Coastal and Estuarine Water Quality State and Trends in Tāmaki Makaurau / Auckland 2010-2019. State of the Environment Reporting

R Ingley

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Technical Report 2021/02

Research and Evaluation Unit | RIMU

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Facing south-west towards Hobsonville Point in the upper Waitematā Harbour, Auckland. Photograph by Natalie Gilligan

Executive summary

This report is one of a series of publications prepared in support of the *State of the environment report* for the Auckland region. Coastal and estuarine water quality is monitored monthly at 31 sites focusing on our three main harbours and two large estuaries. We measure a range of physical and chemical variables or attributes focusing on nutrients and water clarity. These water quality factors can be affected by land use activities, point and diffuse source discharges, and natural seasonal and climatic variation.

Coastal and estuarine water quality is assessed in relation to regional water quality guidelines, and how water quality has changed over the past 10 years in relation to the current state, such as where water quality is good but degrading, poor but improving, or poor and getting worse. The current state was assessed in relation to the regional water quality index based on monthly median values over 2017 to 2019. Trends were assessed for the 10-year period from 2010 to 2019. Trend assessment includes two parts, the assessment of the probability of the direction of the trend, and where there is a high probability of a trend (very likely) we can also estimate the magnitude of that trend.

Half of the monitored sites were found to have good to fair water quality, generally following a spatial gradient where open coastal sites generally have good water quality, while tidal creek sites have poorer water quality.

Previous analysis of coastal and estuarine water quality published in 2018 found that water quality was improving at most sites across the region between 2007 and 2016, driven by improving nutrient concentrations. The analysis in this current report generally agreed with these earlier findings. From 2010 to 2019, over 80 per cent of monitored sites were found to have improving trends in total oxidised nitrogen and chlorophyll α (phytoplankton), and over 50 per cent of monitored sites had improving trends in dissolved reactive phosphorus and water clarity (turbidity). More than 70 per cent of sites were found to have very likely decreasing dissolved oxygen saturation. There were clear spatial differences across the region with a high proportion of degrading trends within the Waitematā Harbour for ammoniacal nitrogen, dissolved reactive phosphorus and turbidity.

In some instances, the rate of improvement was negligible, however where water quality is found to be improving, we can assume that water quality is at least being maintained in the current state. The greatest rates of improvement in nutrient concentrations were found at sites with the poorest water quality in the northern Manukau Harbour. However, concentrations remain high relative to regional reference guidelines and this is reflected in more variable responses in chlorophyll α (phytoplankton), and dissolved oxygen. Reducing sedimentation is a primary focus of the Kaipara Moana Remediation programme that has recently received significant government investment. Water clarity (turbidity) was generally found to be good and improving within the southern Kaipara Harbour.

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1.0 Introduction

The marine environment in the Auckland region encompasses two oceans, three major harbours and numerous estuaries that collectively, include 75 per cent of the total Auckland region. Within these are a wide variety of marine habitats which support a diverse range of plants and animals, including seaweeds, invertebrates, mangroves, seagrass, shellfish, marine mammals, fish, and sea birds.

The aesthetics, use and health of coastal waters are influenced by the quality of surface water that runs from the land through streams, rivers, overland flow paths and stormwater, and point source discharges directly to the coast, and activities in the coastal environment. Land use both inside and outside of the Auckland region also impacts coastal water quality, particularly in the Hauraki Gulf, and Kaipara Harbour. Water quality is also influenced by natural seasonal and decadal variation as well as climatic changes.

Auckland Council's coastal and estuarine water quality monitoring programme focuses on nutrient and water clarity parameters. Other contaminants associated with urban land use and stormwater contamination, such as metals, are monitored in Auckland Council's river water quality, and estuarine sediment and ecology monitoring programmes (see section 1.2) and are not assessed here. Microbiological contamination of beaches and recreational water quality are monitored through the Safeswim programme, www.safeswim.org.nz

This report provides technical information describing how coastal and estuarine water quality has changed over the past 10 years (2010 to 2019) across Auckland. This forms part of a series of technical reports collectively addressing river, groundwater, lake, and coastal water quality, and ecological condition over the same time frames. This information can be added to matauranga Māori knowledge to support Māori in their role as kaitiaki to protect and enhance te mauri o te wai (the life supporting capacity of water).

The current state of coastal and estuarine water quality (based on 2017 to 2019) is described in the 2019 Coastal and Estuarine Water Quality Annual Data Report (Ingley, 2020 TR2020/016) but is also summarised here to provide further context on trend directions, i.e. where water quality is good but declining, or poor but improving. This is part of the feedback loop necessary to assess whether Auckland Council's management strategies are effective in sustaining ecosystem functions, and to identify opportunities for improved future sustainable use of our valued coastal environment.

1.1 Purpose and objectives

Auckland Council's coastal and estuarine water quality monitoring programme supports the following objectives:

- Meet council's obligations under section 35 of the Resource Management Act 1991 (as amended) to monitor and report on the state of the environment.
- Provide evidence of how the council is maintaining and enhancing the quality of the region's coastal environment (Local Government Act 2002). Specifically, evidence for the Environment and Cultural Heritage component of the Auckland Plan 2050. A key direction for the region is to manage the effects of growth and development on our natural environment.
- Help inform the effectiveness of policy initiatives and strategies and operational delivery.
- Assist with the identification of large scale and/or cumulative impacts of contaminants associated with varying land uses and disturbance regimes and links to particular activities.
- Provide baseline, regionally specific data to underpin sustainable management through resource consenting and associated compliance monitoring for coastal and estuarine environments.
- Continuously increase the knowledge base for Aucklanders and promote awareness of regional coastal and estuarine water quality issues and their subsequent management.

1.2 Supporting reports

Previous reports can be obtained from Auckland Council's Knowledge Auckland website, www.knowledgeauckland.org.nz.

Supplementary data files of the trend analysis outputs presented in this report are also available on Knowledge Auckland. For further enquiries and data supply, email environmentaldata@aucklandcouncil.govt.nz

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

This report is one of a series of publications prepared in support of the State of the Environment report for Tāmaki Makaurau / Auckland. Reports on aspects of freshwater and coastal water quality and ecology include:

- *Auckland river water quality: annual reporting and National Policy Statement for Freshwater Management current state assessment, 2019* – TR2021/11
- *Coastal and estuarine water quality 2019 annual report* – TR2020/016
- *Groundwater quality state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/03
- *Lake water quality state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/04
- *Marine ecology state and trends in Tāmaki Makaurau / Auckland to 2019. State of the environment reporting* – TR2021/09
- *Marine sediment contaminant state and trends in Tāmaki Makaurau / Auckland 2004-2019. State of the environment reporting* – TR2021/10
- *Rainfall, river flow, and groundwater level state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/06
- *River ecology state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/05
- *River water quality state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/07

2.0 Methods

2.1 Programme design

Auckland’s coastal water quality monitoring programme was primarily designed for detecting long-term changes in water quality across the region. The network aims to be regionally representative by including a range of exposure levels, contributing catchment land uses, and covers our three main harbours and large estuaries (see Table 2-1, Figure 2-1, and Figure 2-2). This enables Auckland Council to present a region-wide perspective on water quality and infer the likely water quality of other estuaries and coastal waters in the region that are not monitored.

Auckland’s coastal and estuarine water quality monitoring programme currently includes 31 sites. The programme has evolved over time, with sites added or removed according to varying regional management priorities.

Auckland Council’s Research and Evaluation Unit (RIMU) collects coastal and estuarine water quality samples monthly from surface waters. Sites in the inner Hauraki Gulf, Kaipara Harbour, Tāmaki Strait and Manukau Harbour are collected by helicopter, sites in the upper and central Waitematā Harbour are collected by boat and Tāmaki Estuary sites are collected from land.

Natural temporal variation in water quality is avoided as much as possible by maintaining a consistent sampling time relative to the tidal cycle. Collection of water samples by helicopter enables sites spread over a broad area to be sampled within a narrow time window created by tidal constraints, making comparison between sites more robust.

Samples are collected approximately 10 minutes to 2.5 hours after high tide for the Kaipara Harbour, Waitematā Harbour and Hauraki Gulf sites and 2.5 to 4 hours after high tide for the Manukau Harbour. Over the past 10 years, 90 per cent of samples were taken between 9:00 am and 2:00 pm. Maintaining a consistent sample time improves the power of long-term trend detection. Due to the logistical sequencing of monitoring sites, the Kaipara Harbour is consistently sampled earlier in the day, and the Manukau Harbour later in the day. The time at which a sample is collected may affect some parameters, such as temperature and dissolved oxygen.

Physical parameters (such as temperature, salinity, dissolved oxygen) are measured in the field, and samples are taken for further laboratory analysis of nutrients, metals, sediments, and other chemical properties of water.

Further details on data collection and management are provided in the annual data reports (see Ingley, 2020). A summary of laboratory analytical methods for each parameter is provided in Appendix A.

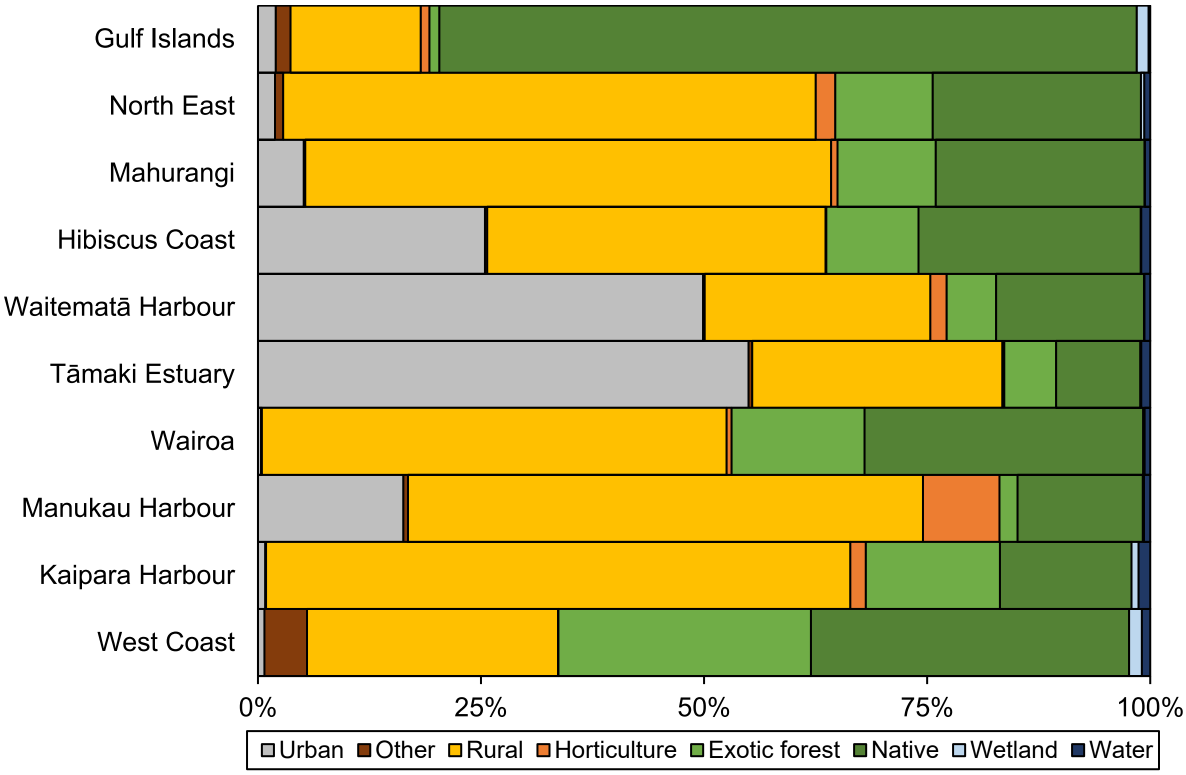


Figure 2-1: Summary of broad land cover classes (based on LCDB 5.0 see Appendix B) within each watershed.

Table 2-1: Current coastal and estuarine water quality sites grouped by location.

	Site	Easting	Northing	Year initiated	Exposure Level	Dominant adjacent land
East Coast	Goat Island	1761787	5984944	1993	Open Coast	Rural*
East Coast	Ti Point	1760058	5978931	1991	Open Coast	Rural*
East Coast	Mahurangi Heads	1754225	5960548	1993	Estuary	Rural*
East Coast	Dawsons Creek	1753782	5966175	1993	Estuary	Rural
East Coast	Orewa	1753660	5949837	1991	Open Coast	Urban *
East Coast	Browns Bay	1757497	5935771	1991	Open Coast	Urban *
Kaipara Harbour	Shelly Beach	1723871	5952426	1991	Estuary	Rural*
Kaipara Harbour	Kaipara River	1725504	5947101	2009	Estuary	Rural
Kaipara Harbour	Makarau Estuary	1727396	5953730	2009	Estuary	Rural
Kaipara Harbour	Kaipara Heads	1708534	5970421	2009	Estuary	Rural*
Kaipara Harbour	Tauhoa Channel	1717821	5970063	2009	Estuary	Rural*
Kaipara Harbour	Hoteo River	1726691	5967495	2009	Estuary	Rural
Waitematā Harbour	Chelsea	1753721	5922776	1991	Estuary	Urban*
Waitematā Harbour	Whau Creek	1748588	5920563	1991	Estuary	Urban
Waitematā Harbour	Henderson Creek	1746715	5923855	1991	Estuary	Urban
Waitematā Harbour	Hobsonville	1749453	5927353	1993	Estuary	Urban
Waitematā Harbour	Paremoremo Creek	1745717	5930201	1993	Tidal Creek	Lifestyle/Native
Waitematā Harbour	Rangitopuni Creek	1742734	5930626	1993	Tidal Creek	Rural
Waitematā Harbour	Brighams Creek	1742829	5928227	1996	Tidal Creek	Urban
Waitematā Harbour	Lucas Creek	1749892	5932176	1993	Tidal Creek	Urban
Tāmaki Estuary	Tāmaki	1769303	5916944	1992	Estuary	Urban*
Tāmaki Estuary	Panmure	1765553	5913693	1992	Estuary	Urban
Tāmaki Strait	Wairoa River	1786561	5910769	2009	Estuary	Rural
Manukau Harbour	Grahams Beach	1749431	5897517	1987	Estuary	Urban/Rural*
Manukau Harbour	Clarks Beach	1749746	5888100	1987	Estuary	Rural
Manukau Harbour	Waiuku Town Basin	1752923	5879195	2012	Tidal Creek	Rural
Manukau Harbour	Shag Point	1748335	5908549	1987	Estuary	Urban/Rural
Manukau Harbour	Puketutu Point	1753938	5908791	1987	Estuary	N/A
Manukau Harbour	Weymouth	1764080	5897952	1987	Estuary	Urban/Rural
Manukau Harbour	Māngere Bridge	1758048	5910932	1987	Estuary	Urban
Manukau Harbour	Manukau Heads	1741520	5900335	2009	Estuary	Urban/Rural*

* Open coast and main harbour body/harbour mouth sites are less subject to direct influences from adjacent land use

Figure 2-2: Location of the 31 coastal and estuarine water quality monitoring sites.

(Area shaded in red shows the extent of urban area in 2019 (Hoffman, 2019)

2.2 Coastal water quality state

Unlike river water quality, there are no widely agreed upon water quality thresholds or guidelines for coastal and estuarine waters in New Zealand. The Australian and New Zealand Environment and Conservation Council (ANZ) published guidelines in 2000 for fresh and marine water quality, however further work is needed to refine guidelines for New Zealand estuarine and marine systems and the default values for south east Australian estuaries were recommended as interim reference values (ANZECC 2000).

As such, the current state of water quality is based on the Auckland regional water quality index (WQI) assessment of the monthly median values over 2017 to 2019 compared to Auckland regional reference values, ANZ guidelines, or guidelines developed for tidal creek environments by Northland Regional Council (Griffiths, 2016) (Table 2-2). The regional water quality index uses different guidelines for tidal creeks, estuaries, and open coastal environments reflecting the natural variability in water quality over the spatial gradient in freshwater inputs and degree of mixing and flushing.

The water quality index provides an overall score based on the frequency, and magnitude of exceedances of regional water quality guidelines, and how many of the different parameters were exceeded (Table 2-2 and Table 2-3). To enable comparison of the current state of individual parameters to trends in those parameters this analysis focuses on the frequency of exceedances. The frequency was grouped into five categories: none, low (1-3 exceedances), moderate (4-6 exceedances), high (7-9 exceedances), and very high (10-12 exceedances). The maximum frequency being 12 months within the year, indicating values are elevated all the time. Further details on methods for the assessment of water quality state are provided in the Coastal and Estuarine Water Quality 2019 Annual Data Report (Ingley, 2020).

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

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

[1] Based on ANZ default guidelines, not 80th percentile of reference sites from Auckland region.
[2] Based on the 90th percentile of estuary reference sites from the Auckland region
[3] Based on Northland Regional Council Tidal Creek Guidelines (Griffiths, 2016)
[4] Based on ANZ default guideline for ammonium (NH4+) not ammoniacal nitrogen (NH3+NH4). At the average pH of seawater, approximately 95% of ammoniacal nitrogen is in the ammonium form.

Table 2-3: Water quality index categories and scoring ranges used by Auckland Council (CCME, 2001).

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

2.3 Trend analysis

As a first step, data was assessed for seasonality using the Kruskal-Wallis test which determined the type of test used for subsequent trend analysis. Seasonal tests compare observations within each month over time, while non seasonal tests compare all observations over time. Data were also inspected for minimum data requirements, and changes in detection limits over time prior to analysis (see sections 2.3.1 and 2.3.2).

Monotonic trends across sites were analysed by assessing the direction of a trend, i.e. how likely is it that parameter is increasing or decreasing? The confidence in the trend direction is calculated using the Kendall (or seasonal Mann-Kendall) test based on the probability that the trend was decreasing. The calculated probability is interpreted based on the categories used by the Intergovernmental Panel on Climate Change and further aggregated to five categories for simplicity as per LAWA (Cawthron Institute 2019; Snelder and Fraser 2018) (see Table 2-4).

For most parameters, a decreasing trend is interpreted as an improvement in water quality, and an increasing trend is a degradation in water quality. For physical parameters such as temperature and salinity we have referred to the likelihood of the direction of the trend as increasing or decreasing and have not assigned this as either improving or degrading. A trend is classified as indeterminate when there is insufficient evidence to determine if the data is trending in a particular direction.

Table 2-4: Trend confidence category levels used to determine the direction of trends.

Trend categories		Probability (%)
Very likely improving	Very likely decreasing	90-100
Likely improving	Likely decreasing	67-90
Indeterminate	Indeterminate	33-67
Likely degrading	Likely increasing	10-33
Very likely degrading	Very likely increasing	0-10

Where water quality is found to be degrading further assessment is critical to understand what actions may be necessary to improve water quality. This includes assessment of the likelihood of the trend, the magnitude of the trend, the risk of adverse ecological outcomes (in relation to the known current state), and consideration of whether the current state is a reflection of naturally occurring processes.

An overarching assumption of the first step of the trend analysis is that there are always differences between observations (McBride, 2019).

The magnitude of the trend is characterised by the slope of the trend line using the Sen slope estimator (SSE) (or the seasonal version (SSSE)). The SSE is the median of all possible inter-observation slopes. The 90 per cent confidence intervals of this median estimate are also calculated.

While a trend may be very likely improving or degrading, the smaller the Sen slope, or rate of change, the longer it would take to be reflected in assessments of the current state assuming a linear rate of change. Trend magnitude is further considered in this report relative to the limit of precision (i.e. the measurement resolution[1]) following the approach in Fraser and Snelder (2018). Trend magnitude can only be estimated *with confidence* for 'very likely' trends.

Trend magnitudes were discussed in previous Auckland Council water quality trend reports in terms of the relativised Sen slope or per cent change per annum relative to the median concentration over 10 years. This per cent annual change approach is useful for comparing between different parameters as it standardises the rate of change to the same units. However, this approach can mask interpretation of trends if there are large differences in median values of a parameter between sites. For example, where sites have high concentrations of contaminants (poor water quality), concentrations may be changing by a large amount but when divided by the median

[1] Where the measurement resolution varied over time (such as due to changes in detection limits), the most common value was used.

value, the trend magnitude appears small. Conversely, where a site has a very low median concentration (such as at reference sites), a small magnitude of change would be amplified to a high percentage per annum.

Analyses were undertaken using purpose-written script designed for undertaking the trend analysis as described in Larned et al. (2018) in the R statistical package (R Core Team, 2020). The script was obtained from Land Water People (LWP-Trends library Version 1901: LWPTrends_v1901.r.) and is readily available at https://landwaterpeople.co.nz/pdf-reports/.

2.3.1 Data requirements and time periods for analyses

Monotonic trends were assessed for the 10-year period from January 2010 to December 2019. Several sites within the Kaipara Harbour were added to the programme in 2009 and therefore the ten-year period from 2010 to 2019 provides the best regional coverage over a standardised time frame. A minimum of 90 per cent of samples across all site per parameter per year (or season) combinations were required for analysis. For example, over a 10-year period of monthly monitoring, this is equivalent to at least 10 samples per year in at least nine of the 10 years. There were less than 90 per cent of samples available for the two sites at Tāmaki Estuary for chlorophyll α and ammoniacal nitrogen and the threshold was lowered to 80 per cent in these specific instances rather than omitting these sites from trend analysis. Interim trends were also calculated for the Waiuku Channel at Town Basin site where there was a minimum of 90 per cent of samples across the eight years available. Any sites or parameters that did not meet these data requirements were not analysed and therefore no trends were reported.

The number and type of water quality parameters measured has varied since the programme's inception as new technology has become more affordable, instrument sensitivity has improved, and the programme objectives modified.

Some discrepancies have been observed in long-term trends particularly for ammoniacal nitrogen, where a step increase was observed coinciding with a change in laboratory service provider (July 2017), and total nitrogen, where a step increase was observed dating to September 2016 coinciding with laboratory analytical changes from automated, to flow injection analysis[2].

[2] Note that ammoniacal N, total oxidised nitrogen, and nitrite analyses also changed from automated to flow injection analyses in August 2016 however no clear step changes were observed and these results are assumed to be comparable over time.

2.3.2 Detection limits and censored values

Values that are less than the detection limit for a parameter are referred to as 'left censored' values. For trend analysis, censored values are replaced with a value half the detection limit. This ensures that any measured value that is equal to the detection limit, is treated as being larger than a value that is less than the detection limit, i.e. a measured concentration of 0.2 mg/L is larger than a value recorded as <0.2 mg/L, and that the difference between two censored values is treated as zero.

The evaluation of the confidence in trend direction is highly reliable, even with a high percentage of censored values. However, the estimation of the magnitude of the trend (Sen slope) decreases in reliability as the proportion of censored values increases. The LWP script specifically identifies where the trend slope was calculated from data with censored observations. In these instances, the magnitude of the trend is considered to be imprecise and is not reported here. Specifically, trend magnitudes were excluded where the Sen slope was based on two censored values or tied non-censored values. Where the Sen slope was influenced by one censored value these trend magnitudes were retained. Therefore, it is not necessary to apply an arbitrary limit of no more than 15 per cent censored values within the data set (Larned et al. 2018).

