Periphyton in Northland rivers

Testing national nutrient criteria, and an analysis of predictors of biomass and cover within the region

Prepared for Northland Regional Council

August 2024

Climate, Freshwater & Ocean Science

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NIWA CLIENT REPORT No: 2023259CH
Report date: August 2024
NIWA Project: ELF24503

Revision	Description	Date
Version 1.0	Final version sent to client	14 September 2023
Version 1.1	Revised final version sent to client	5 April 2024
Version 1.2	Finalised report sent to client	30 August 2024

Quality Assurance Statement		
	Reviewed by:	Michelle Greenwood
	Formatting checked by:	Rachel Wright
	Approved for release by:	Phillip Jellyman

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Executive summary

Northland Regional Council (NRC) approached NIWA and LWP Ltd requesting an analysis of their dataset of periphyton biomass and environmental variables. The background to the request included (a) the requirement in Clause 3.13 in the National Policy for Freshwater Management (NPS-FM) 2020 (updated 2024) to set nutrient concentration criteria for nitrogen and phosphorus for periphyton and other nutrient-affected attributes, (b) the recent availability of national nutrient criteria for periphyton and guidance around their use and (c) local deadlines related to notification of new Northland Regional Plan provisions to give effect to the NPS-FM. The analysis had the following objectives.

1. An assessment of periphyton state at all sites against the periphyton attribute of the NPS-FM and against the New Zealand Guideline for Cyanobacteria.

2. An evaluation of whether the national nutrient criteria recently released by the Ministry for the Environment, with guidance (the 2022 MFE guidance), and updated revised criteria following further analysis, are suitable for setting nutrient concentration criteria for managing periphyton in Northland rivers; and

3. if the outcome of item 2 is that the criteria are not suitable, suggestions / calculations to determine instream concentration criteria for nitrogen and phosphorus to keep periphyton biomass in Northland above the national bottom-line (D band) defined in the NPS-FM periphyton attribute.

4. An updated understanding of the main predictors of periphyton biomass (as chlorophyll *a*) across the Northland region, including an evaluation of the relative influence of the different nutrient variables for which there are data (dissolved inorganic nitrogen (DIN), dissolved reactive phosphorus (DRP), total nitrogen (TN), total phosphorus (TP), ammoniacal nitrogen (NH_4-N), nitrate-nitrite nitrogen (NOx-N) and total Kjeldahl nitrogen (TKN)); and

5. a parallel understanding of relationships between environmental variables and periphyton cover from visual estimates.

The dataset provided by NRC comprised data on periphyton biomass (chlorophyll *a*, CHLA) and cover and associated environmental data. Observations of cover in different periphyton categories were summarised as weighted composite cover (WCC). The dataset spanned up to eight years (from 2015 to 2022) and there were sufficient data for analysis from 38 monitoring sites.

The environmental data included monthly nutrient concentrations (TN, DIN, NOx-N, TKN, NH_4-N, TP, DRP), other water quality variables (monthly electrical conductivity (EC), pH, water temperature, turbidity, visual clarity), and physical habitat variables (bed substrate composition, shade). River flow data were available for 21 periphyton monitoring sites.

Continuous temperature data were available for 16 sites. An analysis of the continuous temperature data indicated reasonable correspondence with monthly spot temperature data at the 16 sites. The spot temperature data from all 38 sites were therefore used in subsequent analyses.

The state of periphyton at Northland's monitoring sites (objective 1)

Grading into bands A, B, C or D of the periphyton attribute was based on calculations of the 92nd percentile of chlorophyll *a* (mg m^{-2}) using at least 3 years of monthly data Thresholds separating bands A and B, B and C and C and D are, respectively, 50, 120 and 200 mg chlorophyll *a* /m^2. When the 92nd percentile in a time series exceeds one of these thresholds, at least three samples in a 36-sample time series (i.e., three complete years with no missed surveys) have exceeded the threshold.

Each time series was adjusted to account for gaps in the time series assuming that the main reason for missed surveys was high flows. We replaced missing data with a value that was the 5th percentile of the existing data (i.e., 95% of the samples had a higher value), which typically represents a thin film. Under high flows at most sites, periphyton tends to be low. Not accounting for missed surveys could bias the 92nd percentile towards a higher value.

We also used the alternative grading method of counting exceedances of the NPS-FM attribute thresholds over each 3 years of data, where at least three exceedances placed the site in the lower (i.e., higher biomass) band.

Based on all the data (up to 8 years), 5% of sites were graded D, 11% into band C, 39% into band B and 45% into band A. Sites placed in band D were Waiharakeke at Stringers Road and Hakaru at Topuni. Sites placed in band C were Awanui at FNDC, Waipapa at Landing, Watercress at SH1, and Opouteke at Suspension Bridge.

Had the data not been adjusted to account for gaps in the time series one more site would have been in band D (Awanui at FNDC, bringing the percentage to 8%) and one fewer site in band A (bringing the percentage to 42%).

Over the same eight-year period, the New Zealand Guideline for Cyanobacteria Alert level (20 – 50 % cover by cyanobacteria) was reported at 15 sites on a total of 36 occasions, and the Action level (more than 50% cover) at eight sites on a total of 17 occasions. There were no reports of either Alert or Action levels at 22 sites.

In terms of frequency of exceedances of the Alert and Action levels, the most affected sites were Waimate at Waimate North Road (exceedances in five of the eight years) and Opouteke at Suspension Bridge (exceedances in four of eight years).

The highest numbers of exceedances were in 2015 (10 Alerts and three Actions) followed by 2020 (four Alerts and eight Actions). Both 2015 and 2020 were relatively dry years.

Validation of MFE nutrient criteria (objectives 2 and 3)

The nutrient criteria for TN, DIN, TP and DRP provided in the 2022 MFE guidance for managing periphyton in rivers and streams are intended for use at a regional scale with specification of "under-protection risk". Under-protection risk acknowledges the uncertainty of the models underlying the criteria. The under-protection risk is the probability that the 92nd percentile of CHLA (CHLA92 – the metric specified in the NPS-FM periphyton attribute) at a given site will exceed the target value (e.g., NPS-FM bottom line of 200 mg m^{-2}) even though the observed nutrient concentration is lower than the criterion for that site.

The criteria apply nationally to all hard-bottomed streams classified into source-of-flow classes in the River Environment Classification (REC; i.e., different criteria apply to different REC classes).

The published nutrient criteria for periphyton were evaluated against the NRC data by following the procedure set out in the 2022 MFE guidance. The outcome was that the national nutrient criteria appeared to be too permissive in Northland (i.e., the nutrient concentrations to maintain/achieve the target attribute states for periphyton in the MfE nutrient criteria were too high for Northland rivers).

The procedure was repeated using updated nutrient criteria based on a revised national model fitted using a different statistical approach. The revised criteria were more consistent with the observed data for Northland sites in that the proportion of under-protected sites more closely matched the under-protection risk specified for each criterion.

The results need to be considered in the context of the small validation dataset of only 38 sites, which is a weak basis for inferring the true performance of the criteria. However, we consider that the revised criteria are the best available for Northland at the present time.

The revised criteria are provided in full in this report for all REC source-of-flow classes found in Northland.

Predictors of periphyton biomass and cover in Northland rivers (objectives 4 and 5)

Objectives 4 and 5 were addressed by first considering the effects of river flows on periphyton biomass (as CHLA) and cover (as WCC), across the region and at the 21 monitoring sites that had sufficient periphyton data and suitable paired flow data. We looked at patterns of flow and periphyton across the region by comparing plots of median flows (averaged by year and by month) with averaged CHLA and WCC.

- CHLA and WCC tended to be lower in years when river flows were highest (e.g., 2017 and 2022) and higher in the years of low flows (e.g., 2019, 2020). River flows were four to six times higher in winter (June – August) than in summer (January – March). CHLA and WCC were correspondingly lower in winter, although the summer – winter difference in periphyton abundance were less marked for CHLA than for WCC.
- CHLA and WCC were related ($R^2 > 0.2$) to the number of days since a high flow event at more than 60% of Northland sites (n=21). The high flow of a specified size (in terms of multiple of annual median flow) was identified as the periphyton removal flow (PRF) at a site level that typically re-sets periphyton to low levels.
- The number of days since a high flow event greater than the threshold identified as the PRF is potentially a measure of the accrual time for periphyton, which assumes that (a) the high flow event was large enough to remove periphyton to low levels, and (b) smaller flow perturbations during that time had a much smaller effect on biomass.
- The relationship between days of accrual (i.e., days since a PRF) and CHLA tended to increase in strength as the proportion of large substrate (the sum of large cobbles, boulders and bedrock) on the streambed decreased (i.e., the bed became less stable). This pattern was not seen for WCC.
- Sites with an identifiable periphyton removal flow were categorised into those at which periphyton is frequently removed and those at which periphyton removal is infrequent because large enough flows are rare.

Four quantitative and qualitative techniques were used to try to tease out patterns of periphyton in relation to environmental variables (including nutrient concentrations and flow metrics) across the dataset of 38 sites. The techniques were: Spearman correlations, graphical comparisons of CHLA, WCC and nutrient concentrations at each site, similarity analyses, and general linear models (GLM). The dependent variables were the 92nd percentiles of CHLA (CHLA92) and WCC (WCC92) at each site (except in the graphical comparisons).

- In the correlation analyses, correlates with CHLA92 or WCC92 across the 38 Northland sites were generally consistent with general understanding of the factors that affect periphyton growth and removal, except that correlations between nutrients and WCC92 were negligible and/or negative. The difference arises because chlorophyll *a* (CHLA92) represents living algae that directly responds to nutrients, while periphyton cover (WCC92) includes non-living and non-algal material (e.g., mucilage, bacteria, trapped organic and inorganic detritus, dead and decaying cells), which respond to nutrients differently or not at all.
- While nutrient concentrations were stronger predictors of CHLA92 than of WCC92, all of the relationships were weak (e.g., maximum Spearman r = 0.39, for CHLA92 vs. TKN95).
- Differences in periphyton – environment relationships were identified between groups of sites with different catchment geology, which was either hard sedimentary (HS, 11 sites), soft sedimentary (SS, 7 sites), or volcanic acidic (VA, 20 sites).
- On average, sites with SS geology had higher CHLA92 than HS or VA sites. WCC92 was more uniform across different geologies. SS sites also had higher concentrations of most nutrients (exception was nitrate-nitrogen) and lower water clarity than sites with HS or VA geology.
- Across sites with HS geology, both N and P variables were relatively strongly and positively correlated with CHLA92 (e.g., maximum Spearman r = 0.61, for CHLA92 vs. median nitrate-nitrogen), but not with WCC92. There were strong correlations for both CHLA92 and WCC92 across the SS dataset (but noting the small size of the dataset). Equivalent correlations across VA sites were weak and often negative.
- There was weak evidence from the similarity analyses for a stronger influence of P than N on CHLA92. This became more evident when one unusual site (Ruakaka) was dropped from the dataset. There was also some evidence that nitrate-nitrogen had a stronger effect than the other nutrient variables on clustering of sites based on WCC92 groups.
- Across all 38 sites, the combination of variables percentage cover of the riverbed with large substrate (Large_subs) and modelled mean annual 7-day low flow (MALF7_mod) best explained CHLA92 (40% of the variance); MALF7_mod alone best explained WCC92 (~45% of the variance).
- In GLM analysis, the best model for CHLA92 also selected Large_subs and MALF7_mod as predictors. The best predictor of WCC92 was the 95th percentile of monthly temperature (Temp_95). Inconsistency with the similarity analysis result for WCC92 (in which MALF7_mod was the best predictor) may be explained by the correlation between MALF7_mod and Temp_95 variables and the fact that low flows are known to be associated with higher water temperatures.
- The similarity and GLM analyses both indicated that non-nutrient variables were stronger predictors of both CHL92 and WCC92 than nutrient variables across these Northland sites.
- Moderate to strong correlations between NH_4-N and TKN (which are important forms of N in Northland) and one or more of the other nutrient variables meant that it was

not possible to determine the effects of NH_4-N or TKN in isolation. However, across all sites, the 95th percentile of TKN produced the strongest correlation with CHLA92 of all the nutrient variables.

Recommendations

The following recommendations arose from the analyses described in this report.

- The revised nutrient criteria are recommended for use in Northland because they are based on the best "general" information we currently have about the relationship between nutrient concentration and peak periphyton biomass (CHLA92) in Northland. It should be remembered that the criteria describe the risks of exceeding biomass thresholds across multiple sites. The criteria should not be interpreted as the concentrations that produce a particular biomass outcome at an individual site.
- It is recommended that the choice of under-protection risk should be a management decision. The choice of under-protection risk can make large differences to the nutrient concentration criteria and therefore to the limits on nutrient discharges (both diffuse and point sources) that will be necessary in catchments. The choice of under-protection risk requires consideration of the acceptable level of risk that target attribute states for periphyton biomass will not be achieved. It is noted that, although the criteria associated with various levels of under-protection risk are derived using scientific methods, the choice of the "right" level of risk is not a scientific question and ultimately lies with the decision maker.
- Others (i.e., in the European Union) have suggested that a UPR of 25% is "most likely to be appropriate". For that reason, we recommend that the 25% level could be a starting point for considering the appropriate level of under-protection risk.
- We recommend continuation of monitoring at least at key sites to (a) enable reporting on whether periphyton target attribute states have been met and (b) contribute to future analyses such as trend determination, nutrient criteria validation and nutrient criteria development.
- We also recommend continuation of the monitoring programme at all current sites because a longer dataset would allow further and more robust testing of all the analyses described in this report. Key points related to this are:
  - Confidence around the value of the 92nd percentile of chlorophyll *a* (CHLA92) will increase with length of record because CHLA92 is a measure of peak biomass which is expected to occur under certain combinations of hydrological and other environmental conditions (e.g., favourable temperature). Multiple years of data may be required to capture optimal combinations of conditions.
  - Nine sites included in the current monitoring programme did not have enough data for inclusion in the present analysis. Two of those sites are in catchments with HS geology, one with SS geology and six with VA geology. These additional sites may enable better testing of differences between the three geology classes and better understanding of the role of nutrients in driving periphyton biomass in different parts of Northland.
  - Given that water temperature was the variable most strongly correlated with both CHLA92 and WCC92, we recommend that efforts continue to gather more

robust data on water temperature (such as continuous temperature records) at all the sites currently being monitored. Continuous records from all sites would allow calculation of additional temperature metrics for testing.

  - We recommend that more detailed data on canopy cover is collected at all sites that may be included in future analyses. Canopy cover (%) would enable calculation of other variables including light at the stream bed (in combination with water clarity and depth), which have proved to be useful predictors in earlier analyses.

- We recommend that (1) at least the validation of nutrient criteria is repeated in 3 to 5 years' time with the then available longer datasets and (2) that NRC supports the updating of the national nutrient criteria in the same timeframe with the then available data. By then we can expect the national dataset to have more sites with longer monitoring periods and this will add to the robustness of the derived criteria.

1 Introduction

Periphyton (as standing crop or biomass, measured as chlorophyll *a*) is an ecosystem health attribute in the National Policy Statement for Freshwater Management (NPS-FM). In response to the inclusion of the periphyton attribute in the NPS-FM, several regional councils, including Northland Regional Council (NRC), established programmes of monthly monitoring of periphyton biomass (as chlorophyll *a*, hereafter CHLA) and cover at river sites across their regions, with parallel collection of data describing water quality and habitat characteristics. These regional data collection programmes were intended to enable councils to at least:

A. Grade sites against the NPS-FM periphyton attribute bands; and

B. Explore relationships between periphyton and environmental variables, to facilitate the development of instream nutrient concentration criteria for managing periphyton biomass.

Regarding A, the NPS-FM periphyton attribute defines as the algal component of periphyton as chlorophyll *a*, mg m^{-2}. Exceedances of specified biomass thresholds are allowed in no more than 8% of samples (i.e., approximately one in 12 samples). Chlorophyll *a* for comparison with periphyton attribute bands can therefore be calculated as the 92^{nd} percentile of the distribution of monthly periphyton biomass observations, referred to hereafter in this report as CHLA92. The NPS-FM specifies that CHLA92 is assessed from monthly observations made over at least three years. Thresholds of 50, 120 and 200 mg m^{-2} define the upper boundaries of the NPS-FM A, B and C bands, which indicate a scale of potential target attribute states from very high to minimum acceptable levels of environmental protection.

Item B above was required to address a note, added to the periphyton attribute in the NPS-FM 2014 (amended 2017), that required councils to set nutrient criteria specifically to ensure that objectives set for periphyton are met. The note has now been superseded by Clause 3.13 in the NPS-FM. Paragraph (1) in latest version of Clause 3.13 (NPS-FM January 2024) states that: "To achieve a target attribute state for any nutrient attribute, and any attribute affected by nutrients, every regional council must, at a minimum, set appropriate instream concentrations and exceedance criteria, or instream loads, for nitrogen and phosphorus)". Periphyton is named first in the list of examples of attributes affected by nutrients (Clause 3.13, paragraph (5)).

An additional important use for regional periphyton datasets is to contribute to a growing number of sites in a national periphyton dataset. This national dataset has been used to explore national and regional relationships between periphyton and nutrient concentrations (e.g., Kilroy et al. 2019). Recently, data from 251 sites representing 10 regions throughout New Zealand (including Northland) were used to derive a national model that explains variation in CHLA92 across sites (Snelder et al. 2022). While relatively small regional datasets almost always yield stronger relationships (as indicated by, for example, higher R^2) than combined national datasets (e.g., Kilroy et al. 2019), models derived from the much larger national datasets can include more explanatory variables that influence periphyton and are therefore likely to be more robust and unbiased when applied across a range of different waterways. The model derived by Snelder et al. (2022) was used to derive national instream nutrient criteria to achieve NPS-FM band A, B and C periphyton target attribute states. Ministry for the Environment recently released guidance on how to use these nutrient criteria (MfE 2022).

Northland Regional Council commissioned work in 2018 to analyse the first 3–4 years of their periphyton monitoring data (August 2014 to about June 2018) to address the two aims (A and B) above. That analysis (Kilroy and Stoffels 2019) identified that water temperature was the strongest predictor of periphyton biomass (as CHLA92) across the Northland region. Other important predictors included dissolved reactive phosphorus (DRP) concentration, substrate (percentage of coarse material on the streambed), and flow metrics (where flow data were available). In addition, dissolved inorganic nitrogen (DIN) concentration was identified as a significant predictor across sites with catchments having hard sedimentary geology. Partitioning sites according to shade status (full sun or partial shade) also influenced relationships with nutrient concentrations and other variables. However, the datasets after partitioning were very small (n = 5 – 19). Therefore, confidence in the generality of the relationships was low.

NRC now have an additional four years of monthly periphyton, water quality and flow data for both grading sites and deriving relationships. While three years of monthly periphyton biomass data meet the NPS-FM requirement for grading a site, previous analyses on datasets from other regions have shown that more stable relationships tend to be derived from longer datasets (Kilroy et al. 2020). This is because hydrological / climatic variability from year-to-year influences periphyton, nutrient concentrations and other variables that affect periphyton such that relationships can vary markedly over time (e.g., Kilroy et al. 2018). Metrics derived from longer datasets are less influenced by these variations.

NRC approached NIWA and LWP Ltd requesting further analysis of the NRC periphyton dataset. There were three main motivations for the request: (a) the requirement in Clause 3.13 in the NPS-FM 2020 to set concentration criteria for DIN and DRP for periphyton and other nutrient-affected attributes, (b) the recent availability of national nutrient criteria for periphyton (Snelder et al. 2022) and guidance around their use (MfE 2022) and (c) local deadlines related to notification of new Northland Regional Plan provisions to give effect to the NPS-FM.

This report provides an analysis of NRC's updated periphyton dataset to provide:

1. an assessment of periphyton state at all sites against the periphyton attribute of the NPS-FM and also against the New Zealand Guideline for Cyanobacteria (Wood et al. 2009);
2. An evaluation of whether the national nutrient criteria recently released by the Ministry for the Environment, with guidance (the 2022 MFE guidance), and updated revised criteria following further analysis, are suitable for setting nutrient concentration criteria for managing periphyton in Northland rivers; and
3. if the outcome of item 2 is that the criteria are not suitable, suggestions / calculations to determine instream concentration criteria for nitrogen and phosphorus to keep periphyton biomass in Northland above the national bottom-line (D band) defined in the NPS-FM periphyton attribute;
4. an updated understanding of the main predictors of periphyton biomass (as chlorophyll *a*) across the Northland region, including an evaluation of the relative influence of the different nutrient variables for which there are data (DIN, DRP, nitrate-nitrogen (NO_3-N), total nitrogen (TN), total phosphorus (TP), total Kjeldahl nitrogen (TKN) and ammoniacal nitrogen (NH_4-N));
5. a parallel understanding of relationships between environmental variables and periphyton cover from visual estimates.

The report is structured into sections as follows.

Section 2 summarises the datasets provided and describes how the data were prepared for subsequent analyses.

Section 3 presents assessments of the state of periphyton at all sites (with sufficient data) as: (a) gradings of all sites against the NPS-FM periphyton attribute bands, including an evaluation of variability in grading over the complete time series at each site; and (b) exceedances of cyanobacteria cover defined in the New Zealand Guideline for Cyanobacteria.

Section 4 describes the validation of the appropriateness for Northland of the national nutrient criteria based on the approach set out in the MfE (2022) lookup tables.

Section 5 focuses on general and site-specific patterns of periphyton CHLA and cover in relation to flow variability. This comprises: (a) an overview of interannual and seasonal patterns of flow and periphyton, at the regional scale, across the seven years of periphyton data collection; and (b) for sites with a flow record, analysis of the responses of biomass and cover to times elapsed since high flows of different magnitudes. The findings from the latter analysis were used to inform relationships explored in Section 5.

Section 6 describes analyses that aimed to identify the main environmental factors that are influencing variation in periphyton biomass and cover across site in the Northland region. Because the Northland dataset is relatively small (maximum of 38 sites with sufficient data), the analyses were constrained to examining relationships between periphyton and single environmental variables (i.e., univariate relationships) or relatively simple multivariate relationships (e.g., no more than four explanatory variables).

Section 7 provides a synthesis of the results from Sections 3 to 6, with conclusions.

The following supporting information is provided in Appendices.

Appendix A: an account of analysis of continuous water temperature data provided by NRC from 16 of the periphyton monitoring sites.

Appendix B: an outline of a trial of an alternative method for deriving nutrient concentration criteria (for TN, DIN, TP and DRP).

Appendix C: the complete set of revised nutrient concentration criteria (for TN, DIN, TP and DRP) for all River Environment Classification (REC) source-of-flow classes that occur in Northland.

Appendix D: plots over time of all the raw CHLA and WCC data at each of the 38 periphyton monitoring sites included in the analyses. The data are over-plotted on time-series of daily mean flows, which were available at 21 of the periphyton sites.

Appendix E: plots of CHLA and WCC against the time elapsed since flow exceeded a range of thresholds defined by multiples of median flow, for the 21 sites with a flow record.

Appendix F: a set of distribution plots for the main variables used in the analyses of relationships between periphyton and environmental variables.

Appendix G: plots of the raw monthly data over time for the nutrient concentration variables considered (TN, NO_3-N, NH_4-N, TKN, TP, DRP) at each site, for the time period covered by the periphyton data.

2 Description of dataset and data preparation

Key messages

Northland Regional Council currently (2023) monitors 33 sites across the region for periphyton biomass and cover and associated environmental variables. Nine of those sites have only short time series (13 samples or fewer) and were not included in the analyses described in this report.

Up to eight years of data (January 2015 to at least December 2022) was available at the remaining 24 sites. In addition, data were available from 14 sites at which monitoring has now ceased or moved to a replacement site. These 14 sites all had at least six years of data

The dataset analysed therefore includes 38 sites, all of which had at least 38 periphyton observations (as biomass (chlorophyll *a*), and cover), associated site habitat observations (e.g., bed substrate composition) and generally complete water quality data over the monitoring period.

A flow record was available for 21 of the 38 sites with sufficient data. Predicted hydrological indices (from published models) were available for all monitoring sites.

2.1 Monitoring sites

Periphyton biomass (as chlorophyll *a*, hereafter CHLA) and cover data, and associated environmental data, were provided from 48 sites that are currently being or have previously been monitored across the Northland Region (Table 2-1). The sites represent 10 of the 13 freshwater management units (FMUs) established for water quality in Northland (Figure 2-1).

Periphyton, water quality and flow data provided by NRC for each site are described in the following sections. Sites are generally referred to in the text below by their shortened site name as indicated on Table 2-1.

2.2 Periphyton data

Monthly collection of periphyton CHLA and cover data started in January or February 2015 at 35 sites. Three sites were added to the network in July 2016 (Tapapa, Punaruku, Pukenui), one in March 2020 (Tangowahine), one in November 2021 (Peria). The time series continued to 2022 (as early as February 2022 and as late as December 2022 for some cover data) for 25 sites. Sites added to the network later than 2016 were either new locations to replace existing sites or new sites. Fourteen sites were dropped from the network between 2020 and 2022 (Table 2-1) but had sufficient data to be included in the analysis.

The 38 sites retained in the dataset had at least 38 observations in the time series of CHLA data (Table 2-1). There were gaps in the time series at all sites, in months when surveys were missed. We assumed that in most cases surveys were omitted because flows were too high for the survey teams to enter the river to collect samples. Surveys were also missed during the COVID-19 lockdowns in 2020 and 2021. The average rate of missing data was 19%, with a range of 6% to 49%.

Cover data comprised estimates of mean percentage cover of the stream bed by periphyton in four main visual categories: Clean (no algae), Film, Mat, and Filamentous. Two subcategories of Mat were also recorded (Sludge and Cyanobacteria). The assessments were made following the protocol described in Kilroy et al. (2008). For analysis, the cover data were summarised as weighted composite cover (WCC), which was calculated as:

$$WCC = \%Filamentous + (\%Mat /2) \quad (1)$$

WCC integrates high-biomass cover that is likely to be interpreted as nuisance periphyton. The weighting assumes that cover by filamentous algae is more problematic than cover by mats (Matheson et al. 2012).

The cover data had more missing data than the CHLA dataset, with an average of 26% of possible surveys omitted (range 6% to 59%). A higher overall rate of omitted cover observations is expected because a complete survey of periphyton cover is more difficult (and less safe) at high flows than collecting rocks for periphyton sampling. In addition, there may have been times when turbid water prevented visual estimates of cover even when flows were not particularly high. Cover and CHLA are likely to be highest after long periods of stable flows, and not during high and turbid flows, when collecting data is more difficult. Because we are primarily interested in peak periphyton CHLA and cover (rather than mean values or lower percentiles), a small percentage of missing data (e.g., <20% surveys missed) will not substantially affect the calculations. However, there may be an effect when the percentage of missed surveys is high (e.g., >30%). Our approach to adjusting time series to account for gaps is described in detail in Section 3.1.1

Two sites with noticeable long gaps in the time series of both CHLA and cover data, and also water quality data, warrant particular mention. The gaps were from July 2018 and October 2020 (Waiharakeke at Stringers Road) and from August 2018 and December 2020 (Raumanga at Bernard Street). NRC advised us that the locations of the two sites had to be moved for logistical or practical reasons. In both cases, monitoring continued at a nearby site before resuming at the original locations (Raumanga at Te Mai Road, and Waiharakeke at Lucas Road) (Table 2-1). We considered merging the data from the two sites on each of the rivers. However, NRC provided the following information to justify not merging the data.

- **Raumanga at Bernard Street.** Raumanga at Te Mai Road, although not far from Raumanga at Bernard St site, does not qualify to be the same site. The periphyton site was temporarily moved to Te Mai Road for Health and Safety reasons between November 2018 and December 2020. This site at Te Mai Road is not very different from Raumanga at Bernard St site in terms of water quality, however the Te Mai site has smaller rocky substrate and more unshaded reach which drives prolific algal and macrophyte growth during summer compared to the Bernard St reach. Also, there is a small intermittent creek (not a major tributary, REC stream order 1) that flows into Raumanga Stream in between these two sites.

- **Waiharakeke at Stringers Road**. This site moved another street upstream (~1. 5km) to Lucas Road (Waiharakeke at Lucas Road) between August 2018 and October 2020. Substrate characteristics are similar at the two sites, but the amount of shading differs. Waiharakeke at Stringers Road is classed as shaded while the site at Lucas Road is more open. Also, a decent sized unnamed tributary (REC stream order 3) flows into the Waiharakeke between these two sites.

These large data gaps were omitted from the time series. That is, the two-year gaps at Raumanga and Waiharakeke were not treated as missed surveys when calculating the 92nd percentile.

Table 2-1: List of sites in Northland at which periphyton is or has been monitored monthly. Sites are in order of FMU and catchment, arranged in alphabetical order. Map code (in the same order) refers to the numbers used to identify sites on Figure 2-1. Under site name, the river name in bold type indicates the abbreviated site name that is used subsequently in text, tables and figures. The ten sites in grey-shaded lines were not included in subsequent analyses because there was insufficient periphyton or other data. Sites in BLUE type are not included in the current monitoring programme (as of the end of 2022) but have sufficient data for inclusion in the analysis (up to at least September 2020 and as late as February 2022). NZsegment was used to obtain modelled data relevant to that site from the digital river network. Obs = number of observations. % missed is the approximate percentage of monthly observations omitted over the monitoring period (earliest observation to most recent observation); * = percentage adjusted to allow for 2-year gaps in the record at these two sites (Waiharakeke and Raumanga) (see Section 2.2). NA = not applicable. Date range shows the year data collection started and, where applicable, ended. The last column shows the REC geology class for each site: HS = hard sedimentary, SS = soft sedimentary, VA = volcanic (acidic).

Map order	Site N	Site name	FMU	Catchment	E	N	NZ-segment	CHLA obs	% missed	Cover obs	% missed	Flow site name	Date range	REC geology
1	100363	**Awanu**i at FNDC	Awanui	Awanui	1625095	6113439	1004707	48	44	39	54	Awanui at School Cut	2015 -	SS
2	105532	**Victoria** at Victoria Valley Road	Awanui	Awanui	1637132	6110554	1005288	80	17	80	17	Victoria at Victoria Valley Road	2015 -	VA
3	100007	**Waiharakeke** at Stringers Road	Bay of Islands	Kawakawa	1692604	6082806	1011114	38	37*	24	59*	Waiharakeke at Willowbank	2015 -	SS
4	324659	**Kerikeri** at Kerikeri Basin Reserve	Bay of Islands	Kerikeri	1687336	6102530	1006886	70	18	73	15	Kerikeri at Peacock Garden	2015 - 22	VA
5	330972	Kerikeri River at Golf View Rd	Bay of Islands	Kerikeri	1686093	6101970	1006967	3		3		Kerikeri at Peacock Garden	2022 -	VA
6	328459	Waipapa at Doonside Road	Bay of Islands	Waipapa	1686818	6104244	1006586	5		6		Waipapa at Doonside Road	2022 -	VA
7	101524	**Waipapa** at Waipapa Landing	Bay of Islands	Waipapa	1688150	6103986	1006609	75	12	72	16		2015 - 22	VA
8	306643	**Pekepeka** at Ohaeawai	Bay of Islands	Waitangi	1680918	6086769	1010389	62	10	61	13		2015 - 20	VA
9	304589	**Waiaruhe** at Puketona	Bay of Islands	Waitangi	1687317	6093000	1009326	70	21	60	32	Waiaruhe at Puketona	2015 -	HS
10	306661	**Waiaruhe D/S Mangamutu** Confluence	Bay of Islands	Waitangi	1682883	6084542	1010833	50	28	49	30		2015 - 20	SS
11	306915	**Waipapa at Waimate North** Road	Bay of Islands	Waitangi	1682092	6095939	1008356	61	13	56	19		2015 – 20	VA
12	304595	**Waitangi at SH10**	Bay of Islands	Waitangi	1686945	6093559	1008952	37	43	35	44	Waitangi at SH10 Bridge	2015 - 20	VA
13	103178	**Waitangi at Waimate North** Road	Bay of Islands	Waitangi	1681894	6093741	1008863	66	26	61	31	Waitangi at Waimate North Road	2015 -	VA
14	101752	Waitangi at Wakelins	Bay of Islands	Waitangi	1695269	6095708	1008431	1		1		Waitangi at Wakelins NIWA	2022 -	HS

Map order	Site N	Site name	FMU	Catchment	E	N	NZ-segment	CHLA obs	% missed	Cover obs	% missed	Flow site name	Date range	REC geology
15	306655	**Watercress** at SH1	Bay of Islands	Waitangi	1687416	6086899	1010303	58	17	54	23		2015 - 20	HS
16	105008	**Ruakaka** at Flyger Road	Bream Bay	Ruakaka	1726626	6029623	1023322	68	24	47	46	Ruakaka at Flyger Rd	2015 -	SS
17	306635	Kenana at Kenana Road	Doubtless Bay	Mangonui	1651704	6122183	1003285						2022 -	VA
18	306673	**Oruaiti at Sawyer Road**	Doubtless Bay	Mangonui	1656099	6121066	1003490	52	24	45	34		2015 - 20	VA
19	304641	**Oruaiti at Windust Road**	Doubtless Bay	Mangonui	1654905	6125633	1002765	69	28	56	42		2015 -	VA
20	306675	Stony Creek at Sawyer Road	Doubtless Bay	Mangonui	1656071	6123396	1003086	65	7	54	23		2015 - 20	VA
21	306641	**Peria** at Honeymoon Valley Road	Doubtless Bay	Taipa	1646259	6111088	1005099	76	7	74	9		2015 - 21	VA
22	330512	Peria at Honeymoon Valley US Dutton Road	Doubtless Bay	Taipa	1646029	6111284	1005099	8		8			2021 -	VA
23	108978	**Mangamuka** at Iwitaua Road	Hokianga	Mangamuka	1649247	6103622	1006665	60	11	64	7		2015 -20	VA
24	313165	**Tapapa** at SH1	Hokianga	Mangamuka	1643757	6105452	1006293	68	13	72	8		2016 -	VA
25	101751	**Waipapa** at Forest Ranger	Hokianga	Waihou	1662582	6096421	1008155	80	17	83	14	NIWA Waipapa at Forest Ranger	2015 -	HS
26	105231	**Punakitere** at Taheke	Hokianga	Waima	1660001	6075453	1012993	45	49	40	55	Punakitere at Taheke	2015 -	SS
27	109096	**Mangakahia** at Twin Bridges	Northern Wairoa	Mangakahia	1677496	6056596	1017633	72	25	55	41	Mangakahia at Gorge	2015 -	VA
28	102258	**Opouteke** at Suspension Bridge	Northern Wairoa	Mangakahia	1678503	6049460	1019255	67	30	59	39	Opouteke at Suspension Bridge	2015 -	VA
29	102256	**Kaihu** at Gorge	Northern Wairoa	Northern Wairoa	1661819	6042219	1020914	79	18	71	26	Kaihu at Gorge	2015 -	VA
30	102106	Mangere at Kara Road	Northern Wairoa	Wairua	1709388	6047363	1019781						2022 -	HS
31	322490	Tangowahine at Tangowahine Valley Road	Northern Wairoa	Tangowahine	1684524	6033194	1022597	13		13			2020 -	SS
32	109021	**Hakaru** at Topuni	Northern Wairoa	Topuni	1734514	5992515	1029173	69	22	68	28	Hakaru at Topuni Creek Farm	2015 -	SS

Map order	Site N	Site name	FMU	Catchment	E	N	NZ-segment	CHLA obs	% missed	Cover obs	% missed	Flow site name	Date range	REC geology
33	100237	**Mangahahuru** at Main Road	Northern Wairoa	Wairua	1718886	6055192	1018008	81	16	76	19	Mangahahuru at County Weir	2022 -	HS
34	109098	Waimamaku at SH12	Waipoua	Waimamaku	1640566	6065018	1015471	73	24	69	28		2015 -	VA
35	103304	**Waipoua** at SH12	Waipoua	Waipoua	1651633	6054443	1018148	86	11	85	12	Waipoua at SH12	2015 -	VA
36	110603	**Ngunguru** at Coalhill Lane	Whananaki Coast	Ngunguru	1727725	6054828	1018116	80	17	70	27	Ngunguru at Kiripaka	2015 -	HS
37	313171	Punaruku at Russell Road	Whananaki Coast	Punaruku	1719724	6083074	1011158	67	14	70	10		2016 -	HS
38	331352	Hatea at A H Reed Park	Whangarei	Hatea	1720983	6048821	1019505	5		3		Hatea at Whareora Road	2022 -	VA
39	100194	**Hatea** at Mair Park	Whangarei	Hatea	1720440	6047390	1019677	75	12	65	24	Hatea at Whareora Road	2015 -22	VA
40	105972	Hatea at Whangarei Falls	Whangarei	Hatea	1720854	6050268	1019155						2022 -	VA
41	109795	**Mangakino** at Mangakino Lane	Whangarei	Hatea	1719727	6053270	1018455	65	6	41	41		2015 -20	HS
42	110431	**Otaika** at Otaika Valley Road	Whangarei	Otaika	1715492	6039912	1021389	84	12	69	27	Otaika at Kay	2015 -	HS
43	304709	**Raumanga** at Bernard Street	Whangarei	Raumanga	1718764	6044939	1020313	60	17*	57	20*	Raumanga at Bernard St	2015 -	VA
44	321117	Raumanga at Te Mai Road	Whangarei	Raumanga	1718330	6044405	1020489	21		19		Raumanga at Bernard St	2018 -20	VA
45	312177	**Pukenui** at Kanehiana Drive	Whangarei	Waiarohia	1715556	6048444	1019614	70	10	73	6		2016 -	HS
46	108359	**Waiarohia at Second Avenue**	Whangarei	Waiarohia	1719097	6045830	1020121	86	10	84	11	Waiarohia at Lovers Lane	2015 -	HS
47	107773	**Waiarohia at Whau Valley**	Whangarei	Waiarohia	1717592	6048676	1019541	65	6	62	11		2015 -20	HS
48	102674	**Kaeo** at Dip Road	Whangaroa	Kaeo	1670326	6115833	1004253	68	29	67	30	Kaeo at Fire Station (level only)	2015 -	SS

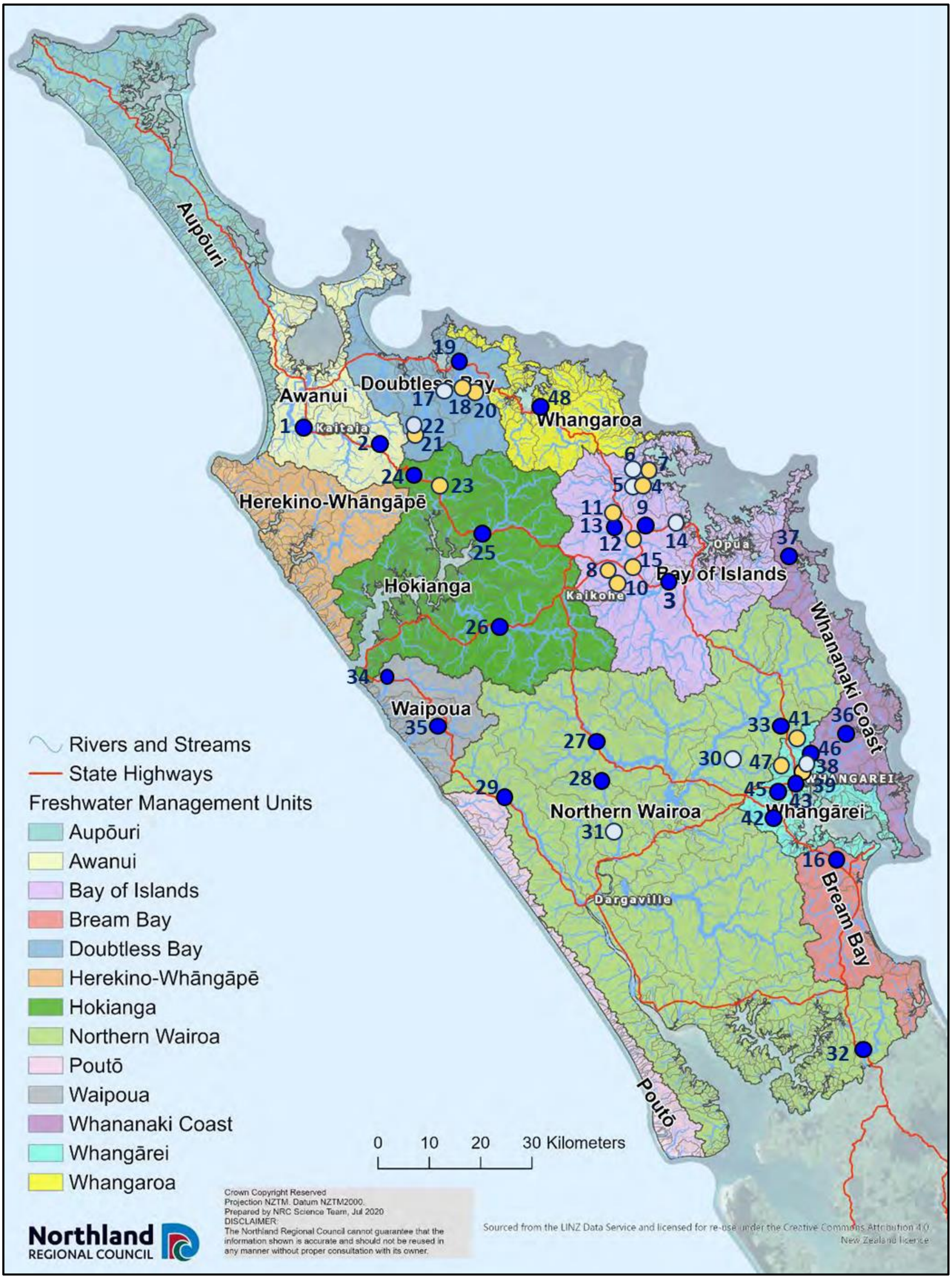

Figure 2-1: Map of Northland showing freshwater management units established for freshwater, with the periphyton monitoring sites overlaid. Numbers next to site symbols (circles) refer to the map code on Table 2.1. Dark blue and light blue circles are sites currently being monitored, Yellow circles are sites no longer monitored. The analyses used data from the dark blue and yellow sites only (38 sites total) as all had at least 38 periphyton observations. Records at the light blue sites were too short to be included. Adapted from the map that is available at https://www.nrc.govt.nz/media/achb5xxf/northland-s-water-quality-freshwater-management-units-2021.pdf.

2.3 Water quality data

Monthly water quality data were provided for all the periphyton monitoring sites, with the time series spanning the same period as the periphyton data. The datasets had very few missing monthly observations). The data comprised nutrient concentrations, turbidity, and field measurement of temperature, electrical conductivity, pH and water clarity. Available variables are summarised in Table 2-2.

The nutrient concentration data (i.e., dissolved and total N and P), included relatively low proportions of concentrations below the laboratory detection limit except for nitrite-nitrogen (NO_2-N) (59% below the detection limit). NO_2-N was used only to calculate dissolved inorganic nitrogen (DIN) and was not included when below detection (see below). Percentages of samples below the detection limits for other nutrient variables (across all sites) were: nitrate-nitrogen (NO_3-N), 5.5%; ammoniacal nitrogen (NH_4-N), 29%; DIN, 6%; dissolved reactive phosphorus (DRP), 0.2%; total nitrogen (TN), 15%; and total phosphorus (TP), 0.15%, and values of these samples were taken to be the detection limits (Snelder et al. 2021a).

The provided dataset of DIN was incomplete. We retained NO_3-N and NH_4-N in the dataset and completed the DIN time series by summing the concentrations of NO_3-N, NO_2-N and NH_4-N (when the latter were above the detection limit).

NRC also requested consideration of total Kjeldahl nitrogen (TKN) as a potential predictor of periphyton biomass and cover. TKN is a measure of reduced N (i.e., organic N plus ammoniacal N). We calculated TKN as TN – DIN + NH_4-N. TKN constitutes the bulk of TN in most of Northland's rivers and indicates the influence of reducing geology and soil types in the region (Rissmann et al. 2018).

The time series of all nutrient concentrations were summarised as median values and 95th percentiles for subsequent analyses (see Sections 4 and 6). The median values and 95th percentiles were not affected by the proportions of samples below detection limits. Concentrations were provided as mg L^{-1} and were converted to mg m^{-3} to avoid numbers with multiple decimal places.

Turbidity data collected as part of a sediment study at Otaika at Otaika Valley Road were removed from the dataset (these data were multiple observations at the same location of high turbidity at short intervals (e.g., 20 minutes)).

A single time series of water clarity at each site was assembled by combining (a) water clarity data from direct black disk readings and (b) measurements made using a clarity tube when water clarity was low (< ~1 m) and then converted to a black disc reading using a published relationship.

2.4 Site habitat data

Monthly observations of bed substrate composition were made at between 2019 and 2022 with an average of ~20 observations at each site (range 2 to 36). Bed substrate was visually assessed as percentage cover of the stream bed in seven categories: Bedrock, Boulder, Large cobble, Small cobble, Gravel, Sand and Silt. Substrate categories were as defined in Clapcott et al. (2011), and the assessment was done as part of the periphyton cover observations, which follow the same protocol as Clapcott et al. (2011) (i.e., observations in 20 views along up to four transects or part-transects in wadeable depths). The substrate data included estimates of embeddedness as percentage cover in four categories: Good, Loose, Tight, Moderate (%)[1]. Embeddedness refers to the degree to which coarse particles are surrounded by fine particles and can provide an indication of the availability or clogging of interstitial spaces (Clapcott et al. 2011). Larger, tightly embedded (i.e., stable) substrate

[1] Order of categories as in the data provided.

particles are more likely to favour accumulation of high periphyton biomass than loosely embedded more mobile substrates. Derived substrate variables are summarised in Table 2-2.

Shade data applicable to all sites was limited to a categorical assessment of shade at three levels (unshaded, partial shade, shaded). Quantitative data on canopy cover (i.e., shade) was available only from 25 sites being monitored as at May 2022, with data collections between May 2022 and April 2023. Densiometer readings were taken along one or more transects at each site, on up to three occasions at each site. The densiometer readings were then converted to canopy cover (%). Densiometer readings were not available from sites at which monitoring ceased before May 2022. The densiometer data were used to verify the shade categories.

2.5 Water temperature

Monthly temperature readings are subject to bias because of the effect of the time of day on the measurement. Therefore, use of continuous (logged) water temperature was recommended by Kilroy and Stoffels (2019) as a more accurate way of characterising water temperature. NRC installed temperature loggers at a subset of periphyton monitoring sites for varying periods, starting in August 2019. Data were provided from 20 sites (Table 2-1). Three sites (Punakitere, Hatea and Otaika) had continuous records from August or September 2019 to January 2023. The other sites had data for shorter periods, which were not always overlapping. Analysis of these data to provide an estimate of sites ranked in order of water temperature (i.e., coolest site to warmest site), with a comparison with the monthly data, is provided in Appendix A.

2.6 Flow data

Flow records were available for 21 sites (Table 2-1). We extracted daily mean flows (midnight to midnight) from each of the records (starting in 2014) for use in subsequent analyses. It was noted[2] that data had been archived (i.e., subjected to quality control procedures) to at least October 2022 for five sites only. A further four sites had archived data to May or June 2022. Archived data ended earlier at the remaining sites (between February 2020 and June 2021). The implication of this was that in the flow analysis (Section 5.3), some periphyton data were matched with unverified flow data. For example, at Victoria at Victoria Valley Road (verified up to February 2020) 22 of 79 CHLA observations were affected. We plotted the records of daily mean flows to check for obvious anomalies and chose to use the full flow records as provided.

The flow data were used to compute several flow indices over the period of periphyton data collection (Table 2-2).

2.7 Environmental data from other sources

In addition to measured variables, additional characteristics were available for each site, based on spatial datasets that are linked to the NZsegment identified for that site (Table 2-1). NZsegments uniquely identify each of the segments defined by the GIS-based digital drainage network which underlies the REC. The digital network was derived from 1:50,000 scale contour maps and represents New Zealand's rivers as segments bounded by upstream and downstream confluences, each of which is associated with a sub-catchment. Two types of additional characteristics were used in this analysis: landcover data and predicted hydrological indices.

[2] Advised by NRC at the time of provision of the flow data (13 June 2023).

2.7.1 Landcover data

Data from the Land Cover Database Version 3 (LCDB3) were available for all stream segments. We extracted percentage cover of the upstream catchment in indigenous forest, pastoral and urban land use for each site. These land-use variables were used to assist in understanding patterns of both periphyton and nutrient concentrations across the sites.

2.7.2 Network predictions of hydrological indices

Hydrological indices were obtained for all monitoring sites from predictions made for all segments of the digital river network in previous studies (Booker and Snelder 2012; Snelder and Booker 2013). These predicted indices were the same as those derived from hydrological records available for 21 monitoring sites (Table 2-2). The predicted hydrological indices were available for all monitoring sites.

Table 2-2: List of variables used in the analyses described in this report. Data on periphyton, nutrient concentrations, other water quality variables and habitat were obtained from observations at each site, generally monthly. Flow data were provided as daily mean flows. Other environmental data were obtained from spatial datasets (see text for details). Abbreviations are those used in Section 6.

