greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

Periphyton and macrophyte outcomes for aquatic ecosystem health in rivers and streams

Technical report to support the draft Natural Resources Plan

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Contents

Executive summary

This report presents technical background to instream plant indicators of river and stream ecosystem health recommended for inclusion in the draft Natural Resources Plan (dNRP) for the Wellington region. It was originally drafted prior to the release of the Regional Plan Working Document for Discussion (WDFD) in September 2013 (GWRC 2013) but was not completed due in part to uncertainty about changes that might be made in response to the release of the National Objectives Framework (NOF) under the National Policy Statement for Freshwater Management (NPS-FM). Although the outcomes recommended in this report differ from the final recommendations for the dNRP documented in Greenfield (2014a) this report presents relevant background analysis and a record of the evolution of outcomes for the dNRP.

Rivers State of the Environment (RSoE) instream plant, macroinvertebrate and supporting environmental data (eg, water quality, land cover, accrual period) collected from the Wellington region between 2004 and 2012 were analysed to assess the suitability of instream plant indicators for use in the dNRP (where they are referred to as 'attributes') and to help identify numeric thresholds to represent the desired levels of ecosystem health (referred to as 'outcomes'). Outcomes representing two levels of ecosystem health were identified – a default 'healthy' level which applies to all rivers and streams in the region and a higher level which applies to rivers and streams identified as supporting 'significant indigenous ecosystems' in Table 16 of the Regional Policy Statement (GWRC 2013). Data analysis and identification of outcomes were based around the Freshwater Environments of New Zealand (FENZ) classification to account for natural variability in river and stream ecosystems across the region.

Periphyton community composition showed some variation across the different FENZ classes. However, the correlation between periphyton community composition and environmental variables was poor, with insufficient taxonomic resolution likely to be a key contributing factor. For this reason numeric outcomes for periphyton community composition should not be included in the dNRP.

Periphyton biomass varied across FENZ classes and was moderately correlated with environmental variables. A regression tree model suggested that water temperature, water clarity, dissolved nutrient concentrations and biomass accrual period are key drivers of periphyton growth. Periphyton biomass was also strongly correlated with Macroinvertebrate Community Index (MCI) score. It is recommended that numeric outcomes for periphyton biomass be included in the dNRP. These outcomes should ideally be based on the relationship between periphyton biomass and macroinvertebrate indicators across different FENZ classes in the Wellington region. Given this information is currently lacking, the following periphyton biomass outcomes based on the New Zealand Periphyton Guidelines (Biggs 2000) are recommended in the interim:

Recommended annual maximum chlorophyll *a* (Chl. *a*) outcomes for 'significant aquatic ecosystem' and 'healthy aquatic ecosystem' levels of protection for FENZ classes in the Wellington region

FENZ class	Significant aquatic ecosystem outcome (Chl. *a* mg/m^2)	Healthy aquatic ecosystem outcome (Chl. *a* mg/m^2)
C7, C10 and UR	50	50
C5, C6a, C6b and C1	50	120
C8, A, C6c and B	120	200

There were insufficient macrophyte data available for the Wellington region to identify numeric outcomes for this attribute.

The following narrative standard is recommended for heterotrophic growths associated with point source discharges:

"*There shall be no bacterial or fungal slime growths visible to the naked eye as plumose growths or mats*".

1. Introduction

Objective 13 of the Regional Policy Statement (RPS) for the Wellington region (GWRC 2013) states that the region's rivers must support healthy functioning ecosystems as a bottom line. Policy 17 of the RPS states that the Regional Plan should include policies and rules that protect the significant indigenous ecosystems[1] associated with rivers listed in Appendix 1 of the RPS. In order to implement the RPS the regional plans for the Wellington region are currently under review and a draft Natural Resources Plan (dNRP) will be released later in 2014. The dNRP will include numeric objectives or 'outcomes' for a range of river and stream health indicators (referred to as 'attributes' in the planning sense). As a default, numeric outcomes will be set at a level that will support 'healthy functioning ecosystems'. Outcomes representing a higher level of protection to support 'significant indigenous ecosystems' will also be identified for those rivers and streams identified in Table 16 of the RPS. Numeric outcomes must take into account natural variation in rivers and streams in the region.

This report was originally drafted prior to the release of the Regional Plan Working Document for Discussion (WDFD) in September 2013 but was not completed due in part to uncertainty about changes that might be made in response to the release of the National Objectives Framework (NOF) under the National Policy Statement for Freshwater Management (NPS-FM). Although the outcomes recommended in this report differ from the final recommendations for the dNRP documented in Greenfield (2014a), this report presents relevant background analysis and a record of the evolution of outcomes for the dNRP.

Biological indicators used to represent the ecological health of rivers and streams in the Wellington region include:

- Instream macrophytes and periphyton
- Macroinvertebrates
- Native fish

This report identifies attributes and, where sufficient data are available, numeric outcomes for instream periphyton[2] and macrophytes[3]. Selection of attributes and numeric outcomes is based on the analysis of Rivers State of the Environment (RSoE) periphyton and environmental data as well as national guidelines where appropriate. Key supporting environmental variables that will need to be managed in order to achieve instream plant outcomes are also briefly discussed.

1.1 Report outline

The river classification used as the basis for river and stream ecosystem health outcomes is outlined in Section 2 while Sections 3 and 4 provide information

[1] Significant river ecosystems were identified as having high value for general aquatic ecosystems (based on the proportion on indigenous forest or scrub in the upstream catchment or for native fish (based on the number of species recorded in the New Zealand Freshwater Fish Database, the presence of nationally threatened species and/or the presence of inanga spawning habitat) (Warr et al. 2009).

[2] Periphyton is the mixture of algae, cyanobacteria and heterotrophic microbes that covers a river or stream bed.

[3] Macrophytes are aquatic plants which grow in or near the water, often in rivers and streams with soft substrate and/or stable flows.

on RSoE monitoring sites and the methods used for data collection and analysis. Sections 5 and 6 present results of analyses of periphyton community composition and biomass data, respectively and where appropriate recommend numeric outcomes for these attributes. Sections 7 and 8 provide recommended attributes and outcomes for macrophytes and heterotrophic growths, respectively. Section 9 outlines the supporting environmental factors that will need to be managed in order to achieve the recommended outcomes.

2. River classification

As stated by Barbour et al. (1999) the identification of a classification framework to partition natural ecosystem variability is a key first step in the development of biological indicators for ecological assessment. The Freshwater Environments of New Zealand (FENZ) classification has been selected as the classification that best represents natural variability in river and stream ecosystems in the Wellington region (Warr 2009) and has been modified to better suit the region (Warr 2010). Amendments involved amalgamating various 100-level classes to reduce the number of classes to allow their use in a resource management context and spitting of class C6 into three classes to better represent differences within this river type. The amended FENZ classification partitions rivers and streams in the Wellington region into 11 classes (Table 2.1, Figure 2.1) and is used as the basis for selection of periphyton community attributes and numeric outcomes.

Table 2.1: Extent and description of each class in the amended FENZ classification for the Wellington region

GW FENZ class	Stream length (km)	Description
A	3,299	A combination of 100-level classes A4 and A2. These are small streams occurring in inland or coastal locations with very low frequency of days with significant rainfall. Gradients of these streams are very gentle to gentle and substrates are predominantly silty or sandy. Predominant location: Central Wairarapa Valley and Kapiti Coast.
C5	3,076	Small streams occurring in moderately coastal locations with mild, maritime climates and low frequency of days with significant rainfall. Stream gradients are generally moderate and substrates are predominantly coarse gravels. Predominant location: Wellington south coast, eastern Wairarapa coast and western Tararua foothills.
C8	1,869	Small inland streams with mild climates and low frequency of days with significant rainfall. Stream gradients are moderate and substrates are generally coarse gravels. Predominant location: Eastern Wairarapa hill country and northern foothills of Tararua Range.
C7	1,729	Small to medium-sized streams occurring in inland locations with mild climates and low frequency of days with significant rainfall. Stream gradients are generally steep and substrates are generally coarse gravels. Predominant location: Lowland hills of the Tararua, Rimutaka and Aorangi ranges.
C10	924	Small streams occurring in inland locations with cool climates and moderate frequency of days with significant rainfall. Gradients of these streams are generally very steep and substrates are generally cobbly. Predominant locations: Small, mid-elevation streams in the Tararua, Rimutaka and Aorangi ranges
C6a	426	This class is a variant of 100-level class C6 and includes C6 rivers that have an upstream catchment dominated by C7 rivers. These are larger rivers occurring in moderately inland locations with warm climates and low frequency of days with significant rainfall and a predominance of coarse gravelly substrates. Stream gradients are gentle. Predominant location: Lower reaches of larger rivers draining the Tararua Range.
UR	356	A combination of 23 100-level classes that occur entirely within the upper Tararua or Rimutaka ranges.
C1	279	Small coastal streams with mild maritime climates and low frequency of days with significant rainfall. Stream gradients are generally very steep and substrates are predominantly coarse gravels. Predominant location: South Wairarapa coast, Rimutaka Range and Kapiti Island.
C6c	198	A variant of 100-level class C6 and includes C6 rivers that have an upstream catchment dominated by class A and/or C8 rivers and streams. Predominant location: Larger rivers draining eastern Wairarapa hill country and lowland areas of the Kapiti Coast.
C6b	17	A variant of 100-level class C6 and includes C6 rivers that have an upstream catchment dominated by class C5 streams. Location: Horokiri and Pauatahanui streams as well as some stream segments on the eastern Wairarapa coast.
B	3	A combination of 100-level classes B1 and B3 of very limited extent in the Wellington region but has been retained due to the peat-dominated nature of the catchments which is likely to result in unique ecological characteristics. Location: Mangaroa Valley, Lake Wairarapa, Paraparaumu.

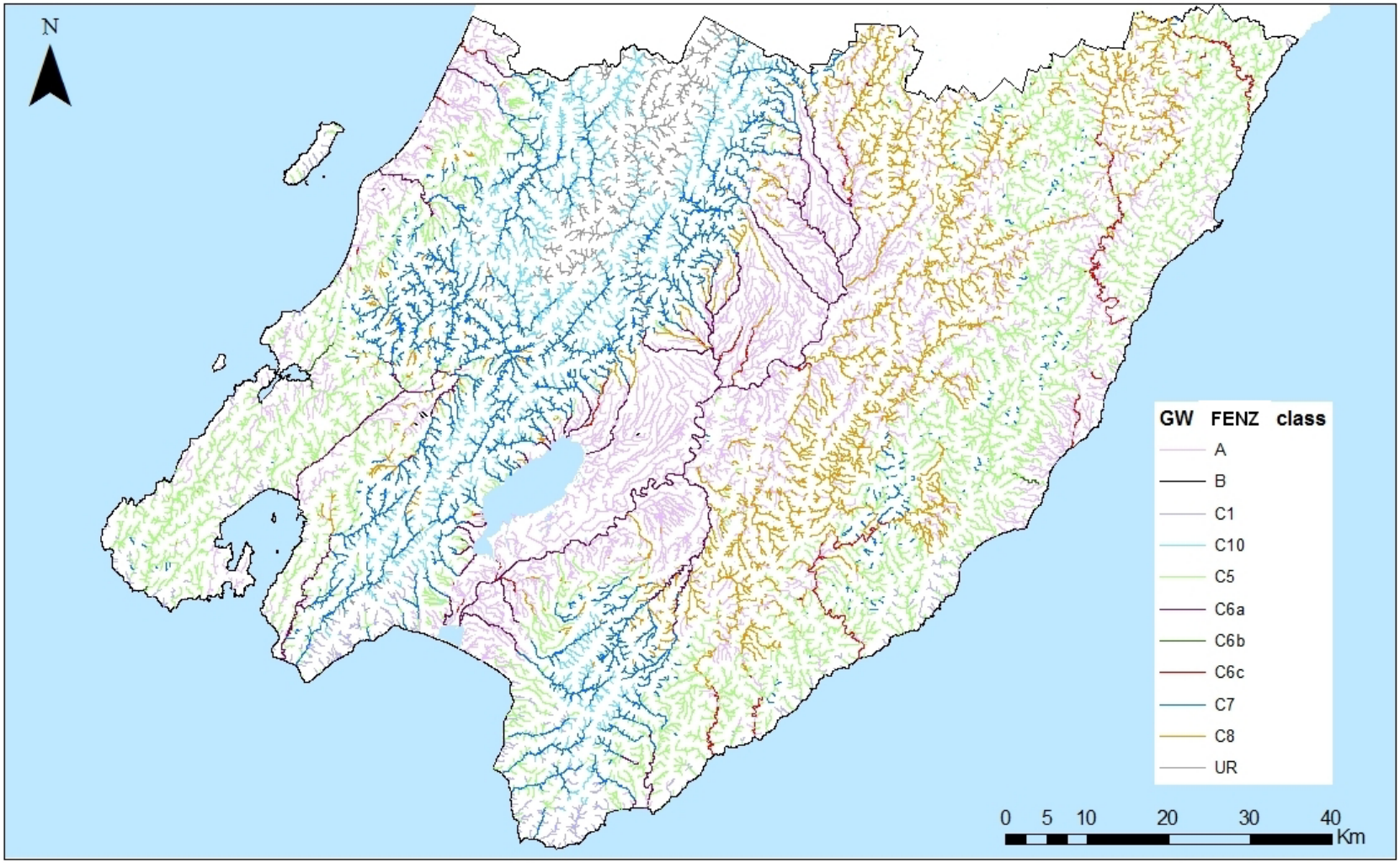


Figure 2.1: Map of the amended FENZ classification for the Wellington region (adapted from Warr 2010)

3. RSoE periphyton monitoring sites and methods

Greater Wellington Regional Council (GWRC) collects periphyton biomass and community composition samples from 46 of its 56 RSoE monitoring sites annually in summer or autumn (Figure 3.1, Appendix 1). Collection of periphyton samples is limited to RSoE sites with predominantly hard substrate.

