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State of coastal water quality for the west coast of the Waikato region 1994-2021

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Disclaimer

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Water Quality monitoring in coastal and marine areas requires ongoing efforts of several people. We would like to thank WRC's coastal environmental monitoring team (Nathan Singleton, Julia Simpson, and Kit Squires) for their work in data collection and management. Former staff members Pete Wilson and Jolene Francis for their work in water quality and catchment management. Dan Borman kindly provided land cover information. Thanks to Michael Townsend and Eloise Ryan for helpful discussion and reviewing this report.

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Abstract

Water quality data from four estuaries and their adjacent coastal beaches on the west coast of the Waikato region was summarised for preliminary state reporting. The report included data from the recreational water quality monitoring programme as early as 1994 to 2021 and the estuarine water quality monitoring programme from 2002 to 2020. The available data was irregular and infrequent prior to 2017. None of the monitoring stations have sufficient data for robust statistical analysis and results should therefore be interpretated with caution. Difference in monitoring methods between different monitoring periods and between different estuaries did not allow for comparison over time or direct comparison between estuaries. Results are presented in relation to ANZECC (2000) and recreational water quality guidelines (MfE 2003) and discussed for each estuary. The report includes recommendations for ongoing monitoring and reporting.

Estuarine water quality was often seasonally driven with typical higher temperatures and less freshwater impact in summer months. Spring/summer phytoplankton blooms may have led to depletion in dissolved inorganic nitrogen at some monitoring stations and at times reduction in dissolved oxygen concentration at individual monitoring stations in Kawhia and Whāingaroa Harbours. Estuarine water quality in relation to ecological health appeared to be most impacted by nutrient and sediment inputs at monitoring stations with high freshwater influence and potentially low flushing capacity. Exceedances of ANZECC water quality guideline for physical and chemical parameters were highest at these stations. Nutrient, sediment, and microbial contaminant concentrations often decreased with lower freshwater impact, thus indicating that these parameters are mostly driven through catchment rather than seaward inputs. The dominating land cover in the relevant area of the catchment of monitoring stations with the highest nutrient and turbidity concentrations was high producing exotic grassland. Further investigations including more detailed land use information, rainfall and river flow data is needed to understand the impact of catchment activities on estuarine water quality on the region's west coast.

Microbial monitoring data from the estuarine health monitoring programme and the recreational water quality monitoring programme showed that water quality for swimming and other contact recreational activities was often good at all sites. Occasional exceedances were recorded at Port Waikato and Ngarunui Beach showing the need for ongoing monitoring. The relationship between guideline exceedance and rainfall events should be investigated. Several monitoring sites showed exceedance of guidelines for shellfish gathering waters, but often current monitoring data was missing. Reinstating targeted monitoring for shellfish gathering sites is recommended.

Summary

This report summarises the existing water quality data from West Coast estuaries and beaches collected by Waikato Regional Council since 1994. It includes data from an estuarine water quality monitoring programme, which focuses on ecosystem health and a recreational water quality monitoring programme with focus on human health. Four estuaries and adjacent beaches were included: Port Waikato, Whāingaroa (Raglan) Harbour, Aotea Harbour and Kawhia Harbour.

Physicochemical data such as temperature, dissolved oxygen, salinity, turbidity, total suspended solids, chlorophyll *a*, nutrients (nitrogen and phosphorus) and microbiological parameters (enterococci, *E. coli* and faecal coliforms) were collected and analysed as part of the estuarine water quality monitoring programme. The report also includes microbiological data of faecal indicator bacteria as part of the recreational water quality programme. Data analysis did not include an assessment of trends, only state, due to limited data availability and differences in monitoring approaches over time. These results should be considered as preliminary, until further data allows a more robust analysis. Physicochemical (dissolved oxygen, chlorophyll *a*, turbidity, and nutrients) and microbiological data was compared against the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000) and the New Zealand Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (2003), respectively.

Overall, at estuarine health monitoring stations nutrients and sediment values showed the most frequent exceedances of guideline values while microbial water quality was often below guideline values. A typical pattern of the highest and most frequent exceedances was observed at monitoring stations with high freshwater input and low flushing potential. Data indicated that all estuaries received nutrients and sediments primarily from catchment rather than ocean sources. Nutrient and sediment concentrations were often higher at locations receiving freshwater from catchment areas with large proportions covered by high producing exotic grassland and thus indicating farming pressure.

At some monitoring stations in Whāingaroa (Raglan) and Kawhia Harbours increased chlorophyll *a* and decreased dissolved oxygen concentrations were recorded. The frequency of these occurrences will need to be investigated when more monitoring data becomes available. While only 12 months record of data was available for Port Waikato, high nutrient and sediment values indicated the potential for ecological impacts in poorly flushed parts of the estuary warranting further investigation. The first year of monitoring data from Aotea Harbour showed that this estuary is least likely impacted by nutrients, sediments or microbial contaminants. Monitoring at all sites should continue to confirm preliminary results and enable trend analysis.

A brief overview of monitoring results each sampling site is provided below:

- Port Waikato- Port Waikato River estuary was monitored in 2012-2013 and showed a clear picture of a system driven by freshwater inputs. Nutrient, sediment and microbial concentrations showed the highest guideline exceedances at the sampling station located furthest up the estuary. Concentrations and levels of exceedance decreased gradually with lower level of freshwater influence with lowest concentrations at the harbour mouth station which remained within most ANZECC and recreational water quality guideline thresholds. The high nutrient and microbial contaminant inputs have the potential to cause eutrophication symptoms in poorly flushed areas of the estuary and may cause health risk from recreation. The short historic monitoring record is insufficient to understand the current state of the estuary. Monitoring should be reinstated including sampling location in poorly flushed areas. This will be necessary to understand the impacts of potentially low water river flows and increased water takes from the Waikato River. Recreational water quality is suitable for swimming most of the

times at Port Waikato Beach and River Estuary. However, high concentrations of microbial contaminants have been detected after rain at both locations. Recreational activities should therefore be avoided two days after rain. The current monitoring sites are sufficient to cover the recreational programme. However, it should be considered to instate faecal coliform monitoring for shellfish gathering areas as there is the potential of the water being unsuitable for this activity.

- Whāingaroa (Raglan) Harbour- Monitoring at Wahingaroa Harbour took place during three different monitoring periods. While comparison over time revealed trends in water quality the data was not comparable due to inconsistencies in monitoring and large periods without monitoring data. However, all monitoring periods showed the highest pressures from nutrients, sediment, and microbial contaminants in the eastern part of the inner harbour with highest exceedances of ANZECC water quality guidelines at these stations. Phytoplankton growth was higher at these stations and dissolved oxygen concentrations were lower in summer along the water column compared to other stations. These stations are closest to parts of the catchment dominated by high producing exotic grassland and may be subject to pressures from farming activities and less well flushed than other parts of the harbour. With decreasing distance to the harbour mouth water quality improved likely due to higher seawater influence. This points towards catchment sources as the main contributor of nutrients, sediments and microbial contaminants in Whaingaroa Harbour. Seasonal patterns in temperature, dissolved oxygen, some nutrient parameters and chlorophyll *a* were observed but water column stratification was not present. Overall, the harbour experiences some pressures from catchment sources that currently do not show major eutrophication issues but have the potential to cause these in future particularly at inner harbour locations. Monitoring should focus on indicators of eutrophication and comparison with other ecological health indicators should be made. Correlation of water quality with rainfall and high river flow events should be investigated. While water quality for contact recreation appeared good most of the time, comparison of recreational water quality data with rainfall data may identify the cause of occasional exceedances. Historic data suggest potential impacts on shellfish gathering water quality which needs to be confirmed by more targeted monitoring in the future.

- Aotea Harbour- Water quality in Aotea Harbour was good based on monthly monitoring data from April 2019 to March 2021. The water was clear and not impacted by microbial contaminants. Nutrient concentrations remained largely under ANZECC guideline values with the exception of ammoniacal nitrogen. The estuary seems to be coping well under the current conditions as there were no signs of eutrophication such as high chlorophyll *a* concentration or low dissolved oxygen concentrations observed. The water column remained fully mixed at all times which decreases the chances of low bottom waster dissolved oxygen concentrations. Freshwater impacts were more prominent at inner harbour stations and may be linked to increased nitrate-nitrite nitrogen concentrations. Freshwater derived and seasonal impacts will need to be further investigated as additional monitoring data becomes available. Monitoring should continue and be compared to wider ecological health as Aotea Harbour has the potential to be a reference sites to derive water quality standards for similar estuaries in the region. Recreational monitoring ended in 2009 but revealed generally good water quality for recreational activities. Slight potential impacts on shellfish gathering waters observed historically could be confirmed with current monitoring data from the estuarine health programme. The estuary is highly likely to be suitable for recreational activities and shellfish gathering unless increased microbial contaminant concentration occur in future

- Kawhia Harbour – Estuarine water quality monitoring showed overall good water quality with high clarity and no major signs of eutrophication in Kawhia Harbour. Due to a tendency to seasonally stratify the harbour is likely susceptible to eutrophication symptoms as indicated by single low dissolved oxygen concentrations at Oparau sampling station in summer months. Monitoring records were too short to form precise conclusions. It is therefore important to continue monitoring with a focus on eutrophication symptoms including bottom water dissolved oxygen concentrations. Recreational water quality sampling showed that water was well suitable for recreation in the past but shellfish gathering water quality may have been impacted after rain. Current monitoring is too infrequent to fully inform about recreational water quality but indicates that water quality continues to be suitable for recreation. An increase for monitoring frequency for the recreational programme at Kawhia Harbour is recommended.

1 Introduction

This report summarises water quality data from Waikato Region's West Coast. It reports on data from sites currently monitored and historic monitoring sites by Waikato Regional Council (WRC) including Port Waikato, Whāingaroa (Raglan) Harbour, Aotea Harbour and Kawhia Harbour (Figure 1-1). For each monitoring site (e.g. an estuary or harbour), data is available from several monitoring stations within the vicinity of the site (e.g. the harbour mouth).

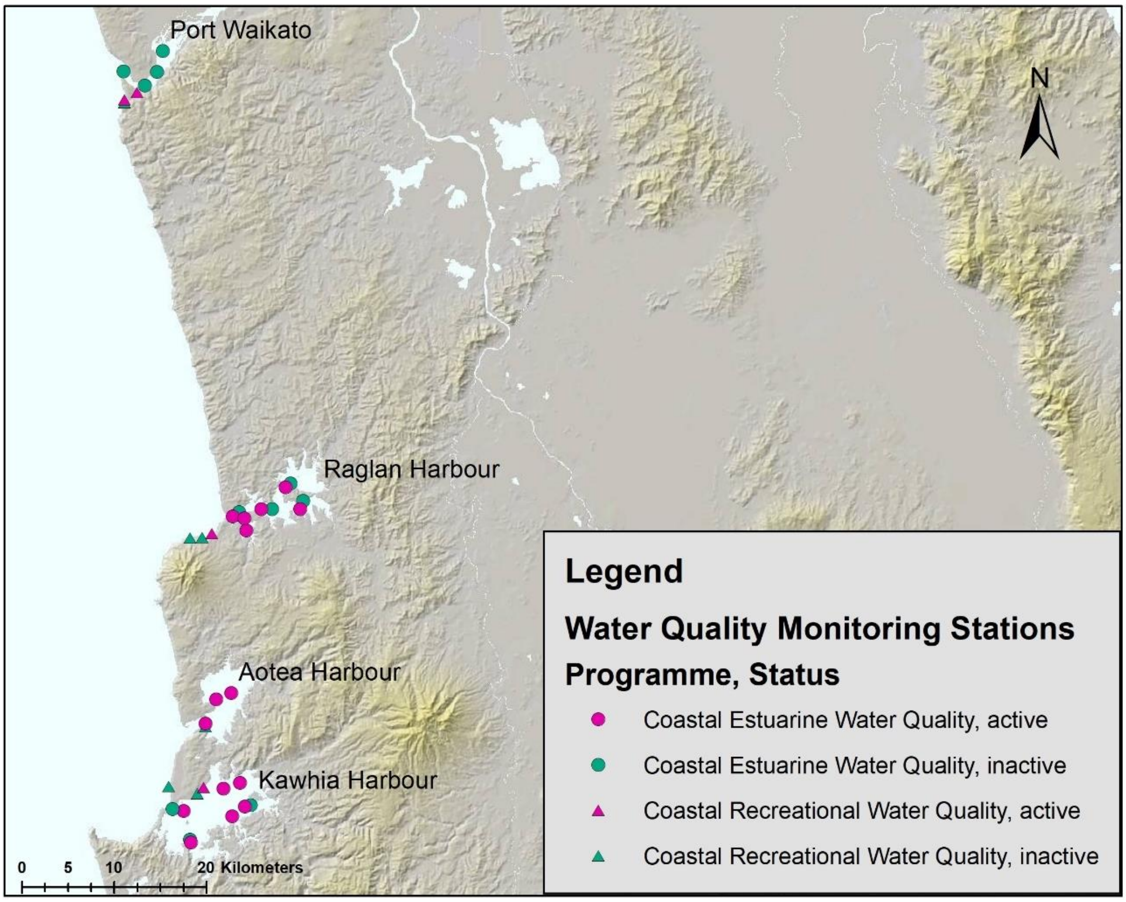

Figure 1-1. Water quality monitoring stations for the West Coast of the Waikato Region for coastal estuarine water quality (ecological health) and coastal recreational water quality. Active stations are currently monitored, and current data is available. Only historical data is available for inactive stations.

Data was collected under two programmes: estuarine water quality and recreational water quality. The estuarine water quality programme focuses on collecting data to determine state and trends of water quality in context to ecological health. It also includes microbial parameters which feed into water quality for contact recreation. Sampling for this monitoring programme is usually conducted monthly, although some historic sites were sampled bimonthly or at irregular intervals. Details for sampling intervals are provided in each chapter below.

The recreational water quality monitoring programme collects weekly samples at stations used for contact recreation (bathing beaches) during the summer monitoring season (November-March) each year. It focuses on water quality for human health by sampling for faecal indicator bacteria including *E. coli* for freshwater, enterococci for saline waters and faecal coliforms as an indicator for shellfish gathering water suitability. All available recreational water quality data from each sampling station up to and including the 2020/21 swimming season is included in this report.

For each estuary, landcover information for the catchment based on the New Zealand Land Cover Database (LCDB) version 5 is provided. Landcover information gives an indication of types of pressures on each estuary from land-based activities in the catchment. For example, nutrient loads from pasture (high producing exotic grassland) are expected to be higher than those from indigenous forest, built-up areas can receive nutrient and microbial inputs from storm or wastewater and horticultural land use may also increase sedimentation and nutrient loading. Where appropriate the report addresses potential connections between land use and water quality results. However, these interpretations are speculative at this stage and would require targeted investigations or long-term monitoring data (e.g., over land use changes) to reveal robust relationships.

This report describes current and historic state of water quality for both objectives, ecological and recreational health within the limitations of the available data. While monitoring for some stations started more than ten years ago, monitoring has not been continuous. Changes in the locations of the stations monitored, monitoring parameters, and the analysis methods restrict the ability to compare data over space and time. Ultimately this lack of consistency restricts the analysis and possible interpretation. For the estuarine water quality monitoring programme, the longest consecutive monitoring record started in October 2017 in Whāingaroa Harbour. All other water quality sites at the West Coast have been monitored for a shorter time. Water quality is influenced by season, weather events, and land-use. Therefore, statistically robust reporting would ideally include at least five years of monitoring for state analysis and ten years for trend analysis using consistent sampling stations and methods (Dudley et al., 2017; Larned et al., 2015; McBride 2005). Consequently, this report includes analysis of state only and results should be considered as preliminary until more data is available. For some bathing beaches monitoring data for more than five summer seasons is available. For these stations, five-yearly ratings according to the microbiological water quality guidelines for marine and freshwater recreational areas (2003) are provided.

2 Methods

2.1 Sampling methods

Since 2017 estuarine water quality sampling is conducted by boat during mid ebb tide, usually within two hours after high tide. Grab samples for chemical and microbiological parameters are collected at a depth of 0.3 m and field parameters (temperature, salinity, dissolved oxygen, and turbidity) are recorded for this depth using either a YSI Pro DSS water quality meter (Whāingaroa Harbour) or an EXO2 multiparameter sonde (Kawhia and Aotea Harbours). Water column profiles for all field parameters and secchi disc (water clarity) readings are recorded at each station. For details, please refer to the standard operating procedures (Doc #11163643).

Sampling methods for the estuarine water quality preprogramme before 2017 differed from the current procedures. At each station, grab samples were collected from surface waters (0.2 m depth) and near bottom waters (approximately 0.5 m above the bottom) using a Van Dorn sampler. Field parameters were measured at the same depth and secchi disc readings were recorded. Sampling was standardised to tide, aiming to sample 1hr either side of mid ebb tide. Parameter selection and laboratory analysis methods differed from the current programme. The details of the differences are beyond the scope of this report and subsequent data offsets cannot be fully assessed as comparative data (e.g. duplicate samples using both laboratory methods) are not available. Table 3-1 provides an overview of all parameters included in this report, their units and the abbreviations are used in result tables and figures for each parameter.

Since 2015 recreational water quality sampling is conducted by wading into approximately knee-deep water and collecting a water sample for microbiological analysis from 15cm below the surface. Water temperature and salinity measurements are taken simultaneously using a YSI Pro

30 conductivity meter. Water samples are chilled and submitted to the laboratory for analysis within 24hrs of sampling. Open-coast samples are analysed for enterococci and estuarine samples are analysed for both, enterococci and *E. coli*. Reporting units for all parameters collected under this programme can be found in table 3.1. Detail about recreational water quality sampling can be found in the relevant SOP (Doc #9127028).

Table 2-1. Water quality parameters reported on.

Parameter	Abbreviation	Units
5-day carbonaceous biological oxygen demand	cBOD5	mg/L
Chlorophyll *a*	Chl a	mg/L
Dissolved oxygen	DO	mg/L
Dissolved oxygen saturation	DO saturation	%
Dissolved reactive phosphorus	DRP	mg/L
Escherichia coli	*E. coli*	cfu/100ml or mpn/100ml
Enterococci	enterococci	cfu/100ml or mpn/100ml
Faecal coliforms	Faecal coliforms	cfu/100ml
Ammoniacal Nitrogen	NH4	mg/L
Nitrite and Nitrate Nitrogen	NNN	mg/L
pH by field meter	field pH	
pH lab measurement	lab pH	
Salinity	Salinity	PSU
Secchi Disc (visibility)	Secchi disc	m
Temperature	Temp	°C
Total Nitrogen	TN	mg/L
Total Phosphorus	TP	mg/L
Total Suspended Solids	TSS	mg/L
Turbidity lab measurement	Lab Turb_FNU	FNU
Turbidity lab measurement	Lab Turb_NTU	NTU
Turbidity by field meter	Field Turb FNU	FNU
Total Kjeldahl Nitrogen	TKN	mg/L

Sampling methods for recreational water quality sampling before 2015 are not documented but are expected to be comparable to the current methods.

2.2 Analysis methods

All censored data (less than or larger than values) was corrected to be included into statistical analysis. Left censored data (results below detection limit of the analysis method) were multiplied by 0.5 and right censored data (results above detection limit of the analysis method) were multiplied by 1.1.

For statistical analysis, data was grouped into monitoring periods, which reflected continuous monitoring data using the same field sampling and laboratory analysis methods. For the recreational water quality, data before 2015 was often recorded at irregular intervals. For example, stations in Whāingaroa Harbour were monitored for enterococci from 1994/95-1996/97 with variable sample numbers per station. Subsequent data was collected biannually between 2000/01 and 2008/09 seasons. For more robust statistical analysis (more data than analysing single seasons) and better data illustration, this data has been grouped into two monitoring periods (1994-1997 and 2000-2009) regardless of irregular sampling frequencies. The available data and monitoring periods for each station are described in the respective “available data” section below and listed in appendices A and B.

Statistical analysis and data illustration were conducted in R (R Core Team, 2019) using R Studio (RStudio Team, 2015). For data under the estuarine water quality programme monthly averages were calculated for each parameter, station and year where more than one data point per month was recorded. Data quantiles were calculated using Hazen percentiles and are summarised in appendices A and B. For depth profile data, the average data value per depth and sampling day was calculated and plotted on depth profile plots.

The data in this report were compared against two sets of guidelines values. Firstly, estuarine physical and chemical water quality data was compared against the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000) for slightly disturbed estuaries (Table 3-2). These guideline values are considered thresholds that are based on reference site data from South-East Australia. For estuarine monitoring stations falling under the slightly disturbed category, the annual median should be compared to the threshold values. The potential risk for adverse ecological effects is considered low if water quality data at monitoring stations remains within the threshold boundaries. It is recommended that further investigation of ecological impacts of water quality are conducted if thresholds are breached. For the purpose of this report, it was assumed that all estuarine monitoring stations fall under the slightly disturbed category and the overall for each relevant parameter was compared against the ANZECC guidelines. Of note is that ANZECC guidelines are based on data from South-East Australia waters only, as no data was available from New Zealand at the time of development. They may therefore not represent New Zealand specific conditions but are currently the most suitable option for guideline values.

Table 2-2. Guideline values used for data comparison, based on ANZECC Guidelines for Fresh and Marine Water Quality for slightly disturbed estuaries South-East Australia (ANZECC, 2000). Values were converted to match the units in WRC's coastal water quality monitoring programme.

Parameter	Limit value	Units
Chl a	<= 0.004	mg/L
TP	< = 0.03	mg/L
DRP	< = 0.005	mg/L
TN	<= 0.3	mg/L
NH4	<= 0.015	mg/L
NNN	<= 0.015	mg/L
DO %	>=80 and <= 110	%
pH	>=7 and <= 8.5	
Turb	10	NTU or FNU

Microbial data from both the estuarine water quality and the recreational water quality monitoring programmes were compared against the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (Ministry for the Environment, 2003). Table 3-3 shows the values for *E. coli* (faecal indicator for freshwater), enterococci (faecal indicator for saline water) and faecal coliforms (faecal indicator for shellfish gathering waters). Values within the green status indicate that conditions are suitable for recreation. Concentrations in the amber range signify that the risk of infection is increased, and caution is advised as waters may not be suitable for recreation. In the red alert range water is considered unsuitable for recreation. Shellfish gathering waters are considered bacteriologically safe when data collected over one gathering season remains within both guideline values (Table 3-3). It is expected that sufficient data is collected for robust statistical analysis during the season.

For active monitoring stations in the recreational water quality programme with monitoring data from five seasons or more, the microbial assessment category (MAC) for each the station was calculated using data from the most recent five seasons. Only open coastal sites fulfilled these criteria, therefore the MAC assessment for marine waters/ enterococci is shown only. The MfE guidelines (2003) define the category based on the 95th percentile of data (Hazen percentile method) with A as the best grade and D the worst representing different levels of infection risk (Table 2-4).

Table 2-3. Guideline values used for data comparison based on MfE Guidelines for Marine and Freshwater Recreational Areas (Ministry for the Environment, 2003).

Environment	Indicator organism	Green	Amber	Red
Freshwater	*E. coli*	< 260 cfu /100ml	>= 260 and < 550 cfu /100ml	>= 550 cfu /100ml
Saline water	enterococci	< 140 cfu /100ml	>= 140 and < 280 cfu /100ml	>= 280 cfu /100ml
Environment	**Indicator organism**	**Limits over shellfish gathering season**		
Shellfish gathering waters	Faecal coliforms	Median <= 14 cfu /100 ml	90th percentile <=43 cfu/100 ml	

Table 2-4. Microbial assessment category for marine recreational monitoring stations based on MfE Guidelines for Marine and Freshwater Recreational Areas (Ministry for the Environment, 2003).

MAC	95th percentile enterococci/ 100ml	Risk of illness from contact with the water
A	≤ 40	< 1%
B	41 – 200	< 5%
C	201 – 500	5 – 10%
D	> 500	> 10%

2.3 General catchment land cover information

Land cover information for each estuary catchment was retrieved from the New Zealand Land Cover Database (LCDB) version 5 in ArcMap. Percentual land cover for each estuary catchment is shown in Figure 3-1. This is broad information about the land cover in the catchment including the extend of vegetation, built environments, water bodies and bare natural surfaces. It provides a very general idea about potential pressures to the estuary from the catchment. Land cover information does not provide details about land use such intensity or type. While two catchments may be similar in relative land cover class proportions their total area occupied for this land cover class may be vastly different. There may also be difference in land use intensity such as intensive dairy farming vs sheep farming. Finally, it does not provide an indication of loads into the catchment from freshwater or point source discharges.

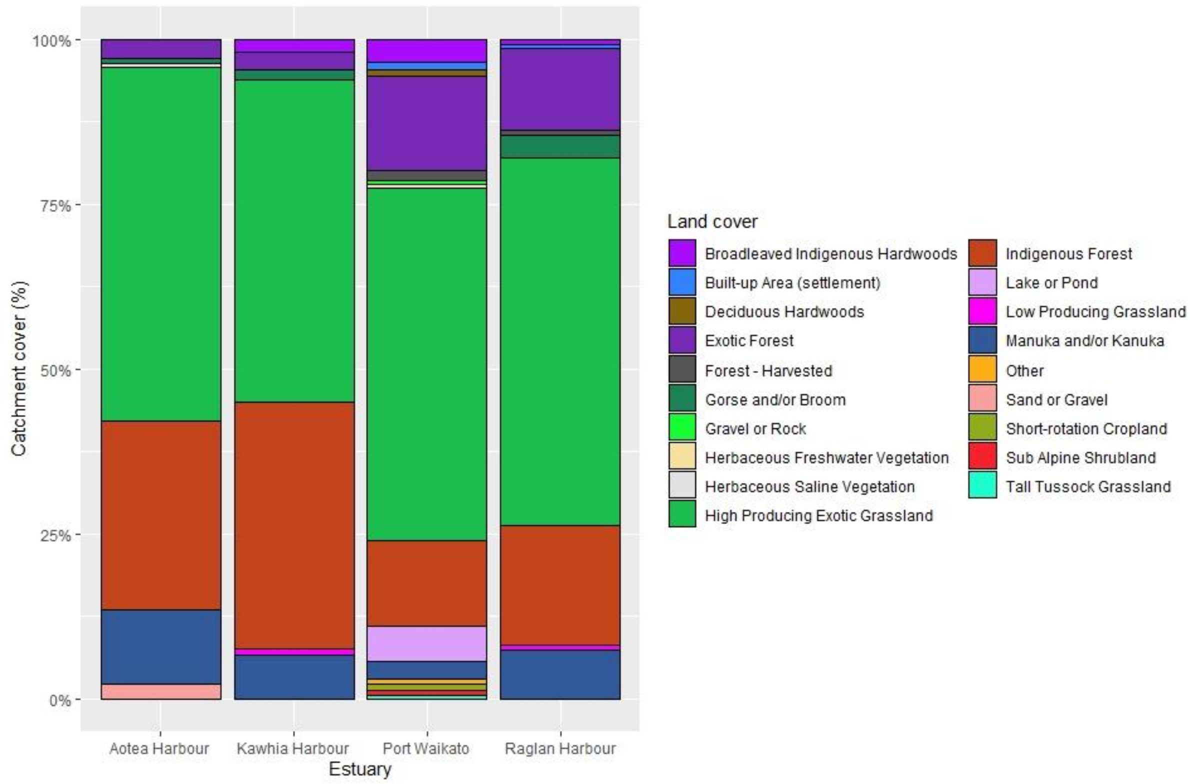

Figure 2-1 Land use cover per catchment for Waikato West Coast Estuaries. Classes over 0.5% cover were included in the graph.

3 Port Waikato

3.1 Monitoring stations and available data

Surface and bottom estuarine water quality samples were collected at four stations from July 2012 to July 2013 at irregular intervals. From July to September 2012 samples were taken every two months, followed by December 2012 and then January 2013. After January 2013, sampling continued bimonthly until July 2013. Site 1 is the furthest up the estuary and experiences the highest freshwater influence. Sites 2 and 3 are located lower in the estuary and Site 4 is closest to the mouth with the least freshwater influence (Table 3-1, Figure 3-1). An overview of monitoring periods per station and parameter is presented in Appendix A.

Recreational water quality stations at Port Waikato include Sunset Beach Surf Club and Maraetai Bay, which are active monitoring sites and Sunset Beach South of Stream which was historically monitored but was discontinued in 2009 (Table 3-1, Figure 3-1). Data for recreational water quality has been collected regularly at Sunset Beach Surf Club since November 2015 for enterococci. Monitoring in Maraetai Bay was restarted in November 2020 including enterococci and *E. coli*. All stations have been monitored with changing frequencies for enterococci from 1994-1997 and for enterococci and faecal coliforms between 2000 and 2009. Maraetai Bay and Sunset Beach Surf Club were also monitored for *E. coli* between 2000 – 2009 and 2015-2016, respectively. All stations were also historically monitored for faecal coliforms between 2000 and 2009, and between 2015-2016 for Sunset Beach Surf Club. Appendix B gives an overview of monitoring periods and sample number available.

Table 3-1. Coastal Water Quality sampling sites at Port Waikato. Coordinates in NZTM.

Station	Programme	Easting	Northing
Site 1 Bottom	Coastal Estuarine Water Quality	1755478	5865026
Site 1 Surface		1755478	5865026
Site 2 Bottom		1754826	5862795
Site 2 Surface		1754826	5862795
Site 3 Bottom		1753521	5861309
Site 3 Surface		1753521	5861309
Site 4 Bottom		1751206	5862861
Site 4 Surface		1751206	5862861
Maraetai Bay	Coastal Recreational Water Quality	1752677	5860597
Sunset Beach South of Stream		1751279	5859495
Sunset Beach Surf Club		1751279	5859795

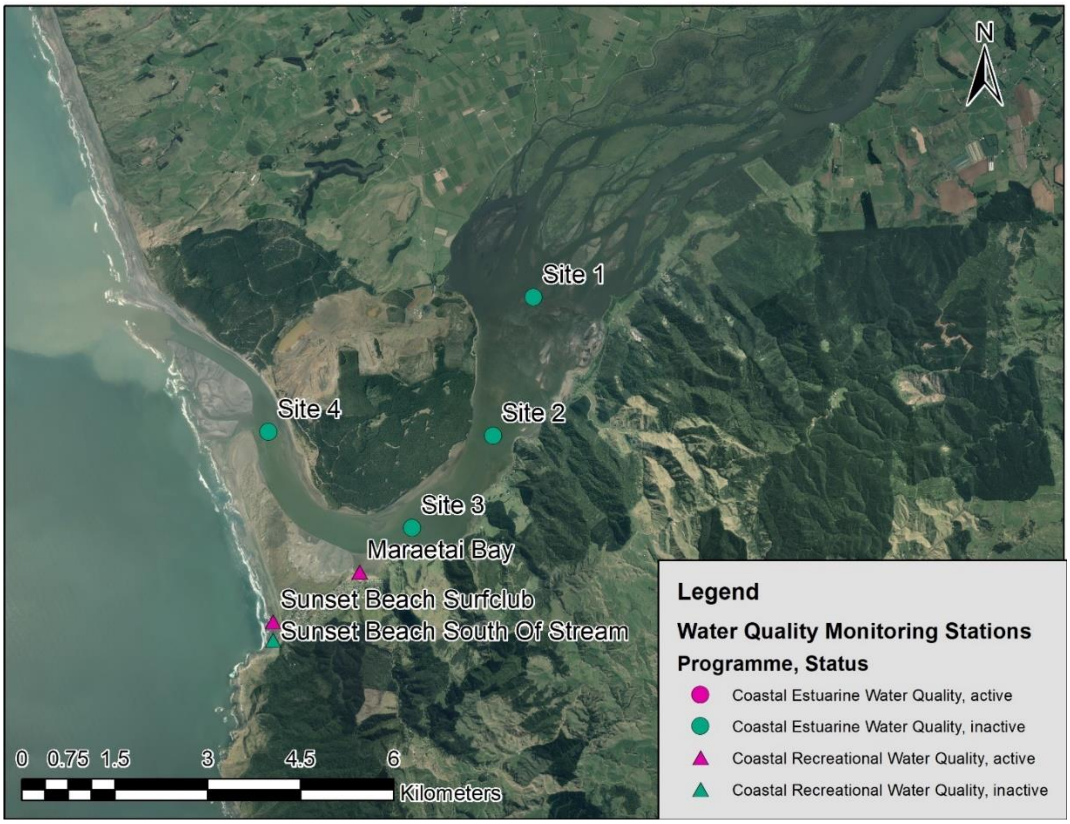

Figure 3-1. Map showing sampling stations at Port Waikato Estuary and Beach.

3.2 Catchment land cover information

The Waikato Estuary catchment comprises a 1,443,846-ha area. Most of the catchment is classified as high producing exotic grassland (53 %, Figure 2-1), with exotic and indigenous forests contributing 14 % and 13 %, respectively. Most of the indigenous forest appears to be in the upper catchment (data not shown). Other land cover classes above 1% coverage include lakes and ponds (5 %), broadleaved indigenous hardwoods (3 %), Manuka/Kanuka (3 %), harvested forest (1.5%) and urban areas/settlements (1 %). Short rotation crop land appears to be concentrated around the lower estuary and makes up (0.9 % of the catchment).

3.3 Results

3.3.1 Estuarine Water Quality

Data for estuarine water quality at Port Waikato sampling stations is plotted in Figures 3-2 to 3-4. Full results are shown in Appendix A.

For most parameters there was no notable difference between bottom and surface samples, but differences between monitoring stations were evident. No temperature stratification was observed. Overall, water temperature showed typical seasonal patterns with lowest temperatures in July (min between 10.8 – 13.9 °C) and highest values in January (max between 20.4 – 23.5 °C, Figures 3.2 and C11.1). Differences between sites were subtle with slightly larger temperature ranges at Site 1 and Site 2. More prominent site-specific differences were observed in water salinity. Salinity values at Site 1 were consistently below 1 PSU indicating the absence of saline water. At Site 2, salinity ranged from less than 1 PSU to approximately 30 PSU showing the highest range of all stations. At this station, salinity steadily increased from September to March and then dropped again in May (Appendix C Figure C11-1). Sites 3 and 4 were mostly in the saline range above 30 PSU (Figure 3-2). Data at all monitoring stations ranged within ANZECC (2000) guideline values for pH in estuaries. Sites 1 and 2 showed the largest pH range between pH 7 and 8.5. Surface water at Site 3 reached pH 7.1 on one occasion but was mostly in the range of pH 7.8 to 8.1. Measurements for pH at Site 4 ranged from pH 7.8 to 8.2. Differences were observed between stations for water clarity (Figure 3-2). Secchi disc measurements showed increasing visibility along the estuary with the lowest values at Site 1 (max = 0.68 m) and the highest at Site 4 (max = 2.53 m). Turbidity values were the inverse of this, highest at Site 1 (max = 34 NTU) and lowest at Site 4 (min = 0.88 NTU). Median values exceeded ANZECC guideline criteria of 10 NTU for all stations except surface water at Site 4 (median = 9.6 NTU).

The five-day carbonaceous biological oxygen ($cBOD_5$) demand was highest at Site 1 with a maximum of 3.6 mg/L in bottom waters and a median 1.9 mg/L in surface waters. Increased concentrations were observed during late summer-autumn (January – May, Appendix C Figure C11-1). At all other stations median cBOD5 remained below 1 mg/L and below 2 mg/L for maximum values. Dissolved oxygen saturation was within ANZECC guidelines at all stations with no apparent difference between surface and bottom waters (Figure 3-3). Median chlorophyll *a* values remained below the ANZECC guideline thresholds at all stations except for bottom water at Site 1 (median = 0.004 mg/L). At Site 1 the threshold was exceeded up to ten-fold for maximum concentration during the sampling period (max surface water = 0.046 mg/L) in November. All elevated values were observed between November and March. Site 2 also showed occasional increased chlorophyll *a* concentration with max values reaching 0.017mg/L in surface waters. In comparison, concentrations at Site 3 and Site 4 were lower with median values at 0.0015 mg/L at both stations and max of 0.007 and 0.005 mg/L, respectively (Figure 3-3). Nitrogen and its constituents showed a clear pattern of highest concentrations at Site 1, Site 2 and partially in the surface waters of Site 3 (Figure 3-3). For total nitrogen, median values at Site 1, 2 and 3 (surface water only) exceeded ANZECC guideline values up to 3-fold (median Site 1 surface = 1 mg/L). While median for ammoniacal nitrogen remained below the relevant ANZECC guideline threshold of 0.015 mg/L, they did increase in July 2012 and 2013 compared to other months (Appendix C, Figure C11-2). Median Nitrate-Nitrite nitrogen concentrations exceeded the ANZECC threshold of 0.015 mg/L at all stations and water depths (Figure 3-3). Median concentrations at Site 1 for surface and bottom waters (0.64 mg/L) exceeded this value approximately 43 fold. The highest concentrations of nitrogen constituents were observed in autumn and winter (May – July, Appendix C Figure C-11-2). ANZECC guidelines for total phosphorus (0.03 mg/L) were exceeded at Site 1 (median surface and bottom= 0.087 - 0.077 mg/L), Site 2 (median surface and bottom = 0.044 - 0.042 mg/L) and bottom waters at Site 3 (median = 0.033 mg/L). Median values, at all stations reached or exceeded the guideline value for dissolved reactive phosphorus of 0.005 mg/L (Figure 3-3). For all phosphorus parameters, Site 1 showed the highest concentrations, with increased DRP concentration in the May, July and September (Appendix C, Figure C-11-2).