Group	Variable name	Units	Metric	Abbreviation	Explanation / notes
Provided by NRC					
Periphyton biomass	Chlorophyll *a*	mg m^{-2}	92^{nd} percentile	CHLA, CHLA92	Metric used in NPS-FM to represents peak potentially "nuisance" periphyton chlorophyll *a* or cover calculated across several years; adjusted to compensate for missing values (see Section 3.1).
Periphyton cover	Weighted composite cover	%	92^{nd} percentile	WCC, WCC92	
	Total N			TN_95, TN_med	Nutrients essential for periphyton growth.
	Dissolved inorganic N	mg m^{-3}		DIN_95, DIN_med	DIN was calculated as nitrate + nitrite-N (NO_x-N) + NH_4-N.
	Nittrate-nitrite nitrogen	mg m^{-3}		NOx-N_95, NOxN_med	NH_4-N is assimilated by algae in a process different from that for NO_3-N. Concentrations and proportions of the two N sources may lead to different growth rates, biomass and community composition (Kilroy et al. 2020a).
	Ammoniacal N	mg m^{-3}	Median, 95^{th} percentile	NH4N_95, NH$N_med	
	Total Kjeldahl N	mg m^{-3}		TKN_95, TKN_med	TN and TP are often better predictors of periphyton than DIN and DRP. One reason for this is that TN and TP reflect periphyton abundance because they include sloughed algae in the water column (i.e., circular reasoning).
Nutrient concen-trations	Total P	mg m^{-3}		TP_95, TP_med	
	Dissolved reactive P	mg m^{-3}		DRP_95, DRP_med	TKN is a measure of organic N plus ammoniacal N (i.e., reduced N) and constitutes bulk of Total N in most Northland rivers (Rissmann et al. 2018). It is an important measure used in monitoring at wastewater treatment plants. TKN is correlated with increases in cyanobacteria (Newell et al. 2019).
	Ratios of N to P	ratio	(ratio of medians)	DINtoDRP TNtoTP	N-P ratios may indicate which nutrient is driving growth.
Water chemistry	Electrical conductivity	µS cm^{-1}	Median	EC_med	EC is a measure of concentration of ions in water and may influence periphyton biomass through the influence of minor nutrients (Ca, Mg). pH can affect algal species composition.
	pH	pH units	Median	pH_med	
Suspended sediment	Water clarity	m	Median	Clarity_med	Clarity and turbidity affect periphyton through their effect on light availability and through indicating potential for fine sediment deposition, which smothers algae.
	Turbidity	NTU	Median, 95^{nd} percentile	Turbidity_95 Turbidity_med	
Water temperature	Monthly spot temperature	°C	Median	Temp_med	Water temperature determines growth rates in periphyton, which may be reflected in biomass. The temperature – growth rate relationship is expected to be generally positive within the range of temperature in NZ rivers.
			95^{th} percentile	Temp_95	
	Continuous temperature	°C	Rank		

Group	Variable name	Units	Metric	Abbreviation	Explanation / notes
Habitat	Large substrate (large cobble and larger)	%	Mean	Large_subs	Bed substrate composition generally determines stability of the bed. Periphyton tends to accrue for longest on large stable substrates, and has shorter accrual times on small, mobile substrate, depending on the frequency of high flows in the river. Sand particles mobilise relatively easily and can be important in removal of periphyton by abrasion.
	Small substrate (gravel and finer)			Small_subs	
	Sand and smaller			Fine_subs	
	Sand only			Sandpc	
	Embeddedness	(category)	Mean	Embed_tight Embed_loose	Embeddedness describes how packed together substrate particles are, and by implication how easily the bed could move under the hydraulic forces of high flows.
	Shade	%	Mean	Shade	Readings from densiometer (25 sites only) or shade category (unshaded, partial shade, shade).
Flow variables, calculated from the flow records linked to 21 sites					
Flow	Mean flow	m^3/s	Mean	Meanflow	Measure of flow magnitude.
	CV of flow	Unitless (proportion)		sdQ	Standard deviation of daily mean flow divided by mean flow. A measure of flow variability.
	Reversals	No./y		Reversals	Mean annual number of times flow reverses from declining to increasing or vice versa.
	Nneg	days		Nneg	Mean annual no. days when flow is less than on the preceding day.
	Flood frequency	No./y		FREx where x is a multiple of median flow	No. of events per year that exceed a threshold expressed in multiples of median flow. Periphyton in different rivers may respond differently to similar magnitude high flows.
	Standardised mean annual 7- and 30-day low flow	$m^3\ s^{-1}$		MALF7, MALF30	Magnitude of annual low flows relative to median flow – lower values suggest rivers that tend to have long low flow periods that could favour periphyton accrual.
	Mean annual 7- and 30-day maximum flow	$m^3\ s^{-1}$		MAX7, MAX30	Magnitude of highest flows annually relative to median flow.
Environmental data from other sources					
Modelled flow	As for calculated variables	As above		As above, metric _mod	Modelled flow metrics available for all 38 periphyton monitoring sites.
Landcover	Percentage of upstream catchment under pastoral, indigenous forest and urban landcover			pc_pastoral, pc_indig_for, pc_urban	From LCDB3 database, for every segment in the REC network.

3 State of periphyton and cyanobacteria cover in Northland

Key messages

Of 38 periphyton monitoring sites in Northland, and based on data collected between 2015 and 2022, 45% were placed in Band A of the periphyton attribute of the NPS-FM, 39% in Band B, 11% in Band C and 5% in Band D.

Sites placed in band D were Waiharakeke at Stringers Road and Hakaru at Topuni. Siites placed in band C were Awanui at FNDC, Waipapa at Landing, Watercress at SH1, and Opouteke at Suspension Bridge.

Percentages of sites in each band varied across 3-year periods (the minimum period over which a site can be graded), with differences likely attributable to hydrological conditions.

Over the same eight-year period, the New Zealand Guideline for Cyanobacteria Alert level (20 – 50 % cover by cyanobacteria) was reported at 15 sites, and the Action level (more than 50% cover) at eight sites.

Twenty-one sites had no reports of Alert or Action level, although only two sites (Awanui at FNDC, Pukenui at Kanehiana Drive) had no reports of cyanobacteria cover at any level between 2015 and 2022.

In terms of frequency of exceedances, the sites most affected by cyanobacteria were Waimate at Waimate North Road (exceedances of the Alert or Action levels or both in five of the eight years) and Opouteke at Suspension Bridge (exceedances in four of eight years).

The highest numbers of exceedances were in 2015 (10 Alerts and three Actions) followed by 2020 (four Alerts and eight Actions). Both 2015 and 2020 were relatively dry years.

3.1 Grading of sites against the periphyton attribute of the NPS-FM

Chlorophyll *a* data from the 38 sites with sufficient data (Table 2-1) were used to grade the sites against the periphyton attribute of the NPS-FM. The periphyton attribute specifies that sites are to be graded based on no more than 8% or 17% of samples exceeding thresholds (i.e., 92nd and 83rd percentiles) defining four bands A to D in a time series of monthly chlorophyll *a* measurements. The 92nd percentile (hereafter CHLA92) applies to “default” sites while the 83rd percentile (in which high chlorophyll *a* is allowable for a longer period) applies to “productive” sites. Productive sites are defined by their classification in both REC climate and geology levels. Some sites in Northland have geology consistent with productive sites (SS class) but no sites are in the specified climate classes. All periphyton sites in Northland must therefore be graded against the default metric. The thresholds separating the four bands (A to D) are: A/B 50 mg m^{-2}, B/C 120 mg m^{-2}, and C/D 200 mg m^{-2}.

3.1.1 Treatment of gaps in the time series

The wording of the periphyton attribute described by the NPS-FM related to the period over which the grading is made is: “*Based on a monthly monitoring regime. The minimum record length for grading a site based on periphyton (chl-a) is 3 years.*” This wording implies that the minimum data used for an assessment against the periphyton attribute must be <u>36 samples collected over three years (i.e., in every consecutive month)</u>. The wording also implies that periods of longer than three years can be used to assess state. The interpretation of the wording is important because the monthly time series at all Northland sites had sampling occasions on which no periphyton data were collected, hereafter termed “missing data”. Inclusion or exclusion of the missing data points can affect a grading, depending on how it is calculated.

As indicated in Section 2.2 and Table 2-1 the time series of chlorophyll *a* at all sites was incomplete (i.e., there were missing observations in some months). In contrast, the time series of water quality data were virtually complete at all sites. This contrast suggests that periphyton samples could not be collected because flows were too high: collection of a quantitative sample for chlorophyll *a* involves wading and can only be carried out in wadeable depths. Water samples for analysis of water quality can be collected under any flow conditions provided the river can be accessed.

In practice, a small proportion of missing periphyton data should make little difference to the analysis because the metric of interest is close to the maximum value (a high percentile). However, at sites with high proportions of missing monthly datapoints (e.g., more than 30% missing), using the raw data without compensating for the missing data could lead to upward bias in chlorophyll *a* when assessments against the NPS-FM are made by calculating CHLA92 over the monitoring period.

An alternative method of grading a site, by counting numbers of exceedances over periods of 36 months, should not be affected by missing data if we make the reasonable assumption that periphyton abundance is always low when samples cannot be collected because of high flows. Note that in the NPS-FM the allowed exceedance of 1 survey in 12 (or 3 in 36) has been rounded to 8% of surveys, which is 2.88 surveys in 36. This presumably means that when 3 surveys in 36 exceed the threshold, the site must be graded at the lower grade. For example, if chlorophyll *a* exceeded 200 mg m^{-2} in three surveys over 36 successive months, the site would be graded into D band rather than C band.

The data were screened for missing data and the percentage missing was calculated for each site from the number of months in the monitoring period for which there was no data, where the missing survey could reasonably be attributed to high flows (see Table 2-1). To compensate for missing data, we completed the time series by inserting into each month with no data a value calculated as the 5^{th} percentile of the observed values at that site. The 5^{th} percentile of chlorophyll *a* varied from 0.1 to 23 mg m^{-2}, with a median value of 0.8 mg m^{-2}. At all sites except Hakaru (at which the 5^{th} percentile was 23 mg m^{-2}) the 5^{th} percentile was in the range representing thin films or no visible algae (e.g., 1 and 9 mg m^{-2}, Kilroy et al. 2013), which is expected after high flows.

The adjustment resulted in a reduction of CHLA92 by 12% on average (median 10%). The range was from <1% (Waipapa_Landing, Stony) to >40% (Punakitere, Awanui). The adjustment made <5% difference to CHLA92 at 11 sites and more than 20% difference at seven sites. Note that alternative methods for filling data gaps (e.g., using 0 mg m^{-2} instead of the 5^{th} percentile) made little difference to CHLA92.[3]

The time series with gaps filled using the 5^{th} percentile are hereafter referred to as the adjusted data or adjusted time series.

3.1.2 Site assessments

To assess sites against the NPS-FM periphyton attribute, all monthly chlorophyll *a* data (2015 onwards) were used to calculate CHLA92 to obtain an overall site grading. The calculation was run

[3] Also note that Kilroy and Stoffels (2019) used the method described above to fill gaps in the time series at each site, prior to calculating metrics for grading sites against the periphyton attribute or developing periphyton – environment relationships.

using both the adjusted data and the original data (including gaps) to assess how the adjustment affected grades across the region.

We also calculated CHLA92, using the adjusted time series in blocks of 36 months (the minimum length of time for grading a site) starting in January 2015, January 2016, etc., up to December 2022. This was done recognising that periphyton typical at a site can change over time for various reasons, including the effects of climate (e.g., prolonged periods of dry or wet conditions associated with large scale climate patterns such as the El Niño –Southern Oscillation) or land use changes (e.g., responses to changes in water quality, habitat or flow patterns driven by activities in the catchment).

To assess the effect of data adjustment on the three-year grades, we also counted the number of surveys in each three-year period returning chlorophyll *a* greater than 200, 120 and 50 mg m^{-2}. The site grading is then:

- band D when more than 8% surveys have chlorophyll *a* >200 mg m^{-2} (i.e., more than 2.88 surveys, effectively, three or more surveys);
- band C when fewer than three surveys are >200 mg m^{-2} but three or more surveys are >120 mg m^{-2};
- band B when fewer than three surveys are >120 mg m^{-2} but three or more surveys are >50 mg m^{-2};
- band A when fewer than three surveys are >50 mg m^{-2}.

All results are presented in Table 3-1.

Table 3-1: Grading of 38 periphyton monitoring sites in Northland against the NPS-FM periphyton attribute. Sites are listed in order of the site number shown on Figure 2-1. Site N is the Northland site code. The six columns following "Dates" show the 92nd percentile of CHLA calculated over rolling three-year periods starting in January, calculated from time series with gaps filled (see Section 3.1). The six subsequent columns show numbers of samples in each three-year period that exceeded the three thresholds separating bands C/D, B/C and A/B. Grey lettering indicates that the 92nd percentile was calculated over fewer than 33 months, and a band was not applied (numbers could be lower when the time series started or ended in different months). A long data gap at two sites (Waiharakeke and Raumanga) precluded assessment in most three-year periods (see Section 2.2). The two columns at the end show the 92nd percentile calculated over the whole period (as indicated by the dates columns). The last column is the result of the calculation when gaps were not filled. Colour-coding: blue = band A, green = B, orange = C, red = D.

			Dates (year_month)		92nd percentile CHLA over three-year periods ending in December:						Counts of exceedances of CHLA thresholds (>200, >120, >50 mg m^{-2}) in three-year periods						92nd percentile over whole period	
Map order	Site N	Site name	Earliest	Latest	2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022	Gaps filled	Gaps not filled
1	100363	Awanui	2015_1	2022_2	173	205	204	218	165	62	2, 7, 10	3, 7, 10	3, 7, 11	3, 7, 9	1, 5, 8	0, 1, 3	174	347
2	105532	Victoria	2015_1	2022_12	36	24	49	74	74	74	0, 0, 3	0, 0, 1	0, 0, 2	0, 1, 6	0, 1, 6	0, 1, 5	52	61
3	100007	Waiharakeke	2015_1	2022_3	259	224	95	4	18	43	6, 8, 11	4, 4, 6	1, 1, 3	0, 0, 0	0, 0, 1	0, 0, 2	219	251
4	324659	Kerikeri_Basin_Reserve	2015_1	2022_2	72	62	44	36	10	9	0, 1, 8	0, 0, 5	0, 0, 2	0, 0, 1	0, 0, 0	0, 0, 0	58	62
7	101524	Waipapa_landing	2015_1	2022_2	160	162	162	162	116	92	1, 7, 12	0, 8, 11	1, 5, 10	1, 4, 11	1, 2, 9	0, 1, 6	160	160
8	306643	Pekepeka	2015_1	2020_9	90	87	87	88	80	33	0, 2, 12	0, 1, 16	0, 0, 19	0, 0, 17	0, 0, 7	0, 0, 0	88	90
9	304589	Waiaruhe_Puketona	2015_1	2022_5	53	44	26	27	25	22	0, 1, 4	0, 1, 3	0, 0, 1	0, 0, 0	0, 0, 1	0, 0, 1	35	45
10	306661	Waiaruhe_ds_Mangamutu	2015_1	2020_10	58	26	26	55	94	122	1, 1, 4	0, 0, 1	0, 0, 0	0, 1, 3	0, 1, 3	0, 1, 3	63	87
11	306915	Waipapa_Waimate_N_Rd	2015_1	2020_10	35	35	37	43	43	43	0, 0, 0	0, 0, 1	0, 0, 2	0, 0, 2	0, 0, 1	0, 0, 0	37	38
12	304595	Waitangi_SH10	2015_1	2020_5	31	8	19	30	33	29	0, 0, 1	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	32	37
13	103178	Waitangi_Waimate_N_Rd	2015_1	2022_5	33	15	96	80	71	27	0, 0, 1	0, 0, 2	0, 3, 5	0, 3, 4	0, 3, 3	0, 0, 1	42	51
15	306655	Watercress	2015_1	2020_10	156	88	29	48	57	57	2, 7, 11	1, 3, 5	1, 1, 2	0, 0, 3	0, 0, 3	0, 0, 2	133	146
16	105008	Ruakaka	2015_1	2022_5	65	64	64	76	67	61	0, 1, 4	0, 1, 4	0, 1, 6	0, 2, 6	0, 1, 4	0, 1, 2	64	68

Map order	Site N	Site name	Dates (year_month) Earliest	Latest	92nd percentile CHLA over three-year periods ending in December: 2017	2018	2019	2020	2021	2022	Counts of exceedances of CHLA thresholds (>200, >120, >50 mg m-2) in three-year periods 2017	2018	2019	2020	2021	2022	92nd percentile over whole period Gaps filled	Gaps not filled
18	306673	Oruaiti_Sawyer	2015_1	2020_9	107	80	65	57	57	44	1, 2, 7	0, 1, 5	0, 1, 7	0, 1, 5	0, 0, 4	0, 0, 1	82	107
19	304641	Oruaiti_Windust	2015_1	2022_12	67	82	82	88	78	34	0, 2, 4	0, 1, 6	0, 0, 9	0, 1, 10	0, 1, 6	1, 2, 2	83	90
20	306675	Stony	2015_1	2020_10	30	15	27	32	32	26	0, 0, 3	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	32	32
21	306641	Peria_Honeymoon	2015_1	2021_9	113	77	105	109	111	93	1, 3, 8	0, 2, 5	0, 2, 9	0, 2, 13	0, 2, 13	0, 1, 6	109	111
23	108978	Mangamuka	2015_1	2020_8	24	14	38	48	50	58	0, 0, 1	0, 0, 1	0, 0, 1	0, 0, 2	0, 0, 2	0, 0, 2	45	47
24	313165	Tapapa	2016_7	2022_12	6	6	29	29	29	16	0, 0, 0	0, 0, 0	0, 0, 2	0, 0, 2	0, 0, 2	0, 0, 1	28	30
25	101751	Waipapa_FR	2015_1	2022_12	26	20	34	48	47	16	0, 0, 0	0, 0, 0	0, 0, 2	0, 1, 3	0, 1, 3	0, 1, 1	31	32
26	105231	Punakitere	2015_1	2022_5	116	20	16	33	49	75	3, 3, 7	1, 1, 2	0, 0, 1	0, 0, 2	0, 0, 3	0, 1, 4	80	141
27	109096	Mangakahia	2015_1	2022_12	106	63	40	44	49	91	1, 3, 8	1, 2, 5	0, 0, 1	0, 0, 2	0, 0, 3	0, 2, 5	85	98
28	102258	Opouteke	2015_1	2022_12	155	135	74	75	63	64	2, 7, 13	2, 4, 9	1, 2, 6	1, 2, 6	0, 0, 4	0, 1, 4	136	151
29	102256	Kaihu	2015_1	2022_12	71	103	81	83	98	123	1, 2, 10	1, 3, 10	0, 1, 6	0, 2, 6	0, 3, 6	0, 4, 6	95	119
32	109021	Hakaru	2015_1	2020_8	731	653	538	300	211	207	11, 19, 25	11, 16, 23	8, 11, 22	5, 9, 22	4, 7, 21	4, 7, 17	575	611
33	100237	Mangahahuru	2015_1	2022_12	20	24	20	20	19	16	0, 0, 0	0, 0, 1	0, 0, 1	0, 0, 1	0, 0, 0	0, 0, 0	19	20
34	109098	Waimamaku	2015_1	2022_12	32	32	39	45	55	45	0, 1, 2	0, 1, 2	0, 1, 3	0, 0, 3	0, 0, 3	0, 0, 3	41	53
35	103304	Waipoua	2015_1	2022_12	5	3	3	4	5	7	0, 0, 1	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	5	6
36	110603	Ngunguru	2015_1	2022_12	75	65	66	66	58	35	0, 1, 8	0, 1, 7	0, 1, 6	0, 0, 6	0, 0, 4	0, 0, 2	66	67

Map order	Site N	Site name	Dates (year_month) Earliest	Latest	92nd percentile CHLA over three-year periods ending in December: 2017	2018	2019	2020	2021	2022	Counts of exceedances of CHLA thresholds (>200, >120, >50 mg m^{-2}) in three-year periods 2017	2018	2019	2020	2021	2022	92nd percentile over whole period Gaps filled	Gaps not filled
37	313171	Punaruku	2016_7	2022_12	8	8	17	18	18	12	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 1	13	17
39	100194	Hatea_Mair_Pk	2015_1	2022_2	11	11	17	28	39	37	0, 1, 2	0, 0, 0	0, 0, 1	0, 0, 1	0, 0, 2	0, 0, 1	29	33
41	109795	Mangakino	2015_1	2020_10	43	14	17	23	23	41	0, 1, 3	0, 0, 0	0, 0, 0	0, 0, 1	0, 0, 1	0, 0, 1	30	31
42	110431	Otaika	2015_1	2022_12	87	38	41	54	54	61	1, 3, 5	0, 1, 1	0, 0, 2	0, 0, 5	0, 0, 7	0, 1, 7	58	66
43	304709	Raumanga_Bernard_St	2015_1	2022_12	93	22	10	20	20	20	0, 3, 4	0, 1, 1	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	43	46
45	312177	Pukenui	2016_7	2022_12	3	3	15	15	12	7	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	8	9
46	108359	Waiarohia_Second_Ave	2015_1	2022_12	105	103	99	82	57	53	0, 1, 10	1, 1, 6	1, 1, 9	1, 1, 9	0, 0, 7	0, 0, 4	73	82
47	107773	Waiarohia_Whau_V	2015_1	2020_10	67	53	44	47	50	58	0, 0, 7	0, 0, 3	0, 0, 1	0, 0, 2	0, 0, 2	0, 0, 1	62	64
48	102674	Kaeo	2015_1	2022_12	29	23	27	19	27	8	0, 0, 1	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	25	30

3.1.3 Commentary on results

Based on all of the data (up to 8 years), and with gaps in the time series filled as described in Section 3.1.1, two sites were graded D (Waiharakeke and Hakaru), four sites were graded band C (Awanui, Waipapa_landing, Watercress and Opouteke). Of the remaining sites, 15 were graded band B and 17 were graded band A.

Using the original data with no gaps filled, one site (Awanui) would have been graded band D rather than C, one site (Punakitere) would have been graded band C rather than B, and one site (Waiamamuku) would have been graded band B rather than band A. Therefore, adjusting for missing data made a small difference to the overall site grading across the 38 sites (three sites affected).

Sites were graded annually over the minimum period of 36 months for 2 – 6 years depending on the length of record at each site. The bands did not change over time at 17 of the 38 sites. At the 21 sites where bands varied over time, the variation was inconsistent. For example, at five sites, band B changed to band A (Kerikeri, Waiaruhe_Puketona, Oruaiti_Windust, Ngunguru, Waiarohia_Whau_V). At three sites the reverse change occurred (A to B, Victoria, Waitangi_Waimate_N_Rd, Waimamaku).

Percentages of sites in each grade also varied over time. The fairest comparisons are those among the three-year periods ending in December 2017 to December 2020, which included at least 35 sites. Of these four periods, the proportion of sites in Grade A was highest for the three years up to December 2019 and lowest for the three years up to December 2017 (Table 3-2). The differences are likely attributable to region-wide variability in hydrological conditions, which is discussed in Section 5 of this report. Percentages of sites in each band based on all the data at each site indicated a higher proportion of sites graded into band C than in most earlier years (Table 3-2).

Table 3-2: Percentages of Northland sites falling into bands A, B, C, and D of the NPS-FM periphyton attribute in four three-year periods. Bands taken from Table 3.1, calculated from the 92nd percentile of the time series of chlorophyll *a* data, with data adjusted for missed surveys.

	Percentage of sites in band, calculated from the 3-year period ending in December:				Percentages based on overall grade
Band	**2017**	**2018**	**2019**	**2020**	
A	37	53	64	54	45
B	46	33	28	37	39
C	11	6	3	3	11
D	6	8	6	6	5

Bands assessed by counting exceedances of the three thresholds (200, 120, and 50 mg m^{-2}) were generally the same as those assessed by calculating the 92nd percentile (Table 3-1). Differences arose because the 92nd percentile does not translate to an exact number of exceedances. For example, in the Waitangi_Waimate_N_Rd, counts placed the site into band C in periods ending in 2019, 2020 and 2021, while the 92nd percentile places the site in band B. The count method is useful because it side-steps the need to account for missed surveys. However, the results are not always consistent with bands produced when the current wording in the NPS-FM is followed exactly. Given the uncertainty around quantifying attribute states, the small differences are likely unimportant.

3.2 Assessment of sites against the New Zealand cyanobacteria guideline

3.2.1 The guideline

The New Zealand Guideline for Cyanobacteria (Wood et al. 2009) sets thresholds for percentage cover by cyanobacteria for the protection of human and animal health in rivers. The predominant species of cyanobacteria seen in New Zealand rivers is the potentially toxic *Microcoleus autumnale* (formerly *Phormidium autumnale*). We assumed that percentage cover by cyanobacteria in the dataset referred mainly to this species. The guidelines specify two levels:

- Alert: 20−50 per cent coverage of potentially toxic cyanobacteria mats attached to substrate. Attaining alert level at recreational sites is a trigger for more intensive monitoring of both cover and levels of toxins.
- Action: More than 50 per cent coverage of the substrate by potentially toxic cyanobacteria mats, or <50 per cent coverage, but accumulation of detached mats along the river margins. Attaining action level at recreational river sites requires a response from regional authorities such as media alerts and erection of signage. Refer to Wood et al. (2009) for details.

3.2.2 Site assessments

To assess sites against the guideline we counted the number of times in each calendar year from 2015 to 2022 when cyanobacteria cover (from the data provided by NRC, see Section 2.2) was between 20% and 50% (i.e., Alert level) and greater than 50% (Action level). Totals over the whole period (up to 8 years) were also counted.

All results are presented in Table 3-3.

3.2.3 Commentary on results

Between January 2015 and December 2022, and across all 38 sites, the Alert level of the cyanobacteria guideline was reported on 36 occasions, and the Action level on 17 occasions (Table 3-3). Sixteen of the 38 monitoring sites were affected and at six of these there was just one exceedance over the entire monitoring period (up to 8 years). The Action level was exceeded at eight sites and the Alert level at 15 sites.

In terms of frequency of exceedances, the most affected sites were Waimate at Waimate North Road (exceedances of the Alert or Action levels or both in five of the eight years) and Opouteke at Suspension Bridge (exceedances in four of eight years).

The highest numbers of exceedances were in 2015 (10 Alerts and three Actions) followed by 2020 (four Alerts and eight Actions). The Action levels reported in 2020 occurred at three sites including Waiaruhe d/s Mangamutu Confluence, at which there were Action levels in 2015 and Waimate at Waimate North Road. The third site at which Action level was reported in 2020 was Waiarohia at Second Avenue, where cover of 100% was reported in June 2020. Cover in all other years was low (<10%). As will be reported in Section 5.2, the years 2015 and 2020 both had relatively low annual median flows compared to the long-term median flow across all sites with a flow record.

Cyanobacteria was more widespread that than the guideline exceedances indicated, with 36 of the 38 monitoring sites having some cover by cyanobacteria at least once between January 2015 and December 2022. Across all sites, cover by cyanobacteria was recorded in 414 of 2170 visual estimates (i.e. 17%). The percentage of records at individual sites was generally higher at sites at which the guidelines were exceeded, but with high variability.

Table 3-3: Exceedances of the New Zealand cyanobacteria guideline's Action and Alert levels of cover at 38 periphyton monitoring sites in Northland. Sites are listed in order of the site number shown on Figure 2-1. Site N is the Northland site code. Numbers of exceedances are shown in each calendar year from 2015 to 2022 as well as over the whole 8-year period. Exceedances in each year are shown even when monitoring was not carried out for the whole year. Alert = cover of more than 20% but less than 50% (orange shading); Action = cover of more than 50% (red shading). Green cells = no exceedances. Grey-shaded cells = no monitoring in that year. The last column shows the percentage of surveys at each site when cyanobacteria was observed at any percentage cover.

Map order	Site N	Site name	Dates (year_month)		2015		2016		2017		2018		2019		2020		2021		2022		Total Alert	Total Action	% Sur-veys
			Earliest	Latest	Alert	Action	Alert	Action	Alert	Action	Alert	Action	Alert	Action	Alert	Action	Alert	Action	Alert	Action			
1	100363	Awanui	2015_1	2022_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	105532	Victoria	2015_1	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
3	100007	Waiharakeke	2015_1	2022_3	2	0	0	0	0	0	0	0					0	0	0	0	2	0	48
4	324659	Kerikeri_Basin_Reserve	2015_1	2022_2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	21
7	101524	Waipapa_landing	2015_1	2022_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
8	306643	Pekepeka	2015_1	2020_9	0	0	0	0	0	0	0	0	0	0	0	0					0	0	3
9	304589	Waiaruhe_Puketona	2015_1	2022_5	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	2	1	33
10	306661	Waiaruhe_ds_Mangamutu	2015_1	2020_10	1	2	0	0	0	0	0	0	0	0	0	3					1	5	41
11	306915	Waipapa_Waimate_N_Rd	2015_1	2020_10	0	0	0	0	0	0	0	0	1	0	1	0					2	0	13
12	304595	Waitangi_SH10	2015_1	2020_5	1	0	0	0	0	0	0	0	1	0	1	0					3	0	34
13	103178	Waitangi_Waimate_N_Rd	2015_1	2022_5	0	0	0	0	0	0	1	0	2	2	0	4	2	0	1	0	6	6	30
15	306655	Watercress	2015_1	2020_10	0	0	0	0	0	0	0	0	0	0	0	0					0	0	7
16	105008	Ruakaka	2015_1	2022_5	2	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	4	1	50
18	306673	Oruaiti_Sawyer	2015_1	2020_9	1	0	0	0	0	0	0	0	1	0	0	0					2	0	36
19	304641	Oruaiti_Windust	2015_1	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
20	306675	Stony	2015_1	2020_10	0	0	0	0	0	0	0	0	0	0	0	0					0	0	13
21	306641	Peria_Honeymoon	2015_1	2021_9	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	17
23	108978	Mangamuka	2015_1	2020_8	0	0	0	0	0	0	0	0	0	0	0	0					0	0	5

Map order	Site N	Site name	Dates (year_month) Earliest	Latest	2015 Alert	2015 Action	2016 Alert	2016 Action	2017 Alert	2017 Action	2018 Alert	2018 Action	2019 Alert	2019 Action	2020 Alert	2020 Action	2021 Alert	2021 Action	2022 Alert	2022 Action	Total Alert	Total Action	% Sur-veys
24	313165	Tapapa	2016_7	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
25	101751	Waipapa_FR	2015_1	2022_12	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	15
26	105231	Punakitere	2015_1	2022_5	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	2	1	60
27	109096	Mangakahia	2015_1	2022_12	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	22
28	102258	Opouteke	2015_1	2022_12	1	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	3	1	36
29	102256	Kaihu	2015_1	2022_12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	24
32	109021	Hakaru	2015_1	2020_8	0	0	0	0	0	0	0	0	0	0	0	0					0	0	19
33	100237	Mangahahuru	2015_1	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
34	109098	Waimamaku	2015_1	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
35	103304	Waipoua	2015_1	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
36	110603	Ngunguru	2015_1	2022_12	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	3	0	42
37	313171	Punaruku	2016_7	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
39	100194	Hatea_Mair_Pk	2015_1	2022_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
41	109795	Mangakino	2015_1	2020_10	0	0	0	0	0	0	0	0	0	0	0	0					0	0	12
42	110431	Otaika	2015_1	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
43	304709	Raumanga_Bernard_St	2015_1	2022_12	0	0	0	0	0	0	0	0					0	0	0	0	0	0	12
45	312177	Pukenui	2016_7	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	108359	Waiarohia_Second_Ave	2015_1	2022_12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	15
47	107773	Waiarohia_Whau_V	2015_1	2020_10	0	0	0	0	0	0	0	0	1	0	0	0					1	0	27
48	102674	Kaeo	2015_1	2022_12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Grand Total					10	3	3	1	2	0	3	0	7	3	4	8	5	1	2	1	36	17	17

4 Validation of national nutrient criteria for Northland

Key messages

In 2022 the Ministry for the Environment (MFE) released guidance on the use look-up tables of nutrient criteria for periphyton, which apply nationally to hard-bottomed streams and rivers.

The criteria are intended to be default values to be used in the absence of local modelling. The criteria have been revised since 2022 following adjustments to the underlying national model.

Criteria are provided for the nutrients: total nitrogen (TN), dissolved inorganic nitrogen (DIN), total phosphorus (TP) and dissolved reactive phosphorus (DRP).

The criteria incorporate “under-protection risk”, which is the percentage of sites that may exceed the target periphyton biomass even when the nutrient criterion is met. Criteria were provided for under-protection risk from 5% to 50%. Choice of acceptable under-protection risk is a policy decision.

The original and revised published nutrient criteria for periphyton were evaluated against the NRC data by following the validation procedure set out in the 2022 MFE guidance.

The validation using data from the 38 Northland periphyton monitoring sites indicated that both the original and revised MFE criteria are too permissive for Northland rivers (i.e., the nutrient concentrations in the criteria to maintain/achieve target attribute states for periphyton were too high for Northland rivers).

However, the revised criteria were more consistent with the observed data for Northland sites than the original criteria in that the proportion of under-protected sites more closely matched the under-protection risk specified for each criterion.

We consider that the revised criteria are the best available for Northland at the present time.

4.1 Introduction

To assist councils in setting nutrient concentration criteria for periphyton, the Ministry for the Environment (MFE) commissioned the development of nutrient criteria to achieve a range of target attribute states based on modelling that was informed by a national dataset of 251 sites located across New Zealand (Snelder et al. 2022). Snelder et al. (2022) provided nutrient criteria in a series of look-up tables that apply to all hard-bottomed (i.e., cobble- or gravel-bed) streams and rivers, which are classified into one of 21 REC source-of-flow classes. Criteria were derived to apply to both shaded and unshaded sites.

An important feature of the criteria provided by Snelder et al . (2022) is the inclusion of under-protection risk. The under-protection risk concept arises due to the uncertainty associated with the statistical models underlying the nutrient criteria in the look-up tables. The models predict the periphyton biomass given the nutrient concentration, but they are uncertain at the level of individual sites. The models are more reliably used to predict the proportion of sites that will exceed a given periphyton biomass, given a nutrient concentration. This proportion can also be interpreted as the risk that an individual site will exceed a given periphyton biomass, given a nutrient concentration. The risk is referred to as the under-protection risk because it is the probability that a randomly chosen site will exceed the target biomass (i.e. that the site is not “protected”) despite having nutrient concentrations equal to, or lower than, the criterion for that site. The criteria therefore require the user to choose both the target periphyton biomass (i.e., target attribute state) and the acceptable level of risk that a site will exceed the threshold.

The derived criteria are intended to provide default values that can be used in the absence of other more appropriate criteria (e.g., potentially from locally derived observations and modelling). Guidance provided by MFE (2022) suggests that use of the look-up tables to define criteria, for example within a region, should be accompanied by a verification that considers whether the nutrient criteria are reasonably consistent with local observations of relationships between periphyton abundance and nutrient concentrations. There are limited ways to assess confidence in the criteria. However, where a monitoring network for periphyton and nutrients exists within a region, a validation analysis can be performed with the following seven steps.

1. Obtain the median concentration of each nutrient and 92nd percentile biomass from the observations at each monitoring site.

2. Obtain the REC source-of-flow class and shade status for each site.

3. For a fixed nutrient and level of under-protection risk, obtain the criteria from the lookup tables for the A, B and C bands for each site based on the site's REC source-of-flow class and shade status.

4. For each nutrient and site, and under-protection risk, interpolate the biomass from the criteria by:

   - treating the biomass thresholds (upper limits) for A, B and C bands of 50, 120 and 200 mg m^{-2} as the variable Y and nutrient criteria from the look-up tables for each band as the variable X and assuming biomass is zero when nutrients are zero;

   - use linear interpolation to estimate the biomass (Y values) predicted by the observed site nutrient concentrations;

   - treating the interpolated biomass as a prediction.

5. Calculate, over all sites, the proportion of sites with observed values that exceed the above predicted values. We refer to these sites as the 'exceeding sites'.

6. Repeat this process for each nutrient and level of under-protection risk.

7. Assess whether the nutrient criteria are consistent with the observations by comparing the proportion of exceeding sites with the proportion indicated by the under-protection risk.

MFE (2022) suggests that reasonable agreement (i.e., ± 20%) between the proportion of exceeding sites and level of under-protection risk can be interpreted as evidence that the nutrient criteria are valid for the sites represented by the monitoring network. MFE (2022) notes that perfect agreement should not be expected and that divergence between the proportion of observations that exceed the predictions, and the under-protection risk can be expected to decrease as the sample size increases.

Below, we report on a verification analysis that was performed using periphyton and nutrient data collected by NRC. Data were provided from 38 periphyton monitoring sites (see Section 2.1), all of which would be classed as hard-bottomed using the definition in Clapcott et al. (2011) (<50% of the bed made up of sand and/or silt).

4.2 Revision of national criteria

Validation of the periphyton nutrient concentration criteria derived by Snelder et al. (2022) using data from other regions (i.e., Wellington, Otago, Southland, and the Manawatu-Wanganui regions) have consistently showed them to be too permissive (i.e., the criteria concentrations are too high). These findings have reduced confidence in the criteria of Snelder et al. (2022).

A study by Snelder and Kilroy (2023) aimed to revise the nutrient criteria based on a regression modelling approach, as used by Snelder et al. (2022), but fitting models using generalised linear models (GLM) instead of the ordinary least-squares regression (OLS) models that were used by Snelder et al. (2022). Briefly, the reason for the change in the modelling approach was because the original OLS model was unable to predict the highest site values of CHLA92 (values >> 200 mg m^{-2}). Based on the assumption that the model errors were normally distributed, these observations were extremely unlikely. This meant that the models tended to under-estimate CHLA92 at sites with high biomass, which in turn meant the criteria tended to be too permissive. It was anticipated that the revision would produce better nutrient criteria because GLM are more able to represent the distribution of the regression model errors.

In this study, therefore, we performed validations for the NRC dataset first using the original criteria of Snelder et al. (2022) and then using the revised criteria of Snelder and Kilroy (2023).

4.2.1 Uncertainty in the nutrient criteria

Snelder and Kilroy (2023) provided details of the methods used to derive revised nutrient criteria for four forms of nutrients (TN, DIN, TP, DRP) to achieve three biomass targets (50, 120 and 200 mg/m^2) for 21 River Environment Classification (REC) source-of-flow classes. Briefly, the GLM models were used to predict CHLA92 for a wide range of the concentrations of each nutrient form for up to 500 individual river locations[4] in each source-of-flow class. The concentrations at which the predicted biomass was 50, 120 and 200 mg/m^2 for each location was obtained from these predictions by linear interpolation. The geometric means of the concentrations associated with each biomass target within each source-of-flow class are the criteria. The geometric mean was calculated as the exponentiated mean of the log of the individual nutrient concentrations.

For each biomass target within each source-of-flow class, Snelder and Kilroy (2023) also obtained the exponentiated standard deviation of the log of the individual nutrient concentrations as a measure of the within-class variability of the concentration criteria. This acknowledges that the derived criteria represent a mean condition for an entire REC class. The “best” estimate of a criterion for a specific site is the criterion produced for the specific segment that the site is located on. Using the mean for that segment’s class rather than the criterion for the site’s specific segment introduces uncertainty because the criterion for the specific segment will differ from the mean for the whole class. The impact of the within class variation on the validation can be assessed with a Monte Carlo simulation of the validation procedure, which is explained later.

4.2.2 Over-prediction of low CHLA92 values

A detail of the revised criteria derived by Snelder and Kilroy (2023) was that the underlying GLM models tended to over-estimate low CHLA92 values (i.e., ≤50 mg m^{-2}). Over-prediction of the low CHLA92 values meant that the derived criteria for the lower biomass threshold (i.e., 50 mg m^{-2}) were too stringent (i.e., the concentrations were too low). This issue was also present in the original OLS models and criteria but was slightly more apparent for revised criteria. Consequently, the results of

[4] In the derivation procedure, river locations were represented by segments of the digital river network that is associated with the REC.

the validations (using either the original or revised criteria) need to be interpreted bearing in mind the known over-prediction of low CHLA92 values.

To address the issue of over-prediction of low CHLA92 values Snelder and Kilroy (2023) suggested that an alternative set of criteria for the 50 mg m^{-2} biomass threshold could be derived using quantile regression. This approach was successfully used to derive criteria for TN and DIN.[5] These criteria were derived for the same levels of under-protection risk as the revised criteria. However, the quantile regression criteria are spatially uniform (i.e., one value applies to all REC source-of-flow classes).

A copy of the revised criteria for all REC source-of-flow classes that occur in Northland are provided in Table C-1 to Table C-4 (for TN, DIN, TP and DRP). In addition, the alternative set of spatially uniform criteria for TN and DIN derived using quantile regression for the 50 mg m^{-2} biomass threshold is provided in Table C-5.

4.3 Data

The data included in the validation were from the 38 sites shown in Figure 2-1, with details in Table 2-1. Each site had at least 38 observations of CHLA (range 38 to 85). NRC also provided monthly observations of concentrations of four forms of nutrient: TN, DIN, TP, DRP.

All but three of the 38 sites belonged to the WW/L REC source-of-flow class (Figure 4-1).

Gaps in the time series of CHLA at each site were filled using the method described in Section 3.1.1. The 92nd percentile of the biomass observations (CHLA92) was calculated from the complete time series at each site, with gaps filled. The time series of nutrient concentrations were generally complete, except for two sites at which there was a two-year gap in the data (see Section 2.2). the median values of TN, DIN, TP and DRP and were calculated from the time series at each site.

[5] Alternative criteria for TP and DRP could not be derived using this method because the quantile regression relationships were consistently non-significant.

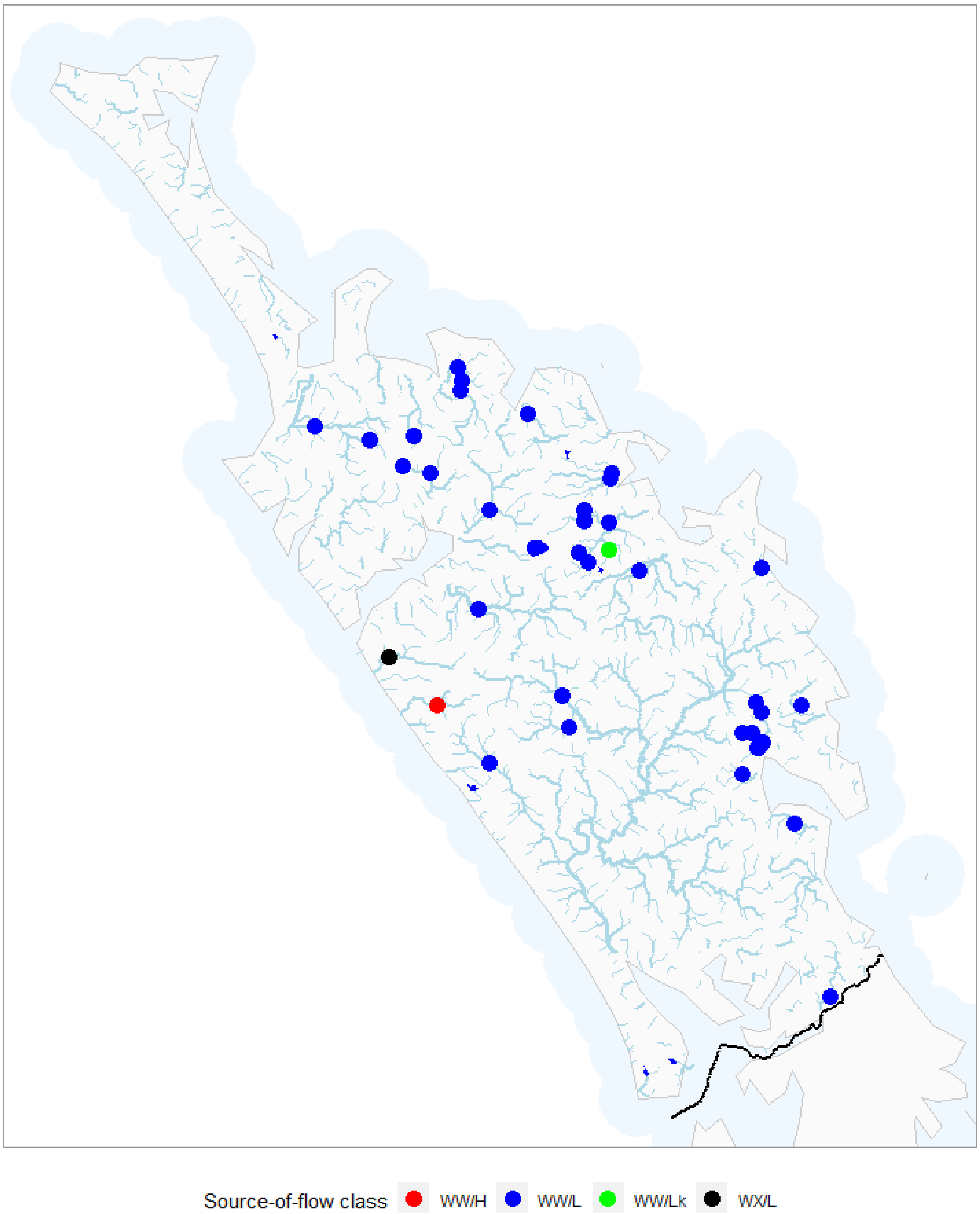

Figure 4-1: Location of the 38 periphyton monitoring sites in the Northland region. Sites are colour-coded by their source-of-flow class. Refer to Figure 2-1 and Table 2-1 for site names and further details.

4.4 Validation analysis using original criteria

The procedure recommended in MFE (2022) was followed (see Section 4.1 above). Predicted values of CHLA92 were derived for each site using the method explained in step 4. The observed and predicted values of CHLA92 at the 38 sites in the Northland region based on the four nutrient forms are shown as scatter plots in Figure 4-2, for six levels of under-protection risk. Theoretically, 5%, 10%, 15%, 20%, 30% and 50% of the sites should have observed biomass that exceeds the predicted biomass when the predictions are made based on the corresponding levels of under-protection risk (i.e., should lie above the red lines on Figure 4-2).

The data shown in Table 4-1 indicate that the proportions of sites for which observed CHLA92 exceeds predicted CHLA92 increases systematically as the under-protection risk increases for all four nutrient forms. However, the proportion of sites for which observed CHLA92 exceeds the predicted is higher than expected according to the level of under-protection risk for all four nutrient forms and for all levels of under-protection risk (Table 4-1). The column headed "discrepancy" is the difference (for each nutrient) between the under-protection risk associated with each criterion and the observed proportion of sites exceeding the threshold. Higher than expected CHLA92 at more sites than suggested by the under-protection risk indicates that the criteria are too permissive (i.e., the criteria concentrations are too high).

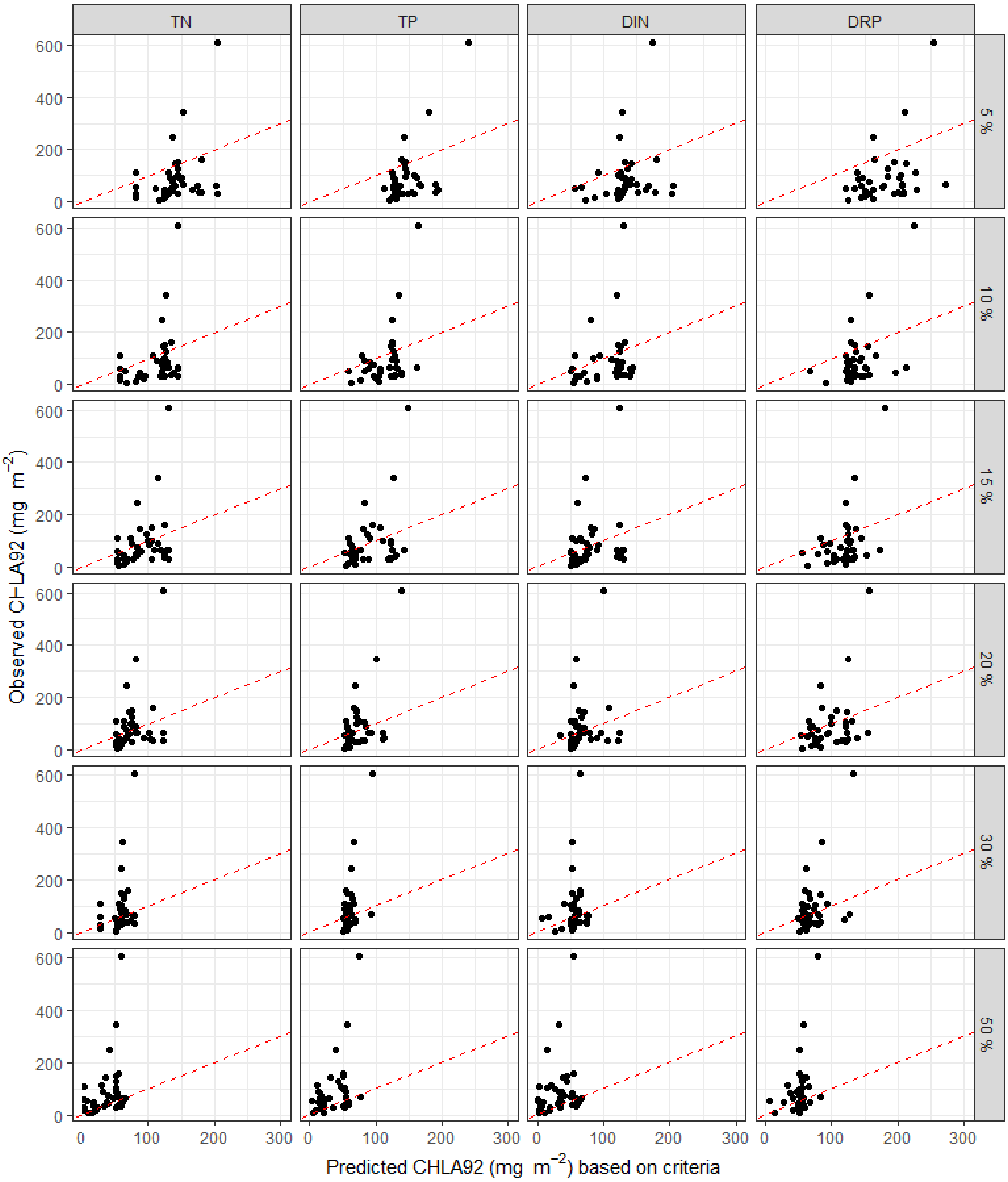

Figure 4-2: The observed and predicted values of CHLA92 at the 38 sites in the Northland region, based on MFE (2022) nutrient criteria. Predicted values are derived from the MFE (2022) nutrient criteria for under-protection risks of 5, 10,15, 20, 30 and 50%. Panel labels indicate the under-protection risks and the nutrient form (TN, DIN, TP and DRP). The dashed red diagonal (one to one) line represents agreement between the predictions and observations. The points lying below the red lines indicate sites for which the observed biomass was less than that predicted by the nutrient criteria and vice versa for points lying above the lines.

Table 4-1: Proportion of sites (%) for which observed biomass exceeds that predicted for six levels of under-protection risk including the four used by the MFE (2022) criteria. The discrepancy is the difference between the under-protection risk and the observed proportion of sites exceeding the threshold (%).

Under-protection risk (%)	Proportion exceeding (%)				Discrepancy (%)			
	TN	TP	DIN	DRP	TN	TP	DIN	DRP
5	16	16	16	8	-11	-11	-11	-3
10	24	21	32	13	-14	-11	-22	-3
15	29	32	39	21	-14	-17	-24	-6
20	42	45	45	26	-22	-25	-25	-6
30	55	55	53	45	-25	-25	-23	-15
50	74	76	82	58	-24	-26	-32	-8

4.5 Validation analysis using revised criteria

The validation analysis was performed again (as above) using the revised criteria of Snelder and Kilroy (2023). The observed and predicted values of CHLA92 at the 38 sites in the Northland region based on the four nutrient forms are shown as scatter plots in Figure 4-3, for seven levels of under-protection risk. Theoretically, 5%, 10%, 15%, 20%, 25%, 30% and 50% of the sites should have observed biomass that exceeds the predicted biomass when the predictions are made based on the corresponding levels of under-protection risk (i.e., should lie above the red lines on Figure 4-3).

We note that the MFE (2022) document provides criteria for four levels of under-protection risk: 5%, 10%, 15%, and 20%, but the 30% and 50% levels were also available for the original criteria. The revised criteria included seven levels of under-protection risk by adding the 25% level. The 25% level was included because it has been suggested as a reasonable choice in best practice guidance for establishing nutrient concentration criteria by the European Commission's science and knowledge service (Phillips et al. 2018, and also in Kelly et al. 2022).

The data shown in Figure 4-3 indicate that the proportion of sites for which observed CHLA92 exceeds predicted CHLA92 increases systematically as the under-protection risk increases for all four nutrient forms. Comparing Figure 4-3 with Figure 4-2 also indicates that the proportion of sites for which observed CHLA92 exceeds predicted CHLA92 is lower for the revised criteria than for the original criteria, suggesting that the proportions may be closer to the expected under-protection risk than for the original criteria.

