Assessing the State of Periphyton in Southland Streams and Rivers

Technical Report

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Executive Summary

The periphyton community is an important component of flowing water systems. It forms the base of the stream food chain and is a primary source of food for aquatic invertebrates, which in turn are food for the higher order consumers such as fish. However, excessive periphyton growth commonly referred to as blooms in streams and rivers can cause detrimental impacts on instream values such as recreation, aesthetics, and ecosystem health.

The current report provides a revised assessment of the state of benthic periphyton commonly referred to as slime algae in the Southland region (expressed as benthic chlorophyll a (chl-a, mg m^{-2}), ash-free dry mass (AFDM, g m^{-2}), or percentage cover). Periphyton state was assessed against:

(a) the bands (A to D) defined in the periphyton attribute of the national objectives framework (NOF) in the National Policy Statement for Freshwater Management (NPS-FM); and

(b) the proposed Southland Water and Land Plan's (pSWLP, 2018) set of thresholds for periphyton.

As a part of Environment Southland's (ES) long-term environmental monitoring programmes, ES has collected periphyton data annually since 2001 and on a monthly basis since December 2014. The report considers the relationship between annual and monthly periphyton biomass monitoring data to revise previous assessments based on annual data only.

Analysis of the monthly frequency benthic chl-a data from run habitat illustrated that all sites (30 sites within 27 different streams and rivers) are likely to be within the NOF band range of A – C. While none of the sites were clasified into Band D (i.e. below the national bottom line), seven sites (23%) had an upper 95% confidence interval value in the D band. We interpret this as illustrating that uncertainty associated with the measurement of benthic chl-a, suggests that for those sites there is a risk they may be in the D band. Therefore, continued monitoring is warranted to reduce uncertainty.

In contrast, the assessment of annual frequency benthic chl-a data from primarily riffle habitat showed that 88% of the sampling sites from 41 different streams and rivers in Southland region fell within the NOF band range of A – C. Nine sites in eight different streams and rivers (12%) failed to meet the national bottom line of ecosystem health standards and reflect degraded ecosystems. Owing to smaller datasets, 95% confidence intervals were not computed for the annual data.

A comparison of assessments at 19 sites with both annual and monthly data available shows that 12 out of 19 sites would be classified into a different NOF band. Importantly assessments using annual data compared to monthly data generally overestimated site mean benthic chl-a by a factor of 1.6. The annual data were collected during the austral summer only, which is likely to have biased the data towards high benthic chl-a. Over-estimation of site mean benthic chl-a from annual measurement frequencies supports the use of monthly frequency data to represent the state of periphyton in Southland rivers and streams.

Analysis of the AFDM and percentage cover of periphyton data from 19 monthly monitoring sites demonstrated that 68% and 21 % of sites were compliant with respective periphyton standards defined in the pSWLP (2018).

1. Recommendations

We recommend that future monitoring and assessment of periphyton in Southland:

1. uses monthly frequency data to assess the state of a river or stream's ecosystem health with respect to periphyton attribute in the NPS-FM;

2. continues monthly frequency periphyton biomass (chl-a and AFDM) and percentage cover assessment as ongoing monthly monitoring is required for:
    (a) a more robust assessment of periphyton biomass in Southland streams and rivers, including reduced uncertainty;
    (b) assessment of Southland streams and rivers water quality compliance with the pSWLP (2018);
    (c) assessment of changes in periphyton biomass over time; and
    (d) developing Southland specific nutrient management criteria for periphyton.

3. review the monthly monitoring programme network design including site numbers and locations. Ideally conduct review in partnership with key stakeholders to ensure that all "important" locations representing identified values, FMUs are adequately represented;

4. revise the narrative chl-a thresholds defined in the pSWLP (2018) as there are practical difficulties with making measurement directly against the wording in the plan. Specifically:
    (a) the sampling chl-a associated with a single type of periphyton (filamentous or diatom/cyanobacteria) is not practical where filamentous algae, diatom and cyanobacteria co-exist in close proximity and are unable to practically be sampled independently;
    (b) refer to the biomass or mean cover in the wadeable area rather than the full river width. It is not possible to sample the full river width of the larger main stem rivers owing to depths greater than 0.7 m, or high water velocity;
    (c) conduct a regional survey of river systems currently defined as Lowland Soft Bed to validate the management unit classification currently applied;

5. as a minimum use monthly frequency data as the basis to further develop periphyton-nutrient relationships to set limits (not discussed in this report). Specifically assess the relationships with DIN and DRP to provide guidance on the development of instream concentration criteria to minimise the risk of nuisance instream periphyton growth, which are now a requirement in the NPS-FM with respect to periphyton.

2. Introduction

2.1. Background

Periphyton[1] is the mixture of algae (including cyanobacteria) and other micro-organisms that grow attached to submerged surfaces in aquatic environments. Periphyton has been identified as a key attribute of ecosystem health. In flowing water systems, the periphyton community plays a major role in nutrient and carbon cycling, affects the natural character and intrinsic values of the ecosystem and influences invertebrate community composition (Boston and Hill, 1991; New Zealand Government, 2017). Periphyton forms the base of the stream food chain and is a primary source of food for aquatic invertebrates, which in turn are food for the higher order consumers such as fish. However, excessive periphyton growth (i.e. blooms) in streams and rivers can cause detrimental impacts on instream values such as ecological, recreation, aesthetics, and ecosystem health.

The amount of periphyton on a stream bed is governed by interactions among environmental factors including flow regime, nutrient status of a stream, light and temperature, and stream bed substrate composition (Biggs, 2000; New Zealand Government, 2017). Streams subject to frequent flood events are generally characterised by lower periphyton biomass than streams that are infrequently flooded. The time available for periphyton to grow between flood events is known as the "accrual period". Nutrient enrichment, primarily by phosphorus and nitrogen typically stimulates periphyton growth in flowing water (Dodds et al., 2002). Rivers and streams receive nutrients from both natural (e.g. weathering of surface material in the watershed, atmospheric fixation, volcanism and groundwater contributions) and anthropogenic sources such as municipal effluent and agricultural runoff (CCME, 2016). Increasing light and temperature positively affect the growth rate of periphyton. Removal of riparian vegetation can lead to increases in both water temperature and light energy reaching the stream bed and, in turn, alter both the biomass and composition of periphyton communities (Sabater et al., 1997).

Stream substrate size plays an important role, fine substrate (sand/silt) is easily mobilised by river flows and therefore provides an unstable habitat for algal growth. Larger substrates (gravels, cobbles and boulders) are more stable and favour the development of attached algae (CCME, 2016). Resilient and healthy river and stream ecosystems are typically characterised by a low-moderate abundance of periphyton and diverse invertebrate communities, including the abundant presence of EPT communities (Ephemeroptera (mayfly), Plecoptera (stonefly) and Tricoptera (caddisfly)). Impaired streams commonly experience frequent periphyton bloom events and are commonly characterised by elevated nutrient levels, infrequent flushing flows and impaired invertebrate and fish communities.

2.2. Periphyton abundance thresholds and stream health

2.2.1 The National Objectives Framework (NOF)

The national objectives framework in the National Policy Statement for Freshwater Management (NPS-FM, New Zealand Government, 2017) includes an attribute for periphyton. The attribute

[1] Periphyton is also referred as "benthic algae" or "slime algae"

provides four bands (A to D) for grading periphyton state, each of which has an accompanying description of the ecological health that can be expected within these bands (Table 1).

Sampling sites are assigned to a NOF Band (A to D) based on the number of times periphyton at that site exceeds certain abundance thresholds (Table 1). Abundance of periphyton is measured as chlorophyll a (chl-a: a green pigment, present in all algae and in cyanobacteria which is essential in photosynthesis) generally at a monthly frequency. Periphyton attached within a defined area of a rock surface was scrubbed off and collected, chl-a (mass per sample) concentration was measured spectrophotometrically, and divided by the sample area to give chl-a per unit area (mg m^{-2}) (see Section 2.2).

Recognising that streams can experience occasional algal blooms due to natural variability in the frequency of floods, an average of one exceedance of the threshold in every 12 monthly measurements is allowed. Assignment of a site to a band requires a minimum of three years of monthly data. In practice the exceedance frequency is one per year (approximately 8% of samples or the 92nd percentile) for sites in the "default" class and two per year (approximately 17% of samples or 83rd percentile) for sites in the "productive" class. Some rivers and streams have naturally high levels of periphyton because of prolonged periods of low, stable flows and/or naturally high nutrient enrichment. These rivers and streams are classified into "Productive" class and defined by River Environment Classification (REC)[2] as "Dry" Climate (i.e. Warm-Dry (WD) and Cool-Dry (CD)) and Geology that have naturally high levels of nutrient enrichment due to their catchment geology (i.e. Soft-Sedimentary (SS), Volcanic Acidic (VA) and Volcanic Basic (VB)) (New Zealand Government, 2017; Snelder and Biggs, 2002).

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[2] A database of catchment spatial attributes, summarised for every segment in New Zealand's network of rivers (Snelder and Biggs, 2002)

Table 1: NOF-bands from the NPS-FM (New Zealand Government 2017) and corresponding numerical and narrative stream characteristics

Attribute	Band			
	A	B	C	D
Chl-a (mg m^{-2})	< 50	50-120	120-200	> 200
Frequency: Default class	1 per year (approx. 8% of the sample or 92^{nd} percentile)	1 per year (approx. 8% of the sample or 92^{nd} percentile)	1 per year (approx. 8% of the sample or 92^{nd} percentile)	1 per year (approx. 8% of the sample or 92^{nd} percentile)
Frequency: Productive class	2 per year (approx. 17% of the sample or 83^{rd} percentile)	2 per year (approx. 17% of the sample or 83^{rd} percentile)	2 per year (approx. 17% of the sample or 83^{rd} percentile)	2 per year (approx. 17% of the sample or 83^{rd} percentile)
Ecosystem health	Rare blooms reflecting negligible nutrient enrichment and /or alteration of the natural flow regime or habitat.	Occasional blooms reflecting low - moderate nutrient enrichment and/or alteration of the natural flow regime.	Periodic short - duration nuisance blooms reflecting moderate - high nutrient enrichment and/or alteration of the natural flow regime.	Regular and/or extended - duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime.
Invertebrate community	Strong predominance of pollution sensitive invertebrates. i.e. stone flies, may flies & caddis flies	Mostly pollution sensitive invertebrates.	Mix of pollution sensitive and tolerant invertebrates.	Strong predominance of pollution tolerant invertebrates. i.e. snails, worms & midges

2.2.2 Southland Water and Land Plan (2018)

In addition to the National Policy Statement for Freshwater Management (NPS-FM) periphyton attribute to support ecosystem health, the pSWLP, (2018) has identified that the management of periphyton in surface waterbodies is essential in order to maintain the desired ecological, aesthetic, and recreational values. Therefore, the plan has defined thresholds for stream periphyton cover (as a percentage of the stream bed), and biomass (of ash-free dry mass[3] (AFDM) and benthic chl-a) to support instream values affected by periphyton in the Southland region. The periphyton thresholds applicable to surface waterbodies classified as "Lowland hard bed", "Hill" and "Mountain" are reproduced below for clarity when we compare the respective standards with results contained within.

[3] The weight of living matter of an algae, plant or animal. For stream periphyton, this is expressed as ash-free dry mass or chl-a.

Lowland hard bed

- For the period 1 November through to 30 April, filamentous algae of greater than 2 cm long shall not cover more than 30% of the visible stream bed. Growths of diatoms and cyanobacteria greater than 0.3 cm thick shall not cover more than 60% of the visible stream bed.

- Biomass shall not exceed 35 grams per square metre (g m^{-2}) for either filamentous algae or diatoms and cyanobacteria.

- Chlorophyll a (chl-a) shall not exceed 120 milligrams per square metre (mg m^{-2}) for filamentous algae and 200 milligrams per square metre (mg m^{-2}) for diatoms and cyanobacteria.

Hill and Mountain

- Filamentous algae of greater than 2 cm long shall not cover more than 30% of the visible stream bed. Growths of diatoms and cyanobacteria greater than 0.3 cm thick shall not cover more than 60% of the visible stream bed.

- Biomass shall not exceed 35 grams per square metre (g m^{-2}) for filamentous algae.

- For filamentous algae, surface waterbodies classified as "Hill", chl-a shall not exceed 120 milligrams per square metre (mg m^{-2}), while surface water bodies classified as "Mountain", chl-a shall not exceed 50 milligrams per square metre (mg m^{-2}).

AFDM and percentage cover thresholds were not applicable to waterbodies classified as "Natural State Waters", "Lowland soft bed" and "Lake fed". The monthly maximum 35 g AFDM m^{-2} is recommended as a guideline for the protection of trout habitat and angling values, while monthly maximum percentage cover of periphyton (<30 % for the filamentous algae (>2 cm) and <60% for the diatoms and cyanobacteria (>0.3 cm)) is recommended as a guideline for the protection of instream aesthetics/recreational values (Biggs, 2000).