RSoE periphyton monitoring sites represent 7 of the 11 FENZ classes in the Wellington region. FENZ classes that are not represented are UR, C10, C1 and B (Table 3.1). Each site was assigned one of two impact categories:

- Reference – sites with ≥ 95% indigenous forest and scrub cover in the upstream catchment based on River Environment Classification (REC) raw data (Snelder et al. 2004)

- Non-reference/Impacted – all other sites

Eight of the 46 sites were classed as reference sites, all of which belong to the C7 FENZ class.

Table 3.1: The total number of RSoE periphyton monitoring sites and number of reference sites within each GWRC-modified FENZ class

GWRC FENZ class	Total number of sites	Number of reference sites
A	1	0
C5	11	0
C8	2	0
C7	13	8
C10	0	0
C6a	15	0
UR	0	0
C1	0	0
C6b	1	0
C6c	3	0
B	0	0

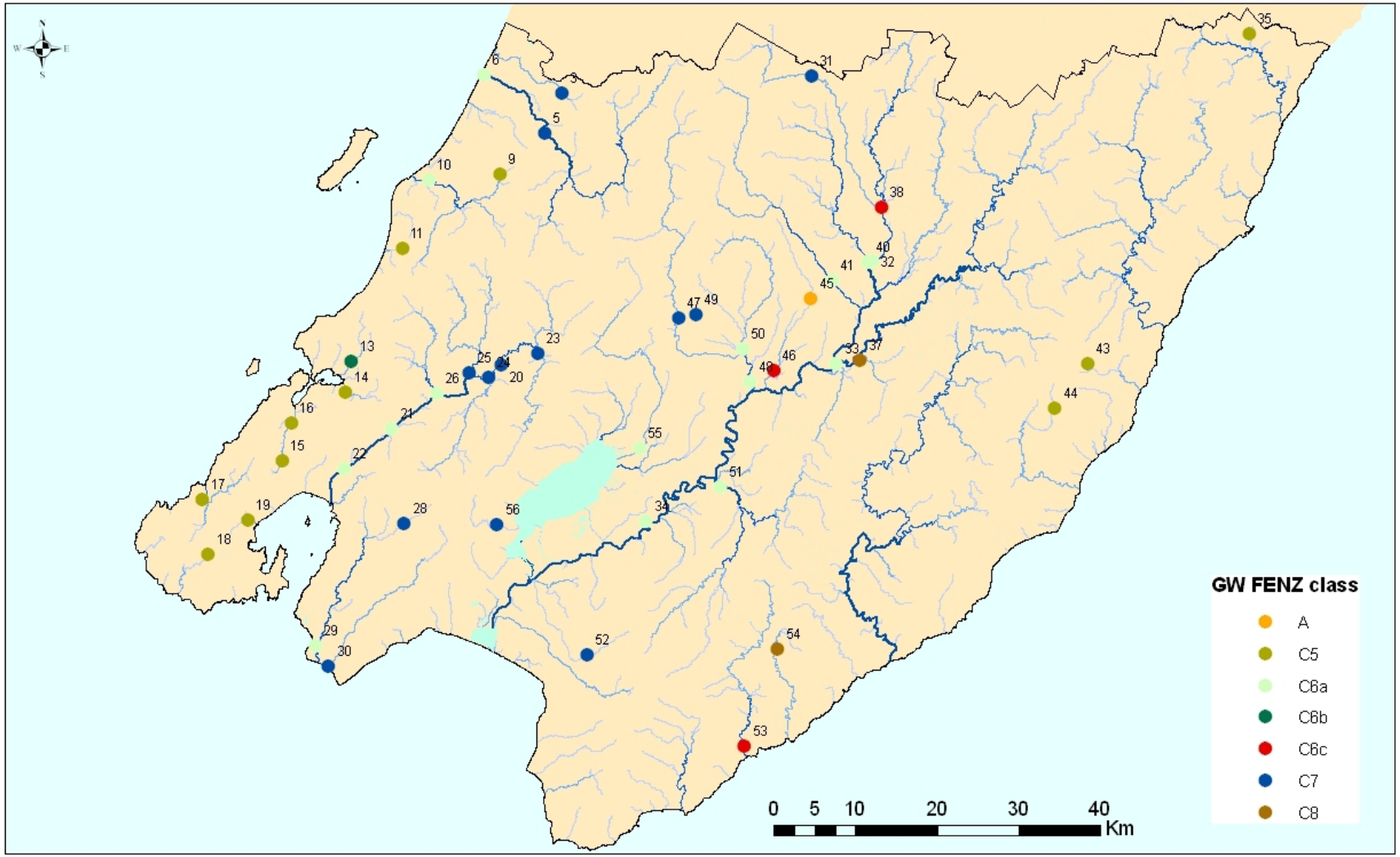


Figure 3.1: Location and GWRC FENZ class of 46 Rivers State of the Environment periphyton monitoring sites in the Wellington region

3.1 Sample collection methods

A single composite periphyton sample is collected from riffle habitat at each site between December and April each year using a modified[4] version of quantitative method 1a (QM-1a) of the Stream Periphyton Monitoring Manual (Biggs & Kilroy 2000). This involves scraping periphyton from the entire surface of 10 rocks collected across a single transect at each site. Rock dimensions are measured and samples are kept chilled in the field and frozen upon return to the office. Where possible, periphyton samples are not collected within two weeks of a flushing flow[5].

Prior to 2007 two periphyton samples were collected from each site for separate analysis of taxonomic composition and periphyton biomass. From 2007 onwards a single sample has been taken from each site and a sub-sample removed from each for assessment of taxonomic composition.

At the same time as periphyton taxonomy and biomass samples are taken, a detailed visual assessment of periphyton cover is carried out in riffle habitat at each site. The assessment involves estimation of periphyton cover across three transects with five views in each transect. Periphyton cover is divided into five categories:

- Thin mats or films (<0.5 mm thick)
- Medium mats (0.5–3 mm thick)
- Thick mats (>3 mm thick)
- Short filaments (<2 cm long)
- Long filaments (>2 cm long)

Results are averaged over the three transects to give a single cover estimate for each periphyton category.

3.2 Periphyton biomass measurement and taxonomic identification methods

Samples are analysed for taxonomic composition using an inverted microscope at magnifications up to 400x, and algal taxa present listed and identified. The relative abundance of each taxon is assessed on a scale of 1 (rare) to 8 (dominant) (Biggs & Kilroy 2000).

Periphyton biomass of each sample is estimated by measurement of chlorophyll *a* concentration and ash-free dry mass (AFDM) using the methods identified in the Stream Periphyton Monitoring Manual (Biggs & Kilroy 2000).

Taxonomic identification of RSoE periphyton samples has been carried out by two laboratories: by the Cawthron Institute (Cawthron) prior to 2007 and by NIWA from 2007 onwards.

[4] Instead of algal material from each of the 10 rocks being analysed separately scrapings from each rock are combined to give a single (composite) sample per site.

[5] A flushing flow is defined as an instantaneous flow greater than three times the median.

A number of differences in taxonomic identification between the two laboratories engaged by GWRC have been identified. They include:

- Different use of the sp. vs spp. nomenclature, eg, algae belonging to the genus *Ankistrodesmus* were identified as Ankistrodesmus *sp*. by Cawthron and as *Ankistrodesmus spp*. by NIWA. This is not an identification problem as such but leads to problems with data analysis. In all such cases records of the two variants were combined to genus level (eg, *Ankistrodesmus)*.

- The level of identification varied between the two labs. For example, Cawthron tended to identify cyanobacteria taxa to genus level while NIWA tended to identify all cyanobacteria as 'algae (blue-green)'. For cyanobacteria in particular it is important that identification be at least to genus level where possible.

Some periphyton taxa were commonly identified by one laboratory but not by the other. For example, *Surirella spp*. were commonly identified by Cawthron but never by NIWA. This is of concern and suggests either inconsistency in identification between the two laboratories or that the different sampling methods used over these two periods resulted in different periphyton taxa being collected.

3.3 Macroinvertebrate and supporting environmental data

Macroinvertebrate samples, water quality measurements/samples and estimates of substrate composition are also collected at the 46 RSoE periphyton monitoring sites (Table 3.1). For each site, the proportion of land cover categories in the upstream catchment using LCDBv2 (MfE 2001) and annual average and annual maximum periphyton accrual periods have been estimated using the methods in Thompson and Gordon (2010).

Table 3.1: Macroinvertebrate and environmental variables used in the analysis of RSoE periphyton data

Variable	Description
Macroinvertebrate Community Index (MCI) scores	MCI scores calculated from samples collected annually at the same time as periphyton sample collection.
Water quality	Median values calculated for water temperature, dissolved oxygen concentration, pH, turbidity, black disc, nitrite-nitrate nitrogen*, total nitrogen, dissolved reactive phosphorus, total phosphorus and total organic carbon measured on a monthly basis at each RSoE site for the period ending in February each year.
DIN:DRP ratio	The annual median summer/autumn (December to May) DIN:DRP ratio calculated for each site.
Substrate composition	Percentage cover of each Wolman substrate class as assessed visually at three points across a single transect on each periphyton sampling occasion.
Land cover	Percentage catchment cover by class from the MfE (2001) Landcover Database (LCDBv2).
Accrual period	Estimated time since the last fresh greater than 3x median flow was estimated for each sample date where sufficient data were available (31 sites). Annual average and average annual maximum accrual periods were estimated for each site (Thompson & Gordon 2010).

*Although dissolved inorganic nitrogen (the sum of nitrite-nitrate nitrogen and ammoniacal nitrogen), which represents all readily available forms of nitrogen, could have been used the vast majority of the dissolved nitrogen in rivers and streams is present as NNN (principally nitrate-nitrogen).

4. Data analysis methods

RSoE periphyton, macroinvertebrate and supporting environmental data collected between 2004 and 2009 were analysed to identify characteristics of the periphyton community and relationships with other variables. Over this period six periphyton and macroinvertebrate samples were collected from each site (apart from sites RS11 and RS54 which were sampled five times). Analyses of relationships between periphyton biomass and Macroinvertebrate Community Index (MCI) score were based on data from annual samples collected between 2004 and 2012 (ie, nine sampling occasions).

4.1 Periphyton community composition

For a number of periphyton taxa identified by both laboratories (see Section 3.2) the identification was uncertain as shown by the use of the cf. term at either genus or species level. For ease of analysis the cf. term was removed from all results and the identification assumed to be correct. Taxa with less than five records across the entire sampling period were removed from the final analysis.

Non-metric multi-dimensional scaling (NMDS) of periphyton taxa relative abundance data from the 46 RSoE sites was used to identify patterns in periphyton community composition in the Wellington region. NMDS maximises rank-order correlation between distance measures and distance in ordination space (allowing for non-linear relationships – as opposed to linear Principal Component Analysis (PCA)). Stress is a measure of the mismatch between the two kinds of distance and values lower than 0.2 are thought to provide meaningful measures in ecological data (Clarke & Warwick 2001). NMDS uses a Bray-Curtis dissimilarity matrix, which was also used in analyses of similarity (ANOSIM) to look for significant differences in community composition between groups of sites (eg, between years, FENZ classes, etc.) and in BEST routines to examine patterns between periphyton community composition and environmental variables.