The face value of all detection limits was used for this analysis where there were differences in detection limits over time, rather than replacing all lower detection limit values with the highest detection limit. This ensures that observations obtained with more sensitive laboratory analytical measurements are not lost under an 'umbrella' of water quality observations with poor resolution. However, this can induce 'improving' trends where observations are lower than were able to be recorded previously, or alternatively induce 'degrading' trends where observations were historically lower than current detection limits. Where there is a risk of induced trends influencing results reported here, they have been clearly identified.

Between July 2017 and June 2018, a higher detection limit was applied for chlorophyll α which resulted in a high percentage of values below this detection limit across all sites. These censored values were omitted from trend analysis. From July 2018, analytical methodology changed from spectroscopy to fluorometry[3] and consequently lower detection limits were obtained. This may induce 'improving' trends at low concentrations. Lower detection limits were also obtained for total oxidised nitrogen, and dissolved reactive phosphorus following a change in laboratory service provider (July 2017) (Appendix A). This may induce 'improving' trends at low concentrations.

[3] Recommended by the coastal discrete water quality national environmental monitoring standards.

3.0 Results and Discussion

3.1 Overview of water quality current state (2017-2019)

A summary of water quality state compared to the regional coastal water quality index is outlined here. Refer to the Coastal and Estuarine Water Quality 2019 Annual Data report (Ingley, 2020) for further details on current water quality state.

The regional water quality index is based on six key parameters, which also align with the key parameters regulated under the National Policy Statement for Freshwater Management 2020 (NPS-FM) (New Zealand Government, 2020). However, it is important to note that the water quality index guidelines for total oxidised nitrogen and ammoniacal nitrogen are based on potential nutrient enrichment relative to reference conditions and are not in relation to toxicity effects unlike the NPS-FM nitrate and ammonia attributes.

Half of the monitored sites were found to have good to fair water quality, generally following a spatial gradient from greater to lesser freshwater influence (Figure 3-1). Open coastal sites generally have good water quality, while tidal creek sites have poorer water quality. Sites within the Manukau Harbour also tended to have poor water quality.

To enable further analysis of individual parameters, the frequency attribute of the water quality index scoring presented in the annual report (Ingley, 2020) has been extracted and summarised here (Figure 3-2). A low frequency of guideline exceedances suggests that the parameter was found to have monthly median concentrations higher than regional reference values occasionally, such as a seasonal peak. A moderate frequency of guideline exceedances suggests that parameter was found to have monthly median concentrations higher than regional reference values for more than one season (more than three months). High and very high frequencies of exceedances reflect values that are elevated more than half of the time, to most or all the time.

Regionally, 19 per cent of monitored sites have elevated total oxidised nitrogen concentrations (high to very high frequency above guidelines), and 16 per cent have elevated dissolved reactive phosphorus concentrations (Figure 3-2). Nearly 50 per cent of sites have elevated ammoniacal nitrogen concentrations, however a potential step increase in ammoniacal nitrogen was previously noted as a potential analytical factor influencing the assessment of current state (Ingley, 2019) and further analysis of this is undertaken in section 3.4.5.

The majority of our monitored estuaries and harbours are shallow intertidally dominated environments where phytoplankton biomass would not be expected to be retained and accumulate to high concentrations (Plew et al. 2020), which is reflected by only six per cent of sites with elevated levels of chlorophyll α relative to regional guidelines. Dissolved oxygen is also an indicator of eutrophic stress in coastal environments and over 20 per cent of sites were found to experience undesirable levels of oxygen saturation at least occasionally (higher or lower than guidelines).

Elevated turbidity (poor water clarity), and high suspended sediment levels are commonly observed when monitoring coincides with higher river flows in the upstream catchments (Ingley, 2019, 2020). Monitoring is typically undertaken during base flow conditions when sediment sources have not been rapidly mobilised. It is therefore unsurprising that nearly 80 per cent of our monitored sites generally have low turbidity levels or only occasionally exceed guideline values.

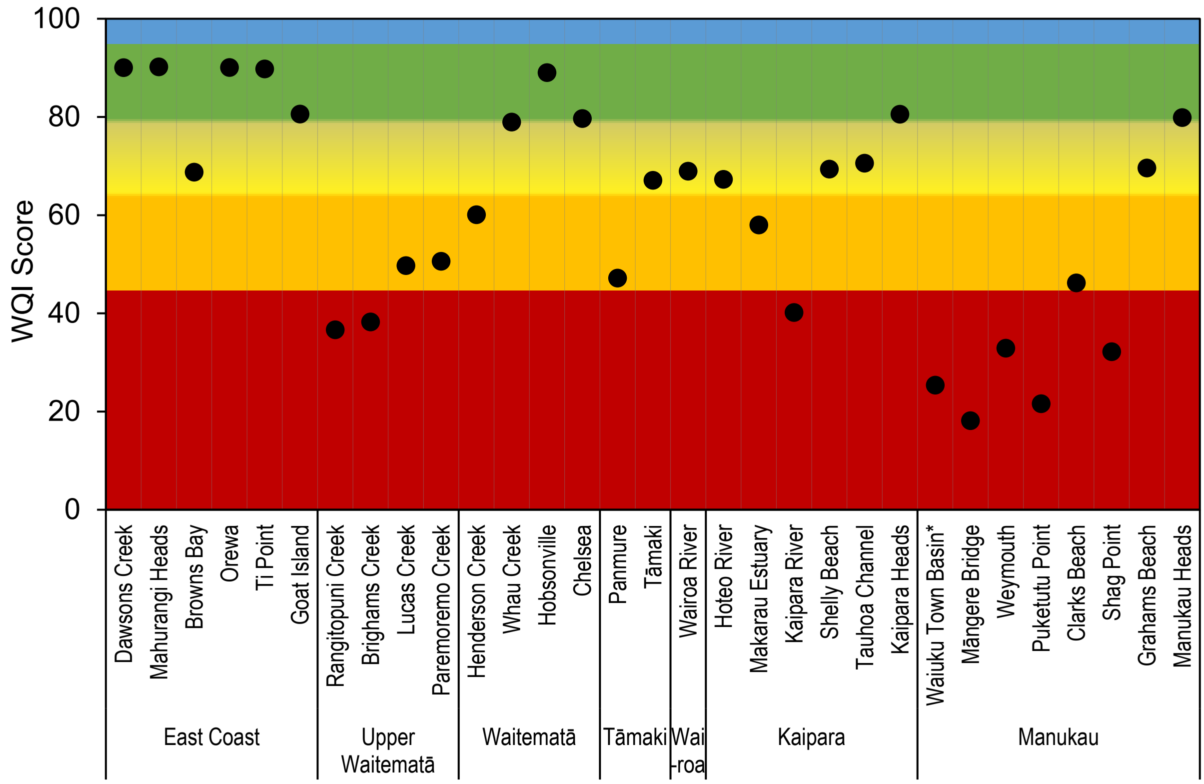
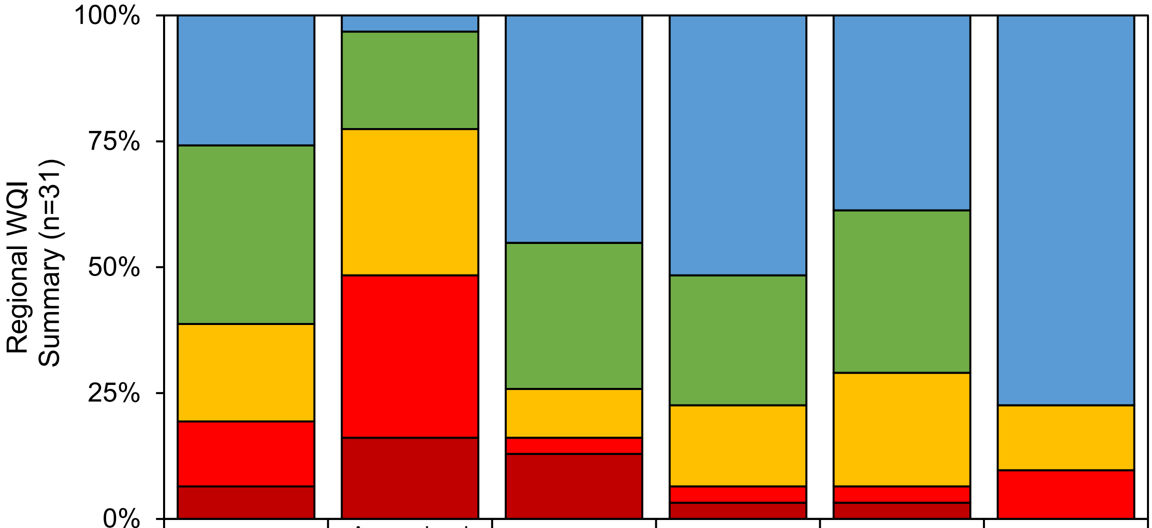


Figure 3-1: Summary of the 2017-2019 overall coastal water quality index score per site as an assessment of current state.

Sites are ordered by increasing salinity within each area.

Coloured bands indicate the overall class from excellent (blue) to poor (red).



	TON	Ammoniacal N	DRP	Turbidity	Chlorophyll α	DO%
None	26%	3%	45%	52%	39%	77%
Low	35%	19%	29%	26%	32%	
Moderate	19%	29%	10%	16%	23%	
High	13%	32%	3%	3%	3%	
Very High	6%	16%	13%	3%	3%	
High DO						13%
Low DO						10%

Figure 3-2: Summary of the proportion of all sites within bands of frequency of exceedances of regional coastal water quality index guidelines (2017-2019).
'None' indicates no values above guidelines, through to very high which indicates values are above guidelines most or all of the time. High and Low DO values refer to exceedances of the upper, or lower, dissolved oxygen guidelines not the frequency those exceedances.

3.2 Climate summary 2010 to 2019

New Zealand's climate varies significantly from year to year and over the long-term. This is associated with decadal circulation and climate variations such as the Interdecadal Pacific Oscillation (IPO) and El Niño Southern Oscillation (ENSO). These cycles affect average sea surface temperature, prevailing winds, and rainfall patterns. This drives differences in nutrient and sediment, concentrations through changes to oceanic upwelling of nutrient rich waters, and soil erosion and nutrient leaching.

La Niña events typically bring warmer sea waters, and more rain to the north eastern areas of the North Island, while El Niño events bring cooler waters and drier conditions (Pearce et al. 2017). These cycles typically account for less than 25 per cent of the variance in seasonal rainfall and temperature patterns at most sites in New Zealand (NIWA, n.d.). Large oscillations between El Niño and La Niña cycles occurred within the 10-year period assessed here, with La Niña conditions in 2010-2011, and El Niño events in 2015-2016 and 2019. Separate analysis of mean annual rainfall across Auckland demonstrated that annual rainfall was higher than the 75th percentile of the last 20 years in 2011, and for three consecutive years in 2016 to 2018 (Johnson, 2021). Rainfall was lower than the 25th percentile in 2010, 2014, and 2019 (Johnson, 2021). Coastal and estuarine water quality monitoring is undertaken at monthly intervals and is not specifically designed to capture high rainfall and river flow events although these are occasionally intercepted (Ingley, 2020).

3.3 Regional summary of coastal water quality 10-year trends

Trends in coastal water quality are firstly assessed from a regional perspective to decipher if trends are following similar patterns across all monitored sites in the Auckland region (Figure 3-3). Trend directions per site and per parameter are shown in maps in Figure 3-4. Further information on each parameter, is outlined in section 3.4 below.

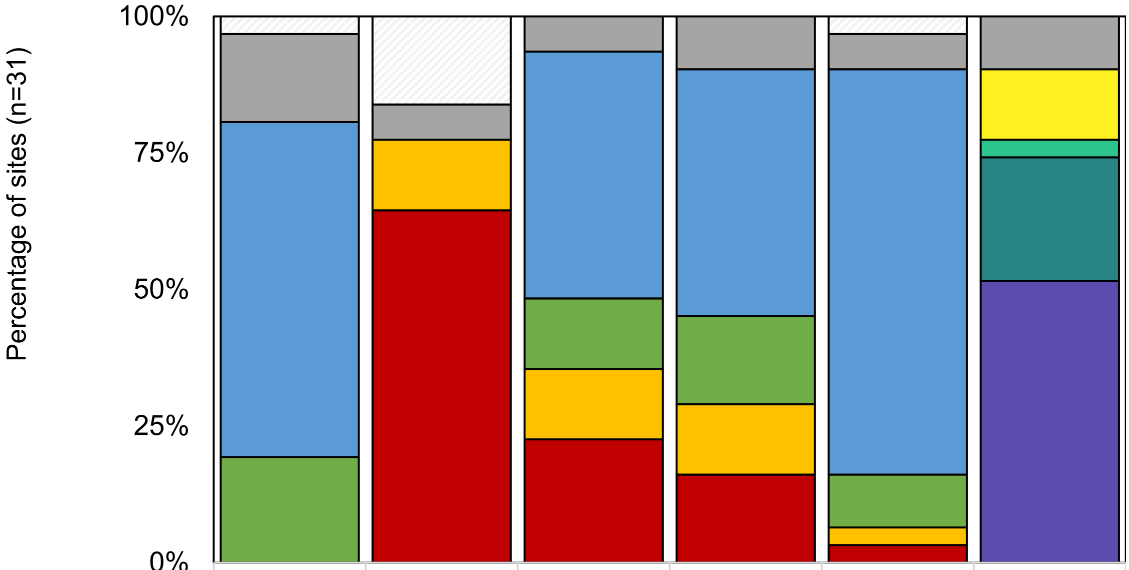
In the previous Auckland coastal water quality state and trends analysis, trend analysis was undertaken by pooling all data within harbours and major estuaries to provide a sub-regional assessment of water quality (Foley et al*.* 2018). The value of pooling data sets was questioned in relation to the river water quality analysis by Buckthought and Neale (2016) and it was recommended that aggregation of site-specific trends would provide a more robust approach. The approach taken here aggregates individual site trends to obtain a regional picture of the proportion of trends that were improving or degrading which enables assessment of overall water quality changes that may be difficult to identify from only examining individual site trends (Snelder and Fraser, 2018).

The coastal water quality index, and concurrent river water quality reporting, focuses on soluble rather than total (soluble and particulate) forms of nutrients. Soluble forms are considered to be more 'bioavailable'. There are different pathways that soluble and total forms follow from land to water and complex relationships and cycling between both forms. In most instances, trend directions at each monitored site were the same between soluble and total forms, however there were differences in the likelihood or probability of those trends. Notable differences in trends between soluble and total forms, and other paired parameters are discussed further in section 3.4.

Over 60 per cent of monitored sites returned improving trends for turbidity. Over 80 per cent of monitored sites returned improving trends for total oxidised nitrogen, and chlorophyll α (phytoplankton) (Figure 3-3). Over 50 per cent of monitored sites returned improving trends for dissolved reactive phosphorus (Figure 3-3). However, lower detection limits obtained over time potentially induced improving trends for chlorophyll α, total oxidised nitrogen and dissolved reactive phosphorus, particularly where concentrations are currently low or there are a high proportion of values below the detection limit. Despite this analytical variability, where water quality trends are improving, we can assume that water quality is at least being maintained in the current state (McBride, 2019).

Over 70 per cent of monitored sites returned degrading trends for ammoniacal nitrogen (Figure 3-3). A step increase in ammoniacal nitrogen was previously identified in annual reporting (Ingley, 2019). This may induce degrading trends and further assessment and partitioning of time periods for ammoniacal nitrogen is undertaken in section 3.4.5. Over 70 per cent of monitored sites also had decreasing dissolved oxygen saturation. In most instances, decreasing dissolved oxygen is indicative of degrading water quality.

The greatest proportion of degrading trends in dissolved reactive phosphorus and turbidity were associated with sites within the Waitematā Harbour (Figure 3-4).



	TON	Ammoniacal N	DRP	Turbidity	Chlorophyll a	DO%
NA	3%	16%	0%	0%	3%	0%
Indeterminate	16%	6%	6%	10%	6%	10%
Very likely increasing						13%
Likely increasing						3%
Likely decreasing						23%
Very likely decreasing						52%
Very likely improving	61%	0%	45%	45%	74%	
Likely improving	19%	0%	13%	16%	10%	
Likely degrading	0%	13%	13%	13%	3%	
Very likely degrading	0%	65%	23%	16%	3%	

Figure 3-3: Regional summary of the proportion of sites within each trend category across coastal water quality index parameter.

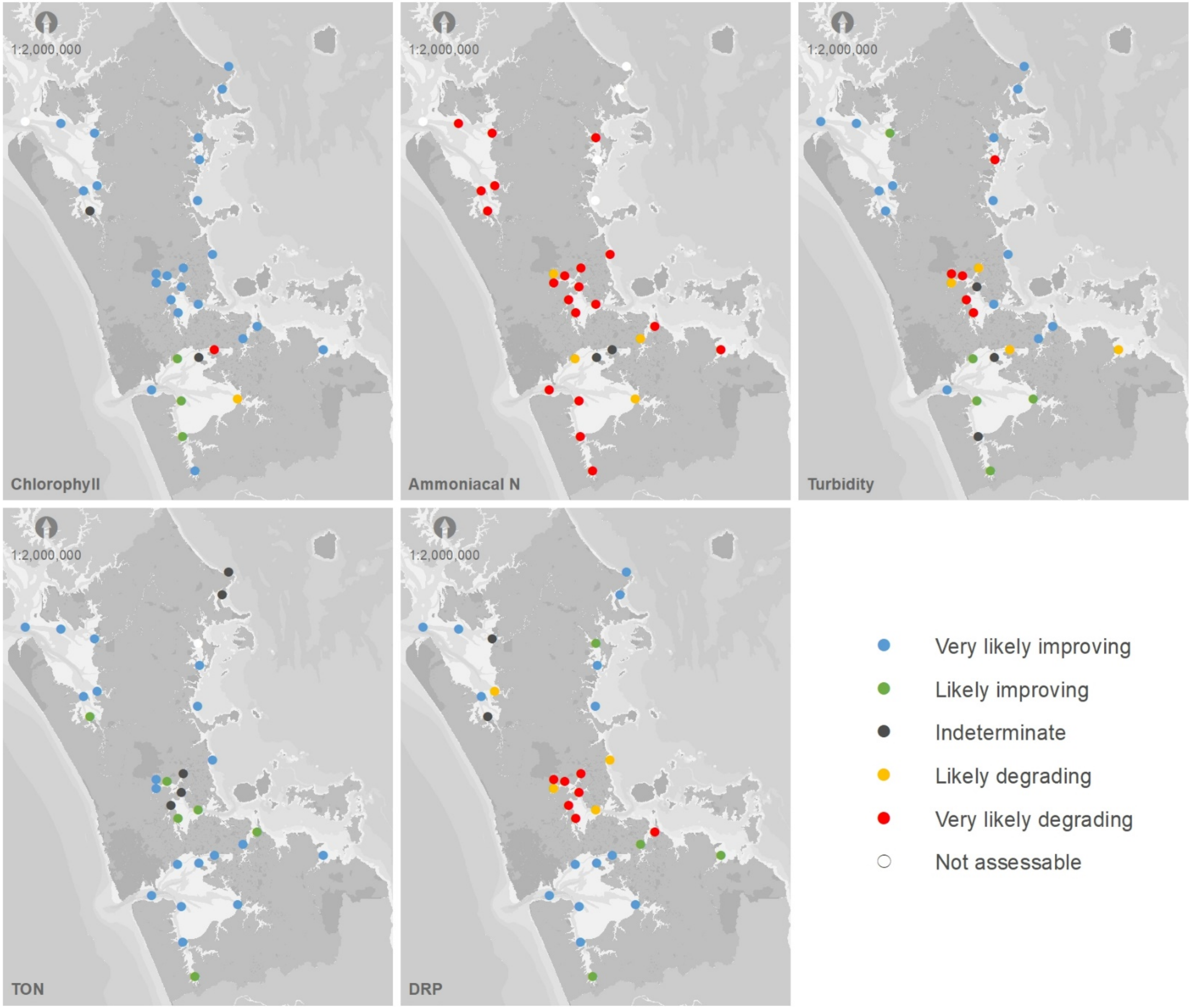


Figure 3-4: Summary maps of 10-year trends (2010-2019) in coastal water quality parameters per site.

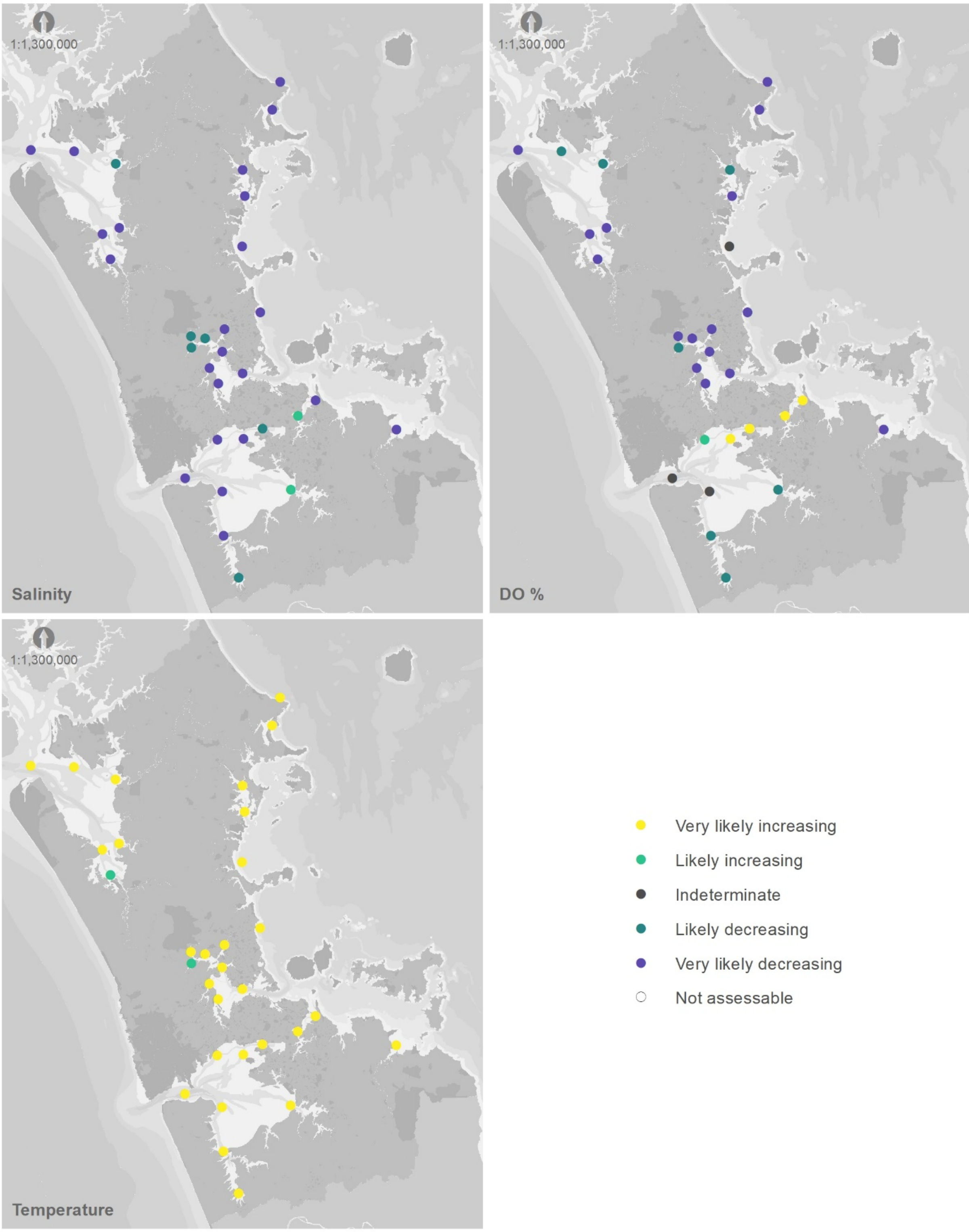


Figure 3-5: Summary maps of 10-year trends (2010-2019) in coastal water quality physical parameters per site.