2.3. Objectives

In the current report, we used data from annual and monthly frequency periphyton monitoring programmes to:

- report on the state of streams and rivers in Southland region with regard to NOF periphyton attributes and pSWLP (2018) water quality standards;
- assess the relationship between state as assessed from annual vs monthly sampling frequencies to facilitate further consideration of the frequency of periphyton sample collection to inform effective periphyton monitoring and reporting;
- assess the uncertainty in state classification by using the upper and lower values of a 95% confidence interval around the mean chl-a to predict an upper and lower state per site;
- provide recommendations for future periphyton monitoring in the Southland region.

3. Methods

As a part of our long-term environmental monitoring programmes, Environment Southland has monitored periphyton annually since 2001 and on a monthly basis since December 2014. We measure periphyton as benthic chlorophyll a (chl-a, mg m^{-2}), ash free dry mass (AFDM, g m^{-2}) and percentage cover.

3.1. Field data collection

3.1.1 Annual programme

Benthic chl-a and AFDM (annual AFDM data were not assessed in the present report) data are collected annually as a part of Environment Southland's long-term state of the environment monitoring programme (SoE Biomonitoring) since 2001. The annual periphyton monitoring programme includes a total of 103 sites located in 55 different streams and rivers in Southland. Samples were collected primarily from riffle habitats during the austral summer. 74 sites (in 49 rivers) have more than six years of data and these were retained for the analysis (n = 6-16, Fig. 1).

3.1.2 Monthly programme

Since December 2014, we have endeavoured to collect benthic chl-a, AFDM and periphyton percentage cover data on a monthly basis from run habitat at 30 sites (Fig. 2). Not all 30 sites have been sampled every month owing to one or both of high flows on the intended day of sample collection and staff resourcing. The 30 sites represent 27 streams and rivers (n = 15-35; Fig. 2). Sites were selected to broadly represent gradients of trophic status (oligotrophic, mesotrophic and eutrophic) and hydrological flushing frequency (low, medium and high), and to include "important" main-stem river locations across the Southland region.

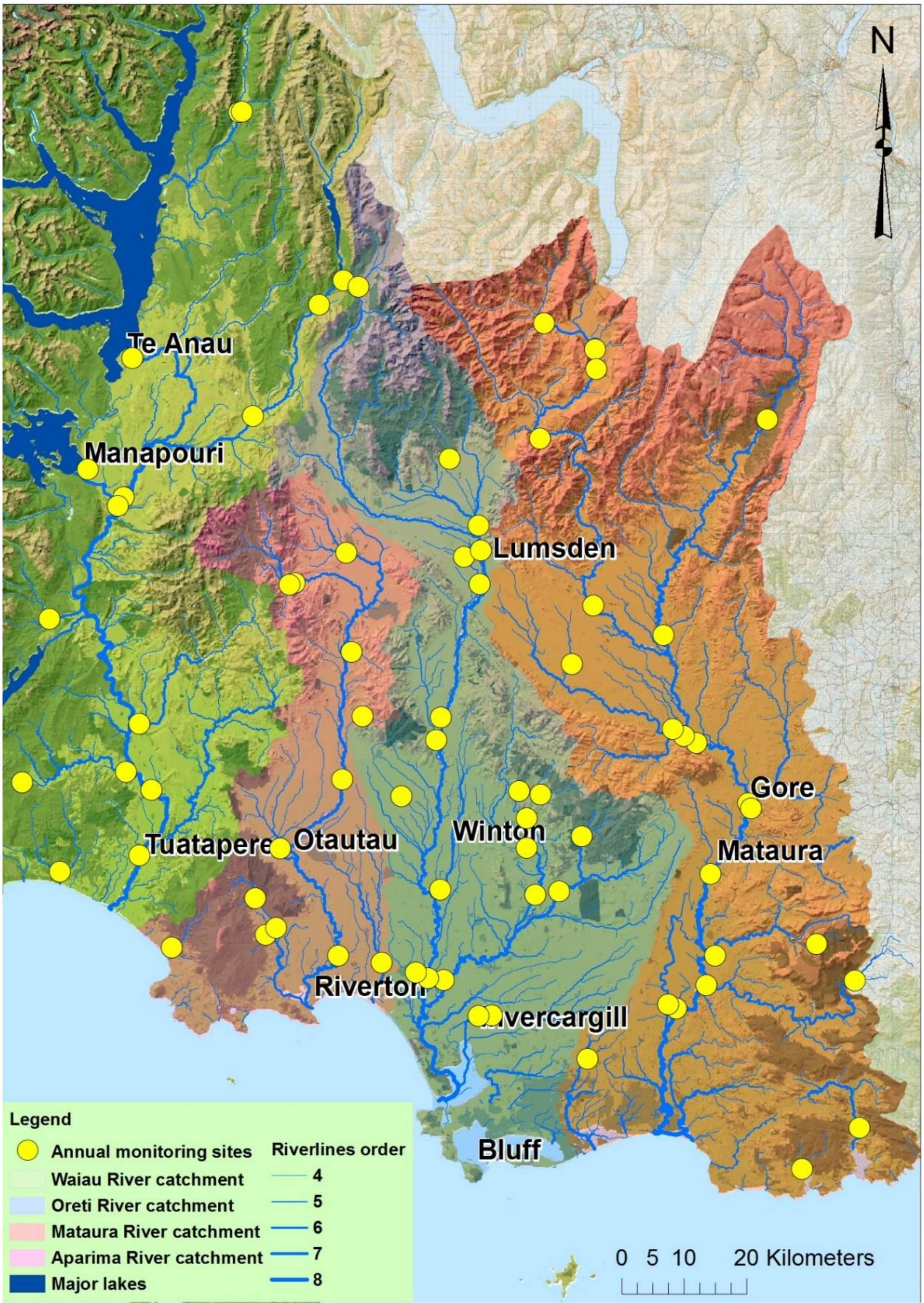

Figure 1: Map of the locations of 74 annual periphyton sampling sites (n = 6-16) retained for analysis in the Southland region

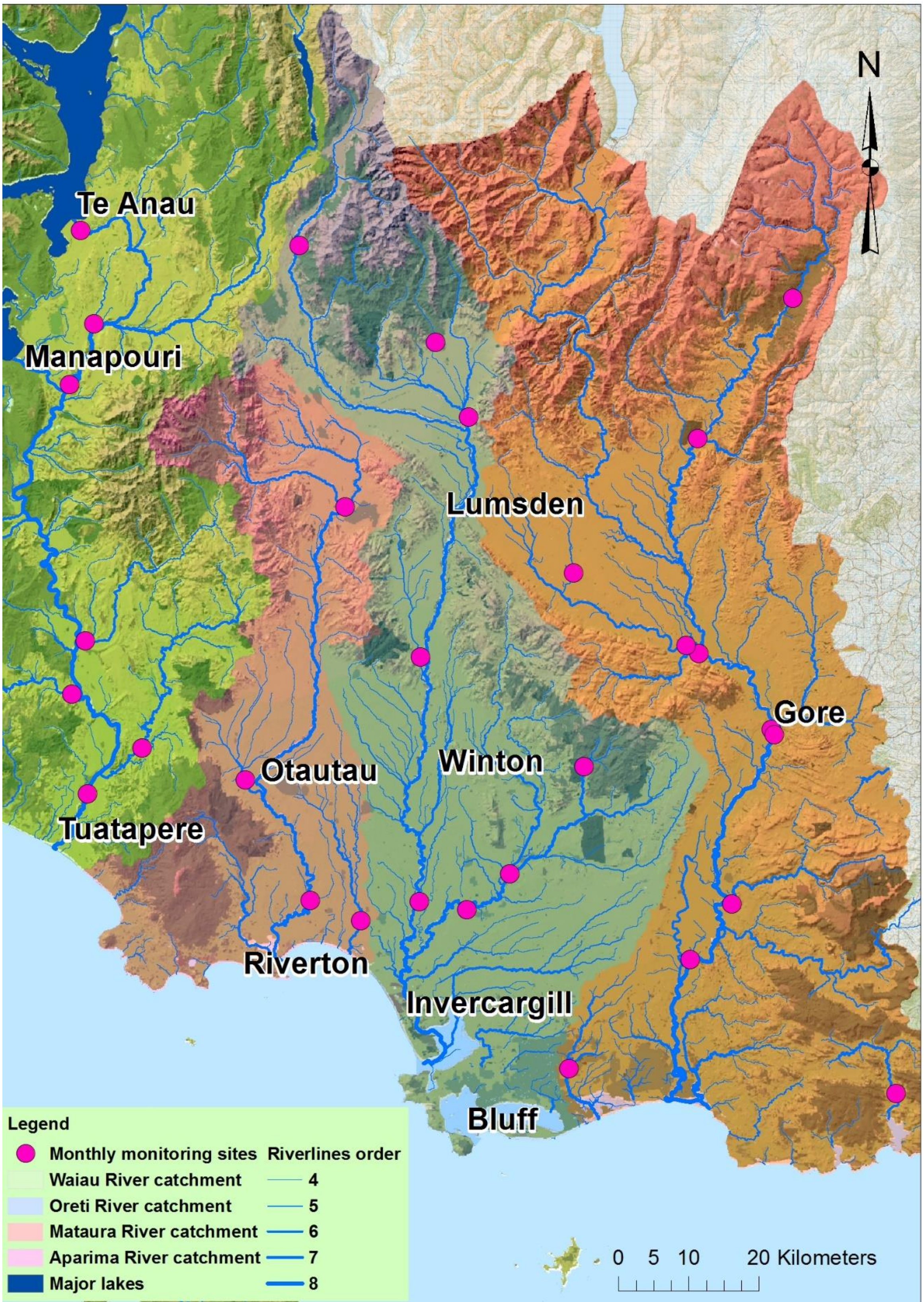

Figure 2: Map of the locations of 30 monthly periphyton sample sites (n = 15-35) in the Southland region

3.2. Quantitative sampling for chl-a and AFDM analyses

All benthic periphyton biomass sampling was conducted according to methods QM-1b and QM-3 described by Biggs and Kilroy (2000), with minor modification. The modifications were:

1. where stream bed substrate in the sample reach comprises both cobbles and boulder and smaller gravel or sand, a combination of QM-1b and QM-3 were used to provide a total of 10 replicate samples (Fig. 3);
2. in small to medium streams 10 replicate samples may be collected from two or more transects, representing the range of hydraulic conditions present.

3.2.1 Quantitative chl-a sampling defined area for cobble or larger substrate (QM-1b)

Ten rocks were collected equally spaced along one or more transects based on width of the stream sampled. Samples were collected from areas of water less than 0.7 m deep (i.e. wadeable depth only). A 65 mm diameter circle was defined on each stone using a ring, periphyton outside the ring area was removed, and the periphyton attached within the defined area was then scrubbed/brushed off and rinsed into a sample container. The 10 samples were pooled into a single labelled sample container. Samples were kept in a dark chilly-bin with ice and transported to Environment Southland, where they were frozen. Samples were stored frozen until analysis by the Cawthron Institute.

3.2.2 Quantitative chl-a sampling defined area for gravel/sand substrate (QM-3)

Ten sampling locations were equally spaced along one or more transects based on size of the stream sampled. Samples were collected from areas of water less than 0.7 m deep (i.e. wadeable depth only). A 65 mm diameter circle was defined on the gravel/sand bed using a 65 mm diameter lid. The lid was pressed gently into the top layer of the gravel/sand bed and sediment within the lid was collected into a tray using a spatula blade. Subsequently, collected gravels/sands were scrubbed and washed thoroughly into a labelled sample container. Samples were kept in a dark chilly-bin with ice and transported to Environment Southland. Samples were stored frozen until analysis by the Cawthron Institute.

Figure 3: Example showing sampling of periphyton based on stream bed composition, (A) cobble/lager substrate bed, (B) gravel/sand bed, and (C) bed with mixture of cobble/lager substrate and gravel/sand, periphyton samples were collected using combination of QM – 1b and QM – 3 to represent percent of each substrate in the stream bed.

3.3. Visual assessment protocol

The percentage of the stream bed occupied by different categories of periphyton was assessed using a bathyscope with a 0.16 m^2 quadrat used to define area of observation. The periphyton categories assessed were - long filaments (>2 cm); short filaments (<2 cm); thick mat (>0.3 cm); thin mat/film (<0.3 cm); cyanobacteria; didymo and sludge (modified from Kilroy et al. 2013; Appendix 1). The percentage cover of periphyton in each category was estimated and recorded in a field sheet to the nearest 5% (Appendix 2). Observations were made at 20 points, five equally spaced along each of four transects set up from the stream bank to a water depth of 0.7 m.