BEST routines were used to assess the best match between the multivariate patterns in the periphyton community composition data (based on Bray Curtis dissimilarity matrix) and patterns from environmental variables associated with each sample (based on Euclidian distance). The extent to which these two patterns match reflects the degree to which the chosen abiotic data explains the biotic pattern (Clarke & Gorley 2006). BEST considers the correlation between all possible combinations of environmental variables and the similarity matrix for assemblage data. The maximum number of variables was set at the default selection of five. Nitrite–nitrate nitrogen (NNN) was excluded from this analysis, as it was highly correlated with total nitrogen (r=0.99).

Analyses were performed on both the full data set (all sites and sampling occasions) and on averaged data for each site (mean scores for all taxa recorded at a site). For all analyses taxonomic identification was aggregated to genus level[6].

[6] Where a number of species were aggregated to genus level relative abundance scores were simply added together (this may mean that the relative abundance of genera that comprised a number of aggregated spp. may be overstated compared to other genera comprising less).

NMDS, associated hypothesis testing and BEST routines were undertaken using PRIMER version 6.1.13 (Primer-E Ltd, UK).

4.2 Periphyton biomass and cover

Non-parametric Kruskal-Wallis one-way ANOVA was used to assess differences in periphyton biomass (as represented by chlorophyll *a* concentration) across FENZ classes.

As chlorophyll *a* and environmental data often did not conform to assumptions of normality and constant variance even with transformation, parametric statistical tests could not be used to assess relationships between these data. Instead, relationships between variables were examined using regression tree analysis in the data mining software package WEKA 3.6.4 (Bouckaert et al. 2010). This is a non-parametric technique that does not assume any particular structure or distribution in the data (De'ath & Fabricius 2000).

Regression trees explain variation in a single response variable by one or more explanatory variables. The tree is constructed by repeatedly splitting the data, defined by a simple rule based on a single explanatory variable. At each split the data is partitioned into two mutually exclusive groups, each of which maximises homogeneity. The splitting procedure is then applied to each group separately. Each group in the final tree is characterised by a mean value of the response variable, group size and the values of the explanatory variables that define it (De'ath & Fabricius 2000). Chlorophyll *a* results were $\log_{10}$ transformed as it is often desirable to transform the response variable to avoid giving greater weight to data exhibiting more variation (De'ath & Fabricius 2000).

Regression tree analysis was undertaken using function M5P with 10-fold cross validation. Cross validation is a procedure for assessing the performance of a model whereby the data is partitioned into folds and each fold in turn is used for testing while the remainder is used for training (Witten & Frank 2005). In addition to cross validation, the 'prune' and 'smooth' options were selected and the minimum number of instances at each leaf node set to four.

The relationship between the $\log_{10}$ of chlorophyll *a* concentration and MCI score was examined using both linear and quantile regression. Linear regression and the non-parametric ANOVA analyses mentioned above were undertaken using Sigma Plot version 11.0. Quantile regression was undertaken using the R package quantregGrowth. There were insufficient data from FENZ classes A, C6b, C6c and C8 for periphyton biomass and MCI relationships to be assessed individually so data from these classes were combined with other FENZ classes with a similar linear regression slope. Classes C6b and C6c were combined with those from class C6a and data from classes A and C8 were combined with those from class C5. A penalised monotonic model was fitted to the dataset for each grouping of FENZ classes with the value of lambda set using cross validation.

5. Periphyton community composition

A total of 67 periphyton genera were found at the 46 RSoE periphyton monitoring sites between 2004 and 2009. The most widespread were the diatom genera *Nitzchia*, *Cocconeis* and *Gomphonema* which were found at all 46 sites (Appendix 2). Diatom genera were also the most abundant with *Gomphonema*, *Synedra* and *Navicula* recorded as having the highest average relative abundance.

5.1 Annual variation

There were significant differences in periphyton taxonomic composition between each year of sampling (Figure 5.1; ANOSIM: *Global R*=0.374, $p<0.001$). However, the stress value of the NMDS was high, indicating that it is not a meaningful representation of the differences in periphyton community composition between years.

Although the degree of inter-annual differences in periphyton composition is unclear it seems that differences do exist. These could be related to both environmental conditions as well as differences in taxonomic identification. The main environmental factor likely to affect periphyton communities from year to year is the time since the last flushing flow on each sampling date, commonly known as the accrual period. Due to a lack of flow data, accrual periods could only be estimated for each sampling date for 31 of the 46 sites. However, across these sites there were considerable differences in accrual periods for each year of sampling and, for one year (2004[7]), the accrual period was lower at many sites than in other years (Figure 5.2).

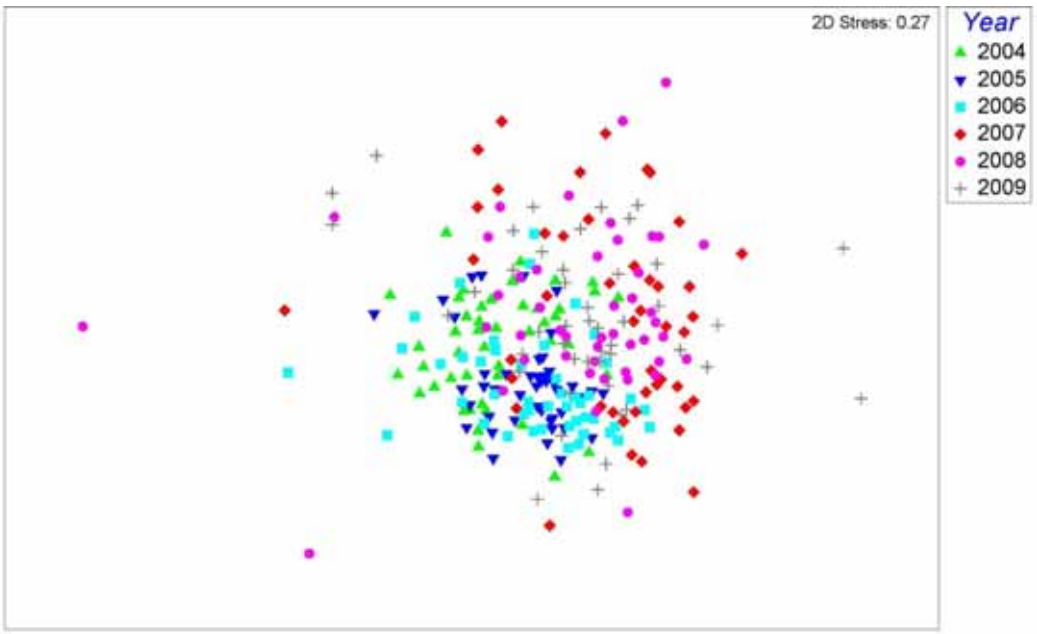


Figure 5.1: MDS ordination of periphyton community composition at 46 RSoE sites sampled annually between 2004 and 2009

[7] 2004 was a very wet year in the Wellington region, with several large floods taking place (Watts 2005).

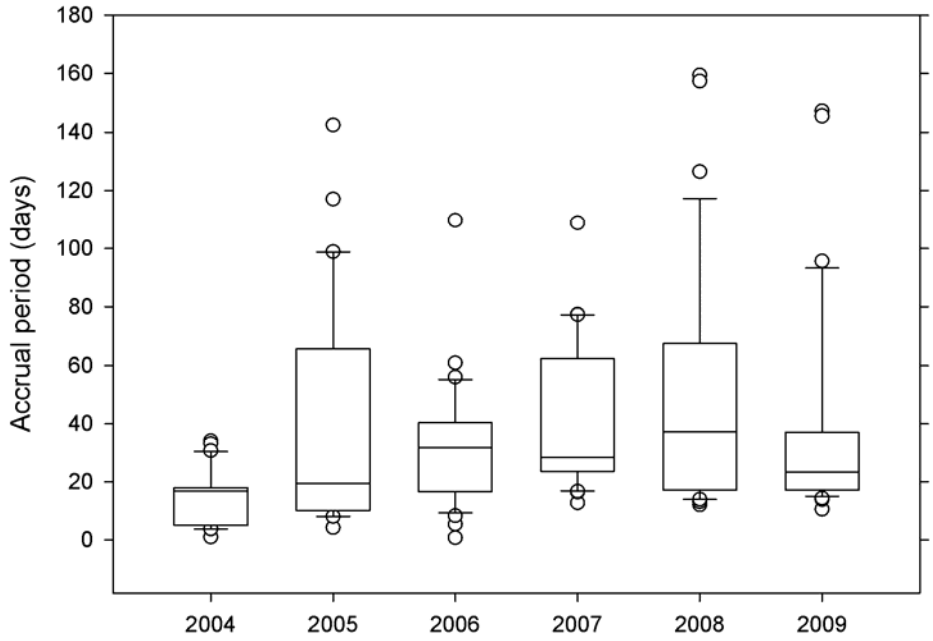


Figure 5.2: Box plots of estimated accrual period (number of days since last fresh of 3 times median flow or greater) at 31 of 46 RSoE monitoring sites on the day of periphyton sampling for each year between 2004 and 2009 inclusive

5.2 Variation between sites and FENZ classes

Periphyton taxonomic composition averaged across all years for each site showed some clustering according to FENZ class (Figure 5.3).

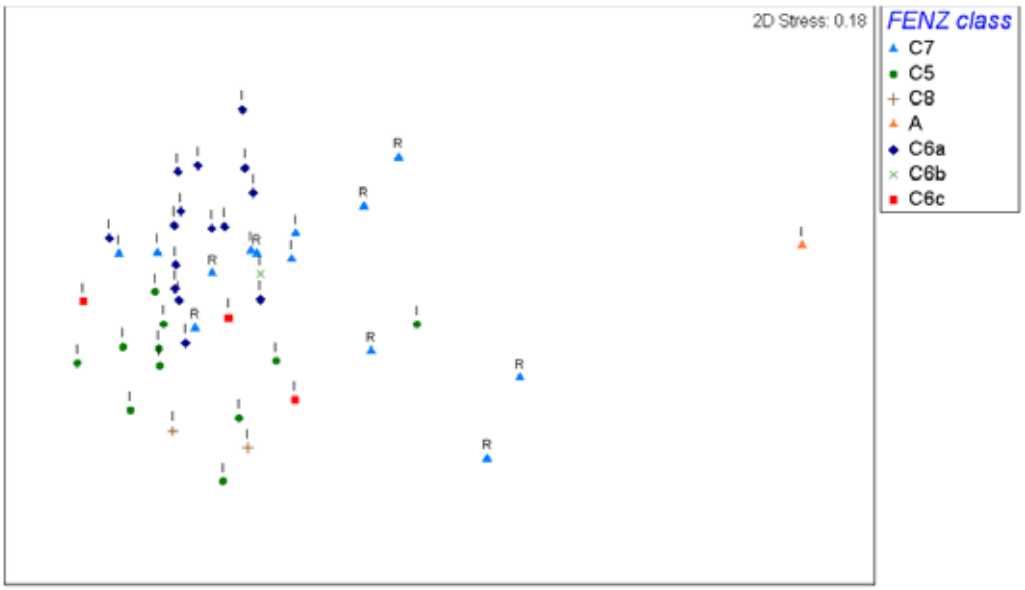


Figure 5.3: Non-metric MDS ordination plot of periphyton community composition at 46 RSoE sites. The result for each site is an average of 6 samples taken between 2004 and 2009 (apart from sites RS11 and RS54 where *n*=5) with results aggregated to genus level or higher. Sites are plotted according to FENZ class. R=reference site, I=impacted

An ANOSIM test showed that overall periphyton community composition differed significantly between FENZ classes (ANOSIM global R=0.389,

p=0.001). These differences are likely to be related to both natural differences across different FENZ classes as well as varying degrees of human impact.

Generally speaking, sites identified as reference sites tended to occur together on the right-hand side of the MDS plot while impacted sites tended to occur on the left-hand side of the plot. An overlaid vector plot showed that 16 periphyton taxa had a strong correlation (Spearman correlation >0.5) with the MDS axes (Figure 5.4).

