Periphyton

State of the Environment Monitoring

Technical Report

2018-2021

Technical Report 2022-103

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Taranaki Regional Council

Taranaki Regional Council
Private Bag 713
Stratford

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Executive summary

Section 35 of the *Resource Management Act 1991* (RMA) requires local authorities to undertake monitoring of the region's environment, including land, air, and fresh and marine water quality. Accordingly, this report describes the results of the Taranaki Regional Council's State of the Environment (SoE) Periphyton Monitoring Programme from the 2018-2021 period.

Periphyton is the 'slime' and algae found on the beds of lakes and rivers. This is a component of a healthy system and forms the base of the food web. The periphyton community is composed predominantly of algae and cyanobacteria (blue-green algae) but also contains heterotrophic bacteria and fungi. Under certain conditions excessive growth of periphyton can occur, forming a nuisance bloom which may have a negative impact on a range of values including ecosystem health, aesthetics, contact recreation, fishing, irrigation, industrial uses and potable water supply.

There are a number of factors that have the potential to influence periphyton growth. At the larger scale, factors include the catchment geology and climate. At a reach scale, factors that influence periphyton growth include stream flow, light, nutrients, water temperature, substrate composition and grazer density.

The *National Policy Statement for Freshwater Management* (NPS-FM) includes a requirement for Councils to undertake monthly monitoring of periphyton biomass. Under the National Objectives Framework (NOF) set out in the NPS-FM, councils are required to measure periphyton, as chlorophyll-*a*, at representative river sites within each region. The NOF sets out a national bottom line for periphyton, requiring improvement if nuisance algal blooms occur regularly or for extended periods.

In 2018, Council initiated a monthly SoE periphyton monitoring programme, tailored to the requirements of the NPS-FM, at twelve sites in the Taranaki region. This inaugural report covers the monitoring results from July 2018 to June 2021. The monitoring data presented here are primarily assessed against the requirements of the NOF in the NPS-FM, although additional assessments are made with regards to separate aesthetic and recreational guidelines.

Monitoring results show that all sites comply with the national bottom line of 200 mg chl-a/m^2 for periphyton biomass as set out in the NOF. Five sites were graded within the A band, three sites in the B band and four sites in the C band. At five of these sites, these gradings must be considered provisional as there were fewer than the 36 samples required.

Periphyton cover was compliant with guideline values for weighted composite cover (WCC) throughout the reporting period at seven of twelve sites, while the guideline was exceeded at the remaining five sites ranging between 10 and 29% of sampling occasions. The results demonstrate that WCC provides a more precautionary assessment of nuisance periphyton cover, compared to treating the cover of thick mats and long filaments separately. Cyanobacteria was below the action threshold at all sites throughout the reporting period, while alert level was reached at five sites.

Trends in periphyton biomass and cover over time were not assessed due to the short time period available for analysis. Trends will be assessed once sufficient data is available.

Relationships between periphyton biomass and nutrients show that patterns are site specific. When nutrient limitation was assessed, nitrogen alone was the limiting nutrient at four sites, and phosphorous was the limiting nutrient at two sites. There was one site where periphyton growth was limited by both nitrogen and phosphorous. At the remaining five sites, the concentrations of both nitrogen and phosphorous were above the limitation thresholds. Phosphorous was not a limiting nutrient at any of the sites with volcanic geology; owing to the naturally elevated phosphorous concentrations in those rivers and streams.

The report contains recommendations to review the current monitoring programme in light of the recently released Periphyton National Environmental Monitoring Standard (NEMS), as well as updates related to the Council's NPS-FM implementation.

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1 Introduction

1.1 General

The *Resource Management Act 1991* (RMA) sets out requirements for local authorities to undertake environmental monitoring. Section 35 of the RMA requires local authorities to monitor, among other things, the state of the environment of their region or district, to the extent that is appropriate to enable them to effectively carry out their functions under the Act.

To this effect, the Taranaki Regional Council (Council) has established a state of the environment monitoring (SoE) programme for the region. Council's SoE programme encompasses a number of individual monitoring activities, many of which are undertaken and managed on an annual basis (from 1 July to 30 June). Where possible, individual consent monitoring programmes have been integrated within the SoE programme to save duplication of effort and minimise costs. The purpose of SoE reporting is to summarise and interpret regional environmental monitoring activity results and report on any changes (trends) in these data. These reports in turn provide key information for Council's regional State of Environment report, which is published every five years. Copies of these reports, including the most recent report *Our Place – Taranaki State of Environment 2022*, are made available on the Council's website.

This report summarises the results of the SoE Periphyton Monitoring Programme over the 2018-2021 monitoring period.

1.2 National Policy Setting

The National Policy Statement for Freshwater Management 2020 (NPS-FM) sets out requirements for councils and communities to maintain or improve freshwater (where it is degraded). The NPS-FM provides a National Objectives Framework (NOF) that specifies nationally applicable standards for particular water quality parameters (referred to as 'attributes'), to assist regional councils and communities to more consistently and transparently work toward their freshwater objectives. The NPS-FM acknowledges iwi and community values by recognising the range of iwi and community interests in fresh water, including environmental, social, economic and cultural values.

The NPS-FM identifies four compulsory values and nine further values that must be considered by the regional council. Ecosystem health is one of four compulsory values that apply to all freshwater bodies. Periphyton is one of the attributes relating to ecosystem health that must be monitored and reported against. The NPS-FM includes a requirement for Councils to undertake monthly monitoring of periphyton biomass at representative sites within each region[1]. In response to this requirement, the Council implemented a pilot monthly monitoring programme to understand the current state of ecosystem health, with specific regard to periphyton, in the 2017-2018 monitoring year.

Table 1 sets out the NOF attribute criteria for periphyton. There are two numeric attribute states: a default class and a productive class. The productive class applies to streams and rivers which have naturally high levels of nutrient enrichment, or experience dry climate – as defined by the River Environment Classification (REC). All monitored sites in the Taranaki region are in the default class for assessment of periphyton against the NOF attribute. Therefore any reference to the NOF attribute state in the remainder of this report is to the default class, unless otherwise stated.

[1] Councils can also undertake monitoring using visual estimates of periphyton cover at sites where there is a low risk of exceeding the relevant periphyton abundance threshold.

Table 1 Periphyton attribute table (NPS-FM, 2020)

NOF Band	Default Class (mg chl-a/m^2)	Productive Class (mg chl-a/m^2)	Narrative attribute state
	Exceeded in no more than 8% of samples	*Exceeded in no more than 17% of samples*	
A	≤50	≤50	Rare blooms reflecting negligible nutrient enrichment and/or alteration of the natural flow regime or habitat.
B	>50 and ≤120	>50 and ≤120	Occasional blooms reflecting low nutrient enrichment and/or alteration of the natural flow regime or habitat.
C	>120 and ≤200	> 120 and ≤200	Periodic short-duration nuisance blooms reflecting moderate nutrient enrichment and/or moderate alteration of the natural flow regime or habitat.
National Bottom Line	**200**	**200**	
D	>200	>200	Regular and/or extended-duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime or habitat.

* The productive class is defined by River Environment Classification (REC) types, with a combination of dry climate categories and soft-sedimentary, volcanic acidic and volcanic basic geology. All sites that do not fall in these categories are in the default class.

1.3 Periphyton

Periphyton is the 'slime' and algae found on the beds of lakes and rivers. This is a component of a healthy system and forms the base of the food web. The periphyton community is composed predominantly of algae and cyanobacteria (blue-green algae) but also contains heterotrophic bacteria and fungi. These heterotrophic microbes comprise only a small proportion of the periphyton communities, and consequently periphyton monitoring uses algal pigments (chlorophyll-a) to measure the biomass. Under certain conditions excessive growth of periphyton can occur, forming a nuisance bloom which may have a negative impact on a range of values including aesthetics, contact recreation, fishing, irrigation, industrial uses and potable water supply.

Ecosystem health can also be impacted, with effects such as reduced macroinvertebrate biodiversity due to alteration of available habitat and impairment of habitat for native fishes. Water quality can also be impacted by factors such as increased suspended detritus, increased pH and ammonia fluctuations, and anoxia within the interstitial spaces of the stream bed.

There are a number of factors that have the potential to influence periphyton growth. The interaction between these factors can act to limit periphyton growth. At the larger scale, factors include the catchment geology and climate. At a reach scale, factors that influence periphyton growth include stream flow, light, nutrients, water temperature, substrate composition and grazer density.

Stream flow is one of the key drivers of periphyton biomass. Of particular importance is the frequency of fresh events which may remove algae. The accrual period is particularly important, and can be defined as the period of periphyton growth since a flushing flow event. The effective flushing flow is the flow required to remove periphyton from rocks as a result of scouring. Previous work has considered a flow of three times the median flow to be the most likely flushing flow (Biggs, 2000). However, more recently it has been recognised that the magnitude of flow required for periphyton removal can vary considerably between rivers and sites. This is largely a function of the physical characteristics of a site, such as substrate size (Hoyle et al. 2017).

Light is required for photosynthesis and hence for periphyton growth to occur. The amount of light reaching the streambed may be affected by shading of the water, as well as light attenuation through the water column. Light attenuation may be increased as a result of turbidity or colour in the water.

Nutrients are important to periphyton growth, particularly when in inorganic form. The major nutrients required for all plants are nitrogen and phosphorus, and a lack of either of these nutrients may limit periphyton growth. It is also important to note that the measured nutrient levels in the water column may themselves be affected as a result of uptake by periphyton.

1.3.1 Periphyton guidelines

A number of periphyton guidelines exist, primarily relating to aesthetics and recreational use (Table 2). These include visual assessment of the cover long filamentous periphyton and the cover of thick mats (Biggs, 2000). These guidelines require less than 60% cover of mats thicker than 3 mm and less than 30% cover of filaments longer than 2 cm.

As a result of these guidelines addressing the cover of thick mats and long filaments separately, it is possible to have moderately high cover of both periphyton forms which do not breach either threshold whilst together presenting an aesthetic nuisance. To address this issue, a weighted composite cover (WCC) metric was developed as a review of the instream plant and nutrient guidelines (Matheson et al. 2012). The WCC metric considers the two growth forms in conjunction with one another and can be used to assess both aesthetic guidelines and ecological condition.

Table 2 Periphyton guidelines in New Zealand

Value	Measure	Threshold	Source
Aesthetic	Long Filaments	30% cover	Biggs, 2000
	Thick Mats	60% cover	Biggs, 2000
	WCC	30	Matheson, 2012
	Chlorophyll-a	120 mg/m^2	Biggs, 2000
Ecological (Trout habitat)	Long filaments	30% cover	Biggs, 2000
Public Health	Cyanobacteria Mats (alert)	20% cover	MfE & MOH, 2009
	Cyanobacteria Mats (action)	50% cover	MfE & MOH, 2009

Cyanobacteria guidelines are also presented. It is important to note that these include cover and additional assessments to determine the state in relation to these guidelines. Therefore the assessments of cover only (as undertaken in this programme), may underestimate the number of times alert and action states are reached.

2 Monitoring methodology

2.1 Program design

The pilot monitoring programme was designed to monitor periphyton, as well as the potential drivers of periphyton biomass at 12 river or stream locations across the region. The monitoring programme includes sampling for a range of physicochemical parameters, hydrological monitoring and habitat assessments.

2.1.1 Site locations

Periphyton monitoring sites are listed in Table 3 and represented spatially in Figure 1.

Table 3 Sites monitored in the monthly periphyton monitoring programme

River	Site	Site Code	GPS location
Kapoaiaia Stream	Cape Egmont	KPA000950	E1665690 N5652452
Manganui River	Midhirst	MGN000195	E1708871 N5651282
Mangaehu River[1]	Raupuha Road	MGH000950	E1726300 N5639062
Makuri Stream[1]	Raupuha Road	MKR000495	E1723795 N5641478
Maketawa Stream	Tarata Road	MKW000300	E1708784 N5665231
Matau Stream	Matau Road	MTA000068	E1733965 N5661062
Punehu Stream	Wiremu Road	PNH000200	E16873232 N5637020
Punehu Stream	SH45	PNH000900	E1677946 N5627786
Hangahatua (Stony) River	Mangatete Road	STY000300	E1677420 N5657868
Tawhiti Stream	Duffy's	TWH000435	E1714287 N5615551
Waingongoro River	Eltham Road	WGG000500	E1710694 N5634849
Waiwhakaiho River	Egmont Village	WKH000500	E1698297 N5666893
Waikaramarama Stream	Waikaramarama Road	WMR000100	E1730866 N5692865

1 The Mangaehu River was removed from the monitoring programme due to Health and Safety concerns in September 2018. The Makuri Stream was introduced as a safer alternative site in November 2018.

The site selection process was weighted to incorporate a number of factors, as set out below:

1 Potential soft-bottomed sites were excluded because they are generally not considered able to support conspicuous periphyton growth. Furthermore, monitoring techniques are not sufficiently refined to collect chlorophyll-*a* samples in soft-bottomed streams.
2 Many larger rivers were excluded on the basis that they could not be safely monitored year round due to depth and/or swiftness of stream flow. A maximum safe wading depth for periphyton sampling is generally considered to be 0.6 m.
3 Preference was given to sites where data associated with explanatory variables such as nutrients and flow was already being collected under other monitoring programmes.