3.4 Water quality trends relative to current state

3.4.1 Salinity

Salinity is a measure of the concentration of dissolved salts in the water column and provides a proxy for the degree of freshwater input at a site. Spatial variation in median salinity between sites varies by up to 10 ppt between the more saline open coastal sites, and brackish upper tidal creek sites. Salinity is strongly seasonal at almost all sites, where it is lower in winter due to greater rainfall and freshwater inputs, particularly at upper tidal creek and estuarine sites. Tidal variation in salinity within sites is controlled as far as possible by monitoring on the turn of the ebb tide.

Recent national-scale analysis of coastal and estuarine water quality found that the influence of freshwater (using salinity as a proxy) explained the greatest variation in water quality between coastal and estuarine water quality monitoring sites (Dudley et al. 2020). Greater freshwater influence was associated with higher concentrations of all forms of nitrogen and phosphorus (total and soluble), and higher turbidity, however; chlorophyll α was not significantly associated with salinity (Dudley et al. 2020). Regional assessments have also found that salinity explained a high proportion of variation in overall water quality index scores between sites despite accounting for large scale physical environmental differences in the use of separate guidelines for tidal creek, estuarine, and open coastal environments (Ingley, 2020).

Over 90 per cent of monitored sites were found to have likely to very likely decreasing trends in salinity, including the open coastal sites where salinity is generally well buffered. This regional uniformity in trend direction suggests wider scale climatic variation potentially associated with low rainfall in 2010, and higher rain fall particularly across 2016 to 2018 (see section 3.2).

3.4.1.1 Magnitude of trends in salinity

The estimated rate of decrease in salinity across all sites averaged 0.1 ppt per annum including the open coastal, and harbour mouth sites (1 ppt over 10 years) (Figure 3-6). Annual median salinity typically varied by less than five ppt within each site over time (except at tidal creek sites). This relatively small scale decrease in salinity over time within sites is therefore not expected to be a significant driver of temporal trends in water quality.

Tidal creek sites are typically more variable due to varying freshwater inflows where, following heavy rain events, surface waters can be very fresh resulting in lower probability (likely) trends in the Upper Waitematā Harbour with only Lucas Creek assessed as ‘very likely decreasing’. However the high natural variability at this site was still reflected in the very wide confidence intervals and poor estimate of the rate of change at this site (Figure 3-6, Appendix C).

Annual median salinity at upper tidal creek sites varied by more than 10 ppt at Brighams Creek and Rangitopuni Creek, and by more than seven ppt at Lucas Creek and Paremoremo Creek. Salinity was highest in 2010, decreasing in 2011, increasing in 2014 to 2015, decreasing again in 2016 to 2018, and increased in 2019. These multiple trend directions in salinity broadly mirror patterns in regional annual average rainfall (Johnson, 2021).

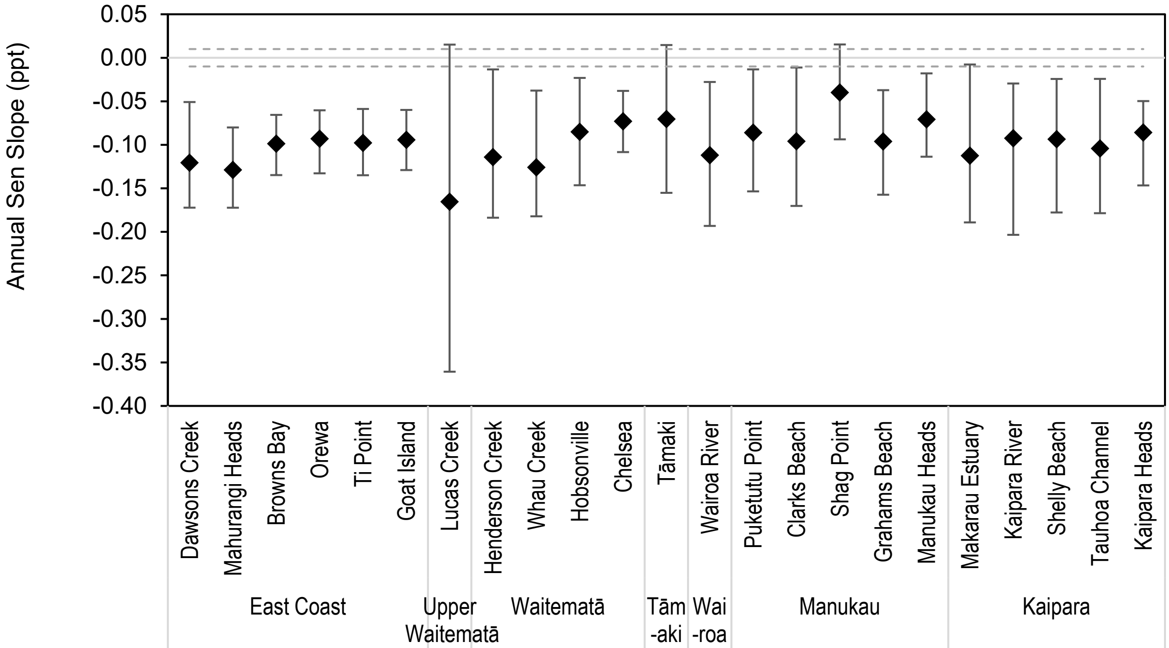


Figure 3-6: Magnitude of 'very likely decreasing' trends in salinity at each site ordered by increasing median salinity within each area. Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution).

3.4.2 Temperature

Water temperature indirectly affects a range of other water quality parameters such as dissolved oxygen, or the toxicity of ammonia. High water temperatures can also cause direct stress to aquatic fauna, especially intertidal species. Sea-surface temperature is strongly influenced by seasonal, and diurnal variability. Seasonally, temperatures peak in January to February, and are coldest in July and August. Temperatures are more variable in upper tidal creek and estuarine sites where they are influenced by freshwater runoff and interaction with intertidal areas that are warmed during the low tide window.

Marine heatwave[4] conditions persisted around the region for the duration of 2018 and above average sea surface temperatures continued into the summer and autumn of 2019 within the Auckland region (NIWA, 2019).

Consequently, it is unsurprising that all monitored water quality sites were found to have very likely increasing trends in temperature between 2010 to 2019, except for Brighams Creek and Kaipara River which were still likely increasing.

Long term trends in sea surface temperature at Leigh Marine Laboratory Climate Station between 1967 to 2017 were found to not be significant, as any trends were masked by strong interannual variability (Pearce et al. 2017; Chiswell and Grant, 2018). A greater rate of warming has been projected for the west coast associated with changes to the East Australia Current within the Tasman Sea (Pearce et al. 2017). Marine heatwave events are expected to increase in frequency, and possibly duration under climate change predictions (Oliver et al. 2019).

3.4.2.1 Magnitude of trends in temperature

The estimated rate of change was the lowest on the East Coast at approximately 0.05 to 0.06 °C per annum, and highest in the Manukau Harbour ranging from 0.11 (+0.05,-0.04) °C per annum at the heads, to 0.18 (+0.11,-0.15) °C per annum in the upper reaches of the Waiuku Inlet (noting that Waiuku Town Basin covers a shorter time period) (Figure 3-7).

However, the range of confidence intervals across all sites was wide varying by 0.03 to >0.1 °C which is suggestive of wide interannual variability in the rate of temperature change (Figure 3-7). The greatest estimates of increasing trends in temperature were across sites within the Manukau Harbour, at the mouth of the Kaipara Harbour, and Tāmaki Estuary where the lowest estimate of the rate of change (lower confidence interval) was 0.03 °C per annum (Waiuku Town Basin) but was typically over 0.05 °C per annum. A greater rate of warming within the Manukau and Kaipara harbours is consistent with projections of a faster rate of warming in the Tasman Sea. It is unclear why the Tāmaki Estuary may be warming at a faster rate than other monitored sites within the Hauraki Gulf or Waitematā Harbours.

Sea surface temperature in the Auckland region is expected to increase by 2.5 °C by 2100 under the business-as-usual-climate scenario (NIWA, 2018).

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[4] Marine heatwaves are defined as periods of five or more days with temperatures greater than the 90th percentile for the last 30 years of record.

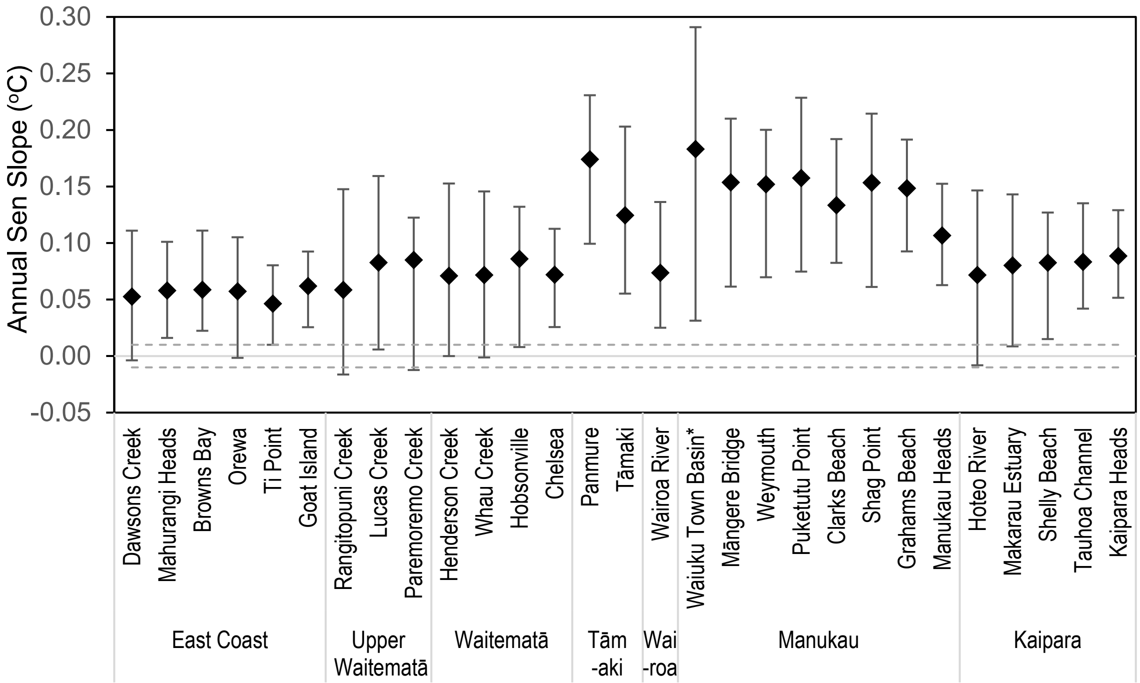


Figure 3-7: Magnitude of 'very likely increasing' trends in temperature at each coastal site, ordered by increasing median salinity within each area.

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution).
* indicates a shorter time period of analysis.

3.4.3 Dissolved oxygen

Dissolved oxygen is a fundamental aspect of the life-supporting capacity of water. Low dissolved oxygen or hypoxia can have adverse effects on aquatic fauna from reduced growth rates, to death in anoxic conditions. Dissolved oxygen varies seasonally and over the course of the day (diurnally), the lowest levels of oxygen saturation typically occur in the early morning before dawn, and maximum levels later in the afternoon. As noted in section 2.1, monitoring is typically undertaken between 9:00 am and 2:00 pm which is more likely to be representative of daily maximum conditions, particularly within the Manukau Harbour.

Over 70 per cent of monitored sites, including the more open coastal reference sites at Goat Island and Ti Point were found to have likely to very likely decreasing dissolved oxygen saturation. This is of potential concern for sites that already experience low oxygen saturation, and potential hypoxic conditions in the surface waters (such as Rangitopuni Creek) particularly as the discrete monitoring undertaken does not capture daily dissolved oxygen minima, and effects may be underestimated.

Previously, regional patterns in dissolved oxygen were found to be increasing from 2007 to 2016 (Foley et al. 2018). Indications of a step increase in oxygen saturation in 2009 coinciding with a change in monitoring equipment potentially influenced the earlier assessment.

Three sites in the northern Manukau Harbour experienced supersaturation of dissolved oxygen (high DO), Māngere Bridge, Puketutu Island, and Shag Point and trends were likely to very likely increasing over time (Figure 3-8). Māngere Bridge was the only monitored site that was found to have very likely increasing concentrations of chlorophyll α so it is possible that increased primary production is driving greater oxygenation of surface waters during the time of day sampled (see 3.4.7). However, Weymouth, in the southern part of the Manukau was the only other site that was found to have likely increasing chlorophyll α but dissolved oxygen saturation was likely decreasing.

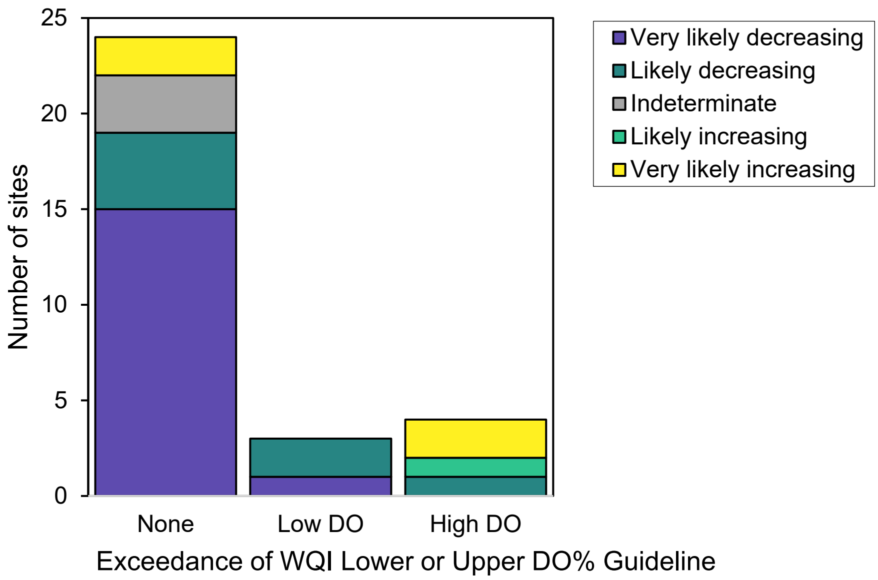


Figure 3-8: Summary of 10-year trends (2010-2019) by exceedance of the upper (High DO) or lower (Low DO) coastal water quality index guidelines (2017-2019). 'None' indicates that dissolved oxygen was within the guideline range.

3.4.3.1 Magnitude of trends in dissolved oxygen

Low dissolved oxygen levels have been observed previously at Panmure within the Tāmaki Estuary (Ingley, 2019), although the most recent current state assessment had dissolved oxygen within the guideline range for this site (Ingley, 2020). The estimated rate of change at this site was greater than the precision of our monitoring (>0.1% saturation). Very likely increasing trends in dissolved oxygen at Panmure and Tāmaki are therefore considered to be an improvement in water quality (Figure 3-9, Appendix C). Conversely, very likely increasing trends within the Manukau are considered to indicate degrading water quality where oxygen levels are currently occasionally supersaturated, as this indicates the potential for low dissolved oxygen levels to occur over the diurnal cycle.

The estimated rate of decreasing oxygen saturation across sites with very likely trends averaged 0.3 per cent saturation per annum with the greatest rate of change at Kaipara River at 0.6 per cent ±0.2 per cent saturation per annum (Figure 3-9, Appendix C). While the current state indicates that dissolved oxygen levels are within regional guidelines at Kaipara River, the most recent annual results have shown that the annual median value was below the ‘low’ guidelines of 90 per cent saturation (Ingley, 2020). The second greatest rate of decreasing oxygen saturation was at Rangitopuni Creek which is already indicated to be subject to stress from hypoxic conditions (Figure 3-9, Appendix C).

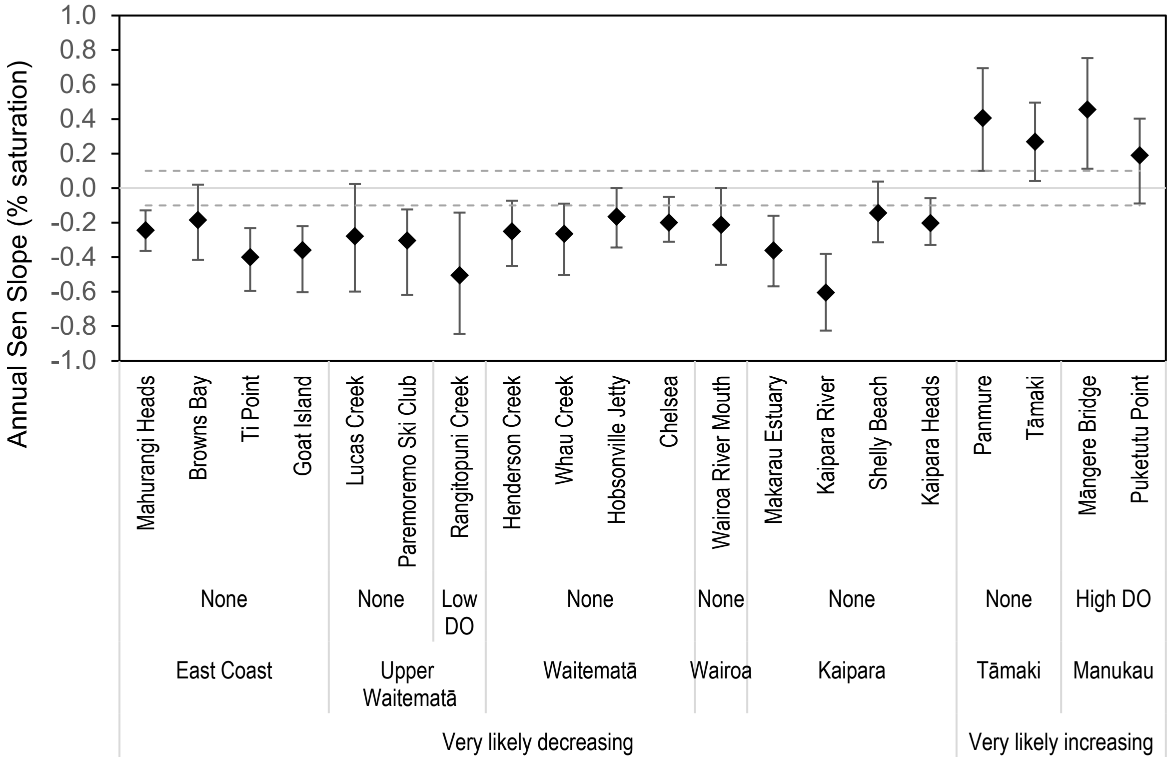


Figure 3-9: Magnitude of ‘very likely’ trends in dissolved oxygen at each site ordered by areas and exceedance of the upper (High DO) or lower (Low DO) coastal water quality index guidelines (2017-2019).
Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution).

3.4.4 Turbidity

Suspended sediment is a measure of the weight of particles that can be transported by water, while turbidity is a measure of how much light can pass through the water or water clarity. These two measures are generally highly correlated, but not always, for example, in some instances there can be a higher weight of particles, but still high clarity such as where larger sand particles are suspended in the water, or alternatively other coloured compounds in the water such as tannins can increase turbidity. Sediments transported to the coast can settle out to the seabed (benthos) where they result in increasing muddiness (estuarine depositional zones), or they can stay in the water column. Depending on currents and tides, weather conditions, and water depth, sediments can settle rapidly, or can also be resuspended into the water. Every major harbour and estuary monitored within Auckland has been found to be affected to some extent by increased sedimentation, particularly in more sheltered tidal creek environments, and sandflats close to the outflows of rivers (Drylie, 2021).

All monitored sites within the Kaipara Harbour, Tāmaki Estuary, and open coastal sites in the Hauraki Gulf were found to have likely to very likely improving turbidity (see Figure 3-4 in section 3.3). There were no 'very likely' trends in turbidity within the Manukau Harbour except at the Manukau Heads which was very likely improving.

Turbidity was likely to very likely degrading at all sites in the upper Waitematā Harbour, and at Henderson Creek and Whau Creek in the central Waitematā regardless of the current state, which ranged from none, to a moderate frequency of exceedances. This is consistent with benthic ecological monitoring which has found increasing sediment mud content at the Henderson Creek and Whau River ecology sites (Drylie, 2021). Sedimentation was identified as the main pressure affecting the ecological health of the Upper Waitematā although fewer ecology monitoring sites demonstrated ongoing increasing muddiness in this area (Drylie, 2021). Hobsonville and Chelsea in the central harbour had relatively low turbidity (no exceedances) and indeterminate, and very likely improving trends respectively. Previous coastal water quality trend analysis did not identify trends in turbidity but highlighted significant increases in total suspended solids in the upper Waitematā Harbour[5] (Foley et al*.* 2018).

The water quality index (WQI) is based on median monthly values which moderate the influence of chance interception of flashy, or episodic sedimentary events and indicates where turbidity is frequently high over a three year rolling period. Māngere Bridge within the Manukau Harbour is the only site with a high frequency of elevated turbidity levels (turbidity is elevated more than half of the year) and turbidity was likely to be degrading (Figure 3-10). The mouth of the Kaipara River is the only site where turbidity levels are higher than the water quality index guideline almost all of the time (very high frequency) indicating there is poor water clarity in this area. This is further corroborated by sediment monitoring which has shown that the adjacent Kaipara Bank sandbank is notably muddier, with a greater rate of increasing muddiness than other benthic monitoring sites within the southern Kaipara Harbour (Drylie, 2021). Sediment tracing studies have demonstrated that the Kaipara and Kaukapakapa River systems

[5] It was particularly noted in Foley et al. 2018 that average TSS concentrations had doubled at Brighams Creek and Rangitopuni Creek in 2016, however several observations in 2016 coinciding with heavy rain events likely skewed this average, and the rate of change in turbidity is discussed further in section 3.5.5.1.

are the main local source of sediment to the Kaipara Harbour south of Shelly Beach, with sediments deposited close to the river mouth on these intertidal sandbanks (Gibbs et al. 2012). Coastal water quality monitoring shows that turbidity levels were very likely improving at this site over the past 10 years (Figure 3-4, Figure 3-11). Sediment tracing studies also demonstrated that Hoteo River has a high sediment load that contributes to sediment deposition at the mouth of this river (Gibbs et al. 2012). This was not evident from this analysis as turbidity is currently below guidelines, and likely improving over time at the Hoteo River estuary mouth. Coastal water quality monitoring is not targeted to storm events that generally contribute greater sediment loads. Event-based sediment loads are also monitored at several upstream river sites including Hoteo River, Kaipara River and Kaukapakapa River (Hicks et al. *in prep* 2021). Reducing sedimentation is a primary focus of the Kaipara Moana Remediation programme that has recently received significant government investment.