3.4. Laboratory analysis

All laboratory analyses were carried out by the Cawthron Institute following the methods described in Biggs and Kilroy (2000) (with modifications).

3.4.1 Chl–a

In the laboratory, the sample was homogenised and subsamples of the homogenate filtered onto glass-fibre filters. Chl-a was extracted from the subsample using a solution of boiling 90% ethanol. The concentration of the chl–a in the extract was measured using a spectrophotometer and reported in micro grams per sample (µg/sample).

3.4.2 Ash-free dry mass (AFDM)

Selected samples (see Section 2.1.2) were also analysed for AFDM. Subsamples were filtered onto pre-weighed glass-fibre filters, dried for 24 h at 105 °C and re-weighed. A sample was then ashed at 400 °C for 4 h and ash weight was recorded (Biggs and Kilroy, 2000). Differences between dry weight and ashed weight was measured as AFDM and reported in grams per sample (g/sample).

3.5. Data processing and storage

Environment Southland receive Cawthron Institute laboratory results directly into the Hilltop lab-mail and sampler systems. Data (chl-a and AFDM) are archived as mass per sample along with site location, date and time of field collection into Hilltop Manager. For the analysis, data from mass per sample was converted to mass per sample area as follow:

For:

$$Chl-a\ (mgm^{-2}) = \frac{\left[\frac{\text{(ug sample)}}{Area\ of\ the\ sampling\ circle\ \times 10}\right]}{1000}$$

For:

$$AFDM\ (g\ m^{-2}) = \frac{g\ sample}{Area\ of\ the\ sampling\ circle \times 10}$$

Where area of the sampling circle was π $(0.0325)^2$ = 0.003317 m^2.

3.6. Data analysis

3.6.1 Descriptive statistics

The periphyton chl-a variables including minimum, maximum, mean, median, n >200 mg m^{-2} and NOF band category were calculated for each site for both the annual and monthly frequency data sets (Appendices 3 & 4). For the annual data, we have conducted analysis on sites with a minimum of six annual data points.

3.6.2 Assessment of 92nd (default class) or 83rd (productive class) percentile exceedance value

For the both annual and monthly data, chl-a threshold for sites in the default (92nd percentile) and productive (83rd percentile) classes were calculated assuming that the distribution of annual/monthly chl-a biomass follows an exponential distribution (Snelder et al., 2014). We use this approach because there are insufficient data to generate a robust estimate of the rate of exceedance of thresholds over time. A more defensible method is to assume the mean from data is more accurate and to then calculate percentiles following the exponential distribution. An additional advantage of this approach is that a confidence interval around the mean can be calculated, thus enabling an upper and lower percentile prediction to be generated to provide some idea of uncertainty around predictions.

The exponential distribution is defined only by its mean value. Therefore, the chl-a corresponding to any given quantile (i.e. proportion of samples) can be defined using the function:

$$Chl - a = - \ln (Pr) \times \mu$$

Where Pr ($0 \leq Pr < 1$) is the probability that abundance is exceeded given the mean chl-a at the site ($\mu > 0$). Setting Pr to 0.08 (or 1/12) provides an estimate of the 92nd percentile, and setting Pr to 0.17 (or 2/12) estimates the 83rd percentile.

3.6.3 Uncertainty of state (i.e. NOF band) classification

Uncertainty in state classification from monthly frequency data was determined using the upper and lower values of a 95% confidence interval around the site mean chl-a, to then predict an upper and lower level of the relevant percentile. However, the 95% confidence interval values were not computed for the annual data due to the relatively small sample size for most of the sites.

3.6.4 Evaluation of exponential distribution

To evaluate the assumption of exponential distribution of monthly chl-a data, we compared 92nd/83rd percentile chl-a exceedance estimated based on observed chl-a data with values estimated assuming the exponential distribution.

3.6.5 Comparison of annual and monthly chl-a monitoring data

For the comparison of state as assessed from annual and monthly chl-a monitoring data, we used estimates of state from 19 sites at which there were both annual and monthly data available. The relevant 92nd/83rd percentile chl-a exceedance values and mean chl-a biomass at each site obtained through two monitoring programmes were compared.

3.6.6 Comparison of AFDM of periphyton to the proposed Southland Water and Land Plan standards

The maximum AFDM value recorded during the period of 2015 - 2017 was used to identify compliance with the relevant water quality standard for each monitoring site (relevant to 19 of 30 sites classified into “Lowland hard bed”, “Hill” and “Mountain”, see Section 1.2.2 defined in Southland Water and Land Plan (2018)). If the maximum AFDM value of the site was lower than the threshold then the site was considered to “pass” and to be compliant with the Southland regional Water and Land Plan, if the maximum value was greater than the threshold it was considered to “fail”.

3.6.7 Comparison of percentage cover of periphyton to the proposed Southland Water and Land Plan standards

The maximum percentage cover of periphyton recorded during the period of 2015-2017 at 19 sites were compared with thresholds (sites classified into “Lowland hard bed” (November to April), “Hill” and “Mountain”, see section 1.2.2) defined in the Southland Water and Land Plan (2018). Streams were classified as “pass” or “fail” by comparing percentage periphyton cover of long filamentous (>2 cm) and diatoms and cyanobacteria (>0.3 cm) at each site with its corresponding threshold value. We determined a site to fail where the maximum of one or both of the percent cover categories were observed to be greater than the standard.

3.6.8 Comparison of chl-a to the proposed Southland Water and Land Plan standards

We have not compared benthic chl-a data to the pSWLP (2018). The pSWLP (2018) has defined chl-a threshold for a single type of periphyton (i.e. for the filamentous algae or diatoms and cyanobacteria). However, in their natural environment, filamentous algae, diatoms and cyanobacteria co-exist in a close proximity and cannot be practically sampled independently. Chl-a values in the present report correspond to the combination of all types of algae present at the time of sampling. Therefore our data did not fulfil the requirements to assessing chl-a standards defined in the Southland Water and Land Plan (2018).

3.7. Statistical analysis

Data were processed using R statistical software (R version 3.0.2). Regression analysis was used to determine the relationship between annual and monthly chl-a exceedance values (92nd for default class and 83rd for productive class), using a linear-fit. The relationship which fitted the data the best (R^2) is reported. A Mann-Whitney U test[d] was used to determine whether differences between means of annual and monthly chl-a biomass were statistically significant. A value of $p < 0.05$ was considered statistically significant.

4. Results

4.1. Evaluation of periphyton state relative to the NPS-FM periphyton attribute bands

4.1.1 Annual chl-a biomass

Of the 74 annual frequency periphyton sampling sites considered, 66 sites were classified into the default class, while 8 sites were classified into the productive class (Appendix 3). 22 (30%) were classed as NOF band “A”, 19 (26%) as band ”B”, 24 (32%) as band “C” and 9 (12%) as band “D” (Table 2; Figures 4 – 7, Appendix 3). At 16 (21%) of the sampling sites chl-a exceeded 200 mg m^{-2} in at least one year. The Makarewa River at Wallacetown recorded the highest mean annual chl-a biomass of 139.7 mg m^{-2} and followed by Mataura River at Mataura Island Bridge (111.5 mg m^{-2}), while Aparima River u/s Dunrobin recorded the lowest mean annual chl-a biomass of 1.6 mg m^{-2}.

4.1.2 Monthly chl-a biomass

Out of 30 monthly periphyton sampling sites, 27 sites were classified into the default class, while three sites were classified into the productive class (Appendix 4). Twelve sites (40%) were in the NOF band “A”, 8 (27%) in the “B” band, and 10 (33%) in the “C” band, none were in the “D” band (Table 2; Figures 4 - 7, Appendix 4). Chl-a exceeded 200 mg m^{-2} at least once at five sites. Waiau River at Tuatapere recorded the highest mean monthly chl-a value of 78.1 mg m^{-2} followed by Dipton Stream at South Hillend-Dipton Road (69.3 mg m^{-2}), while Waikaia River at u/s Piano Flat recorded the lowest mean monthly chl-a value of 2.7.

Table 2: Percentage and number of sites belongs to each NOF band category estimated based on annual and monthly chl-a biomass data.

Attribute	Band			
	A	B	C	D
Chl-a (mg m^{-2})	< 50	50-120	120-200	> 200
Percentage/number of streams & rivers (Annual)	30% (22)	26% (19)	32% (24)	12% (9)
Percentage/number of streams & rivers (Monthly)	40% (12)	27% (8)	33% (10)	0

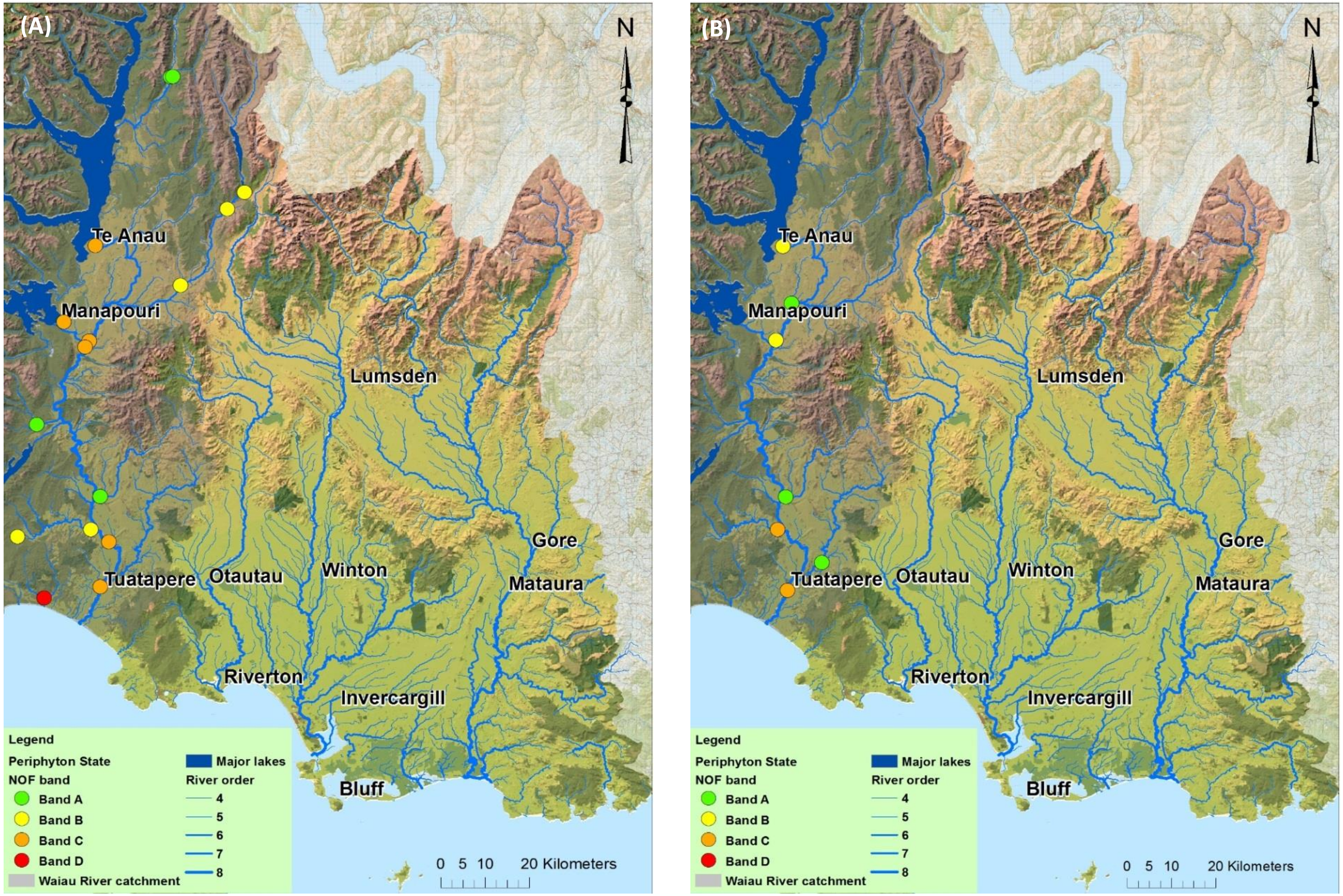

Figure 4: State of Waiau River catchment ecosystem health based on periphyton exceedance values defined by NOF (see Table 2) for (A) annual and (B) monthly chl-a biomass.

