Coastal and Estuarine Water Quality in Tāmaki Makaurau / Auckland 2021-2022 Annual Data Report

S. Kelly and J. Kamke

November 2023

Technical Report 2023/19

Research and Evaluation Unit | RIMU

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Water sampling via helicopter, Goat Island. Photograph by Emma Kearney, Marine Ranger, Department of Conservation

Auckland Westhaven Marina and Viaduct Harbour with city skyline. Photograph by Natalie Gilligan, RIMU

Executive summary

Auckland Council's coastal and estuarine water quality monitoring programme began in 1989 and now includes monthly sampling of 35 monitoring sites (31 council and four Watercare Services sites) located in Kaipara, Manukau, Waitematā and Mahurangi Harbours, Tāmaki Estuary, Wairoa Bay, and along the East Coast from Goat Island to Browns Bay. Water samples are analysed for fundamental water quality parameters, and indicators of water clarity and nutrient status. This report summarises data obtained over the five-year period from July 2017 to June 2022; provides an overall water quality ranking for each site using a water quality index developed for the Auckland region; and provides plots of data obtained over the most recent 12-month period (the July 2021 to June 2022 hydrological year – appended).

Several changes have been made to the way data has been analysed and presented in this annual report:

- Data summaries and the water quality index results are presented over periods of five hydrological years (July 2017 to June 2022) to provide consistency with freshwater reporting. Note that previous marine and estuary water quality reports have presented results over three-year periods, and as such, those earlier results are not directly comparable.
- Additional analyses and plots are provided to aid with data interpretation by showing: important relationships among water quality parameters; the influence of seasonality; and general spatial patterns by clustering sites that had similar results for fundamental water quality parameters, nutrients, and water clarity.

Sites with the strongest freshwater influence displayed the greatest variation in, and lowest median values, of salinity, dissolved oxygen and pH. Linear regressions showed five-year median salinity values explained around 62% of the variation in dissolved oxygen saturation and 67% of the variation in pH. Fluctuations in salinity and pH values were largest at the Brigham and Rangitopuni Creek sites located in the Upper Waitematā Harbour. Gradients away from significant freshwater sources were apparent in the Manukau, Kaipara, Waitematā and Mahurangi Harbours and Tāmaki Estuary. Oceanic influences are strongest at coastal sites from Goat Island to Browns Bay, where median salinity and pH values were consistent with those typical of open coastal waters.

Highest nutrient concentrations were obtained from two Manukau Harbour sites (Puketutu Point and Māngere Bridge), where total and dissolved reactive phosphorus concentrations were particularly elevated. This is not surprising, given that New Zealand's largest wastewater treatment plant (Māngere WWTP) discharges to that area. Waiuku Town Basin also had relatively high and variable nitrogen concentrations. High concentrations at that site were presumably related to its location in an upper section of a long, narrow inlet surrounded by rural and urban land uses, and its proximity to the discharge from the Waiuku wastewater treatment plant.

Patterns in nutrient and chlorophyll *a* concentrations in other southern, central and outer Manukau Harbour sites were comparable to those at similarly situated sites in Kaipara Harbour. In both harbours, nutrient and chlorophyll *a* concentrations declined with distance from major inlets and rivers, through central parts of the harbours and towards their entrances. Similar, patterns occurred between the upper and outer Waitematā Harbour, and mid and outer Tāmaki. The gradient is particularly pronounced for nitrogen, with Rangitopuni and Brighams Creeks in the Upper Waitematā having the highest total nitrogen concentrations. In comparison, nutrient and chlorophyll *a* concentrations in East Coast sites were low and much less variable. This reflects the greater exposure of those sites to flushing by relatively clean marine water.

Turbidity and total suspended solids (TSS) concentrations are affected by organic and inorganic particulate matter[1], including planktonic organisms such as phytoplankton. Boxplots of data obtained between July 2017 and June 2022 show that spatial patterns in turbidity, total suspended solids and chlorophyll *a* were very similar. Linear regressions of median values of those three variables confirmed that sites with high chlorophyll *a* concentrations also have high TSS concentrations and high turbidity (and *vice versa*). Median chlorophyll *a* concentrations explained around 73% and 83% of the variation in turbidity and TSS, respectively ($p<0.0001$), while TSS explained around 88% of the variation in turbidity.

Overall, TSS and turbidity are strongly correlated and display predicable patterns. Phytoplankton appear to have a significant influence on ambient turbidity and TSS concentrations. The influence of sediment runoff on the coastal environment is likely to be greatest during and after significant storm events, which because of helicopter flight safety constraints, are likely to be underrepresented in the data. Including volatile suspended solids in the parameter suite would assist in teasing apart the relative influences of inorganic sediments and organic matter, such as phytoplankton.

As with nutrients, sites in, or near, the entrance of, narrow inlets or rivers in upper harbour and estuary sites had the highest levels of turbidity and TSS. The Kaipara River monitoring site had the highest median values for all three water clarity parameters. Median values at all other Kaipara Harbour sites were similar to, or lower than, those at comparable sites in the Manukau and Waitematā Harbours, Tāmaki Estuary and Wairoa Bay. Open East Coast sites had low TSS, turbidity and chlorophyll *a* concentrations, with median values decreasing slightly at sites from Browns Bay north, due to the influence of clean marine water becoming stronger.

Auckland Council's Water Quality Index (WQI) provides an indicative ranking of water quality based on exceedance of the council's interim guideline values (see section 2.5.1) for dissolved oxygen saturation, ammoniacal nitrogen, total oxidised nitrogen, dissolved reactive phosphorus, chlorophyll *a*, and water turbidity. Separate guidelines are used for open coast, estuarine sites, and tidal creek sites. In general, sites in, or near the entrance of, narrow inlets or rivers in upper harbour and estuary sites tend to have the worst water quality scores, while sites in central and outer sections of estuaries and harbours, and on open coasts have the best scores. However, scores at most sites have varied slightly over time. The exceptions are:

- three sites with persistently "poor" scores in Manukau Harbour (Māngere Bridge, Weymouth and Warkworth Town Basin)

[1] Dissolved compounds also affect turbidity.

- one Manukau Harbour site with a persistently “marginal” score (Clarks Beach), and one with a persistently “fair” score (Grahams Beach)
- one East Coast site with a persistently “good” score (Ti Point).

Overall, the results suggest that sites in, or near the entrance of, narrow inlets or rivers in upper harbour and estuary sites are the most sensitive to land-derived water quality effects. Water quality improves towards central and outer harbour areas, with best quality in exposed open coastal sites.

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1 Introduction

The coastal environment in the Auckland region/Tāmaki Makaurau sits within two oceanic systems and contains three major harbours and numerous estuaries. It includes wide variety of habitats and supports a diverse variety of plants and animals, including seaweeds, invertebrates, mangroves, seagrass, shellfish, marine mammals, fish and seabirds. In addition to its intrinsic natural values, Auckland's coastal environment is also prized for its cultural, recreational and commercial values. Its waters hold particular significance to mana whenua, who whakapapa to significant water bodies and have kaitiaki obligations to protect them as part of the customary practice of taonga tuku iho (protecting treasures passed down from previous generations).

Coastal water quality is naturally affected by multiple factors. It naturally fluctuates on tidal, daily, seasonal, annual, and longer time scales. It is influenced by climatic and weather conditions (e.g. upwelling and downwelling, wind speed and direction, light and rainfall), and by natural biological and chemical processes (e.g. photosynthesis, respiration and denitrification). Water quality is also affected by the natural size, shape and bathymetry of a water body, the nature of the seabed, catchment size and characteristics.

Overlying those natural patterns are the effects of our actions. We alter the aesthetics, use and health of coastal waters by increasing sediment and contaminant loads in the freshwater that flows to the coast; by discharging contaminants from coastal outfalls; and through a variety of activities carried out within the coastal environment. Land-use in, and beyond, the Auckland region has a major influence on coastal water quality in the region (particularly in the Kaipara Harbour and the Hauraki Gulf).

Auckland Council undertakes long-term state of the environment programmes that include monitoring of river water quality and ecology; coastal and estuarine water and sediment quality; and, coastal benthic ecology. Microbiological contamination of beaches and recreational water quality are monitored through the Safeswim programme, www.safeswim.org.nz.

Auckland Council's coastal and estuarine water quality monitoring programme uses standard indicators of sediment and nutrient effects, together with fundamental environmental parameters, which provide information on the ambient characteristics of coastal water and/or are needed to analyse relationships and anthropogenic and climate effects. Other contaminants associated with urban land-use and stormwater contamination, such as metals, are monitored in Auckland Council's river water quality (Ingley et al. 2023) and estuarine sediment and ecology monitoring programmes (Drylie 2021; Mills & Allen 2021), and are not assessed here.

The purpose of this report is to communicate the state of our coastal and estuarine water quality based on council's coastal and estuarine water quality monitoring programme, with updated results for 2021-2022. In this report, data are summarised using the same reporting timeframes as Auckland Council's river water quality report (Ingley et al. 2023) and those specified in the National Policy Statement for Freshwater Management (NPS-FM), with data summaries and the water quality index presented over periods of five hydrological years (July 2017 to June 2022 – see section 2 for more details). Results are provided for individual water quality parameters, along with a combined indicator of water quality at each site, using the regional Water Quality Index (WQI).

The WQI provides an indicative ranking of water quality based on exceedance of the council's interim guideline values for dissolved oxygen saturation, ammoniacal nitrogen, total oxidised nitrogen, dissolved reactive phosphorus, chlorophyll *a*, and water turbidity. Separate guidelines are used for open coast, estuarine and tidal creek sites. Note that care needs to be taken in the interpretation of WQI values, as the coastal water quality is affected by natural and human inputs, and complex interactions occur among natural processes and human actions.

To aid in that interpretation, a selection of additional plots and analyses have been provided. They highlight the influences of seasonal variation; highlight relationships among parameters; and, use cluster analysis and mapping to show general spatial patterns in fundamental water quality parameters, nutrients, and water clarity.

1.1 Programme objectives

The Auckland regional coastal and estuarine water quality monitoring programme characterises the state of Auckland's ambient coastal water quality and tracks long-term changes in it. This supports the following objectives:

Regulatory alignment

- Contributes to Auckland Council's obligations under section 35 of the Resource Management Act 1991 with respect to the state of the environment monitoring and reporting.
- Contributes towards state of the environment reporting under the Hauraki Gulf Marine Park Act (2000).
- Contributes to our ability to maintain and enhance the quality of the region's coastal environment (Local Government Act 2002).
- Provides evidence for the "Environment and Cultural Heritage" component of the Auckland Plan 2050.

Decision making

- Provides baseline, regionally specific data to underpin sustainable management through resource consenting and associated compliance monitoring for coastal and estuarine environments.
- Provides supporting information for assessing the effectiveness of policy initiatives and strategies, and their operational delivery.
- Identifies progressive, slowly accumulating effects with serious long-term consequences.

Public resource

- Provides supporting information that mana whenua can utilise in their role as kaitiaki.
- Continuously increases the knowledge base for Aucklanders and promote awareness of regional coastal and estuarine water quality issues and their subsequent management.

1.2 Supporting reports

This is the 32nd data report since the inception of the coastal water quality monitoring programme in 1987. Prior to 2000, the freshwater and coastal water quality monitoring results were presented within combined reports.

Previous annual data reports and supplementary data files relating to this report can be obtained from Auckland Council's Knowledge Auckland website www.knowledgeauckland.org.nz/natural-environment/

For further enquiries and data supply, please email environmentaldata@aucklandcouncil.govt.nz

For the most recent comprehensive trend analysis, please refer to *Coastal and estuarine water quality state and trends in Tāmaki Makaurau / Auckland* (Ingley, 2021).

Microbiological contamination of beaches and recreational water quality are monitored through the Safeswim programme, www.safeswim.org.nz.

2 Methods

Water quality data is naturally noisy – varying both spatially and through time. Spatial variation occurs along environmental gradients. Differences also occur between environmentally discrete systems or areas. Teasing apart the influences of natural variation from those of human influences requires:

- a robust sampling design;
- consistency in sample collection and sample analysis;
- a good understanding of the factors that influence water quality;
- a good understanding of the characteristics of monitoring sites;
- the use of appropriate data analyses; and,
- careful interpretation.

Auckland Council began monitoring coastal water quality in 1987. Since then, the council has expanded the number of sites monitored and progressively developed sampling, data storage, analysis and reporting methods. Key features of the Regional Coastal Water Quality Monitoring Programme are provided below.

2.1 Programme design

Auckland Council collects coastal and estuarine surface water quality samples monthly by helicopter, boat and from land. The collection of water samples by helicopter enables sites spread over the region to be sampled within a narrow time window created by tidal constraints, making comparison between sites more robust. Natural temporal variation in water quality is avoided as much as possible by maintaining a consistent sampling time relative to the tidal cycle. Samples are collected approximately 10 minutes to 2.5 hours after high tide for the Kaipara Harbour, and Hauraki Gulf sites, and 2.5 to 4 hours after high tide for the Manukau Harbour. Sampling within the Waitematā Harbour is taken at approximately 1 hour before high tide to 2 hours after high tide. Maintaining a consistent sample time improves the power of long-term trend detection.

Sites in the inner Hauraki Gulf, Kaipara Harbour, Tāmaki Strait and Manukau Harbour are collected by helicopter, sites in the upper and central Waitematā Harbour are collected by boat, and sites in the Tāmaki Estuary are collected from land.

2.2 Site locations

The water quality monitoring sites are spread throughout six geographically distinct areas (Figure 2-1 – refer to Appendix 1 for additional site details). Together, they provide information on:

- a range of exposure levels including open coast, harbours, large estuaries, and tidal creeks[2]
- the three main harbours and two of the three largest estuaries in the region (Firth of Thames is not included)
- a variety of contributing catchment land uses, ranging from urban to rural[3].

In this report, data from four of Watercare Services' Manukau Harbour Environment Monitoring Programme (HEMP) sites have also been included for the first time (Wiroa Island, Purakau Mid Channel, Te Whau Point, Puponga Point). Samples from those sites are collected by Auckland Council for Watercare Ltd, and data are held in the council's water quality database.

[2] For the purposes of this assessment, 'tidal creek' monitoring sites are those located in narrow channels upstream of the 'mouth' or confluence with the main estuary or harbour body and where median salinity over 2007-2016 was <30 ppt (polyhaline).
[3] Open coast sites are less subject to direct influences from adjacent land-use due to greater exposure and oceanic influences.

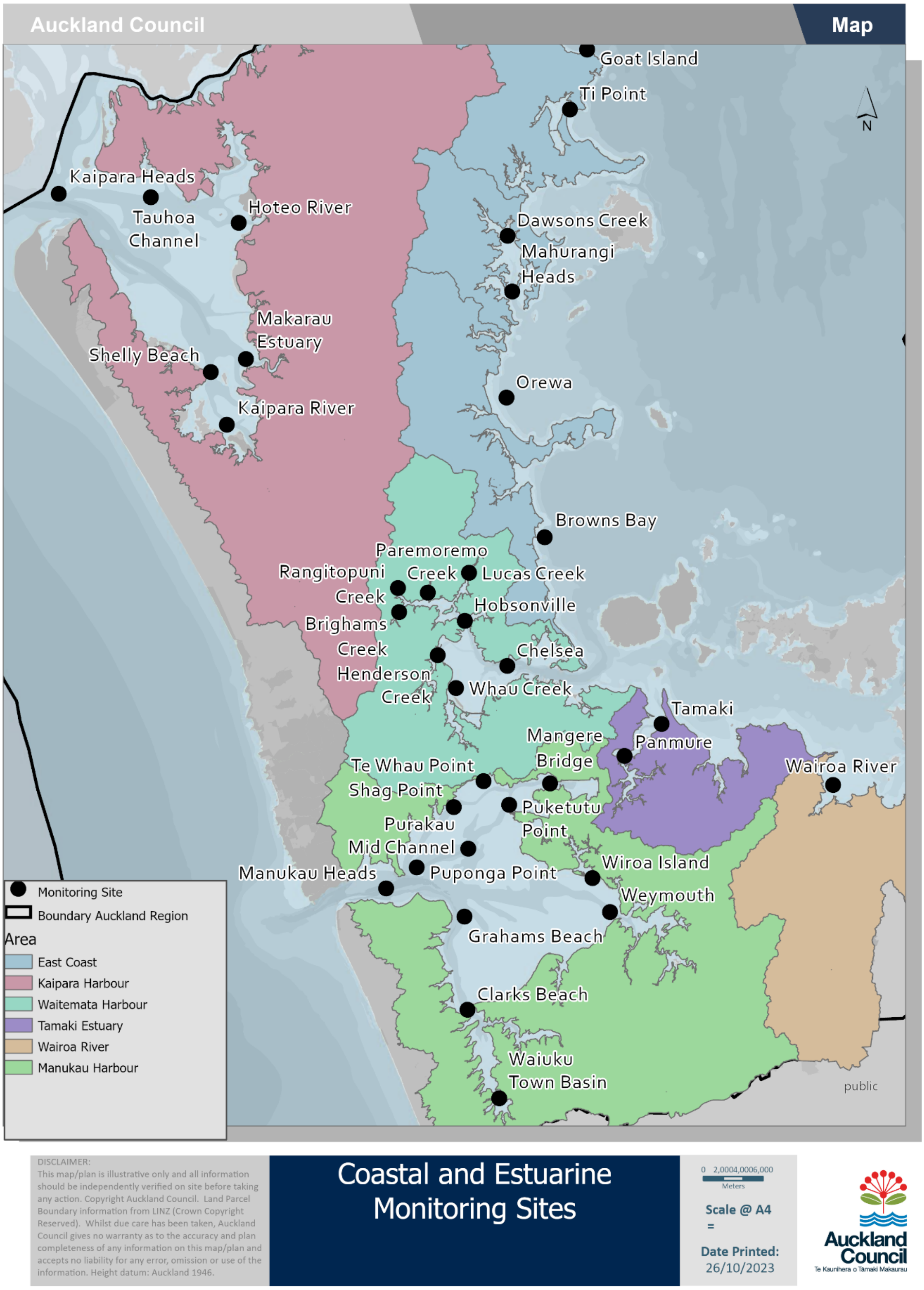


Figure 2-1: Location of the 35 coastal and estuarine water quality monitoring sites and reporting areas.

2.2.1 Tāmaki Estuary site changes

Two sites are monitored within the Tāmaki Estuary. One site is located in the upper estuary (Panmure) and one site was previously located in the lower estuary at Half Moon Bay Marina (referred to as 'Tāmaki' within previous reports).

The construction of the new North Pier at Half Moon Bay Marina surrounded the Tāmaki site within new breakwaters, making it unsuitable for future monitoring (Figure 2-2). Monitoring at an alternate site located at the end of the Half Moon Bay ferry terminal therefore commenced in July 2019 (Figure 2-2), with dual analysis undertaken at both sites for a period of 18 months. Subsequent analyses presented since the 2020 annual data report are focused on the new ferry terminal site also referred to as 'Tāmaki'.

The water quality index assessment in this report requires a minimum of five years of data (see section 2.5.1) and is therefore calculated from information from both the marina and ferry terminal locations.

Figure 2-2: Aerial photograph of Tāmaki Estuary Half Moon Bay (cred: N. Gilligan, RIMU). Original site (yellow asterisk), now enclosed by the marina extension, and the new alternate ferry terminal site (orange asterisk).

2.3 Data collection

Sample collection was undertaken by council staff on a monthly basis (see Sections 2.3.1 and 2.3.2 to for exemptions). The quality of coastal water around the region is determined by measuring 16 parameters including fundamental physical and -chemical parameters (e.g. temperature, salinity, pH), nutrients (dissolved and total nitrogen and phosphorus), suspended solids and turbidity, chlorophyll *a*, and dissolved oxygen. A summary of all parameters monitored is provided in Table B-0-2 in Appendix 2.

Six parameters are determined in the field using an EXO Sonde portable water quality meter (Xylem Analytics), and the remainder are determined by laboratory analysis (see Appendix 2). At each site, water samples were collected from the surface (approx. top 0.3 m) by lowering two, 1 litre plastic bottles into the water or lowering a Van dorn sampler into the water and subsequently filling the bottles.

Over the course of 2019, calibration and validation procedures were reviewed to improve alignment with draft National Environmental Monitoring Standards (NEMS) (Part 4 – Coastal Waters) (draft released in April 2019). The finalised monitoring standard was released in February 2020 (NEMS, 2020) and since then all field measurements have been collected in accordance with it. Previously, field measurements were consistent with equipment accuracy specifications and were operated in accordance with in-house procedures and calibration requirements.

Samples from Auckland Council sites were analysed under contract by RJ Hill Laboratories Ltd (Hills), an IANZ accredited laboratory. Analytical methods follow the “Standard Methods for the Examination of Water and Wastewater” 22nd Edition (APHA 2017).

Samples from Watercare Services’ HEMP sites were analysed by Watercare Laboratories, in accordance with the methods specified in the Monitoring Management Plan (Watercare Services Limited 2011). Laboratory analysis methods between Hills and Watercare Laboratories differ due to different instruments and protocols including different detection limits, which can influence results and should be considered when comparing results between sites, as these may not represent a true difference in the environment.

All field and laboratory data are stored in Auckland Council’s specialised water quality database, KiWQM (Kisters Pty Ltd).

2.3.1 Covid-19 impacts on monitoring

Water quality monitoring was suspended during Covid-19 Alert Level 4 lockdown conditions. Water quality monitoring able to be undertaken from land or via boat was resumed during Level 3 conditions. Water quality monitoring undertaken via helicopter was resumed during Level 2 conditions. Consequently, no samples were collected: within the Waitematā Harbour in March 2020; for the East Coast, Kaipara Harbour, or Manukau Harbour in April 2020; for all sites in the Manukau and Kaipara Harbours in August to October 2021; and the East Coast in September and October 2021.

2.3.2 Data exclusions due to courier delays and access restrictions

Covid-19 restrictions and weather events led to significantly delayed sample delivery on several occasions during the reporting period. Consequently, sample age and temperature at arrival in the laboratory were below the required delivery standards and the relevant data had to be excluded from reporting. This includes Watercare sites in the Manukau Harbour from March to May 2022, and East Coast, Kaipara Harbour and some Auckland Council Manukau Harbour sites in December 2021. In addition, there was restricted access to monitoring sites in the Tāmaki Estuary in December 2021 (Tāmaki), February 2021 and January 2022 (Panmure Bridge), which did not allow sample collection.