The improvement over the original criteria is confirmed in Table 4-2. The consistently negative values for discrepancy show that the criteria are too permissive (i.e., the criteria concentrations are too high), similar to the original criteria. However, comparison with Table 4-1 indicates that the discrepancies are generally smaller for the revised criteria than for the original criteria, and therefore closer to the expected values (i.e., the level of under-protection risk). For all combinations of nutrient and level of under-protection risk in common between Table 4-1 and Table 4-2, the revised criteria had proportions of exceeding sites that were closer to the expected values than the original criteria.

In summary, the validation of the revised criteria indicates they are generally too permissive, but they generally performed better, and never performed worse, than the original criteria. It is noted that the because the revised criteria are known to be too stringent for the lower biomass threshold (i.e., 50 mg m^{-2}) (see Section 4.2.2), the validation used the alternative set of criteria for the

50 mg m^{-2} biomass threshold that was derived using quantile regression as described by Snelder and Kilroy (2023). We suggest that if the biomass target were to be 50 mg m^{-2} (i.e., the A band) a more robust choice of criteria are the spatially uniform TN and DIN criteria derived using quantile regression that are listed in Table C-5.

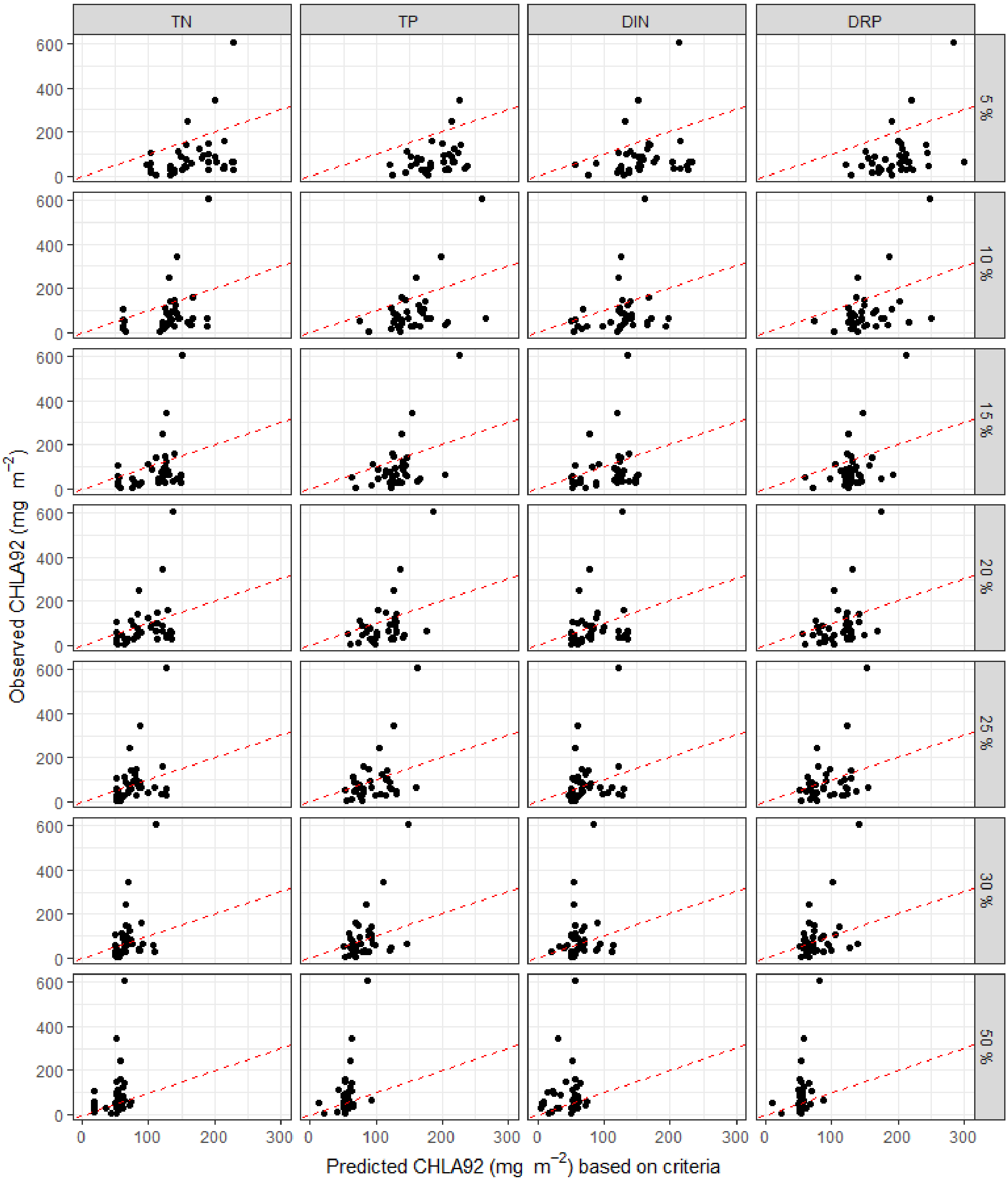

Figure 4-3: The observed and predicted values of CHLA92 at the 38 sites in the Northland region where predicted values are derived from the alternative nutrient criteria. Predicted values are derived from the alternative nutrient criteria for under-protection risks of 5, 10,15, 20, 25, 30 and 50%. Panel labels indicate the under-protection risks and the nutrient form (TN, DIN, TP and DRP). The dashed red diagonal (one to one) line represents agreement between the predictions and observations. The points lying below the red line indicate sites for which the observed biomass was less than that predicted by the nutrient criteria and vice versa for points lying above the lines.

Table 4-2: Proportion of sites (%) for which observed biomass exceeds that predicted for the seven levels of under-protection risk based on the revised criteria. The discrepancy is the difference between the under-protection risk and the observed proportion of sites exceeding the threshold (%).

Under-protection risk (%)	Proportion exceeding (%)				Discrepancy (%)			
	TN	TP	DIN	DRP	TN	TP	DIN	DRP
5	11	8	8	8	-6	-3	-3	-3
10	16	13	21	13	-6	-3	-11	-3
15	24	16	32	16	-9	-1	-17	-1
20	29	21	39	26	-9	-1	-19	-6
25	45	32	45	34	-20	-7	-20	-9
30	45	39	50	45	-15	-9	-20	-15
50	61	55	63	55	-11	-5	-13	-5

4.6 Uncertainty of validation analysis

The above analysis is uncertain for two reasons. First, the observed values of CHLA92 are imprecise (i.e., they are estimates of the population value calculated from the monthly samples). Second, there is within-class variability in the estimates of the criteria for each site (see Section 4.2.1).

We note that the first uncertainty is part of the more general issue that all estimates of attribute states are subject to uncertainty because of sampling error. Recent guidance (Milne et al. 2023) has made suggestions for accounting for this uncertainty under subclause (4) of clause 3.10 of the NPS-FM. However, Milne et al. (2023) acknowledge that robust methods for quantifying attribute state uncertainty have not been identified. Milne et al. (2023) acknowledge that standard statistical assumptions (e.g., observations are randomly varying and drawn from the same population), associated with the calculation of confidence intervals, are likely to be violated for typical NPS-FM attributes. For example, observations of chlorophyll *a* have a seasonal component of variation and are, therefore, not entirely random. Attribute states are also assigned to sites using observation collected over time periods of up to five years. Time periods of this duration are likely to include significant changes that are due to long-term trends and inter-annual fluctuations (Snelder et al. 2021b), which means that the sample does not represent a single population. Therefore, in this study, we ignored the uncertainty associated with observed values of CHLA92 and focussed on accounting for the uncertainty associated with the within-class variability in the criteria.

The within-class variability is quantified by the within-class standard deviation of the nutrient concentration criteria across river locations that is explained in Section 4.2.1 above. A second validation analysis was undertaken that repeated the first analysis but used this standard deviation in a Monte Carlo simulation to generate 1000 “realisations” of the predicted CHLA92 for each site. For each realisation, random errors were added to the criterion for each site and then this “perturbed” criterion was used to produce a realisation of the predicted CHLA92. The random error was derived by drawing from a normal distribution with a standard deviation equal to the standard deviation of the log of the individual nutrient concentrations within each class (see Section 4.2.1). The 1000 realisations produced by the Monte Carlo analysis were summarised to provide best estimates of the proportion of exceeding sites. The uncertainty of the proportion of exceeding sites was quantified by the 95% confidence interval.

Figure 4-4 summarises the results of the Monte-Carlo procedure and shows the proportion of "exceeding" sites and the 95% confidence interval for each level of under-protection risk. In Figure 4-4, for TN and DIN and for all levels of under-protection risk, the confidence bound does not include the associated level of under-protection risk (indicated by horizontal lines). This indicates that the revised criteria for these nutrient forms are inconsistent with the monitoring data. In addition, because the lower confidence limit is always above (greater than) the associated level of under-protection risk (indicated by horizontal lines) we can be at least 95% confident that the criteria are too permissive (i.e., the concentration criteria are higher than they should be) based on the sites used in the validation.

In contrast to TN and DIN, Figure 4-4 indicates that for TP and DRP and for all levels of under-protection risk except for the 5% level, the confidence bound does include the associated level of under-protection risk (indicated by horizontal lines). This indicates that the revised criteria for these nutrient forms are consistent with the monitoring data.

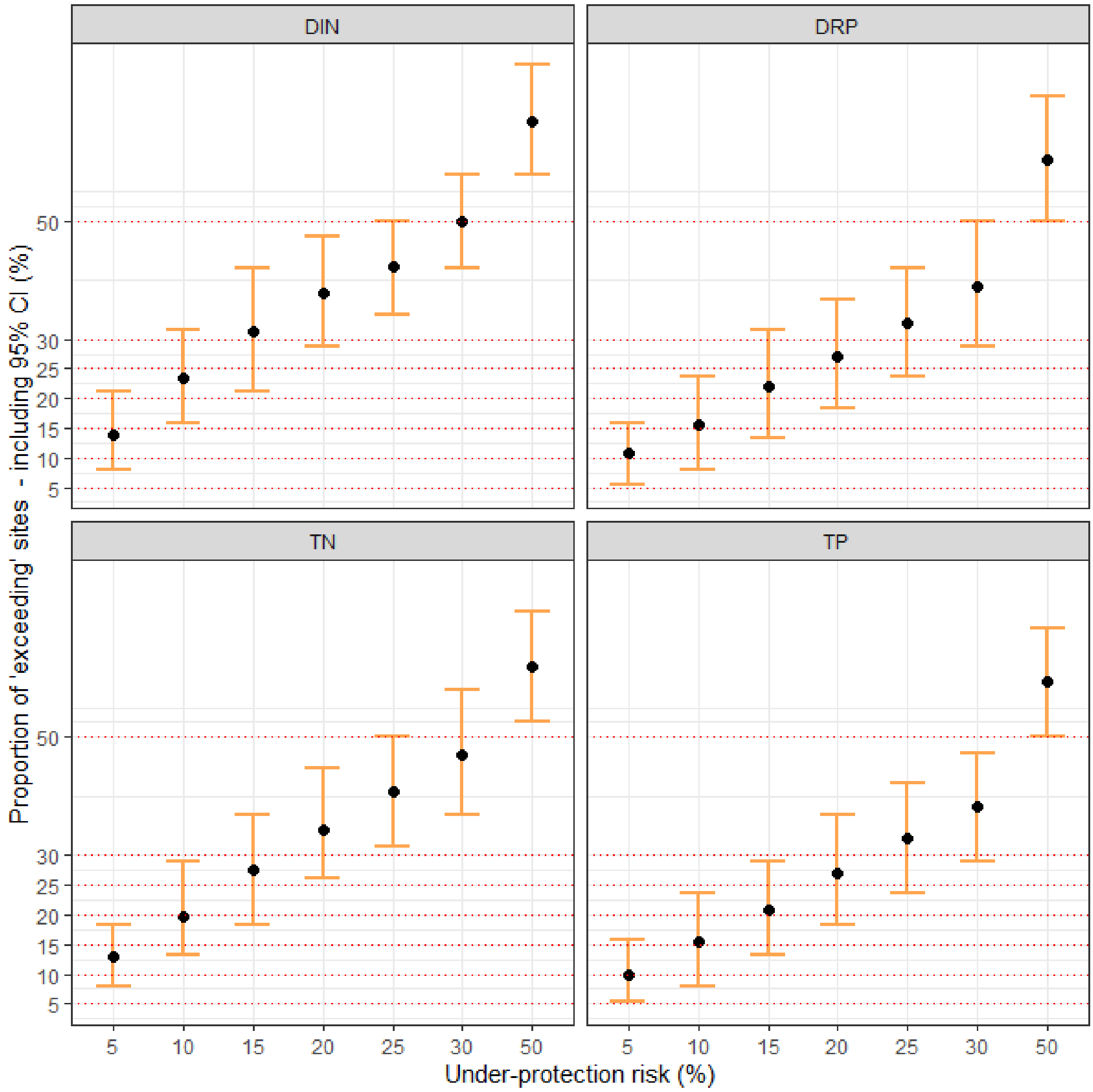

Figure 4-4: Proportion of "exceeding" sites (i.e., sites that are under-protected) for each level of under-protection risk (x-axis) from the first Monte Carlo analysis. The error bars indicate the 95% confidence interval of the observed "exceeding" sites.

4.7 Conclusion

Revised nutrient criteria for periphyton were derived because validations of the original criteria in MfE (2022) in several regions indicated that the criteria were too permissive (the concentrations were too high). The revised nutrient criteria led to fewer sites being under-protected than the original criteria presented in MfE (2022). However, validation using data from the 38 Northland periphyton monitoring sites indicated that the revised criteria are also too permissive (i.e., the concentration criteria are higher than they should be), but generally performed better, and never performed worse, than the original criteria.

When uncertainties were taken into account, the validation indicated that the criteria were inconsistent with the monitoring data for TN and DIN but were consistent with the monitoring data for TP and DRP for all values of UPR, except 5%. The tests described above are reasonably independent of the criteria because, although the same Northland sites were used to fit the models as to perform this validation, the validation dataset included an extra 21 months of data. The dataset used to fit the original model included data up to March 2021 whereas this study used data for the period ending December 2022.

The results of the validation procedure and uncertainty analysis thus indicated that the national criteria for TN and DIN are too permissive for Northland sites. We therefore trialled an alternative approach for determining instream nutrient concentrations to achieve the A, B and C bands for the periphyton attribute in Northland rivers (following objective 3 in Section 1). The approach tried was quantile regression, which was successfully used by Snelder and Kilroy (2023) to derive spatially uniform criteria for TN and DIN for the 50 mg m^{-2} biomass threshold (see Section 4.2.2 above). Quantile regression has also been used previously to suggest nutrient criteria for periphyton (e.g., Matheson et al. 2016). In the case of the Northland dataset, the approach was unsuccessful in that too few of the quantile regression models were statistically significant to enable generalised criteria to be suggested across all levels of under-protection risk. For details of the results refer to Appendix B.

Because relationships between periphyton biomass and nutrient concentrations are relatively weak and confounded by the influence of many other drivers (see Section 6), it is not surprising that some of the validation results indicate a lack of agreement with the monitoring data, and also that an alternative method (quantile regression) could not improve on the revised criteria. These findings need to be considered in the context of the small validation dataset of 38 sites, which is a weak basis for inferring the true performance of the criteria. In our opinion, the revised criteria are the best that can be achieved at the present time and in the absence of more data and/or development of better methods they are the best available for Northland.

Table 4-3 presents a summary of the revised criteria applicable to Northland sites included in the present analysis. A copy of the revised criteria for all REC source-of-flow classes that occur in Northland are contained in tables in Appendix C.

Table 4-3: Examples of revised criteria for REC Source of Flow classes represented by the periphyton monitoring sites, for four nutrients and two levels of under-protection risk. Under-protection risk of 25% was suggested for Europe (see Section 5.4), 10% is an arbitrary lower value, as an example. Criteria are shown in mg L^{-1} for unshaded and shaded sites, where shaded is defined as >60% shade. The blue-shaded cells show the criteria for the source-of-flow class with the highest representation (WW/L) (see Figure 4-1). Grey type indicates criteria that are more than the saturating concentration for that nutrient, under conditions where non-nutrient factors are likely to strongly control periphyton biomass. Note that criteria for the 50 mg m^{-2} threshold are too stringent and include values of zero for TP and DRP. Alternative spatially uniform criteria are shown for TN and DIN, based on quantile regression. See Section 4.2.2 and Table C-5 for more information about alternative criteria for the 50 mg m^{-2} threshold.

Nutr-ient	Under-protect-ion risk	SoF	Nutrient criteria (mg L^{-1}) for CHLA92 targets (mg m^{-2}) of:					
			Unshaded _50	Unshaded _120	Unshaded _200	Shaded _50	Shaded _120	Shaded_200
TN	10	WX/H	0.022	0.148	2.114	0.022	0.741	3.922
	10	WW/L	0.022	0.041	0.702	0.022	0.209	2.296
	10	WX/L	0.022	0.124	1.893	0.022	0.621	3.968
	25	WW/H	0.028	0.848	3.860	0.028	2.840	4.353
	25	WW/L	0.028	0.395	2.868	0.028	1.707	3.789
	25	WX/L	0.028	1.139	4.326	0.028	3.93	4.342
DIN	10	WW/H	0.004	0.025	1.200	0.004	0.269	2.889
	10	WW/L	0.004	0.009	0.365	0.004	0.077	1.598
	10	WX/L	0.004	0.043	1.751	0.004	0.459	3.393
	25	WW/H	0.006	0.596	3.340	0.006	2.409	3.599
	25	WW/L	0.006	0.174	2.070	0.006	1.149	3.083
	25	WX/L	0.006	0.974	3.542	0.006	3.126	3.620
TP	10	WW/H	0	0.006	0.052	0	0.016	0.124
	10	WW/L	0	0.003	0.031	0	0.009	0.073
	10	WX/L	0	0.010	0.083	0.001	0.026	0.171
	25	WW/H	0.001	0.036	0.210	0.002	0.090	0.278
	25	WW/L	0.001	0.022	0.138	0.001	0.054	0.206
	25	WX/L	0.001	0.058	0.254	0.004	0.134	0.296
DRP	10	WW/H	0	0.002	0.044	0	0.008	0.111
	10	WW/L	0	0.001	0.019	0	0.003	0.054
	10	WX/L	0	0.004	0.068	0	0.014	0.139
	25	WW/H	0	0.026	0.179	0.001	0.078	0.219
	25	WW/L	0	0.012	0.117	0	0.036	0.164
	25	WX/L	0	0.044	0.200	0.001	0.107	0.221

5 Predictors of periphyton biomass and cover across Northland: river flows

Key messages

Across Northland, periphyton biomass (as chlorophyll *a*, CHLA) and periphyton cover (as weighted composite cover, WCC) tended to be tended to be lower in years when averaged river flows were highest (e.g., 2017 and 2022) and higher in the years of low flows (e.g., 2019, 2020).

River flows were four to six times higher in winter (June – August) than in summer (January – March). Biomass and cover were correspondingly lower in winter, although the summer – winter difference in periphyton abundance was less marked for biomass than for cover.

Most (>60%) of the monitoring sites with a flow record had clear relationships between periphyton (as biomass or cover) and the number of days since a high flow event. The size of events (in multiples of median flow) varied across sites and such events are referred to as periphyton removal flows (PRFs).

The number of days since a PRF is potentially a measure of the accrual time for periphyton. This assumes that (a) the high flow event was large enough to remove periphyton to low levels, and (b) smaller flow perturbations during that time had a much smaller effect on biomass.

Sites with the strongest relationships between periphyton biomass and/or cover and accrual time defined by a PRF were Victoria River, Waipapa Stream, Mangakahia River, Otaika Stream, and Waiarohia Stream. These sites spanned a range of river size and periphyton abundance.

The relationship between days of accrual (i.e., days since a PRF) and periphyton biomass tended to strengthen as the proportion of large substrate (the sum of large cobbles, boulders and bedrock) on the streambed decreased (i.e., the bed became less stable). This pattern was not seen for periphyton cover.

5.1 Introduction

In this section, we begin to address parts 4 and 5 of the analysis (as listed in Section 1). The brief from NRC called for:

> "… an updated understanding of the main predictors of periphyton biomass (as CHLA [and WCC]) across the Northland region, including an evaluation of the relative influence of the different nutrient variables for which there are data ((dissolved inorganic nitrogen (DIN), dissolved reactive phosphorus (DRP), total nitrogen (TN), total phosphorus (TP), ammoniacal nitrogen (NH_4-N), nitrate-nitrite nitrogen (NOx-N) and total Kjeldahl nitrogen (TKN)))."

Before considering relationships between single or multiple environmental variables (including nutrient concentrations) across sites, we looked at the effects of river flows on periphyton, first over the whole region, then at individual sites.

River flows were considered first because flow is a primary controller of variability in periphyton abundance in rivers over time (Biggs 1995): high, variable flows remove biomass and low, stable flows promote periphyton accrual. The effects of flows are mediated by a range of other factors, the most important of which is nutrient availability (Biggs and Close 1989). Additional important mediating factors include water temperature, light (shade), conductivity (EC, e.g., as an indicator of micronutrients), bed substrate composition, and grazing by macroinvertebrates. With the exception of macroinvertebrate grazing, all these variables were predictors in the national model developed by Snelder et al. (2022) and its updated version (see Section 4). The potential effects of nutrient concentrations and the influence of the other mediating factors are discussed in Section 6.

5.2 General patterns of flow and periphyton over the monitoring period (2015 to 2022)

5.2.1 Data

The dataset used for the analyses below comprised the 21 flow records (daily mean flows) with all monthly observations of CHLA and cover (summarised as WCC, see Section 2.2) from the relevant periphyton monitoring sites joined to the flow record at the date of the observation.

5.2.2 Methods

The complete dataset of flows, CHLA and WCC was used to graphically summarise flows, CHLA and WCC by year and by month across all sites. Flows at each site were standardised by the median flow. Years were defined as calendar years, to encompass the whole periphyton dataset, which ran from January 2015 to December 2022. Broad regional-scale relationships were evaluated from Pearson correlation coefficients between median CHLA or WCC and the median of standardised median flow from all sites, over calendar years and over months.

To inform the analyses described below and to help with interpreting patterns occurring at individual sites, we plotted the flow record at each of the 21 sites with CHLA and cover (as WCC) overlaid. CHLA and WCC data from the 17 sites with no flow record were also plotted over time, for completeness. All the plots are presented in Appendix D, arranged in the order of sites shown in Table 2-1.

5.2.3 Results and commentary

Flows were lowest in the calendar years 2019 and 2020 driven by long periods of summer low flows and lower and shorter winter high flows than in other years (Figure 5-1, and seen in the hydrographs in Appendix D). The median flow in 2019 and 2020 was 0.5 of the long-term median (2015 to 2022). The year 2015 also saw relatively low flows (0.7 times the long-term median). High flow years were 2017 and 2022, when the median flow was >1.3 times the long-term median). Median flow was 1.25 times the long-term median in 2018. Annual medians of both CHLA and WCC (calculated from median values at each site) were negatively correlated with the annual medians of standardised flows, consistent with understanding of the factors that affect periphyton biomass in rivers (median values, Pearson's correlation coefficient (R) = -0.63 and -0.62 respectively).

There was a seasonal pattern of river flows for all the hydrographs (Appendix D, Figure 5-2). In terms of multiples of median flow, river flows in July, August and September (winter) were four to six times higher than in January, February and March (summer), with flows three to four times the long-term median flow in winter (on average) and 0.35 to 0.4 times the long-term median in summer. Variation in CHLA and WCC generally reflected the variation in flows across months.

Other points from Figure 5-1, Figure 5-2 and Appendix D are:

- The difference in CHLA between the driest years (2019, 2020) and the wettest years (2017 and 2022) was less pronounced than that for WCC (Figure 5-1). This is unsurprising because CHLA and WCC measure different aspects of periphyton that may respond differently to wet and dry years. For example, WCC focuses only on the visible mats and filaments in periphyton, while CHLA includes chlorophyll *a* in all types of algae including thin films that are not included in WCC.

- CHLA at most sites was generally greatest in the three driest years (2015, 2019 and 2020) (Figure 5-1) but this was not the case at all sites (Appendix D). Exceptions included Hakaru (periodic high CHLA between 2015 and 2018, but rarely high since then); Kaihu (CHLA >100 mg m^{-2} in most summers, with peak CHLA (~280 mg m^{-2} in 2016; Ngunguru (peak CHLA in 2017 and 2022); Waiarohia (no particular pattern associated with the dry years) (sites 29, 36 and 46 in Appendix D).
- As for the pattern across dry and wet years, WCC showed a more pronounced seasonal pattern than CHLA. However, Figure 5-2 also shows that high periphyton as both CHLA and WCC can occur year-round.
- The patterns of CHLA and WCC in Appendix D indicate that the two measures of periphyton abundance are not always closely correlated at each site.

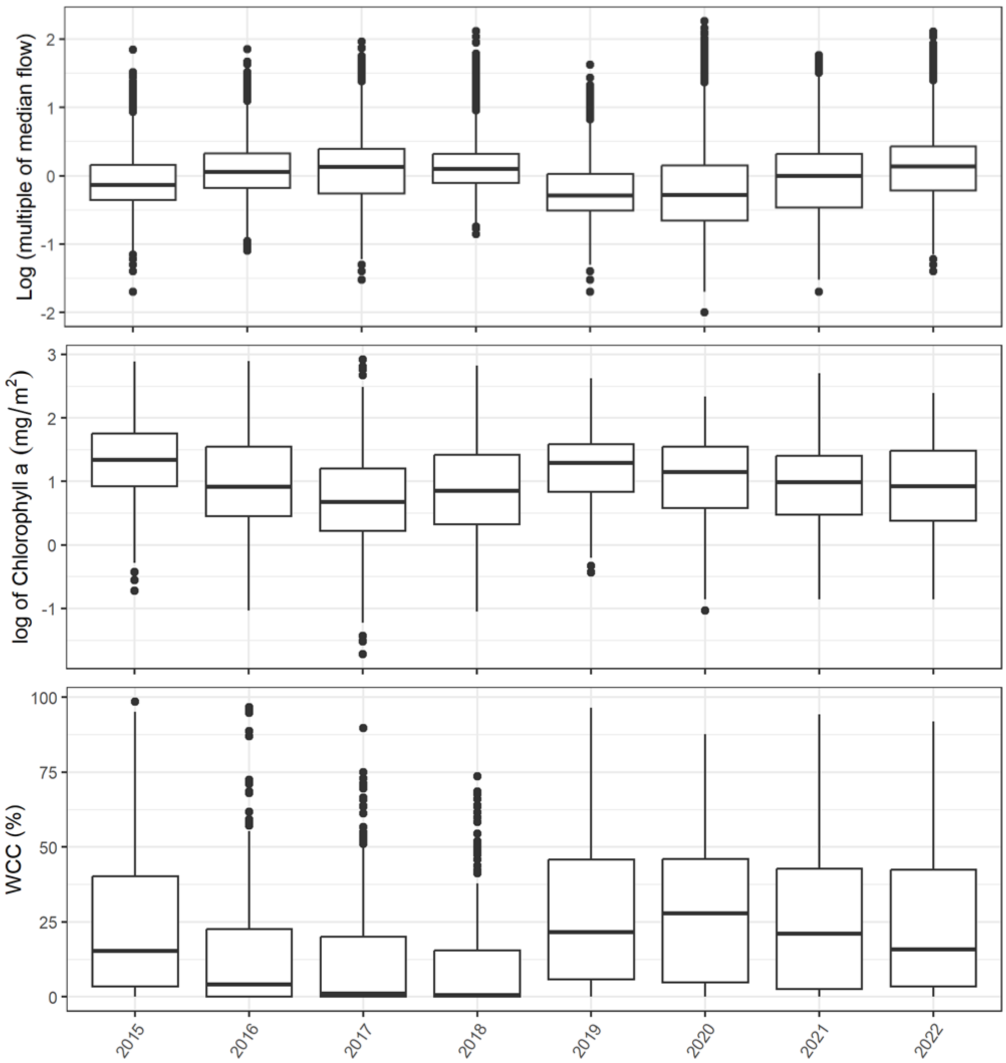

Figure 5-1: Box plots showing the distribution of flow (top), CHLA (middle) and WCC (bottom) over the whole Northland region in each calendar year over the monitoring period. Flow data are from the 21 sites with a flow record. The long-term median flow is at 0 (log_{10} of 1). CHLA and WCC data are from all 38 sites with sufficient periphyton data for the analysis in Section 6.

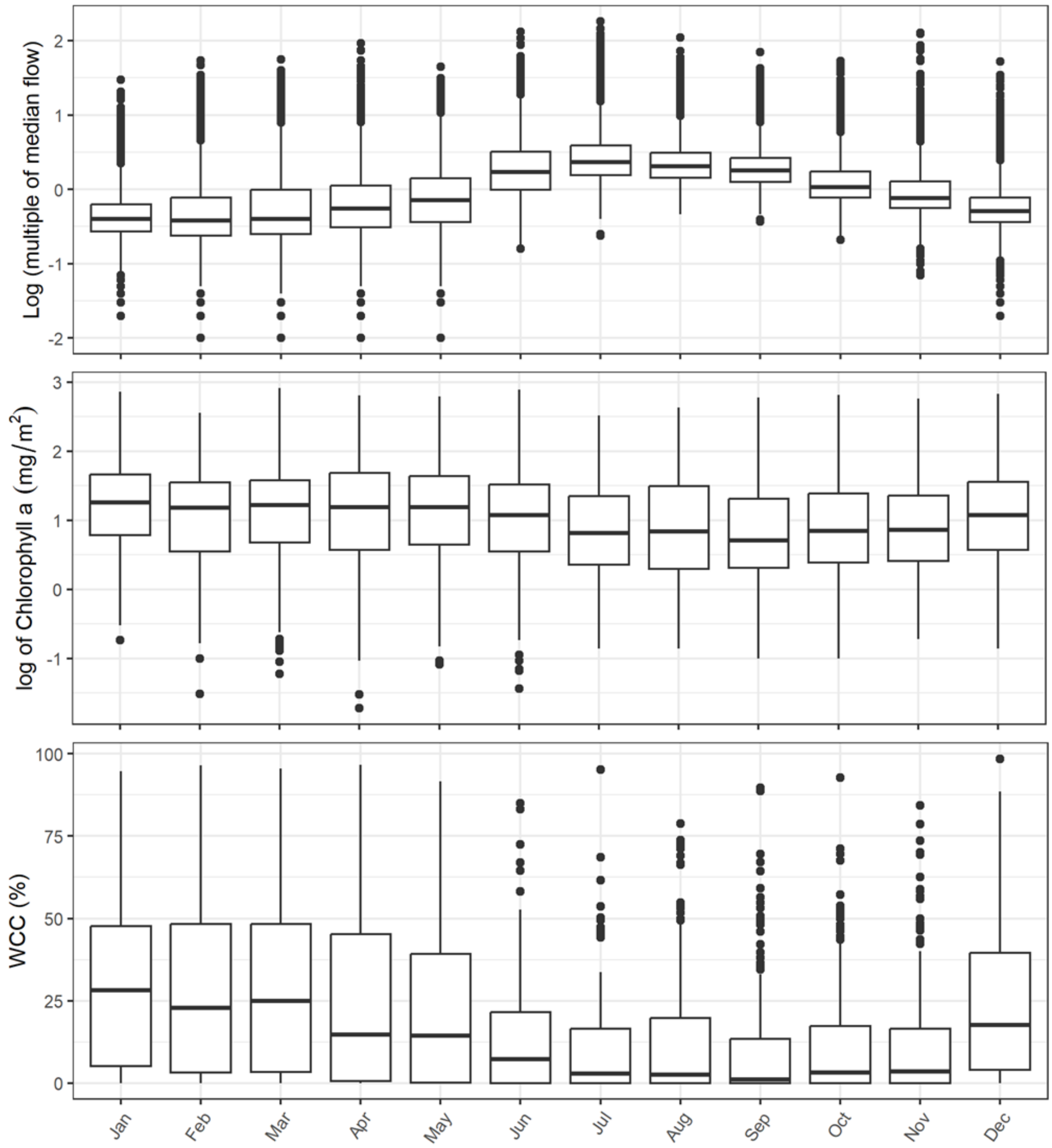

Figure 5-2: Box plots showing the distribution of flow (top), CHLA (middle) and WCC (bottom) over the whole Northland region by month over the monitoring period. Flow data from the 21 sites with a flow record; CHLA and WCC data from all 38 sites with sufficient data for the analysis in Section 6.

5.2.4 Summary

Over the periphyton monitoring period from 2015 to 2022 there was an overall regional association between flows and periphyton abundance (both as CHLA and WCC), which is seen across years and seasons. Seasonal patterns in periphyton abundance were less marked for CHLA than for WCC. Seasonal fluctuations were more pronounced than fluctuations between years.

5.3 The effects of flows on periphyton at each site

5.3.1 Introduction

Periods of low, stable flows are associated with periphyton accrual, while high flows (with associated increased hydraulic forces) remove biomass through sloughing (Biggs and Close 1987) and prevent colonisation and accrual. In New Zealand a flow magnitude of 3 × median flow has been commonly adopted to represent the flow magnitude that typically removes periphyton, based on the finding by

Clausen and Biggs (1997) that FRE3 (the mean annual frequency of events exceeding 3 × median flow, Booker 2013) was the hydrological variable most highly correlated with a range of biological indices in New Zealand rivers.

More recent analyses have indicated that the flow magnitude required to remove periphyton to low levels differs among rivers (Hoyle et al. 2017, Kilroy et al. 2020). The implication is that rivers in which periphyton resists removal until flows are very high (because of high substrate stability, for example) may have potential to support higher periphyton biomass than rivers in which periphyton is easily removed by lower flows. The difference arises because very large floods occur less frequently than smaller floods. Therefore, periphyton has more time to accrue, and may reach higher biomass even if other growth-promoting conditions (e.g., nutrient concentrations) are the same as at sites where periphyton is less resistant to high flows.

The aim of the analysis below was to identify, where possible, the flow magnitude (in multiples of the median flow) at each site in the Northland dataset that typically re-sets periphyton chlorophyll *a* to low levels. Low levels refer to chlorophyll *a* equivalent to cover by thin algal films only (e.g., ~9 mg m-2 on average, Kilroy et al. 2013). The flow magnitude has been referred to as the “effective flow” or “periphyton removal flow” (hereafter PRF). Quantification of PRF magnitudes at different sites may indicate the relative potential for those sites to develop / not develop high periphyton biomass, depending on how frequently the PRF occurs.

5.3.2 Methods

We identified PRFs for both CHLA and WCC in the following steps, using the dataset referred to in Section 5.2.1.

1. Calculate the median flow at each site using the 9-year flow record (from 2014 to 2022, corresponding to the period of monthly periphyton data collection plus one year before monitoring started to account for flow effects on the earlier monitoring dates).

2. For each periphyton observation, extract both the observed CHLA and WCC values, and the number of days since flows had equalled or exceeded a flow threshold defined by range of multiples of median flow, based on the median flow calculated in step 1. Multiples used were 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15 and 20 × median flow.

3. Fit a series of linear regressions at each site between CHLA or WCC (response variable) and time since each defined high flow (independent variable, in days), using $\log_{10}$-transformed time and $\log_{10}$-transformed CHLA data and square-root transformed WCC data.

4. The flow threshold associated with the linear regression that explained the highest proportion of variance in the response (i.e., periphyton CHLA or WCC) was generally taken as PRF.

5. Reconfirm or adjust the assessment of PRF at step 4 by examining (a) all the relationships (as scatter plots) and (b) plots of R^2 against the multiple of median flow. Under (a) look at the slope and intercept as well as R^2. If a PRF is identified from the maximum R^2, the intercept should indicate low CHLA or WCC when accrual time = 0.

6. Sites at which no linear regression (fitted at step 3) explained more than ~20% of the variance in CHLA or WCC were generally judged as having no identifiable PRF. At these sites, R^2 usually varies little across the range of multiples of median flow.

We reviewed maximum R^2 and the corresponding PRF (identified in step 5 above) across sites in relation to the mean and median flow at the site and to CHLA92 and the 92nd percentile of all WCC observations (WCC92) to see if either might be affected by river size or periphyton abundance.

5.3.3 Results

Scatterplots of all of the relationships between CHLA or WCC and days since a high flow are shown in Appendix E. Fitted regression lines with a pronounced positive slope and the origin indicating a low value of CHLA or WCC indicate sensitivity of periphyton to time since high flows.

Chlorophyll *a*

At most sites the R^2 of each fitted regression line plotted against flow threshold (Figure E-1) showed a progressive change as the flow threshold increased, with variation across sites (Figure 5-3).

Days since a flow equalled or exceeded a specific flow threshold explained at least 35% of the variation in CHLA over time at seven of the 21 sites (Table 5-1). At these sites the flow threshold that explained the most variation in CHLA (the PRF) varied from 2 × median flow (at Waiharakeke, Waitangi and Mangakahia) to 11 × median flow (Waipapa). Between 20% and 34% of the variation in CHLA was explained at a further six sites. There was no consistent relationship between maximum R^2 or the threshold at maximum R^2 and mean or median flow, or with CHLA92 (Table 5-1).

The highest R^2 values (>55%) were at Waipapa and Otaika. At both these sites, the raw CHLA data overplotted on the flow record clearly showed a series of accrual periods under low flows (Appendix D, sites 25 and 42).

A PRF for CHLA was not clearly identifiable at eight sites where days since any flow threshold was exceeded explained no more than 18% of the variance in CHLA (Table 5-1). At five of these sites (Kerikeri, Opouteke, Kaihu, Hakaru, and Hatea), CHLA was unrelated to time since thresholds were exceeded across the whole range of thresholds (i.e., $R^2 < 0.08$, Table 5-1, Figure 5-3, Appendix E). The raw CHLA data overplotted on the flow record for these four sites (Appendix D) showed:

- an inconsistent pattern of CHLA over time at Opouteke and Hakaru, with most high CHLA (>100 mg m^{-2} at Opouteke and >400 mg m^{-2} at Hakaru) occurring prior to 2019 (Appendix D, sites 28 and 32);
- variable CHLA at Kaihu throughout the monitoring period, with no marked accrual during the low-flow years of 2015, 2019 and 2020 (Appendix D, site 29);
- at Hatea, most of the high CHLA values (>30 mg m^{-2}) recorded from 2020 to 2021, with occasional high CHLA in 2015 and 2019 (Appendix D, site 39).

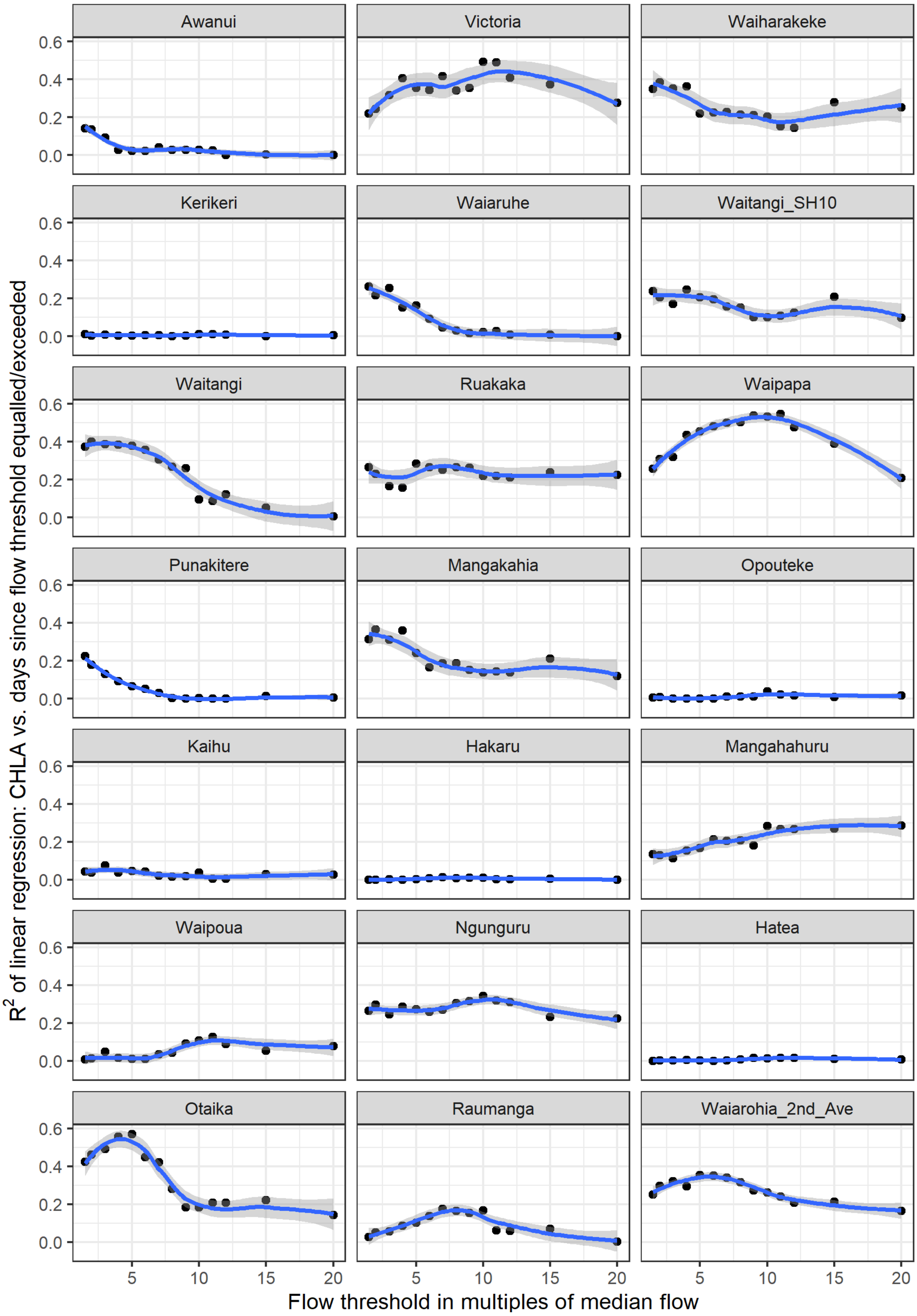

Figure 5-3: R^2 of the linear models fitted to CHLA and days since a flow threshold was equalled or exceeded at each site, plotted against the flow threshold. Sites in the order shown in Table 2.1. Loess smooth lines in blue. The flow thresholds are multiples of median flow from 1.5 x to 20 x median, and were used to compute days since the most recent flow event exceeding each threshold (potentially accrual time).

Table 5-1: Summary results of analysis of the effects of high flow on periphyton as CHLA and WCC. Mean and median flows at each site are shown for reference. The R^2 values shown are the highest obtained across the series of regressions of CHLA or WCC against days since flows exceeding a range of flow thresholds (Thrld), with thresholds defined by multiples of median flow. Very low maxima (R^2 ≤0.20) are in grey type.

Site N	Site name	Flow (m^3 s^{-1})		Periphyton 92nd percentile		CHLA vs. days since threshold		WCC vs days of accrual	
		Mean	Median	CHLA (mg m^{-2})	WCC (%)	Max. R^2	Thrld at max. R^2	Max. R^2	Thrld at max. R^2
1	Awanui at FNDC	5.7	3.2	174	75	0.14	1.5	0.33	1.5
2	Victoria at Victoria Valley Road	1.0	0.6	52	49	0.49	10	0.37	3
3	Waiharakeke at Stringers Road	5.1	2.1	219	56	0.38	2	0.29	2
4	Kerikeri at Kerikeri Basin Reserve	3.7	1.9	58	30	0.01	1.5	0.08	11
9	Waiaruhe at Puketona	4.3	2.4	35	38	0.26	1.5	0.28	1.5
12	Waitangi at SH10	0.3	0.1	32	31	0.25	4	0.28	4
13	Waitangi at Waimate North Road	1.5	0.8	42	41	0.40	2	0.33	2
16	Ruakaka at Flyger Road	0.8	0.3	64	45	0.28	5	0.26	10
25	Waipapa at Forest Ranger	4.0	2.0	31	33	0.55	11	0.44	4
26	Punakitere at Taheke	6.8	3.7	80	40	0.22	1.5	0.51	3
27	Mangakahia at Twin Bridges	8.5	5.0	85	65	0.36	2	0.61	2
28	Opouteke at Suspension Bridge	4.0	2.2	136	70	0.04	10	0.04	1.5
29	Kaihu at Gorge	3.6	2.3	95	63	0.08	3	0.23	1.5
32	Hakaru at Topuni	1.8	0.8	575	88	0.01	7	0.09	20
33	Mangahahuru at Main Road	0.5	0.3	19	31	0.28	20	0.22	10
35	Waipoua at SH12	2.7	1.5	5	3	0.13	11	0.15	7
36	Ngunguru at Coalhill Lane	0.4	0.2	66	53	0.34	10	0.30	11
39	Hatea at Mair Park	1.1	0.6	29	33	0.02	11	0.02	11
42	Otaika at Otaika Valley Road	0.8	0.4	58	36	0.57	5	0.40	4
43	Raumanga at Bernard Street	0.4	0.2	43	35	0.18	7	0.13	3
46	Waiarohia at Second Avenue	0.4	0.2	73	68	0.35	5	0.42	6

Weighted composite cover

Similar to CHLA, at most sites the R^2 of each fitted regression line plotted against flow threshold (Figure 5-4) showed a progressive change as the flow threshold increased. In most cases where R^2 changed over the gradient of thresholds, the highest R^2 corresponded to a relatively low multiple of median flow (Figure 5-4).

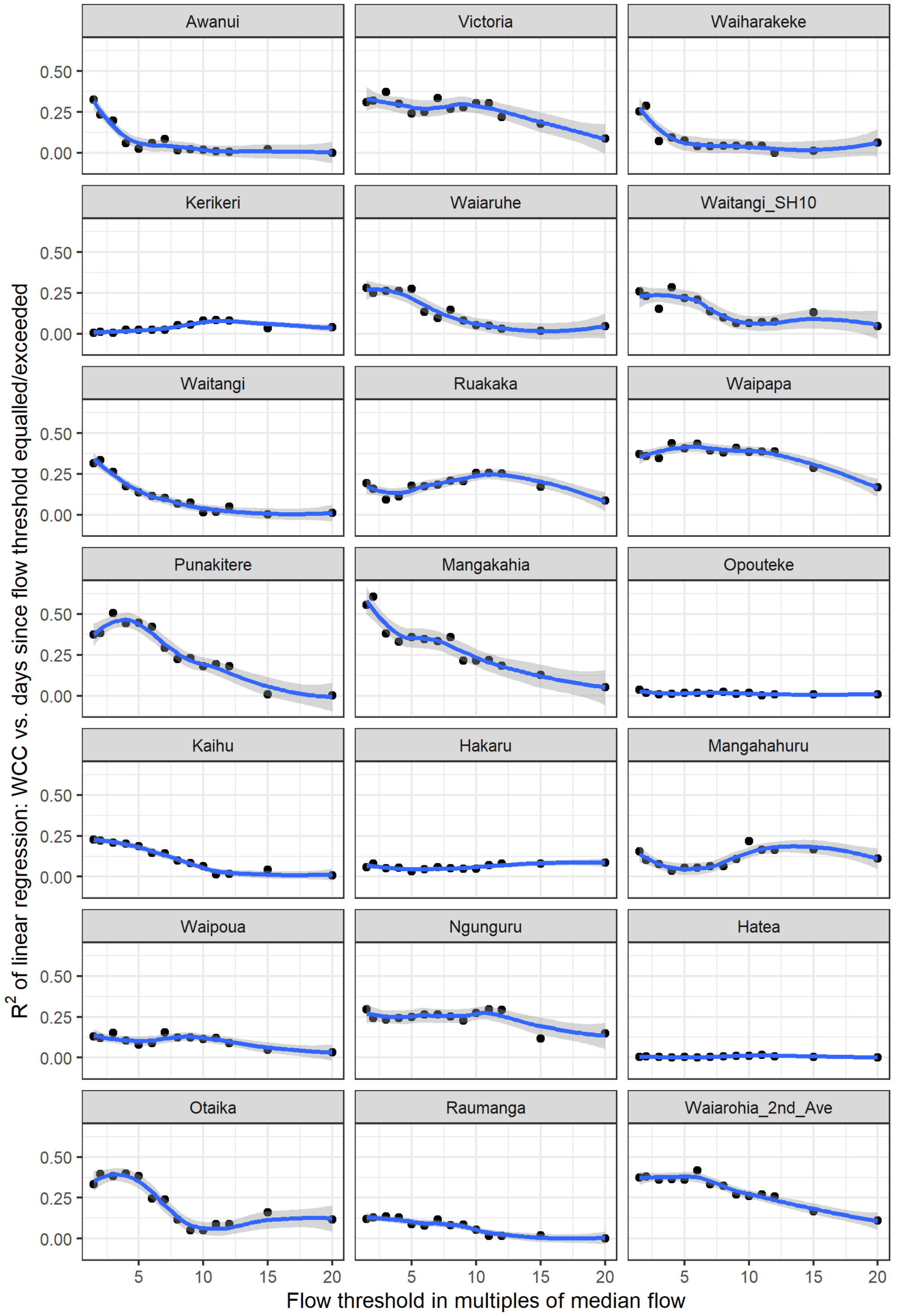

Figure 5-4: R^2 of the linear models fitted to WCC and days since a flow threshold was equalled or exceeded at each site. Sites in the order shown in Table 2.1. Loess smooth lines are show in blue. The flow thresholds are defined in multiples of median flow fom 1.5 x to 20 x median, and were used to compute days since the most recent flow event exceeding each threshold (poentially accrual time).

Days since a flow equalled or exceeded a specific flow threshold explained at least 35% of the variation in WCC over time at six sites (Table 5-1). At these sites the flow threshold that explained the most variation in WCC was taken as the PRF (for cover) (Table 5-1). The flow threshold varied from 2 x median flow (Mangakahia) to 6 x median flow (Wairohia). Between 20% and 34% of the variation in CHLA was explained at a further nine sites. The three highest maximum R^2 values were identified at three sites with relatively high mean and median flows (Punakitere, Waipapa and Mangakahia) but flows spanned the whole range at sites with lower maximum R^2. Maximum R^2 was not consistently related to WCC92 (Table 5-1).

The response of WCC to time since a flow threshold was equalled or exceeded (as maximum R^2) was positively correlated with that for CHLA (Pearson R = 0.74, n = 21) and mean maximum R^2 across all sites was similar (CHLA, 0.25; WCC, 0.27). Thirteen sites showed consistency in responses to time since a flow threshold for WCC and CHLA. Similarity was in either corresponding maximum R^2 values (i.e., difference less than ~0.1) identifying the same or close (less than two multiples of median flow difference) threshold flow as the PRF (Waiharakeke, Waiaruhe, Waitangi, Waitangi_SH10, Mangahahuru, Ngunguru, Otaika, Waiarohia), or showing a very weak response to flow (Hakaru, Opouteke, Waipoua, Hatea, Raumanga) (Table 5-1).

The remaining eight sites showed a contrasting response between the two periphyton abundance measures with either a very different R^2 (Awanui, Punakitere, Kaihu, Mangakahia) or very different flow threshold (e.g., Victoria, Waipapa, Ruakaka) (Table 5-1). In addition, the shapes of the relationships between R^2 and flow threshold differed markedly between CHLA and WCC at some sites (e.g., Victoria, Kerikeri, Waipapa, Punakitere, Mangahuhuru, compare Figure 5-3 and Figure 5-4).