For over 80 per cent of sites, trends in turbidity and total suspended solids were in the same direction (i.e. either degrading or improving, within each monitored site), although there were some differences in the probability of these trends between the two parameters (e.g. likely to very likely). Four sites varied between likely to indeterminate trends. The greatest difference in trend direction between turbidity and total suspended solids was at Mahurangi Heads where turbidity was found to be very likely degrading but total suspended sediments returned indeterminate trends.

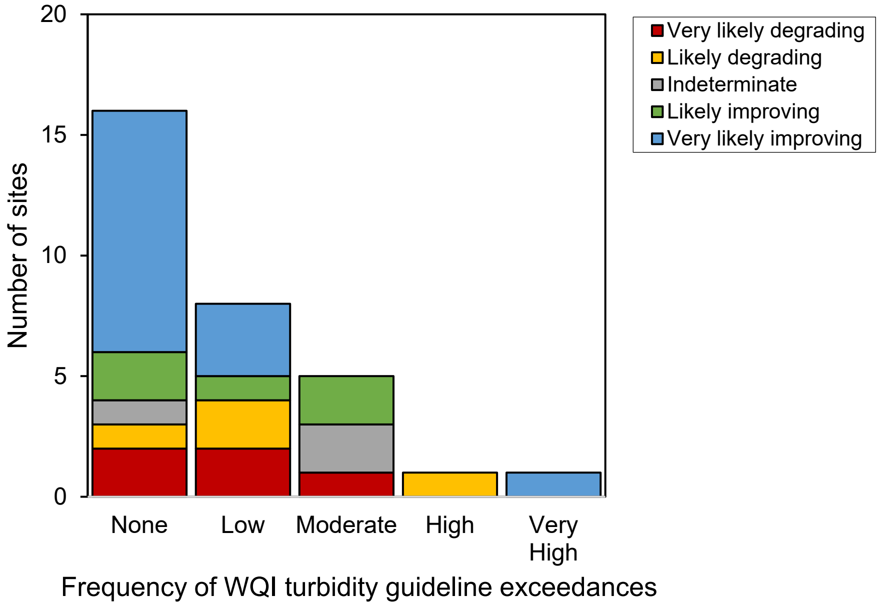


Figure 3-10: Summary of 10-year trends (2010-2019) by the frequency of coastal water quality index guideline exceedances for turbidity (2017-2019).

3.4.4.1 Magnitude of trends in turbidity

The estimated rate of change in turbidity was typically greater than the limit of precision for this parameter (>0.01 NTU per annum) (Figure 3-11).

The open coastal sites monitored on the East Coast were very likely improving but at an estimated rate of less than 0.04 NTU which is equivalent to four per cent of the open coastal guideline value (1 NTU). Turbidity is consistently low, and this estimated rate of change is negligible.

Mahurangi Estuary exhibited some interesting patterns where turbidity was very likely improving in the upper reaches at Dawsons Creek, but very likely degrading at the Mahurangi Heads. Trends in turbidity were assessed seasonally at Dawsons Creek whilst Mahurangi Heads, (like the other East Coast sites) was non-seasonal. The estimated rate of change was greater at Dawsons Creek.

The greatest rate of degradation in turbidity was within the Waitematā Harbour. The greatest but most variable rate of change was at Rangitopuni Creek estimated at 0.17 (+0.15, -0.2) NTU per annum (Figure 3-11, Appendix C). This is equivalent to approximately two per cent of the estuarine and tidal creek turbidity guidelines (10 NTU).

The greatest rate of improvement in turbidity was at Panmure within the Tāmaki Estuary at an estimated rate of 0.49 (+0.13, -0.15) NTU per annum (Figure 3-11, Appendix C). This is equivalent to approximately five per cent of the turbidity guideline per annum. Improving trends were also notable at Kaipara River at an estimated rate of change of 0.47 NTU per annum but with a very wide range of variability in the rate of change (confidence intervals of +0.39,-0.38 NTU per annum) (Figure 3-11, Appendix C).

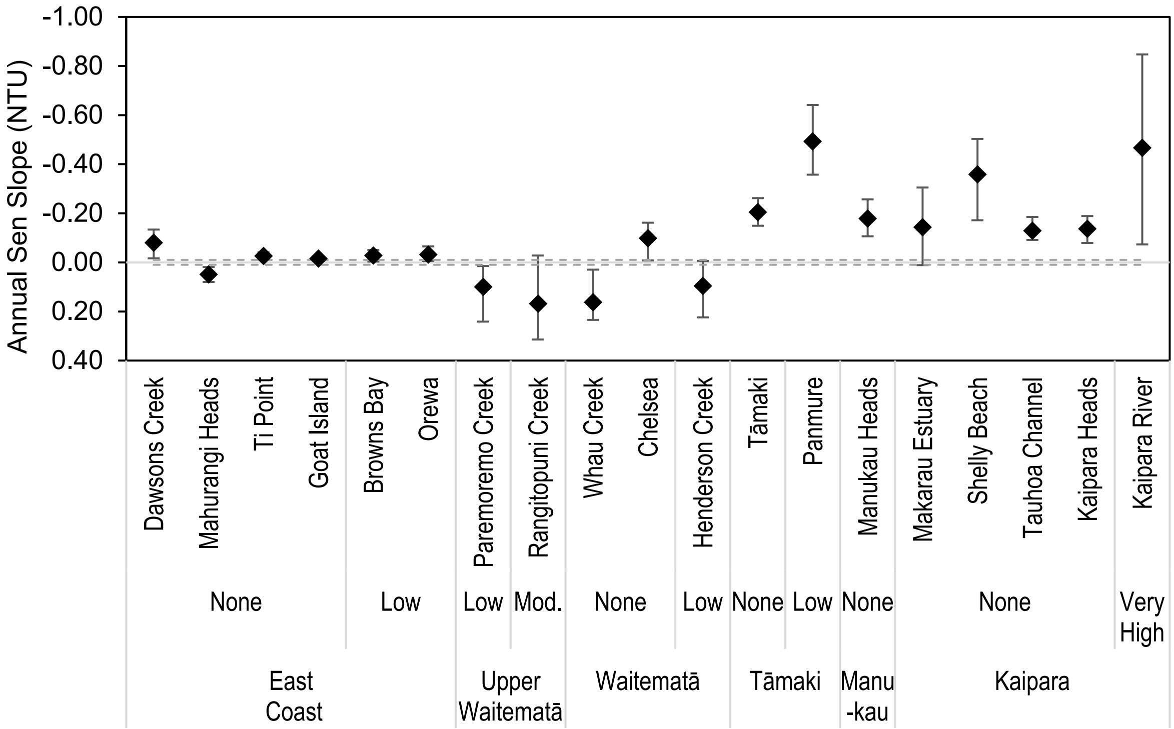


Figure 3-11: Magnitude of 'very likely' trends in turbidity at each coastal site ordered by area and frequency of coastal water quality index guideline exceedances (2017-2019).

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution) Y scale is inverted so negative trends or decreasing concentrations (upper part of graph) are 'improving'.

3.4.5 Nitrogen

Nitrogen is a key nutrient that contributes to the growth of plants and algae and is generally accepted as the limiting nutrient in coastal environments (Plew et al. 2020). However, high concentrations of nutrients can cause excessive growth that can lead to low dissolved oxygen levels and have adverse effects on communities of aquatic fauna and other water values. At very high levels, nitrate, and ammoniacal nitrogen, can also be toxic to aquatic animals, however the water quality index guidelines for total oxidised nitrogen (nitrate+nitrite) and ammoniacal nitrogen, are based on deviation from reference conditions and are **not** associated with potential toxicity effects.

Total nitrogen includes all dissolved and particulate forms of nitrogen. The dissolved fraction is the most readily available for uptake by phytoplankton and algae. The main dissolved inorganic forms of nitrogen are ammonia, nitrite, and nitrate. Nitrite is the intermediate step in the conversion of ammonia to nitrate and is usually short lived in the aquatic environment.

There was a regionally consistent direction of improving trends in total oxidised nitrogen (Figure 3-12). Lower detection limits from 2017 likely induced improving trends at sites with low concentrations (none or low frequency of samples above the guideline) particularly given the high proportion of censored values for this parameter across most sites. However, improving trends in total oxidised nitrogen were also observed across more than 80 per cent of sites in previous trend analysis undertaken for the period of 2007 to 2016 (Foley et al. 2018) and this is indicative that levels are least being maintained at the current state. There was a greater proportion of indeterminate, and not assessable trends for total oxidised nitrogen where there was a low to moderate frequency of exceedances reflecting the high proportion of values that were below the limit of detection for this parameter (Figure 3-12).

Conversely, there was a regionally consistent direction of degrading trends in ammoniacal nitrogen (Figure 3-12). Trends were not assessable for a high proportion of sites, reflecting the high proportion of values that were below the limit of detection for this parameter. Indeterminate trends were returned at sites where concentrations were frequently higher than guidelines (very high, Figure 3-12). A change in laboratory service provider occurred in 2017. Inspection of the data sets either side of this change suggested an abrupt step increase, particularly at low concentrations resulting in an abrupt change in the proportion of censored data per annum (from more than 30 per cent per annum across all sites to less than one per cent) [6]. Trends were not assessed for this parameter in the recent State of the Gulf analysis for this reason, as a step increase would potentially induce degrading trends (Kelly, 2020). To further assess the potential influence of this step increase, the data set was partitioned to before the change in service and the probability of the direction of the trend was calculated for this shorter time period (2010 to 2016) and compared to the 10-year period (Figure 3-13, examples of time series of partitioned trend periods are outlined in Appendix C).

Trends in ammoniacal nitrogen were not assessable for a much higher proportion of sites across the shorter time period due to high proportions of censored values, i.e. typically very low concentrations (Figure 3-13). Nearly 40 per cent of sites were likely to very likely degrading, consistent with the trend direction over the longer time period (Figure 3-13). Between 2010 to 2016, degrading trends were found at all sites within Tāmaki Estuary, and the Waitematā Harbour except for Chelsea at the head of the harbour which was not assessable prior to 2016. Within the Manukau Harbour however, the probability of the direction of trends shifted between the partitioned 2010 to 2016 period and the full 10 years, i.e. from indeterminate to degrading and from improving to indeterminate. This suggests that the observed step increase may have overwhelmed previous small decreases in concentration at these sites (Figure 3-13).

[6] Method verification was requested from R.J. Hill Laboratories which confirmed the analysis of ammonia in saline waters is performing as expected.

Within the Kaipara Harbour, half of the sites did not return assessable trends for the shorter time period. Makarau Estuary and Hoteo River mouth had consistently degrading trends across both the partitioned and full time periods; however Shelly Beach was likely improving prior to 2017.

Therefore, collectively it is considered that ammoniacal nitrogen is likely to very likely degrading within the Tāmaki Estuary and Waitematā Harbour and for parts of the Kaipara Harbour, though any potential improvements after 2016 may have been masked by the step increase. While it is more difficult to ascertain the true trends for sites within the Manukau Harbour, ammoniacal nitrogen concentrations are consistently much higher in the northern Manukau than elsewhere in the region and considerable improvements would be necessary to reduce levels relative to the water quality index guideline.

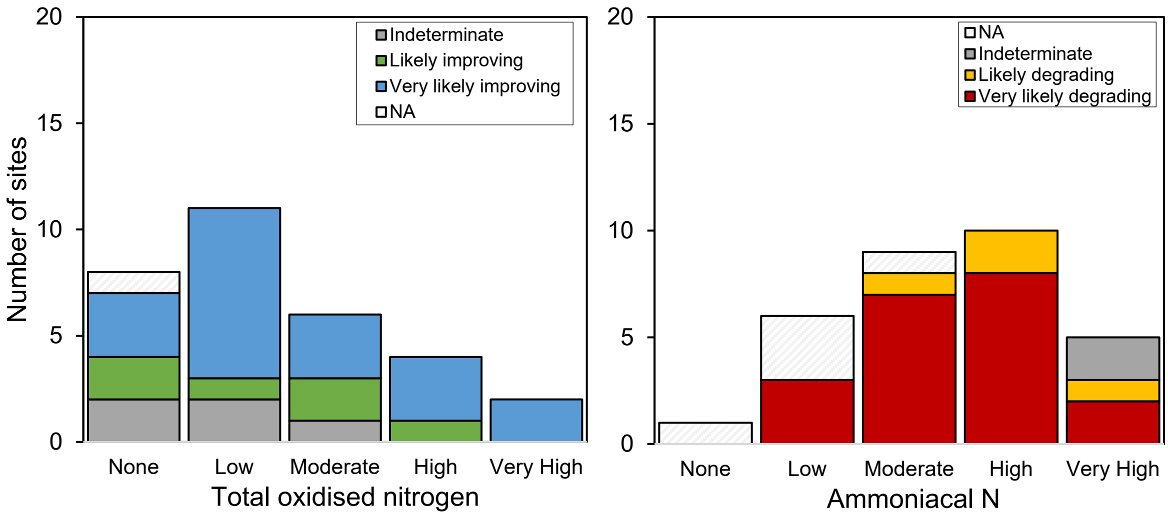
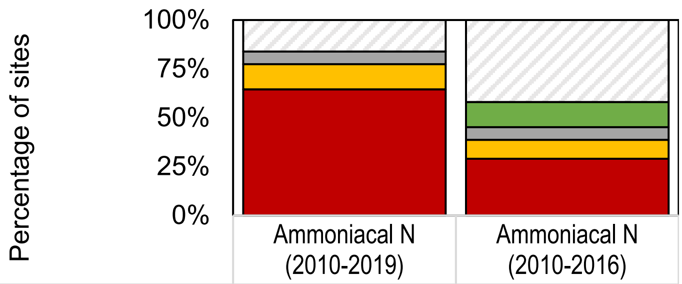


Figure 3-12: Summary of 10-year trends (2010-2019) by the frequency of coastal water quality index guideline exceedances for total oxidised nitrogen and ammoniacal nitrogen (2017-2019).



	Ammoniacal N (2010-2019)	Ammoniacal N (2010-2016)
NA	16%	42%
Very likely improving	0%	0%
Likely improving	0%	13%
Indeterminate	6%	6%
Likely degrading	13%	10%
Very likely degrading	65%	29%

Figure 3-13: Summary of trends in ammoniacal nitrogen over the 10-year period 2010 to 2019 and partitioned to prior to the 2017 service change.

3.4.5.1 Magnitude of trends in nitrogen

The estimated rate of change in total oxidised nitrogen was typically smaller than the limit of precision for this parameter (≤ 0.001 mg/L). The magnitude of trend could not be estimated for four sites that were very likely improving due to a very high proportion of censored values.

The greatest rate of improvement was at sites with high concentrations of total oxidised nitrogen in the northern Manukau Harbour, particularly at Māngere Bridge and Puketutu Point although the very wide confidence intervals indicate wide variability in the rate of this change over the past 10 years (Figure 3-14, Appendix C). Both of these sites have the highest concentrations of total oxidised nitrogen, and the lowest proportion of censored values among all sites within the regional monitoring programme.

The estimated rate of improvement for total oxidised nitrogen at Māngere Bridge of 0.008±0.005 mg/L per annum, is equivalent to approximately 30 per cent of the regional water quality index estuarine guideline value per annum. However, concentrations of total oxidised nitrogen at this site can be more than 10 times the guideline value (Ingley, 2020). Assuming the estimated rate of improvement was sustained over time, improvement relative to the water quality index guideline may take decades.

The magnitude or rate of change in ammoniacal nitrogen is influenced by the change in laboratory analysis outlined above, however the relative differences in trend magnitude between sites, where there were consistent trend directions, may be considered. Eight sites had very likely degrading trends across both the full 10 years (2010-2019) and partitioned (2010-2016) time periods. The apparent step increase from 2017 generally resulted in a larger estimate of the magnitude of degradation for the 10-year period, greater than the limit of precision for this parameter (>0.001 mg/L) (Figure 3-15). However, the opposite is evident at Tāmaki where the estimated rate of degradation was less across the full time period than prior to 2016 which suggests that the step increase may have masked recent, small scale improvements in ammoniacal nitrogen at this site (Appendix C). The greatest rate of degradation within the 10-year period between sites was at Henderson Creek and Whau Creek (Figure 3-15, Appendix C). It was previously reported by Foley et al. (2018) that annual average concentrations of ammoniacal nitrogen had doubled in the Waitematā at Henderson Creek, Whau Creek, and Paremoremo Creek between 2013 and 2016. While, average concentrations can be skewed by outliers, increasing trends in benthic chlorophyll α concentration at Henderson Creek and Whau Creek are also indicative of increasing nutrient availability within these estuaries (Drylie, 2021).

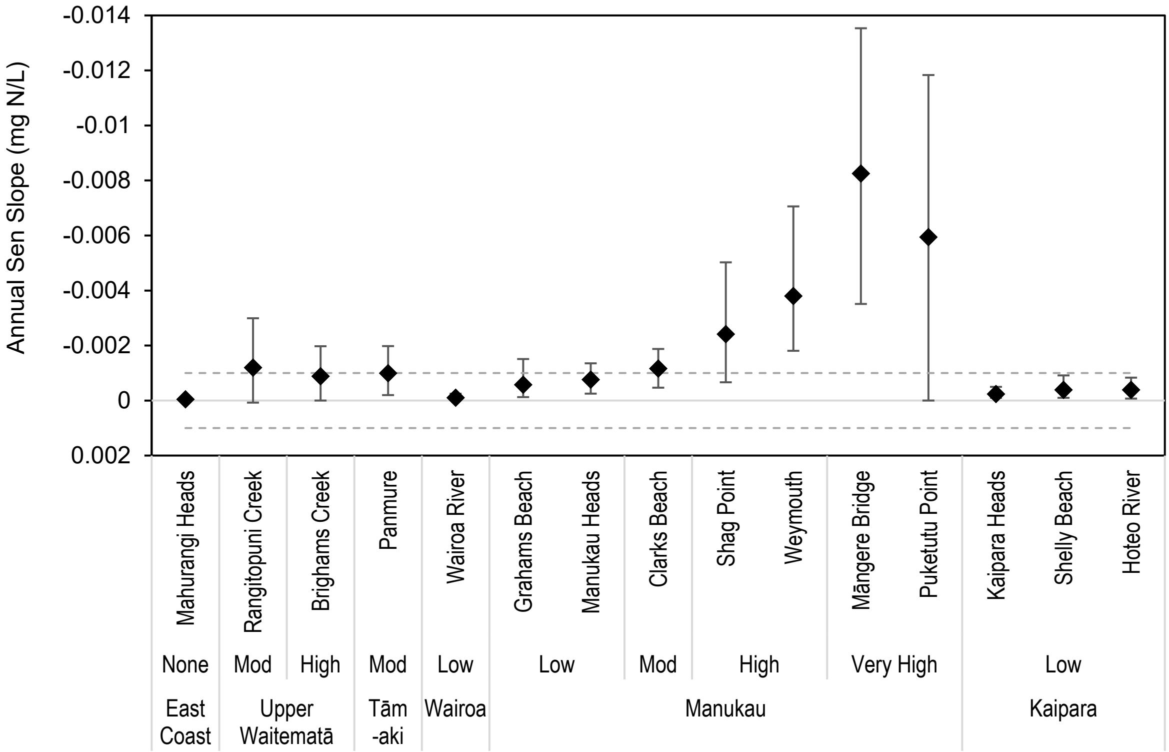


Figure 3-14: Magnitude of 'very likely improving' trends in total oxidised N at each site ordered by area and frequency of coastal water quality index guideline exceedances (2017-2019).

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution).

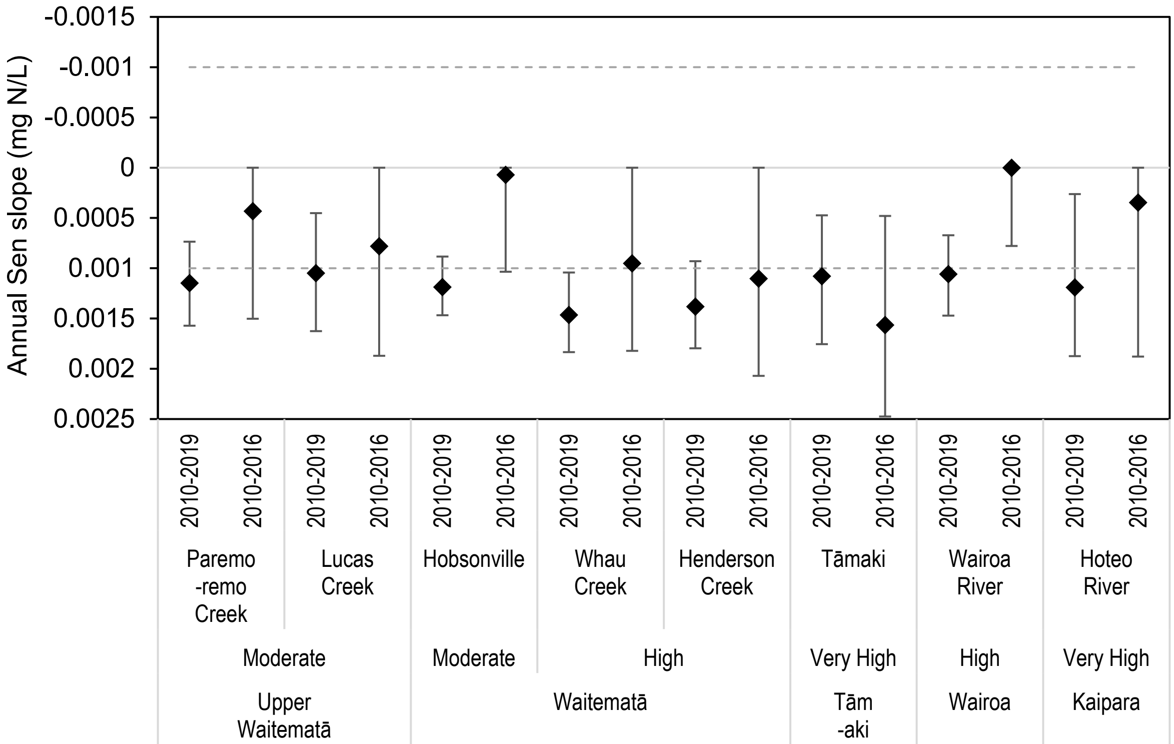


Figure 3-15: Magnitude of consistently 'very likely degrading' trends in ammoniacal nitrogen across partitioned time periods ordered by area and frequency of coastal water quality index guideline exceedances (2017-2019).

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution).