2.4 Data processing

Quality control was undertaken in accordance with Auckland Council's internal standards, including procedures for the collection, transport and storage of samples, and methods for data verification and quality assurance to ensure consistency across the monitoring programme. Quality coding was also undertaken in accordance with internal standards that have been aligned, where possible, with the NEMS quality coding framework.

Data for each variable were analysed for each site, and initially compared to data previously collected over a 10-year period. Historical data were used to obtain the 5th and 95th percentiles, and if any new data fell outside of these boundaries, it was flagged. This allows the processor to check for erroneous data and repair inconsistencies or comment as appropriate. Prior to any analysis, data points that were assigned a 'poor' quality assurance code were removed from the dataset.

2.5 Data analysis

The data analysis period for this report was changed to match Auckland Council's freshwater reporting, which was adjusted to accommodate National Policy Statement for Freshwater Management 2020 (NPS-FM) reporting requirements, and data presented on the Land Air Water Aotearoa (LAWA) website (Ingley et al. 2023). Consequently, data reporting timeframes for this report were changed to a five-year period over the hydrological years[4] from July 2017 to June 2022. Statistical results for a five-year period are generally considered more robust than those from the three-year period previously used.

All data was checked for censored values outside of laboratory analysis detection limits (less than or more than the relevant detection limit). There were no values larger than the detection limit (right censored). Values below detection limit (left censored) were replaced by imputed values generated using regression on order statistics (ROS, as per Snelder & Fraser 2018; Whitehead et al. 2022) for five-year statistics only. For annual statistics over one hydrological year, left censored values were replaced with a value half the detection limit.

Descriptive statistics for the July 2017 to June 2022 hydrological years are presented as box plots which show variation in the data. Box plots were produced using the R statistical software package (R

[4] Each hydrological year starts in July and ends in June, e.g. hydrological year 2022 runs from 1 July 2021 to 30 June 2022.

Core Team 2020), using the Hazen percentile function. The boxes represent the inter-quartile range (25^{th} and 75^{th} percentiles) and the whiskers extend to the 5^{th} and 95^{th} percentile values. Values beyond that range are plotted as outliers. The median is shown as a line within each box. Boxplots for individual hydrological years are provided in Appendix 3. Parameters for sites where more than 50% of data were censored values were excluded from annual box plots and are marked by an asterisk. Summary statistics tables and monthly boxplots over the latest five-yearly assessment period showing parameter exceedances driving the WQI for each site are available as a supplementary data file on Knowledge Auckland.[5]

The interpretation of box plot data is aided through the use of univariate linear regression analyses (carried out in Statistica™ software) and multivariate cluster analysis. Cluster analysis uses multiple variables to group [in this case] sites based on their similarity. Cluster analyses were carried out in Primer-e (version 7) using Euclidian distances and normalised five-year median values (obtained from near-monthly samples) for each variable. Statistically significant (5%) clusters were identified using similarity profile analysis and mapped using ArcGIS software.

2.5.1 Water Quality Index

A Water Quality Index (WQI) is used to simplify how we communicate the state of water quality at each site by incorporating multiple factors into a single score and overall water quality class (Table 2-1).

The WQI used in this report is based on an index developed by the Canadian Council of Ministers for the Environment (CCME 2001), with some modifications. The CCME index framework has been utilised by other New Zealand regional councils (e.g. Greater Wellington Regional Council and Northland Regional Council), and is used internationally in both freshwater and saline water quality reporting (Ballantine 2012).

Our approach is based on exceedances of defined water quality guidelines for a subset of six parameters. Guidelines are derived from three main sources: the 80^{th} percentile of 10 years of data (2007-2016) at reference sites within the Auckland region; Australia and New Zealand default guidelines (ANZECC 2000); and Northland Regional Council tidal creek guidelines (Table 2-2). Separate guidelines are used for open coast, estuarine sites, and tidal creek sites (Foley 2018; Ingley, 2020). These guidelines are not regulatory triggers or thresholds and are only provided to enable comparison between sites and to identify potential issues that warrant further investigation.

Monthly median values between the July 2017 to June 2022 hydrological years were used to calculate the 2022 WQI score. This represents a change to previous years where the WQI score was calculated using the monthly median over three calendar years. For historical context, the annual rolling WQI scores were calculated using the new timeframe for 10 years prior to the current reporting period. See Appendix 4 for further detail on Auckland Council's application of the CCME WQI methodology.

[5] https://www.knowledgeauckland.org.nz/natural-environment/

Table 2-1: Water quality index categories and scoring ranges used by Auckland Council (CCME, 2001).

WQI Class	Score range	Meaning
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment, conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within guidelines all the time.
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels or water quality guidelines.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels or water quality guidelines.
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels or water quality guidelines.
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels or water quality guidelines.

Table 2-2: Water quality index guidelines for the Auckland region

Parameter	Open Coast Guideline	Estuary Guideline	Preliminary Tidal Creek Guideline
Dissolved oxygen (% saturation)	90-110%[1]	90-110%[1]	80--110%[3]
Turbidity (NTU)[1]	<1	<10	<10
Chlorophyll *a* (mg/L)	<0.0023	<0.0031	<0.0039[2]
Soluble reactive phosphorus (mg/L)	<0.012	<0.021	<0.021[3]
Nitrate + nitrite nitrogen (mg/L)	<0.027	<0.029	<0.047[2]
Ammoniacal nitrogen (mg/L)	<0.015[4]	<0.015[4]	<0.018[2]

[1] Based on ANZECC default guidelines, not 80th percentile of reference sites from Auckland region.
[2] Based on the 90th percentile of estuary reference sites from the Auckland region.
[3] Based on Northland Regional Council Tidal Creek Guidelines (Griffiths 2016).
[4] Based on ANZ default guideline for ammonium (NH_4^+) not ammoniacal nitrogen (NH_3+NH_4). At the average pH of seawater, approximately 95% of ammoniacal nitrogen is in the ammonium.

2.6 Limitations

2.6.1 Programme changes

The number of sites within the programme has varied over time, primarily to improve the regional coverage. Some sites have also been discontinued due to budget and resource constraints.

The number and type of water quality parameters measured has varied since programme inception as new technology has become more affordable, instrument sensitivity has improved, and the programme objectives modified. Refer to Appendix 5 for a history of changes over time.

2.6.2 Data continuity

Due to logistical requirements, changing priorities, and improvements to methodologies, some discontinuities exist within the dataset.

The service provider used for laboratory analysis changed in July 2017 from Watercare Services Ltd to Hill Laboratories Ltd (Hills). This changeover coincided with some minor changes to analytical methodologies, and detection limits for select parameters. All samples collected from 2018-2022 were analysed by Hills and laboratory analysis methods are comparable between sites within the year.

Some discrepancies have been observed in longer-term trends, particularly for:

- Ammoniacal nitrogen, where a step increase was observed coinciding with the change in service provider (see Ingley 2021 for further information).
- Total nitrogen, where a series of step increases has been observed one in January 2016 and the other July 2017.
- Chlorophyll *a*, where a higher laboratory detection limit between July 2017 and June 2018 resulted in poor resolution of the data and a high percentage of values below the detection limit (e.g., 71% of values from January to May 2018 compared to 4% of values from June to December 2018). Since June 2018, data was consistently analysed using the method with the more sensitive detection limit.

3 Results and discussion

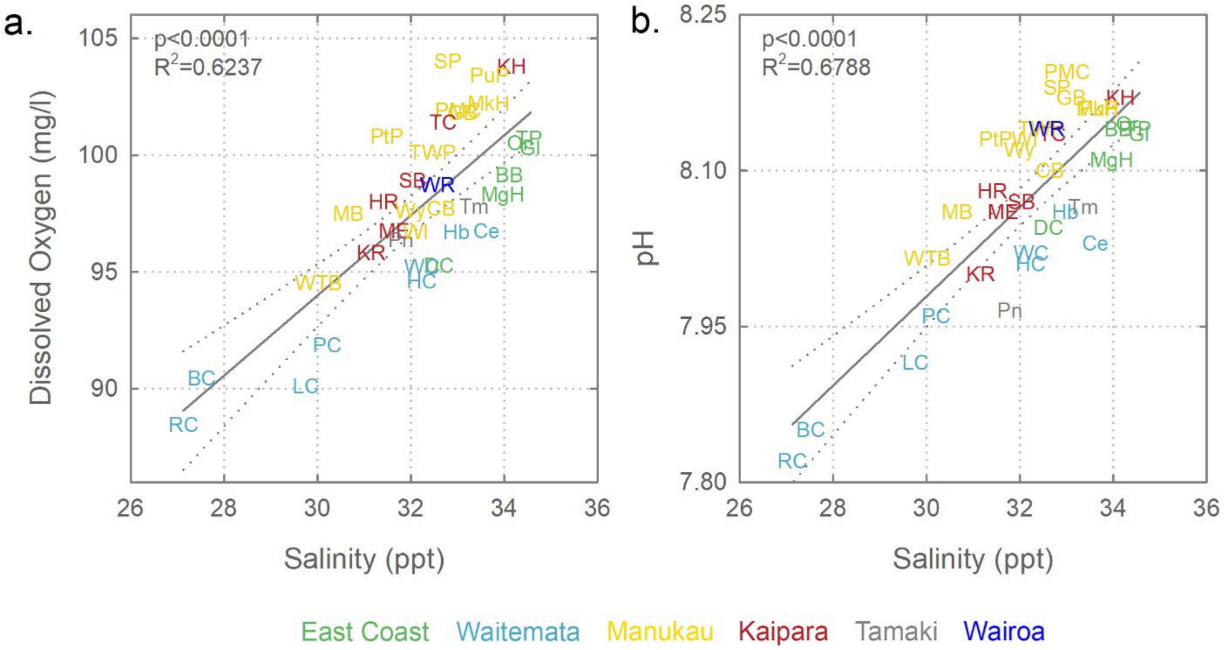
3.1 Fundamental parameters

Fundamental water parameters include: dissolved oxygen (measured as percent saturation and concentration); water temperature; salinity (measured as conductivity and salinity), and pH.

Dissolved oxygen saturation concentrations in surface waters are primarily affected by gaseous exchange between the air-sea interface, the release of oxygen during photosynthesis, and uptake of oxygen during respiration. Dissolved oxygen solubility also decreases with increasing temperature and salinity (Best et al. 2007). Accordingly, spatial patterns in dissolved oxygen saturation tended to match those in salinity and conductivity, with linear regressions showing five-year median salinity and conductivity values each explaining around 62% of the variation in five-year median values of dissolved oxygen saturation ($p<0.00001$). Similarly, pH and salinity are also related, with five-year median values of salinity explaining 67% of the variation in pH (Figure 3-1).

Consequently, tidal creek sites of the Upper Waitematā, which have the strongest freshwater influence (as indicated by salinity values), displayed the greatest variation in, and lowest median values, of salinity, dissolved oxygen and pH (Figure 3-2 to Figure 3-4). Of those sites, fluctuations in salinity and pH values were largest at the Brigham and Rangitopuni Creek sites.

Gradients away from significant freshwater sources were apparent in the Manukau, Kaipara, Waitematā and Mahurangi Harbours and Tāmaki Estuary (Figure 3-2 to Figure 3-4). Oceanic influences are strongest at coastal sites from Browns Bay north, where median salinity and pH values were consistent with those typical of marine waters. These patterns were generally reflected in the results of a cluster analysis that grouped sites based on the similarity of median values of salinity, dissolved oxygen (% saturation) and pH.



BB-Browns Bay, DC-Dawsons Creek, GI-Goat Island, MgH-Mahurangi Heads, Or-Orewa, TP-Ti Point, HR-Hoteo River, KH-Kaipara Heads, KR-Kaipara River, ME-Makarau Estuary, SB-Shelly Beach, TC-Tauhoa Channel, CB-Clarks Beach, GB-Grahams Beach, MB-Mangere Bridge, MkH-Manukau Heads, PtP-Puketutu Point, PuP-Puponga Point, PMC-Purakau Mid Channel, SP-Shag Point, TWP-Te Whau Point, WTB-Waiuku Town Basin, Wy-Weymouth, WI-Wiroa Island, Pn-Panmure, Tm-Tamaki, WR-Wairoa River, BC-Brighams Creek, Ce-Chelsea, HC-Henderson Creek, Hb-Hobsonville, LC-Lucas Creek, PC-Paremoremo Creek, RC-Rangitopuni Creek, WC-Whau Creek.

Figure 3-1: Scatterplots with linear regressions (± 95% CI) fitted showing relationships between median salinity and a) dissolved oxygen saturation, and b) pH in near-monthly coastal water quality samples collected over the five-year period from July 2017 to June 2022.

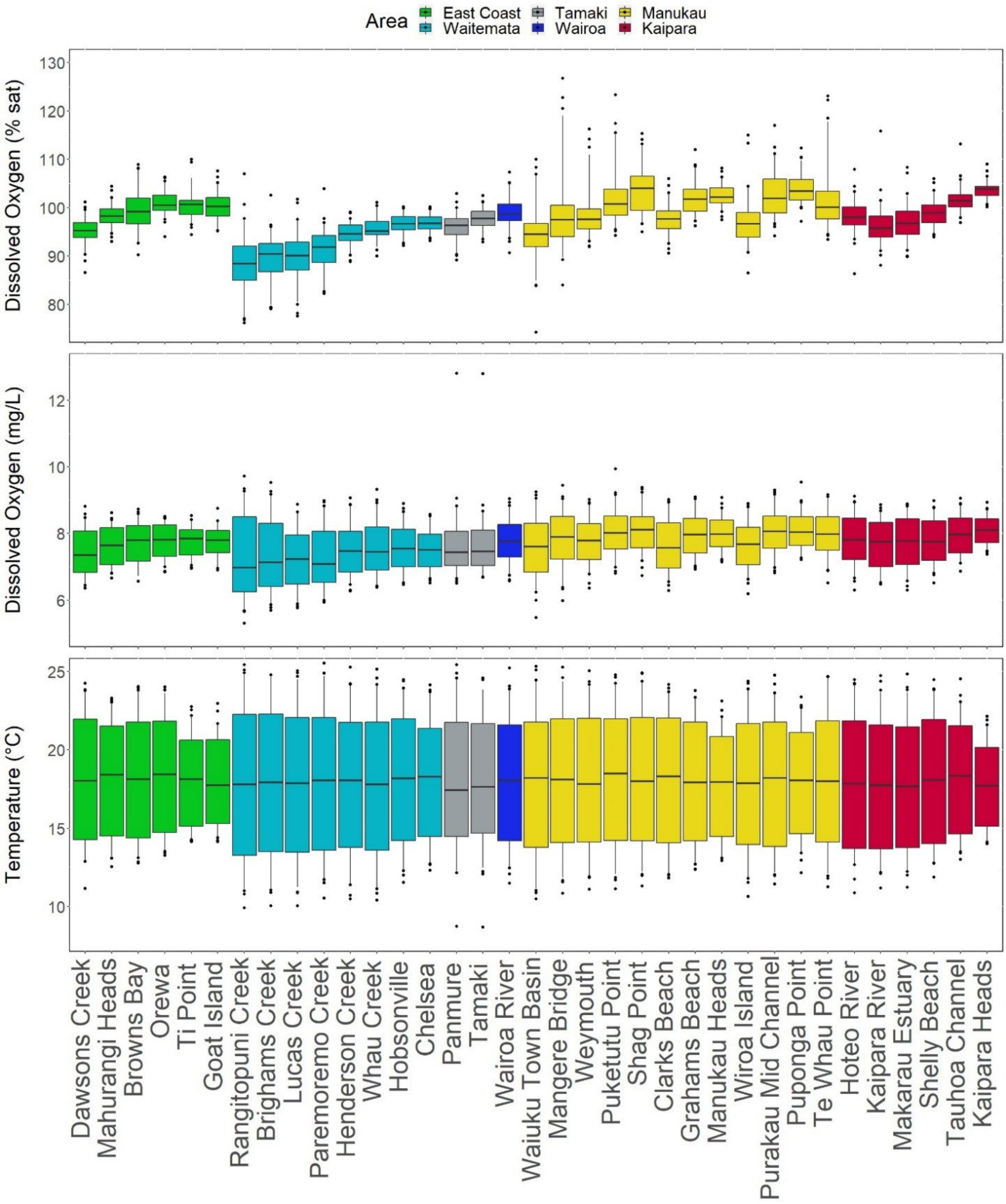


Figure 3-2: Variation in two indices of dissolved oxygen (% saturation and mg/L) and sea surface temperature for coastal water quality data collected over the five-year period from July 2017 to June 2022. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

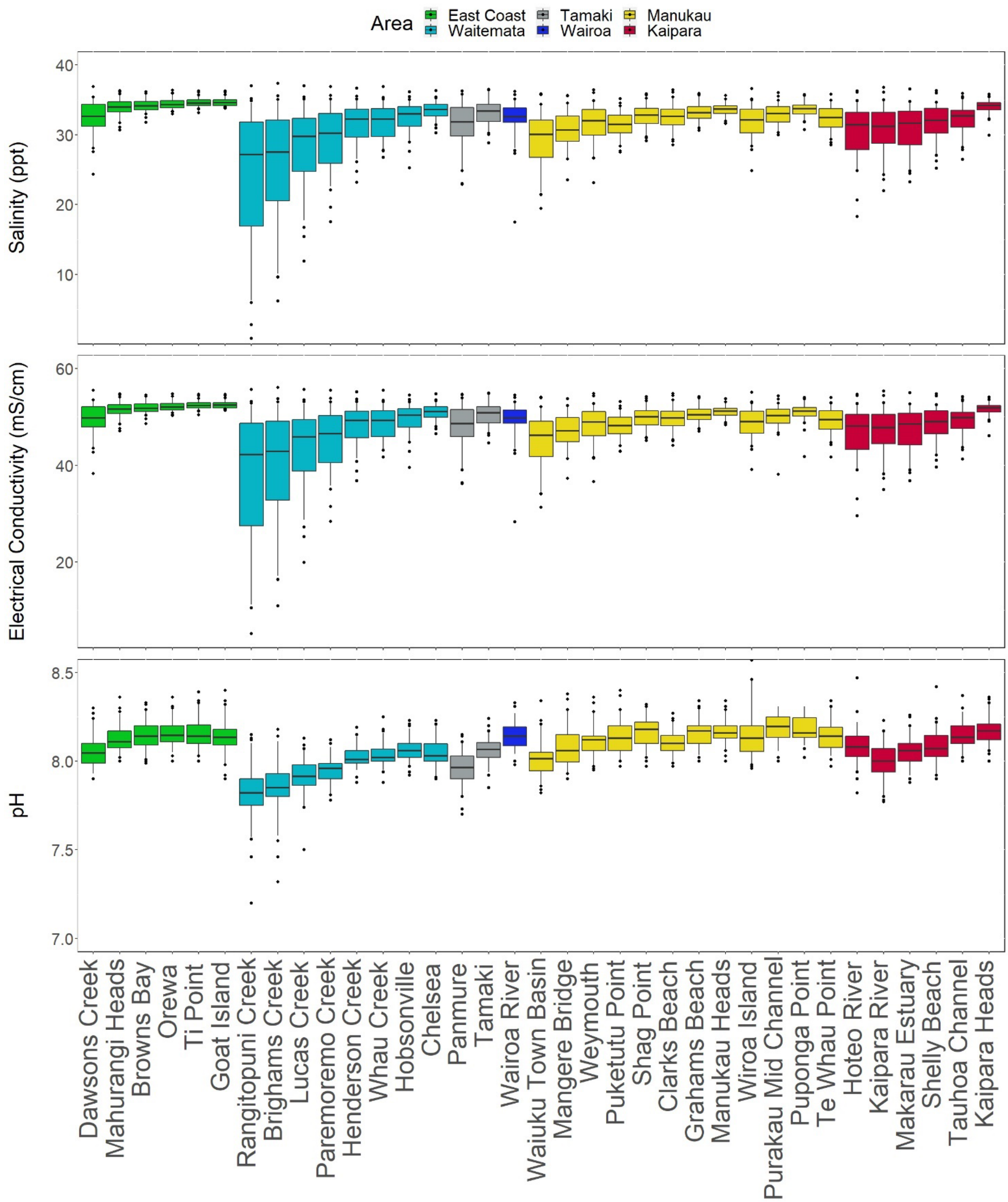


Figure 3-3: Variation in salinity, conductivity, and pH for coastal water quality data collected over the five-year period from July 2017 to June 2022. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity. Box plots show interquartile range (IQR). Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker

= 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

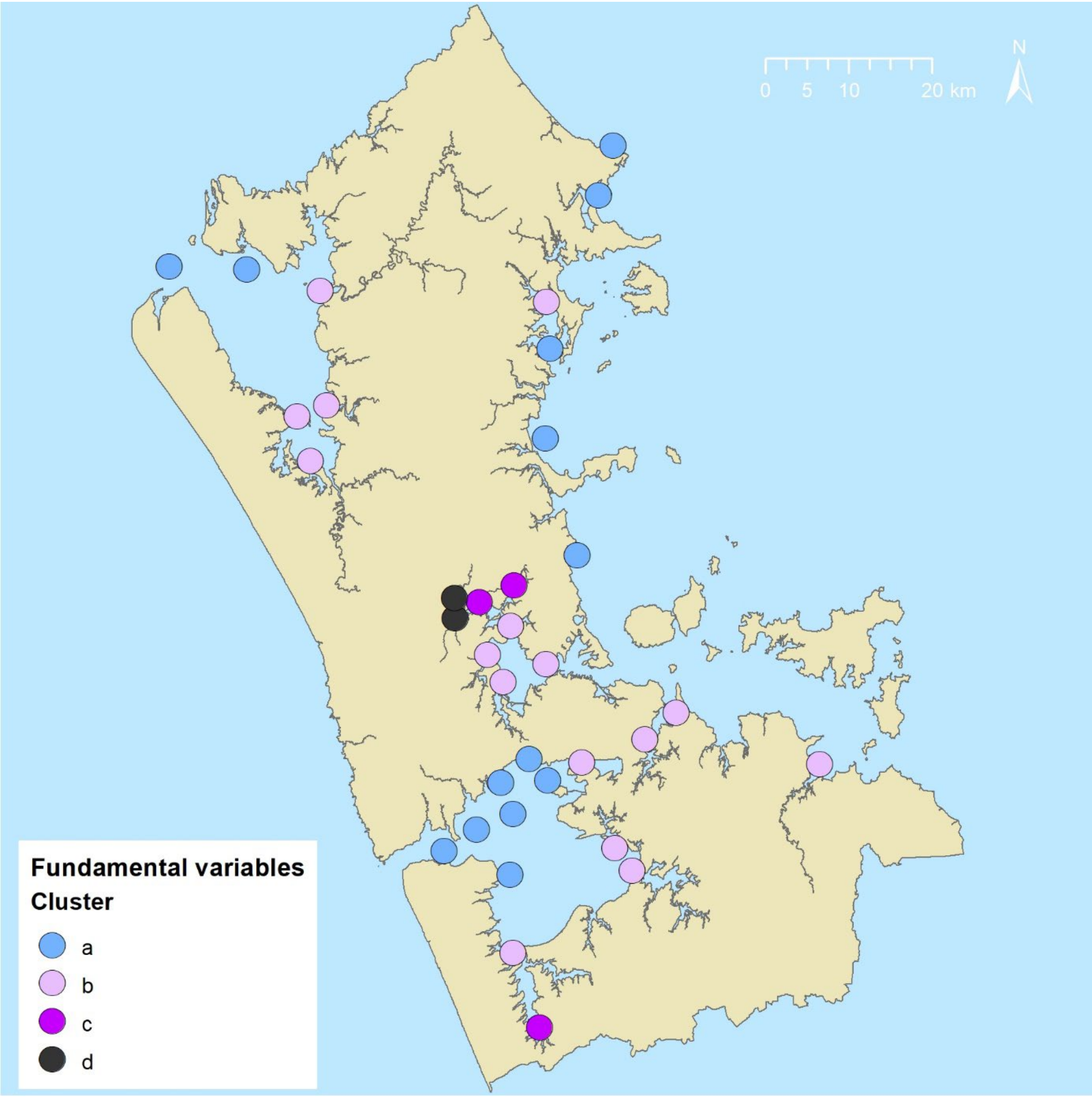


Figure 3-4: Significant clusters identified using multivariate cluster analysis of normalised, five-year median values of salinity, dissolved oxygen (% saturation) and pH for coastal water quality data collected between July 2017 and June 2022. Median salinity, pH, and dissolved oxygen saturation values decrease from Clusters a to d.

