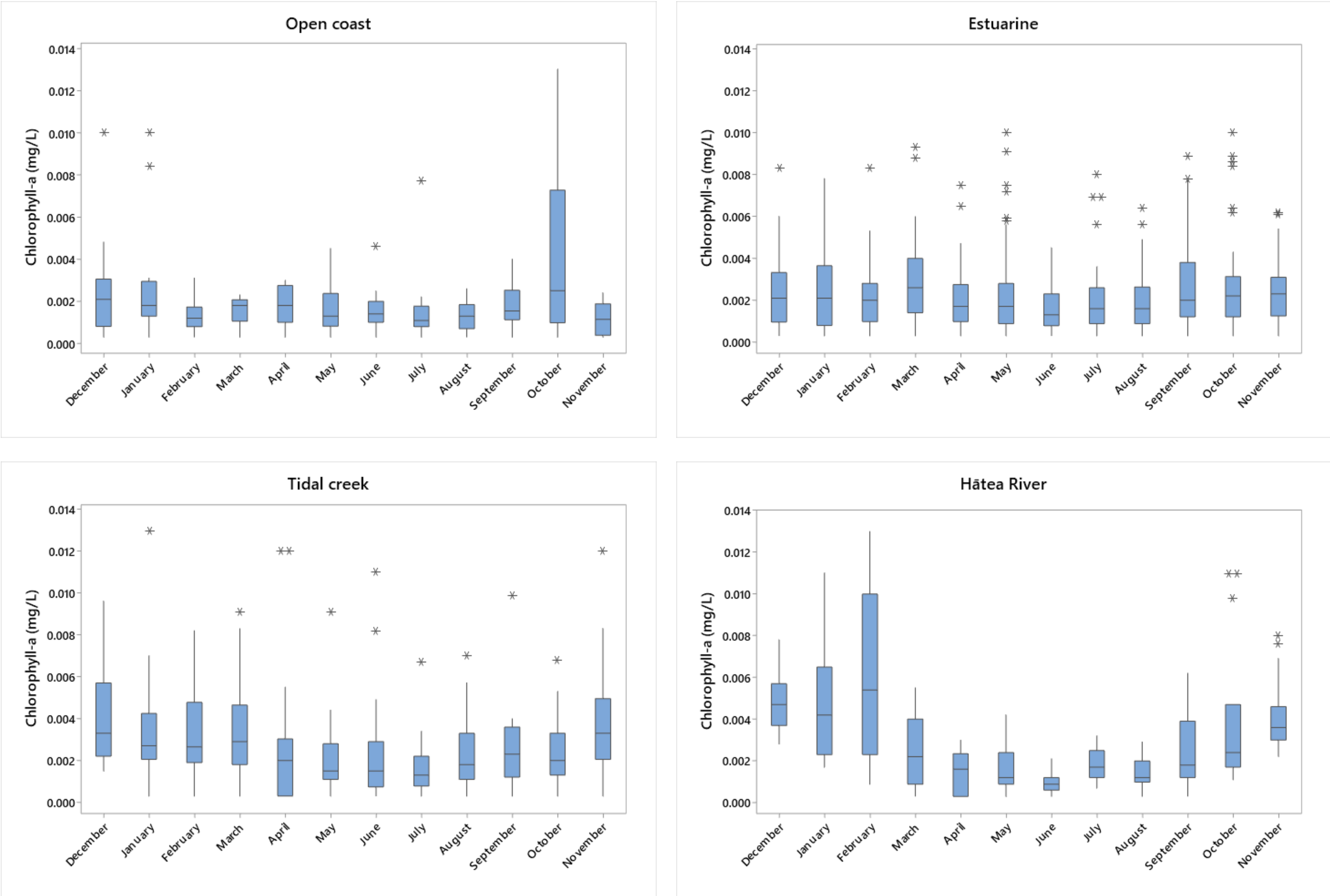

Figure E-6. Seasonal variation in chlorophyll-*a* for the open coast, estuarine, tidal creek and Hātea River management units.