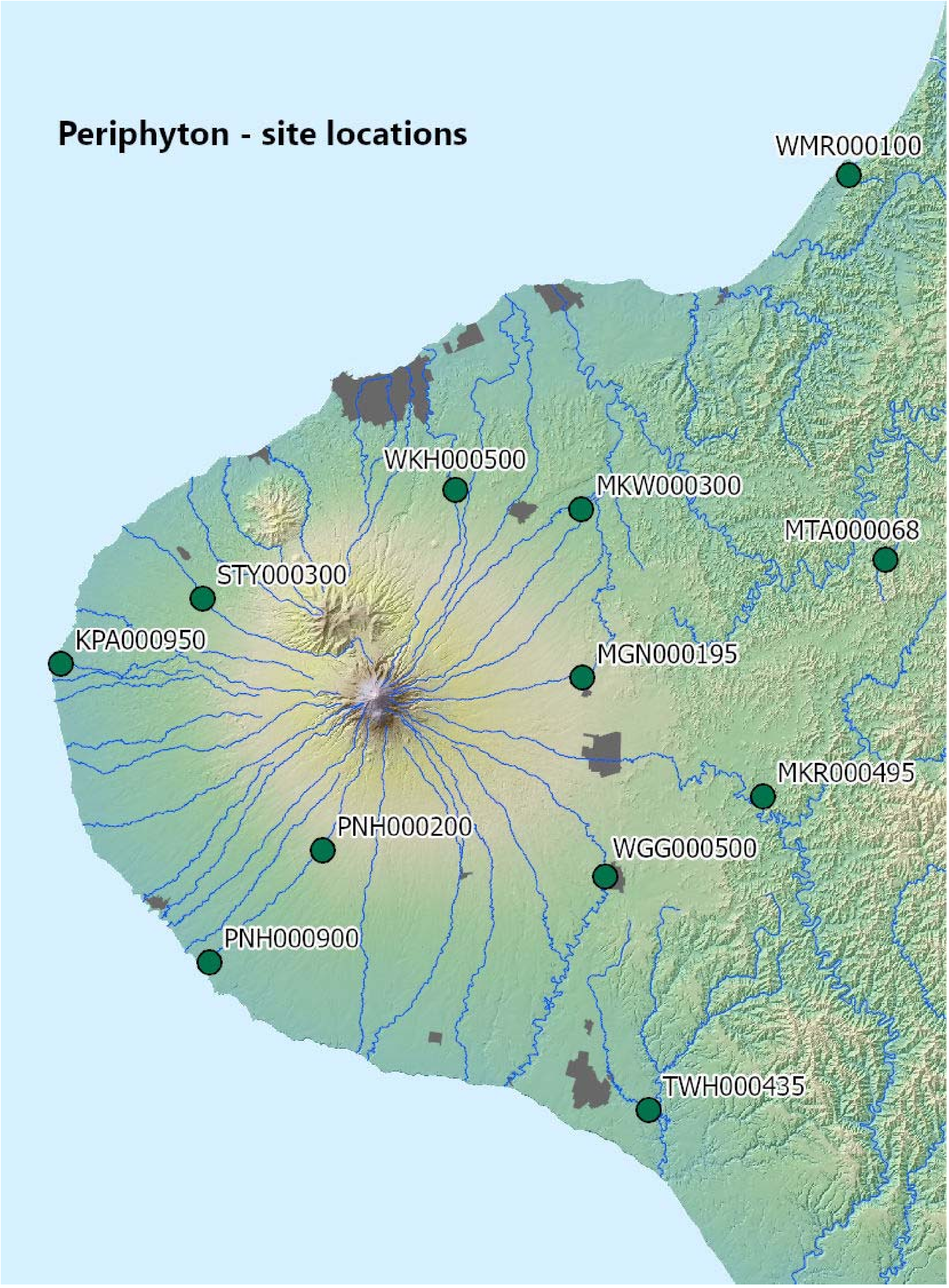


Figure 1 Periphyton monitoring sites in Taranaki

It should be noted that all of the sites monitored fall into the default class specified in the NPS-FM periphyton attribute table, as discussed in section 1.2. Investigation of potential sites prior to the implementation of this monitoring programme determined that the majority of stream reaches in Taranaki which would be classed as productive were soft-bottomed and therefore not capable of supporting conspicuous periphyton growth.

2.2 Sample collection and analysis

Monthly sampling was undertaken at the selected sites, usually in run meso-habitat. Where no run habitat was available, sampling was undertaken in riffle meso-habitat instead. Periphyton biomass samples were collected at all sites using a modified version of quantitative method 1b (QM-1b) of the Stream Periphyton Monitoring Manual (Biggs & Kilroy 2000). These samples were processed for chlorophyll-*a* to provide an assessment of ecosystem health. Visual estimates of periphyton cover were made concurrently using rapid assessment method 2 (RAM-2) of the Stream Periphyton Monitoring Manual (Biggs & Kilroy 2000), providing assessment of aesthetic values. Where flow conditions prevented safe monitoring, neither periphyton biomass or periphyton cover were assessed. On occasion, periphyton biomass was assessed, while periphyton cover was not undertaken due to poor visibility preventing an accurate assessment from being carried out.

Additional physicochemical monitoring is carried out at sites which are not monitored under the physicochemical water quality SoE programme. The physicochemical parameters monitored were reviewed in June 2019 and a number of additional parameters were added in the 2019-2020 monitoring year. All sites where this physicochemical monitoring is not undertaken have the same parameters monitored as a part of the physicochemical water quality SoE programme. Physicochemical monitoring was undertaken when flow conditions prevented safe periphyton monitoring. Sites and physicochemical parameters monitored as a component of this programme are listed in Table 4.

Table 4 Physicochemical monitoring undertaken as a component of the monthly periphyton monitoring programme

Sites with additional physicochemical monitoring	Parameters monitored for the 2018-2021 period	Additional parameters monitored from July 2019
KPA000950	Black disc	Absorbance at 340 nm
MGN000195	Conductivity	Absorbance at 440 nm
MKR000495	Ammoniacal nitrogen	Absorbance at 770 nm
MTA000068	Nitrate-nitrite nitrogen	Total nitrogen
TWH000435	Dissolved inorganic nitrogen	Total phosphorus
WMR000100	Dissolved reactive phosphorus	Turbidity
-	pH	-

Prior to June 2018, all physicochemical testing was carried out in the Taranaki Regional Council laboratory. Following the closure of this laboratory all analysis has been performed by RJ Hill Laboratories, with the exception of chlorophyll-a testing which has been carried out by the Bay of Plenty Regional Council. Limited inter-laboratory comparisons were undertaken prior to the change in laboratory provider. However, these comparisons determined that the results from the two labs were not comparable. Subsequent inter-laboratory comparisons have determined that there was good agreement between the new provider and results from other laboratories included in the comparison, particularly those using ethanol as the extractant as is the case for the Council’s samples (Kilroy and Daly 2020). As a result of these findings, and to prevent the possible step changes in reported results hindering analysis, periphyton monitoring data from June 2017 to June 2018 is not presented or analysed in this report.

2.3 Hydrological monitoring

Continuous flow data is required to estimate the periphyton accrual period. For the majority of sites, a suitable hydrological monitoring station with a long term flow record already existed. A further two sites did not have a hydrological recording station, but sufficient flow gaugings were undertaken and a suitable record exists to allow a synthetic flow to be modelled from a nearby monitoring station. Continuous water level monitoring in conjunction with quarterly flow gaugings were undertaken at the three sites where no suitable hydrological monitoring station existed to either measure or model the flow prior to the commencement of this monitoring programme.

Continuous temperature monitoring was also recorded at 15 minute intervals for all monitored sites, either as a component of the hydrological monitoring station or recorded separately using a tidbit temperature logger.

2.4 Analysis

The site MGH000950 has been excluded from the following analysis because this site was removed from the monitoring programme in September 2018, only three months into this reporting period and only one sample was collected from this site during these three months.

Additionally, trend analysis has not been undertaken as the three year data record from July 2018 is considered insufficient for meaningful trend detection. Trend analysis will be undertaken in future reports once sufficient data exists to allow detection of meaningful trends.

2.4.1 Periphyton cover

Periphyton cover was assessed via the weighted composite cover (WCC) metric, which is calculated by adding the percentage cover of long filaments and half the percent cover of thick mats together. An aesthetic nuisance guideline of ≥30% is suggested for this metric (Matheson et al. 2012).

2.4.2 Periphyton biomass

Site performance was assessed against the NOF periphyton attribute using the Hazen 92nd percentile of chlorophyll-*a* concentration (mg/m^2) over the three year monitoring period. Hazen percentiles are non-parametric and provide a more precautionary approach than parametric methods of percentile calculation. Hazen percentiles are widely used in freshwater reporting in New Zealand and has been used to represent peak chlorophyll-*a* concentration throughout this report.

In the assessment of the NOF periphyton attribute, when high flow conditions have prevented sampling, the consequent missing data point has been replaced with an imputed data point. Samples that were missed for reasons other than high flow are not imputed. The underlying assumption behind this is that flow conditions that are high enough to prevent sampling will cause algal removal, and thus the missed sample can be imputed with a low value. This approach is recommended in several publications. The National Environmental Monitoring Standards for Sampling and Measuring Periphyton in Wadeable Rivers and Streams (NEMS, 2022) recommends that data points missing due to high flows are substituted with a chlorophyll value of <5 mg/m^2. However, in recognition that several monitored sites have particularly low overall chlorophyll levels, we have followed the approach taken by Northland Regional Council (Kilroy & Stoffels, 2019) and instead substituted the 5th percentile of the data for a particular site. This was considered to be more appropriate, particularly for sites that have a 92nd percentile value below 5 mg/m^2.

2.4.2.1 Comparison between sites

The River Environmental Classification (REC) has 6 six factors which can be hierarchically used to classify river segments, based on the upstream catchment. These are summarised in Table 5. For analytical purposes, the landcover class has been modified by grouping together indigenous forest (IF) and scrub (S) as natural (N) landcover. This is consistent with the REC user manual, which considers these two classes, together with tussock (not represented in Taranaki) to be natural or largely undisturbed land cover (Snelder et al 2004).

Table 5 River Environment Classification (REC) classes and categories within each class. Classes not represented within the monitoring network are italicised

Climate	Source of Flow	Geology	Landcover	Network Position	Valley Landform
Warm-extremely wet (WX)	*Glacial-mountain (GM)*	*Alluvium (Al)*	*Bare Ground (B)*	*High Order (HO)*	*High Gradient (HG)*
Warm-wet (WW)	*Mountain (M)*	*Hard sedimentary (HS)*	Indigenous Forest (IF)	Middle Order (MO)	Medium Gradient (MG)
Warm-Dry (WD)	Hill (H)	Soft Sedimentary (SS)	Scrub (S)	Low Order (LO)	Low Gradient (LG)
Cool- extremely wet (CX)	Low elevation (L)	*Volcanic Basic (VB)*	*Tussock (T)*	-	-
Cool-wet (CW)	*Lake (Lk)*	Volcanic Acidic (VA)	Pastoral (P)	-	-
Cool-dry (CD)	*Spring (Sp)*	*Plutonics (Pl)*	*Exotic Forestry (EF)*	-	-
-	*Wetland (W)*	*Miscellaneous (M)*	*Urban (U)*	-	-
-	*Regulated (R)*	-	-	-	-

An analysis comparing peak chlorophyll-a concentration between River Environment Classification (REC) classes has been undertaken. Further, a Kruskal-Wallis test was used to compare groups, followed by a Dunn's test where significant differences between groups were detected.

2.4.3 Drivers of periphyton biomass

Exploratory analysis has been undertaken in order to assess correlations between periphyton biomass and variables which are potential drivers of periphyton biomass. These include flow and accrual period, key physicochemical drivers (nutrients) and shading. Initial investigation considered light at streambed as a modelled driver (Matheson et al. 2012), however the available solar radiation data was of insufficient spatial resolution to continue with this and therefore semi-quantitative assessments of shading were used.

Continuous stream temperature monitoring and habitat assessments were also conducted throughout the monitoring period, however, these parameters have not been analysed in this report. It is recommended that this information is assessed during the next round of reporting.

2.4.3.1 Flow

Hydrographs and dates where samples were collected or were unable to be collected are provided for each site except the Stony River in Appendix I. Bed instability in the Stony River has prevented an accurate flow record from being maintained at the monitoring site in this river. Accrual period was investigated for each site using three times and seven times median flow thresholds and the relationship between periphyton biomass and accrual period was assessed.

2.4.3.2 Physiochemical parameters

The relationship between periphyton biomass (chlorophyll-*a*) and nutrients was assessed through the Pearson correlation coefficient.

3 Results

3.1 Periphyton cover

Periphyton cover is assessed against aesthetic guidelines (Biggs & Kilroy, 2000; Matheson et al. 2012) in Figure 2 and Table 6.

