Instream plant and nutrient guidelines

Review and development of an extended decision-making framework
Phase 3

Prepared for Ministry of Business, Innovation and Employment Envirolink Fund

January 2016

Prepared by:
Fleur Matheson
John Quinn
Martin Unwin

With contributions from:
Karen Shearer, Cawthron Institute
John Hayes, Cawthron Institute
Cathy Kilroy, NIWA
Ton Snelder, AquaLinc
Doug Booker, NIWA
Annika Wagenhoff, Cawthron Institute
Suzie Wood, Cawthron Institute

For any information regarding this report please contact:
Dr Fleur Matheson
Biogeochemist
Aquatic Plants
+64-7-856 1776
fleur.matheson@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

NIWA CLIENT REPORT No:	HAM2015-064
Report date:	January 2016
NIWA Project:	ELF14247

Contents

Tables

Figures

Reviewed by	Approved for release by
Dr Craig Depree	Dr Chris Hickey

Formatting checked by

Executive summary

Regional authorities have been grappling with the requirement to develop water quality standards for instream nutrient concentrations for some time. The requirements of the National Policy Statement on Freshwater Management (NPS-FM) to set limits to protect instream values and manage within them has increased the importance of understanding the relationships between instream plants and a range of values and the effects of environmental factors on plant abundance, particularly when managing cumulative effects of point and non-point nutrient sources.

The aim of this Envirolink Tools project was to provide a decision-making framework to assist regional authorities to define defendable dissolved macronutrient concentrations (phosphorus, P; nitrogen, N) and instream plant abundances as water quality standards for a broad range of river types and hydrological regimes. The report on Phases 1 and 2 of the project reviewed past research, provided several advances, and reviewed the key outstanding gaps in the required framework for instream plant and nutrient management in the New Zealand context. This report describes Phase 3 of this project which aimed to carry out new research and provide a synthesis and improved coordination of existing related research in NIWA-led programmes and key regional authority projects.

The Phase 3 research sought to address key gaps in the instream plant guidelines to protect river values namely:

(i) effects of periphyton and macrophytes on suitability for trout angling and Māori cultural acceptability;

(ii) effects of periphyton on abundance of preferred stream invertebrate prey items of adult trout; and

(iii) refine relationships between periphyton and macroinvertebrate community metrics that are indicators of ecosystem health (MCI, QMCI and %EPT taxa).

The research also aimed to refine the generalised periphyton models developed in Phase 2 using an expanded national dataset by:

(i) investigating the use of seasonal average conditions of nutrients and other environmental drivers

(ii) evaluating semi-quantitative information from kick-net surveys as model input on macroinvertebrate grazer density, and

(iii) exploring whether light attenuation (K_d) can be effectively modelled based on flows and clarity or turbidity without the need to measure absorbance.

A research workshop was held early in the project to enhance synergies between the project and concurrent related research, discuss plans in detail, maximise linkages and to scope research summaries for inclusion in this report.

To examine the effects of periphyton and macrophytes on suitability for trout angling and Māori cultural acceptability two web-based acceptability surveys were developed and distributed. Unfortunately the “mahinga kai values” survey did not attract a sufficient number of responses to enable robust analysis of this dataset. The “angling values” survey results showed that angler

acceptability scores were significantly correlated to instream periphyton and macrophyte abundance. The existing trout fishery-angling guideline of periphyton filament cover (PERIFIL) of 30% corresponded to angler acceptability levels of 70 to 82% indicating that this existing guideline provides a high level of protection. Only a slightly lower level of angler acceptability was indicated for mat cover (PERIMAT) of 30%, suggesting that anglers were almost equally sensitive to cover of mats and filaments.

The survey results also indicated that the provisional instream macrophyte abundance guideline for protection of trout fishery-angling values (≤50% channel cross-sectional area/volume occupied; CAV) corresponded to relatively low levels of angler acceptability (31 to 37%) and that a very high level of angler acceptability (i.e., ≥95%) for the two macrophyte attributes CAV and WSA (percent water surface area occupied) was not achievable. The high level of angler dissatisfaction found in the survey with even relatively low levels of macrophyte abundance probably reflect the predominant angler group represented in the survey, i.e., trout fly anglers, with an underlying preference for cobble-bed rivers and a naturally low abundance of macrophytes. The findings indicate macrophyte CAV and WSA attribute states (A-D) that could be used under the National Objectives Framework (NOF) in relation to trout angler acceptability (Table 1-1).

Table 1-1: Summary table of updated macrophyte guidelines to protect trout fishery-angling values.

Attribute	Band/Class	Criteria[a]
% channel cross sectional area/volume (CAV)	A - Excellent	<10%
	B - Good	10-20%
	C - Fair	20-30%
	D - Poor	>30%
% channel water surface area (WSA)	A - Excellent	<5%
	B - Good	5-10%
	C - Fair	10-20%
	D - Poor	>20%

[a] as annual maximum (this will normally occur in summer during a period of stable flow).

To examine the effects of periphyton on the abundance of macroinvertebrate prey items for adult trout a prey item scoring system was developed which was applied to a national dataset. The system assigned scores to macroinvertebrate taxa as prey items for drifting feeding, benthic browsing and cruise feeding adult trout. Using time-matched periphyton and macroinvertebrate data we examined relationships between periphyton abundance and adult trout prey item availability indices. This analysis indicated several thresholds above which there was a drop in food availability, primarily for drift feeding. Those thresholds were chlorophyll *a* (CHLA) 200 mg/m^2, periphyton weighted composite cover (PERIWCC) 50% and PERIMAT 25%. These thresholds are broadly consistent with the existing guideline for protection of trout fishery-angling values of CHLA <200 mg/m^2 (as mats) and the provisional PERIWCC guideline of ≤55% as an indicator of fair or better ecological condition. However the relatively low PERIMAT threshold indicates a detrimental effect of mats in particular on drift item availability, not currently reflected in the existing periphyton guidelines. Combined with the results of the angler survey, these findings indicate periphyton cover attribute states (A-D) that could be used under the NOF of the NPS-FM in relation to angler acceptability (Table 1-2).

Table 1-2: Summary table of updated periphyton cover guidelines to protect trout-fishery values.

Attribute	Band/Class	Criteria [a]
% cover	A - Excellent	<10% of filaments >2cm long or mats >3mm thick or total cover[b] on visible stream bed in a reach
	B - Good	10-35% of filaments >2cm long or mats >3mm thick or total cover[b] on visible stream bed in a reach
	C - Fair	35-75% of filaments >2cm long or mats >3mm thick or total cover[b] on visible stream bed in a reach
	D - Poor	>75% of filaments >2cm long or mats >3mm thick or total cover[b] on visible stream bed in a reach

[a] 8% allowable frequency of exceedance based on monthly sampling for a minimum of 3 years.
[b] filaments >2cm long plus mats >3mm thick.

We also used this time-matched dataset to re-examine relationships between periphyton abundance and the well-known macroinvertebrate indices MCI, QMCI and %EPT TAXA. This analysis showed that the existing NOF CHLA and provisional PERIWCC "bottom line" thresholds for protection of ecosystem health and ecological condition corresponded to relatively high levels of concordance with equivalent "bottom-line" thresholds for these macroinvertebrate indices (i.e., "fair" category or higher), for %EPT TAXA and MCI in particular. However, the existing NOF CHLA and provisional PERIWCC good and excellent band thresholds corresponded with increasingly lower levels of concordance for the equivalent thresholds for the macroinvertebrate indices, respectively. The results suggest that the existing periphyton guidelines for protection of higher levels of ecosystem health/ecological condition may be insufficient if the latter is based on these macroinvertebrate community indices.

To evaluate the suitability of semi-quantitative information from macroinvertebrate kick-net surveys to be used alongside quantitative data from Surber sampling for calculation of macroinvertebrate densities, we compared the mean number of individuals and taxa among fixed area Surber, fixed area kicknet and approximate area kicknet sampling groups. Our comparison of semi-quantitative (kick-net) vs. quantitative (Surber) macroinvertebrate datasets indicated significant differences in macroinvertebrate densities between some datasets (but not others). The results suggest that it may be possible to use kicknet sampling data in models designed for use with quantitative data but care needs to be taken to ensure that macroinvertebrate densities in the kicknet datasets are equivalent to those typically found in Surber datasets before proceeding.

We explored relationships between K_d, clarity, turbidity and flow variables using the National Rivers Water Quality Network (NRWQN) dataset and linear regression. This analysis showed highly significant relationships between clarity/turbidity and K_d (calculated not directly measured). However sample size was very large. There was little variation in these relationships when sites were segregated by River Environment Classification (REC) climate class. Adding a scaled flow variable (square root of the flow percentile; SQRTflow%ile) did not improve the relationships. The results suggest that K_d might be approximated directly from clarity or turbidity readings without the need to measure absorbance or inclusion of a flow variable.

To investigate relationships between periphyton abundance and seasonal average conditions of nutrients and other environmental drivers we derived nutrient concentrations and water temperatures for specific time periods preceding each annual (summertime) periphyton sampling date. Relationships between periphyton abundance and these derived variables were analysed using linear regression and non-linear, non-parametric quantile regression.

Stepwise multiple linear regression analysis of an expanded national dataset (c.f. Phase 2) to identify predictors of periphyton abundance generated a number of significant models. However, the models only explained between 6 and 26% of the variation in PERIWCC, PERIFIL and PERIMAT. All models had a tendency to overestimate periphyton at observed very low levels and underestimate periphyton at observed moderate to high levels. Use of such models to generate nutrient criteria may therefore result in non-conservative values. The density of macroinvertebrate grazers, either certain species (in PERIFIL and PERIWCC models) or total taxa (in PERIMAT model), featured strongly in the models.

Quantile regression analysis generally indicated non-linear subsidy-stress relationships between (growing season) periphyton abundance and nutrient concentrations, which explains the relatively poor performance of multiple linear regression models for periphyton prediction. Using this approach we identified a set of general nutrient criteria for high-level (≥85%) compliance with the existing periphyton CHLA and PERIWCC guidelines (Table 1-3). Unfortunately it was not possible to derive nutrient criteria by REC class due to unequal representation of classes within the existing national dataset compiled for this project; the dataset was dominated by data for sites in the Cool-Wet REC climate class.

Table 1-3: Summary table of nutrient criteria to achieve ≥85% compliance with periphyton abundance guidelines based on quantile regression of "summer"[a] data.

Periphyton metric	Periphyton guideline	Mean for preceding 12 months (mg/m^3)			
		DIN	DRP	TN	TP
Chla (mg/m^2)	<50	<100	na [b]	nd [c]	<14
	<120	<630	<11	nd [c]	<45
	≤200	<1100	<18	nd [c]	<65
PERIWCC (%)	<20	<35	na [b]	<70	<10
	<30	<140	na [b]	<360	<45
	<40	<360	na [b]	<660	<55
	≤55	nc [d]	na [b]	nc [d]	<75

[a] "summer" period = 1 November to 30 April
[b] na data indicate not achievable – e.g., no significant relationship
[c] nd insufficient data to determine
[d] nc no criteria indicated – i.e., achievable at all nutrient concentrations;

In conclusion, the Phase 3 work-stream of this Tools project has provided a recommended set of refined instream plant guidelines to protect trout-fishery-angling values based on the results of a national angler acceptability survey and analysis of a national periphyton-macroinvertebrate dataset using newly developed trout food availability indices. The project has also provided an evaluation of existing periphyton guidelines to protect ecosystem health indicating that these generally result in a high level of concordance with established "bottom-line" guidelines for MCI and %EPT taxa.

In this project we used non-linear quantile regression to generate a set of general nutrient criteria for high-level compliance with existing periphyton abundance guidelines. This approach has the potential to be used to derive guidelines by river class if a more geographically representative, national periphyton-nutrient database can be compiled in the future. Further advancement of non-linear multi-factor periphyton models is another avenue that can be explored and the addition of certain critical parameters (light, accrual time, macroinvertebrate grazer density) to regional authority State of Environment monitoring datasets is key to progressing that approach. In response to this existing limitation, this report provides advice to assist regional authorities in the collection and calculation of these parameters and techniques to make better use of existing semi-quantitative macroinvertebrate data and river clarity and turbidity data for this purpose.

1 Introduction

Regional authorities have been grappling with the requirement to develop water quality standards for instream nutrient concentrations for some time. The requirements of the National Policy Statement on Freshwater Management (NPS-FM) to set limits to protect instream values and manage within them has increased the importance of understanding the relationships between instream plants and a range of values and the effects of environmental factors on plant abundance, particularly when managing cumulative effects of point and non-point nutrient sources.

The aim of this Envirolink Tools project was to provide a decision-making framework to assist regional authorities to define defendable dissolved macronutrient concentrations (phosphorus, P; nitrogen, N) and instream plant abundances as water quality standards for a broad range of river types and hydrological regimes. It completes the planned Phase 3 of the project, for which Phases 1 and 2 were reported on by Matheson et al. (2012).

The report on Phases 1 and 2 of the project (Matheson et al. 2012) reviewed the past research, provided several advances, and reviewed the key outstanding gaps in the required framework for instream plant and nutrient management in the New Zealand context.

Phase 3 of the project aimed to carry out new research and to provide a synthesis and improved coordination of existing, related research in NIWA-led programmes (i.e., Sustainable Water Allocation and Cumulative Effects) and key regional authority projects. The synergies between the Envirolink project and concurrent related research was enhanced by a research workshop, including regional authority SWIM group members, early in the project (October 2013) to discuss plans in detail and seek to maximise linkages and to scope research summaries to be prepared for the final report.

The research proposed for Phase 3 included:

(1) Addressing key gaps in the guidelines to protect river values identified in Table 9-1 of Matheson et al. (2012), namely:

- effects of periphyton and macrophyte abundance on suitability for trout angling (in collaboration with Fish and Game NZ) via angler site suitability ratings, and on the Māori cultural acceptability through iwi surveys, using “calibrated” photographs of river instream vegetation under a range of conditions gathered in NIWA and regional authority surveys;
- effects of periphyton cover and biomass on abundance of preferred stream invertebrate prey items of adult trout (i.e., larger behavioural drifters), using the National Rivers Water Quality Network (NRWQN) annual matched periphyton cover and invertebrate monitoring (ca. 1300 datapoints) and other suitable existing regional authority data; and
- refining relationships between periphyton cover and biomass and macroinvertebrate community metrics that are indicators of ecosystem health (Macroinvertebrate Community Indices (QMCI and MCI) and % sensitive (EPT) taxa), using an expanded national dataset including new data gathered by regional authorities.

(2) Refining generalised regression models of periphyton abundance (developed in Phase 2) and further advanced in Snelder et al. (2013), with and without grazer influences using an expanded national dataset including new data from suitable regional authority datasets (e.g., Greater Wellington, Horizons, Canterbury, Hawkes Bay) and NRWQN paired summer periphyton cover and invertebrate data. The specific refinements included:

- investigating the use of seasonal average conditions of nutrients and other environmental drivers (i.e., light, temperature, flood frequency, substrate size)
- the use of semi-quantitative information from kick-net surveys to provide model input on macroinvertebrate grazer density, and
- using the existing NRWQN database to explore whether light attenuation (K_d) can be effectively modelled based on flows and clarity or turbidity (i.e., without the need to measure absorbance).

The aim of the project workshop was to draw on concurrent research on effects of flow regimes (including flushing flows), modelling periphyton “at site” frequency distributions, instream nutrient attenuation, environmental tipping points in relation to nutrients and multiple stressors, and cyanobacteria-nutrient relationships to incorporate synopses into the final report.

2 Methods

2.1 Workshop and research summaries

A research provider and regional authority science linkage and input workshop was held on 21 October 2013 at St Andrews on the Terrace, Wellington. The objective of the workshop was to improve coordination of research across providers and regional authorities, review the Phase 2 decision framework, and plan additional inputs of research summaries to the Phase 3 report. There were 15 participants: 6 regional authorities (representing Canterbury, Hawkes Bay, Manawatu-Whanganui, Wellington and Southland), 2 Ministry for the Environment, and 7 research provider (representing NIWA, Cawthron Institute and AquaLinc) personnel. Presentations were made on the aims and plan for Phase 3 of this project and on related research from the MBIE-funded Sustainable Water Allocation and Cumulative Effects Programmes and Cawthron Institute cyanobacterial research. This was followed by discussion of key knowledge gaps. Workshop notes were compiled and circulated for record keeping and feedback. Updated research summaries were provided in November 2014 for inclusion in this report.

2.2 Nuisance abundance acceptability surveys

2.2.1 Survey design

Two web-based acceptability surveys were developed using “Survey Monkey” software to examine the effects of periphyton and macrophyte abundance on angling and mahinga kai values.

To develop the surveys, photographs of streams and rivers showing varying levels of periphyton and macrophyte abundance were collated from NIWA, Cawthron and regional authority sources. For each suitable photograph, periphyton and macrophyte abundance were visually assessed by three scientists experienced at performing these assessments as we were unable to locate any suitable photos with sufficiently matched quantitative data (see Appendix A for photographs and matching data). The periphyton abundance metrics assessed were percent filamentous cover (PERIFIL), percent mat cover (PERIMAT), percent total cover (PERITOT=PERIFIL+PERIMAT) and percent weighted composite cover (PERIWCC). Macrophyte abundance metrics included percent channel cross-sectional area/volume occupied (CAV) and percent water surface area occupied (WSA).

Each survey was designed to gather some basic demographic information about each respondent (i.e., gender, age group) as well as information on the types of angling or mahinga kai activities that each respondent engaged in, how frequently and in which regions. Respondents were asked to consider each photo and indicate if the amount of algae or weed in the river section shown in the photo would prevent them from using the site for angling or mahinga kai activities as applicable. The question posed, with the list of possible responses, was as follows (Figure 2-1):

Q. Would the amount of algae/weed visible in the section of stream/river shown in photo X prevent you from using this site for angling?

- ☐ No, the amount of algae/weed is not a problem at all
- ☐ No, but the amount of algae/weed is not ideal
- ☐ No, the amount of algae/weed is OK but other factors are a problem (explain below – optional)
- ☐ Yes, there is too much algae/weed
- ☐ Yes, there is too much algae/weed and other factors are also a problem (explain below – optional)
- ☐ Yes, there is too little algae/weed
- ☐ Yes, there is too little algae/weed and other factors are also a problem (explain below – optional)

Other factors (e.g. muddy water, too shallow, access difficult, etc).

Figure 2-1: The question posed to respondents for each stream photograph in the angling acceptability survey.

We used 46 photos in the angling values survey and 58 photos in the mahinga kai values survey. The surveys were reviewed by a social scientist and feedback obtained from key stakeholder representatives. A small pilot survey was also conducted prior to finalising each survey for distribution.

2.2.2 Survey execution

We distributed the angling values survey to a target audience of 5,000 anglers via direct email invitation to a random subset of New Zealand Fish and Game's adult licence holder dataset and a general email with weblink circulated to coarse angling clubs via the President of the New Zealand Federation of Coarse Anglers. To distribute the mahinga kai values survey we sent out a direct email invitation to a list supplied by the Te Arawa Lakes Trust and a general email with weblink to runanga from Moeraki, Tainui, Manawatu and Murihiku/Te Ao Marama. Information about the survey and weblink were also circulated to Freshwater Maori, the Environmental Protection Agency Maori Advisory Committee, the New Zealand Freshwater Sciences Society and the New Zealand Hydrological Society members and it was also posted on the NIWA website. The surveys remained open for a period of one month. A prize draw ($250 voucher) was run for each survey to encourage participation.

2.2.3 Data analysis

The mahinga kai values survey attracted only 30 respondents this being insufficient for robust statistical analysis. Subsequent feedback on the mahinga kai values survey indicated a preference for a face-to-face interview as opposed to completion of an online survey. This may explain the low response rate for this survey. Unfortunately, undertaking face-to-face interviews was beyond the scope and resources available for this project.

To analyse the photo response data from the angling values survey, we applied two different numerical scoring systems to the various response options to generate a mean angler acceptability score (AAS) for each photograph (Table 2-1).

Table 2-1: Alternative scoring systems applied to photo response data in the angling survey to generate mean angler acceptability scores.

Response option	Simple score system	Weighted score system
No, the amount of algae/weed is not a problem at all	100	100
No, but the amount of algae/weed is not ideal	100	75
No, the amount of algae/weed is OK but other factors are a problem	100	100
Yes, there is too much algae/weed	0	0
Yes, there is too much algae/weed and other factors are also a problem	0	0
Yes, there is too little algae/weed [a]	0	125
Yes, there is too little algae/weed and other factors are also a problem [a]	0	125

[a] these two response options were rarely selected (0-4% of responses per photo).

For each photo we calculated mean (± SE, standard error) AAS for the following dominant respondent groups:

1. All respondents.
2. Very frequent vs. frequent vs. infrequent vs. occasional anglers.
3. Dry fly vs. nymph vs. wet fly vs. spin vs. line & bait anglers.

Mean (± SE) AAS for each respondent group were plotted against the corresponding photo plant abundance data to generate response relationships. We interpreted the response relationships as follows:

- A mean AAS of 100 corresponds to 100% of respondents indicating that the amount of algae/weed *would not* prevent them from using the site – therefore 100% acceptable, 0% unacceptable.
- A mean AAS of 75 corresponds to 75% of respondents indicating that the amount of algae/weed *would not* prevent them from using the site – therefore 75% acceptable, 25% unacceptable.
- A mean AAS of 25 corresponds to 25% of respondents indicating that the amount of algae/weed *would not* prevent them from using the site – therefore 25% acceptable, 75% unacceptable.
- A mean AAS of 0 corresponds to 0% of respondents indicating that the amount of algae/weed *would not* prevent them from using the site – therefore 0% acceptable, 100% unacceptable.

2.3 Periphyton effects on food of adult trout and macroinvertebrate community indices

2.3.1 Data collation and scoring system development

Periphyton and macroinvertebrate datasets were obtained from participating regional authorities (Canterbury, Southland, Horizons, Greater Wellington, Hawkes Bay). The NRWQN dataset was also used. An adult trout prey item scoring system for the macroinvertebrate taxa represented in the above datasets was developed (Shearer et al. 2014). The system assigns scores to macroinvertebrate taxa as prey for drift feeding, benthic browsing and cruise feeding adult trout and provides an overall availability index for each feeding mode at each macroinvertebrate sampling site (see section 2.3.2). Note that cruise feeding is common in still water environments (lakes and river backwaters) whereas drift feeding and benthic browsing prevail in flowing waters (K. Shearer and J. Hayes pers. comm.). See Appendix B (Table B-1) for a list of the normalised scores (scaled 0-10, with values of 0 and 10 representing the lowest and highest scores, respectively).

Matched periphyton and macroinvertebrate data were extracted from suitable datasets for analysis (Table 2-2). For assessment of periphyton effects on food of adult trout, only quantitative macroinvertebrate data (i.e., fixed area sampling & full sample count) were suitable for use. The NRWQN, Hawkes Bay (post-2010) and Horizons datasets fit this criteria, although the Horizons data were collected by kicknet rather than Surber sampling of a fixed area. Southland data was full count but collected by semi-quantitative kicknet sampling of an approximate area. To evaluate the equivalency of macroinvertebrate datasets collected using fixed area Surber, fixed area kicknet and approximate area kicknet, we compared the mean number of individuals and taxa across these three groups.

Table 2-2: Matched periphyton and macroinvertebrate data in NRWQN and regional authority datasets.

Dataset source	No. of periphyton records matched to macroinvertebrate records[a]		Type of invert data				
	Chl*a*	PeriWCC	Surber (0.7 m^2 sampled) [b]	Kicknet (0.6-1 m^2 sampled) [c]	Full count	Fixed count	Coded abundance
ECAN	0	313	No	Yes	No	Yes (100)	No
ES	786	0	No	Yes	Yes	No	No
GWRC	413	433	No	Yes (0.8 m^2)	No	Yes (200)	No
HBRC [d]	452	89	Yes	No	Yes (112)	No	Yes (340)
HZRC [e]	131	128	No	Yes (0.6 m^2)	Yes	No	No
NRWQN	0	1411	Yes	No	Yes	No	No

[a] same site, samples collected ≤14 d of each other, where >1 match closest match data used

[b] 7 x 0.1 m^2 sampled and pooled for analysis

[c] if a fixed area is sampled by kicknet the size of that area is indicated

[d] coded abundance macroinvertebrate data prior to 2011, no. of records indicated in parentheses

[e] data supplied only from 2008 onwards

2.3.2 Calculation of trout food availability indices

We calculated the following adult trout prey item indices for each macroinvertebrate sampling record in the dataset:

- total drift feeding score (DFS)
- total benthic browsing score (BBS)
- total cruise feeding score (CFS)
- count of high ranked drift items (drift count)
- count of high ranked benthic items (benthic count), and
- count of high ranked cruise items (cruise count).

To calculate total DFS, BBS and CFS for each sample we summed the individual count x score data for each taxon then divided by 10 (the maximum ranking score), i.e.,:

Total DFS = [∑(taxon no. of individuals x taxon drift feeding score)]/10

Total BBS = [∑(taxon no. of individuals x taxon benthic browsing score)]/10

Total CFS = [∑(taxon no. of individuals x taxon cruise feeding score)]/10

To calculate the drift count, benthic count and cruise count in each sample we simply summed the count data for each taxon having a score of 5 or more in each of the feeding/browsing categories, i.e.,:

Drift count = ∑(no. of individuals for each taxon with drift feeding score ≥5)

Benthic count = ∑(no. of individuals for each taxon with benthic browsing score ≥5)

Cruise count = ∑(no. of individuals for each taxon with cruise feeding score ≥5)

2.3.3 Calculation of macroinvertebrate community indices

We calculated MCI and QMCI indices according to Stark and Maxted (2007). Percent (%) EPT (taxa) was calculated as the number of EPT taxa present in a sample divided by the total number of taxa present, multiplied by 100.

2.3.4 Data analysis

We examined relationships between periphyton abundance (as CHLA, PERIWCC, PERIFIL and PERIMAT) and adult trout prey item availability indices (DFS, BBS, CFS, drift count, benthic count and cruise count) and macroinvertebrate community indices (MCI, QMCI and %EPT TAXA) using linear regression (Statistica) and non-linear, non-parametric quantile regression (R software, QuantregGrowth package). For quantile regression we applied a penalized, cubic function according to Muggeo (2014).

2.4 Refining periphyton models

2.4.1 Use of semi-quantitative macrograzer data

To evaluate the use of semi-quantitative information from kick-net surveys to provide model input on macroinvertebrate grazer density we compared the full count data collected by fixed area Surber sampling, fixed area kicknet sampling and approximate area (i.e., semi-quantitative) kick net sampling as described in section 2.3. We used the list of macrograzers formulated in Matheson et al. (2012) Table C-3 for this analysis.

2.4.2 Light attenuation model

To explore whether light attenuation (K_d) might be estimated from clarity or turbidity and flow data (i.e., without the need to measure absorbance) we used the NRWQN monthly water quality dataset from 1989 to 2012 inclusive. Light attenuation is a critical variable in the calculation of light at the stream bed - see Matheson et al. (2012) and Snelder et al. (2014) for further information. Here, we calculated K_d from clarity and absorbance according to Davies-Colley and Nagels (2008), which is equivalent to the following equations applied in Excel:

Log K_d = (0.2145*LOG(G340,10))-(0.5034*LOG(CLAR))-0.0649

K_d =POWER(10, Log K_d)

Where G340 is absorbance and CLAR is black disk clarity (m).

For each record in the dataset we calculated the discharge measured at the time of monthly sampling as a percentile of the discharge record for the site in the dataset (flow%ile). We examined whether K_d could be effectively predicted from clarity, turbidity and flow%ile.

2.4.3 Use of seasonal average conditions in models

To investigate the use of seasonal average conditions of nutrients and other environmental drivers as improved predictors of periphyton cover we compiled a modified NRWQN dataset containing annual, date-matched periphyton, macroinvertebrate, water quality, substrate and flood frequency data. This differs from the NRWQN dataset used in Phases 1 and 2 of this project which used a single summary value for each parameter at each site, generally derived from the entire NRWQN monitoring record. The new NRWQN dataset contained 1350+ records (c.f. 65 records in the Phases 1 and 2 dataset). A list of the key variables contained in each dataset is presented in summary form below (Table 2-3).

Table 2-3: A list of the key variables contained in the Phases 1 and 2 and the Phase 3 NRWQN modelling datasets.

Phases 1 and 2 NRWQN model variables	Phase 3 NRWQN model variables [a]
PERIFIL, PERIMAT, PERIWCC (%, average annual max. value from monthly sampling, SQRT transformed)	PERIFIL, PERIMAT, PERIWCC (%, annual value collected on annual macroinvertebrate sampling date, SQRT transformed)
MACROGRAZER DENSITY – total only (n/m^2, average annual value)	MACROGRAZER DENSITY – total and for each grazer species (n/m^2, annual value)
NO_3, NH_4, DIN, DRP, TN, TP (mg/m^3, average value over entire record, LOG transformed)	NO_3, NH_4, DIN, DRP, TN, TP (mg/m^3, mean and median value for 12 months preceding annual macroinvert. sampling date, mean value for preceding spring, mean value for preceding 2 and 3 months, value measured preceding 1, 2 and 3 months, LOG transformed)
$FRE3_{\text{inst, no filter}}$ (n/y, average 1994-1999)	Average days of accrual (DA) after flow 1.5, 2, 3, 5 times median flow (mean for 12 month period preceding the annual macroinvertebrate sampling date). Note: annual average accrual (for a given flow event) is calculated by dividing 365 by the annual frequency of that flow event. For example: DA(3x median flow) = 365/FRE3
SUBSTRATE INDEX (average annual value)	SUBSTRATE INDEX (annual value)
Light (PAR) at bed (µmol/m^2/s, average value) Calculated for each NRWQN site using average clarity and absorbance values, one-off measurements of % shading and mean water depth, and average regional irradiance data.	Light (PAR) at bed (µmol/m^2/s, mean value for month preceding macroinvertebrate sampling date). Calculated from NRWQN monthly clarity and absorbance data, one-off measurements of % shading and mean water depth (as used in Phase 1 and 2), and ambient irradiance data from the nearest climate station for month prior to sampling.
TEMP (^{o}C, 95%ile for entire record)	TEMP (^{o}C, mean and median value for 12 months preceding annual macroinvert. sampling date, mean value for preceding spring, mean value for preceding 2 and 3 months, value measured preceding 1, 2 and 3 months)

[a] Underlined parameters are those also available in the regional authority dataset which were used together with NRWQN data for bivariate quantile regression analysis.

Some variables were transformed for analysis as indicated in Table 2-3. Stepwise multiple linear regression (SMLR) analysis was performed (using Statistica©, Statsoft) using the Phase 3 dataset to identify significant predictors of the periphyton cover metrics for comparison with Phases 1 and 2 SMLR modelling results.

With the regional authority datasets there was insufficient data available to calculate days of accrual, substrate index and light at bed so multi-factor modelling to predict periphyton abundance, or testing of the models generated with the NRWQN dataset, was not possible. Instead, using a combined NRWQN-regional authority dataset we applied quantile regression analysis (using the penalised cubic function in R QuantregGrowth package) to evaluate bivariate non-linear relationships between periphyton abundance metrics and available predictor variables (i.e., macrograzer density, nutrients and water temperature) for threshold identification based on the outer percentiles.

3 Results

3.1 Angling values acceptability survey

The angling values survey gathered information from 652 of 5000 targeted respondents; a response rate of 13%. Two-thirds of the respondents were males aged 41 to 70. The respondents were primarily trout anglers, although some were also salmon anglers. Only a small proportion of respondents were engaged in angling for coarse fish or eels. More than 80% of respondents were frequent or very frequent anglers. Summary tables showing the proportion of respondents by gender and age group, by target species and angling method, and by angling frequency in total, and by target species and angling type, are provided in Appendix D (Table D-1, Table D-2, Table D-3, Table D-4).

Over half of the survey respondents engaged in angling for one or more target species in the lower South Island. The proportion of respondents angling at North Island and South Island locations was 36% and 64%, respectively. The proportion of respondents angling in each region in total, and by target species and angling type is provided in Appendix D (Table D-5, Table D-6).

The angler acceptability scores generated for the survey photos by weighted scoring system were significantly lower than those generated by the simple scoring system (paired *t*-test, $p<0.05$). This reflects the significant number of respondents that frequently selected response option 2 (amount of algae/weed would not prevent use of site, but amount was not ideal) which had an arbitrary weighting of 75. In contrast, response options 6 and 7 (there is too little algae/weed) which had a counter rating of 125 were rarely selected.

Angler acceptability scores generated by both scoring systems were significantly correlated to instream plant abundance as represented by all metrics (PERIWCC, PERITOT, PERIFIL, PERIMAT, CAV and WSA) (Figure 3-1, Figure 3-2, Table 3-1). Slightly more significant relationships between angler acceptability and instream plant abundance as PERIWCC, PERITOT, PERIMAT and CAV were found when the weighted scoring system was applied rather than the simple scoring system. However, relationships between angler acceptability and instream plant abundance as PERIFIL and WSA were slightly improved when the simple scoring system was used as opposed to the weighted scoring system. Thus, there was no consistent evidence from the survey results for the superiority of either scoring system so results using both scoring systems are presented below.

For periphyton metrics with an existing angling guideline (i.e., PERIFIL 30%) survey results indicated that this guideline corresponds to an acceptability score of between 70 and 84% (i.e., proportion of anglers that would find that level of instream plant abundance acceptable, Table 3-2).

The results for periphyton mat cover indicate a possibly higher angler sensitivity to mats dominated by cyanobacteria than other types of mat forming periphyton (Figure 3-1). However, we were unable to locate many suitable photos showing mat cover for the survey so our ability to robustly assess this differential response was limited (i.e., n=5 photos showing cyanobacterial mat cover vs. n=2 photos showing non-cyanobacterial mat cover).

The provisional trout fishery-angling guideline for macrophyte abundance of CAV (50%) corresponded to 31 and 37% angler acceptability. For macrophyte indices (CAV and WSA), we examined the hypothesis that water clarity may have an overriding influence on angler acceptability scores. However, we found no clear pattern to suggest that turbid water at a site consistently resulted in a lower acceptability score.

Angler acceptability scores for macrophyte indices suggested an overriding influence of CAV on scoring (Figure 3-2). The reason for this is that a number of photos with high CAV (i.e., >50%) but low WSA (i.e., <50%) had very low acceptability scores. In contrast, there were no photographs that had WSA >50% and CAV <50%. This conclusion was also supported by the results of stepwise multiple linear regression analysis which identified CAV as the dominant index influencing acceptability score, although inclusion of WSA resulted in an improved ability to predict the score (Table 3-1). To generate a more robust bivariate relationship between WSA and acceptability score we removed scores for photographs that had CAV >50% and WSA <50% from that analysis. The highly significant relationship generated after this refinement confirms the value of WSA, alongside CAV, as an important index related to angler acceptability.

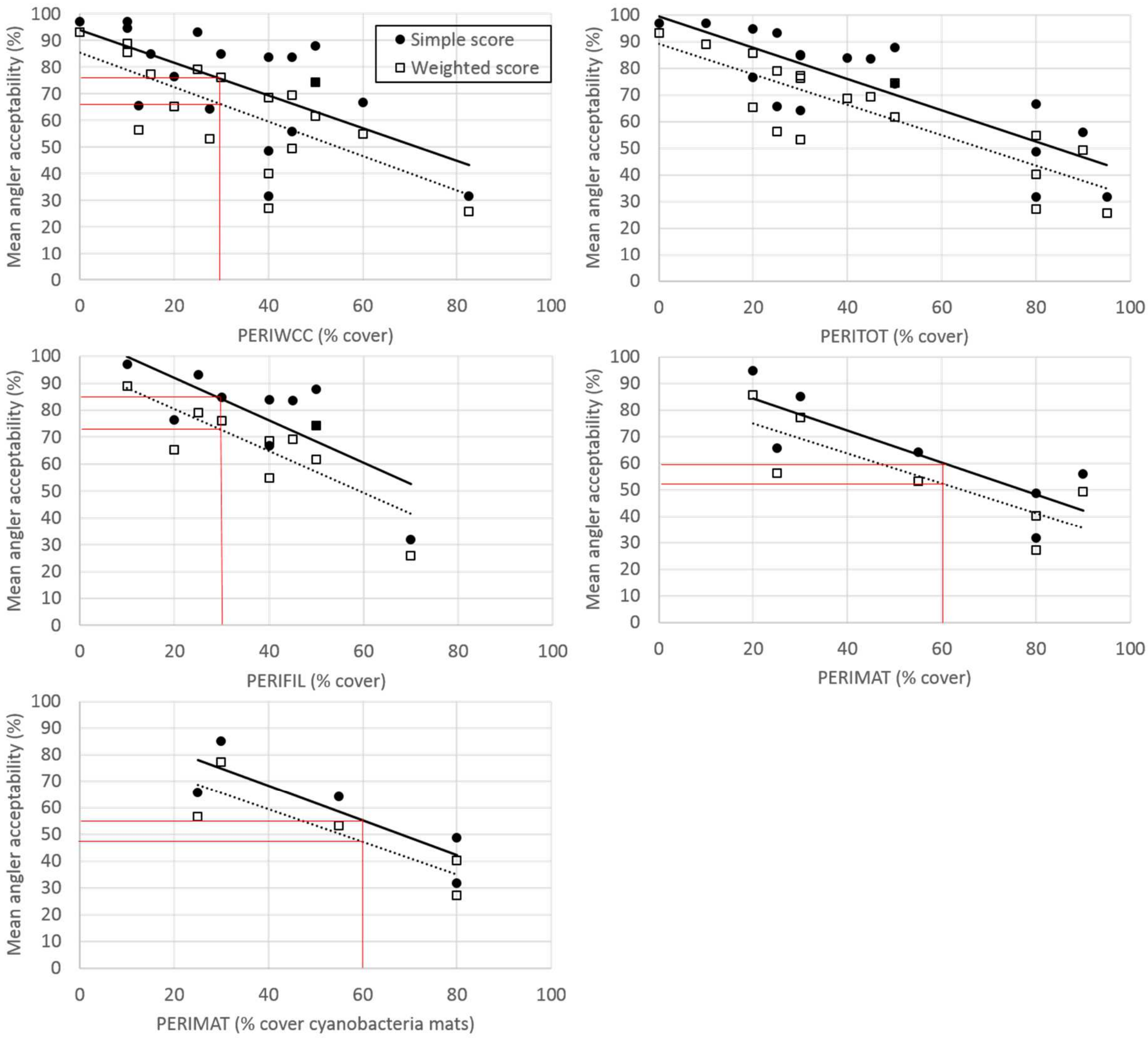


Figure 3-1: Relationships between angler acceptability score and periphyton nuisance abundance indices for survey photographs. Red lines show angler acceptability scores corresponding to existing guidelines.