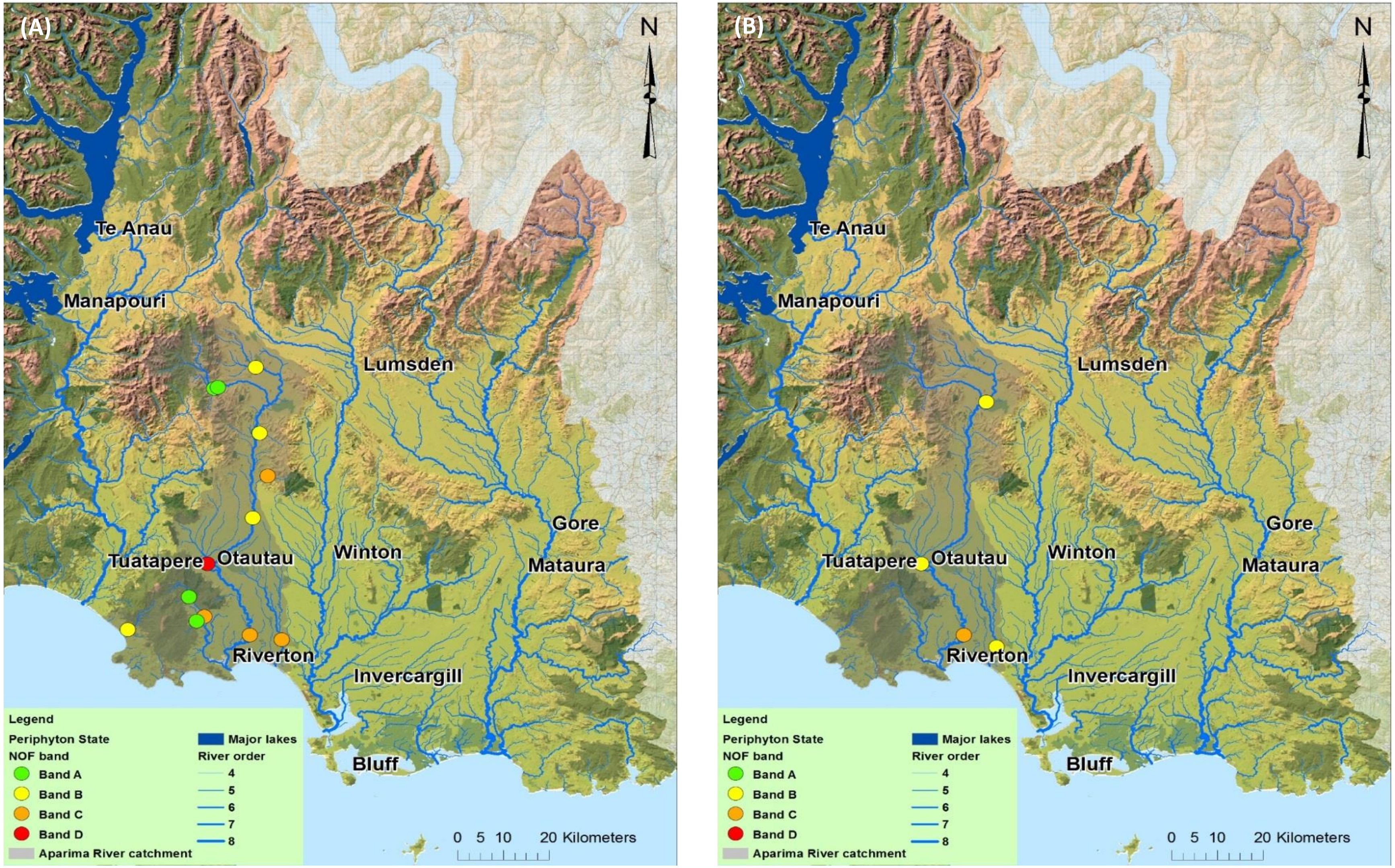

Figure 5: State of Aparima River catchment ecosystem health based on periphyton exceedance values defined by NOF (see Table 2) for (A) annual and (B) monthly chl-a biomass.

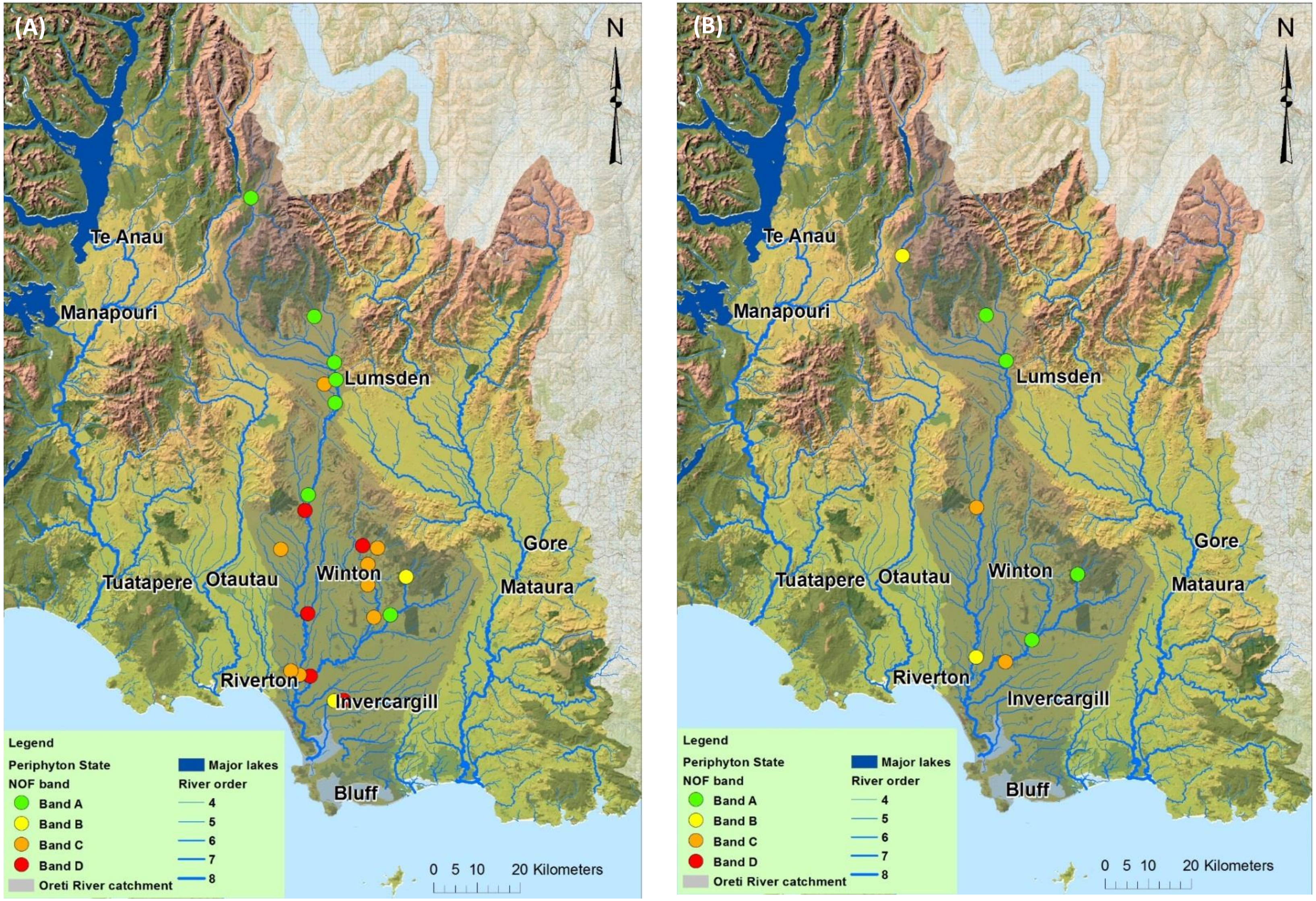

Figure 6: State of Oreti River catchment ecosystem health based on periphyton exceedance values defined by NOF (see Table 2) for (A) annual and (B) monthly chl-a biomass.

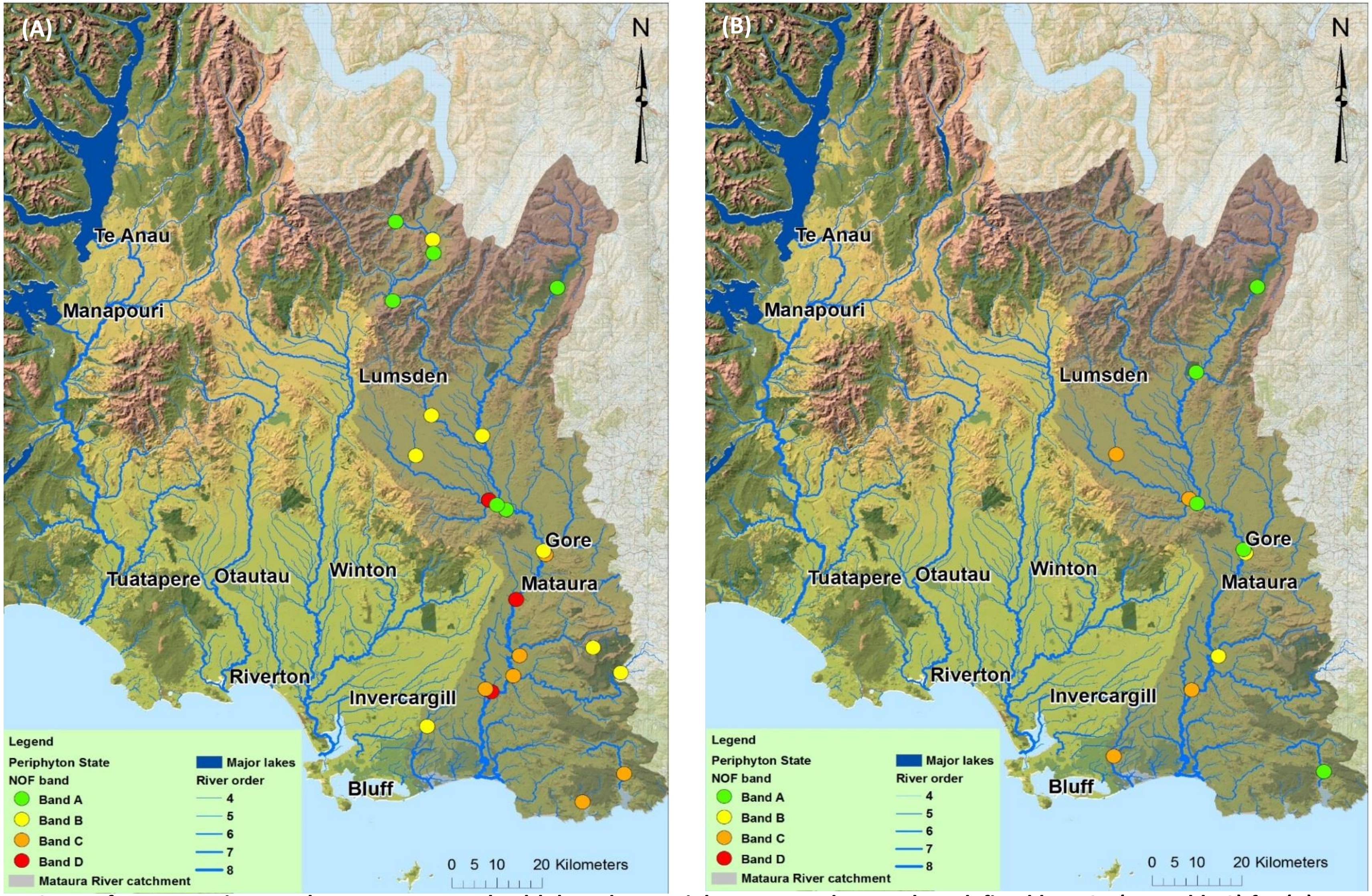

Figure 7: State of Mataura River catchment ecosystem health based on periphyton exceedance values defined by NOF (see Table 2) for (A) annual and (B) monthly chl-a biomass.

4.1.3 Upper and lower 92nd/83rd percentile chl-a confidence limits for monthly chl-a biomass

Classification of sampling sites into NOF bands based on 95% lower and upper confidence intervals for each site are presented in Table 3. The results illustrate that 23 (77%) sites were within the NOF band range of A – C, whereas, 7 (23%) of sites have an upper confidence interval prediction which suggests they could be in the D band.

Table 3: Classification of sampling sites into NOF bands using the lower and upper values of a 95% confidence interval (ci) around the mean chl-a to predict an lower and upper level of state (i.e. NOF band) per site. * Productive class.