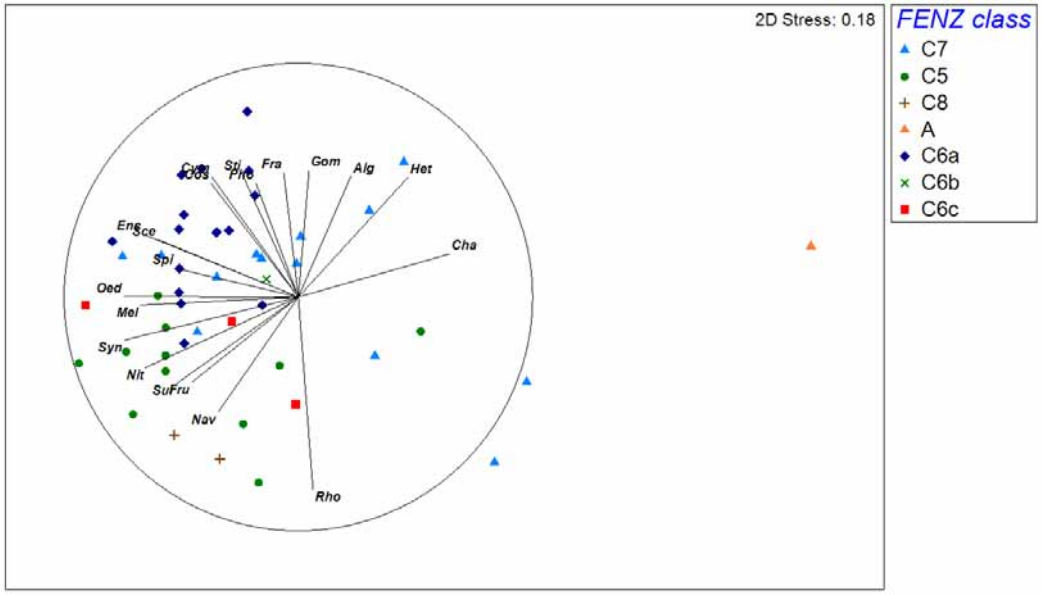


Figure 5.4: MDS ordination plot of periphyton composition at 46 RSoE sites. A vector plot has been overlaid to show periphyton taxa with a strong correlation (Spearman correlation >0.5). Cha=*Chamaesiphon, Rho=Rhoicosphenia, Nav= Navicula, Sur=Surirella, Fru=Frustulia, Nit=Nitzschia, Syn=Synedra, Mel=Melosira,Oed=Oedogonium, Spi= Spirogyra, Sce=Scenedesmus, Enc=Encyonema, Cym=Cymbella, Cos=Cosmarium, Sti=Stigeocloneum, Pho=Phormidum, Fra=Fragilaria, Gom=Gomphonema, Alg=Algae (blue-green), Het=Heteroleibleinia*

Sites on the right hand side of the ordination tended to be reference sites belonging to FENZ class C7 and included the upper-most sites on the Ruamahanga, Waiohine, Hutt, Waitohu and Wainuiomata rivers as well as Beef Creek at Headwaters. These sites were characterised by the presence of the cyanobacteria taxa *Chamaesiphon* and *Heteroleibleinia* and the diatom *Gomphonema*. *Chamaesiphon* and *Heteroleibleinia* tend to occur in clean water streams while *Gomphonema* occurs across a wide range of stream conditions (Biggs & Kilroy 2000). Cyanobacteria taxa identified in the general 'algae (blue-green)' category were also highly correlated with these sites (however, this category was only used by NIWA in samples identified between 2007 and 2009 and is likely to consist of the same *Chamaesiphon* and *Heteroleibleinia* taxa identified by Cawthron between 2004 and 2006). Although not characteristic of this class (ie, they were also present in other classes), the most abundant taxa at C7 reference sites included the diatoms *Rhoicosphenia*, *Gomphonema* and *Navicula*.

Sites belonging to the C6a FENZ class are grouped at the top left-hand of the ordination. These sites were generally on larger rivers draining the Tararua Range and were characterised by the presence of the green algae *Stigeoclonium*, the diatoms *Cymbella* and *Fragilaria,* the desmid *Cosmarium* and the cyanobacterium *Phormidium*. The most abundant taxa in these rivers tended to be *Gomphonema, Stigeoclonium*, *Phormidium* and *Cymbella.*

Sites on the left-hand side of the ordination tended to belong to FENZ class C5. These sites were generally on smaller streams draining hard sedimentary catchments around Wellington City (eg, Karori Stream) and on the eastern Wairarapa coast (eg, Motuwaireka Stream). They were characterised by the green algae *Oedogonium* and *Spirogyra* and the diatoms *Synedra* and *Melosira*.

Sites at the bottom left quarter of the ordination are mostly sites in the eastern Wairarapa hill country belonging to FENZ classes C5, C8 and C6c. These sites tended to be dominated by the diatoms *Navicula, Nitzschia* and *Rhoicosphenia*. The dominance of *Rhoicosphenia* at these sites may be related to their small size and higher flow velocities as *Rhoicosphenia* has been recorded as dominant in these types of streams (Biggs & Kilroy 2000). Sites near the bottom of the Huangarua, Kopuaranga and Taueru rivers are often dominated by the green alga *Cladophora* which is widespread in naturally high conductivity waters around the North Island (Biggs & Kilroy 2000).

The only RSoE site representative of the FENZ A class, Parkvale Stream at Lowes Reserve (RS45), had a very different periphyton community composition to all other sites as shown by its position on the far right of the ordination. This site was dominated by the red alga *Audouinella*. The dominance of *Audouinella* at this site may be related to its spring-fed nature as this taxon is often found in shady lowland rivers with very stable substrate (Biggs & Kilroy 2000).

The diatom *Gomphonema* was dominant at many RSoE sites. Species within this genus have been observed in a range of conditions from clean to nutrient-enriched. Other genera widespread across the RSoE monitoring network are *Navicula*, *Nitzschia*, *Synedra* and *Cymbella*. For periphyton community composition to be a useful indicator of stream condition in the future greater taxonomic resolution and identification certainty will be needed for these ubiquitous genera.

5.3 Relationships with environmental variables

A BEST routine was used to explore which environmental variables best explained patterns in periphyton community composition at RSoE sites. Environmental variables included estimates of catchment land cover, water quality, nutrient ratios, substrate composition and accrual period for each site (refer Table 3.1, Section 3.3).

The five variable solution with the highest correlation to periphyton community data (r=0.463) included total nitrogen, total organic carbon, water temperature, annual average maximum accrual days and percent silt on the stream bed. Water temperature occurred in all ten of the best solutions while annual average maximum accrual days and total nitrogen and occurred in nine

and eight of the ten best solutions, respectively. Annual average maximum accrual days and median water temperature were the two single variables with the strongest correlation with periphyton community composition (r=0.288 and 0.243, respectively).

Overall, patterns in environmental variables for which data were available were only weakly correlated with periphyton community composition. This may be due to lack of taxonomic resolution in the periphyton community data or the absence of data for other important environmental variables such as stream shade.

6. Periphyton biomass

Periphyton biomass is the quantity of organic matter that has accumulated from periphyton production per unit area of stream bed (Biggs 2000) and is represented in RSoE monitoring by measurements of chlorophyll *a* concentration and ash-free dry mass (AFDM). Only chlorophyll *a* data are presented here as the two are highly correlated (r=0.90, p<0.001).

6.1 Periphyton biomass across FENZ classes

There was a significant difference in periphyton biomass across the six FENZ classes represented by RSoE periphyton monitoring sites (Kruskal-Wallis one-way ANOVA, p< 0.01). These differences in biomass are likely to be primarily driven by the varying degree of impact from human activities at the sampling sites rather than natural differences. To check this, estimates of the proportion of natural vegetation cover in the upstream catchment from the FENZ database were collated for each site. These were then compared to median periphyton biomass for each FENZ class (Figure 6.1). Note that there are very few periphyton monitoring sites in classes A, C8, C6c and C6b and results from these sites are indicative only.

Sites belonging to class C7 had the lowest median periphyton biomass (3.8 mg chlorophyll *a*/m^2). Sites in this class tended to have a very high proportion of natural cover in the upstream catchment (median value of 0.98). In contrast, the highest periphyton biomass was found at sites belonging to class C6c (median=69.3 mg chlorophyll *a*/m^2). Sites in this class tended to have a very low proportion of natural catchment vegetation cover (median value of 0.04).

Class C7 is the only FENZ class for which reference site data are available (8 sites). The maximum periphyton biomass recorded across reference sites was 35 mg/m^2 (Tauanui River at Whakatomotomo Road in 2008) while the median was 3 mg/m^2.

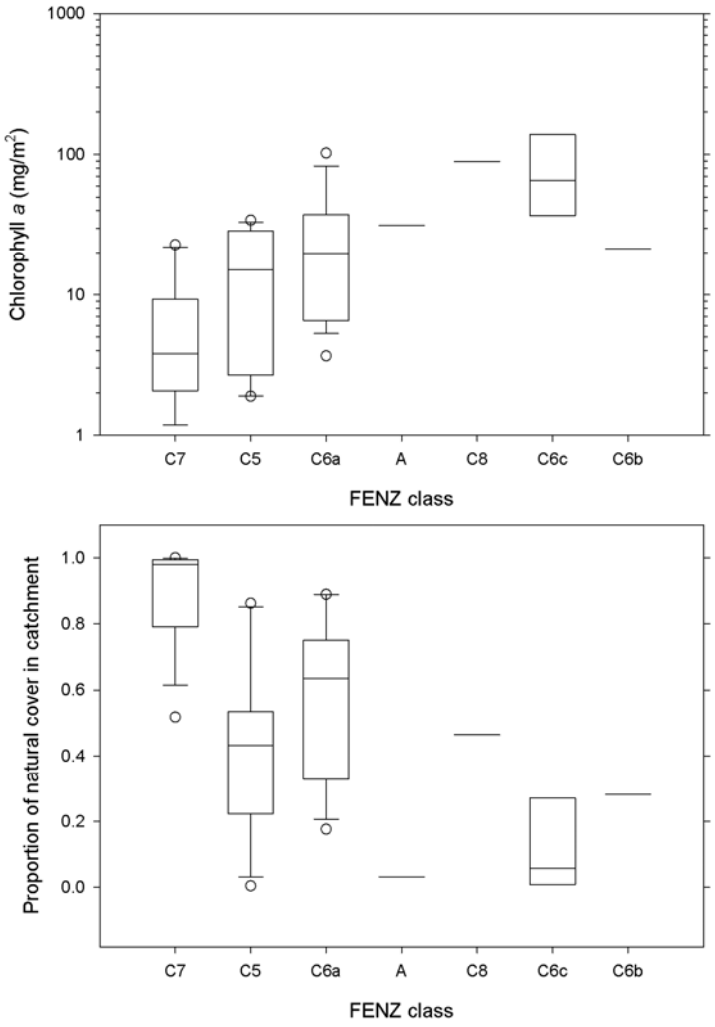


Figure 6.1: Box plots summarising (top) mean chlorophyll *a* concentrations at 46 RSoE monitoring sites from six sampling occasions between 2004 and 2009 and (bottom) the proportion of natural cover in the upstream catchment of each periphyton sampling site. Sites are grouped into FENZ classes, C7 *n*=13, C5 *n*=11, C6a *n*=15, A *n*=1, C8 *n*=2, C6c *n* =3, C6b *n*=1. Note the logarithmic scale of the *y*-axis in the top plot

6.2 Relationship with community composition

Impacted sites in eastern Wairarapa rivers such as Taueru River at Gladstone, Kopuaranga River at Stewarts and Huangarua River at Ponatahi Bridge had the highest mean periphyton biomass (as represented by chlorophyll *a* concentration) (Figure 6.2). In years in which particularly high periphyton biomass occurred at these sites (eg, up to 1,221 mg/m^2 at Kopuaranga and 692 mg/m^2 at Taueru in 2008) the dominant periphyton taxon tended to be *Cladophora*.