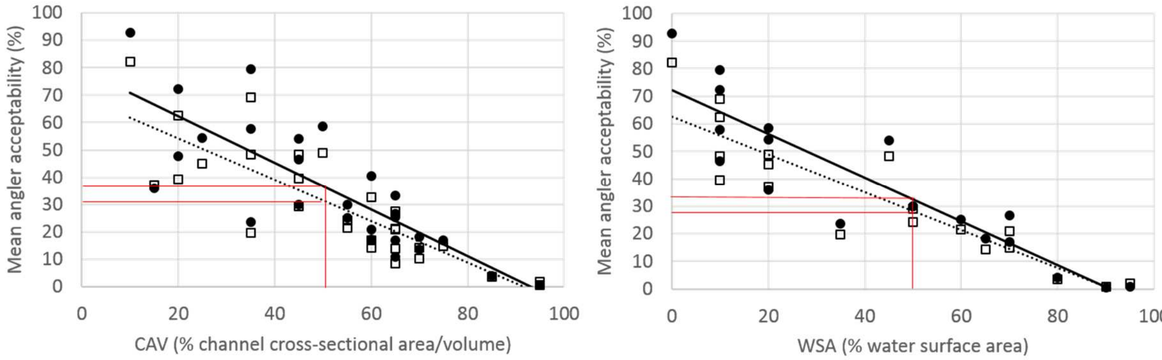


Figure 3-2: Relationships between angler acceptability score and macrophyte nuisance abundance indices for survey photographs. Scores where CAV>50% and WSA<50% have been excluded from the WSA graph due to the overriding influence of CAV on acceptability score. Red lines show angler acceptability scores corresponding to existing guidelines.

Table 3-1: Linear regression relationships between angler acceptability score (AAS, %) and instream plant nuisance abundance indices for survey photographs.

Nuisance index	Simple mean method	Weighted mean method
PERIWCC	AAS=-0.61*PERIWCC+93.93, r^2=0.38, n=18, p=0.006	AAS=-0.64*PERIWCC+85.26, r^2=0.48, n=18, p=0.002
PERITOT	AAS=-0.59*PERITOT+99.49, r^2=0.68, n=18, p<0.001	AAS=-0.57*PERITOT+89.06, r^2=0.71, n=18, p<0.001
PERIFIL[a]	AAS=-0.79*PERIFIL+107.84, r^2=0.55, n=10, p=0.014	AAS=-0.7*PERIFIL+91.16, r^2=0.51, n=10, p=0.021
PERIMAT[b]	AAS=-0.6*PERIMAT+96.17, r^2=0.69, n=7, p=0.010	AAS=-0.56*PERIMAT+86.05, r^2=0.81, n=6, p=0.006
PERIMAT[c](cyano)	AAS=-0.65*PERIMAT + 93.97, r^2 = 0.72, n=5, p=0.068	AAS=-0.61*PERIMAT + 83.7, r^2 = 0.67, n=5, p=0.044
CAV	AAS=-0.85*CAV+79.31, r^2=0.67, n=28, p<0.001	AAS=-0.76*CAV+69.27, r^2=0.69, n=28, p<0.001
WSA	AAS=-0.5*WSA+50.91, r^2=0.40, n=25, p=0.001	AAS=-0.42*WSA+43.35, r^2=0.38 n=25, p=0.001
WSA[d]	AAS=-0.79*WSA+72.06, r^2=0.81,n=19, p<0.001	AAS=-0.69*WSA+62.59, r^2=0.81, n=19, p<0.001
CAV & WSA[e]	AAS=75.19-0.69*CAV–0.13*WSA, r^2=0.80, n=25, p<0.001	AAS= 66.31–0.65*CAV-0.65*WSA, r^2=0.82, n=25, p<0.001
CAV & WSA[d]	AAS = 72.25-0.01*CAV – 0.78*WSA, r^2=0.90, n=19, p<0.001	AAS= 64.48–0.11*CAV-0.6*WSA, r^2=0.90, n=19, p<0.001

[a] excludes scores where PERIFIL = 0 but PERIMAT > 0 due to influence of PERIMAT on PERIFIL score
[b] excludes scores where PERIMAT = 0 but PERIFIL > 0 due to influence of PERIFIL on PERIMAT score
[c] for PERIMAT scores where dominant growth form is cyanobacterial mats only
[d] excludes scores where CAV > 50% and WSA < 50% due to influence of CAV on WSA score
[e] results of stepwise multiple linear regression analysis without excluding scores where CAV > 50% and WSA < 50%

Table 3-2: Proportion of anglers that find the abundance of periphyton or macrophytes acceptable for existing guidelines according to each method of score calculation.

Nuisance metric	Existing guideline	Simple mean method	Weighted mean method
PERIWCC	<20% (excellent ecological condition – provisional) [a]	82%	73%
PERIWCC	30% (aesthetics) [b]	76%	66%
PERIWCC	<40% (good or better ecological condition – provisional) [a]	70%	60%
PERIWCC	≤55% (fair or better ecological condition – provisional) [a]	60%	50%
PERIFIL	30% (angling, aesthetics) [b]	84%	70%
PERIMAT	60% (aesthetics) [b]	60%	52%
PERIMAT (cyano)	60% (aesthetics) [b]	55%	47%
CAV	≤50% (trout fishing-angling – provisional) [a]	37%	31%
WSA	≤50% (aesthetics – provisional) [a]	33%	28%

[a] Matheson et al. (2012)
[b] MfE (2000)

We found no clear difference in response relationships associated with frequency of angling. However, response curves for spin and line-bait anglers indicated a slightly higher sensitivity to nuisance plant abundance relative to dry fly, nymph and wet fly anglers. Graphs showing the response relationships by angling frequency and method categories are provided in Appendix D (Figure D-1, Figure D-2, Figure D-3, Figure D-4, Figure D-5, Figure D-6, Figure D-7, Figure D-8).

3.2 Periphyton effects on food of adult trout

3.2.1 Dataset comparison

A comparison of the density of individuals and taxa in macroinvertebrate full count samples collected via three different approaches showed that the fixed area kicknet sampling done by Horizons yielded a lower density of macroinvertebrates than either the fixed area Surber sampling done by NRWQN/Hawkes Bay and the approximate area kicknet sampling done by Southland (Table 3-3). The similarity in macroinvertebrate densities between the fixed area Surber sampling by NRWQN/Hawkes Bay and the approximate area kicknet sampling by Southland suggested that these two datasets were sufficiently equivalent and could be pooled for further analysis. Basic attributes of the combined NRWQN/Hawkes Bay/Southland dataset, matched to periphyton records (n=2286) and used for further analysis, are provided below (Table 3-4).

Table 3-3: Comparison of macroinvertebrate densities among datasets collected using Surber versus kicknet sampling.

Metric	Statistic	Fixed area Surber (0.7 m²) [a] NRWQN + Hawkes Bay	Fixed area kicknet (0.6 m²) Horizons	Approximate area kicknet (0.6-1 m²) [a] Southland
No. of records	Sum total	1586	151	771
Density of individuals (n/m²)	Minimum Mean ± SE Maximum	3 3681 ± 115 [b] 46013	3 589 ± 42 [a] 3073	61 3307 ± 137 [b] 46730
Density of grazer individuals (n/m²)	Minimum Mean ± SE Maximum	0 2161 ± 79 [b] 38253	2 428 ± 32 [a] 2439	6 2188 ± 92 [b] 32976
No. of taxa	Minimum Mean ± SE Maximum	1 18.0 ± 0.1 [ab] 36	2 17.2 ± 0.5 [a] 33	4 18.4 ± 0.2 [b] 37

[a] 7 x 0.1 m² sampled and pooled for analysis

[b] Assumed that 1 m² area sampled

Different alphabetic superscripts indicate significant differences in mean values among groups (ANOVA, post-hoc Tukey HSD, p<0.05)

Table 3-4: Attributes of the combined NRWQN-Hawkes Bay-Southland quantitative dataset used for analysis of periphyton abundance relationships to trout food availability.

Variable	Count	Min.	Mean ± SE	Max.
CHLA (mg/m²)	786	0	50 ± 3	990
PERIWCC (%)	2286[a]	0	14 ± 0.4	100
PERIFIL (%)	1500	0	9 ± 0.4	100
PERIMAT (%)	1500	0	8 ± 0.4	100
Total drift feeding score (DFS) [b]	2286	0	595 ± 13	4746
Total benthic browsing score (BBS) [c]	2286	3	449 ± 12	8444
Total cruise feeding score (CFS) [d]	2286	0	243 ± 6	2990
Count of high rank drift items (drift count) [e] (n/m²)	2286	0	655 ± 16	6171
Count of high rank benthic items (benthic count) [f] (n/m²)	2286	0	56 ± 3	3312
Count of high rank cruise items (cruise count) [g] (n/m²)	2286	0	29 ± 1	826

[a] Southland do not measure cover so for this analysis we estimated PERIWCC from CHLA using the following formula (C. Kilroy, *pers. comm*.): PERIWCC=[LOG CHLA-0.291)+0.307]². For more details see Appendix I Studies assisting derivation of NOF periphyton attribute

[b] DFS = [∑(n individuals x drift feeding score for each taxon)]/10

[c] BBS = [∑(n individuals x benthic browsing score for each taxon)]/10

[d] CFS = [∑(n individuals x cruise feeding score for each taxon)]/10

[e] Drift count = ∑n individuals for all taxa with drift feeding score ≥5

[f] Benthic count = ∑n individuals for all taxa with benthic browsing score ≥5

[g] Cruise count = ∑n individuals for all taxa with cruise feeding score ≥5

3.2.2 Linear and quantile regression

Both linear regression and non-linear quantile regression were used to examine relationships between periphyton abundance and adult trout food availability. Although significant linear regression relationships were found, analysis using non-linear quantile regression analysis to account for subsidy stress relationships was considered superior and results are presented below. The results of the linear regression analysis are presented in Appendix E.

Quantile regression was used to more closely examine the periphyton-trout food availability relationships. Examining the outer quantiles of bivariate relationships is useful in situations where factors other than those for which there are data likely influence the response variable (Cade and Noon 2003). There are currently no established guideline values for the prey item availability indices used here (K. Shearer and J. Hayes, *pers. comm.*). These guidelines require development. With no established guidelines we instead examined the plots to identify shifts in the relationships suggestive of periphyton thresholds above which trout food availability is affected.

The relationship between CHLA and trout food availability indices generally showed a classic (hump-shaped) subsidy-stress response, with food availability limited at the extremes of periphyton biomass and more abundant at moderate biomass levels (Figure 3-3). The plots indicate a tipping point in drift food availability above a periphyton biomass of around 200 mg/m^2 CHLA (i.e., Log CHLA = 2.3); however data is quite limited at this extreme end of the plot.

Limited data at the extremes of the relationships create the tendency for the quantile regression function curves to leverage off isolated (outlier) points particularly for the outer percentile curves. This is impossible to avoid unless isolated data points at the extremes are removed from the dataset. The effect is most clearly illustrated in the plot showing the relationship between CHLA and the count of high rank cruise prey items (bottom left) where there is a single low CHLA value matched to a relatively high cruise count value.

The data also suggest that there are more marked responses to trout food availability in 'good' rivers (i.e., 90th and 95th percentile regression lines) while the presumably low diversity rivers (as indicated by 50th percentile regression line) show a much lesser response.

In general, PERIWCC, PERIFIL and PERIMAT values showed stronger relationships with counts of high rank drift prey than with total drift food scores (Figure 3-4, Figure 3-5, Figure 3-6). This may be due to the influence of high abundances of low ranked food items on the total scores.

The quantile regression plots for PERIWCC and PERIFIL generally did not indicate a strong effect of increasing periphyton abundance on trout food availability, particularly for the higher percentile curves. A slight negative trend was evident for the median (i.e., 50th) percentile in most plots. An exception to this was the count of high rank drift items which showed a strong decline once PERIWCC values exceeded approximately 50% (SQRT PERIWCC c.7).

In contrast the plots for PERIMAT showed a more consistent pattern of declining trout food availability with increased periphyton abundance particularly for drift and cruise feeding. The plots suggest a decline in food availability at PERIMAT values above approximately 25% (c. SQRT PERIMAT 5).

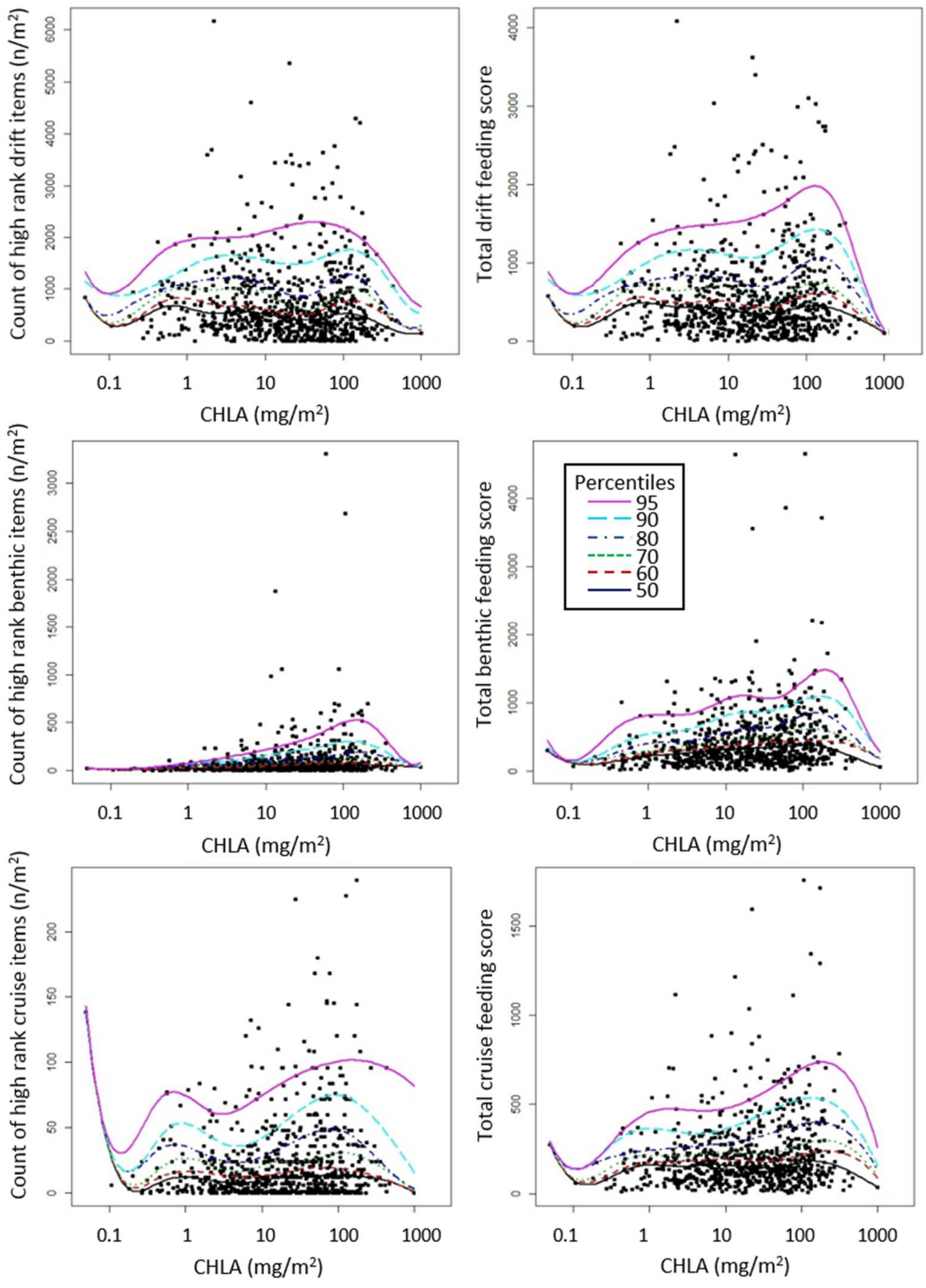


Figure 3-3: Relationship between periphyton biomass as chlorophyll *a* (mg/m²) and trout food availability indices. Trout food availability indices are shown as counts of high rank prey items (left) and total feeding scores (right) for drift feeding (top), benthic browsing (centre) and cruise feeding (bottom) with percentiles 50, 60, 70, 80, 90 and 95 shown.

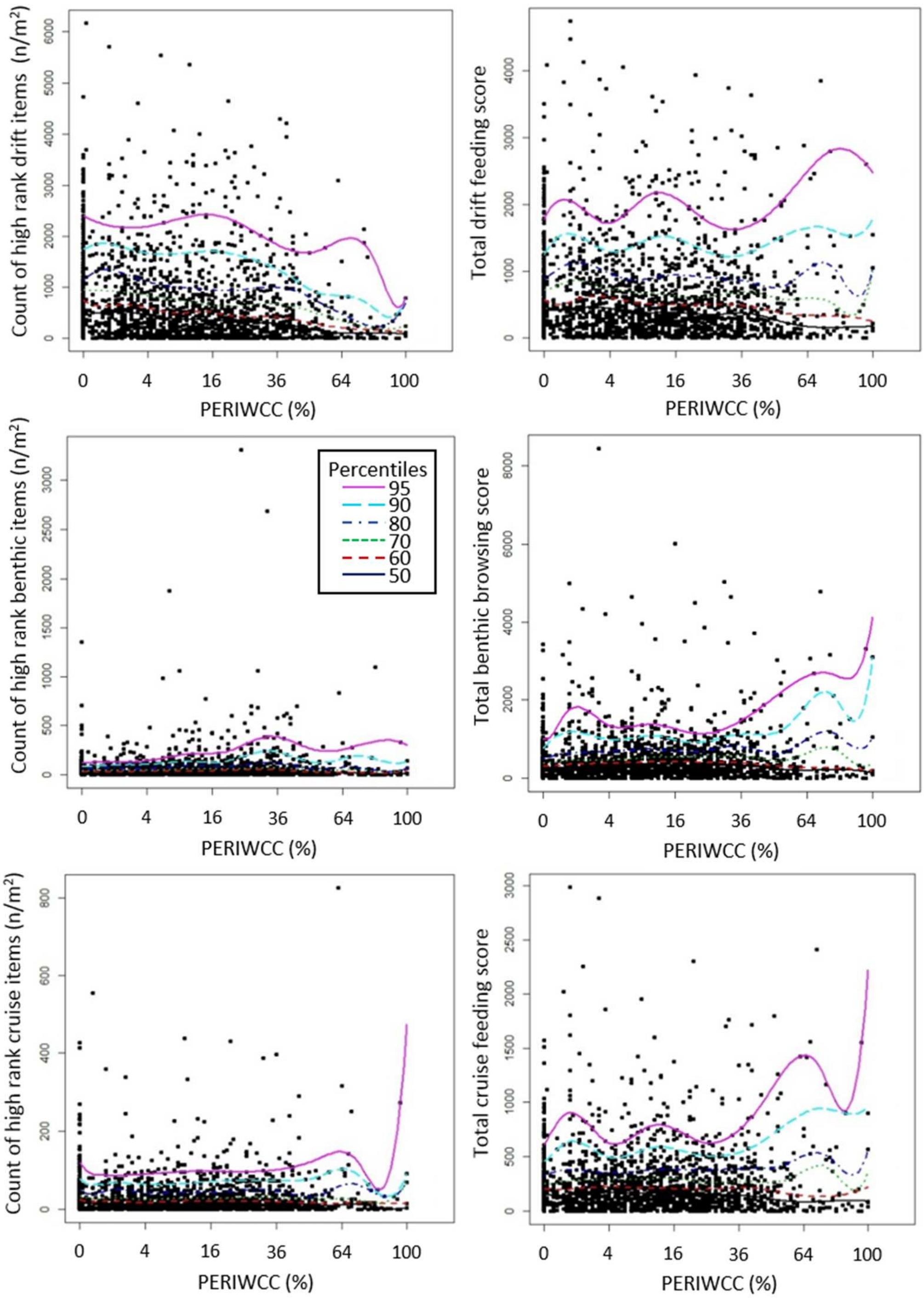


Figure 3-4: Relationship between periphyton abundance as weighted composite cover (%) and trout food availability indices. Trout food availability indices are shown as counts of high rank prey items (left) and total feeding scores (right) for drift feeding (top), benthic browsing (centre) and cruise feeding (bottom) with percentiles 50, 60, 70, 80, 90 and 95 shown.

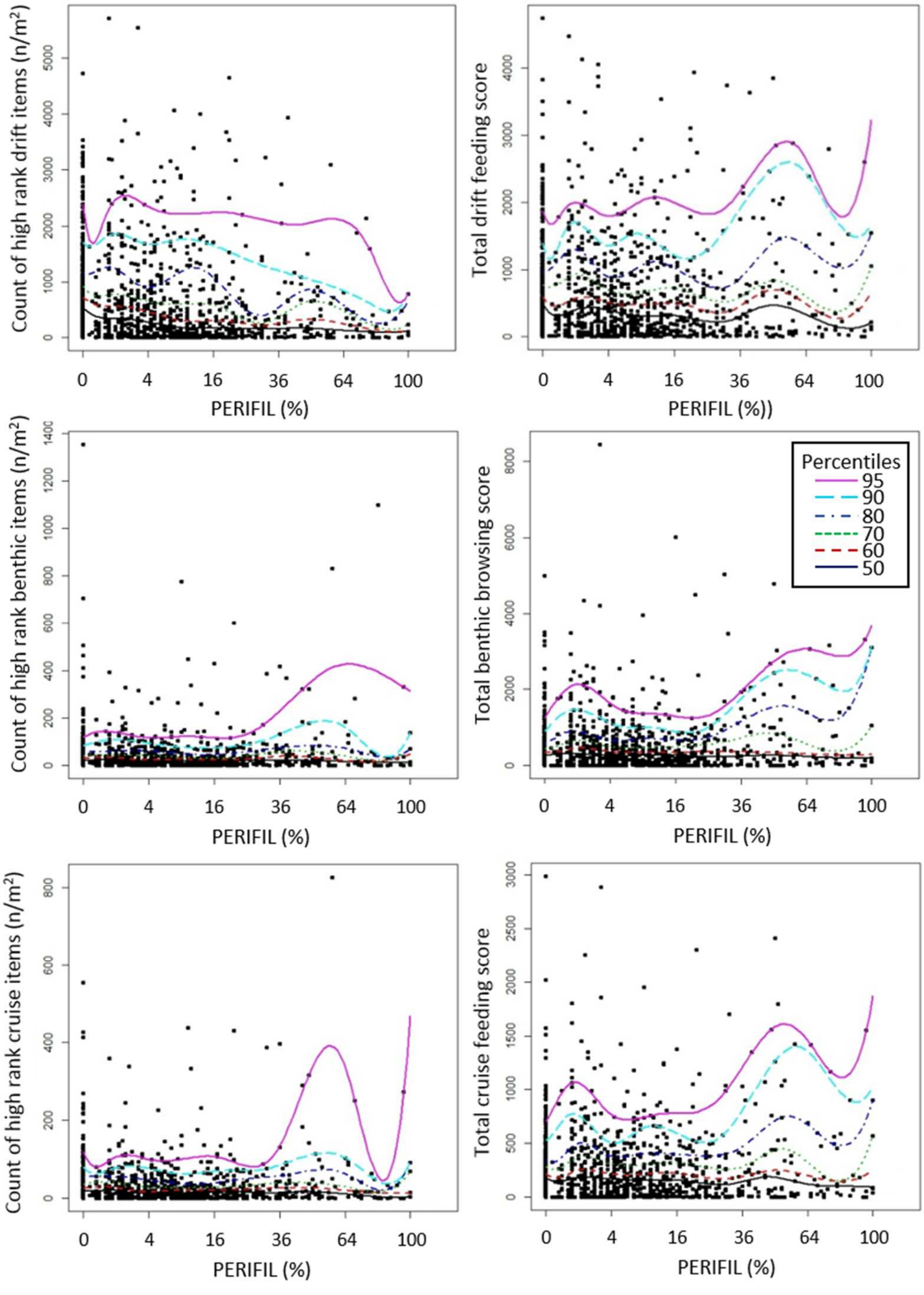


Figure 3-5: Relationship between periphyton abundance as filamentous cover (%) and trout food availability indices. Trout food availability indices are shown as counts of high rank prey items (left) and total feeding scores (right) for drift feeding (top), benthic browsing (centre) and cruise feeding (bottom) with percentiles 50, 60, 70, 80, 90 and 95 shown.

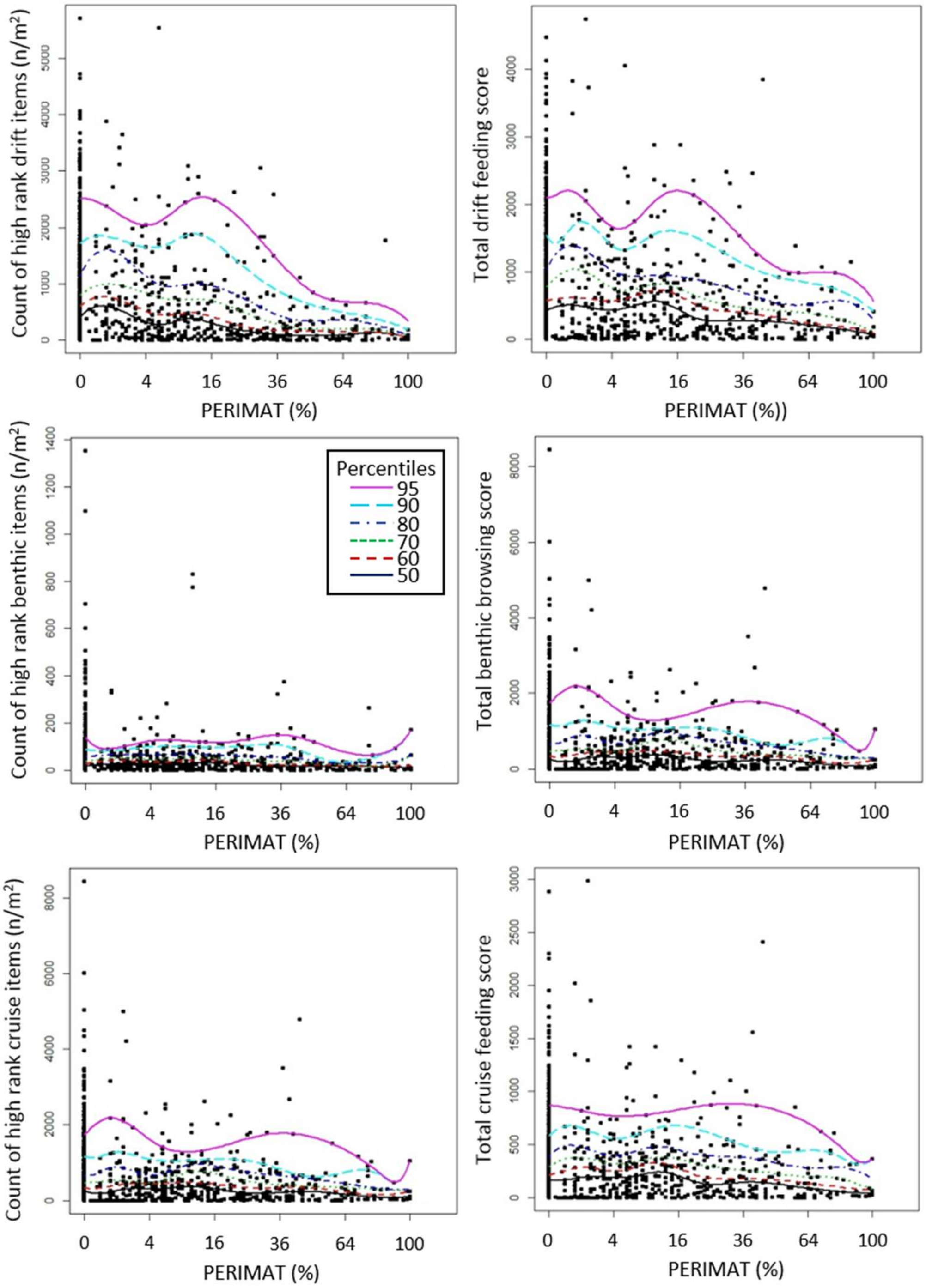


Figure 3-6: Relationship between periphyton abundance as mat cover (%) and trout food availability indices. Trout food availability indices are shown as counts of high rank prey items (left) and total feeding scores (right) for drift feeding (top), benthic browsing (centre) and cruise feeding (bottom) with percentiles 50, 60, 70, 80, 90 and 95 shown.

3.3 Periphyton effects on macroinvertebrate community indices

3.3.1 Linear regression

All macroinvertebrate community indices showed significant negative relationships to periphyton abundance (Table 3-5). The periphyton abundance measure most strongly related to the macroinvertebrate indices was CHLA. The macroinvertebrate index most strongly related to periphyton abundance measures was QMCI.

Table 3-5: Linear regression relationships between periphyton abundance indices and macroinvertebrate community indices. All relationships were significant ($p<0.0001$).

Ecosystem health indices (y)	Periphyton abundance indices (x)			
	LOG (CHLA+1)	SQRT PERIWCC	SQRTPERIFIL	SQRTPERIMAT
MCI	y = 123.2 - 12.5*x; r = -0.48	y = 113.4 -2.6*x; r = -0.38	y = 111.9 - 2.5*x; r = -0.35	y = 109.3 - 1.6*x; r = -0.20
QMCI	y = 7.1 - 1.1*x; r = -0.50	y = 5.9 - 0.3*x; r = -0.46	y = 5.6 - 0.3*x; r = -0.40	y = 5.4 - 0.21*x; r = -0.30
% EPT taxa	y = 56.8 - 6.5*x; r = -0.35	y = 52.3 - 1.5*x; r = -0.31	y = 51.6 - 1.5*x; r = -0.30	y = 49.6 - 0.7*x; r = -0.13

3.3.2 Quantile regression

Quantile regression analysis confirmed that the macroinvertebrate ecosystem health indices MCI, QMCI and %EPT taxa generally declined with increasing periphyton abundance as measured by CHLA (Figure 3-7) and PERIWCC (Figure 3-8). The relationships were broadly monotonic but not linear.

To evaluate the relationships we determined the proportion of sampling records complying with equivalent periphyton and macroinvertebrate ecosystem health/ecological condition guidelines (i.e., those recommended to ensure excellent, good, fair and poor condition). Of note, a large proportion of the records fall within the periphyton "excellent" band (i.e., CHLA <50 mg/m^2 and PERIWCC <20%) and substantial declines in the macroinvertebrate indices are evident as CHLA and PERIWCC increase within this band.

An increase in CHLA from 50 to 120 to 200 mg/m^2, representing an approximate shift in ecosystem health from A (excellent) to D (poor) according to the NOF periphyton attribute table, resulted in the proportion of sampling records complying with the equivalent MCI, QMCI and %EPT TAXA category boundaries (i.e., MCI 120 to 100 to 80, QMCI 6 to 5 to 4 and %EPT TAXA 75 to 50 to 25) increasing from 15 to 52 to 85%, 28 to 45 to 73% and <5% to 30 to 94%, respectively (data shown in Figure 3-7).

We also evaluated the levels of compliance with the PERIWCC ecological condition categories derived by Matheson et al. (2012). An increase in PERIWCC from 20 to 40 to 55%, representing an approximate shift in ecosystem condition from excellent to poor, resulted in the number of sampling records complying with the equivalent MCI, QMCI and %EPT TAXA category boundaries (as above) increasing from 12 to 49 to 82%, 17 to 25 to 43% and <5 to 25 to 94% (data shown in Figure 3-8).

The results suggest that the NOF periphyton CHLA ecosystem health "bottom line" boundary of 200 mg/m^2 results in a high level of correspondence with equivalent macroinvertebrate indices of ecosystem health. Similarly, the PERIWCC ecological condition bottom line of 55% results in a high level of correspondence with MCI and %EPT indices of ecosystem health, although not QMCI. The other NOF CHLA and PERIWCC guidelines representing the fair-good band boundary of CHLA 120 mg/m^2 and PERIWCC 40%, and the good-excellent boundary of CHLA 50 mg/m^2 and PERIWCC 20% in particular, did not result in a high level of correspondence with equivalent macroinvertebrate indices of ecosystem health. The results indicate an increasing lack of equivalency between periphyton and macroinvertebrate indices and that the existing periphyton guidelines may not be sufficient to maintain higher levels of ecosystem health/ecological condition if the latter is based on macroinvertebrate community indices. This effect was more pronounced for %EPT TAXA and MCI, compared to QMCI.

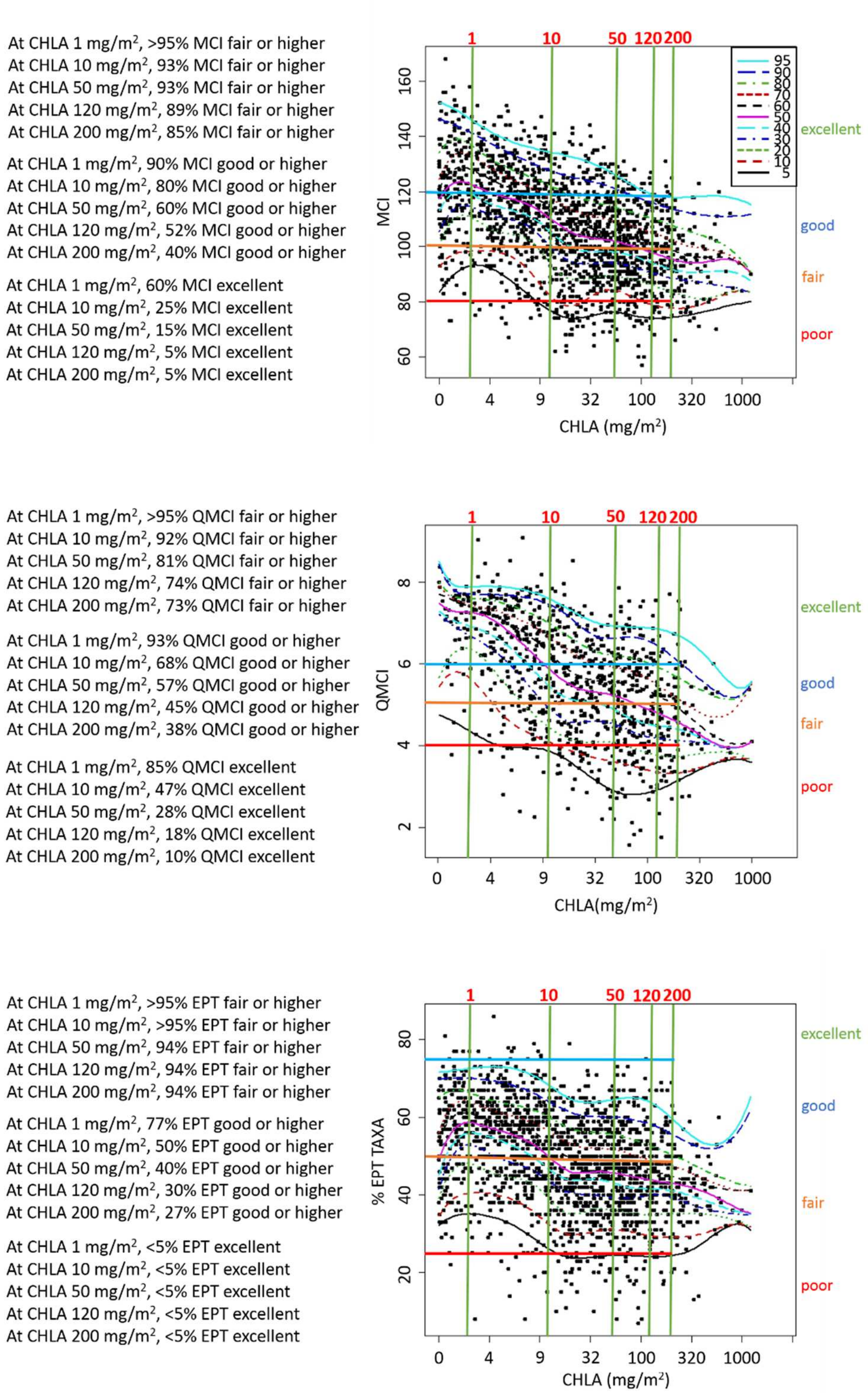
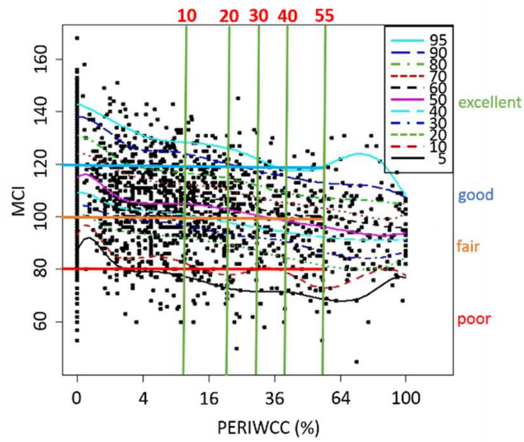


Figure 3-7: Relationships between periphyton abundance as chlorophyll *a* (mg/m²) and selected macroinvertebrate ecosystem health indices. Macroinvertebrate ecosystem health indices are shown as MCI (top) QMCI (centre) and % EPT TAXA (bottom). Quantile regression lines for 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 95 percentiles are shown. For macroinvertebrate indices boundaries between excellent and good condition are MCI 120, QMCI 6 and %EPT TAXA 75%, boundaries between good and fair condition are MCI 100, QMCI 5 and % EPT TAXA 50%, and boundaries between fair and poor condition are MCI 80, QMCI 4 and %EPT TAXA 25%. See Stark and Maxted (2007) and Matheson et al. (2012) for macroinvertebrate boundaries.