Site Name	Max chl-a	Mean chl-a			92nd /83rd percentile chl-a exceedance			NOF – band category
		95% ci lower	Mean	95% ci upper	95 % ci lower	Exceedance value	95% ci upper	
Waikaia River u/s Piano Flat	16	1	3	4	3	7	10	A
Irthing Stream at Ellis Road	23	2	3	4	4	8	11	A
Mataura River at Gore	11	2	4	6	6	10	15	A
Cromel Stream at Selbie Road	39	2	5	8	5	13	21	A
Waikaia River at Waikaia	60	0	5	10	1	13	26	A
Wairaki River ds Blackmount Road	45	1	6	10	3	14	26	A
Otamita Stream at Mandeville	33	4	6	8	9	15	21	A
Hedgehope Stream 20m u/s Makarewa Confl*	121	1	12	23	2	21	40	A
Dunsdale Stream at Dunsdale Reserve	39	8	11	14	21	29	37	A
Whitestone River d/s Manapouri-Hillside	84	5	15	26	12	39	66	A/B
Waikawa River at Progress Valley	39	10	16	23	25	42	58	A/B
Orauea River at Orawia Pukemaori Road*	130	7	24	41	12	42	72	A/B
Oreti River at Three Kings	90	15	23	32	38	59	80	A/B
Upukerora River at Te Anau Milford Road	157	12	26	39	31	65	99	A/B
Hamilton Burn at Affleck Road	124	14	27	39	35	67	99	A/B
Oreti River at Branxholme	148	14	34	53	36	85	134	A/B/C
Waimatuku at Waimatuku Township Road	124	19	35	50	48	87	127	A/B/C
Otautau Stream at Otautau-Tuatapere Road	139	24	41	57	62	103	145	B/C
Mimihau Stream at Wyndham	199	23	43	63	57	108	158	B/C
Waikaka Stream at Gore*	196	39	61	82	70	108	146	B/C
Mararoa River at Weir Road	124	28	46	65	70	117	164	B/C
Makarewa River at Counsell Road	127	32	50	68	82	127	171	B/C
Waimea Stream at Mandeville	292	25	50	76	63	127	192	B/C
Lill Burn at Lill Burn-Monowai Road	250	27	54	81	68	137	205	B/C/D
Aparima River at Thornbury	301	23	58	93	57	146	235	B/C/D
Mataura River at Mataura Island Bridge	205	32	62	92	80	156	232	B/C/D
Longridge Stream at Sandstone	190	46	64	82	116	161	206	B/C/D
Waituna Creek at Marshall Road	187	38	65	92	96	165	234	B/C/D
Dipton Stream at South Hillend-Dipton Road	362	34	69	105	86	175	264	B/C/D
Waiau River at Tuatapere	332	42	75	108	105	189	273	B/C/D

(light green)	Band A
(yellow)	Band B
(orange)	Band C
(red)	Band D

4.2. Evaluation of exponential distribution

The 92nd/83rd percentiles of chl-a based on monthly frequency chl-a were strongly correlated with estimated values using the exponential distribution (r^2 = 0.88; Fig. 8), supporting the assumption that the chl-a data distribution is consistent with the proposed exponential distribution.

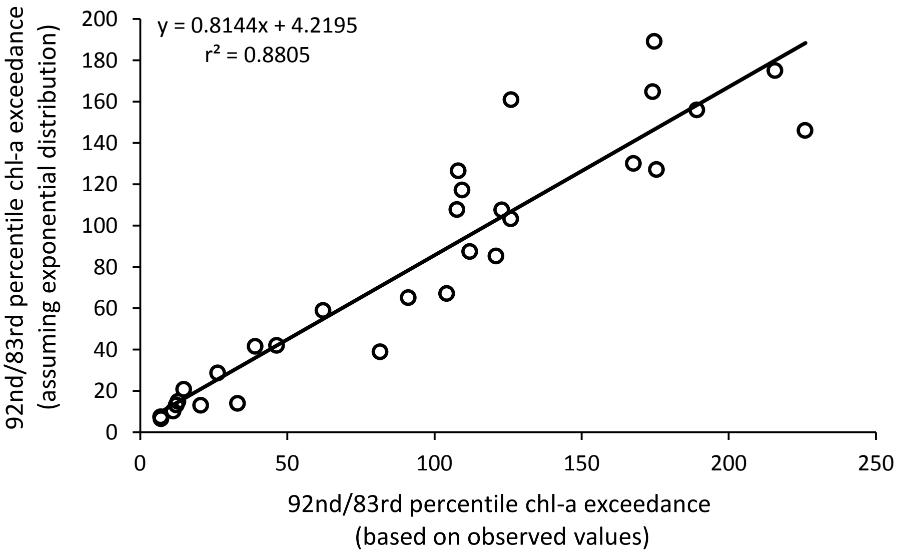

Figure 8: Relationship of 92nd/83rd percentile chl-a from the observed chl-a values and estimated using the exponential distribution.

4.3. Comparison of annual and monthly chl-a

4.3.1 92nd/83rd percentile chl-a

Comparison of annual and monthly 92nd/83rd percentile chl-a, for 19 sites is presented in Table 4 and Figure 9. Sixteen out of 19 sites had higher 92nd/83rd percentiles of chl-a using the annual monitoring data than using the monthly monitoring data. Furthermore, 12 out of 19 sites would classified into a different NOF band. Annual chl-a data estimated lower 92nd/83rd percentile chl-a than the monthly data at only three sites: Lill Burn at Lill Burn-Monowai Road, Longridge Stream at Sandstone and Waiau River at Tuatapere.

Table 4: Comparison of NPS-FM periphyton attribute state classification for 19 sites at which both annual and monthly frequency monitoring data were available. *Productive class

Site	92nd/83rd percentile chl-a (mg m^{-2}) (Annual)	92nd/83rd percentile chl-a (mg m^{-2}) (Monthly)	NOF – band category
Waikaia River u/s Piano Flat	47.6	7	Band A
Irthing Stream at Ellis Road	13.9	8	
Mataura River at Gore	61.7	10	
Cromel Stream at Selbie Road	33.9	13	
Wairaki River ds Blackmount Road	20.9	14	
Otamita Stream at Mandeville	20.4	15	
Dunsdale Stream at Dunsdale Reserve	117.7	29	
Waikawa River at Progress Valley	158.6	42	
Upukerora River at Te Anau Milford Road	128.4	65	Band B
Otautau Stream at Otautau-Tuatapere Road*	167.9	103	
Waikaka Stream at Gore*	175.1	108	
Mararoa River at Weir Road	121.4	117	
Waimea Stream at Mandeville	216.1	127	Band C
Lill Burn at Lill Burn-Monowai Road	109.3	137	
Aparima River at Thornbury	179.6	146	
Mataura River at Mataura Island Bridge	281.6	156	
Longridge Stream at Sandstone	87.7	161	
Dipton Stream at South Hillend-Dipton Road	258.4	175	
Waiau River at Tuatapere	171	189	

Band A (defined by 92nd/83rd percentile chl-a < 50 mg m^{-2})

Band B (defined by 92nd/83rd percentile chl-a 50 - 120 mg m^{-2})

Band C (defined by 92nd/83rd percentile chl-a 120 - 200 mg m^{-2})

Band D (defined by 92nd/83rd percentile chl-a > 200 mg m^{-2})

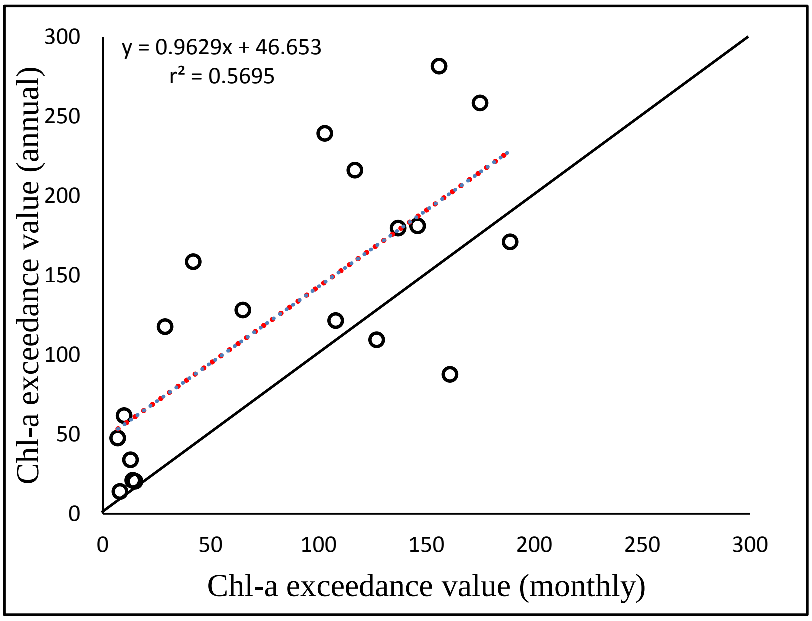

Figure 9: Relationship between annual and monthly 92nd/83rd percentile chl-a values. Black line indicates 1:1 relationship. Dotted line indicates linear relationship between annual and monthly chl-a values.

4.3.2 Comparison of means for annual frequency vs monthly frequency data.

Eight of the 19 sites (42%) had significantly higher mean chl-a using annual data than monthly mean chl-a biomass (Mann-Whitney U test, $p<0.05$) (Table 5). Sixteen of the 19 sites exhibited nominally higher mean chl-a for the annual monitoring data (average of 1.6 times higher) compared to monthly chl-a (Table 5).

Table 5: Comparison of annual and monthly mean chl-a. * Productive class.

Site	Annual		Monthly		p - value
	n	Mean	n	Mean	
Waikaia River u/s Piano Flat	15	18.9	25	2.6	< 0.01
Irthing Stream at Ellis Road	16	5.5	32	3	0.07
Mataura River at Gore	8	24.4	19	4.1	< 0.05
Cromel Stream at Selbie Road	14	13.4	31	5.2	0.28
Wairaki River ds Blackmount Road	14	8.3	24	5.6	< 0.05
Otamita Stream at Mandeville	13	8.1	30	5.9	0.5
Dunsdale Stream at Dunsdale Reserve	15	46.6	30	11.4	< 0.001
Waikawa River at Progress Valley	16	62.8	21	16.5	< 0.001
Upukerora River at Te Anau Milford Road	13	50.8	27	25.8	0.14
Otautau Stream at Otautau-Tuatapere Road	14	94.7	22	40.9	< 0.01
Mararoa River at Weir Road	13	48.1	18	46.5	0.78
Waimea Stream at Mandeville	16	85.5	29	50.3	0.13
Lill Burn at Lill Burn-Monowai Road	16	43.3	20	54.1	0.56
Aparima River at Thornbury	13	71.1	23	57.9	0.31
Waikaka Stream at Gore*	14	98.8	22	60.8	0.2
Mataura River at Mataura Island Bridge	14	111.5	18	61.8	< 0.05
Longridge Stream at Sandstone	6	34.7	15	63.8	0.11
Dipton Stream at South Hillend-Dipton Road	12	102.3	29	69.3	< 0.01
Waiau River at Tuatapere	11	67.7	23	74.9	0.05

4.4. Comparison of periphyton AFDM and percentage cover with Southland Water and Land Plan (2018) standards

Out of 19 sites, six (32%) exceed the Southland Water and Land Plan (2018) AFDM threshold value of 35 g AFDM m^{-2}. Thresholds for periphyton percentage cover was exceeded at 15 sites (79%) (Fig. 10 and 11, Table 6).

Table 6: AFDM (g m^{-2}) and percentage cover of periphyton at 30 monthly biomonitoring sites (3 years maximum) compliance with the Southland Water and Land Plan (2018) periphyton thresholds. Green – "Pass", Red – "Fail", Grey – "Not applicable"

Site	Waterbody classification	AFDM[a]	Periphyton % cover		
		g m^{-2}	Thick Mat[b] (> 3 mm)	Long filamentous[c] (> 20 mm)	Overall pass/fail
Aparima River at Thornbury	Lowland hard bed	33	35	49	
Cromel Stream at Selbie Road	Hill[#]	39	58	64	
Dipton Stream at South Hillend-Dipton Road	Lowland hard bed	119	72	36	
Dunsdale Stream at Dunsdale Reserve	Natural state Waters	15	1	1	
Hamilton Burn at Affleck Road	Lowland hard bed	29	24	40	
Hedgehope Stream 20m u/s Makarewa Confluence	Lowland soft bed	42	8	52	
Irthing Stream at Ellis Road	Hill[#]	7	4	2	
Lill Burn at Lill Burn-Monowai Road	Lowland soft bed	121	68	47	
Longridge Stream at Sandstone	Lowland hard bed	60	1	59	
Makarewa River at Counsell Road	Lowland soft bed	33	12	41	
Mararoa River at Weir Road	Hill[#]	39	81	65	
Mataura River at Gore	Hill[#]	9	14	2	
Mataura River at Mataura Island Bridge	Lowland hard bed	27	79	77	
Mimihau Stream at Wyndham	Lowland soft bed	35	16	51	
Orauea River at Orawia Pukemaori Road	Lowland soft bed	39	69	14	
Oreti River at Branxholme	Lowland hard bed	21	9	36	
Oreti River at Three Kings	Hill[#]	51	63	14	
Otamita Stream at Mandeville	Lowland soft bed	16	7	0	
Otautau Stream at Otautau-Tuatapere Road	Lowland hard bed	16	1	74	
Upukerora River at Te Anau Milford Road	Hill[#]	23	68	5	
Waiau River at Tuatapere	Lake Fed	151	85	25	
Waikaia River at Waikaia	Hill[#]	24	68	3	
Waikaia River u/s Piano Flat	Mountain	17	61	68	
Waikaka Stream at Gore	Lowland soft bed	35	51	83	
Waikawa River at Progress Valley	Lowland soft bed	30	7	11	
Waimatuku Stream at Waimatuku Township Road	Lowland hard bed	45	2	97	
Waimea Stream at Mandeville	Lowland hard bed	28	3	27	
Wairaki River ds Blackmount Road	Hill[#]	12	27	15	
Waituna Creek at Marshall Road	Lowland soft bed	141	21	19	
River d/s Manapouri-Hillside	Hill[#]	35	44	36	

Thresholds
[a] AFDM > 35 g m^{-2}
[b] Thick mat (> 3mm) > 60%
[c] Long filamentous (> 2 cm) > 30 %
[#] The pSWLP specifies AFDM > 35 g m^{-2} from filamentous algae only, however we are unable to sample filamentous algae independently of cyanobacteria or diatoms. Therefore comparisons are against total AFDM.