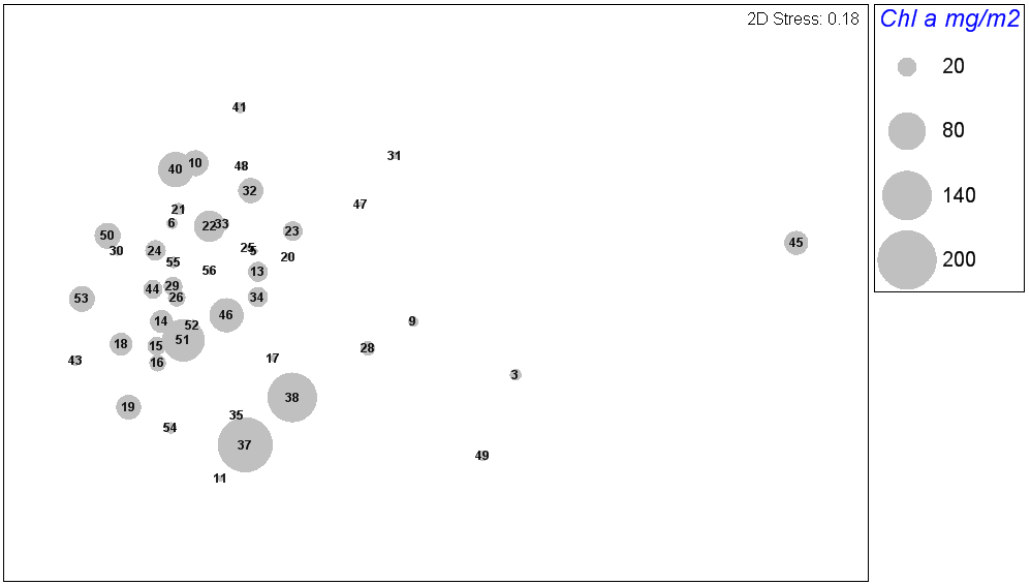


Figure 6.2: MDS ordination of periphyton community composition at 46 RSoE monitoring sites with mean periphyton biomass (as represented by mg/m^2 of chlorophyll *a*) represented by the size of the bubbles and calculated from six samples collected annually between 2004 and 2009

Other sites where high mean periphyton biomass occurred included some of the class C6a rivers such as the Waikanae River at Greenaway Road (149 mg/m^2 in 2007), Hutt River at Boulcott (163 mg/m^2 in 2006), Ruamahanga River at Te Ore Ore (67 mg/m^2 in 2005) and Waipoua River at Colombo Road (179 mg/m^2 in 2006). At all of these sites *Phormidium* or *Heteroleibleinia* cyanobacteria were the dominant periphyton taxon during years of high periphyton biomass.

High periphyton biomass was also regularly recorded at the Parkvale Stream at Weir (eg, 304 mg/m^2 in 2009). During years of high biomass this site was dominated by the green alga *Spirogyra*.

6.3 Relationship with periphyton cover

Periphyton biomass measurements are closely linked to aquatic ecosystem health (Biggs 2000) but because of the time and expense involved in sample collection measurements are currently made only once per year at each site. This means that in any one year the maximum periphyton biomass is unlikely to be captured despite the annual sampling targeting the summer/autumn period (when periphyton growth tends to be greatest).

The relationship between periphyton biomass and periphyton cover was investigated to assess whether visual estimates of periphyton cover could be used to estimate periphyton biomass. If periphyton biomass can be estimated from visual estimates of periphyton cover with reasonable confidence, data from monthly visual cover assessments could be used to obtain a more frequent estimate of periphyton biomass at RSoE sites.

The relationship between periphyton biomass and cover data was assessed by examining periphyton data collected at the 46 hard-bottomed RSoE sites[8] between 2005 (2004 periphyton cover data were not available) and 2009. These data were analysed using regression tree analysis in WEKA 3.6.4 with 10% cross validation. A two-leaved model tree was produced, each with its own linear model (LM) (Table 6.1).

Table 6.1: Equations of linear models produced for each of the two leaves of the model tree analysis of the relationship between periphyton chlorophyll *a* concentration and periphyton cover data from each of six annual sampling occasions between 2004 and 2009 at 46 RSoE sites

Linear model	Equation
LM1 (long filamentous algae ≤ 0.5%)	Log_{10} chlorophyll *a* = 0.0057 * thin mat or film + 0.0196 * medium mat + 0.0285 * thick mat + 0.0313 * short filaments + 0.002 * long filaments + 0.1349
LM2 (long filamentous algae >0.5%)	Log_{10} chlorophyll *a* = 0.001 * thin mat or film + 0.003 * medium mat + 0.0041 * thick mat + 0.0037 * short filaments + 0.0106 * long filaments + 1.1604

Overall the model had an r^2 value of 0.46 suggesting that there is a moderately strong relationship between visual assessment of periphyton cover and periphyton biomass. However, this relationship is not considered to be strong enough to be used to estimate periphyton biomass at RSoE sites.

Kilroy et al. (2010) found that multiple regression analysis of data from the Manawatu-Wanganui region yielded a highly significant model for predicting chlorophyll *a* concentration from visual assessment of periphyton cover. Although there was considerable uncertainty in the predictions it was considered that precise relationships were not essential as the estimates were to be used to assess compliance with proposed One Plan periphyton biomass standards. Thus, rather than an exact prediction of periphyton biomass at each site, the range of levels of percentage cover of different algal types that correspond to periphyton biomass standards was all that was needed.

It is recommended that the same periphyton cover categories as those used in the Manawatu-Wanganui region[9] be used for annual cover assessments undertaken at RSoE sites when periphyton biomass samples are collected. Also in accordance with the Manawatu/Wanganui method it is recommended that the number of transects over which visual estimates are carried out be increased from three to five with four observations being carried out across each. These data could be then be used to assess whether the periphyton cover/biomass model identified for the Manawatu-Wanganui region could be used in the Wellington region. If this is the case, visual estimates of periphyton cover undertaken each month during water quality sampling runs could be used to estimate periphyton biomass on monthly basis.

[8] Periphyton cover assessments were not available for sites RS32 and RS52 in 2005, sites RS35, RS37, RS51, RS52, RS53 and RS54 in 2006, site RS18 in 2008 and site RS50 in 2009.

[9] The model developed for the Manawatu-Wanganui region was based on slightly different periphyton cover categories to those currently used in the Wellington region: fine films, slimy/sludgy coatings, cohesive mats, fine green filaments and long coarse filaments.

6.4 Relationship with environmental factors

Chlorophyll *a* results from six annual samples taken at each of the 46 sites between 2004 and 2009 were compared to median results for each water quality variable for that same (hydrological) year, substrate composition data taken at the time of periphyton sampling and annual average and average annual maximum accrual period estimates for each site (Figure 6.3).

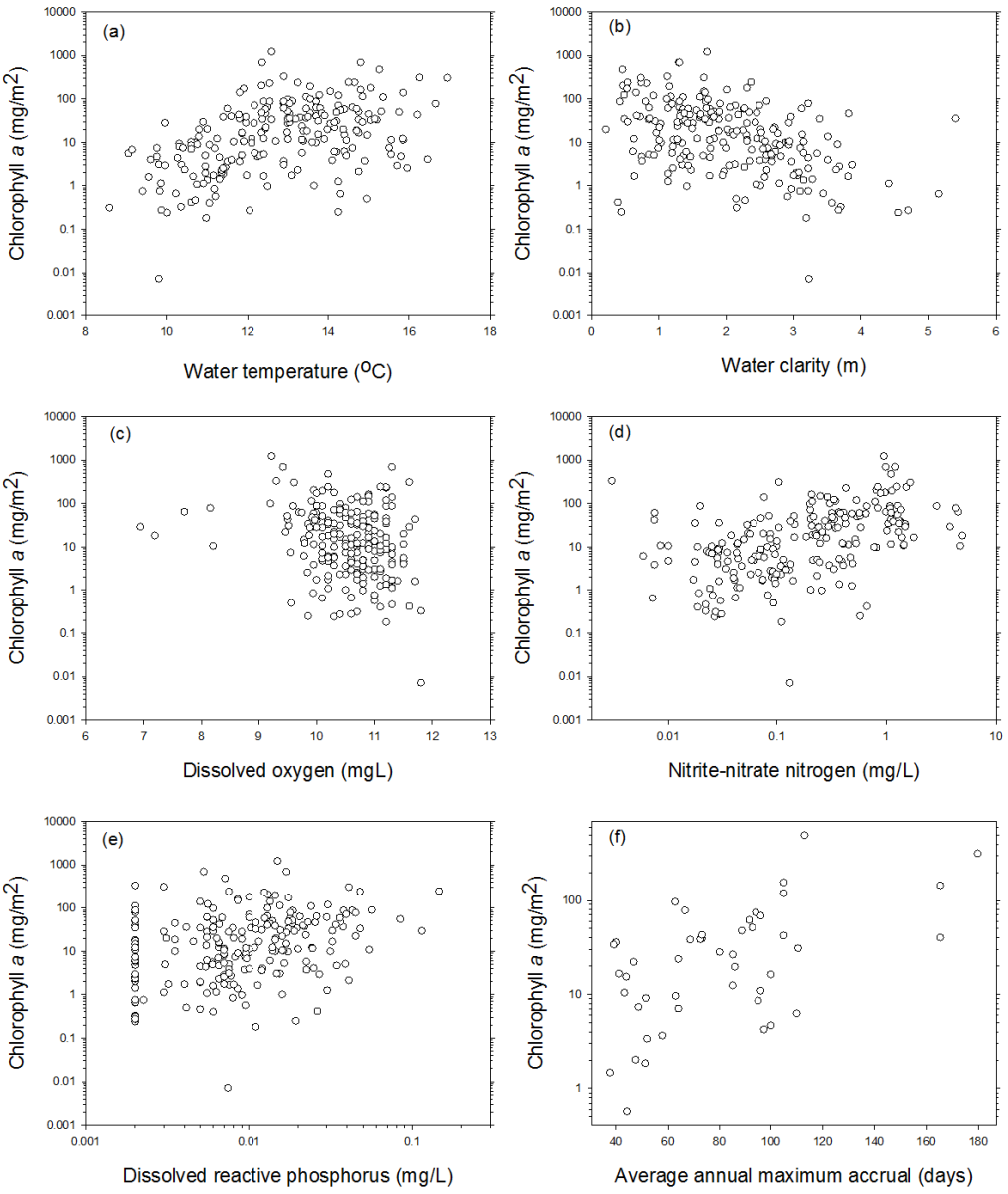


Figure 6.3: Scatter plots of chlorophyll *a* concentration against annual median (a) water temperature, (b) water clarity, (c) dissolved oxygen, (d) nitrate-nitrite nitrogen, (e) dissolved reactive phosphorus, and (f) average annual maximum accrual, measured at 46 RSoE monitoring sites between 2004 and 2009. Note the logarithmic scales on the *y*-axes and some of the *x*-axes

Regression tree analysis undertaken to assess the relationship between chlorophyll *a* concentration and environmental variables produced a tree with four 'leaves', each with its own linear model (LM) (Table 6.2, Figure 6.4).

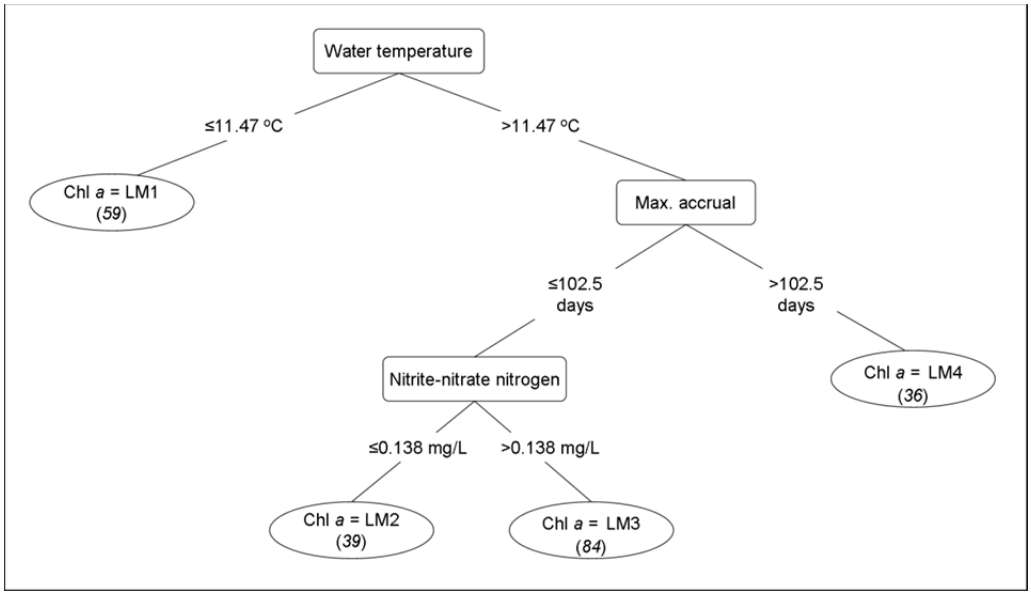


Figure 6.4: Regression tree representing periphyton chlorophyll *a* concentration (mg/m^2) as predicted by measured environmental variables. Each of the three splits (non-terminal nodes) is labelled with the variable and its values that determine the split. Each of the four leaves (terminal nodes) is labelled with the number of the linear model (LM) produced and the number of observations (italicised in brackets)

Table 6.2: Equations of linear models produced for each of the four leaves of the regression tree analysis of the relationship between periphyton chlorophyll *a* concentration and measured environmental variables

Linear model	Equation
LM1	Log_{10} chlorophyll *a* = 0.026 * Water Temperature- 0.2056 * Turbidity- 0.3589 * water clarity - 28.3444 * Dissolved Reactive Phosphorus + 42.4161 * Total Phosphorus + 0.0121 * Mean accrual + 0.0056 * max. accrual + 0.4498
LM2	Log_{10} chlorophyll *a* = 0.0111 * Water Temperature - 0.0066 * Turbidity- 0.0399 * water clarity + 0.0947 * Nitrite-Nitrate Nitrogen + 0.9208 * Dissolved Reactive Phosphorus - 0.0086 * Mean accrual + 0.0051 * max. accrual + 0.0007 * Median low flow DIN:DRP + 0.6709
LM3	Log_{10} chlorophyll *a* = 0.0111 * Water Temperature - 0.1372 * Dissolved Oxygen - 0.0789 * Turbidity - 0.0399 * Black Disc + 0.2308 * Nitrite-Nitrate Nitrogen + 0.9208 * Dissolved Reactive Phosphorus - 0.0111 * Mean accrual + 0.0051 * max. accrual + 0.0004 * Median low flow DIN:DRP + 2.6422
LM4	Log_{10} chlorophyll *a* = 0.0111 * Water Temperature- 0.0118 * Turbidity - 0.3334 * Black Disc + 1.7414 * Dissolved Reactive Phosphorus - 0.0269 * Mean accrual + 0.0096 * max. accrual + 1.9132

Environmental variables used to predict chlorophyll *a* concentrations in all four linear models identified were water temperature, water clarity, turbidity, dissolved reactive phosphorus, and average and maximum annual accrual periods. Total phosphorus was used in LM1 while nitrite-nitrate nitrogen and the median low flow DIN:DRP ratio was used in models LM2 and LM3. Dissolved oxygen concentration was also used in LM3.