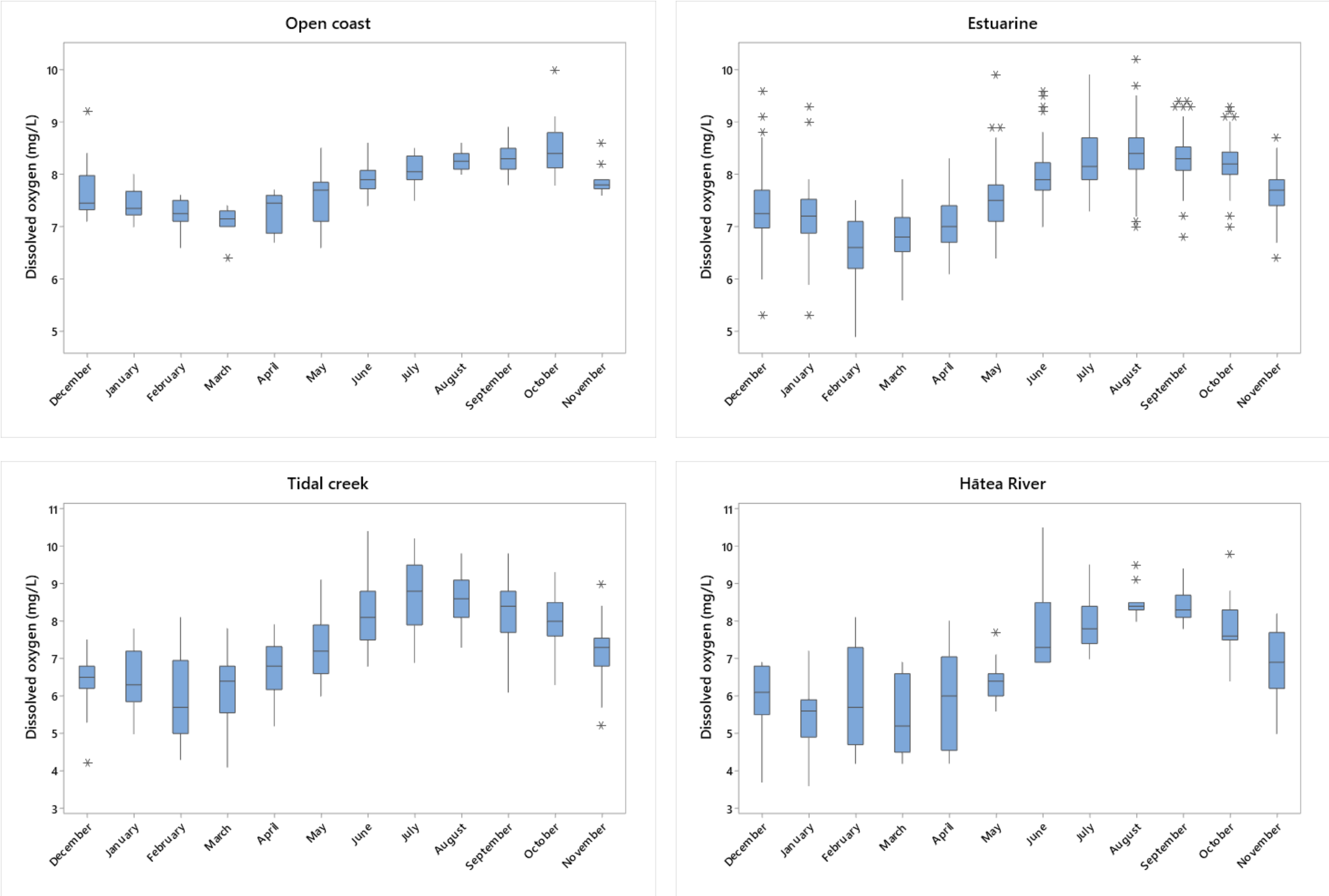

Figure E-7. Seasonal variations in Dissolved oxygen (mg/L) in the open coast, estuarine, tidal creek and Hātea River management units.