Like nutrient concentrations, microbial parameters showed the highest concentrations at Site1 and Site 2 (Figure 3-4). The *E. coli* 75th percentile exceeded the recreational amber alert level guideline value of 280 cfu/100 mL and for surface waters at Site 1 the red alert level value of 550 cfu/100mL (75th percentile: 498, 575, 360, 478 for Site 1 Bottom, Site 1 Surface, Site 2 Bottom, and Site 2 Surface, respectively). Enterococci concentrations were also highest at Site 2 in bottom waters (Figure 3-4). Ninety fifth percentile concentrations at this station, Site 2 and surface waters at Site 3 exceeded the red alert guideline levels for recreational water quality with 390, 300 and 300 cfu / 100 mL, respectively. Median values remained below guideline alert levels at all stations and Site 4 always remained below guideline alert levels. Guideline levels for shellfish gathering waters based on faecal coliform concentrations (median ≤ 14 cfu / 100 mL, 90th %tile ≤ 43 cfu / 100 mL) were exceeded at all station expect Site 4 (Figure 3-4). At all monitoring station microbial concentrations were lower from November until March (Appendix C, Figure C-11-3).

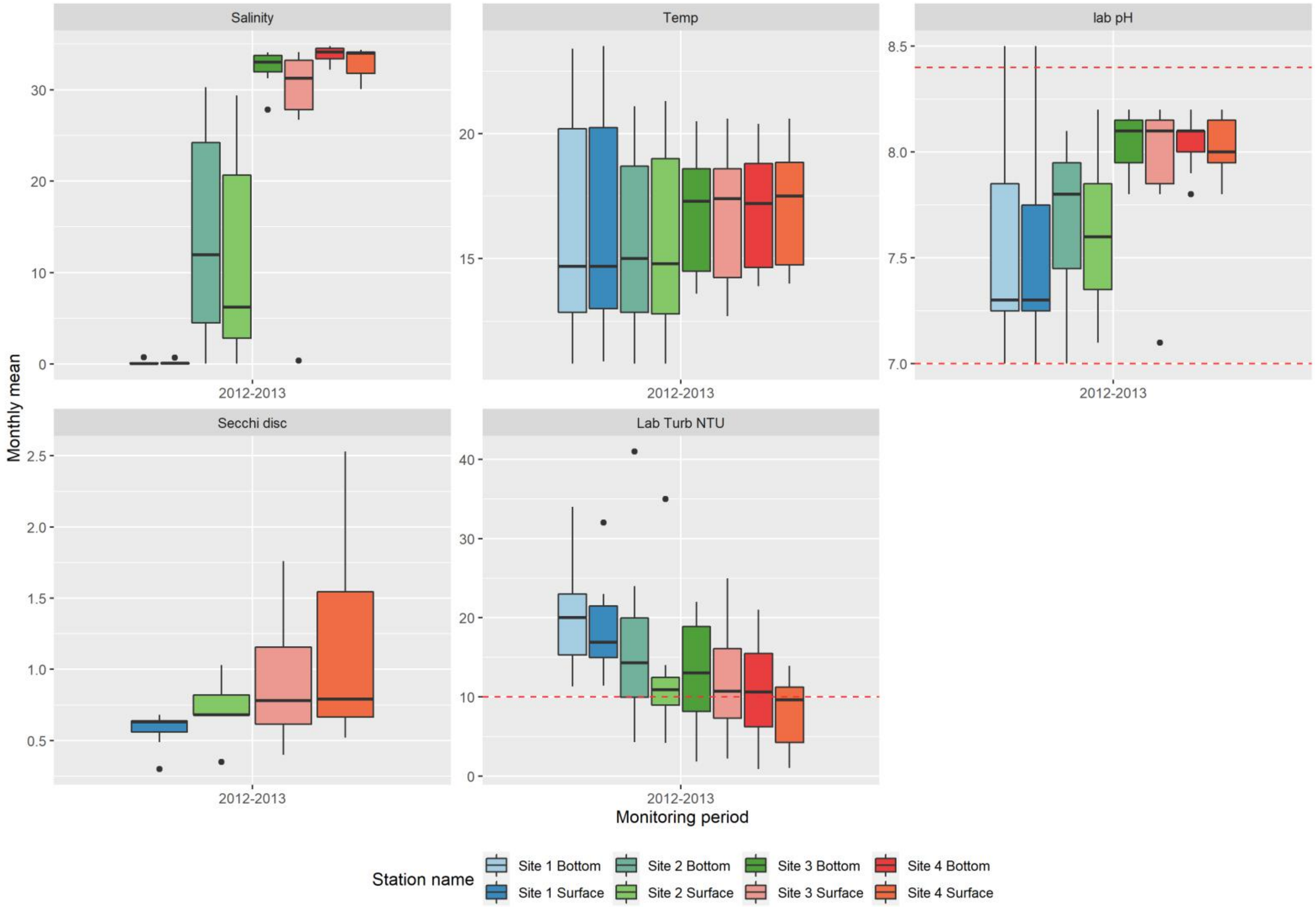

Figure 3-2. Distribution of physical estuarine water quality monitoring data per monitoring period for Port Waikato. The box represents the interquartile range between the 25th percentile (lower boarder) and the 75th (upper boarder), the bold line inside the box represents the median. Vertical lines (whiskers) below and above show the data range. Outliers (calculated at 1.5 interquartile range) are shown as black circles. Dashed red lines represent ANZECC guideline limits for the applicable parameter (see Table 2-2). For parameter units refer to table 2-1.

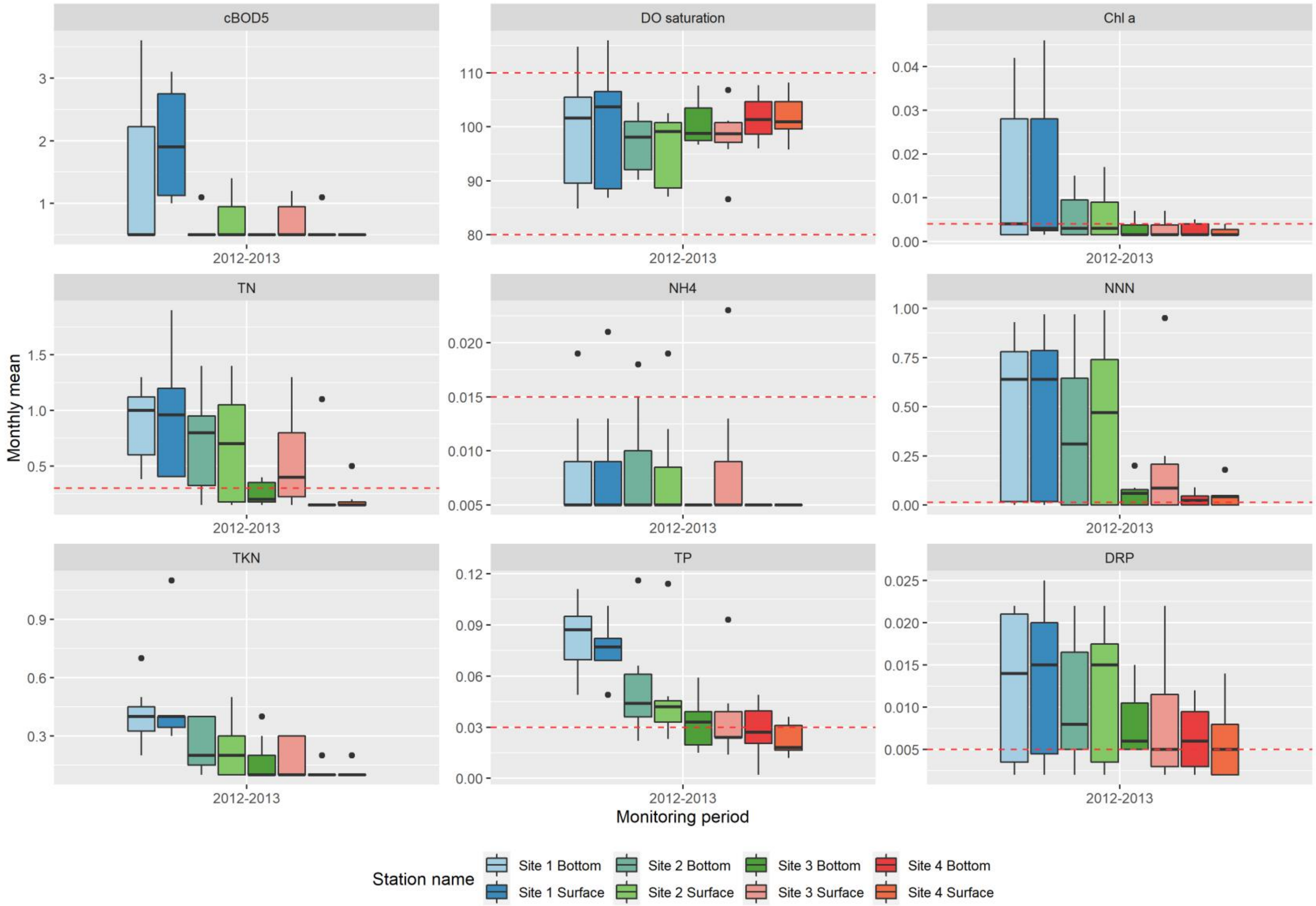

Figure 3-3. Distribution of chemical estuarine water quality monitoring data per monitoring period for Port Waikato. See figure 3-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the applicable parameter (see Table 2-2). For parameter units refer to table 2-1.

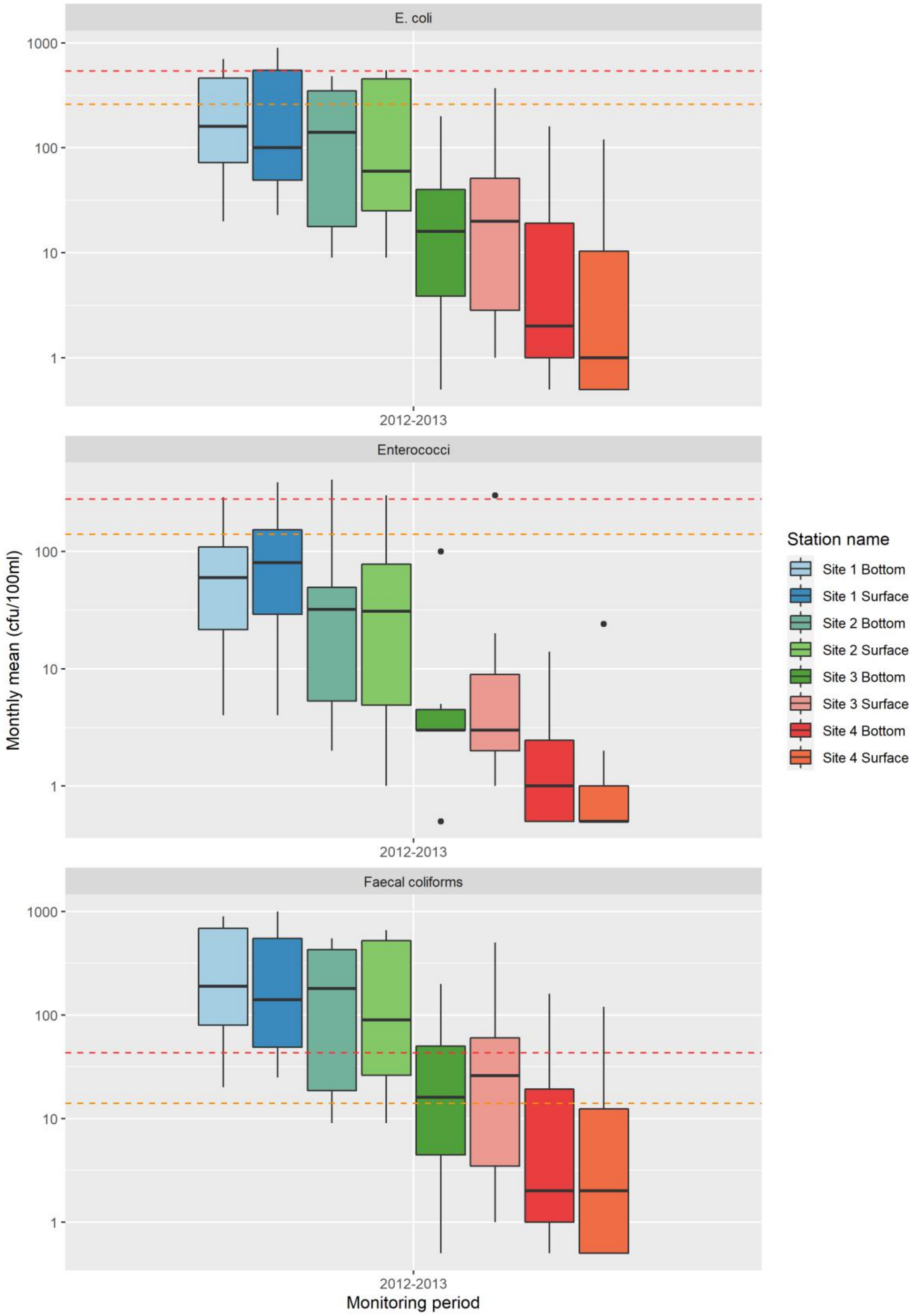

Figure 3-4. Distribution of microbial estuarine water quality monitoring data per monitoring period for Port Waikato. Y-axis is at log scale. See figure 3-2 for boxplot range definition. Dashed red lines represent the red alert and dashed amber lines the amber alert limit for *E. coli* and enterococci according to the recreational water quality guidelines for marine and freshwater. For faecal coliforms, the dashed red line denotes limit for the 90%th percentile and the dashed amber line the median limit for shellfish gathering waters (see Table 2-3).

3.3.2 Recreational water quality

Recreational water quality at Sunset Beach Surf Club was often suitable for swimming. Throughout the 1994-97 and 2000-09 monitoring seasons, *E. coli* and enterococci concentrations were below guideline values (Figure 3-5). Since 2015, there have been a few occasions where enterococci values have exceeded amber and red alert levels of 140 and 280 cfu / 100 mL, respectively. Due to these events the 95th percentile for enterococci at Sunset Beach Surf Club over the last five years (up to the 2020/21 summer season) was 280 cfu / 100 mL. Therefore, the station received a "C" MAC rating, which means a 5-10% risk of infection from contact with the water. Faecal coliform concentrations remained below the median guideline value for shellfish gathering waters of 14 cfu / 100 mL but breached the 90th percentile value of 43 cfu / 100 mL in the monitoring season 2015/16 (data "since 2015") with 47 cfu / 100 mL. The other monitoring station at Sunset Beach, "Sunset Beach South of Stream" remained below guideline values for enterococci between 1994 - 1997 and 2000-2009 (Figure 3-5). The estuarine station, Maraetai Bay showed 95th percentile values below guideline alert levels for enterococci (95th %ile = 24, 88, 94 cfu / 100 mL for monitoring seasons 1994-1997, 2000-2009, and since 2015, respectively) but occasional exceedances of amber and red alert levels were observed (2000-2009 Max = 300 cfu/100 mL, since 2015 max = 158 cfu / 100 mL). Occasional exceedances of *E. coli* concentrations were also found in 2000-2009 and since 2015 with 95th percentile values at 387 and 794 cfu / 100 mL, respectively. Concentrations for faecal coliforms at Sunset Beach South of Stream were under the guideline limits for shellfish gathering waters in 2016 (Figure 4-5, Appendix B). Maraetai Bay was only monitored for faecal coliforms until Feb 2009 where data exceeded both limits for shellfish gathering waters (median= 52 cfu/100 mL, 90th percentile = 300 cfu/100 mL).

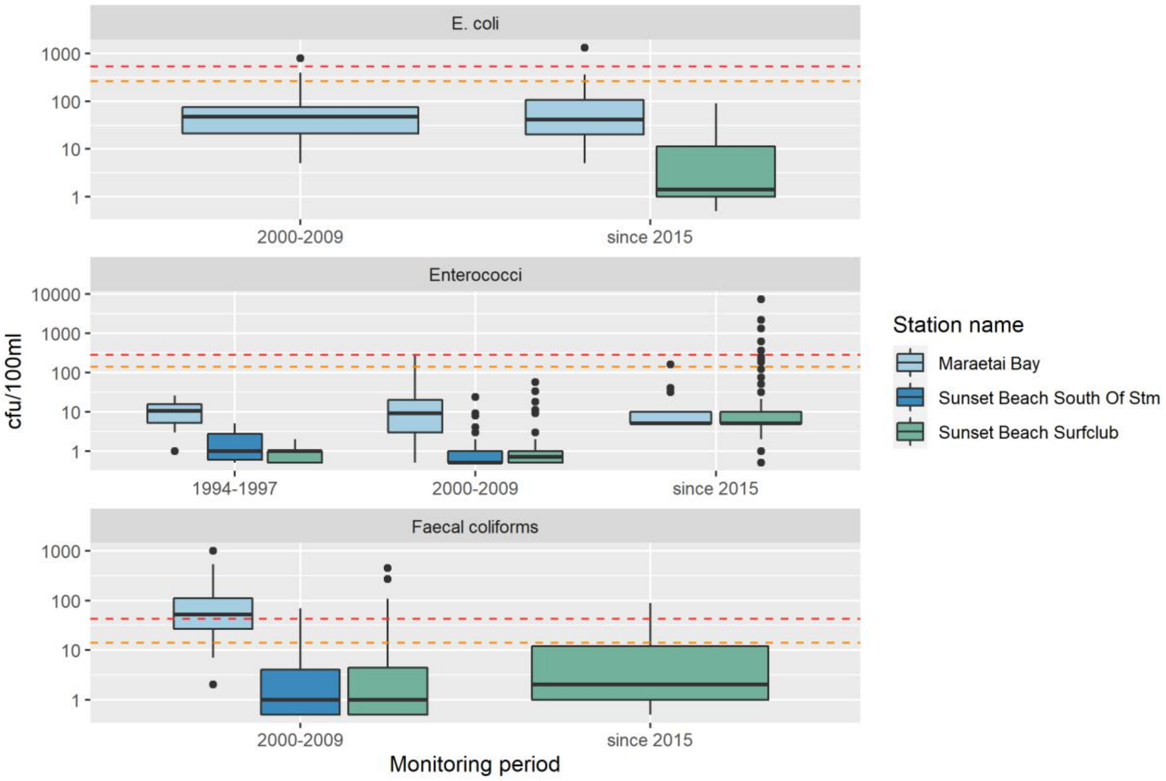

Figure 3-5. Distribution of microbial recreational water quality monitoring data per monitoring period for Port Waikato. Y-axis is at log scale. See figure 3-2 for boxplot range definition. Dashed red lines represent the red alert and dashed amber lines the amber alert limit for *E. coli* and enterococci according to the recreational water quality guidelines for marine and freshwater. For faecal coliforms, the dashed red line denotes limit for the 90%th percentile and the dashed amber line the median limit for shellfish gathering waters (see Table 2-3).

3.4 Discussion

3.4.1 Estuarine water quality

At Port Waikato, water quality was driven by freshwater inputs and improved gradually with increasing seawater influence. Site 1, the uppermost location in the estuary, was always freshwater dominated with salinity values consistently below 1 PSU. At this station water clarity was lowest and accordingly turbidity measurements were highest. Likewise, nutrient concentrations for nitrogen and phosphorus and their constituents were highest of all stations in this estuary. The nutrient concentrations likely drove phytoplankton growth at this station that were reflected in the higher chlorophyll *a* concentration relative to the other monitoring stations. Increased phytoplankton biomass and organic inputs from the Waikato River were likely fuelling the increased carbonaceous biological oxygen demand, which was much higher than at all other monitoring stations (Figure 3-3). Microbial parameters were also highest at Site 1 indicating that contamination originated from the catchment and transported into the estuary by freshwater flows. Site 2 which experienced highest salinity fluctuations from freshwater (0.05 PSU) to brackish (30 PSU) showed low secchi disc readings and higher turbidity, higher nutrient, and microbial contamination concentrations than at Site 3 and Site 4 (Figures 3-2 to 3-4). At these two stations freshwater influence was much reduced (median salinity 31 and 34 PSU) and nutrient concentrations decreased. Median total nitrogen and total phosphorus values were under ANZECC guideline values at Site 4 and microbial parameters much reduced compared to Site 1 and 2. The gradual improvement of water quality with higher dilution of freshwater suggests that nutrients, sediments, and microbial contaminations originate from catchment sources and are brought into the estuary via freshwater inputs rather than from oceanic sources.

Although some indications of typical seasonal patterns were observed in Port Waikato River Estuary, the monitoring timeframe was too short and too infrequent to confirm these. It appears that lower river flow in summer months, as was observed by decreasing salinity at Site 2, brought lower nutrient concentrations into the estuary compared to other times of the year when river flows are likely to be higher (Appendix C Figure C-11-2). Nitrogen concentrations and increasing temperatures in spring and early summer then likely fuelled phytoplankton blooms in spring which led to Nitrate-Nitrite nitrogen depletion in these months (Appendix C Figure C-11-2). The phytoplankton bloom likely caused increased biomass in the estuary that led to higher carbonaceous biological oxygen demand in late summer and autumn. Additional monitoring data together with climate and river flow data is necessary to confirm these assumptions.

Microbial concentrations were also reduced in summer months when there was likely lower river flow (Appendix C Figure C-11-3). Likewise, other parameters like DRP and turbidity that are also associated with land run off showed the same pattern of lower concentrations in summer months and higher concentrations for the rest of the year. Such patterns will need to be confirmed with additional data.

Overall, the data from the estuarine water quality monitoring programme at Port Waikato Estuary showed the impact of the Waikato River on estuary water quality. Data often exceeded guideline limits; with the frequency and magnitude of exceedances increasing with greater freshwater influence. While higher nutrient and microbial values are expected with freshwater influence, the exceedances in the lower estuary could have ecological impacts in areas where the flushing potential is low (e.g., side arms of the estuary). Since the data was temporally limited and collected seven years ago, additional monitoring is required to assess the current water quality at Port Waikato Estuary.

3.4.2 Recreational water quality

E. *coli* and enterococci showed occasional exceedances at recreational monitoring stations in Port Waikato. For enterococci the frequency and magnitude of enterococci exceedances at Sunset Beach Surf Club increased since 2016 (Appendix D, Figure D12-1). Since the 2019-20 season, these exceedances occurred often when samples were collected during rainfall (data not shown). Repeat samples did not confirm the exceedance approximately 48 hours after sampling indicating that they were flushed out relatively quickly. Contaminant loading from the Waikato River appears to be the most likely source of microbial contamination at Sunset Beach as it a relatively larger source and analysis of estuarine monitoring data indicated that the river is likely the main source of contamination in the estuary (section 3.4.1). It appears highly likely that high river flows due to rainfall events were transporting more contaminants to Sunset Beach. To confirm this, river flow and rainfall data should be analysed together with the recreational monitoring data. If a strong correlation between enterococci concentrations and factors such as rainfall, river flows, or tidal influence can be found, the development of now- and forecasting models for contaminant concentrations using these parameters as a proxy would be a very valuable approach. Recreational monitoring at Sunset Beach and Maraetai Bay should continue due to the occasional exceedances and the overall C- MAC grading for Sunset Beach. There were no apparent differences between the two Sunset Beach monitoring stations and therefore the currently active station at the Surf Club should be sufficient to inform recreational water quality at this beach.

Faecal coliform concentrations have not been monitored at Sunset Beach since 2016. The historic monitoring at both Sunset Beach stations showed that there were no concerning concentrations detected before until 2009. But in 2015/16 the 90th percentile alert was breached at the Surf Club Station. Faecal coliform concentrations at Maraetai Bay between 2000 and 2009 exceeded both guideline limits for shellfish gathering waters. This indicates that water quality may be compromised for shellfish gathering at these stations. Since there is no recent data, sampling would need to be reinstated to confirm if there are current issues with faecal contamination.

4 Whāingaroa (Raglan) Harbour

4.1 Monitoring sites and available data

Four stations (Inner Harbour North, Inner Harbour South, Mid Harbour and Outer Harbour) were monitored in Whāingaroa (Raglan) Harbour for surface and bottom water pre 2017 under the estuarine water quality monitoring programme (Figure 4-1, Table 4-1). The first monitoring period for these stations began in August 2002 and continued bimonthly until April 2003, followed by monthly monitoring until June 2003. The second monitoring period started in July 2013 and sampled bimonthly until May 2014 and included June 2014. The current iteration of the estuarine water quality monitoring programme started in October 2017 and is conducted monthly. The following monitoring stations are sampled under this programme: Opotoru, Mid Harbour, Harbour Mouth, Waingaro, Wainui, and Waitetuna (Figure 4-1, Table 4-1). Appendix A provides a full overview of monitoring periods per station and parameters.

Recreational water quality has been monitored at four stations in the Whāingaroa area including Manu Bay, Motor Camp North of Bridge, Ngarunui Beach and Whale Bay. Ngarunui Beach and Motor Camp North of Bridge are the only monitoring stations currently sampled. Ngarunui Beach has been monitored weekly each swim season (Nov-March) since 2015/16 for enterococci and Motor Camp North of Bridge was reintroduced to the programme in 2020 for enterococci and *E. coli*. Recreational monitoring before 2015 was not regular for all stations and parameters. An overview over monitoring periods, sample number per station and parameter is shown in Appendix B. Monitoring stations are shown in Figure 4-1 and listed in Table 4-1.

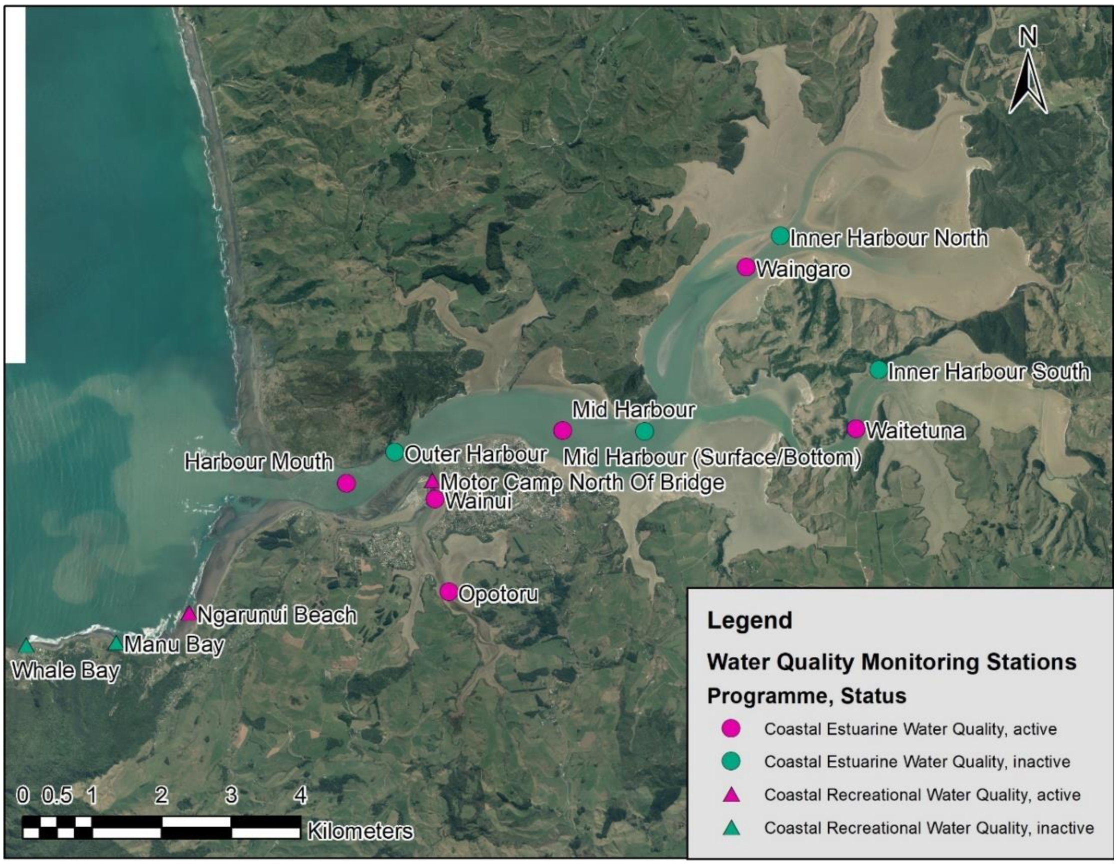

Figure 4-1. Map showing sampling sites at Whāingaroa Harbour and Beaches.

Table 4-1. Coastal Water Quality sampling locations at Whāingaroa Harbour and beaches. Coordinates in NZTM.

Station	Programme	Easting	Northing
Inner Harbour North (Bottom)	Coastal Estuarine Water Quality	1769258	5818229
Inner Harbour North (Surface)		1769258	5818229
Inner Harbour South (Bottom)		1770669	5816305
Inner Harbour South (Surface)		1770669	5816305
Mid Harbour (Bottom)		1767304	5815415
Mid Harbour (Surface)		1767304	5815415
Opotoru		1764488	5813108
Outer Harbour (Bottom)		1763713	5815119
Outer Harbour (Surface)		1763713	5815119
Mid Harbour		1766128	5815428
Harbour Mouth		1763019	5814670
Waingaro		1768767	5817776
Wainui		1764291	5814440
Waitetuna		1770345	5815453
Manu Bay	Coastal Recreational Water Quality	1759704	5812380
Motor Camp North of Bridge		1764251	5814716
Ngarunui Beach		1760754	5812810
Whale Bay		1758411	5812344

4.2 Catchment land cover information

Whāingaroa Harbour's catchment includes 52595 ha with 55% of this classified as high producing exotic grassland (Figure 2-1). Other major land cover classes include indigenous forest (18%), exotic forest (12%), Manuka and Kanuka (7%), and Gorse and/or Broom (3%). Urban areas and urban parkland combined make up for 0.7% of the catchment. Figure 4-2 shows that the lower catchment area is dominated by high producing exotic grassland and a few smaller areas of Manuka/Kanuka and indigenous forest. Apart from the eastern area of the catchment all rivers and stream flow through this land cover class before discharging into the estuary. Native and exotic forest are located mostly in the upper catchment.

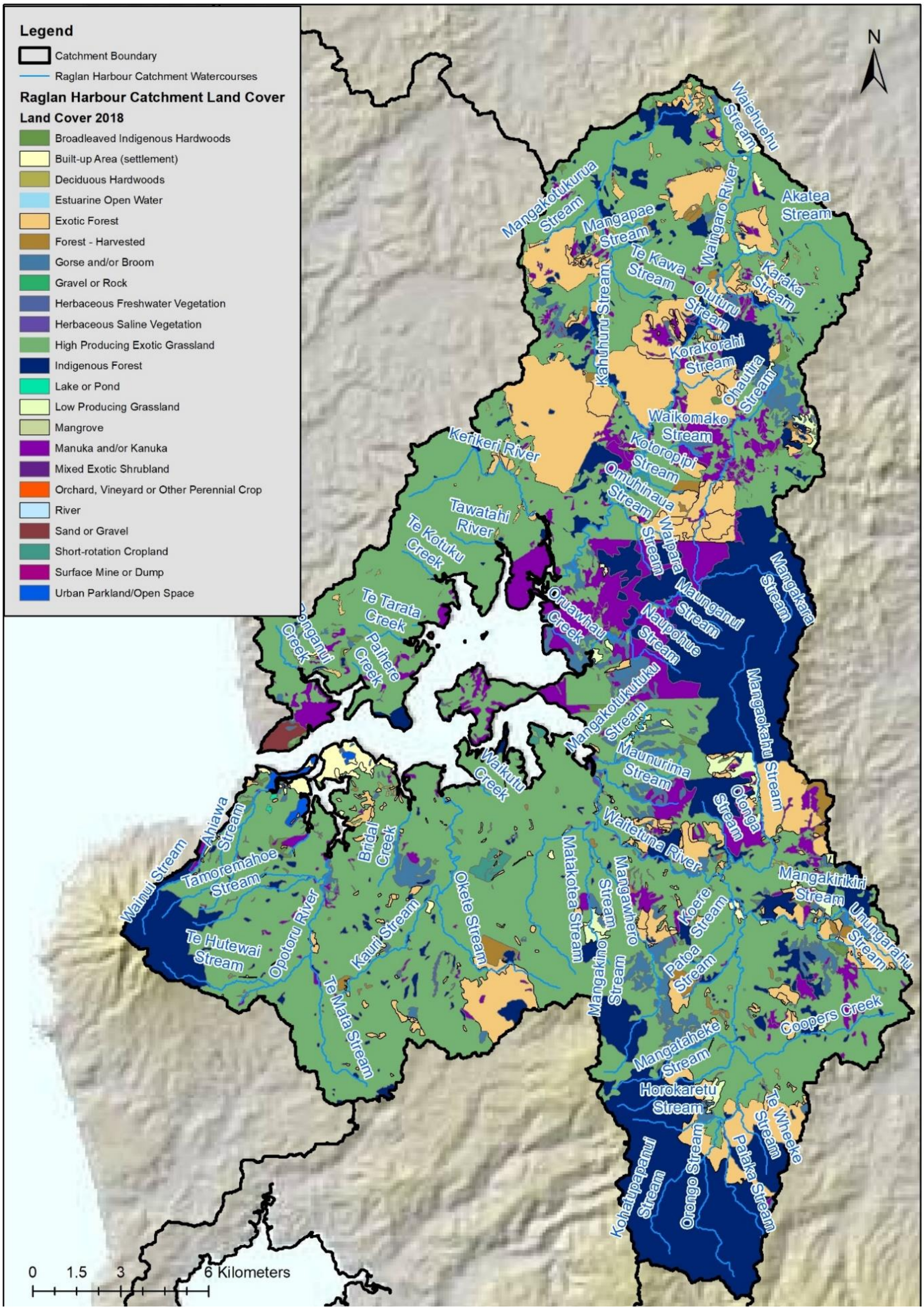

Figure 4-2. Map of land cover information for the Whāingaroa Harbour catchment.

4.3 Results

4.3.1 Estuarine Water Quality

Depth profiles showed temperature variation followed a regular pattern of warmer records from December to March and colder temperatures from June to August. No temperature stratification was observed at stations monitored since 2017 (Figure 4-3). While trend analysis was not possible for this dataset the temperature boxplot (Figure 4-6) indicated broader temperature ranges over time. Maximum temperatures in 2002/03 and 2013/14 at all stations ranged between 19 and 23 °C compared to a maximum temperature range between 24 and 26 °C since 2017 (Appendix A). At the same time minimum temperatures in 2002/03 and 2013/14 ranged between 10 and 14 °C while temperature minimums since 2017 ranged between 10 and 12°C. No major differences in water temperature were found between stations of the same monitoring period (Figure 4-6).

No halocline has been observed since 2017 but at times surface waters were less saline that bottom waters (Figure 4-4). From June to August 2018 and August to October 2019, less saline surface than bottom water was observed at Opotoru, Waingaro, Wainui, and Mid Harbour. Differences between surface and bottom water salinity was also detected in previous monitoring periods at inner harbour monitoring stations (Figure 4-6). Salinity was decreased during winter months at all stations monitored since 2017 and previous monitoring periods. (Appendix C, Figure C-11-4). Inner harbour monitoring stations (Inner Harbour North, Inner Harbour South, Waitetuna and Waingaro) showed a larger salinity range compared to outer harbour stations (Figure 4-6).

Water clarity parameters including secchi disc, total suspended solids and turbidity showed decreased water clarity at stations in the inner harbour and best visibility at the Harbour Mouth and Outer Harbour stations (Figures 4-6 and 4-7). During the 2002/03 monitoring period, turbidity values often exceeded the ANZECC guideline of 10NTU/FNU at the inner harbour stations with median values of approximately 14 NTU. In 2013/14 median turbidity at Mid Harbour also exceeded the guideline with median of 12.8 NTU in surface waters. Turbidity monitoring for current stations restarted in October 2019 which provides one year of data. This data showed that median turbidity was below guideline values at all stations (Figure 4-7). Based on data since 2017, the water was least turbid at Harbour Mouth, Opotoru and Wainui, whereas inner harbour stations in the east (Waingaro, Waitetuna and Mid Harbour) showed slightly higher values. Secchi disc reading confirmed this impression as Waingaro, Waitetuna and Mid Harbour did not exceed median secchi disc readings of 1 m. Median readings at Wainui, Opotoru, and outer Harbour were consistently above 1 m (Figure 4-6). No clear seasonal increases were identified for turbidity or total suspended solids.

In summer months (January to March), dissolved oxygen concentrations were slightly reduced along the water column for all currently monitored stations but most prominently for Opotoru, Waingaro, and Waitetuna (Figure 4-5). The lowest concentration recorded was in bottom waters at Waitetuna with 6.16 mg/L. In the monitoring period since 2017 surface water dissolved oxygen concentrations followed a typical seasonal pattern with lowest measurements in February and highest between June to August (Appendix C, Figure C-11-6). Dissolved oxygen saturation always remained within ANZECC guidelines at all stations (Figure 4-8). Chlorophyll *a* concentrations were highest at inner harbour stations including Inner Harbour North, Inner Harbour South, Waitetuna and Waingaro but median concentrations remained below the ANZECC guideline values of 0.004 mg/L (Figure 4-8). During late spring to summer (November to February) chlorophyll *a* concentration increased at all stations and often exceeded the ANZECC guideline at Waingaro, Waitetuna, Inner Harbour North, Inner Harbour South, and occasionally at Mid Harbour (Appendix C, Figure C-11-6).