Table 6 Proportion of samples exceeding aesthetic and public health guidelines from July 2018 to June 2021

Site	No. visual assessments	% of samples exceeding guidelines				
		Weighted Composite Cover	% Thick Mats	% Long Filaments	Cyanobacteria - alert	Cyanobacteria - action
KPA000950	32	19	0	13	6	0
MGN000195	31	0	0	0	0	0
MKR000495	26	19	0	19	23	0
MKW000300	30	10	0	7	13	0
MTA000068	34	29	18	6	6	0
PNH000200	34	0	0	0	0	0
PNH000900	33	0	0	0	0	0
STY000300	28	0	0	0	0	0
TWH000435	23	0	0	0	0	0
WGG000500	31	0	0	0	3	0
WKH000500	29	14	0	7	0	0
WMR000100	33	0	0	0	0	0

The guideline for weighted composite cover was exceeded on occasion at five sites over the 2018-2021 monitoring period. The proportion of exceedances at these sites ranged from 10% to 29% of sampling occasions, while the remaining seven sites complied with the guidelines on all sampling occasions.

The guideline for cover of thick mats was exceeded at only one site, in the Matau Stream (MTA000068). The proportion of exceedances at this site was 18% of sampling occasions. The guideline for cover of long filaments was exceeded at five sites. The proportion of exceedances at these sites ranged from 6% to 19% of sampling occasions. This demonstrates that at all sites except MTA000068, the weighted composite cover was influenced primarily by long filamentous periphyton. Additionally, the table demonstrates that weighted composite cover generally provides a more precautionary assessment than treating long filament and thick mat guidelines separately.

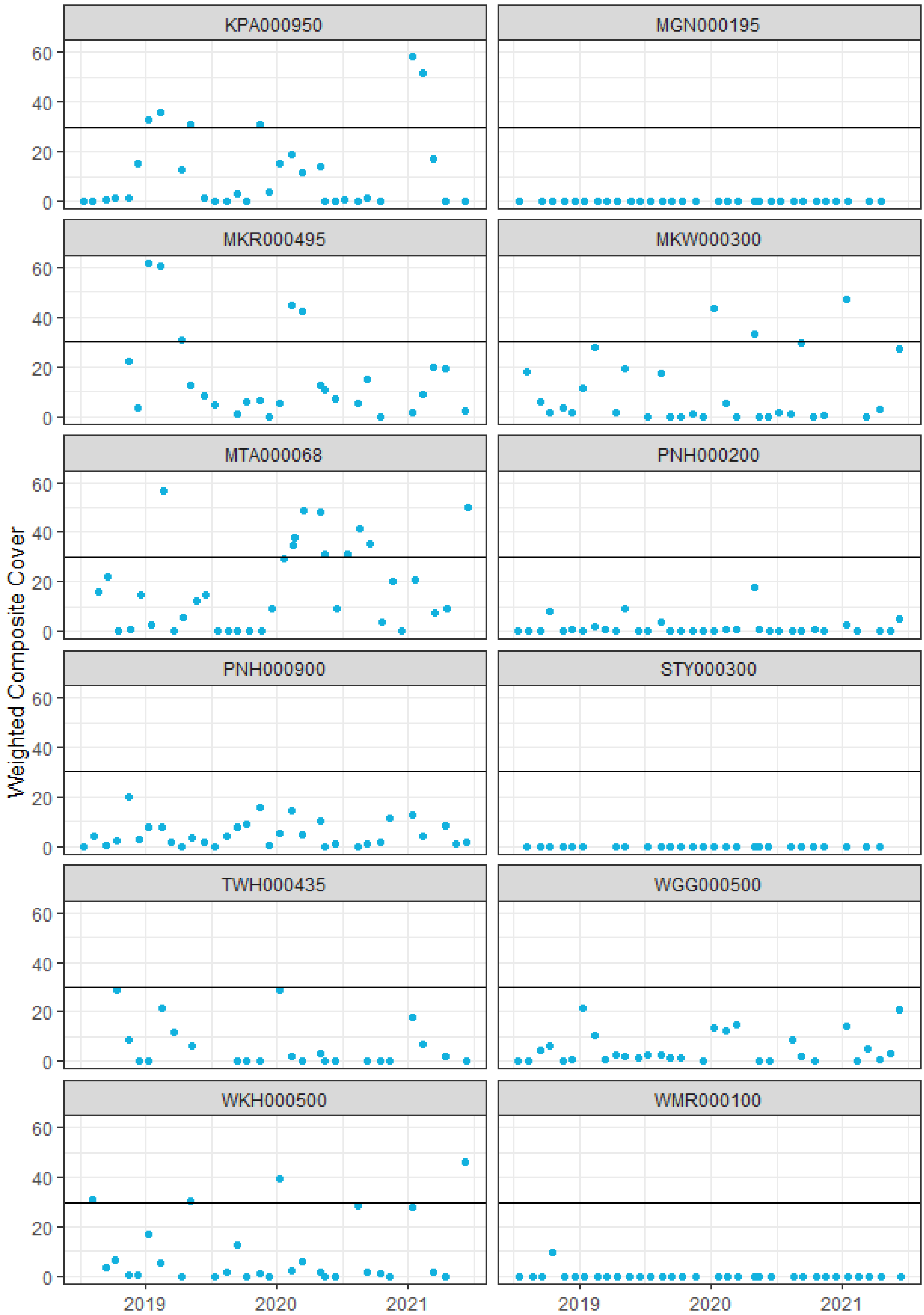


Figure 2 Weighted composite cover (WCC) at individual sites. Horizontal lines indicate the guideline for aesthetic values, which is set at 30 WCC (Matheson et al. 2012)

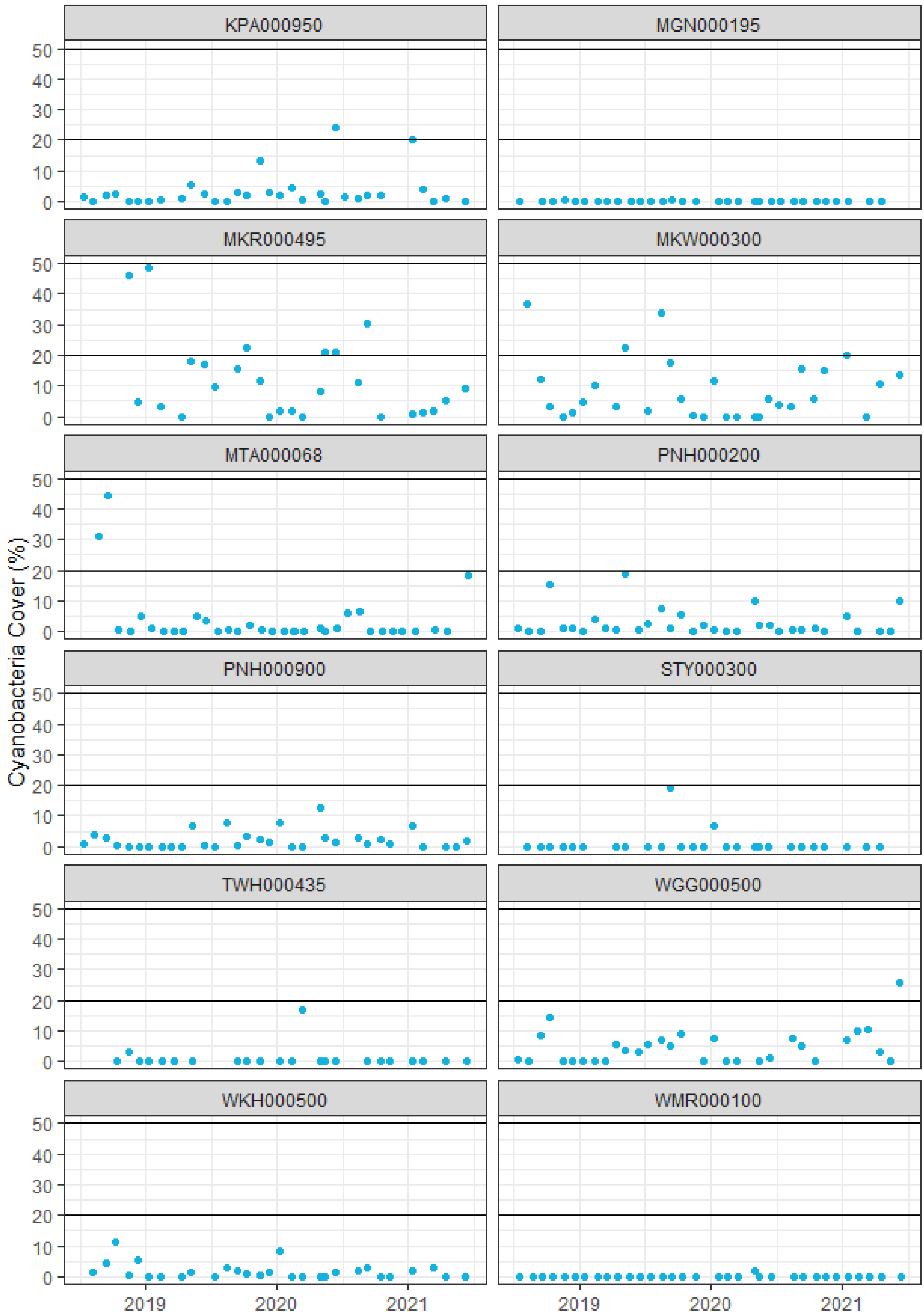


Figure 3 Cyanobacteria cover at monitoring sites. Horizontal lines indicate the alert (20%) and action (50%) levels in the interim cyanobacteria guidelines (MFE/MoH 2009)

Cyanobacteria cover was also assessed in Table 6 and is shown in Figure 3. No exceedances of the action level were recorded in the three year period, while the alert level was reached on fifteen occasions across five sites. The proportion of exceedances at these sites ranged between 3% and 23% of sampling occasions, with a 10% difference between the highest and second highest proportion of exceedances. It should be noted that the periphyton assessment was not specifically targeted at cyanobacteria, and therefore no assessment of exposed or detaching mats was made. Consequently, these results likely underestimate the number of occasions where the alert or action threshold was reached.

3.2 Periphyton biomass

Periphyton biomass, measured as chlorophyll-*a* (mg/m^2), is used as a representation of ecosystem health and is presented in Figure 4, while the attribute state for the monitored sites is presented spatially in Figure 5. Numbers on the plot represent the number of monthly data points used to calculate the NOF grade for each site. This number includes imputed values which have been calculated for monthly data points which were not sampled due to high stream flows. See methods section 2.4 and discussion for further details of the method used to impute data points and the rationale for doing so. A summary of available data is provided in Table 7. After values were imputed, site TWH000435 was missing five monthly data points over the 36 month period, or 14% of data for this site, which relates primarily to difficulties accessing the site during or following wet weather. A further three sites were missing one data point, again due to difficulties with site access (in these cases relating to either access permission being temporarily refused due to COVID concerns by the landowner or due to stock impeding access).

Table 7 Number of visual assessments and chlorophyll-a samples collected at each site during the period 2018-2021

Site	Visual Assessments	Biomass Samples		
	N	Collected	Imputed	Total
KPA000950	32	33	2	35
MGN000195	31	31	5	36
MKR000495*	26	26	6	32*
MKW000300	30	30	6	36
MTA000068	34	35	0	35
PNH000200	34	34	2	36
PNH000900	33	33	2	36
STY000300	28	29	7	36
TWH000435	23	29	2	31
WGG000500	31	31	4	35
WKH000500	29	29	7	36
WMR000100	33	36	0	36

* Site has been monitored for thirty-two months of the thirty-six month/three year monitoring period.

The NOF attribute state for periphyton is based on no more than 8% of samples exceeding a threshold at each site. This is equivalent to the 92nd percentile when there are 36 samples, and should be considered indicative for sites where there are fewer than 36 samples.