Samples in the LM1 leaf were predominantly from C7 reference sites in the upper reaches of the Ruamahanga, Waiohine, Otaki, Hutt, Wainuiomata and Waitohu rivers as well as Beef Creek. Also in this leaf were some samples from shaded non-reference sites such as Motuwaireka Stream at Headwaters, Whareroa Stream at Waterfall Road and a tributary of the Mataikona Stream at Sugar Loaf Road. These sites almost always had very low periphyton biomass.

Samples in the LM2 leaf tended to be from class C6a sites in the lower reaches of larger rivers such as the Otaki, Orongorongo, Tauherenikau, Waingawa and Waiorongomai rivers. All samples from the Totara Stream at Stonvar site also fell within this leaf. Periphyton biomass at these sites tended to be low to moderate.

Samples in LM3 were from a wide range of sites. Sites with all samples within this leaf were Mangatarere Stream at SH2, Ruamahanga River at Gladstone, Ruamahanga River at Pukio, Waipoua River at Colombo Road, Waiohine River at Bicknells, Hutt River at Manor Park, Hutt River at Boulcott, Mangaroa River at Te Marua, Pauatahanui Stream at Elmwood and Porirua Stream at Glenside. Sites with the most samples within this leaf were urban Wellington sites, Makara Stream at Kennels and Wainuiomata River at White Bridge. These sites tended to have moderate to high periphyton biomass.

The majority of the 36 samples that fell under the LM4 leaf were from FENZ class C6c or A sites in eastern Wairarapa or the central Wairarapa Valley. All samples from the Horokiri Stream at Snodgrass were also within this leaf. Most of these sites have high to very high periphyton biomass.

Overall the regression tree had an r^2 value of 0.37 and a root mean squared error of 0.65. This means that the model produced by the regression tree analysis explains 37% of the variation in chlorophyll *a* concentration but that there is considerable uncertainty in its predictions of periphyton biomass based on environmental variables.

Although the model produced by the regression tree analysis explains only a low to moderate amount of the variation in chlorophyll *a* concentration it provides some strong suggestions as to the environmental drivers of periphyton growth and biomass at RSoE sites. The model suggests that water temperature, water clarity, dissolved nutrient concentrations and accrual period may all affect periphyton biomass – with different relationships between these variables and periphyton biomass depending on water temperature, maximum accrual period and nitrogen concentration. However, it is important to remember that although these environmental variables are correlated with periphyton biomass this does not imply causation.

The regression tree analysis suggests that sites with low median water temperatures will almost always support low periphyton biomass while those with higher temperatures can still support low periphyton biomass as long as accrual periods are not too long and nutrient concentrations remain low. Sites with higher water temperatures but a shorter accrual period are likely to have higher periphyton biomass if nutrient concentrations are high. Sites with high

water temperatures and long accrual periods will often have high periphyton biomass even in the absence of high nutrient concentrations.

Water temperature, nutrient concentrations and accrual period/flushing flow frequency are widely recognised as key factors affecting periphyton growth (Biggs 2000, Matheson et al. 2012). Other factors identified in the literature include light availability, invertebrate grazing, baseflow velocity and substrate size. Substrate size data were included in this analysis but were not identified as being correlated with periphyton biomass. Of the other factors light availability is probably the most important. However, no data for this variable were available for RSoE sites.

It is recommended that estimates of light availability are calculated for the 46 RSoE sites at the same time as periphyton biomass samples are collected using the method recommended by Matheson et al. (2012). This method uses measurements of black disc, water absorption co-efficient, incident radiation (available from climate stations), water depth and riparian shade to estimate light availability at the stream bed. It is also recommended that statistics for water temperature, nutrient concentrations and other water quality variables are calculated using summer-time data rather than year-round data as a stronger model of the relationship between environmental factors and periphyton biomass may result. This region-specific model could then be used in the selection of outcomes for environmental variables such as nutrient concentrations and instream temperature.

6.5 Relationship with macroinvertebrate health

In addition to being a key indicator of periphyton community health, periphyton biomass also affects other indicators of stream health, in particular macroinvertebrate community composition.

Nine paired measurements of log10 chlorophyll *a* concentration and MCI score at each of the 46 RSoE sites showed a significant (R^2=0.43, p<0.001) linear relationship (Figure 6.5). Although there is a large amount of scatter in the data, this analysis indicates that streams with low periphyton biomass tend to support the highest MCI scores and vice versa. Streams with low periphyton biomass tend to be dominated by sensitive collector/browser stoneflies, mayflies and caddisflies, whereas streams with high algal biomass tend to be dominated by more tolerant filter-feeding caddisflies, snails, collector browser beetles and oligochaete worms (Biggs 2000).

Quantile regression was used to examine whether relationships between periphyton biomass and macroinvertebrate health could be used to identify numeric outcomes for periphyton biomass that correspond to macroinvertebrate outcomes for each FENZ class identified in Greenfield (2014b) (Figures 6.6 & 6.7).

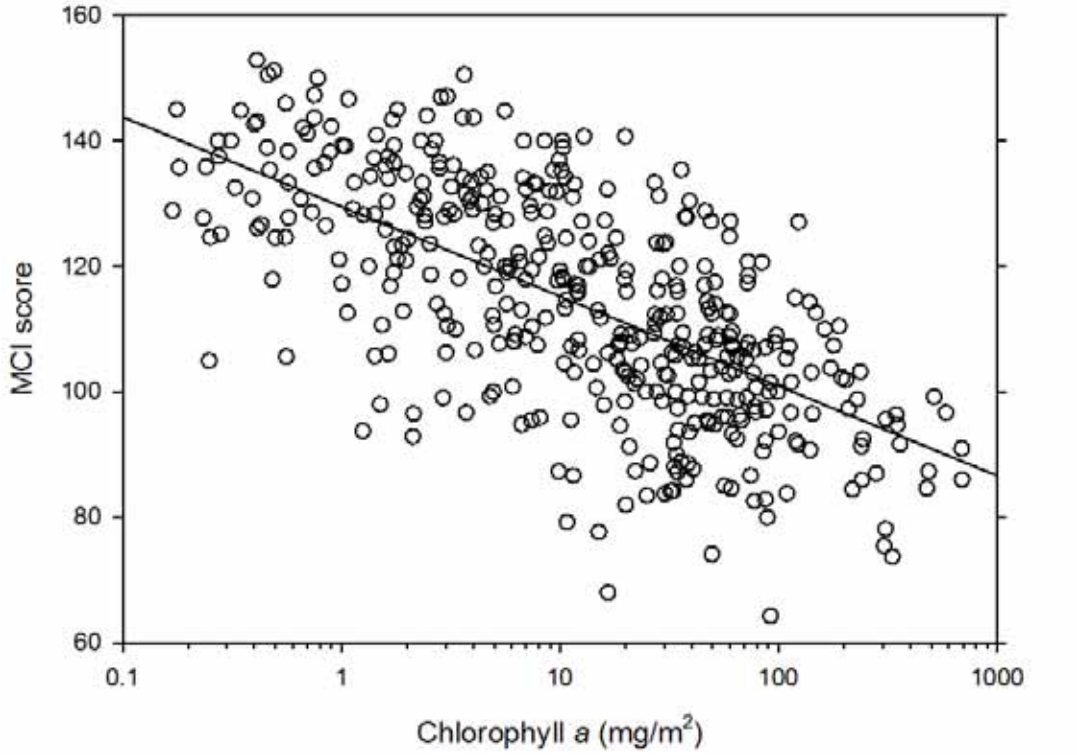


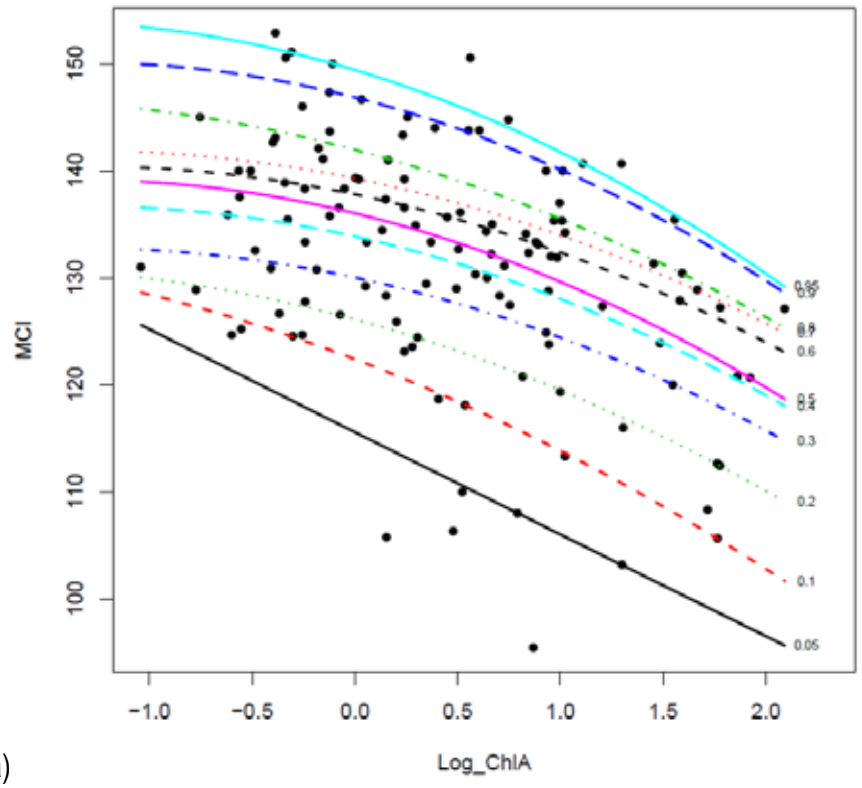
Figure 6.5: The relationship between paired measurements of chlorophyll *a* concentration and MCI score at 46 RSoE sites on each of 9 sampling occasions between 2004 and 2012. Note the logarithmic scale of the *x*-axis

The periphyton biomass corresponding to MCI outcomes for 'significant aquatic ecosystems' and 'healthy aquatic ecosystems' was identified for each FENZ class using the 90th quantile relationship (Table 6.3). An upper quantile was used as these are considered to be more appropriate for the identification of thresholds than traditional central tendency regression (Matheson et al. 2012).