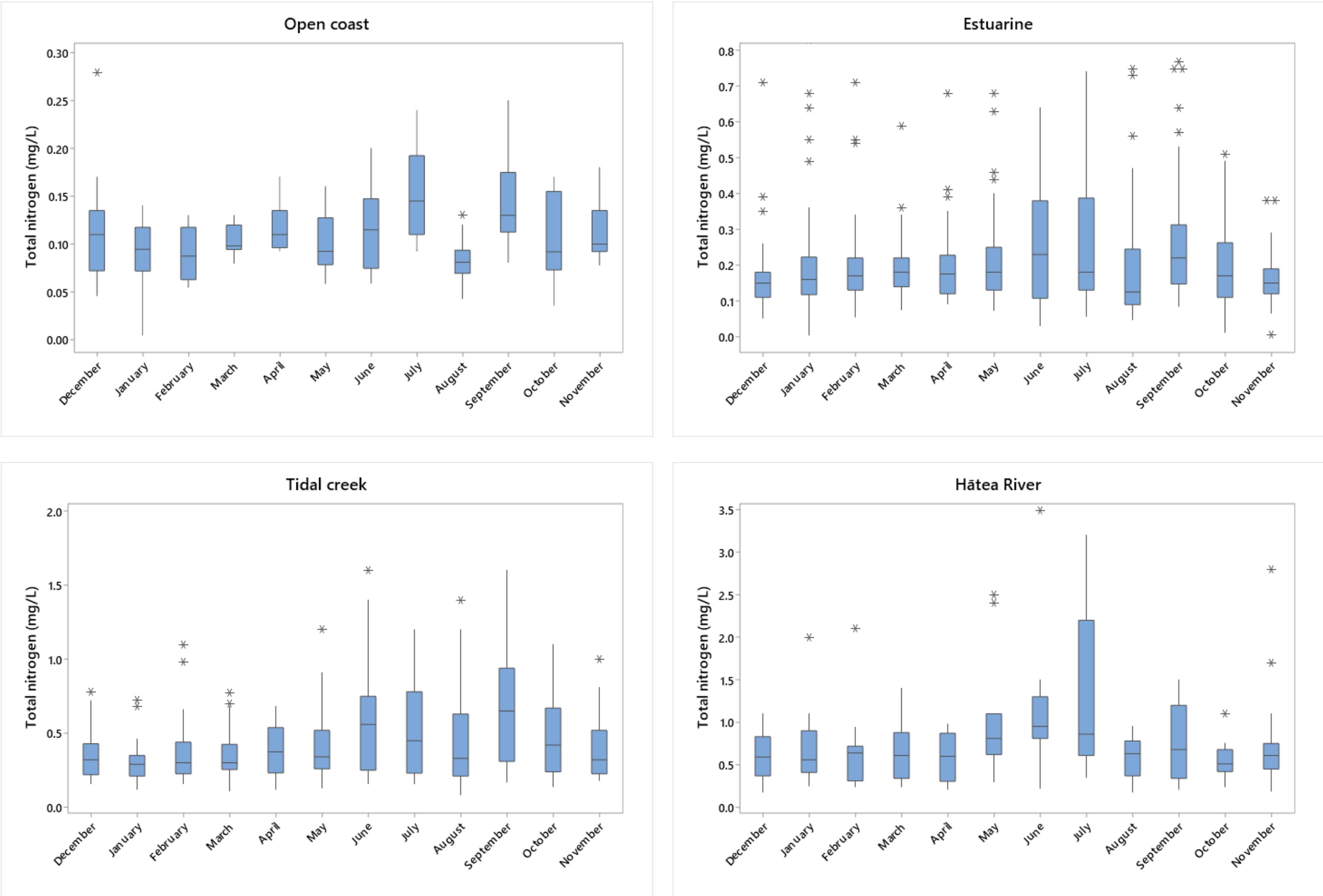

Figure E-8. Seasonal variation in total nitrogen in the open coast, estuarine, tidal creek and Hātea River management units.