5.3.4 Commentary

The number of days since a high flow event greater than the threshold identified as the PRF is potentially a measure of the accrual time for periphyton, which assumes that (a) the high flow event was large enough to remove periphyton to low levels, and (b) smaller flow perturbations during that time had a much smaller effect on biomass.

Identifying a PRF in this way does not imply that periphyton is resistant to flows that do not exceed the threshold. Periphyton removal is a continuous process that occurs across all elevated flows, and even at low flows (see below) but, for a given type of algae, we expect that removal becomes more effective once hydraulic forces exceed a certain threshold.

Caveats to the method we used to define PRF include that long accrual periods can culminate in natural sloughing, leading to unexpectedly low biomass (Bouletreau et al. 2006). In addition, the condition of the periphyton (i.e., its age) can influence the effect of a particular high-flow event (Katz et al. 2018). For these reasons, and acknowledging other influences on periphyton within a site, the periphyton vs. time since an event greater than a given threshold relationships are not expected to have very high explanatory power (e.g., no greater than 70% explained), which is what we found in this analysis.

Several sites had especially clear relationships between periphyton (both CHLA and WCC) and accrual time defined by a PRF (e.g., Victoria, Waipapa, Mangakahia, Otaika, Waiarohia). These sites spanned a range of river size and periphyton abundance (shown in Table 5-1). These sites are classified as flow sensitive (s_high or s_low in Table 5-2). It is assumed that the common feature of the sites is stability of PRF over time so that the response by periphyton to different sized high flows remains generally constant and predictable. Differentiation of flow sensitive sites into s_high and s_low is based on the proportion of time the flow exceeds the PRF, with a threshold of 10% separating the two categories (following Hoyle et al. 2017).

Table 5-2: Sites with a flow record showing substrate at each site and PRF category. The PRF category is based on the maximum R^2 from Table 5-1, with $R^2 < 0.2$ = insensitive to flow (ins) and $R^2 > 0.2$ sensitive to flow (s_). Sensitive sites further subdivided based on the proportion of time flow exceeds the threshold (% time > threshold) calculated from the flow record: low = <10% and high = >10% of the time with flow greater than the PRF threshold (following Hoyle et al. 2017). Substrate categories as defined in Table 2-2.

		Substrate (%)		Chlorophyll *a*			WCC		
Site N	Site name	Fine_ subs	Large_ subs	CHLA92 (mg m^{-2})	%time > threshld	PRF cat	WCC92 (%)	%time > threshld	PRF cat
1	Awanui at FNDC	22	55	170	35.6	ins	74	35.6	s_high
2	Victoria at Victoria Valley Road	7	28	51	2.2	s_low	48	12.7	s_high
3	Waiharakeke at Stringers Road	18	24	216	34.3	s_high	49	34.3	s_high
4	Kerikeri at Kerikeri Basin Reserve	0	83	57	33.8	ins	30	2.4	ins
9	Waiaruhe at Puketona	13	21	34	35.7	s_high	38	35.7	s_high
12	Waitangi at SH10	15	0	31	8.8	s_low	30	8.8	s_low
13	Waitangi at Waimate North Road	17	5	42	26.9	s_high	41	26.9	s_high
16	Ruakaka at Flyger Road	42	1	64	11.2	s_high	45	4.3	s_low
25	Waipapa at Forest Ranger	7	17	31	7.8	s_low	33	7.8	s_low
26	Punakitere at Taheke	17	63	79	38.2	s_high	39	10.1	s_high
27	Mangakahia at Twin Bridges	3	41	84	25.5	s_high	64	14.2	s_high
28	Opouteke at Suspension Bridge	2	45	136	2.4	ins	69	24.9	ins
29	Kaihu at Gorge	2	57	95	12.3	ins	62	36.1	s_high
32	Hakaru at Topuni	1	97	562	6.2	ins	87	39.3	ins
33	Mangahahuru at Main Road	21	4	19	0.9	s_low	31	0.9	s_low
35	Waipoua at SH12	2	57	5	7.1	ins	3	7.4	ins
36	Ngunguru at Coalhill Lane	12	8	66	2.8	s_low	52	3.8	s_low
39	Hatea at Mair Park	2	54	27	3.3	ins	32	3.3	ins
42	Otaika at Otaika Valley Road	19	10	56	6.3	s_low	36	9.0	s_low
43	Raumanga at Bernard Street	12	33	41	4.9	ins	35	12.6	ins
46	Waiarohia at Second Avenue	7	28	71	8.4	s_low	68	6.7	s_low

5.3.5 Effects of flow on periphyton within sites: conclusions

Periphyton abundance (as CHLA or WCC) was related (with R^2 range from 0.20 to 0.61) to the number of days since a high flow (the periphyton removal flow, or PRF) at 13 and 15 (respectively) of the periphyton monitoring sites, or about 60% and 70% of sites. No such effect was detected at the remaining sites. Differences across sites in whether a PRF was identifiable or not could be explained by substrate composition at some sites for CHLA, but not all. Percentage cover by large substrate explained over 50% of the variance maximum R^2 across the 21 sites. Differences in the responses of CHLA and WCC within sites may be attributable to periphyton community composition in some cases. There appears to be no short-cut to defining the PRF threshold at a particular site. A "first principles" approach to quantifying a PRF would be to consider site geomorphology using the methodology in Hoyle et al. (2017). Haddadchi at al. (2020) applied an adaptation of the method to predict PRF magnitude and frequency across all New Zealand.

Variability across sites in whether a PRF can be identified, and, if it can, the size of the PRF, together help to explain why generalised hydrological indices (such as FRE3) rarely explain a high proportion of the variance in peak periphyton biomass between sites (e.g., in the national model in Snelder et al. (2022)).

6 Predictors of periphyton biomass and cover across Northland: nutrient concentrations and other environmental variables

Key messages

Periphyton biomass was represented by the 92nd percentile of CHLA (CHLA92) and periphyton cover by the 92nd percentile of WCC (WCC92). Environmental variables included nutrient concentrations, other water quality and habitat measures, and flow indices.

We found that **nutrient concentrations were stronger predictors of CHLA92 than WCC92**. **However, the relationships were weak.**

Differences in periphyton – environment relationships were identified between groups of sites with different catchment geology, which was either hard sedimentary (HS, 11 sites), soft sedimentary (SS, 7 sites), or volcanic acidic (VA, 20 sites).

Sites with SS geology had higher CHLA92, nutrients and turbidity than HS or VA sites. Such **environmental differences between catchments with different geology affected relationships across all sites**. For example, turbidity was positively related to CHLA92 across the 38 sites, which is counterintuitive.

WCC92 was more uniform than CHLA92 across geologies and showed smaller differences in correlations between the three groups of sites.

Within the subset of 11 sites with HS geology **both N and P variables were relatively strongly and positively correlated with CHLA92**, but not with WCC92. There were strong correlations for both CHLA92 and WCC92 across the SS dataset (but noting the small size of the dataset). Equivalent correlations across VA sites were weak and often negative.

Across all 38 sites, there was marginal evidence for a stronger influence of P than N on CHLA92, which became more evident when one unusual site (Ruakaka) was dropped from the dataset. There was also weak evidence that nitrate-nitrogen had a stronger effect than other nutrient variables on WCC92.

However, across all 38 sites, the **best predictors of CHLA92 were the percentage of the stream bed under large substrate combined with the hydrological variable mean annual 7-day low flow.**

The **best single predictors of WCC92 across all 38 sites were water temperature or mean annual 7-day low flow**, depending on the analysis. These two variables are correlated and both are likely to play a role in driving WCC92.

The results indicate that **non-nutrient variables are more important predictors of both CHLA92 and WCC92 than nutrient concentrations across the 38 Northland sites.**

Moderate to strong correlations between NH_4-N and TKN (important forms of N in Northland) and other nutrient variables meant that it was not possible to determine the effects of NH_4-N or TKN in isolation. However, **the 95th percentile TKN did show the strongest positive correlation with CHLA92 across all 38 sites.**

6.1 Introduction

This section continues to address the part of the brief that asked for:

> "… an updated understanding of the main predictors of periphyton biomass (as CHLA and WCC) across the Northland region, including an evaluation of the relative influence of the different nutrient variables for which there are data (DIN, NO_3-N, DRP, TN, TP, TKN, NH_4-N)."

In this section we explore relationships between periphyton (CHLA92 and WCC92) and nutrient concentrations along with other variables (including flow metrics) within the Northland region, using data from 38 sites with time series covering from 6.5 to 8 years. Twenty-five of these sites are currently being monitored (Table 2-1).

Kilroy and Stoffels (2019) identified water temperature, DRP, bed substrate composition and flow metrics as significant predictors of CHLA92 in Northland across 39 sites that had been monitored for 3 – 4 years. In the analysis below we applied several techniques to try to tease out patterns of periphyton in relation to environmental variables across Northland using the updated datasets.

6.2 Spatial dataset

A spatial dataset was compiled including data from the 38 sites with sufficient data (Table 2-1). The dependent variables were the 92nd percentiles of CHLA (CHLA92, as used in the nutrient criteria validation, Section 4) and WCC (WCC92). Potential predictors are summarised in Table 2-2. Predictors derived from time series were summarised as both medians and 95th percentiles. The 95th percentiles were included acknowledging that peak values of some water quality variables may be significant in shaping benthic ecosystems. For example, the NPS-FM attribute for dissolved reactive phosphorus includes the 95th percentile of DRP as a metric. Site-specific habitat data including bed substrate composition, embeddedness and shade were summarised as mean values. Water temperature was represented by medians and 95th percentiles of monthly spot measurements, which were shown to be closely related to temperature metrics calculated from continuous logged records (see Appendix A). We used hydrological variables derived from the flow records at 21 sites to assess relationships with the equivalent modelled hydrological variables, which were available for all sites (Table 2-2).

6.3 Approach

Given the relatively small size of the dataset, as well as using the usual regression-based techniques for identifying correlations between periphyton and one or more environmental variables, we took a more qualitative and descriptive approach to understanding patterns and abundance of periphyton across sites and at individual sites. Four approaches were applied.

6.3.1 Correlations

We first considered relationships between CHLA92 or WCC92 and single environmental variables using non-parametric Spearman rank correlations. The correlation matrix was also used to identify closely correlated predictors that could be dropped from the dataset in subsequent analyses.

In view of the finding by Kilroy and Stoffels (2019) of differences in relationships between periphyton and nutrients or other environmental variables in subsets of sets with different catchment geology, correlation matrices were also generated for groups of sites with hard sedimentary (HS), soft sedimentary (SS) and volcanic acidic (VA) geology. Refer to Table 2-1 for the names of sites in each geology group. Most sites were assigned to the VA category (20 sites).

We also considered correlations within groups of sites assigned to three shade categories because the national nutrient criteria differ for shaded and unshaded sites (see Section 4).

6.3.2 Review of raw data against nutrient concentrations

Relationships between CHLA92 or WCC92 and nutrient concentrations were explored by examining plots of the raw data. We generated boxplots of the raw CHLA and WCC data at each site in increasing order of abundance for comparison with boxplots of the nutrient data in the same order. This enabled quick identification of general patterns and of unusual sites. For unusual sites, values of other variables such as substrate, or flow classification (if the site had a flow record) were checked to try to explain why those sites were outliers.

While this method is non-statistical, it has been recommended as a way of extracting important information from water quality datasets that are not best suited for rigorous statistical approaches (Schreiber et al. 2022). In this case, the main issue was the small size of the dataset.

The exercise was repeated with CHLA, WCC and nutrient concentrations plotted in order of the percentage of the catchment under intensive pastoral landuse (pc_pastoral). This step was taken after identifying in preliminary correlation analyses that pc_pastoral was strongly correlated with some of the nutrient concentration variables.

6.3.3 Similarity analyses

The spatial dataset was further explored using a multivariate approach (non-metric multi-dimensional scaling, NMDS, and subsequent analysis of similarities, ANOSIM) to examine similarities in environmental variables across sites and potentially identify the environmental variables most strongly associated with high or low periphyton biomass (CHLA92) or cover (WCC92) across Northland. Sites were assigned to categories based on CHLA92 or WCC92 values. For CHLA92, the categories were bands A to D in the NPS-FM attribute and an additional low biomass category, AA, defined by CHLA92 < 20 mg m^{-2}. For WCC92, the categories were defined as proposed by Matheson et al. (2022), where WCC of <20%, 20-39%, 40-55% and >55% were recommended as indicators of, respectively, “excellent”, “good”, “fair” and “poor” ecological condition at sites where other stressors are minimal. We used <20% (A), 20-39% (B), 40-55% (C) and >55% (D).

For NMDS, similarity matrices were first created from values of environmental variables at each site. The values were normalised (i.e., rescaled so that all datapoints fall between 0 and 1) prior to creating the matrices. Two-dimensional NMDS plots were generated from the similarity matrix with datapoints (i.e., sites) positioned so that closely related sites plot close together and dissimilar sites are more widely separated. A stress value indicates the accuracy of the two-dimensional representation of sites. Low stress values (<0.1) indicate very good representation, values 0.1 – 0.2 are good, and high values (> 0.3) indicate that more dimensions may be needed to accurately show the relationships of all the sites to each other. Overlays on the plots show both the direction and strength (indicated by line length) of gradients of individual environmental variables across sites.

ANOSIM uses a resampling procedure to determine the extent to which two sets of samples i.e., groups of sites assigned to the biomass and cover categories defined above) differ (Clarke et al. 2014). The output includes a sample statistic (R, range 0 to 1) which indicates the degree of separation of groups, with 0 meaning random placing of samples with no grouping evident and 1 meaning complete separation. A P-value is also computed based on resampling. ANOSIM was run using datasets including the full suite of selected environmental variables, and on datasets excluding nutrient and other variables in turn, to assess their effect. Removal of any variable strongly correlated with (i.e., potentially influencing) periphyton biomass might be expected to reduce clustering of sites according to their biomass group (i.e., the ANOSIM statistic would be lower). Removing an unimportant variable(s) would either have little effect on R or could increase R because a confounding variable has been removed.

Finally, similarity matrices generated from the CHLA92 and WCC92 data only were compared with the environmental dataset in a routine (BEST) that finds the combination of environmental variables that best matches a biological similarity matrix (in this case CHLA92 and WCC92).

These analyses were run in PRIMER v. 7.

6.3.4 GLM models

The fourth approach was to use generalised linear models (GLM) to examine relationships between each of CHLA92 and WCC92 and up to three environmental variables. Use of GLM accommodates data that do not meet the assumptions required for applying ordinary least-squared (OLS) regression techniques. In particular, transformation of the dependent variable data is commonly necessary in OLS analyses, but transformation complicates interpretation and reporting of the outcomes of regression analyses (Schreiber et al. 2022).

The distributions of the dependent variables in both the spatial and yearly datasets were used to select the appropriate GLM model family. The CHLA92 data approximately conformed to a lognormal distribution, indicating the GLM in the Gaussian family with a log link. The WCC92 data are proportional data constrained to between 0 and 1 (or 0% to 100%), indicating that binomial family is appropriate. A true binomial model accepts data with only two outcomes represented by 1 or 0 but can be modified to accept dependent variables that are proportions by adding an extra term (weights, in this case 1, which represents maximum proportion). Predictions all lie between 0 and 1. The WCC data (percentages) were converted to proportions for the analysis.

Distribution plots for all the variables are shown in Appendix F.

Prior to the GLM we ran bestglm in R to determine the combinations of predictors that generated the best models. Because of the small size of the spatial dataset (n = 38) we did not consider models with more than four predictors. The top five models based on the Akaike Information Criterion (AIC) were reviewed in each case. Pseudo-R^2 values were generated using the Nagelkerke method in as additional measure for comparing model performance against a null model (i.e., the predicted response set at the mean value of the dependent variable).

6.4 Results

6.4.1 Correlations

Correlations across all sites

Significant correlations (Spearman correlation coefficient exceeding 0.33, with $p < 0.05$, negative or positive) were observed between 12 environmental variables and CHLA92 and between three environmental variables and WCC92. Significant correlations with the two temperature variables (Temp_med and Temp_ 95) and Turbidity_95 were common to both periphyton metrics; significant correlations with TN_95, TKN_95, TP_95, Embed_loose (negative), Embed_tight, Large_subs, MALF7_mod and MALF30_mod applied to CHLA92 only (Table 6-1).

Table 6-1: Spearman correlation coefficients between CHLA92 or WCC92 and environmental variables across all 38 periphyton monitoring sites. Variables are listed in the groups and order shown in Table 2-2. Correlations ≥0.33 are highlighted in bold. * = p < 0.05; ** = p < 0.005.

Variable	Correlation coefficient with: CHLA92	WCC92	Variable	Correlation coefficient with: CHLA92	WCC92
Measured nutrient concentrations			**Other measured water quality variables (cont.)**		
TN_med	0.28	-0.11	Temp_ med	**0.53****	**0.43***
TN_95	**0.33***	0.01	Temp_ 95	**0.35***	**0.53****
DIN_med	0.17	-0.21	**Measured habitat variables**		
DIN_95	0.23	-0.09	Embed_loose	**-0.33***	-0.17
NOxN_med	0.17	-0.22	Embed_tight	**0.41***	0.27
NOxN_95	0.24	-0.13	Large_subs	**0.38***	0.17
NH4N_med	0.17	-0.17	Small_subs	-0.26	-0.17
NH4N_95	0.26	-0.01	Sandpc	-0.10	-0.08
TKN_med	0.32	0.07	Fine_sed	-0.11	-0.09
TKN_95	**0.39***	0.16	**Modelled hydrological variables**		
TP_med	0.26	-0.01	FRE2	0.05	0.35
TP_95	**0.35***	0.15	FRE3	0.12	0.36
DRP_med	0.22	0.03	FRE4	0.20	0.39
DRP_95	0.23	-0.02	MALF30_mod	**-0.39***	-0.19
DINtoDRP	0.05	-0.25	MALF7_mod	**-0.36***	-0.19
TNtoTP	0.06	-0.16	Max30	0.22	0.09
Other measured water quality variables			Max7	0.09	0.04
EC_uS_cm_med	0.20	0.11	nNeg_mod	-0.25	-0.28
pH_med	0.17	0.15	Reversals_mod	-0.08	0.02
Clarity_m_med	-0.11	-0.05	sdQ_mod	0.26	0.17
Turbidity_NTU_med	0.07	-0.03	**Modelled catchment variable**		
Turbidity_NTU_95	**0.33***	**0.39***	pc_pastoral	**0.43***	0.15

Other points to note from Table 6-1 are:

- For all nutrient concentration variables, correlations with CHLA92 were stronger with 95th percentiles of concentrations than with median concentrations.
- Of the nutrient variables, TN_95, TKN_95 and TP_95 had the strongest correlations with CHLA92. These three variables were inter-correlated ($r > 0.62$).
- Relationships between the nutrient variables and WCC92 were weaker than with CHLA92, and generally negligible and /or negative. The strongest positive correlation was with TKN ($r = 0.16$).

- The strongest correlations overall were with temperature variables, and the association with temperature was similar for WCC92 and CHLA92.
- The correlation between CHLA92 and the proportion of pastoral landuse in the upstream catchment was stronger than that with any of the nutrient variables.

Hydrological variables derived from flow records were reasonably strongly correlated with modelled versions of the same variables (i.e., FRE2, FRE3, FRE4, nNeg, Reversals), with r > 0.63 in all cases (range 0.63 for FRE3 to 0.80 for reversals). The modelled flow variables were therefore considered as potential predictors in the 38-site dataset.

Selection of variables for subsequent analyses

As shown in Table 6-1, the 95th percentile nutrient concentration metrics were more closely correlated with CHLA92 than median nutrient concentrations, although medians and 95th percentiles were highly correlated (r > 0.89) for TN, DIN, NOx-N, NH_4N and DRP. A higher percentile (than median) of these nutrient concentrations may be a better representation of nutrient availability for periphyton at a site because of pronounced seasonal patterns in nutrient concentrations at many sites, evident in time-series plots of nutrient concentrations (Appendix G). For example, concentrations of NO_x-N can be extremely low in the warmer months because of the combination of lack of runoff in low flows and high rates of instream biological uptake. Therefore, NO_x-N (and DIN) concentrations in summer do not reflect N supply at that time. Where seasonal fluctuations are pronounced, supply in the long term may more closely reflect the higher winter concentrations. However, in view of the strong correlations between the medians and 95th percentiles, and because median values are conventionally used to indicate nutrient supply at a site (e.g., Snelder et al. 2022), the median values were retained in the analysis for the above five nutrient variables.

The median and 95th percentile of other variables (TKN, TP, Turbidity and Temperature) were less closely correlated (r < 0.8) and both metrics were considered as potential predictors alongside other nutrient and non-nutrient predictors. The final selection of variables was made from the 31 variables included in the correlation matrix in Figure 6-1.

Figure 6-1 highlights intercorrelated clusters of nutrient concentrations, substrate metrics, and modelled flow variables. Variables that were highly correlated (r > 0.8) with one or more other variables were removed from the subsequent analysis. The exception was that some correlated nutrient concentration variables were retained because these were of particular interest. For example, NH4N_med was most strongly correlated with TKN_med, TKN_95 and DIN_med (r = 0.8), but both TKN and NH4N were retained. TKN_med was selected as it was generally less strongly correlated with other variables than TKN_95. TN_med, DIN_med and DINtoDRP were removed (correlated with NOxN_med, r > 0.88). TP_95 was selected over TP_med as the latter was strongly correlated with DRP_med (r = 0.95).

Six substrate variables were reduced to Large_subs and Sandpc. In view of the analysis in Appendix A Temp95 (calculated from monthly spot measurements) was retained. Clarity_m_med and Turbidity_ 95 were retained. Flow variables were reduced to MALF7, Reversals, Nneg, FRE3, FRE4.

The final variable selection included 18 variables of which 13 were measured in the field and five were modelled hydrological variables.

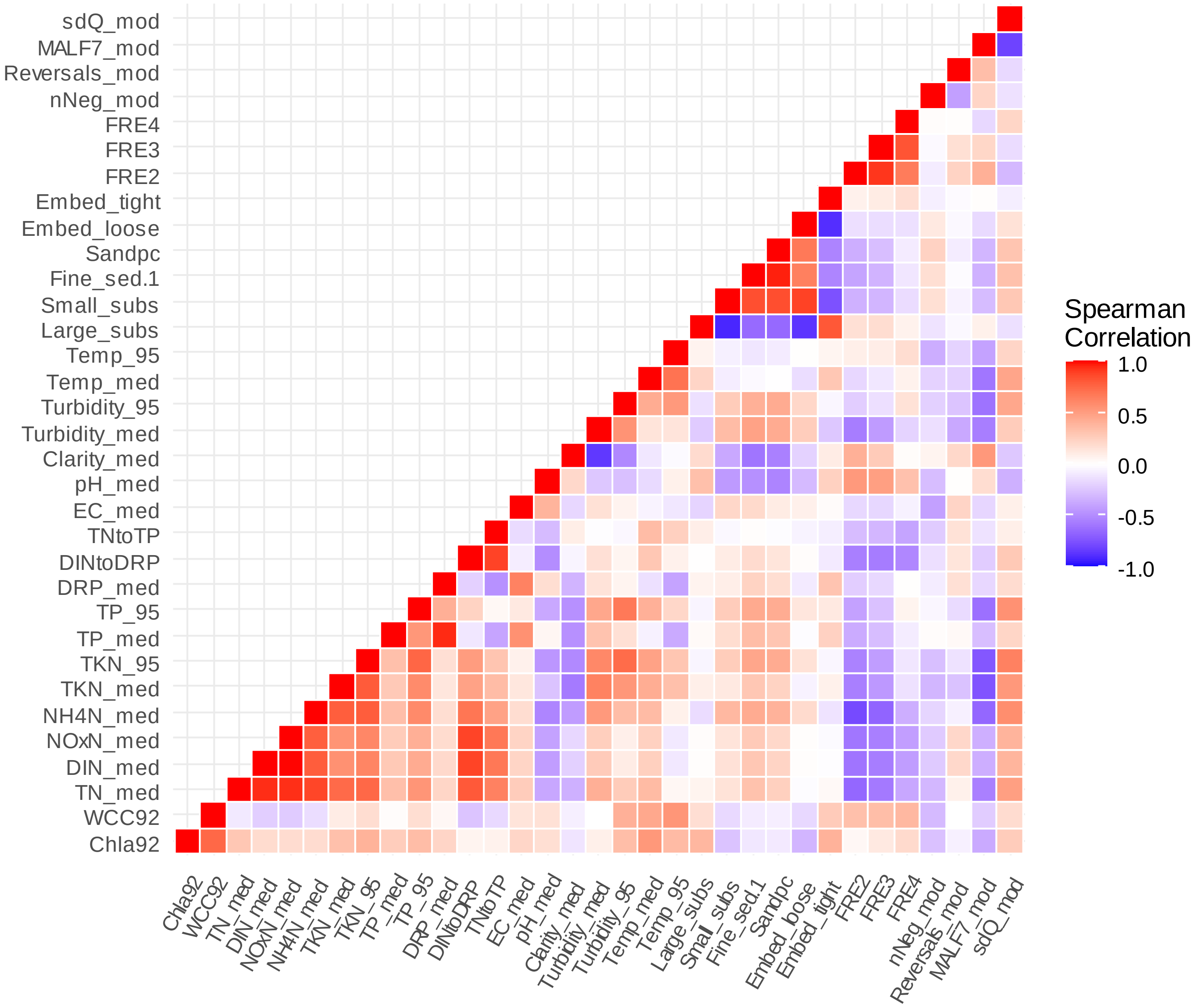

Figure 6-1: Spearman correlation matrix from which the final selection of independent variables was made. The two dependent variables, CHLA92 and WCC92 are on the bottom two rows and are themselves moderately strongly correlated (r = 0.72).

Correlations across subsets of sites with different catchment geology

Spearman correlations between periphyton (as CHLA92 and WCC92) and the 18 variables selected for the between-site analysis are shown in Table 6-2. The main message from Table 6-2 is that correlations between CHLA92 and the potential predictors were stronger across sites with HS and SS geology than within the VA groups. Mean absolute Spearman correlations (i.e., negative correlations converted to positive before calculating the average of the 18 correlation coefficients) for CHLA92 across the HS and SS sites were about three times the mean value across the VA sites (Table 6-2). The difference between groups for WCC92 was lower. Because the larger size of the VA dataset means that lower correlation coefficients are more likely, the mean P-value is a fairer comparison. Mean P-values for correlations in the VA dataset were higher than in the HS or SS datasets, especially for CHLA92, indicating genuinely weaker correlations overall across sites with VA geology than HS or SS geology (Table 6-2). We note that the SS dataset is very small (n = 7) therefore the results should be treated with caution.

CHLA92 across sites in HS and SS groups was generally correlated with TP_95, DRP_med and EC_med, and also with NOxN_med, NH4N_med and Temp_95 across HS sites only, and substrate variables across SS sites only. The relationship between CHLA92 and N variables across SS sites tended to be negative (though weak), except for TKN (stronger positive relationship).

For WCC92 the main patterns were positive relationships with Temp_95 across HS and VA sites, and also with Clarity_med across HS sites only. The negative relationships with N variables across SS sites, seen for CHLA92, were more pronounced for WCC92, and the relationships between WCC92 and substrate variables were comparable to those for CHLA92. Both CHLA92 and WCC92 were positively related to FRE4 across the HS and SS groups. These relationships are counterintuitive because periphyton biomass is expected to be lower when flood frequencies are higher. The positive relationships may simply reflect the low range of FRE3 and FRE4 values across the SS group and the generally low range across all sites (see below).

Table 6-2: Spearman correlation coefficients (r) between CHLA92 or WCC92 and environmental variables across subsets of sites defined by the REC geology classification. Numbers of sites: for HS, n = 11; for SS, N = 7; for VA, n = 20. Blue highlighted cells show correlations ≥0.6 (positive or negative), grey highlighted cells show correlations ≥0.45 and <0.6 (positive or negative). * = p < 0.05.

	Correlations with CHLA92			Correlations with WCC92		
Variable	HS	SS	VA	HS	SS	VA
NOxN_med	0.65*	-0.21	0.00	0.21	-0.64	-0.27
NH4N_med	0.45	-0.11	-0.10	0.03	-0.50	-0.25
TKN_med	0.18	0.39	0.02	-0.13	0.00	0.06
TP_95	0.60	0.61	-0.18	0.22	0.29	-0.12
DRP_med	0.51	0.49	-0.17	0.09	0.27	-0.23
TNtoTP	0.61*	-0.46	0.07	0.21	-0.64	-0.09
EC_ med	0.52	0.46	-0.09	0.19	0.39	0.05
pH_med	0.01	0.79*	0.14	-0.38	0.71	0.20
Temp_ 95	0.45	-0.04	0.24	0.63*	0.39	0.50*
Clarity_ med	0.08	-0.14	0.15	0.54	-0.18	-0.32
Turbidity_ 95	0.22	0.32	0.07	0.25	0.00	0.43
Large_subs	0.27	0.82*	0.31	-0.18	0.43	0.07
Sandpc	0.07	-0.71	-0.19	0.18	-0.71	0.04
FRE3	0.31	-0.21	0.22	0.43	0.43	0.37
FRE4	0.33	0.14	0.16	0.46	0.61	0.29
nNeg_mod	-0.41	-0.14	0.11	-0.38	0.21	-0.20
Reversals_mod	0.58	-0.64	-0.02	0.33	-0.25	-0.05
MALF7_mod	-0.58	-0.86*	0.11	-0.36	-0.57	-0.05
Mean absolute r	0.38	0.42	0.13	0.29	0.40	0.20
Mean P-value	0.29	0.41	0.54	0.42	0.37	0.48

Both CHLA92 and WCC92 were strongly and positively correlated with pH across SS sites. However, median pH varied little across sites. The range across the seven sites was 6.9 to 7.9, which is within the "typical" range for New Zealand rivers of 6.5 to 8.5 (Davies-Colley and Wilcock 2004). The strong correlation may be an artefact of small sample size (n = 7).

Differences in correlations in the subsets of sites with upstream catchments in different geology classes are likely related to the ranges of both CHLA92 or WCC92, and each of the environmental variables within each subset, shown in Figure 6-2. Key points from Figure 6-2 include:

- The seven sites with SS geology (see Table 2-1) had, on average, higher CHLA92 than sites with HS or VA geology, but WCC92 overlapped more with the HS and VA groups.
- The SS sites also had (on average and compared to HS and VA sites) higher DRP_med, Fine_sed, Sandpc, TKN_95, TKN_med, TP_95, TP_med, Turbidity_95, and Turbidity_med, and lower Clarity_med. The SS sites were primarily in catchments with high pc_pastoral, and correspondingly lower pc_indig_for.
- Differences in substrate between the three geology classes logically reflected geology. SS sites had highest cover by sand and fine sediment, on average, while most VA sites had higher cover by large substrate than HS and SS sites.
- Flow variables also differed across the groups, with generally lower Reversals and MALF at SS sites than at HS or VA sites (on average), indicating more stable flows at SS sites. In addition, SS and HS sites generally had higher values of FRE4, while FRE4 covered a wider range across VA sites.

The effect of shade

Sites were assigned to one of three shade categories: no shade (n = 15), partial shade (n = 15), shaded (n = 8). Plots of CHLA92, WCC92 in each category indicate differences in periphyton biomass and cover between the groups (Figure 6-3). CHLA92 at the shaded sites did not clearly differ from that in the unshaded and partially shaded groups (two sample t-test, $p > 0.2$), but this was attributable to an outlier with high CHLA92 (in the Waiharakeke at Stringers Road) in the shaded group. WCC92 was on average higher at unshaded sites than across either partially shaded or shaded sites (two-sample t-tests, $p < 0.05$). Water temperatures (particularly Temp_95) were higher at the unshaded sites than at either the partially shaded or shaded sites (two-sample t-tests, $p < 0.01$).

Relationships between CHLA92 and environmental variables across sites within the three shade groups were strongest within the small group of shaded sites. Across the eight sites there were correlations of $r > 0.6$ with TKN_med, TP_95, DRP_med, Temp_95 and MALF7_mod. The mean absolute correlation across the variables shown in Table 6-2 was 0.44. Correlations within partially shaded and unshaded groups were weaker (mean absolute r of 0.16 and 0.25, respectively). The pattern for WCC92 was similar (i.e., very low correlations within the partially shaded groups, slightly higher in the shaded and unshaded groups).

Overall, the correlations did not suggest any major differences in general relationships with the other variables although shade clearly affects CHL92 and WCC92 (as would be expected) (Figure 6-3). Ideally, a continuous shade variable would be available as a potential predictor. Such a variable was available for only a subset of the sites (the 25 sites that are currently included in the monitoring programme). Inclusion of temperature as a variable allows for some differentiation between shaded and unshaded site, although temperature will also be influenced by factors other than shade, such as altitude.

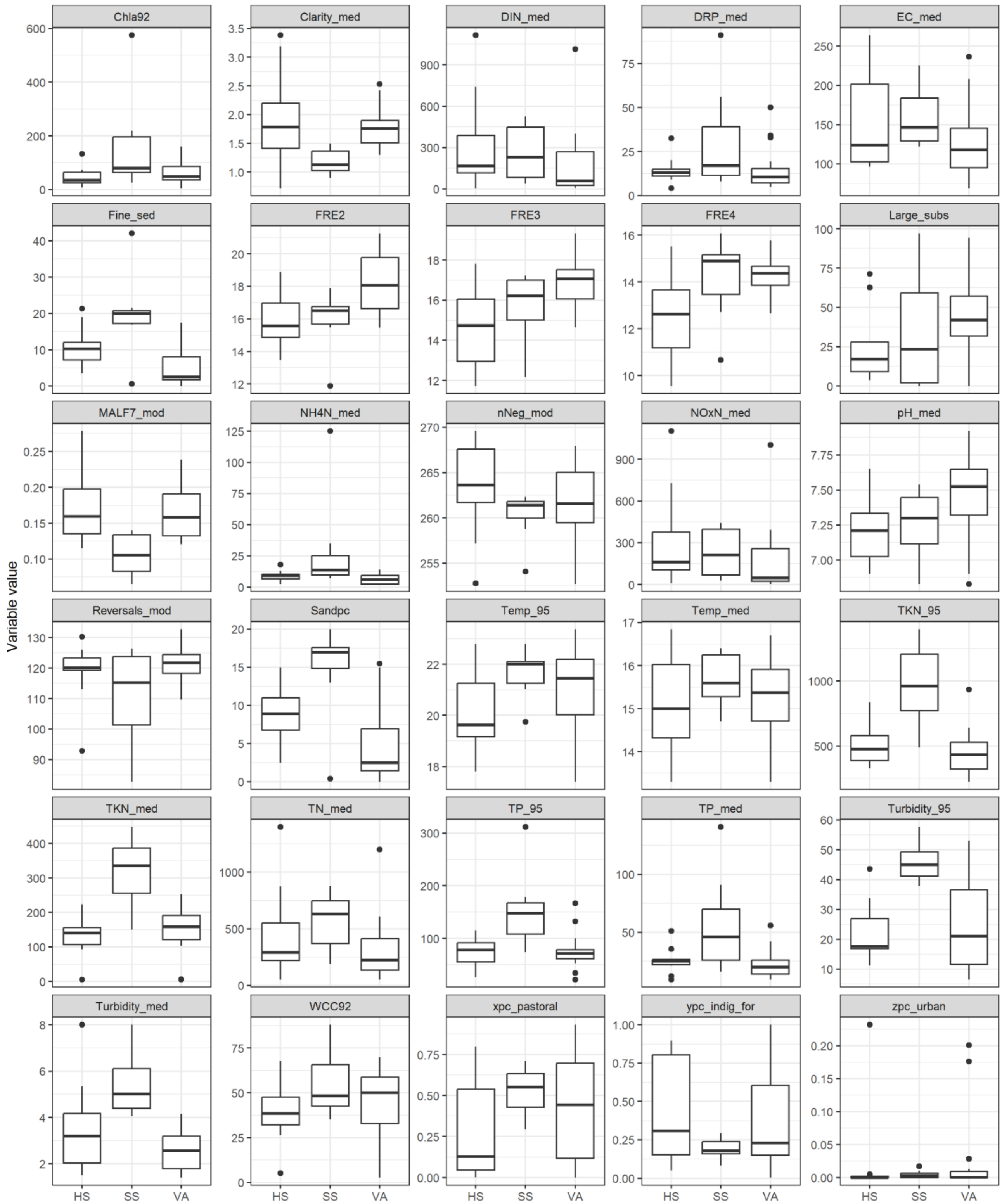

Figure 6-2: Box plots showing the distribution of periphyton, water quality, habitat, modelled hydrological and land cover data across sites in the three geology classes in Northland. Numbers of sites under three geology classes: hard sedimentary (HS), n = 11; soft sedimentary (SS), N = 7; volcanic acidic (VA), n = 20. Units for variables as in Table 2-2.

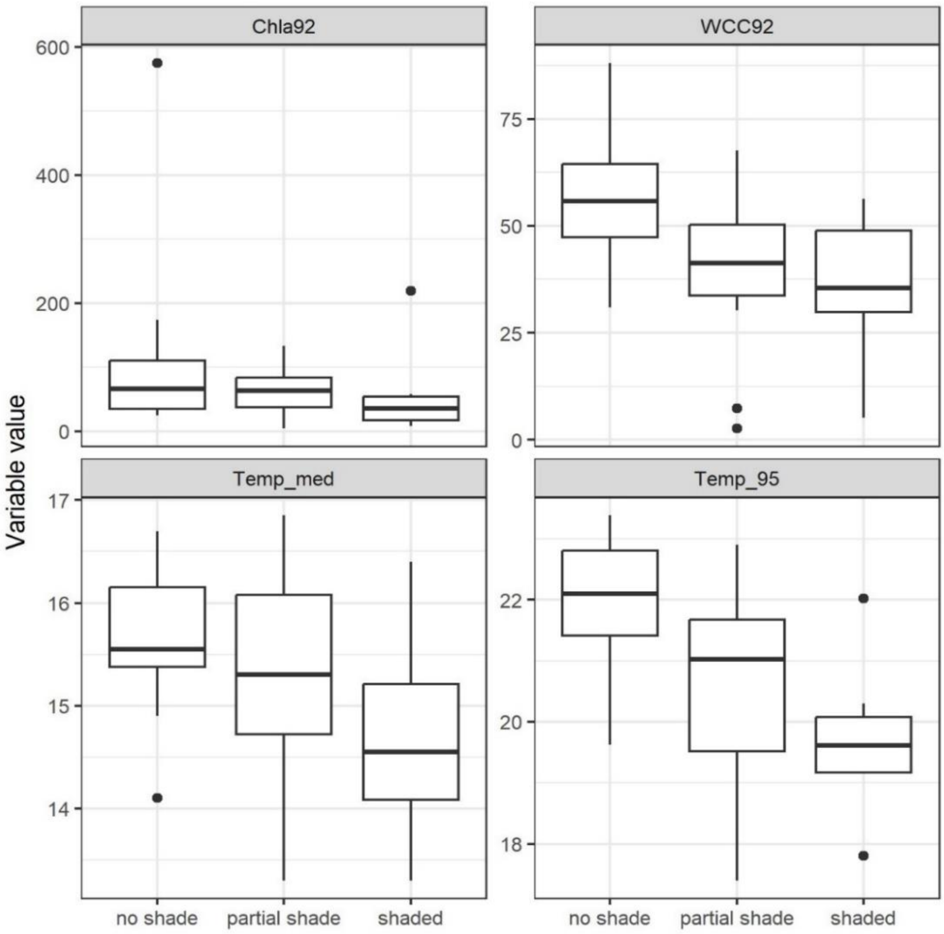

Figure 6-3: Comparison of periphyton biomass and cover, and water temperature, between groups of sites assigned to three categories of shade.

6.4.2 Review of raw data against nutrient concentrations

Correlations show the extent of general correspondence or lack of correspondence between CHLA92 or WCC92 and nutrient concentrations across all sites. Looking at the raw data in a small dataset allows identification of sites that appear to be unusual or outliers. Reviewing values of other environmental variables (such as substrate) could provide possible explanations for outlier status. The following considers CHLA data.

- Comparing boxplots of CHLA in Figure 6-4 (top plot) with corresponding boxplots of TN and NO_3-N concentration data indicates an approximate gradient of increasing N concentrations with CHLA (with variability) across the first ~24 sites (up to Otaika, median NO_3-N and TN of 1100 and 1400 mg m^{-3} respectively), with variability. Thereafter the pattern is less clear, with no median TN or NO_3-N higher than that at Otaika.

  Two sites with similar CHLA, but TN and NO_3-N concentrations lying either side of the general gradient are Victoria (low N) and Raumanga_Bernard Street (high N). The two sites have similar DRP and TP (slightly higher at Victoria). Both sites were classed as shaded and have similar substrate (Table 5-1). Other aspects of water quality differed slightly: Victoria had higher water clarity, lower turbidity and lower EC than Raumanga.

  Both sites have flow records. Victoria fell into the s_low group (Table 5-2), which means that periphyton is sensitive to removal by high flows in a predictable way but, for less than 10% of the time, high flows exceed the threshold that removes periphyton to low levels. Few floods to remove periphyton implies that accrual periods are relatively long so that periphyton can accumulate. Raumanga_Bernard Street fell into the ins (flow-insensitive) group (Table 5-2), which means that chlorophyll *a* was not well explained by the time elapsed since a high flow of any size.

Despite these similarities and differences, a simple explanation for the apparently low CHLA at Raumanga relative to the gradient in nitrogen variables is that the large block of missing data from November 2018 to December 2020 (see Section 2.2) coincided with the long dry period between 2018 and 2020 (seen on the raw data plots in Appendix D, site 43). CHLA was high at many sites during this period, including at Victoria. Omission of that period has likely led to lower CHLA92 than is realistic at Raumanga_Bernard Street.

- Another outlier on Figure 6-4 is Ruakaka, which has higher concentrations of all nutrients than suggested by its rank in the middle of the CHLA gradient (assuming that periphyton is driven primarily by nutrient availability). Geology at Ruakaka is classed as SS, which is characterised by high DRP and TP (Figure 6-2).

  Ruakaka was in the s_high group in Table 5-2 (i.e., sensitive to removal by high flows, with flows exceeding the threshold that removes periphyton for a high proportion of the time). An s_high grouping suggests that periphyton is frequently removed by high flows. Ruakaka also had the highest proportion of loosely embedded substrate (Embed_loose >92%), and 42% cover by fine substrate (Table 5-2), including over 15% sand. Therefore, despite high available nutrients, this site appears to be too unstable to support growth of periphyton to high biomass levels. The site is also classed as shaded (57% canopy cover as measured by densiometer, data not shown).

  When Ruakaka was removed from the dataset, the corelation between CHLA92 and TP_95 and DRP_med increased substantially (Pearson correlations from 0.38 to 0.56 (TP_95), and 0.37 to 0.57 (DRP_med)). Correlations with the nitrogen variables changed little.

Figure 6-5 shows the equivalent boxplots for WCC and nutrient concentrations. Examples are not explored, but again Ruakaka stands out as an outlier with respect to nutrient concentrations. The plots show an essentially random arrangement of nutrient concentrations along the gradient of WCC, reflected in low correlation coefficients (Table 6-1).

Sites plotted in order of increasing pc_pastoral (<1% at Tapapa and Punaruku to >90% at Waipapa_Waimate)N_Rd and Pekapeka) indicated the positive association between pc_pastoral and CHLA but less clearly with WCC (Figure 6-6, Table 6-3). No sites were obvious outliers except that the sites with highest pc_pastoral could have low periphyton (both CHLA and WCC).

The raw data in Figure 6-6 shows that increasing pc_pastoral was associated with increasing nutrient concentrations. Spearman correlation coefficients were highest between pc_pastoral and TN_med, NH4N_med, TKN_med, and TKN_95 ($r > 0.60$) (Table 6-3). Table 6-3 also shows that the variables TN_med, and NOxN_med, TKN_med, TN_med, TKN_med, TKN_95, NH4N_med and TP_95 were generally highly intercorrelated. While several of these variables were included in the following two analyses, their relationships with each other means that their relationships with CHL92 and WCC92 cannot be separated.

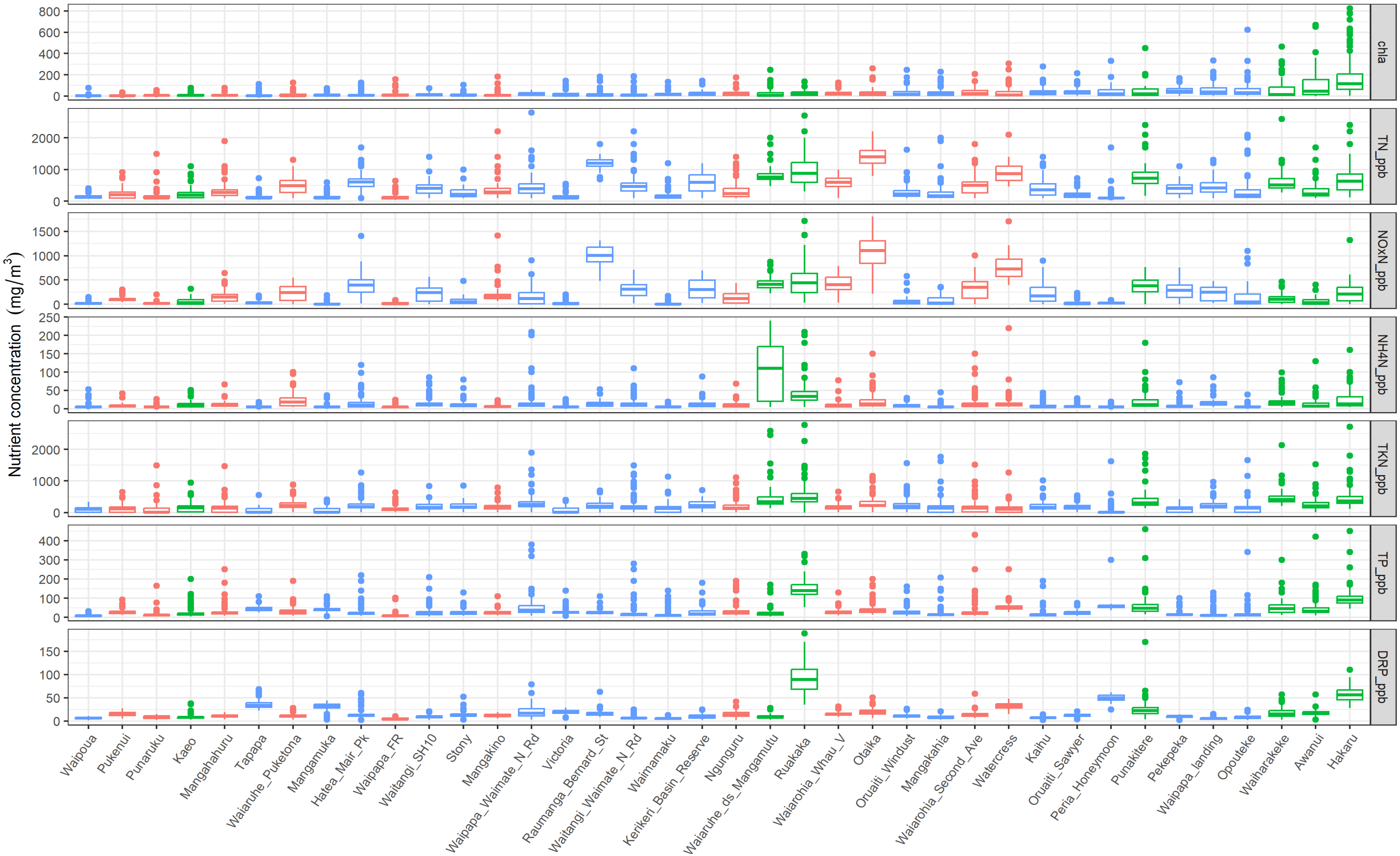

Figure 6-4: Boxplots of CHLA and nutrient concentration data at the 38 periphyton monitoring sites. Sites are plotted in order of increasing mean CHLA. Colour coding indicates REC geology at that site: red HS, green SS, blue VA.

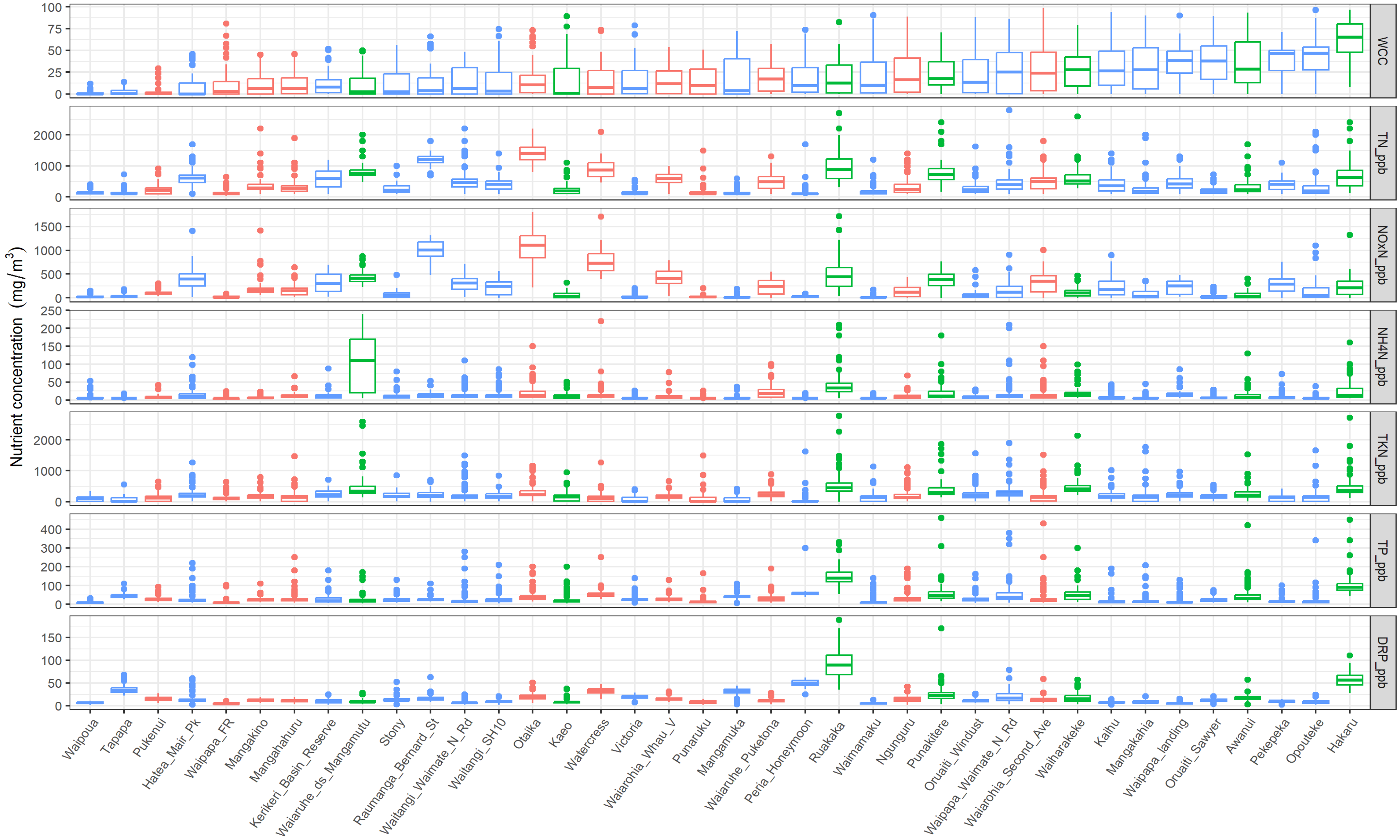

Figure 6-5: Boxplots of WCC and nutrient concentration data at the 38 periphyton monitoring sites. Sites are plotted in order of increasing mean WCC. Colour coding indicates REC geology at that site: red HS, green SS, blue VA.