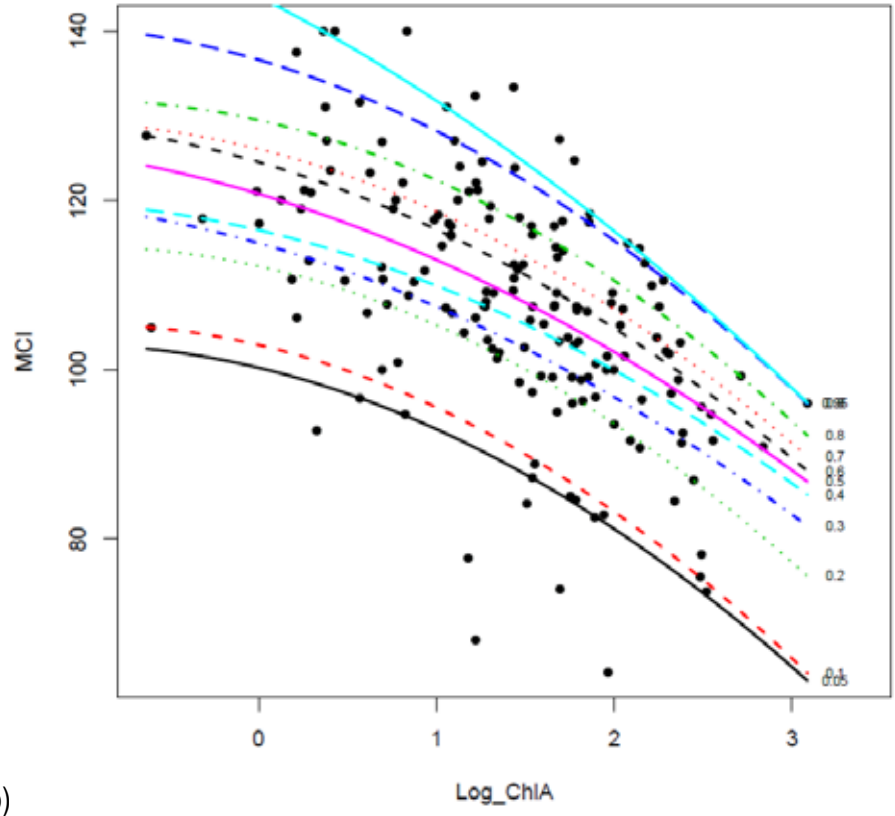
There were insufficient data to identify a periphyton biomass threshold that corresponds to the 'healthy aquatic ecosystem' MCI outcome for FENZ class C7. Similarly, thresholds identified for classes C6c, C8 and A are not shown as there are insufficient data from these classes to identify robust thresholds.

Table 6.3: Chlorophyll *a* concentration corresponding to MCI outcomes identified in Greenfield (2014) for 'healthy' and 'significant' aquatic ecosystems using the 90th quantile of the relationship between MCI scores and periphyton biomass from annual paired measurements at 46 RSoE sites sampled between 2004 and 2012

FENZ class	Significant aquatic ecosystem		Healthy aquatic ecosystem	
	MCI	Chl *a* (mg/m^2)	MCI	Chl *a* (mg/m^2)
C7	135	25	120	–
C6a	130	5	115	100
C5	130	5	105	100



(a)



(b)

Figure 6.6: Quantile regression relationships between log-transformed chlorophyll *a* concentration and MCI score for samples collected on nine sampling occasions between 2004 and 2012 at RSoE sites in
(a) FENZ class C7 (*n*=13), and
(b) FENZ classes C6a, C6b and C6c (*n*=19)

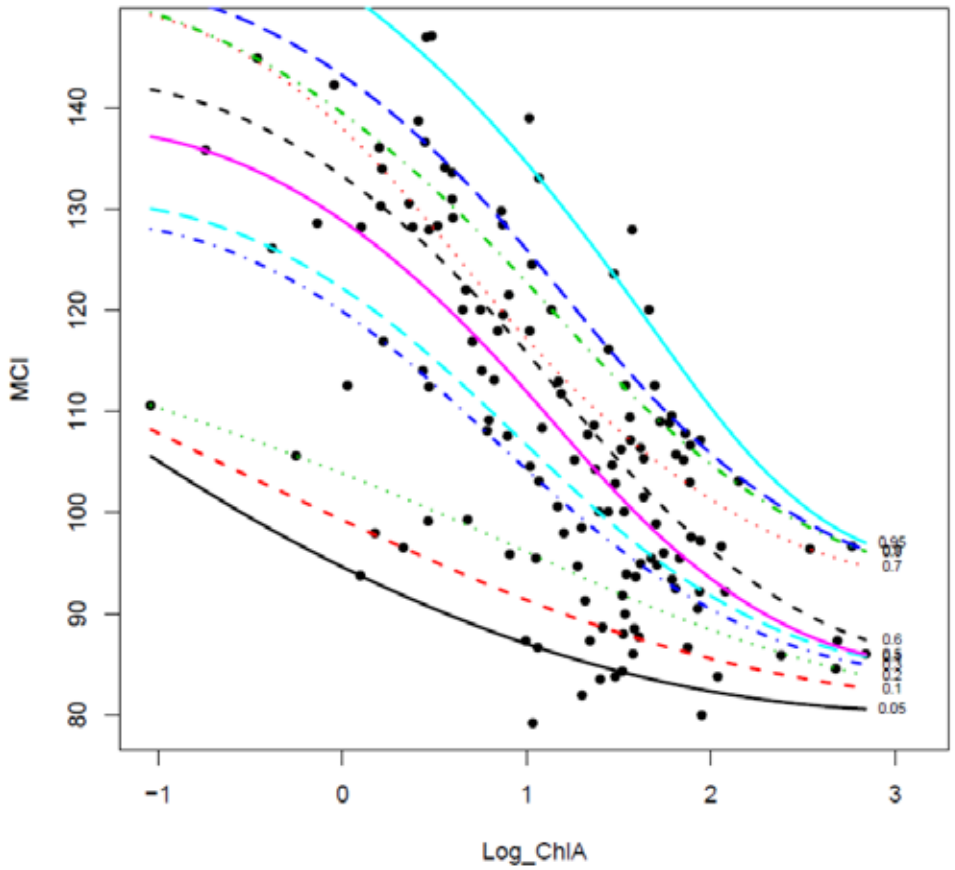


Figure 6.7: Quantile regression relationships between log-transformed chlorophyll *a* concentration and MCI score for samples collected on nine sampling occasions between 2004 and 2012 at RSoE sites in FENZ classes C5, C8 and A (*n*=14)

Despite higher MCI score outcomes for class C6a than for class C5, periphyton biomass thresholds identified for these classes were the same due to the greater slope of the relationship for class C5 than C6a. Similarly despite a higher MCI outcome, the 'significant' periphyton biomass threshold identified for class C7 was higher than for classes C6a and C5. The increased slope of the relationship between periphyton biomass and MCI scores for class C5 compared with classes C6a and C7 may be a reflection of the periphyton community composition typically found at sites in these river classes.

The 'significant aquatic ecosystem' threshold identified for classes C6a and C5 is very low and is likely to be within the margin of error of the method used for measuring periphyton biomass.

Although a useful starting point, further work is needed before periphyton biomass thresholds identified using quantile regression can be used as outcomes in GWRC's Regional Plan. More data collection may also be needed in FENZ classes which are currently under-represented.

7. Recommended periphyton attributes and outcomes

At this stage it is not recommended that an attribute relating to periphyton species composition is used in the dNRP. Although there is much potential for use of periphyton species composition data as an indicator of river and stream health in New Zealand (Biggs 2000), these methods are currently insufficiently developed to use in the regional planning process.

In contrast, periphyton biomass is widely used as a river health indicator and the analyses presented in this section as well as results from other studies suggest that periphyton biomass varies depending on a number of environmental variables, including flood frequency and dissolved nutrient concentrations. It is also correlated with macroinvertebrate community health. As such, it is recommended that periphyton biomass be used as an attribute in the dNRP.

Until further work can be undertaken to identify appropriate thresholds using quantile regression it is recommended that periphyton biomass outcomes to represent 'significant aquatic ecosystem' and 'healthy aquatic ecosystem' boundaries for each FENZ class be based on the trophic state boundaries identified in the New Zealand Periphyton Guideline (Biggs 2000).

Biggs (2000) estimates that the boundary between oligotrophic (low nutrient status) and mesotrophic (moderate nutrient status) conditions is represented by mean monthly and annual maximum chlorophyll *a* concentrations of 15 and 50 mg/m^2, respectively. An annual maximum of 200 mg/m^2 is estimated to represent the boundary between mesotrophic and eutrophic conditions.

An additional chlorophyll *a* threshold of 120 mg/m^2 has been used by Environment Canterbury (Hayward et al. 2009) and Horizons Regional Council (Ausseil & Clark 2007). This threshold is identified in Biggs (2000) as protecting trout habitat and angling values in rivers dominated by filamentous algae. However, it has also been used to represent a state of enrichment that is intermediate between the oligotrophic/mesotrophic and mesotrophic/eutrophic (high nutrient status) thresholds.

Interim periphyton biomass outcomes for FENZ classes not represented in the RSoE periphyton monitoring site network should be set to those of the most geographically similar class.

7.1 Classes C7, C10 and UR

Rivers and streams in these classes are located in the upper Tararua, Rimutaka and Aorangi ranges and are subject to short accrual periods and naturally low nutrient concentrations. As such these rivers and streams are likely to support only low periphyton biomass in their natural state.

A maximum annual chlorophyll *a* concentration of 50 mg/m^2 is recommended as the interim outcome for both 'significant aquatic ecosystem' and 'healthy aquatic ecosystem' levels of protection for these FENZ classes (Table 7.1).

Table 7.1: Recommended annual maximum chlorophyll *a* outcomes for "significant aquatic ecosystem" and "healthy aquatic ecosystem" levels of protection for FENZ classes in the Wellington region

FENZ class	Significant aquatic ecosystem outcome (Chl. *a* mg/m^2)	Healthy aquatic ecosystem outcome (Chl. *a* mg/m^2)
C7, C10 and UR	50	50
C5, C6a, C6b and C1	50	120
C8, A, C6c and B	120	200

7.2 Classes C5, C6a, C6b and C1

Rivers and streams in these classes have moderate accrual periods and occur at lower altitude and, as such, are likely to support naturally higher periphyton biomass than rivers in classes C7, C10 and UR.

It is recommended that maximum annual chlorophyll *a* concentrations of 50 and 120 mg/m^2 be used as the interim outcomes for 'significant' and 'healthy' aquatic ecosystems in these classes, respectively (Table 7.1). The 'healthy' aquatic ecosystem outcome is of the same order as the 100 mg/m^2 threshold derived for the C5 class using quantile regression.

7.3 Classes C8, A, C6c and B

Rivers and streams in these classes generally have long accrual periods and occur at low altitude. As such, they are likely to support moderate periphyton biomass even under natural conditions.

The outcomes for 'significant aquatic ecosystems' and 'healthy aquatic ecosystems' in these classes are recommended as maximum annual chlorophyll *a* concentrations of 120 and 200 mg/m^2, respectively (Table 7.1).

The thresholds set out in Biggs (2000) are an annual maximum periphyton biomass. As assessment of periphyton biomass is currently only made once per year it is unlikely that the maximum periphyton biomass at RSoE sites is adequately captured. As discussed in Section 6.3, it is recommended that the relationship between periphyton biomass and visual assessment of periphyton cover be investigated to assess whether monthly assessments of periphyton cover can be used to estimate periphyton biomass.

8. Macrophytes

Although macrophytes are often present in soft bottomed rivers and streams in the Wellington region they have only recently been included in the RSoE programme (monthly assessments of macrophyte cover began in August 2011). Current assessment methods follow those recommended in Matheson et al. (2012).

As with periphyton communities in hard bottomed streams, macrophytes are a natural component of soft bottomed rivers and streams. However, abundant plant growth can have adverse effects on aquatic ecosystem health. Macrophyte community composition and biomass are likely to be affected by a range of environmental factors. These include light availability, flood frequency, flow velocity, sediment nutrient concentrations, substrate and colonist availability (Matheson et al. 2012). It is recommended that one or more attributes relating to macrophytes be included in the dNRP.

8.1 Recommended macrophyte attributes and outcomes

There are currently insufficient data upon which to base region-specific numeric outcomes for macrophyte indicators. A recent review of the New Zealand instream plant and nutrient guidelines (Matheson et al. 2012) recommended a provisional guideline for macrophyte abundance of $\leq 50\%$ of stream cross-sectional area or volume. However, it is not recommended that this guideline be used in GWRC's Regional Plan until there are sufficient macrophyte abundance data to assess its applicability to the Wellington region.

9. Heterotrophic growths

Heterotrophic growths are assemblages of heterotrophic bacteria and fungi attached to the substrate, and are commonly called "sewage fungus" when they become abundant enough to be visible as mats or plumose growths. The presence of abundant sewage fungus growths can adversely affect ecological (as well as aesthetic and recreational) values.

9.1 Recommended heterotrophic growth attributes and outcomes

Significant sewage fungus growths generally only occur downstream of significant inputs of dissolved organic matter caused by poorly treated point-source discharges (eg, wastewater outfalls). It is thus recommended that any outcome relating to sewage fungus growths is used as a standard, which should apply at all times and all river flows.