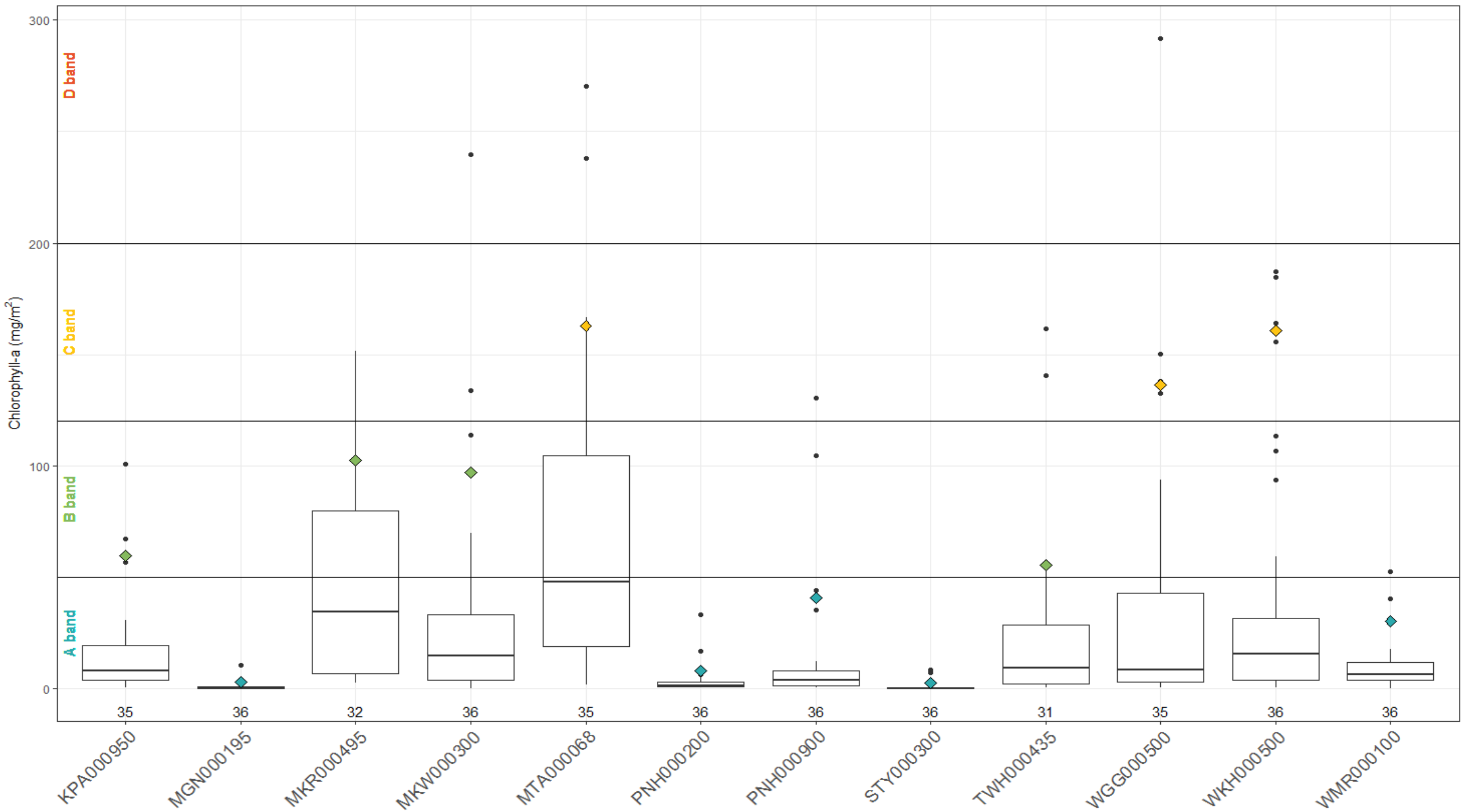


Figure 4 Periphyton biomass measured as chlorophyll-*a* during the period July 2018 to June 2021. Diamonds represent the Hazen 92nd percentile of the data, which value determines the attribute state

Horizontal lines represent the thresholds between NOF bands. The number of values used to calculate the percentile at each site is shown on the graph (including imputed data points). Note that where there are fewer than 36 data points the NOF band is indicative.

Five sites are categorised as within the A band, four in the B band and three within the C band. As all sites are C band or higher, all monitored sites meet the national bottom line for the periphyton attribute. Three sites have extremely low 92nd percentiles of under 10 mg/m^2 chlorophyll-*a*, with no samples exceeding the 50mg/m^2 threshold. These three sites are in the mid to upper reaches of streams arising in Te Papakura o Taranaki (formerly Egmont National Park). Two of the sites within the C band are in the mid reaches of large rivers arising within Te Papakura o Taranaki, while the third site is in a small hill country stream.

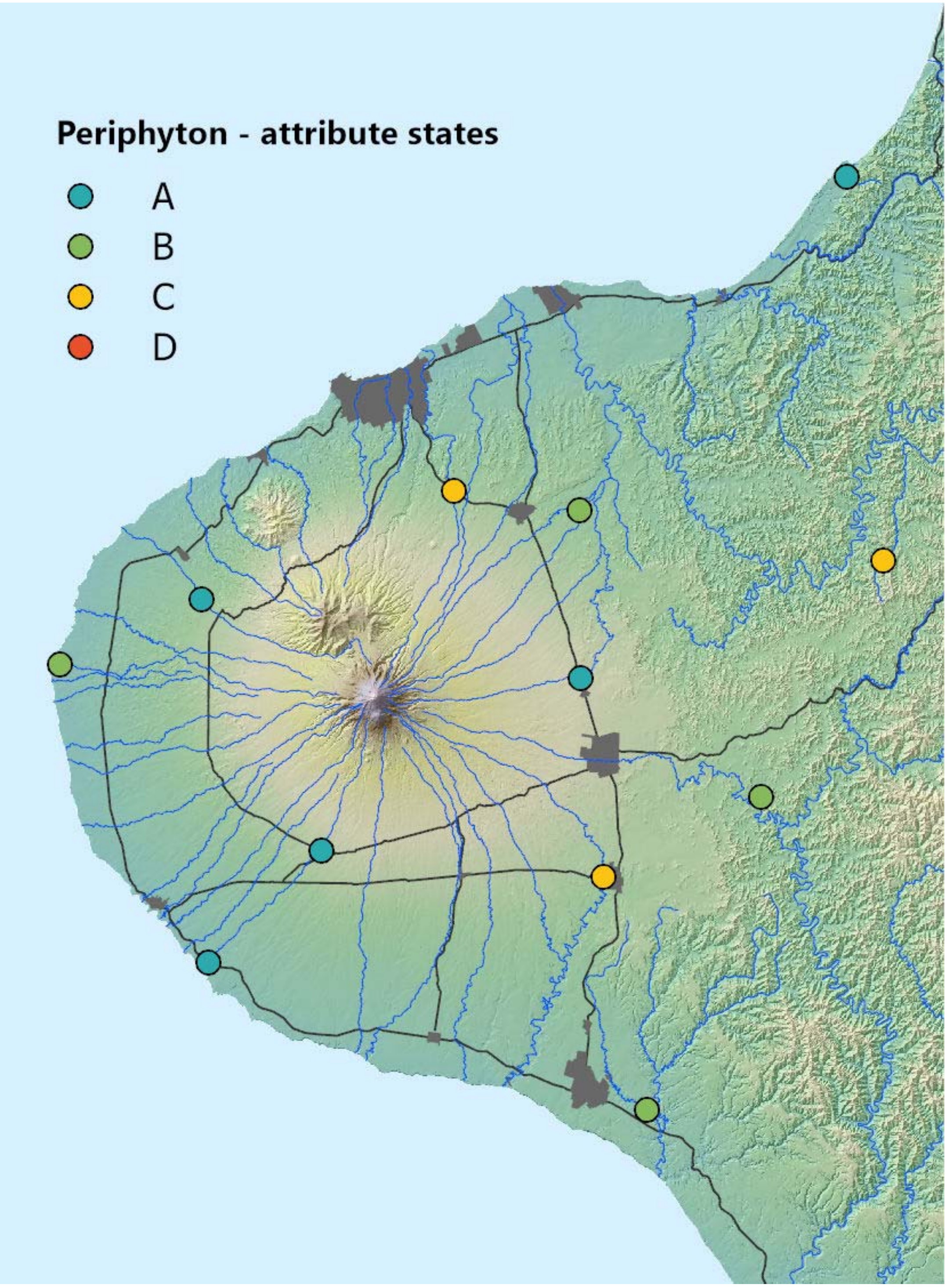


Figure 5 Periphyton attribute state at monitoring sites in Taranaki. Note that the reported state is indicative for sites with fewer than 36 data points

3.2.1 Comparisons between sites

Comparisons of peak chlorophyll-a (92nd percentile) have been made between classes for each of the six REC categories (Figure 6). Land cover was the only REC factor where a significant difference between classes was recorded. Peak chlorophyll-*a* was significantly lower at sites where the upstream catchment was dominated by natural land cover compared to pasture (p=0.01). This pattern would be expected to be caused by differences in other variables which are themselves influenced by land cover such as shading, water temperature and nutrient concentrations.

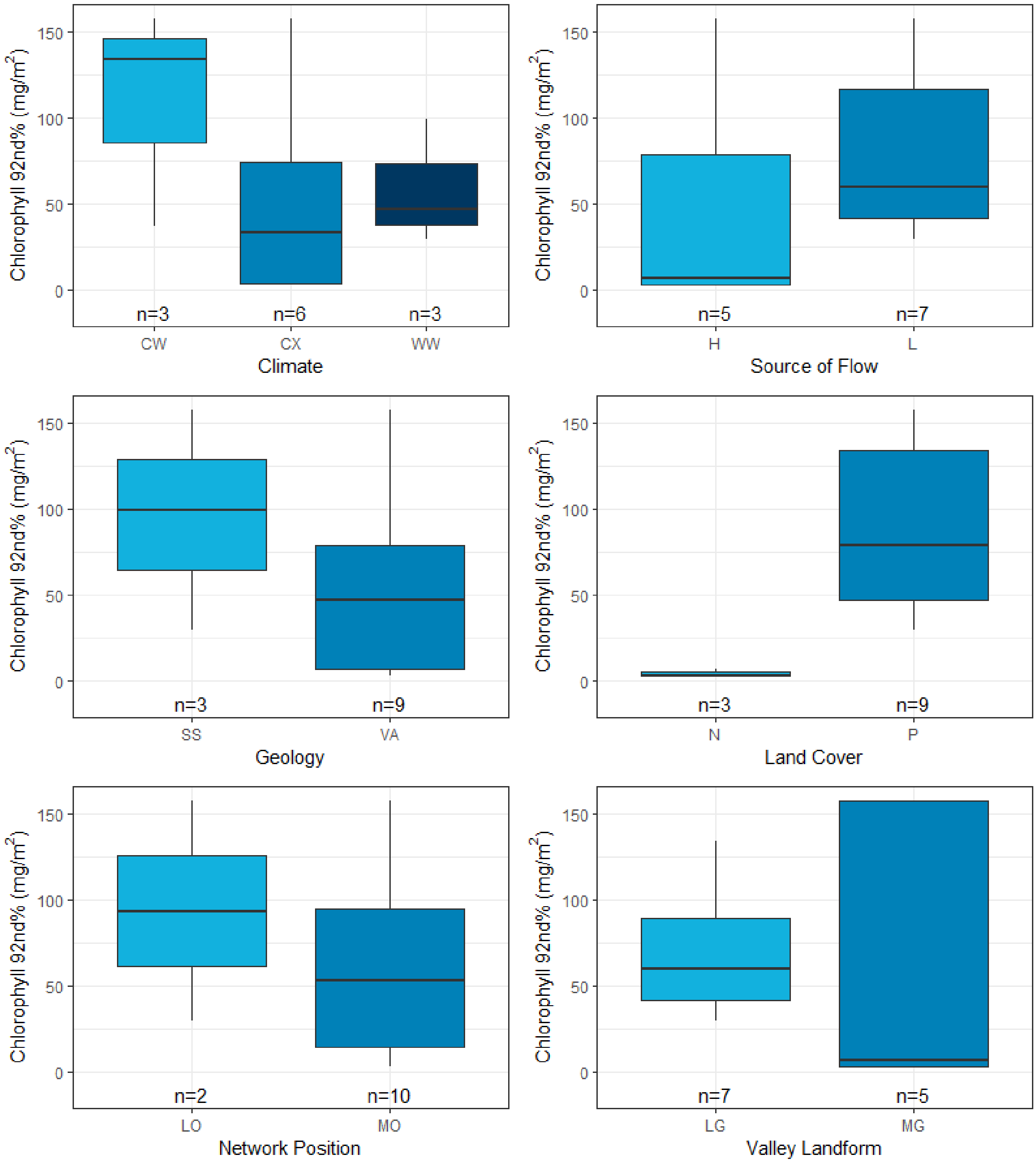


Figure 6 Peak chlorophyll-a (92nd percentile) for REC classes represented by the monitored sites for each of the six REC factors. A significant difference between groups was recorded for the factor land cover (CW=Cool-Wet, CX = Cool-Extremely wet, WW = Wet-Warm, H = Hill, L = Low elevation, SS = Soft Sediment, VA = Volcanic acidic, N = Natural land cover, P = Pastoral, LO = Low order, MO = Middle order, LG = Low gradient, MG = Medium gradient)

3.3 Drivers of periphyton biomass

3.3.1 Flow

The relationship between periphyton biomass and accrual period (based on a 3 times median flow being a flushing flow) is presented in Figure 7. It is evident from this basic analysis that the effective flushing flow (EFF) required to reset the accrual period is site specific and using these pre-determined flow thresholds is not appropriate to analyse EFF. Further analysis has been hindered by the limited data available. This will be investigated further in the next triennial report or once a minimum of five years of data has been collected, using an approach similar to that used by Northland Regional Council (Kilroy & Stoffels, 2019).