At PERIWCC 10%, 92% MCI fair or higher
At PERIWCC 20%, 88% MCI fair or higher
At PERIWCC 30%, 90% MCI fair or higher
At PERIWCC 40%, 90% MCI fair or higher
At PERIWCC 55%, 82% MCI fair or higher

At PERIWCC 10%, 62% MCI good or higher
At PERIWCC 20%, 58% MCI good or higher
At PERIWCC 30%, 53% MCI good or higher
At PERIWCC 40%, 49% MCI good or higher
At PERIWCC 55%, 41% MCI good or higher

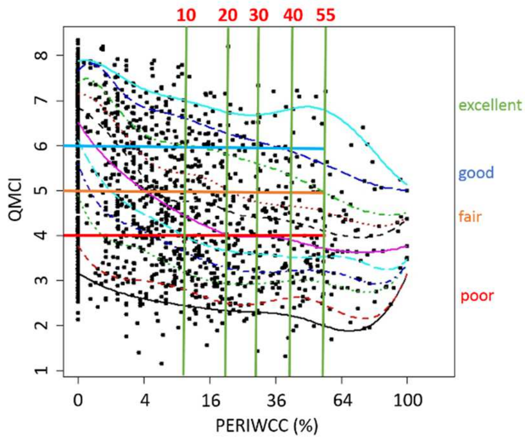
At PERIWCC 10%, 17% MCI excellent
At PERIWCC 20%, 12% MCI excellent
At PERIWCC 30%, 8% MCI excellent
At PERIWCC 40%, <5% MCI excellent
At PERIWCC 55%, 5% MCI excellent



At PERIWCC 10%, 60% QMCI fair or higher
At PERIWCC 20%, 52% QMCI fair or higher
At PERIWCC 30%, 50% QMCI fair or higher
At PERIWCC 40%, 48% QMCI fair or higher
At PERIWCC 55%, 43% QMCI fair or higher

At PERIWCC 10%, 36% QMCI good or higher
At PERIWCC 20%, 32% QMCI good or higher
At PERIWCC 30%, 27% QMCI good or higher
At PERIWCC 40%, 25% QMCI good or higher
At PERIWCC 55%, 20% QMCI good or higher

At PERIWCC 10%, 21% QMCI excellent
At PERIWCC 20%, 17% QMCI excellent
At PERIWCC 30%, 12% QMCI excellent
At PERIWCC 40%, 9% QMCI excellent
At PERIWCC 55%, 8% QMCI excellent



At PERIWCC 10%, >95% EPT fair or higher
At PERIWCC 20%, 93% EPT fair or higher
At PERIWCC 30%, 90% EPT fair or higher
At PERIWCC 40%, 95% EPT fair or higher
At PERIWCC 55%, 94% EPT fair or higher

At PERIWCC 10%, 40% EPT good or higher
At PERIWCC 20%, 40% EPT good or higher
At PERIWCC 30%, 33% EPT good or higher
At PERIWCC 40%, 25% EPT good or higher
At PERIWCC 55%, 18% EPT good or higher

At PERIWCC 10%, <5% EPT excellent
At PERIWCC 20%, <5% EPT excellent
At PERIWCC 30%, <5% EPT excellent
At PERIWCC 40%, <5% EPT excellent
At PERIWCC 55%, <5% EPT excellent

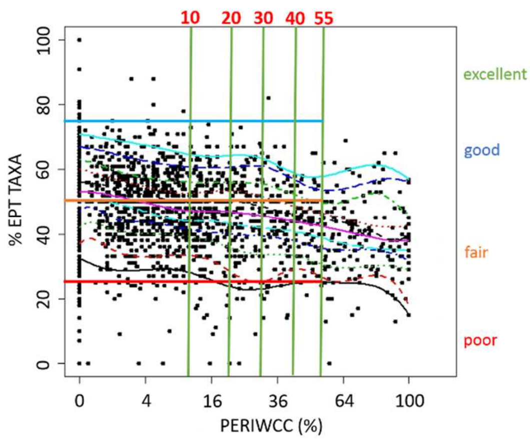


Figure 3-8: Relationships between periphyton abundance as PERIWCC (%) and selected macroinvertebrate ecosystem health indices. Macroinvertebrate ecosystem health indices are shown as MCI (top) QMCI (centre) and % EPT TAXA (bottom). Quantile regression lines for 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 95 percentiles are shown. For macroinvertebrate indices boundaries between excellent and good condition are MCI 120, QMCI 6 and %EPT TAXA 75%, boundaries between good and fair condition are MCI 100, QMCI 5 and % EPT TAXA 50%, and boundaries between fair and poor condition are MCI 80, QMCI 4 and %EPT TAXA 25%. See Stark and Maxted (2007) and Matheson et al. (2012) for macroinvertebrate boundaries.

3.4 Refining periphyton models

3.4.1 Light attenuation modelling

Using the NRWQN dataset (from January 1989 to June 2013) we confirmed that there is a strong relationship between clarity/turbidity and light attenuation (K_d) (Figure 3-9). However note that the sample size is very large and the log-log scales mean that for any particular clarity value the range of corresponding K_d values is considerable. For example, a clarity value of 0.3 m (-0.52 log clarity) has a corresponding range of actual K_d values from 1.25 to 3.5 (0.1 to 0.55 log K_d). The strong relationship between clarity and K_d is not surprising given that the K_d values in this dataset have been calculated from clarity and absorbance (G340). The overall relationship between clarity and K_d is represented by the following equation: Log K_d = (-0.5877*Log Clar) + 0.0556 (r^2=0.9370, p=0.0000).

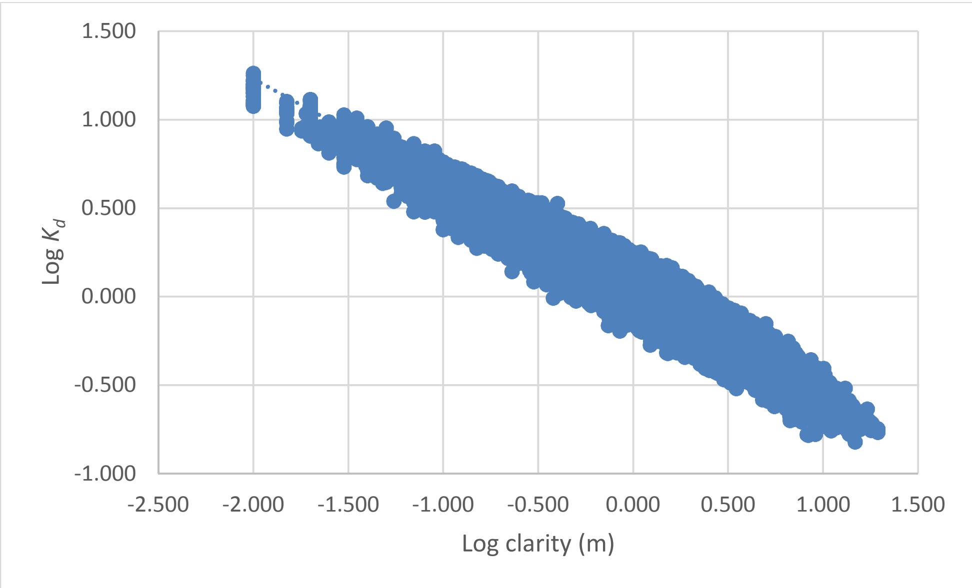


Figure 3-9: Relationship between K_d and clarity in the NRWQN dataset.

The following example illustrates how K_d might be approximated from clarity using this equation without the need to measure absorbance.

Example: Black disk clarity is 2.

Log K_d = (-0.5878*0.3010) + 0.0556

Log K_d = -0.1213

K_d = 10 $_{-0.1213}$ (in excel, POWER (10, -0.1212))

K_d = 0.7565

The overall relationship between turbidity and K_d is represented by the following equation: Log K_d = (0.0457*Log Turbidity)-0.2033 (r^2=0.8539, p=0.0000) (Figure 3-10).

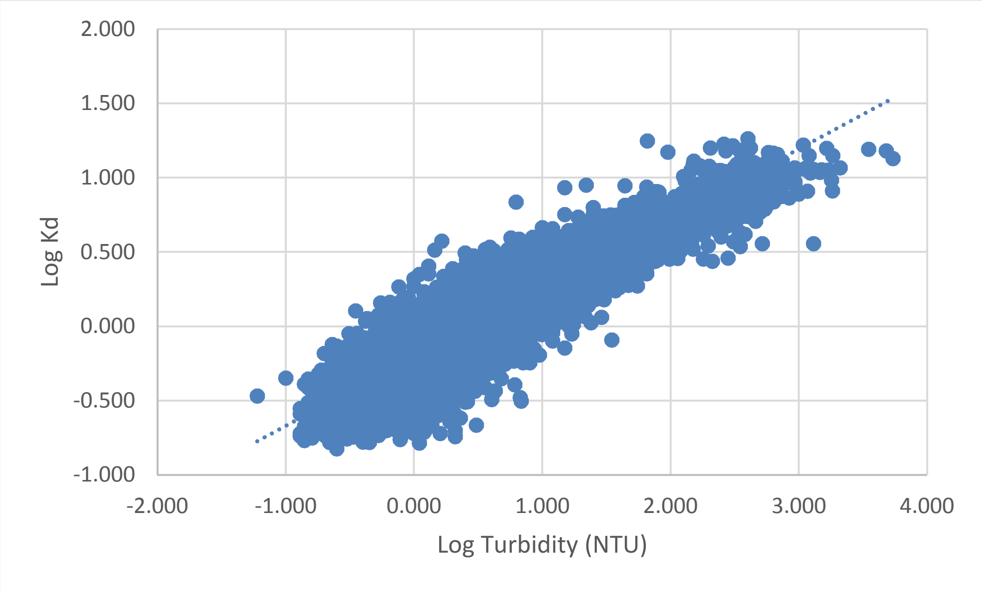


Figure 3-10: The relationship between K_d and turbidity in the NRWQN dataset.

The relationships for K_d with clarity and turbidity are also summarised below for each of the REC climate classes represented in the NRWQN (Table 3-6, and Appendix F Figure F-1). In the NRWQN dataset we found that K_d, clarity, turbidity and absorbance data differed significantly among the REC climate classes (Appendix F Figure F-2).

Table 3-6: Relationships for K_d with clarity or turbidity for REC climate classes represented in the NRWQN dataset.

REC climate class	Clarity (m)	Turbidity (NTU)
CD	Log K_d = (-0.6039*Log Clar) + 0.1033, R^2 = 0.9574, n=2611	Log K_d = (0.4556*Log Turb) - 0.1334 R^2 = 0.8354, n=2611
CW	Log K_d =(-0.585*Log Clar) + 0.029 R^2 = 0.9495, n=12737	Log K_d = (0.4675*Log Turb) - 0.2274 R^2 = 0.8646, n=12737
CX	Log K_d = (-0.5669*Log Clar) + 0.0442 R^2 = 0.9199, n=3469	Log K_d = (0.4627*Log Turb) - 0.2184 R^2 = 0.8124, n=3469
WW	Log K_d = (-0.5343*Log Clar) + 0.1352 R^2 = 0.9478, n=3179	Log K_d = (0.4152*Log Turb) - 0.1102 R^2 = 0.8593, n=3179
WX	Log K_d = (-0.5426*Log Clar) + 0.1237 R^2 = 0.9914, n=293	Log K_d = (0.4035*Log Turb) - 0.0943 R^2 = 0.9283, n=293

Adding an appropriate scaled flow variable (i.e., SQRT flow%ile) generated slight improvements in predictability of K_d, particularly for K_d values derived from turbidity. The relationships between clarity/turbidity, flow and K_d are shown for all NRWQN sites together and for sites subdivided by REC climate class in Appendix F (Figure F-3, Table F-1).

3.4.2 Refined prediction models – Multiple linear regression

Stepwise multiple linear regression analysis using the Phase 3 dataset parameters to identify predictors of periphyton abundance identified a number of significant models (Table 3-7, Table 3-8 and Table 3-9). Only periphyton cover models could be generated as the only suitable multi-factor dataset available for this is the NRWQN which does not contain CHLA data. The models generated only explained between 6 and 26% of the variation in PERIWCC, PERIFIL and PERIMAT. All models had a tendency to overestimate periphyton abundance at observed very low levels and underestimate periphyton abundance at observed moderate to high levels (see Appendix F).

For PERIWCC and PERIFIL the most significant models (% variation explained 26% and 16%, respectively) were those incorporating individual grazer species (model 1), rather than only total macrograzer density or no macrograzers at all (models 2 and 3) (Table 3-7, Table 3-8). For most of the macrograzer species identified in the models (i.e., for *Deleatidium*, *Eriopterini*, *Pcynocentrodes*, *Latia*, *Beraeoptera*, *Zelandobius*) their relationships to periphyton abundance were negative, suggesting that they play a role in limiting periphyton development. However in some cases (i.e., *Aoteapsyche*, *Potamopyrgus*) the association was positive suggesting that their abundance is enhanced by higher levels of periphyton cover as a food source. *Aoteapsyche* was included in the list of macrograzers identified in Matheson et al. (2012); however, this taxa should probably be removed from the macrograzer list in future as it is primarily a filterer that grazes periphyton to maintain flow through its net. For PERIMAT the most significant model contained total macrograzer density as the primary predictor variable suggesting that the overall abundance of macrograzers is an important controller of periphyton mat development. However the models generated for PERIMAT explained less of the variation (i.e., 6 to 12%) in the periphyton metric than those generated for PERIWCC and PERIFIL (i.e., 16 to 26%).

Other parameters that featured in the most significant model for PERIWCC (model 1, Table 3-7) were water temperature measured 3 months prior to sampling date (positive association), days of accrual following a flood of 1.5 times the median flow (positive association) and flow velocity measured on the sampling date (positive association). Nutrients did not feature in this model but were evident in the other models where grazer species were excluded, notably mean NH_4-N concentration for the 12 months preceding the sampling date (model 3, Table 3-7).

For PERIFIL, nutrients featured more strongly in the most significant model (model 1, Table 3-8), specifically the mean NH_4-N concentration for the preceding spring period (positive association). Interestingly the NH_4-N concentration measured 3 months prior to sampling date and the NO_3-N concentration measured 2 months prior to sampling were negatively related to PERIFIL, presumably reflecting uptake of these elements by developing periphyton biomass in spring-early summer. Mean temperature for the 12 months preceding sampling date was also an important variable in the PERIFIL model (positive association), as well as days of accrual following a flood exceeding three times the median flow (positive association).

Nutrients were also a prominent feature of the most significant PERIMAT model (model 1, Table 3-9), in particular the median NO_3-N concentration for the 12 months preceding the sampling date (positive association). Both the TN concentration and water temperature measured 2 months prior to the sampling date exerted positive influences in the model. The mean TP concentration for the 12 months preceding the sampling date had a negative relationship to PERIMAT. Substrate size was also included in the model, with higher levels of PERIMAT associated with larger substrate size.

Light at the bed did not feature in any of the models. This was surprising as light is a critical factor influencing periphyton growth but may be due to the approximate nature of the calculation for this parameter (direct measurement is preferable) and/or the predominance of unshaded (high light) sites in the NRWQN (see Figure 3-20 and associated text for further discussion). Light at the bed featured in the multiple linear regression models developed in Phase 1 and 2 of this project which used single time-averaged datapoints for each NRWQN site and where light at bed values were derived from an average long-term regional irradiance level combined with average shading level, water depth, clarity and absorbance values for each site (see Matheson et al. 2012). In the Phase 3 NRWQN dataset we replaced the average long-term regional irradiance level with the average irradiance level for the month prior to that when periphyton sampling took place derived from nearest climate station records. We also used average clarity and absorbance values for the 12 months preceding each periphyton sampling date but retained a single estimate of shading level and mean water depth in our calculations.

Table 3-7: PERIWCC stepwise multiple linear regression model results – parameters [a].

Model 1: All grazer species and total grazer density included, Adj. R^2 = 0.26	Model 2: Only total grazer density included, Adj. R^2 = 0.16	Model 3: Grazers not included at all, Adj. R^2 = 0.16
LOG (+1) Aoteapsyche (55.4, 0.69)	LOG NH_4N_mean_12 (26.9, 2.03)	LOG NH_4N_mean_12 (18.3, 1.74)
LOG (+1) Deleatidium (41.4, -0.70)	SUBSTRATE INDEX (16.1, 0.54)	SUBSTRATE INDEX (16.1, 0.54)
TEMP_month_3 (16.9, 0.10)	TEMP_mean_12 (11.0, 0.18)	LOG DA FRE 5 (8.8, 0.59)
LOG (+1) Eriopterini (15.2, -0.63)	LOG DA FRE 5 (8.3, 0.57)	TEMP_mean_12 (11.4, 0.18)
LOG (+1) Pycnocentrodes (12.3, -0.32)	LOG DA FRE 1.5 (6.9, 0.55)	LOG WVEL (6.6, 0.99)
LOG (+1) Potamopyrgus (9.2, 0.30)	LOG WVEL (6.3, 0.97)	LOG DA FRE 1.5 (5.8, 0.51)
LOG DA FRE 1.5 (7.4, 0.45)	LOG MACROGRAZERS (6.2, -0.34)	LOG (+1) NH_4N_month_3 (5.3, -0.85)
LOG (+1) Latia (6.9, -0.52)	TEMP_month_3 (5.6, 0.08)	TEMP_month_3 (5.2, 0.08)
LOG (+1) Beraeoptera (6.5, -0.36)	LOG (+1) NH_4N_month_3 (5.5, -0.87)	LOG (+1) TPunf_month_1 (4.4, 0.40)
LOG (+1) Zelandobius (4.6, -0.41)		
LOG WVEL (3.9, 0.74)		

[a] Model parameters included are listed in order of importance with F value and coefficient in parentheses.

Table 3-8: PERIFIL stepwise multiple linear regression model results - parameters [a].

Model 1: All grazer species and total grazer density included, Adj. R^2 = 0.25	Model 2: Only total grazer density included, Adj. R^2 = 0.17	Model 3: Grazers not included at all, Adj. R^2 = 0.17
LOG (+1) Aoteapsyche (38.9, 0.52)	TEMP_mean_12 (36.9, 0.23)	TEMP_mean_12 (36.9, 0.23)
LOG (+1) Pycnocentrodes (23.1, -0.39)	LOG DA FRE 3 (19.9, 0.66)	LOG DA FRE 3 (19.9, 0.66)
TEMP_mean_12 (21.0, 0.17)	LOG NH_4N_mean_12 (18.1, 1.72)	LOG NH_4N_mean_12 (18.1, 1.72)
LOG (+1) Deleatidium (18.6, -0.43)	LOG (+1) NO_3N_month_2 (12.3, -0.58)	LOG (+1) NO_3N_month_2 (12.3, -0.58)
LOG NH_4N_spring (14.9, 1.18)	LOG (+1) NH_4N_month_3 (7.1, -0.88)	LOG (+1) NH_4N_month_3 (7.1, -0.88)
LOG (+1) Beraeoptera (8.9, -0.38)	LOG TPunf_mean_12 (6.8, 0.51)	LOG TPunf_mean_12 (6.8, 0.51)
LOG (+1) Potamopyrgus (7.8, 0.25)	LOG WVEL (6.3, 0.87)	LOG WVEL (6.3, 0.87)
LOG (+1) Eriopterini (7.1, -0.39)	SUBSTRATE INDEX (6.3, 0.30)	SUBSTRATE INDEX (6.3, 0.30)
LOG (+1) Latia (6.8, -0.47)	LOG TNunf_month_2 (4.5, 0.65)	LOG TNunf_month_2 (4.5, 0.65)
LOG DA FRE 3 (6.4, 0.37)		
LOG (+1) NH_4N_month_3 (5.4, -0.70)		
LOG (+1) NO_3N_month_2 (5.1, -0.26)		

[a] Model parameters included are listed in order of importance with F value and coefficient in parentheses.

Table 3-9: PERIMAT stepwise multiple linear regression model results - parameters [a].

Model 1: All grazer species and total grazer density included, Adj. R^2 = 0.12	Model 2: Only total grazer density included, Adj. R^2 = 0.07	Model 3: Grazers not included at all, Adj. R^2 = 0.06
LOG MACROGRAZERS (24.0, -0.90)	LOG NO_3N_median_12 (16.9, 1.13)	LOG NO_3N_median_12 (14.8, 1.06)
LOG (+1) Pycnocentria (19.5, 0.53)	SUBSTRATE INDEX (14.0, 0.49)	SUBSTRATE INDEX (12.9, 0.47)
LOG (+1) Aoteapsyche (18.8, 0.48)	LOG TPunf_mean_12 (11.8, -0.72)	LOG TPunf_mean_12 (9.0, -0.63)
LOG NO_3N_median_12 (18.5, 0.95)	LOG DA FRE 5 (9.8, 0.52)	LOG DA FRE 5 (8.8, 0.49)
LOG (+1) Eriopterini (16.8, -0.68)	LOG MACROGRAZERS (9.1, -0.40)	TEMP_month_2 (6.1, 0.07)
LOG TPunf_mean_12 (10.1, -0.67)	TEMP_month_2 (6.0, 0.07)	LOG (+1) DIN_month_2 (4.1, -0.48)
LOG TNunf_month_2 (6.4, -0.76)	LOG (+1) DIN_month_2 (4.0, -0.48)	
SUBSTRATE INDEX (5.9, 0.31)		
TEMP_month_2 (5.1, 0.06)		

[a] Model parameters included are listed in order of importance with F value and coefficient in parentheses.

3.4.3 Refined prediction models – Quantile regression

Periphyton versus nutrients

It was not possible to robustly examine quantile regression relationships between "growing season" (macroinvertebrate-matched) periphyton data and preceding time-averaged nutrients by REC climate class due to unequal representation of these classes in the combined NRWQN and regional authority dataset (Table 3-10). Consequently relationships between periphyton and nutrients were generally examined for all REC classes combined.

Table 3-10: Number of records in combined NRWQN and regional authority dataset for each combination of periphyton abundance metric vs. nutrient variable by REC class.

Periphyton metric	REC climate class categories	Mean for preceding 12 months				Mean for preceding spring			
		DIN & NH_4-N	DRP	TN	TP	DIN & NH_4-N	DRP	TN	TP
CHLA	All	871	981	56	666	609	689	54	627
	Prod.[a]	54	60	0	47	42	47	0	45
	CD	115	134	7	117	101	123	7	114
	CW	564	608	49	448	419	472	47	423
	CX	61	66	0	49	44	46	0	46
	WD	29	38	0	18	14	15	0	13
	WW	97	129	0	34	31	33	0	31
	WX	5	6	0	0	0	0	0	0
	% of records in Nov-Apr period	98	98	100	97	97	97	100	97
PERIWCC	All	1736	1941	1270	1820	1565	1620	1214	1700
	Prod. [a]	54	50	29	52	22	17	5	22
	CD	292	354	272	311	205	199	185	224
	CW	1093	1194	764	1141	1028	1072	777	1113
	CX	234	260	179	249	236	249	198	261
	WD	19	23	2	21	12	12	0	12
	WW	79	89	37	79	68	71	38	71
	WX	19	21	16	19	16	17	16	19
	% of records in Nov-Apr period	95	95	95	95	95	95	95	95

[a] Prod. = Productive periphyton River Environment Classification (REC) classes (climate/geology): WD/SS, WD/VB, WD/VA, CD/SS, CD/VB, CD/VA. Nov-Apr is "summer" period as defined by the NOF.

We examined periphyton abundance relationships to mean annual concentrations and mean preceding spring time nutrient concentrations of TN, TP, DIN and DRP. The results based on mean annual and spring time nutrient concentrations were broadly similar. Relationships based on mean annual concentrations were considered likely to be more robust due to the larger number of records available for derivation. Therefore results based on mean annual nutrient concentrations are presented below and results based on spring-time concentrations are provided in Appendix H.

Our analysis attempted to identify nutrient concentrations that would achieve an acceptable level of compliance with existing periphyton abundance guidelines. The NOF periphyton attribute table allows for a general 8% exceedance frequency of CHLA guidelines at monitoring sites (i.e., 1 month in 12 based on monthly monitoring throughout the year) (MfE 2015). The multi-site, multi-year dataset analysed here generally contains baseflow data for spring and summer only, meaning there is a greater likelihood of periphyton abundance exceeding acceptable guidelines compared to an annual dataset. Thus on that basis we allowed for an approximate doubling of the allowable exceedance frequency to 15% (i.e., 1 month in 6) and consequently selected the regression line corresponding to the 85th percentile as most appropriate for this analysis. Note that we have assumed that the NOF at-site 8% non-compliance frequency can be applied equally across multiple sites. We considered that this is a reasonable assumption as this is a general guideline applicable to all sites nationally. For each relationship plot we checked to ensure that multiple data points from a single site did not unduly influence the quantile regression lines and in some instances we excluded certain justifiably atypical sites from the analysis.

Chlorophyll a vs annual mean nutrients

There was insufficient data to robustly examine the relationship between CHLA and annual mean TN (for the 12 months preceding the periphyton sampling date) (Table 3-10). The NRWQN does not measure CHLA and few regional authorities measure both CHLA and TN. For TP, a strong positive association with CHLA was evident for the outer quantiles (Figure 3-11). Removal of records from the sites in the productive periphyton REC classes had little effect. The results suggest that an annual mean TP concentration of <14 mg/m^3 would result in >85% of records complying with the NOF CHLA excellent band of <50 mg/m^2. To realise 85% compliance with the NOF CHLA good and fair band boundaries of 120 and 200 mg/m^2, TP concentrations of <45 mg/m^{3}and <65 mg/m^{3}are indicated, respectively.

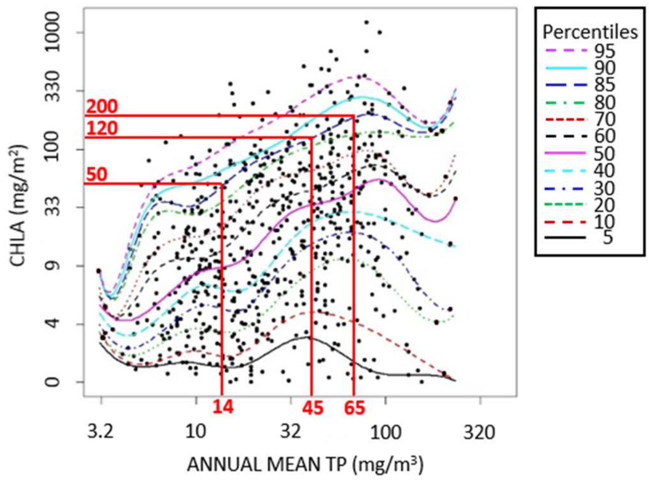


Figure 3-11: Periphyton abundance as chlorophyll a versus mean total phosphorus. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95). Nutrient concentrations corresponding to 85% compliance with periphyton CHLA guidelines are shown in red.

For DIN and DRP a positive relationship with CHLA was evident for annual mean DIN concentrations between about 16 and 1260 mg/m^3 and for annual mean DRP concentration between approximately 2.5 and 18 mg/m^3. Ignoring the extreme lower end of the regression lines where outlier samples have a spurious influence, the plots suggest that annual mean DIN concentrations of <100 mg/m^3, and <1100 mg/m^3correspond to ≥85% of records complying with the NOF CHLA excellent and fair bands of <50 and ≤200 mg/m^2, respectively. For compliance with the good band of <120 mg m^2 fluctuations in the quantile regression model fit create uncertainty and a range of DIN concentrations is indicated (from 200 to 700 mg m^{-3}). For DRP, the results suggest that ≥85% compliance with the NOF excellent band of <50 mg/m^2 is not achievable because a substantial number of records exceed CHLA 50 mg/m^2, and there is considerable fluctuation in the regression line, at very low DRP concentrations. Annual mean concentrations of <11 mg/m^3 and <18 mg/m^3correspond to non-exceedence of the CHLA good and fair bands of <120 and ≤200 mg/m^2, respectively.

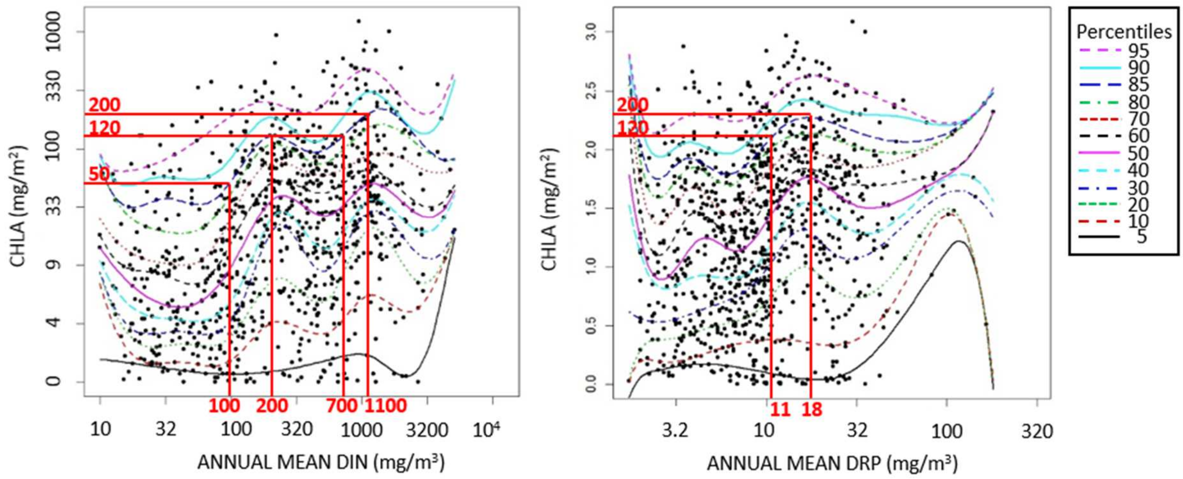


Figure 3-12: Periphyton abundance as chlorophyll *a* versus mean dissolved inorganic nitrogen (left) and dissolved reactive phosphorus (right). Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95). Nutrient concentrations corresponding to 85% compliance with periphyton CHLA guidelines are shown in red.

PERIWCC vs annual mean nutrients

The relationships between PERIWCC and annual mean TN and TP generally showed increasing periphyton abundance as total nutrient concentrations increased up to around TN 600 mg/m^3 (log TN = 2.8) and TP 200 mg/m^3 (log TP = 2.3).(Figure 3-13). At higher total nutrient concentrations, there were fewer records, especially for TP, and the analysis indicates a decrease in PERIWCC. These records were generally associated with low elevation sites on large rivers where phytoplankton growth and turbid water likely constrain periphyton growth. For both TN and TP, we examined the effect of records for sites within the productive periphyton REC classes. Removing the small percentage of records for these sites had minimal effect on the quantile regression lines.

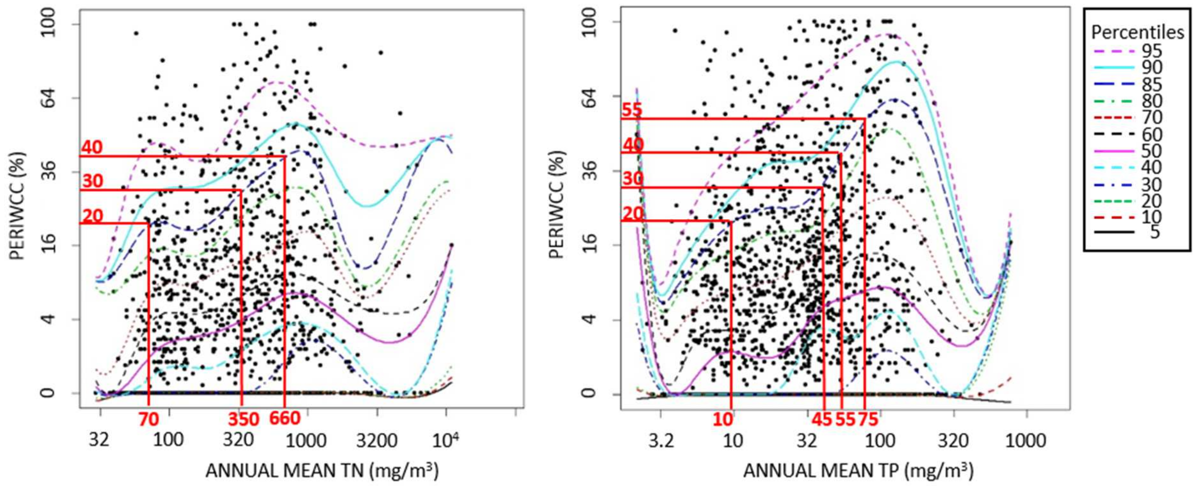


Figure 3-13: Periphyton abundance as PERIWCC versus mean TN (left) and TP (right) for the preceding 12 months. Regression lines are shown for the 5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95 percentiles. Nutrient concentrations corresponding to 85% compliance with periphyton PERIWCC guidelines are shown in red. Monowai Dam site excluded from PERIWCC vs. TP dataset.

The results for TN indicate that a mean TN concentration of <355 mg/m^3 (LOG TN = 2.55) corresponds to <15% of records exceeding the PERIWCC aesthetic guideline of 30%. The results also suggest a steep increase in PERIWCC as TN concentrations increase from around 30 to 80 mg/m^3 and then a further steep increase between 200 to 1000 mg/m^3. For 85% compliance with the provisional ecological condition PERIWCC guidelines of <20% (excellent condition) and <40% (good or better condition) (Matheson et al. 2012), mean TN concentrations of <70 mg/m^3 and <660 mg/m^3 are indicated, respectively. The quantile regression model fits suggest that compliance with the ≤55% (fair or better condition) guideline would be achievable at all nutrient concentrations in the data range.

For TP we found that at concentrations <4 mg/m^3 a number of records had surprisingly moderate periphyton abundance (PERIWCC ≥25%). However, virtually all of these records were for the flow-regulated NRWQN site below the Monowai dam (REC climate/geology: CW/HS). Records for this site were therefore removed from the analysis. The remaining small number of records with high PERIWCC and low TP were for the NRWQN Clutha River at Luggate Bridge site. Ignoring the influence of that site, the results suggest that a mean TP concentration of <45 mg/m^3 corresponds to <15% of records exceeding the aesthetic guideline PERIWCC of 30% (SQRT PERIWCC = 5.5). To achieve ≥85% compliance with the provisional excellent, good and fair ecological condition PERIWCC guidelines of <20, <40 and ≤55%, indicative mean TP concentrations were <10 mg/m^3, <55 mg/m^3 and ≤75 mg/m^3, respectively.

For DIN (ignoring the spurious leveraging at the extreme lower end of the regression lines) the regression lines suggest that concentrations of <35 mg/m^3, <140 mg/m^3 and <355 mg/m^3 correspond to ≥85% compliance with PERIWCC guidelines of <20%, <30% and <40%, respectively (Figure 3-14). The results suggest that compliance with the ≥55% PERIWCC guideline is achievable at all nutrient concentrations within the data range. For DRP the moderate number of samples having moderately high PERIWCC values (i.e., >30% at low DRP concentrations (i.e., <2 mg/m^3) suggests that compliance with PERIWCC guidelines based on DRP concentration is not achievable.

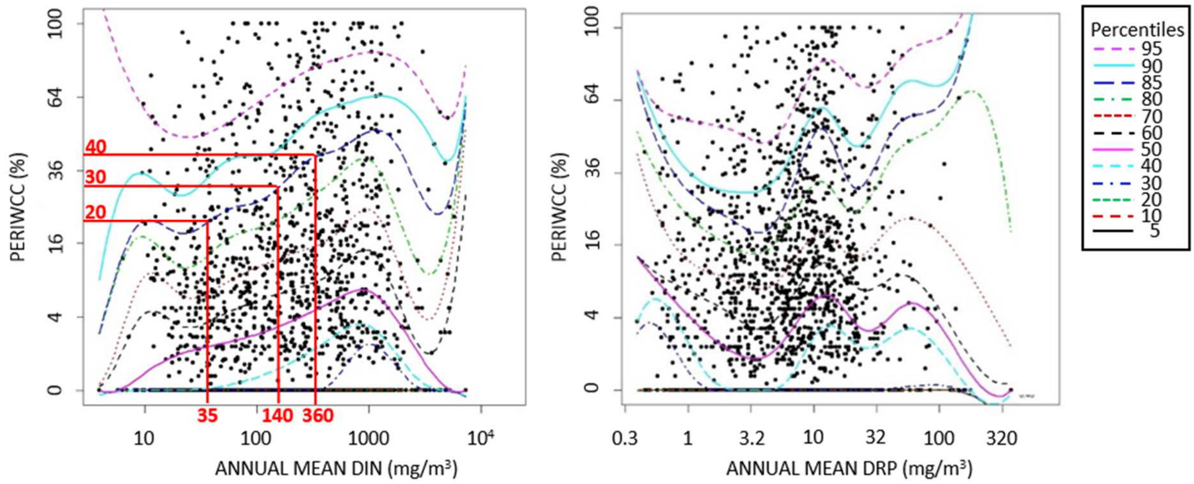


Figure 3-14: Periphyton abundance as PERIWCC versus mean DIN (left) and DRP (right) for the preceding 12 months. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95). Nutrient concentrations corresponding to 85% compliance with periphyton PERIWCC guidelines are shown in red.

Periphyton versus macrograzers

PERIWCC versus macrograzers

With quantile regression we explored further the relationships between periphyton abundance and macroinvertebrate grazer density. We examined relationships between PERIWCC and total grazer density as well as the density of the most common individual macrograzer taxa (i.e., those with an average abundance of ≥1/m^2 in the NRWQN/Hawkes Bay records) (Figure 3-15, Figure 3-16).

We found little evidence to support the hypothesis that total macrograzer density controls PERIWCC. PERIWCC exceeded the aesthetic guideline of 30% with total macrograzer densities as low as 10/m^2. However we did find evidence for control of PERIWCC by a number of individual macrograzer taxa including *Deleatidium*, *Beraeoptera*, *Eriopterini*, *Nesameletus*, *Olinga*, *Pycnocentrodes, Zelandobius* and *Zelandoperla*. These taxa included some of the taxa identified as significant in the multiple linear regression models (section 3.4.3, i.e., *Deleatidium*, *Beraeoptera, Eriopterini*, *Pycnocentrodes* and *Zelandobius*) but also several other taxa not previously identified (i.e., *Nesameletus*, *Olinga* and *Zelandoperla*). Examining the relationships between PERIWCC and the densities of the 8 selected macrograzer taxa (refer to caption Figure 3-16) suggests that ≥85% compliance with the PERIWCC aesthetic and provisional ecological condition guideline boundaries of <20%, <30%, <40% and ≤55% corresponds to selected grazer taxa densities of >800/m^2, >450/m^2, >55/m^2 and ≥13/m^2, respectively (Figure 3-16).

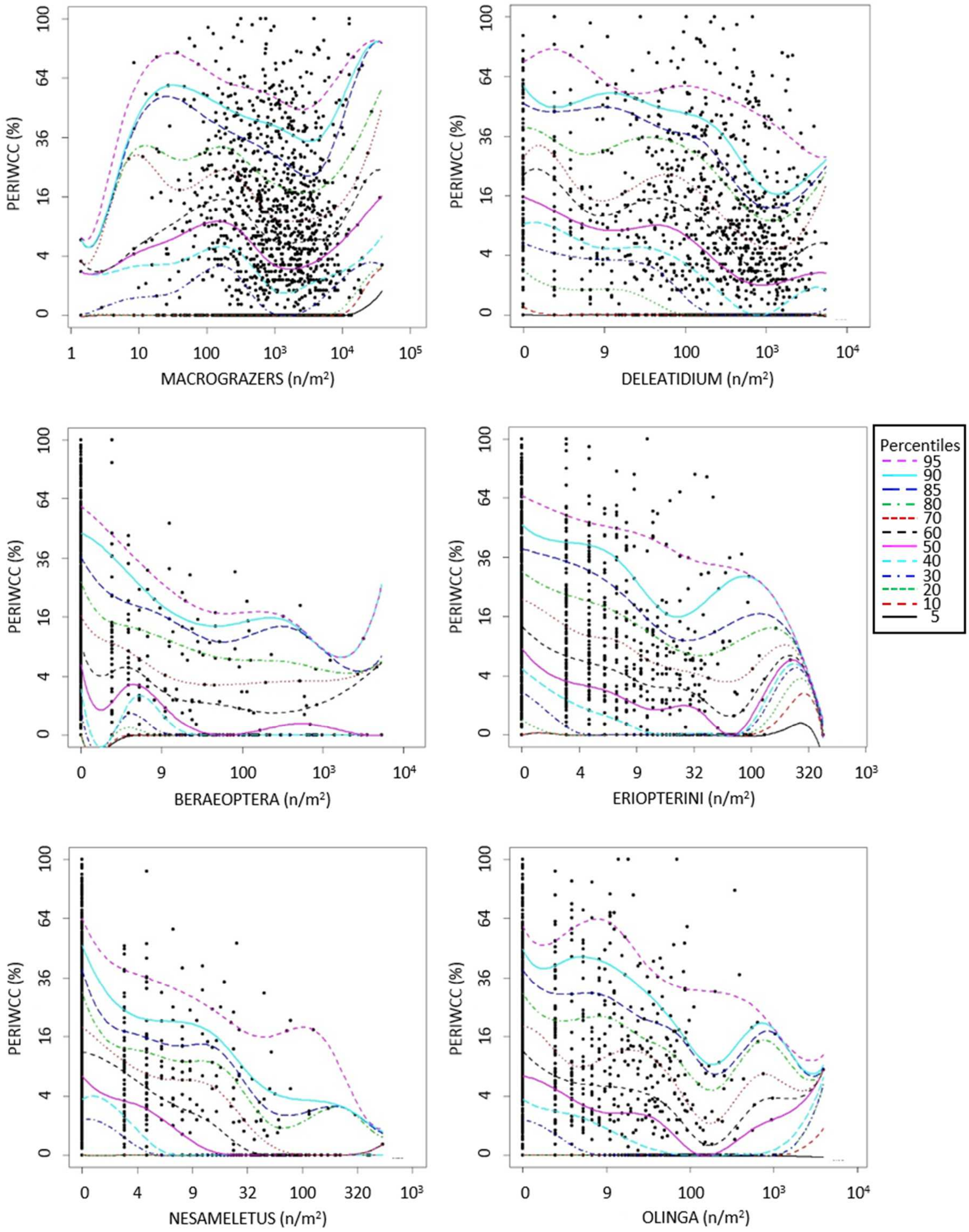


Figure 3-15: Periphyton abundance as PERIWCC versus abundance of all macroinvertebrate grazers and abundances of specific macroinvertebrate grazer taxa. All grazers (top left), *Deleatidium* (top right), *Beraeoptera* (centre left), *Eriopterini* (centre right), *Nemameletus* (bottom left) and *Olinga* (bottom right). Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90, 95).