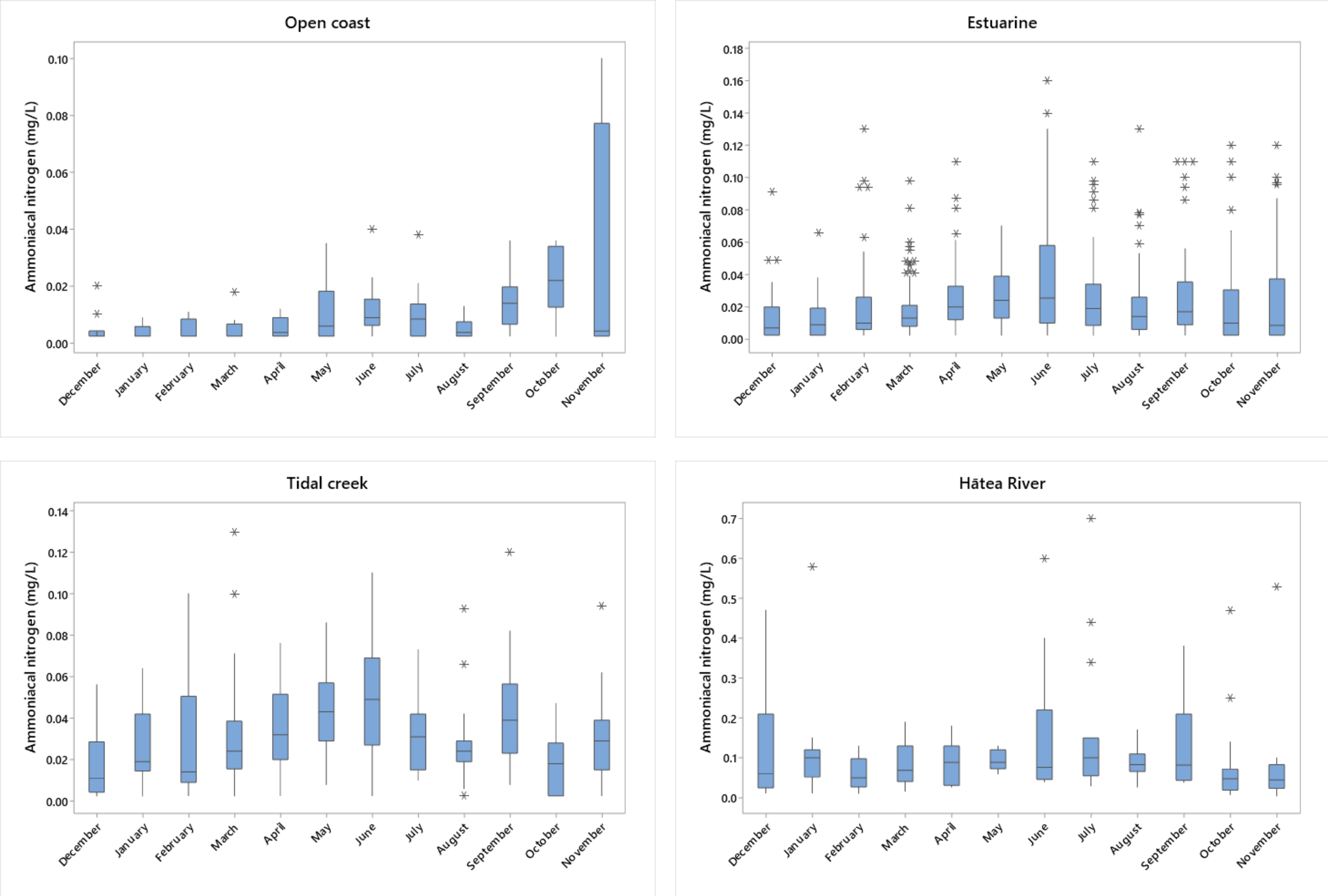

Figure E-9. Seasonal variation in ammoniacal nitrogen in the open coast, estuarine, tidal creek and Hātea River management units.