3.3.2 Physicochemical parameters

The results of the Pearson correlation analysis between periphyton biomass and nutrients are shown in Table 8. It should be noted that the nutrient variables in the table are not independent, with correlations expected between the various nitrogen forms, and also between the phosphorus forms. Conductivity is included because there is often a correlation between periphyton and conductivity, and this may be stronger than relationships with individual nutrients. This may relate to availability of trace nutrients. Negative correlation coefficients indicate that periphyton is increasing as nutrients decrease, i.e. the uptake of nutrients by periphyton is greater than the replenishment of nutrients from upstream, while positive coefficients show that periphyton increases as nutrients increase, so the supply of nutrients is greater than uptake by periphyton.

Dissolved nutrients are in a form available for utilisation by plants, while total nutrient concentrations may show stronger correlations with periphyton biomass at some sites. This is likely to relate to nutrient uptake/replenishment dynamics. Nutrients are constantly being supplied from upstream while at the same time being utilised by periphyton and plants. This dynamic means that nutrient concentrations in a sample reflects the balance of these factors at a specific time and place rather than the total available nutrients for periphyton growth.

Table 8 Pearson correlation coefficients between periphyton biomass and physicochemical variables. Significant correlations are indicated in bold ($p < 0.05$) or italics ($p < 0.01$)

Site	DIN	NH4	NNN	TN	DRP	TP	COND
KPA000950	**-0.349**	-0.160	**-0.348**	-0.383	0.150	0.060	0.222
MGN000195	-0.356	-0.186	-0.351	-0.345	-0.085	-0.166	0.058
MKR000495	-0.170	-0.158	-0.146	-0.204	-0.244	-0.235	0.139
MKW000300	-0.261	-0.208	-0.243	**-0.338**	-0.188	-0.231	0.130
MTA000068	0.014	**-0.347**	0.032	-0.048	0.049	0.221	0.067
PNH000200	0.077	0.084	0.070	0.159	-0.118	**0.358**	-0.054
PNH000900	-0.225	-0.173	-0.225	-0.202	-0.054	-0.087	-0.258
STY000300	-0.239	-0.128	-0.207	-0.095	0.003	-0.132	0.157
TWH000435	**-0.382**	-0.249	**-0.377**	-0.285	-0.090	-0.117	**0.383**
WGG000500	-0.221	0.010	-0.219	-0.206	-0.053	0.022	-0.061
WKH000500	-0.017	-0.292	0.012	-0.193	-0.072	-0.307	0.086
WMR000100	0.086	-0.194	0.089	0.238	***0.454***	0.022	0.179

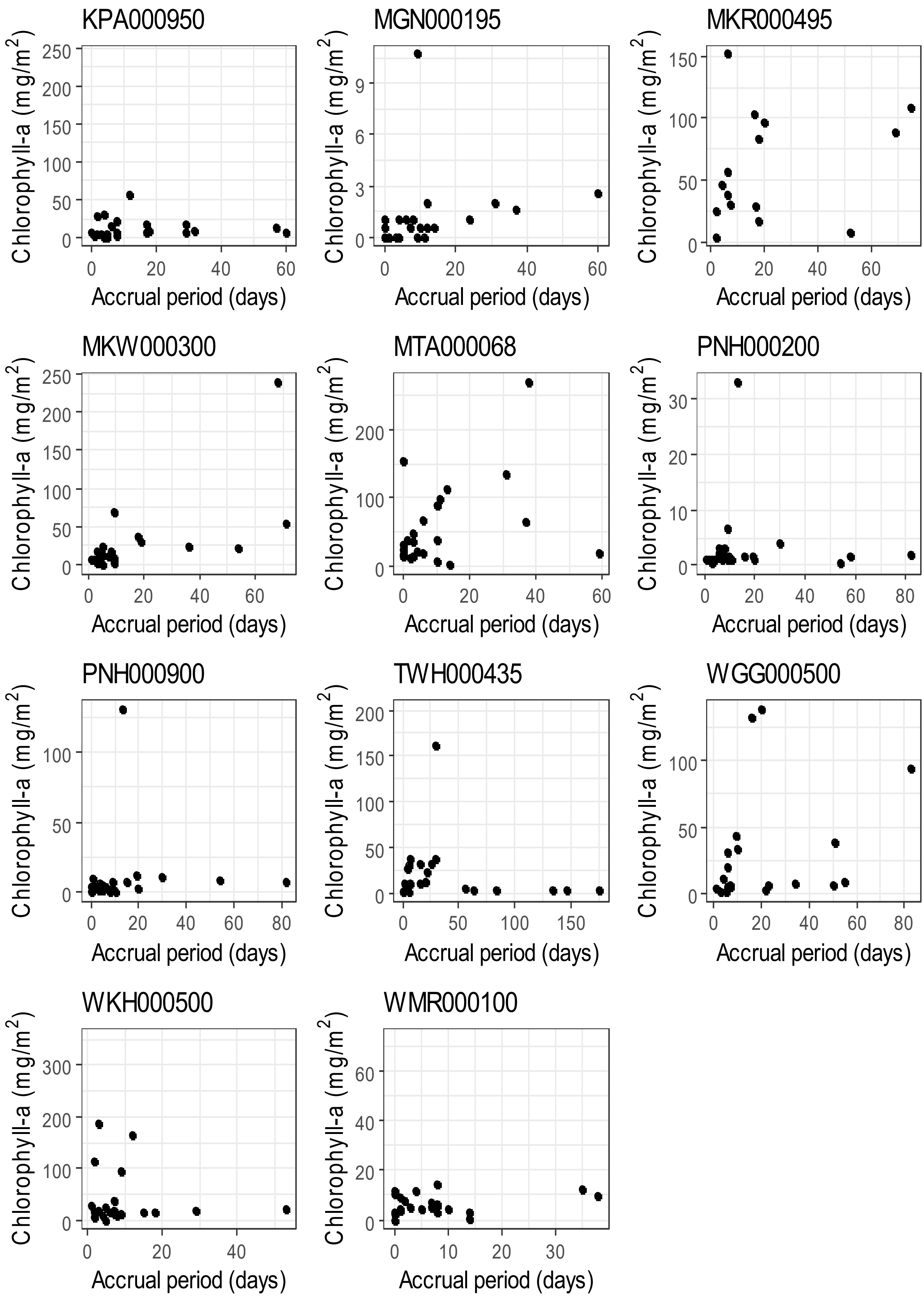


Figure 7 Periphyton biomass as a factor of the accrual period (days since 3x median flow)

At individual sites only KPA000950 and TWH000435 had a significant correlation between periphyton and DIN. Correlations of periphyton and NNN showed the same patterns which is expected because NNN is the major component of DIN and therefore these variables are not independent. Only one site, WMR000100, has a significant correlation with DRP, which was a strong positive correlation. Site MKW000300 had a significant correlation between periphyton and TN, while PNH000200 periphyton was strongly correlated with TP.

Nutrient limitation occurs when concentrations of available nutrients are lower than the capacity of the periphyton to use the nutrients. This can vary as other factors change, for example shading. Nutrient limitation is assessed based on assumed saturating concentrations of DIN and DRP in Figure 8. Thresholds of 0.295 g/m^3 for DIN and 0.01 g/m^3 DRP are used (Biggs, 2000). Points represent single samples, while site limitation is assessed based on a minimum of 55% of samples being limited by a particular nutrient or combination of nutrients.

Assessment of the nutrient limitation plots in Figure 8 shows that at the sites MGN000195, PNH000200, STY000300 and WKH000500 periphyton growth is limited by nitrogen, while site WMR000100 has phosphorus as the limiting nutrient for periphyton growth. At site MTA000068, both phosphorus and nitrogen concentrations may limit periphyton growth, while site MKR000495 is limited by phosphorus and at times nitrogen as well. The remaining five sites generally have DIN and DRP concentrations that do not limit periphyton growth. No sites with volcanic acidic geology are limited by dissolved reactive phosphorus concentrations.

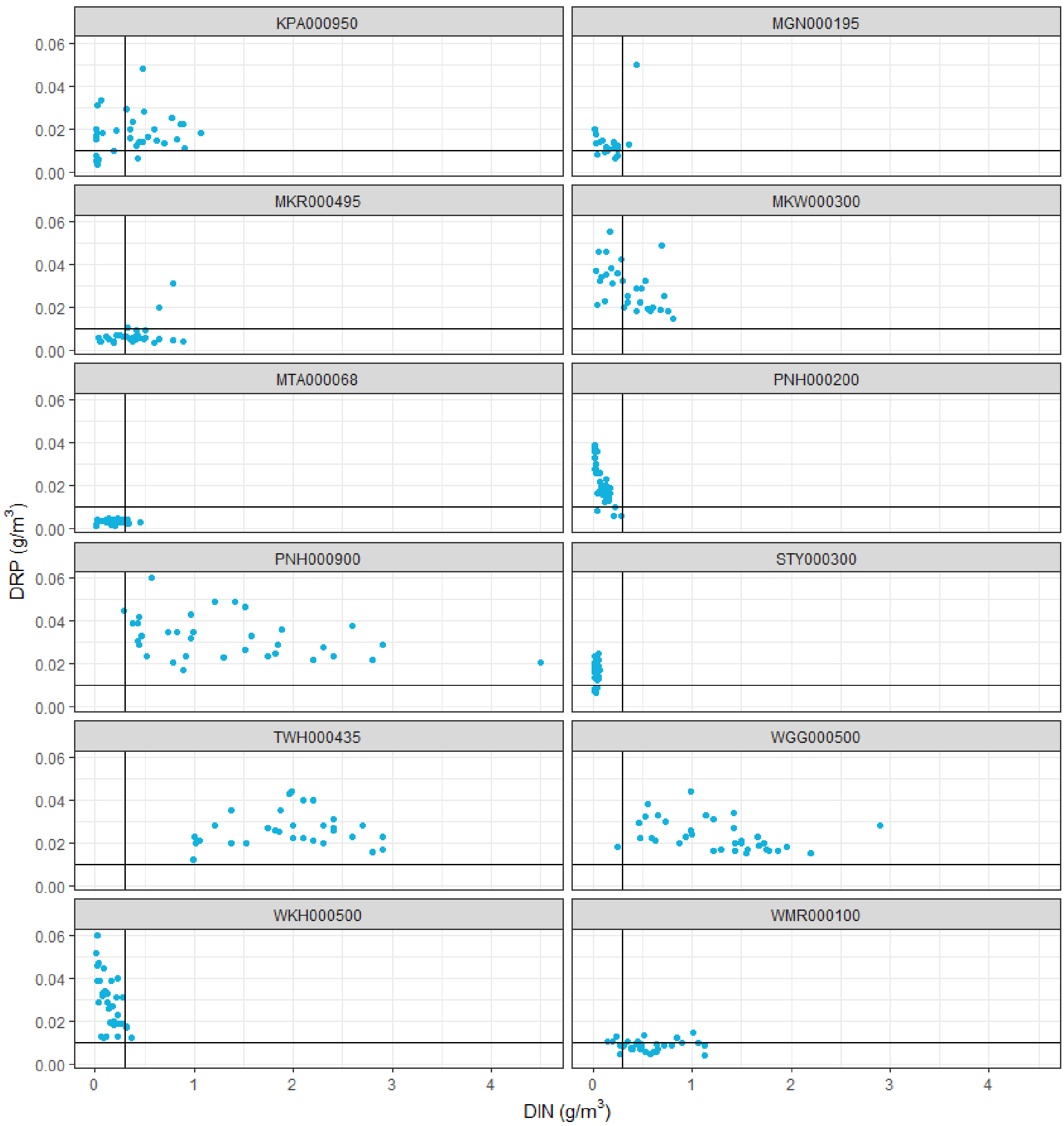


Figure 8 Nutrient limitation plots based on concentrations. For samples below the horizontal line periphyton growth is P-limited, while samples to the left of the vertical line are N-limited

4 Discussion

All monitored sites in Taranaki achieve at least C band for periphyton biomass and meet minimum national requirements (i.e. the periphyton national bottom line).

The NOF attribute is based on a maximum of 8% of samples exceeding particular thresholds. When 36 monthly samples are collected over the three year period, this is equivalent to a maximum of three samples (or one sample per year) over that period exceeding the threshold and is the same as comparing the 92nd percentile (MFE, 2022). However, when there are fewer than 36 samples, the 92nd percentile must be interpolated from the data that exists, rather than being the value of the third highest sample. In these cases the 92nd percentile is not equivalent to the maximum of 8% of samples exceeding criteria, therefore potentially altering the assessment of attribute state.

For the purpose of assessing site performance against the NOF periphyton attribute, when high flow conditions have prevented sampling, the consequent missing data point has been replaced with an imputed data point for chlorophyll-*a*. Samples that were missed for other reasons are not imputed. The underlying assumption behind this is that flow conditions that are high enough to prevent sampling will cause algal removal, and thus the missed sample can be imputed with a low value. This approach is used in several publications and is recommended in the NEMS (Kilroy & Stoffels, 2019; NEMS, 2022). The NEMS recommends that data points missing due to high flows are substituted with a chlorophyll value of <5 mg/m^2 (NEMS, 2022). However, in recognition that several monitored sites have particularly low overall chlorophyll levels, we have followed the approach taken for Northland Regional Council (Kilroy & Stoffels, 2019) and instead substituted the 5th percentile of the data for a particular site. This was considered to be more appropriate, particularly for sites that have a 92nd percentile value below 5 mg/m^2.