3.4.6 Phosphorus

Phosphorus is a key nutrient that can stimulate the growth of algae and plants. Phosphorus is found in water in both dissolved, and particulate forms. Total phosphorus is a measure of both forms while dissolved reactive phosphorus (DRP) reflects the portion that is immediately available for uptake and growth by plants. Particulate associated phosphorus can also be associated with erosion and suspended sediment.

Lower detection limits, and improved precision of analysis associated with a change in analytical methodology from 2017 (Appendix A) likely induced improving trends at sites with low concentrations (none or low frequency of samples above the guideline) (Figure 3-16). However, this is indicative that levels are at least being maintained at the current state.

Approximately one third of monitored water quality sites were likely to very likely degrading and the majority of these were at sites where dissolved reactive phosphorus is currently low or below guideline levels (Figure 3-16). There was a clear spatial pattern in trends where all sites in the Waitematā Harbour were likely to very likely degrading and all sites on the East Coast, and in the Kaipara and Manukau Harbours were likely to very likely improving except for Browns Bay (East Coast) and Makarau Estuary (Kaipara) that returned likely degrading trends (see Figure 3-4 in section 3.3).

Sites that exceeded the water quality index dissolved reactive phosphorus guideline almost all of the time (very high frequency of exceedances) were found to be likely to very likely improving (Figure 3-16). These sites are all within the Manukau Harbour, including the northern harbour sites, and the upper Waiuku inlet.

All trends in dissolved reactive phosphorus were consistent with trends in total phosphorus within the Manukau Harbour in both direction and probability. All other improving trends in dissolved reactive phosphorus were consistent with trends in total phosphorus although there were some differences in probability (very likely to likely). Within the Waitematā Harbour, however, where there were very likely degrading trends in dissolved reactive phosphorus, trends in total phosphorus were likely improving or indeterminate. The reasons for this discrepancy are unclear particularly given the likely degrading trends in turbidity and potential sediment bound sources of total phosphorus within the Waitematā.

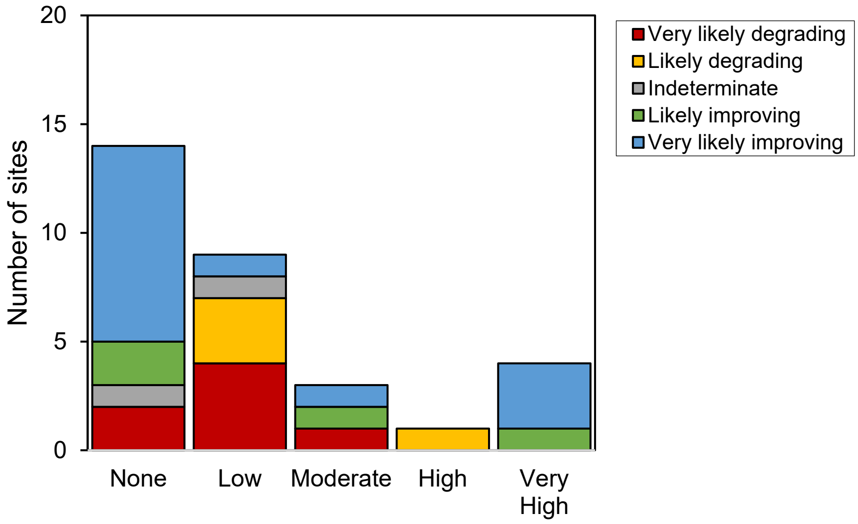


Figure 3-16: Summary of 10-year trends (2010-2019) by the frequency of coastal water quality index guideline exceedances for dissolved reactive phosphorus (2017-2019).

3.4.6.1 Magnitude of trends in phosphorus

The estimated rate of change in dissolved reactive phosphorus was less than the limit of precision for this parameter (≤ 0.001 mg/L) at all sites except in the northern Manukau Harbour (Figure 3-17). The limit of precision is equivalent to approximately eight per cent of the open coastal water quality guideline, and five per cent of the estuary/tidal creek guidelines.

The greatest estimated rate of degradation was 0.0003 (+0.0004 -0.0003) mg/L per annum at Rangitopuni Creek in the Upper Waitematā Harbour. This is equivalent to 1.4 per cent of the estuary/tidal creek guideline per annum. There is currently a moderate frequency of exceedances of the guideline at this site.

There was a very low rate of improvement across areas with currently low concentrations of dissolved reactive phosphorus across the East Coast, and Kaipara Harbour sites. Improved precision (to 0.0001 mg/L), and lower detection limits from 2017 likely induced improving trends at these sites with very low concentrations.

The greatest rate of improvement was at the three sites in the northern Manukau Harbour where there is a very high frequency of exceedances (Figure 3-17). The greatest rate of change was at Puketutu Point adjacent to the Māngere Wastewater Treatment plant, estimated at 0.005 ±0.001 mg/L per annum (Figure 3-17, Appendix C). This is a notable rate of improvement equivalent to more than 20 per cent of the water quality index guideline per annum. However, concentrations of dissolved reactive phosphorus at this site can reach levels more than five times greater than the water quality index guideline value.

The next greatest rate of improvement was at Weymouth in the Manukau Harbour where there is currently a moderate frequency of exceedances (Figure 3-17). The estimated rate of improvement was 0.0008 ±0.0003 mg/L per annum (Figure 3-17,). This is equivalent to four per cent of the estuarine water quality index guideline per annum.

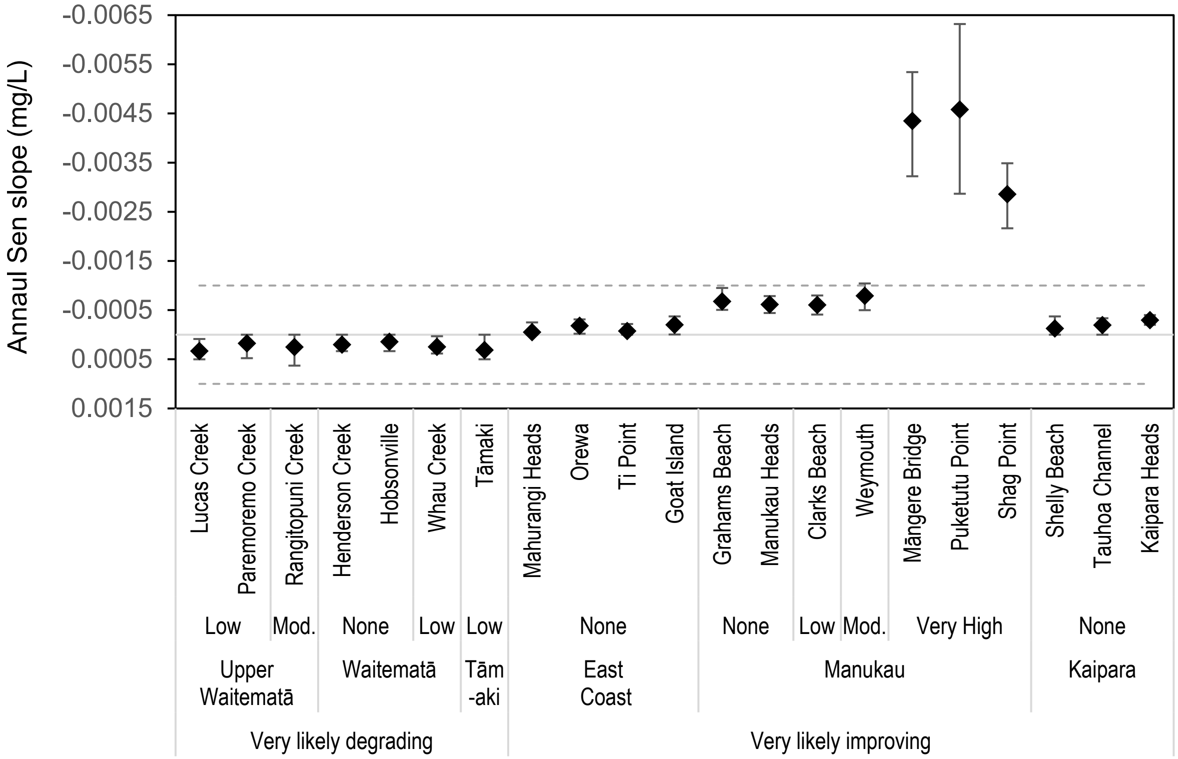


Figure 3-17: Magnitude of 'very likely' trends in dissolved reactive phosphorus at each site ordered by area and frequency of coastal water quality index guideline exceedances (2017-2019).

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution).

3.4.7 Chlorophyll α

Chlorophyll α is a green pigment found in plants and is measured as an indicator of phytoplankton abundance. Phytoplankton naturally increase in the spring and summer as water temperatures and light levels increase. Blooms of macroalgae, and phytoplankton may be primary symptoms of eutrophication, or excess nutrients, which can cause secondary changes in water clarity, dissolved oxygen, and affect benthic communities (Plew et al. 2020; Robertson et al. 2016). Phytoplankton are considered to be less likely to accumulate to excessive levels, or to result in low oxygen levels in shallow intertidally dominated estuaries (and harbours) that are well mixed and flushed (Plew et al. 2020).

Lower detection limits, associated with a change in analytical methodology from June 2018 (Appendix A) likely induced improving trends at sites with low concentrations (none or low frequency of samples above the guideline) (Figure 3-18). However, this is indicative that levels are at least being maintained at the current state.

Chlorophyll α levels were elevated most of the time at Māngere Bridge (high frequency) and this was the only site that was found to be very likely degrading (Figure 3-18, Appendix C). Most sites within the Manukau Harbour had chlorophyll α levels that were elevated more frequently than just within summer months (moderate frequency), including the only site that was likely degrading, Weymouth (Pahurehure Inlet) (Figure 3-18, Appendix C).

Chlorophyll α levels within the Kaipara Harbour were generally low, or occasionally above guidelines and concentrations were very likely improving, except at Kaipara River where chlorophyll α levels were frequently high, and trends could not be determined.

All sites that had a moderate to high frequency of elevated chlorophyll α levels were found to have dissolved oxygen levels either above, or below regional guideline levels except for Clarks Beach in the Manukau Harbour (see 3.4.3). However at Kaipara River, the site with the highest frequency of elevated chlorophyll α levels, dissolved oxygen levels were within guidelines.

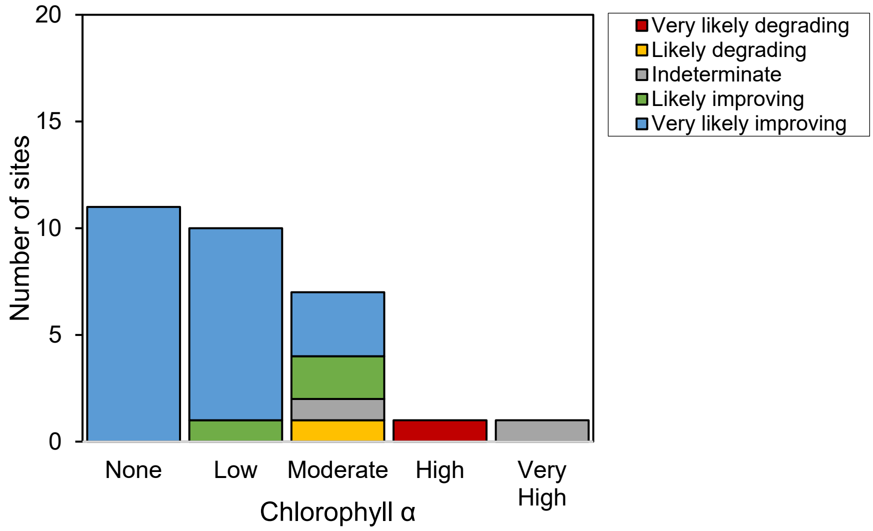


Figure 3-18: Summary of 10-year trends (2010-2019) by the frequency of coastal water quality index guideline exceedances for chlorophyll α (2017-2019).

3.4.7.1 Magnitude of trends in chlorophyll a

Where chlorophyll α concentrations are currently low (no exceedances of water quality index guideline 'none') the estimated rate of improvement was most commonly less than the limit of precision (0.0001 mg/L) for this parameter and it is likely that improving trends were induced by a reduction in the detection limit from 0.0006 to 0.0002 mg/L (Appendix A). The greatest rate of improvement within this category was at Dawson's

Creek in the Mahurangi Harbour at 0.00014 (+0.00007, -0.00006) mg/L per annum (Figure 3-19). This is equivalent to less than five per cent of the estuary guideline value.

The greatest estimated rate of improvement overall was at the Waiuku Town Basin in the southern Manukau Harbour at 0.0002 (+0.00016,-0.00024) mg/L per annum which is equivalent to approximately six per cent of the estuary guideline value (Figure 3-19, Appendix C). The only site that was very likely degrading was Māngere Bridge in the northern Manukau Harbour at an estimated rate of 0.00014 (+0.00018, -0.0011) mg/L per annum (Figure 3-19, Appendix C). The wide range of variability in these estimates indicates that the rate of change was highly variable through time (i.e. not linear).

The magnitude of trend could not be estimated for one site (Whau Creek) that was very likely improving due to a high proportion of censored values.

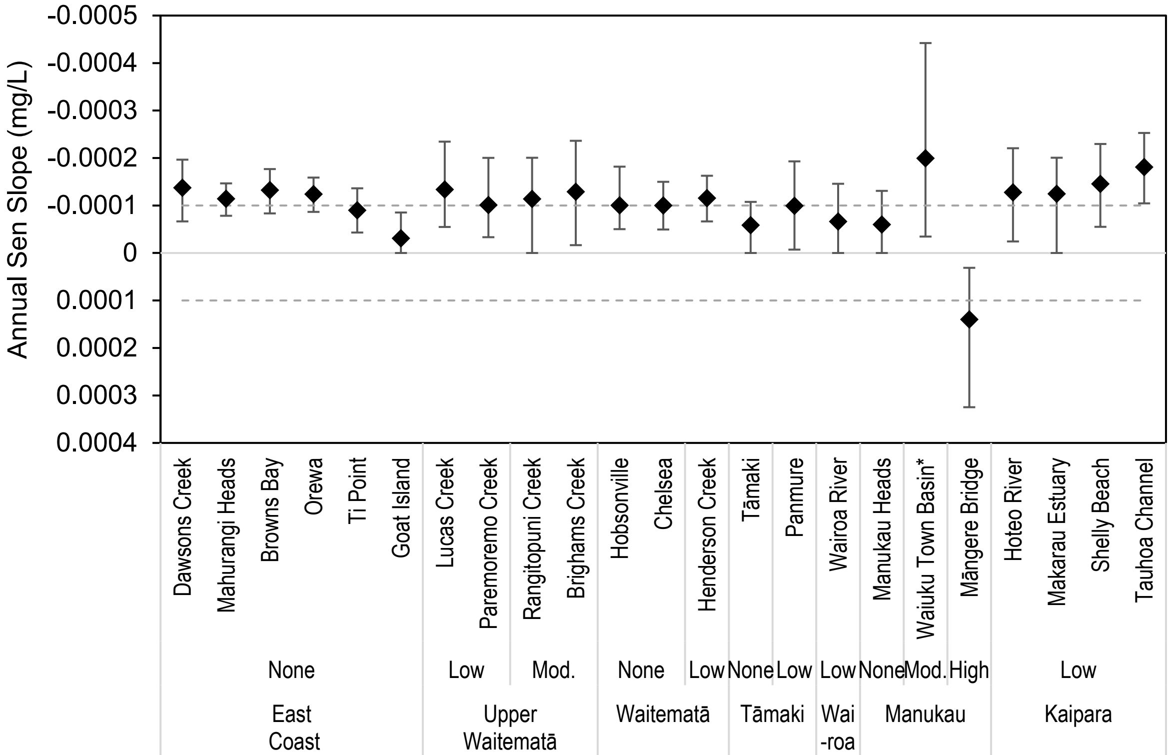


Figure 3-19: Magnitude of 'very likely' trends in chlorophyll α at each site ordered by area and frequency of coastal water quality index guideline exceedances (2017-2019).
Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)
Y scale is inverted so negative trends or decreasing concentrations (upper part of graph) are 'improving'.

* indicates a shorter time period of analysis.

4.0 Summary

This report provides information on the current state of coastal and estuarine water quality in relation to national and regional guidelines, and how water quality has changed over the past 10 years in relation to the current state, i.e. where water quality is good but declining, poor but improving, or poor and getting worse.

Current state assessment is based on the preceding three-year period from 2017 to 2019 based on the Auckland regional coastal water quality index. Water quality state was assessed in detail in the 2019 annual data report (Ingley, 2020).

The 10-year period assessed covers environmental management across the Auckland region as governed by the Hauraki Gulf Marine Park Act 2000, the New Zealand Coastal Policy Statement 2010, Auckland Council Air, Land & Water Plan 2010, and the Auckland Unitary Plan 2016.

State and trend analysis of coastal and estuarine water quality was recently undertaken for the period of 2007 to 2016 (Foley et al. 2018). This report provides an update to that analysis to provide consistency of trend analysis methods, and to align the time period analysed across the suite of state of the environment monitoring programmes to the end of 2019. Overall, Foley et al. 2018 found that water quality was improving at most sites across the region, driven by improving nutrient concentrations. This updated analysis generally agreed with these findings although there were key differences in trends in dissolved oxygen, and turbidity.

From 2010 to 2019, over 80 per cent of monitored sites were found to have improving trends in total oxidised nitrogen and chlorophyll α (phytoplankton), and over 50 per cent of monitored sites had improving trends in dissolved reactive phosphorus and water clarity (turbidity). In some instances, the rate of improvement was negligible, or within analytical variability however where water quality is found to be improving, we can assume that water quality is at least being maintained in the current state (McBride, 2019). However, this analysis found clear spatial differences with a high proportion of degrading trends within the Waitematā Harbour for ammoniacal nitrogen, dissolved reactive phosphorus and turbidity. This analysis also found that dissolved oxygen saturation was very likely decreasing at more than 70 per cent of sites although the rate of change was likely negligible except where oxygen saturation is already depressed such as in upper tidal creek environments.

The rate of improvement in both total oxidised nitrogen and dissolved reactive phosphorus concentrations was the greatest at Māngere Bridge and Puketutu Point in the northern Manukau Harbour near the Māngere Wastewater Treatment Plant. However, concentrations of nutrients are still high relative to reference levels and

Māngere Bridge was the only site where chlorophyll α (phytoplankton) was very likely degrading over time, accompanied by changes in surface water oxygen saturation, and turbidity levels were high and very likely degrading. A hydrodynamic, and nutrient model for the Manukau Harbour is in development by Watercare which will improve our understanding of nutrient dispersal and phytoplankton responses for this harbour.

Turbidity levels were generally found to be low and improving within the southern half of the Kaipara Harbour except near the mouth of the Kaipara (and Kaukapakapa) River. While turbidity was also very likely improving, turbidity is frequently elevated in this area (poor water clarity) and increasing muddiness has been found on the adjacent sandbanks (Drylie, 2021). Reducing sedimentation is a primary focus of the Kaipara Moana Remediation programme that has recently received significant government investment.

Previous analysis found that coastal surface water temperatures were significantly increasing from 2007 to 2016 (Foley et al. 2018), and subsequent marine heatwave events in 2018 and 2019 returned very likely increasing trends in temperature across the time period assessed here. Further assessment of the rate of change shows that surface waters were warming faster on the west coast within the Kaipara and Manukau Harbours, consistent with national level projections of greater warming in the Tasman Sea (Pearce et al. 2017).

A key direction for Auckland is to manage the effects of urban growth and development on our natural environment. The greatest changes in land cover (and inferred land use) over the past 10 years (summer 2008/09 to 2018/19) were associated with urban growth in the Hibiscus Coast, Waitematā, and Tāmaki watersheds (Appendix B). These include the major urban developments of Orewa and Silverdale (Hibiscus Coast), Flat Bush and Highbrook (Tāmaki), and Hobsonville and Albany in the upper Waitematā. While several water quality parameters were found to be degrading within the Waitematā Harbour, these trends were not specifically associated with Lucas Creek, or Hobsonville which are the primary receiving catchments for these greenfield growth areas. Notable improvements in dissolved oxygen saturation and turbidity were observed within the Tāmaki Estuary.

4.1 Response to previous recommendations

The last regional water quality state and trends report made four key recommendations for future analyses (Foley et al. 2018).

The first two recommendations are in relation to broader management and policy responses across Auckland Council and council-controlled organisations to seek to improve water quality outcomes and further commentary on this is outside of the scope of this report.

It was recommended to review the integration of the monitoring network across state of the environment programmes which is also outside of the scope of this report. However, it is noted that monitoring requirements will be reviewed in relation to expanding requirements under the National Policy Statement for Freshwater Management (NPS-FM 2020) as they pertain to sensitive coastal receiving environments.

Lastly, it was recommended that continuous water quality monitoring could be undertaken in select locations to improve our understanding of variability in water quality over time particularly during high flow and storm conditions. Auckland Council is currently partnering with the National Institute of Water and Atmospheric Research (NIWA) in their 'Managing Mud' programme. This programme includes installation/monitoring of an array of three continuous water quality monitoring buoys in the Wairoa River coastal embayment by Auckland Council. The programme aims to link coastal suspended sediment and turbidity parameters with stream derived sediment loads and to track the sources of sediments to enable improved catchment management.

4.2 Knowledge gaps and future directions

A method has been developed through the National Institute of Water and Atmospheric Research to predict the susceptibility of New Zealand estuaries to the effects of excess nutrient inputs or eutrophication, assess the current trophic state, and to predict how changes in nutrient inputs may affect estuaries (Robertson et al. 2016a, Robertson et al. 2016b; Plew et al. 2020). The Estuarine Trophic Index (ETI) tools are based on an assessment of the total load of nitrogen inputs to an estuary, the physical type of estuary (e.g. intertidal area, depth, extent of mixing), and the responses of macroalgae and/or phytoplankton to nutrient inputs within those environments as primary indicators.

This approach has recently been further extended to consider the effects on estuaries associated with setting limits for nitrogen for receiving environments under the National Policy Statement for Freshwater Management, assuming that current state criteria for macroalgae or phytoplankton responses were equivalent to the bottom-line approach set by the freshwater national objectives framework (NOF) (Snelder et al. 2020). It is noted that the macroalgae responses are currently based primarily on estuaries from the South Island, and the phytoplankton response guidelines are based on Basque estuaries and are proposed as interim values only (Plew et al. 2020).

Further consideration of this approach is necessary for the Auckland region including, but not limited to, refinement of the modelled nutrient loads such as with the Auckland LSPC+ model, and assessment of the responses of marine algae to nutrient loads within Auckland estuaries with particular consideration of potential light limitation associated with turbidity. It is anticipated that a discussion paper with be prepared with a particular emphasis on tools for the assessment of the current trophic state of our estuaries as this is of direct relevance to our evaluation of the state of the environment undertaken to support our obligations under the Resource Management Act 1991.

There are inherent limitations in discrete monthly water quality monitoring in both spatial and temporal coverage, of changes in coastal water quality. As outlined above, continuous water quality monitoring is currently being undertaken within the Wairoa embayment and other additional information sources include remote sensing, providing wide spatial coverage, at regular (daily to monthly coverage) time intervals.