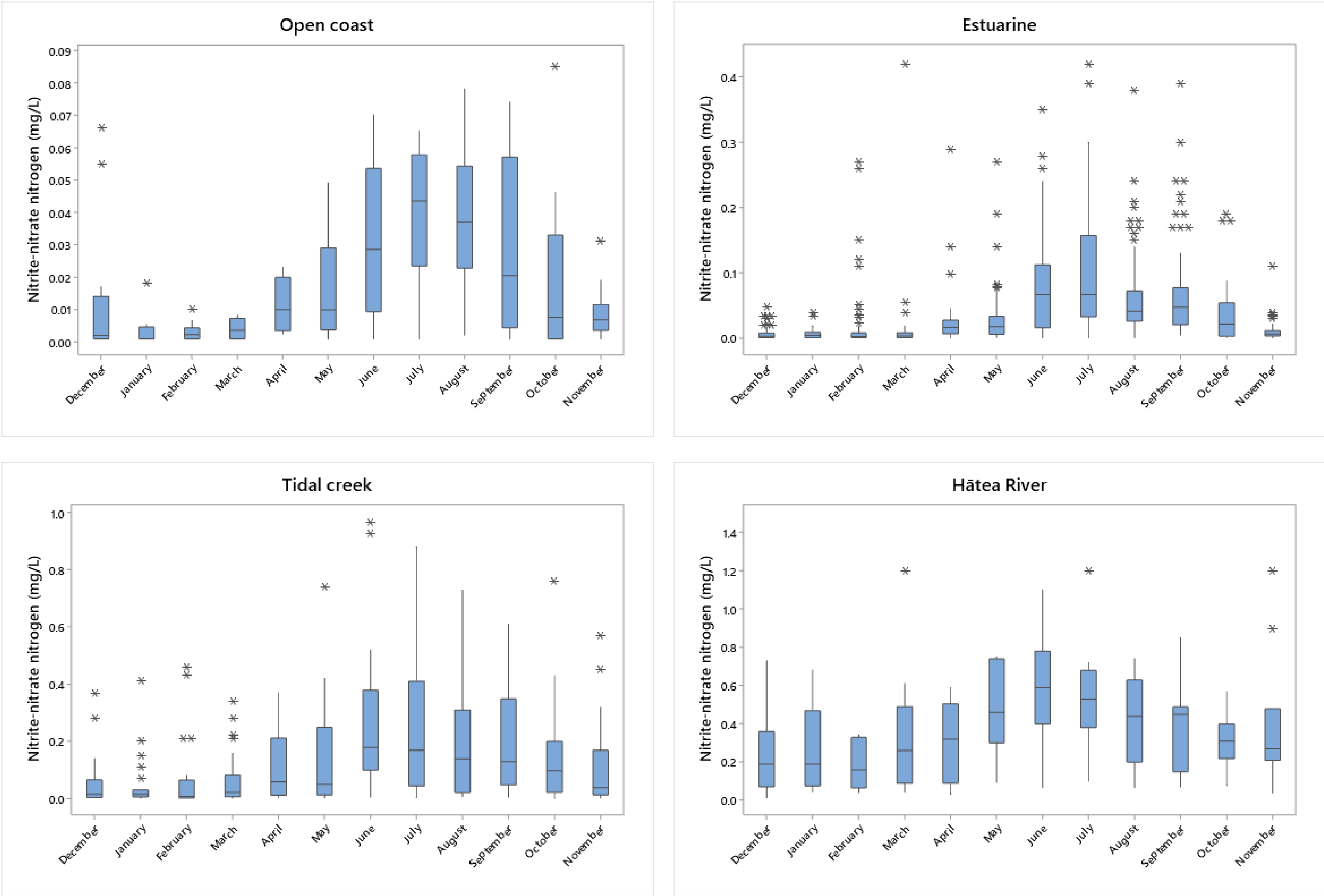

Figure E-10. Seasonal variation in nitrate-nitrite nitrogen in the open coast, estuarine, tidal creek and Hātea River management units.

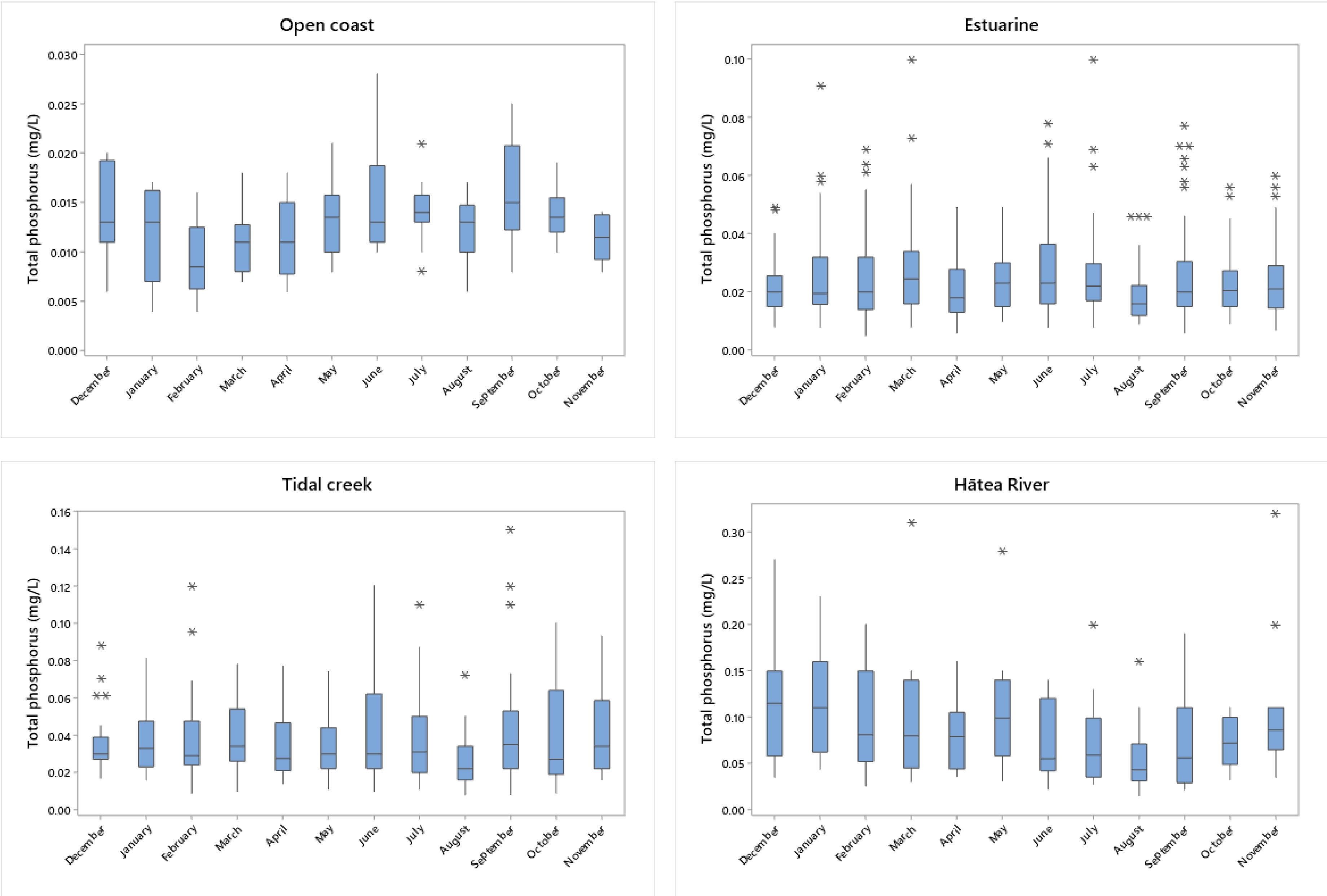

Figure E-11. Seasonal variation in total phosphorus concentrations (mg/L) in the open coast, estuarine, tidal creek and Hātea River management units.

