Periphyton in the Manawatu-Whanganui region

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State, trends and seasonality, 2009-2015

Prepared for Horizons Regional Council

July 2016

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Executive summary

Horizons Regional Council (HRC) has monitored periphyton and a range of associated physico-chemical variables in up to 61 river sites in the Manawatu-Whanganui region since December 2008. The programme has multiple aims, including assessment of compliance with One Plan periphyton targets and development of periphyton-environment relationships to assist in river management.

HRC requested an analysis of the six-year dataset (up to April 2015) in four broad areas: state and trends in periphyton; compliance with targets and guidelines; seasonality of periphyton and compliance; factors influencing periphyton standing crop. This report covers the first three of these components, following an overview of measures of periphyton, which was also requested in the brief. A short description of the outcome of each component follows. More comprehensive summaries precede each section in the report.

The **overview of periphyton measures** reviews measures for quantifying periphyton standing crop, including: estimation of algal biovolume, pigment densities (chlorophyll *a*) and organic material (ash-free dry mass); and estimation of streambed cover using visual and photographic techniques. New and automated methods are included. Measures of productivity are discussed briefly.

State and trends in periphyton were assessed for chlorophyll *a* and % cover by mats, filaments and cyanobacteria.

> For **state** we defined categories of each metric starting at a very low level. Half of the 47 sites with a six-year record were in the very low (i.e., good) category for chlorophyll *a*; fewer sites were in this category for mats, filaments and cyanobacteria. Sites with very low chlorophyll *a* had dissolved inorganic nitrogen (DIN) < 100 mg/m^3.
>
> For **trends**, after the effects of flow were taken into account, between December 2008 and April 2015 chlorophyll *a* increased at 15% of 41 sites with six years of data and a linked flow record. There was no evidence for a trend at the remaining sites. % cover by mats declined at 27% of sites, and did not increase at any sites; % cover by filaments increased at 7% of sites and declined at 5%. All the sites at which chlorophyll *a* increased over time were in relatively unimpacted headwaters.

Compliance was assessed for the One Plan targets, National Policy Statement for Freshwater Management (NPS-FM) periphyton bands and the NZ cyanobacteria guidelines.

> Over the whole monitoring period, 39% of all 47 sites were 100% compliant with the **One Plan chlorophyll a** target, and 20% of sites exceeded the target in >10% of surveys. Higher proportions of sites were fully compliant with the **One Plan targets for mats** (70%) and **filaments** (39%).
>
> For the **NPS-FM**, over 50% of sites were assigned to band A (the best state), and 30% to Band B. Between May 2012 and April 2015, four sites (8%) were in band D (below the "bottom line").
>
> For the **cyanobacteria guideline**, 75% of all sites were always below the "alert" level of 20% cover, and 12.5% of sites exceeded the "action" level of 50% cover.

In a **summary of state, trend and compliance results**, the overall state of all sites in the monitoring programme was compared using a ranking based on all the assessments of state and compliance. The worst 15 sites included most sites downstream of point-source discharges, as well as further sites in the Mangatainoka and middle Manawatu, Whangaehu and lower Rangitikei Rivers. All these sites could be targeted for management.

In the **seasonality** analysis, April - June was identified as the quarter when chlorophyll *a* and % cover by filaments were most likely to be at their maximum (leading to exceedances of OP targets). The pattern appeared to be flow-driven rather than temperature driven and did not correspond with overall seasonal patterns in nutrient concentrations. Maximum % cover by mats showed no marked seasonality. Peak cover by cyanobacteria occurred most often in February, coinciding with peak water temperature.

1 Introduction

Horizons Regional Council (Horizons) commenced monthly monitoring of periphyton cover and biomass at 48 river sites in the Manawatu-Whanganui Region in late 2008. The monitoring programme had multiple aims, including assessment of regional compliance with periphyton targets specified in the One Plan (http://www.horizons.govt.nz/about-us/one-plan/) and development of a regional model for predicting periphyton at unmonitored river sites and in response to catchment changes.

The data were reviewed after one and three years of data collection, as joint projects involving Horizons Regional Council staff and NIWA (Kilroy et al. 2010, 2012). These reports each addressed several questions including compliance with the Proposed One Plan (at the time), accuracy of chlorophyll *a* determination, relationships between periphyton, flows and other environmental variables, and conversion of visually assessed periphyton cover into a chlorophyll *a* equivalent.

With six years of data now available, the Horizons dataset is the most comprehensive of its type in New Zealand and possibly elsewhere in the world. The number of sites included in the programme has increased over the years to 61 currently, on 25 rivers. There is therefore considerable scope to expand the analyses carried out in previous years, and to verify and begin to explain the patterns observed.

Since mid-2011, an additional assessment of cover by benthic cyanobacteria (primarily the potentially toxic taxon *Phormidium*) has been carried out at least monthly at many of the Horizons sites. Analysis of this four-year dataset may allow identification of potential controllers of the distribution of this nuisance taxon, over both space and time, which could assist with its management in other regions.