NIWA has undertaken development of a GIS imagery service for satellite remote sensing of water quality data, including water temperature, chlorophyll α concentrations (phytoplankton), and several measures of water clarity including data from July 2002 to present (Pinkerton et al. 2020-Demo). This imagery service provides proxies of these variables, or a semi-quantitative estimation that requires regional validation. The continuous water quality monitoring currently being undertaken provides an opportunity to undertake such validation in the future. The resolution of the satellite imagery does not provide information for upper estuarine, tidal creek, or near shore environments or for individual sites. However, future use of this service could enable assessment of current water quality state, and trends over time, at a harbour-wide scale, or to assess transects or other spatial distribution information within Auckland such as providing more information on the relative influences of oceanic, and land derived inputs to coastal water quality.

The analysis presented here forms part of the knowledge base supporting the future work necessary to develop the long-term vision for Auckland's waterways, to set effective objectives considering their influence on estuaries and the wider coastal environment as Auckland Council responds to the requirements set out in the National Policy Statement for Freshwater Management (2020).

5.0 Acknowledgements

The Auckland Council coastal water quality monitoring programme has benefitted from the efforts of numerous people since its inception in 1987.

We acknowledge the efforts of several Environmental Specialist staff and students from RIMU who undertook sample collection and quality control processes over the past 10 years with particular thanks to current specialists Dimitri Colella, Natalie Gilligan, Sheldon Benito, and Martin Meyer. Thanks to Vanitha Pradeep and Jade Khin for data management and quality assurance processes.

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Appendix A Summary of analytical methods

Table 6-1: Analytical methods for water quality parameters assessed.

Parameter	Units	Lab/ Field	Equipment/ 2010-2014	Equipment 2014-2019	Detection Limit	Detection Limit
Dissolved oxygen	% sat	Field	YSI 556	EXO sonde, optical method	0	0
Dissolved oxygen	mg/L	Field	YSI 556	EXO sonde, optical method	0	0
Temperature	°C	Field	YSI 556	EXO sonde, thermistor	-5	-5
Conductivity	mS/cm	Field	YSI 556	EXO sonde, 4-electrode nickel cell	0	0
Salinity	ppt	Field	YSI 556	EXO sonde, 4-electrode nickel cell	0	0
pH		Field	YSI 556	EXO sonde, glass combination electrode	0	0
Parameter	**Units**	**Lab/ Field**	**WCS Lab Method 2010-2017**	**Hills Lab Method 2017-2019**	**WCS Detection Limit**	**Hills Detection Limit**
Total suspended solids	mg/L	Lab	APHA (2005/2012) 2540 D	APHA (2017) 2540 D	0.2	3
Turbidity	NTU	Lab	APHA (2005-2012) 2130 B (Mod)	APHA (2017) 2130 B (Mod)	0.05	0.05
Ammoniacal nitrogen	mg N/L	Lab	APHA (2005-2012) 4500-NH3 G (Mod) APHA (online edition) 4500-NH3 H (from July 2016)	APHA (2017) 4500-NH3 H (Mod)	0.005	0.005
Total oxidised nitrogen	mg N/L	Lab	APHA (2005-2012) 4500-NO3 F (Mod)/ APHA (online edition) 4500-NO3 I (from July 2016)	APHA (2012) 4500-NO3 I	0.002	0.001
Total nitrogen	mg N/L	Lab	APHA (2005-2012) 4500-P J, 4500-NO3 F (Mod) / APHA (online edition) 4500-P J (Mod),4500-NO3 I (from July 2016)	APHA (2017) 4500-N C, 4500-NO3 I (Mod)	0.02/ 0.01 (from Sept 2014)	0.01
Dissolved reactive phosphorus	mg P/L	Lab	APHA (2005-2012) 4500-P B, F (Mod) APHA (online edition) 4500-P F	APHA (2017) 4500-P G (Mod)	0.005/ 0.002 (from Sept 2014)	0.001
Total phosphorus	mg P/L	Lab	APHA (2005-2012) 4500-P B, J (Mod)	APHA (2017) 4500-P B, E (Mod)	0.005/ 0.004 (from Sept 2014)	0.004
Chlorophyll a	mg/L	Lab	APHA (2005-2012) 10200 H (Mod) Spectroscopy	APHA (2017) 10200 H (Mod) Flurometry	0.0006	0.0002

Appendix B Land Cover Aggregation

Table 6-2: Summary of LCDB Land Cover Classes and Broad Aggregations.

LCDB Land Cover Classes within catchments upstream of river water quality monitoring sites	Aggregated Land Cover Classes	Broad Level Dominant Land Cover
Broadleaved Indigenous Hardwoods	Native forest	Native
Indigenous Forest	Native forest	Native
Manuka and/or Kanuka	Native forest	Native
Deciduous Hardwoods	Exotic forest	Exotic
Exotic Forest	Exotic forest	Exotic
Forest – Harvested	Exotic forest	Exotic
Orchard, Vineyard or Other Perennial Crop	Horticulture	Rural
Short-rotation Cropland	Horticulture	Rural
Gorse and/or Broom	Rural	Rural
High Producing Exotic Grassland	Rural	Rural
Low Producing Grassland	Rural	Rural
Built-up Area (settlement)	Urban	Urban
Transport Infrastructure	Urban – Transport Infrastructure	Urban
Urban Parkland/Open Space	Urban Parkland	Urban
Sand or Gravel	Other	NA
Surface Mine or Dump	Other	NA
Lake or Pond	Water	NA
Mangrove	Water	NA
Flaxland	Wetland	NA
Herbaceous Freshwater Vegetation	Wetland	NA

Summary of changes in land cover

Across the Auckland region, the overall proportion of land cover (based on LCDB 5.0 only) within each watershed has been relatively consistent over the trend analysis period. The greatest changes in the last 11 years (summer 2008/09-2018/19) were associated with urban growth in the Hibiscus Coast, Waitematā, and Tāmaki watersheds (Table 6-3). These include the major urban developments of Orewa and Silverdale (Hibiscus Coast), Flat Bush and Highbrook (Tāmaki), and Hobsonville and Albany in the upper Waitematā.

Table 6-3: Summary of changes in urban land cover within each major watershed over the 10-year period.

Watershed	Percentage of watershed with urban land cover	
	2008	**2018**
Islands	2.0%	2.0%
North East	1.9%	1.9%
Mahurangi	4.6%	5.1%
Hibiscus Coast	**22.0%**	**25.4%**
Waitematā	**48.6%**	**49.9%**
Tāmaki	**52.2%**	**55.0%**
Wairoa	0.3%	0.3%
Manukau Harbour	15.6%	16.3%
Kaipara	0.7%	0.8%

Appendix C Selected time series plots

Note Y axes vary between plots to best fit the data for the specific site and parameter

Salinity

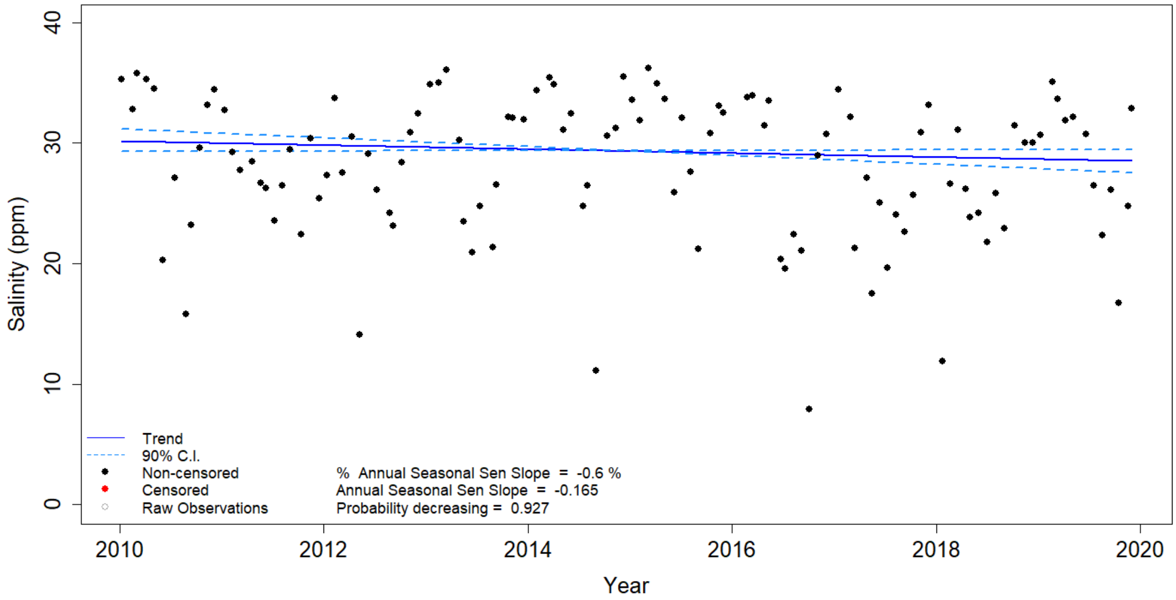


Figure 6-1: Field observations of salinity over time fitted with annual Sen Slope and 90% confidence intervals for Lucas Creek.

Dissolved oxygen

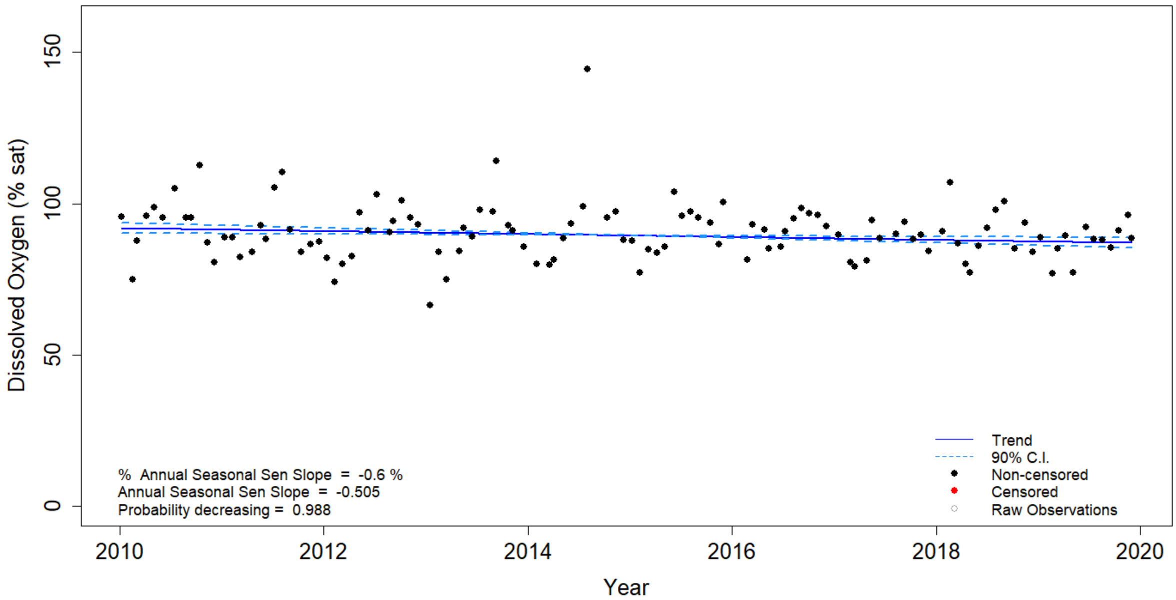
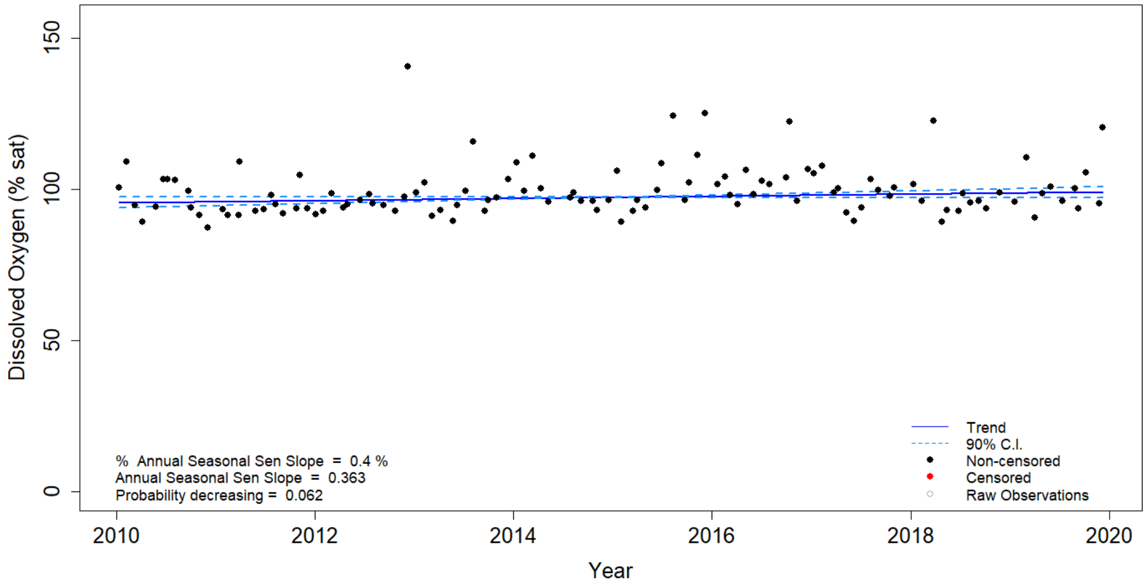
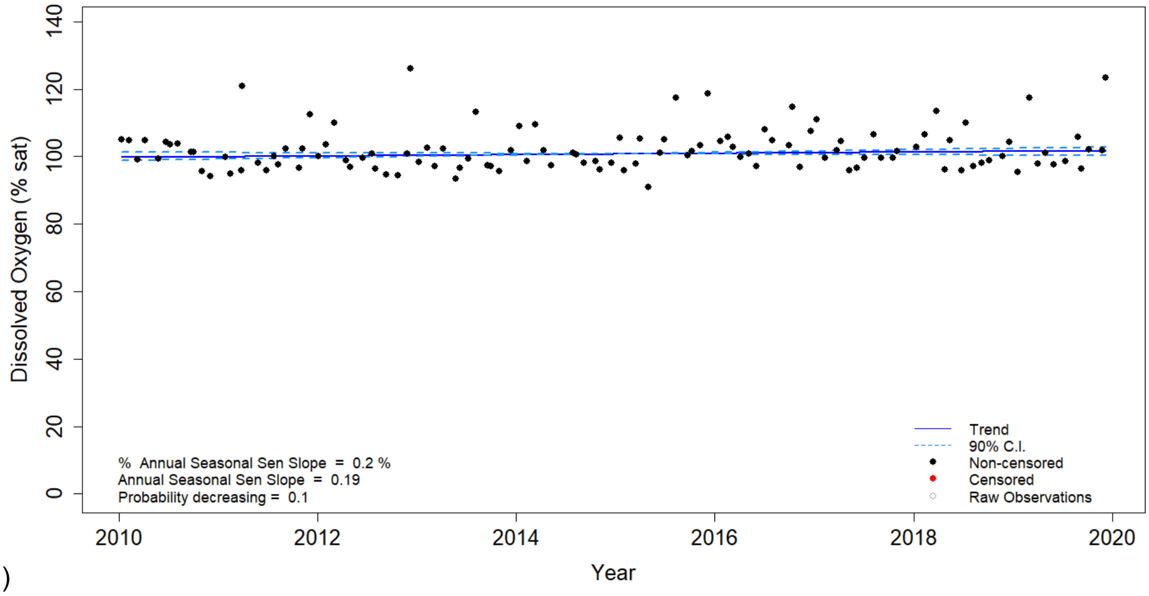


Figure 6-2: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals for Rangitopuni Creek.

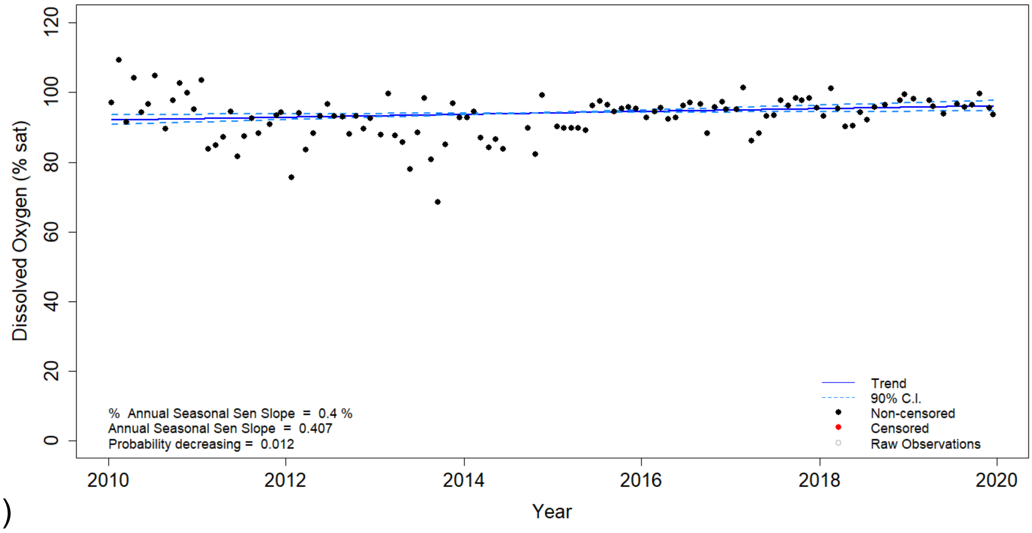


i)

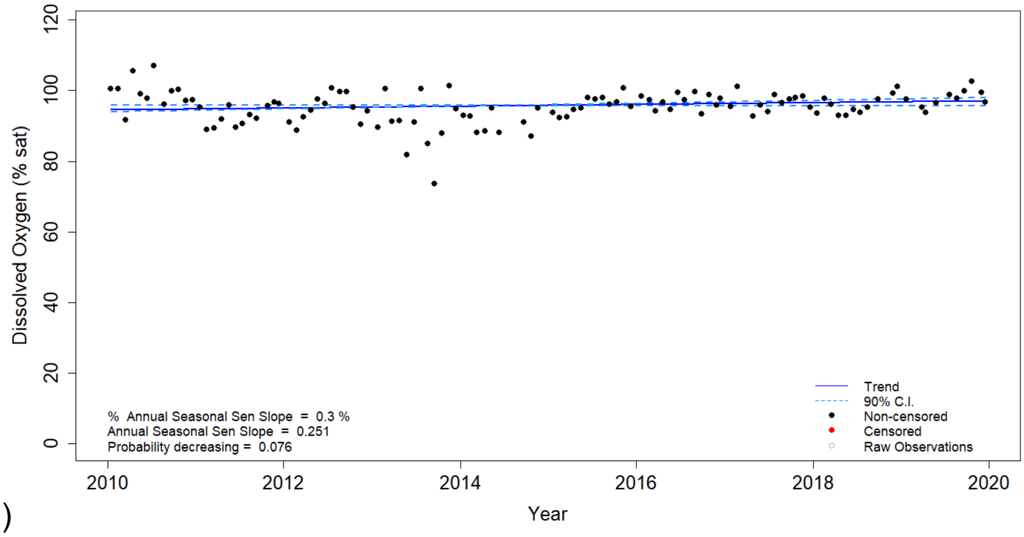


ii)

Figure 6-3: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals in the northern Manukau Harbour i) Mangere Bridge and ii) Puketutu Island.



i)



ii)

Figure 6-4: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals for Tamaki Estuary i) Panmure and ii) Tamaki at Half Moon Bay.

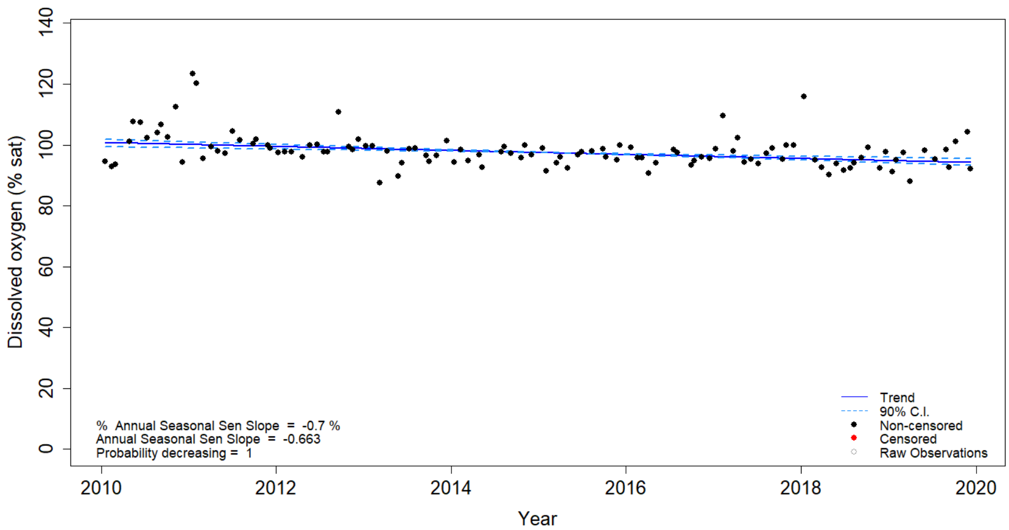
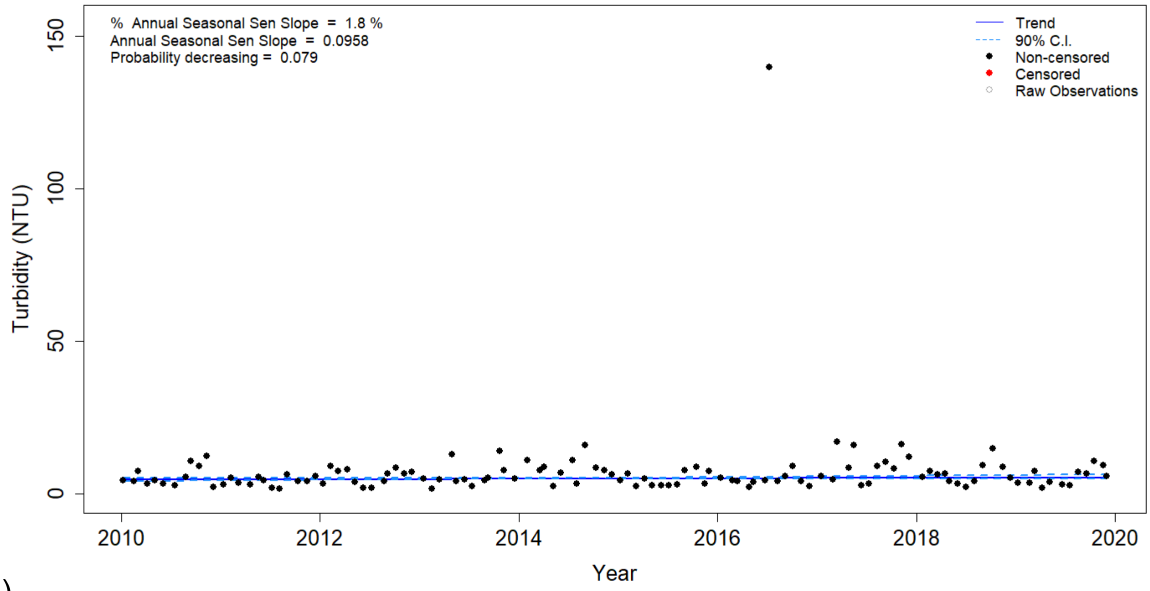
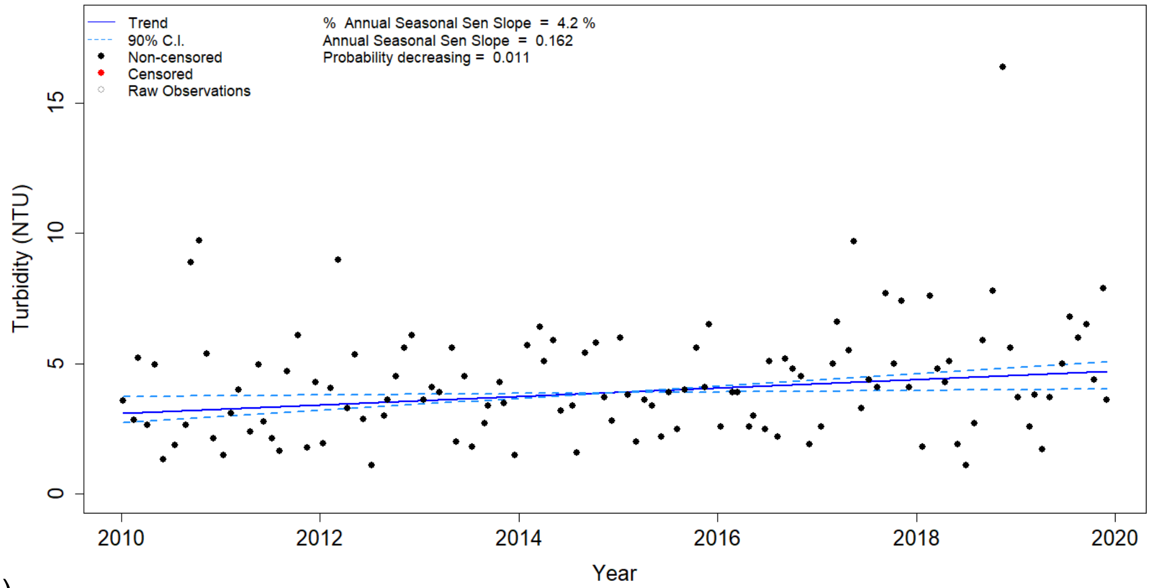


Figure 6-5: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals for Kaipara River.