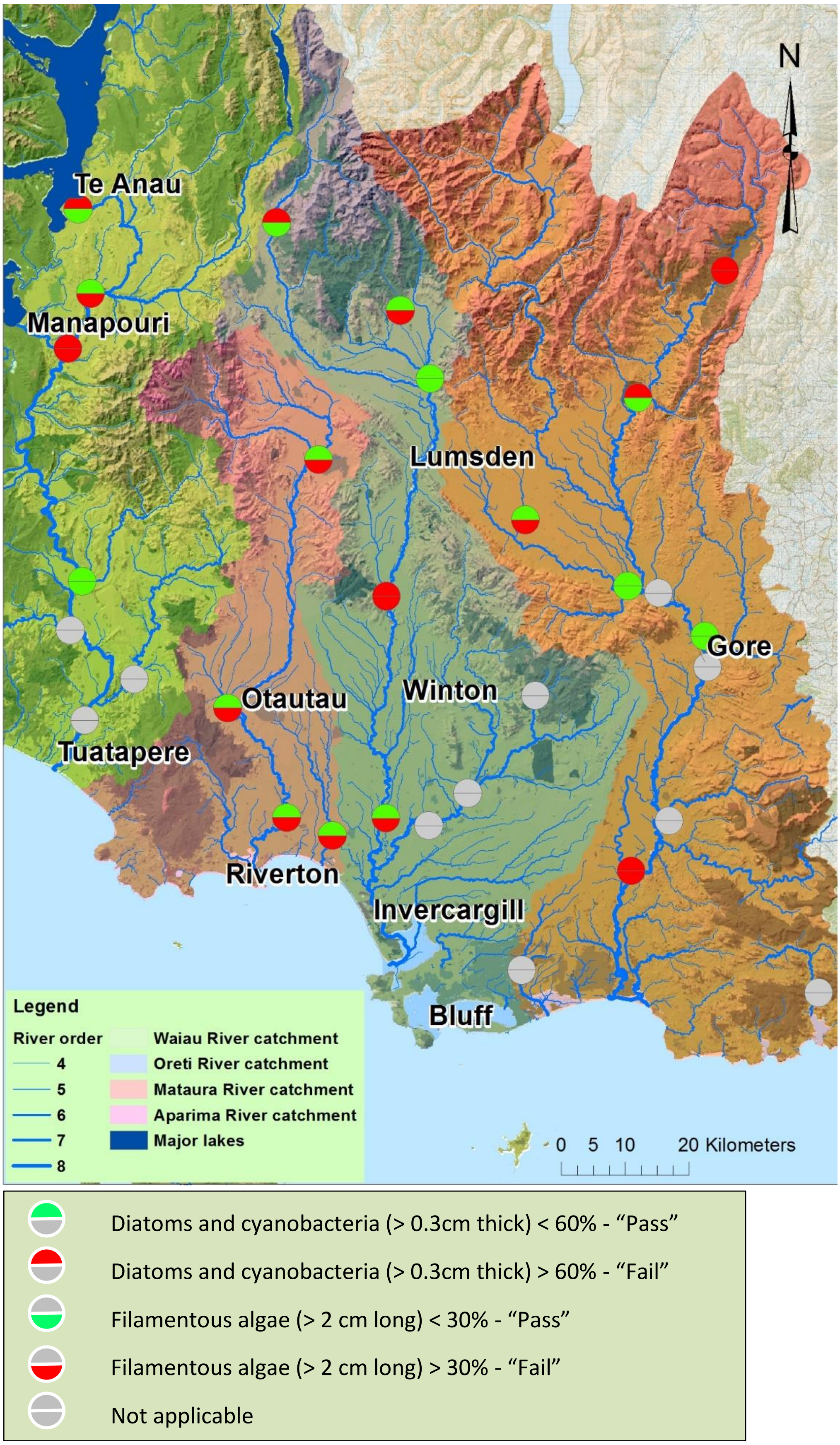

Figure 10: Compliance with Southland regional Water and Land Plan (2018) percentage cover of periphyton (maximum) thresholds for the time period of 2015 – 2017, Green – “Pass”, Red – “Fail”.

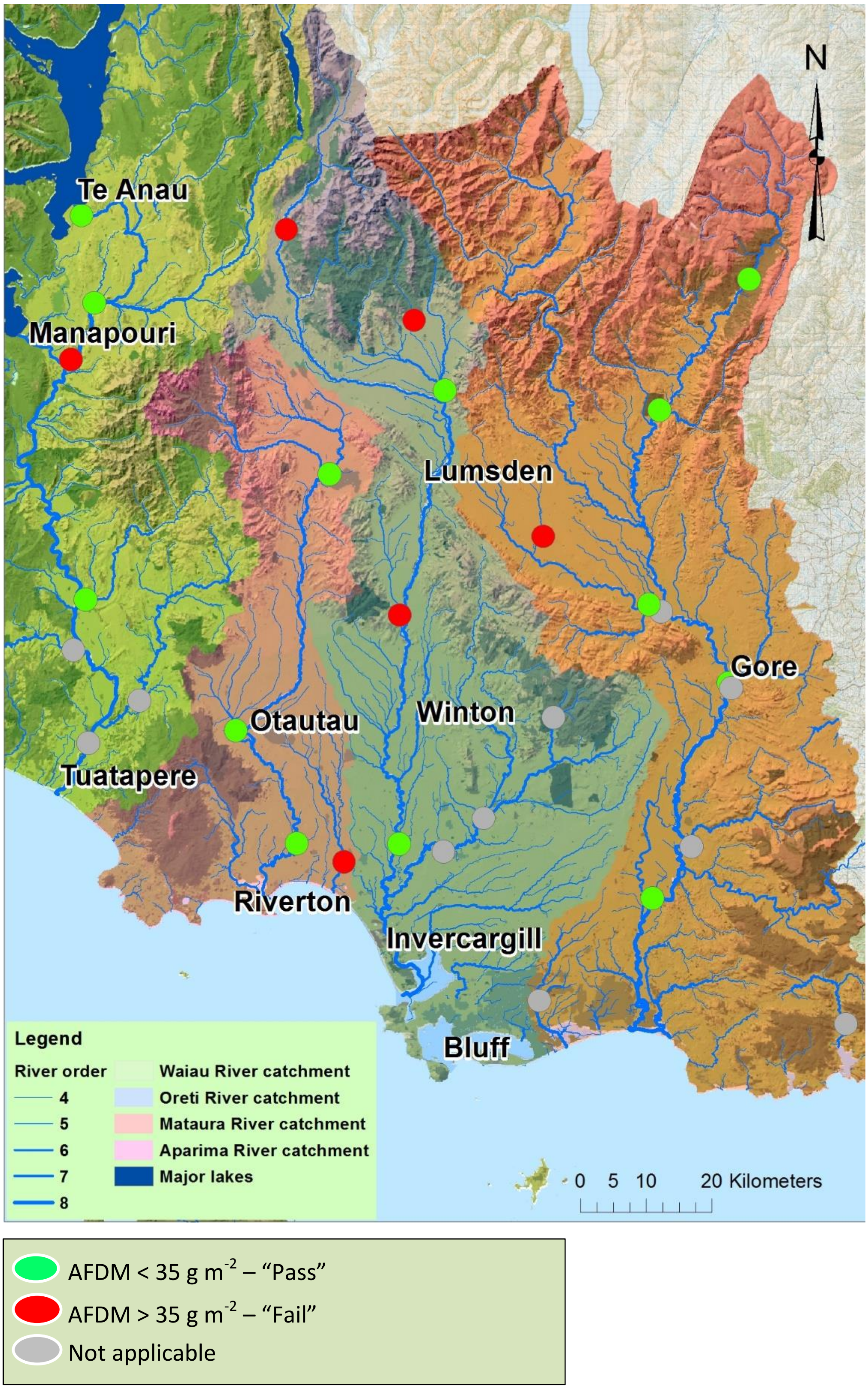

Figure 11: Compliance with Southland regional Water and Land Plan (2018) maximum AFDM (g m^{-2}) (maximum) thresholds for the time period of 2015 – 2017, Green – "Pass", Red – "Fail".

5. Discussion

5.1. Comparison of annual and monthly monitoring data

Comparison of annual and monthly $92^{nd}/83^{rd}$ percentiles of chl-a at 19 sites with both frequencies of data showed that estimates derived from annual-frequency monitoring were, on average, 1.6 times higher than those from monthly frequency monitoring. As a result, 12 out of 19 sites classified into different NOF band categories based on two monitoring methods (Table 3). Nominally higher $92^{nd}/83^{rd}$ percentiles of chl-a and mean chl-a for annual monitoring data could be attributed to collection of the annual data during the summer period only. As a result the date was biased towards high periphyton abundance, because highest abundance is generally recorded in summer (Kilroy et al., 2017). The outcome is an apparent over-estimation of chl-a from estimates based on the annual mean from annual frequency data compared to the mean chl-a estimated from monthly monitoring data. Consequently, the number of streams and rivers that are classified into the NPS-FM D-band for periphyton based on annual chl-a monitoring data is likely to be overestimated. For this reason we focused the remainder of the discussion on estimates of state from monthly frequency data.

We acknowledge the limitations of this comparison, specifically that comparison of site mean for annual and monthly frequency data are based on data collected from different time periods (annual; 2001–2017, monthly; 2015–2017). We have chosen to provide the comparison in the face of these limitations in an attempt to quantify the reliability of estimates for the annual data set because:

- the annual data set represents considerable investment of monitoring resources over time;
- the annual data set provides greater spatial representation; and
- this has been the basis of previous assessments of the state of periphyton in the Southland region (Snelder et al., 2013 and Environment Southland, 2015).

5.2. Current state of Southland streams and rivers: in terms of both the NOF periphyton attributes and Southland Water and Land Plan (2018) guidelines

Periphyton is one of seven attributes included in the National Objective Framework (NOF) of New Zealand's National Policy Statement for Freshwater Management 2017 (New Zealand Government 2017) to ensure the maintenance of healthy freshwater ecosystems.

Periphyton state determined from monthly chl-a data demonstrated that 30 of 30 sites within 27 different streams and rivers are likely to be within the NOF band range of A – C. While none of the sites are classified in the band - D category based on the existing data, seven of have an upper prediction value in the D band illustrating uncertainty with respect to their state classification, and risk they may be in the D band. Continued monitoring effort will improve our understanding of their respective site state band.

Examination of periphyton AFDM and percentage cover data at 19 monthly monitoring sites against the Southland Water and Land Plan (2018) illustrated that 68% (Fig. 11) are compliant with the AFDM threshold defined in the proposed Southland Water and Land Plan (2018), while only 21% of sites are compliant with periphyton percentage standards (Fig 10). 32% and 79 % of the sites failed the respective AFDM and percentage cover standards in the proposed Southland Water and Land Plan.

The proposed Southland Water and Land Plan provides a number of management units with standards that vary by unit to protect respective values. One unit included is the “Lowland soft bed” (L.S.B.) unit, which has no standards for periphyton applied. Eleven sites in the current monthly monitoring programme’s 30 sites are classified as L.S.B., however field observations have revealed that these river reaches have hard gravel substrates which support conspicuous periphyton growth and permit the collection of benthic chl-a data. Therefore we recommend a regional survey of river systems currently defined as L.S.B. is conducted to validate the management unit classification currently applied.

It was not possible to assess compliance with the chl-a standards in the proposed Southland Water and Land Plan. The wording in the plan provides chl-a standard with respect to filamentous algae or diatom/cyanobacteria separately. However, in practice chl-a measurements reflect a combination of algae types present at any one time. It is not possible to confidently sample different types of periphyton independently as they grow in complex community assemblages on the benthic substrate. We therefore recommend that the wording of the standards be reconsidered.