3.2 Nutrients and primary productivity

Nitrogen and phosphorus are the key nutrients of concern in the marine environment, with nitrogen generally considered to be the nutrient of most concern. Nutrients are necessary to sustain the plant and algae growth that forms the foundation of the marine food chain. Slight increases in nutrients can increase ecosystem productivity, but excess nutrient levels are detrimental and potentially lead to nuisance phytoplankton (planktonic microalgae) and seaweed blooms and may cause other adverse effects including toxicity. Nutrients naturally up-well from deep offshore waters, are recycled through decomposition and geochemical processes, and are washed off the land. Wastewater discharges, fertilisers and livestock effluent add to natural nutrient sources and can cause detrimental effects.

The effects of coastal nutrients on productivity are also mediated by other environmental factors, particularly the form of the nutrients present, light availability, proximity to catchment sources, and catchment loads. Stratification of the water column also affects the transfer of nutrients between bottom and surface waters.

Nitrogen and phosphorus come in soluble and non-soluble forms. Soluble forms of nitrogen and phosphorus are immediately available for uptake by algae and marine plants. Soluble inorganic forms of nitrogen include nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N)[6], and ammoniacal nitrogen (NH_3-N and NH_4^+-N). Soluble phosphorus compounds are typically grouped as dissolved (or soluble) reactive phosphorus (DRP or SRP). Other nutrient forms typically included in water quality assessments and monitoring programmes are total nitrogen (TN), and total phosphorus (TP). They represent all forms of nitrogen and phosphorus present in a water sample.[7]

All plants and marine algae, also require light to survive and grow. Plants and algae convert light to energy using a pigment called chlorophyll. Chlorophyll *a* is the form commonly used as a proxy for the abundance or biomass of phytoplankton in water quality monitoring programmes.

Light availability varies seasonally, and with water clarity and depth. Generally, coastal primary productivity is limited in late autumn-winter, when days are shorter and light intensity tends to be relatively low. This is reflected in low chlorophyll *a* concentrations, reduced nutrient uptake by phytoplankton, and consequently, increasing water-column nutrient concentrations. In spring-summer, nitrate inputs from upwelling and longer, brighter days enable phytoplankton populations to rapidly grow, but growth quickly becomes limited by the availability of nutrients. This is reflected in increasing chlorophyll *a* concentrations through spring, high nutrient uptake by phytoplankton, and consequently, reducing nutrient concentrations (see Figure 3-5)[8]. This has the following consequences:

[6] The sum of nitrate and nitrite is referred to as total oxidised nitrogen or TON.
[7] Total organic nitrogen and total Kjeldahl nitrogen (TKN – the sum of organic and ammoniacal nitrogen) may also be assessed.
[8] This pattern tends to be strongest at sites with elevated nutrient concentrations.

- In winter, spatial differences in chlorophyll *a* concentrations among sites subject to different nutrient inputs tend to be relatively small, but differences in nutrient concentrations tend to be relatively large.
- In summer, spatial differences in chlorophyll *a* concentrations among sites with different nutrient inputs tend to be relatively large, but differences in nutrient concentrations tend to be relatively small.

These general patterns are subject to variation caused by shifts in natural processes such as climatic conditions (e.g. changes in wind strength and direction, which affects the upwelling of nutrients from deep water) [9] and variation in nutrient loads from human activities. However, as a general rule, sites with higher median chlorophyll *a* and nutrient concentrations also tend to display larger levels of seasonable variability.

Those general patterns are reflected in boxplots of water quality results for the key indicators of nutrient effects (Figure 3-6 and Figure 3-7), and site groupings obtained through cluster and similarity profile analysis of the following median values:

- chlorophyll *a* and soluble forms of nitrogen and phosphorus
- chlorophyll *a*, total nitrogen and total phosphorus (Figure 3-9).

Scatterplots from each site also show that relationships between median concentrations of key nutrients and chlorophyll *a* are non-linear and vary depending on the nutrient type and form. In general, pooled chlorophyll *a* concentrations from the monitoring sites initially increase with increasing nutrient concentrations, but the rate of increase diminishes as nutrient concentrations get higher (Figure 3-8).

Nutrient concentrations at two Manukau Harbour sites stood out (Puketutu Point and Mangere Bridge) for their high median and 95^{th} percentile concentrations. At those sites, total and dissolved reactive phosphorus concentrations were particularly high (TP medians of 0.09-0.105 mg/L and 95^{th} percentiles of 0.144-0.214 mg/L; and DRP medians of 0.076-0.077 mg/L and 95^{th} percentiles of 0.115-0.18 mg/L). This is not surprising, given that New Zealand's largest wastewater treatment plant (Mangere WWTP) discharges to that area (Figure 3-9). Waiuku Town Basin also had relatively high and variable nitrogen concentrations. They presumably reflect its location in an upper section of a long, narrow inlet surrounded by rural and urban land uses, and its proximity to the discharge from the Waiuku wastewater treatment plant.

Patterns in total and dissolved nutrient and chlorophyll *a* concentrations in other southern, central and outer Manukau Harbour sites are comparable to those at similarly situated sites in Kaipara Harbour (see Figure 3-9 for patterns using total nutrients, noting that those for dissolved nutrients are similar). In both harbours, nutrient and chlorophyll *a* concentrations decline with distance from major inlets and rivers, through central parts of the harbours, and towards their entrances.

[9] Note a variety of other biological, chemical and physical processes can influence these general patterns.

Similar, patterns occur between the upper and outer Waitematā, and mid and outer Tāmaki (Figure 3-6 and Figure 3-7). The gradient is particularly pronounced for nitrogen, with Rangitopuni Creek in the Upper Waitematā having the highest maximum and 95th percentile total nitrogen concentrations between 2018 and 2022 in this harbour. Total nitrogen concentrations in the adjoining Brighams Creek site were similarly high. Nutrient and chlorophyll *a* concentrations decline towards the harbour/river entrances where marine influences become more dominant. Due to their location, eastern coastal sites are also dominated by marine influences, and experience even greater flushing. At those sites, terrestrial nutrient inputs have less influence on primary productivity and chlorophyll *a* concentrations are lower.

Overall, the results suggest that sites in, or near the entrance of, narrow inlets or rivers in upper harbour and estuary sites are the most sensitive to nutrient effects. As noted above, WWTPs are obvious nutrient point sources for some sites, but all of the monitoring sites in the southern Manukau, upper Waitematā, Kaipara and Mahurangi are also subject to diffuse agricultural and horticultural nitrogen sources. The majority of these sites are also subject to urban inputs. The relative contributions of the various point and diffuse sources to overall coastal nutrient loads were not investigated as part of this report. It is recommended that future studies focus on the relative contribution of different nutrient sources.

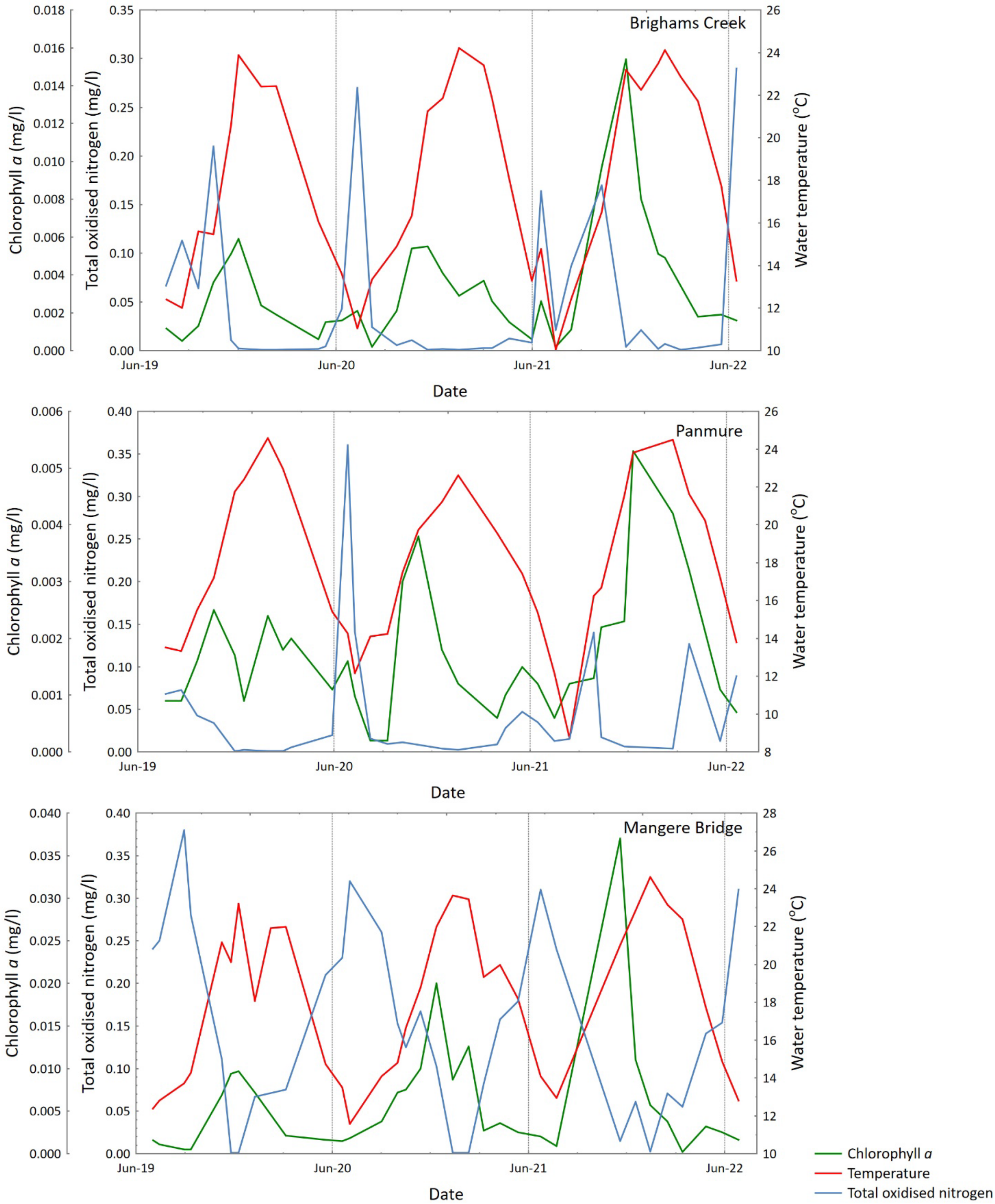


Figure 3-5: Examples of variation in water temperature (used as a proxy for season), total oxidised nitrogen and chlorophyll *a* concentrations at sites in the Waitemata Harbour (Brighams Creek), Tāmaki Estuary (Panmure) and Manukau Harbour (Mangere Bridge).

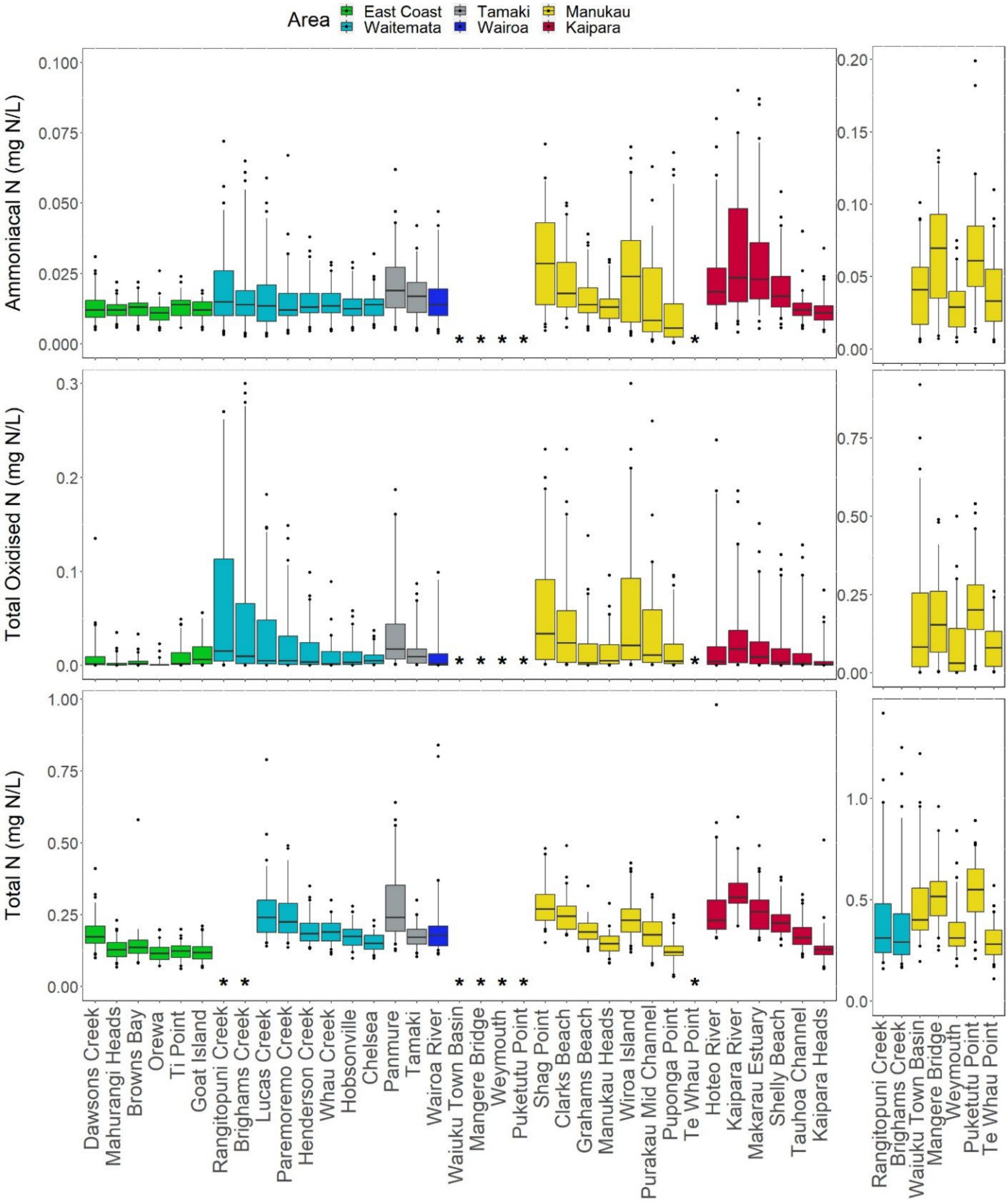


Figure 3-6: Variation in ammoniacal nitrogen, total oxidised nitrogen and total nitrogen concentrations in near-monthly coastal water quality samples collected over the five-year period from July 2017 to June 2022. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity. Sites marked with an asterisk are plotted on inset graphs to the right for better visualisation. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

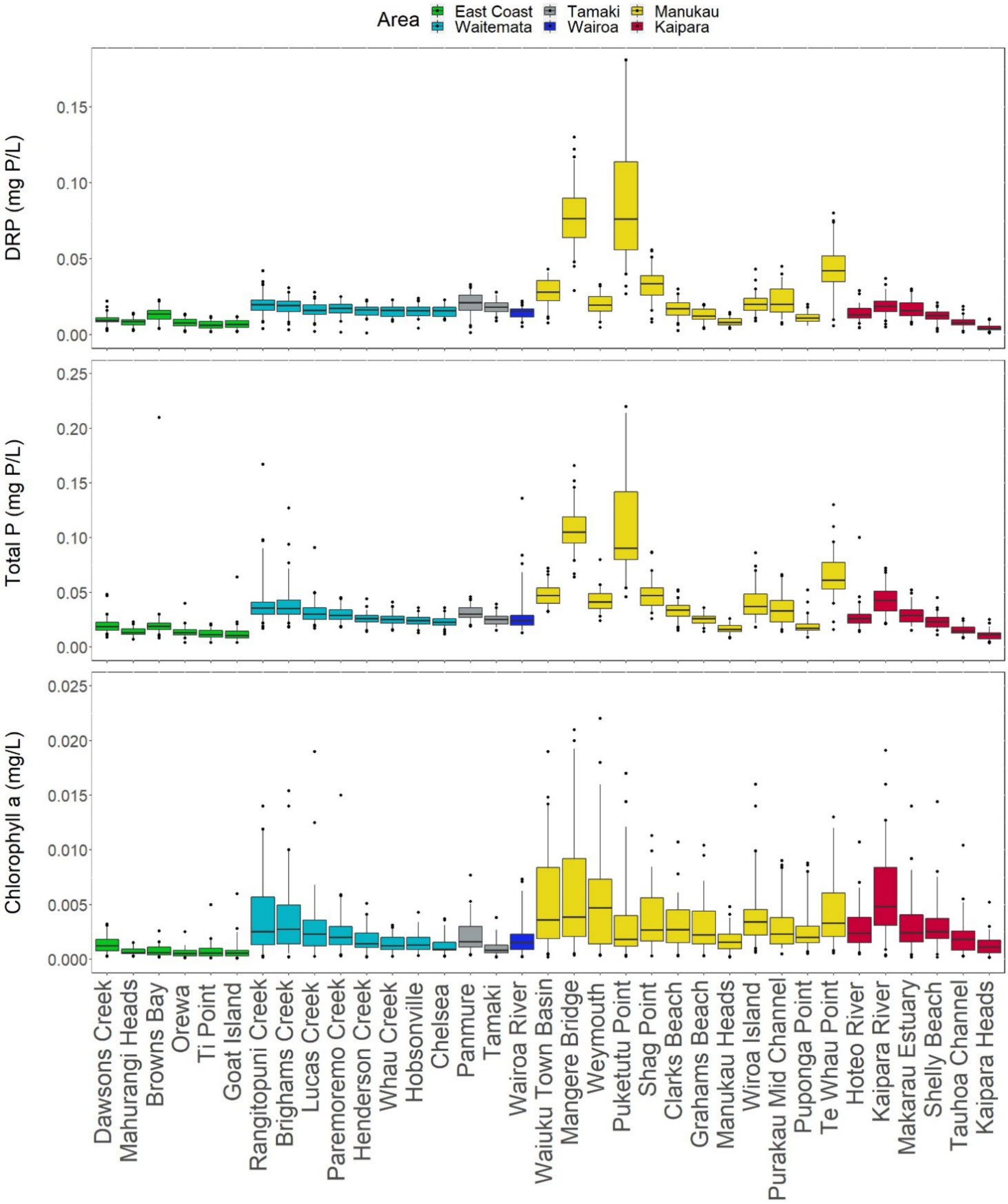
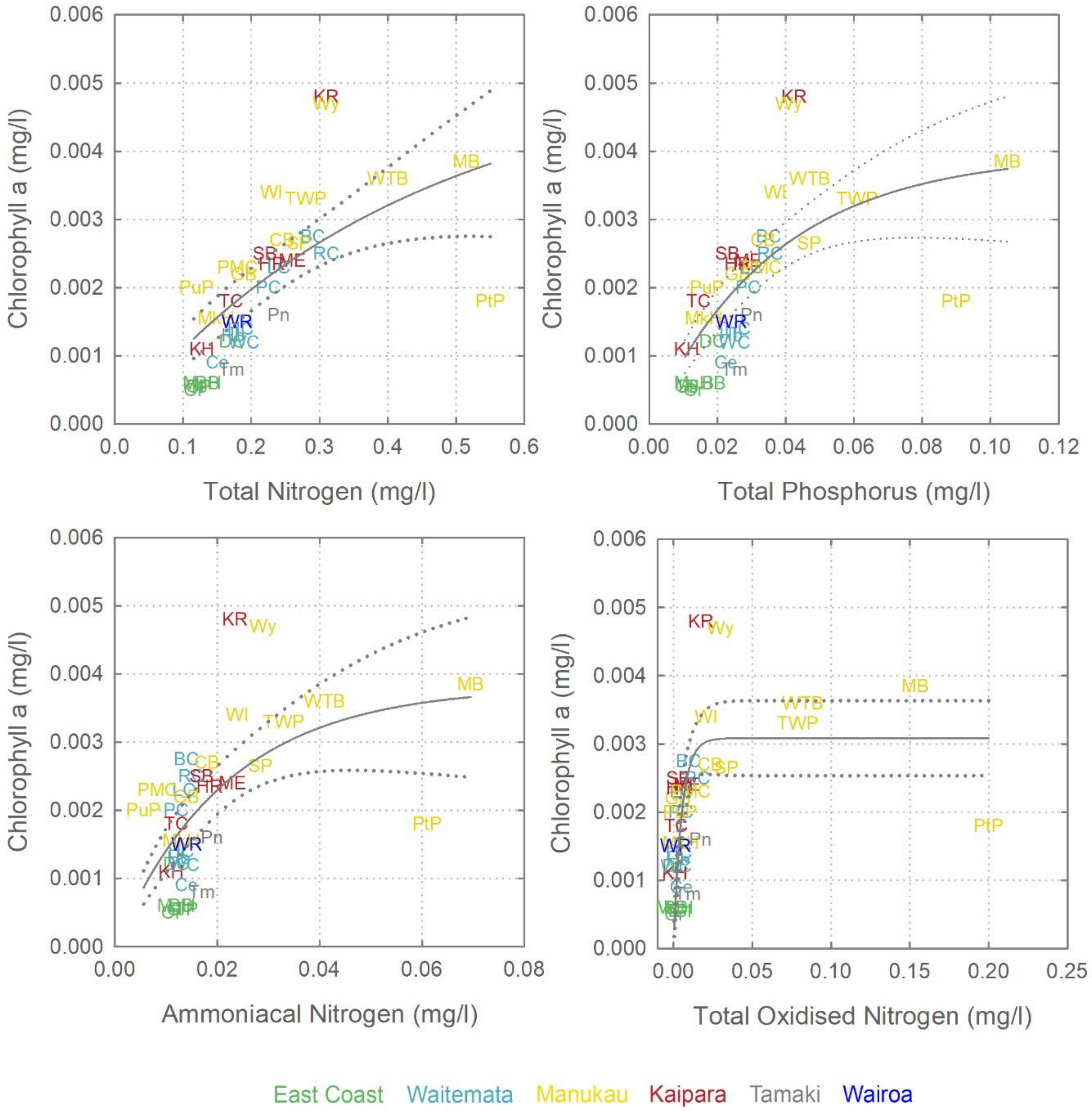


Figure 3-7: Variation in dissolved reactive phosphorus, total phosphorus and chlorophyll *a* concentrations in near-monthly coastal water quality samples collected over the five-year period from July 2017 to June 2022. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.