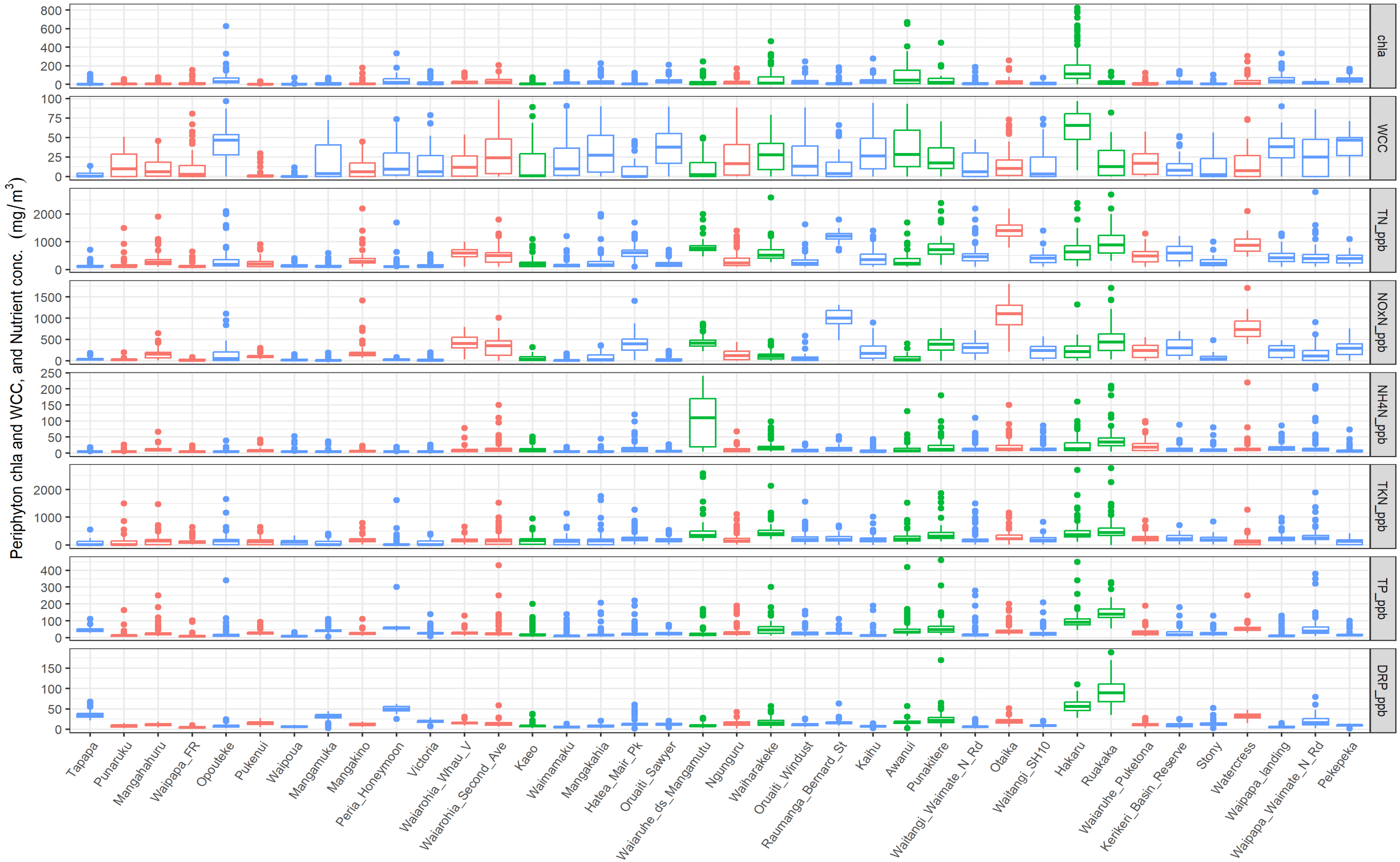

Figure 6-6: Boxplots of CHLA, WCC and nutrient concentration data at the 38 periphyton monitoring sites, with sites arranged in order of pc_pastoral. Colour coding indicates REC geology at that site: red HS, green SS, blue VA.

Table 6-3: Spearman correlation matrix between pc_pastoral, CHLA92, WCC92, nutrient variables, Turbidity_95, and Clarity_med. Correlations ≥ 0.60 highlighted in bold type. * = p < 0.05; ** = p < 0.005, *** = p < 0.0005. No correction was made for multiple comparisons.

	pc_ pastoral	CHLA92	WCC92	TN_ med	NOxN_ med	NH4N_ med	TKN_ med	TKN_ 95	TP_ 95	DRP_ med	Clarity_ med
CHLA92	0.43*										
WCC92	0.15	**0.72*****									
TN_med	**0.63*****	0.28	-0.11								
NOxN_med	0.53**	0.17	-0.22	**0.94*****							
NH4N_med	**0.62*****	0.17	-0.17	**0.88*****	**0.78*****						
TKN_med	**0.63*****	0.32	0.08	**0.74*****	0.55***	**0.79*****					
TKN_95	**0.60*****	0.39*	0.16	**0.75*****	**0.61*****	**0.79*****	**0.80*****				
TP_95	0.50**	0.35*	0.15	0.54***	0.41*	**0.60*****	0.59***	**0.76*****			
DRP_med	0.10	0.22	0.03	0.22	0.18	0.17	0.13	0.17	0.41*		
Clarity_med	-0.27	-0.11	-0.05	-0.34*	-0.17	-0.43*	-0.58***	-0.54***	-0.48**	-0.32*	
Turbidity_95	0.28	0.34*	0.39*	0.27	0.08	0.35*	0.54**	0.73***	0.67***	0.06	-0.51**

6.4.3 Similarity analyses

Sixteen of the environmental variables listed in Table 6-2 were combined to construct a similarity matrix. Two variables (FRE3 and TNtoTP) were dropped from the original 18 because of relatively strong correlations with, respectively FRE4 and NO3N_med. The NMDS plot generated from the matrix had stress of 0.17, which is a moderately good representation of the environmental features of the 38 sites in two dimensions. The six variables that most strongly structured the environmental space across the sites were EC_med, TP_95, TKN_med, Turbidity_95, MALF7 and nNeg (Figure 6-7).

With sites grouped by CHLA92, groups AA and A sites (low biomass) clustered to the left and centre of the plot but with high overlap with groups B and C. Groups C and D clustered in the same general area but were widely separated from one another (Figure 6-7a). Sites 10 (Waipapa) and 16 (Ruakaka) were outliers. Environmental gradients of increasing MALF7 and nNeg were associated with the low CHLA92 groups on the left of the plot and increasing nutrient concentrations (TP_95 and TKN_med) with the higher CHLA92 groups to the right. The large overlap between sites in different groups meant that there was no detectable difference between the five groups according to ANOSIM (overall test statistic R = 0.067, P = 0.161).

Sites grouped by WCC92 showed a pattern similar to the CHL92 groups in that the few sites in the low WCC92 group (A) clustered together at the left of the plot (Figure 6-7b), but the three other groups overlapped. Nevertheless, the overall test statistic was higher than that for CHLA92 with more evidence for group separation (overall test statistic R = 0.102, P = 0.027). Groups C and D differed most strongly (between-group R = 0.139, P = 0.009).

Grouping sites by REC geology class showed strong separation between classes (overall test statistic R = 0.402, P = 0.001, Figure 6-7c). The three groups differed strongly (P < 0.003 in all three comparisons).

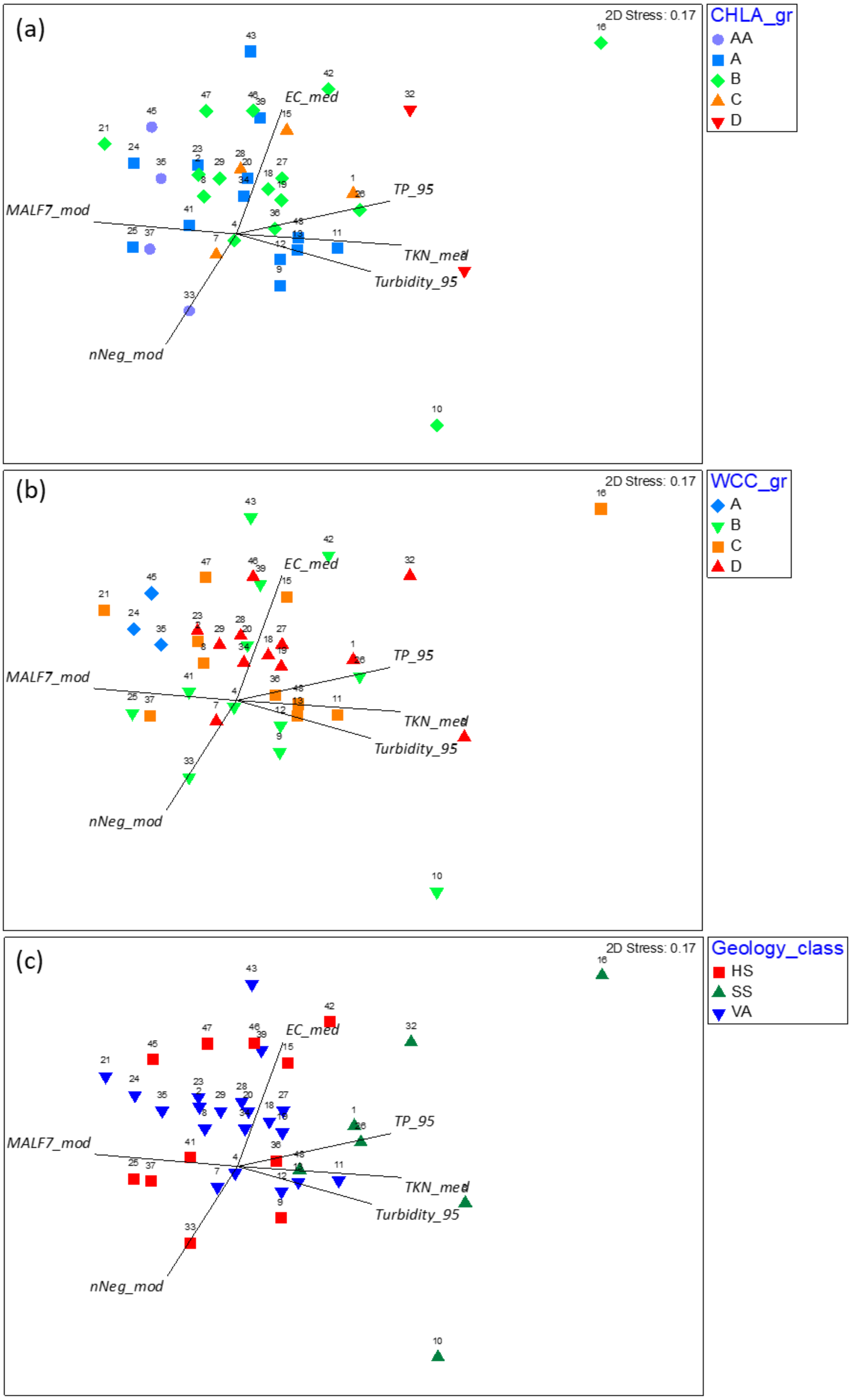

Figure 6-7: NMDS plots showing relative similarities among the 38 sites in environmental variables with different site groupings. Sites grouped by (a) CHLA92; (b) WCC92 (refer to Section 6.2.3 for group definitions); and (c) REC geology class. The overlay shows gradients of environmental variables with Pearson correlations (r) along the direction of the line of r > 0.65, with line length proportional to r.

Removing nitrogen concentration variables (NOxN_med, or TKN_95 plus NH4N_med, or all three) from the initial set of 16 predictor variables used to construct the similarity matrix slightly increased the R statistic for the CHLA92 groups (Table 6-4), indicating slightly better separation of the CHLA92 groups when the N variables were not included. Excluding DRP_med and TP_95 (but including the N variables) made only a marginal difference to the R statistic using all 16 variables (Table 6-4). This was interpreted as marginal evidence for a stronger influence of P than N, on clustering the sites based on the CHLA92 groups. Highest R was achieved when all nutrient variables were omitted.

Excluding NOxN_med or all three N variables marginally reduced R in the ANOSIM on WCC92 groups but excluding TKN_95 plus NH4N_med increased R (Table 6-4). The highest R was achieved when NOxN_med was the only nutrient variable included (Table 6-4). This was interpreted as weak evidence that NOxN_med had a stronger effect than the other nutrient variables on clustering of the WCC92 groups.

Table 6-4: Summary result of ANOSIM run on datasets with nitrogen and phosphorus variables removed in turn. All sites and all other variables were included in the dataset. Compare the shaded line (no variables excluded) with the unshaded lines below. The test statistic (R) is the most important result. Highest R values for CHLA92 and WCC92 are shown in blue highlighted cells. Groups distinguished from one another (pairwise comparisons p < 0.05) are also shown.

Variables included / excluded			CHLA92 groups			WCC92 groups		
DRP_med, TP_95	NOxN_med	NH_4N_med, TKN_95	R Statistic	P	Pairwise, P < 0.05	R Statistic	P	Pairwise, P < 0.05
included	included	included	0.067	0.162	D and A	0.102	0.027	D and C
included	**excluded**	included	0.083	0.127	D and A	0.091	0.041	D and C
included	**excluded**	**excluded**	0.111	0.069	D and A, B	0.096	0.029	D and C
included	included	**excluded**	0.095	0.093	D and A	0.111	0.018	D and C
excluded	included	included	0.073	0.158	D and A	0.120	0.011	D and A, C
excluded	included	**excluded**	0.111	0.061	none	0.139	0.003	D and A, B, C
excluded	**excluded**	included	0.088	0.113	D and A	0.109	0.021	D and A, C
excluded	**excluded**	Included (TKN only)	0.124	0.039	D and A, B; B and AA	0.118	0.012	D and A, C
excluded	**excluded**	Included (NH4N only)	0.087	0.112	D and A	0.115	0.018	D and A, C
excluded	**excluded**	**excluded**	0.127	0.026	D and A, B; B and AA	0.122	0.008	D and A, C

In summary, removal of the N or P variables led to small changes in already relatively low R values in ANOSIMs on sites groups based on gradients of CHLA92 and WCC92 (Table 6-4). The results suggest that NOxN_med may influence separation of the WCC92 groups more strongly than the other nutrient variables. However, separation of the CHLA92 groups was strongest when all nutrient variables were omitted.

For the BEST analysis, similarities across sites in CHLA92 were best explained by a combination of Large_subs, and MALF7_mod with a test statistic (rho) of 0.398 (p = 0.07) equivalent to explaining about 40% of the variance in CHLA92) (Table 6-5). Forcing inclusion of the nutrient variables in turn reduced rho. Similarities across sites in WCC92 were best explained by MALF7 (rho = 0.452) (Table 6-5). Forcing inclusion of the nutrient variables in turn again reduced rho.

This result again underscored the relatively low importance of nutrient concentrations in determining periphyton abundance, compared to non-nutrient predictors.

In view of the environmental differences between groups of sites in the three REC geology classes, we ran the BEST analysis on the VA sites only, the HS sites only and the HS and SS sites together. SS sites alone were not considered given the very small size of the dataset. As suggested from the correlations in Table 6-2, only a low proportion in the variance in CHLA92 was explained across sites in the VA class, with stronger associations across HS sites and combined HS and SS sites (Table 6-5). Nutrient predictors (TP_95, TKN_med and DRP_med) were included only for HS sites (Table 6-5).

Table 6-5: Summary results of BEST analysis run on the whole dataset and on groups of sites with different REC geology classifications. The test statistic (rho) is roughly equivalent to the proportion of variance explained (cf. R^2).

Dataset	n	Variables best explaining CHLA92	Rho	Variables best explaining WCC92	Rho
All sites	38	MALF7_mod, Large_subs,	0.398	MALF7_mod	0.452
VA	20	MALF7_mod, DRP_med, NH4-N_med	0.170	nNeg_mod, MALF7_mod	0.411
HS	11	TP_95, MALF7_mod, TKN_med, DRP_med	0.506	Sand_pc, nNeg_mod, MALF7_mod	0.481
HS + SS	18	MALF7_mod, Large-subs, Turbidity_95	0.535	MALF7_mod, Sand_pc, pH_med	0.441

6.4.4 GLM models

The subset of 16 predictors used in the NMDS and ANOSIM analyses was used in the bestglm routine, to extract the best five models with no more than four predictors. Large_subs and MALF7 were predictors in all five models for CHLA92, and these two variables together produced the best model (Table 6-6, with minimum AIC). Adding a third variable slightly increased R^2 at the expense of increasing AIC. Other predictors were pH_med, DRP_med, nNeg_mod, EC_med and TP_95. Adding a fourth variable did not lead to substantial model improvement in terms of R^2, with model 3 only slightly better than model 2 (Table 6-6). The first two predictors Large_subs and MALF7, were effectively uncorrelated (r = 0.08). There were stronger correlations between some of the additional predictors (e.g., DRP_med and TP_95 (r = 0.41), EC_med and both DRP_med (r = 0.63) and pH_med (r = 0.39)).

Overall, the model performance comparisons indicated little difference in model fit between models ranked first and fifth in bestglm. Regarding absolute model fit (as indicated by R^2 in a linear regression model), a rule of thumb is that a McFadden's pseudo-R^2 from 0.2 to 0.4 indicates very good model fit.[6] By this rule, the GLM models for predicting CHA92 were marginal (i.e., not very good, but not very bad either).

All five top combinations of predictors of WCC92 included Temp_95, with the best model including Temp_95 only. Models 2, 3 and 4 included one additional predictor. Of the four additional predictors (Table 6-6) Large_subs and Sandpc were strongly correlated (r = -0.65), suggesting that they might be substituting for each other. FRE4 and TNtoTP were only moderately correlated with each other or

[6] An explanation and background to this "rule-of-thumb" is on regression - McFadden's Pseudo-R^2 Interpretation - Cross Validated (stackexchange.com)

with FRE4 or TNtoTP (maximum r = 0.39). The combination of Temp_95 and FRE4 (model 2) increased the McFadden pseudo-R^2 to within the range indicating very good model fit (see above) with very little effect on AIC.

Table 6-6: Summary results of the five best GLMs for predicting CHLA92 and WCC92 from environmental variables across 25 river sites in Northland. Model performance comparisons are AIC and Mc Fadden "pseudo-R^2" values. Numbers in parentheses are model coefficients for that variable.

Model	Intercept	Predictor 1	Predictor 2	Predictor 3	Predictor 4	Model performance comparisons	
						AIC	McFadden "pseudo-R^2"
Models for explaining CHLA92							
1	6.100	Large_subs (0.015)	MALF7 (–17.760.)			392.8	0.151
2	2.695	Large_subs (0.014)	MALF7 (–16.609)	pH (0.449)		393.1	0.154
3	6.205	Large_subs (0.013)	MALF7 (–16.112))	DRP_med (0.011)	TP_95 (–0.004)	393.1	0.158
4	11.883	Large_subs (0.015)	MALF7 (–16.713)	nNeg_mod (–0.023)		393.6	0.153
5	5.704	Large_subs (0.015)	MALF7 (–16.412)	EC_med (0.0016)		394.0	0.153
Models for explaining WCC92							
1	–5.671	Temp_95 (0.260)				48.7	0.203
2	–7.113	Temp_95 (0.228)	FRE4 (0.154)			48.9	0.259
3	–5.724	Temp_95 (0.256)	Large_subs (0.004)			49.8	0.232
4	–5.881	Temp_95 (0.282)	TNtoTP (–0.014)			49.8	0.232
5	–5.613	Temp_95 (0.261)	Sandpc (–0.008)			50.2	0.219

6.5 Commentary

The four relatively simple approaches to exploring relationships between CHLA92 or WCC92 generally complemented each other, with each providing a slightly different perspective on relationships between periphyton biomass or cover and environmental variables, including nutrient concentrations.

In the first approach – of simple correlations across all sites – the direction of correlations between environmental variables and CHLA92 or WCC92 were generally consistent with understanding of how the variables might influence periphyton (e.g., Snelder et al. 2022). Correlations between nutrient concentrations and CHLA92 were positive, as expected. However, correlations between nutrient variables and WCC92 were mostly negligible ($r < 0.2$) and/or negative. Both CHLa92 and WCC92 were positively correlated with temperature variables. Substrate composition was also related to periphyton in the expected direction (i.e., high proportions of tightly embedded and large substrate were associated with higher CHLA92 or WCC92 (positive relationships), while high proportions of fine or small loose substrate were associated with low CHLA92 or WCC92).

Flow variables representing flood frequency (FRE2, FRE3, FRE4) were only weakly related to CHLA92 or WCC92, possibly reflecting that the effects of high flows on periphyton vary across sites, as demonstrated in the analysis in Section 5. The strongest relationships with flow were the negative relationships with the low-flow variables (MALF30, MALF7) indicating lower biomass or cover as the low flows increased to become closer to the median flow (i.e., less extreme). Flow variability (represented by Nneg and Reversals) was also negatively related to CHLA92 and WCC92.

An exception (from consistency of relationships with general understanding of periphyton drivers) was that correlations with water clarity were negative (although weak) and with turbidity positive, which is not consistent with our understanding that high light (from clearer water) promotes algal growth and therefore periphyton biomass. On the other hand, increasing shade (in three categories) was associated with decreasing CHLA92 or WCC92, which was consistent with our understanding of the effects of light on periphyton. The counterintuitive relationships between water clarity and turbidity and periphyton across all sites can be better understood by referring to the ranges of CHLA92, WCC92, clarity and turbidity in subsets of sites with different geology (Figure 6-2). Figure 6-2 indicates that high CHLA92 coupled with low clarity (and high turbidity) at sites with SS geology are likely driving the positive correlations between turbidity and CHLA92 or WCC92 over all 38 sites (Table 6-1). In other words, the positive correlation between peak periphyton and turbidity may be an artefact of the effect of the geological categories, in particular the association between SS geology and high periphyton biomass and cover.

There were marked differences in correlations between CHLA92 and WCC92 and environmental variables within groups of sites with different catchment geology (as defined by the REC). In particular, CHLA92 at sites with HS geology was strongly correlated with the nitrogen concentration variables, but corresponding correlations across VA sites were weak. This finding was also reported by Kilroy and Stoffels (2019). Although the numbers of sites in each geology class are small, it appears that the geology of the upstream catchment is important in determining periphyton – nutrient relationships in Northland.

Across subsets of sites with HS and SS geology, and across the whole dataset, correlations with nutrient concentrations variables were typically higher for CHLA92 than for WCC92. The exception was across sites with VA geology, where correlations were low between environmental variables and both periphyton variables (Table 6-2).

Stronger relationships between nutrient concentrations and CHLA92 than with metrics describing periphyton cover (such as WCC92) have been identified in previous studies (e.g., Kilroy et al. 2017). The most likely explanation is that chlorophyll *a* represents the living part of algae that is directly responding to nutrient supply. In contrast, periphyton cover is made up of a mixture of different types of algae, with variable amounts of chlorophyll *a* and other algal and non-algal material (e.g., mucilage, bacteria, trapped organic and inorganic detritus, dead and decaying cells), which respond to nutrients and other environmental variables in different ways.

Kilroy et al. (2013) showed that it is possible to make reasonably accurate predictions of chlorophyll *a* from visual estimates. However, the relationship likely varies across sites and regions. CHLA and WCC have been shown to be relatively closely related at some Northland periphyton monitoring sites (e.g., with WCC explaining at least half the variance in chlorophyll *a*) (Kilroy and Lambert 2019) but the overall relationship across 39 sites (monitored in Northland at that time) showed considerable scatter. When time series at each site were summarised as medians, the relationship between log-transformed CHLA and WCC was strong (R^2 = 0.78), which is similar to the correlation observed between CHLA92 and WCC92 across the current 38 sites (r = 0.72, Table 6-3). Despite the relatively strong relationship, there was evidently enough variability that relationships with nutrient concentrations differed between the two measures of periphyton, as was clear in the plots of the raw data (Figure 6-4, Figure 6-5).

In the second approach to analysis of the present dataset, inspection of raw CHLA and WCC data alongside the nutrient concentration data allowed identification of unusual sites in the dataset. Higher or lower CHLA data than expected (from their nutrient concentrations) could be explained by looking at other environmental factors, especially substrate and flows. The most striking of these sites was Ruakaka, which has relatively low CHLA and WCC relative to high concentrations of both N and P. Possible reasons for the discrepancy were unstable physical conditions at Ruakaka, combined with relatively high shade, both of which could limit periphyton growth.

It should be noted that Ruakaka was not unusual (in terms of nutrient concentrations) when the sites were arranged in order of increasing cover by pastoral land-use in their catchments (pc_pastoral). Increasing pc_pastoral was associated with increases in all nutrient concentration variables, with Ruakaka at the high end of the range of pc_pastoral (71%).

We also note that the large change in correlation between CHLA92 and phosphorus variables after dropping Ruakaka illustrates one of the problems of using relatively small datasets, which is that single datapoints can have a large influence on the outcome of analyses. Consequently, simple relationships derived from the data may show misleading patterns.

In the third approach, the analyses based on similarities highlighted that no set of the available environmental variables enabled clear discrimination between groups of sites with low and high periphyton (as either CHLA92 or WCC92). Successively removing nutrient concentration and other variables from the dataset provided marginal evidence for a stronger influence of P than N on clustering the sites based on the CHLA92 groups. There was also weak evidence that NOxN_med had a stronger effect than the other nutrient variables on clustering of the WCC92 groups.

Despite the above findings around clustering of site groups based of CHLA92 and WCC92, the combinations of variables that best explained differences in CHLA92 or WCC92 across sites (as continuous variables in the BEST routine) did not include nutrients. The variables that best explained CHLA92 were MALF7_mod and Large_subs and WCC92, MALF7_mod alone.

The fourth approach (GLMs) produced results consistent with those from both the simple correlations and the similarity analysis BEST routine, with the top model for CHLA92 also including Large_subs and MALF7_mod as predictors. Similar models (with a higher R^2, but additional variables) included DRP_med and TP_95, which may suggest a relatively larger role for P than N in predicting CHLA92. However, the coefficient for TP_95 was negative, which is counterintuitive and difficult to interpret.

In the GLM models for WCC92, Temp_95 dominated the predictors, consistent with the strong simple correlation between Temp_95 and WCC92 (Table 6-1). Selection of TNtoTP as a predictor in model 4 for WCC92 may suggest a relatively larger role for N than P in predicting WCC2, because TNtoTP is more strongly correlated with N variables (e.g., NOxN, DIN, TN) than with P variables. However, for both CHLA92 and WCC92, the contribution of nutrient variables to the GLM models was small.

Selection of Temp_95 for predicting WCC92 was inconsistent with the result from the BEST analysis in which MALF7_mod was selected as the best predictor). Temp_95 and MALF7_mod were moderately correlated (Pearson r = -0.56). The correlation is consistent with higher water temperatures being associated with lower flows (Booker and Whitehead 2022). Therefore, the two variables are likely substituting for one another. We know from Section 5 that WCC at some sites is likely to be strongly influenced by flows, indicating that MALF7_mod may be the variable that is actually affecting WCC92. However, the positive effect of water temperature on algal growth rates is also well established. Both variables could be interpreted as drivers of WCC92.

NRC requested that we specifically consider the roles of NH_4-N and TKN as predictors of periphyton in Northland. Both these variables are highly correlated with other nutrient variables, which makes isolation of any relationships impossible. Nevertheless, TKN was one of the stronger gradients identified in the similarity analyses (Figure 6-7), although biomass and cover groups were not well discriminated by the combinations of environmental variables tested. In addition, TKN_med was in the combination of variables that best explained CHLA92 across sites with HS geology (noting that the samples size was small, n = 11) (Table 6-5). Finally, NH4-N_med was a predictor of CHLA92 across 20 sites with VA geology, but this overall model was weak (Table 6-5).

6.6 Predictors of periphyton biomass and cover across Northland: conclusions

In terms of the direction of relationships, predictors of CHLA92 or WCC92 across the 38 Northland sites, simple correlations were generally consistent with our understanding of the factors that affect periphyton growth and removal (e.g., positive correlations with nutrient concentrations and temperature and negative correlations with measures of substrate instability and flow variability). However, few relationships were strong (e.g., only two relationships with Spearman r ≤ 0.50).

Key conclusions from the analysis using four different approaches were:

- Nutrient concentrations were stronger predictors of CHLA92 than WCC92.
- There was marginal evidence for a stronger influence of P than N on clustering the sites based on CHLA92 groups corresponding to grades in the NPS-FM periphyton attribute. This was supported by simple correlations particularly when one unusual site (Ruakaka) was dropped from the dataset.
- However, within a subset of 11 sites with HS geology both N variables (NOxN_med, NH4N_med and TNtoTP) and P variables (TP_95, DRP_med) were relatively strongly correlated with CHLA92.
- Across all 38 sites, the combination of variables Large_subs and MALF7 best explained CHLA92, accounting for about 40% of the variance and indicating that non-nutrient variables are more important predictors of CHLA92 than nutrient concentrations across these sites.
- There was some evidence that NOxN_med was a better predictor of WCC92 than the other nutrient variables, but the effect was small.
- The best single predictor of WCC92 was Temp_95 based on simple correlations and from GLM models. MALF7_mod was the best predictor based on a similarities approach. Temp_95 and MALF7_mod were correlated and both are likely to play a role in driving WCC92.

7 Synthesis, conclusions and recommendations

In this study we used a dataset (provided by Northland Regional Council, NRC) of periphyton biomass (chlorophyll a, CHLA) and cover (weighted composite cover, WCC) and associated environmental data (including nutrient concentrations, other water quality variables, physical habitat variables and river flows) from 38 river monitoring sites in Northland to address the following:

1. an assessment of the state of periphyton at each site against the periphyton attribute of the NPS-FM and the New Zealand Guideline for Cyanobacteria, including looking at changes over time;
2. an evaluation of whether the national nutrient criteria recently released by the Ministry for the Environment, with guidance (the 2022 MFE guidance) are suitable for setting nutrient concentration criteria for managing periphyton in Northland rivers; and
3. if the outcome of item 2 is that the Table 3 values are not suitable, suggestions / calculations to determine instream concentration criteria for DIN and DRP to keep periphyton biomass in Northland above the national bottom-line (D band) defined in the NPS-FM the periphyton attribute;
4. an updated understanding of the main predictors of periphyton biomass (as chlorophyll *a*) across the Northland region, including an evaluation of the relative influence of the different nutrient variables for which there are data (dissolved inorganic nitrogen (DIN), dissolved reactive phosphorus (DRP), total nitrogen (TN), total phosphorus (TP), and ammoniacal nitrogen (NH_4-N));
5. a parallel understanding of relationships between environmental variables and periphyton cover from visual estimates.

7.1 The state of periphyton at Northland's monitoring sites

Based on all of the data (up to 8 years), two sites (5%) were graded D (Waiharakeke and Hakaru) and four sites (11%) into band C (Awanui, Waipapa_landing, Watercress and Opouteke). Of the remaining sites, 15 (39%) were in band B and 17 (45%) in band A. Had the data not been adjusted to accounts for gaps in the time series one more site would have been in band D and one fewer site into in band A.

Over the same eight-year period, the New Zealand Guideline for Cyanobacteria Alert level (20 – 50 % cover by cyanobacteria) was reported at 15 sites on a total of 36 occasions, and the Action level (more than 50% cover) at eight sites on a total of 17 occasions. The most affected sites were Waimate at Waimate North Road and Opouteke at Suspension Bridge. Twenty-one sites had no Alerts or Actions, although only two sites (Awanui at FNDC, Pukenui at Kanehiana Drive) had no reports of cyanobacteria cover at any level between 2015 and 2022.

7.2 Validation of national nutrient criteria

This analysis addressed items 2 and 3 in the list above.

MFE (2022) provided look-up tables of nutrient criteria for periphyton (as CHLA92) and guidance on their use. The criteria were developed in an MFE funded project (Snelder et al. 2022) and have been updated since then after revision of the original model.

The nutrient criteria are intended to be used at a regional scale with specification of a given level of "under-protection risk". The under-protection risk is quantified as the proportion of a set of sites (in a region, for example) at which CHLA92 exceeds the target value (e.g., the NPS-FM bottom line of 200 mg m^{-2}) even though the observed nutrient concentration is lower than the criterion for that site.

Validations of the original and revised criteria for TN, DIN, TP and DRP, using a procedure described in MfE (2022) showed that the original criteria were too permissive for Northland rivers. The revised criteria were also too permissive, but performed better in that the proportion of under-protected sites more closely matched the under-protection risk specified for each criterion.

The results of the validation of the revised criteria need to be considered in the context of the small dataset of 38 sites, which is a weak basis for inferring the true performance of the criteria. In our opinion, the revised criteria are the best that can be achieved at the present time and in the absence of more data and/or development of better methods they are the best available for Northland.

As examples of the numerical values of the criteria, the following table shows the revised criteria for an under-protection risk of 25% for source-of-flow class WW/L (which applies to 35 of the 38 Northland periphyton monitoring sites used in this analysis). Grey type indicates criteria that are more than the saturating concentration for that nutrient, under conditions where non-nutrient factors are likely to strongly control periphyton biomass (see Appendix C). The full set of criteria for all source-of-flow classes occurring in Northland is provided in Appendix C.

	Nutrient criteria (mg L^{-1}) with 25% under-protection risk for CHL92 targets (mg m^{-2}) of:					
Nutrient	**50, unshaded**	**120, unshaded**	**200, unshaded**	**50, shaded**	**120, shaded**	**200, shaded**
TN	0.028	0.395	2.868	0.028	1.707	3.789
DIN	0.006	0.174	2.070	0.006	1.149	3.083
TP	0.001	0.022	0.138	0.001	0.054	0.206
DRP	0	0.012	0.117	0	0.036	0.164

7.3 Predictors of periphyton biomass and cover in Northland rivers

These analyses addressed items 4 and 5 in the list above.

The investigation into predictors of periphyton (as CHLA and WCC) was carried out in two stages. We first considered the effects of river flows on periphyton (as CHLA or WCC) across the region and at 21 sites for which a flow record was available. We then used combined periphyton and environmental data to explore relationships between CHLA (summarised as CHLA92, the 92nd percentile of chlorophyll *a* at each site) and WCC (summarised as WCC92, the 92nd percentile of weighted composite cover at each site).

7.3.1 The effects of river flows

Patterns of flow relative to CHLA and WCC were examined graphically across years and across months (averaged over years). Over the periphyton monitoring period from 2015 to 2022 there was an overall regional association between flows and periphyton abundance (both as CHLA and WCC), across both years and seasons.

- Low flow years were 2019, 2020 and 2015, in that order. Flows were highest in 2017 and 2022, followed by 2018.
- Annual medians of both CHLA and WCC (calculated from median values at each site) were negatively correlated with the annual means of flows standardised to the median flow (Pearson's correlation coefficient (R) = -0.63 and -0.62, respectively).
- River flows were, on average, four to six times higher in winter (June – August) than in summer (January – March). Variation in CHLA and WCC generally reflected the variation in flows across months.
- Seasonal patterns in periphyton abundance were less marked for CHLA than for WCC. Seasonal fluctuations were more pronounced than fluctuations across years.

An analysis was then carried out aiming to identify, where possible, the flow magnitude (in multiples of the median flow) at each of the 21 sites with a flow record that typically re-sets periphyton chlorophyll *a* to low levels (e.g., thin films). Quantification of this "periphyton removal flow" (PRF) may indicate the relative potential of different sites to develop / not develop high periphyton biomass. We also looked for common factors across sites where PRFs were identified or not. The outcomes of the analysis were:

- CHLA and /or WCC were related to the time elapsed since a high flow of a specified size (i.e., a PRF) at 13 sites for CHLA and 15 sites for WCC (i.e., ~60% – 70% of sites), as defined by an $R^2 > 0.2$. No such effect was detected at the remaining sites.
- Differences across sites in whether a PRF for CHLA was identifiable or not could be explained by substrate composition at some sites. The proportion of large substrate on the streambed explained over 50% of the variance in maximum R^2 for CHLA in a negative relationship. The equivalent variance explained for WCC was <15%.
- Sites identified as having periphyton that is sensitive to flow can be categorised into those at which periphyton is frequently removed and those at which removal is infrequent because large enough flows are rare. Following Hoyle et al. (2017) these groups of sites can be examined in relation to the response of periphyton (CHLA and WCC) to nutrient availability.

Variability across sites in whether a PRF can be identified, and, if it can, the size of the PRF, together help to explain why generalised hydrological indices (such as FRE3) rarely explain a high proportion of the variance in peak periphyton biomass between sites (e.g., in the national model in Snelder et al. (2022)).

7.3.2 The effects of nutrient concentrations and other environmental variables

We applied four quantitative and qualitative techniques to try to tease out patterns of periphyton in relation to environmental variables (including nutrient concentrations, other water quality variables, physical habitat variable and flow metrics) across the 38 periphyton monitoring sites in Northland. The techniques were: simple Spearman correlations, graphical comparison of gradients of CHLA and WCC against nutrient concentrations, similarity analyses, and general linear models (GLM). NRC specifically requested that the nutrients NH_4-N and TKN be considered as predictors.

We considered relationships across the whole dataset but, in view of results from an earlier analysis (Kilroy and Stoffels 2019), we also looked at subsets of sites with different REC geology classifications (HS, SS or VA).

In the **correlation analysis**:

- predictors of CHLA92 or WCC92 across the 38 Northland sites in simple correlations were often consistent with our understanding of the factors that affect periphyton growth and removal (e.g., positive correlations with nutrient concentrations and temperature and negative correlations with measures of substrate instability). However, correlations between nutrients and WCC92 were negligible and/or negative.
- Most relationships were relatively weak (e.g., few relationships with Spearman r ≥0.50).
- Nutrient concentrations were stronger predictors of CHLA92 than of WCC92.
- Within a subset of 11 sites with HS geology both N variables (NOxN_med, NH4N_med and TNtoTP) and P variables (TP_95, DRP_med) were relatively strongly correlated with CHLA92.

The **graphical comparisons** allowed identification of unusual sites in the dataset.

- The most striking of these sites was Ruakaka, which has low CHLA and WCC relative to high concentrations of both N and P. The discrepancy was explained by unstable physical conditions, sensitivity to flow (in the flow analysis above) and relatively high shade.
- Removing Ruakaka from the dataset caused the correlations between CHLA92 and both TP and DRP to increase (from R ~0.38 to R ~0.56), suggesting that TP and/or DRP concentrations may be significant in driving periphyton biomass (chlorophyll *a*) because correlations with N variables were weaker and changed only marginally. No such pattern was noted for WCC92.
- The large change in correlation with CHLA92 after dropping Ruakaka illustrates one of the problems of using relatively small datasets, which is that single datapoints can have a large influence on the outcome of analyses. Consequently, simple relationships derived from the data can show misleading patterns.

In the **similarity analysis**:

- None of the trialled combinations of environmental variables enabled clear discrimination between groups of sites with low and high periphyton (as either CHLA92 or WCC92).
- Successively removing nutrient concentration and other variables from the dataset provided marginal evidence for a stronger influence of P than N on clustering the sites based on CHLA92 groups corresponding to grades in the NPS-FM periphyton attribute. This was supported by correlations between CHLA92 and TP or DRP when one site (Ruakaka) was dropped from the dataset (see above).
- There was weak evidence that NOxN_med had a stronger effect than the other nutrient variables on clustering of the WCC92 groups, although the effect was small.
- Across all 38 sites, the combination of variables Large_subs and MALF7_mod best explained CHLA92, accounting for about 40% of the variance and suggesting that non-nutrient variables are more important predictors of CHLA92 than nutrient concentrations across these sites.

- Similarities across sites in WCC92 were best explained by MALF7_mod alone, which explained ~45% of the variance of WCC92 across sites.

In the **GLM analysis**:

- The best model for CHLA92 selected Large_subs and MALF7 as predictors, consistent with the similarity analysis (above). These predictors also had some of the highest coefficients in the simple correlations.

- Temp95 dominated the predictors in best models for WCC92, consistent with the strong simple correlation between Temp_95 and WCC92, but inconsistent with the result of the similarity analysis in which MALF7_mod was the best predictor. Temp_95 and MALF7_mod are moderately correlated and both may potentially affect WCC92. Additional predictors in alternative models were Large_subs, Sandpc, FRE4 and TNtoTP.

7.4 Conclusions

The main conclusions from our analyses were:

- Based on all of the data (up to 8 years) from 38 periphyton monitoring sites across Northland, two sites were graded D band for the periphyton attribute of the NPS-FM (i.e., below the bottom line), four sites were graded C band, 15 were graded B band and 17 were graded A band. Had the data not been adjusted to accounts for gaps in the time series one more site would have been graded D band and one fewer site would have been graded A band.

- Validation of nutrient criteria for managing periphyton provided in MFE (2022) and revised nutrient criteria (derived using a different statistical approach) showed that the revised criteria were more consistent with the observed data in that the proportion of under-protected sites more closely matched the under-protection risk specified for each criterion. The revised criteria are provided in this report.

- We consider that the revised criteria are the best that can be achieved at the present time and in the absence of more data and/or development of better methods they are the best available for Northland.

- The revised nutrient criteria for DRP and TP performed slightly better than those for TN and DIN, which was consistent with findings in the analyses to identify predictors of CHLA92.

- Nutrient concentrations in general were better predictors of CHLA92 (indicator of periphyton biomass) than WCC92 (i.e., representing the percentage of streambed covered by algae) (based on simple correlations).

- The main predictors of CHLA92 across Northland periphyton monitoring sites appear to be non-nutrient variables: percentage of the stream bed under large substrate combined with the hydrological variable mean annual 7-day low flow, as indicated by three separate analyses.

- There was marginal evidence for a stronger influence of P than N on clustering the 38 sites into CHLA92 groups based on bands in the NPS-FM periphyton attribute.

- The main predictor of WCC92 across Northland periphyton monitoring sites was Temp_95 (i.e. higher temperature readings during summer months). MALF7_mod was the best predictor based on a similarities approach. Temp_95 and MALF7_mod were correlated and both are likely to play a role in driving WCC92.

- There was some evidence that nitrogen (nitrate/nitrite or total nitrogen) was a better predictor of WCC92 than the other nutrient variables, but the effect was small.

- Differences in periphyton – environment relationships were identified between groups of sites with different catchment geology, which was either hard sedimentary (HS, 11 sites), soft sedimentary (SS, 7 sites), or volcanic acidic (VA, 20 sites).

- For example, within a subset of 11 sites with HS geology , both N variables and P variables were relatively strong predictors of CHLA92.

- Moderate to strong correlations between NH_4-N and TKN and one or more of the other nutrient variables meant that it was not possible to determine the effects of NH_4-N or TKN in isolation. However, across all sites, the 95th percentile of TKN produced the strongest correlation with CHLA92 of all of the nutrient variables.

7.5 Recommendations

As a result of the analyses described in this report, we make the following recommendations, which relate to use of the revised criteria and the level of under-protection risk associated with them; continuation of the time series at existing monitoring sites; and further analyses using the data from the NRC periphyton monitoring network.

- The revised nutrient criteria are recommended for use in Northland because they are based on the best "general" information we currently have about the relationship between nutrient concentration and peak periphyton biomass (CHLA92) in Northland. It be remembered that the criteria describe the risks of exceeding biomass thresholds across multiple sites. The criteria should not be interpreted as the concentrations that produce a particular biomass outcome at an individual site.

- It is recommended that the choice of under-protection risk should be a management decision. The choice of under-protection risk can make large differences to the nutrient concentration criteria and therefore to the limits on nutrient discharges (both diffuse and point sources) that will be necessary in catchments. The choice of under-protection risk requires consideration of the acceptable level of risk that target attribute states for periphyton biomass will not be achieved. It is noted that, although the criteria associated with various levels of under-protection risk are derived using scientific methods, the choice of the "right" level of risk is not a scientific question and ultimately lies with the decision maker.

- Others (i.e., in the European Union) have suggested that a UPR of 25% is "most likely to be appropriate". For that reason, we recommend that the 25% level could be a starting point for considering the appropriate level of under-protection risk.

- We recommend continuation of monitoring at least at key sites to (a) enable reporting on whether periphyton target attribute states have been met and (b) contribute to future analyses such as trend determination, nutrient criteria validation and nutrient criteria development.

- We also recommend continuation of the monitoring programme at all current sites because a longer dataset would allow further and more robust testing of all the analyses described in this report. Key points related to this are:
  - Confidence around the value of the 92nd percentile of chlorophyll *a* (CHLA92) will increase with length of record because CHLA92 is a measure of peak biomass which is expected to occur under certain combinations of hydrological and other environmental conditions (e.g., favourable temperature). Multiple years of data may be required to capture optimal combinations of conditions.
  - It is noted that nine sites included in the current monitoring programme (shown in Table 2-1) did not have enough data for inclusion in the present analysis. Two of those sites are in catchments with HS geology, one with SS geology and six with VA geology. These additional sites may enable better testing of differences between the three geology classes and better understanding of the role of nutrients in driving periphyton biomass in different parts of Northland. It is therefore recommended that monitoring continues at these sites.
  - Given that water temperature water was the variable most strongly correlated with both CHLA92 and WCC92, we recommend that efforts continue to gather more robust data on water temperature (such as continuous temperature records, as described in Appendix A) at all of the sites currently being monitored. In the analyses in this report, we chose to use the monthly spot temperatures because a correlation with continuous temperature metrics could be demonstrated, and continuous records were not available from all sites. In addition to providing more robust data, continuous records from all sites would allow calculation of additional temperature metrics for testing (such as daily maxima or rates of exceedances of certain temperature thresholds).
  - We recommend that more detailed data on canopy cover is collected at all sites that may be included in future analyses. Similar to continuous water temperature, canopy cover (%) data (calculated from densiometer readings) was available for only a subset of the sites included in the analysis. Therefore, the only variable related to light availability at all sites was shade in three categories (unshaded, partial shade, shaded). Canopy cover (%) would enable calculation of other variables including light at the stream bed (in combination with water clarity and depth), which have proved useful predictors in earlier analyses (e.g., Snelder et al. 2014).
- We recommend that (1) at least the validation of nutrient criteria is repeated in 3 to 5 years' time with the then available longer datasets and (2) that NRC supports the updating of the national nutrient criteria in the same timeframe with the then available data. By then we can expect the national dataset to have more sites with longer monitoring periods and this will add to the robustness of the derived criteria.

8 Acknowledgements

This analysis and report were funded by Envirolink (Contract no. C01X2208 _ 2309-NLRC233 and Contract no. NIW2360 2426-NLRC242), and Northland Regional Council. We thank Brandon Ruehle, Manas Chakraborty, Jason Donaghy and Gail Townsend (Northland Regional Council) for initiating the project, for provision of periphyton, water quality, water temperature and habitat data, and for discussions during the project, including regarding an update of an earlier version of this report. Thanks to Kathy Walter for organising the flow data and Michelle Greenwood for review comments.

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Appendix A Analysis of continuous temperature data

Continuous water temperature dataset: data preparation

Continuous water temperature data were provided from 20 sites (Table A-1). Four sites with temperature data did not have sufficient periphyton data for inclusion in the main analysis. The data were provided at 15-minute intervals from which we calculated hourly averages. Hourly data were detailed enough to show diurnal patterns and were more manageable for comparing sites and periods.

Table A-1: Continuous temperature data provided from 20 periphyton monitoring sites in Northland. Site N refers to the site number shown on Figure 2-1. The sites in bold type had continuous records of more than three years. Data from grey-shaded sites were not included in the analysis as these sites had inadequate periphyton data. Percentage complete applies to the amount of data collected between the start and finish dates.

Site N	Periphyton site name	Start date	End date	Total period	Days of data	% complete
1	Awanui at FNDC	6-May-20	21-Apr-21	350	242	69
2	Victoria at Victoria Valley Road	6-May-20	29-Nov-22	937	597	64
3	Waiharakeke at Stringers Road	2-Nov-21	14-Sep-22	316	303	96
5	Kerikeri at Golf View Road	14-Dec-21	14-Sep-22	274	261	95
6	Waipapa at Doonside Road	25-May-22	14-Sep-22	112	112	100
16	Ruakaka at Flyger Road	31-May-22	25-Jan-23	239	234	98
19	Oruaiti at Windust Road	2-Nov-21	14-Sep-22	316	315	100
22	Peria at Honeymoon Valley US Dutton Rd	2-Nov-21	13-Sep-22	315	310	98
24	Tapapa at SH1	6-May-20	13-Sep-22	860	516	60
26	**Punakitere at Taheke**	**3-Sep-19**	**25-Jan-23**	**1240**	**1176**	**95**
31	Tangowahine at Tangowahine Valley Road	2-Nov-21	16-Sep-22	318	305	96
33	Mangahahuru at Main Road	4-May-20	8-Feb-22	645	330	51
34	Waimamaku at SH12	2-Nov-21	16-Sep-22	318	305	96
36	Ngunguru at Coalhill Lane	5-May-20	15-Sep-22	863	507	59
37	Punaruku at Russell Road	1-May-20	21-Apr-21	355	244	69
39	**Hatea at Mair Park**	**5-Aug-19**	**25-Jan-23**	**1269**	**1262**	**99**
42	**Otaika at Otaika Valley Road**	**1-Aug-19**	**25-Jan-23**	**1273**	**1270**	**100**
43	Raumanga at Bernard Street	2-Nov-21	12-Sep-22	314	294	94
46	Waiarohia at Second Avenue	2-Nov-21	16-Sep-22	318	298	94
48	Kaeo at Dip Road	2-Nov-21	14-Sep-22	316	315	100

We plotted all the data at all 20 sites using the same time axes (e.g., Figure A-1). The data plots were checked for erroneous data, which was discarded (e.g., periods with very large or very small daily fluctuations, which suggested that the logger was not under water, or unusual spikes).

The records at three sites (Punakitere, Hatea and Otaika) started in August or September 2019 and continued up to January 2023. These three records appeared to be good (no erroneous data, or it had already been removed). These records are referred to below as "long-term". The time-series of data at other sites were relatively short, discontinuous, and not always overlapping. Therefore, the shorter records from other sites were overlaid on the long-term records to help identify errors or unusual patterns.