Turbidity



i)



ii)

Figure 6-6: Field observations of turbidity over time fitted with annual Sen Slope and 90% confidence intervals in the central Waitemata Harbour i) Henderson Creek and ii) Whau Creek.

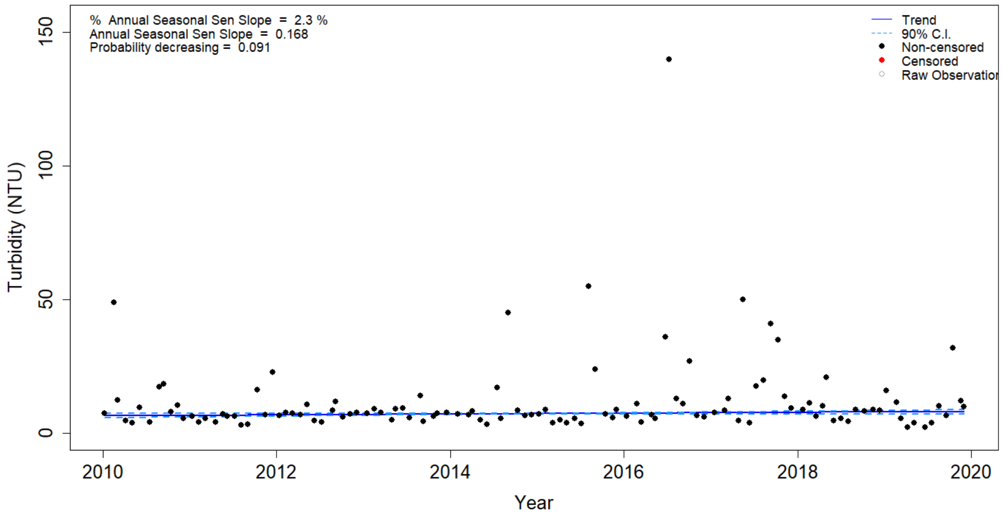


Figure 6-7: Field observations of turbidity over time fitted with annual Sen Slope and 90% confidence intervals for Rangitopuni Creek.

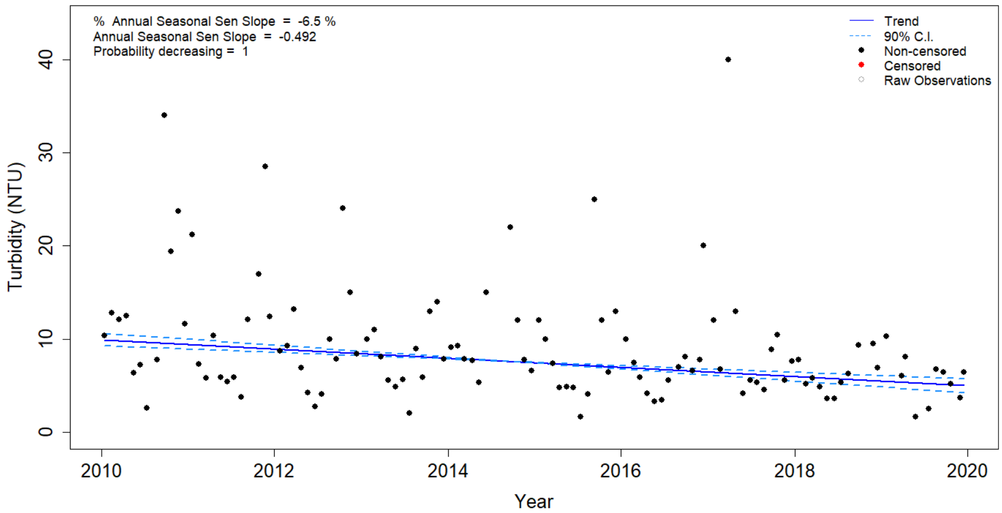


Figure 6-8: Field observations of turbidity over time fitted with annual Sen Slope and 90% confidence intervals for Tamaki Estuary – Panmure.

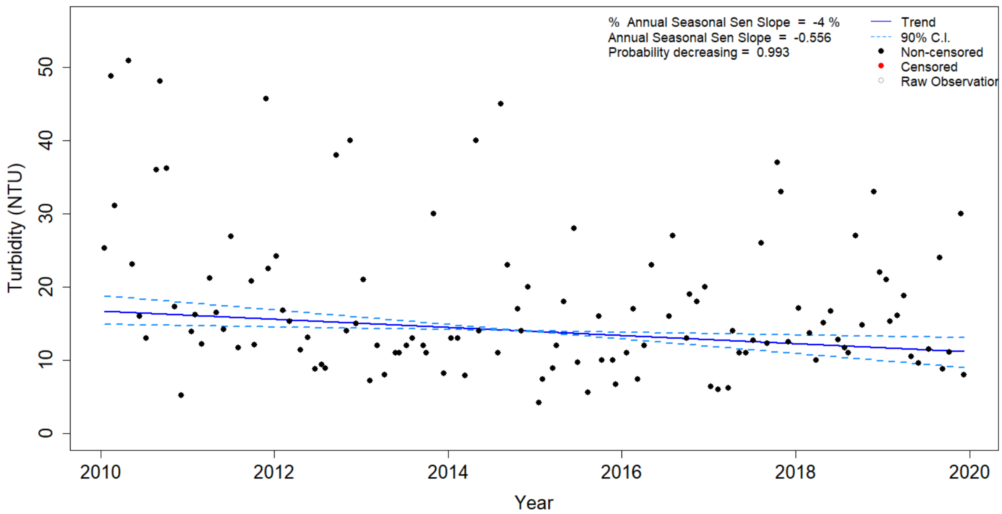
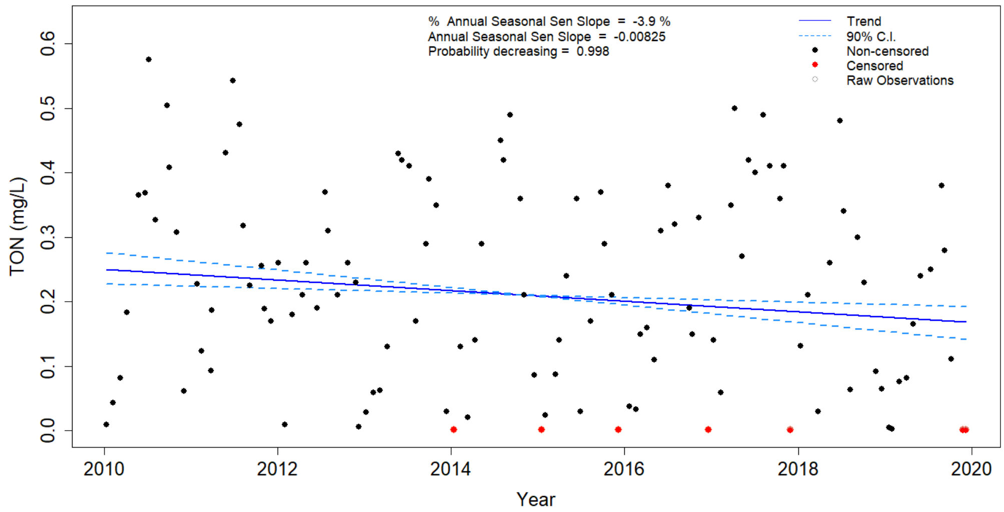
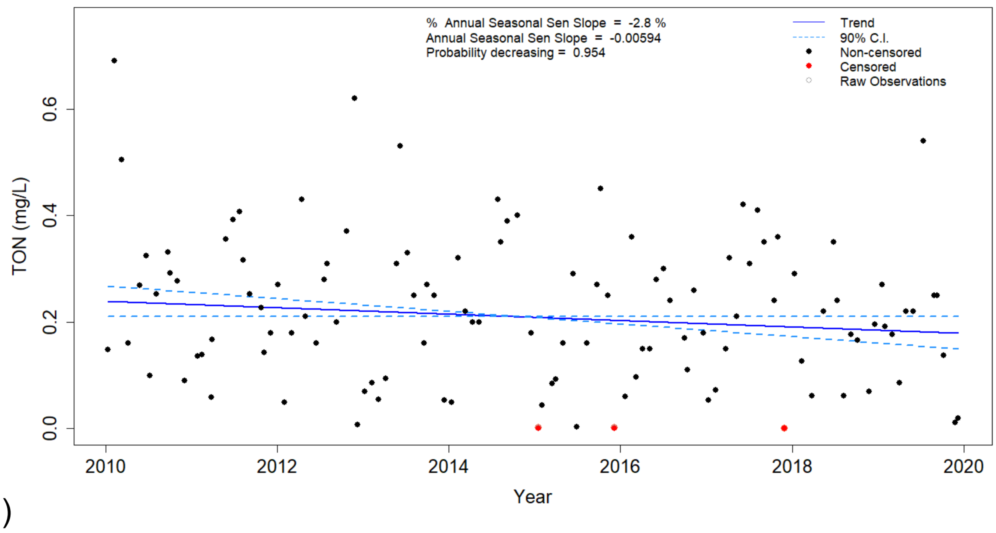


Figure 6-9: Field observations of turbidity over time fitted with annual Sen Slope and 90% confidence intervals for Kaipara River mouth.

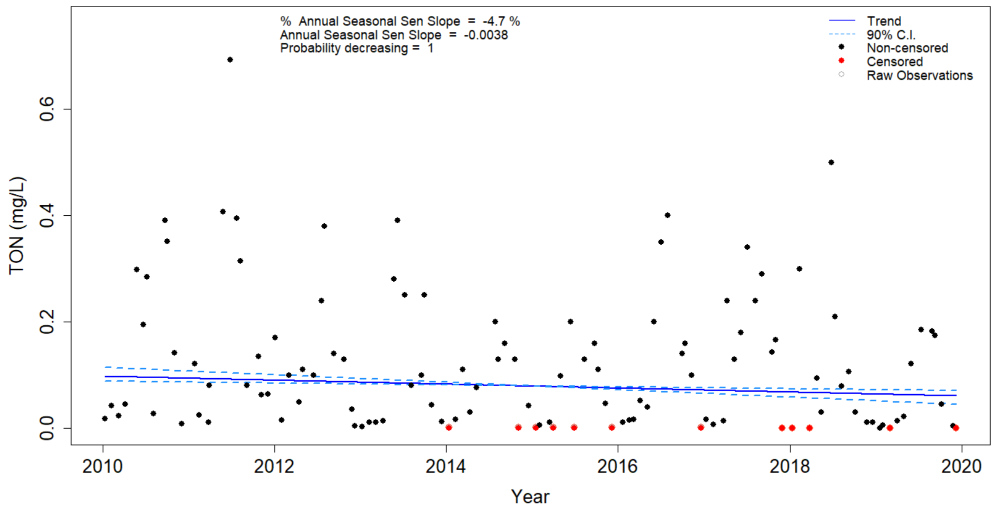
Total Oxidised Nitrogen



i)



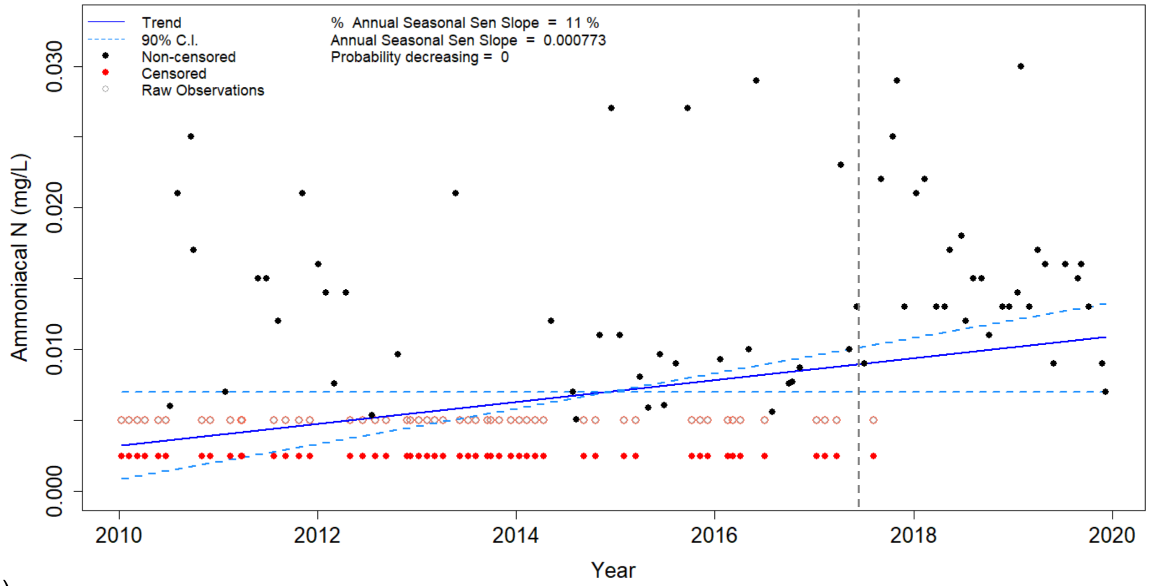
ii)



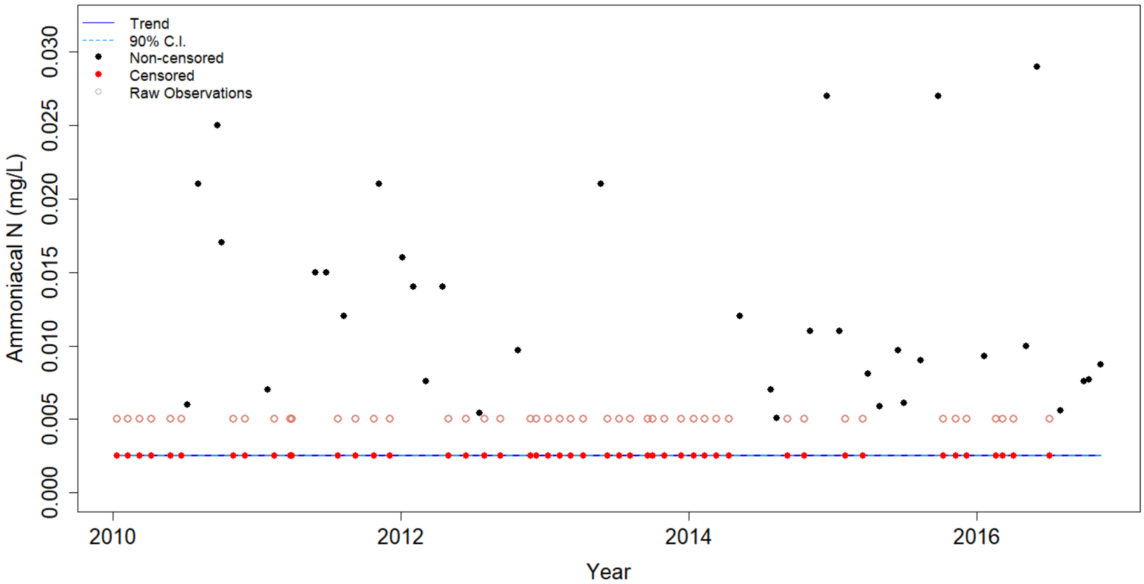
iii)

Figure 6-10: Field observations of total oxidised nitrogen over time fitted with annual Sen Slope and 90% confidence intervals in the Manukau Harbour at i) Mangere Bridge, ii) Puketutu Island, and iii) Weymouth.

Ammoniacal N



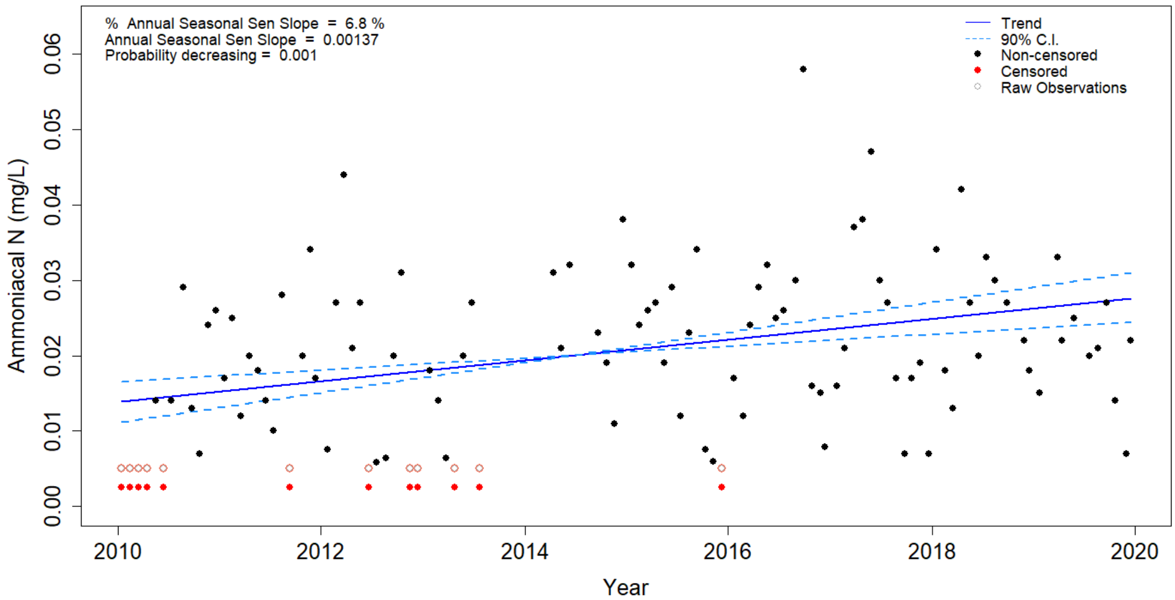
i)



ii)

Figure 6-11: Field observations of ammoniacal nitrogen over time fitted with annual Sen Slope and 90% confidence intervals at the Manukau Heads showing the influence of analytical changes between:

- **i) the full ten-year period with service change from July 2017 shown by black dashed line**
- **ii) partitioned to the calendar year before the lab change.**