BB-Browns Bay, DC-Dawsons Creek, GI-Goat Island, MgH-Mahurangi Heads, Or-Orewa, TP-Ti Point, HR-Hoteo River, KH-Kaipara Heads, KR-Kaipara River, ME-Makarau Estuary, SB-Shelly Beach, TC-Tauhoa Channel, CB-Clarks Beach, GB-Grahams Beach, MB-Mangere Bridge, MkH-Manukau Heads, PtP-Puketutu Point, PuP-Puponga Point, PMC-Purakau Mid Channel, SP-Shag Point, TWP-Te Whau Point, WTB-Waiuku Town Basin, Wy-Weymouth, WI-Wiroa Island, Pn-Panmure, Tm-Tamaki, WR-Wairoa River, BC-Brighams Creek, Ce-Chelsea, HC-Henderson Creek, Hb-Hobsonville, LC-Lucas Creek, PC-Paremoremo Creek, RC-Rangitopuni Creek, WC-Whau Creek.

Figure 3-8: Scatterplots with non-linear regressions (exponential rise to a maximum) fitted (± 95% CI) showing relationships between key nutrient forms and chlorophyll *a* concentrations in near-monthly coastal water quality samples collected over the five-year period from July 2017 to June 2022. Regressions are not fitted where relationships are clearly non-linear.

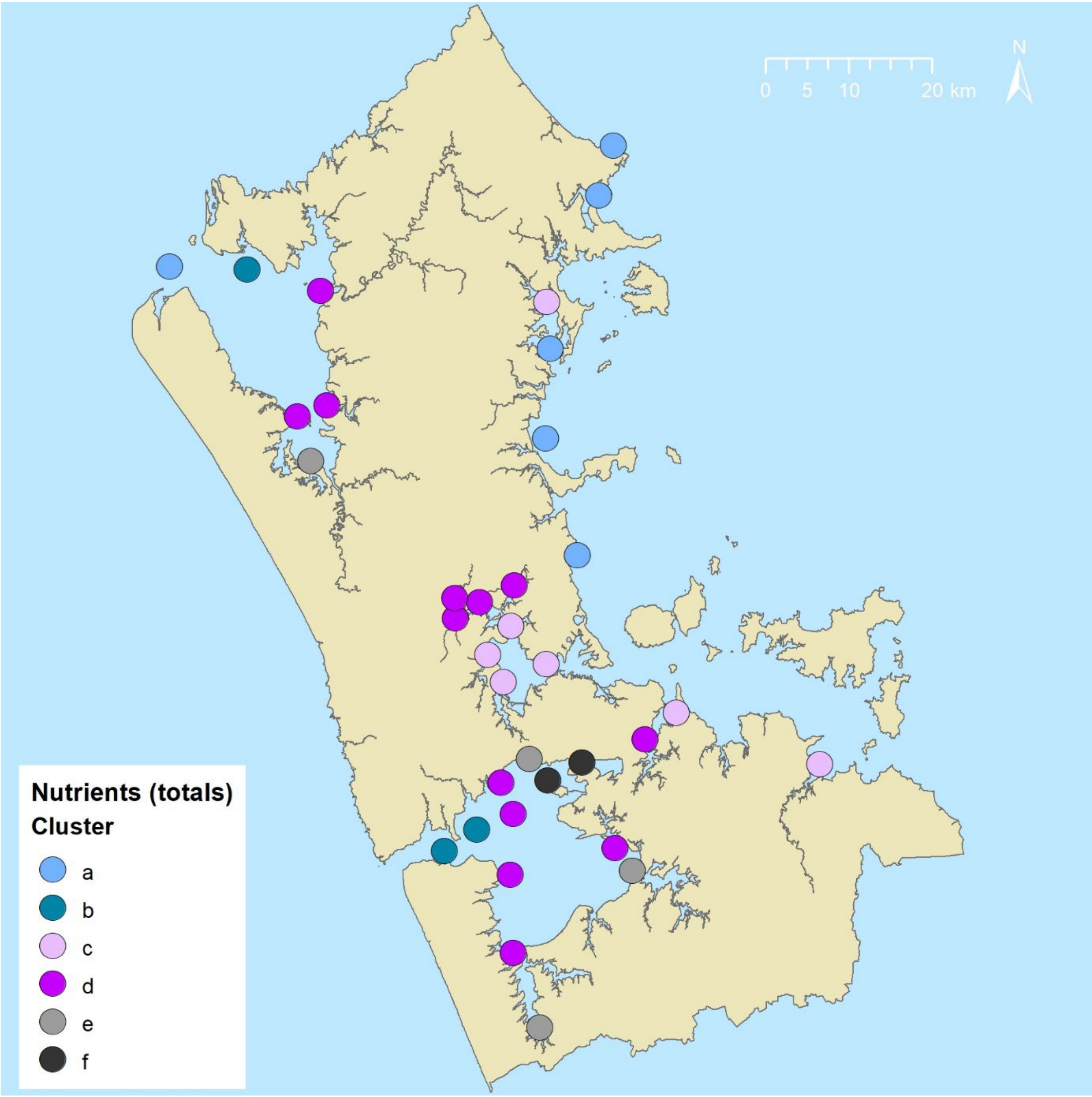


Figure 3-9: Statistically significant clusters identified using multivariate cluster and similarity profile analysis of normalised, five-year median values of total nitrogen, total phosphorus and chlorophyll *a* concentrations in near-monthly coastal water quality samples collected between July 2017 and June 2022. Concentrations increase from clusters a to f.

3.3 Suspended solids and turbidity

Water clarity is influenced by suspended particulate and dissolved matter, such as fine sediments and organic and inorganic matter, planktonic organisms (particularly phytoplankton), and coloured organic compounds. It is commonly assessed or monitored by measuring water turbidity[10] and total

[10] Done electronically using a nephelometer (commonly referred to as a turbidity meter), with readings in Nephelometric Turbidity Units (NTU).

suspended solids (TSS). While both parameters do not exclusively monitor for sediments they are often used as proxy for sediment concentration in coastal waters.

Turbidity and suspended solids naturally vary in response to sediments and organic matter in catchment runoff, proximity to catchment sources, factors that influence particle settling and resuspension (such as exposure, particle size and depth), and the speed and degree of dilution by 'clean' water. For instance, bands of high turbidity can often be seen along shallow shorelines. These 'turbidity fringes' are produced in shallow waters when wave height and water depth are sufficient to suspend sediments from the seafloor. Extensive turbidity fringes are generated in large harbours and estuaries – moving up and down intertidal flats as tides rise and fall. Turbidity maxima can also be produced in river mouths where fresh and saline waters mix. Natural effects are compounded by human activities that increase catchment erosion, remobilise sediments or other particulate material, or promote phytoplankton growth.

Significant storm or rainfall events are known to be the major contributor of sediment loads into the coastal marine environment and increase turbidity and TSS concentrations. Such events are often missed in monthly coastal state of the environment monitoring as storms may not coincide with scheduled sampling events, and stormy conditions do not allow for safe sampling helicopter operations. Consequently, results presented here are unlikely to capture peaks in TSS and turbidity values from event-driven sediment runoff on the region's harbours and estuaries. Auckland Council operates an event-based sediment monitoring programme in a selection of streams and rivers (Hicks et al. 2021) which could provide useful information about sediment loads to some coastal areas during storm events.

Boxplots of data obtained between July 2017 and June 2022 show that spatial patterns in turbidity, TSS and chlorophyll *a* concentrations were very similar (Figure 3-10). This was confirmed with linear regressions showing relationships between five-year median values of the three variables (Figure 3-11). Locations with high chlorophyll *a* concentrations also have high TSS concentrations and high turbidity (and *vice versa*). Median chlorophyll *a* concentrations explained around 73% and 83% of the variation in turbidity and TSS, respectively ($p<0.0001$), while TSS explained around 88% of the variation in turbidity (Figure 3-11).

As with nutrients, sites in, or near the entrance of, narrow inlets or rivers in upper harbour and estuary sites had the highest levels of turbidity and TSS. Turbidity and TSS cluster analysis shows the same pattern, with distinct groups of sites in the upper-, mid- and outer-harbours (Figure 3-12). Monitoring sites in the southern Manukau, Upper Waitematā, Wairoa, Kaipara and Mahurangi are subject to diffuse agricultural runoff. This is likely to be a significant source of sediment, but earthworks associated with urban development, forest harvesting and the resuspension of legacy sediment inputs to the coast are also likely to be contributing factors to high turbidity in some places, as is phytoplankton.

The Kaipara River coastal monitoring site had the highest median values for all three water clarity parameters, compared to all other sites (Figure 3-10 and Figure 3-11), resulting in it forming its own, distinct cluster (Figure 3-12). This site is relatively shallow and likely to experience some tidal resuspension and at the same time is in the sheltered southern arm of the harbour which may result in longer residence times. More in depth investigations are needed to explain the relatively high turbidity values at this site which is outside the scope of this report. It is also notable that apart from the Kaipara River site, median TSS and turbidity values at all other Kaipara Harbour sites were similar to, or lower than, those at comparable sites in Manukau and Waitematā Harbours, Tāmaki River and Wairoa Bay (Figure 3-10 to Figure 3-12).

Open east coast sites stand out for having low TSS, turbidity and chlorophyll *a* concentrations. Median values decrease slightly at sites from Browns Bay north as the influence of clean oceanic water increases.

Overall, median coastal suspended solids and turbidity are strongly correlated and display predicable patterns. Strong correlations between those variables and median chlorophyll *a* concentrations also suggests that phytoplankton have a substantial influence ambient turbidity and suspended solids concentrations. The influence of sediment runoff is likely to be greatest after significant storm events, which (because of helicopter safety constraints) are likely to be under-represented by this monitoring programme. Including volatile suspended solids in the parameter suite would assist in teasing apart the relative influences of inorganic sediments and organic matter such as phytoplankton.

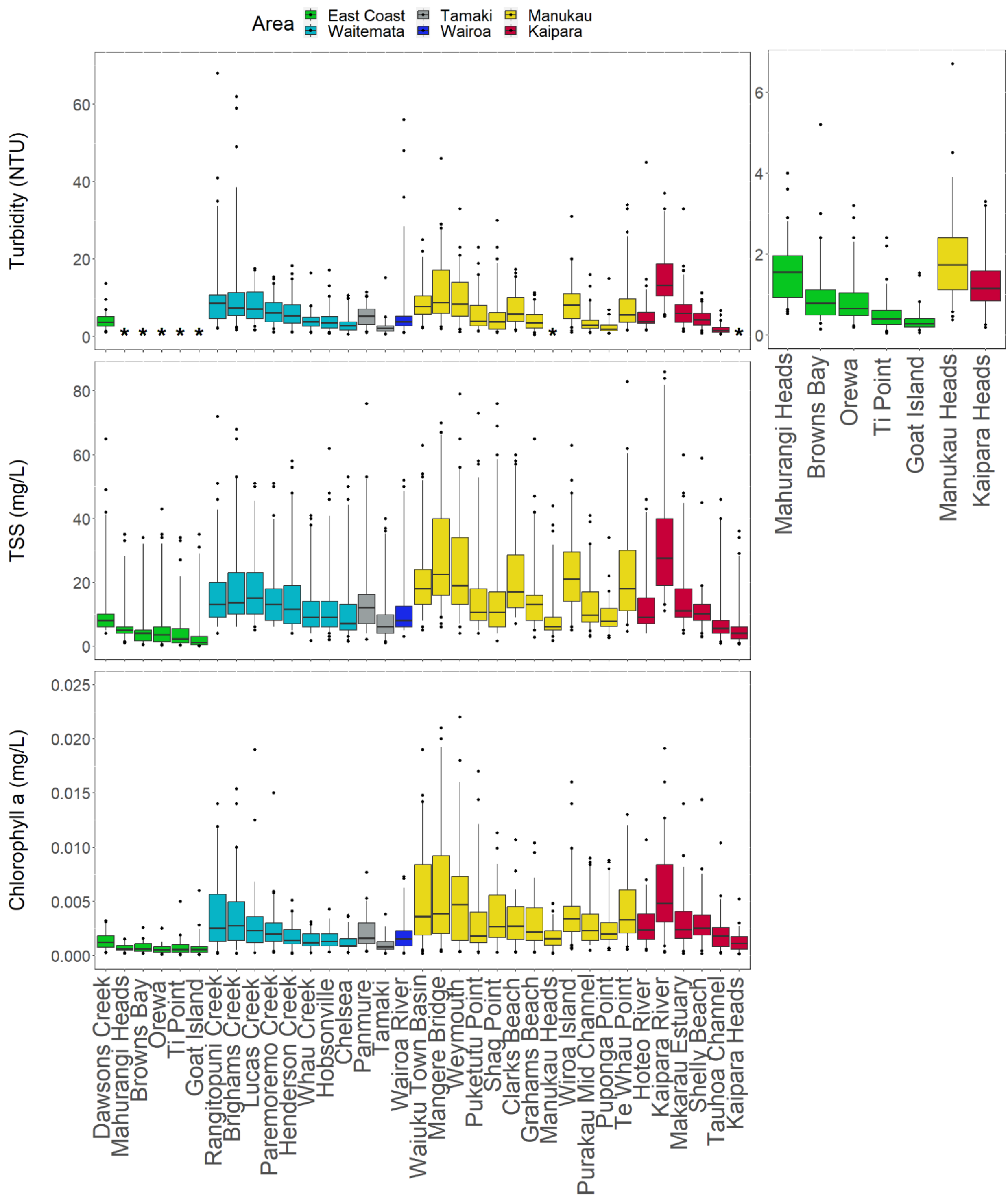


Figure 3-10: Variation in turbidity, total suspended solids and chlorophyll *a* concentrations in near-monthly coastal water quality samples collected over the five-year period from July 2017 to June 2022. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity. Sites marked with an asterisk are plotted on inset graphs to the right for better visualisation. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers

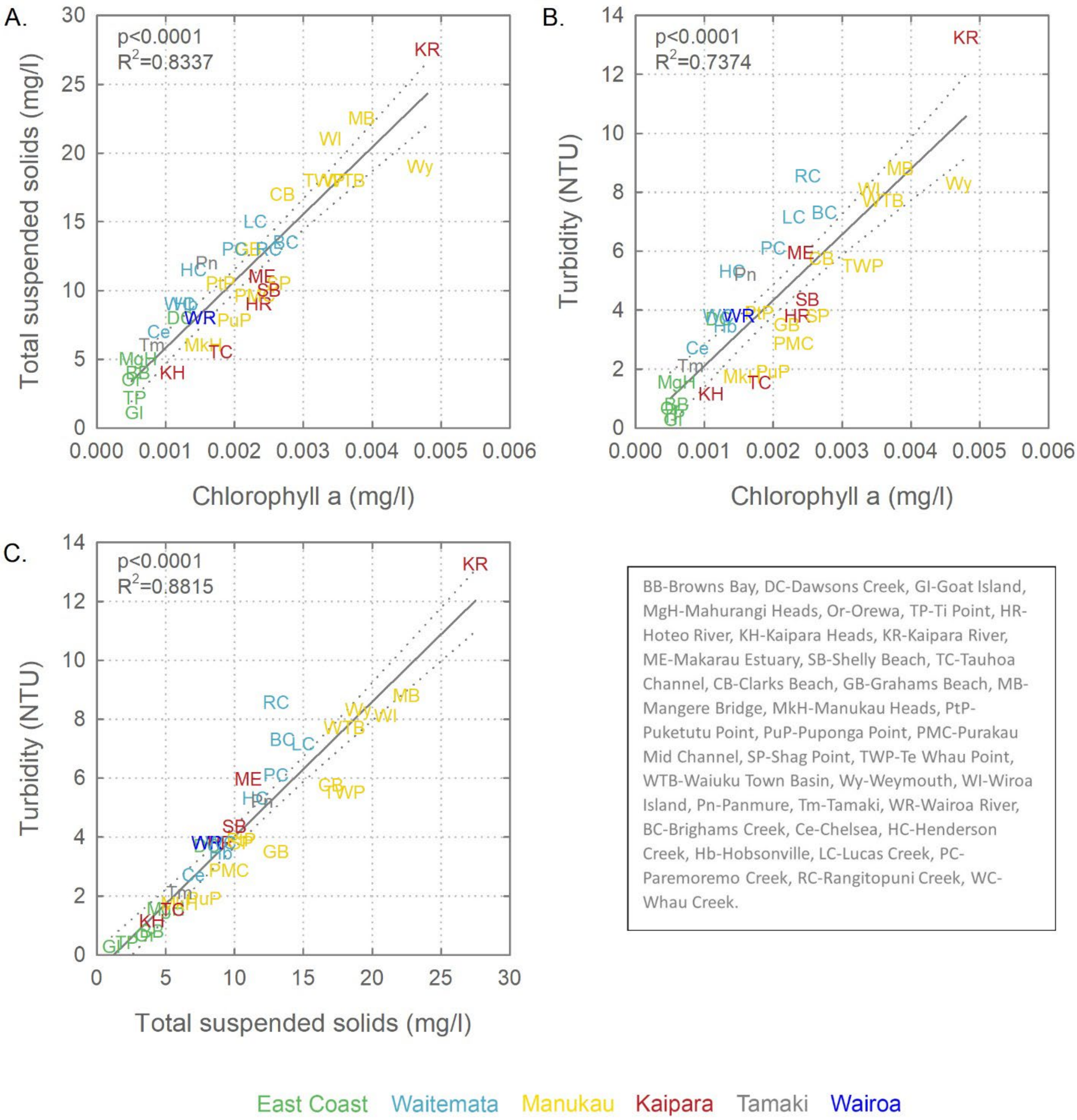


Figure 3-11: Scatterplots with linear regressions fitted (± 95% CI) showing relationship between median turbidity, total suspended solids and chlorophyll *a* concentrations in near-monthly coastal water quality samples collected over the five-year period from July 2017 to June 2022.

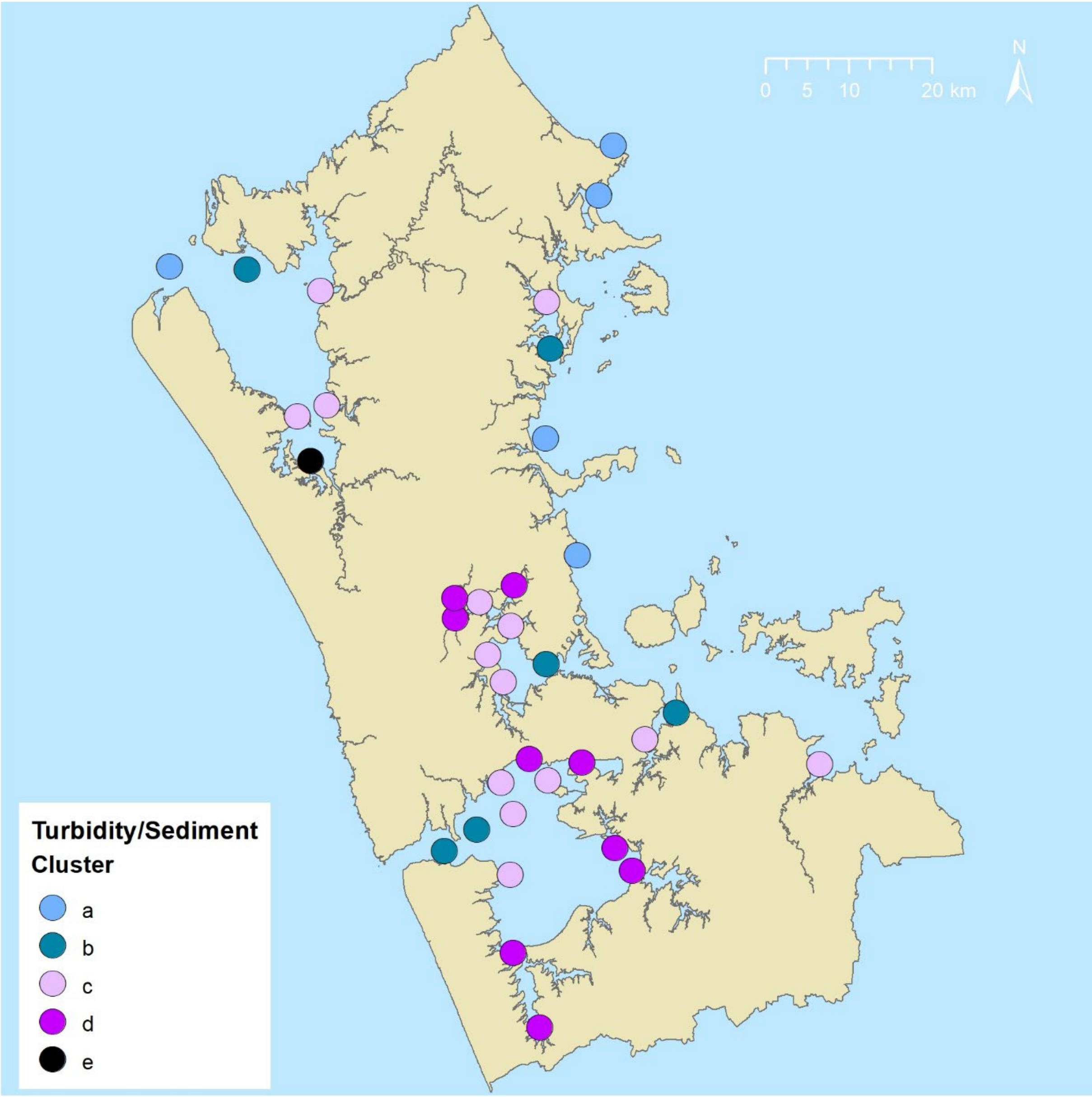


Figure 3-12: Statistically significant clusters identified using multivariate cluster and similarity profile analysis of normalised, five-year median values of total suspended solids concentrations and turbidity in near-monthly coastal water quality samples collected between July 2017 and June 2022. Concentrations increase from clusters a to e.