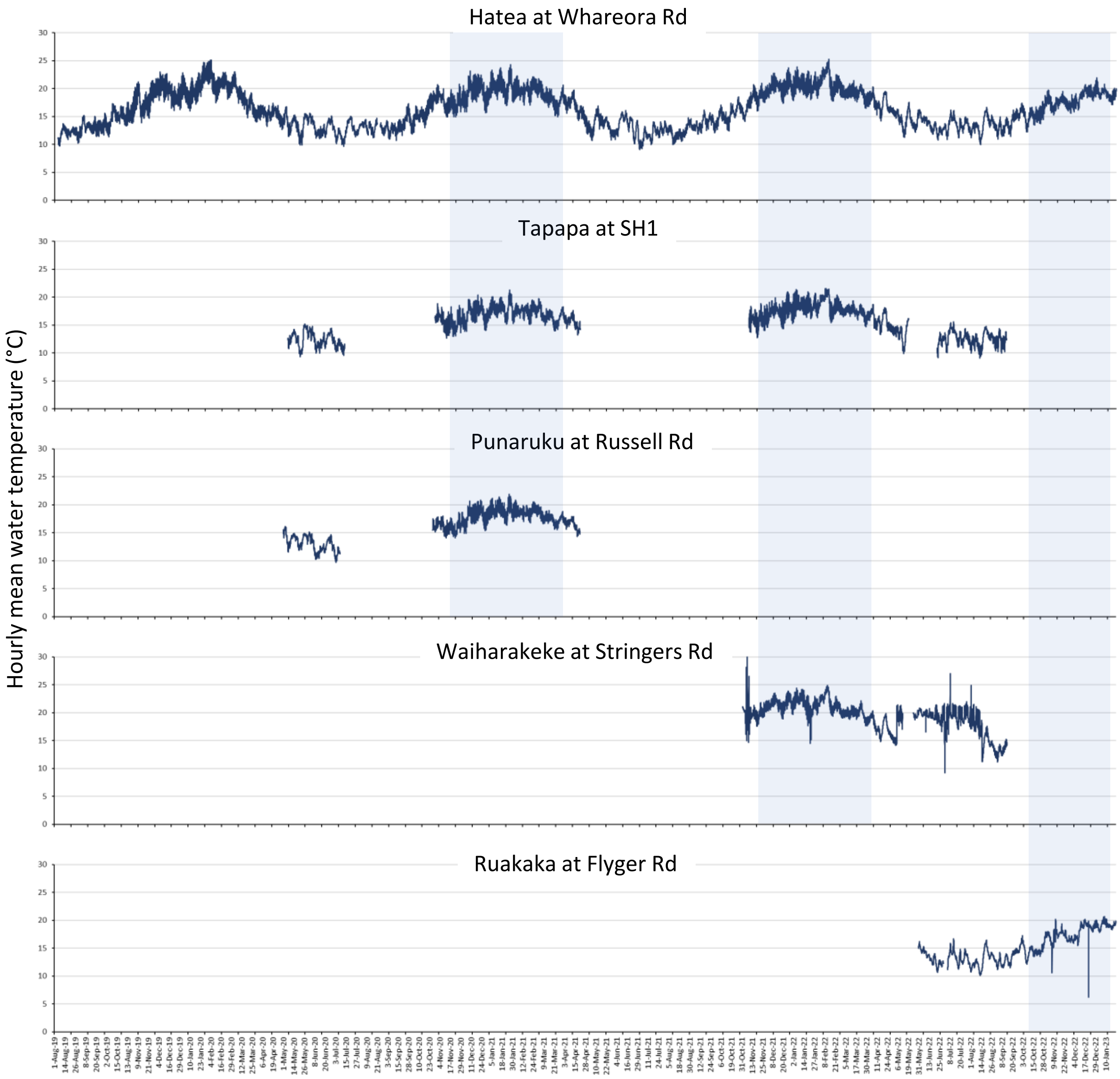


Figure A-1: Examples of raw hourly temperature data from five sites covering different periods. The blue shaded panels show the sections of summer temperature data that were compared across sites relative to the three long term datasets (such as from Hatea, top plot).

Most data from the sites with shorter records were collected from late spring (November) to early autumn (April), with little data in winter. In relation to effects on periphyton, data collected during the warmer months is likely to be more relevant than winter data, because most periphyton growth is in spring to autumn. Furthermore, in Northland, periphyton accumulation in winter is generally controlled by high flows.

Approach to data analysis

We first linked logged temperatures to the measurement time of all monthly measurements made at each site and compared the two datasets. This was to confirm (or not) that the logged temperatures corresponded to water temperature measured at the periphyton sampling site.

The temperature data do not include a period for which there is overlapping data at all sites. The three long records were therefore used as reference sites. All but two sites had at least three months of good data between November and April, which could be compared with data from at least eight other sites. The two exceptions were:

- **Oruaiti**: the record over the summer of 2021 – 22 indicated that the logger could have been exposed to air from about 2 January to about 26 January 2022, with much higher diurnal ranges than in earlier and later data, or at other sites (e.g., 12 – 33 °C). There were also unusually wide diurnal temperature ranges during March 2022. These sections of data were not used. (It is noted that monthly water temperature observations between November 2021 and March 2022 were all in the expected range (18.6 to 22.5 °C, measured at around mid-day); also, periphyton samples were collected from the site on 20 January and 16 February 2022, so evidently the reach did not dry up completely).
- **Ruakaka**: the only data from Ruakaka at Flyger Road was from June 2022 to 25 January 2023, and this overlapped only with the data from the three long-term sites (Figure A-1).

Comparisons of five sets of sites (named set A to set E) were as follows:

- Set A Three sites (Victoria, Tapapa, Ngunguru) had data over the summers (November to April) of 2020 – 21 and 2021 – 22 and a small amount of winter data (2020, 2022). Three sites (Punaruku, Awanui, Mangahahuru) had data in over summer 2020 – 21 only. All these records looked good. Data during summer 2020 – 21 was compared directly with corresponding data from the long-terms records (i.e., 9 sites compared).
- Set B. A further set of six sites (Kaeo, Peria, Waiharakeke, Waiamuku, Waiarohia, Raumanga, Tapapa and Ngunguru) had good data over the summer of 2021 – 22 which was compared with that from the three long-term records from November 2021 to April 2022 (i.e., 11 sites compared).
- Sets C and D. Comparisons were also run from 14 November 2021 to 2 January 2022 (set C) and 27 January to 22 February 2022 (set D), to provide comparisons with the record at Oruaiti (see notes above).
- Set E. The remaining periphyton site (Ruakaka) data were compared from 15 October to 24 January only (maintaining the focus on summer data) (4 sites compared).

Summary temperature statistics (i.e., mean, median, standard deviation, and a range of percentiles) were calculated across the hourly record from sites in each of sets A to E (viz., mean, minimum, maximum, standard deviation, and a set of percentiles).

The 95th percentile was selected for the ranking procedure on the basis that peak temperatures may have the strongest influence on periphyton growth rates and therefore periphyton biomass (i.e., CHLA and WCC)). In each set of sites compared the temperature difference between each site and each of the three long-term records was computed. This produced three sets of temperature differences, one for each of the three long-term records. Sites had from one to four comparisons (depending on how much overlapping data they had), with five comparisons at the three long-term sites. Differences were averaged across sites and the average differences were used to rank sites from warmest to coolest.

The ranks were compared with each other, with the temperature metrics calculated from monthly data at each site and, and with modelled temperatures at the NZSegment corresponding to each site.

Results

Logged water temperatures corresponded closely with monthly spot temperatures measured at the same time (to the nearest hour) (Figure A-1). This correspondence confirmed that the logged temperatures were a good representation of water temperatures at the periphyton sites (assuming that monthly spot measurements were made in the reach where periphyton samples were collected).

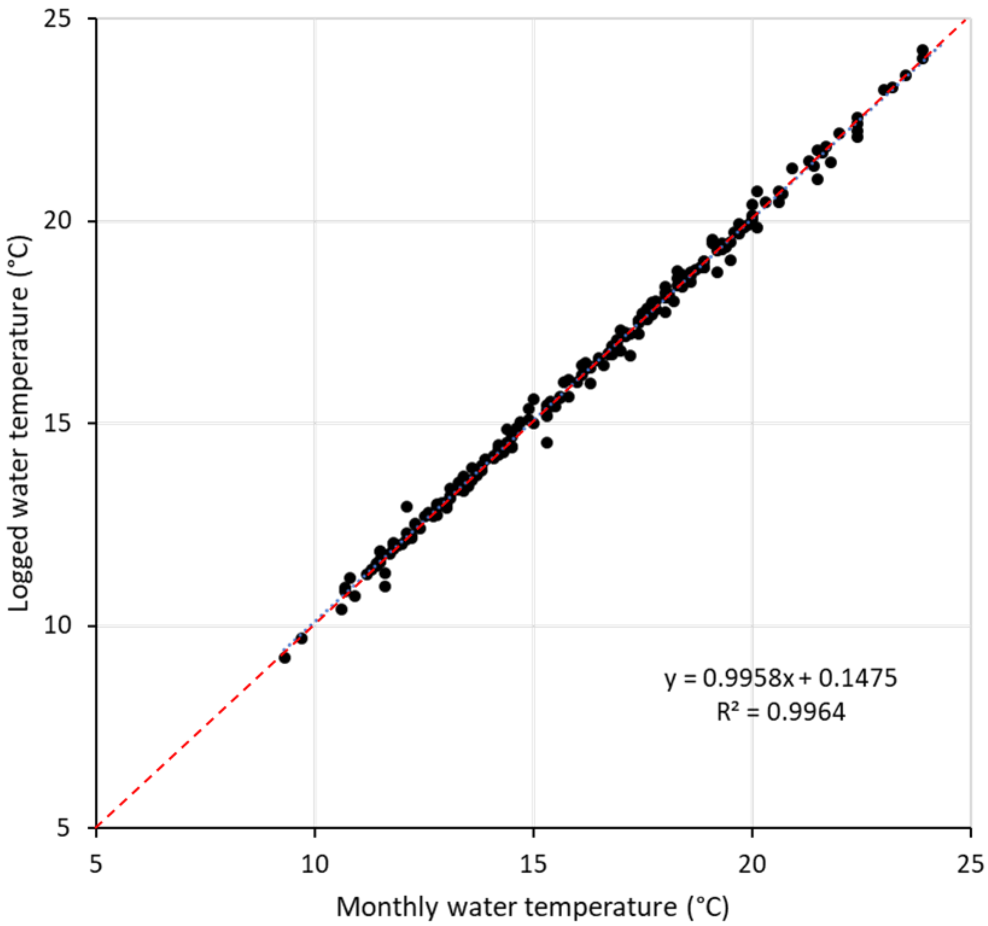


Figure A-1: Plot of logged water temperature against monthly spot temperatures at the same time. The 1:1 line (red dashed line) corresponds almost exactly to the regression line (blue dotted line, largely obscured.

Mean discrepancies of the 95th percentile of summer temperature from the three long-term records ranged from -4.2 °C (Mangahahuru minus Punakitere)) to +3.9 °C (Waimamaku minus Otaika). The range of discrepancies was similar across the three long-term records (5.1 – 5.2 °C) and this range was consistent with the range (highest minus lowest) in the 95th percentile of monthly temperatures (calculated from all available monthly data) at the same sites (5.4 °C).

Site ranking according to mean discrepancies was generally consistent across comparisons with the three long-term sites. The two coolest sites were the same and the two warmest sites were the same (Table A-1). The largest inconsistencies were for Punaruku (ranks of 3, 5, and 3), and Ruakaka at Flyger Road (ranks of 6, 3, and 5). These were two of three sites for which there was only one comparison (the other was Awanui). Comparisons with Punaruku and Ruakaka with Otaika were inconsistent with the comparisons with Hatea and Punakitere, although with no more than three ranks difference. There was no particular basis for selecting between the ranks based on Hatea and Punakitere except that Hatea was more centrally placed in the ranking. Averaging the three ranks would have produced a ranking the same as that from the comparison with Punakitere.

Table A-1: Ranks for water temperature (coolest to warmest) derived from the comparison with data from three sites with long term data. The long-term sites are highlighted with grey shading. Discrepancies are the mean of the difference between the 95th percentile of temperature over equivalent periods at the site and each of the three long term sites (Hatea, Otaika and Punakitere).

Peri site	Comparison with Hatea		Comparison with Otaika		Comparison with Punakitere	
	Rank	Mean discrepancy (°C)	Rank	Mean discrepancy (°C)	Rank	Mean discrepancy (°C)
Mangahahuru at Main Road	1	-2.8	1	-1.2	1	-4.3
Tapapa at SH1	2	-2.5	2	-1.0	2	-4.0
Punaruku at Russell Road	3	-1.8	5	0.1	3	-3.3
Otaika at Otaika Valley Road	4	-1.3	4	0.0	4	-2.9
Raumanga at Bernard Street	5	-0.6	6	0.8	6	-2.1
Ruakaka at Flyger Road	6	-0.5	3	-0.4	5	-2.9
Victoria at Victoria Valley Road	7	-0.1	8	1.4	8	-1.6
Hatea at Mair Park	8	0.0	7	1.3	7	-1.7
Ngunguru at Coalhill Lane	9	0.4	9	1.9	9	-1.1
Waiharakeke at Stringers Road	10	0.6	10	2.0	10	-0.9
Waiarohia at Second Avenue	11	0.7	11	2.1	11	-0.8
Oruaiti at Windust Road	12	0.8	12	2.2	12	-0.6
Awanui at FNDC	13	1.6	14	3.5	14	0.1
Punakitere at Taheke	14	1.7	13	2.9	13	0.0
Kaeo at Dip Road	15	2.1	15	3.5	15	0.7
Waimamaku at SH12	16	2.5	16	3.9	16	1.0

The selected (Hatea) discrepancies were positively correlated with the observed median and 95nd percentile of discrepancies calculated from monthly observations (r = 0.76 and 0.87 respectively). These strong correlations suggest that even though the monthly observations are made at different times of day, they are still capturing reasonably good information about the relative peak temperatures across sites.

Commentary and conclusion

It was possible to generate a ranking of sites from coolest to warmest across 16 periphyton monitoring sites in Northland by comparing relatively short (~6 months) sections of continuous data at 13 sites with three-year continuous records at three sites. The rankings produced relative to each continuous record were generally consistent with each other and indicated a difference of over 5 °C between the coolest site (Mangahahuru) and the warmest site (Waimamaku).

We found that the calculated temperature discrepancies in the continuous records correlated reasonably well with those calculated from the medians and 95th percentiles of monthly temperature observations at each site. We therefore chose to retain the observed monthly temperature data in the analyses described in Section 5 of this report, making the assumption that the sites that had only monthly data would follow the same pattern (i.e., continuous data would have generally reflected the monthly data). The correlation between site discrepancies calculated from logged and monthly data was not perfect but was strong enough to provide confidence that the monthly data is capturing realistic differences in water temperatures across sites.

Water temperature is predictable from air temperature (which is available across the country from the Virtual Climate Station Network (VCSN) and other variables including flow (Booker and Whitehead 2022). Water temperature – air temperature relationships are site-specific. Therefore, logged water temperature data from each site are required to make a model, and the data should ideally cover at least a whole year.

The data provided from 20 Northland sites could potentially be used for such modelling, especially at sites where the time series covered at least a year. The data collection year for the temperature data is not important because continuous data are generally available for all the predictors. However, such modelling is time consuming and was beyond the resources of the present project. Instead, we used a simpler approach, which was to rank the sites based on the temperature data available.

Reference

Booker, D.J., Whitehead, A.L. (2022) River water temperatures are higher during lower flows after accounting for meteorological variability. River Research and Applications, 38(1): 3-22. 10.1002/rra.3870

Appendix B Summary of trial of the use of quantile regression to derive nutrient concentration criteria for periphyton in Northland

Part 3 of the analysis requested by NRC (summarised in Section 1) was:

> if the outcome of item 2 is that the criteria are not suitable, suggestions / calculations to determine instream concentration criteria for nitrogen and phosphorus to keep periphyton biomass in Northland above the national bottom-line (D band) defined in the NPS-FM periphyton attribute.

Here, "Item 2" refers to the validation of national nutrient criteria for Northland, described in Section 4.

Because the results of the validation procedure and uncertainty analysis indicated that the national criteria for TN and DIN were too permissive for the Northland sites (see Section 4.7), an alternative approach (quantile regression, QR) was trialled on the Northland dataset.

In contrast to an ordinary least squares (OLS) regression model, or a general linear model (GLM), which fit a model to the conditional mean of the dependent variable, QR models fit to a user-defined quantile of the data (e.g., the 0.8 quantile; Cade and Noon, 2003). We applied the following method (from Snelder and Kilroy 2023):

1. For each nutrient, we regressed observed CHLA92 values against log (base 10)-transformed observed site median nutrient concentrations. The models were fitted to six quantiles (0.95, 0.9, 0.85, 0.8, 0.75, 0.7 and 0.5) corresponding to the 5%, 10%, 15%, 20%, 25%, 30% and 50% levels of under-protection risk).
2. We assessed the significance of the fitted nutrient concentration in each model (where a model pertains to the combination of nutrient and quantile) and when the fitted coefficient was significant (i.e., $P < 0.1$).

Results are summarised in Figure B-1 and Table B-1. The key result is that the only significant results were for 0.95 and 0.9 percentiles (i.e.,5% and 10% levels of under-protection risk for DRP and TP. We consider that these represent very restrictive conditions for specifying nutrient criteria and therefore have not taken the analysis further.

Note that the QR approach was used successfully by Snelder and Kilroy (2023) to derive spatially uniform criteria for DIN and TN for the 50 mg m^{-2} CHLA92 target in the national dataset (see Section 4.2.2.)

References

Cade, B.S., Noon, B.R. (2003) A gentle introduction to quantile regression for ecologists. Frontiers in Ecology and the Environment 1: 412-420.

Snelder T, Kilroy C (2023) Revised Nutrient Criteria for Periphyton Biomass Objectives. Updating criteria referred to in Ministry for Environment 2022 guidance. LWP Client Report 2023–08. LWP Ltd, Christchurch, New Zealand.

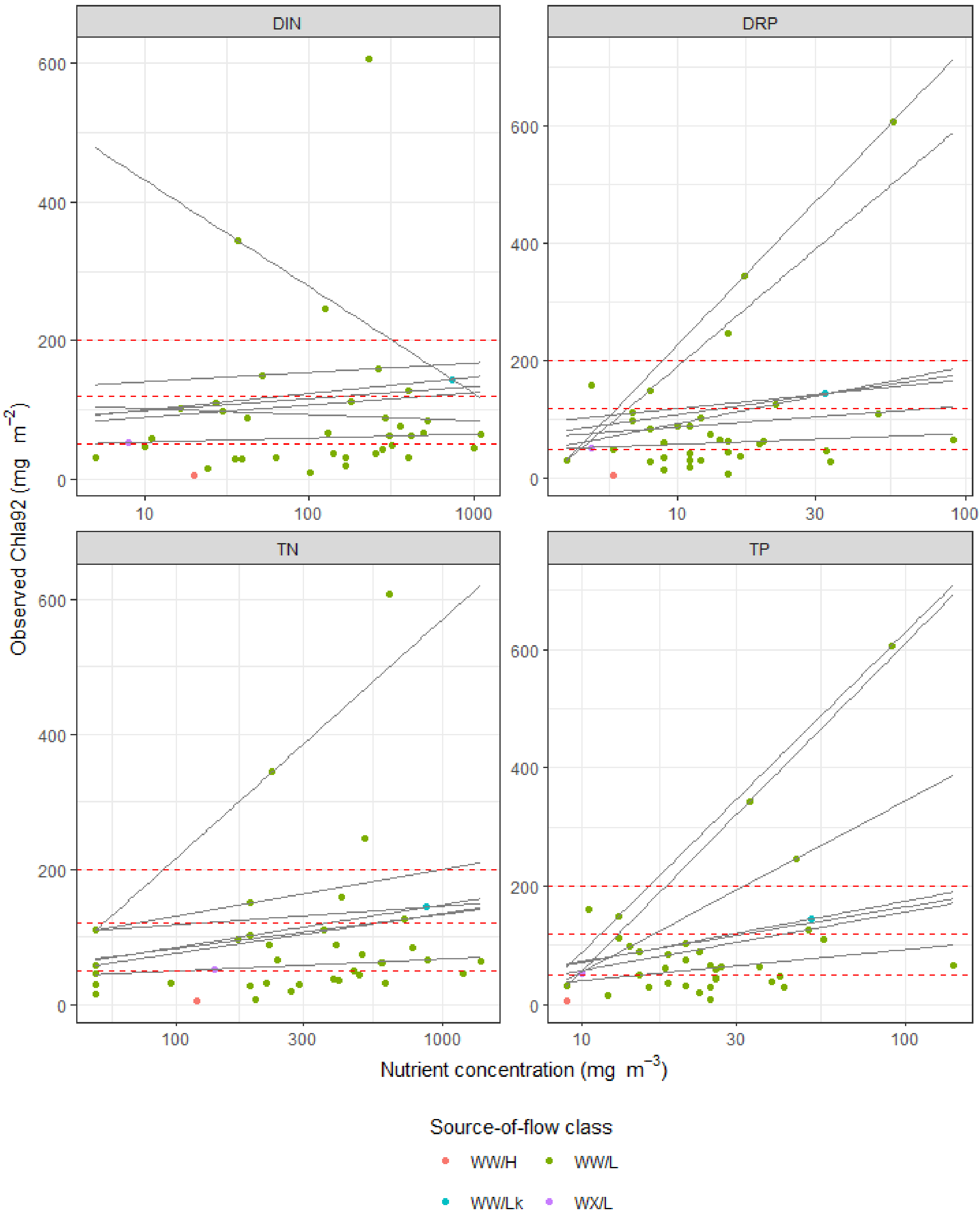


Figure B-1: Relationships between CHLA92 and median concentrations of DIN, TN, DRP and TP at the 38 monitoring sites. The grey lines are quantile regressions fitted to the 0.95, 0.9, 0.85, 0.8, 0.7 and 0.5 quantiles. Most of these regression lines are not statistically significant (i.e., P > 0.1 in Table B-1). The red dashed lines indicate biomass of 20. 120 and 200 mg m^{-2}, which are the upper thresholds of the A, B and C bands Points are coloured to indicate the Source-of-flow class of the monitoring site.

Table B-1: Quantile regression model coefficients and P-values for TN, DIN, TP and DRP for seven levels of under-protection risk. Statistically significant relationships ($P < 0.1$) are highlighted in grey.

		TN		DIN		TP		DRP	
Quantile	Under-protection risk	Coefficient	P	Coefficient	P	Coefficient	P	Coefficient	P
0.5	50%	17.6	0.403	5.9	0.655	52.2	0.372	18.2	0.666
0.7	30%	58.8	0.154	-8.7	0.744	98.7	0.371	36.0	0.775
0.75	25%	50.5	0.287	17.7	0.622	92.0	0.522	97.0	0.511
0.8	20%	62.9	0.416	17.4	0.739	103.8	0.572	69.8	0.693
0.85	15%	27.6	0.803	23.9	0.775	288.7	0.195	49.2	0.830
0.9	10%	69.5	0.662	13.5	0.924	553.6	0.025	415.9	0.093
0.95	5%	353.2	0.148	-153.7	0.490	540.7	0.011	508.2	0.015

Appendix C Revised nutrient concentration criteria for source-of-flow classes that occur in Northland

Table C-1: Revised criteria derived from the GLM model for TN (mg m^{-3}) for seven levels of under-protection risk at shaded and unshaded locations. Levels of under-protection risk (UPR) are 5, 10, 15, 20, 25, 30 and 50%. Criteria greater than the saturating concentration of approximately 1,000 mg m^{-3} indicate combinations of conditions where periphyton biomass is strongly controlled by non-nutrient factors. Under such conditions, even when nutrient concentrations exceed saturating levels, the biomass threshold(s) may not be exceeded.

UPR	SoF	Unshaded_50	Unshaded_120	Unshaded_200	Shaded_50	Shaded_120	Shaded_200
5	CW/H	1	21	385	1	110	1559
5	CX/H	2	140	1810	6	678	3570
5	WD/L	1	3	25	1	8	134
5	WD/Lk	1	8	140	1	39	707
5	WW/H	1	26	477	1	137	1965
5	WW/L	1	12	209	1	59	999
5	WW/Lk	1	22	414	1	116	1748
5	WX/H	1	43	752	2	227	2601
5	WX/L	1	35	635	2	189	2477
10	CW/H	1	75	1142	3	376	3038
10	CX/H	4	475	3280	19	1886	4198
10	WD/L	1	6	96	1	27	459
10	WD/Lk	1	28	504	2	144	1934
10	WW/H	1	91	1461	4	458	3366
10	WW/L	1	41	702	2	209	2296
10	WW/Lk	1	80	1349	3	416	3046
10	WX/H	1	148	2114	5	741	3922
10	WX/L	1	124	1893	4	621	3968
15	CW/H	2	179	2137	7	845	3806
15	CX/H	9	1079	3930	47	2965	4335
15	WD/L	1	14	238	2	70	933
15	WD/Lk	1	71	1117	3	367	2983
15	WW/H	2	219	2646	8	1057	4039
15	WW/L	1	99	1513	4	499	3036
15	WW/Lk	2	201	2400	8	988	3644
15	WX/H	3	355	3191	13	1650	4321
15	WX/L	2	297	3192	11	1417	4375
20	CW/H	3	366	3024	15	1534	4130
20	CX/H	19	1916	4196	99	3633	4371
20	WD/L	1	29	473	2	151	1504
20	WD/Lk	2	150	1929	6	750	3503
20	WW/H	4	445	3369	17	1975	4334

UPR	SoF	Unshaded_50	Unshaded_120	Unshaded_200	Shaded_50	Shaded_120	Shaded_200
20	WW/L	2	207	2307	9	1014	3477
20	WW/Lk	4	419	3105	16	1825	4068
20	WX/H	5	719	3954	28	2624	4391
20	WX/L	4	606	3997	23	2460	4363
25	CW/H	6	676	3,637	28	2,332	4,254
25	CX/H	70	3,337	4,366	356	4,247	4,380
25	WD/L	2	58	804	3	290	2,146
25	WD/Lk	3	293	2,733	12	1,292	3,727
25	WW/H	7	848	3,860	33	2,840	4,353
25	WW/L	4	395	2,868	17	1,707	3,789
25	WW/Lk	7	803	3,555	31	2,579	4,289
25	WX/H	10	1,341	4,315	54	3,383	4,373
25	WX/L	9	1,139	4,326	45	3,393	4,342
30	CW/H	10	1136	3975	51	3077	4344
30	CX/H	70	3337	4366	356	4247	4380
30	WD/L	2	109	1215	5	502	2751
30	WD/Lk	5	542	3294	22	2017	3961
30	WW/H	12	1464	4243	61	3372	4348
30	WW/L	7	721	3298	30	2360	4008
30	WW/Lk	12	1400	3884	58	3156	4350
30	WX/H	19	2139	4382	99	3977	4364
30	WX/L	16	1894	4363	83	4021	4374
50	CW/H	31	2519	4411	158	4071	4490
50	CX/H	220	4191	4500	1041	4498	4500
50	WD/L	4	332	2310	15	1188	3826
50	WD/Lk	14	1445	3885	68	3324	4374
50	WW/H	37	3019	4499	189	4312	4500
50	WW/L	19	1864	3939	90	3324	4400
50	WW/Lk	36	2812	4444	186	3971	4500
50	WX/H	60	3577	4500	307	4500	4500
50	WX/L	50	3618	4500	259	4498	4500

Table C-2: Revised criteria derived from the GLM model for DIN (mg m^{-3}) for seven levels of under-protection risk at shaded and unshaded locations. Levels of under-protection risk (UPR) are 5, 10, 15, 20, 25, 30 and 50%. Criteria greater than the saturating concentration of approximately 1,000 mg m^{-3} indicate combinations of conditions where periphyton biomass is strongly controlled by non-nutrient factors. Under such conditions, even when nutrient concentrations exceed saturating levels, the biomass threshold(s) may not be exceeded.

UPR	SoF	Unshaded_50	Unshaded_120	Unshaded_200	Shaded_50	Shaded_120	Shaded_200
5	CW/H	1	7	267	1	55	1502
5	CX/H	1	167	2099	4	1070	3172
5	WD/L	1	1	7	1	3	42
5	WD/Lk	1	2	39	1	8	370
5	WW/H	1	5	258	1	47	1733
5	WW/L	1	2	74	1	15	603
5	WW/Lk	1	3	148	1	28	1189
5	WX/H	1	10	578	1	111	2314
5	WX/L	1	7	435	1	81	2331
10	CW/H	1	30	1053	1	284	2705
10	CX/H	3	733	2990	15	2152	3540
10	WD/L	1	2	27	1	7	193
10	WD/Lk	1	5	220	1	46	1328
10	WW/H	1	25	1200	1	269	2889
10	WW/L	1	9	365	1	77	1598
10	WW/Lk	1	17	805	1	162	2375
10	WX/H	1	58	1819	1	622	3426
10	WX/L	1	43	1751	1	459	3393
15	CW/H	1	100	2004	2	794	3265
15	CX/H	6	1481	3393	48	2827	3591
15	WD/L	1	4	80	1	19	490
15	WD/Lk	1	16	647	1	154	2161
15	WW/H	1	86	2196	2	867	3475
15	WW/L	1	28	947	1	254	2257
15	WW/Lk	1	55	1712	1	566	3010
15	WX/H	1	204	2804	3	1512	3600
15	WX/L	1	150	2909	2	1349	3593
20	CW/H	1	261	2687	4	1533	3451
20	CX/H	15	2102	3548	126	3238	3588
20	WD/L	1	8	195	1	48	937
20	WD/Lk	1	45	1319	1	395	2679
20	WW/H	1	245	2808	3	1741	3576
20	WW/L	1	72	1588	2	620	2760
20	WW/Lk	1	157	2428	3	1286	3371
20	WX/H	1	558	3441	7	2346	3601

UPR	SoF	Unshaded_50	Unshaded_120	Unshaded_200	Shaded_50	Shaded_120	Shaded_200
20	WX/L	1	424	3418	5	2343	3592
25	CW/H	2	576	3,133	9	2,232	3,547
25	CX/H	34	2,635	3,608	298	3,471	3,590
25	WD/L	1	15	387	1	108	1,479
25	WD/Lk	1	113	1,907	2	834	2,944
25	WW/H	1	596	3,340	7	2,409	3,599
25	WW/L	1	174	2,070	3	1,149	3,083
25	WW/Lk	1	397	2,859	6	1,957	3,557
25	WX/H	2	1,191	3,599	15	3,039	3,598
25	WX/L	2	974	3,542	11	3,126	3,620
30	CW/H	3	1082	3360	21	2797	3607
30	CX/H	75	3010	3608	599	3573	3596
30	WD/L	1	30	673	2	223	2063
30	WD/Lk	1	253	2458	4	1422	3178
30	WW/H	2	1218	3560	16	2886	3558
30	WW/L	1	381	2519	6	1663	3300
30	WW/Lk	2	881	3206	12	2483	3563
30	WX/H	4	1874	3604	36	3472	3585
30	WX/L	3	1794	3592	27	3469	3592
50	CW/H	10	2379	3764	92	3544	3800
50	CX/H	340	3688	3800	1519	3800	3800
50	WD/L	1	124	1604	4	690	3174
50	WD/Lk	2	920	3137	17	2553	3704
50	WW/H	8	2545	3800	78	3747	3800
50	WW/L	4	1241	3261	26	2606	3708
50	WW/Lk	6	2126	3753	54	3387	3800
50	WX/H	16	3220	3800	180	3800	3800

Table C-3: Revised criteria derived from the GLM model for TP (mg m^{-3}) for seven levels of under-protection risk at shaded and unshaded locations. Levels of under-protection risk (UPR) are 5, 10, 15, 20, 25, 30 and 50%. Criteria greater than the saturating concentration of approximately 50 mg m^{-3} indicate combinations of conditions where periphyton biomass is strongly controlled by non-nutrient factors. Under such conditions, even when nutrient concentrations exceed saturating levels, the biomass threshold(s) may not be exceeded.

UPR	SoF	Unshaded_50	Unshaded_120	Unshaded_200	Shaded_50	Shaded_120	Shaded_200
5	CW/H	0	2	21	0	6	54
5	CX/H	0	8	66	0	21	144
5	WD/L	0	0	1	0	0	4
5	WD/Lk	0	1	6	0	2	16
5	WW/H	0	2	21	0	6	52
5	WW/L	0	1	12	0	3	30
5	WW/Lk	0	1	11	0	3	27
5	WX/H	0	4	34	0	10	85
5	WX/L	0	4	34	0	10	83
10	CW/H	0	6	54	0	17	120
10	CX/H	0	22	147	1	57	234
10	WD/L	0	0	4	0	1	11
10	WD/Lk	0	2	18	0	5	44
10	WW/H	0	6	52	0	16	124
10	WW/L	0	3	31	0	9	73
10	WW/Lk	0	3	30	0	8	71
10	WX/H	0	10	84	1	27	180
10	WX/L	0	10	83	1	26	171
15	CW/H	0	13	98	1	33	187
15	CX/H	1	45	215	3	106	272
15	WD/L	0	1	9	0	3	23
15	WD/Lk	0	4	36	0	10	88
15	WW/H	0	12	99	1	31	195
15	WW/L	0	7	60	0	18	126
15	WW/Lk	0	7	59	0	17	121
15	WX/H	0	20	152	1	52	239
15	WX/L	0	20	144	1	51	241
20	CW/H	1	23	149	1	57	237
20	CX/H	2	79	257	5	162	289
20	WD/L	0	2	16	0	5	38
20	WD/Lk	0	7	64	0	19	140
20	WW/H	0	21	157	1	55	248
20	WW/L	0	13	97	1	33	171
20	WW/Lk	0	13	96	1	32	167
20	WX/H	1	35	208	2	90	282
20	WX/L	1	35	205	2	88	281

UPR	SoF	Unshaded_50	Unshaded_120	Unshaded_200	Shaded_50	Shaded_120	Shaded_200
25	CW/H	0.91	38	200	2.4	90	267
25	CX/H	3.52	122	279	9.1	210	296
25	WD/L	0.08	3	27	0.2	8	57
25	WD/Lk	0.28	12	102	0.7	32	185
25	WW/H	0.85	36	210	2.2	90	278
25	WW/L	0.51	22	138	1.3	54	206
25	WW/Lk	0.48	21	136	1.3	53	208
25	WX/H	1.43	59	251	3.8	141	295
25	WX/L	1.41	58	254	3.7	134	296
30	CW/H	2	60	241	4	131	284
30	CX/H	6	167	289	15	247	296
30	WD/L	0	5	40	0	13	81
30	WD/Lk	0	20	147	1	53	222
30	WW/H	1	57	250	4	135	294
30	WW/L	1	35	176	2	82	231
30	WW/Lk	1	35	175	2	83	231
30	WX/H	2	93	283	6	190	296
30	WX/L	2	90	281	6	182	297
50	CW/H	4	123	285	9	217	299
50	CX/H	14	245	300	36	287	300
50	WD/L	0	13	77	1	31	140
50	WD/Lk	1	48	219	3	116	261
50	WW/H	3	126	296	9	226	300
50	WW/L	2	77	229	5	152	266
50	WW/Lk	2	78	231	5	151	269
50	WX/H	6	183	300	14	266	300
50	WX/L	6	175	300	14	268	300

Table C-4: Revised criteria derived from the GLM model for DRP (mg m-3) for seven levels of under-protection risk at shaded and unshaded locations. Levels of under-protection risk (UPR) are 5, 10, 15, 20, 25, 30 and 50%. Criteria greater than the saturating concentration of approximately 25 mg m^{-3} indicate combinations of conditions where periphyton biomass is strongly controlled by non-nutrient factors. Under such conditions, even when nutrient concentrations exceed saturating levels, the biomass threshold(s) may not be exceeded.

UPR	SoF	Unshaded_50	Unshaded_120	Unshaded_200	Shaded_50	Shaded_120	Shaded_200
5	CW/H	0	1	14	0	2	43
5	CX/H	0	3	53	0	11	123
5	WD/L	0	0	0	0	0	1
5	WD/Lk	0	0	1	0	0	4
5	WW/H	0	1	13	0	2	41
5	WW/L	0	0	5	0	1	17
5	WW/Lk	0	0	3	0	0	9
5	WX/H	0	1	26	0	4	78
5	WX/L	0	1	21	0	3	62
10	CW/H	0	3	47	0	9	109
10	CX/H	0	12	133	0	39	193
10	WD/L	0	0	1	0	0	3
10	WD/Lk	0	0	5	0	1	18
10	WW/H	0	2	44	0	8	111
10	WW/L	0	1	19	0	3	54
10	WW/Lk	0	1	11	0	2	30
10	WX/H	0	5	84	0	16	158
10	WX/L	0	4	68	0	14	139
15	CW/H	0	7	95	0	23	165
15	CX/H	0	31	185	1	86	216
15	WD/L	0	0	2	0	0	7
15	WD/Lk	0	1	14	0	2	44
15	WW/H	0	6	95	0	20	166
15	WW/L	0	3	45	0	9	102
15	WW/Lk	0	1	26	0	5	59
15	WX/H	0	13	143	0	41	208
15	WX/L	0	10	122	0	34	189
20	CW/H	0	15	141	0	46	199
20	CX/H	0	64	211	2	137	223
20	WD/L	0	0	5	0	1	15
20	WD/Lk	0	2	31	0	5	85
20	WW/H	0	13	143	0	43	200
20	WW/L	0	6	80	0	19	138
20	WW/Lk	0	3	48	0	11	90
20	WX/H	0	27	188	1	83	224

UPR	SoF	Unshaded_50	Unshaded_120	Unshaded_200	Shaded_50	Shaded_120	Shaded_200
20	WX/L	0	23	170	0	66	213
25	CW/H	0.18	29.7	180	0.62	80	213
25	CX/H	0.93	106.6	221	3.17	177	224
25	WD/L	0.02	0.6	10	0.03	2	27
25	WD/Lk	0.03	3.3	60	0.07	11	123
25	WW/H	0.15	26.3	179	0.52	78	219
25	WW/L	0.08	11.7	117	0.25	36	164
25	WW/Lk	0.06	7	72	0.16	22	120
25	WX/H	0.32	52.5	214	1.09	128	223
25	WX/L	0.26	43.5	200	0.91	107	221
30	CW/H	0	52	203	1	119	221
30	CX/H	2	149	224	6	201	224
30	WD/L	0	1	18	0	4	44
30	WD/Lk	0	7	94	0	21	152
30	WW/H	0	49	207	1	120	224
30	WW/L	0	22	145	0	62	181
30	WW/Lk	0	13	99	0	37	146
30	WX/H	1	92	223	2	166	223
30	WX/L	1	74	216	2	146	224
50	CW/H	1	119	226	4	189	230
50	CX/H	6	206	230	21	228	230
50	WD/L	0	4	44	0	12	92
50	WD/Lk	0	21	156	0	66	193
50	WW/H	1	119	230	3	188	230
50	WW/L	0	61	186	2	124	211
50	WW/Lk	0	38	151	1	79	188
50	WX/H	2	168	230	7	224	230
50	WX/L	2	148	230	6	208	230

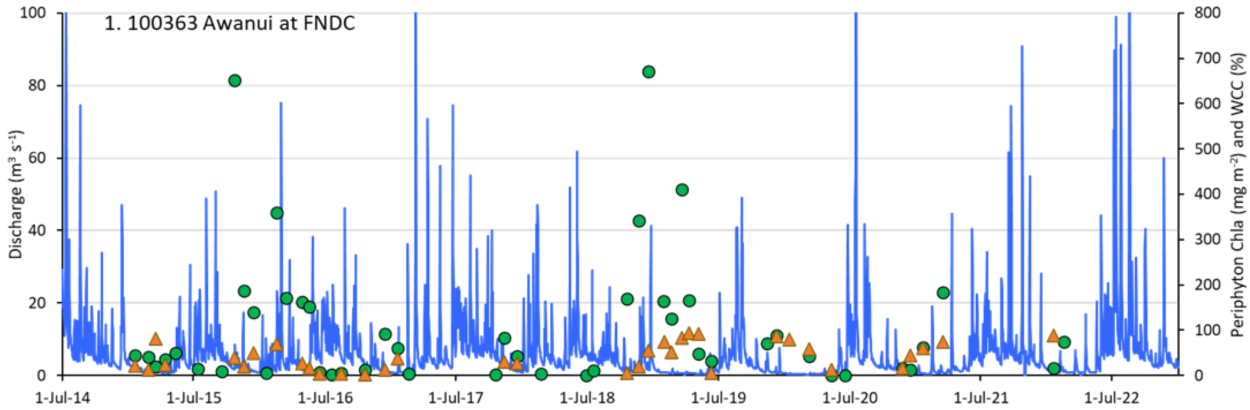
Table C-5: Spatially uniform criteria derived by Snelder and Kilroy (2023) based on quantile regression models for the 50 mg m^{-2} biomass threshold. Criteria were derived for TN and DIN and the levels of under-protection risk shown in the table. The P-value indicates the confidence in the regression coefficient fitted to the nutrient concentration by the relevant quantile regression model. The criteria have units of mg m^{-3}.

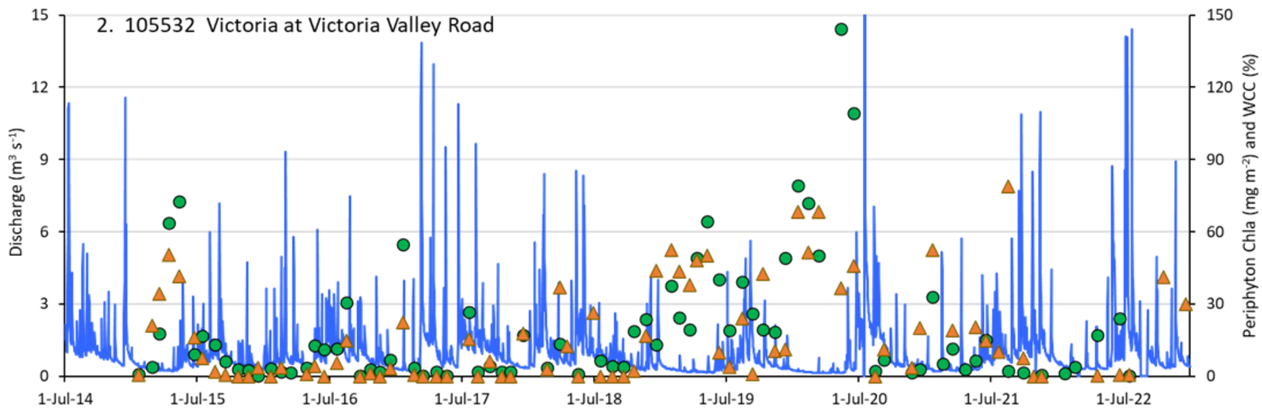
Nutrient	Quantile	Under-protection risk (%)	P value	Criteria
TN	0.5	50	0	137.5
	0.7	30	0	41.1
	0.75	25	0	27.8
	0.8	20	0	23.9
	0.85	15	0	21.8
	0.9	10	0.009	21.9
	0.95	5	0.037	20.3
DIN	0.5	50	0	61.3
	0.7	30	0	12.6
	0.75	25	0	5.5
	0.8	20	0	4.5
	0.85	15	0	4.1
	0.9	10	0.029	4
	0.95	5	0.354	2.5

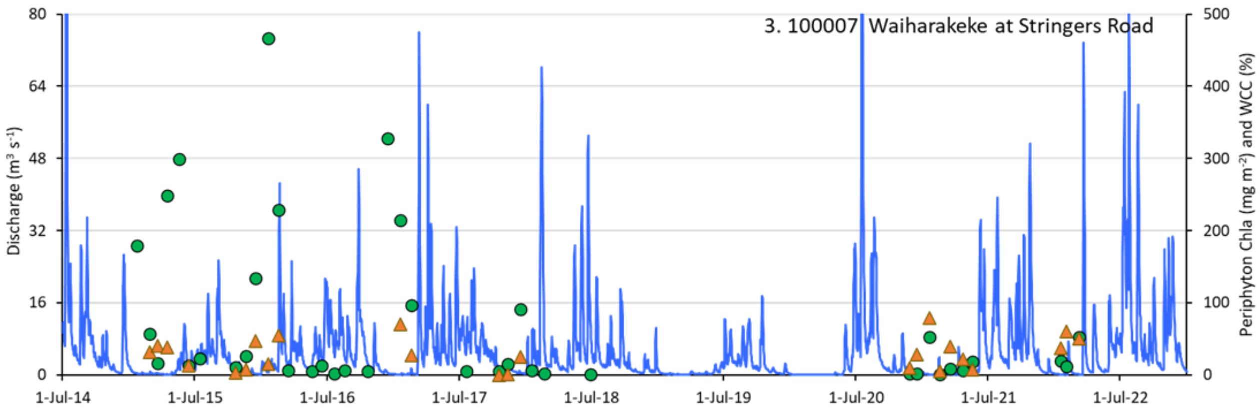
Appendix D Periphyton plotted over time at each site, with flow

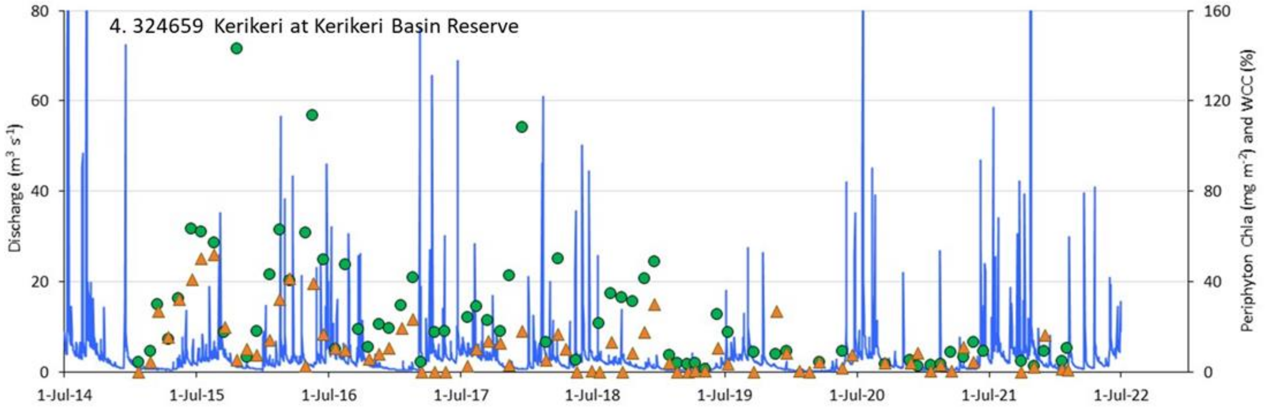
The plots below show all the monthly periphyton data collected from 38 sites in the Northland region. Plots are shown in the same order used in Table 2-1, with numbering corresponding to that in Table 2-1 and Figure 2-1. NRC site number and full periphyton site names are shown. Sites with insufficient data (as indicated on Table 2-1) are not shown. The periphyton data (chlorophyll *a*, green circles; WCC, orange triangles) are overplotted on hydrographs of daily mean flows at the 21 sites with a flow record. Data from the 17 sites with no flow record are plotted on the same axes with flow set at zero.

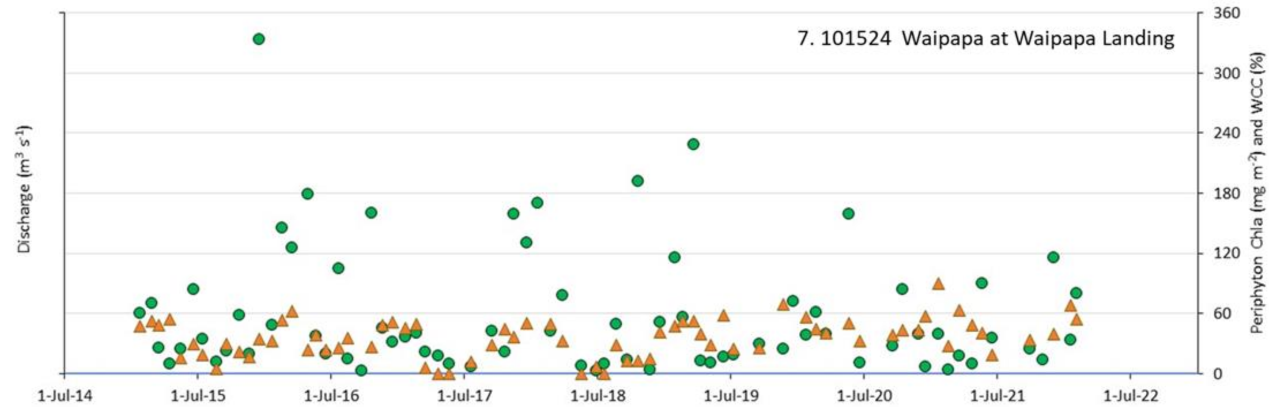
The scales for both flow (left) and periphyton (right) differ across plots so that the range of values can be seen at each site. In all cases, the scale for flow is truncated at about half of the absolute maximum value for the period so the smaller flow fluctuations can be seen more clearly.