Total nitrogen was highest Inner Harbour South and Outer Harbour Surface waters between 2013 and 2014 and Waitetuna and Waingaro since 2017 (Figure 4-8). Median values reached the ANZECC guideline value of 0.3 mg/L at Inner Harbour South and came close to it at Waitetuna (median = 0.28 mg/L). Because of the sort monitoring time seasonal patterns pre 2017 could not be identified but since 2017 total nitrogen concentrations clearly peaked between May and September (Appendix C, Figure C -11-6). Ammoniacal nitrogen concentrations were also highest at inner harbour stations and medians exceeded the ANZECC guideline value of 0.015 mg/L at all stations except outer harbour bottom waters in 2002/03, at Inner Harbour North surface waters and Inner Harbour South surface and bottom waters in 2013/14, and at all stations monitored since 2017 (Figure 4-9). No seasonal pattern was observed from ammoniacal nitrogen since 2017 (Appendix C, Figure C-11-7). In the previous monitoring periods, concentrations were lower during summer months. With the exception of bottom waters at Inner Harbour North and Mid Harbour in 2002/03 where all median values exceeded the ANZECC guideline of 0.015 mg/L for nitrate-nitrite nitrogen (Figure 4-9). Inner harbour stations including Waitetuna and Waingaro had higher concentrations than stations in the outer or mid- harbour and median values exceeded the guideline value up to 14 times (at Inner Harbour South Surface in 2013/14). Throughout all monitoring periods the higher concentrations were measured between April and September with peaks from June to August (Appendix C, Figure C-11-7). In summer months (November to March) nitrate-nitrate nitrogen was lowest and often below the ANZECC guideline.

Median total phosphorus values consistently exceeded ANZECC guideline value of 0.03 mg/L in 2002/03 except at the outer harbour surface station (Figure 4-9). In the following monitoring periods median values remained under guideline values but nearly reached those at Inner Harbour South Bottom and Waitetuna. There were no apparent seasonal peaks in total phosphorus concentrations. The dissolved reactive phosphorus ANZECC guideline (0.005 mg/L) was exceeded by median values at all stations and monitoring periods more than 75% of the time. Highest values were recorded in each monitoring period at Inner Harbour stations and Waitetuna (Figure 4-9). Data since 2017 showed lower concentrations between November and March compared to other months (Appendix C, Figure C-11-7).

E. *coli* and enterococci concentrations remained below recreational water quality guidelines values with few exceptions (Figure 4-10). Highest concentrations were measured at Inner and Mid Harbour stations including Waitetuna where 95th percentile values breached amber and read alert levels. Outer harbour bottom waters in 2013/14 also breached the amber guideline level for enterococci at the highest 5% of data Faecal coliform concentrations were generally below the median guideline value for shellfish gathering waters except for Inner Harbour South surface and bottom stations in 2002/03 (median= 14 and 16 cfu/100ml, respectively). However, the 90th percentile guideline value was exceeded at all stations in 2002/03 and 2013/14 with values ranging from 50 to 3088 cfu/100mL. In the monitoring period since 2017 Waitetuna and Opotoru waters also breached the 90th percentile threshold for shellfish gathering waters with 190 cfu/100mL and 80 cfu/100mL, respectively. The other stations remained below guideline values during this monitoring period. For all three microbial parameters, 2003/04 and 2013/14 data indicated higher concentrations in winter months but monitoring periods were too short to confirm this (Appendix C, Figure C-11-8). No apparent seasonal pattern was detected in the data since 2017.

4.3.2 Recreational water quality

Most of the time, recreational water quality monitoring data from Whāingaroa was below alert level values for swimming based on enterococci concentrations at all stations and monitoring periods (Figure 4-11). The 5 yearly MAC grading based on enterococci at Ngarunui Beach was "B" with a 95th percentile value of 46.2 cfu/100mL an overall low infection risk. *E*. *coli* concentrations at Ngarunui Beach also remained below recreational water quality guidelines in previous monitoring periods

(Figure 4-11). At Motor Camp North of Bridge from 1994-97 the 95th percentile *E. coli* value was 367 cfu/ 100ml, an amber alert level but remained below alter levels 90th of the time. In the 2020/21 swimming season, *E*. *coli* (and enterococci) monitoring was reinstated at this station. *E*. *coli* concentrations remained below guidelines levels 90% of the time (Figure 4-11).

Faecal coliform concentrations at Ngarunui Beach and Manu Bay were always below guideline values for shellfish gathering waters when monitored between 2000 and 2009. Motor Camp North of Bridge faecal coliform concentrations exceeded the median (16.5 cfu/100mL) and the 90th percentile (127 cfu/100mL) limits for shellfish gathering waters in the 1994-97 monitoring period. During the 2000-09 monitoring period, the 90th percentile (47 cfu/100ml) value also exceeded the guideline. The station is currently not monitored for faecal coliforms.

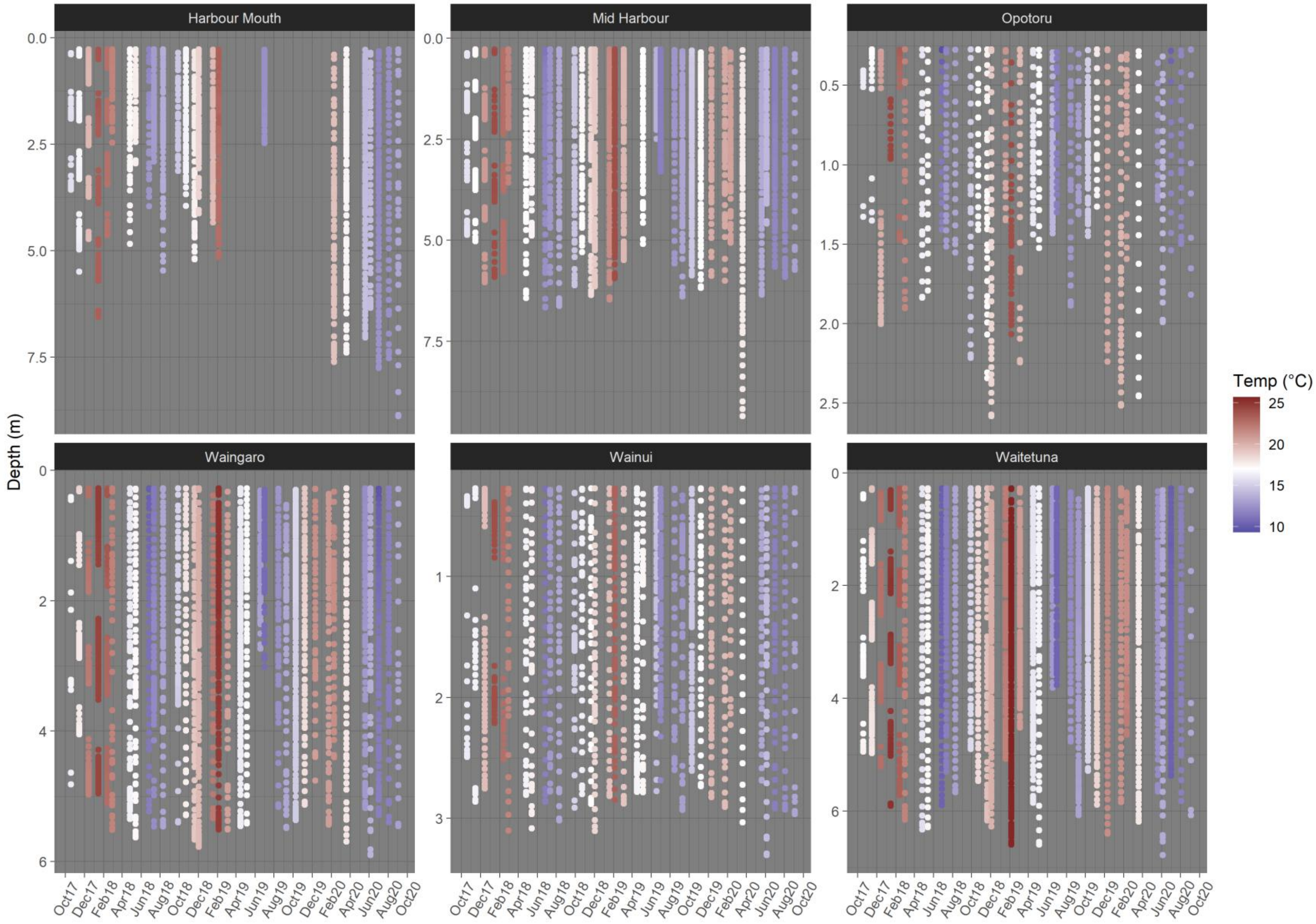

Figure 4-3. Temperature-depth profile plots for Whāingaroa Harbour sampling stations over time since October 2017.

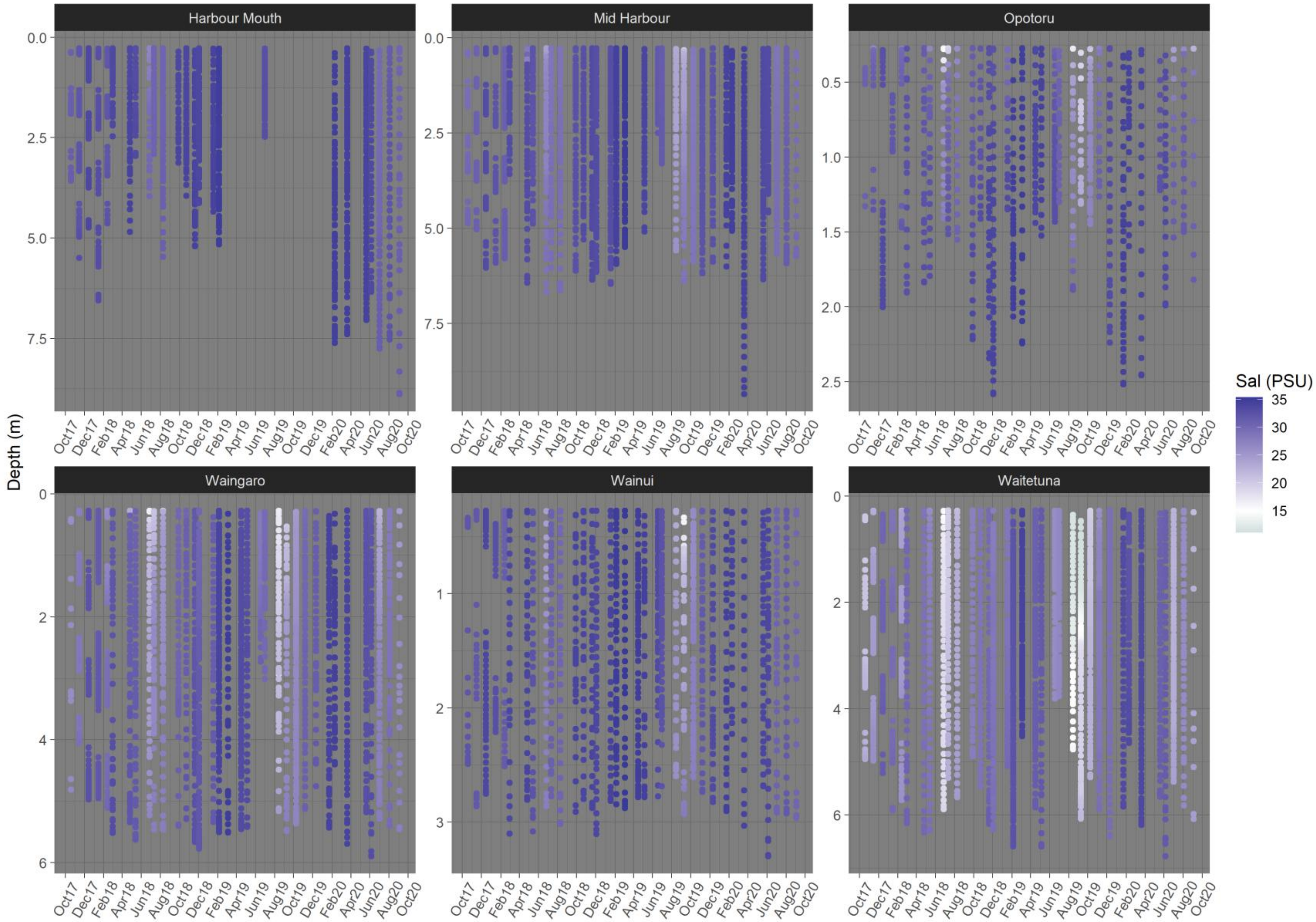

Figure 4-4. Salinity-depth profile plots for Whāingaroa Harbour sampling stations over time since October 2017.

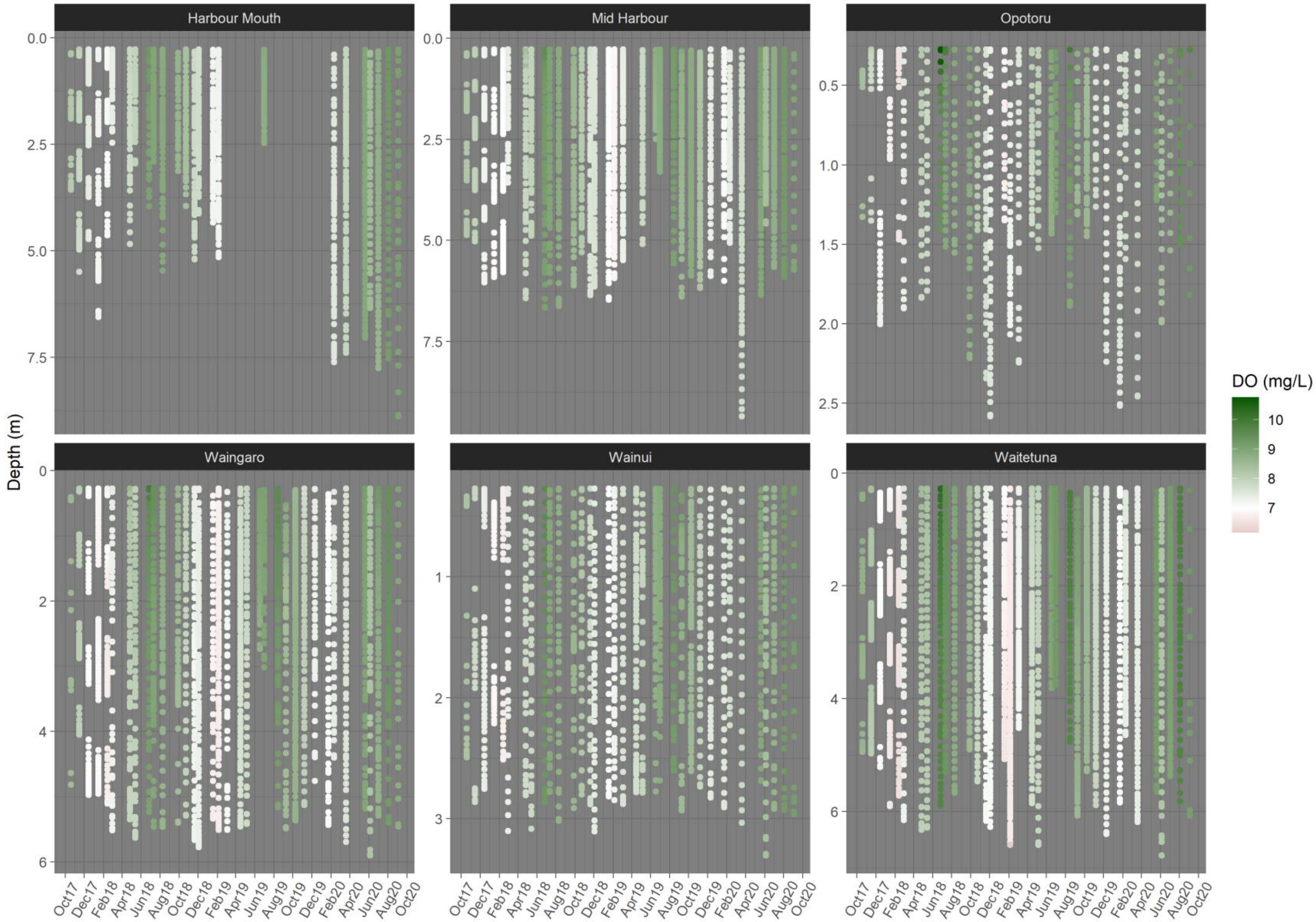

Figure 4-5. Dissolved oxygen-depth profile plots for Whāingaroa Harbour sampling stations over time since October 2017.

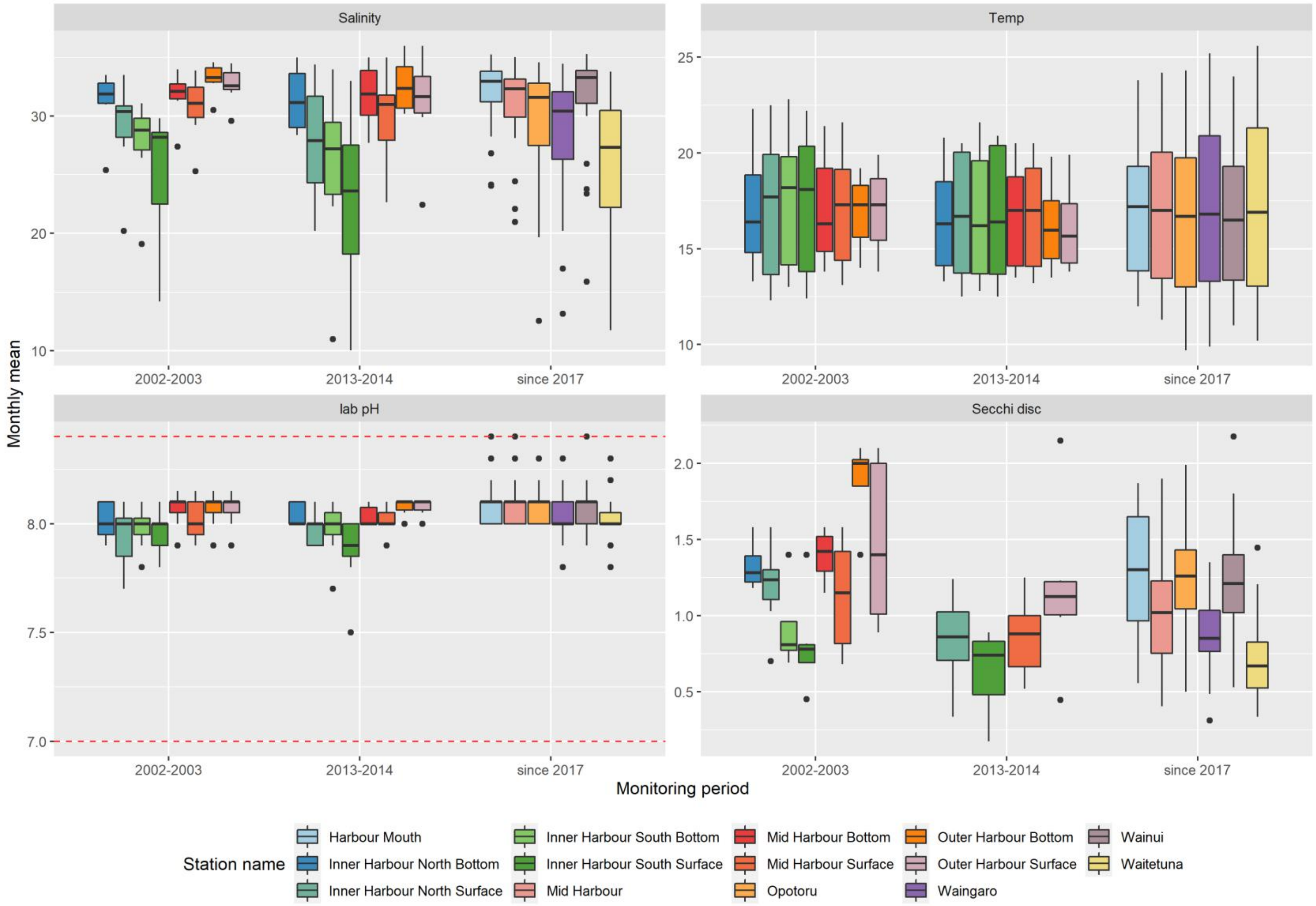

Figure 4-6. Distribution of physical estuarine water quality monitoring data per monitoring period for Whāingaroa Harbour Part 1. See figure 3-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the respective parameter (Table 3-2). For parameter units refer to table 2-1.

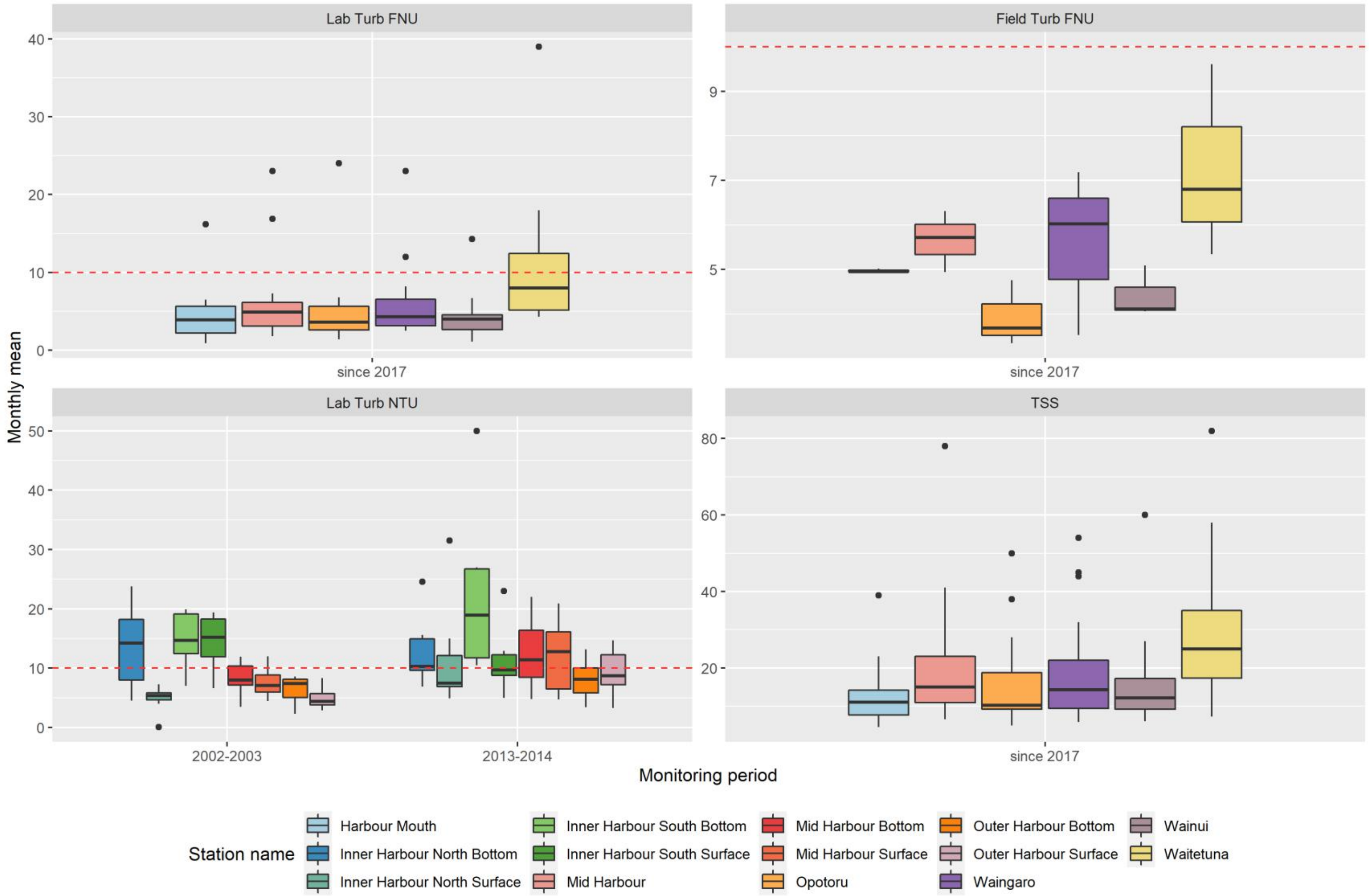

Figure 4-7 Distribution of physical estuarine water quality monitoring data per monitoring period for Whāingaroa Harbour Part 2. For better visualisation two outliers >150 NTU were removed for Lab Turbidity in 2013-2014 at Inner Harbour South Surface and Bottom. See figure 3-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the respective parameter (Table 3-2). For parameter units refer to table 2-1.

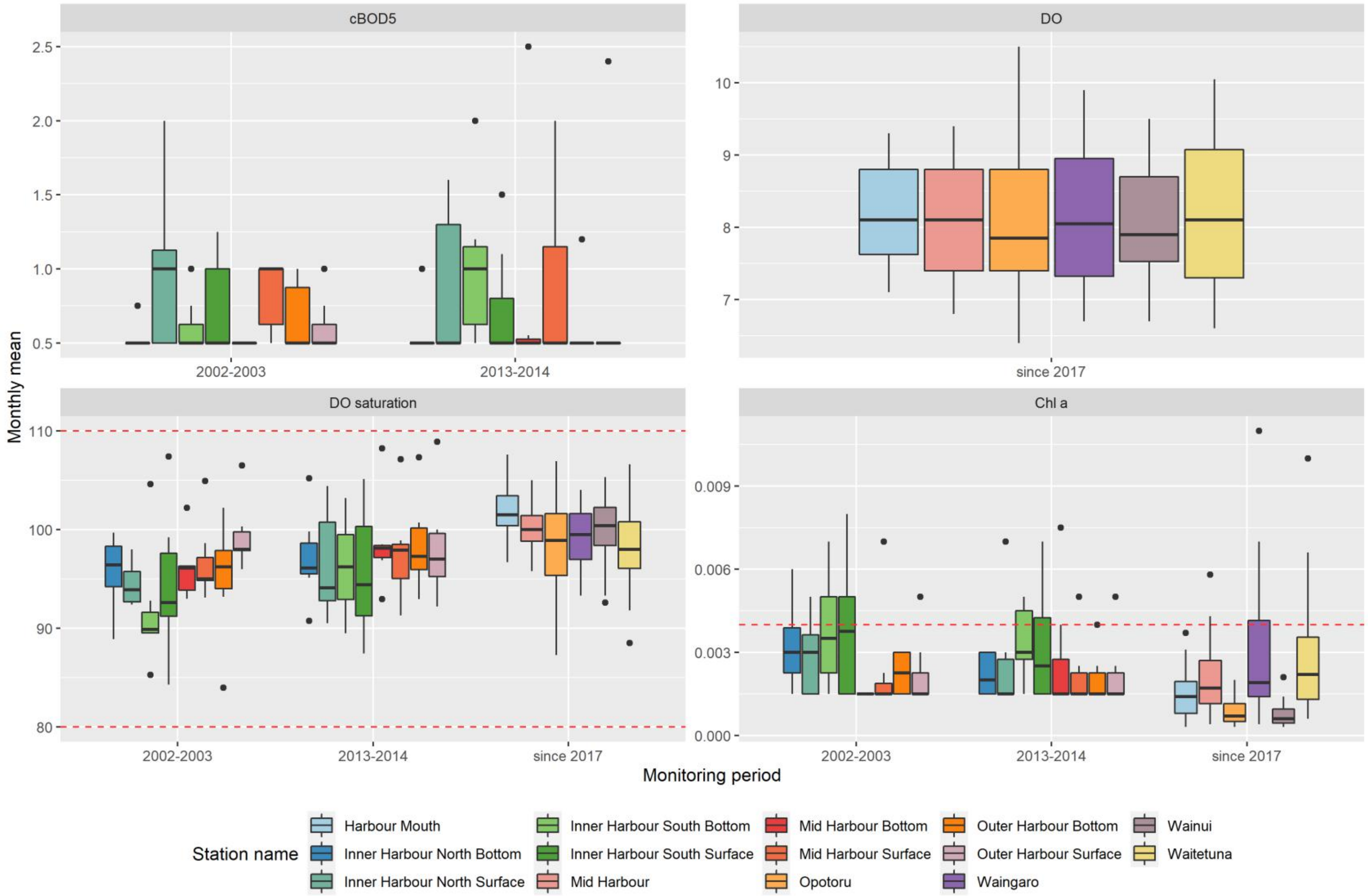

Figure 4-8. Distribution of chemical estuarine water quality monitoring data per monitoring period for Whāingaroa Harbour part 1. See figure 3-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the respective parameter (Table 3-2). For parameter units refer to table 2-1.

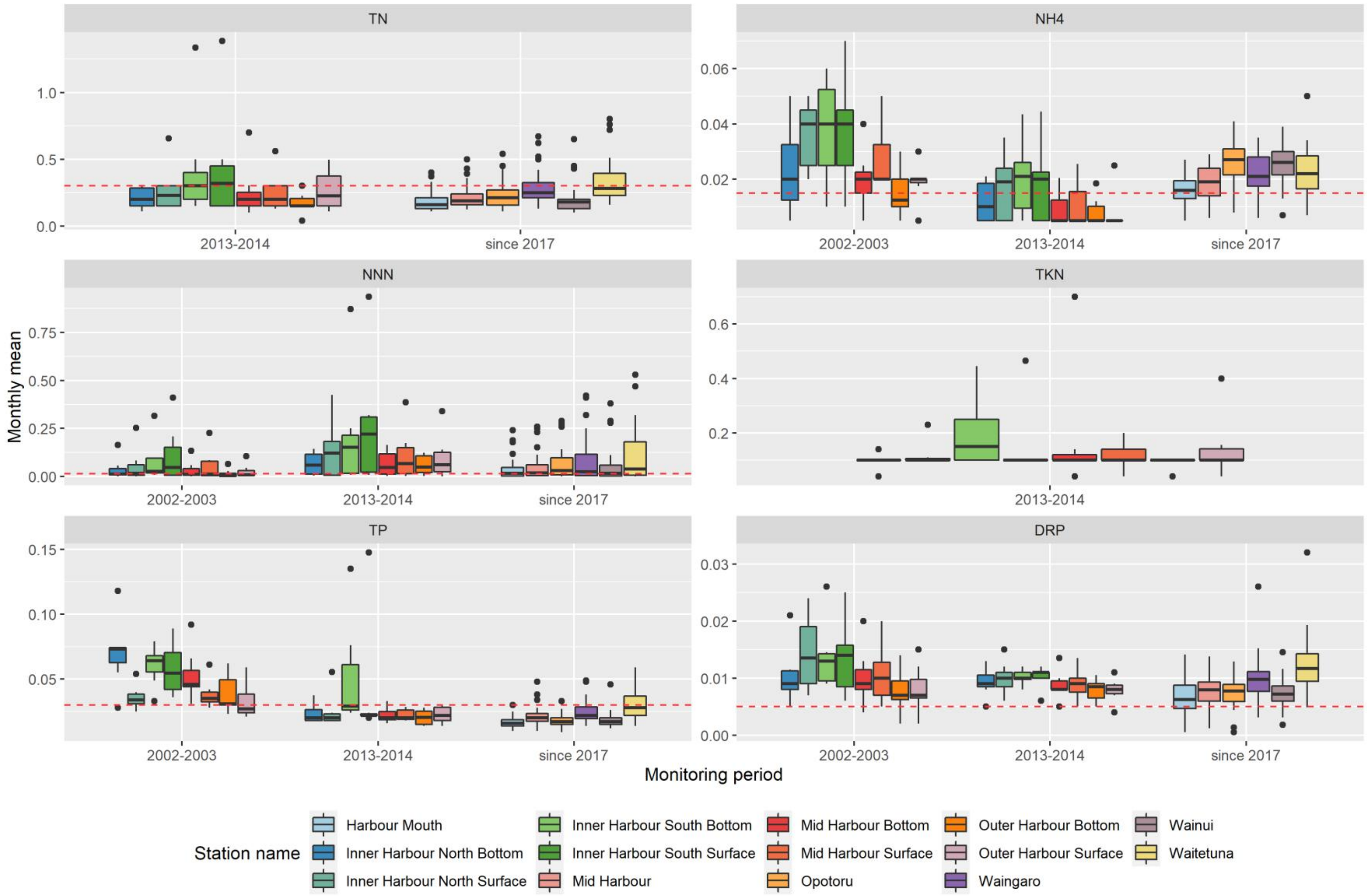

Figure 4-9. Distribution of chemical estuarine water quality monitoring data per monitoring period for Whāingaroa Harbour part2. See figure 3-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the respective parameter (Table 3-2). For parameter units refer to table 2-1.

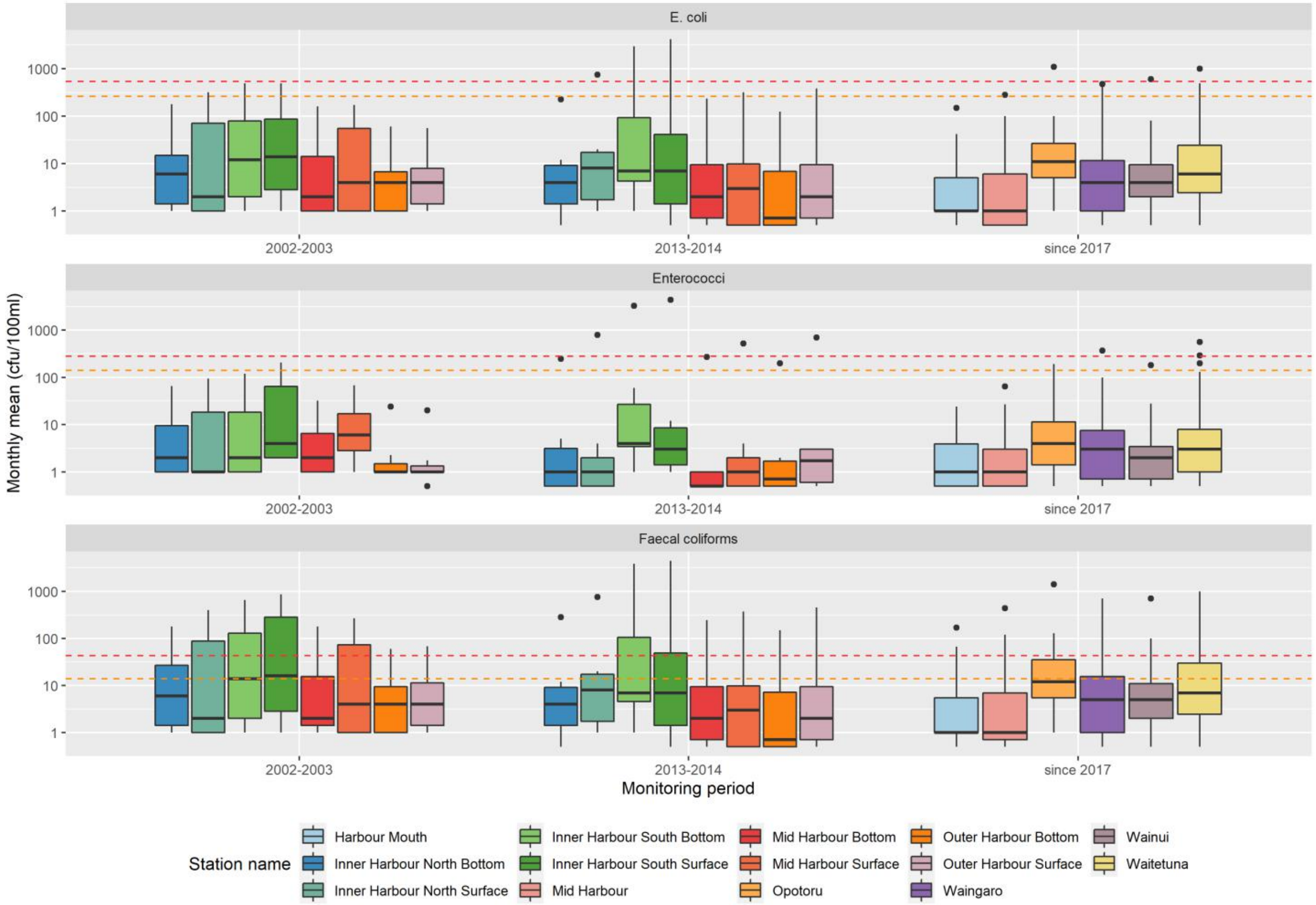

Figure 4-10. Distribution of microbial estuarine water quality monitoring data per monitoring period for Whāingaroa Harbour. See figure 3-2 for boxplot range definition. Dashed red lines represent the red alert and dashed amber lines the amber alert limit for *E. coli* and enterococci according to the recreational water quality guidelines for marine and freshwater. For faecal coliforms, the dashed red line denotes limit for the 90%th percentile and the dashed amber line the median limit for shellfish gathering waters (Table 3-3).