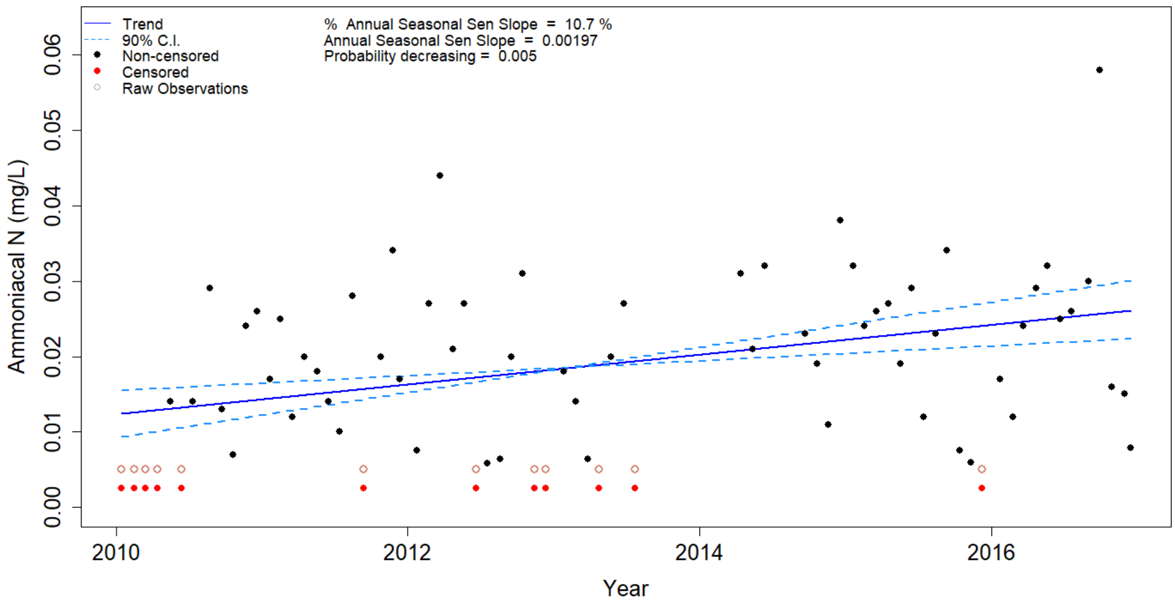
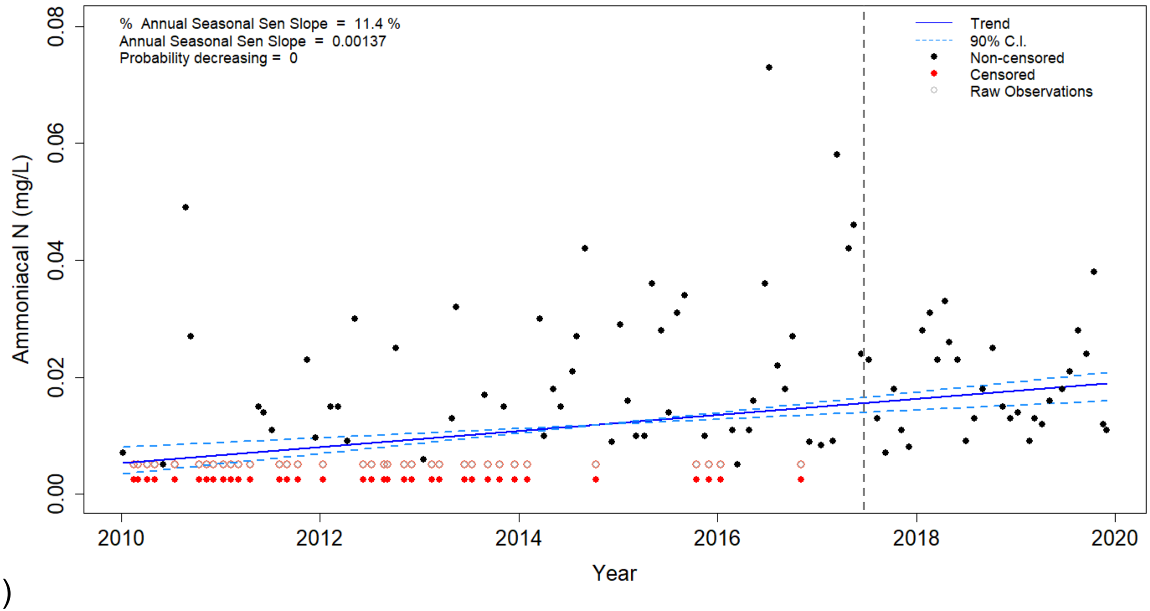
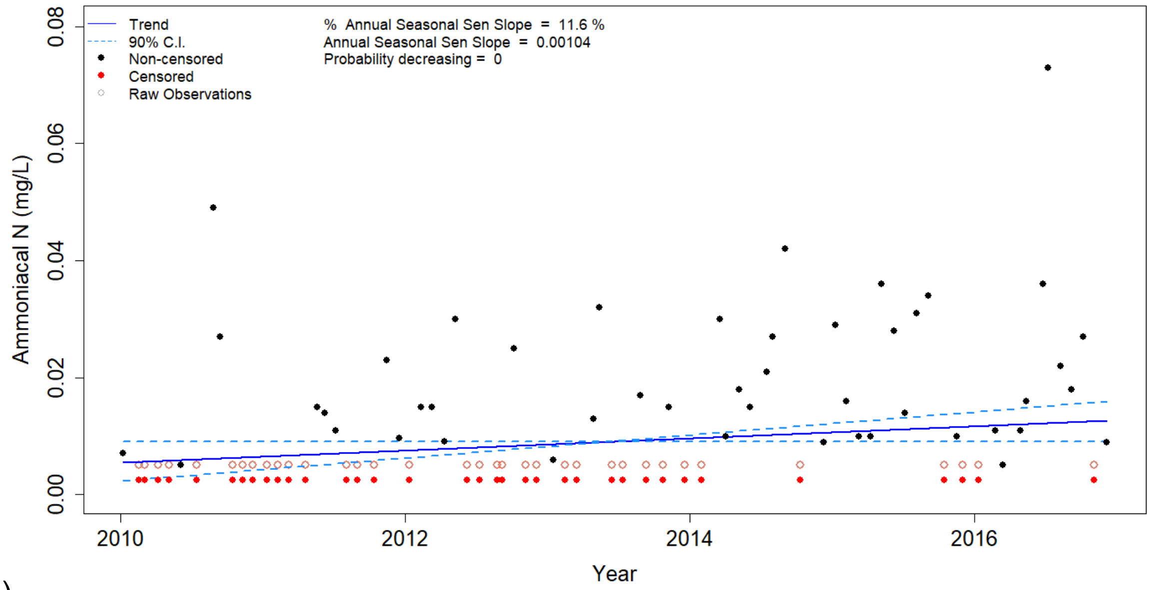


Figure 6-12: Field observations of ammoniacal nitrogen over time fitted with annual Sen Slope and 90% confidence intervals at Tamaki Estuary - Tamaki showing the influence of analytical changes between:

- **i) the full ten-year period with service change from July 2017 shown by black dashed line**
- **ii) partitioned to the calendar year before the lab change.**



i)

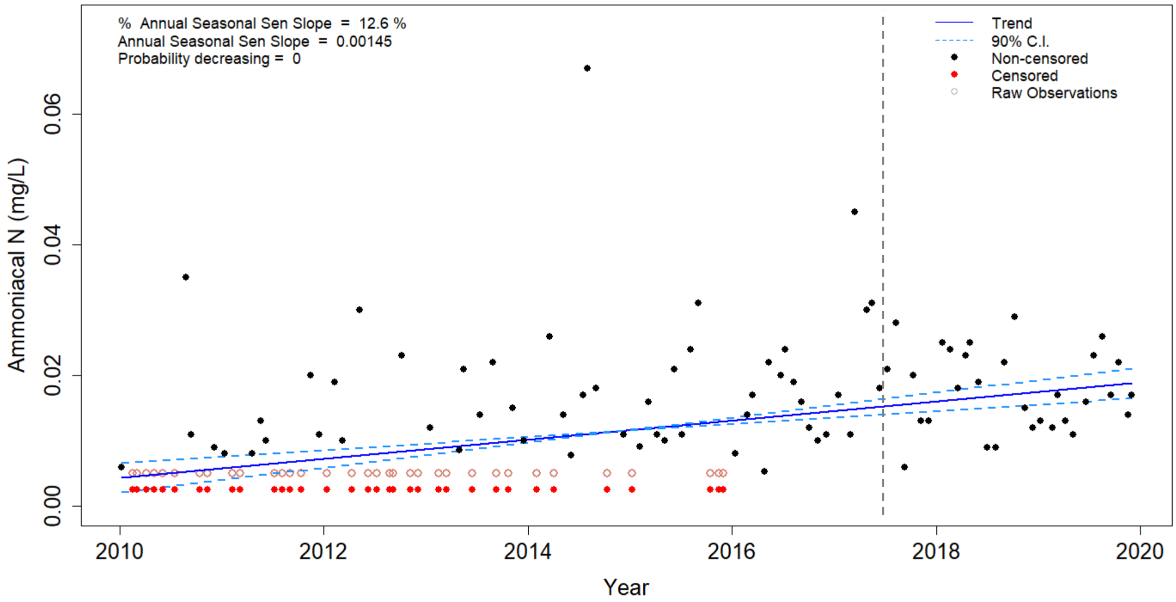


ii)

Figure 6-13: Field observations of ammoniacal nitrogen over time fitted with annual Sen Slope and 90% confidence intervals at Henderson Creek showing the influence of analytical changes between:

i) the full ten-year period with service change from July 2017 shown by black dashed line

ii) partitioned to the calendar year before the lab change.



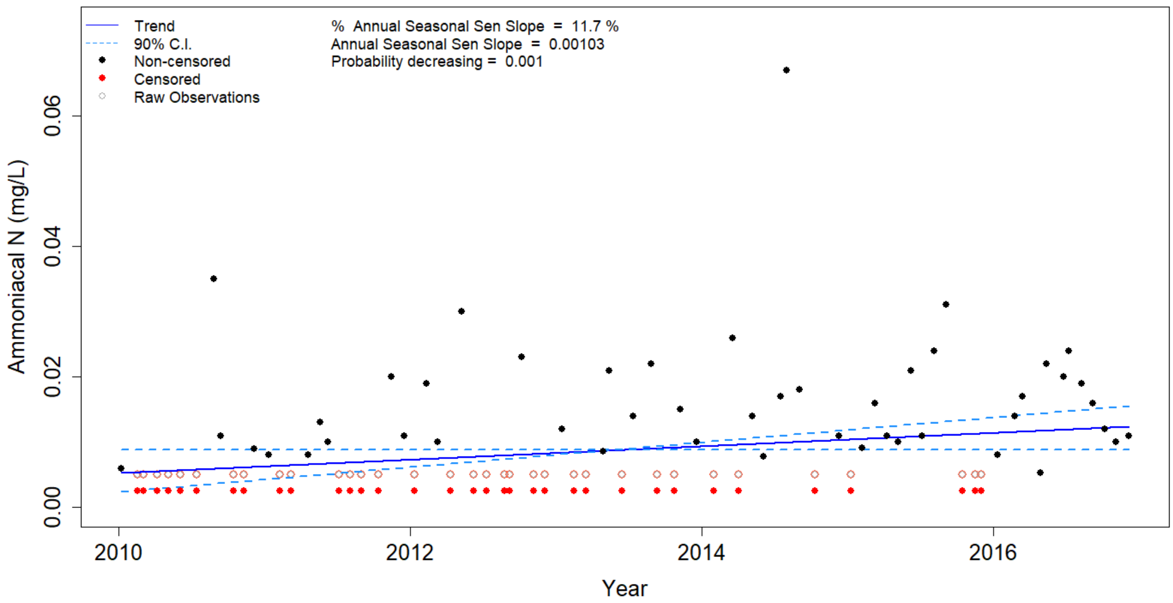
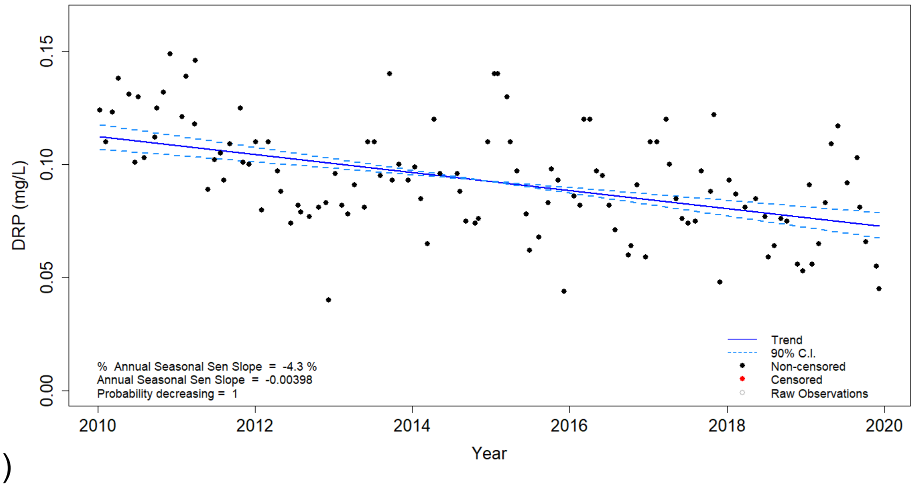


Figure 6-14: Field observations of ammoniacal nitrogen over time fitted with annual Sen Slope and 90% confidence intervals at Whau Creek showing the influence of the analytical changes between:

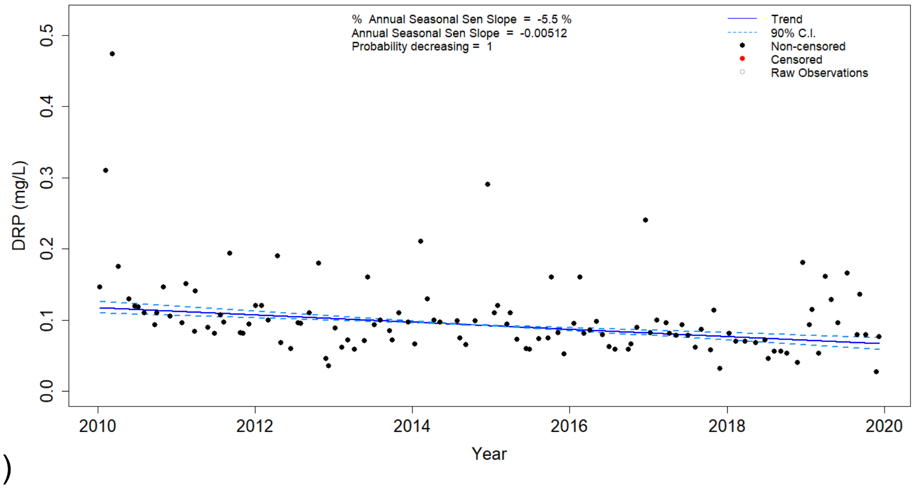
iii) the full ten-year period with service change from July 2017 shown by black dashed line

iv) partitioned to the calendar year before the lab change.

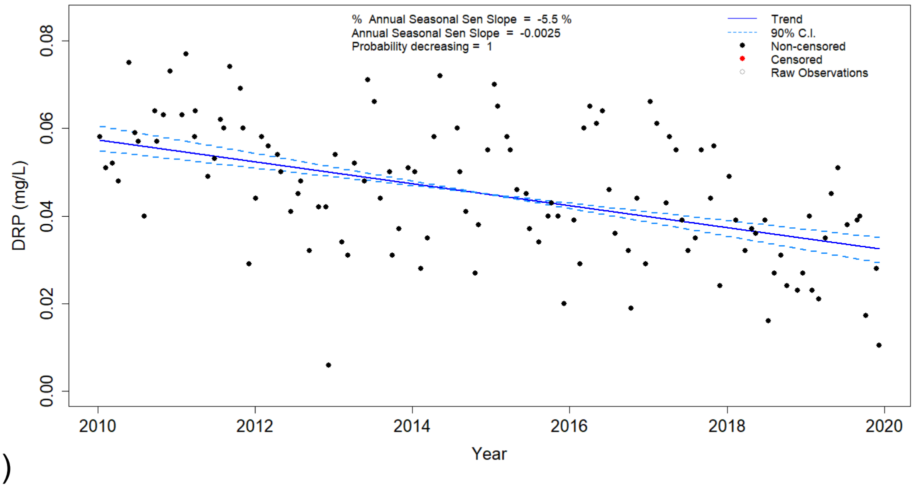
DRP



i)



ii)



iii)

Figure 6-15: Field observations of dissolved reactive phosphorus over time fitted with annual Sen Slope and 90% confidence intervals in the northern Manukau Harbour i) Mangere Bridge, ii) Puketutu Island, and iii) Shag Pt.

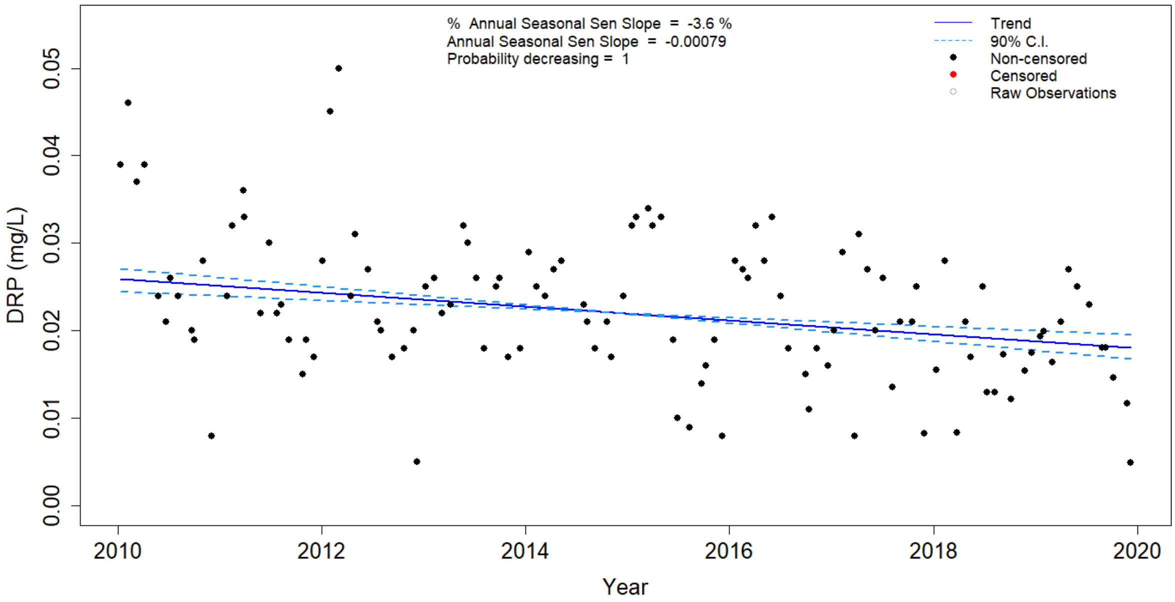


Figure 6-16: Field observations of dissolved reactive phosphorus over time fitted with annual Sen Slope and 90% confidence intervals in the Manukau Harbour at Weymouth.

Chlorophyll a

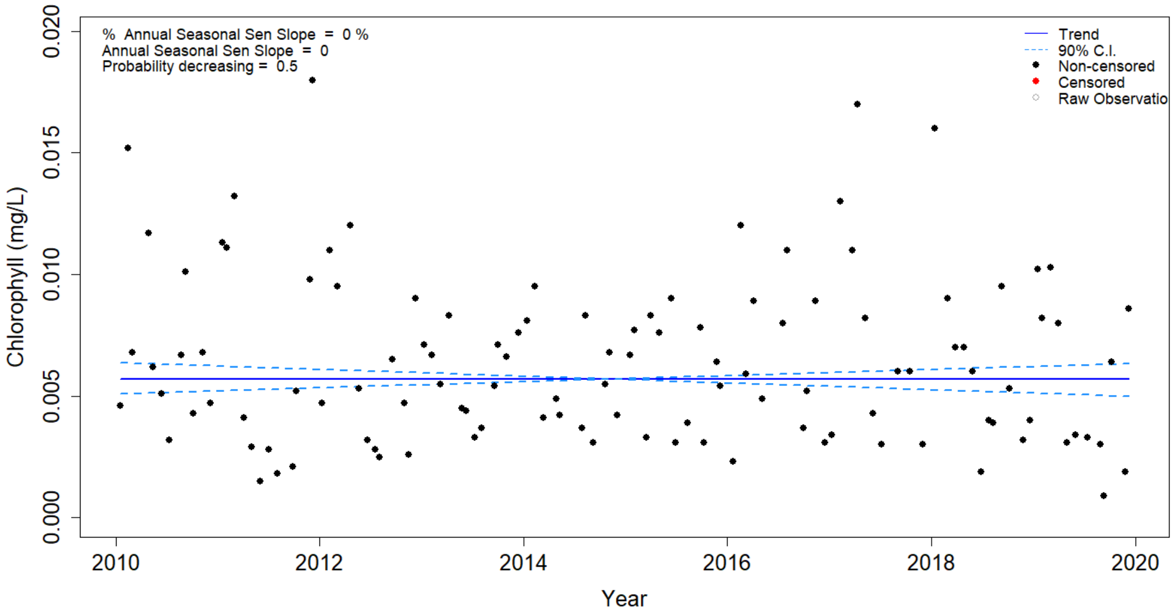


Figure 6-17: Field observations of chlorophyll α over time fitted with annual Sen Slope and 90% confidence intervals at Kaipara River mouth.

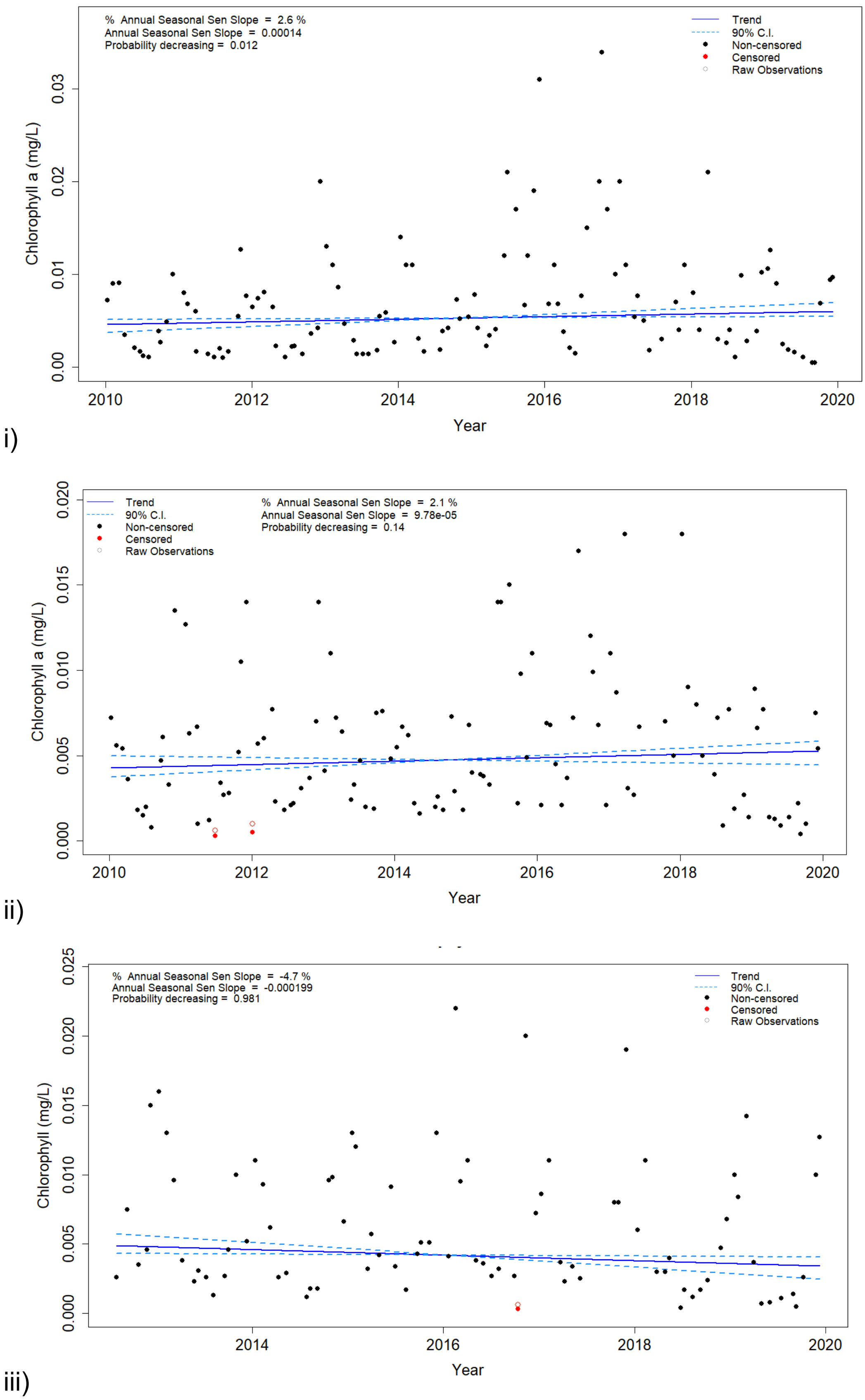


Figure 6-18: Field observations of chlorophyll a over time fitted with annual Sen Slope and 90% confidence intervals in the Manukau Harbour at i) Mangere Bridge, ii) Weymouth and iii) Waiuku Town Basin.

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