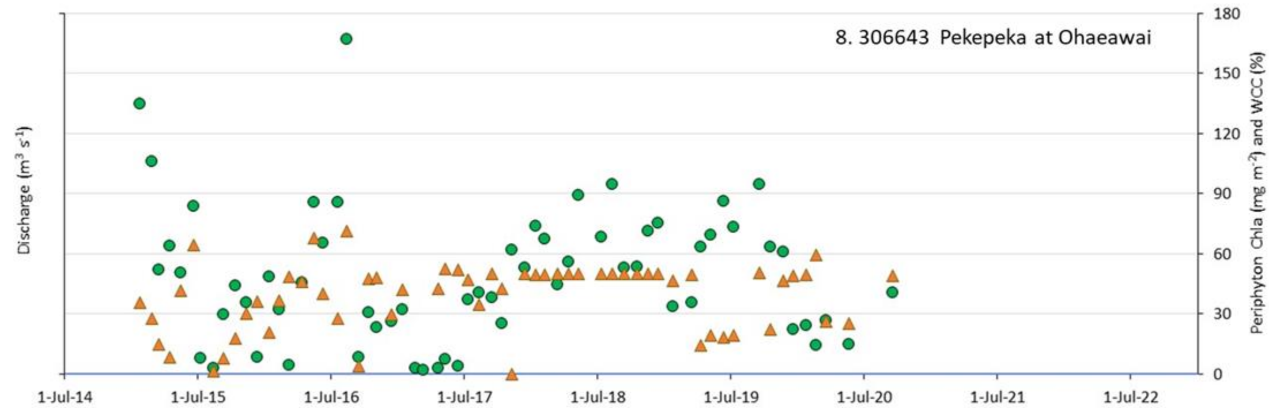


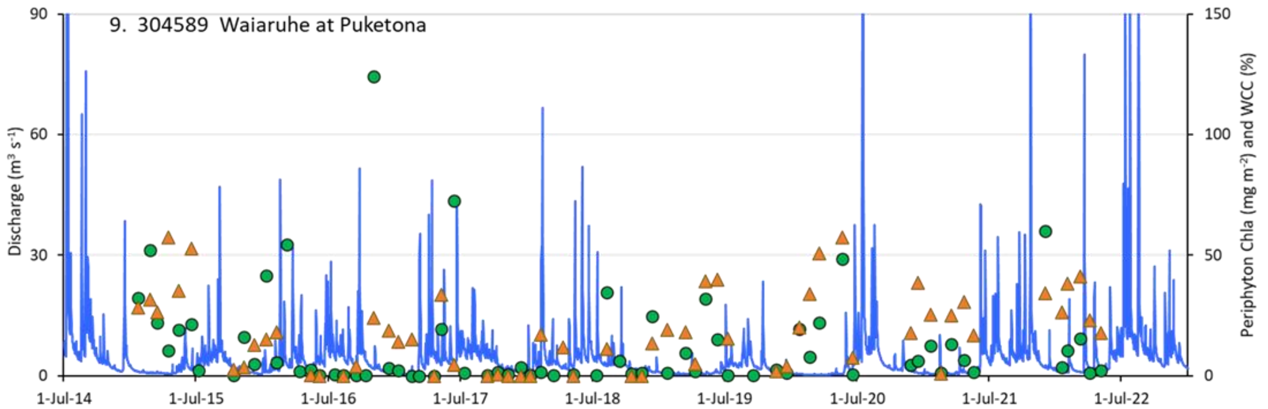


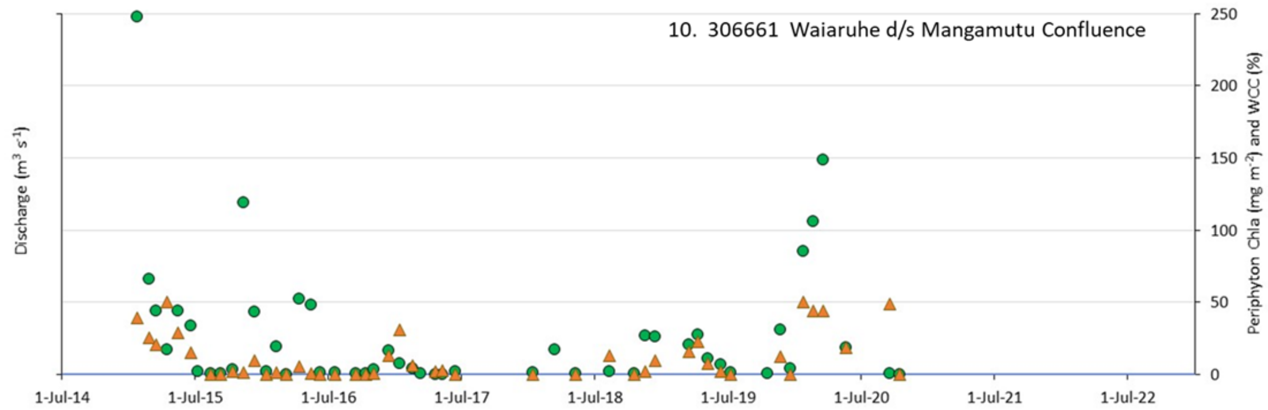


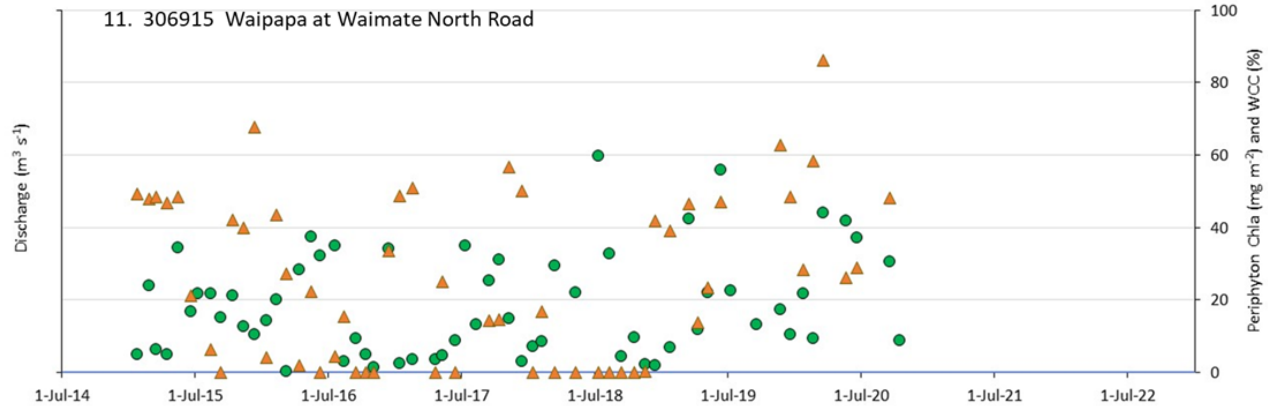

4. 324659 Kerikeri at Kerikeri Basin Reserve
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
20
40
60
80
160
120
80
40
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

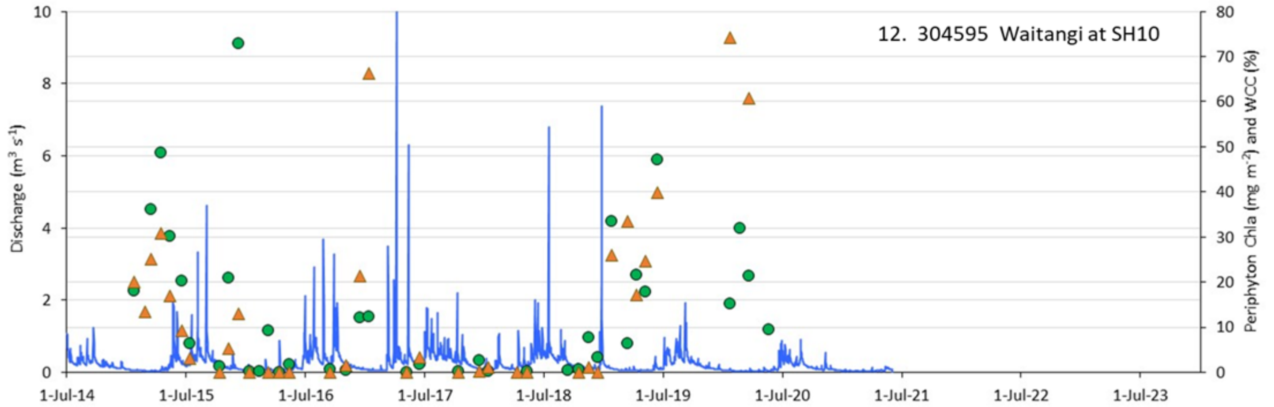

7. 101524 Waipapa at Waipapa Landing
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
360
300
240
180
120
60
0
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

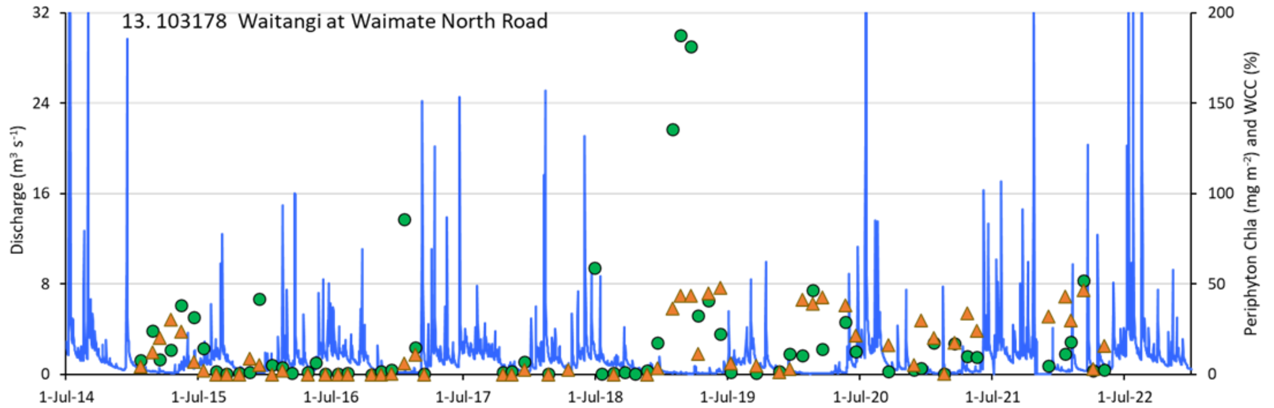

8. 306643 Pekepeka at Ohaeawai
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
180
150
120
90
60
30
0
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

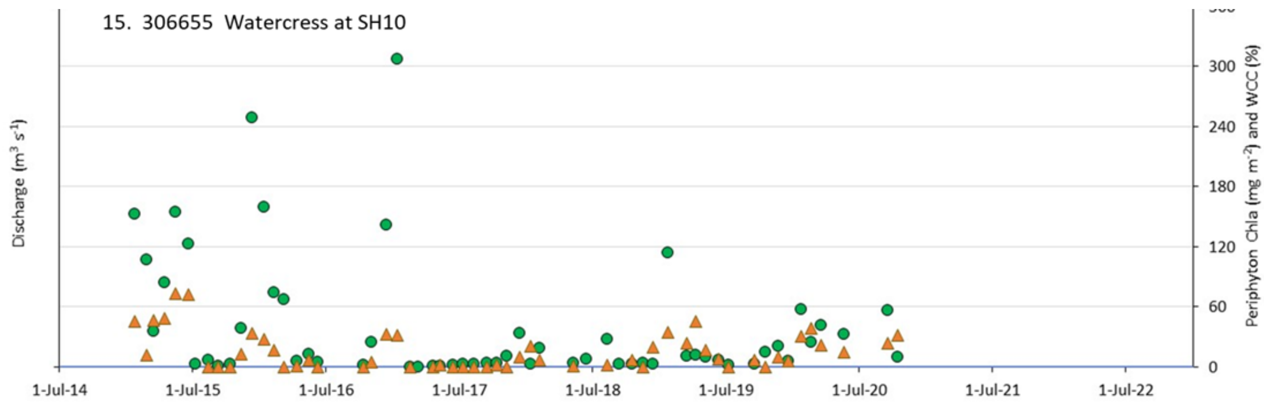

9. 304589 Waiaruhe at Puketona
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
30
60
90
150
100
50
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

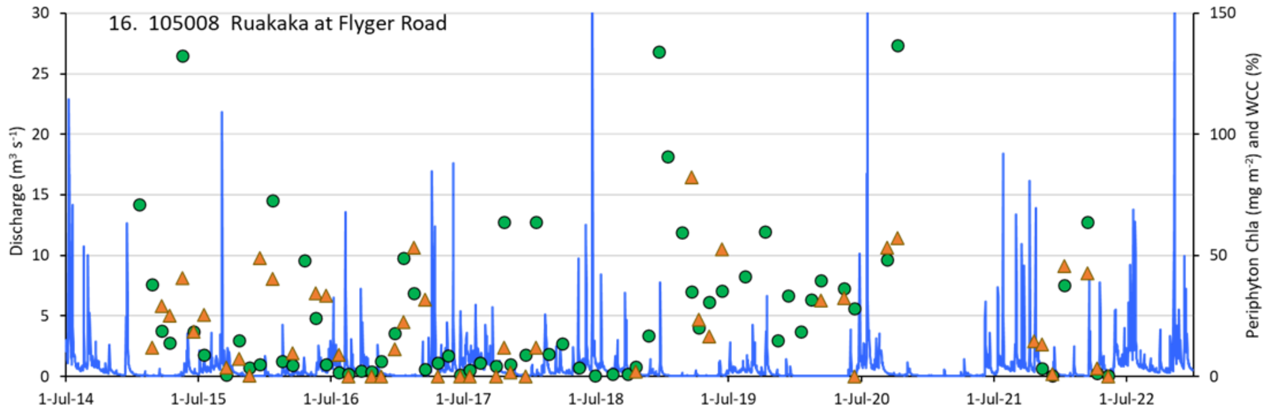

10. 306661 Waiaruhe d/s Mangamutu Confluence
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
250
200
150
100
50
0
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

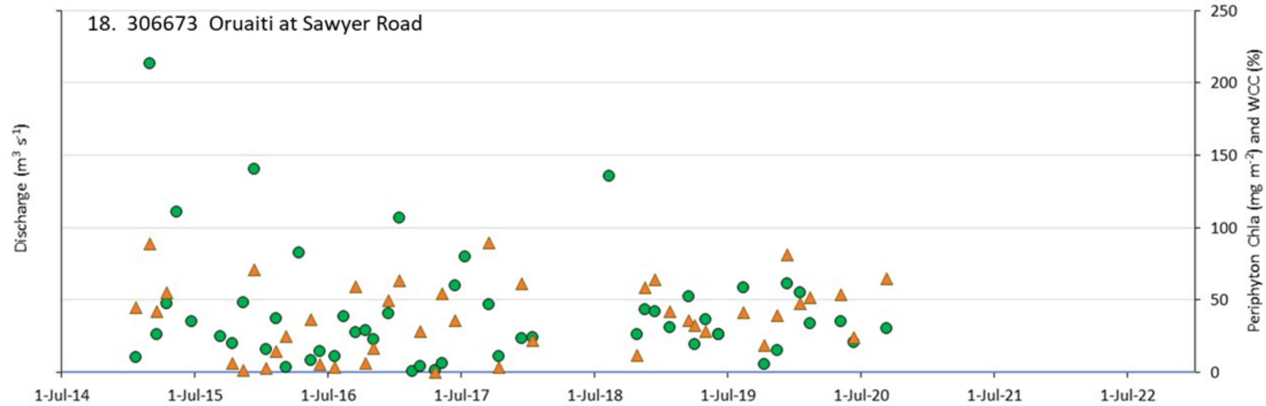

11. 306915 Waipapa at Waimate North Road
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
100
80
60
40
20
0
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

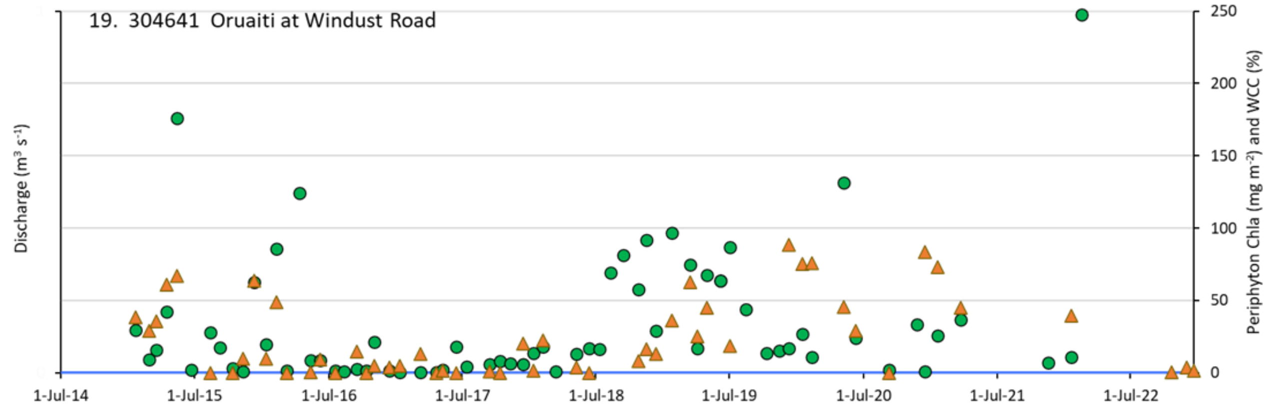

12. 304595 Waitangi at SH10
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
10
8
6
4
2
0
80
70
60
50
40
30
20
10
0
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22
1-Jul-23

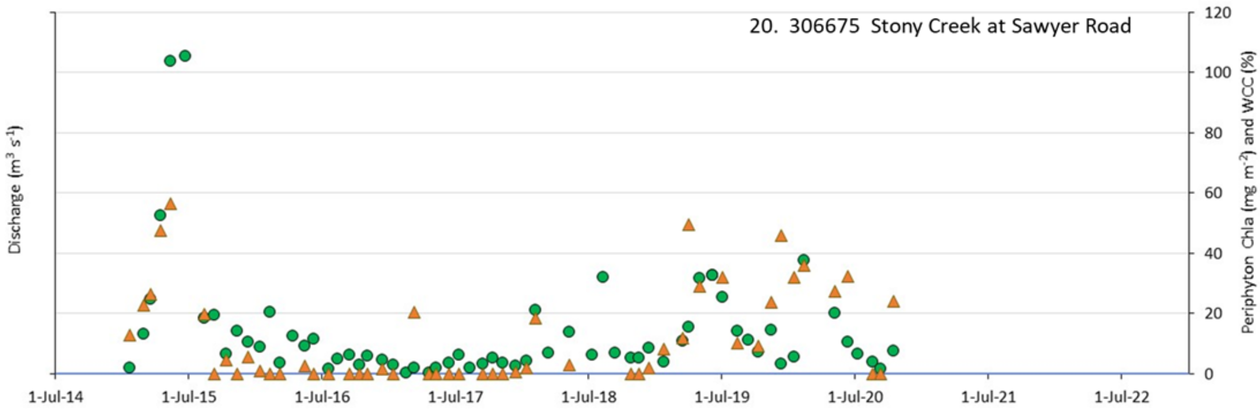

13. 103178 Waitangi at Waimate North Road
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
32
24
16
8
0
200
150
100
50
0
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


15. 306655 Watercress at SH10
Discharge ($m^3 s^{-1}$)
Periphyton Chla ($mg m^{-2}$) and WCC (%)
0
60
120
180
240
300
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

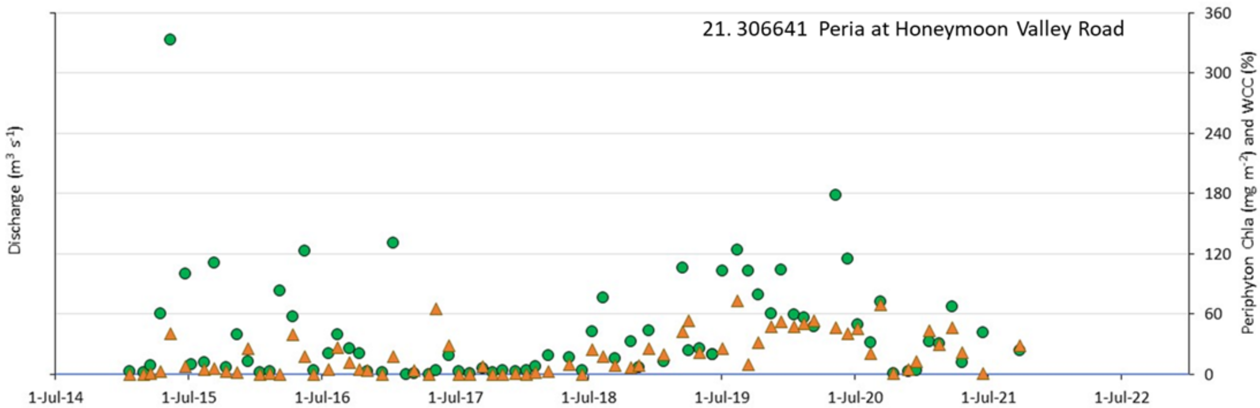

16. 105008 Ruakaka at Flyger Road
Discharge ($m^3 s^{-1}$)
Periphyton Chla ($mg m^{-2}$) and WCC (%)
0
5
10
15
20
25
30
50
100
150
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


18. 306673 Oruaiti at Sawyer Road
Discharge ($m^3 s^{-1}$)
Periphyton Chla ($mg m^{-2}$) and WCC (%)
0
50
100
150
200
250
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

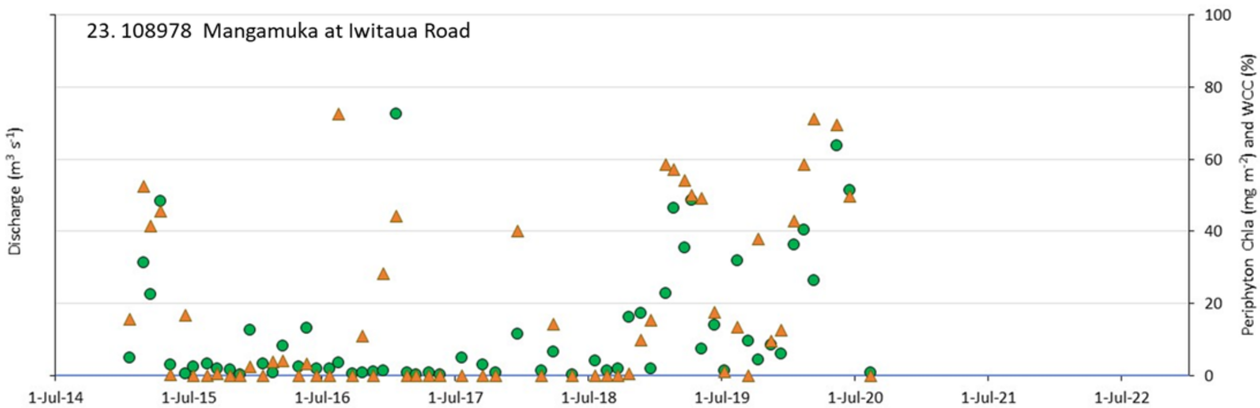

19. 304641 Oruaiti at Windust Road
Discharge ($m^3 s^{-1}$)
Periphyton Chla ($mg m^{-2}$) and WCC (%)
0
50
100
150
200
250
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22



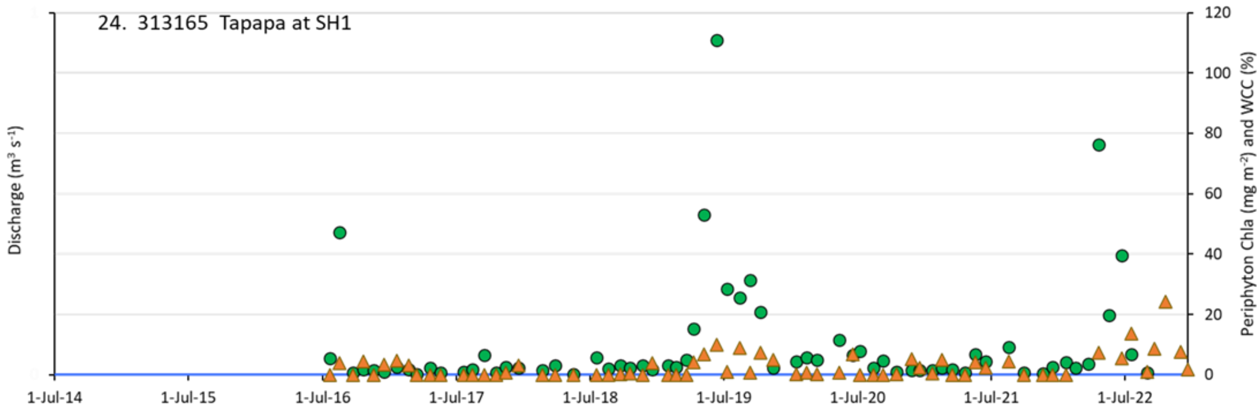
20. 306675 Stony Creek at Sawyer Road
Discharge (m3 s-1)
Periphyton Chla (mg m-2) and WCC (%)
0
20
40
60
80
100
120
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22



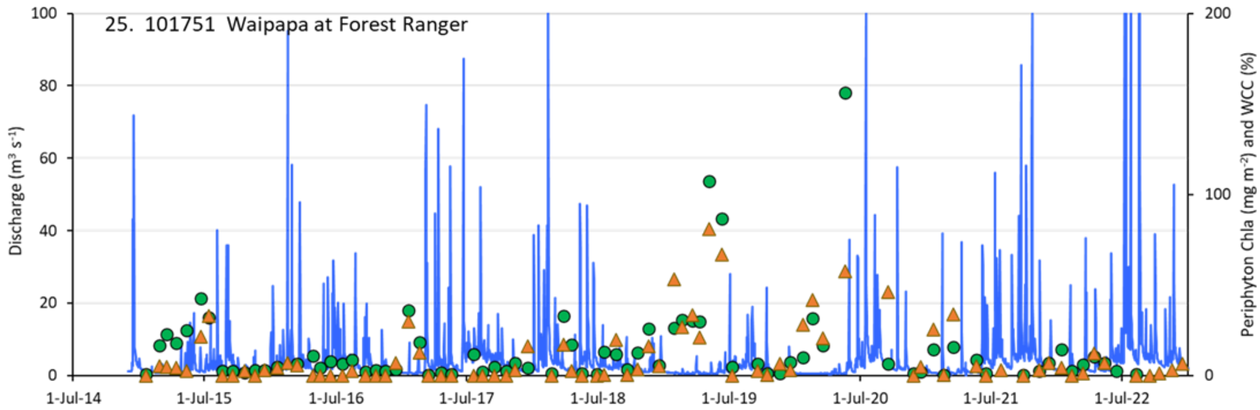
21. 306641 Peria at Honeymoon Valley Road
Discharge (m3 s-1)
Periphyton Chla (mg m-2) and WCC (%)
0
60
120
180
240
300
360
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

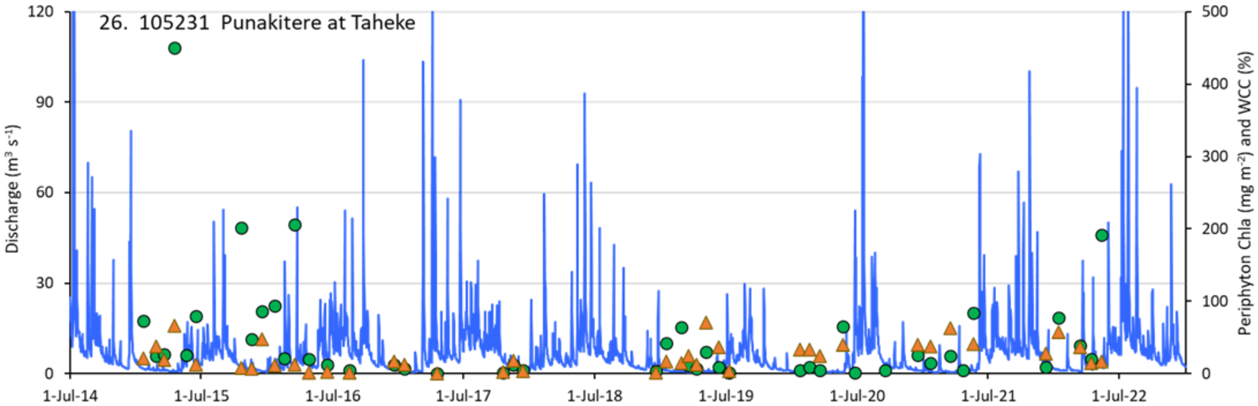


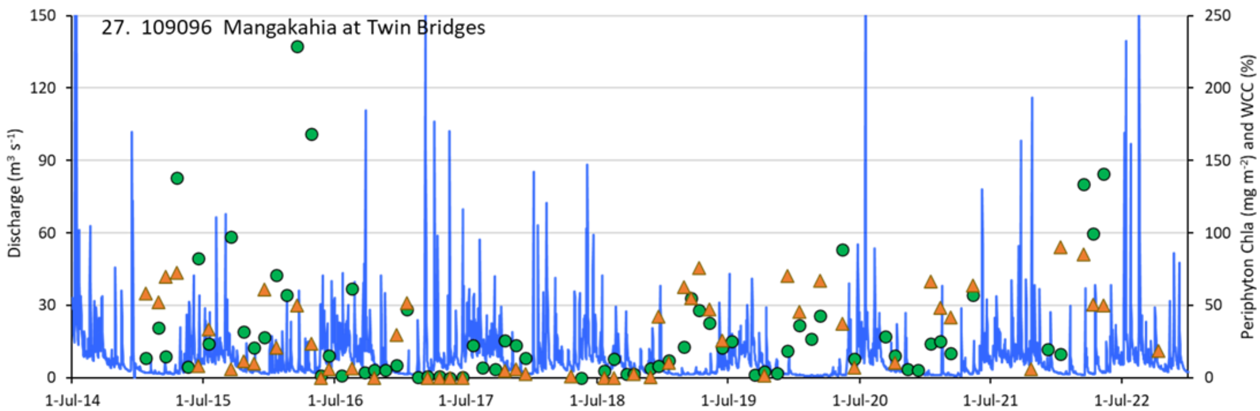
23. 108978 Mangamuka at Iwitaua Road
Discharge (m3 s-1)
Periphyton Chla (mg m-2) and WCC (%)
0
20
40
60
80
100
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

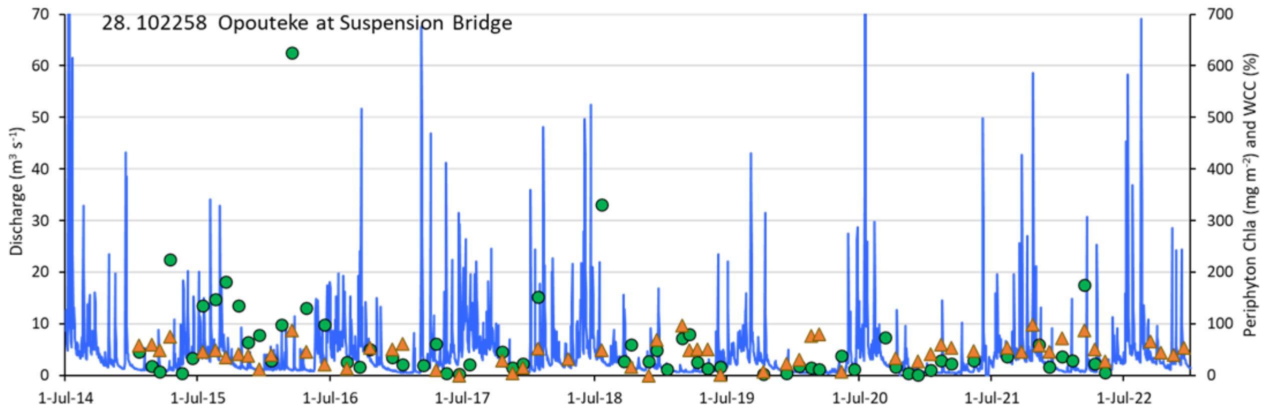


24. 313165 Tapapa at SH1
Discharge (m3 s-1)
Periphyton Chla (mg m-2) and WCC (%)
0
20
40
60
80
100
120
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


25. 101751 Waipapa at Forest Ranger
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
20
40
60
80
100
200
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


26. 105231 Punakitere at Taheke
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
30
60
90
120
100
200
300
400
500
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


27. 109096 Mangakahia at Twin Bridges
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
30
60
90
120
150
50
100
200
250
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


28. 102258 Opouteke at Suspension Bridge
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
10
20
30
40
50
60
70
100
200
300
400
500
600
700
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
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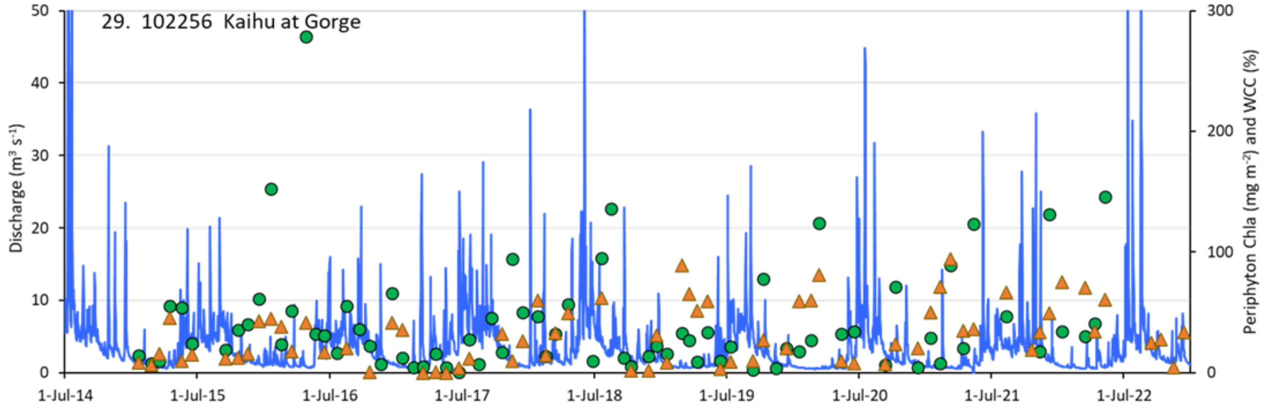
1-Jul-20
1-Jul-21
1-Jul-22


29. 102256 Kaihu at Gorge
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
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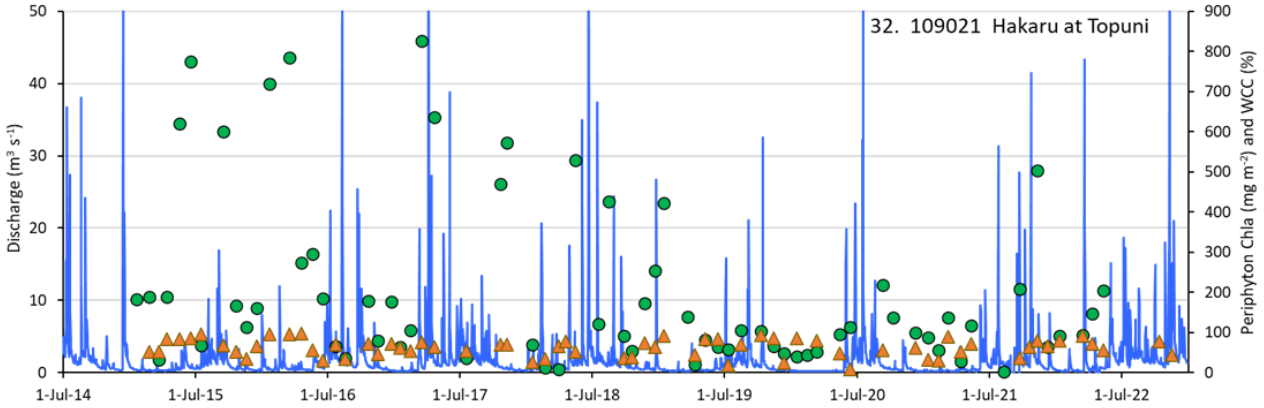
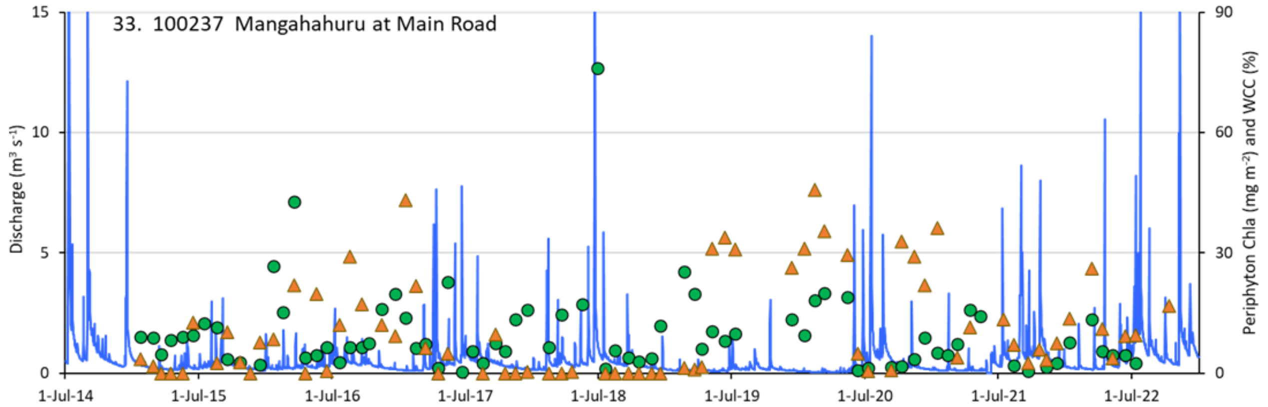
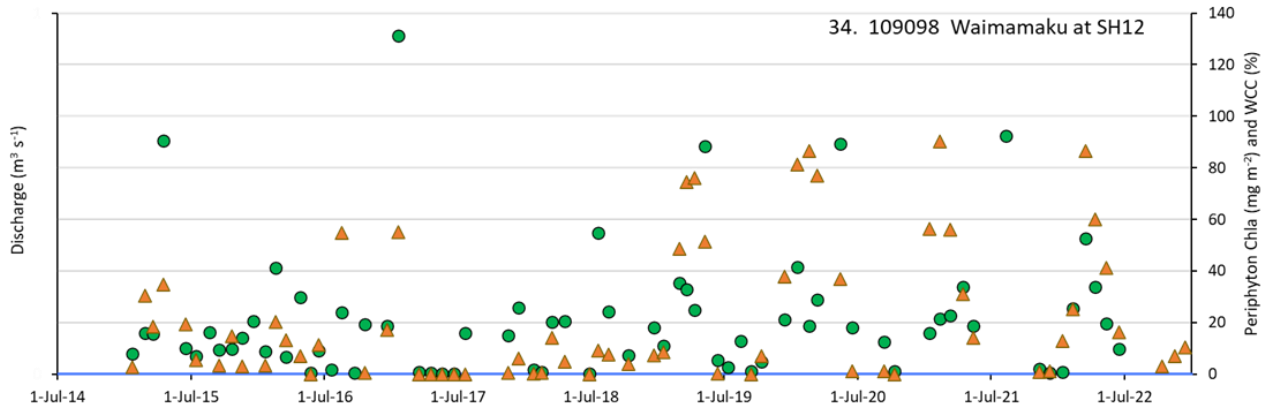
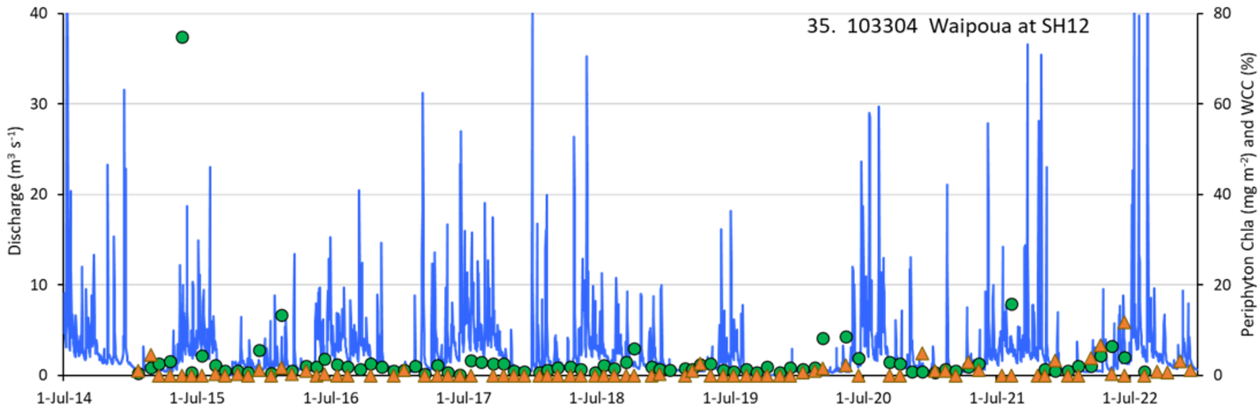
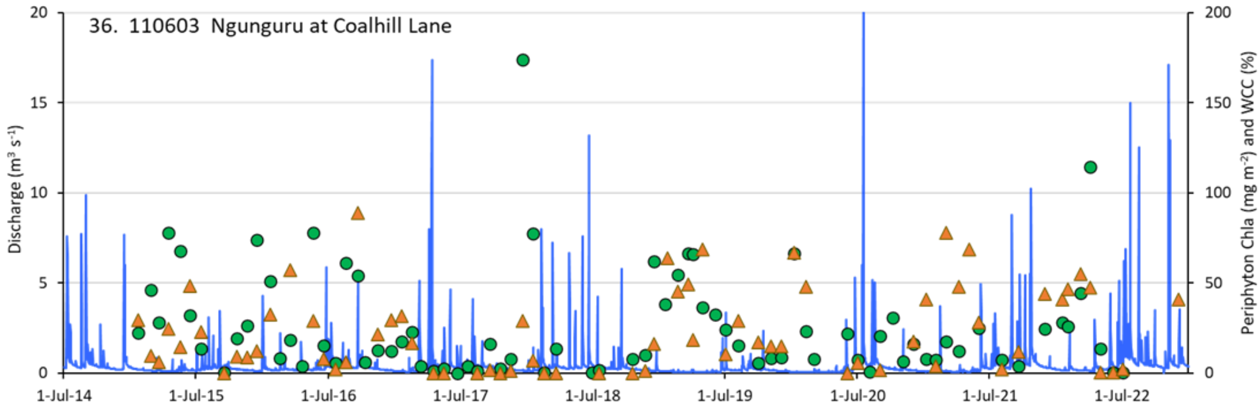
1-Jul-21
1-Jul-22

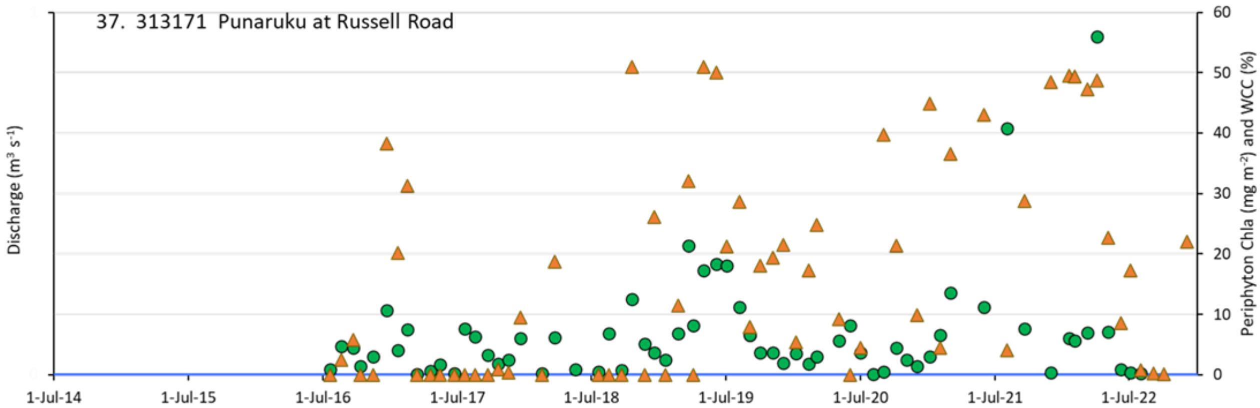

32. 109021 Hakaru at Topuni
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

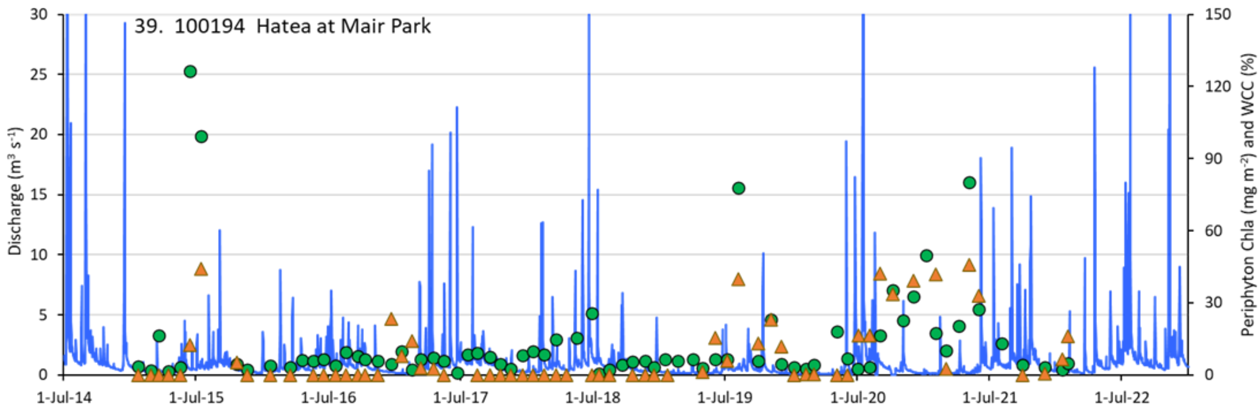

33. 100237 Mangahahuru at Main Road
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

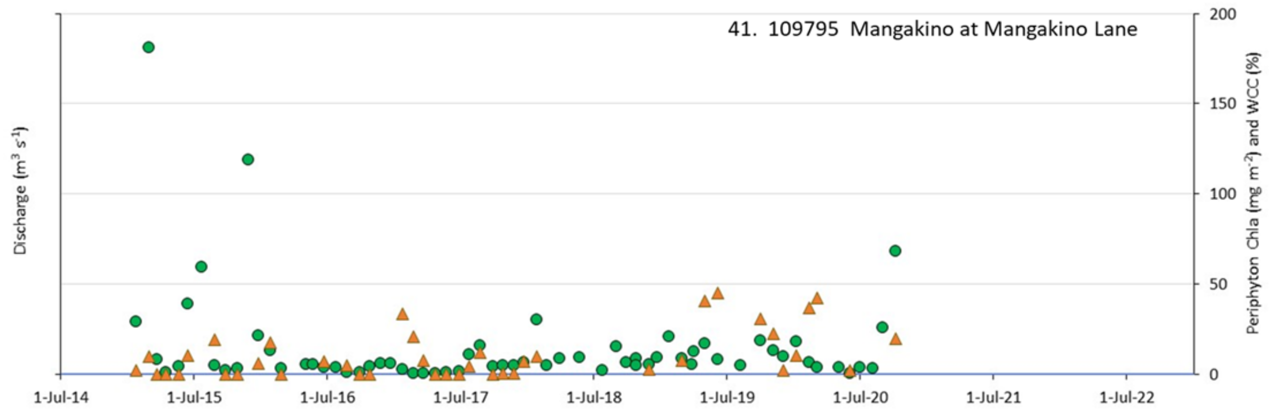

34. 109098 Waimamaku at SH12
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

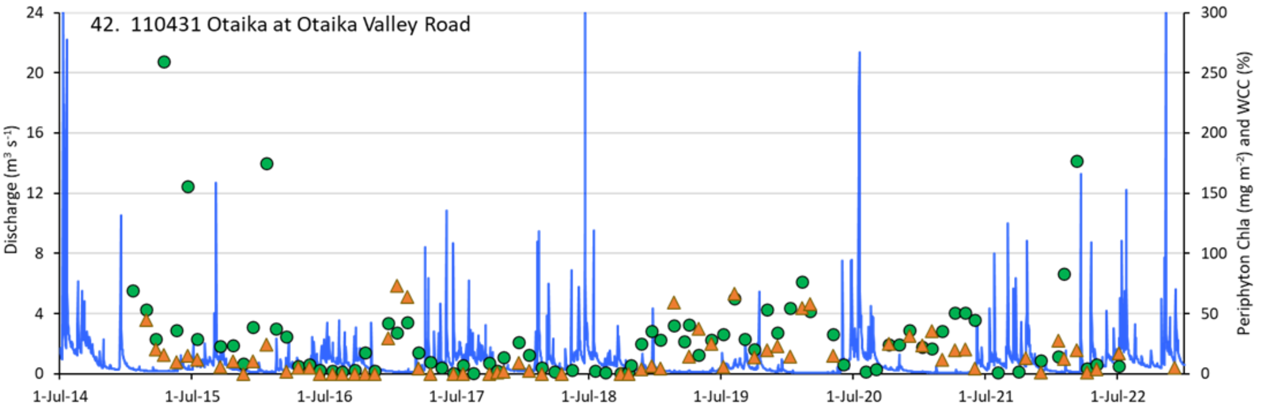

35. 103304 Waipoua at SH12
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
10
20
30
40
0
20
40
60
80
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

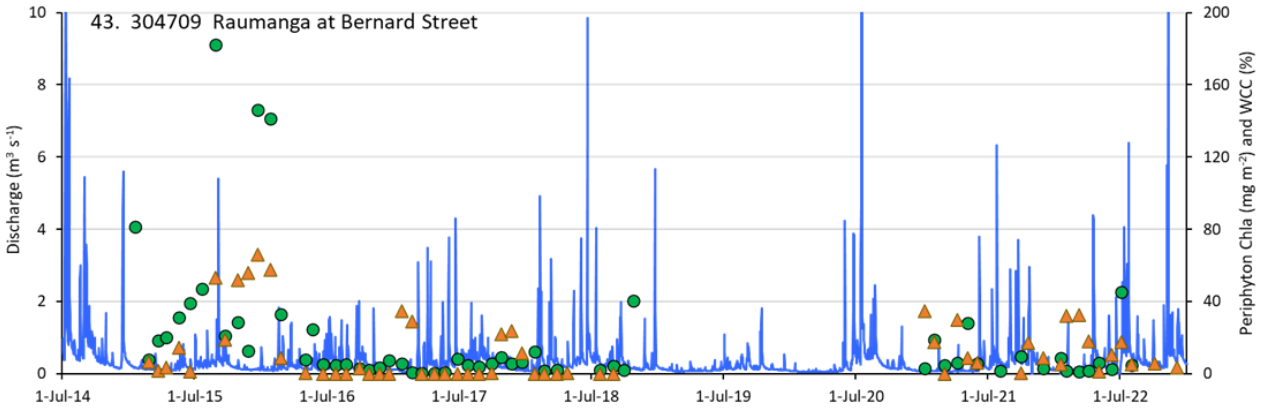

36. 110603 Ngunguru at Coalhill Lane
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
5
10
15
20
0
50
100
150
200
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

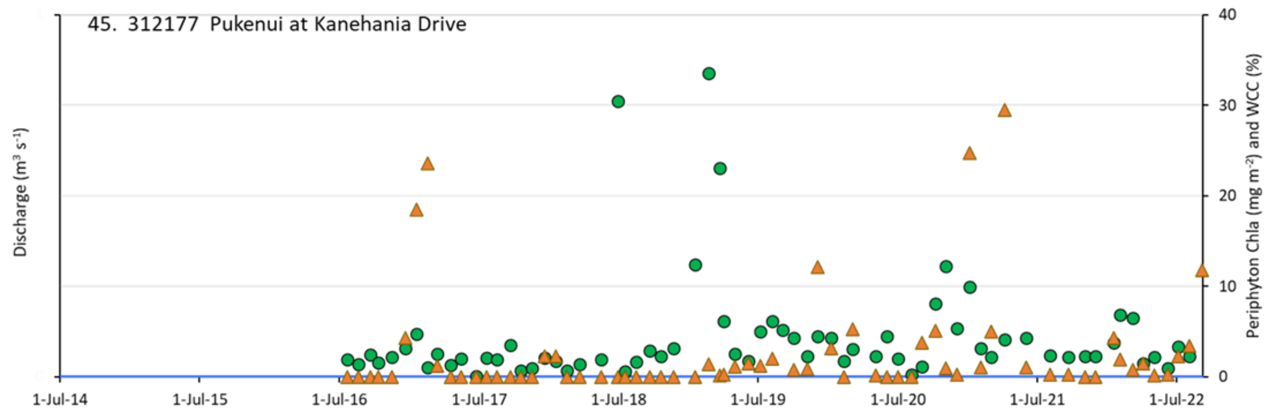

37. 313171 Punaruku at Russell Road
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
10
20
30
40
50
60
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