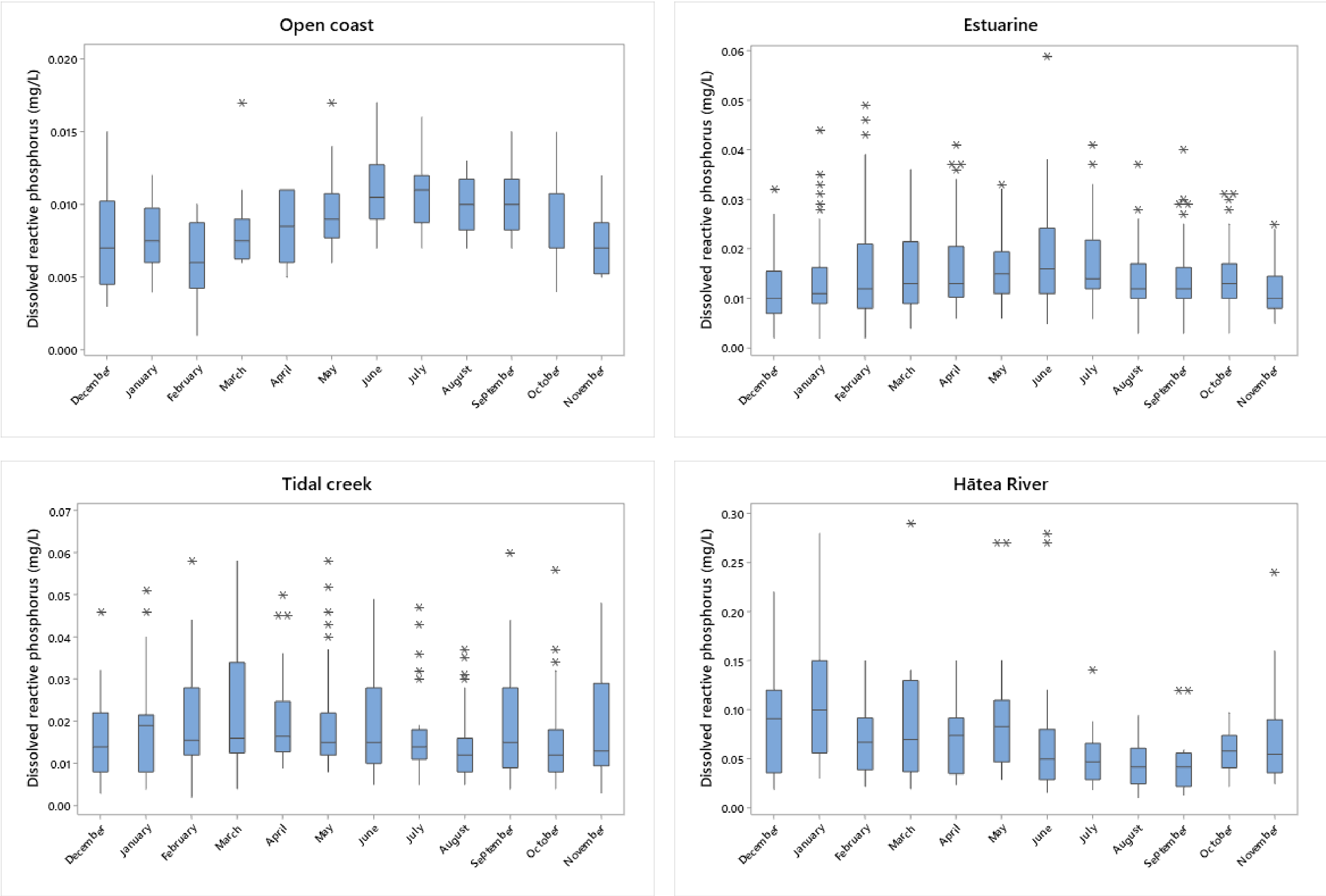

Figure E-12. Seasonal variation in dissolved reactive phosphorus concentrations (mg/L) in the open coast, estuarine, tidal creek and Hātea River management units.

Appendix F. Correlations.