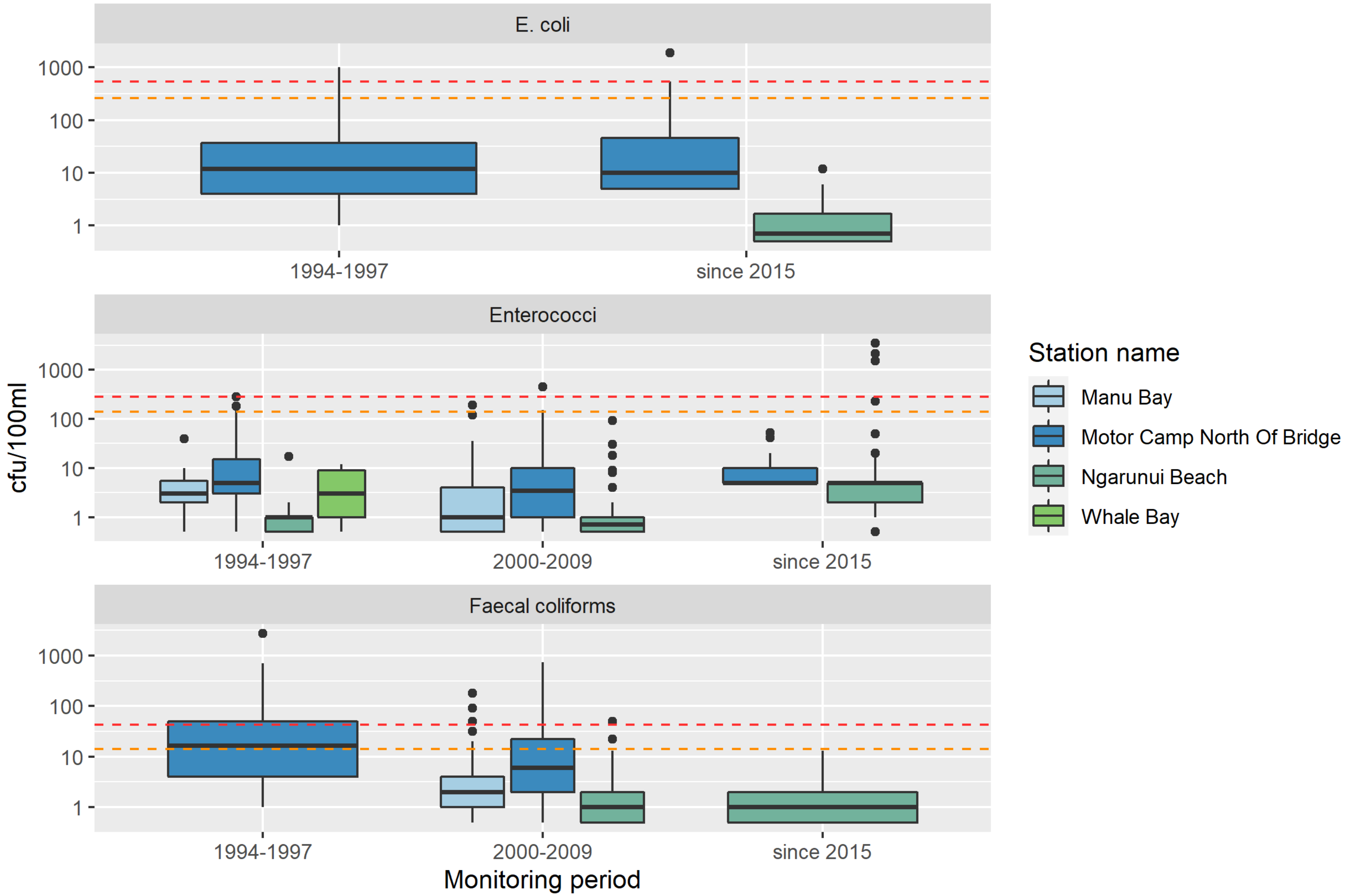

Figure 4-11. Distribution of microbial recreational water quality monitoring data per monitoring period for Whāingaroa (Raglan) Harbour. See figure 3-2 for boxplot range definition. Dashed red lines represent the red alert and dashed amber lines the amber alert limit for *E. coli* and enterococci according to the recreational water quality guidelines for marine and freshwater. For faecal coliforms, the dashed red line denotes limit for the 90%th percentile and the dashed amber line the median limit for shellfish gathering waters (Table 3-3).

4.4 Discussion

4.4.1 Estuarine water quality

Water quality data from three different monitoring periods in Whāingaroa Harbour was included in this report. Comparisons of data from monitoring station in proximity and different monitoring periods should, at most, be consider a suggestion for future investigations or analysis focus. This data cannot replace time trend analysis and therefore cannot help understanding whether water quality has improved or worsened over time.

Throughout the harbour the water column was well mixed and followed a typical seasonal temperature pattern with cooler temperatures in winter and warmer temperatures in summer. Different climatic influence was also observed in the increased freshwater influence in winter months leading to lower salinity especially in surface water and at inner harbour stations where freshwater influence is naturally larger. This is likely linked to increased rainfall and higher river flows. Comparing salinity and other data that is impacted by freshwater inputs to river flow and rainfall data was out of scope for this summary report. This type of analysis should be included in state reporting once a full 5 years of monitoring is completed. Comparison of historic monitoring data with data from the current programme showed greater temperature extremes in more recent years. Because sampling methods in the different monitoring periods were not comparable it is uncertain whether the observed differences are presenting actual conditions or sampling bias. However, greater temperature extremes can cause temperature stress for organisms in the estuary and limit their resilience to other stressors. Warmer temperatures also result in lower oxygen solubility which can add to oxygen stress. Because of the possibly wide range of implications, temperature trends should be investigated once sufficient data is available.

Pressures from nutrients, sediments and microbial contaminants were often elevated at inner harbour monitoring stations in particular, Inner Harbour South and Waitetuna, which often had the highest concentrations of all monitoring stations. Inner Harbour North and Waingaro showed elevated concentrations as well but not as prominent as at the southern monitoring stations. Water quality at harbour mouth or outer harbour was usually better, with less sediment, lower nutrient and microbial concentrations and better visibility. This points towards the catchment being the primary source for sediments and nutrients. The majority of the Waitetuna catchment which discharges into the southeast of Whaingaroa Harbour is composed of high producing exotic grassland, which may explain the increased nutrient, sediment, and microbial contaminants inputs. While the catchments in other parts of the harbour also contain significant proportions of high producing exotic grassland, these parts of the catchment are generally smaller overall or have additionally a higher proportions of other land cover classes such as exotic and indigenous forest or Manuka and/or Kanuka (Figure 4-2). The relation between different land use types and water quality in the harbour should be explored in more detail in the future.

Inner harbour monitoring stations (Waingaro, Waitetuna and Opotoru) were most noticeably reduced in dissolved oxygen concentrations along the water column in summer months. Dissolved oxygen concentrations were always above 6 mg/L and did not reach levels that would cause stress to aquatic organisms. However, it was noticeable that these inner harbour stations were more reduced in oxygen concentration that the outer harbour stations. All stations showed reduced dissolved oxygen concentrations during summer as the higher water temperatures decreased oxygen solubility of the water. The inner harbour stations were slightly warmer than outer harbour stations which would slightly increase the temperature effect. But Waingaro and Waitetuna stations also showed much higher chlorophyll *a* concentrations compared to the other stations in the current monitoring programme. Chlorophyll *a* concentrations were highest from November to March each year around the same time that dissolved oxygen concentrations were lowest. Increased phytoplankton growth can lead to lower dissolved oxygen concentrations by increased respiration of the phytoplankton cells at night, fuelling the growth of heterotrophic organisms and thus increasing oxygen demand, and by eventually dead cells increasing organic matter input that then increased oxygen consumption when decaying.

Nutrient parameters including total nitrogen, nitrate-nitrite nitrogen and dissolved reactive phosphorus showed some seasonality with higher nutrient concentrations outside of summer months and peaks between June and September. This is likely related to lower freshwater inputs in summer which appear to be a major source of nutrients in the harbour. Nitrate-nitrite nitrogen and dissolved reactive phosphorus are both related to land run off which is expected to be higher during high river flows. As mentioned above, freshwater flow and rainfall data should be included in future analyses to confirm potential correlations between rainfall, river flow and nutrient concentrations in Waingaroa Harbour. Data analysis did not show a clear seasonal pattern for ammoniacal nitrogen. From October to March 2017/18 and 2019/20 concentrations noticeably lower than in other months but in 2018/19 the same was not observed. Seasonality of ammoniacal nitrogen should be examined when more monitoring data becomes available.

E. coli and enterococci concentrations were below the recreational water quality guideline alert levels most of the time. This shows that water quality for recreational activities was not compromised even at inner harbour locations where high impacts from farming activities are likely. However, shellfish gathering water quality may have been compromised in all monitoring periods in the southern inner harbour and the entire harbour during 2002/03 and 2013/14 when guideline values were exceeded. If shellfish gathering occurs in the south-eastern and southern arms of the harbour then it should be considered to monitor for faecal coliforms with increased frequency during the main gathering season to gain a better understanding of the suitability of the water for shellfish gathering.

Increased microbial concentrations at Opotoru sampling stations were observed compared to other station in the monitoring period since 2017. While these concentrations were below alert levels for enterococci and *E. coli* they were among the highest observed at all monitoring stations in the monitoring period since 2017. Nutrient and turbidity data did not indicate more or the same pressures at this station than at Waitetuna or Waingaro where high turbidity and nitrate-nitrite nitrogen pointed towards land run off impacts possibly related to farming. Therefore, the increased microbial contamination might be related to different pressures at Opotoru. Ammoniacal nitrogen concentrations were also higher at Optoru than at other stations (Figure 4-9). Increased microbial and ammoniacal nitrogen concentrations without other nutrient or sediment increases could be related to contamination from wastewater. As more data becomes available this should be revaluated and possible reasons for the increased concentrations should be investigated.

4.4.2 Recreational water quality

Recreational water quality data showed that water quality was suitable for swimming most of the time at all stations in Whāingaroa Harbour. Occasional exceedances of guideline values were observed. At inner estuary stations such as Motor Camp North of Bridge these could be related to rainfall events when land run off is more likely. Rainfall data should be included in future analysis. Ngarunui Beach also showed occasional exceedances for enterococci in the latest monitoring season. Based on sampling information the relevant samples were collected after rainfall (data not shown). It would be useful to identify a suitable rainfall site to correlate rainfall and microbial contaminant data.

Faecal coliform data from previous monitoring seasons showed that water quality for shellfish gathering may at time have been compromised at Motor Camp North of Bridge. The closely located Wainui monitoring station in the estuarine health programme did not exceed guideline level for shellfish gathering waters but showed that higher concentrations of faecal coliform occurred occasionally (95th percentile = 85 cfu/100ml). The estuarine monitoring programme does not focus on the shellfish gathering season and is not conducted at the required frequency. Therefore, this data may not be ideal to indicate the suitability of shellfish gathering waters. Since Whāingaroa Harbour is frequently used for shellfish gathering and historic data indicated that water quality may be impacted it should be considered reinstating faecal coliform monitoring with focus on the shellfish gathering season to confirm is issues are still present.

5 Aotea Harbour

5.1 Monitoring sites and available data

Monthly estuarine water quality monitoring began in Aotea Harbour in April 2019 at three stations, Pakoka-Te Maari, North Harbour and Mixed and is ongoing (Figure 5-1, Table 5-1). Data until March 2021 is included in this report (Appendix A). Due to Covid 19 alert levels sampling in April 2020 could not take place.

Recreational water quality monitoring was carried out for enterococci at one station (Aotea) briefly in 1996/97 and from 2001-2009 every second season for enterococci and faecal coliforms. Due to the limited data available from 1996/97, all data was included in one monitoring period (Appendix B). Microbial data from the estuarine monitoring programme provides some insight into the suitability of the water for contact recreation and shellfish gathering.

Table 5-1. Coastal Water Quality sampling locations at Aotea Harbour. Coordinates in NZTM.

Station	Programme	Easting	Northing
Aotea	Coastal Recreational Water Quality	1760084	5791908
Mid Harbour	Coastal Estuarine Water Quality	1760059	5792201
North Harbour	Coastal Estuarine Water Quality	1761218	5794852
Pakoka-Te Maari	Coastal Estuarine Water Quality	1762885	5795487

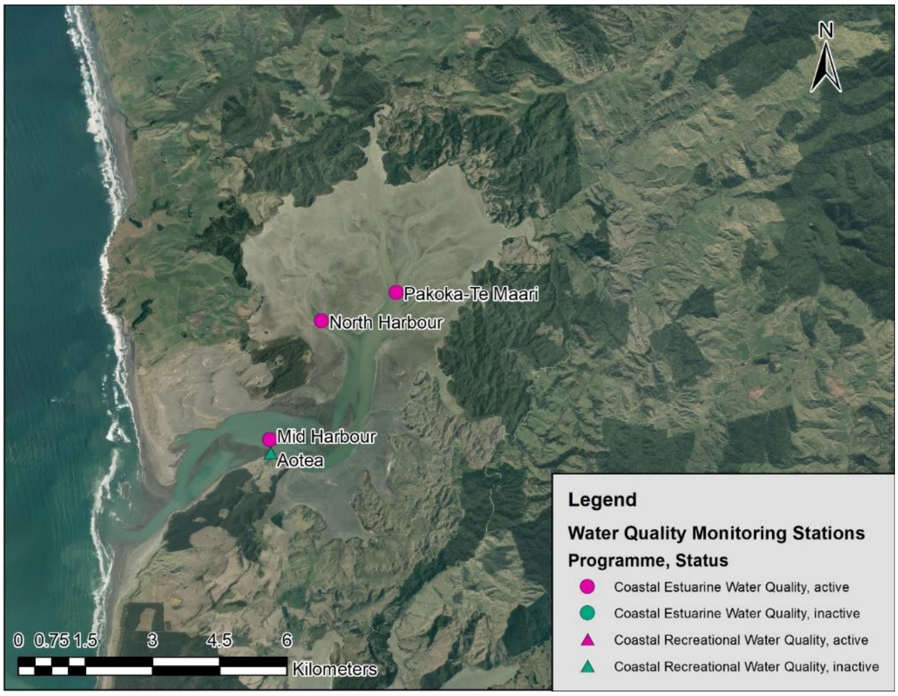

Figure 5-1. Map showing sampling stations at Aotea Harbour. Red dots donate to sites sampled for the estuarine water quality monitoring programme and orange dots sites for the recreational water quality programme.

5.2 Catchment land cover information

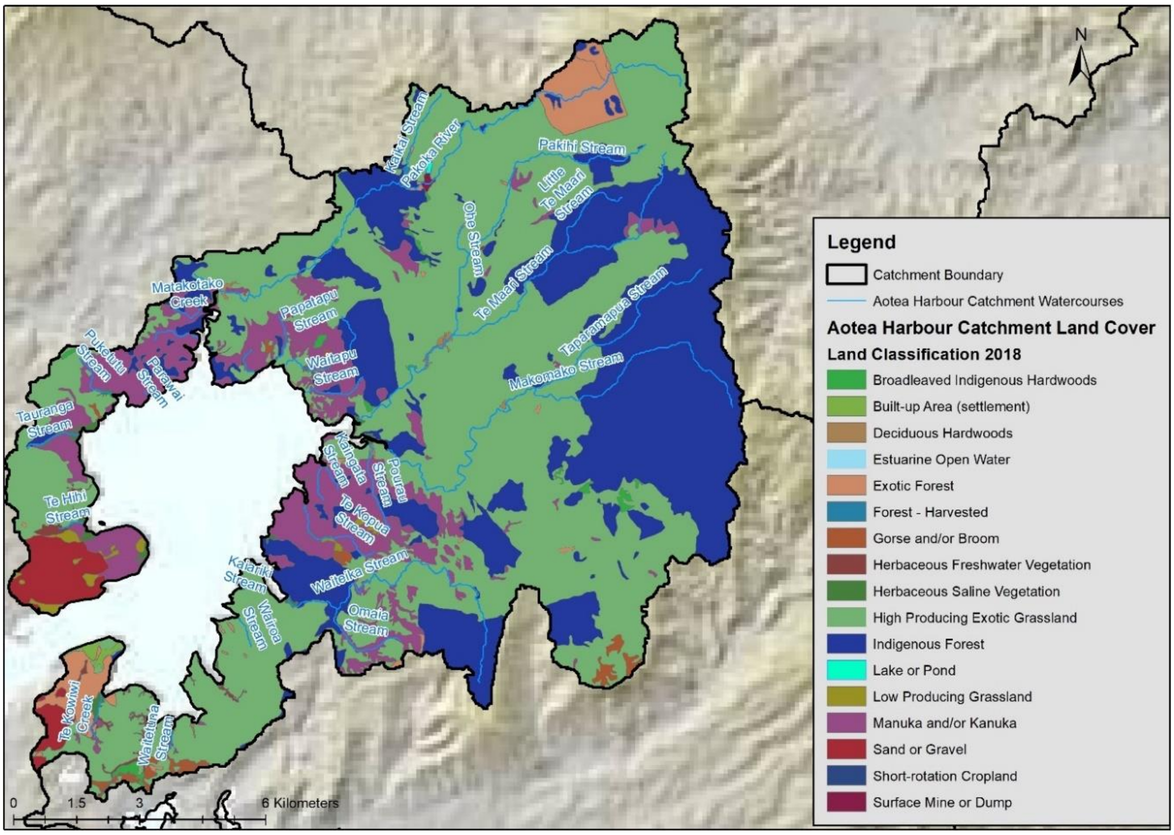

Figure 5-2. Map showing land cover for the Aotea Harbour catchment.

Aotea Harbour catchment includes an area of 16,891 ha with the dominant land cover classes being high producing exotic grassland (53%), indigenous forest (28%) and Manuka/Kanuka (11%, Figure 2-1). Other land cover classes with over 1% coverage are exotic forest (3%) and sand and gravel (2%). Urban / Settlement areas make up 0.15 % of the catchment. Native forest and high producing exotic grassland are located in the upper and lower catchment (Figure 5-2). Manuka/Kanuka are mainly in the lower catchment. The lower reaches of many streams are in native forest and Manuka/Kanuka shrub.

5.3 Results

5.3.1 Estuarine Water Quality

Aotea Harbour depth profiles showed that the water column at all monitoring stations was relatively well mixed with no major temperature or salinity stratification (Figure 5-3). Freshwater influence on salinity at Pakoka Te Maari was briefly observed in the upper water column in September 2019.
Salinity ranged from 28 to 35.5 PSU at all monitoring stations. Mid Harbour experienced the least salinity fluctuations while North Harbour and Pakoka Te Maari showed a larger salinity range (Figure 5-4). Salinity values decreased in winter and spring (June – October) at all stations with the largest salinity drops at Pakoka Te Maari and North Harbour in Winter 2019 (Appendix C Figure C-11-9). There was no difference in water temperature between stations. It followed a typical seasonal pattern which ranged from 13 °C in winter to 21 °C in Summer (Figure 5-4 and Appendix C, Figure C-11-9). Measurements of pH were within the expected range for estuarine waters (Figure 5-4). Visibility in Aotea Harbour waters is generally good at all stations with median secchi disc readings of approximately 2m and no major differences between monitoring stations. Turbidity values were consistently below the ANZECC guideline values of 10 FNU and total suspended solids always below 20 mg/L (Figure 5-4). No apparent seasonal patterns were observed for water clarity parameters (Appendix C, Figure C-11-9).

Throughout the monitoring period the water column remained well oxygenated along the water column at all monitoring stations and remained above 7 mg/L (Figure 5-3). Dissolved oxygen concentrations ranged from 7.3 to 9.4 mg/L with median values between 8.0 and 8.3 mg/L and no major differences between monitoring stations (Figure 5-5). While dissolved oxygen saturation remained at similar values throughout the year, dissolved oxygen concentration dropped from approximately 8.5-9.4 mg/L in July and August to 7.4 to 8.0 mg/L from January to March. Chlorophyll *a* concentrations were similar at all monitoring stations and remained well below the ANZECC guideline value of 0.004 mg/L at all times (Figure 5-5). No obvious seasonal differences in chlorophyll *a* concentrations were detected (Appendix C, Figure C-11-10).

Median concentrations of total nitrogen and nitrate-nitrite nitrogen remained under ANZECC guideline values at all stations (Figure 5-5) At Mid Harbour, median ammoniacal nitrogen concentration also remained below the ANZECC guideline of 0.015 mg/L (median =0.0135 mg/L) but median values at North Harbour and Pakoka-Te Maari reached and slightly exceeded the guideline (0.015 and 0.016 mg/L, respectively).Higher concentrations of nitrogen parameters are concentrated in autumn and winter 2019 (May – October) with nitrate-nitrite nitrogen exceeding the guideline up to 6 fold at North Harbour. In winter 2020 the highest nitrate-nitrite nitrogen concentrations were approximately double the ANZECC guideline value of 0.015 mg/L (Appendix C, Figure C-11-10). Median values for total phosphorus and dissolved reactive phosphorus remained under the guideline level (Figure 5-5). No obvious seasonal patterns for phosphorus parameters were detected. Microbial parameters remain consistently below guideline values at all stations (Figure 6-6) and did not show a seasonal pattern.

5.3.2 Recreational water quality

Water quality for contact recreation was good in Aotea Harbour. Enterococci concentrations remained under guideline alert levels with one exception in 2003 when the amber alter level was exceeded (Figure 5-7). There were occasional exceedances for faecal coliform concentrations from 2003 to 2009 (Appendix D, Figure D-12-3). Due to these, the 90th percentile guideline level for shellfish gathering waters was exceeded (47 cfu/ml) but the median remained below alert levels. Aotea harbour hasn't been monitored for recreational purposes since 2009 but microbial parameters from the estuarine water quality monitoring programme showed that water quality was well below guideline levels for all three indicator bacteria.

5.4 Discussion

5.4.1 Estuarine water quality

Estuarine water quality monitoring in Aotea harbour showed a preliminary picture of overall good water quality and only slight pressure due to nutrients, sediments, and microbial contaminants. The water column was well mixed throughout the year with no thermo- or halocline. This mixing decreases the likelihood of low oxygen in bottom waters putting pressure on sensitive organisms. Accordingly, the water column was well oxygenated throughout the entire monitoring phase and at all stations. Dissolved oxygen concentrations were higher during winter months when water temperatures were lower thus being more soluble to oxygen. Both dissolved oxygen and water temperature followed a typical seasonal pattern.

Increased salinity during summer and decreased salinity during winter reflected likely higher freshwater impact in winter. This effect was stronger at North Harbour and Pakoka Te Maari which are both located closer to the shore and therefore more likely to reflect freshwater impacts and experienced less dilution from seawater. Comparing water quality sampling results to rainfall and river flow data was out of scope for this summary report but should be considered for future reports including more than two years of data to investigate these assumptions.

Nitrate-nitrite concentrations increased at the same time salinity decreased and were generally higher at the monitoring stations with less seawater impact. This points towards freshwater inputs as the source of inorganic nitrogen in the catchment. This should be observed in future years and confirmed with a more in-depth seasonal analysis. Ammoniacal nitrogen and dissolved reactive phosphorus concentrations did not coincide as clearly with freshwater peaks but would be expected to increase with higher freshwater inputs as well. Due to the relatively short data record seasonal patterns might not be detectable.

Overall, the harbour system appears to be functioning well with current nutrient inputs. Although median values for ammoniacal nitrogen at North Harbour and Pakoka Te Maari met or exceeded the ANZECC guideline values, signs of eutrophication such as increased chlorophyll *a* concentration or low dissolved oxygen were not observed. Water clarity was excellent thought the year and water turbidity was unlikely to inhibit phytoplankton growth. Once sufficient water quality data is available to estimate statistically robust percentile values, water quality should be compared to wider ecosystem health such as sediment conditions and the presence of macroalgae. If water quality proves to be sufficient to support healthy habitats, Aotea Harbour might be a suitable reference site to set water quality standards for similar estuaries for policy purposes.

5.4.2 Recreational water quality

Recreational water quality in Aotea Harbour was good based on historic recreational water quality monitoring and considering the current results from estuarine health monitoring. Swimming and other recreational activities are not likely to be impacted. Historic faecal coliform data indicated impaired water quality for shellfish gathering with the 90th percentile value exceeding guideline criteria. However, the current monitoring data from the estuarine water quality programme did not show any indication that water quality was unsuitable for shellfish gathering purposes with not a single sample higher than 10 faecal coliforms/100 mL. In case future monthly monitoring shows indications of decreasing microbial water quality reinstating recreational monitoring should be considered.

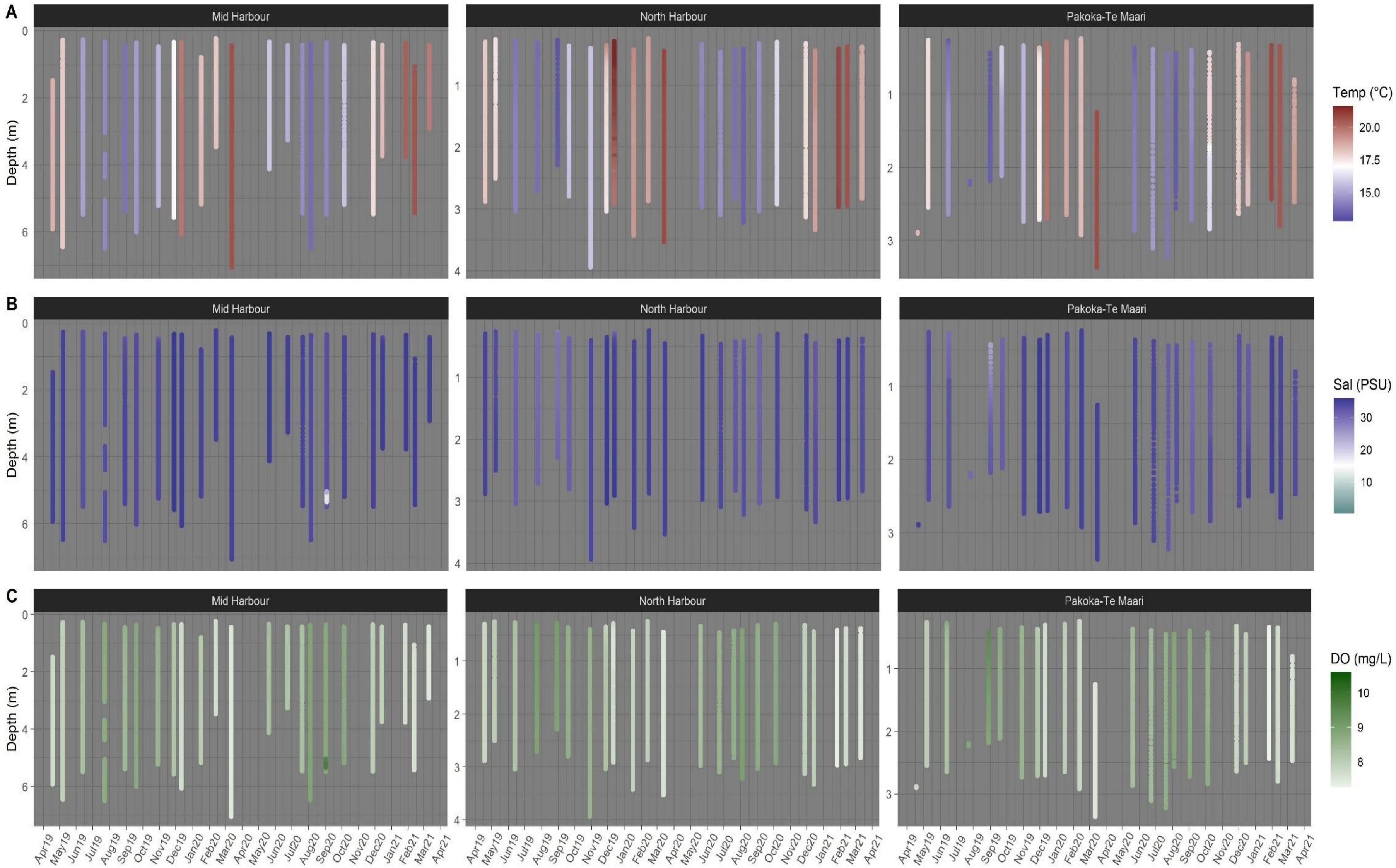

Figure 5-3. Depth profile plots for Aotea Harbour sampling stations over time since April 2019 including Temperature (A), Salinity (B) and Dissolved oxygen concentration (C).

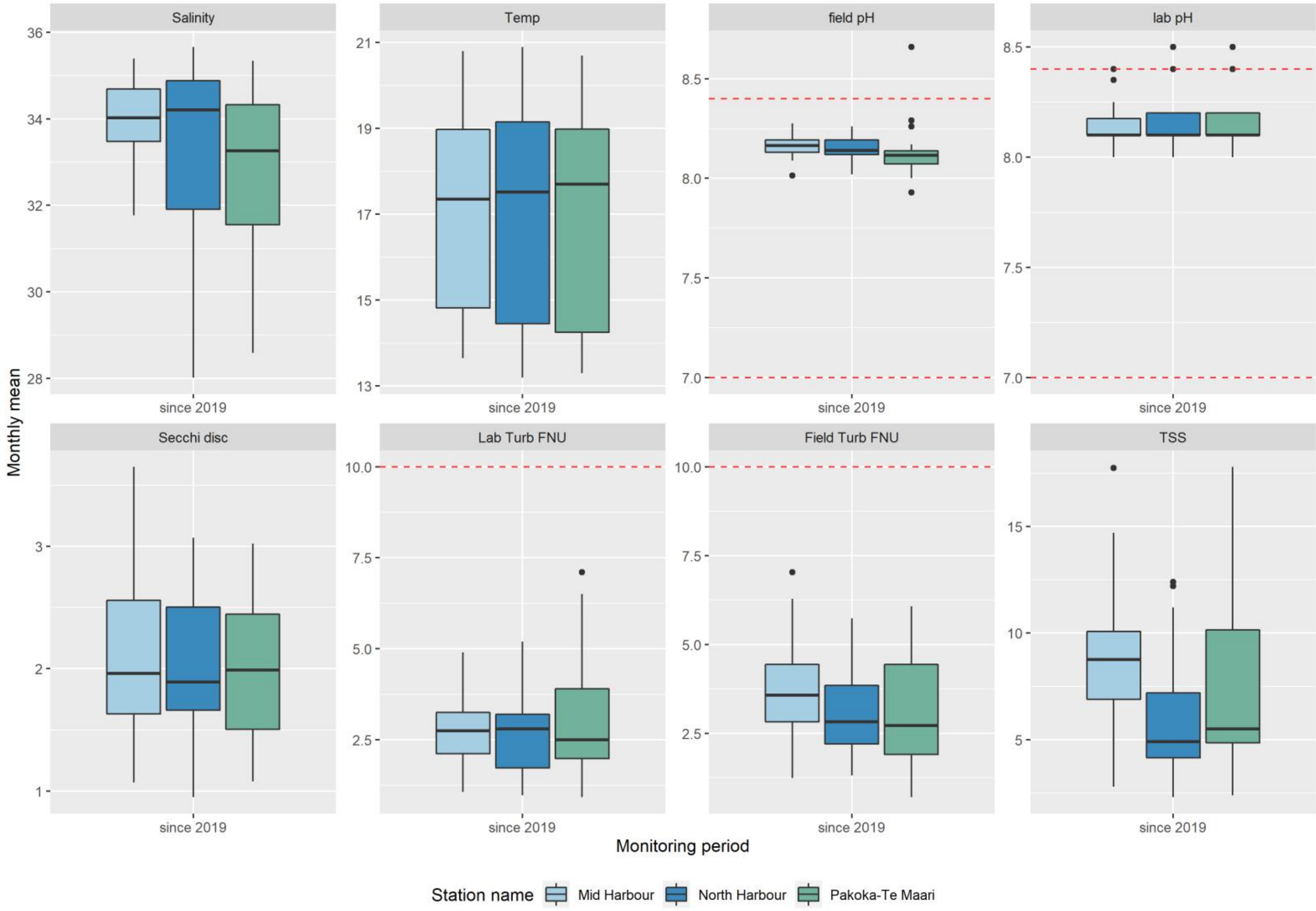

Figure 5-4.Distribution of physical estuarine water quality monitoring data per monitoring period for Aotea Harbour. See figure 3-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the respective parameter (Table 3-2). For parameter units refer to table 2-1.

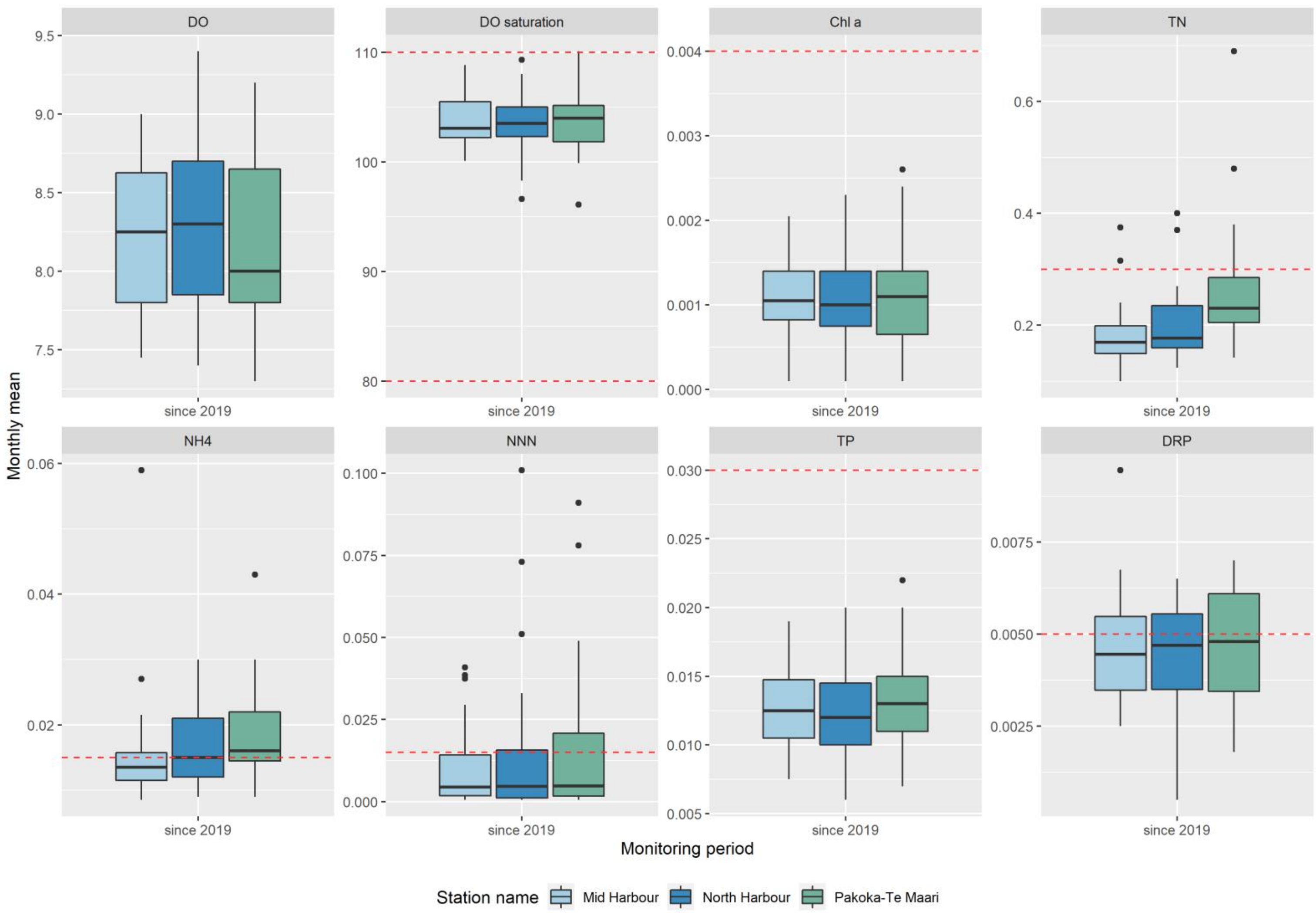

Figure 5-5. Distribution of chemical estuarine water quality monitoring data per monitoring period for Aotea Harbour. See figure 3-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the respective parameter (Table 3-2). For parameter units refer to table 2-1.