Periphyton cover data shows that a number of sites do not always meet aesthetic guidelines for the percentage of thick mats, long filaments or weighted composite cover. No sites which are classed as being within the NOF A band have exceeded any of these guidelines in the reporting period.

In general, the correlations between periphyton and nutrients did not align with the expected patterns based on concentrations of limiting nutrients. The sites where strong correlations with DIN were observed were both considered not to be nutrient limited. The exception to this pattern was site WMR000100 where dissolved reactive phosphorus showed a strong positive correlation with periphyton, and the periphyton growth was considered to be phosphorus limited.

The influence of underlying geology on nutrient concentrations can be examined by looking at the nutrient concentrations. The monitored sites are classed by REC as either having volcanic acidic (9 sites) or soft sedimentary (3 sites) geology. The sites with soft sedimentary geology can be classified as having periphyton growth limited either by phosphorus, or by both phosphorus and nitrogen. In contrast, the sites with volcanic acidic geology have periphyton growth limited either by nitrogen, or are not limited by either nitrogen or phosphorus. This clearly demonstrates the influence of the underlying geology, with volcanic geology having higher natural concentrations of phosphorus. The implication of this pattern, is that in areas with volcanic acidic geology, management actions which decrease available nitrogen concentrations are more likely to effectively limit periphyton growth than actions which decrease available phosphorus concentrations. In areas with soft sedimentary geology, the reverse applies. It should be noted that there are other controls on periphyton growth, such as shade and temperature. These should be considered in conjunction with nutrient limitation in respect to any potential management actions.

4.1 Site specific factors

There are also some specific issues which are impacting on particular sites.

The monitoring site in the Stony River is subjected to periodic headwater erosion events which result in a large amount of silt, sand and fine gravels moving through the river system. This high sediment supply causes significant scouring, limiting periphyton development. This also causes the riverbed to change periodically, and at times changes to the streambed have prevented sampling due to alterations to the channel shape and water depth limiting the wadeable area where sampling is possible. This is a separate issue to high flows preventing sampling. Furthermore, the channel instability in this river prevents maintenance of a rating curve. Flow data is consequently unavailable, limiting any future analysis of drivers of periphyton growth at this site. Given the importance of flow as a driver of periphyton growth and the relatively low levels of periphyton at this site, consideration should be given to removing this site from the monitoring programme. Any decision to retain the site should be made with the understanding that site-specific drivers cannot be fully assessed.

The Tawhiti Stream at Duffy's has had an increase in the cover of macrophyte beds since monitoring began (although only categorical macrophyte data is collected, preventing a full analysis of the extent of the change). It appears there has been a corresponding decrease in the measured periphyton chlorophyll-*a* concentrations and coverage of long filamentous periphyton over this time, although the limited data record prevents further analysis of this trend. There are two primary reasons why this might be the case, being that the macrophytes might limit periphyton growth through shading and competition for nutrients and space, and secondly because in a macrophyte dominated stream, macrophytes provide one of the largest habitat areas for periphyton to colonise. Periphyton growing on macrophytes is known as epiphyton, and is not included in chlorophyll-*a* measurements due to practical sampling difficulties. Macrophytes and periphyton both contain chlorophyll-*a*, and therefore macrophytes in a sample will elevate the measured concentrations of chlorophyll-*a*. Selection of sampled areas within a reach to exclude macrophytes potentially may introduce bias into the sampling, whilst shifting a sampling site may provide an alternative option. Consideration should be given to assessment of both periphyton and macrophytes at this site and any other site where significant macrophyte beds and periphyton growth co-occur. This is also recommended in the periphyton NEMS, which states that macrophyte abundance may also need to be recorded in stream reaches with high macrophyte cover, in order to adequately assess aquatic plant growth. Assessment of drivers of periphyton growth may be hindered where macrophyte beds occur, because macrophytes and periphyton are affected by the same factors. Consequently it may not be possible to separately account for the relationships of periphyton and macrophytes with environmental drivers at such sites.

4.2 Future proposed changes to periphyton monitoring

A number of recent developments will affect this monitoring programme. It is recommended that a review of the programme should be undertaken in light of these developments with a view to implementing changes in the next monitoring period.

A periphyton NEMS (National Environmental Monitoring Standard) was finalised in July 2022. There will be a number of changes to sampling procedures required to implement this standard. These affect mostly visual assessments, although site selection may also need to be reviewed to ensure that monitored reaches are representative of the river as a whole.

The periphyton monitoring network will also need to be reviewed in light of the Council's new proposed Freshwater Management Units (FMUs), which are a requirement of the NPS-FM. This will be necessary to ensure each FMU is adequately represented with monitoring sites. Further criteria to be considered, in terms of site representativeness, include stream order, REC class and overall spatial coverage.

Additional work could also be carried out in the future to spatially document stream reaches capable of supporting conspicuous periphyton growth. Currently, all sites monitored in the Taranaki region are in the default class. The region does have stream reach which is in the productive class, but an investigation of suitable sites prior to implementation of this programme found that the majority of rivers and streams in that area are soft bottomed and therefore not capable of supporting conspicuous periphyton growth. A more comprehensive investigation would be useful for supporting these findings.

5 Recommendations

1. THAT monthly SoE periphyton monitoring is continued.
2. THAT the SoE periphyton monitoring methodology is reviewed and procedures updated to ensure consistency with the periphyton NEMS.
3. THAT the monitoring sites are reviewed in light of both the periphyton NEMS and the update to the proposed Freshwater Management Units for the Taranaki region to ensure that suitable and representative monitoring sites are included for each FMU.
4. THAT mapping of stream reaches which are not capable of supporting conspicuous periphyton growth is undertaken to aid in selection of suitable monitoring sites and formally document stream reaches excluded from periphyton monitoring.
5. THAT consideration is given to macrophyte monitoring where this would be more informative than periphyton monitoring, or in conjunction with periphyton monitoring where warranted.

Bibliography and references

Biggs BJF & Kilroy C. 2000. Stream periphyton monitoring manual. Prepared for New Zealand Ministry for the Environment. 226p.

Biggs BJF. 2000. New Zealand Periphyton Guideline: detecting, monitoring and managing nutrient enrichment of streams. Ministry for the Environment. 122p.

Clapcott J. 2015. National rapid habitat assessment protocol development for streams and rivers. Prepared for Northland Regional Council. Cawthron report No. 2649. 29 p plus appendices.

Matheson F, Quinn J & Hickey C. 2012. Review of the New Zealand instream plant and nutrient guidelines and development of an extended decision making framework: Phases 1 and 2 final report. Prepared for the Ministry of Science and Innovation Envirolink fund. NIWA client report HAM2012-081.

Hoyle JT, Kilroy C, Hicks DM & Brown L. 2017. The influence of sediment mobility and channel geomorphology on periphyton abundance. Freshwater Biology 62: 258-273.

Kilroy C, Daly O 2020. Inter-laboratory comparison of analysis of chlorophyll-a from periphyton samples. Prepared for Envirolink (Tasman District Council). NIWA client report 2020321CH.

Ministry for the Environment 2022. Guidance on look-up tables for setting nutrient targets for periphyton: second edition. Wellington: Ministry for the Environment.

Kilroy C & Stoffels R. 2019. Periphyton growth in Northland rivers: Current status, and development of relationships for nutrient limit-setting. Prepared for Northland regional Council (Envirolink fund). NIWA client report 2019064CH.

Ministry for the Environment 2020. National Policy Statement for Freshwater Management 2020; Ministry for the Environment publication ME1518, August 2020.

Ministry for the Environment & Ministry of Health 2009. Cyanobacteria in Recreational Fresh Waters – Interim Guidelines. Prepared for the ministry for the Environment and the Ministry of Health by SA Wood, DP Hamilton, WJ Paul, KA Safi and WM Williamson. Wellington: Ministry for the Environment.

Snelder T, Biggs B & Weatherhead M. 2004. New Zealand River Environment Classification User Guide. March 2004 (Updated June 2010). Wellington: Ministry for the Environment.

Snelder T, Kilroy C & Booker D. 2022. Derivation of nutrient criteria for periphyton biomass objectives: using regional council monitoring data.

Taranaki Regional Council. 1996. *State of the Environment – Taranaki Region 1996.* TRC publication.

Taranaki Regional Council. 2003. *Taranaki – Our Place Our Future. Report on the state of the environment of the Taranaki region – 2003.* TRC publication.

Taranaki Regional Council. 2006. *Trends in the quality of the surface waters of Taranaki.* TRC Internal Report.

Taranaki Regional Council. 2009. *Taranaki Where We Stand. State of the Environment Report 2009.* TRC publication.

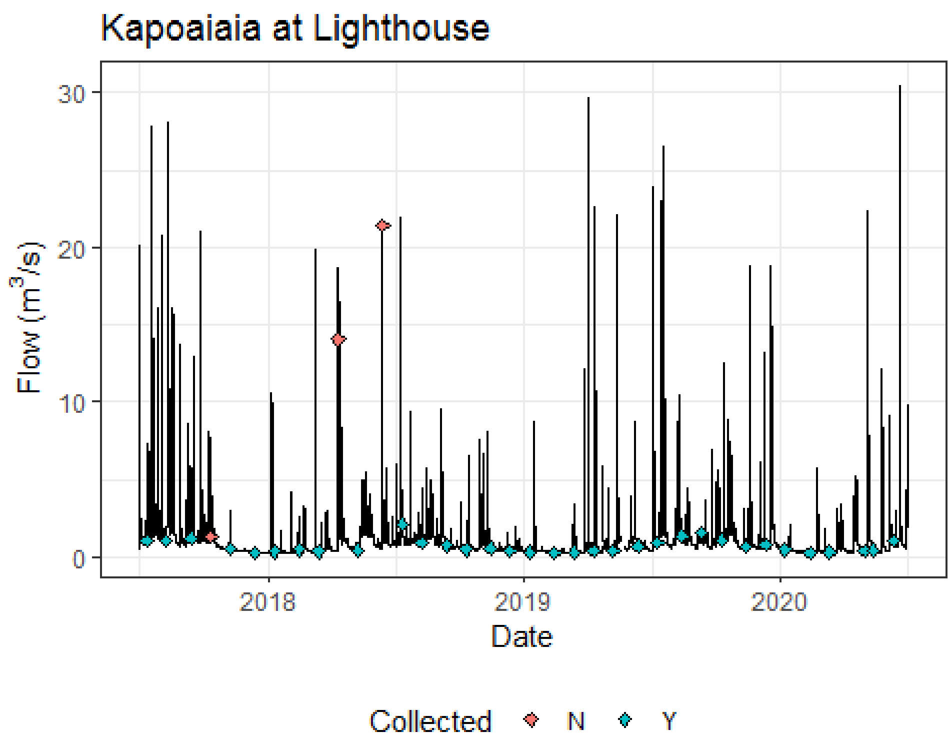
Taranaki Regional Council. 2015. *Taranaki – as one. State of the Environment Report 2015.* TRC publication.