Site	Ent	FC	Turbidity	TSS	Secchi	Chl-a	DO	TN	NH_4	NNN	TP	DRP
Brampton Reef	FC 1.0	ENT 1.0	None	None	None	None	None	None	None	None	None	None
Mangawhai	None	NH_4 0.85	None	None	n/a	None	Temp -0.94	None	FC 0.85	None	None	None
Waipū Cove	None	None	None	None	n/a	None	Temp -0.85	NH_4 0.80	TN 0.80	None	DRP 0.84	TP 0.84
Mair Bank	FC 0.98	ENT 0.98	None	None	None	None	None	None	None	None	DRP 0.82	TP 0.82

Site	Ent	FC	Turbidity	TSS	Secchi	Chl-a	DO	TN	NH_4	NNN	TP	DRP
Wahiwaka Creek	None	None	TSS 0.93	Turbidity 0.93 Secchi -0.81	TSS -0.81	None	Temp -0.84	None	DRP 0.80	None	None	NH_4 0.80
Wairoa River	None	None	TSS 0.81	Turbidity 0.81	None	None	Temp -0.86	None	None	None	None	None
Kerikeri River	Rainfall 72hrs 0.84	Rainfall 48hrs 0.80	None	None	None	None	Temp -0.79	None	None	None	None	None
Waipapa River	None	None	TP 0.80	None	None	None	None	None	None	None	Turb 0.80	None
Mangapai River	FC 0.97 TN 0.95 TP 0.93	ENT 0.97 TN 0.93 TP 0.90	None	None	None	None	Temp –0.86	ENT 0.95 FC 0.93 TP 0.94	None	None	ENT 0.93 FC 0.90 TN 0.94	None
Causeway bridge	None	Chl-a 0.82	Chl-a 0.91 TN 0.89 TP 0.90	None	n/a	FC 0.82 TN 0.81 TP 0.90 Turb 0.91	None	Chl-a 0.81 Turb 0.89 TP 0.84	None	None	Chl-a 0.90 Turbidity 0.90 TN 0.84	None
Insley St causeway	None	Chl a 0.95 DRP 0.80 TP 0.90	None	None	n/a	DRP 0.83 FC 0.95 TP 0.92	Temp – 0.84	NNN 0.85 Salinity – 0.83 TP 0.84	None	TN 0.85	FC 0.90 TN 0.84 Chl a 0.92 DRP 0.91	Chl a 0.83 FC 0.80 TP 0.91
Otaika Creek	None	None	TP 0.82	None	n/a	None	Salinity -0.80 Temp -0.92	None	None	None	Turbidity 0.82	None
Kawakawa River	FC 0.93	ENT 0.93 Turbidity 0.83	FC 0.83 Rainfall 48hrs 0.81	None	None	None	ET100 -0.88	None	None	None	None	None

Site	Ent	FC	TSS	Turbidity	Secchi	Chl a	DO	TN	NH_4	NNN	TP	DRP
Aurere Estuary	FC 0.91 TP 0.80 Turbidity 0.88 Rainfall 24hrs 0.95 Rainfall 0.88	ENT 0.91 TN 0.80 TP 0.84 Turb 0.88 Rainfall 0.90	None	Ent 0.8 FC 0.88 Rainfall 0.86	n/a	None	None	FC 0.80 TP 0.90	None	None	ENT 0.80 FC 0.84 TN 0.90	None
Paihia	FC 1.0	ENT 1.0 Rainfall 48hrs 1.0	None	None	None	None	Temp -0.80	None	None	None	None	None
Burgess Island	FC 0.99	ENT 0.99 NNN 0.83 Salinity – 0.83 TN 0.85	None	None	None	None	Temp –0.88	FC 0.85	None	FC 0.83 Salinity -0.85	None	None
Five Fathom Channel	None	NH_4 0.81	Turb 0.85	TSS 0.85	None	None	Temp -0.88	None	FC 0.81	None	None	None
Hargreaves Basin	None	None	Turb 0.91	TSS 0.91	None	None	Temp -0.85	None	None	None	None	None
Kapua Point	FC 1.0	ENT 1.0	Turb 0.93	TSS 0.93	None		Temp -0.87	None	None	None	None	None
Oruawharo River	None	None	None	None	None	None	Temp -0.92	None	None	None	None	None
Te Hoanga Point	NNN 0.96 TN 0.97	None	Turb 0.94	TSS 0.94	None	None	Temp -0.88	None	None	None	None	None
Te Kopua	None	NNN 0.96 TN 0.97	Turb 0.86	TSS 0.86	None	None	Temp -0.91	FC 0.97 NNN 0.89	None	FC 0.96 TN 0.89	None	None
Tapu Point	FC 0.82	Rainfall 48hrs 0.80	None	None	None	None	Temp -0.81	None	None	Salinity -0.80	None	None
Doves Bay	FC 1.0	Ent 1.0 TP 0.82	None	None	None	None	None	None	None	None	ENT 0.82 FC 0.82	None
Wainui Island	FC 0.96 Rainfall 0.87	ENT 0.96	None	None	None	None	None	None	None	None	None	None
Mangawhai Ramp	FC 0.99 Salinity -0.89 TN 0.89 TP 0.90 Turb 0.95	ENT 0.99 Salinity -0.86 TN 0.98 TP 0.88 Turb 0.93	None	TP 0.88 ENT 0.95 FC 0.93 Salinity – 0.87 TN 0.94	n/a	None	None	ENT 0.98 FC 0.98 Sal -0.89 TP 0.91 Turb 0.94	None	None	DRP 0.84 ENT 0.90 FC 0.88 Sal –0.83 TN 0.91 Turb 0.88	TP 0.84