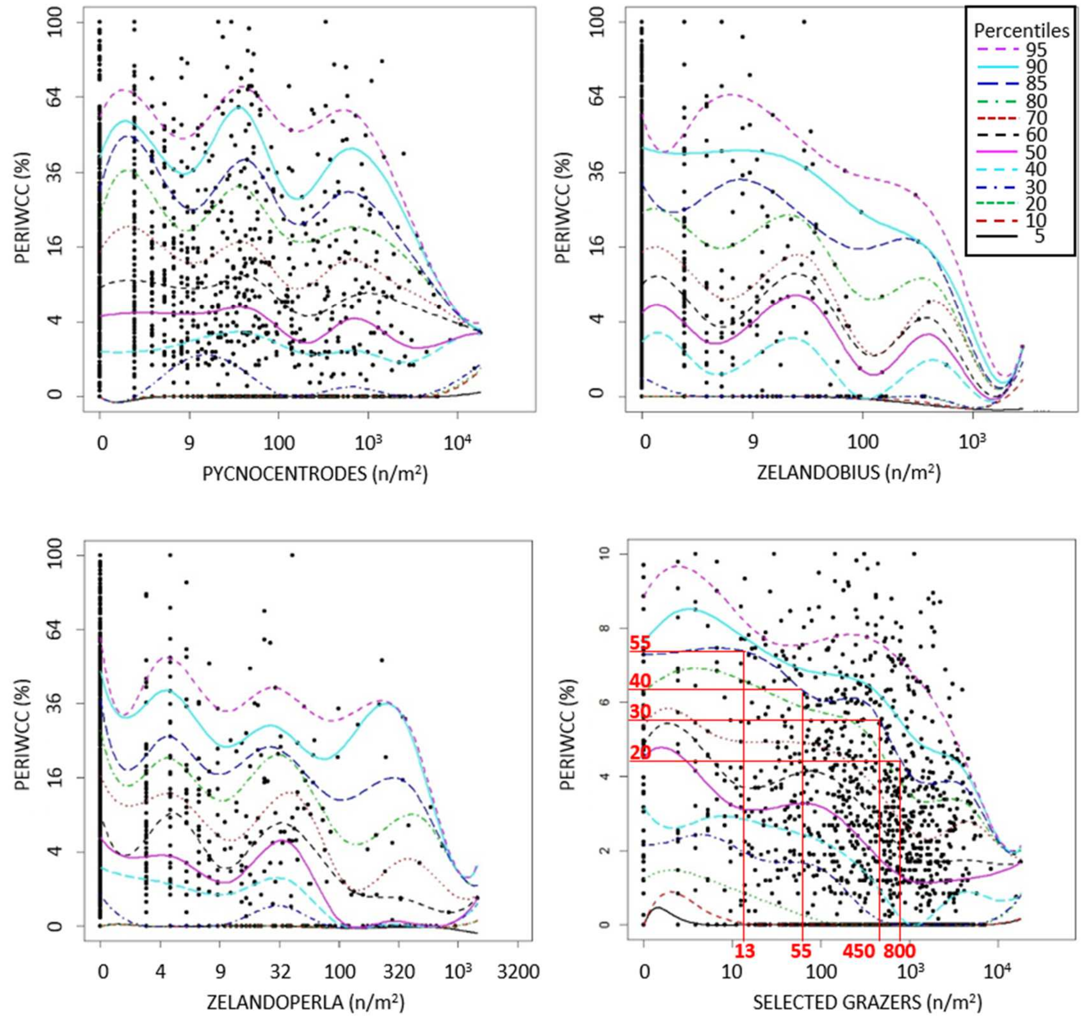


Figure 3-16: Periphyton abundance as PERIWCC versus abundances of specific macroinvertebrate grazer taxa. *Pycnocentrodes* (top left), *Zelandobius* (top right), *Zelandoperla* (bottom left) and total abundance of selected macrograzer taxa (i.e., *Deleatidium*, *Beraeoptera*, *Eriopterini*, *Nesameletus*, *Olinga*, *Pycnocentrodes*, *Zelandobius* and *Zelandoperla*) (bottom right). PERIWCC 20% = SQRT PERIWCC 4.5, PERIWCC 30% = SQRT PERIWCC 5.5, PERIWCC 40% = SQRT PERIWCC 6.3 and PERIWCC 55% = SQRT PERIWCC 7.4. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95).

Chla versus macrograzers

Relationships between macrograzer densities and periphyton abundance as CHLA were weaker than the relationships with PERIWCC (Figure 3-17, Figure 3-18). This presumably reflects the lower number of records in this dataset and the limited national scale representation, with matched CHLA and quantitative macroinvertebrate data only available for Southland and Hawkes Bay, and the latter only available from 2011.

The relationship between CHLA and the densities of the selected 8 macrograzer taxa suggests that ≥85% compliance with the NOF CHLA ecosystem health excellent band of <50 mg/m^2 is not achievable based on macrograzer control of periphyton abundance. For ≥85% compliance, with the NOF CHLA good and fair bands of <120 and ≤200 mg/m^2 corresponds to macrograzer densities of >100/m^2 and >700/m^2 of these taxa (Figure 3-18).

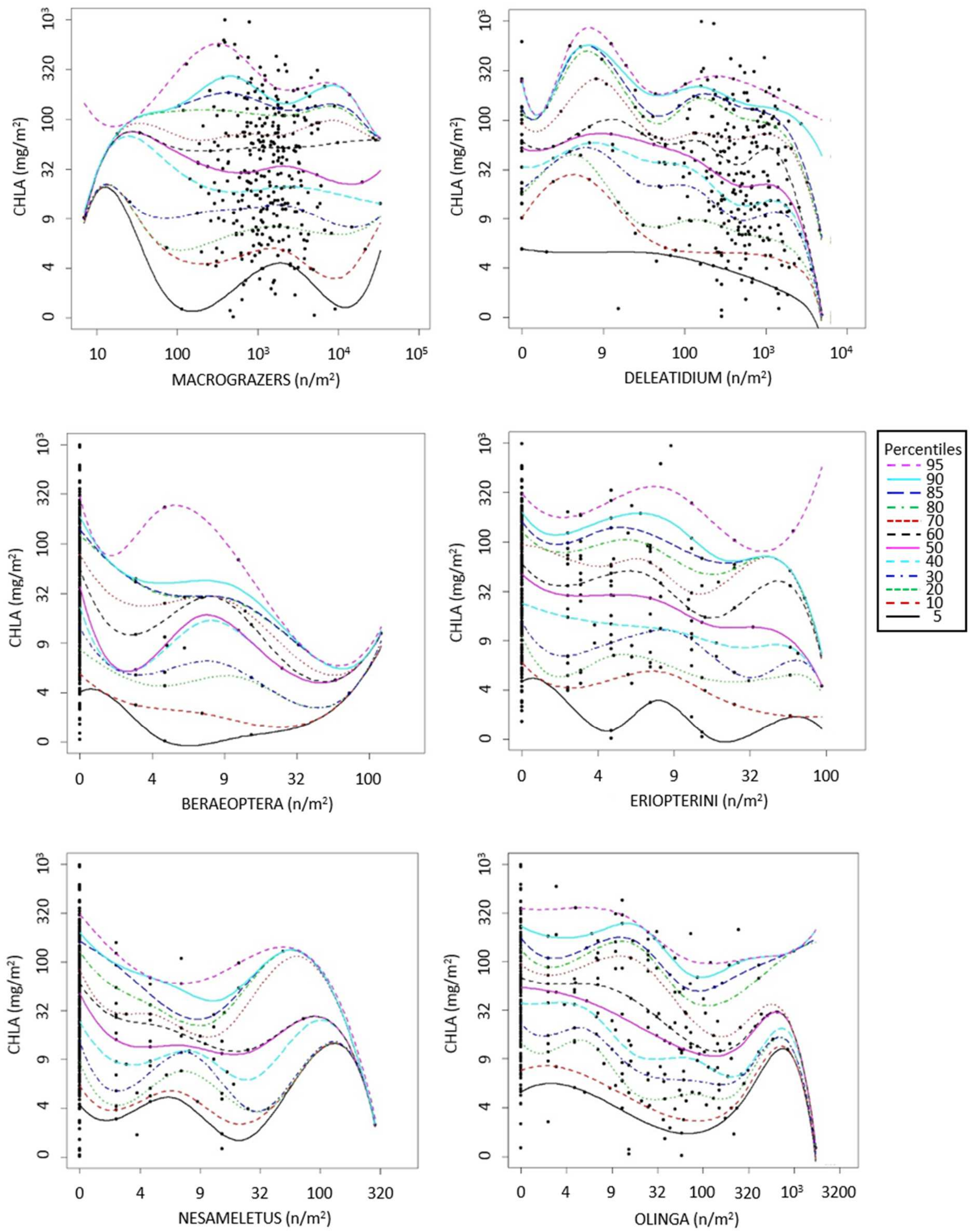


Figure 3-17: Periphyton abundance as chlorophyll *a* versus abundance of all macroinvertebrate grazers and abundances of specific macroinvertebrate grazers. All grazers (top left), *Deleatidium* (top right), *Beraeoptera* (centre left), *Eriopterini* (centre right), *Nemameletus* (bottom left) and *Olinga* (bottom right).. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95).

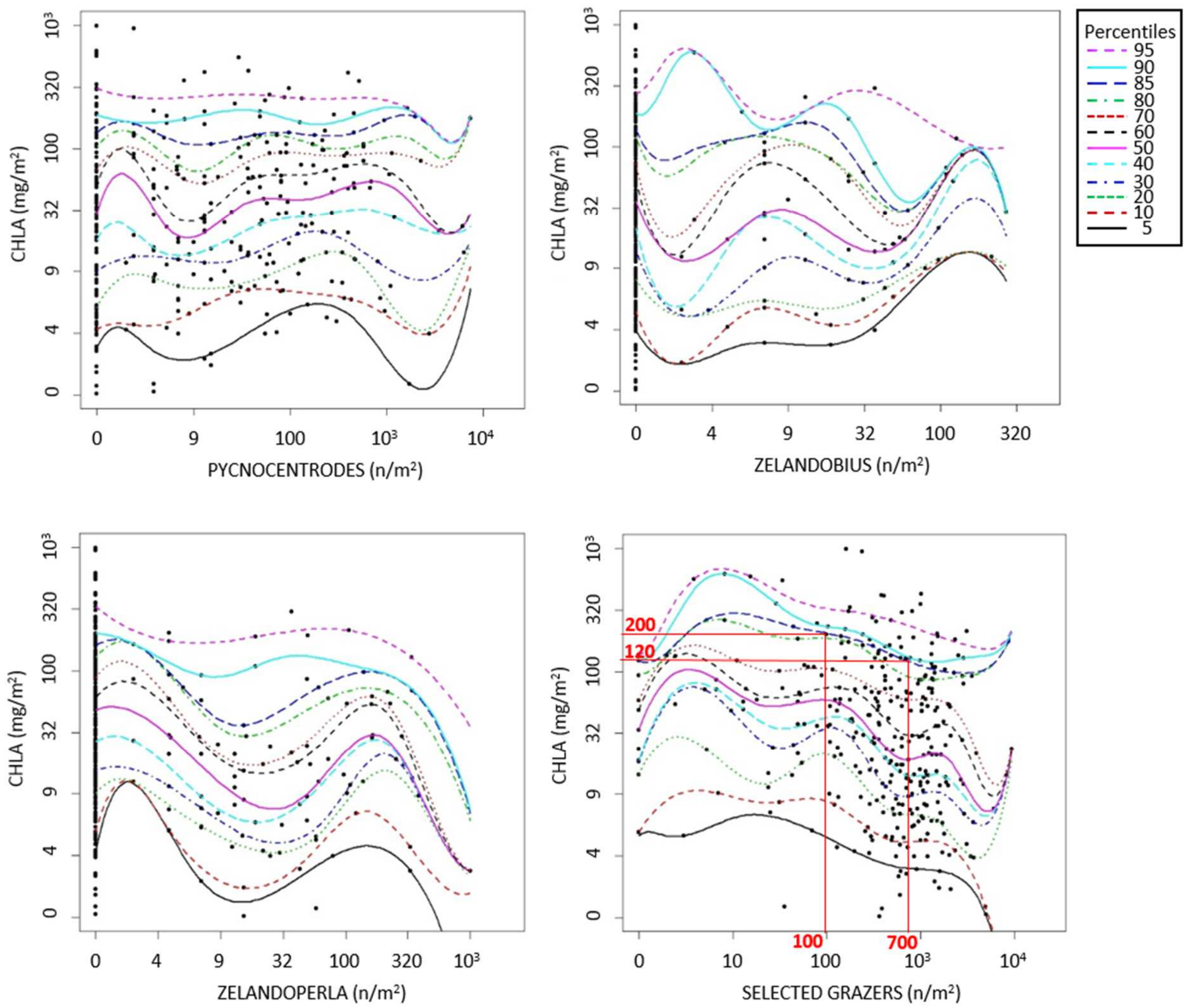


Figure 3-18: Periphyton abundance as chlorophyll *a* versus abundances of specific macroinvertebrate grazer taxa. *Pycnocentrodes* (top left), *Zelandobius* (top right), *Zelandoperla* (bottom left) and total abundance of selected macrograzer taxa (i.e., *Deleatidium*, *Beraeoptera*, *Eriopterini*, *Nesameletus*, *Olinga*, *Pycnocentrodes*, *Zelandobius* and *Zelandoperla*) (bottom right).. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and95).

Periphyton versus water temperature

Quantile regression indicated strong positive relationships between periphyton abundance as PERIWCC and CHLA, and annual mean water temperature (for preceding 12 months) up to c. 13-14°C (Figure 3-19). Above that temperature periphyton abundance showed a tendency to decline, at least for some quantiles. Overall, the results suggest that ≥85% compliance with the PERIWCC aesthetic and provisional ecological condition guidelines of <20%, <30%, <40% and ≤55% would require mean water temperatures <10.7°C, <12.0°C, <13.1°C and ≤16.0°C, respectively. For ≥85% compliance with the NOF CHLA excellent, good and fair bands of <50, <120 and ≤200 g/m^2, mean water temperatures ≤7.5°C, ≤12.4°C and ≤16.8°C are indicated, respectively.

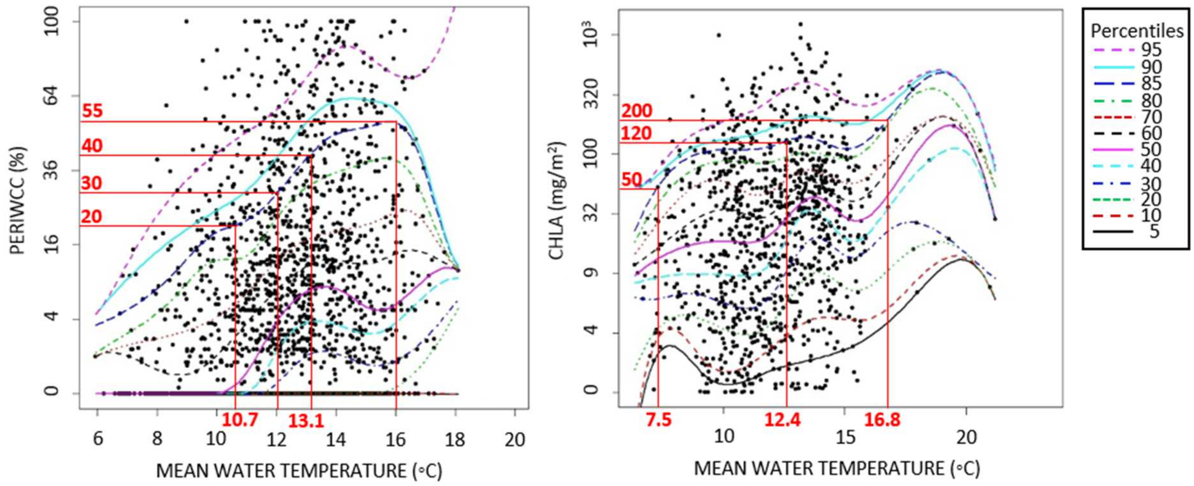


Figure 3-19: Periphyton abundance as PERIWCC (left) and chlorophyll *a* (right) versus mean water temperature for the preceding 12 months. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95).

Periphyton versus other variables

We used the NRWQN records to further examine relationships between PERIWCC and light at the stream bed, days of accrual following floods of various magnitude and substrate index with quantile regression. Data for these variables were not available in the regional authority datasets compiled for this study.

PERIWCC versus light at bed

We found no evidence of a lower light threshold regulating periphyton abundance as PERIWCC. However the majority of the records in the NRWQN dataset are for sites with relatively high estimated light at bed levels (i.e., >300 µmol m^{-2} s^{-1}) which would not be expected to constrain periphyton growth. There are very few records (i.e., 3% of 1175) for sites with relatively low estimated light at bed levels (i.e., <100 µmol m^{-2} s^{-1}). PERIWCC showed signs of being constrained by photoinhibition at high average light levels (>600 µmol m^{-2} s^{-1}) with very few records of PERIWCC >30% at average light at bed levels >1000 µmol m^{-2} s^{-1} (Figure 3-20).

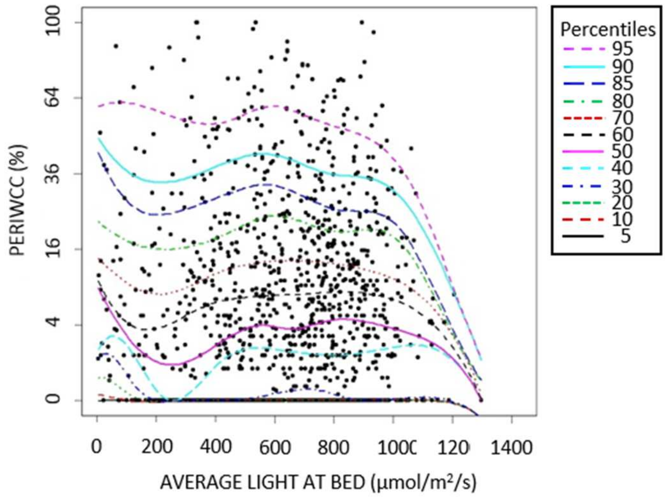


Figure 3-20: Periphyton abundance as PERIWCC versus average light at the stream bed. Quantile regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95).

PERIWCC versus days of accrual

Examining the relationship between days of accrual after a flood 1.5 times the median flow (DA1.5) and PERIWCC we found that a number of sites (Taieri at Outram, Tukituki at Red Bridge, Opuha at Skipton, Waitaki at Kurow and Waitaki at SH1 bridge) had records of PERIWCC >30% with only 1 day of accrual (Figure 3-21). This suggests that periphyton may be resistant to disturbance at flood flows of this magnitude, at least at some sites. In all but one of the above cases, filaments were the dominant form of periphyton recorded. Mats are generally regarded as being more resistant to flushing flows than filaments. Taking into account the records from these sites, the results suggest that achieving ≥85% compliance with the provisional PERIWCC excellent ecological condition guideline of <20% would not be achievable. The analysis indicates a high degree of uncertainty for ≥85% compliance with the PERIWCC aesthetic guideline of 30%. Fluctuation in the regression curve indicates that the DA1.5 required are in the broad range of 10 to 85. However, non-exceedance of the PERIWCC good and fair condition guidelines was indicated for an unlimited number of DA1.5.

At a subset of the above sites (i.e., Taieri at Outram, Tukituki at Red Bridge, Opuha at Skipton) there were four records of PERIWCC >30% with 1 day of accrual following a flood of magnitude 2 times the median flow (DA2) (Figure 3-21). In three of these cases, filaments were dominant. With 10 days of accrual or less following a flood 2 times the median flow there 17 records of PERIWCC >30% from 12 different NRWQN sites. Overall the results for PERIWCC versus DA2 suggest that ≥85% compliance with the PERIWCC excellent ecological condition guideline of <20% would not be achievable. To comply with the PERIWCC aesthetic guideline of 30%, a range from 20 to 100 days is indicated. An unlimited number of DA2 is indicated for compliance with the PERIWCC good and fair condition guidelines.

With less than five days of accrual following a flood of three times the median flow there were three records of PERIWCC >30% from three sites (Taiera at Outram, Tukituki at Red Bridge and Ohinemuri at Karangahake) (Figure 3-21). With 10 days of accrual or less following a flood of three times the median flow there were 9 records from 8 sites corresponding to PERIWCC >30%. With 25 days of accrual or less there were 38 records from 20 sites where PERIWCC was >30%. Including all of these records in the analysis, the results suggest that achieving ≥85% compliance with the PERIWCC excellent ecological condition guideline of <20% would require <11 days of accrual (DA3). A highly variable DA3 range is indicated for compliance with the PERIWCC aesthetic guideline of 30% due to fluctuation in the regression line. The broad range indicated for compliance with this guidelines is 16 to 140 DA3. To achieve ≥85% compliance with the PERIWCC good and fair ecological condition guidelines of <40% and ≤55% respective accrual periods of <280 days and <630 days are indicated by the data.

There was only 1 record (from Tukituki at Red Bridge) of PERIWCC >30% with less than 5 days accrual following a flood of five times the median flow (Figure 3-21). There were only 3 records of PERIWCC >30% with 10 or less days of accrual following a flood of five times the median flow. They were for the following sites: Grey at Waipuna, Tukituki at Red Bridge and Ruamahanga at Wardells. There were 18 records from 13 sites of PERIWCC >30% with 25 or less days of accrual following a flood of five times the median flow. The results suggest that achieving ≥85% compliance with the PERIWCC excellent ecological condition guideline of <20% and the PERIWCC aesthetic guideline of 30% would require <16 DA5 and <150 DA5, respectively. To achieve ≥85% compliance with the PERIWCC good and fair ecological condition guidelines of <40% and ≤55% a very long accrual period of <1260 days and an unlimited number of days are indicated, respectively.

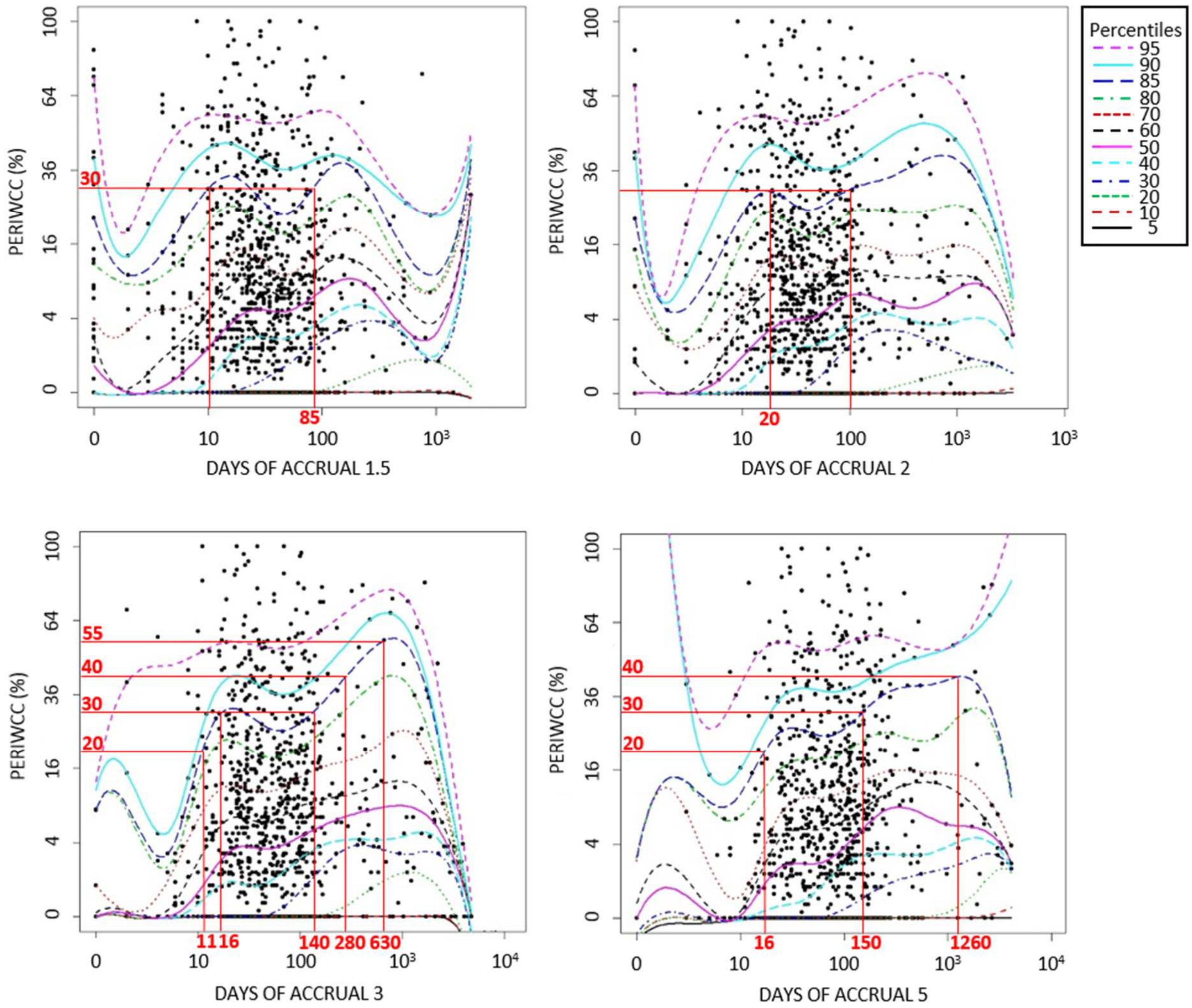


Figure 3-21: Periphyton abundance as PERIWCC versus days of accrual following floods of various magnitude. A flood 1.5 times the median flow (top left), a flood 2 times the median flow (top right), a flood 3 times the median flow (bottom left) and a flood 5 times the median flow (bottom right). Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90, 95).

PERIWCC versus substrate index

Quantile regression did not indicate a strong relationship between PERIWCC and substrate index measured at the time of periphyton sampling across the NRWQN records although there are few soft-bottomed river sites in this monitoring network (Figure 3-22). With a substrate index ≤4 (average large gravel or finer) there were 30 records from 16 sites of PERIWCC >30% (SQRT PERIWCC = 5.5). With a substrate index ≤3 (average small gravel or finer) there were 2 records from 2 sites of PERIWCC >30%.

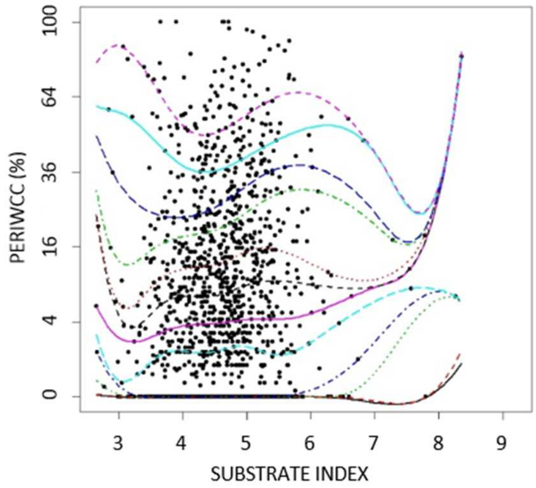


Figure 3-22: Periphyton abundance as PERIWCC versus substrate index measured at the time of periphyton sampling. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95). Note smaller index = smaller substrate size.

4 Discussion

4.1 Evaluation of existing periphyton guidelines

Several documents provide existing values-based periphyton guidelines (Table 4-1). In this report we have conducted analyses of new and updated national-scale datasets to evaluate certain components of the existing angling, ecological condition and ecosystem health guidelines.

Table 4-1: Existing New Zealand periphyton guidelines recommended to protect specific instream values. All guidelines are provisional.

Value	Attribute	Band	Criteria	Reference
Aesthetics/ recreation	AFDM	n/a	<35 g/m^2 as seasonal maximum[a] of filaments >2cm long on visible stream bed in a reach[b] but averaged across full width	MfE (2000)
Aesthetics/ recreation	chl *a*	n/a	<120 g/m^2 as seasonal maximum[a] of filaments >2cm long on visible stream bed in a reach[b] but averaged across full width	MfE (2000)
Aesthetics/ recreation	% cover	n/a	<30% as seasonal maximum[a] of filaments >2cm long on visible stream bed in a reach[b]	MfE (2000)
Aesthetics/ recreation	% cover	n/a	<60% as seasonal maximum[a] of mats >3mm thick on visible stream bed in a reach[b]	MfE (2000)
Aesthetics/ recreation	% cover	n/a	<30% as seasonal maximum[a] weighted composite cover[c] on visible stream bed in a reach[b]	(Matheson et al. 2012)
Benthic biodiversity	chl *a*	n/a	<50 mg/m^2 as seasonal maximum on visible stream bed in a reach[b] but averaged across full width	MfE (2000)
Benthic biodiversity	chl *a*	n/a	<15 mg/m^2 as mean monthly on visible stream bed in a reach[b] but averaged across full width	MfE (2000)
Contact recreation	chl *a*	n/a	≤100 mg/m^2 as seasonal maximum of exposed surface area	MfE (1992)
Contact recreation	AFDM	n/a	≤40 g/m^2 as seasonal maximum of exposed surface area	MfE (1992)
Contact recreation	% cover	n/a	<40% as seasonal maximum cover of filaments or mats (>3 mm thick)	MfE (1992)
Ecological condition[c]	% cover	Excellent	<20% as annual maximum[a] weighted composite cover[c]	Matheson et al. (2012)
Ecological condition[c]	% cover	Good	<20-39% as annual maximum[a] weighted composite cover[c]	Matheson et al. (2012)
Ecological condition[c]	% cover	Fair	40-55% as annual maximum[a] weighted composite cover[c]	Matheson et al. (2012)
Ecological condition[c]	% cover	Poor	>55% as annual maximum[a] weighted composite cover[c]	Matheson et al. (2012)
Ecosystem health	chl *a*	A	<50 mg/m^2 as annual maximum[e]	MfE (2013)
Ecosystem health	chl *a*	B	50-120 mg/m^2 as annual maximum[e]	MfE (2013)
Ecosystem health	chl *a*	C	120-200 mg/m^2 as annual maximum[e]	MfE (2013)
Ecosystem health	chl *a*	D	>200 mg/m^2 as annual maximum[e]	MfE (2013)
Trout fishery-angling	chl *a*	n/a	<120 mg/m^2 as seasonal maximum[a] of filaments >2 cm long on visible stream bed in a reach[b]	MfE (2000)

Value	Attribute	Band	Criteria	Reference
Trout fishery-angling	chl *a*	n/a	<200 mg/m² as seasonal maximum[a] of mats >3 mm thick on visible stream bed in a reach[b] but averaged across full width	MfE (2000)
Trout fishery-angling	% cover	n/a	<30% as seasonal maximum[a] of filaments >2 cm long on visible stream bed in a reach[b] but averaged across full width	MfE (2000)

[a] 1 November to 30 April

[b] reach is defined as a relatively homogenous section of river, usually a run

[c] of filaments (>2 cm long) + (mats (>3 mm thick)/2)

[d] where other stressors are minimal

[e] exceeded on no more than 2 occasions, with no exceedances in successive months (based on a monthly monitoring regime)

The angling values survey conducted as part of this study has provided end-user evaluation of the existing angling filament cover guideline (<30%, MfE 2000). The survey results suggest that this guideline corresponds to a relatively high level of angler acceptability (70 to 84%).

There are currently no guidelines for mat cover or weighted composite cover to protect angling values. The existing aesthetic guidelines of 60% mat cover and 30% weighted composite cover corresponded to 52 to 60% and 66 to 76% angler acceptability, respectively, which are lower than the levels of angler acceptability for the existing filamentous cover guideline.

Our survey results suggest that anglers are almost equally sensitive to cover of mats (with or without cyanobacteria) and filaments and that a mat cover guideline lower than 60% may be appropriate to protect angling values. For example a 30% mat cover guideline would correspond to 69 to 78% angler satisfaction according to our survey results, only slightly lower than the level of angler satisfaction indicated for the existing filamentous cover guideline of 30%. This also suggests that it may not be necessary to down-weight the nuisance effect of mats relative to filaments as per the weighted composite cover metric and that a simple composite metric of filaments+mats (i.e., nuisance periphyton total cover) may be sufficient. For example, if mat cover is 15% and filaments cover is 15% this gives a weighted composite cover of 22.5% and a total cover of 30%. A weighted composite cover of 22.5% corresponds to 71 to 80% angler satisfaction while a total cover of 30% corresponds to a very similar 72 to 82% angler satisfaction according to our survey results.

Using time-matched data in a large, combined NRWQN and participating regional authority dataset we also re-evaluated the relationship between periphyton abundance and ecosystem health based on the selected macroinvertebrate community indices MCI, QMCI and %EPT Taxa. We found that the existing NOF CHLA and provisional PERIWCC "bottom line" thresholds for protection of ecosystem health/ecological condition corresponded to relatively high levels of concordance with equivalent "bottom-line" thresholds for these macroinvertebrate indices (i.e., "fair" category or higher), for %EPT TAXA and MCI in particular. However, the existing NOF CHLA and provisional PERIWCC excellent and good band thresholds corresponded with much lower levels of concordance for the equivalent thresholds for the macroinvertebrate indices. The results suggest that the existing periphyton guidelines for protection of higher levels of ecosystem health/ecological condition are increasingly insufficient if the latter is based on these macroinvertebrate community indices.

Using a newly-developed macroinvertebrate prey item scoring system (Shearer and Hayes 2014) we examined relationships between periphyton abundance and trout food availability. Using this system we developed two sets of simple new indices. They were: (1) total food availability scores for each type of feeding: drift feeding, benthic browsing and cruise feeding, and (2) counts of high ranked prey items (scores 5 or more) for each type of feeding. In our analysis we found that periphyton abundance was more strongly related to counts of high rank prey items than with total food availability scores, presumably due to the influence of high abundances of low ranked food items on the total scores and we suggest that the counts of high ranked prey items are probably a more robust set of indices for general use than the total food availability scores.

The analysis of periphyton abundance versus trout food availability indices, particularly the counts of high rank prey items indicated several thresholds above which there was a drop in food availability, primarily for drift feeding. Those thresholds were CHLA 200 mg/m^2, PERIWCC 50% and PERIMAT 25%. These thresholds are broadly consistent with the existing CHLA guidelines for protection of angling interests (as mats) and the NOF CHLA fair or better ecosystem health guideline of ≤200 mg/m^2, as well as the provisional PERIWCC guideline of ≤55% as an indicator of fair ecological condition. However the relatively low PERIMAT threshold appears to be indicative of a detrimental effect of mats in particular on drift item availability not currently reflected in the existing periphyton guidelines.

Overall, based on the combined results of the angling acceptability survey and our analysis of relationships between periphyton abundance and trout food availability we suggest a set of updated periphyton cover guidelines to protect trout-fishery-angling values (Table 4-2).

Table 4-2: Updated periphyton guidelines recommended to protect trout-fishery values.

Value	Attribute	Band/Class	Criteria	Reference
Trout fishery-angling	% cover	A - Excellent	<10%[ab] of filaments >2cm long or mats >3 mm thick or total cover[f] on visible stream bed in a reach	This study
Trout fishery-angling	% cover	B - Good	10-35%[ac] of filaments >2cm long or mats >3 mm thick or total cover[f] on visible stream bed in a reach	This study
Trout fishery-angling	% cover	C - Fair	35-75%[ad] of filaments >2cm long or mats >3 mm thick or total cover[f] on visible stream bed in a reach	This study
Trout fishery-angling	% cover	D - Poor	>75%[ae] of filaments >2cm long or mats >3 mm thick or total cover[f] on visible stream bed in a reach	This study

[a] 8% allowable frequency of exceedance based on monthly sampling for a minimum of 3 years
[b] corresponds to c. ≥95% angler acceptability
[c] corresponds to c. >75% angler acceptability
[d] corresponds to c. >50% angler acceptability
[e] corresponds to c. <50% angler acceptability
[f] filaments >2cm long plus mats >3mm thick

4.2 Evaluation of existing macrophyte guidelines

Few national or international documents provide existing recommended effects-based macrophyte guidelines. Those based on percent occupation of channel cross-sectional area/volume (CAV) or water surface area (WSA) are summarised in Table 4-3. As discussed in Matheson et al. (2012) guidelines based on biomass (i.e., g/m^2) and undefined "cover" are problematic and not recommended. In this study the angler acceptability survey provided an evaluation of the provisional trout fishery-angling guideline suggested by Matheson et al. (2012).

Table 4-3: Existing national or international instream macrophyte guidelines based on percent occupation of channel cross-sectional area/volume or water surface.

Value	Attribute	Band/Class	Criteria	Reference
Aesthetics/recreation	% channel water surface area (WSA)	n/a	≤50%	Matheson et al. (2012)
Ecological condition/flow conveyance/recreation/trout fishery-angling	% channel cross sectional area/volume (CAV)	n/a	≤50%	Matheson et al. (2012)
General – mountain/hill streams	% channel volume	n/a	<75%	Haslam (1978)
General – upland floodplain streams	% channel volume	n/a	<50%	Haslam (1978)
General – lowland streams	% channel volume	n/a	<25%	Haslam (1978)
General	% channel volume	n/a	<50%	Dawson & Kern-Hanson (1979)

The results of our angler values survey indicate that the provisional instream macrophyte abundance guideline for protection of trout fishery-angling (≤50% CAV, Matheson et al. 2012) corresponds to relatively low levels of angler acceptability (31 to 37%). It may therefore need to be lowered to more adequately protect this value. A WSA guideline to protect trout fishery-angling values was not provided in Matheson et al. (2012) due to a lack of any pre-existing guidance on this attribute, but it is considered highly relevant to this value and consequently was evaluated in the angler acceptability survey.