The RPS (GWRC 2013) sets that the narrative standards of the Third Schedule of the Resource Management Act (RMA) will be used as the basis for the definition of water quality limits in the Regional Plan. The Third Schedule of the RMA defines that "*there shall be no undesirable biological growths as a result of any discharge of contaminant into the water*".

A number of regional plans[10] have made use of narrative standards in relation to sewage fungus growth. Ausseil (2013) also recommends a narrative limit for waters in the Wellington region managed for contact recreation and amenity purposes. A similar narrative outcome is recommended for waters to be managed for aquatic ecosystems (both 'healthy' and 'significant'): "*There shall be no bacterial or fungal slime growths visible to the naked eye as plumose growths or mats*".

[10] For example the Manawatu Catchment Water Quality Regional Plan and the Regional Water Plan for Southland.

10. Supporting factors controlling instream plant growth

The magnitude and nature of instream plant growth is controlled by many factors including light and nutrient availability, flow and substrate characteristics, colonist availability and herbivory (Matheson et al. 2012). While many of these factors vary naturally the majority are heavily influenced by human activities.

In order for instream plant outcomes to be achievable in the Wellington region GWRC's Regional Plan must include measures to manage the key environmental factors driving of instream plant growth that are affected by human activities. These key factors are discussed below.

10.1 Hydrological regime

A natural flow regime involving flushing flows and sufficient base flow during dry periods is essential to ensure that instream plant communities remain balanced. Activities such as removal of flow into reservoirs during summer for irrigation can result in prevention of small to medium sized floods from flowing down the river, reducing the natural ability of the system to remove excess instream plant biomass (Biggs 2000).

In addition to flushing flows, sufficient base flow during dry periods is necessary to ensure in stream plant proliferation does not occur. Abstraction and diversion of flows during summer can result in water velocities falling to a level where instream plant removal is reduced and water temperatures rise, increasing growth rates (Biggs 2000).

10.2 Nutrient supply

Nutrient enrichment from point source discharges and runoff from land use is a key contributing factor contributing to increased instream plant biomass in streams and rivers. Nutrient enrichment can also occur naturally through leaching from nutrient-rich rocks such as tertiary marine mudstones/sandstone and limestone.

Key sources of nutrients in the Wellington region are municipal sewage discharges, contaminated stormwater discharges and runoff/leaching from agriculture and horticulture (both via shallow groundwater and directly via overland runoff) (Perrie et al. 2012).

10.3 Light availability

In small streams, the amount of shading provided by riparian vegetation can be a key factor controlling instream plant biomass due to its effect on light intensity at the stream bed (Biggs 2000). Increasing the amount of riparian shade may be a key management activity in small streams with long accrual periods because it will be difficult to achieve nutrient concentrations that are low enough to limit instream plant growth in these streams.

11. Summary and recommendations

The only instream plant indicators for which sufficient RSoE data are available to assess their suitability as attributes for the Natural Resources Plan are periphyton community composition and biomass.

Periphyton community composition showed some variation across the different FENZ classes. However, there was a poor correlation between periphyton community composition and supporting environmental variables, with insufficient taxonomic resolution in monitoring data likely to be a key contributing factor. Therefore it is not recommended that numeric outcomes for periphyton community composition be included in GWRC's dNRP.

Analysis of periphyton biomass data showed that biomass varied across FENZ classes and was moderately correlated with environmental variables. Key environmental variables included water temperature, water clarity, nutrient concentration and biomass accrual period. Periphyton biomass was also strongly correlated with MCI score. It is recommended that numeric outcomes for periphyton biomass be included in GWRC's Natural Resources Plan. These outcomes should ideally be based on the relationship between periphyton biomass and macroinvertebrate indicators across different FENZ classes in the Wellington region. In the interim, until sufficient data are gathered to enble this, periphyton biomass outcomes should be based on the New Zealand Periphyton Guidelines (Biggs 2000).

There are currently insufficient data available for the Wellington region to identify numeric outcomes for macrophytes. Narrative standards are recommended for heterotrophic growths but should apply to point source discharges only.

In order for rivers and streams to meet the recommended outcomes, key environmental factors that affect instream plant growth such as hydrological regime, nutrient supply and light availability will need to be managed as far as practicable.

11.1 Recommendations for future work

11.1.1 Data collection

More instream plant and environmental data needs to be collected from rivers and streams in FENZ classes A, C8 and C6c. These classes include small streams in the Wairarapa Valley, Kapiti Coast and eastern Wairarapa as well as larger rivers in eastern Wairarapa.

Collection of periphyton samples needs to be accompanied by an estimate of the biomass accrual period prior to the sampling date. Standard methods for estimating date-specific accrual periods need to be identified.

11.1.2 Taxonomic identification

There are several notable differences in the periphyton taxa identified by Cawthron prior to 2007 and by NIWA from 2007 onwards. In future a proportion of RSoE periphyton samples should be analysed by an external party for quality assurance purposes.

Samples identified by NIWA between 2007 and 2009 report only two cyanobacteria taxa: those grouped into the algae (blue-green) category and c.f. *Phormidium*. Given the prominence of cyanobacteria, particularly *Phormidium* in some of the region's rivers, it is important that cyanobacteria taxa be identified to genus level at least.

11.1.3 Periphyton biomass

Further analysis of the relationship between periphyton biomass and environmental variables should be undertaken. Key aspects to explore further include collection of estimates of light availability at RSoE sites and refinement of the water quality statistics to focus on summer-time conditions.

Further analysis and, where possible, sampling should also be undertaken to assess the relationship between periphyton biomass and macroinvertebrate indicators within each FENZ class. If possible this relationship should be used to identify periphyton biomass outcomes that are directly linked to macroinvertebrate outcomes.

11.1.4 Periphyton cover

Periphyton cover and biomass estimates collected at RSoE sites should be used to identify whether the periphyton cover/biomass model identified for the Manawatu-Wanganui region could be used in the Wellington region. If this is the case, visual estimates of periphyton cover undertaken each month during water quality sampling runs could be used to estimate periphyton biomass on a monthly basis.

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Appendix 1: RSoE site details and accrual periods

Site code	Site name	GWRC FENZ class	Site type	Average accrual (days)	Average maximum accrual (days)
RS03	Waitohu Stream at Forest Park	C7	Reference	19	58
RS05	Otaki River at Pukehinau	C7	Reference	16	47
RS06	Otaki River at Mouth	C6a	Impacted	17	52
RS09	Waikanae River at Mangaone Walkway	C5	Impacted	30	97
RS10	Waikanae River at Greenaway Rd	C6a	Impacted	28	93
RS11	Whareroa Stream at Waterfall Rd	C5	Impacted	26	95
RS13	Horokiri Stream at Snodgrass	C6b	Impacted	33	111
RS14	Pauatahanui Stream at Elmwood Bridge	C5	Impacted	30	94
RS15	Porirua Stream at Glenside O. Cable	C5	Impacted	21	73
RS16	Porirua Stream at Wall Park	C5	Impacted	21	72
RS17	Makara Stream at Kennels	C5	Impacted	25	85
RS18	Karori Stream at Makara Peak	C5	Impacted	21	73
RS19	Kaiwharawhara Stream at Ngaio Gorge	C5	Impacted	26	91
RS20	Hutt River at Te Marua Intake Site	C7	Impacted	15	51
RS21	Hutt River opposite Manor Park Golf Club	C6a	Impacted	20	64
RS22	Hutt River at Boulcott	C6a	Impacted	20	67
RS23	Pakuratahi River 50m Below Farm Creek	C7	Impacted	15	47
RS24	Mangaroa River at Te Marua	C7	Impacted	24	89
RS25	Akatarawa River at Hutt Confluence	C7	Impacted	20	63
RS26	Whakatikei River at Riverstone	C6a	Impacted	26	86
RS28	Wainuiomata River at Manuka Track	C7	Reference	27	96
RS29	Wainuiomata River at White Bridge	C6a	Impacted	27	80
RS30	Orongorongo River at Orongorongo Stn	C7	Impacted	17	49
RS31	Ruamahanga River at McLays	C7	Reference	13	38
RS32	Ruamahanga River at Te Ore Ore	C6a	Impacted	16	40
RS33	Ruamahanga River at Gladstone Bridge	C6a	Impacted	14	39
RS34	Ruamahanga River at Pukio	C6a	Impacted	20	69
RS35	Mataikona tributary at Sugar Loaf Rd	C5	Impacted	28	100
RS37	Taueru River at Gladstone	C8	Impacted	45	180
RS38	Kopuaranga River at Stuarts	C6c	Impacted	28	113
RS40	Waipoua River at Colombo Rd Bridge	C6a	Impacted	22	96
RS41	Waingawa River at South Rd	C6a	Impacted	15	44
RS43	Motuwaireka Stream at headwaters	C5	Impacted	30	110
RS44	Totara Stream at Stronvar	C5	Impacted	32	100
RS45	Parkvale tributary at Lowes Reserve	A	Impacted	49	165
RS46	Parkvale Stream at Weir	C6c	Impacted	49	165
RS47	Waiohine River at Gorge	C7	Reference	15	44
RS48	Waiohine River at Bicknells	C6a	Impacted	14	41
RS49	Beef Creek at headwaters	C7	Reference	19	64
RS50	Mangatarere Stream at State Highway 2	C6a	Impacted	21	63
RS51	Huangarua River at Ponatahi Bridge	C6a	Impacted	29	105
RS52	Tauanui River at Whakatomotomo Rd	C7	Reference	24	85
RS53	Awhea River at Tora Rd	C6c	Impacted	27	105
RS54	Coles Creek tributary at Lagoon Hill Rd	C8	Impacted	27	105
RS55	Tauherenikau River at Websters	C6a	Impacted	15	43
RS56	Waiorongomai River at Forest Park	C7	Reference	16	52

Appendix 2: List of periphyton taxa present at RSoE sites

Genus	No. of sites where present	Avg. relative abundance	Max. relative abundance
Achnanthidium	27	0.33	1.50
Ankistrodesmus	29	0.28	1.33
Audouinella	22	0.66	6.67
Chamaesiphon	27	0.30	1.33
Cladophora	21	0.95	6.00
Closterium	6	0.05	0.67
Cocconeis	46	1.98	5.33
Cosmarium	21	0.32	2.17
Cyclotella	9	0.05	0.33
Cymbella	45	2.34	7.83
Diatoma	32	1.09	6.00
Encyonema	40	1.32	3.00
Epithemia	18	0.49	3.40
Eunotia	12	0.11	0.83
Fragilaria	43	1.16	3.17
Frustulia	28	0.31	2.17
Gomphoneis	38	1.01	3.50
Gomphonema	46	4.70	8.50
Gyrosigma	4	0.08	1.60
Heteroleibleinia	44	1.30	3.33
Leptolyngbya	15	0.11	0.83
Lyngbya	12	0.16	2.00
Melosira	43	2.25	6.67
Merismopedia	10	0.08	0.83
Microspora	6	0.10	1.33
Monoraphidium	8	0.03	0.33
Mougeotia	9	0.15	1.67
Navicula	45	3.58	8.83
Nitzschia	46	3.23	9.00
Nostoc	10	0.07	0.67
Oedogonium	41	1.39	3.17
Oscillatoria	8	0.07	0.67
Pediastrum	4	0.03	0.67
Phormidium	37	1.33	5.50
Pinnularia	16	0.22	1.60
Planothidium	44	1.15	4.17
Pseudanabaena	6	0.03	0.33
Reimeria	29	0.45	1.67
Rhoicosphenia	43	1.94	8.00
Rhopalodia	4	0.05	1.00
Rossithidium	41	0.76	2.00
Scenedesmus	35	0.53	2.50
Spirogyra	32	1.77	5.33
Stigeoclonium	36	2.08	7.33
Surirella	21	0.19	1.17

Genus	No. of sites where present	Avg. relative abundance	Max. relative abundance
Synedra	45	3.70	8.50
Tabellaria	5	0.04	0.67
Tribonema	11	0.16	1.50
Ulothrix	13	0.25	1.50
Vaucheria	6	0.08	1.00
Genera with <5 records			
Achnanthes	*	*	*
Amphora	*	*	*
Chlamydomonas	*	*	*
Chroococcus	*	*	*
Coelastrum	*	*	*
Compsopogon	*	*	*
Crucigenia	*	*	*
Cryptomonas	*	*	*
Diploneis	*	*	*
Eudorina	*	*	*
Euglena	*	*	*
Gloeocystis	*	*	*
Meridion	*	*	*
Spirulina	*	*	*
Staurastrum	*	*	*
Stauroneis	*	*	*
Zygnema	*	*	*