3.4 Water quality index

Auckland Council's Water Quality Index (WQI) provides an indicative ranking of water quality based on exceedance of the council's interim guideline values for dissolved oxygen saturation, ammoniacal nitrogen, total oxidised nitrogen, dissolved reactive phosphorus, chlorophyll *a*, and water turbidity. Separate guidelines are used for open coast, estuarine sites, and tidal creek sites (Foley, 2018; Ingley, 2020), but the index does not take into account complex relationships between variables. As noted earlier, the purpose of the WQI is to simplify how the state of water quality at each site is communicated by incorporating multiple factors into a single score and overall water quality class. While the WQI is a useful, high level communication tool, care needs to be taken in the interpretation, as coastal water quality is affected by natural and human inputs, and complex interactions occur among natural processes and human actions. It is therefore recommended that readers refer to earlier results sections to obtain a more comprehensive picture of coastal water quality and its drivers.

In this report, WQI results have been calculated using monthly median values over five-year rolling periods. This differs from the previous year, where a three-year period was used (Ingley & Groom 2022). Consequently, WQI results presented in this report are not comparable to those presented in earlier annual reports. However, annual results from 2012 to 2022 have been produced here using the amended method and are provided in Table 3-1, while Figure 3-13 provides a map of the latest results. Additionally, monthly boxplots over the latest five-yearly assessment period showing parameter exceedances driving the WQI for each site are available as a supplementary data file on Knowledge Auckland.[11]

In general, sites in, or near the entrance of, narrow inlets or rivers in upper harbour and estuary sites tend to have the worst water quality scores, while sites in central and outer sections of estuaries and harbours, and on open coasts have the best scores (see Figure 3-13 for the latest results). This is consistent with findings by Ingley (2020) that showed WQI scores improve with increasing salinity. At most sites water quality scores varied over time, although overall, there has been no consistent pattern in that variation (Figure 3-14, Table 3-1). Sites that have not varied since the 2008-2013 period include:

- three sites with persistently "poor" scores in Manukau Harbour (Mangere Bridge, Weymouth, Warkworth Town Basin)
- one Manukau Harbour site with a persistently "marginal" score (Clarks Beach), and one with a persistently "fair" score (Grahams Beach)
- one East Coast site with a persistently "good" score (Ti Point).

Two of the three Manukau sites with persistently "poor" scores were southern harbour sites (Waiuku Town Basin and Weymouth), and one was a northern harbour site (Māngere Bridge) (Figure 3-13). Water quality at five of the remaining Manukau sites varied from "marginal" to "poor" (PuketutuPoint,

[11] https://www.knowledgeauckland.org.nz/natural-environment

Purakau Mid Channel, Shag Point, Te Whau Point and Wiroa Island), while Puponga Point varied from "poor" to "good", and Manukau Heads from "fair" to "good".

Water quality at most East Coast sites have predominantly been scored as "good" or "excellent". However, "marginal" and/or "fair" scores were recorded at the Dawsons Creek, Orewa and Goat Island sites at the beginning of the 2012 to 2022 period, and at the Browns Bay site over the entire period.

Water quality at the Upper Waitematā Harbour sites has generally varied between "marginal" and "poor" (though the Paremoremo site scored "fair" in 2021), while water quality at central Waitematā sites has generally varied between "marginal" and "good" (though the Whau Creek site scored "excellent" in 2014). Sites in Tāmaki Inlet also varied between "marginal" and "poor" at the upper (Panmure) inlet site, and between "marginal" and "fair" at the outer (Tāmaki) site. The Wairoa site in the Tāmaki Strait varied between "marginal" and "good".

Water quality scores at the Kaipara sites varied from between "marginal" and "poor" at the Kaipara River site, and "good" to "excellent" at Kaipara Heads. The Tauhoa Channel site varied between "fair" and "good", with the remaining sites varying between "marginal" and "fair".

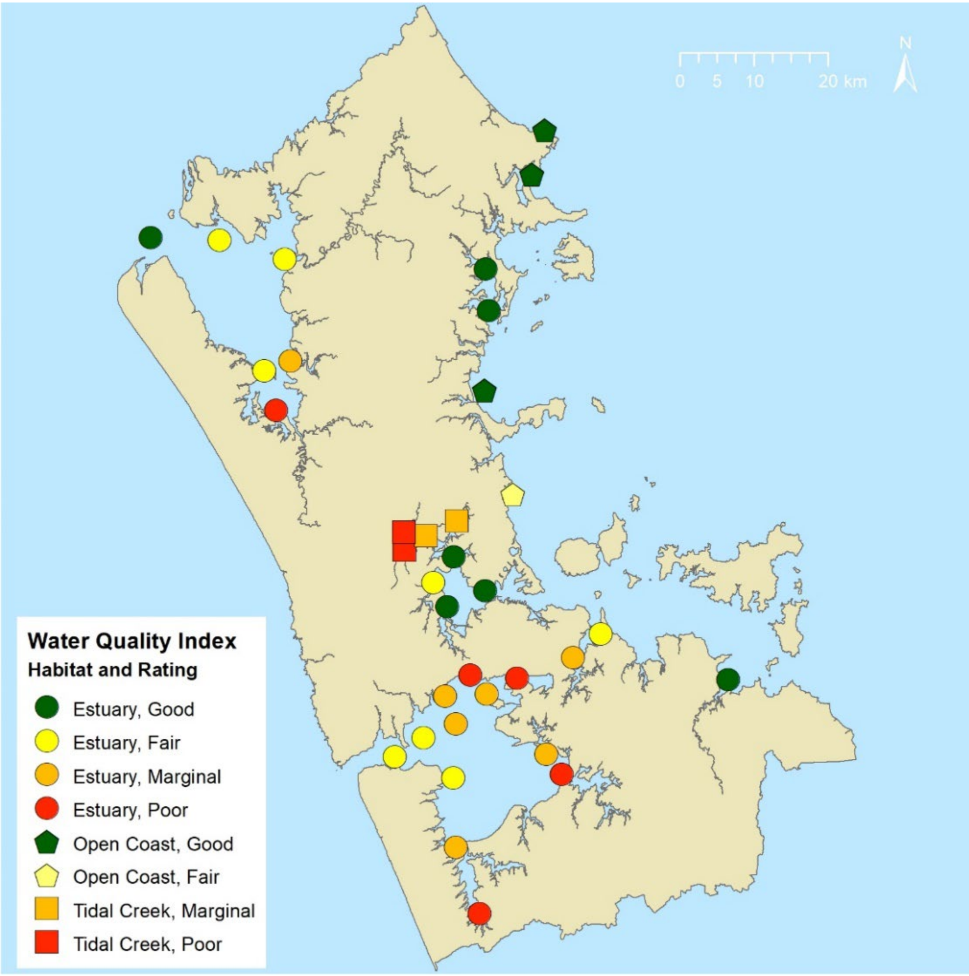


Figure 3-13: Water Quality Index results for the latest five-year period (2018 to 2022 calendar years, inclusive). Sites are classified by habitat type and index ranking.

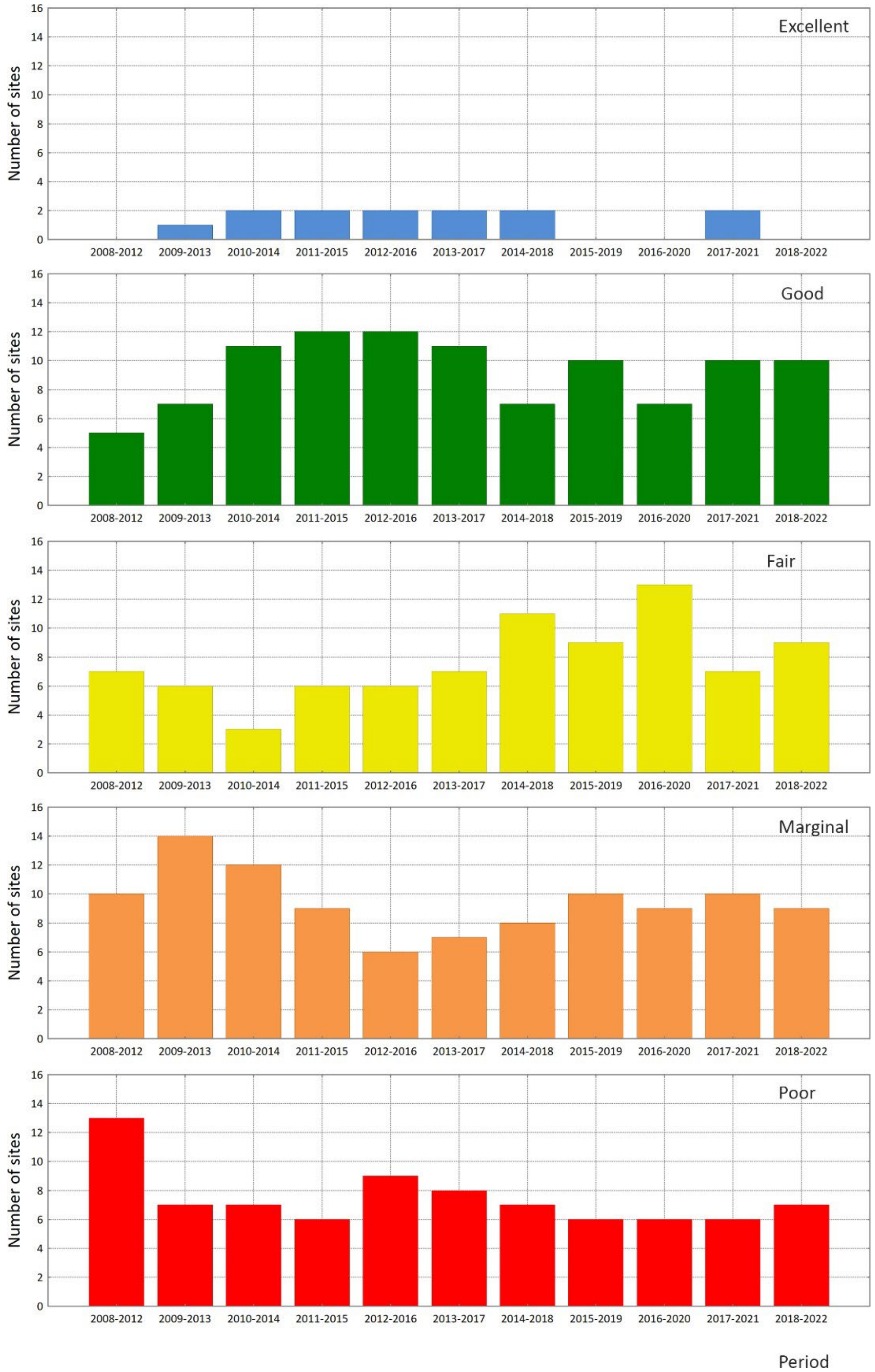


Figure 3-14:Variation in Water Quality Index results since the 2008-2013 period.

Table 3-1: Water Quality Index calculations based on monthly median values for rolling five-year periods between 2012 and 2022.

Blue = Excellent, Green = Good, Yellow = Fair, Orange = Marginal, Red = Poor.

Area	Site	WQI Score										
		2008-2012	2009-2013	2010-2014	2011-2015	2012-2016	2013-2017	2014-2018	2015-2019	2016-2020	2017-2021	2018-2022
East Coast	Browns Bay	59	59	69	69	70	78	79	79	70	69	69
	Dawsons Creek	71	80	80	90	90	90	90	90	90	81	90
	Goat Island	52	71	90	81	90	90	90	90	90	100	81
	Mahurangi Heads	90	100	100	100	100	100	100	90	90	90	90
	Orewa	70	70	80	90	89	90	90	90	90	90	90
	Ti Point	90	90	90	90	90	90	90	81	81	90	90
Waitematā	Brighams Creek	38	48	58	57	39	48	47	48	48	49	39
	Chelsea	71	90	90	90	90	81	81	80	71	81	90
	Henderson Creek	80	81	81	80	81	70	70	70	69	60	71
	Hobsonville	81	81	90	90	90	90	71	61	71	80	81
	Lucas Creek	42	51	61	51	51	51	50	51	50	60	61
	Paremoremo Creek	51	60	61	61	61	60	50	51	51	70	61
	Rangitopuni Creek	38	48	48	47	39	38	46	46	46	48	38
	Whau Creek	71	90	100	90	80	80	80	89	79	80	90
Tāmaki	Panmure	33	34	34	33	35	36	34	45	56	56	59
	Tāmaki	60	70	70	69	78	68	68	69	68	69	69
Clevedon	Wairoa River	51	51	90	90	90	90	71	70	70	70	80
Manukau	Clarks Beach	47	47	47	46	48	48	47	46	47	47	47
	Grahams Beach	69	79	69	70	71	71	71	70	70	70	70
	Mangere Bridge	33	32	33	33	34	33	31	32	26	33	34
	Manukau Heads	79	79	80	80	81	81	71	81	71	81	71
	Puketutu Point	41	45	43	43	40	44	39	43	29	45	46
	Puponga Point	37	54	61	80	80	90	80	80	81	81	71

Area	Site	WQI Score										
		2008-2012	2009-2013	2010-2014	2011-2015	2012-2016	2013-2017	2014-2018	2015-2019	2016-2020	2017-2021	2018-2022
	Purakau Mid Channel	33	40	55	54	57	58	57	49	57	57	58
	Shag Point	44	45	45	45	46	54	52	46	54	40	49
	Te Whau Point	32	28	33	45	34	34	40	32	35	35	37
	Waiuku Town Basin		20	24	24	24	24	24	25	26	27	28
	Weymouth	34	36	36	38	39	39	38	39	38	39	41
	Wiroa Island	20	29	43	43	44	42	42	41	41	43	45
Kaipara	Hoteo River	58	59	59	68	69	68	68	66	67	69	69
	Kaipara Heads	81	81	90	100	100	100	100	90	90	100	81
	Kaipara River	56	57	57	62	50	57	55	47	49	47	40
	Makarau Estuary	57	58	57	66	66	67	65	65	67	58	58
	Shelly Beach	55	58	59	68	68	69	67	68	69	69	69
	Tauhoa Channel	79	79	80	80	80	80	70	71	71	80	71

* Years 2014-2016 to 2017-2019 are based on the marina site while 2018-2020 is based on a transition between the marina site and new ferry terminal location. 1. Open Coast guidelines 2. Tidal Creek guidelines

3.5 Conclusions

Patterns in the latest water quality monitoring results reflect the influences of:

- natural spatial and temporal variation, and interactions among water quality variables
- the assimilation capacity of the coastal water bodies (which in turn are likely to be influenced by factors that affect coastal water volumes and water exchange, such as the size and shape of the water body, and distance from open coastal waters)
- freshwater inputs (as indicated by patterns in salinity) and associated nutrient and sediment loads from diffuse catchment sources (which in turn are likely to be influenced by catchment size, landuse and geology)
- nutrient loads from major point-sources (particularly Mangere WWTP).

New analyses also suggest that phytoplankton has a substantial influence on ambient turbidity and suspended solids concentrations. Including volatile suspended solids in the coastal monitoring parameter suite would assist in teasing apart the relative influences of inorganic sediments and organic matter (including phytoplankton) on those parameters.

Overall, the results indicate that coastal sites in, or near the entrance of, narrow inlets or rivers in upper harbour and estuary locations are the most sensitive to, and most affected by freshwater inputs (and point sources). In contrast, high flushing and dilution diminishes the influence of freshwater runoff on exposed coastal sites.

4 Acknowledgements

The Auckland Council coastal water quality monitoring programme has benefitted from the efforts of numerous people since its inception in 1987. During the 2020 to 2022 sampling seasons, special thanks to Dimitri Colella, Freya Ewing, Natalie Gilligan, Julia O’Grady, and Sheldon Benito for organising and undertaking the sampling, to Kylie Robertson for data management and quality assurance processes.

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5 References

ANZECC (2000). Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment & Conservation Council, and Agriculture and Resource Management Councils of Australia & New Zealand, Canberra, Australia., 316 pp.

ANZG (2018). Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at: www.waterquality.gov.au/anz-guidelines [Accessed: 2020]

APHA (2017). Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC

Ballantine, D. (2012). Developing a composite index to describe river condition in New Zealand. NIWA Client Report, HAM2012-131, NIWA, Hamilton, 62 pp.

Best, M.A., Wither, A.W., Coates, S. (2007). Dissolved oxygen as a physico-chemical supporting element in the Water Framework Directive. *Marine Pollution Bulletin,* 55: 53-64

CCME (2001). Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg

Drylie, T.P. (2021). Marine ecology state and trends in Tāmaki Makaurau / Auckland to 2019. State of the environment reporting. Auckland Council technical report, TR2021/09, Auckland Council, Auckland

Dudley, B.D., Burge, O.R., Plew, D., Zeldis, J. (2020). Effects of agricultural and urban land cover on New Zealand's estuarine water quality. *New Zealand Journal of Marine and Freshwater Research,* 54: 372-392

Foley, M.M. (2018). Updating the methodology used to calculate overall water quality scores at marine water quality sites in the Auckland Region. Technical report, 2018/027, Auckland Council, Auckland, 18 pp.

Griffiths, R. (2016). Recommended Coastal Water Quality Standards for Northland. Northland Regional Council, Whangarei

Hicks, D.M., Holwerda, N., Grant, C.M. (2021). Rural catchment sediment yields from the Auckland region: State of the environment reporting. Auckland Council technical report, TR2021/12, Auckland Council, Auckland, 99 pp.

Ingley, R. (2019). Coastal and estuarine water quality: 2018 annual data report. Technical Report, 2019/027, Auckland Council, Auckland, 68 pp.

Ingley, R. (2020). Coastal and estuarine water quality: 2019 annual data report Technical report, TR2020/016, Auckland Council, Auckland, 75 pp.

Ingley, R. (2021). Coastal and estuarine water quality state and trends in Tāmaki Makaurau / Auckland 2010-2019. Technical report, TR 2021/02, Auckland Council, Auckland, 63 pp.

Ingley, R., Groom, J. (2022). Coastal and Estuarine Water Quality in Tāmaki Makaurau / Auckland: 2020 Annual Data Report. Technical report, 2022/20, Auckland Council, Auckland, 49 pp.

Ingley, R., Groom, J., Buckthought, L. (2023). River water quality in Tāmaki Makaurau / Auckland 2022 annual reporting and National Policy Statement for Freshwater Management current state assessment. Auckland Council technical report, in press, Auckland Council, Auckland

Law, C., Bell, J., Bostock, H., Cornwall, C., Cummings, V., Currie, K., Davy, S., Gammon, M., Hepburn, C., Hurd, C., Lamare, M., Mikaloff-Fletcher, S., Nelson, W., Parsons, D., Ragg, N., Sewell, M., Smith, A., Tracey, D. (2018). Ocean Acidification in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research,* 52: 155-195

Mills, G.N., Allen, H. (2021). Marine Sediment Contaminant State and Trends in Tāmaki Makaurau / Auckland 2004-2019. State of the Environment Reporting. Auckland Council technical report, TR2021/10, Auckland Council, Auckland

Perrie, A. (2007). The state of water quality in selected rivers and streams in the Wellington region, 2003-2006. Publication No. GW/EMI-T-07/218, Greater Wellington Regional Council, Wellington

R Core Team (2020). R: A language and environment for statistical computing. Version R-4.0.2. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/

Semadeni-Davies, A., Hughes, A., Elliott, S. (2015). Assessment of the CLUES model for the implementation of the National Policy Statement on Freshwater Management in the Auckland region. Auckland Council technical report, TR2015/014, NIWA, Auckland

Semadeni-Davies, A., Montogomery, J., Haddadchi, A. (2022). Development of a sediment monitoring programme for Kaipara Moana. NIWA Client report prepared for Aquanet Consulting and the Ministry for the Environment, 2022045AK, NIWA, Auckland

Snelder, T., Fraser, C. (2018). Aggregating trend data for environmental reporting. Client report for Ministry for the Environment, 2018-01, LWP, Lyttelton, 35 pp.

Waitangi Tribunal (1985). Report of the Waitangi Tribunal on the Manukau claim. The Waitangi Tribunal, Wellington, 100 pp.

Watercare Services Limited (2011). Project Manukau Mangere Wastewater Treatment Plant monitoring management plan. Watercare Services Limited, Auckland, 131 pp.

Whitehead, A., Fraser, C., Snelder, T., Walter, K., Woodward, S., Zammit, C. (2022). Water quality state and trends in New Zealand rivers: Analyses of national data ending in 2020. NIWA client report for Ministry for the Environment, 2021296CH, NIWA, Christchurch, 73 pp.

Appendix 1: Current monitoring sites

Table A-0-1: Current coastal and estuarine water quality monitoring sites.