The survey results suggest that a very high level of angler acceptability (i.e., ≥95%) for the two macrophyte attributes is unachievable. Even with 0% CAV and 0% WSC our survey results suggest that angler satisfaction is only 63 to 79%. The high level of angler dissatisfaction found in this survey with even relatively low levels of macrophyte abundance is probably a reflection of the predominant angler group represented in the survey, i.e., trout fly anglers, who would have an underlying preference for cobble-bed rivers with a naturally low abundance of macrophytes (most commonly as inconspicuous native bryophytes – mosses and lichens). Only a small percentage of the survey respondents were coarse fish anglers who likely have a preference for soft-bottomed, lowland streams where coarse fish and macrophytes (often introduced species) are typically more abundant.

On the basis of the angling values survey results we suggest the following updated macrophyte guidelines to protect trout fishery-angling values (Table 4-4).

Table 4-4: Updated macrophyte guidelines to protect trout fishery-angling values.

Value	Attribute	Band/Class	Criteria[a]	Reference
Trout-fishery-angling	% channel cross sectional area/volume (CAV)	A - Excellent	<10%[b]	This study
Trout-fishery-angling	% channel water surface area (WSA)	A - Excellent	<5%[b]	This study
Trout-fishery-angling	% channel cross sectional area/volume (CAV)	B - Good	10-20%[c]	This study
Trout-fishery-angling	% channel water surface area (WSA)	B - Good	5-10%[c]	This study
Trout-fishery-angling	% channel cross sectional area/volume (CAV)	C - Fair	20-30%[d]	This study
Trout-fishery-angling	% channel water surface area (WSA)	C - Fair	10-20%[d]	This study
Trout-fishery-angling	% channel cross sectional area/volume (CAV)	D - Poor	>30%[e]	This study
Trout-fishery-angling	% channel water surface area (WSA)	D - Poor	>20%[e]	This study

[a] as annual maximum (this will normally occur in summer during a period of stable flow)

[b] corresponds to angler acceptability >70% according to simple mean method

[c] corresponds to angler acceptability 60-70% according to simple mean method

[d] corresponds to angler acceptability 50-60% according to simple mean method

[e] corresponds to angler acceptability <50% according to simple mean method

4.3 Nutrient control of periphyton abundance

Nutrient availability is one of a number of factors that affect periphyton abundance in rivers. Therefore management of periphyton abundance via controls on nutrient concentrations alone is difficult.

At present there are several documents that provide national guidance on nutrient concentrations required to limit the development of instream nuisance periphyton abundance. A further approach yet to be formally reported is outlined in Appendix I Studies assisting with the derivation of the NOF periphyton attribute. A common theme in all of the existing guideline documents is that very low nutrient concentrations are usually required to constrain or prevent the development of high periphyton biomass in flowing waters, except in situations where one or more of the other key factors that affects periphyton abundance (e.g., frequency of flushing flows, light availability) has an overriding influence.

The New Zealand Periphyton Guideline (MfE 2000) currently provides a set of nutrient guidelines to limit the development of nuisance periphyton relative to days of accrual following a flow event that scours periphyton from the river bed (Table 4-5). These guidelines indicate that very low concentrations of DIN (i.e., <20 mg/m^3) and DRP (<1 mg/m^3) are required to ensure compliance with the periphyton CHLA benthic biodiversity guideline of 50 mg/m^2 but higher concentrations are allowable to protect angling interests (i.e., higher allowable CHLA levels of 120 mg/m^2 and 200 mg/m^2), particularly where accrual time is 20 days or less.

Table 4-5: New Zealand Periphyton Guideline recommended nutrient concentrations to ensure that peak periphyton biomass does not exceed biomass guidelines. From MfE (2000).

Study	Chl *a* = 50 mg/m²		AFDM = 35 g/m² Chl *a* = 120 mg/m² (filamentous) Chl *a* = 200 mg/m² (diatom)	
Days of accrual	DIN mg/m³	DRP mg/m³	DIN mg/m³	DRP mg/m³
20	<20	<1	<295	<26
30	<10	<1	<75	<6
40	<10	<1	<34	<2.8
50	<10	<1	<19	<1.7
75	<10	<1	<10	<1
100	<10	<1	<10	<1

The New Zealand Periphyton Guideline (MfE 2000) described above superceded an original set of water quality guidelines (MfE 1992) that provided a more general recommendation that DIN concentrations <40-100 mg/m^3 and DRP concentrations <15-30 mg/m^3 would be required to constrain periphyton abundance in flowing waters.

In the Phase 1 and 2 components of this study (Matheson et al. 2012) we used an analysis of the NRWQN dataset (average data by site, n=65) and a literature review to review relationships between periphyton abundance, nutrient availability and other factors regulating periphyton development. From this we produced a general, multi-factor Bayesian Belief Network (BBN) model to predict the likelihood of average annual maximum periphyton abundance as filamentous cover exceeding the aesthetic guideline of 30%. Annual mean concentrations of DIN and DRP were components of this model.

The DIN and DRP components of the BBN model employed four risk categories as follows:

Very low risk: mean DIN <50 mg/m^3, mean DRP <3 mg/m^3

Low risk: mean DIN 50 to 150 mg/m^3, mean DRP 3 to 6 mg/m^3

Moderate risk: mean DIN 150 to 300 mg/m^3, mean DRP 6 to 15 mg/m^3

High risk: mean DIN >300 mg/m^3, mean DRP >15 mg/m^3

The model also assigned 2 to 4 risk categories to other factors considered to be key regulators of periphyton abundance, i.e., light availability, water temperature, frequency of flooding, dominant substrate size and macrograzer abundance. The model was shown to be reasonably effective at predicting sites in the NRWQN that were periodically at risk of exceeding the PERIFIL aesthetic guideline of 30%.

In this phase of the project we re-examined nutrient relationships to periphyton abundance, both as CHLA and PERIWCC using a larger, combined NRWQN and regional authority dataset of annual, time-matched, growing season periphyton-nutrient data and a non-linear quantile regression approach. These analyses yielded the following set of general nutrient thresholds to achieve ≥85% "growing-season" compliance with existing periphyton abundance guidelines (Table 4-6). We suggest 85% compliance with periphyton during the growing season is approximately equivalent to the NOF compliance requirement of 92% for monthly observations (i.e., NOF permits 1 breach per year with monthly data; MFE 2014). For comparison we also provide annual mean and preceding spring-time nutrient thresholds for ≥80%, ≥90% and ≥95% compliance in Appendix E (Table J-1, Table J-2, Table J-3, Table J-4). We were unable to derive thresholds by river REC class due to an uneven representation of classes within the dataset.

Table 4-6: Nutrient criteria to achieve ≥85% compliance with periphyton abundance guidelines based on quantile regression of "summer" [a] data.

Periphyton metric	Periphyton guideline [b]	Mean for preceding 12 months (mg/m^3)			
		DIN	DRP	TN	TP
Chl*a* (mg/m^2)	<50	<100	na [c]	nd [d]	<14
	<120	<630	<11	nd [d]	<45
	≤200	<1100	<18	nd [d]	<65
PERIWCC (%)	<20	<35	na [c]	<68	<10
	<30	<140	na [c]	<350	<45
	<40	<360	na [c]	<660	<55
	≤55	nc [e]	na [c]	nc [e]	<75

[a] "summer" period = 1 November to 30 April.
[b] chl*a* 50 mg/m^2 equivalent to c. 21% PERIWCC, 120 mg/m^2 = c. 34% PERIWCC and 200 mg/m^2 = c. 45% PERIWCC, see Appendix I Studies assisting in the derivation of the NOF periphyton attribute.
[c] na data indicate not achievable – e.g., no significant relationship.
[d] nd insufficient data to determine.
[e] nc no criteria indicated – i.e., achievable at all nutrient concentrations.

The quantile regression approach mostly generated higher nutrient thresholds based on CHLA relative to PERIWCC especially for DIN. The results based on PERIWCC may be more robust due to the larger number of records (i.e., n=1565 vs. 609) and broader geographical coverage of this dataset.

The dissolved nitrogen criteria derived here for compliance with CHLA guidelines are higher than those recommended in the New Zealand Periphyton Guideline (MfE 2000). However the latter are generally regarded as being quite conservative. For example, the New Zealand Periphyton guideline recommends mean DIN concentrations in the range of <10 to <20 mg/m^3 (depending on accrual time) for compliance with the CHLA benthic biodiversity/NOF excellent band guideline of 50 mg/m^2. The criteria derived here by quantile regression suggest that annual mean DIN concentrations <100 mg/m^3 would be sufficient to achieve ≥85% "growing season" compliance with this guideline. For compliance with the MfE (2000) CHLA angling guidelines mean DIN concentrations in the range of <10 to <295 mg/m^3 are required. The nutrient criteria derived by quantile regression suggest that higher concentrations of <630 mg/m^3 and <1100 mg/m^3 would be sufficient to comply with the 120 mg/m^2 and 200 mg/m^2 MfE (2000) CHLA angling guidelines/NOF good and fair band guidelines, respectively.

All of the studies described above have used a different approach to generate nutrient criteria in various forms. Each of the approaches has certain advantages and limitations (Table 4-7). Two of the most recent approaches utilise multi-factor models recognising the complex nature of controls on periphyton abundance, but at this stage the models developed have relatively low predictive power. Further advancement and improvement of multi-factor models as developed by Snelder at al. (2014 and unpub.) and Matheson et al. (2012) requires regional authorities to gather information on key variables to fill critical gaps in the multi-factor datasets available. In addition, the use of non-linear rather than linear models needs further exploration to achieve better predictive performance. Further work using the quantile regression approach has the potential to yield nutrient thresholds by river class if a larger, more nationally representative, periphyton-nutrient dataset can be acquired.

Table 4-7: Summary of different approaches that have been used to generate nutrient criteria for regulation of periphyton abundance in New Zealand rivers.

Document	Approach	Form of nutrient criteria	Advantages	Disadvantages/Limitations
MfE (1992)	Literature review, unpub. data, expert opinion	General threshold ranges for DIN and DRP to constrain periphyton abundance	Provides a basic guideline range above which periphyton growth would be unconstrained by nutrients and below which a progressive reduction in biomass would be expected.	Threshold ranges are relatively broad. Not based on rigorous analysis.
MfE (2000)	Analysis of a substantial periphyton research dataset (Biggs et al.)	Numeric thresholds for DIN and DRP to ensure CHLA below benthic biodiversity and angling guidelines based on days of accrual	Provides a set of nutrient criteria to comply with CHLA guidelines for benthic biodiversity and angling that are consistent with the periphyton A, B and C classes adopted under NOF.	Ignores other factors that can influence periphyton abundance so only applies in situations where the main drivers of periphyton abundance are the frequency of flushing flows and nutrient concentrations. Days of accrual data requires specialist interrogation of hydrological flow records to compute. Does not provide nutrient guidelines by river class.
Matheson et al. (2012)	Linear and quantile regression analysis of NRWQN dataset plus literature review to delineate risk categories in model	A multi-factor Bayesian Belief Network model to predict likelihood of exceeding periphyton filamentous cover guideline. Four risk categories for DIN and DRP in the model.	Provides a model that includes all key factors considered to regulate periphyton abundance in rivers. The model performance was reasonable when tested against the NRWQN dataset.	Has only been tested with NRWQN dataset because regional authority datasets currently do not contain information on all factors. The model applies to the periphyton filamentous cover guideline only. Does not provide nutrient guidelines by river class.
Snelder et al. unpub.	Linear regression analysis of NRWQN plus modelled data to develop linear models to predict periphyton abundance for all NZ river segments	Nutrient concentration thresholds for compliance with CHLA A, B and C NOF classes for each REC climate/source of flow river class	Provides a comprehensive set of nutrient criteria that vary by REC climate/source of flow class in accordance with conceptual expectations.	CHLA data limited so PERIWCC data used as a proxy. Strong reliance on modelled rather than actual data. Based on multi-factor linear regression models that do not explain a high proportion of the variability in periphyton abundance and tend to underestimate higher observed abundances. Nutrient criteria based on these criteria may therefore be over-generous.
This study	Quantile regression analysis of combined NRWQN and multi-regional authority dataset	General threshold ranges for ≥85% compliance with periphyton CHLA and WCC guidelines during the growing season.	Based on actual data. Only requires nutrient and periphyton data, data for other regulating factors not required. Approach could yield values by REC class for compliance with CHLA and cover guidelines if more data from poorly represented REC climate/source of flow classes were available	Analysis is based on a new non-linear quantile regression module in R that is still under development and currently does not provide a means to compute the statistical significance of the model fits.

4.4 Advancing multi-factor models

Regional authority State of Environment monitoring datasets are a nationally important asset and the key to advancing models to predict periphyton (and macrophyte) abundance in New Zealand streams and rivers. Regional authority datasets currently lack information on a number of parameters that are important to the advancement of multi-factor models (Table 4-8).

Light at bed is an important factor that we should strive to include in our future instream plant abundance models. It was not available in any of the regional authority datasets provided for this study but it has been calculated (not measured directly) for sites in the NRWQN. In the Phase 1 and 2 report we provided a method for estimation of this parameter based on a set of relatively easily measured parameters (i.e., water depth, black disk clarity or turbidity, absorbance G340, % shade and ambient irradiance). Water depth, black disk and % shade can be measured onsite at the time of periphyton assessment. Ambient irradiance data can be obtained from the nearest climate station if onsite measurements are not practical. Since ambient irradiance varies substantially during the course of the day, light at bed should be calculated as a daily average value. In Phase 3 of this project we have shown that light attenuation might be approximated directly from black disk or turbidity measurements without the need to measure absorbance and equations are provided in section 3.4.2 of this report for that purpose. However, direct measurement of light attenuation or light at bed onsite is preferable.

Another important parameter not readily available in regional authority datasets is days of accrual following floods of various magnitude. Ideally days of accrual following floods ranging from 1.5 to 10 times the median flow should be calculated, based on the results of the latest research in the Sustainable Water Allocation Programme (see Appendix I), and recorded in regional authority databases for each periphyton sampling date. In the future, refined advice on the most relevant hydrological and geomorphological parameters for prediction of periphyton abundance is likely to be forthcoming from this ongoing research programme.

In the Phase 1 and 2 report we also recommended that regional authorities collect data on substrate index and macrograzer density. The latter requires regional authority quantitative macroinvertebrate sampling (i.e., sampling of a fixed area and full count of individuals in a sample). Quantile regression analysis of a combined NRWQN and regional authority dataset (section 3.4.4) showed that the density of a specific set of macrograzers is strongly related to periphyton abundance. Future multi-factor predictive models of instream periphyton abundance should therefore benefit from inclusion of density data for these macrograzer species. Data on substrate index was not available in the regional authority datasets compiled for this study. A re-examination of the NRWQN dataset did not suggest a strong relationship between substrate index and periphyton abundance, although this dataset is characterised by a predominance of hard-bottomed (high substrate index) sites.

Table 4-8: Parameters for regional authorities to include in their monitoring databases to enable improved prediction of periphyton abundance using multi-factor models in the future on a national scale.

Parameters	Components required to calculate	How and when to measure
Light at bed ($\mu mol/m^2/s$)	Mean water depth (m)	Measure at time of periphyton sampling or more frequently. Measure water depth at minimum of five points in one or more transects across the channel in a representative reach. Calculate mean value.
	Black disk	Measure at time of periphyton sampling or more frequently using a horizontal black disk and the standard protocol for this technique, see Davies-Colley (1988), MfE (1994).
	Turbidity (NTU)	Alternative to black disk. Take a water sample from the centre of the channel at the time of periphyton sampling or more frequently for laboratory or field measurement of turbidity using an approved method.
	Shade (%)	Measure at the time of periphyton sampling in one or more transects across river in a representative reach using a spherical densiometer or light meter or visually estimate to nearest 5%. Calculate mean value.
	Ambient irradiance ($\mu mol/m^2/s$)	Obtain irradiance data from the nearest climate station (preferably within 20 km). Convert data from total daily W/m^2 to average daily $\mu mol/m^2/s$.
Light at bed ($\mu mol/m^2/s$)	not applicable	To measure light at bed directly use an underwater sensor, or set of sensors, deployed at bed level in a representative location or transect for a minimum period of 24 h within the month preceding or at the time of periphyton sampling. Optional: Compare to irradiance level just below the water surface to determine % light attenuation through the water column. Compare to ambient irradiance data to determine % light attenuation due combined effect of shading and water column attenuation.
Days of accrual (d)	not applicable	For floods of various magnitude above median flow. Requires automated interrogation of the continuous flow record for a site (actual or modelled).
Substrate index	not applicable	Measure at time of periphyton sampling or at least once per annum. Determine % of bed comprised of boulder, large cobble, small cobble, large gravel, small gravel, sand, silt and clay in one or more transects across river in a representative reach. Substrate composition can be converted to a substrate index (SI) following Quinn and Hickey (1994), i.e., SI = 0.08x%boulder + 0.07x% large cobble + 0.06x%small cobble + 0.05x%large gravel + 0.04*%small gravel + 0.03x% sand + 0.02x%silt.
Macrograzer density	not applicable	Measure at time of periphyton sampling in summer. Use Surber sampling (or kicknet sampling of a fixed area, if test results indicate similar animal densities to Surber) and do a full count of each sample to obtain densities of various key macrograzer taxa.

5 Conclusions

The Phase 3 component of this Tools project has provided several recommended refinements to existing (provisional) instream plant abundance guidelines. These refinements are based on the results of an angler acceptability survey and an analysis of relationships between periphyton abundance and the availability of macroinvertebrate prey items for adult trout (the latter using a newly developed prey item scoring system). The refinements include:

- A set of updated periphyton cover guidelines to protect trout-fishery-angling values (see Table 4-2).
- A set of updated macrophyte guidelines to protect trout-fishery-angling values (see Table 4-4).

The project has also generated a new set of general nutrient criteria for compliance with provisional periphyton CHLA and PERIWCC guidelines. These nutrient criteria (see Table 4-6) were derived by applying non-linear quantile regression analysis to a combined NRWQN-regional authority dataset of annual, time-matched periphyton-nutrient data.

The quantile regression approach requires only periphyton and nutrient data to derive guidelines so avoids the need for development of complex multi-factor models; however a large amount of data is required for robust analysis. In the future this approach could be used to derive guidelines by river class (e.g., based on the River Environment Classification, REC) if sufficient matched periphyton and nutrient data can be obtained for each river class of interest. The database compiled for this project was dominated by data for sites in the Cool-Wet River Environment Classification class.

Further advancement of multi-factor models to predict periphyton abundance will likely require the development of non-linear as opposed to linear models. Relationships between periphyton and regulating variables frequently indicated non-linear subsidy-stress relationships. Moreover, the predictive performance of multi-factor linear regression models in this and predecessor studies (i.e., Matheson et al. 2012, Snelder et al. 2014) has been relatively low with a strong tendency to underestimate periphyton abundance at high observed values. Use of these models to generate nutrient criteria may therefore result in non-conservative values.

State of Environment monitoring datasets are a nationally important asset and the key to advancing models to accurately predict periphyton (and macrophyte) abundance in New Zealand rivers. Regional authority datasets currently lack information on light availability, accrual time following floods of various magnitude, substrate index and the density of key macroinvertebrate grazer species which are potentially important to the advancement of multi-factor periphyton models. This report provides advice to assist regional authorities in the collection and calculation of these relevant parameters (see Table 4-8).

6 Acknowledgements

We thank all the regional authority scientists who have supported this project, supplied monitoring datasets and photographs, and/or contributed to the project workshop; in particular Graham Sevicke-Jones, Summer Greenfield and Alton Perrie (Greater Wellington Regional Council), Roger Hodson (Environment Southland), Sandy Haidekker and Adam Uytendaal (Hawkes Bay Regional Council), Logan Brown (Horizons Regional Council) and David Kelly (Environment Canterbury). Thanks to Michelle Greenwood and Doug Booker (NIWA) for supplying NRWQN days of accrual data and Dr Paula Blackett (AgResearch) for peer review of the values surveys. We are grateful to Maurice Rodway (Southland Fish and Game) and Hera Smith (Te Arawa Lakes Trust) for feedback and assistance with pilot testing and distribution of the surveys and to the anonymous participants in the pilot surveys.

7 Glossary of abbreviations and terms

AAS	Angler Acceptability Score
ANOVA	Analysis of Variance
Accrual time	The time available for periphyton biomass to accrue between floods
BBS	Benthic Browsing Score
BRT	Boosted Regression Tree
CAV	Channel Cross-sectional Area/Volume Occupied
CD	Cool Dry (REC Climate Class)
CFS	Cruise Feeding Score
CHLA	Chlorophyll *a*
Criteria (water quality)	A numerical concentration limit or narrative statement that has been established to support and protect the designated uses of water at a specified site. It is based on scientific criteria or water quality guidelines but may be modified by other inputs such as social or political constraints. (ANZECC 2000).
CW	Cool Wet (REC Climate Class)
CX	Cold Extremely Wet (REC Climate Class)
DA	Days of Accrual
DFS	Drift Feeding Score
DIN	Dissolved Inorganic Nitrogen, which comprises nitrate-N (NO_3^-), ammoniacal-N (NH_4^+) and nitrite-N (NO_2^-).
DRP	Dissolved Reactive Phosphorus
ECAN	Canterbury Regional Council
Ecosystem Health	The life-supporting capacity, ecosystem processes and indigenous species including their associated ecosystems, of fresh water . A compulsory value under the NPS-FM.
EPT	Ephemeroptera, Plecoptera and Trichoptera
ES	Southland Regional Council
FRE3	Frequency of floods greater than 3 times the median flow
GWRC	Greater Wellington Regional Council
Guideline (water quality)	The concentration of all metallic cations, except those of the alkali metals, present in water. In general, hardness is a measure of the concentration of calcium and magnesium ions in water and is frequently expressed as mg/L calcium carbonate equivalent. (ANZECC 2000).
HBRC	Hawkes Bay Regional Council
HSD	Honestly Significant Difference

HZRC	Horizons Regional Council
K_d	Light attenuation coefficient
Limit	Limit has both a general meaning (maximum or minimum value) as well as a specific meaning under the NPSFM. The term limit is defined in the NPSFM as "the maximum amount of resource use available, which allows a freshwater objective to be met". (MfE 2014). The NPSFM Implementation Guide expands on the above definition by stating that a limit is a specific quantifiable amount. The NPSFM Implementation Guide gives an example of a maximum contaminant load for a water quality limit. The Implementation Guide says this would be a "common type of limit", but does not suggest that this is the only type of limit. However, it does not give examples of what other types of limits might be.
MBIE	Ministry of Business, Innovation and Employment
MCI	Macroinvertebrate Community Index
N	Nitrogen
NH_4-N	Ammoniacal Nitrogen
NIWA	National Institute of Water and Atmospheric Research
NO_3-N	Nitrate Nitrogen
NOF	National Objectives Framework
NPS-FM	National Policy Statement for Freshwater Management
NRWQN	National Rivers Water Quality Network
(Management) Objective	Describes the intended environmental outcomes(s) (definition from National Policy Statement for Freshwater Management). Freshwater objectives are set in regional planning documents and describe the desired state of the water body, having taken into account all desired values.
P	Phosphorus
PAR	Photosynthetically Available Radiation
PERIFIL	Periphyton Filament Cover
PERIMAT	Periphyton Mat Cover
PERITOT	Periphyton Total Cover of Filaments and Mats
PERIWCC	Periphyton Weighted Composite Cover of Filaments and Mats
QMCI	Quantitative Macroinvertebrate Community Index
REC	River Environment Classification
Reference condition	An environmental quality or condition that is defined from as many similar systems as possible and used as a benchmark for determining the environmental quality or condition to be achieved and/or maintained in a particular system of equivalent type. (ANZECC 2000).

SMLR	Stepwise Multiple Linear Regression
Standard (water quality)	An objective that is recognised in enforceable environmental control laws of a level of government.
SQRT	Square Root
SQRTflow%ile	Square Root of the Flow Percentile
SWAP	Surface Water Allocation Programme
SWIM	Surface Water Integrated Management
Target	Under NPS-FM, is a limit that must be met at a defined time in the future. This meaning only applies in the context of over-allocation. (MfE 2014)
Trigger value (TV)	These are the concentrations (or loads) of the key performance indicators measured for the ecosystem, below which there exists a low risk that adverse biological (ecological) effects will occur. They indicate a risk of impact if exceeded and should 'trigger' some action, either further ecosystem specific investigations or implementation of management/remedial actions. (ANZECC 2000).
TEMP	Water Temperature
TN	Total Nitrogen
TP	Total Phosphorus
Uses	The uses for a water body – equivalent to values.
Values	Under the NPSFM, is any national value, and any value in relation to fresh water that a regional council identifies as appropriate for regional or local circumstances (including any use value). Values are equivalent to uses.
WSA	Channel Percent Water Surface Area Occupied
WW	Warm Wet (REC Climate Class)
WX	Warm Extremely Wet (REC Climate Class)

8 References

ANZECC, ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. *National Water Quality Management Strategy Paper* No. 4, Australian and New Zealand Environment and Conservation & Agriculture and Resource Management Council of Australia and New Zealand. 317p.

Biggs, B.J.F. (1996) Patterns in benthic algae of streams. Pp. 31-56 in Stevenson, R.J., Bothwell, M.L., Lowe, R.L. (eds) *Algal Ecology: Freshwater benthic ecosystems.* Academic Press, San Diego.

Biggs, B.J.F. (2000) Eutrophication of streams and rivers: dissolved nutrient chlorophyll relationships for benthic algae. *Journal of the North American Benthological Society,* 19: 17-31.

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

Chapra, S., Flynn, K., Rutherford, J. (2014) Parsimonious Model for Assessing Nutrient Impacts on Periphyton-Dominated Streams. *Journal of Environmental Engineering,* 140: 04014014.

Davies-Colley, R.J. (1998) Measuring water clarity with a black disk. *Limnology and Oceanography, 33:* 616–623.

Davies-Colley, R.J., Nagels, J.W. (2008) Predicting light penetration into river waters. *Journal of Geophysical Research – Biogeosciences,* 113: G03028, doi: 03010.01029/02008JG000722.

Dawson, F.H., Kern-Hansen, U. (1979) The effect of natural and artificial shade on the macrophytes of lowland streams and the use of shade as a management technique. *Internationale Revue Gesamten Hydrobiologie* ,64: 437–455.

Haslam, S.M. (1978) *River plants: the macrophytic vegetation of watercourses*. Cambridge University Press: 396.

Heath, M.H., Wood, S.A., Roger, G. Young, R.G., Ryan, K.G. (in prep.) The role of nitrogen and phosphorus in regulating *Phormidium autumnale* (cyanobacteria) growth and anatoxin production. *PloS One*.

Kilroy, C., Booker, D.J., Drummond, L., Wech, J.A., Snelder, T.H. (2013) Estimating periphyton standing crop in streams: a comparison of chlorophyll *a* sampling and visual assessments. *New Zealand Journal of Marine and Freshwater Research, 47*: 208-224.

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. *NIWA Report* No. HAM2012-081: 127.

McDowell, R.W. (2015) Relationship between sediment chemistry, equilibrium phosphorus concentrations (EPC0) and phosphorus concentrations at baseflow in rivers of the New Zealand National River Water Quality Network. *Journal of Environmental Quality,*44: 921-929.

Measures, R., Kilroy, C. (2014) Opuha River periphyton management investigations 2013-2014. *NIWA Report* No. CHC2014-67: 47.

Ministry for the Environment (MfE) (1992) *Water Quality Guidelines* No. 1. Guidelines for the Control of Undesirable Biological Growths in Water: 60.

Ministry for the Environment (MfE) (2000) *New Zealand Periphyton Guideline: Detecting, Monitoring and Managing Enrichment of Streams*: 122.

Ministry for the Environment (1994) *Water Quality Guidelines* No. 2. Guidelines for the Management of Water Colour and Clarity. Ministry for the Environment, Wellington: 77.

Ministry for the Environment (2014) *National Policy Statement for Freshwater Management:* 34. http://mfe.govt.nz/publications/rma/nps-freshwater-management-2014/nps-freshwater-management-jul-14.pdf.

Muggeo, V.M.R. (2014) *R Package 'quantregGrowth': Growth charts via regression quantiles.*

Quinn, J.M., Hickey, C.W. (1994) Hydraulic parameters and benthic invertebrate distributions in two gravel-bed New Zealand rivers. *Freshwater Biology,* 32: 489–500.

Shearer, K., Hayes, J., Quinn, J., Matheson, F. (2014) Interpreting Aquatic Macroinvertebrate Data – Time For A Closer Look. *Proceedings of the Water Symposium 2014*, Blenheim, 24-28 November.

Snelder, T., Biggs, B., Kilroy, C., Booker, D. (2013) National Objective Framework for periphyton. Report for the Ministry for the Environment. NIWA Report *No. CHC2013-122*.

Snelder, T.H., Biggs, B.J.F., Woods, R.A. (2005) Improved eco-hydrological classification of rivers. *River Research and Applications, 21:* 609–628.

Snelder, T.H., Booker, D.J. (2013) Natural flow regime classifications are sensitive to definition procedures. *River Research and Applications,*29: 822-838.

Snelder, T. H., Booker, D.J., Quinn, J.M., Kilroy, C. (2014) Predicting Periphyton Cover Frequency Distributions across New Zealand's Rivers. *Journal of the American Water Resources Association,* 50: 111-127.

Stark, J.D., Maxted, J.R. (2007) A user guide for the Macroinvertebrate Community Index. Report for the Ministry for the Environment. *Cawthron Report* No. 1166*:* 59.

Unwin, M., Snelder, T., Booker, D., Ballantine, D., Lessard, J. (2010) Predicting Water Quality in New Zealand Rivers from Catchment-scale Physical, Hydrological and Land Cover Descriptors Using Random Forest Models. *NIWA Report* No. CHC2010-037: 21.

Appendix A Angler acceptability survey photographs and data

Values are means of expert visual assessments.

Photo 1: PERIFIL=0%; PERIMAT=20%

Photo 2: CAV=45%; WSA=50%

Photo 3: PERIFIL=0%; PERIMAT=80%

Photo 4: CAV=35%; WSA=10%

Photo 5: CAV=20%; WSA=10%

Photo 6: PERIFIL=0%; PERIMAT=30%

Photo 7: CAV=45%; WSA=45%

Photo 8: CAV=65%; WSA=15%

Photo 9: PERIFIL=0%; PERIMAT=25%

Photo 10: CAV=75%; WSA=70%

Photo 11: CAV=10%; WSA=0%

Photo 12: PERIFIL=20%; PERIMAT=0%

Photo 13: CAV=45%; WSA=10%

Photo 14: PERIFIL=50%; PERIMAT=0%

Photo 15: CAV=55%; WSA=50%

Photo 16: PERFIL=30%; PERIMAT=0%

Photo 17: CAV=50%; WSA=20%

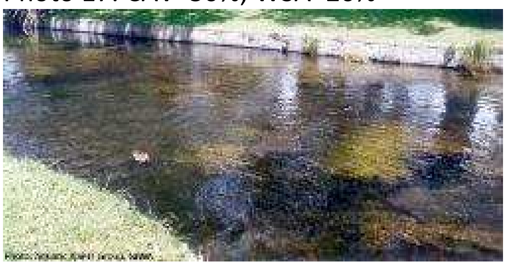


Photo 18: PERIFIL=25%; PERIMAT=0%

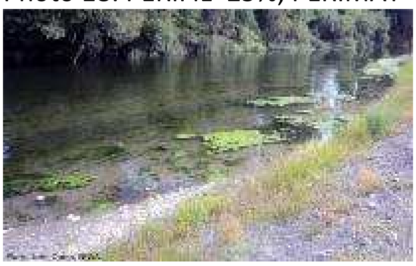


Photo 19: CAV=35%; WSA=35%

Photo 20: PERIFIL=70%; PERIMAT=25%

Photo 21: CAV=70%; WSA=65%

Photo 22: PERIFIL=40%; PERIMAT=40%

Photo 23: CAV=65%; WSA=30%

Photo 24: PERIFIL=50%, PERIMAT=0%

Photo 25: CAV=95%; WSA=95%

Photo 26: PERIFIL=0%; PERIMAT=80%

Photo 27: CAV=85%; WSA=80%

Photo 28: CAV=60%; WSA=0%

Photo 29: CAV=20%; WSA=0%

Photo 30: PERIFIL=10%; PERIMAT=0%

Photo 31: CAV=65%; WSA=30%

Photo 32: CAV=55%; WSA=60%

Photo 33: CAV=95%; WSA=90%

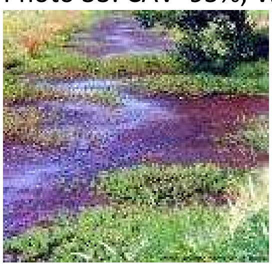


Photo 34: PERIFIL=40%; PERIMAT=0%

Photo 35: CAV=65%; WSA=70%

Photo 36: CAV=60%; WSA=20%

Photo 37: PERIFIL=0%; PERIMAT=55%

Photo 38: CAV=25%; WSA=20%

Photo 39: CAV=60%; WSA=20%

Photo 40: CAV=15%; WSA=20%

Photo 41: CAV=70%; WSA=25%

Photo 42: PERIFIL=0%; PERIMAT=90%

Photo 43: CAV=35%; WSA=10%

Photo 44: PERIFIL=45%; PERIMAT=0%

Photo 45: PERIFIL=0%, PERIMAT=0%

Photo 46: CAV=65%; WSA=10%

Appendix B Adult trout macroinvertebrate prey item scores

Contributed by Karen Shearer and John Hayes

Table B-1: List of adult trout macroinvertebrate prey item normalised scores for different types of feeding behaviour. Scores range from 0 (lowest value prey item) to 10 (highest value prey item).

Taxa	Drift feeding	Benthic browsing	Cruise feeding
Acarina	0.00	0.00	0.00
Dolomedes	0.66	0.00	0.83
Hydra	0.00	0.00	0.00
Collembola	0.00	0.00	0.00
Amphipoda	0.16	1.00	0.30
Cladocera	0.08	0.00	0.50
Copepoda	0.00	0.00	0.00
Halicarcinus			
Helice			
Isopoda			
Mysidae			
Ostracoda	0.00	0.00	0.00
Paracalliope	0.16	1.00	0.30
Paraleptamphopus			
Paranephrops	0.00	6.67	0.00
Paratya	0.63	5.33	2.40
Tanaidacea	0.03	0.00	0.03
Hirudinea	0.16	2.00	0.40
Hydrozoa	0.00	0.00	0.00
Antiporus	0.71	3.00	0.90
Berosus	0.08	1.00	0.10
Coleoptera			
Dytiscidae	0.52	2.50	0.65
Elmidae	0.48	2.00	0.20
Enochrus	0.16	2.00	0.20
Hydraenidae	0.00	0.00	0.00
Hydrophilidae	0.12	1.50	0.15
Liodessus	0.24	1.00	0.30
Ptilodactylidae	0.95	4.00	0.40
Rhantus	0.95	4.00	1.20
Scirtidae	0.48	2.00	0.20
Staphylinidae			
Anthomyiidae	0.32	1.33	0.40
Aphrophila	0.48	2.00	0.60
Austrosimulium	0.16	0.67	0.10
Blephariceridae	0.16	0.67	0.20
Ceratopogonidae	0.48	1.00	0.60
Chironomidae	0.32	0.33	0.20
Chironomus	0.32	0.33	0.20
Corynoneura	0.32	0.33	0.20
Cricotopus	0.32	0.33	0.20
Culex	0.32	0.67	2.00
Culicidae	0.32	0.67	2.00
Diamesinae	0.63	0.67	0.40
Diptera			
Dixidae	0.16	0.67	0.20
Dolichopodidae	0.08	0.33	0.10
Empididae	0.08	0.33	0.10
Ephydridae	0.16	0.67	0.20
Eriopterini	0.32	1.33	0.40
Harrisius	0.32	0.33	0.20
Hexatomini	0.32	1.33	0.40
Limnophora			

Taxa	Drift feeding	Benthic browsing	Cruise feeding
Limonia	0.24	1.00	0.30
Lobodiamesa	0.63	0.67	0.40
Maoridiamesa	0.63	0.67	0.40
Mischoderus	0.40	1.67	0.50
Molophilus	0.24	1.00	0.30
Muscidae	0.32	1.33	0.40
Nannochorista	0.00	0.00	0.00
Neocurupira	0.16	0.67	0.20
Neolimnia	0.32	1.33	0.40
Nothodixa	0.16	0.67	0.20
Orthocladiinae	0.32	0.33	0.20
Paradixa	0.16	0.67	0.20
Paralimnophila	0.32	1.33	0.40
Parochlus	0.32	0.33	0.20
Paucispinigera	0.32	0.33	0.20
Pelecorhynchidae	0.48	2.00	0.60
Peritheates	0.16	0.67	0.20
Podonominae	0.32	0.33	0.20
Polypedilum	0.32	0.33	0.20
Psychodidae	0.08	0.33	0.10
Scatella	0.16	0.67	0.20
Sciomyzidae	0.32	1.33	0.40
Stratiomyidae	0.48	2.00	0.60
Tabanidae	0.71	6.00	0.90
Tanyderidae	0.40	1.67	0.50
Tanypodinae	0.08	0.33	0.10
Tanytarsini	0.32	0.33	0.20
Tanytarsus	0.32	0.33	0.20
Thaumaleidae			
Tipulidae	0.37	1.57	0.47
Zelandotipula	0.71	3.00	0.90
Acanthophlebia	4.76	1.00	1.20
Ameletopsis	0.95	1.00	1.20
Arachnocolus			
Atalophlebioides	3.17	0.67	0.80
Austroclima	4.76	1.00	1.20
Austronella	3.17	0.67	0.80
Coloburiscus	1.90	3.00	1.20
Deleatidium	6.35	1.33	1.60
Ichthybotus	0.42	0.00	0.53
Mauiulus	3.17	0.67	0.80
Neozephlebia	3.17	0.67	0.80
Nesameletus	6.35	1.33	8.00
Oniscigaster	7.94	1.67	10.00
Rallidens	6.35	1.33	8.00
Siphlaenigma	4.76	1.00	6.00
Tepakia	3.17	0.67	0.80
Zephlebia	6.35	1.33	1.60
Anisops	0.21	0.00	1.33
Diaprepocoris			
Hydrometra	0.13	0.00	0.83
Mesoveliidae			
Microvelia	0.00	0.00	0.00
Saldidae	0.00	0.00	0.00
Sigara	0.21	0.00	1.33
Hygraula	0.32	2.00	0.40
Lepidoptera	0.32	2.00	0.40
Archichauliodes	0.79	10.00	1.00
Sisyra	0.00	0.00	0.00
Aeshna	0.00	10.00	2.00

Taxa	Drift feeding	Benthic browsing	Cruise feeding
Anisoptera	0.00	6.00	1.32
Antipodochlora	0.00	7.00	0.00
Austrolestes	0.00	6.00	3.60
Hemicordulia	0.00	6.00	1.20
Ischnura	0.00	4.00	2.40
Odonata	0.00	5.63	1.95
Procordulia	0.00	7.00	1.40
Xanthocnemis	0.00	5.00	3.00
Zygoptera	0.00	5.00	3.00
Acroperla	0.95	4.00	0.40
Austroperla	0.95	4.00	0.40
Cristaperla	0.48	2.00	0.20
Megaleptoperla	1.19	5.00	0.50
Spaniocerca	0.48	2.00	0.20
Spaniocercoides	0.48	2.00	0.20
Stenoperla	1.67	7.00	0.70
Taraperla	0.95	4.00	0.40
Zelandobius	0.48	2.00	0.20
Zelandoperla	0.95	4.00	0.40
Alloecentrella	0.48	2.00	0.60
Aoteapsyche	2.54	2.67	1.60
Beraeoptera	0.16	0.67	0.20
Confluens	0.32	1.33	0.40
Costachorema	10.00	7.00	8.40
Cryptobiosella			
Diplectrona	2.54	2.67	1.60
Ecnomidae			
Edpercivalia	0.00	0.00	0.00
Helicopsyche	0.16	0.00	0.20
Hudsonema	1.27	5.33	1.60
Hydrobiosella	5.71	4.00	4.80
Hydrobiosidae	7.14	5.00	3.00
Hydrobiosis	8.57	6.00	7.20
Hydrochorema	4.29	3.00	3.60
Hydropsychidae	2.54	2.67	1.60
Hydroptilidae	0.16	0.00	0.20
Neurochorema	4.29	3.00	3.60
Oecetis	0.32	1.33	0.40
Oeconesidae	0.40	1.67	0.50
Olinga	0.63	2.67	0.80
Orthopsyche	2.54	2.67	1.60
Oxyethira	0.16	0.00	0.20
Paroxyethira	0.16	0.00	0.20
Philorheithrus	0.79	3.33	1.00
Plectrocnemia	5.71	4.00	4.80
Polycentropodidae	6.43	4.50	5.40
Polyplectropus	7.14	5.00	6.00
Psilochorema	4.29	3.00	3.60
Pycnocentrella	0.48	2.00	0.60
Pycnocentria	0.67	2.63	0.80
Pycnocentrodes	0.48	2.00	0.60
Tiphobiosis	0.00	0.00	0.00
Trichoptera	2.18	2.47	1.90
Triplectides	1.11	4.67	1.40
Triplectidina	0.48	2.00	0.60
Zelandoptila	1.43	1.00	1.20
Zelolessica	0.32	1.33	0.40
Bivalvia			
Ferrissia	0.00	0.00	0.00
Glyptophysa	0.13	1.67	0.17

Taxa	Drift feeding	Benthic browsing	Cruise feeding
Gyraulus	0.03	0.33	0.03
Hyridella	0.00	0.00	0.00
Latia	0.00	0.67	0.00
Lymnaeidae	0.26	3.33	0.33
Melanopsis	0.00	3.00	0.00
Mollusca	0.05	1.03	0.06
Physella	0.05	0.67	0.07
Potamopyrgus	0.00	0.67	0.00
Sphaeriidae	0.00	0.00	0.00
Nematoda	0.00	0.00	0.00
Nematomorpha	1.06	6.67	0.67
Nemertea	0.00	0.00	0.00
Oligochaeta	0.00	0.00	0.00
Platyhelminthes	0.00	1.00	0.00
Polychaeta	0.00	0.00	0.00

Appendix C Periphyton modelling parameters

Table C-1: Periphyton linear regression model parameters and their units.