Site	Ent	FC	TSS	Turbidity	Secchi	Chl a	DO	TN	NH_4	NNN	TP	DRP
Tern Point	FC 1.00	ENT 1.00	None	TP 0.87 Salinity -0.83	n/a	None	Temp -0.83	None	None	None	Turbidity 0.87	None
Te Haumi	None	None	None	None	None	None	None	None	None	None	None	None
Ruakaka Estuary	DRP 0.80 Turbidity 0.90	DRP 0.80 Turbidity 0.88	None	TP 0.97 DRP 0.90 ENT 0.90 FC 0.88	n/a	None	Temp -0.84	NH_4 0.85 NNN 0.93 Salinity -0.88 TP 0.80	TN 0.85 Salinity -0.80 TN 0.85 TP 0.80	TN 0.93	TN 0.80 Turb 0.97 NH_4 0.80 DRP 0.96	ENT 0.80 FC 0.80 TP 0.96 Turb 0.90
Russell	FC 0.89	ENT 0.89	None	None	None	None	None	None	None	DRP 0.89	None	NNN 0.89
Te Puna Inlet	None	Rainfall 48hrs 0.80	None	None	None	None	Temp -0.87	None	None	None	None	None
Waikare Inlet	FC 0.86	ENT 0.86	None	None	None	None	Temp -0.83	None	None	None	None	None
Waipū Estuary	None	Turbidity 0.86	Turb 0.85 TP 0.83	FC 0.86 TP 0.96 TSS 0.85	n/a	None	Temp -0.82	None	Salinity – 0.86	Salinity -0.84	DRP 0.81 TSS 0.83 Turbidity 0.96	TP 0.81
Johnston Point	None	None	None	None	n/a	None	None	None	None	None	None	None
Waitangi River	FC 1.0 TP 0.85	Ent 1.0 TP 0.84	None	None	None	None	Temp -0.83	none	None	None	FC 0.84 ET 0.85	None
Kaiwaka Point	FC 1.00	ENT 1.00	None	None	None	None	None	None	None	Salinity -0.83	None	None
One Tree Point	None	None	None	None	None	None	Temp – 0.83	None	None	None	None	None
Portland	None	None	None	None	None	None	Temp –0.83	None	None	None	None	None
Tamaterau	FC 1.00	ENT 1.00	None	None	None	None	Temp -0.89	None	None	None	None	None

Site	Ent	FC	Turbidity	TSS	Secchi	Chl a	DO	TN	NH_4	NNN	TP	DRP
Kissing Point	FC 0.88	ENT 0.88	None	None	None	None	None	NH_4 0.85 NNN 0.88	TN 0.85	TN 0.88	DRP 0.94	TP 0.94
Limeburners Creek	FC 0.83 Rainfall 0.83	ENT 0.83	None	None	None	None	None	None	None	DRP 0.86 TP 0.82	DRP 0.97 NNN 0.82	NNN 0.86 TP 0.97
Lower Hātea	FC 0.94 Salinity -0.80	ENT 0.94	None	None	None	None	None	NH_4 0.88	TN 0.88	None	DRP 0.84	TP0.84
Town Basin	FC 0.98 Rainfall 24hrs 0.92 Rainfall 48hrs 0.81	Ent 0.98 Rainfall 0.88	None	None	None	None	None	None	None	None	DRP 0.85	Salinity 0.76 TP 0.85
Waiharohia	FC 0.95 Turbidity 0.87 Rainfall 24hrs 0.81	ENT 0.95 Turb 0.93	ENT 0.87 FC 0.93 TSS 0.83	Turb 0.83	None	None	None	None	None	None	DRP 0.91	TP 0.91

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