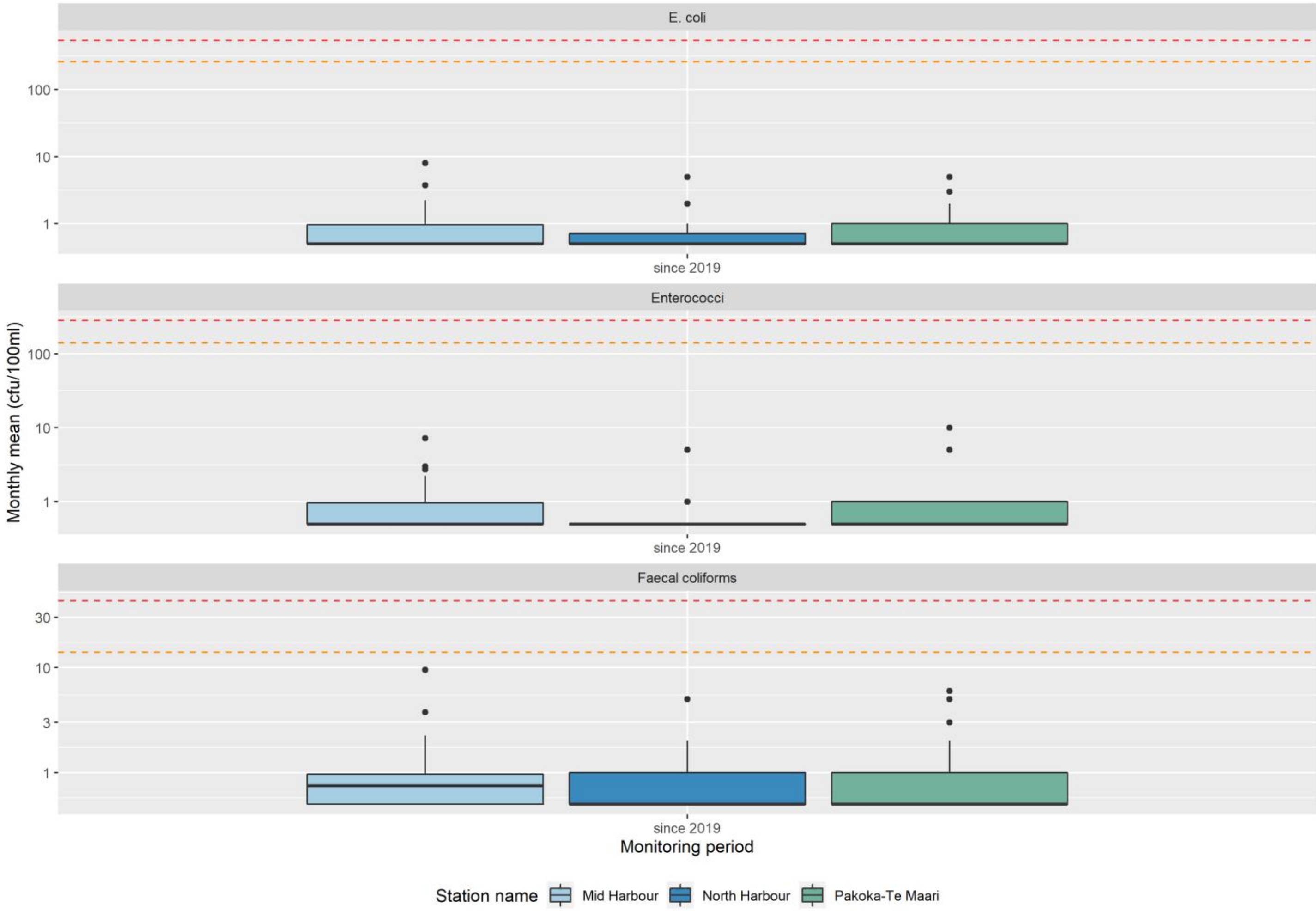

Figure 5-6. Distribution of microbial estuarine water quality monitoring data per monitoring period for Aotea Harbour. See figure 3-2 for boxplot range definition. Dashed red lines represent the red alert and dashed amber lines the amber alert limit for *E. coli* and enterococci according to the recreational water quality guidelines for marine and freshwater. For faecal coliforms, the dashed red line denotes limit for the 90%th percentile and the dashed amber line the median limit for shellfish gathering waters (Table 3-3).

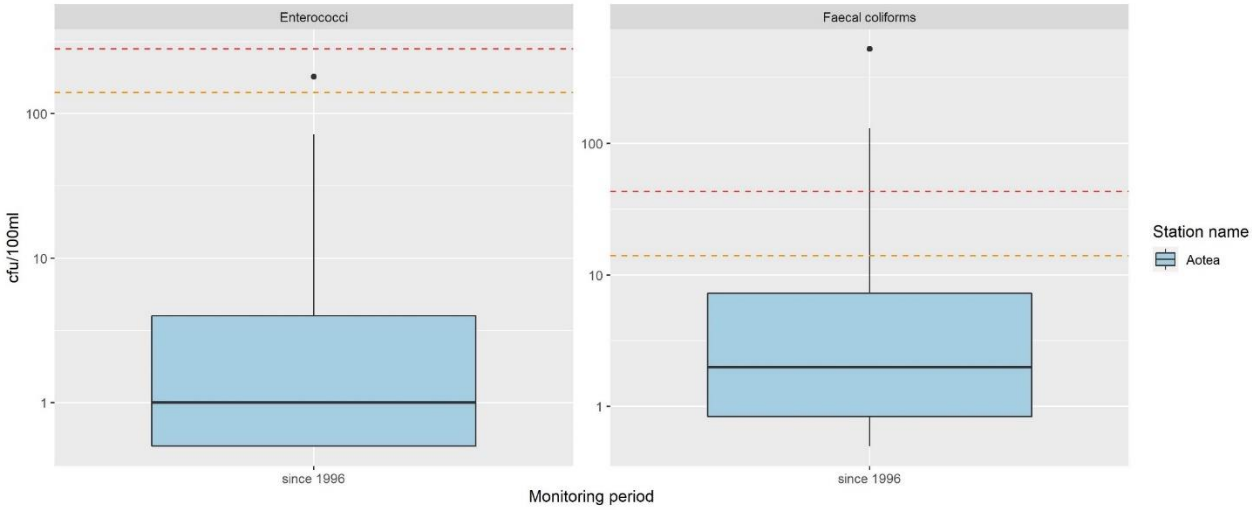

Figure 5-7. Distribution of microbial recreational water quality monitoring data per monitoring period for Aotea Harbour. See figure 3-2 for boxplot range definition. Dashed red lines represent the red alert and dashed amber lines the amber alert limit for *E. coli* and enterococci according to the recreational water quality guidelines for marine and freshwater. For faecal coliforms, the dashed red line denotes limit for the 90%th percentile and the dashed amber line the median limit for shellfish gathering waters (Table 3-3).

6 Kawhia Harbour

6.1 Monitoring sites and available data

Estuarine Water Quality monitoring data was collected from July 2008 until July 2009 at Kawhia Harbour at four monitoring stations (Site1 – Site 4) including surface and bottom samples (Table 6-1, Figure 6-1). From July 08 – May 09 samples were collected every second month. The following two month were sampled monthly. The current monitoring programme started in April 2019 with six monitoring stations including Te Kauri, Te Toi, Waiharakeke, Mid Harbour, Mangaroa, and Oparau (Table 7-1, Figure 7-1). Monthly sampling is ongoing and data until March 2021 have been included in this report. Sampling in April 2020 could not take place due to Covid 19 alert levels. An overview of all monitoring stations, periods and sample number can be found in Appendix A.

Recreational water quality data was monitored at three stations, Karewa Beach, Kawhia Wharf and Ocean Beach (Table 6-1, Figure 6-1). Sampling occurred from 1994-97 for enterococci and from 2001-2009 every second season for enterococci and faecal coliforms. An overview of all monitoring stations, periods and sample numbers can be found in Appendix B.

Table 6-1. Coastal Water Quality sampling locations at Kawhia Harbour. Coordinates in NZTM.

Station	Programme	Easting	Northing
Site 1 Bottom	Coastal Estuarine Water Quality	1764990	5783376
Site 1 Surface	Coastal Estuarine Water Quality	1764990	5783376
Mangaora Bottom	Coastal Estuarine Water Quality	1762037	5785172
Mangaora Surface	Coastal Estuarine Water Quality	1762037	5785172
Site 3 Bottom	Coastal Estuarine Water Quality	1758423	5779634
Site 3 Surface	Coastal Estuarine Water Quality	1758423	5779634
Site 4 Bottom	Coastal Estuarine Water Quality	1756489	5782977
Site 4 Surface	Coastal Estuarine Water Quality	1756489	5782977
Te Kauri	Coastal Estuarine Water Quality	1764349	5783208
Te Toi	Coastal Estuarine Water Quality	1762974	5782150
Waiharakeke	Coastal Estuarine Water Quality	1758503	5779310
Mid Harbour	Coastal Estuarine Water Quality	1757709	5782755
Oparau	Coastal Estuarine Water Quality	1763820	5785801
Karewa Beach	Coastal Recreational Water Quality	1759194	5784607
Kawhia Wharf	Coastal Recreational Water Quality	1759893	5785308
Ocean Beach	Coastal Recreational Water Quality	1756093	5785403

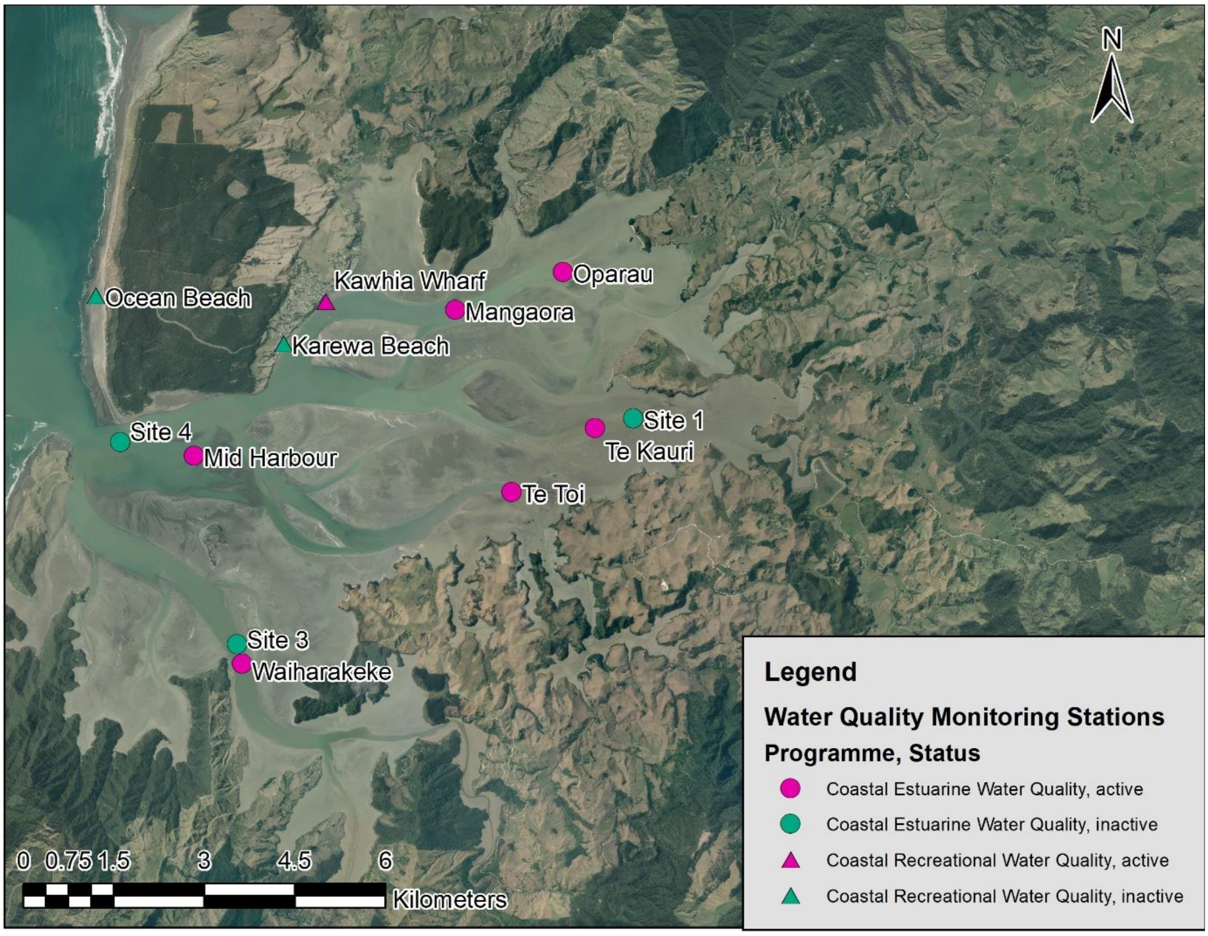

Figure 6-1. Map showing sampling stations at Kawhia Harbour.

6.2 Catchment land cover information

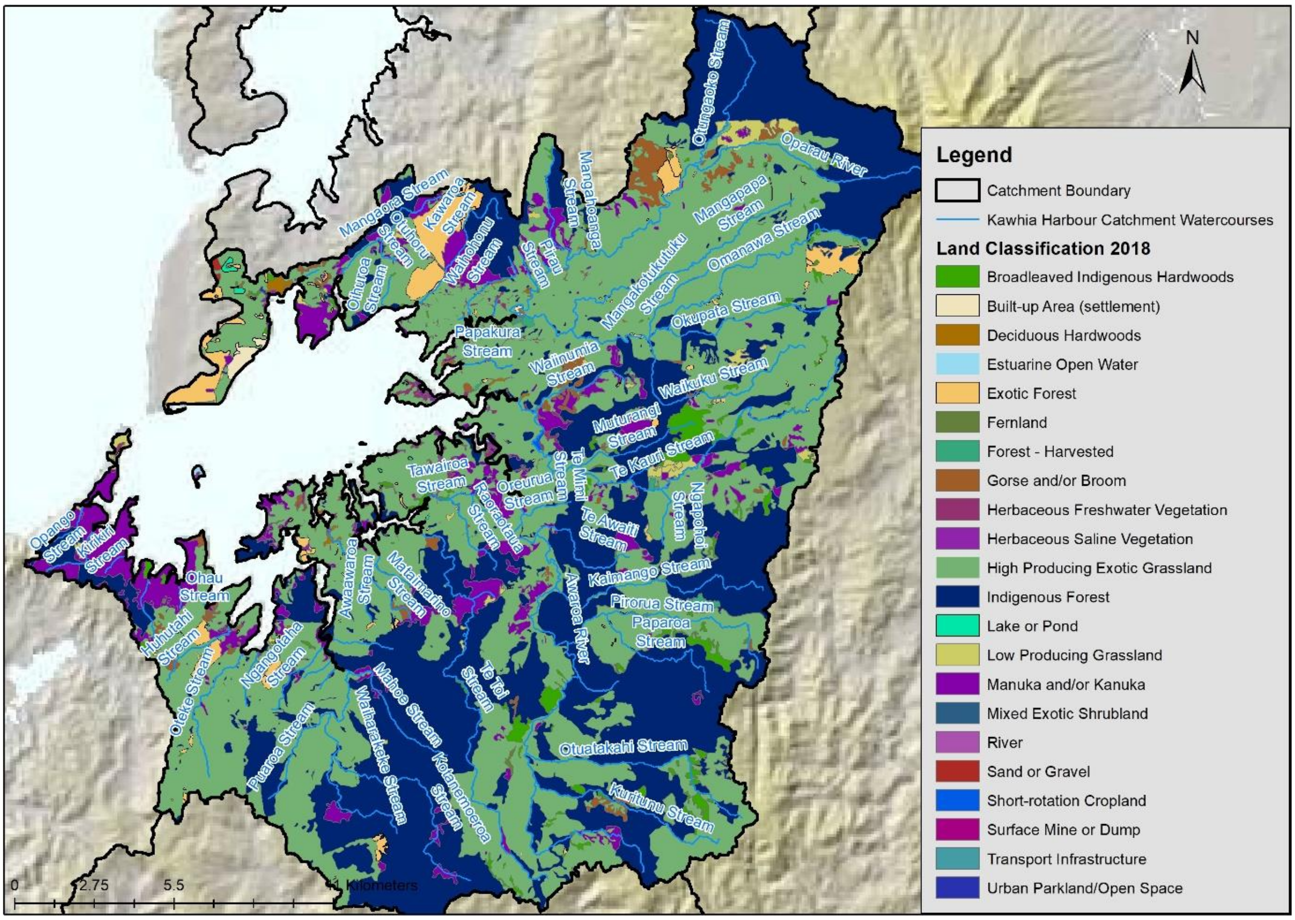

Figure 6-2. Map showing land cover for the Kawhia Harbour catchment.

The Kawhia Harbour catchment covers 48,012 ha and high producing exotic grassland makes up 48% of it (Figure 2-1). Thirty seven percent of the catchment are classified as indigenous forest and 7% as Manuka or Kanuka. Other land cover classes with more than one percent coverage are exotic forest (2.5%), broadleaved indigenous hardwood (2%), and gorse and broom (1.5%). Indigenous forest and Manuka/Kanuka are found in the upper catchment while the lower catchment is mostly classified as high producing exotic grassland.

6.3 Results

6.3.1 Estuarine Water Quality

Depth profiles collected at each monitoring station in Kawhia Harbour since 2019 revealed that the water column was occasionally not fully mixed (Figure 6-3 to 6-5). Slight temperature stratification of the water column was observed at Mangaora, Te Kauri, and Oparau in late November 2019 and January 2020 but not in December 2019 (Figure 6-3). No strong saline stratification was observed but salinity generally decreased in winter and was lower in surface waters on some occasions (Figure 6-4). This was also observed at the historic monitoring stations where surface waters showed slightly lower salinity values and a larger salinity range (Figure 6-6). While at most stations the water column was well oxygenated, Oparau bottom waters showed reduced oxygen concentrations of less than 5 mg/L (approx. 50% saturation) in October 2019 and less than 7 mg/L (approx.75% saturation) in November 2019 (Figure 6-5). These values were below ANZECC guidelines for minimum dissolved oxygen saturation (80%). Monitoring in 2008/09 did not record any low dissolved oxygen values at surface or bottom sites (Figure 6-8) but there was no monitoring station close to Oparau at the time. Median values of discrete depth measurements at all monitoring stations were within ANZECC guidelines (Figure 6-8). Dissolved oxygen concentrations were highest from July to October and lowest from November to March (Appendix C Figure C-11-14).

Figure 6-6 shows the range of temperature data over the two different monitoring periods. While there is insufficient data for statistical analysis, median temperature values appear to have increased between monitoring periods. In 2008/09 median temperatures ranged from 14-15°C at all sites and in the current monitoring period temperatures range from 17-18°C. This seems to be mainly related to higher water temperatures in winter in the current monitoring period (Appendix C, Figure C-11-12). At all times and all stations salinity was in the brackish to marine range between 12 and 35 PSU. Stations located closer to the harbour mouth were more saline than those in the inner harbour. Difference in salinity between historic and current monitoring stations were also observed (Figure 6-6). For comparable stations (Te Kauri -Site 1, Mangaora, Waiharakeke- Site 3, and Mid Harbour -Site 4) salinity values ranged slightly lower at the historic stations (Figure 6-6). Water clarity was usually good in Kawhia Harbour, with median turbidity values below ANZECC guideline values at all stations in the current monitoring period. In the 2008/09 monitoring period, median values at Site 1 and Site 3 exceeded guideline values (Figure 6-7). Median secchi disc readings at outer harbour stations and Site 2 and Te Toi were above 1m. Median values at inner harbour sites ranged between 0.6 and 0.9m (Figure 6-7).

Chlorophyll *a* median values were below the ANZECC guideline value of 0.004 mg/L at all stations and at all times. Inner Harbour values were slightly higher than outer harbour stations in 2019/20, peaking in Sep-Feb (Appendix C, Figure C-11-14). The highest median values were recorded at Oparau, with 0.0028 mg/L and the maximum value at this station exceeded guideline values with 0.0056mg/L Total nitrogen concentrations were below guideline criteria at least 50% of the time over all monitoring periods and stations (Figure 6-9). Few exceedances occurred outside of summer months only (March – September, Appendix C, Figure C-11-14). Ammoniacal nitrogen data was collected only once in 2008/09 and are therefore not considered. In the 2019/20 monitoring period median values at Oparau, Mangaora, Te Kauri, and Waiharakeke were above the guideline values (0.015 mg/L) with the strongest exceedances in winter months and no apparent differences between monitoring stations (Figure 6-9, Appendix C, Figure C-11-15). Similarly, nitrate and nitrite nitrogen concentrations were highest during winter and lowest in summer (Appendix C, Figure C-11-15). Median concentrations at all monitoring stations in 2008/09 and Oparau and Te Kauri since 2019 exceeded the ANZECC guideline value of 0.015 mg/L (Figure 6-9).

Median total phosphorus concentrations in 2008/09 at Site1 and Site 3 exceeded the ANZECC guideline value of 0.03 mg/L (Figure 6-9). Since 2019, almost all measurements at all stations were below the guideline value (Figure 6-9, Appendix C, Figure C-11-15). No apparent seasonal patterns were observed. DRP concentrations observed in 2008/09 and since 2019 exceeded the ANZECC guideline value of 0.005 mg/L at least 50% of the time at all stations except Mid Harbour (Figure 6-9). Concentrations were slightly lower in summer months (Dec-Feb) but a clear seasonal pattern was not identified (Appendix C, Figure C-11-15). Microbial water quality was good for most stations, parameters, and monitoring periods (Figure 6-10). No guideline values were exceeded in 2019/20 for *E. coli* and enterococci. In 2008/09, median and 90th percentile guideline values for shellfish gathering waters were exceeded at Site 1 surface and bottom. Other stations with occasionally high faecal coliform concentrations but not breaching guideline levels were Managaora (2008/09 and since 2019), Te Kauri, and Te Toi.

6.3.2 Recreational water quality

Recreational water quality was generally good at all monitoring stations between 1994 and 1997 where enterococci concentrations remained consistently under guideline values (Figure 6-11). Faecal coliforms were not monitored during this time. From 2000 to 2009 enterococci concentrations remained below guideline alert levels most of the time. No exceedances for either enterococci or faecal coliforms were observed at Ocean Beach. At Karewa Beach enterococci concentrations were below guideline alter levels 95% of the time. However, the 90^{th} percentile alert level limit for shellfish gathering waters based on faecal coliforms (43 cfu/100mL) was slightly exceeded at this station (90^{th} percentile = 52 cfu/100mL). At Kawhia Wharf enterococci concentrations were below guideline levels most of the time but the 95^{th} percentile enterococci concentration was 480 cfu/100mL and therefore exceeded the red alert level in 2000-2009. At this station the 90^{th} percentile guideline limit for shellfish gathering water was also breached with a faecal coliform concentration of 144 cfu/100mL.

6.4 Discussion

6.4.1 Estuarine water quality

The estuarine water quality in Kawhia Harbour was often good with many water quality parameters at concentrations that adhere to ANZECC and recreational water quality guidelines. The water was clear at most monitoring stations with secchi disc readings of more than 3 meters at mid harbour and turbidity values below 10 FNU (Figure 6-7). Seasonal temperature differences were observed in Kawhia harbour at all monitoring stations with falling temperatures in June to August and increasing temperatures the following months until reaching maxima in December to February (Appendix C, Figure C-11-12). Spring and summer temperatures are likely promoting phytoplankton growth which was seen in increasing chl *a* concentration recorded in the current monitoring programme. Phytoplankton growth requires a nitrogen source and dissolved inorganic nitrogen such as nitrate-nitrite nitrogen is the most accessible form. Phytoplankton growth can therefore lead to nitrate-nitrite nitrogen depletion which was observed over the summer months at Kawhia Harbour's monitoring stations and is also reflected in lower total nitrogen concentrations during summer months (Appendix C, Figure C-11-14 & C-11-15). Phytoplankton blooms in summer increase the overall primary production which promotes the growth of heterotrophic organisms increasing the oxygen demand in the water column. This may have led to the lower dissolved oxygen concentrations and saturations that were observed in summer to early autumn. Higher concentrations of total nitrogen and its constituents were observed in winter months which may be related to more rainfall during this time and the beforementioned potential nitrogen depletion in summer due to phytoplankton growth. Seasonal difference for total phosphorus and dissolved reactive phosphorus were not at apparent. Slight drops in dissolved phosphorus were observed from November 2019 and November 2020 onwards (Appendix C, Figure C-11-15). The harbour system therefore seems to follow typical seasonal patterns, but additional data is needed to confirm this assumption.

Depth profiles data from the current monitoring programme showed that some monitoring stations in Kawhia Harbour were slightly prone to temperature stratification over the spring and summer months (Figure 6-3). Seasonal stratification can lead to reduced dissolved oxygen concentrations in bottom waters. At Oparau the onset of a thermocline was observed in October 2019 when surface water began to warm and colder waters sank to the bottom (Figure 6-3). In November 2019 the water column was fully stratified. At the same time increased phytoplankton growth may have fuelled growth of heterotrophic microorganisms leading to increased oxygen consumption. With no mixing of the water column the observed reduced oxygen concentrations at Oparau bottom waters could have been the consequence of the phytoplankton bloom. As the bottom water dissolved oxygen saturation was below 5mg/L / approximately 50% saturation it may have cause oxygen stress for sensitive organisms. The monitoring frequency of the SOE programme was too low to determine the duration of low oxygen events or if these occurred more frequently. However, this data did show that seasonal low dissolved oxygen events are occurring in Kawhia harbour which have the potential to increase if pressures on the estuary such as nutrient loading were to become more sever. Further monitoring data over several seasons will be needed to understand the sensitivity of the system to stratification and eutrophication driven low dissolved oxygen events. If more events are detected in future the investigations of the spatial and temporal extend of these events should be undertaken.

Pressures on microbiological water quality appear to be low in Kawhia Harbour. Enterococci and *E. coli* concentrations were always well below guideline levels at all monitoring stations and, showing that the risk of illness from contact with the water was low. However, signs of mild pressure on the suitability of shellfish gathering waters were observed in 2008/09 at Site 1 (Figure 6-10). At the current nearby monitoring station Te Kauri shellfish gathering water guideline levels were not breached but showed a few high faecal coliform concentrations around October -December 2020. Te Kauri, Te Toi and Mangaora monitoring stations experienced higher microbial contamination at the same time (Appendix C, Figure C-11-16). This could be due to rain events. It was recorded that samples in November 2020 were collected during rain, but no suitable rainfall site was available for Kawhia Harbour which prevents comparison to rainfall data. This may point towards increased risk of contracting gastroenteric infections from shellfish collected after rainfall in Kawhia Harbour. More monitoring data, including sampled collected during rainfall will be needed to confirm this assumption.

Location specific differences in water quality were subtle between most monitoring stations in Kawhia Harbour indicating that pressures might be evenly spread across the estuary. Nutrient, sediment, and microbial contaminant concentration were similar at all monitoring stations except Mid Harbour. This station experienced less freshwater influence than all other stations and showed clearer waters indicated by higher secchi disc readings and lower turbidity (Figures 6-6 and 6-7). At Mangaora station water clarity parameters (Secchi disc, turbidity) indicated slightly clearer water, but more data is necessary to determine if the differences are significant. Nutrient inputs were lower at Mid Harbour and often stayed within ANZECC guidelines whereas they were exceeded at other stations (Figure 6-9). This points towards catchment loads rather than offshore loads as dominants source of nutrients in Kawhia Harbour.

Monitoring identified differences between stations monitored from 2008 to 2009 and closely located stations in the current monitoring programme. While it is tempting to speculate that differences may be due to changes in water quality the differences in sampling time, methods and analysis techniques between the two monitoring phases do not allow for this data to be directly compared. Salinity values at the historic monitoring stations were generally higher than at the current monitoring stations. However, sampling took place at different tidal stages in 2008/09 compared to the current monitoring programme which may be the reason for the observed differences. This would have also impacted concentrations of nutrients, turbidity, and microbial contaminants. Some laboratory analysis methods and the detection limits have changed between the monitoring phases (e.g., chlorophyll *a*) and will have impacted results. Therefore, data comparison between the two monitoring phases has been limited in this report. Inconsistent monitoring methods may also be the (partially) the cause of the observed temperature differences. But a general increase in temperature cannot be excluded. As further monitoring data becomes available temperature trends should be investigated. The inability to compare data from the two monitoring phases greatly limits our understanding water quality in Kawhia harbour. It stresses the importance of consistent long-term monitoring.

Overall estuarine water quality in Kawhia Harbour appears to experience mild pressures from nutrients which were most prominent in winter months and inner harbour sites. This is likely due to nutrient run off into the streams feeding the estuary. Most of these stream flow through high producing exotic grassland which has the potential to increase nutrient concentrations. The estuary appears to be coping well with current pressures as most monitoring stations did not show sign of eutrophication, showed good water clarity and no major microbiological contamination. However, low DO events at Oparau stations and the tendency of several monitoring stations to seasonal stratify points towards a certain susceptibility for eutrophication. If nutrient loads into the estuary were to increase stronger eutrophication effects may occur at more places in the estuary. Future monitoring data is needed to confirm the assumptions made based on preliminary results.

6.4.2 Recreational water quality

Water quality in Kawhia harbour was often suitable for contact recreation based on concentrations of faecal indicator bacteria. The Ocean Beach monitoring station was least impacted as can be expected from a highly dynamic location with high flushing ability. Monitoring stations in the harbour were slightly more impacted but exceedances were limited to single events. Recreational monitoring was reinstated at Kawhia Wharf in November 2020. Sampling is limited to monthly due to logistical challenges reaching the station more frequently. While the reduced frequency may limit the ability to detect exceedances, current results confirm the high suitability for contact recreation. Shellfish gathering water quality may be slightly more impacted as the 90^{th} percentile guideline limit was breached in the past in the inner harbour locations. Due to the lack of current monitoring at the required weekly frequency focused on the shellfish gathering season there in no information about the current water quality state for shellfish gathering. Based on data from the estuarine water quality monitoring programme, it is unlikely that shellfish gathering water quality is adversely affected at Kawhia Harbour.

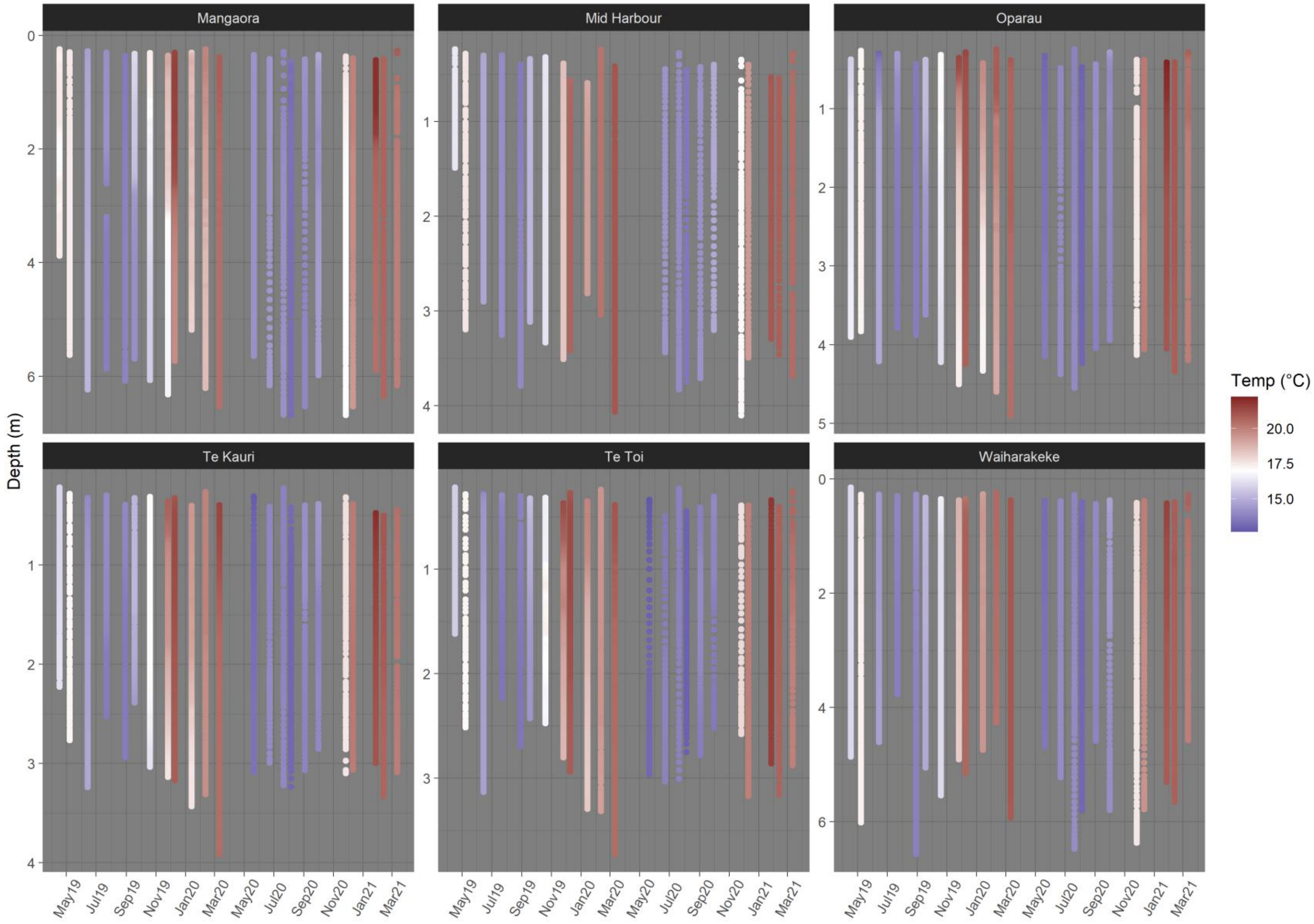

Figure 6-3. Temperature-depth profile plots for Kawhia Harbour sampling stations over time since April 2019.

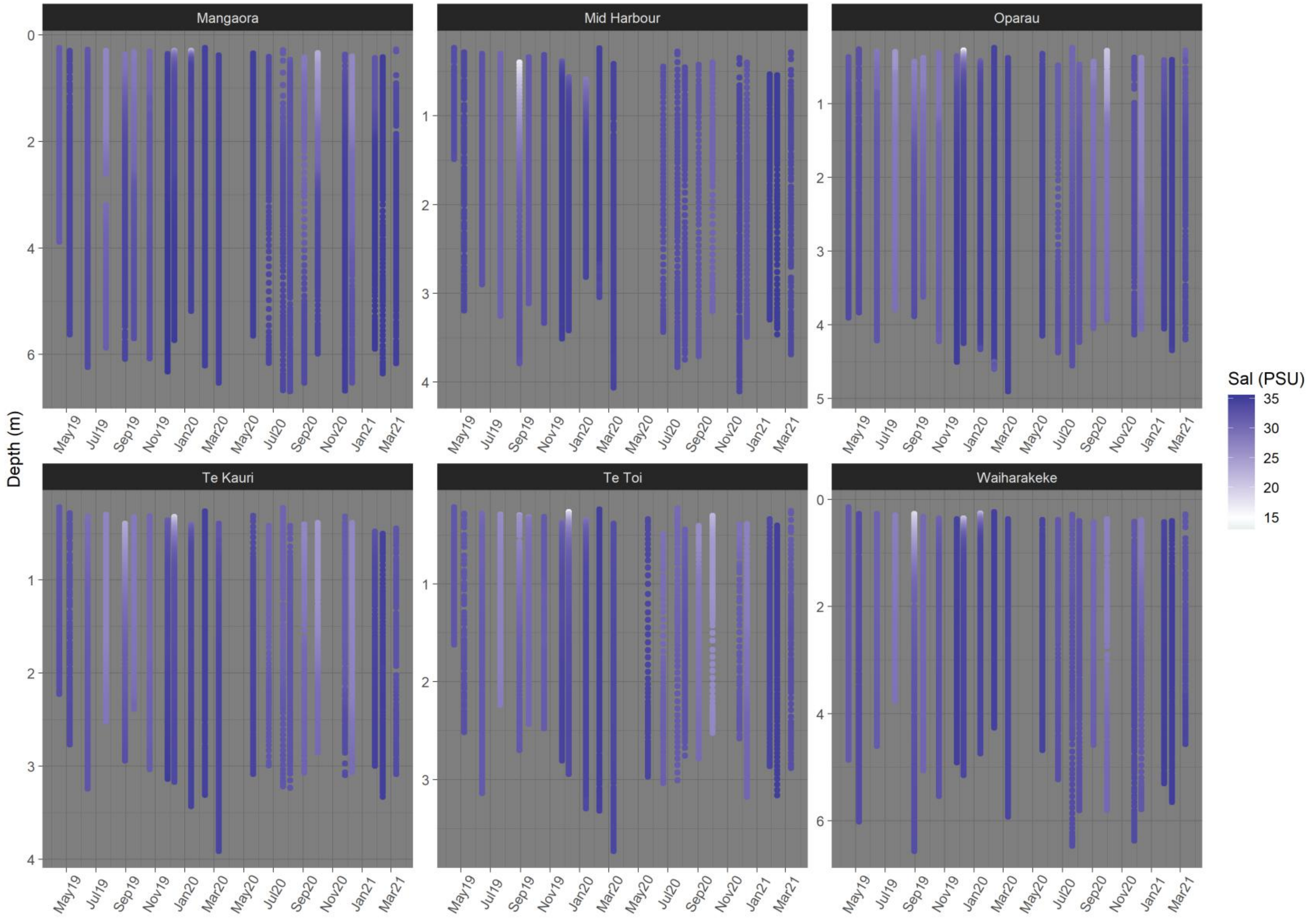

Figure 6-4. Salinity-depth profile plots for Kawhia Harbour sampling stations over time since April 2019.