Parameter	Units	Description
SQRT PERIWCC	SQRT (% cover)	Square root of the mean percentage cover of wadeable stream bed occupied by periphyton as weighted composite cover (i.e., % filaments + (% mats/2)) estimated visually at 7 points across a transect on the macroinvert sampling date
SQRT PERIFIL	SQRT (% cover)	Square root of the mean percentage cover of wadeable stream bed occupied by filaments estimated visually at 7 points across a transect on the macroinvert sampling date
SQRT PERIMAT	SQRT (% cover)	Square root of the mean percentage cover of wadeable stream bed occupied by mats estimated visually at 7 points across a transect on the macroinvert sampling date
LOG AVERAGE LIGHT AT STREAMBED	LOG (µmol/m^2/s)	Log of average light at streambed calculated from mean daily radiation from nearest climate station for the month that preceding the month when macroinvert sampling occurred, a one-off percent stream shade estimate for the site and light attenuation through the water column based on water depth, absorbance and water clarity measured on the macroinvert sampling date.
LOG DAYS OF ACCRUAL FRE 1.5	LOG (no. of days)	Log of the number of days of accrual that had elapsed between the last flow event that exceeded 1.5 times the annual median and the macroinvert sampling date.
LOG DAYS OF ACCRUAL FRE 2	LOG (no. of days)	Log of the number of days of accrual that had elapsed between the last flow event that exceeded 2 times the annual median and the macroinvert sampling date.
LOG DAYS OF ACCRUAL FRE 3	LOG (no. of days)	Log of the number of days of accrual that had elapsed between the last flow event that exceeded 3 times the annual median and the macroinvert sampling date.
LOG DAYS OF ACCRUAL FRE 5	LOG (no. of days)	Log of the number of days of accrual that had elapsed between the last flow event that exceeded 5 times the annual median and the macroinvert sampling date.
SUBSTRATE INDEX	No units	Substrate index calculated from % cover estimates of boulder, large cobble, small cobble, large gravel, fine gravel, sand, silt and clay. Index values range from 0-10.
LOG WVEL	LOG (m/s)	Log of the mean water velocity measured at seven points across a transect on the macroinvert sampling date
LOG NO3N_mean_12	LOG (mg/m^3)	Log of mean of monthly NO3N for 12 months prior to macroinvert sampling date
LOG NH4N_mean_12	LOG (mg/m^3)	Log of mean of monthly NH4N for 12 months prior to macroinvert sampling date
LOG DIN_mean_12	LOG (mg/m^3)	Log of mean of monthly DIN (NO3N+NH4N) for 12 months prior to macroinvert sampling date
LOG TNunf_mean_12	LOG (mg/m^3)	Log of mean of monthly TN in an unfiltered sample for 12 months prior to macroinvert sampling date
LOG DRP_mean_12	LOG (mg/m^3)	Log of mean of monthly DRP for 12 months prior to macroinvert sampling date
LOG TPunf_mean_12	LOG (mg/m^3)	Log of mean of monthly TP in an unfiltered sample for 12 months prior to macroinvert sampling date
TEMP_mean_12	°C	Mean of monthly water temperature for 12 months prior to macroinvert sampling date
LOG NO3N_median_12	LOG (mg/m^3)	Log of median of monthly NO3N for 12 months prior to macroinvert sampling date
LOG NH4N_median_12	LOG (mg/m^3)	Log of median of monthly NH4N for 12 months prior to macroinvert sampling date
LOG DIN_median_12	LOG (mg/m^3)	Log of median of monthly DIN (NO3N+NH4N) for 12 months prior to macroinvert sampling date
LOG TNunf_median_12	LOG (mg/m^3)	Log of median of monthly TN in an unfiltered sample for 12 months prior to macroinvert sampling date

Parameter	Units	Description
LOG DRP_median_12	LOG (mg/m^3)	Log of median of monthly DRP for 12 months prior to macroinvert sampling date
LOG TPunf_median_12	LOG (mg/m^3)	Log of median of monthly TP in an unfiltered sample for 12 months prior to macroinvert sampling date
TEMP_median_12	°C	Median of monthly water temperature for 12 months prior to macroinvert sampling date
LOG (+1) NO3N_mean_2	LOG (mg/m^3)	Log of mean (+1) of monthly NO3N for 2 months prior to macroinvert sampling date
Log NH4N_mean_2	LOG (mg/m^3)	Log of mean of monthly NH4N for 2 months prior to macroinvert sampling date
LOG DIN_mean_2	LOG (mg/m^3)	Log of mean of monthly DIN (NO3N+NH4N) for 2 months prior to macroinvert sampling date
LOG TNunf_mean_2	LOG (mg/m^3)	Log of mean of monthly TN in an unfiltered sample for 2 months prior to macroinvert sampling date
LOG DRP_mean_2	LOG (mg/m^3)	Log of mean of monthly DRP for 2 months prior to macroinvert sampling date
LOG TPunf_mean_2	LOG (mg/m^3)	Log of mean of monthly TP in an unfiltered sample for 2 months prior to macroinvert sampling date
TEMP_mean_2	°C	Mean of monthly water temperature for 2 months prior to macroinvert sampling date
LOG NO3N_mean_3	LOG (mg/m^3)	Log of mean of monthly NO3N for 3 months prior to macroinvert sampling date
LOG NH4N_mean_3	LOG (mg/m^3)	Log of mean of monthly NH4N for 3 months prior to macroinvert sampling date
LOG DIN_mean_3	LOG (mg/m^3)	Log of mean of monthly DIN (NO3N+NH4N) for 3 months prior to macroinvert sampling date
LOG TNunf_mean_3	LOG (mg/m^3)	Log of mean of monthly TN in an unfiltered sample for 3 months prior to macroinvert sampling date
LOG DRP_mean_3	LOG (mg/m^3)	Log of mean of monthly DRP for 3 months prior to macroinvert sampling date
LOG TPunf_mean_3	LOG (mg/m^3)	Log of mean of monthly TP in an unfiltered sample for 3 months prior to macroinvert sampling date
TEMP_mean_3	°C	Mean of monthly water temperature for 3 months prior to macroinvert sampling date
LOG (+1) NO3N_month_1	LOG (mg/m^3)	Log of NO3N (+1) measured the month prior to macroinvert sampling date
LOG (+1) NH4N_month_1	LOG (mg/m^3)	Log of NH4N (+1) measured the month prior to macroinvert sampling date
LOG DIN_month_1	LOG (mg/m^3)	Log of DIN measured the month prior to macroinvert sampling date
LOG TNunf_month_1	LOG (mg/m^3)	Log of TN in an unfiltered sample measured the month prior to macroinvert sampling date
LOG DRP_month_1	LOG (mg/m^3)	Log of DRP measured the month prior to macroinvert sampling date
LOG (+1) TPunf_month_1	LOG (mg/m^3)	Log of TP in an unfiltered sample measured the month prior to macroinvert sampling date
TEMP_month_1	°C	Water temperature measured the month prior to macroinvert sampling date
LOG (+1) NO3N_month_2	LOG (mg/m^3)	Log of NO3N (+1) measured two months prior to macroinvert sampling date
LOG (+1) NH4N_month_2	LOG (mg/m^3)	Log of NH4N (+1) measured two months prior to macroinvert sampling date
LOG (+1) DIN_month_2	LOG (mg/m^3)	Log of DIN measured two months prior to macroinvert sampling date
LOG TNunf_month_2	LOG (mg/m^3)	Log of TN in an unfiltered sample measured two months prior to macroinvert sampling date
LOG DRP_month_2	LOG (mg/m^3)	Log of DRP measured two months prior to macroinvert sampling date
LOG TPunf_month_2	LOG (mg/m^3)	Log of TP in an unfiltered sample measured two months prior to macroinvert sampling date

Parameter	Units	Description
TEMP_month_2	ºC	Water temperature measured two months prior to macroinvert sampling date
LOG NO3N_month_3	LOG (mg/m^3)	Log of NO3N measured three months prior to macroinvert sampling date
LOG (+1) NH4N_month_3	LOG (mg/m^3)	Log of NH4N (+1) measured three months prior to macroinvert sampling date
LOG (+1) DIN_month_3	LOG (mg/m^3)	Log of DIN (+1) measured three months prior to macroinvert sampling date
LOG TNunf_month_3	LOG (mg/m^3)	Log of TN in an unfiltered sample measured three months prior to macroinvert sampling date
LOG DRP_month_3	LOG (mg/m^3)	Log of DRP measured three months prior to macroinvert sampling date
LOG (+1) TPunf_month_3	LOG (mg/m^3)	Log of TP in an unfiltered sample measured three months prior to macroinvert sampling date
TEMP_month_3	ºC	Water temperature measured three months prior to macroinvert sampling date
LOG NO3N_spring	LOG (mg/m^3)	Log of mean of monthly NO3N measured in the spring prior to macroinvert sampling date
LOG NH4N_spring	LOG (mg/m^3)	Log of mean of monthly NN4N measured in the spring prior to macroinvert sampling date
LOG DIN_spring	LOG (mg/m^3)	Log of mean of monthly DIN measured in the spring prior to macroinvert sampling date
LOG TNunf_spring	LOG (mg/m^3)	Log of mean of monthly TN in an unfiltered sample measured in the spring prior to macroinvert sampling date
LOG DRP_spring	LOG (mg/m^3)	Log of mean of monthly DRP measured in the spring prior to macroinvert sampling date
LOG TPunf_spring	LOG (mg/m^3)	Log of mean of monthly TP in an unfiltered sample measured in the spring prior to macroinvert sampling date
TEMP_spring	ºC	Mean of monthly water temperatures measured in the spring prior to macroinvert sampling date
LOG (+1) Elmidae	LOG (n/m^2)	Log of density of Elmidae specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Eriopterini	LOG (n/m^2)	Log of density of Eriopterini specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Deleatidium	LOG (n/m^2)	Log of density of Deleatidium specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Zephlebia	LOG (n/m^2)	Log of density of Zephlebia specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Megaleptoperla	LOG (n/m^2)	Log of density of Megaleptoperla specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Zelandobius	LOG (n/m^2)	Log of density of Zelandobius specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Zelandoperla	LOG (n/m^2)	Log of density of Zelandoperla specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Aoteapsyche	LOG (n/m^2)	Log of density of Aoteapsyche specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Beraeoptera	LOG (n/m^2)	Log of density of Beraeoptera specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Helicopsyche	LOG (n/m^2)	Log of density of Helicopsyche specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Hudsonema	LOG (n/m^2)	Log of density of Hudsonema specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Olinga	LOG (n/m^2)	Log of density of Olinga specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Pycnocentria	LOG (n/m^2)	Log of density of Pycnocentria specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Pycnocentrodes	LOG (n/m^2)	Log of density of Pycnocentrodes specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG (+1) Latia	LOG (n/m^2)	Log of density of Latia specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date

Parameter	Units	Description
LOG (+1) Potamopyrgus	LOG (n/m^2)	Log of density of Potamopyrgus specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date
LOG MACROGRAZERS	LOG (n/m^2)	Log of density of all macrograzer specimens (+1) in 0.7 m^2 sample collected on the macroinvert sampling date

Appendix D Additional angling survey results

Table D-1: Percentage of angling survey respondents by gender and age group.

Demographic parameter	Category	% of respondents
Gender	Male	97
	Female	3
Age group	Under 21	1
	21-30	12
	31-40	13
	41-50	17
	51-60	26
	61-70	24
	71-80	6
	81 and over	0

Table D-2: Percentage of angling survey respondents by target species and angling method.

Target species	Angling method	% of respondents
Trout	Dry fly	69
	Nymph	69
	Wet fly	57
	Spin	65
	Line and bait	17
Salmon	Dry fly	4
	Nymph	4
	Wet fly	8
	Spin	36
Perch	Line and bait	5
Tench	Line and bait	2
Koi	Line and bait	1
Catfish	Line and bait	0
Rudd	Line and bait	1
Goldfish	Line and bait	1
Eels	Line and bait	5
Other		4

Table D-3: Percentage of angling survey respondents by angling frequency.

Angling frequency	% of respondents
Very frequently	54
Frequently	30
Infrequently	5
Occasionally	11

Table D-4: Percentage of angling survey respondents angling in each frequency category by target species and angling type.

Target species	Angling method	Percentage of respondents by angling frequency (%)			
		VF	F	IF	OC
Trout	Dry fly	27	22	6	17
	Nymph	31	20	4	15
	Wet fly	18	19	5	18
	Spin	24	21	3	17
	Line & bait	4	5	5	6
Salmon	Dry fly	1	1	5	1
	Nymph	1	1	4	1
	Wet fly	2	2	5	3
	Spin	13	10	4	9
Perch	Line & bait	1	1	5	2
Tench	Line & bait	0	0	5	1
Koi	Line & bait	0	0	5	1
Catfish	Line & bait	0	0	4	0
Rudd	Line & bait	0	0	4	1
Goldfish	Line & bait	0	0	4	0
Eels	Line & bait	0	0	5	3
Other		1	1	3	1

VF - very frequently, 13+ times per year/season

F – frequently, 5-12 times per year/season

IF – infrequently, 1-4 times per year/season

OC – occasionally, <1 time per year/season

Table D-5: Percentage of angling survey respondents by angling location.

Angling location	% of respondents
Northland	1
Auckland	1
Waikato	7
Bay of Plenty	9
Taranaki	2
Gisborne	1
Hawkes Bay	5
Manawatu-Whanganui	5
Wellington	5
Nelson	2
Tasman	2
West Coast	5
Marlborough	2
Canterbury	31
Otago	16
Southland	9

Table D-6: Percentage of angling survey respondents angling in each region by target species and angling type.

Target species	Angling method	Proportion of respondents by region (%)															
		N	A	Wk	B	Tr	G	H	Mw	L	N	T	Wc	M	C	O	S
Trout	Dry fly	0	0	5	5	1	0	5	4	4	1	2	3	1	19	12	8
	Nymph	0	0	6	6	1	1	5	4	4	1	2	3	1	17	11	7
	Wet fly	0	0	5	7	1	0	3	3	3	1	1	3	1	13	9	6
	Spin	0	0	3	5	1	0	2	4	3	1	1	3	1	23	11	5
	Line & bait	0	0	1	2	0	0	0	0	0	0	0	0	0	6	5	2
Salmon	Dry fly	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0
	Nymph	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0
	Wet fly	0	0	0	0	0	0	0	0	0	0	0	1	0	6	2	0
	Spin	0	0	0	0	0	0	0	0	0	0	0	2	0	25	6	1
Perch	Line & bait	0	0	1	0	0	0	0	0	0	0	0	0	0	2	2	0
Tench	Line & bait	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0
Koi	Line & bait	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0
Catfish	Line & bait	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Rudd	Line & bait	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Goldfish	Line & bait	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Eels	Line & bait	0	0	0	1	1	0	0	0	0	0	0	0	0	2	1	0
Other		0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0

N = Northland, A = Auckland, Wk = Waikato, B = Bay of Plenty, Tr = Taranaki, G = Gisborne, H = Hawkes Bay, Mw = Manawatu-Whanganui, W = Wellington, N = Nelson, T = Tasman, Wc = West Coast, M = Marlborough, C = Canterbury, O = Otago, S = Southland.

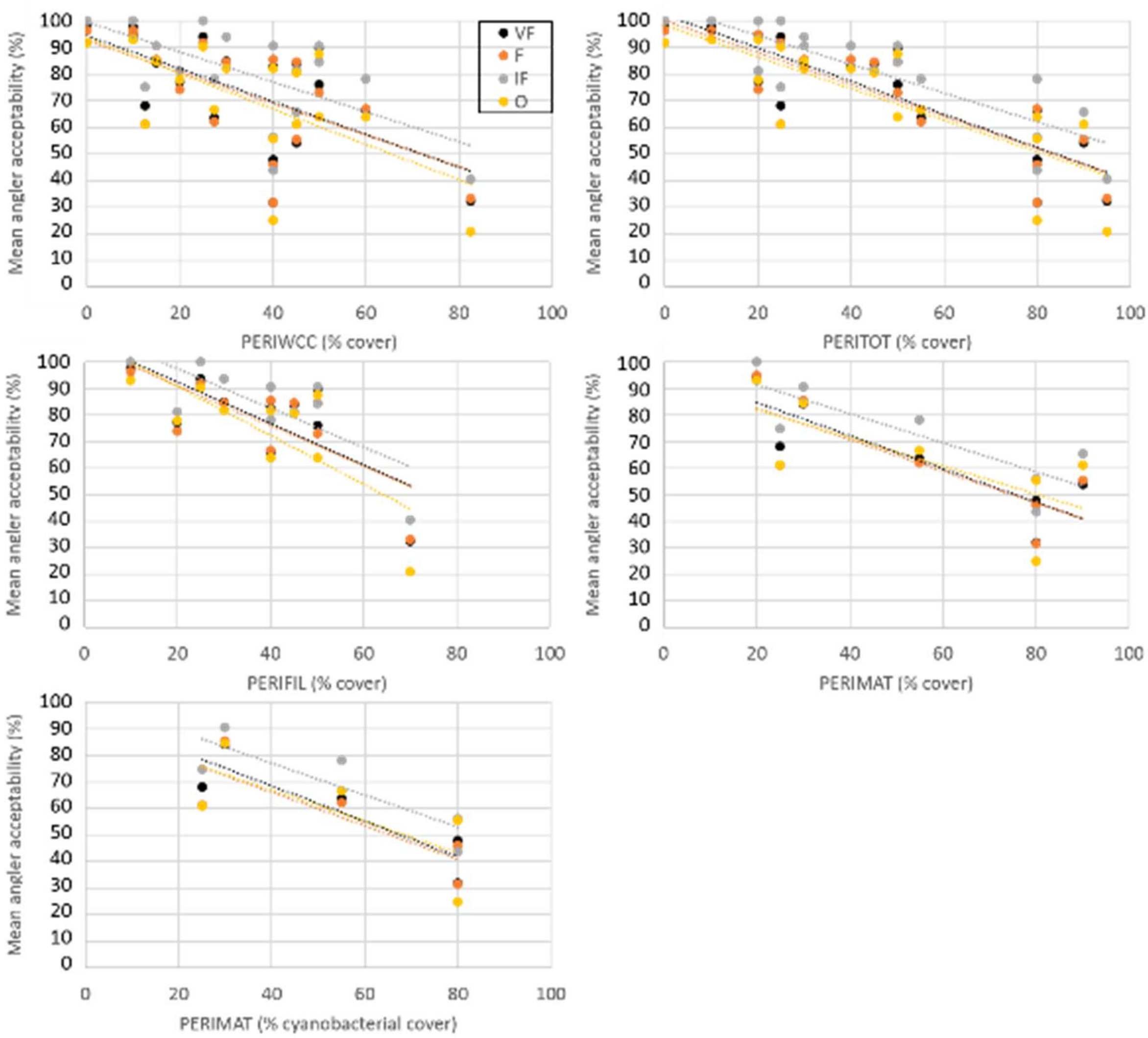


Figure D-1: Relationships between angler acceptability score (simple mean method) and periphyton nuisance abundance indices by angling frequency.

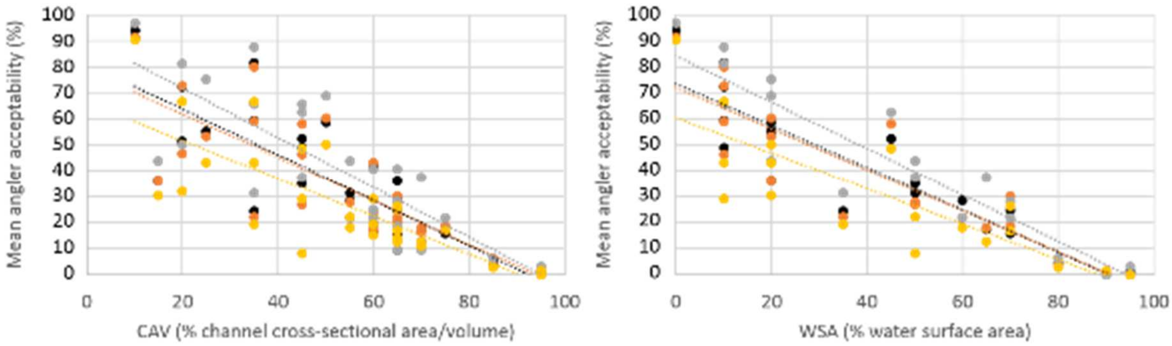


Figure D-2: Relationships between angler acceptability score (simple mean method) and macrophyte nuisance abundance indices by angling frequency.

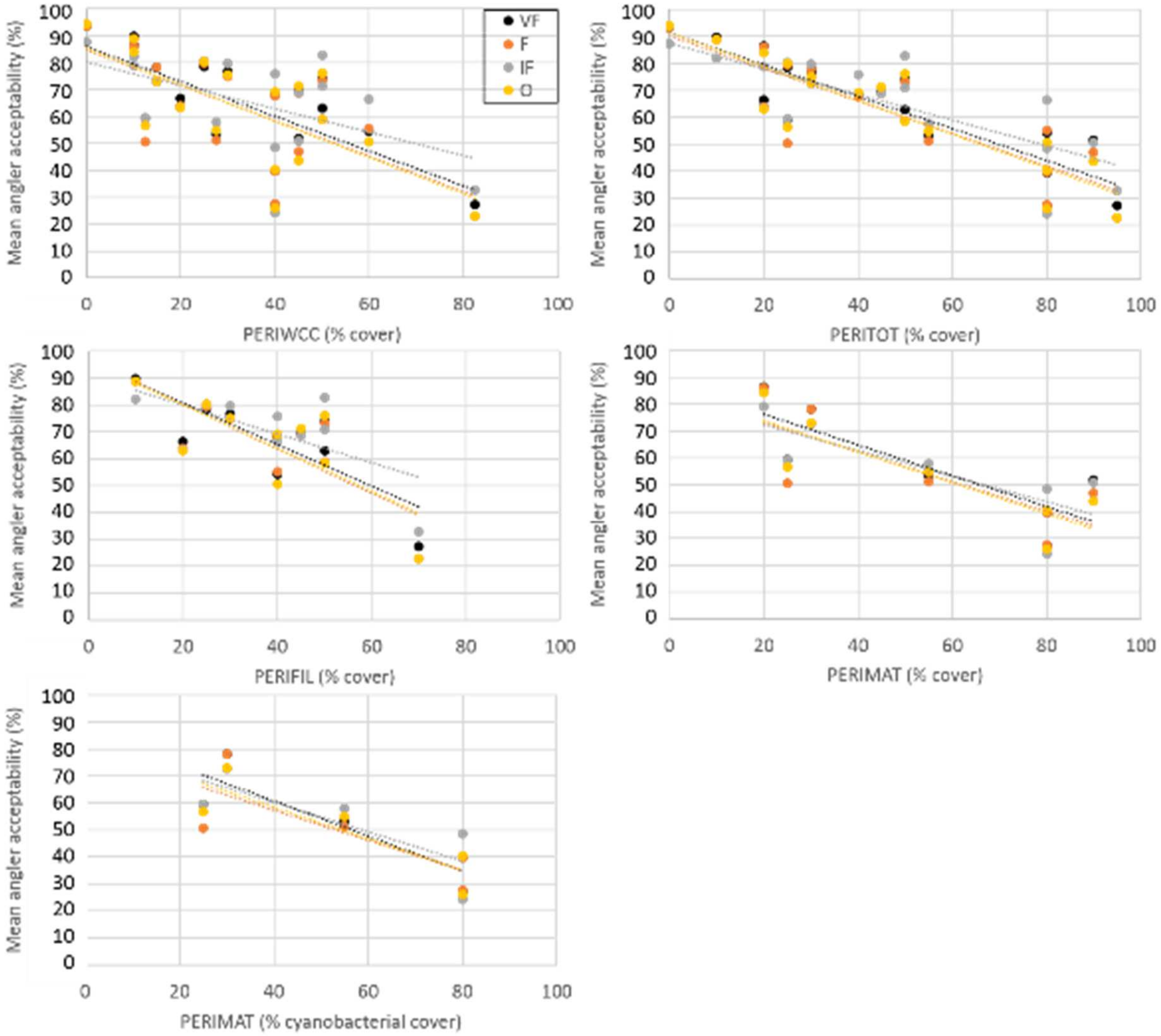


Figure D-3: **Relationships between angler acceptability score (weighted mean method) and periphyton nuisance abundance indices by angling frequency.**

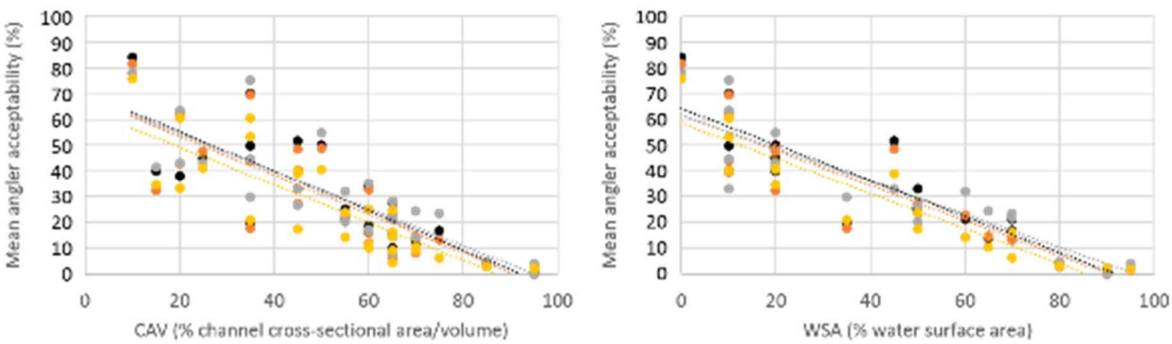


Figure D-4: **Relationships between angler acceptability score (weighted mean method) and macrophyte nuisance abundance indices by angling frequency.**

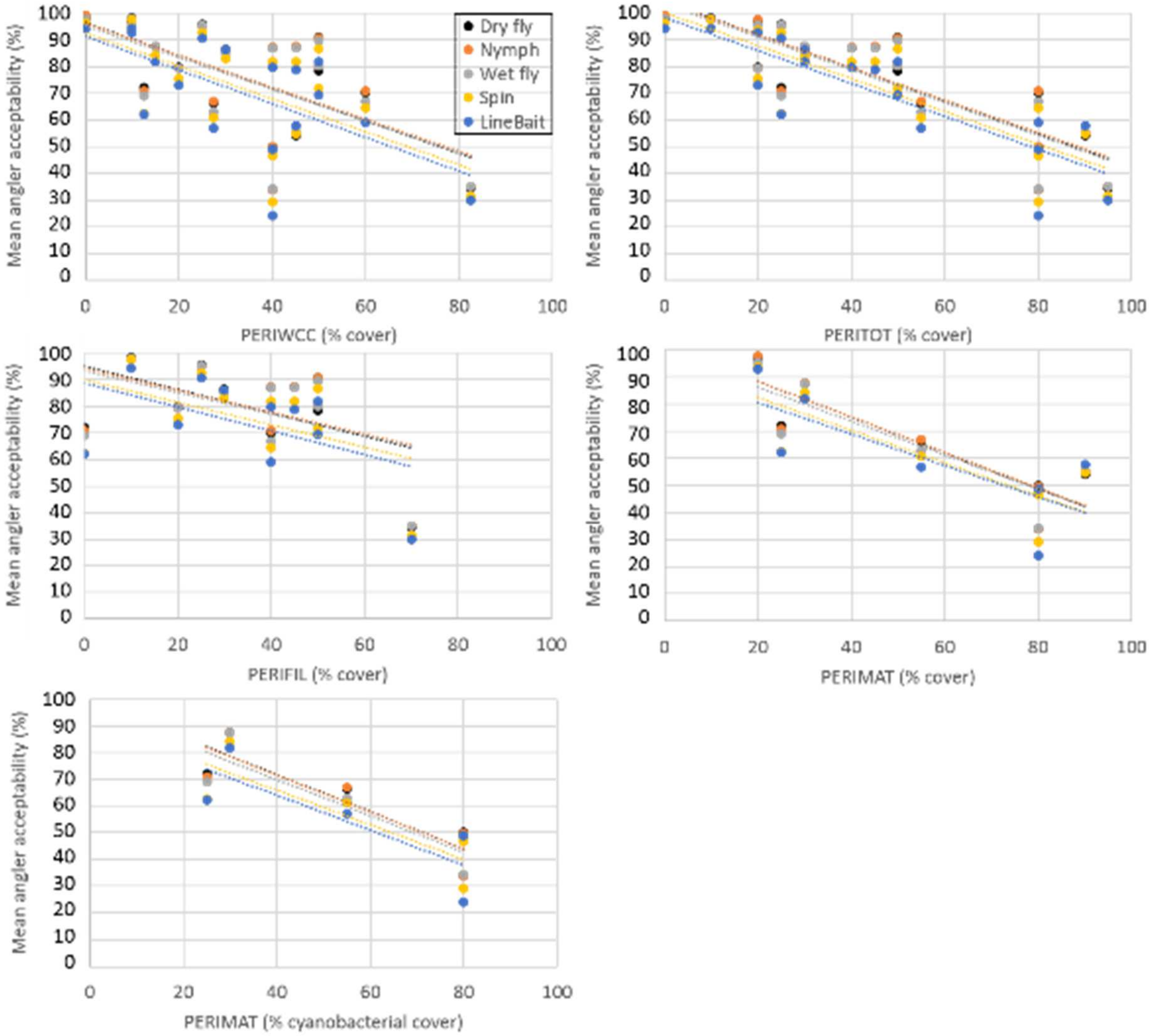


Figure D-5: Relationships between angler acceptability score (simple mean method) and periphyton nuisance abundance indices by angling method.

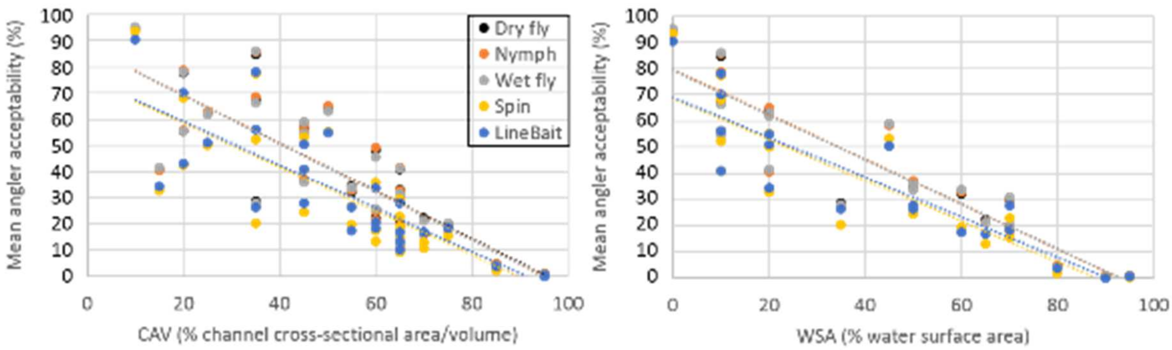


Figure D-6: Relationships between angler acceptability score (simple mean method) and macrophyte nuisance abundance indices by angling method.

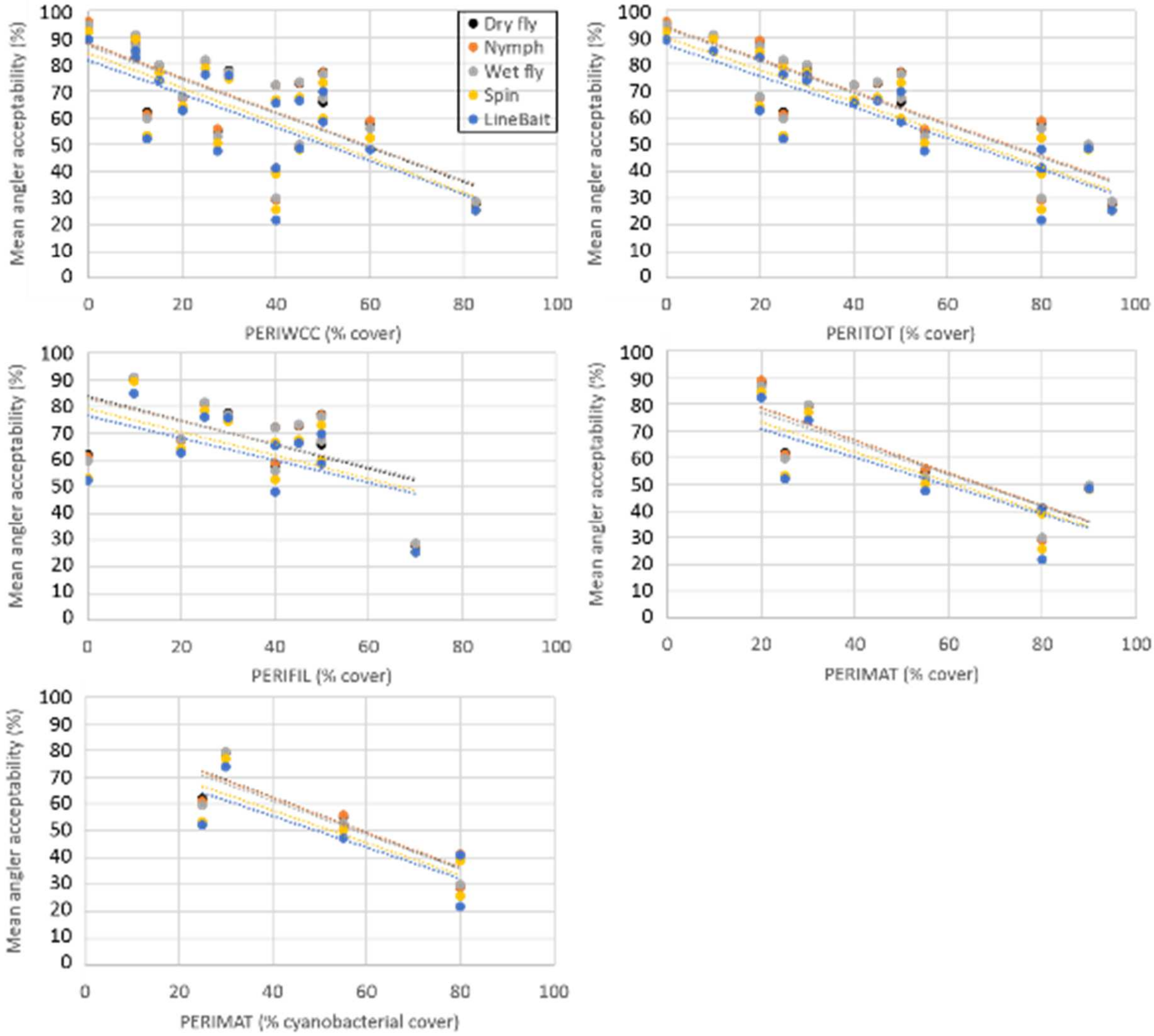


Figure D-7: Relationships between angler acceptability score (weighted mean method) and periphyton nuisance abundance indices by angling method.