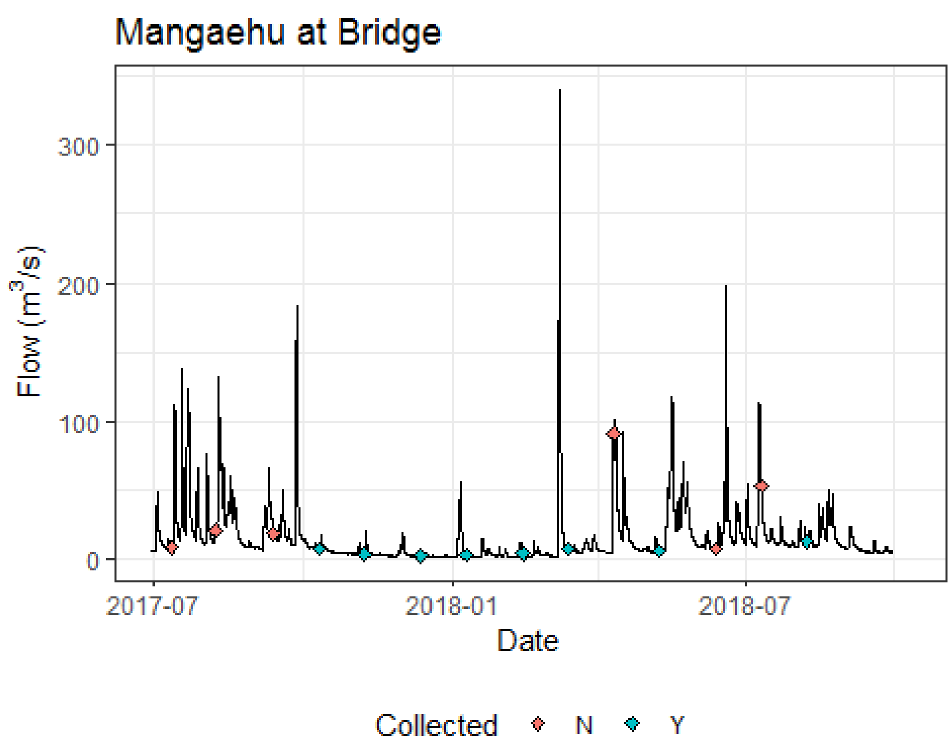
Glossary

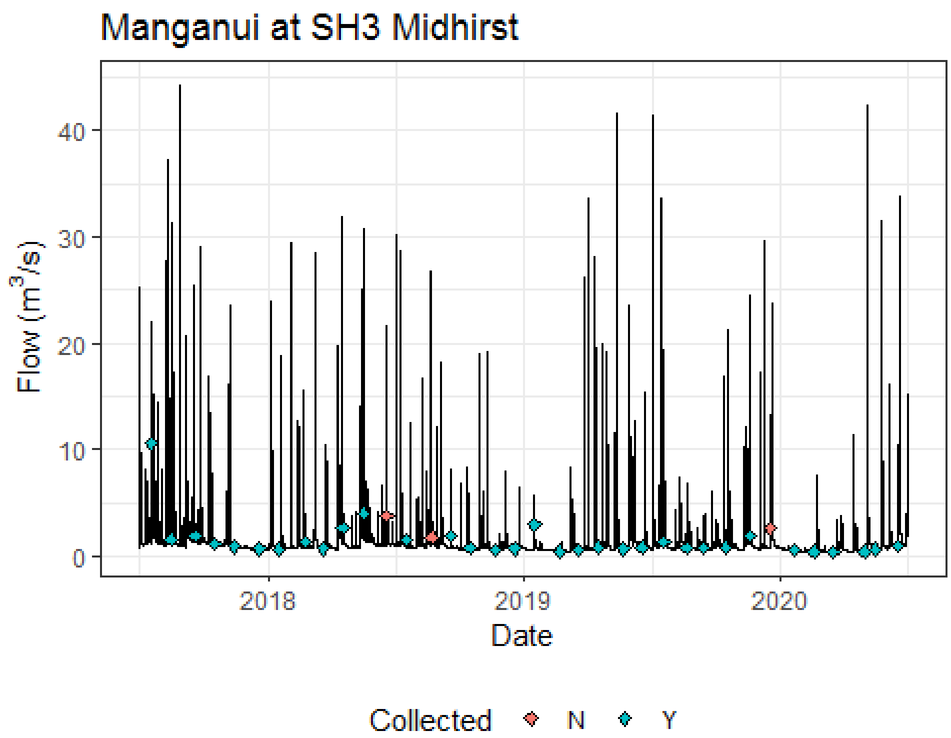
NPS-FM	National Policy Statement for Freshwater Management
FMU	Freshwater Management Unit
NOF	National Objectives Framework
NEMS	National Environmental Monitoring Standard
Chl-a	Chlorophyll-a; measured in in mg/m^2 (milligrams per square metre)
COND	Conductivity ; expressed as µS/cm at 25°C
DIN	Dissolved organic nitrogen (g/m^3 N)
DRP	Dissolved reactive phosphorus (g/m^3 P)
NNN	Nitrate-nitrite nitrogen (g/m^3 N)
NH4	Ammoniacal nitrogen (g/m^3 N)
TN	Total nitrogen (g/m^3 N)
TP	Total phosphorus (g/m^3 P)
QM-1b	Quantitative method 1b; a field method for collection of a periphyton biomass sample
RAM-2	Rapid assessment method 2; a field method for visual estimation of periphyton cover
Accrual period	The period since a flow event of sufficient magnitude to cause periphyton removal
EFF	Effective flushing flow; the flow magnitude required to cause algae removal
Epiphyton	Periphyton growing on macrophytes or other periphyton (instead of on rocks)
Strahler order	Method of reflecting catchment morphology. Headwater streams are assigned the order '1'. When two tributaries of the same order merge, the order increases by 1. When two tributaries of different orders merge, the higher order is retained. This can be used to approximate stream size and some hydrological characteristics.
REC	River Environment classification

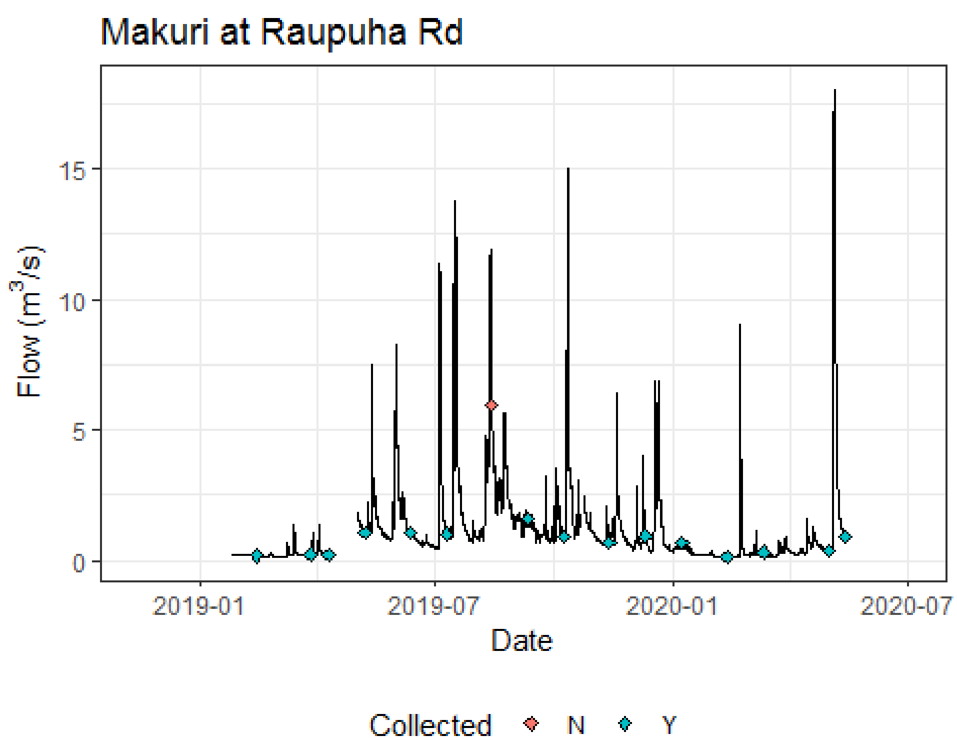
Appendix I

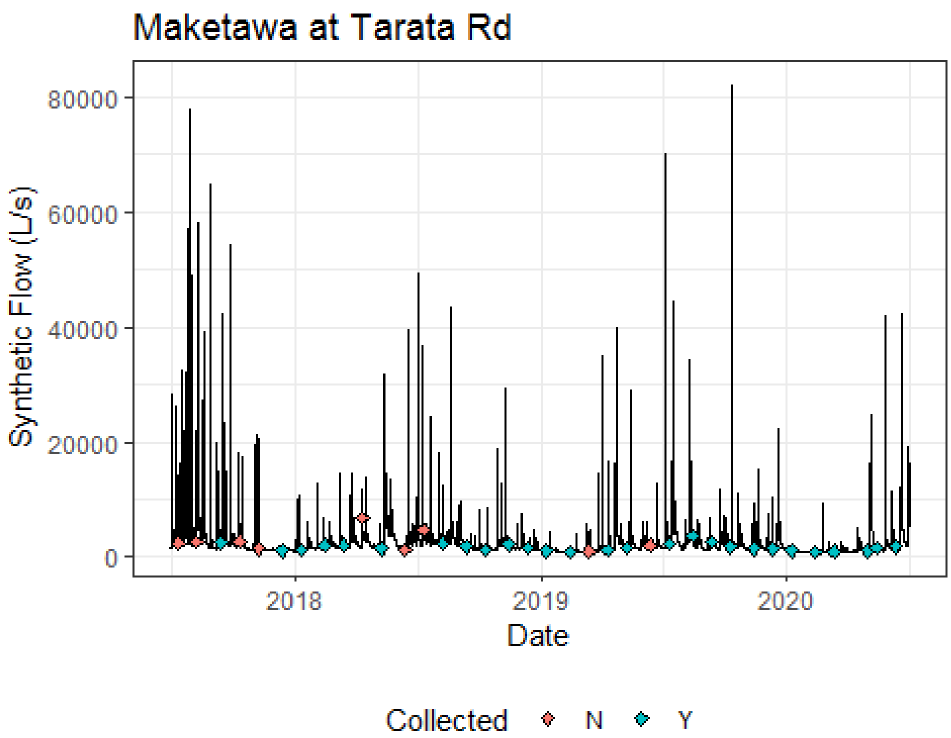
Periphyton Flow Sampling Dates


Kapoaiaia at Lighthouse
Flow (m3/s)
30
20
10
0
2018
2019
2020
Date
Collected
N
Y

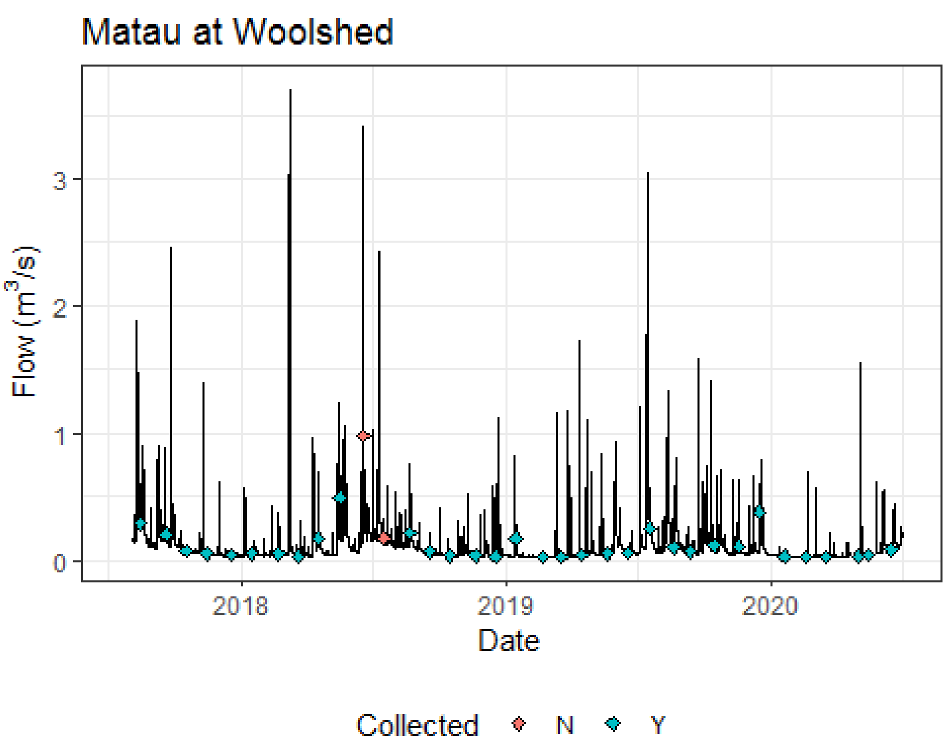

Mangaehu at Bridge
Flow (m3/s)
300
200
100
0
2017-07
2018-01
2018-07
Date
Collected
N
Y


Manganui at SH3 Midhirst
Flow (m3/s)
0
10
20
30
40
2018
2019
2020
Date
Collected
N
Y

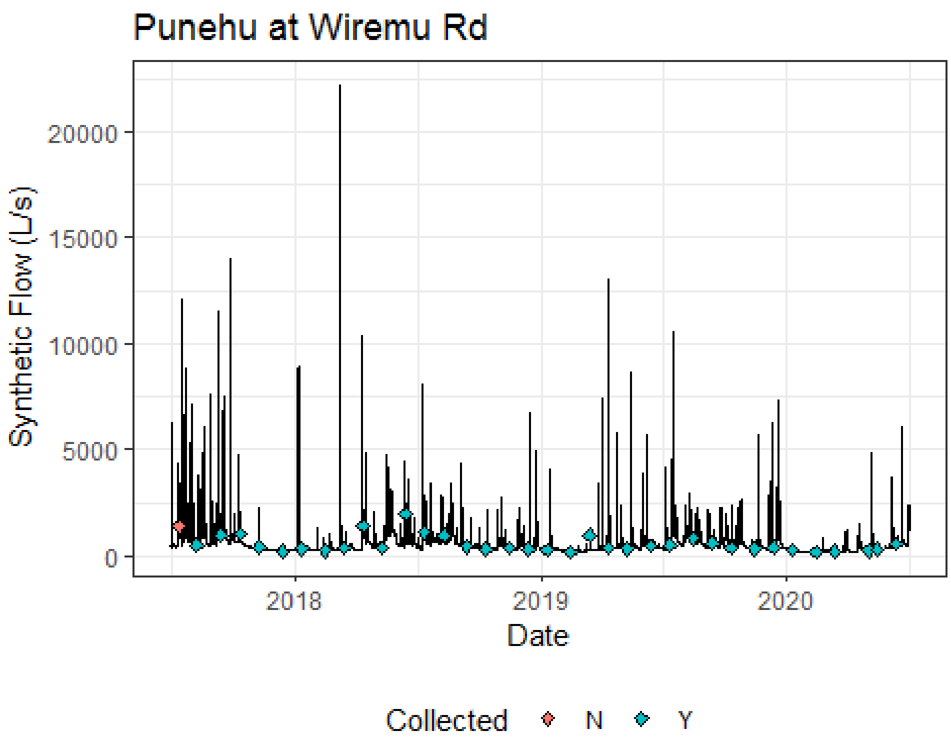

Makuri at Raupuha Rd
Flow (m3/s)
0
5
10
15
2019-01
2019-07
2020-01
2020-07
Date
Collected
N
Y