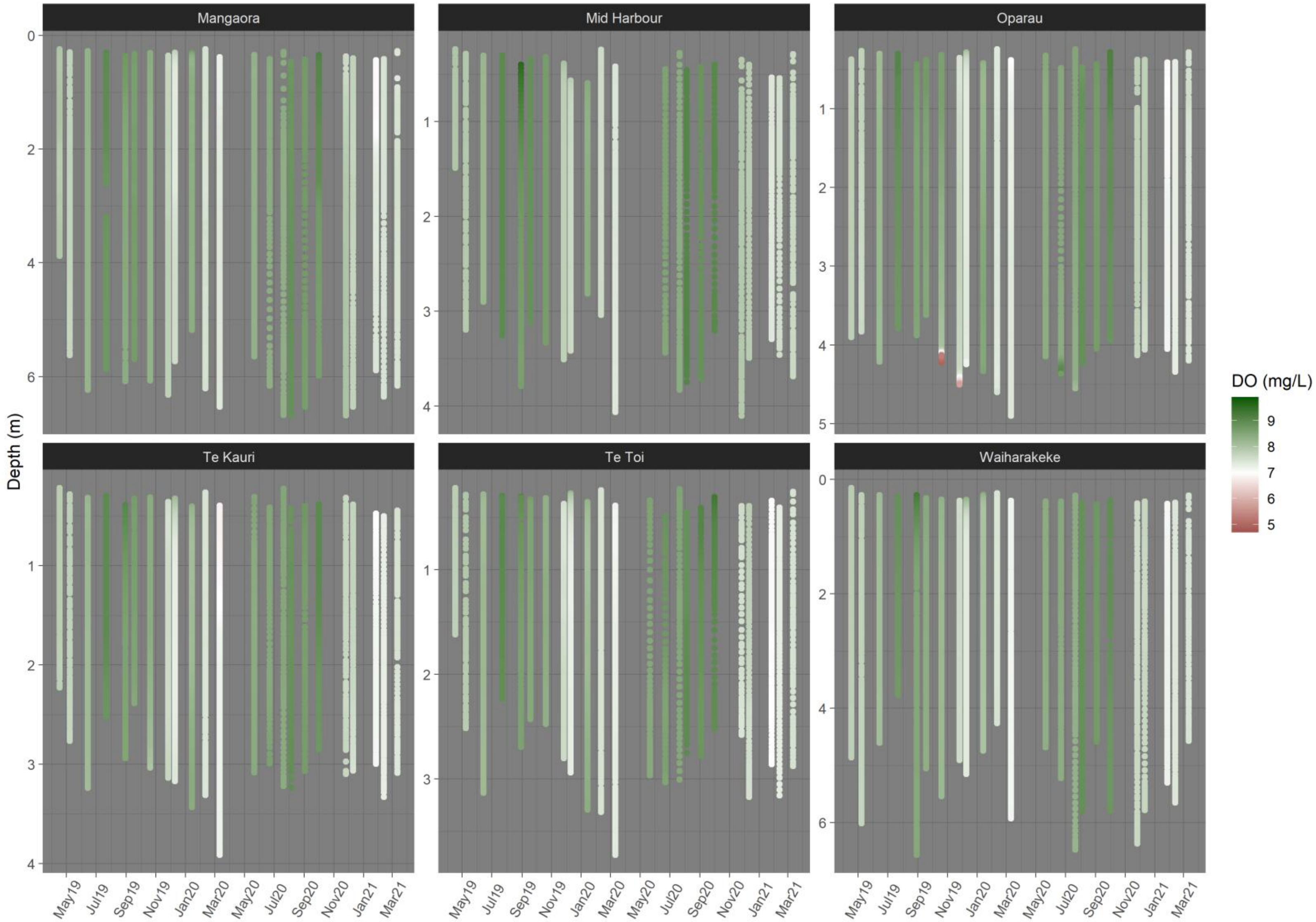

Figure 6-5. Dissolved oxygen-depth profile plots for Kawhia Harbour sampling stations over time since April 2019.

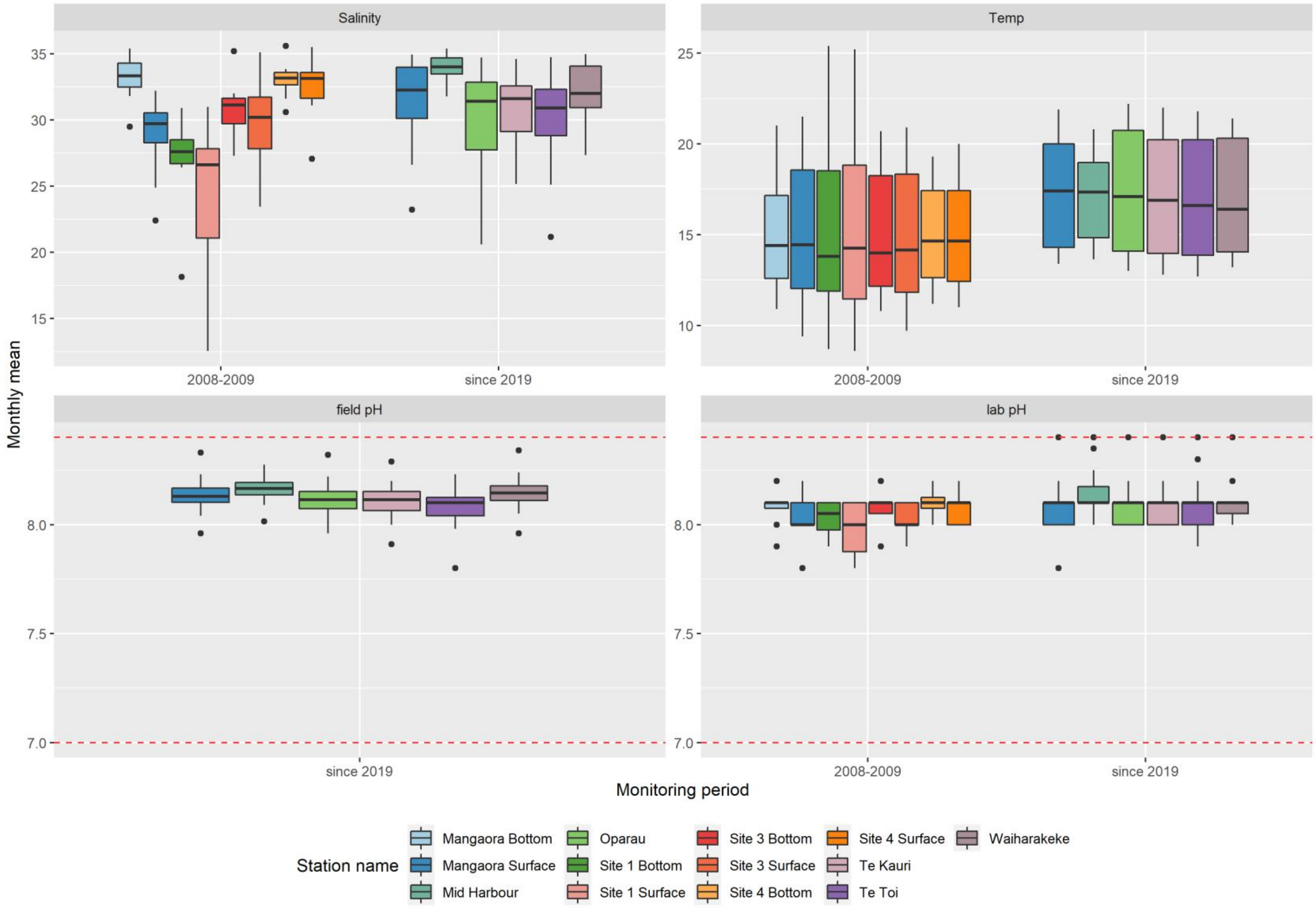

Figure 6-6. Distribution of physical estuarine water quality monitoring data per monitoring period for Kawhia Harbour Part 1. See figure 3-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the applicable parameter (see Table 2-2). For parameter units refer to table 2-1.

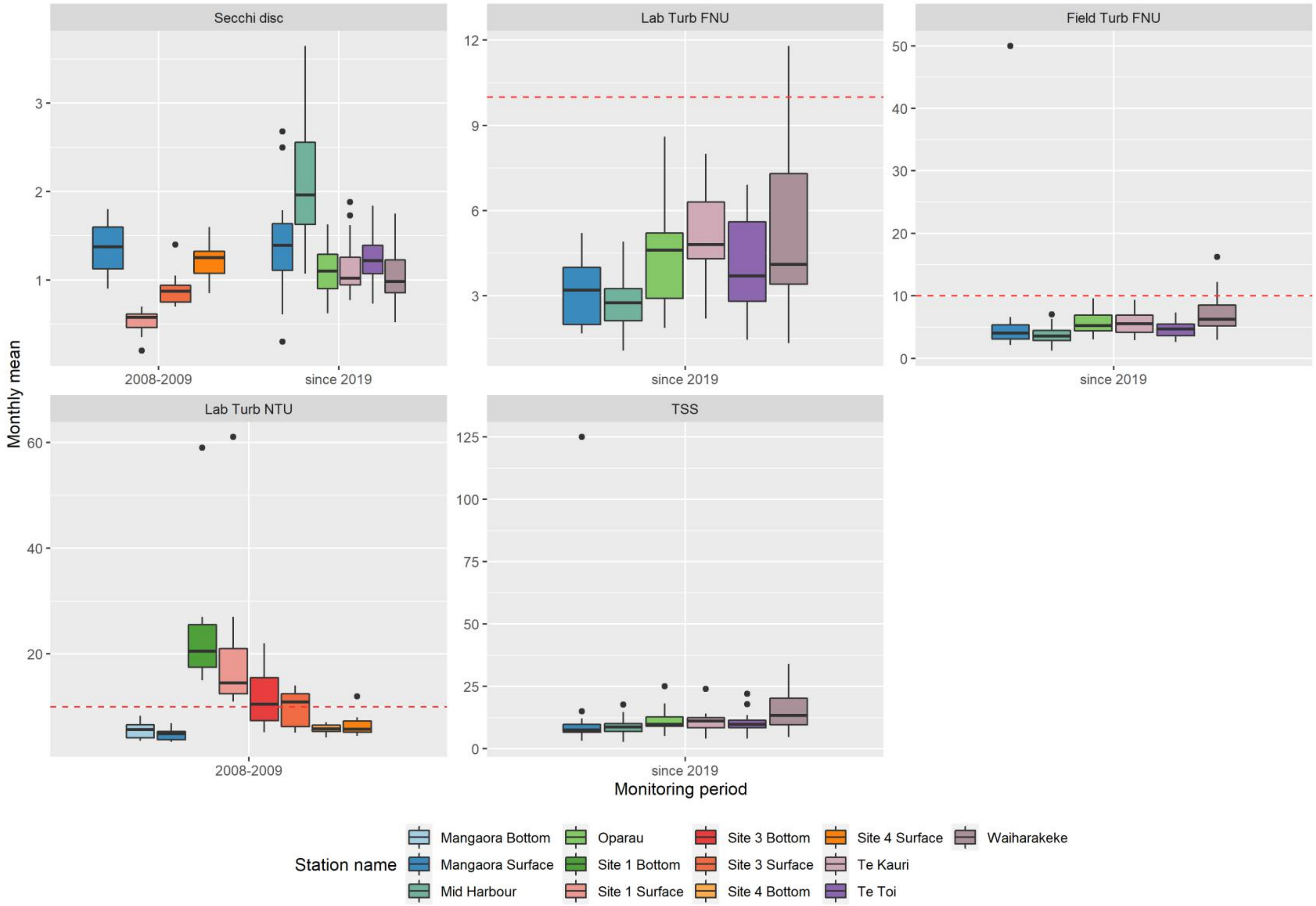

Figure 6-7. Distribution of physical estuarine water quality monitoring data per monitoring period for Kawhia Harbour Part 2. See figure 3-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the applicable parameter (see Table 2-2). For parameter units refer to table 2-1.

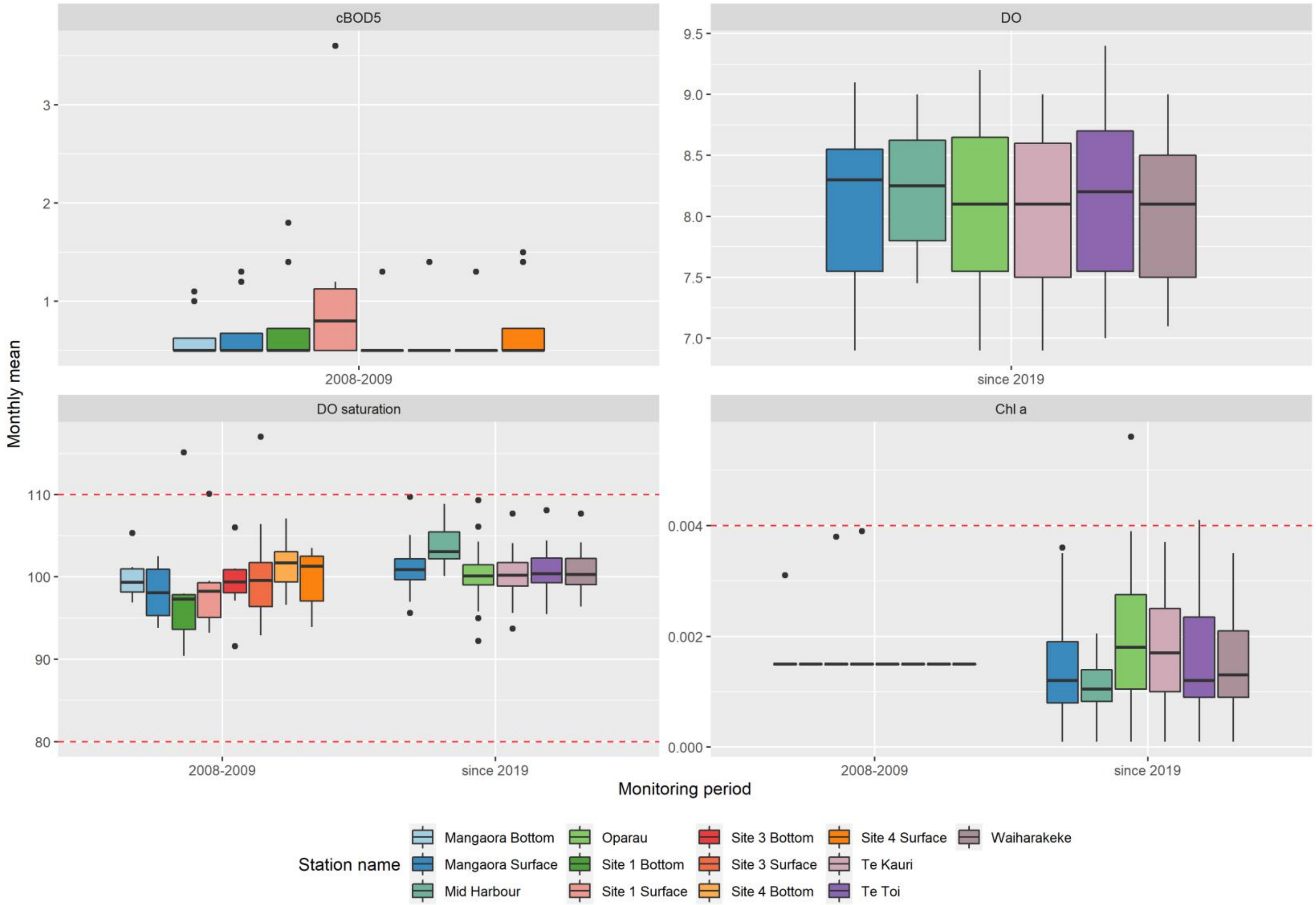

Figure 6-8. Distribution of chemical estuarine water quality monitoring data per monitoring period for Kawhia Harbour Part 1. See figure 2-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the applicable parameter (see Table 2-2). For parameter units refer to table 2-1.

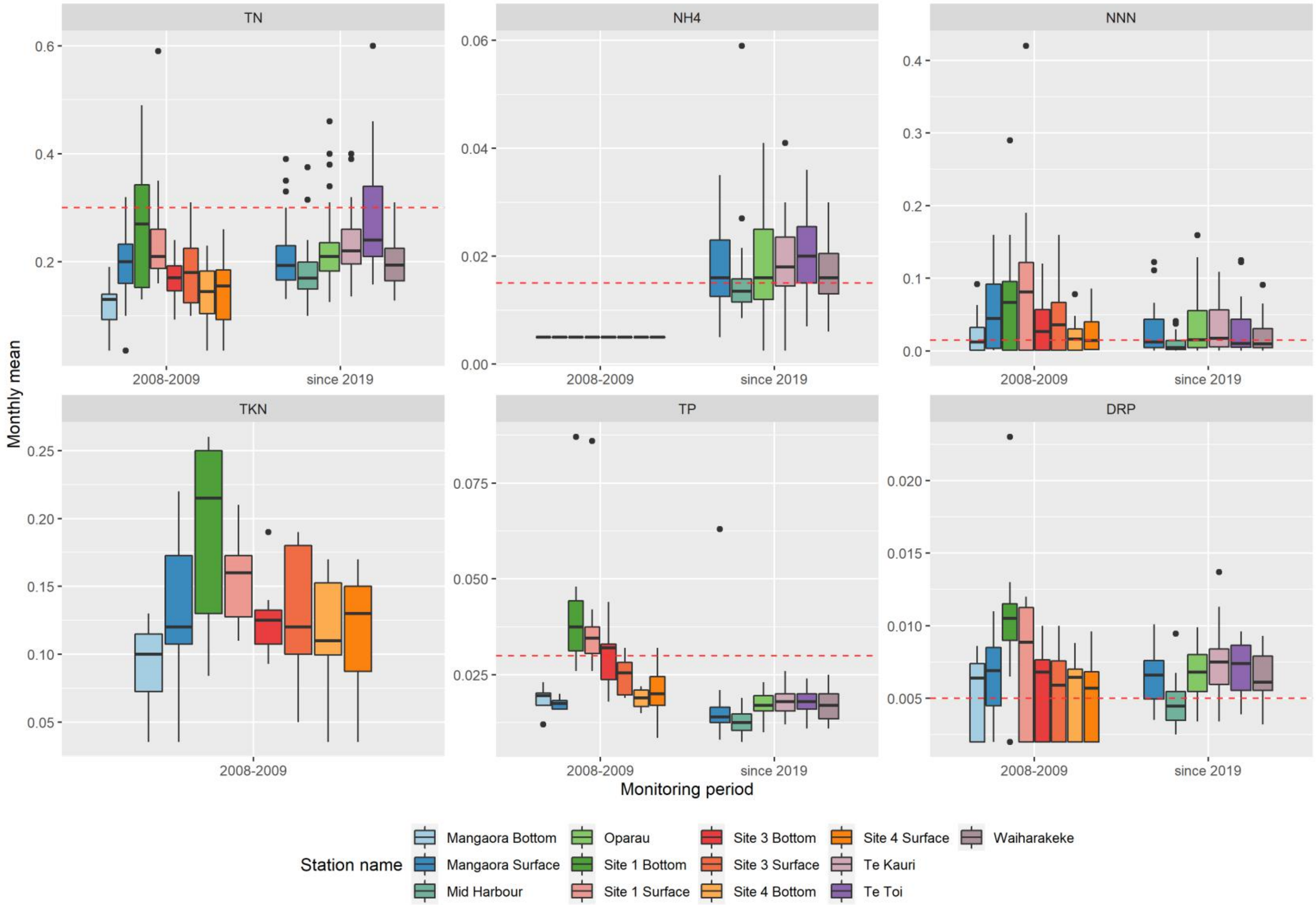

Figure 6-9. Distribution of chemical estuarine water quality monitoring data per monitoring period for Kawhia Harbour Part 2. See figure 2-2 for boxplot range definition. Dashed red lines represent ANZECC guideline limits for the applicable parameter (see Table 2-2). For parameter units refer to table 2-1.

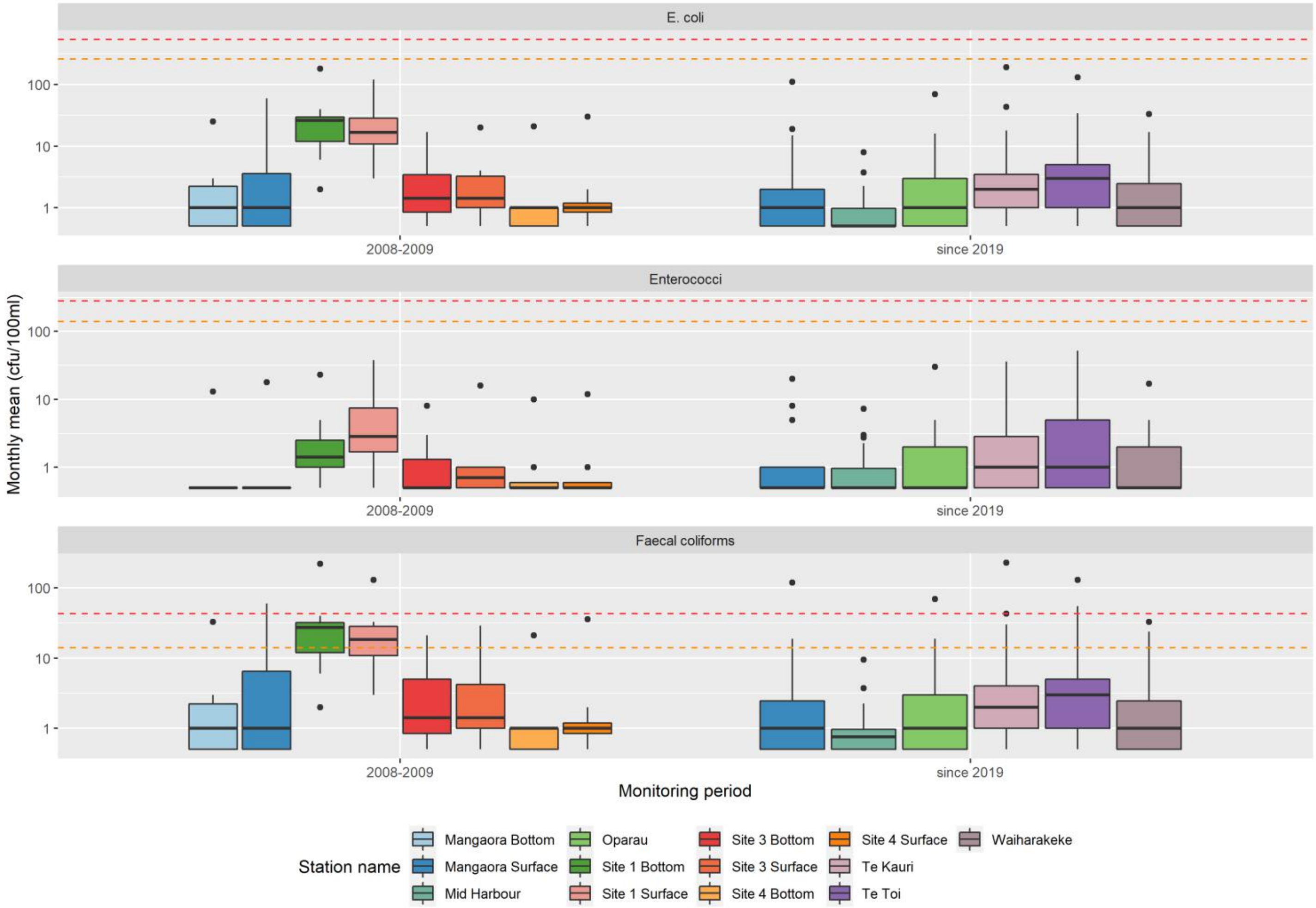

Figure 6-10. Distribution of microbial estuarine water quality monitoring data per monitoring period for Kawhia Harbour. The box represents in interquartile range between the 25th percentile (lower boarder) and the 75th (upper boarder), the bold line inside the box represents the median. Vertical lines (whiskers) below and above show the data range. Outliers (calculated at 1.5 interquartile range) are shown as black circles. Dashed red lines represent the red alert and dashed amber lines the amber alert limit for *E. coli* and enterococci according to the recreational water quality guidelines for marine and freshwater. For faecal coliforms, the dashed red line denotes limit for the 90%th percentile and the dashed amber line the median limit for shellfish gathering waters (Table 3-3).

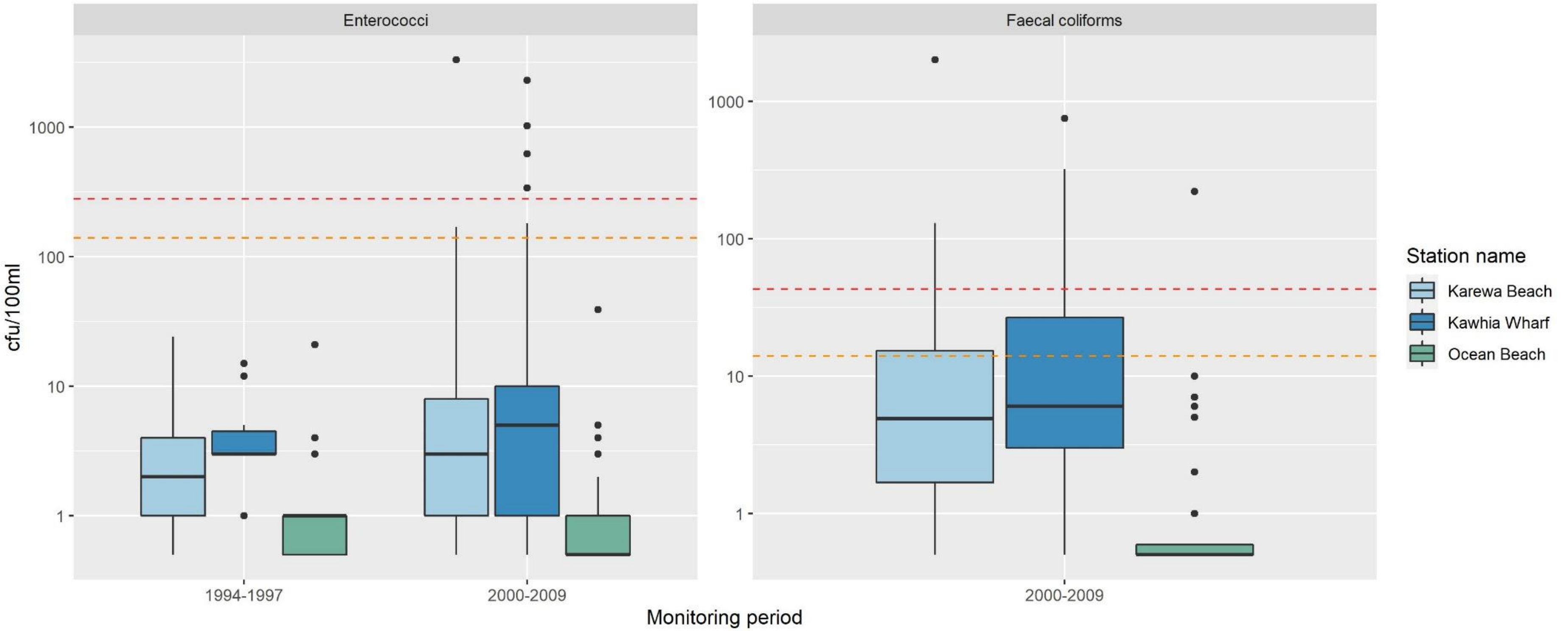

Figure 6-11. Distribution of microbial recreational water quality monitoring data per monitoring period for Kawhia Harbour. The box represents in interquartile range between the 25th percentile (lower boarder) and the 75th (upper boarder), the bold line inside the box represents the median. Vertical lines (whiskers) below and above show the data range. Outliers (calculated at 1.5 interquartile range) are shown as black circles. Dashed red lines represent the red alert and dashed amber lines the amber alert limit for *E. coli* and enterococci according to the recreational water quality guidelines for marine and freshwater. For faecal coliforms, the dashed red line denotes limit for the 90%th percentile and the dashed amber line the median limit for shellfish gathering waters (Table 3-3).

7 Conclusion and recommendations

7.1 General conclusions

Overall, preliminary state analysis for Waikato West Coast estuaries revealed that nutrient contamination has likely been the main pressure on water quality in all estuaries regardless of monitoring period. At inner estuary monitoring stations which are less well flushed and/or experienced greater freshwater inputs, nutrient values were usually highest and often exceeded ANZECC guideline values. This pointed towards the catchments as main source of nutrients (and sediment) at all estuaries included in this report. The onset of a possible impact of nutrient inputs were observed at some Whāingaroa and Kawhia inner harbour stations were chlorophyll *a* levels were elevated in spring/summer and dissolved oxygen concentration decreased in summer. Because of short monitoring timeframes at these estuaries no conclusion can be made if these were single or regular occurrences. Future monitoring will need to investigate the extent of lower oxygen concentrations and whether these are natural seasonal occurrences due to increasing temperatures, caused by water column stratification and/or enhanced by nutrient pressures. The most effected monitoring stations were Waingaro and Waitetuna in Whaingaroa Harbour and Oparau in Kawhia Harbour. All of these stations are located nearest to freshwater input from parts of the catchments with highest proportion of high producing exotic grassland land coverage. This indicates farming activities having an impact on estuarine water quality. Despite relatively high levels of nutrients at Port Waikato the estuary did not show signs of low dissolved oxygen concentrations which is likely due to its better flushed nature. Less well flushed areas of Port Waikato Estuary may experience nutrient related stress (algal blooms, low DO) and synoptic surveys should be conducted to investigate this. At Aotea Harbour the impact of nutrients was less prominent compared to the other west coast estuaries. It was the only estuary included in this report where the dominating lower catchment land cover class was not high producing exotic grassland but instead exotic forest and Manuka/Kanuka scrub. It remains unclear if and how much different land uses impact water quality in west coast estuaries of the Waikato Region. More detailed analysis of water quality in each harbour with respect to catchment land use including more detailed land use type and land use intensity is needed to better understand potential impacts from catchment activities.

Similar to patterns in nutrient parameters, turbidity levels were highest and visibility lowest at inner estuary sites and improved with less freshwater impact. ANZECC guidelines were often exceeded at the inner harbour sites. To assess potential ecological impacts of increased turbidity, longer data records are needed and should be considered together with sedimentation data from the relevant sites. Land use information and rainfall and or river flow data should be included in future analysis to investigate the relationship to land use activities and freshwater inputs.

Microbial water quality for recreation was generally good at all sites. Open ocean sites experienced little pressure except for recent years at Port Waikato. Data showed that the quality of shellfish gathering waters may be impacted by faecal contamination at inner estuary sites. The relevant data was often more than 10 years old, and the current status could not be assessed. Monitoring for shellfish gathering water quality should be resumed at relevant gathering sites to obtain a current state.

Physical and chemical parameters included in estuarine water quality reporting were compared to ANZECC (2000) guideline values for slightly disturbed estuaries. At almost all monitoring stations the upper guideline values for ammoniacal nitrogen and dissolved reactive phosphorus were exceeded or reached. This may indicate that the guidelines are not fully suitable for estuaries on the west coast of the Waikato. The ANZECC (2000) guideline values were not based on New Zealand data but derived from estuary water quality data of South-East Australia. Is has been suggested previously that these guidelines may be too conservative for New Zealand as nutrient values in Australian water are naturally higher than in New Zealand (Hunt, 2014; Griffith, 2015). Until sufficient water quality data becomes available from suitable reference estuaries in New Zealand to derive New Zealand specific guidelines, this cannot be addressed. This should be considered when interpreting water quality data and comparing it to ANZECC guideline values. However, it does not mean all exceedance of guidelines for these parameters are related to natural concentrations. Nutrient concentrations should be carefully evaluated on a case-by-case basis.

Overall, the lack of consistent long-term monitoring data greatly restricted analysis and interpretation of results in this report. Different monitoring periods in the same estuary (e.g., Waingaroa Harbour) suggested changes in water quality parameters such as water temperature, nutrients, and turbidity over time but due to sporadic short-term monitoring with inconsistent methods the appropriate analysis to confirm changes could not be completed. None of the monitoring stations included in this report had a consistent data record of more than four years. **Therefore, all results are preliminary, and the interpretations should be regarded as speculative**.

7.2 Recommendations

The following recommendations apply to all sites included in this report. Individual recommendations for each estuary were given in the relevant chapters. However, most of these recommendations are covered in the below recommendations.

- Water quality reporting requires continuous and consistent monitoring that allows for statistically robust state and trend analysis. State analysis should include at least 5 years of monthly monitoring data (be based on the most recent 5 years if longer records are available) and at least 10 years of monthly monitoring data for trend analysis. All monitoring should be continued using consistent sampling (including instruments for in situ measurements) and laboratory analysis methods to allow for robust reporting in future.
- This preliminary report has shown that freshwater influence and rainfall events may have an impact on water quality of all estuaries of the region's west coast. To appropriately address this in future reporting appropriate river flow and rainfall sites should be identified and monitoring data included. If water quality data from appropriate freshwater monitoring stations is available combined freshwater and estuarine water quality reporting should be considered for targeted locations.
- Once sufficient water quality data for robust reporting is available then investigate the effects of different land uses and intensity in estuarine catchments and sub catchments.
- The interpretation of water quality data would greatly benefit from accurate hydrological information in each estuary including residence times for different areas. This was out of scope for this summary report, but available information should be included in future reporting when sufficient water quality data is available for state reporting. If accurate information is not available, then the acquisition of it should be prioritised.
- Several estuarine monitoring sites showed elevated faecal coliform concentrations in the past and have not been monitored for several years to assess shellfish gathering water quality. To address potential issues for shellfish gathering waters at the region's west coast, shellfish gathering sites should be identified and an appropriate monitoring programme should be designed and instated.