	Site	NZTM Easting	NZTM Northing	Year initiated	Exposure Level	Dominant catchment land-
East Coast	Goat Island	1761787	5984944	1993	Open Coast	N/A
	Ti Point	1760058	5978931	1991	Open Coast	N/A
	Mahurangi Heads	1754225	5960548	1993	Estuary	Rural
	Dawsons Creek	1753782	5966175	1993	Estuary	Rural
	Orewa	1753660	5949837	1991	Open Coast	N/A
	Browns Bay	1757497	5935771	1991	Open Coast	N/A
Kaipara Harbour	Shelly Beach	1723871	5952426	1991	Estuary	Rural
	Kaipara River	1725504	5947101	2009	Estuary	Rural
	Makarau Estuary	1727396	5953730	2009	Estuary	Rural
	Kaipara Heads	1708534	5970421	2009	Estuary	Rural
	Tauhoa Channel	1717821	5970063	2009	Estuary	Rural
	Hoteo River	1726691	5967495	2009	Estuary	Rural
Waitematā Harbour	Chelsea	1753721	5922776	1991	Estuary	Urban
	Whau Creek	1748588	5920563	1991	Estuary	Urban
	Henderson Creek	1746715	5923855	1991	Estuary	Urban
	Hobsonville	1749453	5927353	1993	Estuary	Urban
	Paremoremo Creek	1745717	5930201	1993	Tidal Creek	Lifestyle/Native
	Rangitopuni Creek	1742734	5930626	1993	Tidal Creek	Rural
	Brighams Creek	1742829	5928227	1996	Tidal Creek	Urban
	Lucas Creek	1749892	5932176	1993	Tidal Creek	Urban
Tāmaki Estuary	Tāmaki*	1768895	5916761	1992	Estuary	Urban
	Panmure	1765553	5913693	1992	Estuary	Urban
Tāmaki Strait	Wairoa River	1786561	5910769	2009	Estuary	Rural
Manukau Harbour	Grahams Beach	1749431	5897517	1987	Estuary	Rural
	Clarks Beach	1749746	5888100	1987	Estuary	Rural
	Waiuku Town Basin	1752923	5879195	2012	Estuary	Rural
	Shag Point	1748335	5908549	1987	Estuary	Urban/Rural
	Puketutu Point	1753938	5908791	1987	Estuary	N/A**
	Weymouth	1764080	5897952	1987	Estuary	Urban/Rural
	Māngere Bridge	1758048	5910932	1987	Estuary	Urban
	Manukau Heads	1741520	5900335	2009	Estuary	Urban/Rural
	Wiroa Island[WC]	1761984	5900693	2011	Estuary	Urban/Rural
	Purakau Mid Channel[WC]	1749758	5904803	1995	Estuary	Urban
	Te Whau Point[WC]	1751679	5911376	1995	Estuary	Urban
	Puponga Point[WC]	1745368	5902877	2011	Estuary	Urban/Rural

** Updated to ferry terminal location*
*** Site is adjacent to the Māngere Wastewater Treatment Plant discharge "non-compliance zone" and is less subject to the direct influence of diffuse land derived contaminants*
[WC] Watercare Services site

Appendix 2: Physical-chemical parameters

Table B-0-1: Summary of marine water quality parameters, detection limits, analytical methods and two sources of data collection.

Parameter	Unit	Detection Limit	Method	Source
Dissolved oxygen	ppm	0.1	EXO2 Sonde (Xylem Analytics)	Field
Dissolved oxygen saturation	% sat	0.01	EXO2 Sonde (Xylem Analytics)	Field
Temperature	°C	0.01	EXO2 Sonde (Xylem Analytics)	Field
Conductivity	mS cm	0.01	EXO2 Sonde (Xylem Analytics)	Field
Salinity	ppt	0.2	EXO2 Sonde (Xylem Analytics)	Field
pH	pH units	0.01	EXO2 Sonde (Xylem Analytics)	Field
Total suspended solids	mg/L	3	APHA (2012) 2540 D	Lab
Turbidity	NTU	0.05	APHA (2012) 2130 B (modified)	Lab
Chlorophyll *a*	mg/L	0.0002	APHA (2012) 10200 H (modified)	Lab
Nitrate nitrogen (NO_3N)	mg/L	0.001	Calculation ((NO_3N+NO_2N) – NO_2)	Lab
Nitrite nitrogen (NO_2N)	mg/L	0.001	APHA (2012) 4500-NO_2 I (modified)	Lab
Total oxidised nitrogen (NO_2N + NO_3N)	mg/L	0.001	APHA (2012) 4500-NO_3 I (modified)	
Ammoniacal nitrogen (NH_4-N)	mg/L	0.005	APHA (2012) 4500-NH_3 H (modified)	Lab
Total Kjedahl nitrogen (TKN)	mg N/L	0.01	Calculation: TN – (NO_3N + NO_2N)	Lab
Total nitrogen (TN)*	mg N/L	0.01	APHA (2012) 4500-N C & 4500 NO_3 I (modified)	Lab
Soluble reactive phosphorus	mg/L	0.001	APHA (2012) 4500-P G	Lab
Total phosphorus*	mg/L	0.004	APHA (2012) 4500-P B & E (modified)	Lab

** Note: analysis methods have changed from July 2017*

Table B-0-2: Summary of parameters assessed.

Parameter	Description
Salinity and chloride	Salinity and chloride levels decrease as the influence of freshwater increases. Consequently, levels tend to be lower and more variable in estuaries. Salinity levels affect the toxicity of some contaminants.
Temperature	Sea surface temperature is driven by seasonal changes in solar radiation and climatic conditions (e.g., El Niño or La Niña weather patterns). The level of deep-water upwelling, which is driven by offshore winds, has a large influence on interannual variations in sea surface temperature. Shallow tidal creek sites are typically more variable due to proportionally higher freshwater inputs and warming of water from exposed intertidal sediments on the incoming tide. Temperature affects biological processes and moderates the toxicity of contaminants.
pH	pH is a measure of acidity/alkalinity. Seawater is highly buffered and tends to have relatively stable pH levels between pH 7.8 and 8.3. pH is more variable in upper tidal creek areas because of greater freshwater inputs. pH affects biological processes and moderates the toxicity of contaminants. The accuracy of pH measurement methods used here are not expected to detect recent changes in ocean acidification in NZ (annual change of 0.0013 ± 0.0003 (Law et al. 2018).
Dissolved Oxygen (DO)	Oxygen is released by plants and algae during photosynthesis and taken up by plants, algae, animals and bacteria for respiration. Oxygen-scavenging compounds associated with organic matter also affect DO levels. High DO values can reflect high primary production, while low DO values can reflect high rates of decomposition of organic matter. In extreme cases, low DO levels due to respiration and/or chemical uptake can stress or kill aquatic organisms i.e., reduce the life-supporting capacity of the water. DO levels are diurnally and seasonally variable. DO is typically higher during the day and decreases at night. Colder waters also typically hold more oxygen than warmer waters.
Turbidity Suspended solids	Turbidity is a measure of the degree to which light is scattered in water by particles, such as sediment and plankton. Total suspended solids are a measure of the amount of suspended material in the water column such as plankton, non-living organic material, silica, clay and silt. Coastal turbidity and suspended solids are influenced by the runoff of terrestrial sediments and resuspension of marine sediments. High turbidity and suspended solids concentrations reduce the aesthetic quality of seawater and inhibit photosynthesis by algae and plants. Terrestrial sediments may also cause estuary infilling, contribute to mangrove expansion, smother biota and habitats, clog gills and impede the feeding of aquatic organisms. These variables are usually closely correlated, but can vary where tannins or other coloured compounds can increase turbidity but are not associated with solid particles. Estuarine waters are generally more turbid than marine waters due to flocculation, phytoplankton production, and the resuspension of sediments.

Parameter	Description
	Land-derived sediment loads are dominated by stormflows, which are only occasionally intercepted by council's routine monthly monitoring.
Nitrite (NO_2), Nitrate (NO_3) Total Oxidised Nitrogen (TON, NO_2 +NO_3-N) Ammoniacal Nitrogen (NH_3 + NH_4-N) Total Kjedahl Nitrogen (TKN) Total Nitrogen (TN)	Nitrite is the intermediate step in the conversion of ammonia to nitrate. It is usually short-lived in the aquatic environment in the presence of oxygen and is typically an indication of a source of nitrogenous waste in the immediate vicinity of the sampling site. Ammonium-N and nitrate-nitrite-N are dissolved forms of nitrogen that are immediately available for phytoplankton and macroalgae uptake and growth, and are used as key indicators for that nutrient Ammonia is reported as a combination of un-ionised ammonia (NH_3) and the ammonium ion (NH_4^+), at normal pH values ammonium (NH_4^+) dominates. Un-ionised ammonia is the more toxic form to aquatic life and is highly dependent on water temperature, salinity and pH. Total Kjedahl Nitrogen is the sum of ammoniacal nitrogen and organic nitrogen (amino acids and proteins). Total Nitrogen includes all forms of dissolved and particulate nitrogen (TKN + TON). Particulate nitrogen consists of plants, algae and animals, and their remains, as well as ammonia adsorbed onto mineral particles. Particulate nitrogen can be found in suspension or in the sediment. Total Nitrogen is usually higher in upper estuarine sites where particulate matter is higher. Low dissolved forms of nitrogen compared to total nitrogen suggest that most of the nitrogen present is particulate matter such as plants, algae, and animals, and adsorbed to sediment particles. Organic nitrogen is usually removed in wastewater treatment as settled sludge and ammoniacal nitrogen is nitrified to nitrate. Nitrate is then removed through denitrification processes. High nutrient levels cause algal blooms, nuisance plant growth and eutrophication. High concentrations of some nutrients are also toxic to aquatic organisms (e.g., ammonia).
Dissolved Reactive Phosphorus (DRP) Total Phosphorus (TP)	Phosphorus is found in water as dissolved and particulate forms. Dissolved Reactive Phosphorus is immediately available for uptake and growth by phytoplankton and macroalgae. Particulate phosphorus consists of algae, plants and animals and their remains, as well as phosphorus in minerals and adsorbed onto mineral surfaces. Total Phosphorus is a measure of both dissolved and particulate forms in a water sample. The adsorption and desorption of phosphate from mineral surfaces forms a buffering mechanism that regulates dissolved phosphate concentrations in rivers and estuaries. Sources of phosphorus include natural input, sewage and animal effluent, cleaning products, fertilisers, and industrial discharges. Earthworks and forestry can also release phosphorus through soil erosion. Wetland drainage can expose buried phosphorus.
Chlorophyll *a*	Chlorophyll *a* is used as an indicator of phytoplankton concentration which can indicate trophic status. Chlorophyll *a* levels vary naturally according to seasonal cycles and climatic conditions. However, excess nutrients caused by human activity can increase chlorophyll *a* levels to the point where water quality is affected. Effects include altered water colour and clarity, unpleasant odours, altered pH levels and lowered oxygen concentrations.

Appendix 3: Box plots of data obtained during the July 2020 to June 2021, and July 2021 to June 2022 hydrological years.

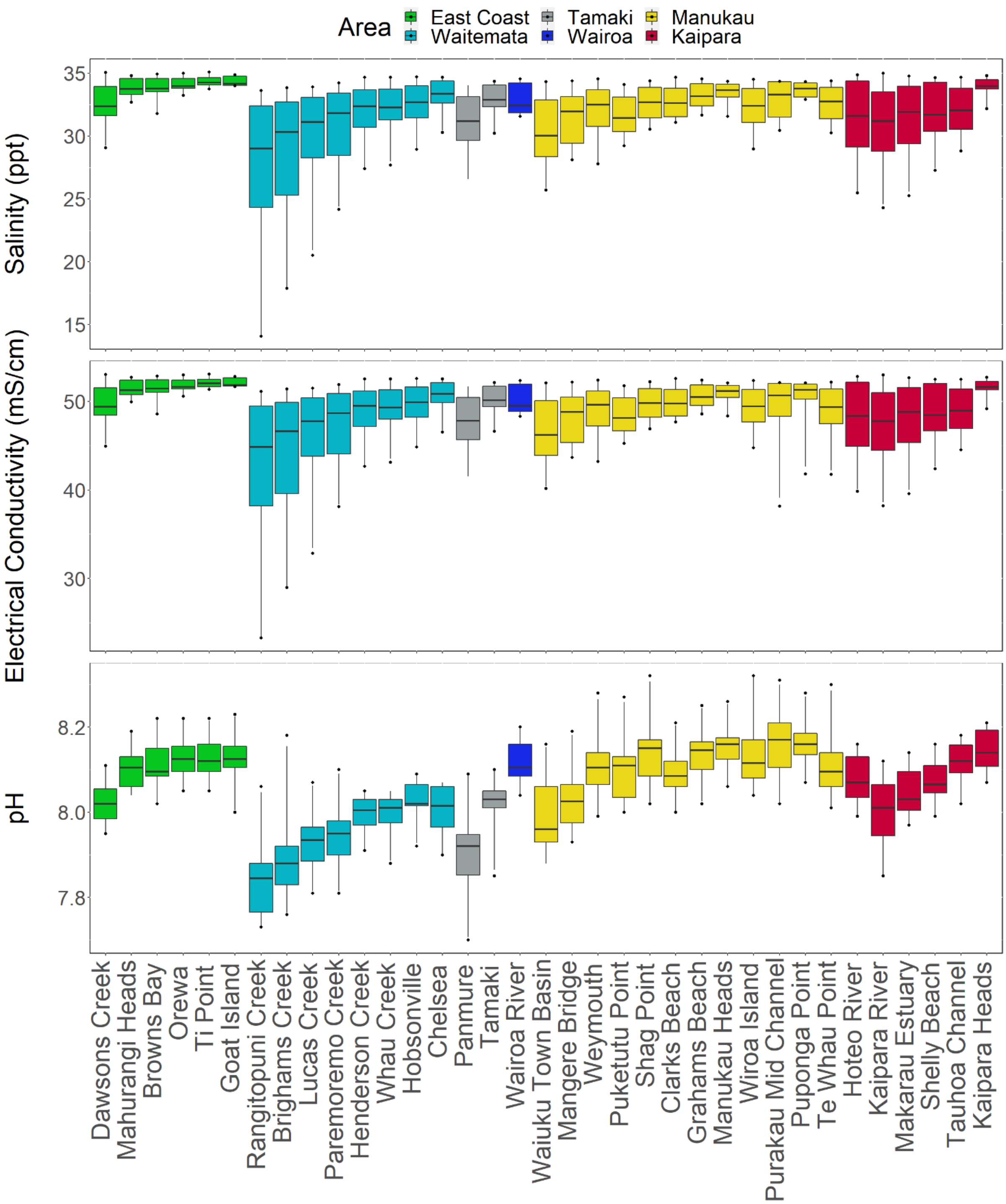

Figure 0-1 Boxplots of salinity, electrical conductivity, and pH for the July 2020 to June 2021 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

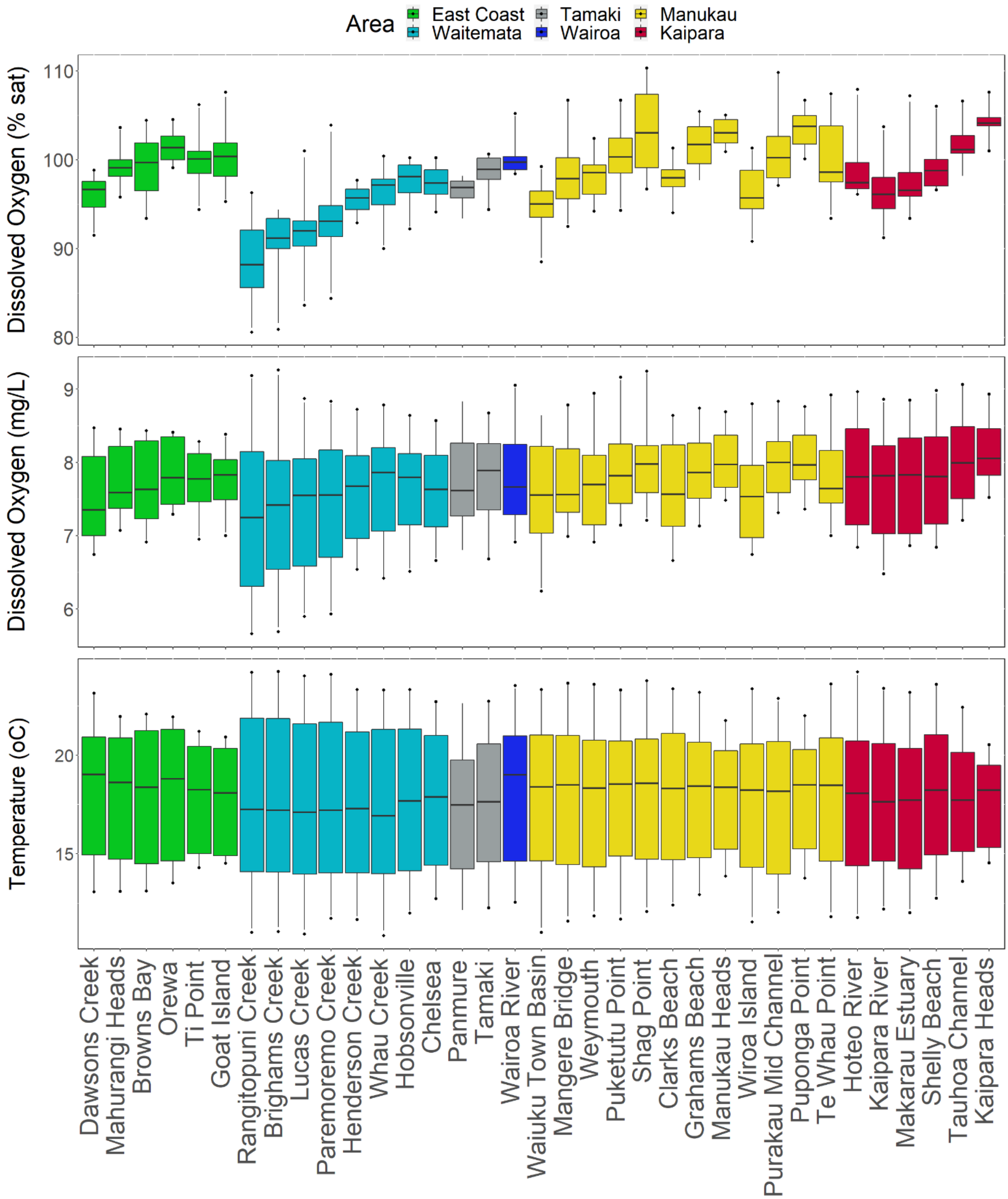

Figure 0-2 Boxplots of dissolved oxygen and water temperature for the July 2020 to June 2021 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

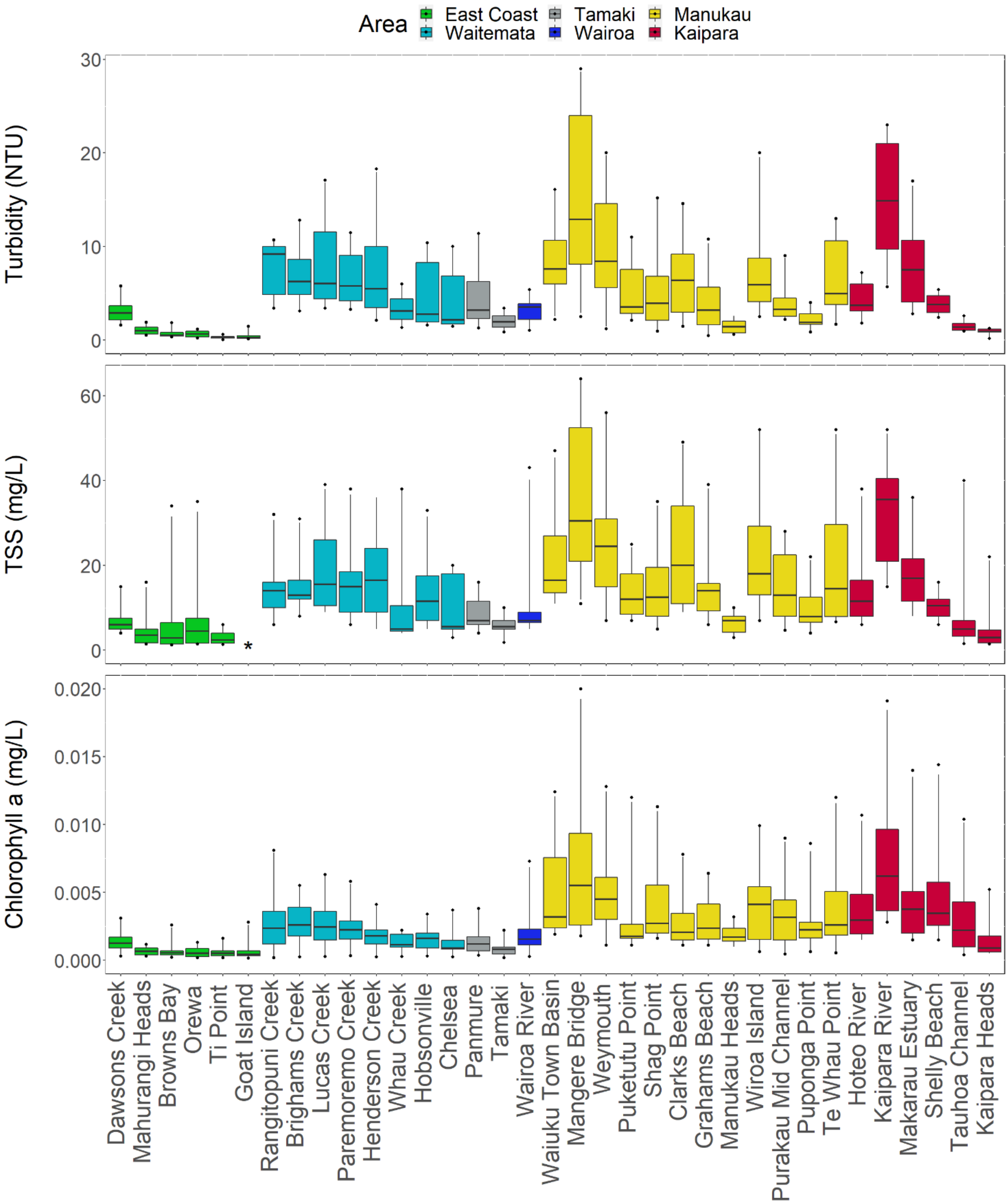

Figure 0-3 Boxplots of turbidity, total suspended solids (TSS), and chlorophyll *a* for the July 2020 to June 2021 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers. Asterix marks sites with more than 50% censored data.