We are conscious that through the limit setting process the community may identify additional locations where periphyton does or could impact ecological, recreational, and cultural values where it would be valuable to monitor periphyton. As such, consideration should be given to reviewing chl-a monitoring programmes. Consideration could be given to representativeness of the 30 monthly sites, optimal use of resources from the annual programme.

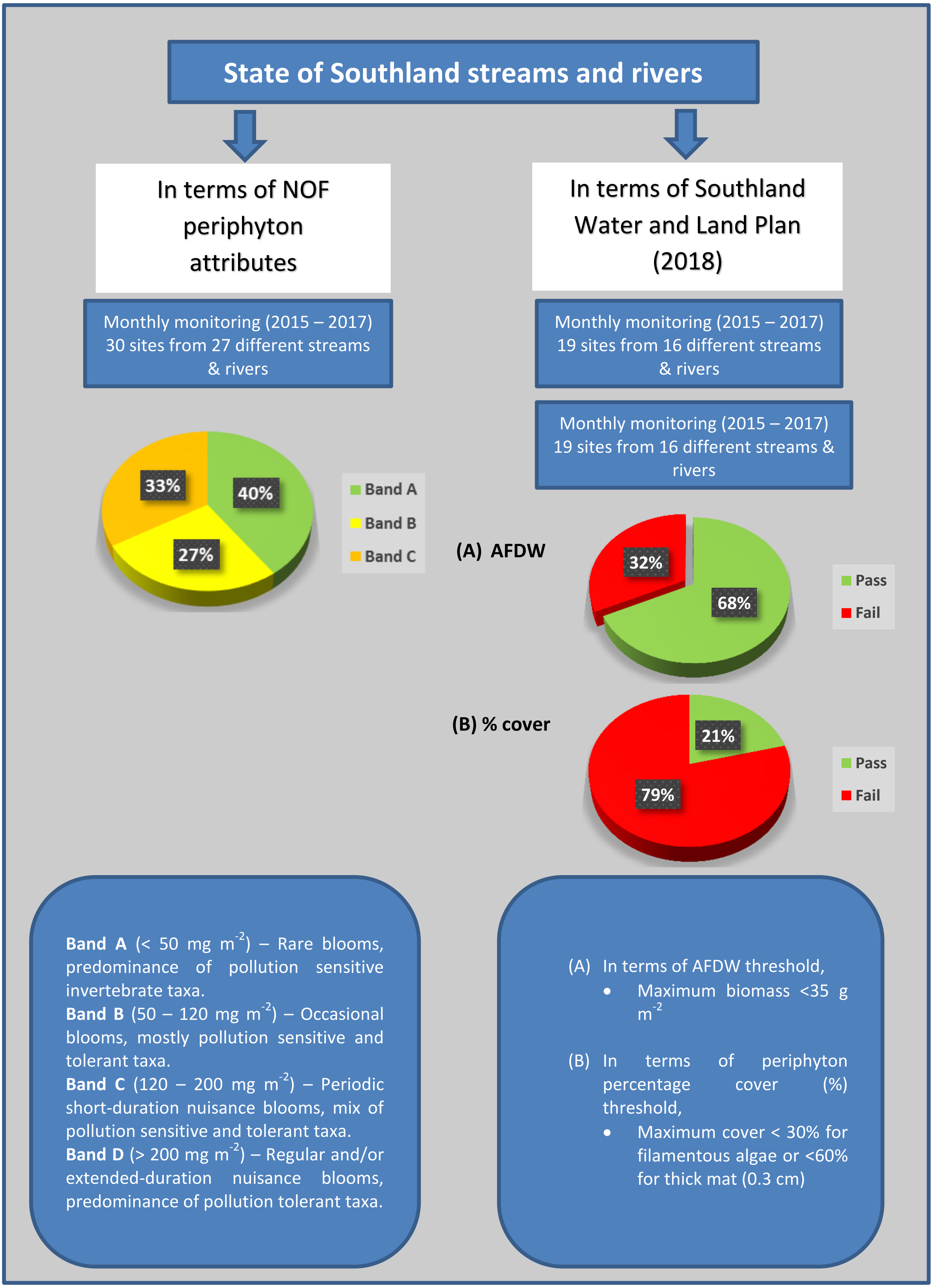

Figure 12: Summary diagram - State of Southland streams and rivers in terms of both the NOF periphyton attribute and Southland regional Water and Land Plan (2018) guidelines.

5.3. Recommendations

We recommend that future monitoring and assessment of periphyton in Southland:

1. uses monthly frequency data to assess the state of a river or stream's ecosystem health with respect to periphyton attribute in the NPS-FM;

2. continues monthly frequency periphyton biomass (chl-a and AFDM) and percentage cover assessment as ongoing monthly monitoring is required for:
   (a) a more robust assessment of periphyton biomass in Southland streams and rivers, including reduced uncertainty;
   (b) assessment of Southland streams and rivers water quality compliance with the pSWLP (2018);
   (c) assessment of changes in periphyton biomass over time; and
   (d) developing Southland specific nutrient management criteria for periphyton.

3. review the monthly monitoring programme network design including site numbers and locations. Ideally conduct review in partnership with key stakeholders to ensure that all 'important' locations representing identified values, FMU's are adequately represented;

4. revise the narrative chl-a thresholds defined in the pSWLP (2018) as there are practical difficulties with making measurement directly against the wording in the plan. Specifically:
   (a) the sampling chl-a associated with a single type of periphyton (filamentous or diatom/cyanobacteria) is not practical where filamentous algae, diatom and cyanobacteria co-exist in close proximity and are unable to practically be sampled independently;
   (b) refer to the biomass or mean cover in the wadeable area rather than the full river width. It is not possible to sample the full river width of the larger main stem rivers owing to depths greater than 0.7 m, or high water velocity;
   (c) conduct a regional survey of river systems currently defined as Lowland Soft Bed to validate the management unit classification currently applied;

5. as a minimum use monthly frequency data as the basis to further develop periphyton-nutrient relationships to set limits (not discussed in this report). Specifically assess the relationships with DIN and DRP to provide guidance on the development of instream concentration criteria to minimise the risk of nuisance instream periphyton growth, which are now a requirement in the NPS-FM with respect to periphyton.

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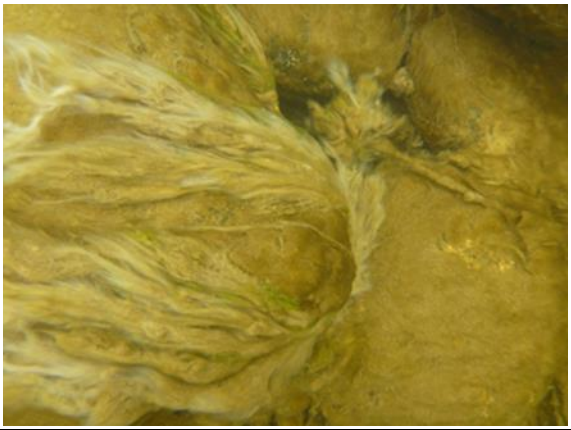
7. Appendices

Appendix 1: Categories of periphyton for visual assessment

Categories of periphyton	
Long filaments (more than 2 cm long)	
	
Short filaments (less than 2 cm long)	
	
Thick mat (more than 3 mm thick)	
	

Thin mat/film (less than 0.5 mm thick)	
	
Cyanobacteria (group of photosynthetic bacteria, some of which are nitrogen fixing. They range from unicellular to filamentous and include colonial species)	
	
Didymo (*Didymosphenia geminate*, stalked diatom typically occur in rivers with low nutrient concentrations. They produce thick smothering mats covering large proportions of the river bed. First discovered in the Waiau River, Southland)	
	

Sludge (loose and easily dislodged compared to mats. Oftern in slower moving water)	
	

Appendix 2: Field sheet used to record percentage cover of each periphyton category

Stick label for site name and sample number here

Transcect 1 (Downstream)

Technicians:
Start Time NZST:
Date:
Entered:
Checked:

Wetted width (m):
Channel width (m):

Macrophytes (measure if cover >5%) View of entire width 1m u/s of transect

	Surface (%)	Depth (%)	Surface (m^2)	Species
Emergent Macrophytes: (Also sprawling emergent with 100% depth)	,	N/A		EC PK Po Rt Na Gf Mg Pv
Submerged Macrophytes:				
Surface Reaching		N/A		EC PK Po Rt Na Gf Mg Pv
Below Surface (Also sprawling emergent with <100% depth)				EC PK Po Rt Na Gf Mg Pv

	View 1	View 2	View 3	View 4	View 5
Depth [m]					
Velocity (@ 0.6d) 20sec					
Densiometer (0.3m above H_2O surface) (# of dots occupied out of 96)					
PAR at bed [µmol s^{-1} m^{-2}]					

Periphyton: Rock Observation (% Cover from each view)

Each column in the table below should not exceed 100%

Sludge (slimy coatings that easily fall apart)					
Thin mat/film (<0.5mm)					
Medium mat (0.5-3mm)					
Thick mat (>3mm)					
Short filaments (≤ 2cm)					
Long Filaments (>2cm)					
Cyanobacteria					
Didymo					
Sediment <2mm (% Cover)					

Comments

Transect 4

Finish Time NZST:
Settled Depth (mm):
Wetted width (m):
Channel width (m):

Macrophytes (% Cover >5%) View of entire width 1m u/s of transect

	Surface (%)	Depth (%)	Surface (m^2)	Species
Emergent Macrophytes: (Also sprawling emergent with 100% depth)		N/A		EC PK Po Rt Na Gf Mg Pv
Submerged Macrophytes: Surface Reaching		N/A		EC PK Po Rt Na Gf Mg Pv
Below Surface (Also sprawling emergent with <100% depth)				EC PK Po Rt Na Gf Mg Pv

Canadian Pondweed (Ec), Curled pondweed (Pk), Blunt pondweed (Po), Water buttercup (Rt), Water cress (Na), Floating Sweet Grass (Gf), Monkey musk (Mg), Potato vine (Pv)

	View 1	View 2	View 3	View 4	View 5
Depth [m]					
Velocity (@ 0.6d) 20sec					
Densiometer (0.3m above H_2O surface) (# of dots occupied out of 96)					
PAR at bed [µmol s^{-1} m^{-2}]					

Periphyton: Rock Observation (% Cover from each view)

Each column in the table below should not exceed 100%

Sludge (slimy coatings that easily fall apart)					
Thin mat/film (<0.5mm)					
Medium mat (0.5-3mm)					
Thick mat (>3mm)					
Short filaments (≤ 2cm)					
Long Filaments (>2cm)					
Cyanobacteria					
Didymo					
Sediment <2mm (% Cover)					

Comments

Transect 3

Wetted width (m):

Channel width (m):

Macrophytes (% Cover >5%) View of entire width 1m u/s of transect

	Surface (%)	Depth (%)	Surface (m^2)	Species
Emergent Macrophytes: (Also sprawling emergent with 100% depth)		N/A		EC PK Po Rt Na Gf Mg Pv
Submerged Macrophytes:				
Surface Reaching		N/A		EC PK Po Rt Na Gf Mg Pv
Below Surface (Also sprawling emergent with <100% depth)				EC PK Po Rt Na Gf Mg Pv

Canadian Pondweed (Ec)
Curled pondweed (Pk)
Blunt pondweed (Po)
Water buttercup (Rt)
Water cress (Na)
Floating Sweet Grass (Gf)
Monkey musk (Mg)
Potato vine (Pv)

	View 1	View 2	View 3	View 4	View 5
Depth [m]					
Velocity (@ 0.6d) 20sec					
Densiometer (0.3m above H_2O surface) (# of dots occupied out of 96)					
PAR at bed [µmol s^{-1} m^{-2}]					

Periphyton: Rock Observation (% Cover from each view)

Sludge (slimy coatings that easily fall apart)					

Each column in the table below should not exceed 100%

Thin mat/film (<0.5mm)					
Medium mat (0.5-3mm)					
Thick mat (>3mm)					
Short filaments (≤ 2cm)					
Long Filaments (>2cm)					
Cyanobacteria					
Didymo					
Sediment <2mm (% Cover)					

Comments

Transect 2

Wetted width (m):

Channel width (m):

Macrophytes (% Cover >5%) View of entire width 1m u/s of transect

	Surface (%)	Depth (%)	Surface (m^2)	Species
Emergent Macrophytes: (Also sprawling emergent with 100% depth)		N/A		EC PK Po Rt Na Gf Mg Pv
Submerged Macrophytes:				
Surface Reaching		N/A		EC PK Po Rt Na Gf Mg Pv
Below Surface (Also sprawling emergent with <100% depth)				EC PK Po Rt Na Gf Mg Pv