8 References

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9 Appendix A

Table of statistical results for estuarine water quality per sampling station, monitoring period and parameter.

https://discover.wairc.govt.nz/otcs/llisapi.dll/link/16413826

10 Appendix B

Table of statistical results for recreational water quality per sampling station, monitoring period and parameter.

https://discover.wairc.govt.nz/otcs/llisapi.dll/link/16415001

11 Appendix C – Estuarine Water quality data over time

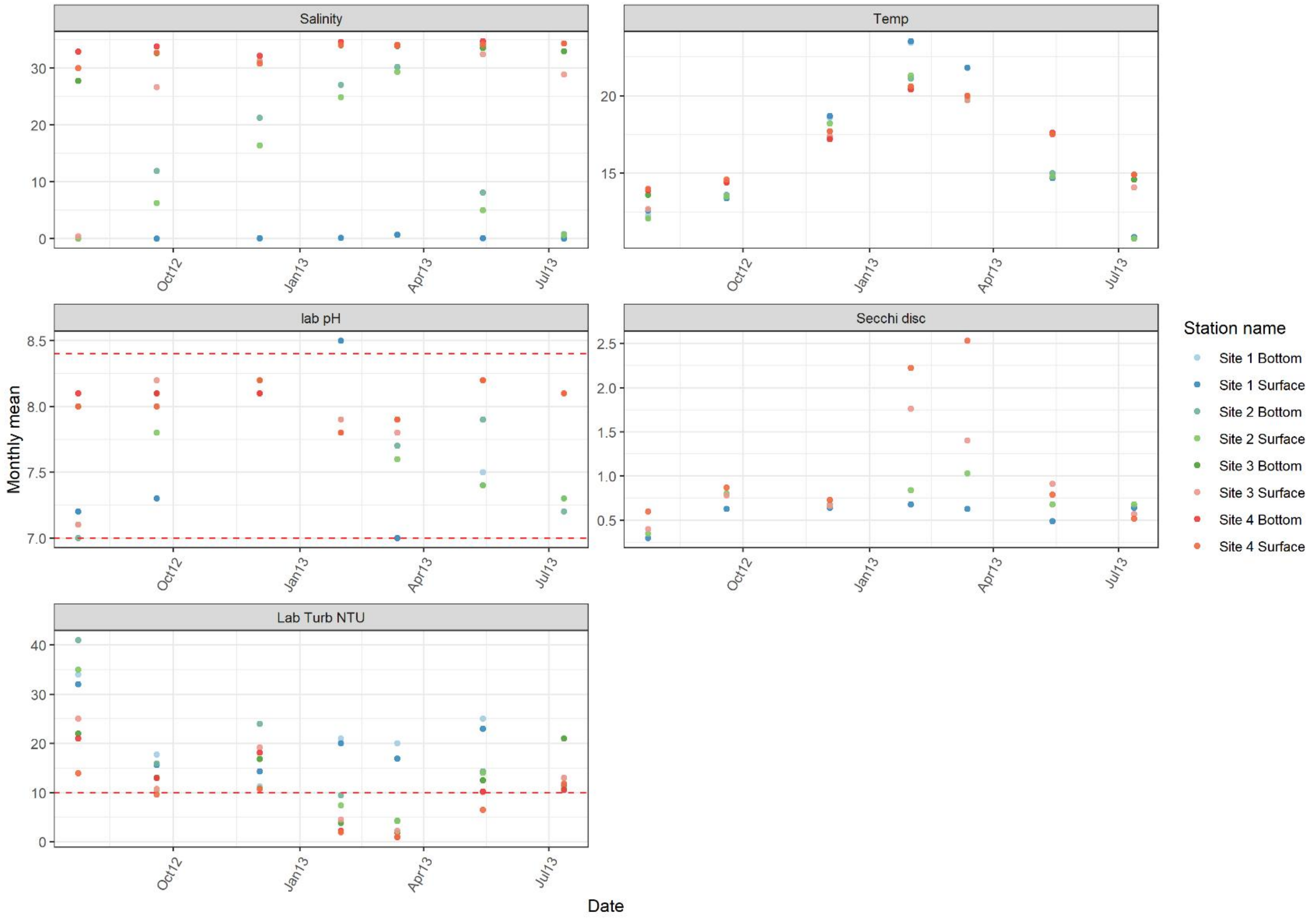

Figure C-11-1. Physical water quality parameters over time for Port Waikato. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

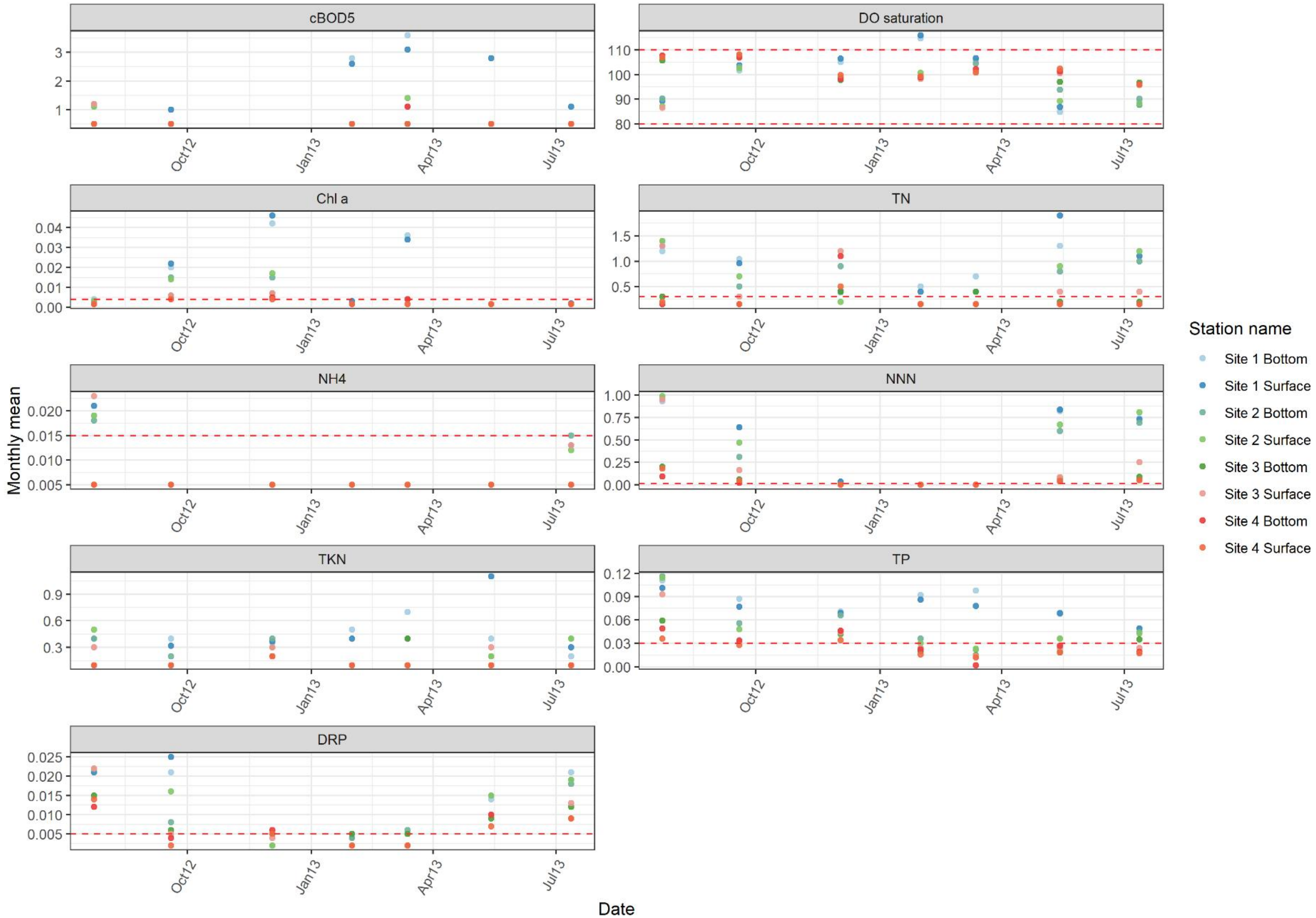

Figure C-11-2. Chemical water quality parameters over time for Port Waikato. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

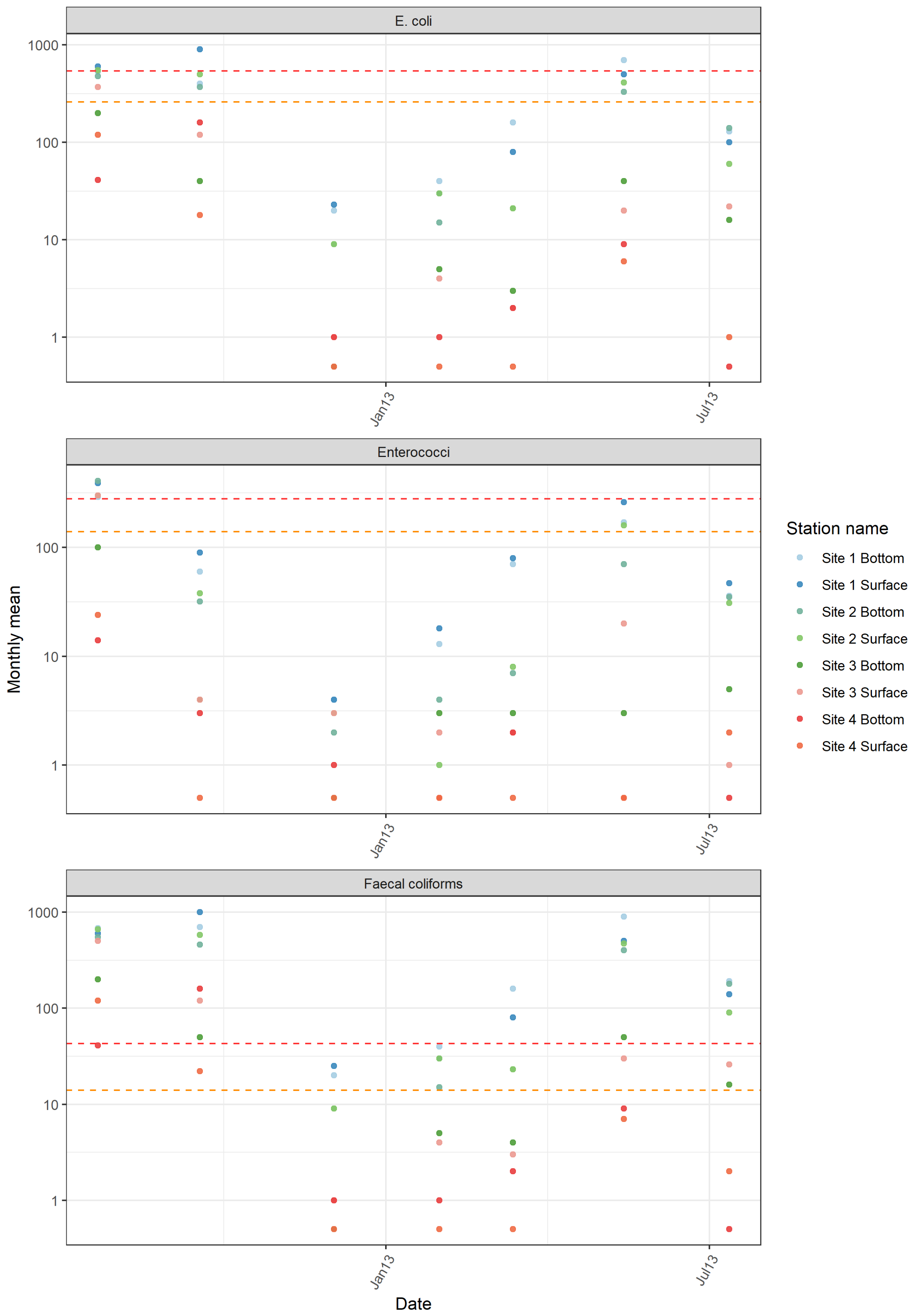

Figure C-11-3. Microbiological water quality parameters over time for Port Waikato. Dashed red lines denote red alert and dashed amber lines denote amber levels for recreational water quality.

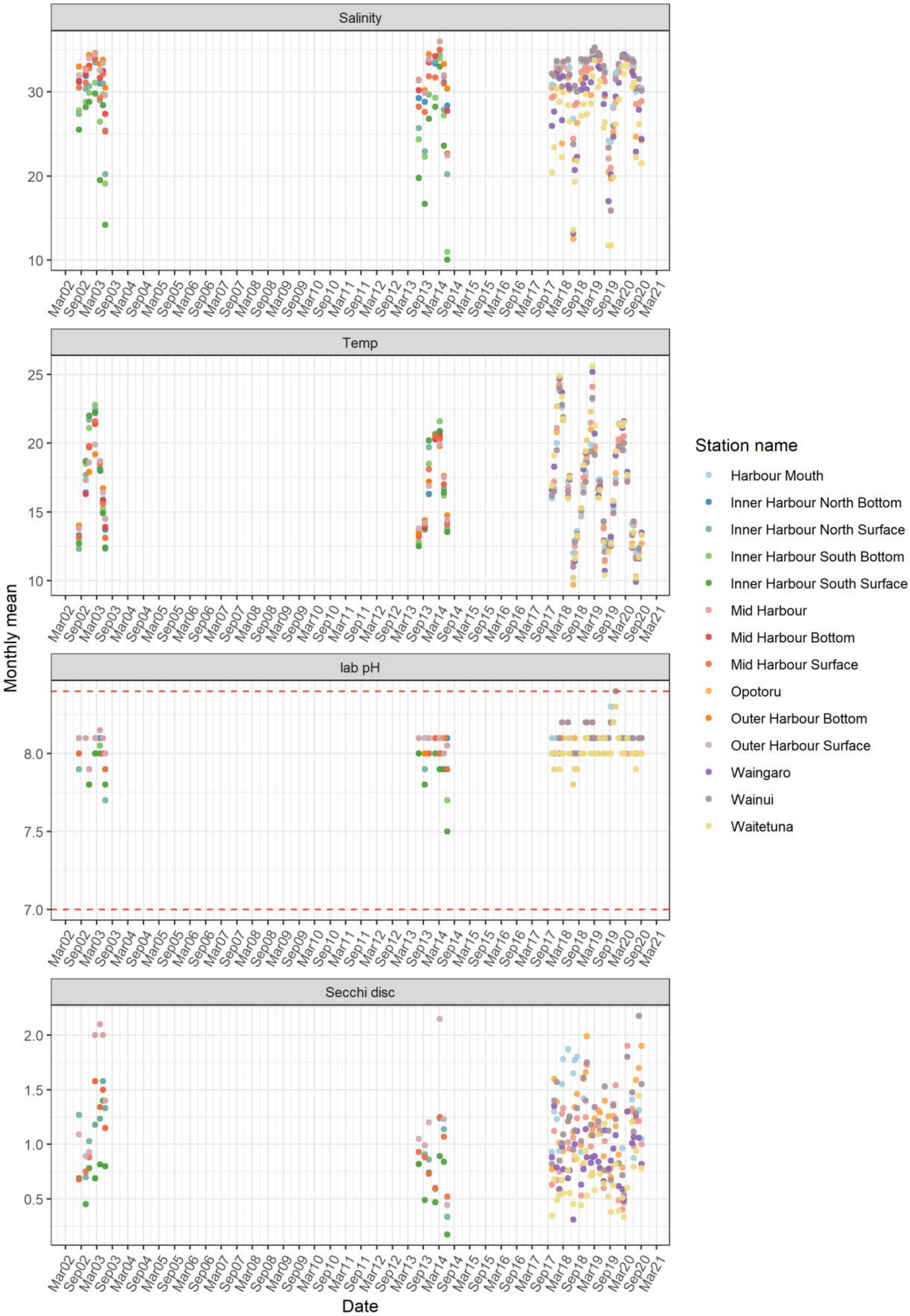

Figure C-11-4. Physical water quality parameters over time for Whāingaroa (Raglan) Harbour Part 1. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

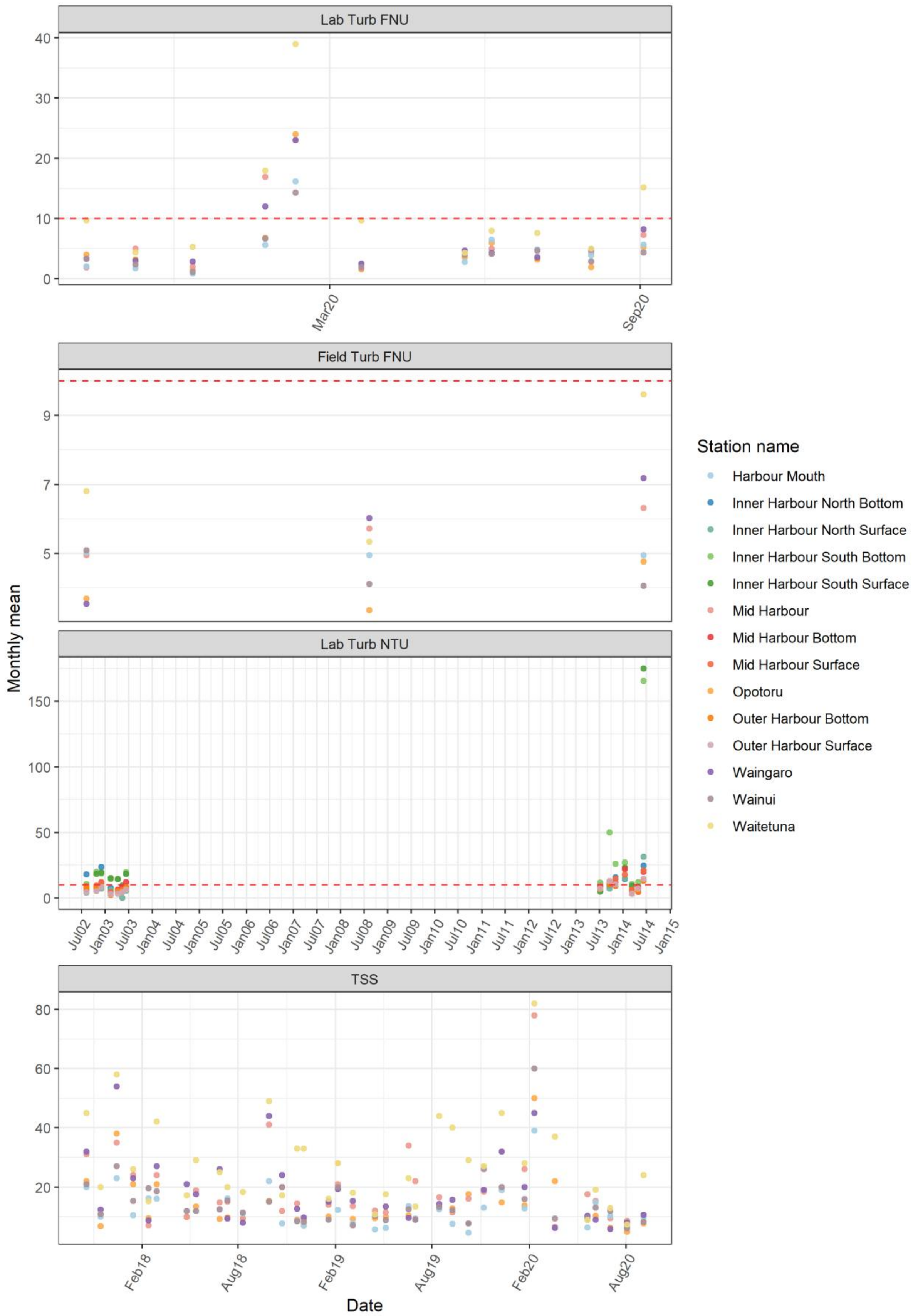

Figure C-11-5. Physical water quality parameters over time for Whāingaroa (Raglan) Harbour Part 2. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

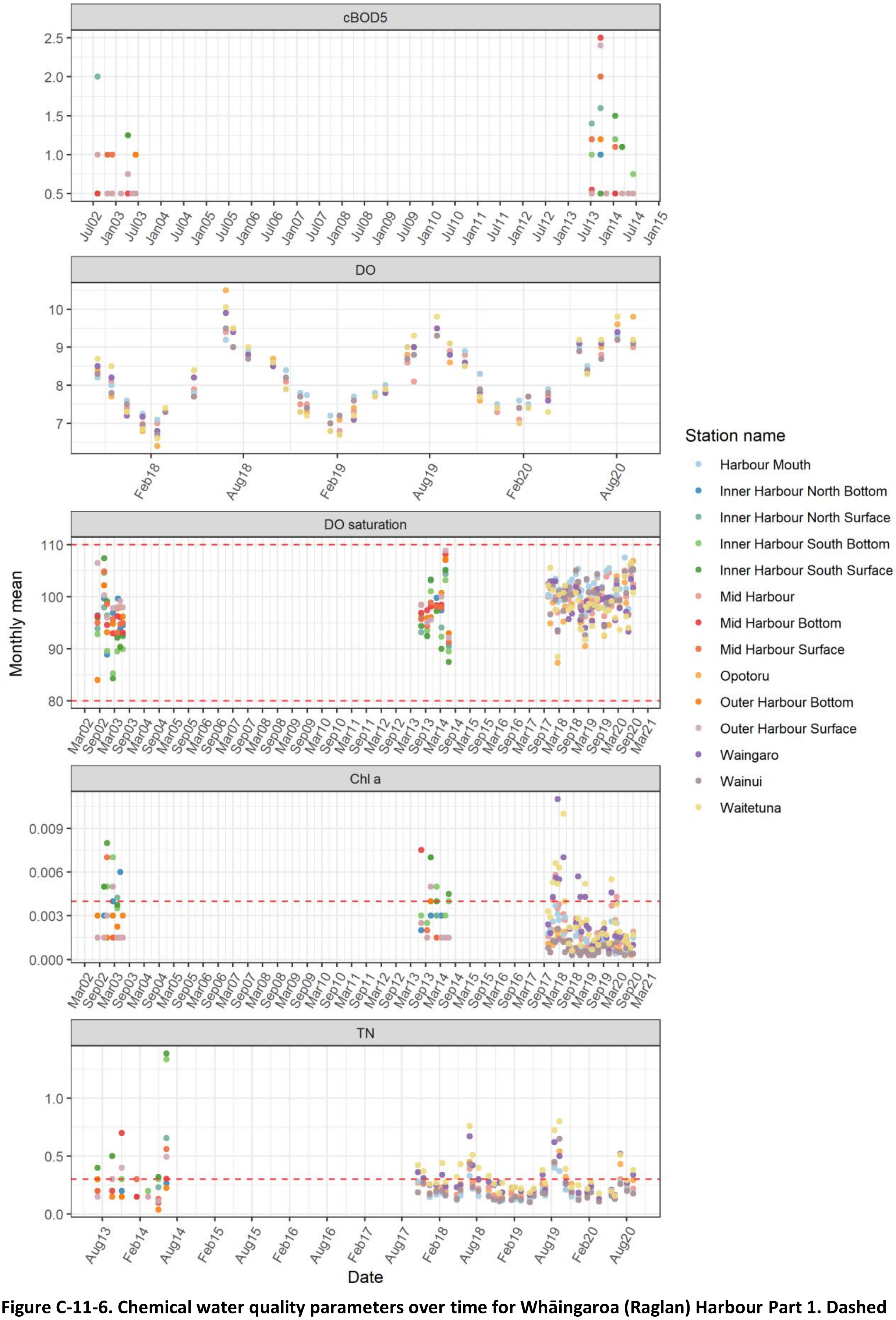

Figure C-11-6. Chemical water quality parameters over time for Whāingaroa (Raglan) Harbour Part 1. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

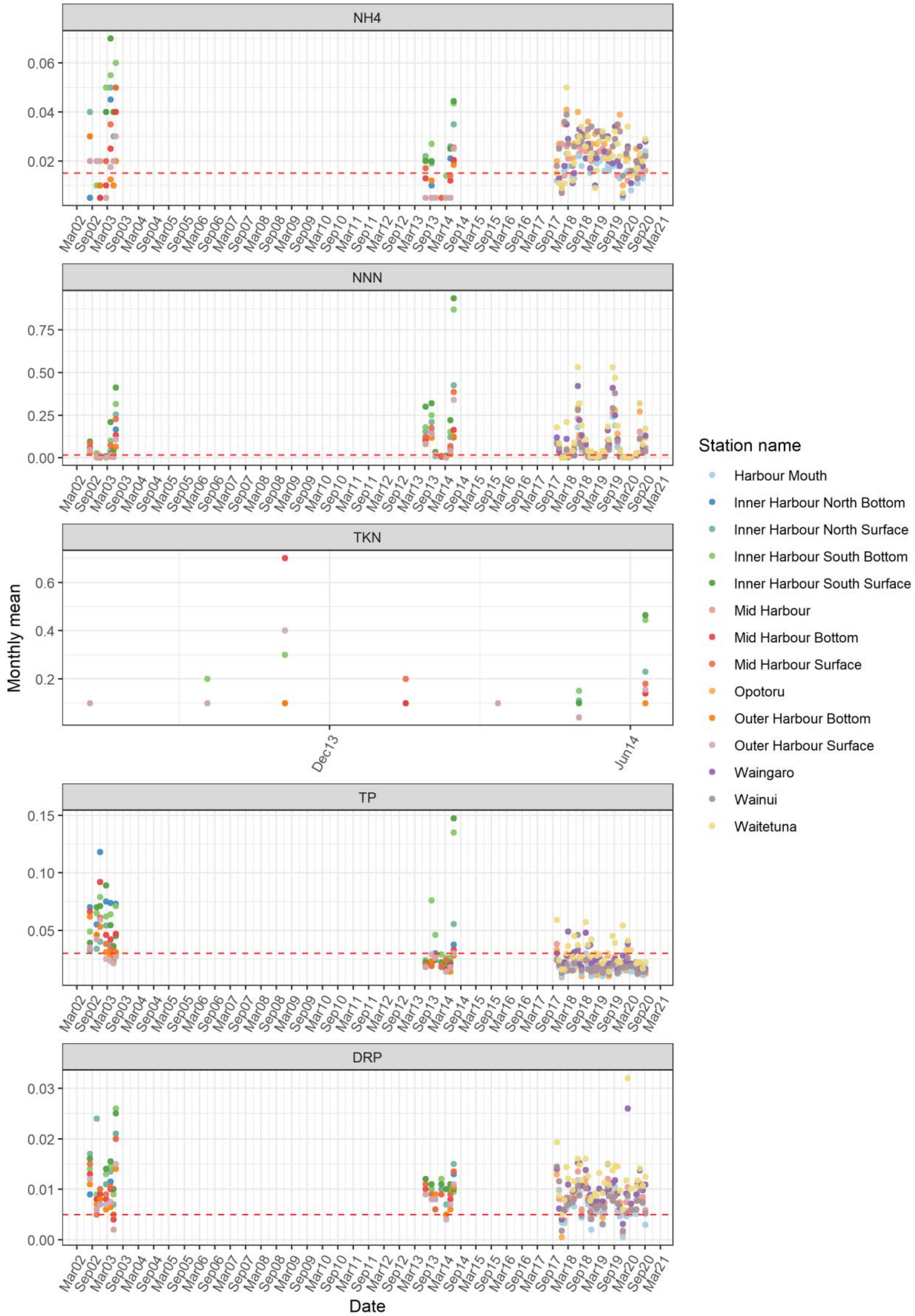

Figure C-11-7. Chemical water quality parameters over time for Whāingaroa (Raglan) Harbour Part 2. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

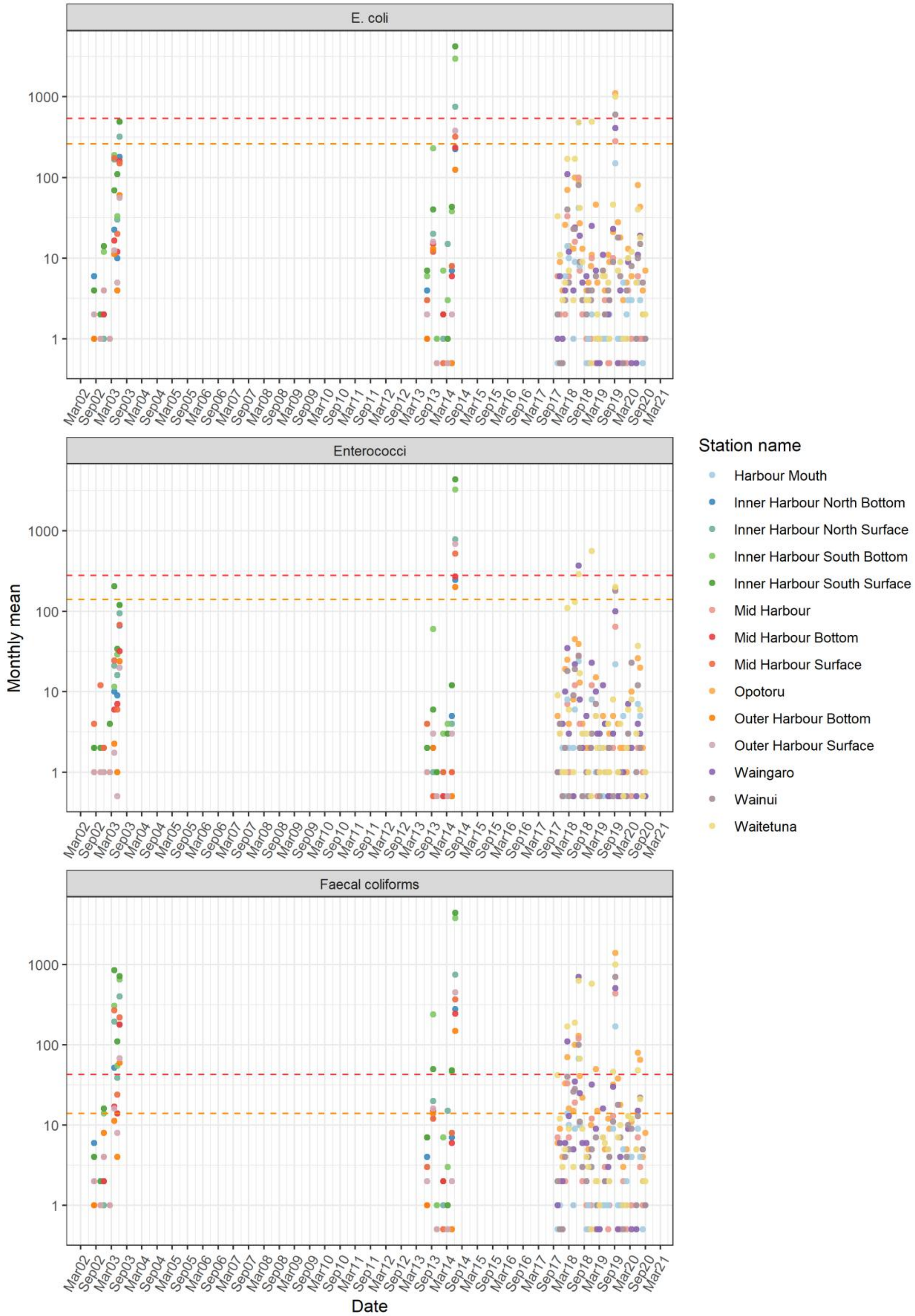

Figure C-11-8. Microbiological water quality parameters over time for Whāingaroa (Raglan) Harbour. Dashed red lines denote red alert and dashed amber lines denote amber levels for recreational water quality.

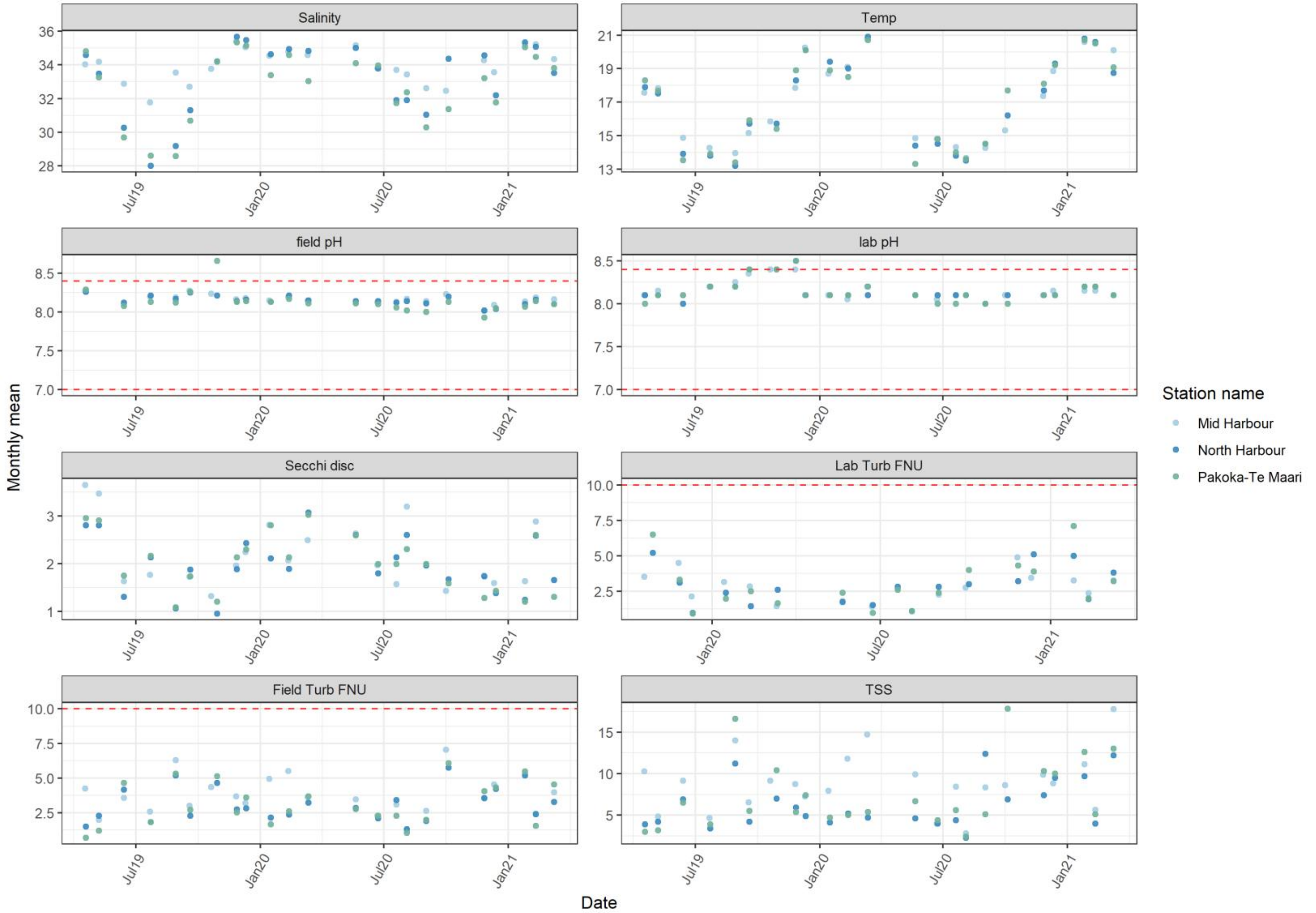

Figure C-11-9. Physical water quality parameters over time for Aotea Harbour. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

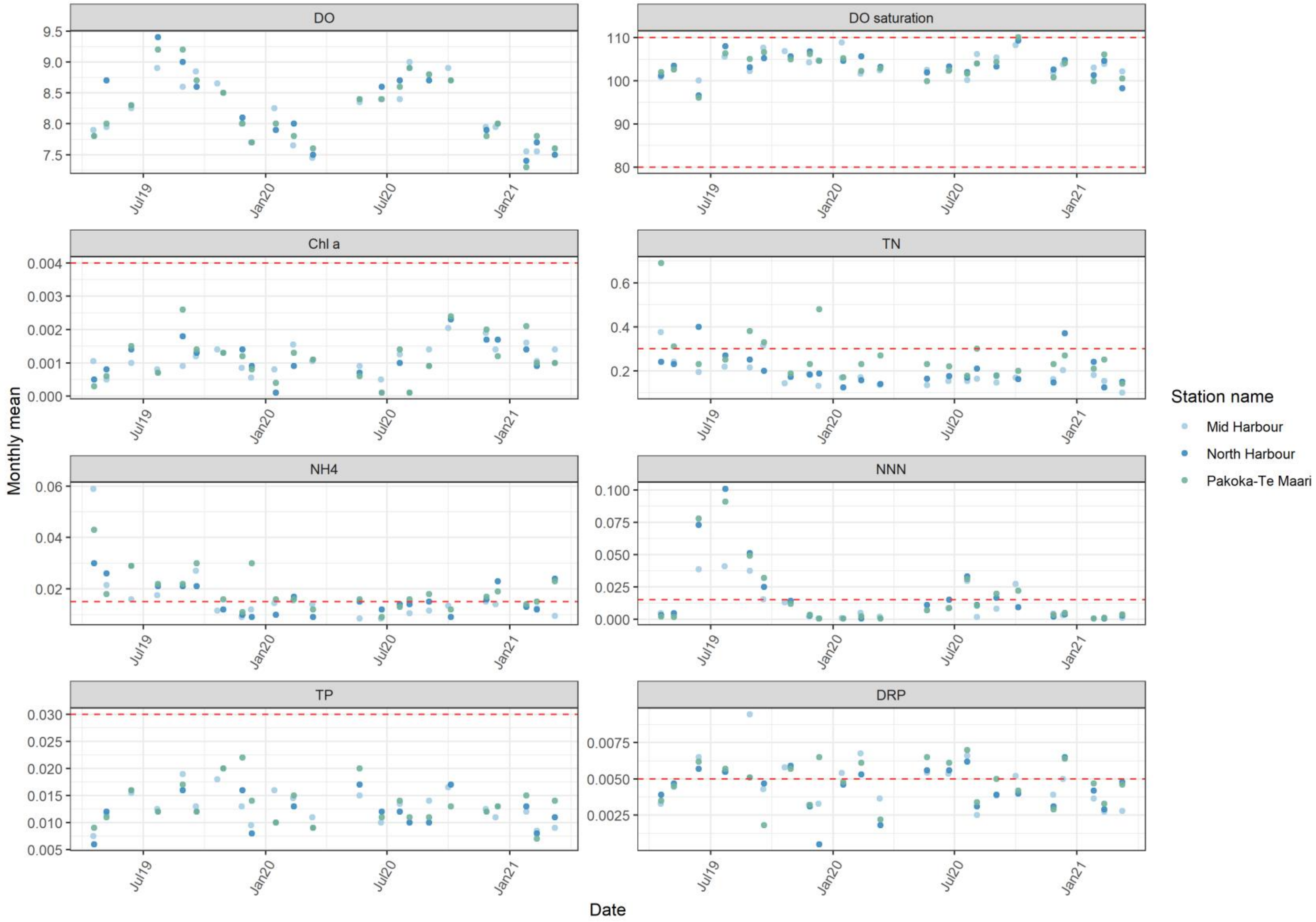

Figure C-11-10. Chemical water quality parameters over time for Aotea Harbour. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

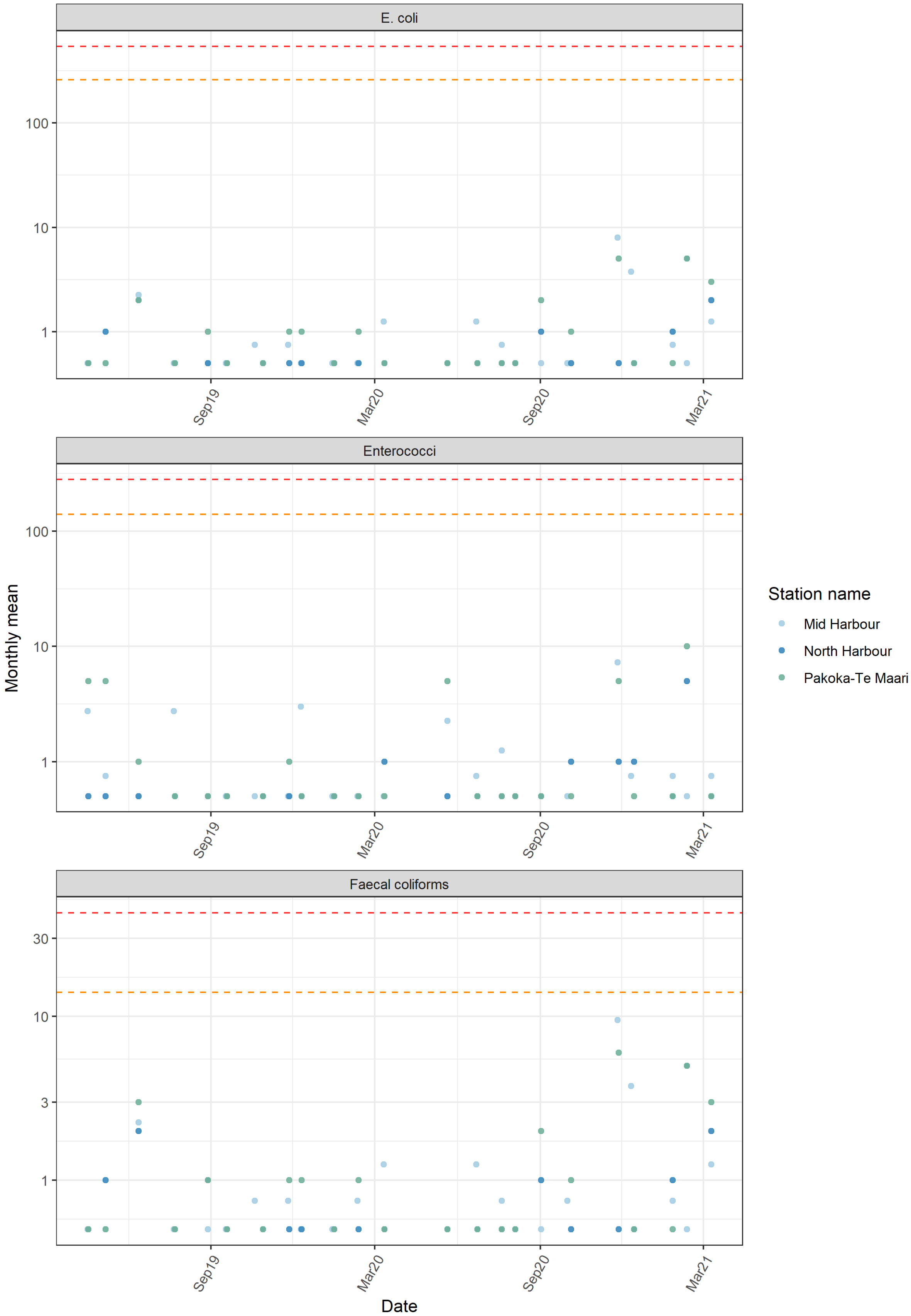

Figure C-11-11. Microbiological water quality parameters over time for Aotea Harbour. Dashed red lines denote red alert and dashed amber lines denote amber levels for recreational water quality.