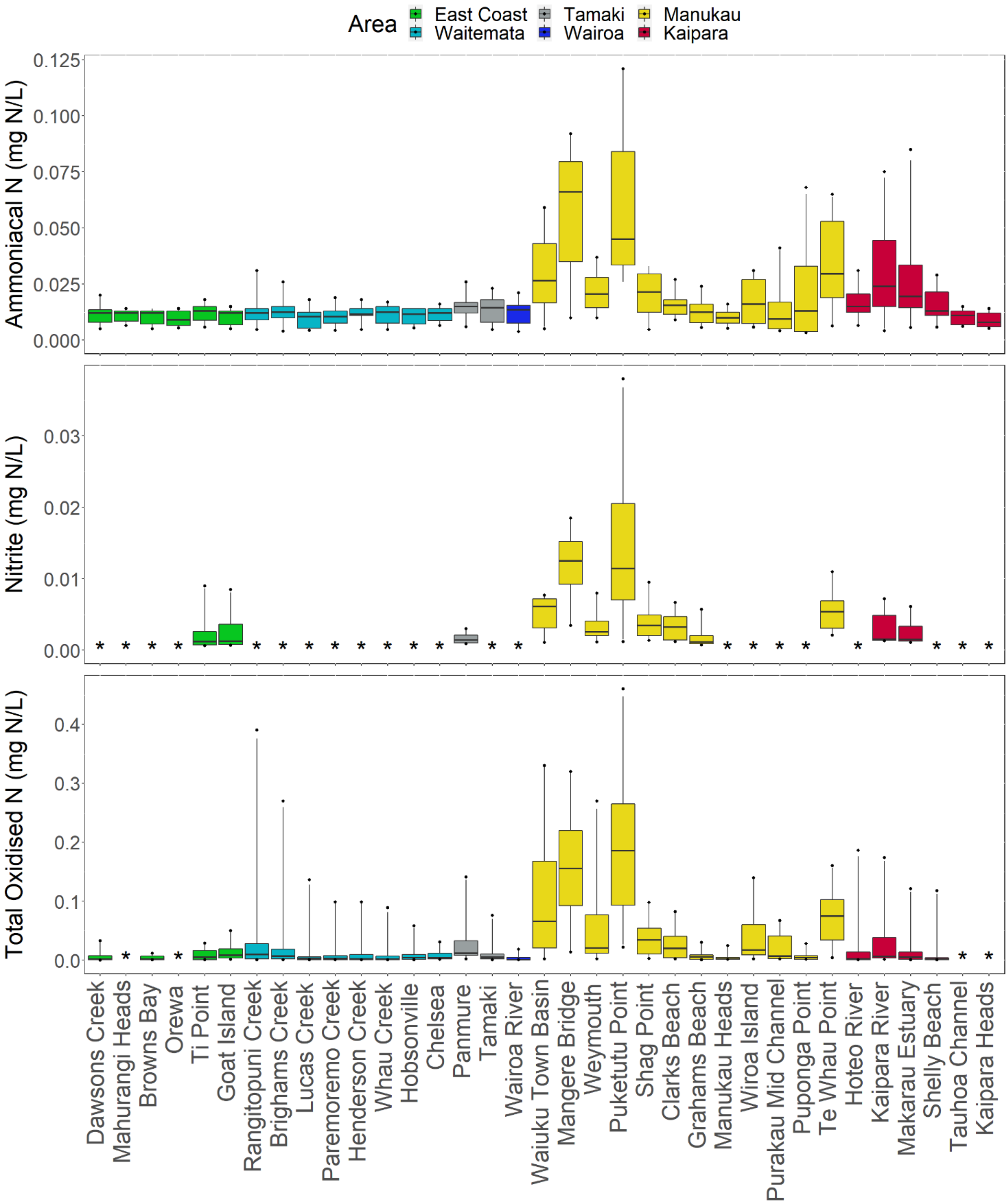

Figure 0-4 Boxplots of ammoniacal-, nitrate-, and total oxidised nitrogen for the July 2020 to June 2021 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers. Asterix marks sites with more than 50% censored data.

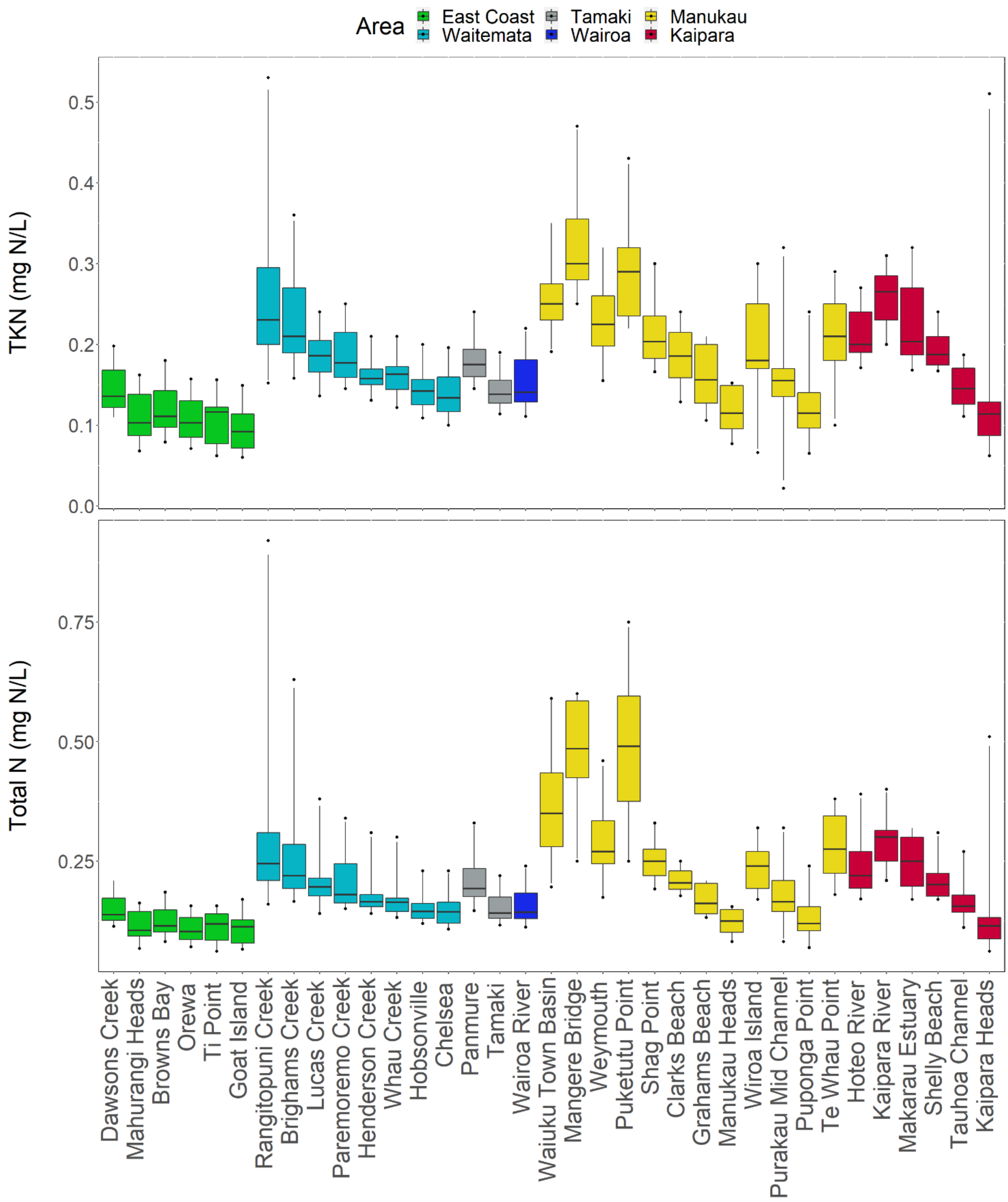

Figure 0-5 Boxplots of total Kjeldahl and total nitrogen for the July 2020 to June 2021 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

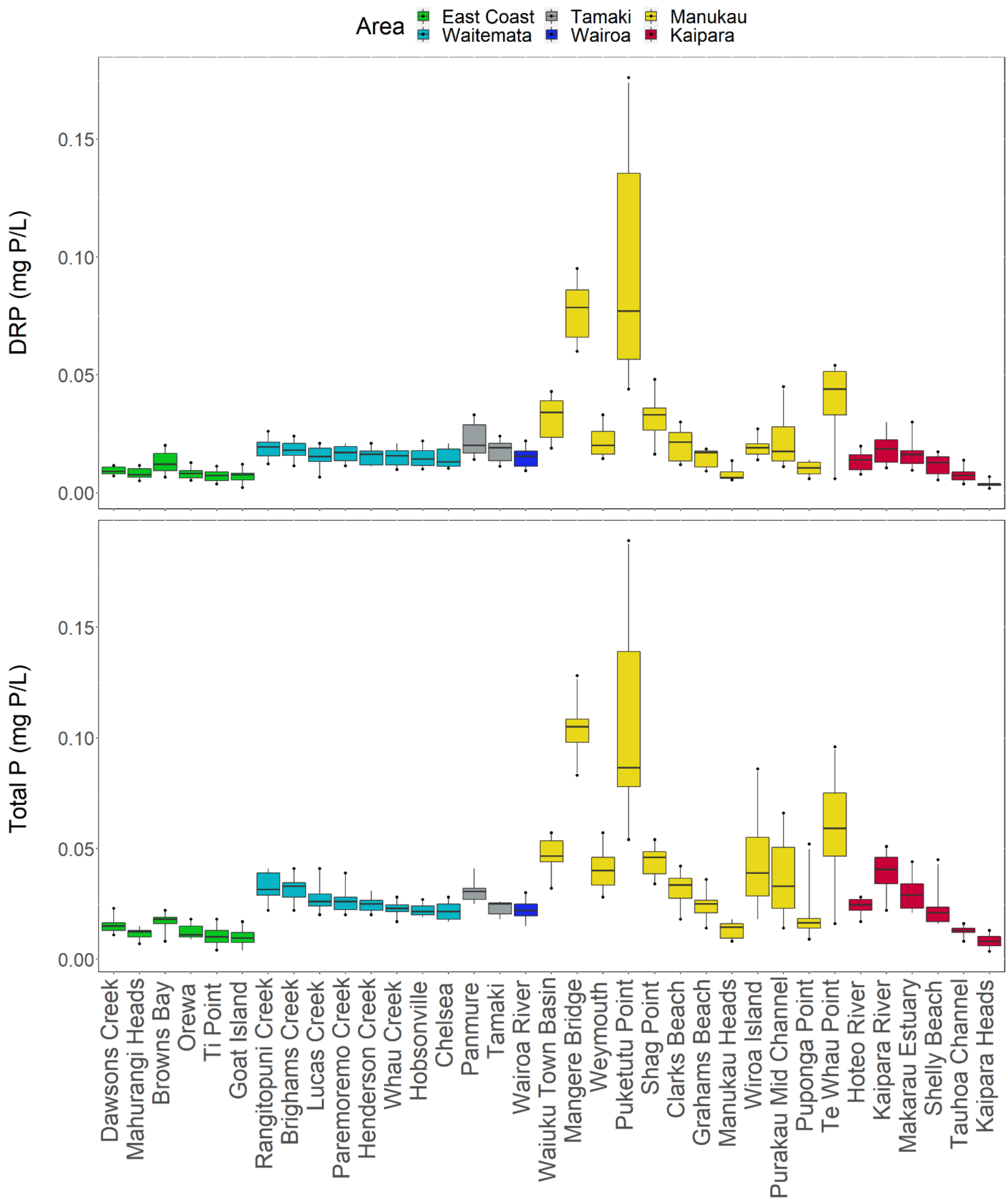

Figure 0-6 Boxplots of dissolved reactive phosphorus (DRP) and total phosphorus for the July 2020 to June 2021 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

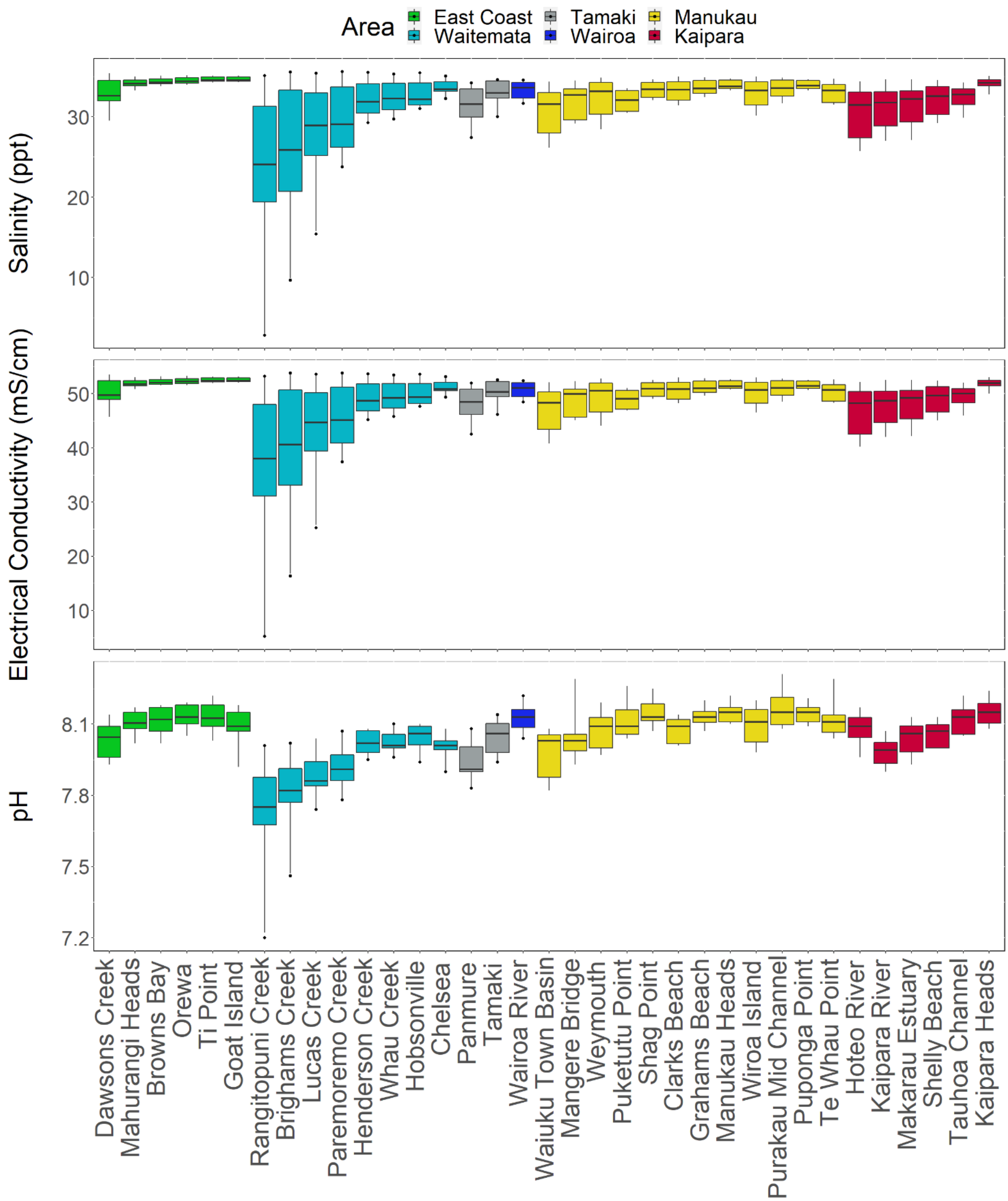

Figure 0-7 Boxplots of salinity, electrical conductivity, and pH for the July 2021 to June 2022 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

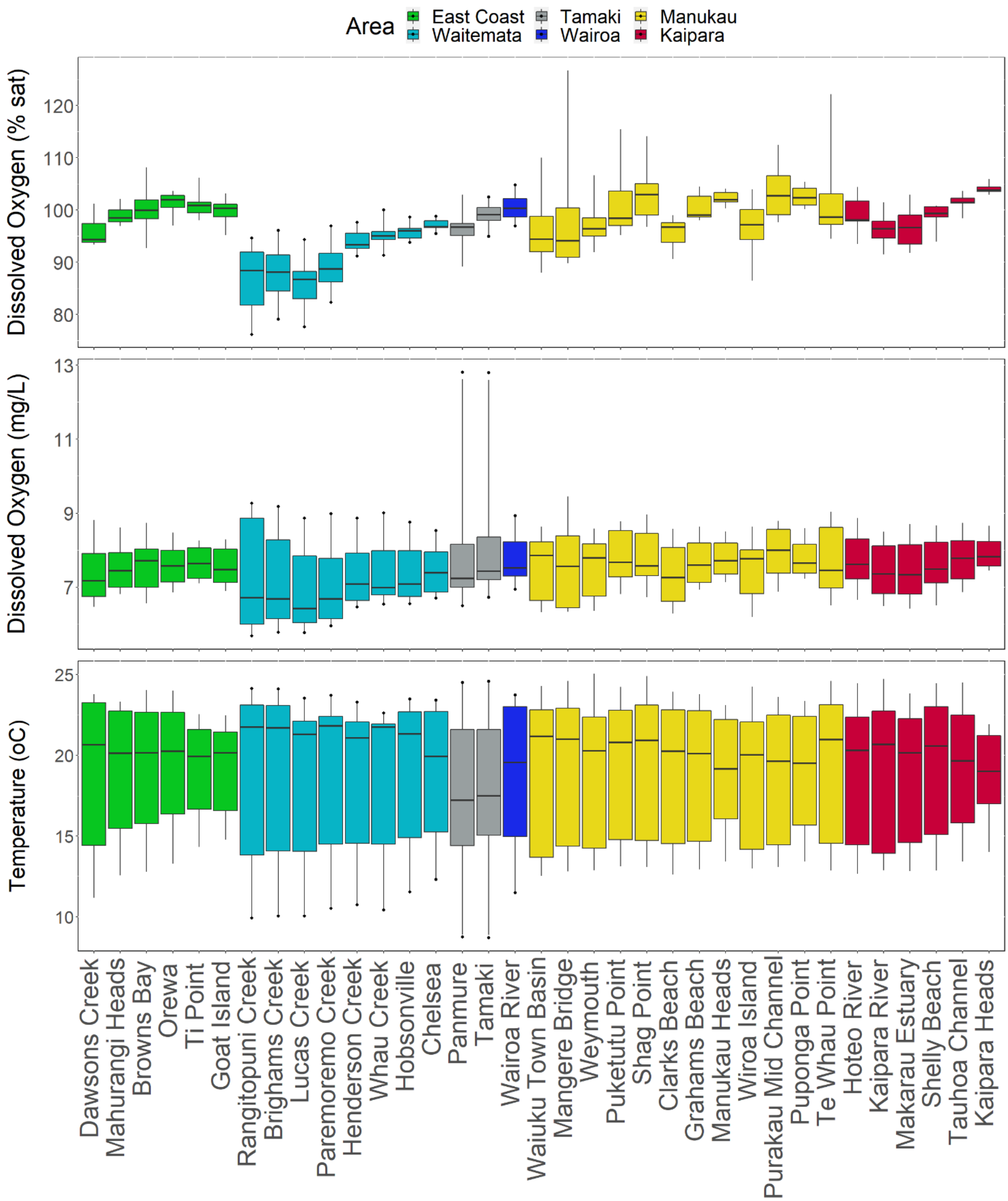

Figure 0-8 Boxplots of dissolved oxygen and water temperature for the July 2021 to June 2022 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

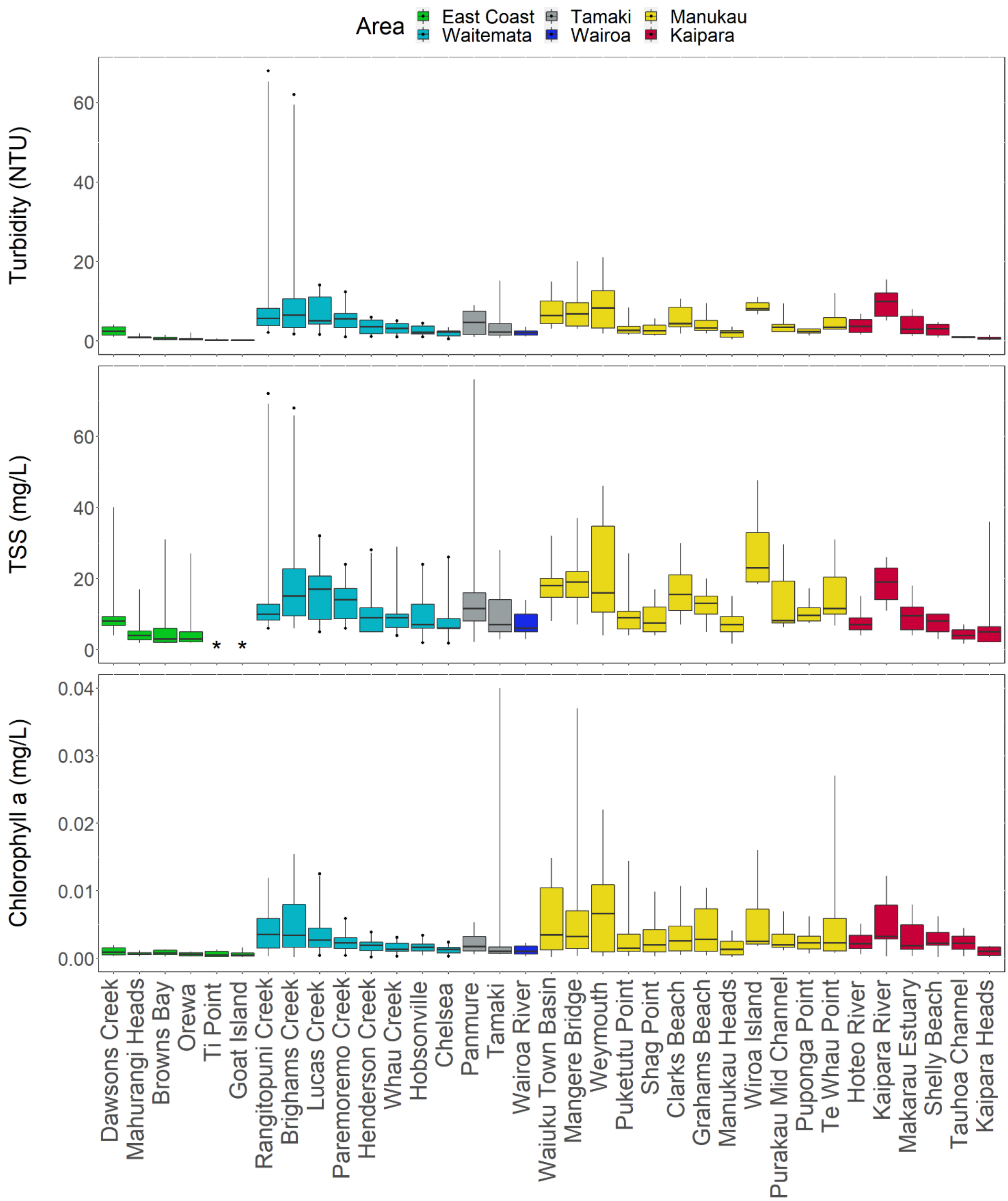

Figure 0-9 Boxplots of turbidity, total suspended solids (TSS), and chlorophyll *a* for the July 2021 to June 2022 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