Canadian Pondweed (Ec)
Curled pondweed (Pk)
Blunt pondweed (Po)
Water buttercup (Rt)
Water cress (Na)
Floating Sweet Grass (Gf)
Monkey musk (Mg)
Potato vine (Pv)

	View 1	View 2	View 3	View 4	View 5
Depth [m]					
Velocity (@ 0.6d) 20sec					
Densiometer (0.3m above H_2O surface) (# of dots occupied out of 96)					
PAR at bed [µmol s^{-1} m^{-2}]					

Periphyton: Rock Observation (% Cover from each view)

Sludge (slimy coatings that easily fall apart)					

Each column in the table below should not exceed 100%

Thin mat/film (<0.5mm)					
Medium mat (0.5-3mm)					
Thick mat (>3mm)					
Short filaments (≤ 2cm)					
Long Filaments (>2cm)					
Cyanobacteria					
Didymo					
Sediment <2mm (% Cover)					

Comments

Appendix 3: Descriptive statistics, 92nd (default) and 83rd (productive) exceedance value of the annual benthic chl – a (excluding uncertainty in state classification) of 74 sampling sites. Data were collected during the period of 2001 to 2017. 92nd /83rd percentile exceedance value of chl – a biomass was calculated based on mean and exponential distribution. *Productive class

Site	n	Min	Mean	Median	Max	n > 200 mg m^{-2}	92nd/83rd percentile chl-a exceedance value	NOF – band category
Aparima River u/s Dunrobin	10	0.1	1.6	1.3	3.9	0	4.0	Band A
Mataura River d/s Robert Creek confluence	11	0.3	2.5	1.6	7.8	0	6.4	
McKay Creek at Milford Road	11	0.3	3.0	2.2	8.3	0	7.5	
Irthing Stream at Ellis Road	16	0.2	5.5	4.1	25.9	0	13.9	
Eglington River at McKay Creek Confluence	12	0.3	5.6	5.5	14.3	0	14.1	
Oreti River at Benmore	16	0.5	7.2	3.3	28.3	0	18.2	
Mataura River at Garston	7	3.4	7.5	6.9	10.3	0	18.9	
Pourakino River at Jubilee Hill Road	11	1.6	7.8	6.6	18.3	0	19.7	
Hedgehope Stream at Block Road*	10	0.5	10.9	8.8	25.5	0	20.1	
Otamita Stream at Mandeville	13	2.1	8.1	5.4	26.5	0	20.4	
Wairaki River at Blackmount Road	14	0.9	8.3	5.7	22.9	0	20.9	
Oreti River at McKellars Flat	10	0.5	10.2	3.1	66.3	0	25.9	
North Etal Stream u/s Dunrobin Valley Rd	13	0.6	11.0	9.0	51.8	0	27.9	
Cromel Stream at Selbie Road	14	0.1	13.4	4.1	58.5	0	33.9	
Mataura River at Parawa	16	0.5	14.0	6.8	66.3	0	35.3	
Murray Creek at Double Road	9	3.2	14.6	16.3	24.7	0	36.9	
Oteramika Stream at Seaward Downs*	12	3.2	22.1	13.8	75.8	0	39.2	
Pig Creek at Borland Lodge	13	0.2	17.2	16.9	48.8	0	43.3	
Cascade Creek at Pourakino Valley Road	11	2.4	17.4	16.3	72.3	0	44.1	
Mataura River at Otamita Bridge	7	2.1	18.4	8.2	84.4	0	46.5	
Oreti River at Lumsden Bridge	13	0.8	18.5	3.7	180.8	0	46.8	
Waikaia River u/s Piano Flat	15	0.0	18.9	8.2	126.6	0	47.6	
Waikaia River at Waipounamu Bridge Road	16	0.3	19.9	5.6	120.6	0	50.1	

Site	n	Min	Mean	Median	Max	n > 200 mg m^{-2}	$92^{nd}/83^{rd}$ percentile chl-a exceedance value	NOF – band category
Thicket Burn at Lake Hauroko	12	4.6	20.1	14.6	44.6	0	50.8	Band B
Mokoreta River at Egremont Road	10	2.2	20.6	9.3	78.4	0	52.0	
Mararoa River at Mararoa Road Bridge	11	0.4	20.9	12.1	112.1	0	52.9	
Aparima River at Wreys Bush	11	0.5	22.4	13.3	81.5	0	56.5	
Mararoa River at South Mavora Lake	6	3.6	23.3	15.1	61.1	0	58.8	
Mataura River at Gore	8	2.2	24.4	7.3	145.5	0	61.7	
Mimihau Stream Tributary at Venlaw Forest	13	3.2	25.4	16.7	84.4	0	64.1	
Brightwater Spring West at Garston Kings	10	0.8	26.8	27.9	78.4	0	67.7	
Mararoa River at Kiwiburn	12	0.7	29.7	21.5	112.0	0	75.1	
Hamilton Burn at Goodall Road	14	1.1	32.4	14.6	174.8	0	81.9	
Waituna Creek 30m upstream Gorge Road-Invercargill Highway*	8	7.1	47.3	38.9	115.0	0	86.7	
Longridge Stream at Sandstone	6	8.4	34.7	31.5	63.3	0	87.7	Band C
Waimeamea River at Young Road	13	3.3	36.7	35.4	108.5	0	92.7	
Taringatura Creek at Taromaunga	14	2.4	37.0	41.6	72.3	0	93.5	
Mataura River at Keowns Road Bridge	12	2.4	40.7	14.7	198.9	0	102.8	
Waihopai River u/s Queens Drive	13	6.3	41.1	28.5	120.6	0	103.8	
Lill Burn at Lill Burn-Monowai Road	16	2.1	43.3	22.1	193.5	0	109.3	
Dunsdale Stream at Dunsdale Reserve	15	2.1	46.6	30.3	159.7	0	117.7	
Mararoa River u/s Weir Road	13	2.1	48.1	51.2	91.7	0	121.4	
Upukerora River at Te Anau-Milford Road	13	3.0	50.8	27.5	194.0	0	128.4	
Murray Creek at Cumming Road	11	7.8	51.0	25.3	132.6	0	128.7	
Hillpoint Stream at Waikana Road	14	4.6	51.2	53.3	124.2	0	129.4	
Waianiwa Creek 1 at Lornville Riverton Highway*	12	18.3	72.8	67.5	142.6	0	133.4	
Waiau River 100m u/s Clifden Bridge	12	1.2	53.9	37.9	168.8	0	136.2	
Waiau River at Duncraigen Road	7	12.7	59.0	66.3	114.5	0	149.0	
Oreti River at Wallacetown	16	5.8	60.5	30.8	361.7	1	152.7	

Site	n	Min	Mean	Median	Max	n > 200 mg m^{-2}	92nd/83rd percentile chl-a exceedance value	NOF – band category
Trenders Creek at Hall Road	12	6.2	61.7	40.5	193.5	0	155.8	
Waikawa River at Progress Valley	16	7.2	62.8	38.5	211.0	1	158.6	
Waikopikopiko Stream at Haldane CurioBay	13	1.8	65.6	36.7	301.4	1	165.8	
Home Creek at Manapouri	14	4.2	65.9	28.0	427.7	1	166.5	
Otautau Stream at Otautau-Tuatapere Road*	14	19.1	94.7	74.0	253.2	1	167.9	
Pourakino River at Ermedale Road	12	8.5	67.0	56.7	192.9	0	169.2	
Waiau River u/s Tuatapere	11	5.0	67.7	52.0	169.7	0	171.0	
Otapiri Stream at Anderson Road	16	6.2	68.2	65.0	156.7	0	172.1	
Mimihau Stream at Mimihau School Road	11	4.1	68.8	61.5	134.0	0	173.7	
Mokoreta River at Wyndham River Road	16	3.6	69.0	72.5	192.9	0	174.3	
Makarewa River at King Road	12	4.9	70.4	60.1	162.8	0	177.9	
Aparima River at Thornbury	13	0.3	71.1	36.1	244.5	1	179.6	
Waikaka Stream at Gore*	14	16.0	98.8	71.0	415.9	1	181.1	
Bog Burn d/s Hundred Line Road	6	33.3	74.4	78.4	102.5	0	188.0	
Waimatuku Stream at Lorneville Riverton Hwy	12	3.3	76.4	41.4	349.6	1	192.9	
Makarewa River at Winton - Hedgehope Hwy*	10	16.3	109.1	110.0	277.3	1	199.9	
Waimea Stream at Mandeville	16	4.8	85.6	30.8	356.4	3	216.1	Band D
Winton Stream at Lochiel	16	9.7	88.6	84.7	229.1	1	223.8	
Waihopai River at Waihopai Dam	6	42.4	92.3	104.3	130.3	0	233.1	
Mataura River 200m d/s Mataura Bridge	16	13.9	98.8	91.9	307.4	1	249.6	
Rowallan Burn East at Rowallan Road	13	6.9	99.4	78.4	193.5	0	251.1	
Makarewa River at Wallacetown*	13	6.6	139.7	78.4	468.4	3	256.1	
Dipton Stream at South Hillend Road	12	2.7	102.3	100.6	204.0	1	258.4	
Silver Stream at Lora Gorge Road	16	12.2	106.0	113.3	213.8	2	267.8	
Mataura River at Mataura Island Bridge	14	27.5	111.5	93.7	271.2	2	281.6	

Band A Band B Band C Band D

Appendix 4: Descriptive statistics, 92nd (default) and 83rd (productive) exceedance value of the monthly benthic chl – a of sample sites. Data were collected during the period of 2015 to 2017. 92nd/83rd percentile exceedance value of chl – a biomass was calculated based on mean and exponential distribution. *Productive class.

Site	n	Min	Mean	Median	Max	n > 200 mg m^{-2}	92nd/83rd percentile chl-a exceedance value	NOF – band category
Waikaia River u/s Piano Flat	26	0	2.6	1.6	15.7	0	7	Band A
Irthing Stream at Ellis Road	33	0	3.0	1.7	22.9	0	8	
Mataura River at Gore	20	0	4.1	2.3	11.5	0	10	
Cromel Stream at Selbie Road	31	0.01	5.2	2.9	39.2	0	13	
Waikaia River at Waikaia	25	0	5.3	1.5	60.3	0	13	
Wairaki River ds Blackmount Road	24	0.01	5.6	1.8	45.2	0	14	
Otamita Stream at Mandeville	30	0.02	5.9	4.7	33.2	0	15	
Hedgehope Stream 20m u/s Makarewa Confl*	24	0.01	11.7	2.4	120.6	0	21	
Dusdale Stream at Dusdale Reserve	30	0.02	11.4	10.1	39.2	0	29	
Whitestone River d/s Manapouri-Hillside	23	0.02	15.5	4.8	84.4	0	39	
Waikawa River at Progress Valley	21	0.03	16.5	10.3	39.2	0	42	
Orauea River at Orawia Pukemaori Road*	21	0	23.8	5.4	129.6	0	42	
Oreti River at Three Kings	30	0.04	23.3	16.9	90.4	0	59	Band B
Upukerora River at Te Anau Milford Road	28	0	25.8	13.6	123.6	0	65	
Hamilton Burn at Affleck Road	35	0.05	26.6	6.9	156.7	0	67	
Oreti River at Branxholme	18	0	33.8	21.6	147.7	0	85	
Waimatuku at Waimatuku Township Road	26	0	34.6	16.3	123.6	0	87	
Otautau Stream at Otautau-Tuatapere Road	22	2.95	40.9	30.9	138.6	0	103	
Mimihau Stream at Wyndham	22	0.09	42.6	27.1	198.9	0	108	
Waikaka Stream at Gore*	23	0.11	60.9	60.3	123.6	0	108	
Mararoa River at Weir Road	18	0.01	46.5	51.2	126.6	0	117	
Makarewa River at Counsell Road	20	0.02	50.1	58.8	292.3	1	127	
Waimea Stream at Mandeville	30	0.07	50.4	20.6	250.2	1	127	

Site	n	Min	Mean	Median	Max	n > 200 mg m^{-2}	92nd/83rd percentile chl-a exceedance value	NOF – band category
Lill Burn at Lill Burn-Monowai Road	20	0.24	54.1	51.2	301.4	3	137	Band C
Aparima River at Thornbury	24	0	57.9	16.1	195.9	0	146	
Mataura River at Mataura Island Bridge	18	0.01	61.8	45.2	204.9	1	156	
Longridge Stream at Sandstone	25	0.09	63.8	57.3	189.9	0	161	
Waituna Creek at Marshall Road	15	12.96	65.3	51.2	186.9	0	165	
Dipton Stream at South Hillend-Dipton Road	29	0.02	69.3	29.2	361.7	4	175	
Waiau River at Tuatapere	24	0	74.9	46.7	331.5	1	189	

Band A Band B Band C Band D