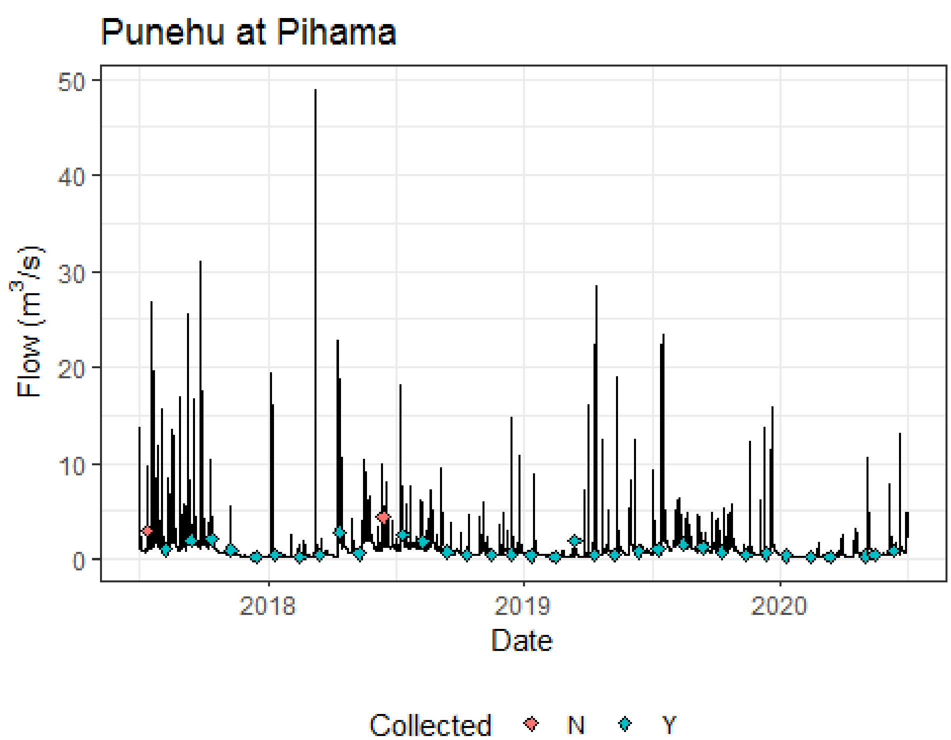


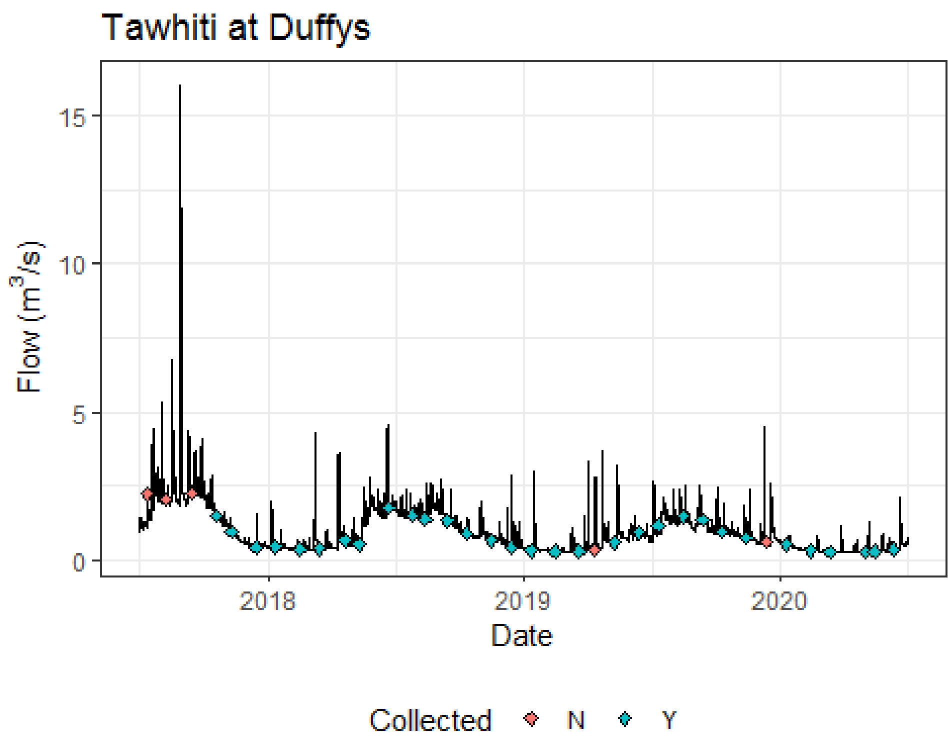
Maketawa at Tarata Rd
Synthetic Flow (L/s)
80000
60000
40000
20000
0
2018
2019
2020
Date
Collected
N
Y

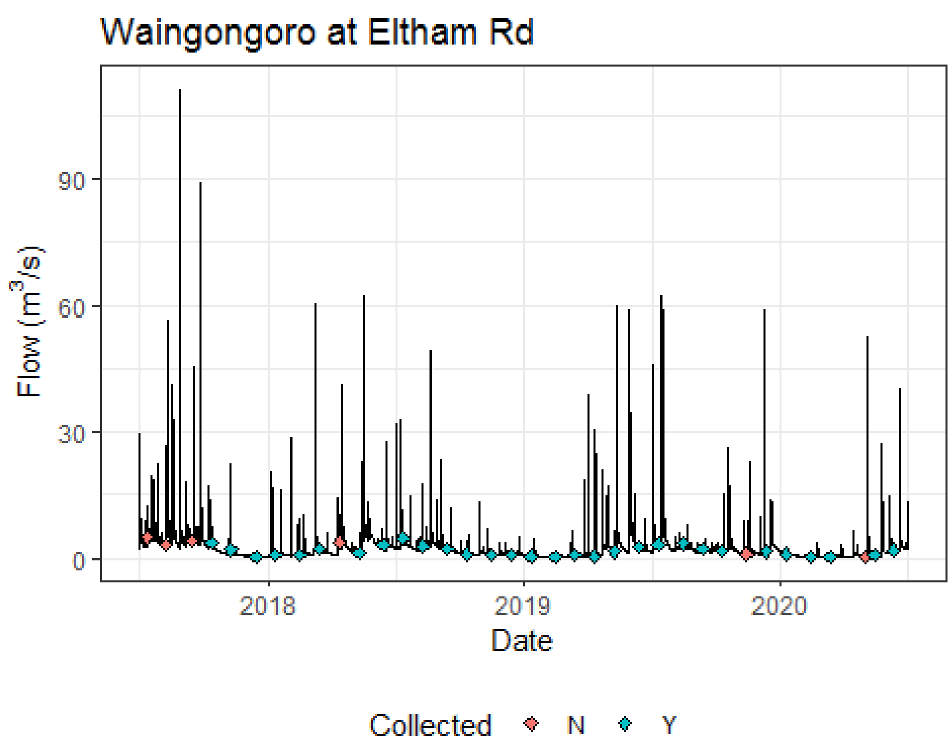


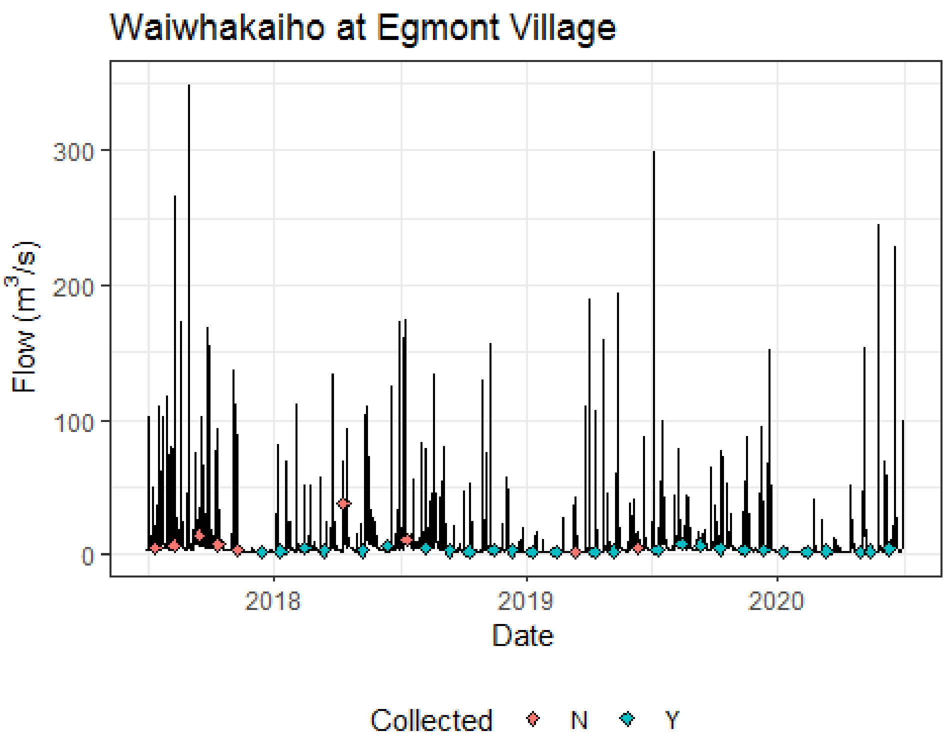
Matau at Woolshed
Flow (m³/s)
3
2
1
0
2018
2019
2020
Date
Collected
N
Y

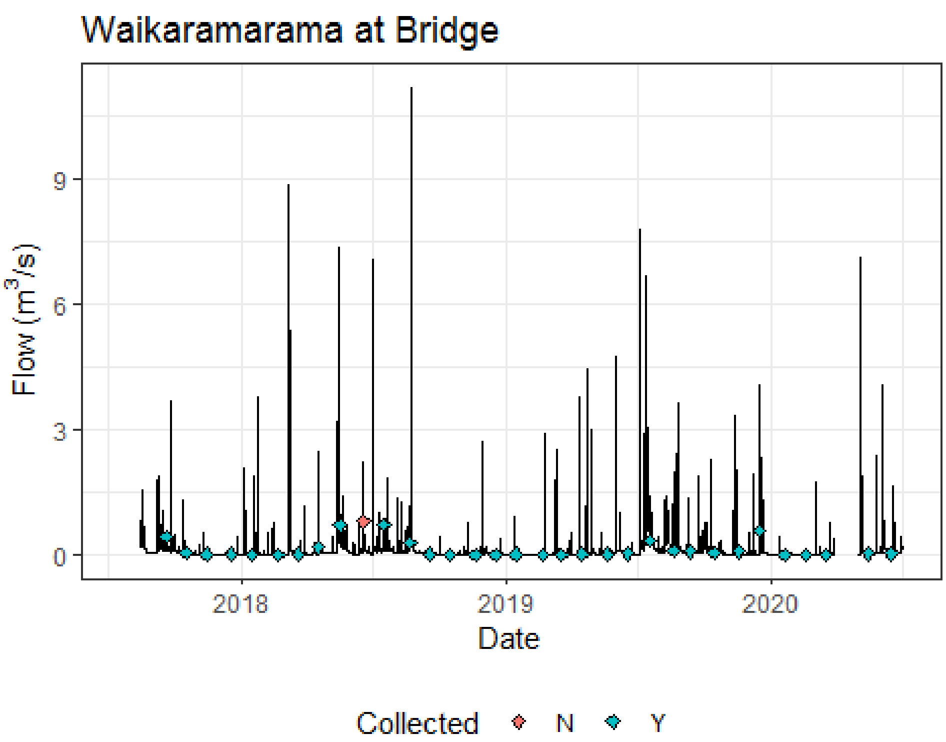

Punehu at Wiremu Rd
Synthetic Flow (L/s)
20000
15000
10000
5000
0
2018
2019
2020
Date
Collected
N
Y


Punehu at Pihama
Flow (m3/s)
50
40
30
20
10
0
2018
2019
2020
Date
Collected
N
Y


Tawhiti at Duffys
Flow (m3/s)
15
10
5
0
2018
2019
2020
Date
Collected
N
Y


Waingongoro at Eltham Rd
Flow (m3/s)
90
60
30
0
2018
2019
2020
Date
Collected
N
Y


Waiwhakaiho at Egmont Village
Flow (m3/s)
300
200
100
0
2018
2019
2020
Date
Collected
N
Y


Waikaramarama at Bridge
Flow (m3/s)
9
6
3
0
2018
2019
2020
Date
Collected
N
Y