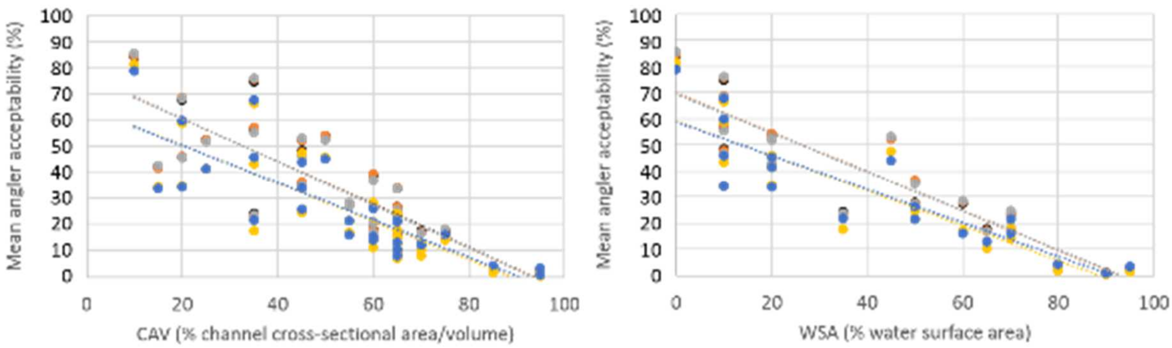


Figure D-8: Relationships between angler acceptability score (weighted mean method) and macrophyte nuisance abundance indices by angling method.

Appendix E Periphyton-trout food linear regression results

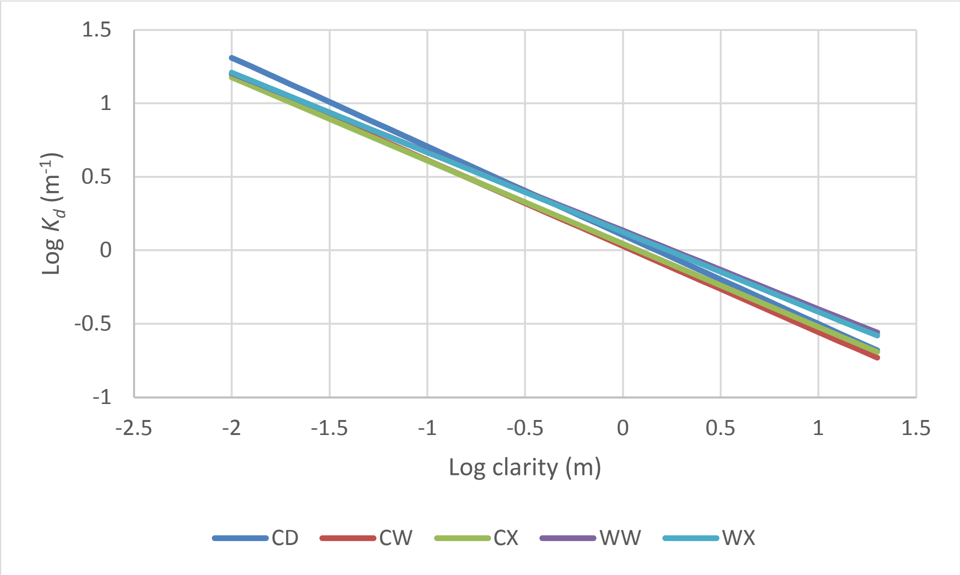
The results of linear regression analysis suggested that higher levels of CHLA were associated with higher prey availability for benthic browsing and cruise feeding (

Table E-1). Higher levels of periphyton mat cover were negatively related to total drift feeding, benthic browsing and cruise feeding scores and to counts of high rank drift and cruise feeding prey items. Higher levels of periphyton filamentous and weighted composite cover were associated with higher total benthic browsing scores and counts of high rank benthic items but lower counts of high rank drift items.

Table E-1: Linear regression relationships between periphyton abundance indices and adult trout prey item indices. Significant relationships are shown in bold.

Trout prey item indices (y)	Periphyton abundance indices (x)			
	LOG CHLA	SQRT PERIWCC	SQRT PERIFIL	SQRT PERIMAT
Total drift feeding score (DFS)	y = 517.7 + 35.3x; r = 0.0456 p = 0.2017	y = 625.2 - 10.5x; r = -0.0397 p = 0.0579	y = 623.3 - 5.4x; r = -0.0180 p = 0.4868	**y = 655.1 – 5.0x; r = -0.1251 p = 0.00000**
Total benthic browsing score (BBS)	**y = 272.3 + 114.4x; r = 0.1845 p = 0.00000**	**y = 393.9 + 19.4x; r = 0.0793 p = 0.0001**	**y = 416.6 + 24.3x; r = 0.0850 p = 0.0010**	**y = 484.2 - 2.3x; r = -0.0619 p = 0.0176**
Total cruise feeding score (CFS)	**y = 163.2 + 38.5x; r = 0.1345 p = 0.0002**	y = 231.1 + 4.1x; r = 0.0349 p = 0.0953	y = 245.3 + 6.7x; r = 0.0490 p = 0.0576	**y = 269.1 - 1.3x; r = -0.0695 p = 0.0077**
Count of high ranked drift items (drift count) (n/m²)	y = 756.8 - 34.1x; r = -0.0320 p = 0.3698	**y = 782.3 - 45.0x; r = -0.1401 p = 0.0000**	**y = 720.2 - 48.3x; r = -0.1408 p = 0.00000**	**y = 697.1 - 8.2x; r = -0.1795 p = 0.0000**
Count of high ranked benthic items (benthic count) (n/m²)	**y = 27.8 + 45.6x; r = 0.1599 p = 0.00001**	**y = 38.5 + 6.3x; r = 0.1116 p = 0.00000**	**y = 36.1 + 2.5x; r = 0.0695 p = 0.0070**	y = 42.5 - 0.2x; r = -0.0364 p = 0.1631
Count of high ranked cruise items (cruise count) (n/m²)	**y = 15.6+ 5.1x; r = 0.1147 p = 0.0013**	y = 29.0 + 0.1x; r = 0.0063 p = 0.7626	y = 31.5 + 0.9x; r = 0.0336 p = 0.1932	**y = 35.5 - 0.3x; r = -0.0728 p = 0.0052**

Appendix F Light attenuation modelling results



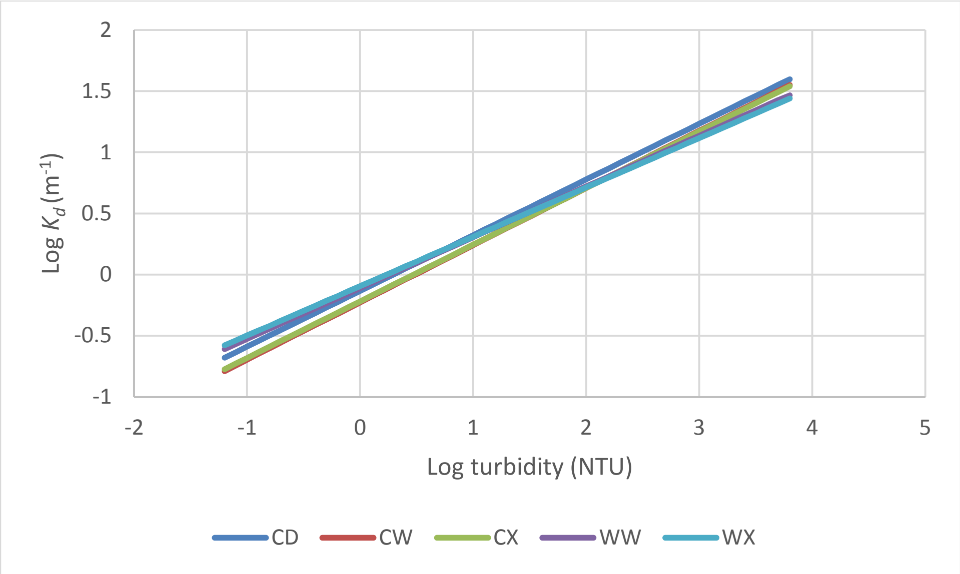


Figure F-1: Relationships for K_d with clarity (top) and turbidity (bottom) by River Environment Classification (REC) climate class for the NRWQN dataset.

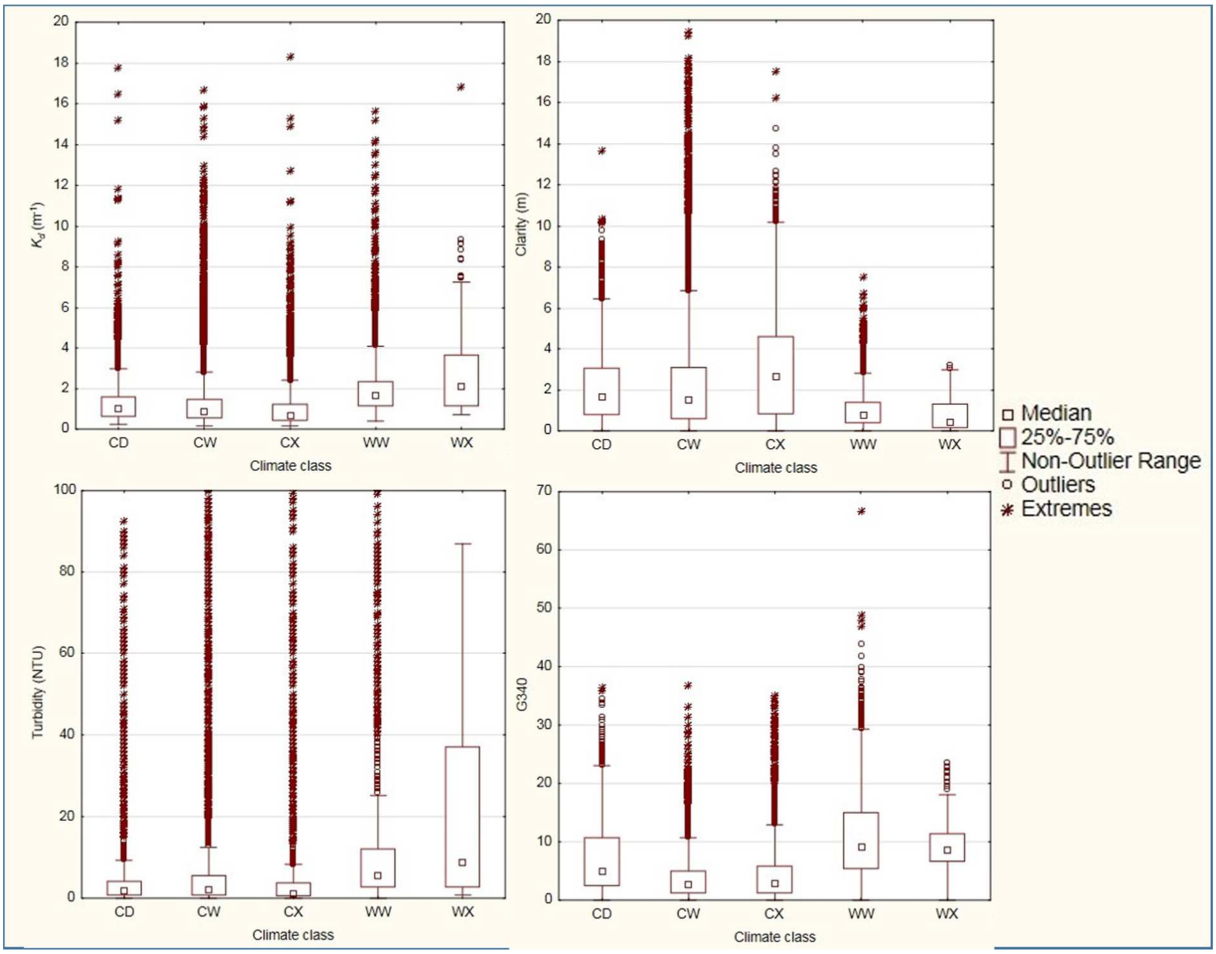


Figure F-2: Boxplots of NRWQN K_d, clarity, turbidity and absorbance data grouped by River Environment Classification climate class. Note that not all extreme values are shown in clarity and turbidity graphs.

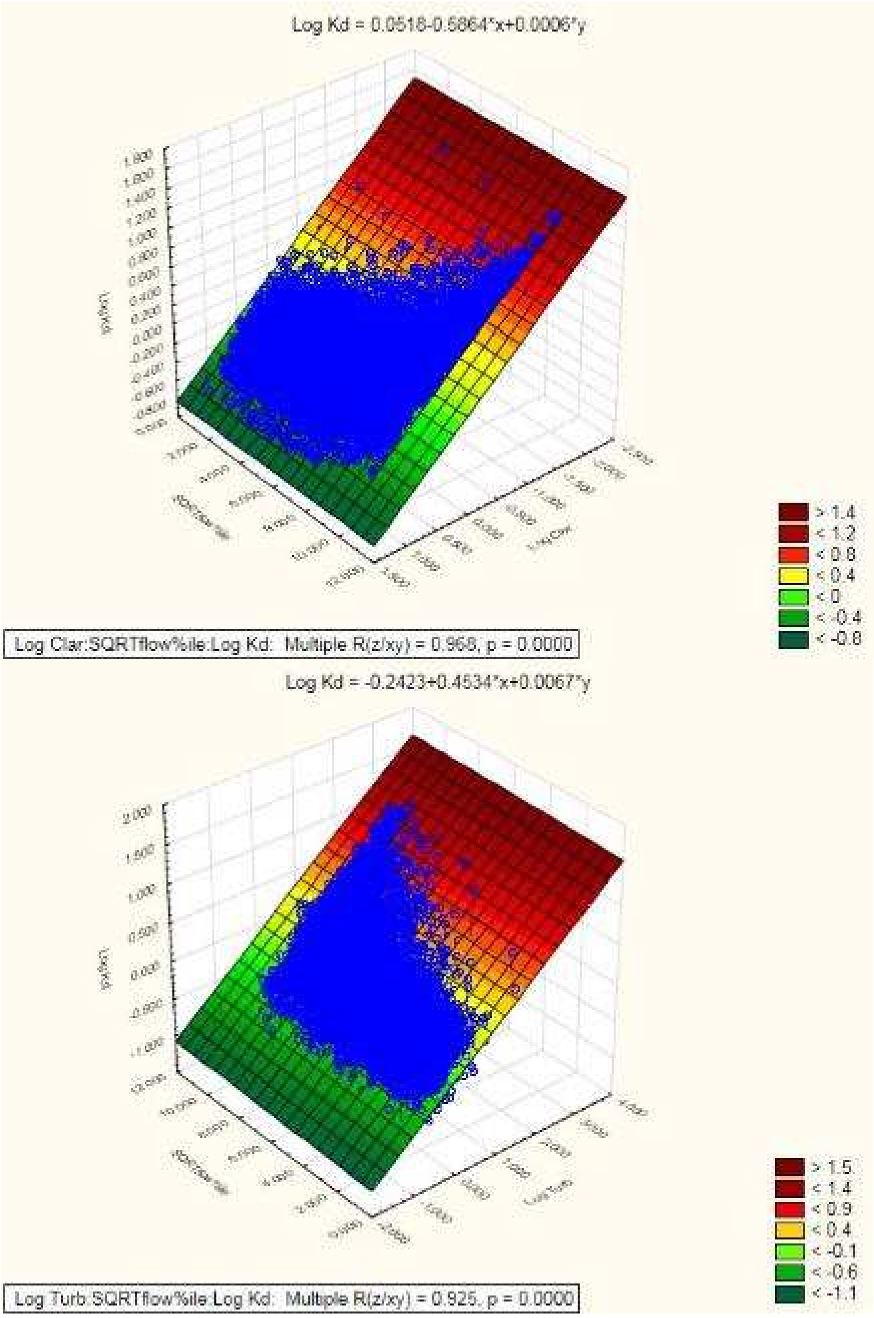


Figure F-3: Relationships between K_d and flow with clarity (top) or turbidity (bottom) for all NRWQN sites (data from 1989 to 2013 inclusive). X = Log Clar or Log Turb, y = SQRTflow%ile, z = Log K_d.

Table F-1: Relationships between K_d and flow with clarity (top) or turbidity (bottom) by River Environment Classification (REC) climate class for NRWQN dataset.

REC climate class	Clarity (m)	Turbidity (NTU)
CD	Log K_d = 0.0903 - 0.5989 * Log Clar + 0.0018* SQRTflow%ile R^2 = 0.9577, n=2611	Log K_d = -0.1934 + 0.4337 * Log Turb + 0.0101* SQRTflow%ile R^2 = 0.8400, n=2611
CW	Log K_d = 0.0269-0.5843* Log Clar + 0.0003* SQRTflow%ile R^2 = 0.9495, n=12737	Log K_d = -0.2535 + 0.4589 * Log Turb + 0.0045* SQRTflow%ile R^2 = 0.8646, n=12737
CX	Log K_d = -0.0338 - 0.5406 * Log Clar + 0.0108* SQRTflow%ile R^2 = 0.9233, n=3469	Log K_d = -0.3654 + 0.4146* Log Turb + 0.024* SQRTflow%ile R^2 = 0.8310, n=3469
WW	Log K_d = 0.115 - 0.5265 * Log Clar + 0.0032 * SQRTflow%ile R^2 = 0.9483, n=3179	Log K_d = -0.146 + 0.402* Log Turb + 0.007* SQRTflow%ile R^2 = 0.8638, n=3179
WX	Log K_d = 0.1403 - 0.5529 * Log Clar - 0.0031 * SQRTflow%ile R^2 = 0.9916, n=293	Log K_d = -0.1033 + 0.3976 * Log Turb +0.0023 * SQRTflow%ile R^2 = 0.9285, n=293

Appendix G Stepwise multiple linear regression models: relationships between observed and predicted values

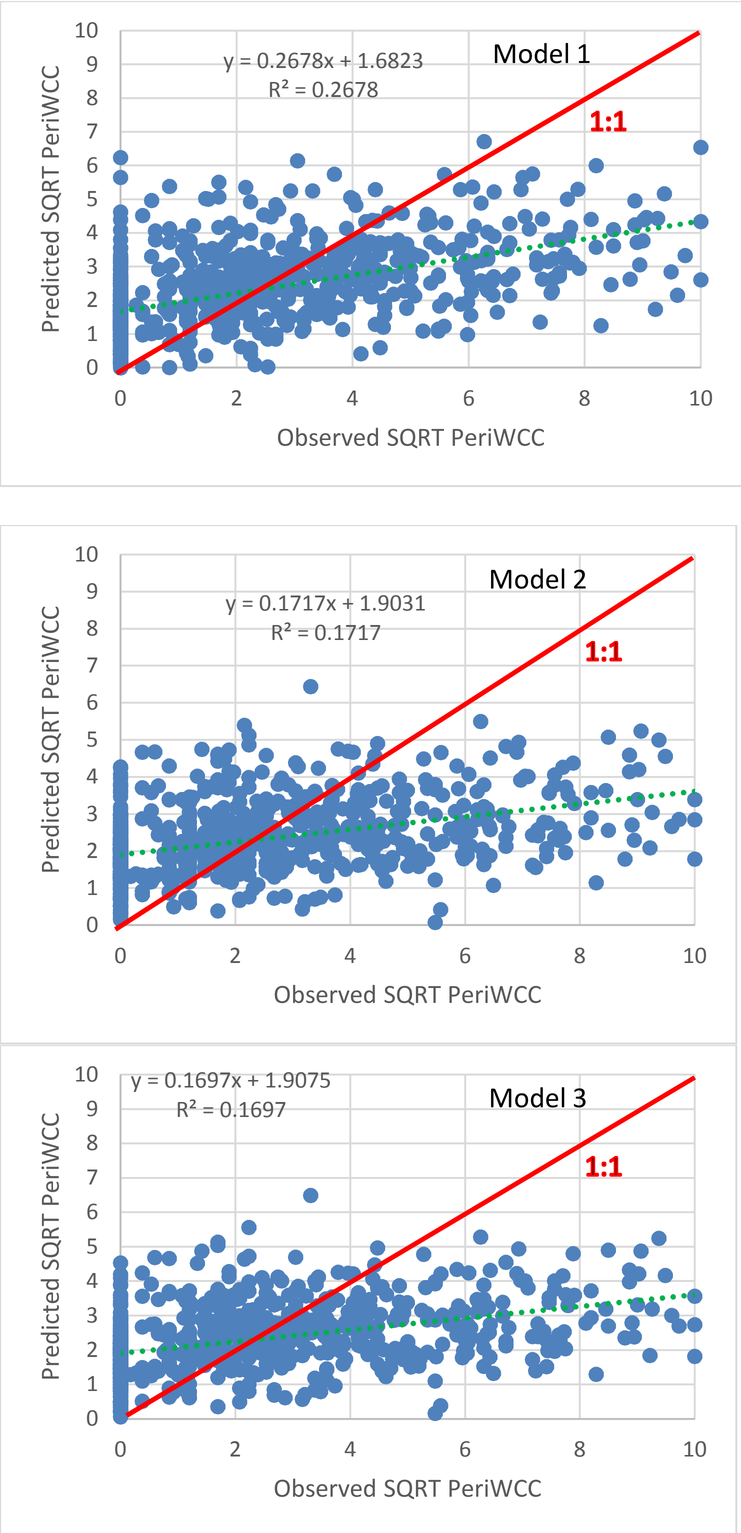


Figure G-1: PERIWCC stepwise multiple linear regression model results for Model 1 (top), Model 2 (centre) and Model 3 (bottom). Model 1 includes grazer species, Model 2 includes grazer total density only and Model 3 excludes any grazers.

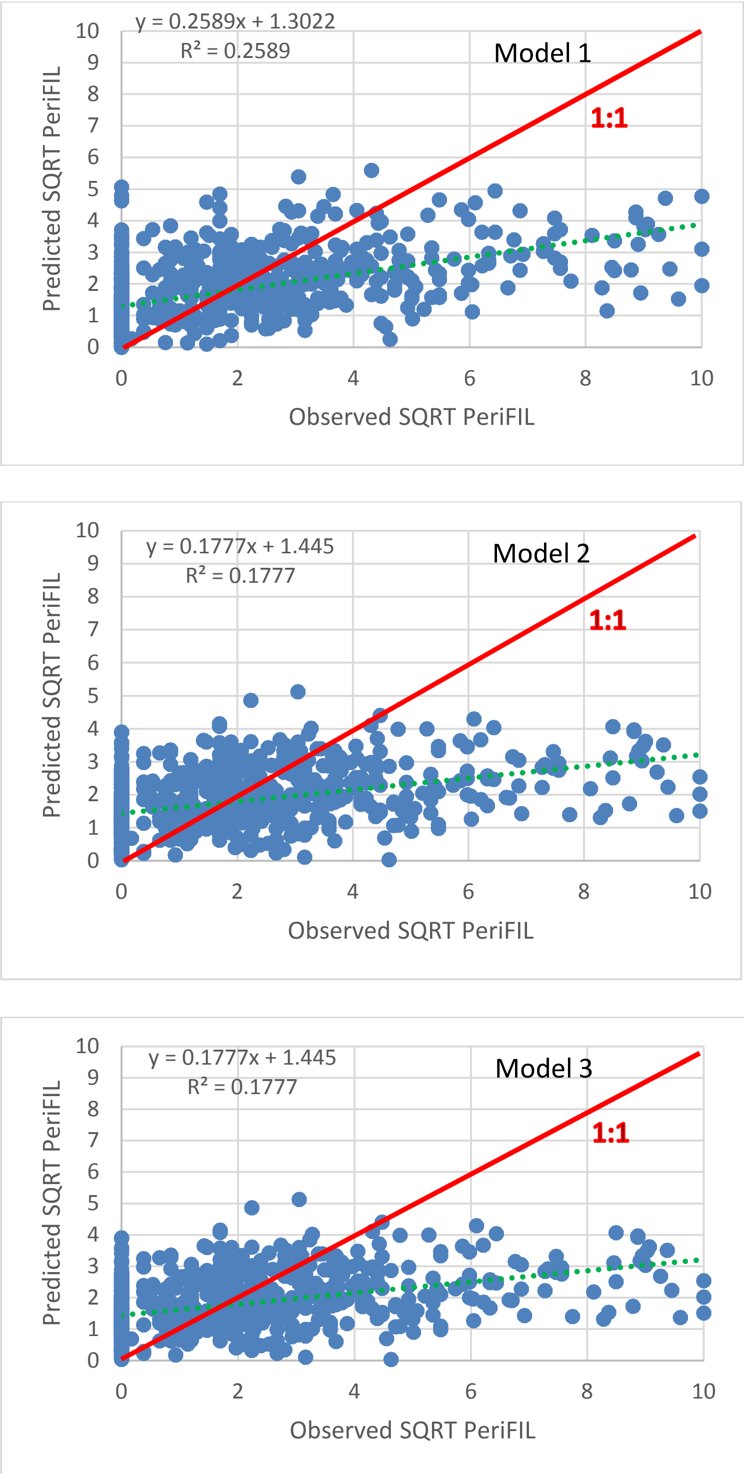


Figure G-2: PERIFIL stepwise multiple linear regression model results for Model 1 (top), Model 2 (centre) and Model 3 (bottom). Model 1 includes grazer species, Model 2 includes grazer total density only and Model 3 excludes any grazers.

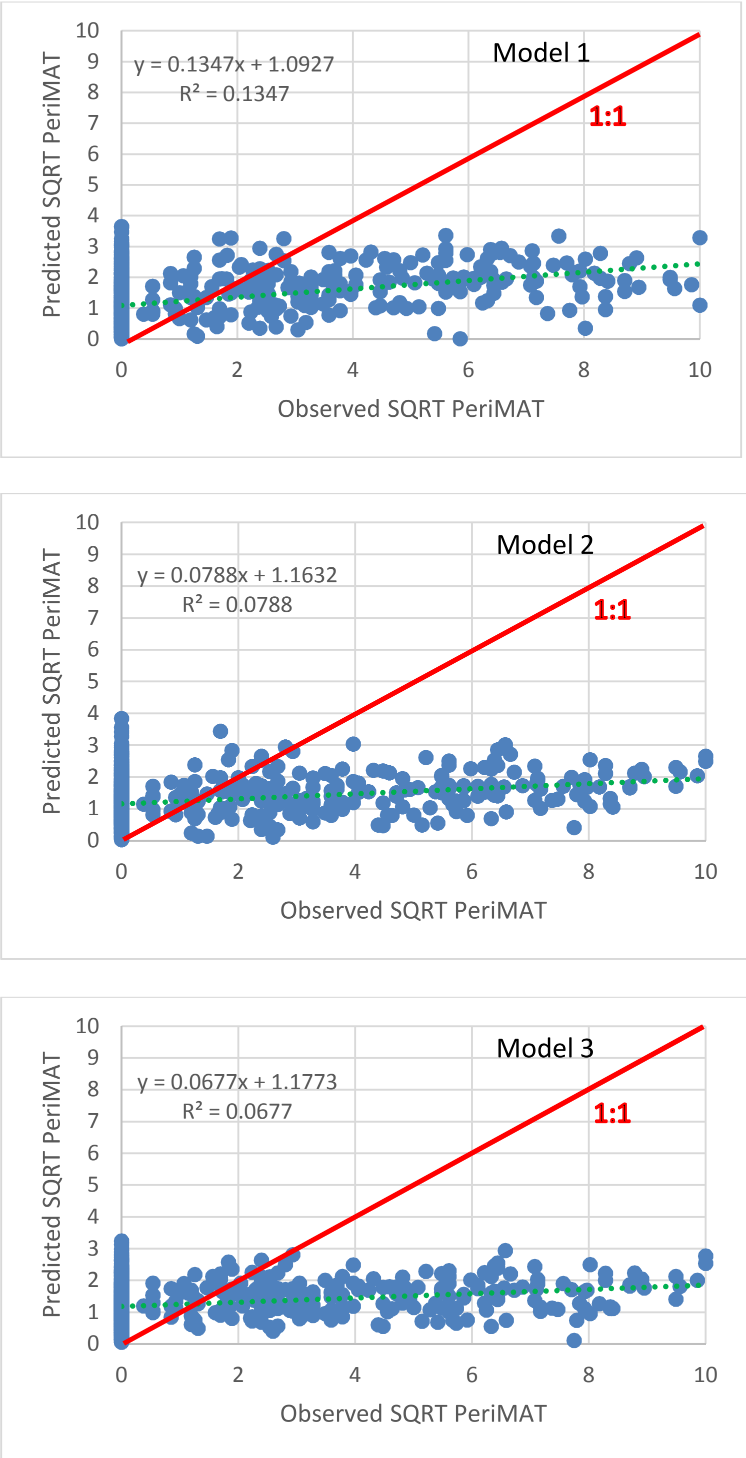


Figure G-3: PERIMAT stepwise multiple linear regression model results for Model 1 (top), Model 2 (centre) and Model 3 (bottom). Model 1 includes grazer species, Model 2 includes grazer total density only and Model 3 excludes any grazers.

Appendix H Quantile regression relationships between growing season periphyton abundance and preceding spring time nutrient concentrations

Chlorophyll a vs spring time nutrients

As with annual mean nutrient concentrations there was insufficient data to robustly examine the relationship between CHLA and preceding spring mean TN (Table 3-10). For TP, the results suggest that preceding spring mean TP concentrations of <10 mg/m^3, <35 mg/m^3 and <70 mg/m^3 correspond to 85% compliance with CHLA guidelines of <50, <120 and ≤200 mg/m^2, respectively (Figure H-1).

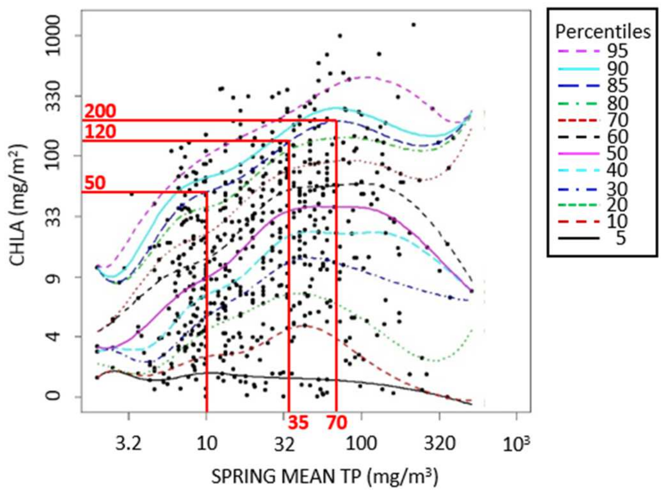


Figure H-1: Periphyton abundance as chlorophyll *a* versus preceding spring mean total phosphorus. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90, 95). Nutrient concentrations corresponding to 85% compliance with periphyton chlorophyll *a* guidelines are shown.

Periphyton abundance as CHLA generally increased with preceding spring-time DIN and DRP concentration (Figure H-2). A small number of records (7 from 5 rivers in the CW and WW REC climate classes: Cascade Creek, Cromel Stream, Waikaia River, Awhea River, Coles Creek) measured CHLA ≥50 mg/m^3 with DIN concentrations <50 mg/m^3. A larger number of records (11 from 7 different rivers representing a range of REC climate/source of flow/geology classes: Mararoa River, Aparima River, Pourakino River, Waikaia River, Upukeroa River, Waiau River, Awhea River, Coles Creek) detected CHLA ≥50 mg/m^3 with DRP concentrations <3 mg/m^3 and substantially more records (40 from 24 rivers) with DRP concentrations <6 mg/m^3.

Overall the results suggest that a mean spring-time DIN concentration <110 mg/m^3 is required to ensure that ≤15% of records exceed the NOF CHLA excellent band guideline of <50 mg/m^2. Similarly, preceding spring-time DIN concentrations of <600 mg/m^3 and <1200 mg/m^{3}correspond to ≤15% of records to exceed the NOF CHLA good and fair band guidelines of <120 mg/m^2 and ≤200 mg/m^2, respectively. For DRP, preceding spring-time mean concentrations of <3 mg/m^3, <11 mg/m^{3}and <50 mg/m^{3}are indicated to achieve compliance with these guidelines, respectively.

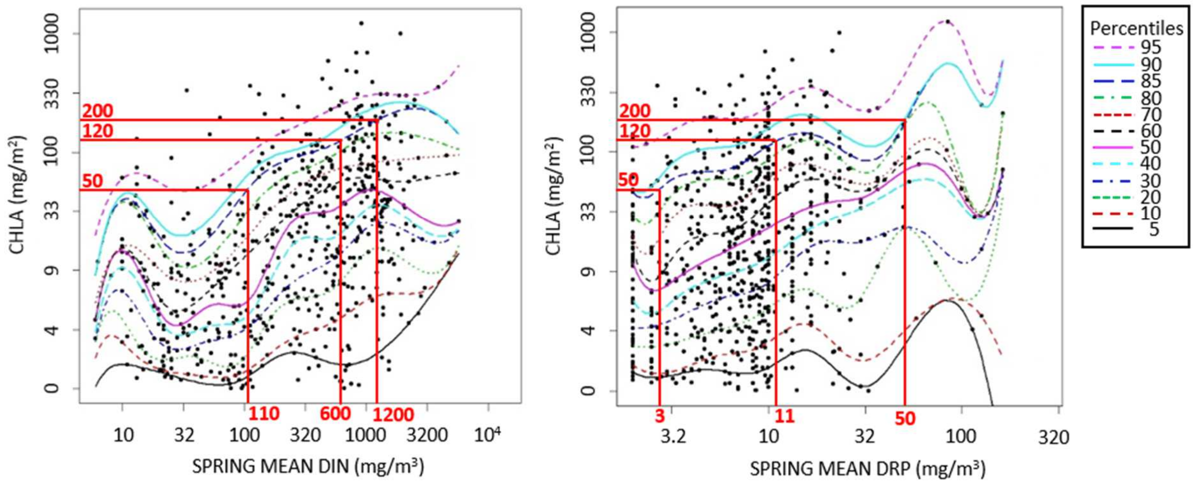


Figure H-2: Periphyton abundance as chlorophyll *a* versus preceding spring-time mean dissolved inorganic nitrogen (left) and dissolved reactive phosphorus (right). Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95). Nutrient concentrations corresponding to 85% compliance with periphyton chlorophyll a guidelines are shown.

PERIWCC vs spring time nutrients

Periphyton abundance as PERIWCC generally increased positively with mean preceding spring-time nutrient concentrations up to TN concentration of around 1000 mg/m^3 (Log TN = 3.0) and TP concentrations of approximately 130 mg/m^3 (Log TP = 2.1) (Figure H-3). The results suggest that ≥85% compliance with PERIWCC guidelines of <20%, <30% and <40% and ≤55% corresponds to TN concentrations of ≤65, ≤250 and ≤ mg/m^3, respectively. Non-exceedance of the 55% PERIWCC guideline is indicated for all TN concentrations in the range examined. For TP, realising 85% compliance with PERIWCC guidelines corresponds to concentrations of ≤10 (Log TP = 1.0), ≤15 (Log TP = 1.18), ≤65 (Log TP = 1.8) and <115 (Log TP = 2.05) mg/m^3, respectively.

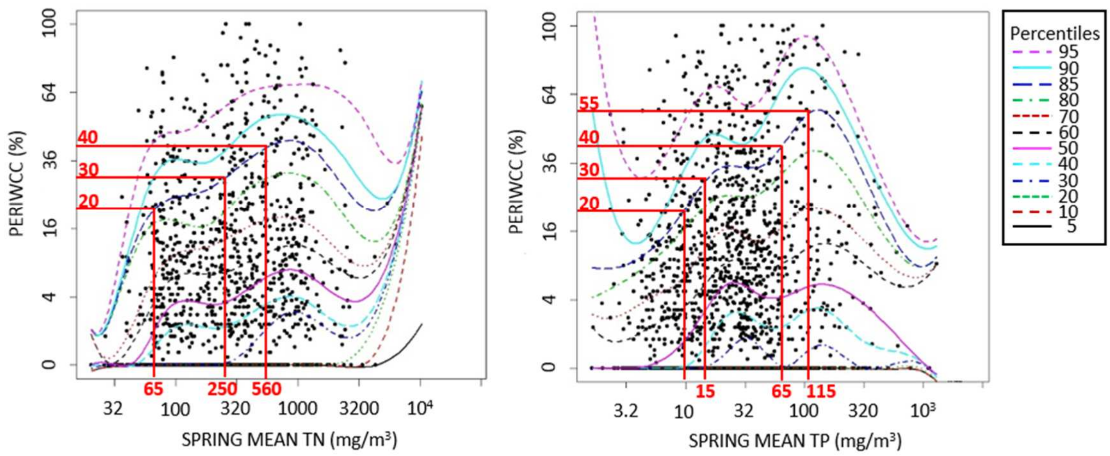


Figure H-3: Periphyton abundance as PERIWCC versus mean TN (left) and TP (right) for the preceding spring. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95). Nutrient concentrations corresponding to 85% compliance with periphyton PERIWCC guidelines are shown. Monowai Dam site was excluded from PERIWCC vs TP dataset.

For DIN we found that a small number of records had a relatively high periphyton abundance as weighted composite cover (PERIWCC 20-30%, SQRT PERIWCC 4.6-5.5) with very low spring-time DIN concentrations <3.3 mg/m^3 (Log DIN <0.5) (Figure H-4). All of these records were for the NRWQN Tarawera River at Lake Recorder, an atypical lake outflow site. Removing records for this site from the analysis increased the spring-time DIN concentration threshold corresponding to 85% compliance with the PERIWCC aesthetic guideline of 30% from around 150 mg/m^3 to 190 mg/m^3. To achieve ≥85% compliance with the provisional ecological condition guidelines of <20% and <40%PERIWCC, spring-time mean DIN concentrations of <16 mg/m^3 and <350 mg/m^3 are indicated by quantile regression. Overall, there were 52 records from 23 sites (representing a range of REC climate classes but predominantly CW) of PERIWCC ≥30% with spring-time DIN concentrations ≤50 mg/m^3 (LOG DIN = 1.7).

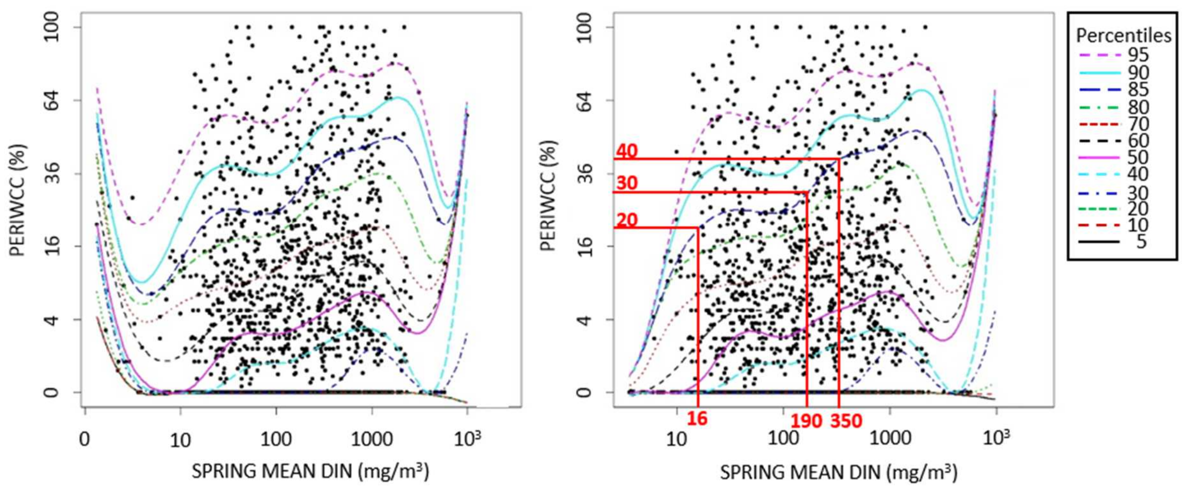


Figure H-4: Periphyton abundance as PERIWCC versus preceding spring-time mean DIN concentrations with (left) and without (right) NRWQN Tarawera site data. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95). Nutrient concentrations corresponding to 85% compliance with periphyton PERIWCC guidelines are shown.