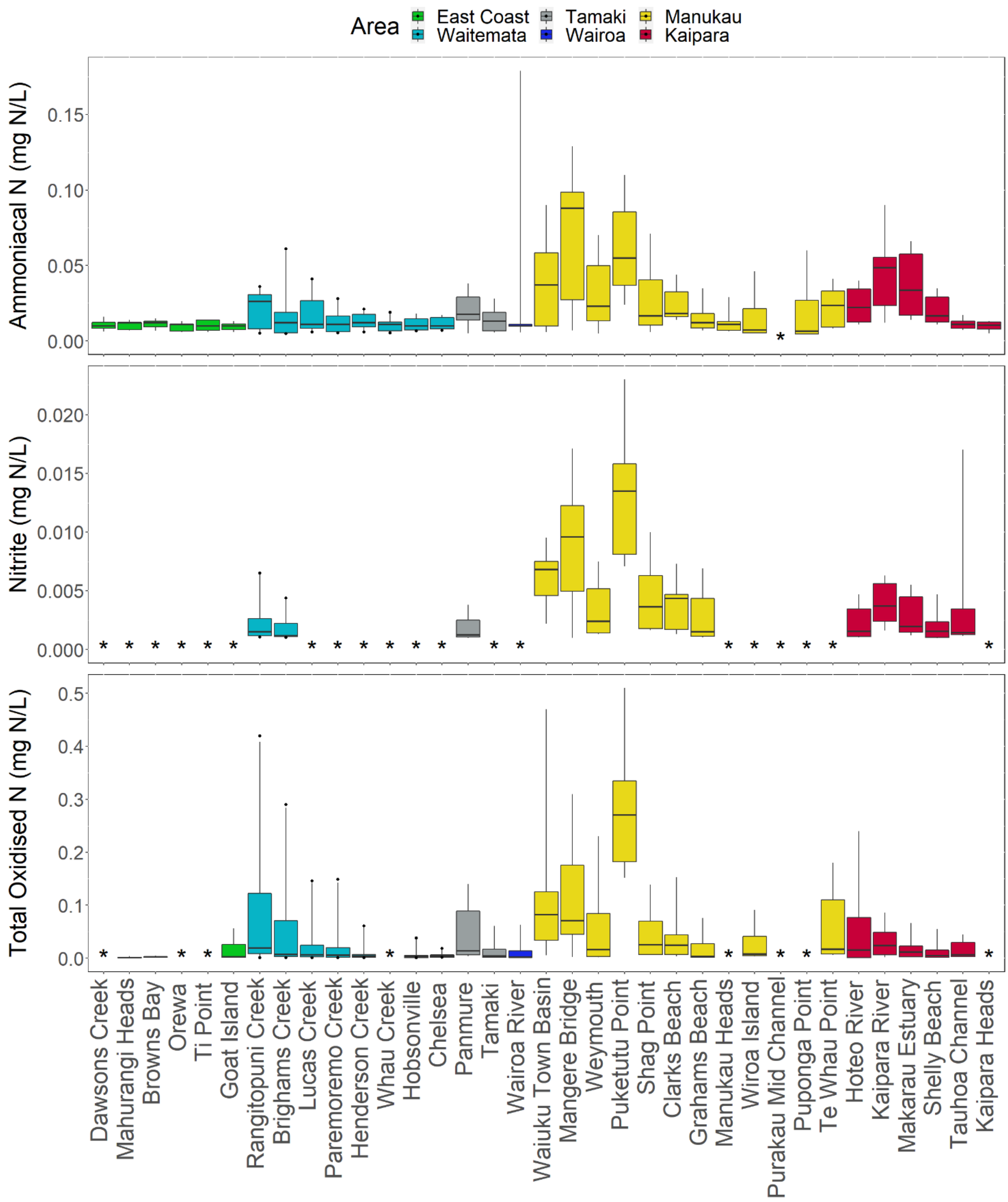

Figure 0-10 Boxplots of ammoniacal-, nitrate-, and total oxidised nitrogen for the July 2021 to June 2022 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

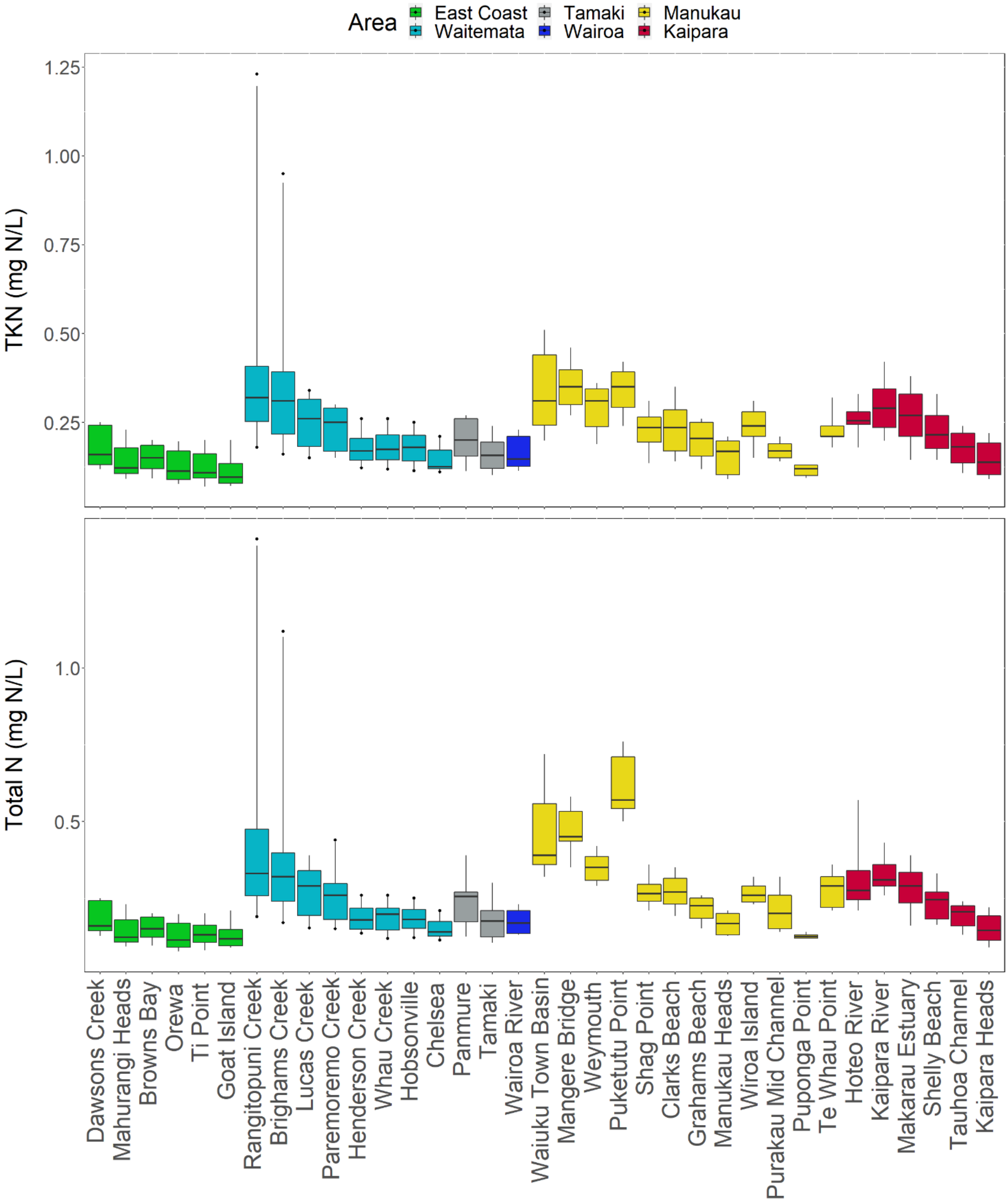

Figure 0-11 Boxplots of total kjeldahl and total nitrogen for the July 2021 to June 2022 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

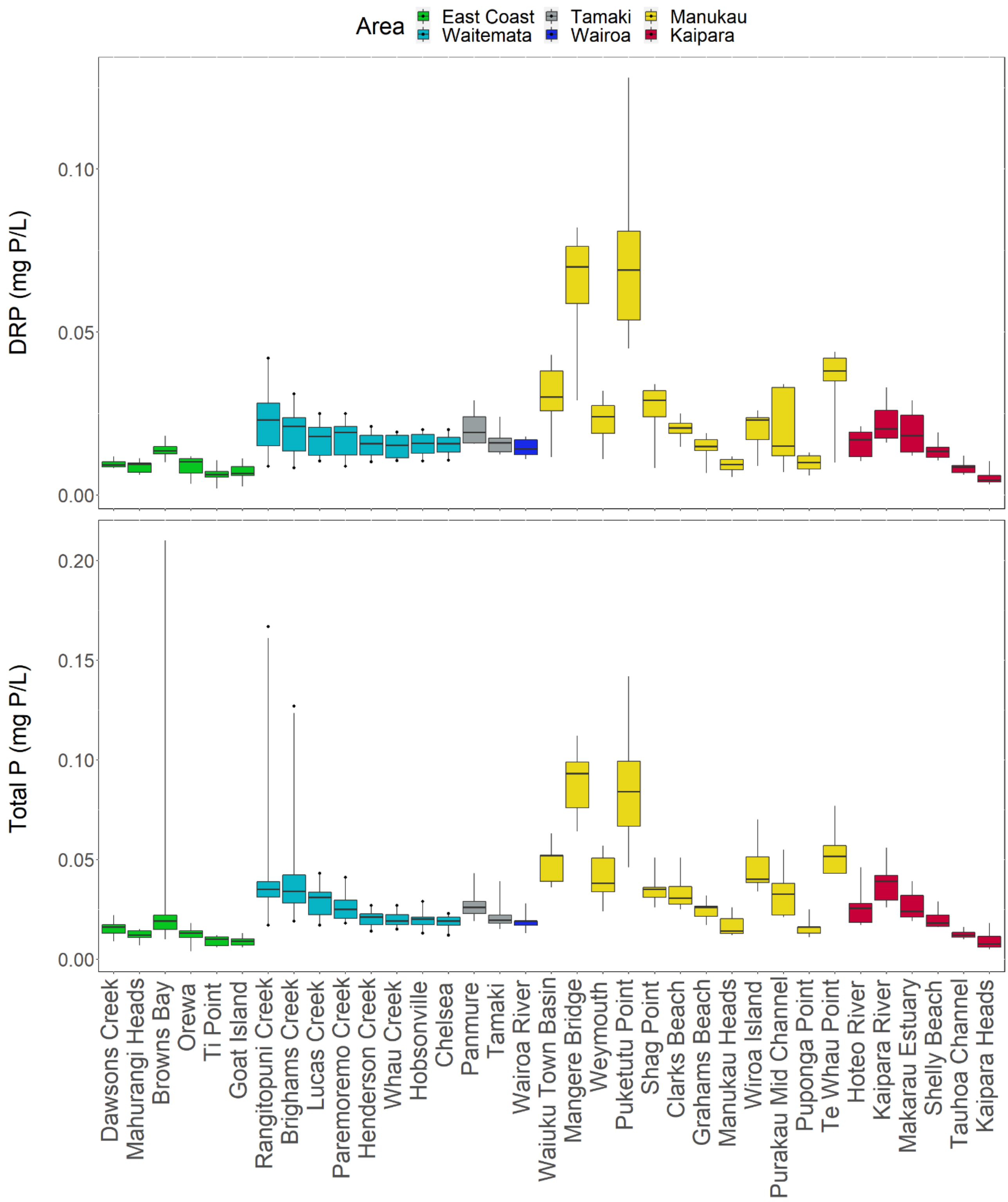

Figure 0-12 Boxplots of dissolved reactive phosphorus (DRP) and total phosphorus for the July 2021 to June 2022 hydrological year. Box plot boundaries showing Hazen percentiles: Middle line = Median, lower quartile = 25th percentile, lower whisker = 5th percentile, upper quartile = 75th percentile, upper whisker = 95th percentile, upper and lower dots = outliers.

Appendix 4: Water Quality Index. Background and methodology

The communication of water quality data is often hampered by the volume of results and the complexity of the information. In this report, a water quality index developed by the Canadian Council of Ministers for the Environment (CCME) (2001) was applied to the marine water quality data collected by Auckland Council to enable improved understanding and communication of the work.

The CCME approach uses water quality results to produce four water quality indices, and these indices can be used to assign a water quality class to each monitoring site. The four indices are:

- Scope – this represents the percentage of parameters that failed to meet the objective at least once during the time period under consideration (the lower this index, the better).
- Frequency – this represents the percentage of all individual tests that failed to meet the objective during the time period under consideration (the lower this index, the better).
- Magnitude – this represents the amount by which failed tests exceeded the objective (the lower this index, the better). This is based on the collective amount by which individual tests are out of compliance with the objectives and is scaled to be between 1 and 100. This is the most complex part of the index derivation, and the reader is referred to CCME (2001) for full details.
- WQI – this represents an overall water quality index based on a combination of the three indices described above. It is calculated thus:

$$WQI = 100 - \left[\left\{\sqrt{(Scope^2 + Frequency^2 + \ Magnitude^2)}\right\} \div 1.732\right]$$

The divisor 1.732 normalises the resultant values to a range between 0 and 100, where 0 represents the “worst” water quality and 100 represents the “best” water quality.

The WQI is used by Auckland Council to assign a water quality class to each site using the following ranges:

- between 95 and 100 = excellent water quality;
- between 80 and 94 = good water quality;
- between 65 and 79 = fair water quality;
- between 45 and 64 = marginal water quality;
- lower than 44 = poor water quality.

Significant modifications were made to the application of the WQI methodology in 2018 including: alteration of parameters included; separate coastal and estuarine guidelines; setting a static period for reference site guidelines; and, using a rolling three-year average value to calculate scores (Foley, 2018). Ingley (2019) applied an additional modification to use rolling median, not mean, values. This was adopted to resolve the effects of skew on mean values caused by anomalous events within a single year and is consistent with ANZ recommendations and other regional councils’ application of the method (Perrie 2007; Griffiths 2016; ANZG 2018). Consequently, previous WQI scores are not directly comparable.

Three-year median values moderate major inter-annual variation due to natural environmental changes (e.g., heavy rainfall and storms) or human impacts such as development. Exceedances are consequently indicative of sustained high concentrations (chronic effects) at that site.

Identification of objectives

Before an index can be calculated, appropriate objectives need to be defined.

National-scale analysis of coastal and estuarine water quality found that salinity was strongly correlated with estuarine water quality and that salinity was a more powerful explanatory variable than differences in urban or agricultural land cover in the contributing watershed (Dudley et al. 2020). It is important to control for such physical variability between sites in the mixing of freshwater flows with oceanic water to detect the effects of terrestrial derived contaminants on water quality. Consequently, different index objectives were defined for open coastal and estuarine environments, and more recently preliminary objectives were defined for upper tidal creek environments.

A set of static objectives were defined using 10 years of data from the least modified open coastal, and estuarine sites within the programme (2007-2016). The estuary reference sites, were selected from harbours with predominantly urban catchments but located in areas that are subject to greater mixing and dilution, which consequently represent guidelines that are regionally achievable.

Both strong El Niño and La Niña conditions were experienced between 2007-2016.

These data were also compared to the existing ANZECC default guidelines (ANZECC 2000). Auckland Council data was used when the 80th percentile exceeded ANZECC guidelines; and the ANZECC guidelines were used when they were more permissive than Auckland Council data. Defining guidelines based on sites in Auckland is reflective of local conditions and represent guidelines that are achievable.

Table D-0-1: Reference sites used to calculate objectives.

Open coast sites	Estuary sites
Goat Island	Chelsea
Ti Point	Hobsonville
	Manukau Heads

Four monitored sites in the upper Waitematā Harbour were defined as ‘tidal creeks’. For the purposes of this assessment, these were sites that were located in narrow channels upstream of the creek ‘mouth’ or confluence with the main estuary or harbour body and where median salinity over 2007-2016 was <30 ppt (polyhaline).

The 2018 annual coastal water quality report suggested that separate guidelines should also be defined for tidal creek environments (Ingley, 2019). While guidelines can be aspirational, it is important that they are achievable under natural or reference conditions and, further, can be achieved under best case management conditions. The established 'estuary' guidelines may not be suitable for tidal creek environments due to differences in coastal hydrodynamics, flushing times, and proximity to freshwater inputs, and may therefore not identify when improvements in water quality are being achieved (or *vice versa*) in tidal creek environments.

Whilst the 80th percentile of reference sites is commonly used to set water quality guidelines, the ANZG (2018) framework acknowledges that in highly disturbed systems, the 90th percentile of reference sites may be more appropriate. Tidal creeks could be considered 'highly disturbed' in relation to the greater freshwater (and associated contaminant) inputs at these sites relative to estuarine reference sites. Guidelines developed for tidal creeks by Northland Regional Council (NRC) based on tidal creek reference data from its regional monitoring network (including sites in the northern Kaipara Harbour) were also considered (Griffiths 2016).

Preliminary guidelines have been proposed in this report, based on the guidelines developed for tidal creeks by NRC, or the 90th percentile of Auckland estuary reference sites where the NRC guidelines appeared to be overly generous for Auckland tidal creeks (i.e., a conservative approach was adopted). It is recommended further review is undertaken if/when additional tidal creek sites in the Kaipara or Manukau harbours are monitored in the future.

Comparing the tidal creek sites to separate tidal creek guidelines resulted in a weaker relationship between overall salinity and water quality index scores (Ingley 2019). This was expected as it was anticipated that using the tidal creek guidelines would result in a more even distribution of scores for these sites.

Parameters

A summary of all parameters monitored in the coastal and estuarine water quality programme is provided in Table B-0-2. A subset of six of these parameters were selected for use within the Water Quality Index; Dissolved Oxygen, Turbidity, Total Oxidised Nitrogen, Soluble Reactive Phosphate, and Chlorophyll *a*.

These parameters were selected to minimise potential 'double counting' of closely related parameters (e.g., turbidity and TSS) and are reflective of the most bioavailable form of nutrients, which combined with chlorophyll *a* provides an indication of trophic status. Physical parameters such as temperature, pH and salinity are excluded from the WQI, however these provide important context to further interpret water quality state.

Appendix 5: Programme history

The coastal and estuarine water quality programme (also known as the marine or saline water quality programme) was designed to assess regional water quality over decadal time scales.

The marine water quality program commenced in 1987 with six sites in the Manukau Harbour, following the Waitangi Tribunal decision on the Manukau Claim (Waitangi Tribunal 1985). Additional sites were added to the program in the early 1990s as water quality concerns across the region began to grow. Between 1991 and 1993, the programme was expanded to include sites in the Waitematā Harbour, Hauraki Gulf, and Kaipara Harbour. This network was the status quo until an Auckland Regional Council programme review in 2008 resulted in the addition of one site in the Manukau Harbour (Manukau Heads), two sites in Tāmaki Strait, and six sites in the Kaipara. An additional site in Manukau Harbour (Waiuku Town Basin) was added in 2012 based on water quality concerns voiced by the Franklin Local Board.

In June 2014, the monitoring site "Confluence" in the Upper Waitematā Harbour was dropped from the sampling programme. In July 2015, a further four sites were dropped from the sampling programme due to budget constraints, Omokiti Beacon in the Kaipara, Tūranga Estuary in the Tāmaki Strait, Rarawaru and Waimarie in the Upper Waitematā Harbour. These sites were discontinued following an analysis of the relevance of the data at each site.

Parameters

Parameters used to determine the health of the region's coastal waters were chosen because they are affected by human activities (e.g., land-use and climate change) and can affect the growth and survival of marine plants, algae and animals.

Faecal coliforms were removed from the list of laboratory tests in 2009 as enterococci were considered a more appropriate bacteria indicator in coastal marine waters. However, a decision was made to remove enterococci from sampling parameters in 2014 because an analysis of the results showed that the temporal variability requires a much more focused programme. For this information Auckland Council (along with Watercare, Surf Lifesaving Northern Region, and Auckland Regional Public Health Service) runs Safeswim, a programme which provides water quality forecasts and up-to-date information on risks to human health and safety at 84 beaches and eight freshwater locations around Auckland (www.safeswim.org.nz).

Total nitrogen (TN) was added to the list of chemical variables in 2009 as the current nitrogen species analysed allow for it to be calculated.

A review of the programme in 2005 resulted in the removal of the biological oxygen demand (BOD) parameter from the list of analytical laboratory tests. This was due to laboratory analysis consistently returning results at the detection limit (<2 ppm) and no improved methodology was forthcoming or available.

The measurement of water clarity using a Secchi disk also ceased in July 2005 due to the difficulty of accurately estimating readings from the helicopter. Turbidity (measured in NTU) was deemed to be useful approximate parameter instead.

Laboratory analysis

The service provider for laboratory analysis changed in July 2017 from Watercare Services Ltd to Hill Laboratories. This changeover coincided with some changes to analytical methodologies, and detection limits for selected parameters.

Sampling equipment

In November 2008, a hand-held multi-parameter water probe was introduced to the programme. The hand-held probe (YSI 556 MPS) was able to take *in situ* measures of salinity, conductivity, temperature and two dissolved oxygen readings (% saturation and concentration recorded in mg/L). Previously, these parameters were measured in the laboratory by Watercare Services. In December 2014, the YSI 556 MPS multi-parameter meter was upgraded to the EXO 2 multi-parameter sonde (Xylem Analytics).

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