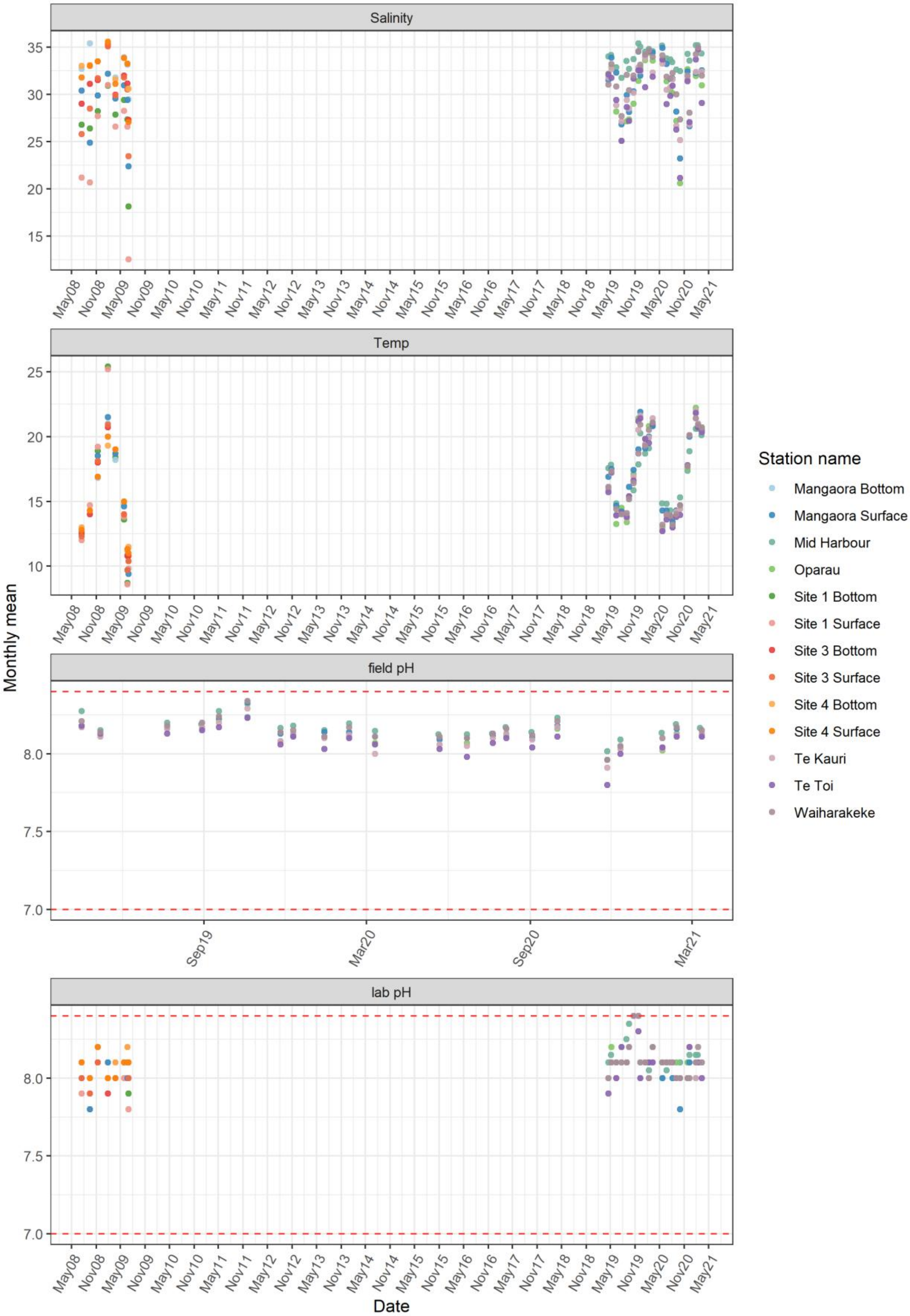

Figure C-11-12.Physical water quality parameters over time for Kawhia Harbour Part 1. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

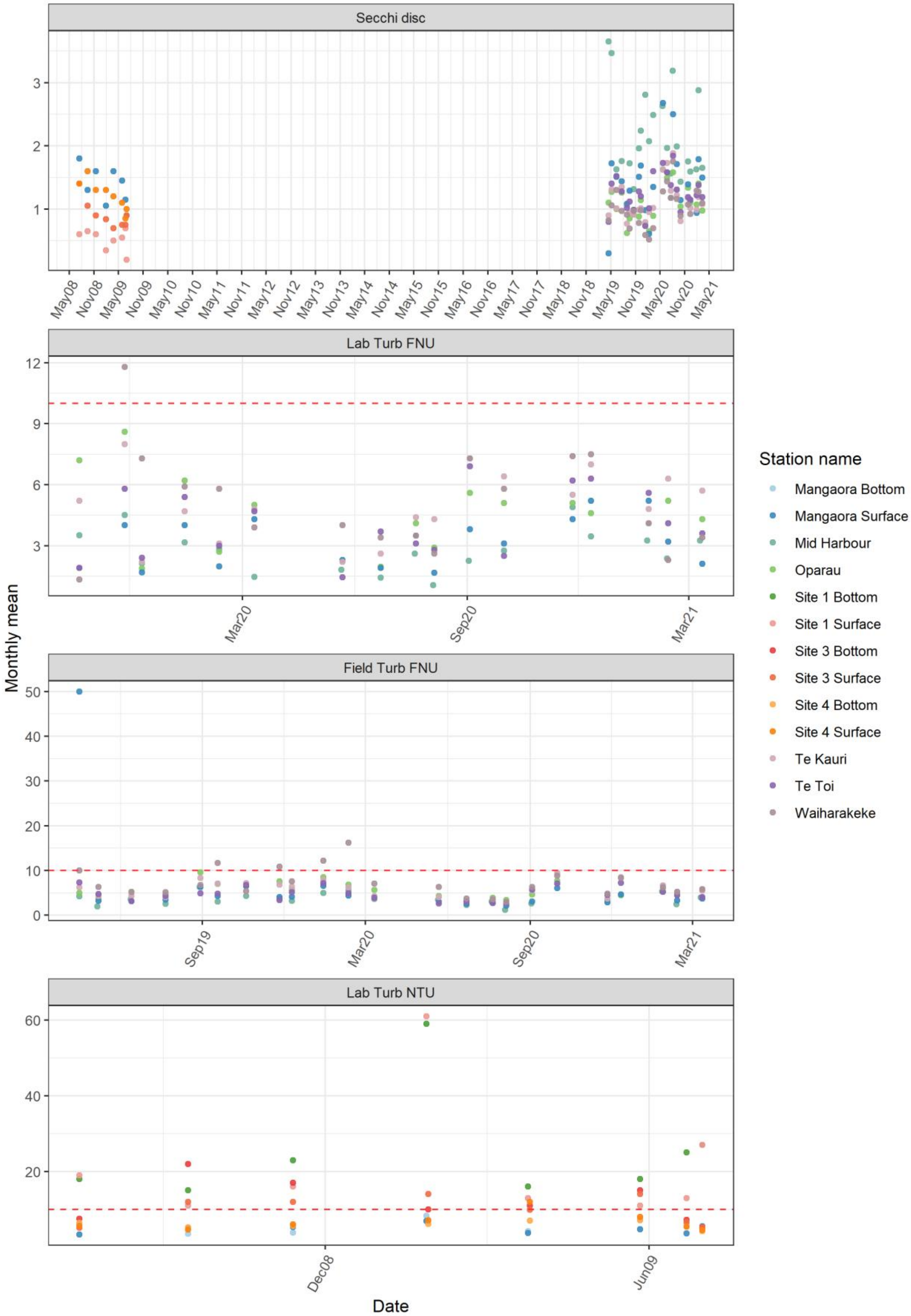

Figure C-11-13. Physical water quality parameters over time for Kawhia Harbour Part 2. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

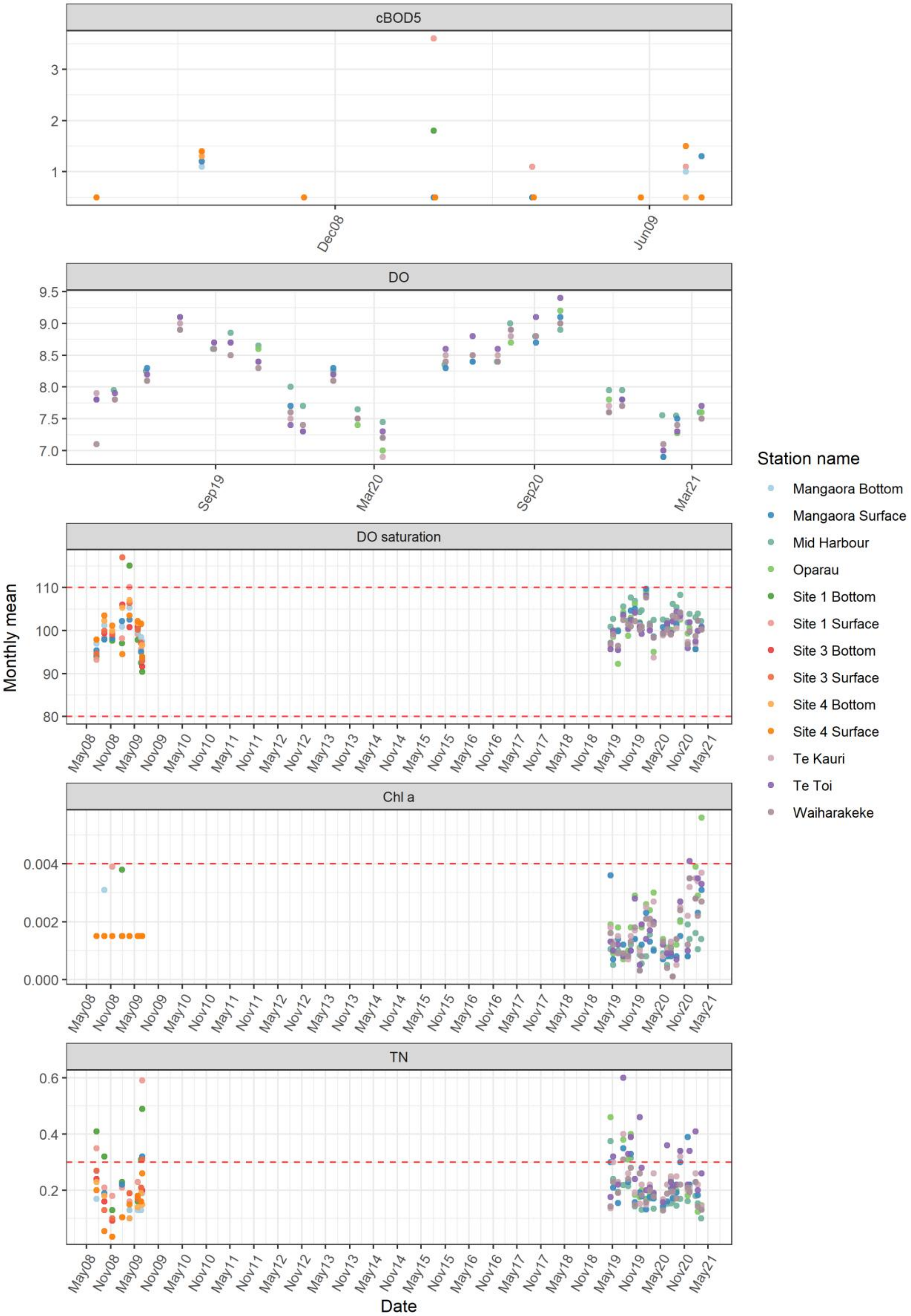

Figure C-11-14. Chemical water quality parameters over time for Kawhia Harbour Part 1. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

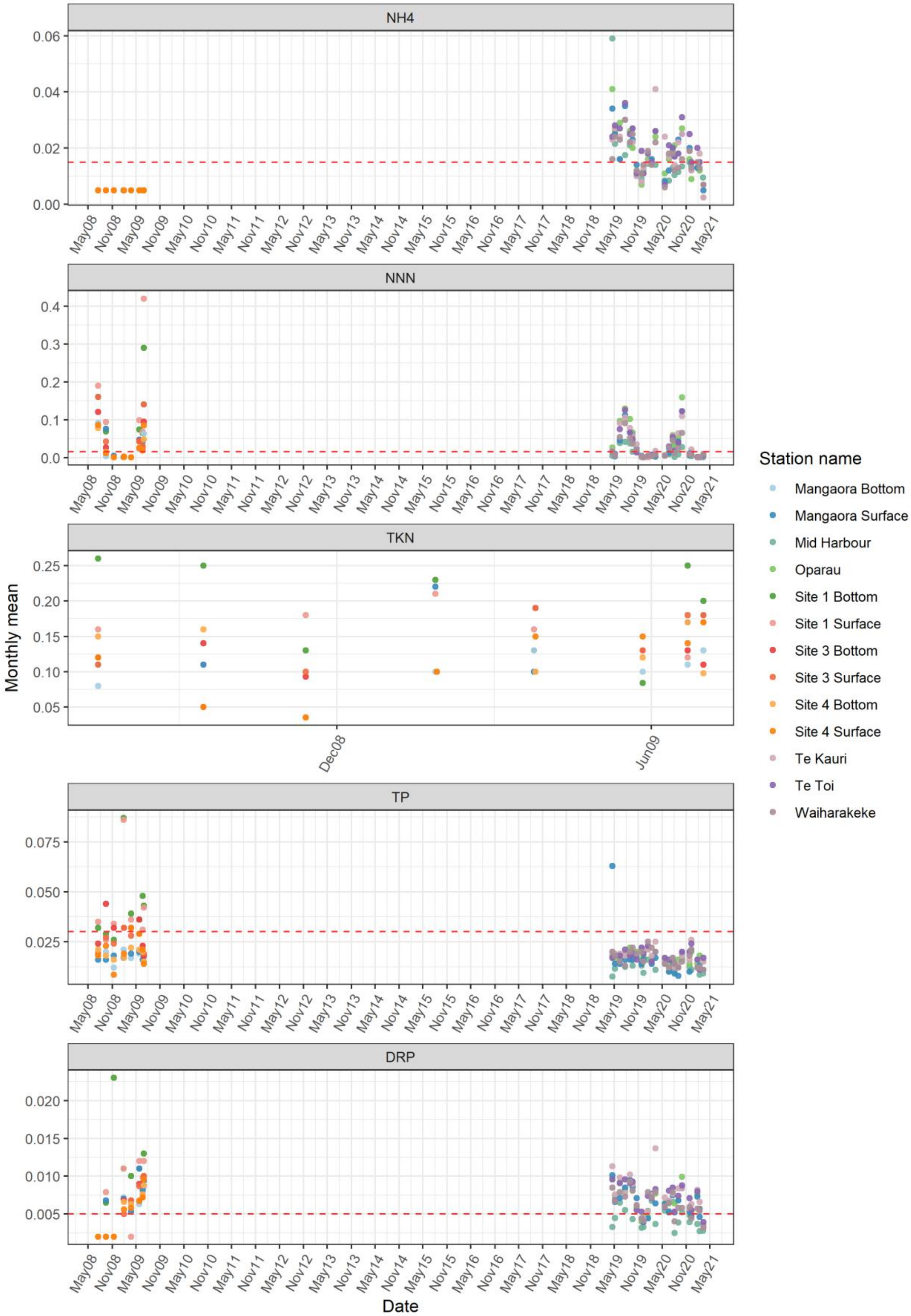

Figure C-11-15. Chemical water quality parameters over time for Kawhia Harbour Part 2. Dashed red lines denote ANZECC (2000) guidelines values. For parameter units refer to table 2-1.

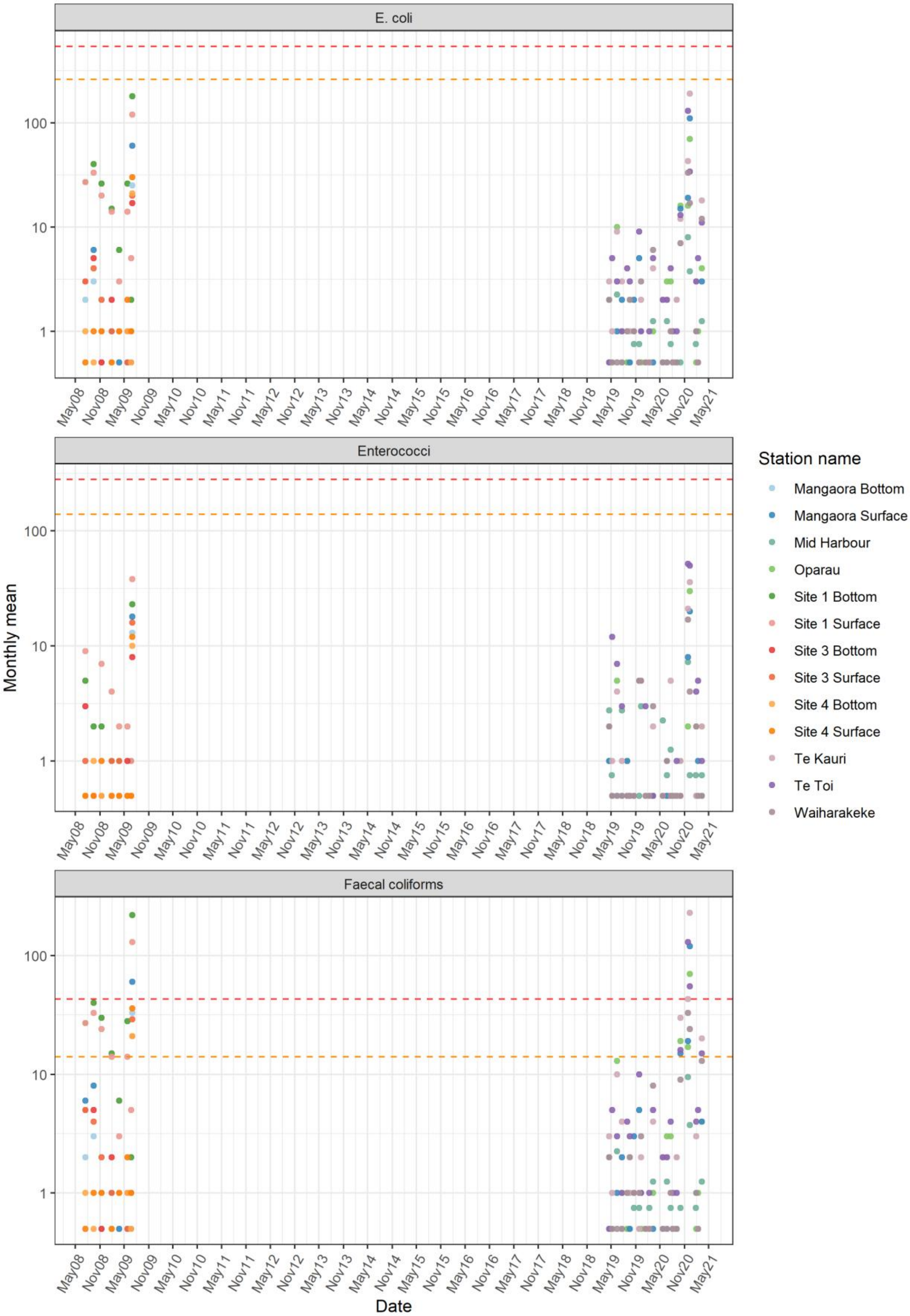

Figure C-11-16. Microbiological water quality parameters over time for Kawhia Harbour. Dashed red lines denote red alert and dashed amber lines denote amber levels for recreational water quality.

12 Appendix D – Recreational water quality data over time

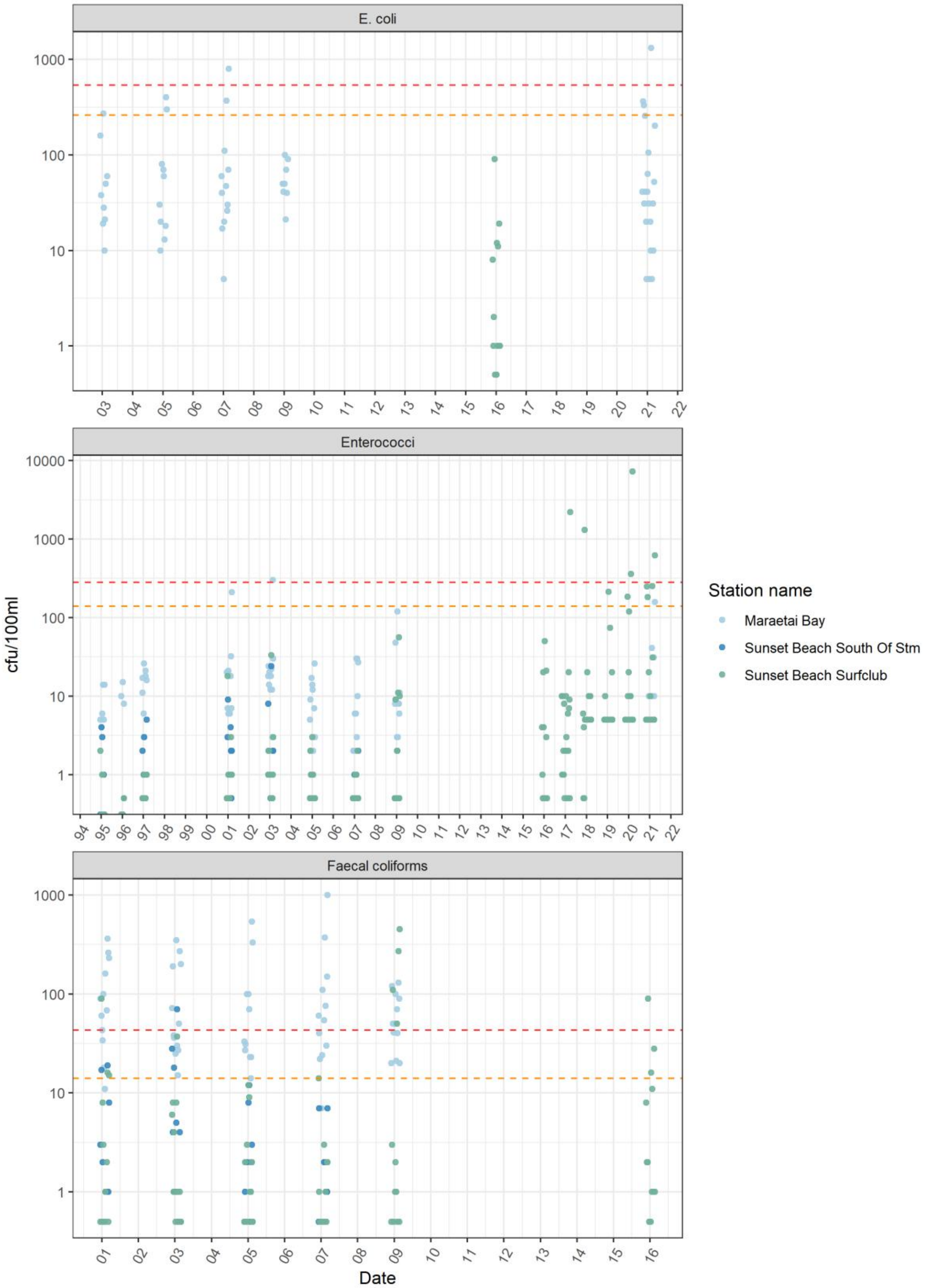

Figure D-12-1. Recreational water quality data over time for Port Waikato. Dashed red lines denote red alert and dashed amber lines denote amber levels for recreational water quality.

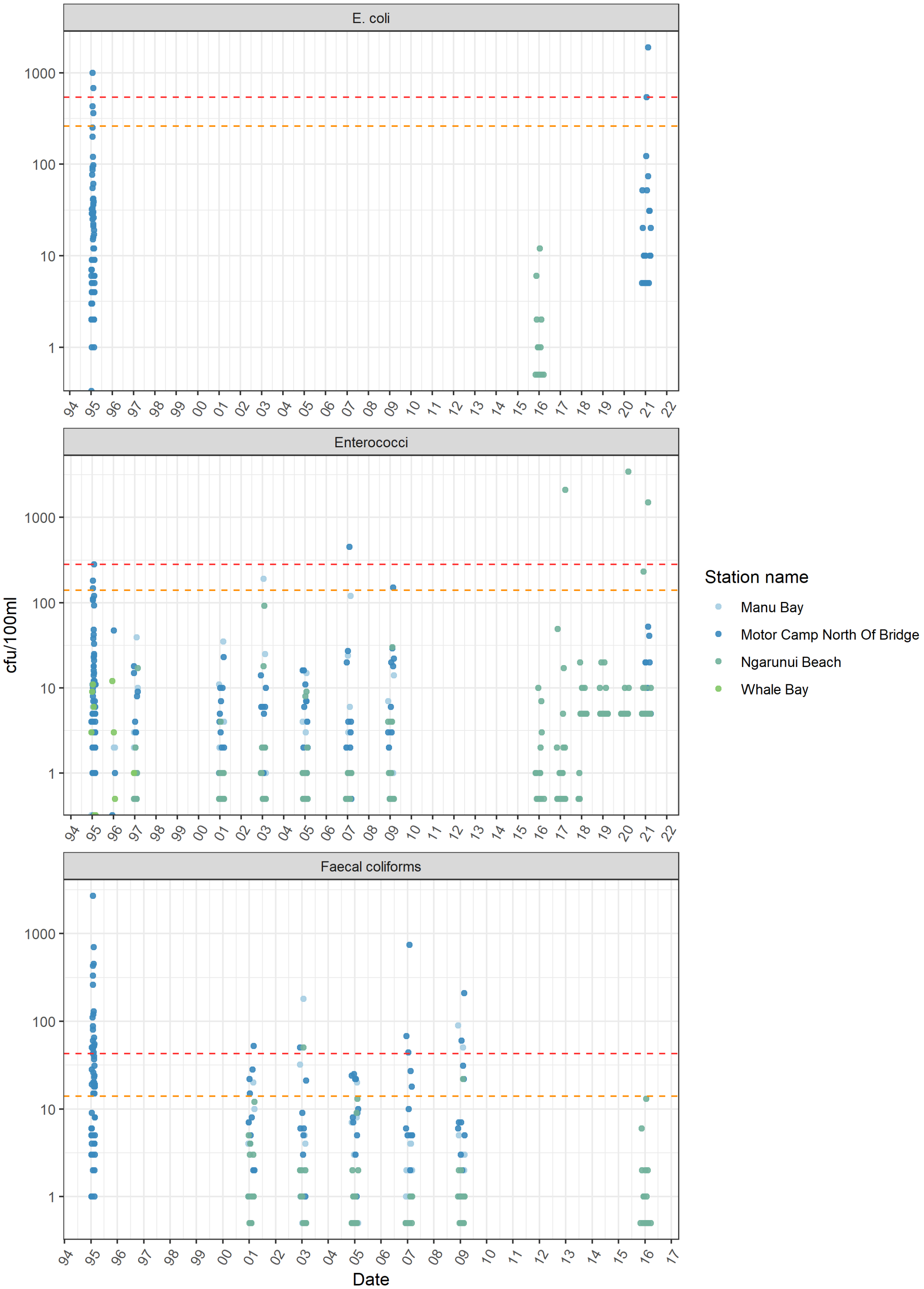

Figure D-12-2. Recreational water quality data over time for Whāingaroa (Raglan) Harbour. Dashed red lines denote red alert and dashed amber lines denote amber levels for recreational water quality.

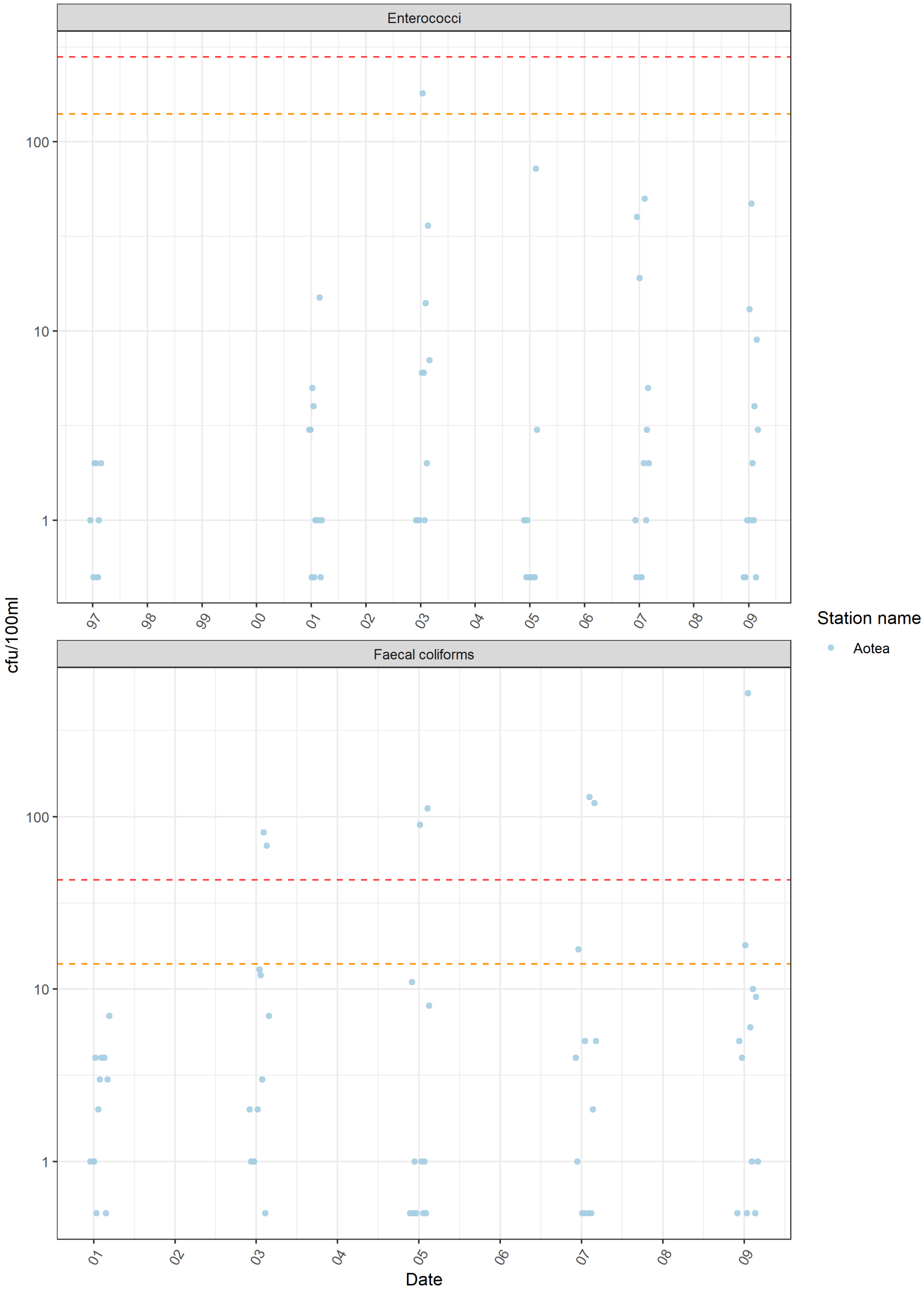

Figure D-12-3. Recreational water quality data over time for Aotea Harbour. Dashed red lines denote red alert and dashed amber lines denote amber levels for recreational water quality.

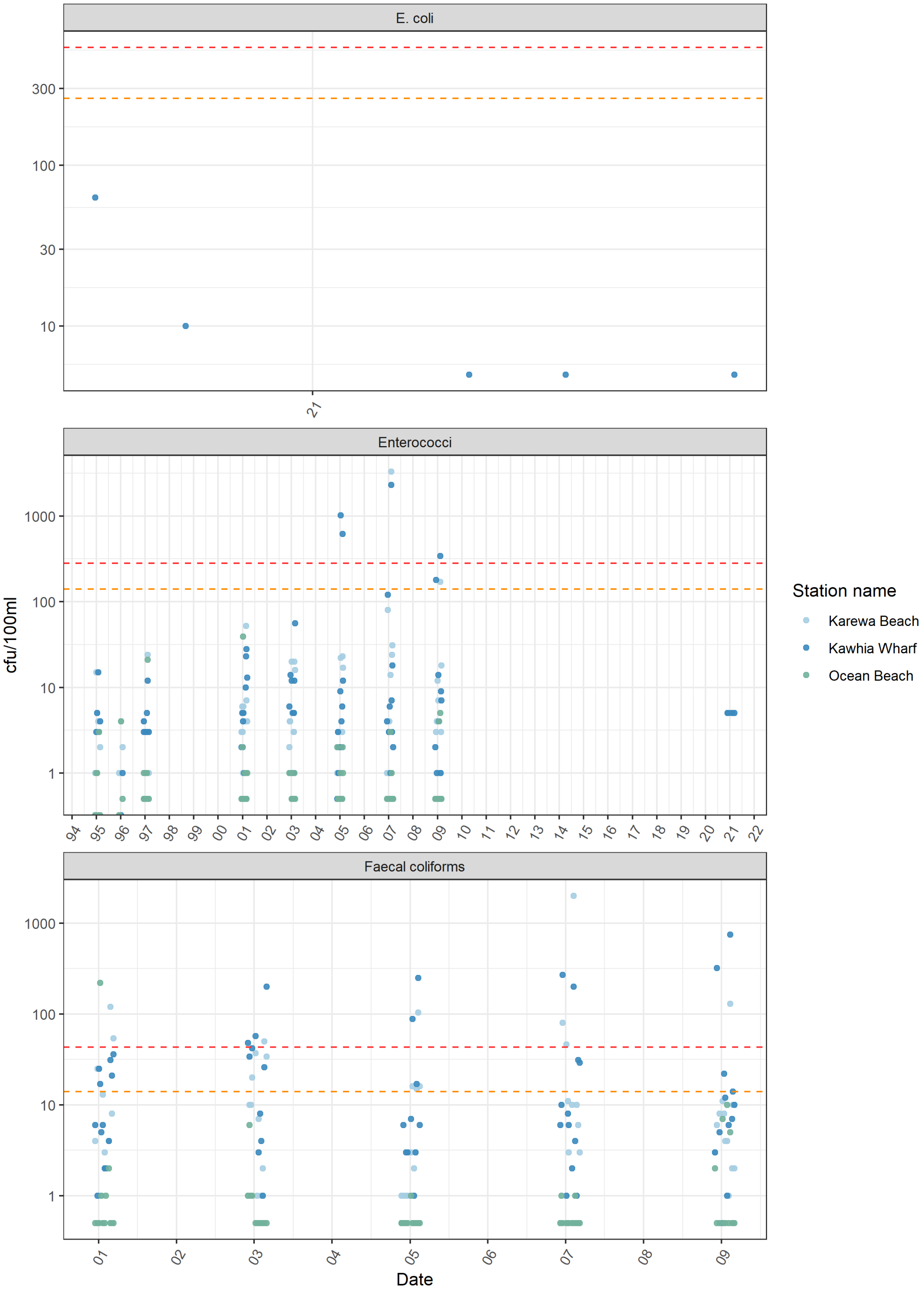

Figure D-12-4. Recreational water quality data over time for Kawhia Harbour. Dashed red lines denote red alert and dashed amber lines denote amber levels for recreational water quality.