Periphyton abundance as PERIWCC did not show a steadily increasing relationship to spring-time DRP concentrations (Figure H-5). A large number of records (76 records from 27 sites, mostly CW/HS) were for PERIWCC ≥30% with corresponding spring-time DRP concentrations ≤3 mg/m^3. Consequently, it was not possible to identify a DRP concentration threshold for 85% compliance with the PERIWCC aesthetic guideline of 30%. Furthermore, it was not possible to identify DRP concentrations for 85% compliance with the provisional PERIWCC ecological condition guidelines.

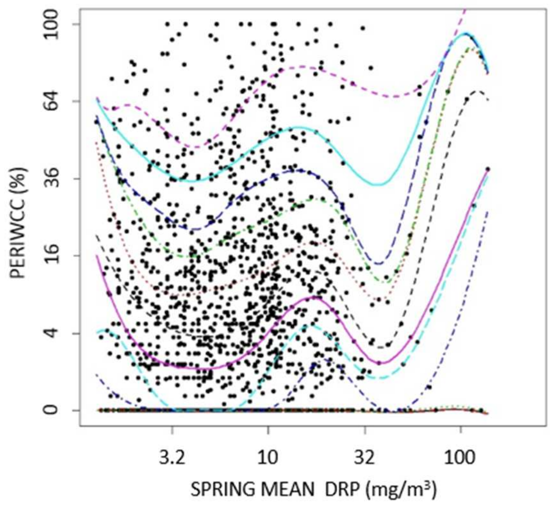


Figure H-5: Periphyton abundance as PERIWCC versus preceding spring-time mean DRP. Regression lines for the following percentiles are shown (5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 and 95).

Appendix I Research summaries

Studies assisting derivation of NOF periphyton attribute

Prepared by: Ton Snelder

Introduction

Three recent and linked projects have been strongly associated with the derivation of the periphyton attribute that was established by the National Objectives Framework (NOF) which appeared as part of an amendment to the National Policy Statement for Freshwater Management (NPS-FM; Ministry for the Environment, 2014). The first project examined at site frequency distributions of observed periphyton cover (Snelder et al. 2013). The second project was undertaken in association with the NOF Periphyton Panel convened by the Ministry for the Environment (MfE). The panel comprised freshwater ecologists (including experts in periphyton) who assisted MfE to define the NOF periphyton attribute, including abundance thresholds and exceedance frequencies. The third project was undertaken by NIWA and Aqualinc and attempted to derive nutrient concentration criteria to achieve the NOF periphyton objectives for all New Zealand's rivers. A short summary of these three projects is provided below.

At site frequency distributions of observed periphyton cover

Periphyton abundance is often low in rivers that have frequent large floods but may be high after long periods without floods and with favourable growing conditions. This suggests the theoretical exponential distribution may be an adequate approximation for the distribution of periphyton abundance at sites. If periphyton abundance is exponentially distributed, the probability that cover is equal to or greater than zero is one (or 100% of the time) and decreases asymptotically to zero for large values of cover. The exponential distribution has the mean as its single parameter so that if the mean can be estimated, the probability that cover exceeds any given threshold can be estimated or, conversely, the cover that is equalled or exceeded can be estimated given any probability.

The study by Snelder et al. (2014) used data provided by the National Rivers Water Quality Network (NRWQN) of 77 sites located on 48 of New Zealand's rivers. The data comprised monthly observations of two categories of periphyton cover (filaments and mats) for the time period 1989 to 2010 (22 years). In addition, a variety of other relevant observations were available including monthly water quality variables and continuous flow data.

The study showed that frequency distributions for periphyton cover (filaments and mats) were well approximated by the exponential distribution and quantified the errors associated with this approximation. The study also used linear regression models to express mean periphyton cover as a function of site nutrient concentrations, hydrological indices, light, temperature, and substrate. These results were similar to those of Matheson et al. (2012) however the study took the approach a step further. It was shown that the probability that cover exceeds any given threshold can be estimated from both the observed mean cover and the mean cover predicted by the regression model. The study quantified the errors associated with these approaches to estimating periphyton cover having different probabilities of occurrence.

Definition of the NOF periphyton attribute

The description of periphyton abundance using frequency distributions proposed by Snelder et al. (2014) was used to define the NOF periphyton attribute. The criteria based on the frequency of exceedance of a specified periphyton biomass recognises that periphyton biomass varies considerably over time as a result of processes causing accrual and loss (Biggs 1996). Accrual depends primarily on nutrient supply, light and temperature, and loss is driven primarily by high flows (Biggs 1996). For any stream or river, the lengths of periods between high flows (i.e., the accrual period) vary at a range of temporal scales including within-year (seasonal) and between-years. In unusually dry years, accrual periods can be particularly long and almost any stream, whether in natural or impacted state, has the potential to develop high periphyton biomass given a long accrual period. This suggests that criteria for periphyton biomass should not be based on an absolute maximum value or an annual maximum. Thus, the NOF periphyton attribute is specified by the combination of biomass thresholds and the percentage of the time the threshold can be exceeded.

The periphyton thresholds specified by the NOF assumes that periphyton abundance is observed on a monthly basis. In simple terms, for most rivers in New Zealand, the NOF periphyton criteria nominally restricts the exceedance of specified maximum biomass to once per year (based on monthly sampling). However, to accommodate for the effect variation in accrual period length, the criteria is defined in terms of an allowable exceedance frequency of 8% (based on an average exceedence of one month in twelve). This allows for the possibility that the biomass threshold may be exceeded more than once per a year for short monitoring periods (e.g., over periods of 1 to 2 years) but the site meets the objective over the longer term (Snelder et al. 2013). The NOF makes an exception to the 8% exceedance frequency for sites that tend to have naturally high periphyton biomass due to natural enrichment and naturally long accrual periods. Details of how the "Productive" periphyton class is defined and the associated criteria are provided in Ministry for the Environment (2014) and Snelder et al. (2013).

Another aspect of the studies undertaken as part of the definition of the NOF periphyton objectives was deciding on an abundance measure. The NOF periphyton abundance attribute is based on CHLA on the basis that this substance is contained in all types of algae and the metric reflects the total algal biomass (i.e., the amount of live algae) in a sample. In addition, statistical models relating periphyton abundance to other measures such as water chemistry, flow regimes and ecological measures (e.g., MCI scores) have been found to be generally stronger for CHLA than other measures such as cover.

Assessment of the NOF periphyton objectives involved estimating the current state and extent of locations that do not meet the proposed bottom line. This assessment was complicated by a lack of periphyton CHLA monitoring data. Data was restricted to four regions (the Manawatu-Whanganui, Canterbury, Wellington and Southland). In addition the available data was based on monthly sampling in only two regions (Manawatu-Whanganui and Canterbury) with a duration of only four and two years respectively. These data were therefore generally insufficient to accurately estimate the 8^{th} percentile CHLA concentrations. The approach taken therefore was to assume that the available data could be used to provide a reasonable estimate of the site mean CHLA concentrations and to assume that the data were exponentially distributed; a hypothesis that was based on the earlier study by Snelder et al. (2014). Tests indicated that the CHLA distributions at the sites were consistent with the exponential distribution (Snelder et al. 2013). Regression models were then used to express mean CHLA as a function of site nutrient concentrations, hydrological indices, light, temperature, and substrate in a similar manner to Snelder et al. (2014). Predictions of the mean CHLA were then made for all REC network segments. Finally, the proportion that do not meet the bottom line were estimated by transforming the mean into the 8% exceedance CHLA concentration using the exponential distribution.

Derivation of nutrient concentration criteria to NOF periphyton objective

The NOF periphyton objectives recognise that managing trophic state within an acceptable range is a key aspect of maintaining riverine ecosystem health. The NOF does not specify nutrient concentration objectives for rivers because the relationship between trophic state and nutrient concentrations varies between rivers due to the influence of other factors such as flow regime, substrate, light and temperature. Generally, these other factors can be considered natural characteristics of the river environment, although these may be altered by resource use. This means that in most cases, achieving periphyton biomass objectives requires the management of nutrient (nitrogen and phosphorus) concentrations. In addition, nutrient criteria to achieve a specified periphyton objective are spatially variable due to the variation in flow regimes, substrate, light and temperature.

The third project, which is summarised here but yet to be formally reported, was an attempt to use the available periphyton data to derive guideline nutrient concentrations to meet the three NOF attribute states in all rivers in New Zealand. The attribute states are defined by CHLA thresholds of 50 mg/m^2 (A/B band threshold), 120 mg/m^2 (B/C band threshold) and 200 mg/m^2 (C/D band threshold) and an 8% exceedance frequency, based on monthly sampling. Natural variation in flow regimes, substrate, light and temperature was accounted for by deriving criteria for each of 23 river classes defined by the second (Source-of-Flow) level of the River Environment Classification (REC).

The most comprehensive and nationally representative data set available for deriving nutrient-periphyton criteria is associated with the NRWQN. However, CHLA is not routinely monitored at NRWQN sites, so weighted composite cover (WCC) was used as a proxy measure in the analysis and a conversion of WCC to CHLA was applied. The conversion was based on a relationship between site mean WCC and site mean CHLA derived using data supplied by Horizons and Canterbury Regional Council (total number of observations = 1084) (Cathy Kilroy *pers. comm.*). A linear regression relationship Log10 Chl a = 0.291 + 0.307 ($\sqrt{WCC}$) (n = 66 sites, r^2 = 0.59), was used to transform WCC to CHLA. Application of this conversion resulted in three proxy thresholds of 21%, 34% and 45% WCC, which correspond to the NOF A/B, B/C and C/D band thresholds.

Data from the 78 NRWQN sites/date combinations identified by Snelder et al. (2014) were used to develop regression models that explained between site variation in periphyton abundance as a function of explanatory variables that represented nutrients, flow regimes, substrate, light and temperature. Importantly, the explanatory variables had also been estimated in a variety of modelling studies for every segment of the national digital river network represented by the REC. For example, predictions of nutrient concentrations for all segments were provided by Unwin et al. (2010) and various flow indices by Snelder and Booker (2013).

The first step was to extract the WCC exceeded 8% of the time (WCC.exc8) for each of the 78 NRWQN sites/date combinations. Two separate linear regression models of WCC.exc8 as a function of the environmental predictors were then fitted following Snelder et al. (2014). Model 1 was used to evaluate TN concentration thresholds and included TN and the ratio of DIN to DRP as predictors but not DRP. Model 2 was used to evaluate DRP concentration thresholds and included only DRP as the nutrient predictor.

The two regression models were then used to make multiple sets of predictions of WCCexc8 for all segments in the REC network with stream order > 3. For each set of predictions, the nutrient concentrations TN (Model 1) and DRP (Model 2) were held constant over all segments. The range of TN and DRP was varied for each set of predictions in 100 increments from 1 to 10,000 mg m^{-3} and 0.1 to 500 mg m^{-3} respectively. The DIN to DRP ratio was fixed in Model 1 at a uniform value of 13.5, which is the median N:P ratio across all segments in the national (REC) network.

The final step was to use the predictions to calculate, for each REC class, the TN and DRP concentration that resulted in 20% of REC segments (in that class) exceeding the three proxy CHLA thresholds (21%, 34% and 45%). The choice of 20% of segments exceeding the threshold was a judgment that recognises that the segment scale predictions are uncertain. Allowing a proportion of segments to exceed the threshold therefore represents a trade-off between defining nutrient criteria that are overly restrictive and the reverse; criteria that are not sufficiently protective.

The TN and DRP concentration criteria that were derived in this analysis varied between REC classes. This variability is a result of the strong influence of the explanatory variables other than nutrient concentrations that were represented in the regression models. The differences in concentration criteria between REC classes was consistent with the conceptual models of periphyton abundance (Snelder et al. 2014) and our understanding of the characteristics of the REC classes. For example, REC classes representing wet and extremely wet environments (i.e., CX, CW, WW) have frequent high flows and relatively high base flows as a result of climate driven frequent rainfall (Snelder et al. 2005). These classes have higher nutrient concentration criteria than classes with dry climates due to the more frequent flushing by high flows and relative lack of low flow events. The criteria also varied in expected ways with variation in the topography. For example, within the CW climate class the nutrient criteria are lowest for the lake (Lk) topography class. This reflects the buffering of flow variation in catchments with lakes and consequently lower flow variability than would be expected for this climate class were lakes not present. There is also a tendency for the Hill topography class to have higher nutrient criteria than the Mountain class. This is due to hill dominated catchments having a relatively non-seasonal and consistent response to precipitation, whereas mountain dominated catchments tend to have stable winter flows due to precipitation falling as snow and high low flows due to snow-melt during summer.

There was a tendency for the warmer classes to have lower nutrient concentration criteria than the cool classes. This is also consistent with the influence of temperature and light in the regression models. Both of these variables had positive regression coefficients in our models indicating the periphyton abundance increases with increasing values of these predictors. It is also consistent with the expectation that summer water temperatures and solar radiation are generally higher in the warm (generally northern) regions of New Zealand. Thus, after accounting for the other variables in the models, nutrient concentrations must be lower to achieve a given periphyton abundance threshold in a REC class that represents warm climates compared to cool climates.

In conclusion, this approach to derivation of nutrient criteria accounts for national variation in the response of periphyton to nutrients, hydrology, temperature and light. However, the results are provisional, primarily because the NRWQN data was not collected with the intention of deriving nutrient concentration criteria. This limitation possibly contributes to the large uncertainties associated with the regression models (Snelder et al. 2014), which also affects our confidence in the derived criteria. Uncertainty may be able to be reduced in future by improving data collection methods and consistency and collecting data for a wider range of sites.

Periphyton – nutrient – flows research in NIWA's Sustainable Water Allocation Programme

Prepared by: Cathy Kilroy, Doug Booker, Jo Hoyle, Michelle Greenwood, Richard Measures, Murray Hicks

Introduction

The primary focus of NIWA's Sustainable Water Allocation Programme (SWAP) is to identify and quantify the trade-offs between water resource use and environmental outcomes. In rivers, water use leads to modified flow regimes, which may influence primary production (periphyton, aquatic plants) by altering rates of biomass accumulation and removal and influencing interactions with sediment transport, sometimes leading to nuisance proliferations of algae or plants. Flow alteration is often accompanied by catchment changes that affect nutrient inputs. Therefore the effect of flow regime changes on riverine primary production needs to be considered in the context of nutrient loads and concentrations. A closely related issue is survey methodology. Primary production of periphyton is generally assessed as standing crop, or biomass, which can be measured in a variety of ways, including laboratory-determined biomass, visual assessment of cover, and more automated methods based on imaging. Efficient assessment of periphyton biomass is particularly topical, following inclusion of a periphyton attribute (as CHLA) in the National Objective Framework (NOF) for freshwaters (released in July 2014 as an amendment of National Policy Statement for Freshwater Management (NPS-FM) (Ministry for the Environment, 2014)).

Projects covering aspects of both these issues have been included in ecology objectives of the Sustainable Water Allocation Programme since 2012. Updates on five projects are provided below.

Geomorphological control of periphyton removal thresholds

The hydrological index FRE3 (mean annual frequency of floods greater than three times the median flow) has been used to derive relatively strong relationships linking periphyton, flows and nutrient concentrations (Biggs 2000a). However, site-specific predictions using these relationships are frequently unrealistic. This may stem from our limited ability to transform flow data into ecologically meaningful physical processes that directly affect periphyton removal (e.g., drag, abrasion, bed movement). In this project we examined whether geomorphic variables, such as frequency of bed movement, are useful co-predictors in periphyton abundance-flow-nutrient relationships. We collected data on channel topography and bed material size for 20 river reaches in the Manawatu-Whanganui Region, from which monthly periphyton and nutrient data were available. For each reach hydraulic modelling was used to determine the discharge required to mobilise bed sediment of various sizes. Relationships between periphyton and discharge thresholds were then examined.

Across sites, threshold flows for periphyton removal ranged between 1 and 10 times the median flow. At many sites this threshold corresponded to the threshold for moving sand, suggesting that sand abrasion may be a key control on periphyton abundance. Furthermore, relationships between soluble inorganic nitrogen and periphyton abundance were found to be strong at sites where sand was mobilized infrequently (i.e., sites with stable substrata), but weak at sites where sand was mobilized often. The overall results indicate that integrating understanding of geomorphology, hydrology and ecology can improve prediction of periphyton abundance in New Zealand rivers. The next step in this project is to carry out in-river experiments to directly quantify the effects of sand abrasion on periphyton removal.

Interactions between flows, nutrients, periphyton, and invertebrates

Three thresholds for CHLA were specified for the periphyton attribute in the NOF: 50, 120 and 200 mg/m^2, with 8% exceedance of 200 mg/m^2 indicating conditions below the National Bottom Line. The NOF thresholds were set based on a body of knowledge linking periphyton biomass with various instream values (including the previous guidelines). The aim of this project is to explore experimentally the range of flow (e.g., water velocity, discharge variability) and nutrient conditions leading to the periphyton NOF thresholds, and to characterise benthic communities (i.e., periphyton and macroinvertebrate community composition) at those thresholds. The experiments are being conducted in a new streamside channel facility set up beside the Kowai Stockwater Race, Springfield, Canterbury. The first experiment started in December 2014. Subsequent experiments will test hypotheses guided by relationships observed in field data (e.g., monthly data from 24 river sites collected by Environment Canterbury over three years; surveys in the Native Fish Ecosystems project in SWAP). The experimental data will also be available for testing DELWAQ model simulations in a Hydro-ecological modelling project also being carried out within the Sustainable Water Allocation Programme (see project 5 below).

Case study of periphyton management

Dam-regulated rivers are particularly susceptible to nuisance proliferations of periphyton. The primary driver of proliferations is prolonged stable flow, which favours biomass accumulation. One potential management solution is to manipulate flows to promote biomass removal and minimise biomass development. Such management is necessarily constrained by the water usage needs that led to dam construction in the first place. However, there may be enough flexibility to make substantial improvements in river condition. This project focusses on periphyton management in the Opuha River, Canterbury, downstream of the Opuha Dam. Two types of nuisance periphyton cause problems in the river. Between the dam and the confluence with the Opihi River, blooms of *Didymosphenia geminata* severely degrade the aesthetic values of the river and frequently block irrigation intakes. In the Opihi River downstream of the confluence with the Opuha, large blooms of the potentially toxic cyanobacterium *Phormidium* have apparently increased since the dam was commissioned. In collaboration with Opuha Water Ltd., we are exploring:

(a) the effectiveness of occasional flushing flows, and ways to optimise those events, using a combination of surveys and hydraulic analyses;

(b) the potential for more subtle flow manipulations (such as overnight reductions in flow followed by smaller flushing events) to reduce biomass using in-river experiments; and

(c) the potential for environmental factors other than flows (e.g., water temperature and water chemistry) to exacerbate periphyton proliferations, using a survey approach.

Results in the project to date include: (a) optimisation of flushing flow effectiveness by maximising the water volume released, extending the flush duration, and timing the flush to coincide with tidal conditions at the river outlet - which all help to increase periphyton removal and minimise deposition of algae along the river banks as the flow recedes; (b) identification of a likely increase in water temperature coinciding with installation of the dam, which may have exacerbated periphyton growth in summer; (c) confirmation that surveys at fixed points on transects enable good time-series data of visual estimates of periphyton cover, even when different teams carry out the surveys. Experimental investigations into the effects of periphyton exposure on subsequent biomass development and removal are underway (Measures and Kilroy 2014).

Surveying and estimating periphyton cover and biomass

Thresholds for periphyton to meet instream values in terms of percentage cover of the streambed were included in the periphyton guidelines released in 2000 (Biggs 2000b), and have been widely applied. However, few data were available directly linking visually assessed cover to laboratory-measured CHLA. In a study in 2011-12 we carried out detailed surveys of periphyton using both visual assessments and sample collection for CHLA analysis in three Canterbury rivers at three different times of the year. The study also included an assessment of inter-operator variability in both methods. Key conclusions were: (a) visual assessments (comprising percentage cover estimates of up to eight periphyton categories) distinguished sites and survey occasions as effectively as did CHLA; (b) CHLA could be estimated from the visual assessments with reasonable accuracy; (c) views of 20 areas (through an underwater viewer) on the river bed were adequate to represent average cover of the surveyed reach; and (d) the main source of inter-operator variability was in distinguishing categories of algal cover with low biomass, and so has minimal effect if the data are used to derive estimates of CHLA (Kilroy et al. 2013). Ongoing research in this project is now focusing on trialling automated methods (i.e., photographic and spectral imaging, and image analysis) for monitoring periphyton, including linking image-derived data to measured CHLA.

Physically-based periphyton modelling

We are exploring simulation of periphyton growth using a physically-based modelling approach. To do this we have applied DELWAQ, a coupled physically-based hydraulic-ecology model. Hydraulic models have been developed for several river reaches that have also been monitored for ecological patterns in the Native Fish Ecosystems project. We are trialling the use of DELWAQ to simulate predictor (grazing invertebrates)-prey (periphyton) patterns. Results will be compared with field observations and experimental observations. The benefit of such modelling is that it is likely to improve our understanding of the processes and advance our fundamental knowledge. The other major benefit to this open-source physically-based approach is that it can be applied to a wide variety of situations (gravel-bed rivers, spring-fed rivers, estuaries, settling ponds, lakes).

Ecological thresholds research

Prepared by: Annika Wagenhoff

Water quality objectives (or guidelines, standards) can be defined using reference conditions as benchmarks. This approach has been used to develop trigger values for water quality attributes given in the ANZECC (2000) guidelines. However, in New Zealand and other countries, river managers seek to define scientifically defendable water quality objectives, in particular for nutrient concentrations, based on their ecological effects. Nutrient objectives can be defined based on an unwanted ecological outcome, which has a causal relationship to nutrient enrichment, such as high mean annual maximum algal biomass or percentage periphyton cover.

Nutrient objectives should also protect river ecosystems from moving beyond an ecological threshold, defined as a point beyond which a system undergoes an undesirable regime shift or an abrupt change to its structure and functioning that may be difficult to reverse. Such regime shifts have been observed in shallow lakes, but not much is known about whether regime shifts occur in river ecosystems or what are the best indicators of significant ecosystem change.

We compiled a regional data set for 58 state-of-environment monitoring sites from Horizons Regional Council for ecological threshold analysis across stress gradients using a space-for-time approach. These sites were chosen to span a wide range in percentage pastoral land use in the catchment and these also covered a wide range in nutrient concentrations and levels of fine sediment. Medians were calculated for dissolved and total nitrogen and phosphorus from monthly data collected during the three years preceding the ecological sampling. A large set of structural and functional ecological indicators were calculated to capture multiple attributes of ecosystem health and investigate which would be best suited to indicate an ecological threshold across the enrichment gradient. Structural indicators were derived from macroinvertebrate and periphyton taxonomic data as well as from visual assessments of the percentage of periphyton cover on the streambed. Three functional indicators were determined; gross primary production (GPP), ecosystem respiration (ER), and the cotton decay coefficient, the latter is a surrogate for microbial organic matter processing.

We chose two different statistical approaches to look for response shapes that may be indicative of ecological thresholds, including those 1) with an initial period of resistance, 2) showing a dramatic step change, or 3) showing a subsidy-stress pattern. First, a piecewise linear regression model was fitted to each pair of a nutrient attribute and an ecological indicator to test whether it was a significantly better fit than a linear model with no breakpoint. None of the piecewise models for each of the 56 stressor-response pairs were statistically significant. This indicates that there is little evidence for thresholds (abrupt change) in stressor–response relationships between nutrient concentrations and variables that describe a biotic community or an ecosystem function.

Secondly, a boosted regression tree (BRT) model was fitted to the data of each ecological indicator with multiple predictors describing either a stress gradient (nutrient concentrations, fine sediments) or another environmental gradient (such as flow, temperature and shading amongst others). BRT models are more flexible in fitting complex nonlinear relationships and automatically handle interactive effects between multiple predictors. This exploratory approach was chosen to investigate; 1) whether potential threshold responses are more complex than the simple shapes described by piecewise models, and 2) whether the presence of multiple stressors and other environmental variables affects the response across nutrient gradients, and hence may mask threshold responses when looking at single stress gradients as with piecewise models.

Five out of 14 BRT models had good predictive power and featured nutrient attributes within the first four highest-ranked predictors. For example, the Macroinvertebrate Community Index (MCI) score was best predicted by concentrations in total nitrogen (TN) and phosphorus (TP). The partial dependence plot indicated an initial period of resistance to increasing concentrations of TN. Similarly, the cotton decay coefficient was best predicted by concentrations of dissolved inorganic nitrogen (DIN) and phosphorus (DRP), and the plot indicated an initial period of resistance to increasing concentrations of DIN. These resistance periods ended at nitrogen (TN/DIN) concentrations of approximately 200 mg/m^3, which are within the range of values observed at reference sites in New Zealand. Exploration of two-way interaction plots suggested little evidence for complex interactive effects between predictors.

Overall, our space-for-time analysis illustrated the strength of some indicators of macroinvertebrate and periphyton communities as well as functional indicators to discriminate between reference and impact condition with regard to nutrient concentrations at the regional scale. Furthermore, a gradual change in response to increased nutrient enrichment rendered indicators suitable for tracking enrichment-induced ecosystem change relative to reference condition. On the other hand, analysis of these indicators provided limited evidence of additional ecological thresholds when moving beyond nutrient reference conditions. It is possible, however, that the aggregate indices we examined are insensitive to threshold responses of individual species. Examination of species-level responses in addition to responses of community-level and ecosystem-level indicators will provide further evidence of ecological thresholds, strengthening the definition of effects-based water quality objectives.

Update on *Phormidium* Research

Prepared by: Susie Wood

Over the past decade there has been an apparent increase in blooms of the mat-forming cyanobacteria *Phormidium* in some New Zealand rivers. *Phormidium* can form expansive mats covering entire river substrates. It also produces potent neurotoxins that pose a risk to human and animal health.

The Horizons Regional Council undertook weekly monitoring at 10 sites in 7 rivers (January 2012 to June 2013) to investigate how water column nutrient concentrations influence *Phormidium* blooms. Data analysis suggests that *Phormidium* blooms tend to occur when water column dissolved reactive phosphorus (DRP) concentrations are less than 10 mg/m^3 and dissolved inorganic nitrogen (DIN) water column concentrations are greater than 200 mg/m^3. This corroborates earlier studies that have shown *Phormidium* isolated from New Zealand rivers cannot fix nitrogen, thus some water column nitrogen is required for growth (Heath et al. in prep.).

There were two sites with blooms where DRP was higher (ca. 20 mg/m^3). Both sites were downstream of sewage treatment plants that dose with Alum during their treatment processes. Alum reduces sewage water DRP concentrations but can result in an increase in the phosphorus load of discharged particulates. The phosphorus bound to these particles maybe released if entrapped within *Phormidium* mats (see further discussion below). In contrast to all other sites with blooms the DIN concentrations at the Horseshoe Bend site on the Tokomaru River were low (ca. <50 mg/m^3). *Phormidium* co-occurs in the mats with other microorganisms (*e.g.,* bacteria, diatoms) and preliminary analysis indicates bacterial species capable of nitrogen fixation are present. These organisms may supply a nitrogen source for *Phormidium*. Further investigation is required to confirm this and investigate other DIN sources at this site.

To explain this discrepancy between low DRP water column concentrations and high biomass we explored the possibility that *Phormidium* mats mat have alternate source of phosphorus. Unlike other river periphyton, *Phormidium* mats are thick and cohesive, with water trapped in a mucilaginous matrix and solute exchange with river water limited to diffusion though boundary layers. A feature of most *Phormidium* mats is a thin layer of fine sediment at the substrate / mat interface. We hypothesized that daytime photosynthetic activity by *Phormidium* could elevate pH inside the mats, or night time respiration could reduce dissolved oxygen sufficiently to facilitate desorption of loosely bound phosphates from sediment incorporated within mats, thus allowing *Phormidium* to utilize it for growth.

To investigate this idea further, a 'river mesocosm chamber' containing *Phormidium* covered rocks was set up at the edge of the Mangatainoka River (Manawatu catchment) for two days in March 2014. Microelectrodes and optodes were used to measure pH and oxygen concentrations within the mats. Water samples were collected mid-river and from within the *Phormidium* mats every 2 to 4 hours for analysis of DRP, DIN and elemental concentrations. To assess sedimentation rates, sediment traps were deployed at three locations on the Mangatainoka River. Phosphorus can be bound to fine sediments in numerous chemical forms that vary in their bioavailability. Therefore phosphorus fractionation was used to determine the concentrations of loosely adsorbed, reductant soluble, and metallic oxide-bound phosphorus in sediment from the three sites.

The results of the optode and semi-microelectrode experiments demonstrated that photosynthetic activity by *Phormidium* can cause elevated pH (>9), during daytime, and that night-time respiration can cause oxygen depletion (<4 mg/L) within the mats. The water within the *Phormidium* mats had 300-fold higher DRP concentrations than bulk river water and also elevated concentrations of other elements, including iron, suggesting that phosphorus is being released from entrapped fine sediment particles. Microscopic analysis of particles entrapped within the mats revealed sediments were largely comprised of fine material (<63 µm). Sedimentation rates of fine sediment (<63 µm) were similar among sites. However, phosphorus fractionation demonstrated markedly higher concentrations of biologically available phosphorus at sites with *Phormidium* blooms, most likely due to the surrounding agricultural land use.

Collectively these data indicate that fine sediment is a source of phosphorus that contributes to *Phormidium* growth and bloom formation. Once *Phormidium* mats are established, water column nutrient concentrations are of little relevance to biomass accrual. However, during the initial stage of mat formation water column nutrients probably define whether *Phormidium* will dominate. Some cyanobacteria are known to be very adept at luxury uptake of phosphorus and this may give *Phormidium* a competitive advantage over other periphyton when bulk river water phosphorus concentrations are low.

Update on instream nutrient attenuation and periphyton in the Tukituki River

Prepared by: John Quinn

Nutrients and instream plants (periphyton and macrophytes) interact dynamically in rivers with nutrients stimulating plant growth that in turn reduces downstream nutrient concentrations, eventually to levels that limit further growth. Furthermore, plant metabolism influences dissolved oxygen and pH that can alter nutrient fluxes between the sediment and water column. Thus an understanding of the drivers of plant growth and nutrient attenuation is needed to predict the spatial extent of effects of nutrient inputs on instream plant biomass, so that, for example, cumulative effects can be accounted for. This has been the subject of investigations, using longitudinal surveys and *in situ* recirculating chambers, that have focused primarily along a 90 km periphyton dominated reach of the mid-lower Tukituki River during summers of 2011-15 at flows ranging from 3 to 20 m^3/s and a range of climatic conditions. High attenuation rates of dissolved inorganic nitrogen (DIN av. 10 $mg/m^2/h$) and DRP (av. 0.24 $mg/m^2/h^1$) have been recorded and DIN and DRP inputs at the top of the study reach (from upwelling groundwater and sewage treatment plant discharges) were effectively removed within 30-60 km downstream under low flows (<10 m^3/s) in summer.

Attenuation rates of dissolved inorganic N and P were influenced particularly by nutrient concentrations, flow rate, periphyton biomass, ecosystem metabolism, gross primary production and diel lighting. Denitrification rates were measurable but did not contribute substantially to nitrate removal under summer low-flow conditions. Nutrient concentrations also influenced the periphyton community type and relationships with current velocity. At high nutrient levels at the top of the Tukituki gradient, cyanobacteria-dominated mats predominate in moderate–high velocity areas, whereas filamentous green algae are negatively correlated with velocity and confined to the slower margins. In contrast, under very low nutrient levels downstream, cyanobacterial mats were absent whereas cover of filamentous greens was strongly correlated with current velocity likely responding to the higher flux of nutrients with increasing current velocity.

Measurements of sediment Equilibrium Phosphorus Concentration (EPCo, McDowell 2015), in collaboration with AgResearch scientist Dr Richard McDowell, were carried out along the Tukituki in 2014 to investigate the role of sediment as a P source under baseflow conditions. Results showed that EPCo was correlated with surface-water DRP concentrations, indicating that fine sediment may indeed be a P source. Furthermore, laboratory experiments demonstrated that photosynthesis-driven, diurnal pH fluctuations (up to pH 9–10 in the afternoon during summer) can stimulate release of sediment-bound P.

Densities of macroinvertebrates (particularly net-spinning caddis) were significantly higher under stable low-flow conditions in February 2013 than under variable, higher flows in February 2012. Nutrient transfer to invertebrates (and further up the food chain to fish and birds) appears to be an important removal mechanism during stable flow conditions in summer. Research to further quantify these effects is ongoing.

Results from the Tukituki have supported the development and refinement of a mechanistic model of periphyton growth and nutrient attenuation that is a key component of the TRIM model developed by team member Dr Kit Rutherford. TRIM has been used to support decisions on management of the Tukituki catchment and a related nutrient-periphyton model presented in a paper (Chapra, Flyle and Rutherford, 2014) on “Parsimonious model for assessing periphyton dominated streams” that won the ASCE 2015 Wesley W. Horner Award.

Appendix J Quantile regression nutrient thresholds based on other percentiles

Table J-1: Nutrient criteria to achieve ≥95% compliance with periphyton abundance guidelines based on quantile regression of "summer" [a] data.

Periphyton metric	Periphyton guideline [b]	Mean for preceding 12 months (mg/m³)				Mean for preceding spring (mg/m³)			
		DIN	DRP	TN	TP	DIN	DRP	TN	TP
Chla (mg/m²)	<50	na [c]	na [c]	nd [d]	<5.9	<45	na [c]	nd [d]	<5
	<120	<60	na [c]	nd [d]	<17	<170	<3	nd [d]	<17
	<200	<100	<3.8	nd [d]	<27	<320	<4	nd [d]	<27
PERIWCC (%)	<20	na [c]	na [c]	<45	<4.8	<9	na [c]	<40	na [c]
	<30	na [c]	na [c]	<50	<6.4	<11	na [c]	<48	na [c]
	<40	na [c]	na [c]	<65	<10	<13	na [c]	<62	<7
	≤55	<65	na [c]	<300	<20	<18	na [c]	<235	<11

[a] "summer" period = 1 November to 30 April.

[b] chl*a* 50 mg/m² equivalent to c. 21% PERIWCC, 120 mg/m² = c. 34% PERIWCC and 200 mg/m² = c. 45% PERIWCC, see Appendix I Studies assisting in the derivation of the NOF periphyton attribute.

[c] na data indicate not achievable – e.g., no significant relationship.

[d] nd insufficient data to determine.

Table J-2: Nutrient criteria to achieve ≥90% compliance with periphyton abundance guidelines based on quantile regression of "summer" [a] data.

Periphyton metric	Periphyton guideline [b]	Mean for preceding 12 months (mg/m³)				Mean for preceding spring (mg/m³)			
		DIN	DRP	TN	TP	DIN	DRP	TN	TP
Chla (mg/m²)	<50	<20	na [c]	nd [d]	<9	<75	<2	nd [d]	<6
	<120	<140	<11	nd [d]	<30	<450	<8	nd [d]	<25
	<200	<700	<18	nd [d]	<45	<700	<12	nd [d]	<45
PERIWCC (%)	<20	na [c]	na [c]	<55	<7	<10	na [c]	<55	<6
	<30	<35	na [c]	<85	<12	<13	na [c]	<65	<9
	<40	<140	na [c]	<380	<40	<160	na [c]	<280	<12
	≤55	<360	na [c]	<800	<60	<320	na [c]	<700	<50

[a] "summer" period = 1 November to 30 April.

[b] chl*a* 50 mg/m² equivalent to c. 21% PERIWCC, 120 mg/m² = c. 34% PERIWCC and 200 mg/m² = c. 45% PERIWCC, see Appendix I Studies assisting in the derivation of the NOF periphyton attribute.

[c] na data indicate not achievable – e.g., no significant relationship.

[d] nd insufficient data to determine.

Table J-3: Nutrient criteria to achieve ≥85% compliance with periphyton abundance guidelines based on quantile regression of "summer" [a] data.

Periphyton metric	Periphyton guideline [b]	Mean for preceding 12 months (mg/m^3)				Mean for preceding spring (mg/m^3)			
		DIN	DRP	TN	TP	DIN	DRP	TN	TP
Chla (mg/m^2)	<50	<100	na [c]	nd [d]	<14	<110	<3	nd [d]	<11
	<120	<630	<11	nd [d]	<45	<600	<11	nd [d]	<35
	<200	<1100	<18	nd [d]	<65	<1200	<50	nd [d]	<70
PERIWCC (%)	<20	<35	na [c]	<70	<10	<16	na [c]	<65	<10
	<30	<140	na [c]	<360	<45	<190	na [c]	<250	<15
	<40	<360	na [c]	<660	<55	<360	na [c]	<560	<65
	≤55	nc [e]	na [c]	<890	<75	<1500	na [c]	<800	<110

[a] "summer" period = 1 November to 30 April.

[b] chl*a* 50 mg/m^2 equivalent to c. 21% PERIWCC, 120 mg/m^2 = c. 34% PERIWCC and 200 mg/m^2 = c. 45% PERIWCC, see Appendix I Studies assisting in the derivation of the NOF periphyton attribute.

[c] na data indicate not achievable – e.g., no significant relationship.

[d] nd insufficient data to determine.

[e] nc no criteria indicated – i.e., achievable at all nutrient concentrations.

Table J-4: Nutrient criteria to achieve ≥80% compliance with periphyton abundance guidelines based on quantile regression of "summer" [a] data.

Periphyton metric	Periphyton guideline [b]	Mean for preceding 12 months (mg/m^3)				Mean for preceding spring (mg/m^3)			
		DIN	DRP	TN	TP	DIN	DRP	TN	TP
Chla (mg/m^2)	<50	<100	<3	nd [d]	<18	<150	<3	nd [d]	<15
	<120	<630	<14	nd [d]	<55	<890	<15	nd [d]	<50
	<200	<1100	<18	nd [d]	<100	<1600	<50	nd [d]	<85
PERIWCC (%)	<20	<160	na [c]	<280	<40	<140	na [c]	<290	<15
	<30	<380	na [c]	<680	<55	<280	na [c]	<500	<60
	<40	<1100	na [c]	<900	<80	<1500	na [c]	<830	<120
	≤55	nc [e]	na [c]	nc [e]	<120	nc [e]	na [c]	nc [e]	nc [e]

[a] "summer" period = 1 November to 30 April.

[b] chl*a* 50 mg/m^2 equivalent to c. 21% PERIWCC, 120 mg/m^2 = c. 34% PERIWCC and 200 mg/m^2 = c. 45% PERIWCC, see Appendix I Studies assisting in the derivation of the NOF periphyton attribute.

[c] na data indicate not achievable – e.g., no significant relationship.

[d] nd insufficient data to determine.

[e] nc no criteria indicated – i.e., achievable at all nutrient concentrations.