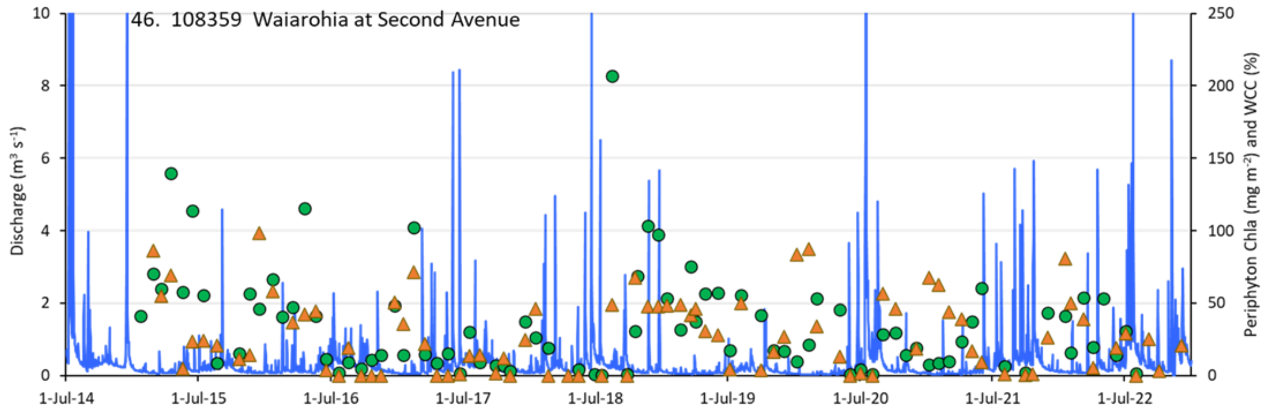

39. 100194 Hatea at Mair Park
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
5
10
15
20
25
30
0
30
60
90
120
150
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

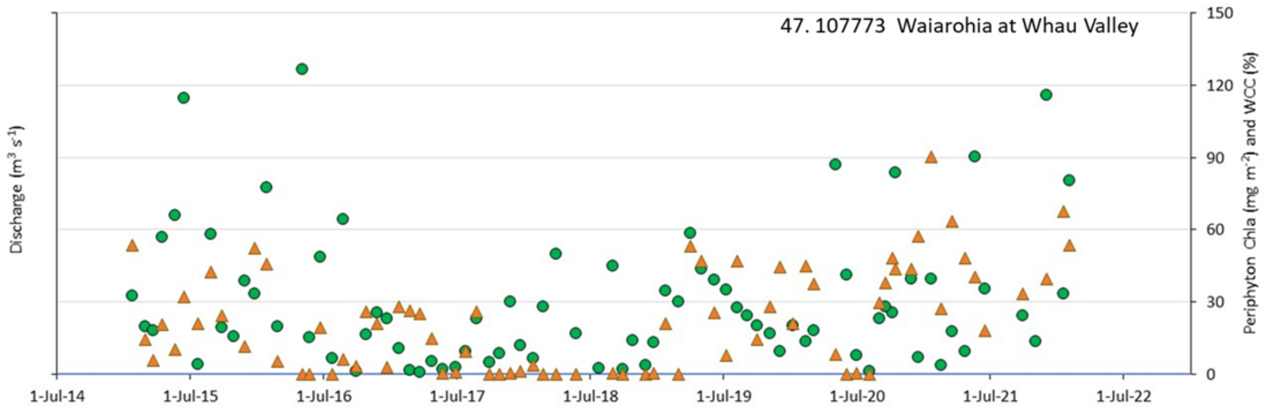

41. 109795 Mangakino at Mangakino Lane
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
50
100
150
200
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

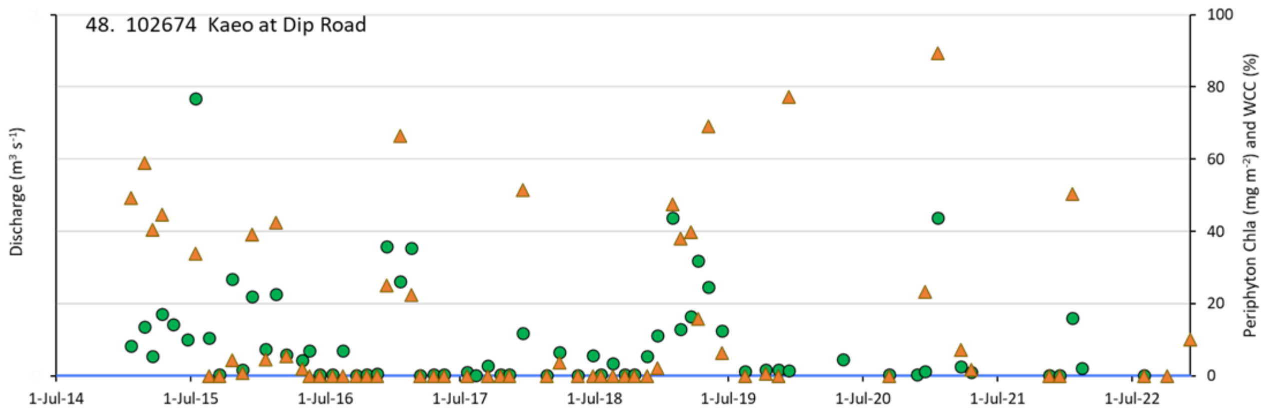

42. 110431 Otaika at Otaika Valley Road
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
4
8
12
16
20
24
0
50
100
150
200
250
300
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


43. 304709 Raumanga at Bernard Street
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
2
4
6
8
10
0
40
80
120
160
200
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


45. 312177 Pukenui at Kanehania Drive
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
0
10
20
30
40
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

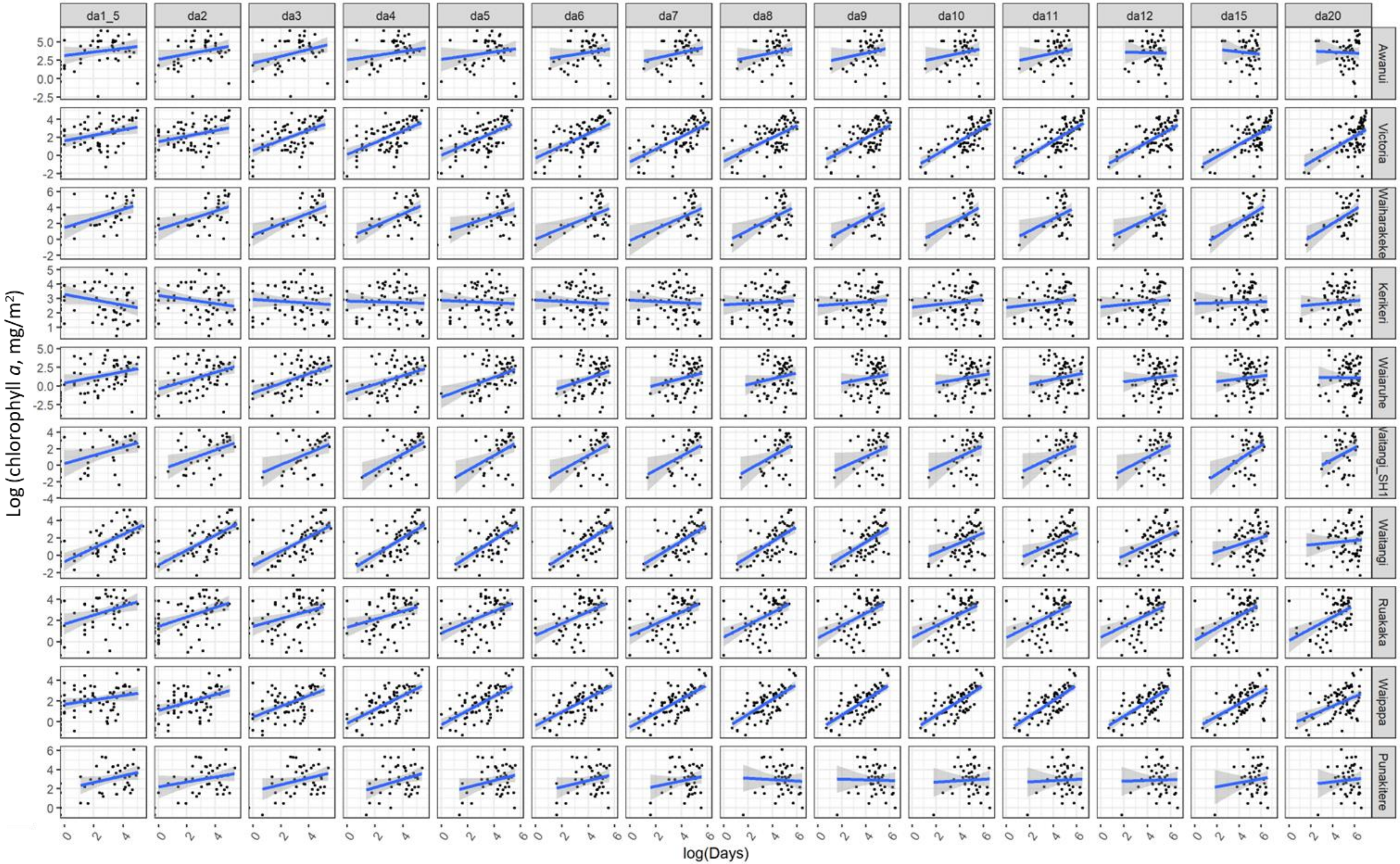

46. 108359 Waiarohia at Second Avenue
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


47. 107773 Waiarohia at Whau Valley
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22


48. 102674 Kaeo at Dip Road
Discharge (m³ s⁻¹)
Periphyton Chla (mg m⁻²) and WCC (%)
1-Jul-14
1-Jul-15
1-Jul-16
1-Jul-17
1-Jul-18
1-Jul-19
1-Jul-20
1-Jul-21
1-Jul-22

Appendix E Plots of CHLA and WCC against days since flows exceeding a range of flow thresholds

Each figure below has two parts, the first showing the series of plots at the first 10 sites and the second the series of plots at the remaining 11 sites.



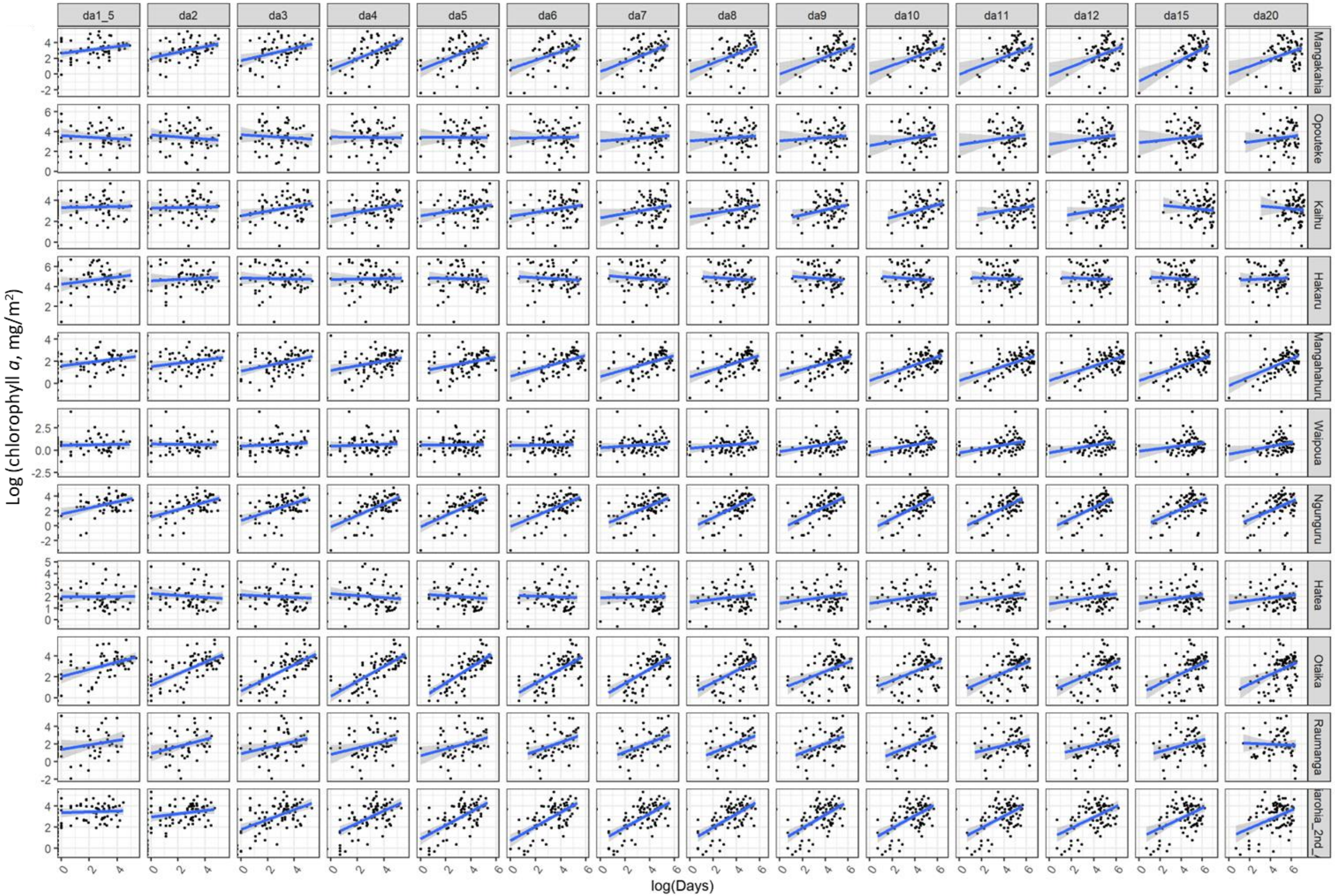
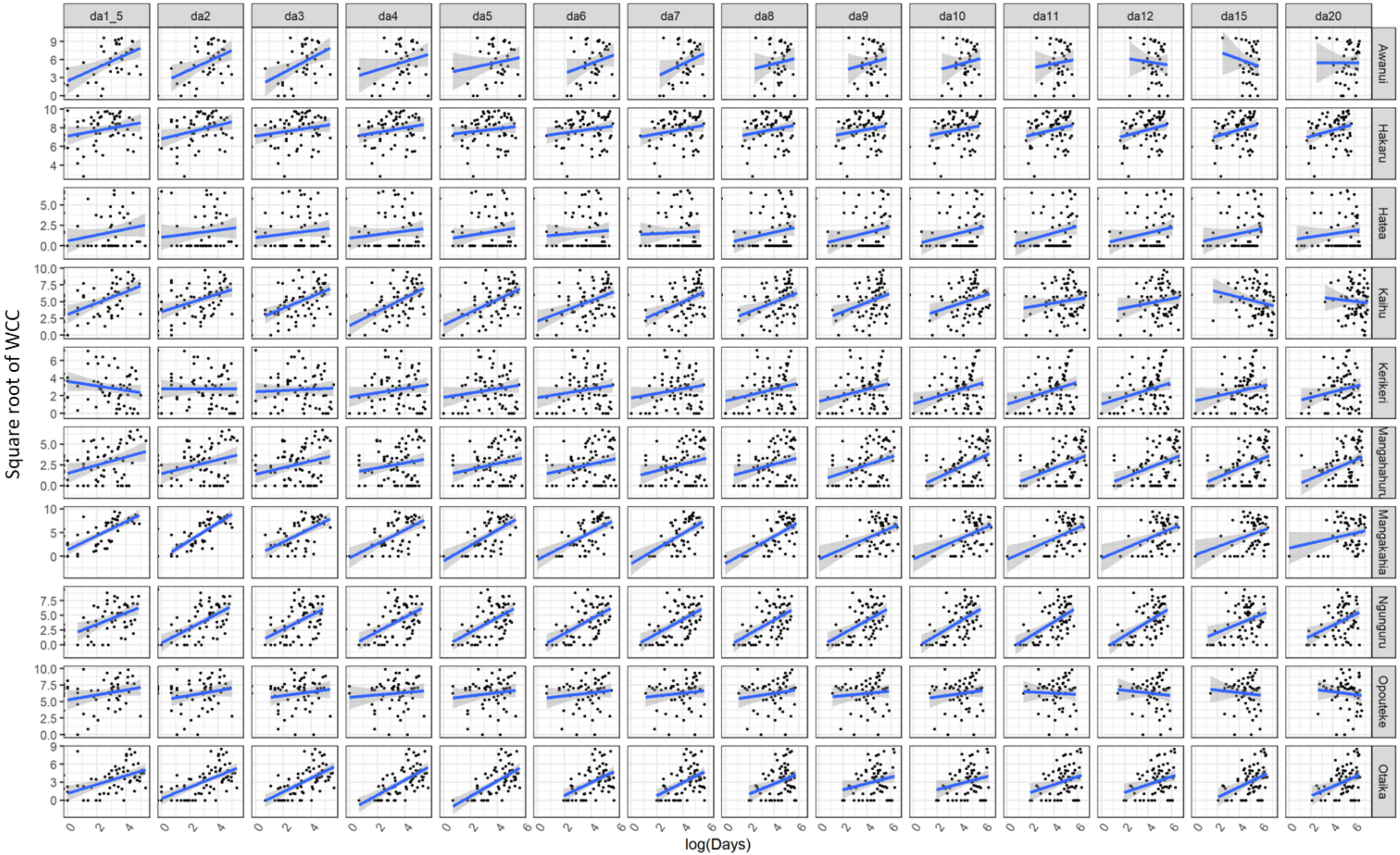


Figure E-1: Log10 CHLA plotted against log$_{10}$Number of days since a flow exceeded a threshold. Flow thresholds are shown at the top as da1_5 to da20 (i.e., thresholds defined by multiples of median flow, from 1.5 to 20 times). Sites (shown at the right) are the same order as in Table 2.1. A linear regression line (blue) is fitted to each set of data.


da1_5
da2
da3
da4
da5
da6
da7
da8
da9
da10
da11
da12
da15
da20
Awanui
Hakaru
Hatea
Kaihu
Kerikeri
Mangahahuru
Mangakahia
Ngunguru
Opouteke
Otaika
Square root of WCC
log(Days)

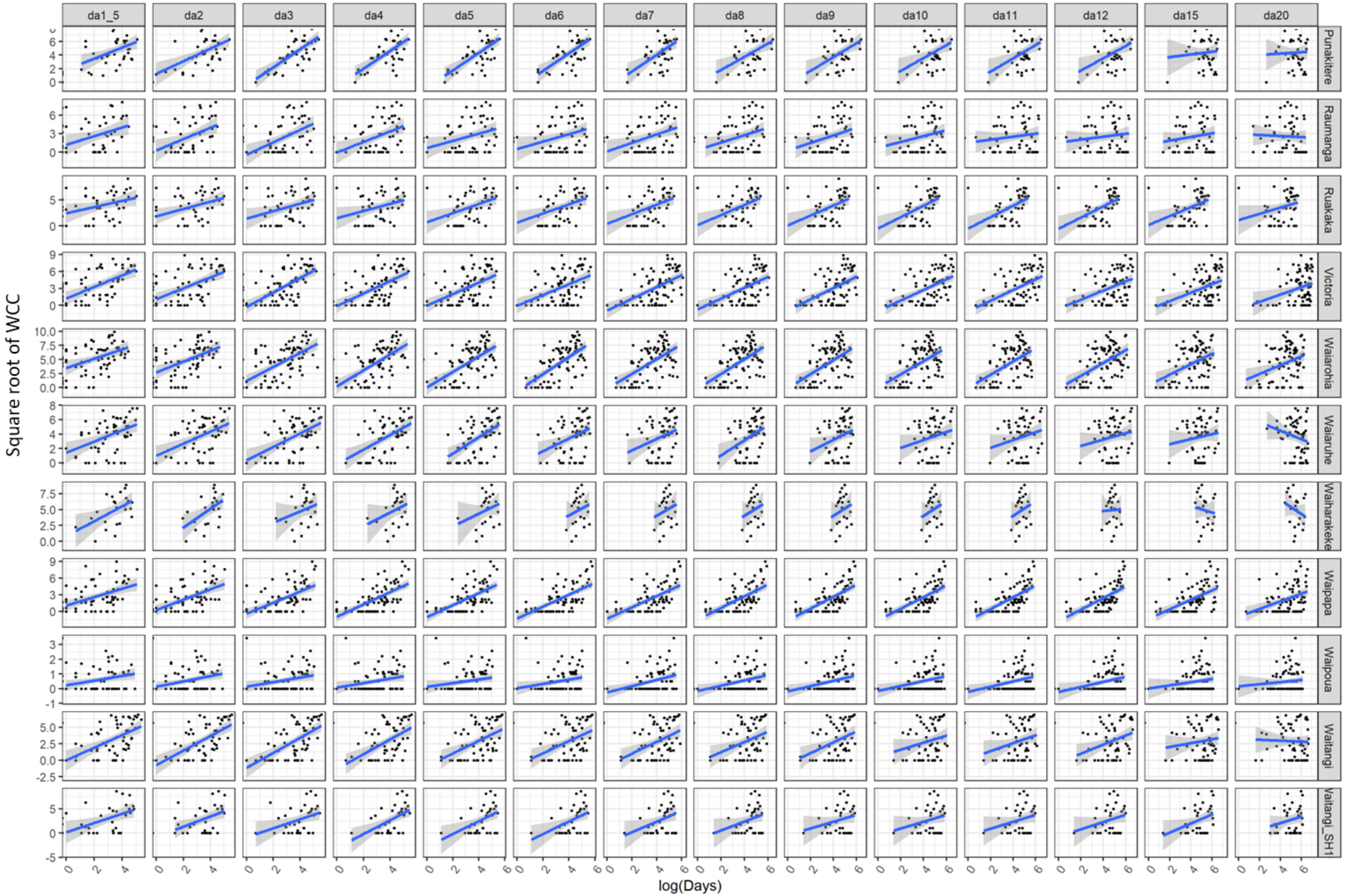


Figure E-2: Square root of WCC plotted against log_{10} No. days since a flow exceeded a threshold. Flow thresholds are shown at the top as da1_5 to da20 (i.e., thresholds defined by multiples of median flow, from 1.5 to 20 times). Sites (shown at the right) are the same order as in Table 2.1. A linear regression line (blue) is fitted to each set of data.

Appendix F Distribution plots

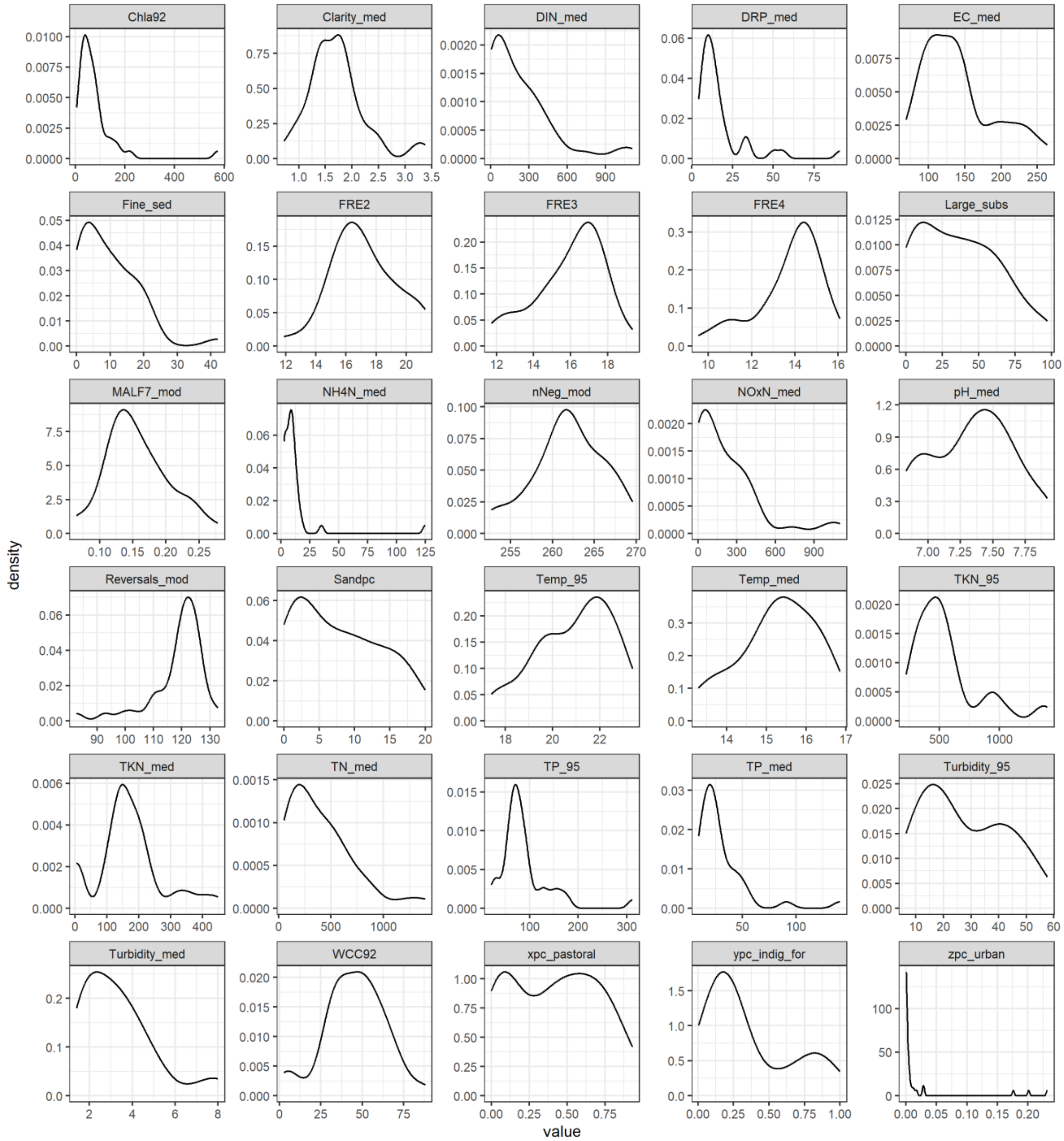


Figure F-1: Distribution plots of periphyton and environmental variables. The plots were generated from the dataset of aggregated values for each variable for the 38 sites (i.e., n = 38). Variables arranged in alphabetical order.

Appendix G Plots of nutrient concentrations over time at each site

These plots are presented to illustrate whether there have been obvious trends in nutrient concentrations at any sites over the periphyton monitoring period, to assist in interpretation of the periphyton data. The presence or not of obvious trends was assessed visually only (a formal trend analysis was beyond the scope of this study).

A few outliers were removed from the dataset so that the data at other sites could be seen more clearly. Removed outliers are listed below. Units for all concentrations are mg m^{-3}.

- TN >3000 at Ruakaka (n = 3, 2016, 2017, 2021), Otaika (n = 1, 2017), Hakaru (n = 1, 2018), Watercress (n = 2, 2017, 2020), Waiaruhe (n = 2, 2015, 2020), Waipapa_Waimate_Nth_Rd (n = 1, 2015);
- NO_3-N > 2000 at Ruakaka (n = 1, 2021);
- NH_4-N > 250 at Waiharakeke (n = 1, 2015), Waitangi_Waimate_N_Rd (n = 1, 2022), Ruakaka (n = 5, 2016, 2017, 2018, 2022), Waiarohia_Second_Ave (n = 1, 2018), Waiaruhe_ds_Mangamutu (n = 5, 2015, 2019, 2020), Waipapa_Waimate_N_Rd (n = 1, 2017);
- TKN > 3000 at Otaika (n = 1, 2018) and Watercress (n = 2, 2017, 2020);
- TP > 500, Ruakaka (n = 3, 2016, 2017, 2018); Punakitere (n = 1, 2017); Hakaru (n = 1, 2016), Otaika (n = 1, 2018), Waiaruhe (n = 1, 2020), Watercress (n = 2, 2017, 2020);
- DRP >200 at Ruakaka (n = 2, in 2017 and 2018), Waiaruhe (n = 1, 2020).

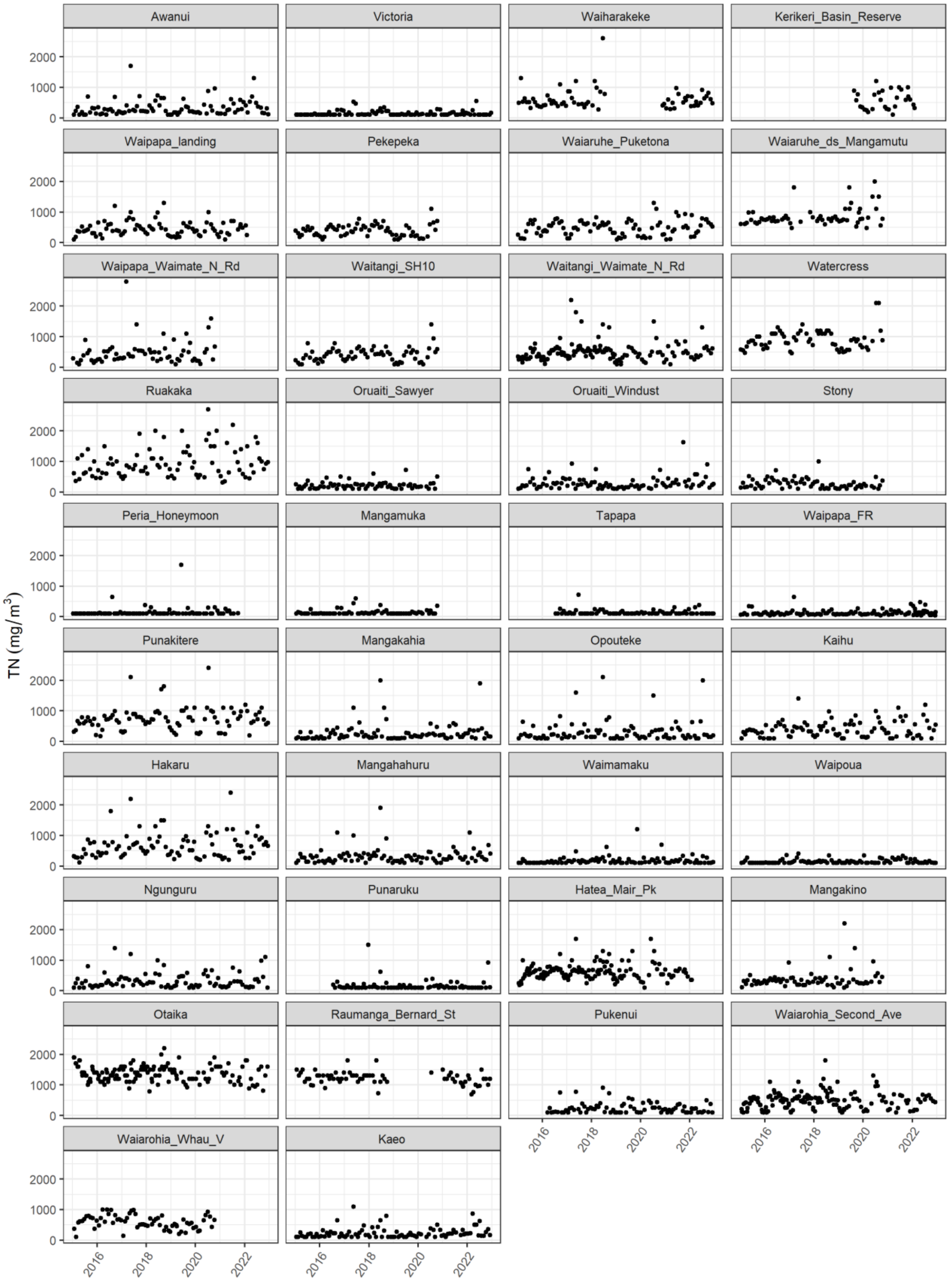


Figure G-1: Time series of TN concentrations at each of the periphyton monitoring sites. Sites arranged in the order shown in Table 2-1, across first, then down.

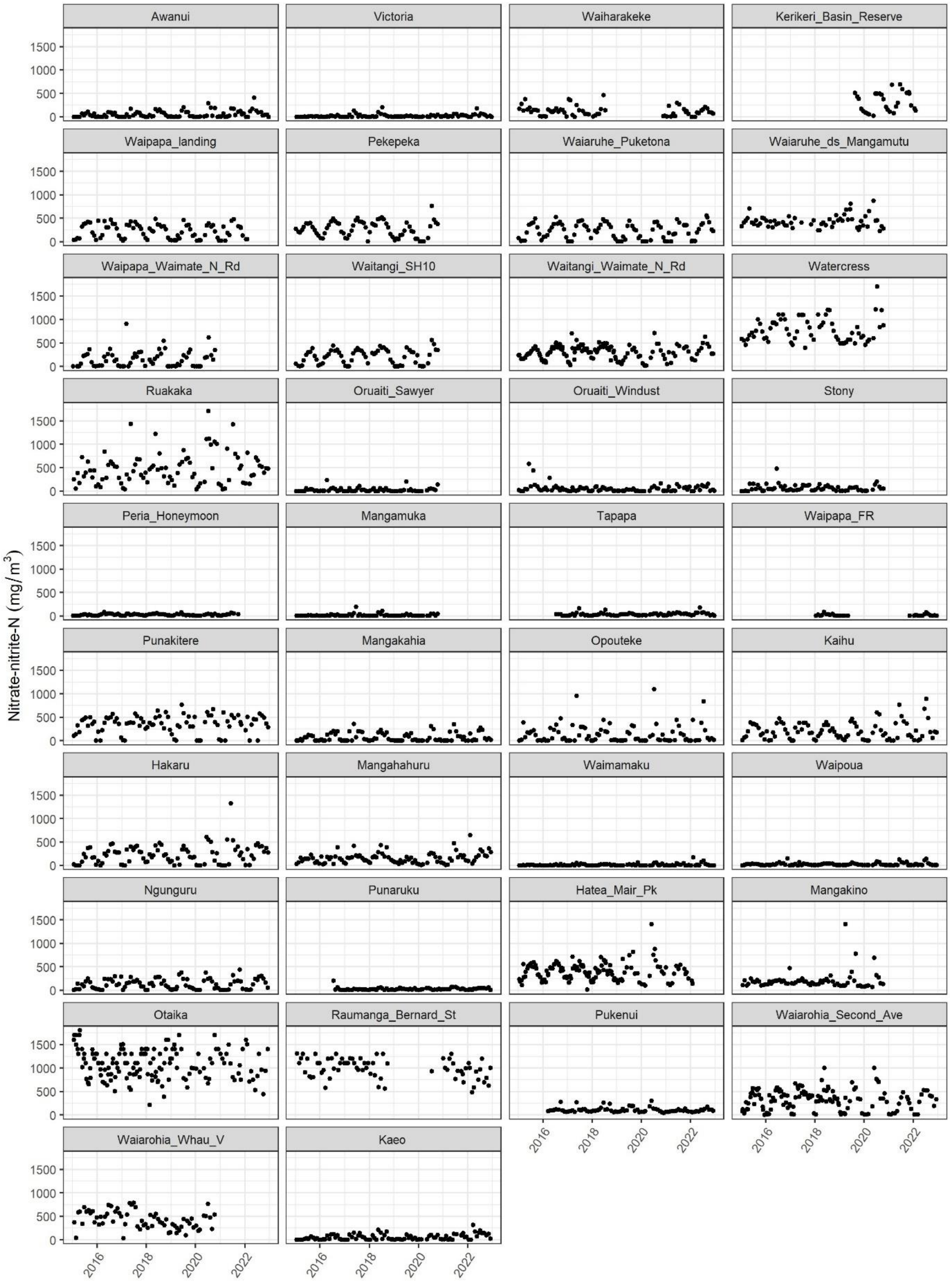


Figure G-2: Time series of Nitrate-nitrite N concentrations at each of the periphyton monitoring sites. Sites arranged in the order shown in Table 2-1, across first, then down.

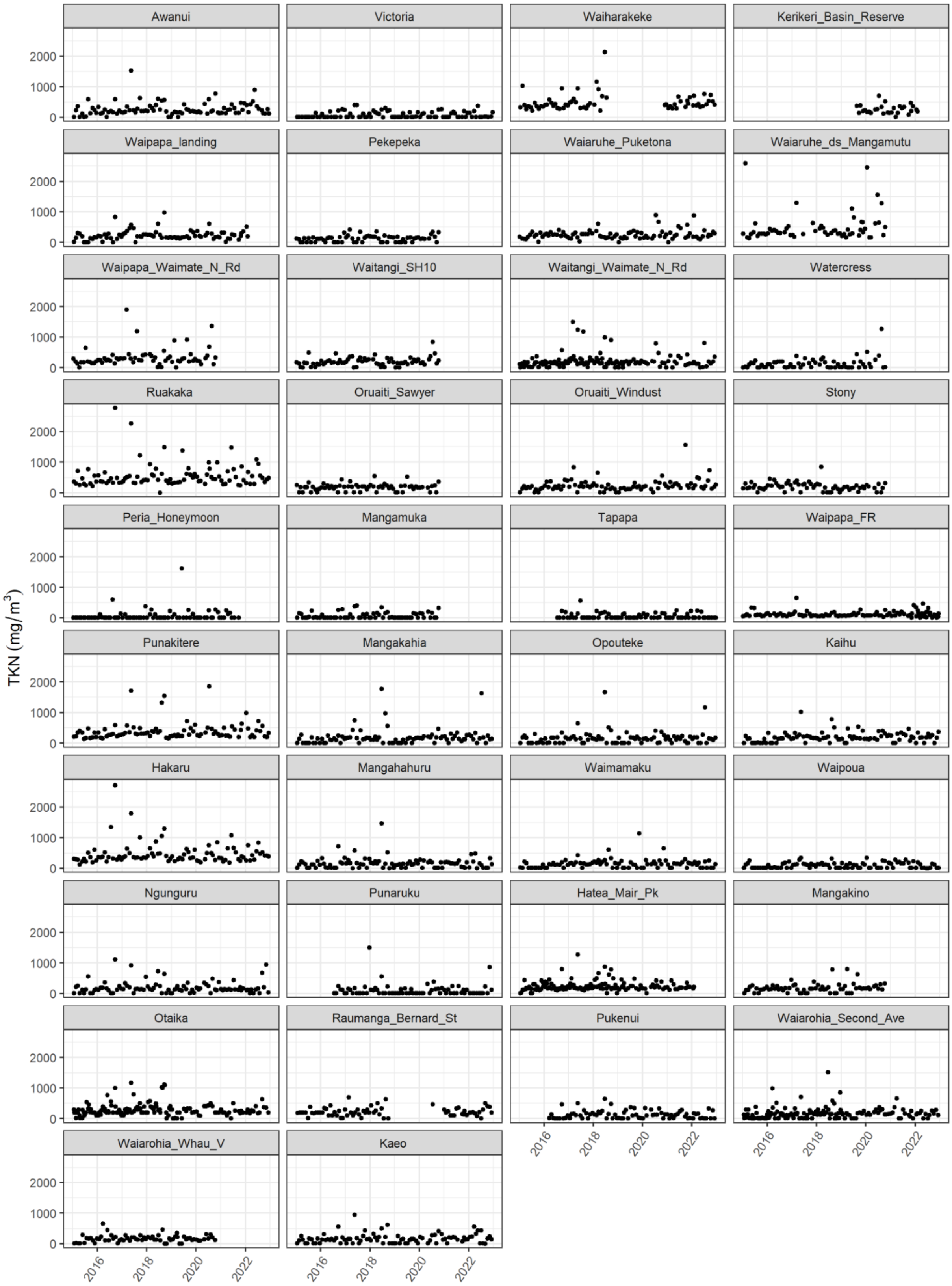


Figure G-3: Time series of NH_4-N concentrations at each of the periphyton monitoring sites. Sites arranged in the order shown in Table 2-1, across first, then down.

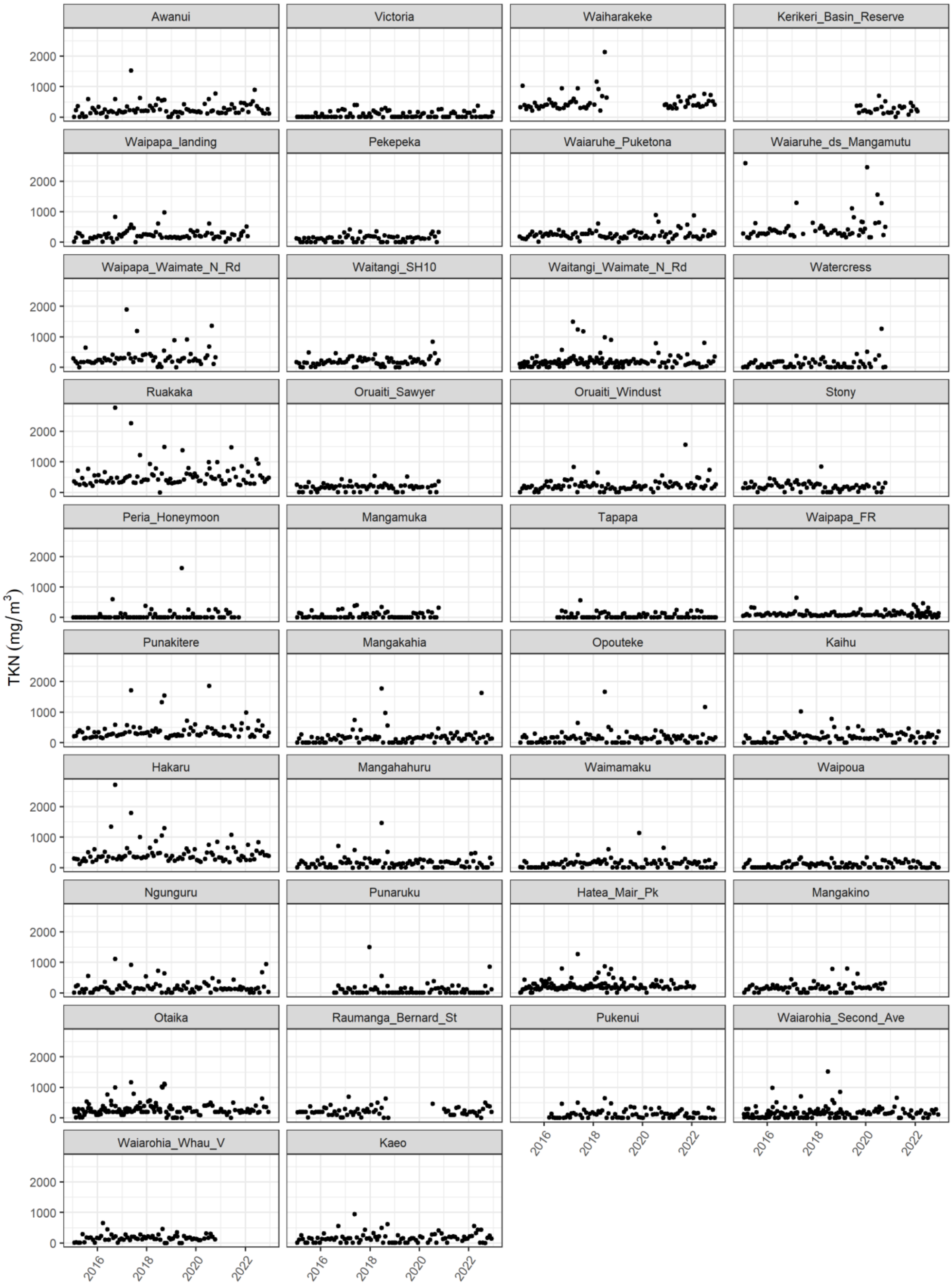


Figure G-4: Time series of TKN concentrations at each of the periphyton monitoring sites. Sites arranged in the order shown in Table 2-1, across first, then down.

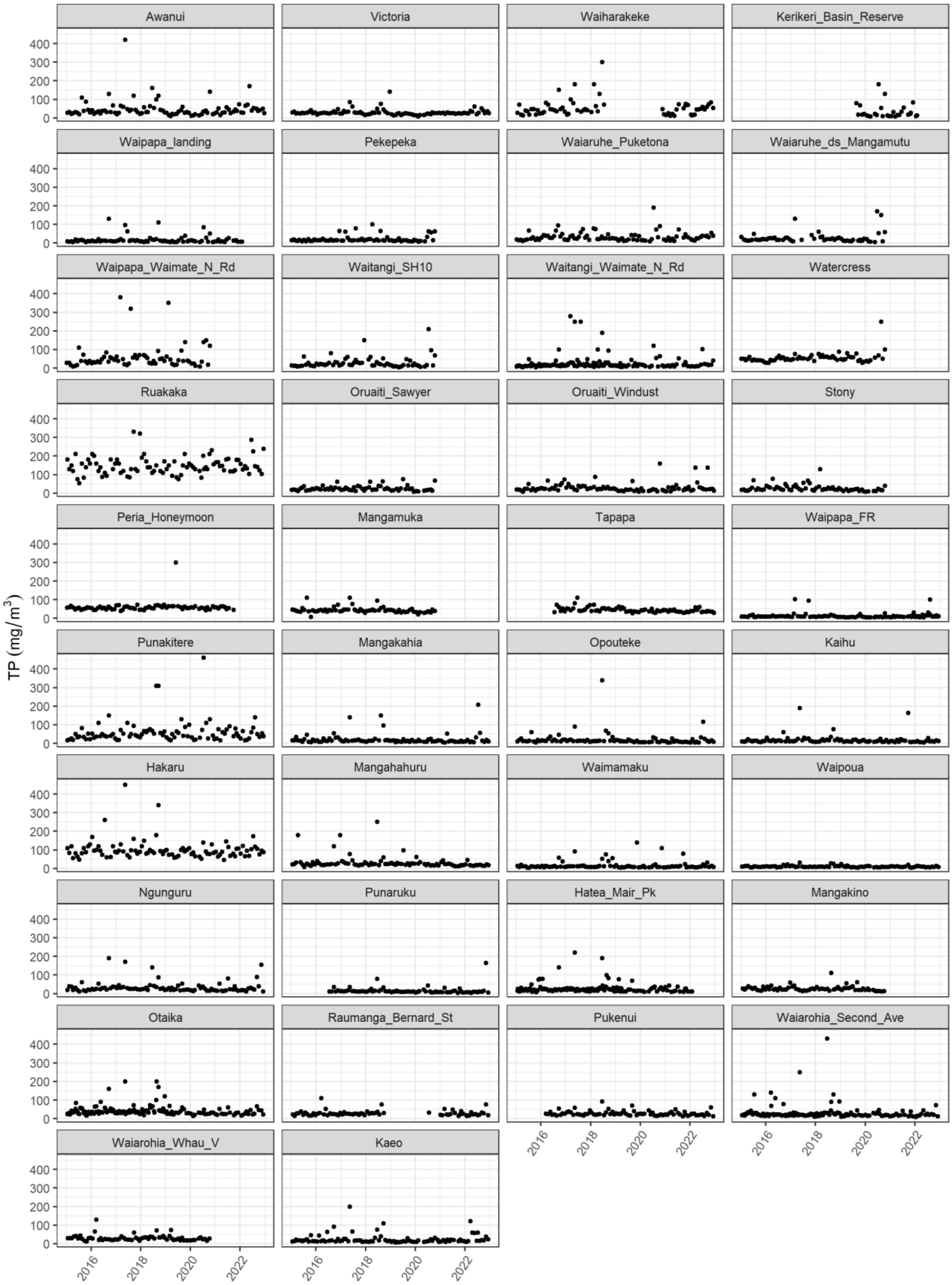


Figure G-5: Time series of TP concentrations at each of the periphyton monitoring sites. Sites arranged in the order shown in Table 2-1, across first, then down..

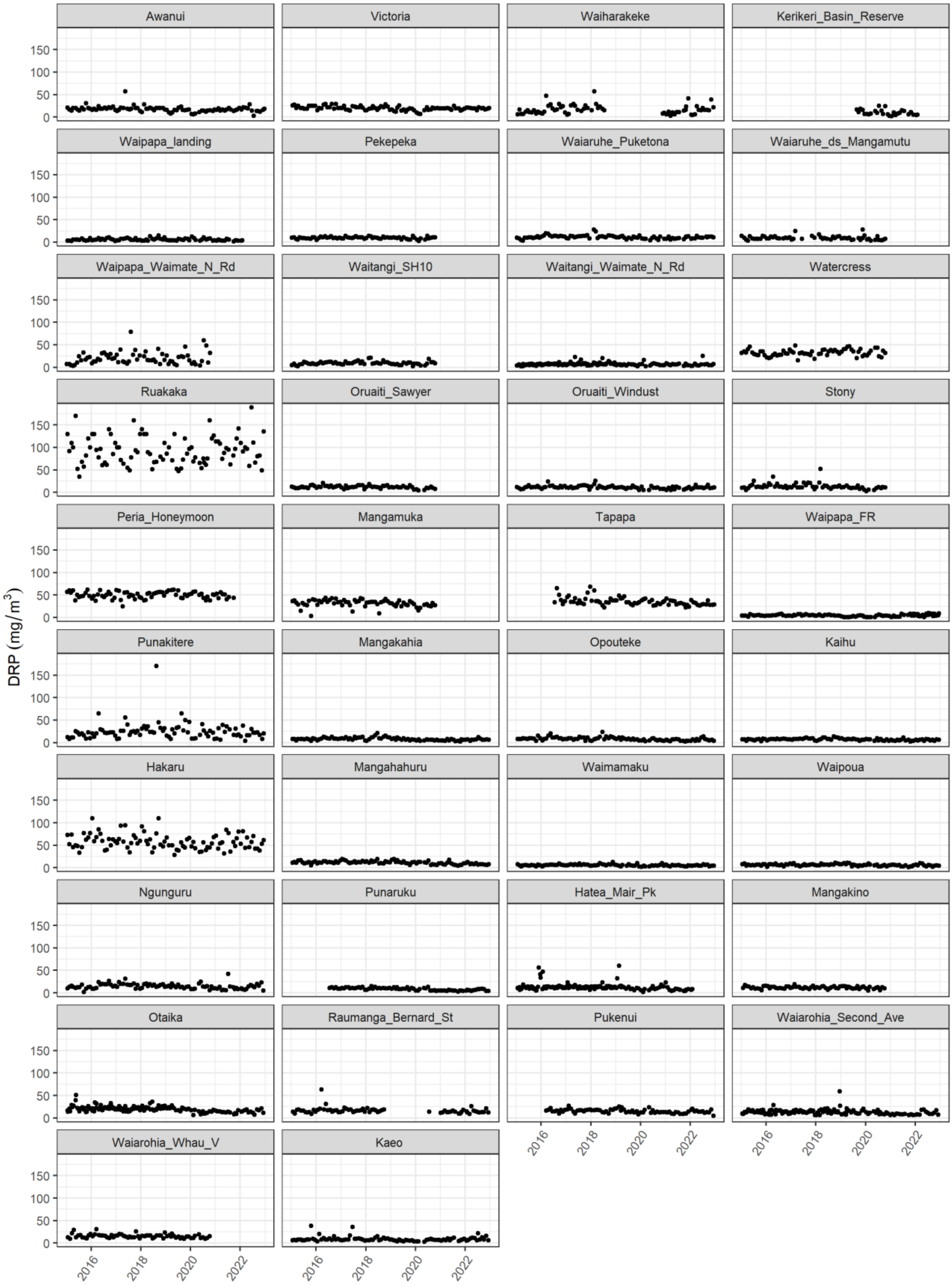


Figure G-6: Time series of DRP concentrations at each of the periphyton monitoring sites. Sites arranged in the order shown in Table 2-1, across first, then down.