In May 2015, Horizons asked NIWA to scope a study, based on the periphyton and associated environmental data now available, to be carried out with input from Horizons staff. The research was planned as a collaboration between DairyNZ and Horizons Regional Council. Its aim was to provide information to assist in better management of the impacts of periphyton on river health and other river values throughout the region, thereby contributing to fulfilling community expectations for water quality (including periphyton), as established within the One Plan. The study was co-funded by Horizons Regional Council and DairyNZ. The following topics were proposed to be covered:

i. an overview of the different measures of periphyton;

ii. the state/trends of periphyton in the region;

iii. an assessment of how the levels of periphyton compare to targets in the One Plan and the periphyton bands as described in the National Objective Framework (NOF) for periphyton in the National Policy Statement for Freshwater Management National (NPS-FM);[1]

iv. seasonality or timing of annual maximum standing crop and exceedances of management thresholds;

[1] Subsequently in this report, the abbreviation NPS-FM is used specifically to refer to the rules around the periphyton attribute in the National Objective Framework in the National Policy Statement for Freshwater Management (NZ Government 2014).

v. factors influencing periphyton growth and abundance (river flow, N, P, etc.);

vi. a synthesis of the results, to relate them back to what the most effective mitigations might be to lower the magnitude or frequencies of exceedance of periphyton targets in the region. The aim was to identify if there are specific periods, flows conditions, etc., that should be targeted for management of nutrient concentrations (for example) more than others. Horizons would aim to link this to information on water age, farm practice, discharges, etc. as a part of a related project;

vii. a summary of any recommendations on the monitoring or science around periphyton.

In this report we address topics i. to iv. Topics v. and vi. Will be covered in a separate report.We used three datasets provided to NIWA by Horizons: (1) periphyton percentage cover and chlorophyll *a* collected monthly (or fortnightly from some sites) from up to 61 sites, starting in December 2008 (or later for some sites); (2) associated monthly water quality data at all sites, normally collected on the day of the periphyton survey; and (3) for most sites, a flow record from a nearby hydrological recording site.

Following this introduction (Section 1), the report is structured as follows:

Section 2 provides an overview of measures of periphyton (topic i above).

In **Section 3**, we provide background on Horizons periphyton monitoring programme, the procedures used and details of the data used in subsequent analyses.

Section 4 addresses topic ii above (the state/trends of periphyton in the region). The state of rivers in terms of periphyton are assessed in more detail than simply calculating compliance with targets or guidelines. Data from the sites having the full six years of data are analysed to detect trends. The trend analysis includes consideration of the role of river flow conditions in driving trends.

Topic iii (comparison with targets in the One Plan and the periphyton bands in the NPS-FM) is covered in **Section 5**, which summarises compliance with periphyton thresholds, including rates of compliance over the whole monitoring period and in the last three years. Rates of compliance with thresholds for benthic cyanobacteria specified in the New Zealand cyanobacteria guidelines (Ministry for the Environment and Ministry of Health 2009) are also included.

In **Section 6**, topic iv (seasonality or timing of annual maximum standing crop and exceedances of management targets) is covered in an analysis of numbers of exceedances or maxima in different months. Environmental factors driving seasonality are discussed.

2 Overview of measures of periphyton

Key messages

Periphyton is the film of algae, other small organisms, and organic/inorganic material that coats substrates in streams. In certain conditions periphyton can be excessive, causing degradation of stream ecosystems and values. Excessive growth can be triggered by changes in water quality and flow regime, and is influenced by temperature and light.

Monitoring and measuring periphyton are required to evaluate stream condition, document compliance with guidelines, and to identify streams requiring remediation. Guidelines aim to protect a range of stream values and different periphyton measures apply to each. For example, total biomass (e.g., as chlorophyll *a*) is appropriate for ecological values; and visually assessed percentage cover for aestheric values.

The quantity of periphyton present at a site at a particular time is referred to as "standing crop". Standing crop can be measured using techniques based on sample collection for estimation of biomass, or on estimates of cover on the stream bed.

Measures of periphyton standing crop are distinct from measures of periphyton productivity. Standing crop is net biomass including loss processes as well as growth; measures of productivity reflect growth rates and gross production potential.

This overview covers measures currently used to quantify periphyton standing crop, including: estimation of algal biovolume, pigment densities (chlorophyll *a*) and organic material (ash-free dry mass); and estimation of streambed cover using visual and photographic techniques. New and automated methods are included, as are measures under development. Measures of productivity are discussed briefly.

A summary comparison of the measures and methods discussed is provided in table form, including a description, pros and cons, and applicability in different situations.

2.1 Background

The term "periphyton" refers to the biological material that grows attached to or associated with the rocks or sediment covering the beds of rivers and lakes. Periphyton comprises mainly algae (hence the synonym "benthic algae") and is a natural component of river and stream ecosystems. As the productive foundation for the aquatic food web, it provides food for many aquatic invertebrates which in turn are food for fish. However, in suitable conditions, periphyton can proliferate to nuisance levels. Favourable conditions for proliferations are generally thought to include: low, stable flows and water velocities, stable substrates, nutrient enrichment, high sunlight and warm water temperatures. Nuisance growths have the potential to:

i. adversely affect aquatic communities by changing physical stressors such as pH and dissolved oxygen (which themselves can reduce losses through reducing invertebrate densities and therefore grazing pressure);

ii. impact on recreational values (such as swimming and fishing);

iii. reduce aesthetic values.

Some types of nuisance periphyton (depending on the dominant species in the assemblage) can also physically clog irrigation intakes, cause toxic effects on animals and humans (in the case of benthic cyanobacteria), or make water unpalatable for stock drinking purposes. For all these reasons, the quantity and type of periphyton generally reflects the overall health or condition of a river or stream.

This indicator role of periphyton abundance has long been recognised in New Zealand, and led to the drafting of the first periphyton guideline in 1992 (MfE 1992) followed by updated guidelines in 2000 (Biggs 2000a). Since 2000, targets for periphyton abundance based on the Biggs (2000a) recommendations have been adopted by many Regional Councils, led by Horizons Regional Council's Proposed One Plan in 2008. Most recently, periphyton has been included as an attribute in the National Objective Framework described in the National Policy Statement for Freshwater Management (NPS-FM) (NZ Government 2014). All regions are now obliged to classify rivers in their regions in accordance with the NPS-FM (Snelder et al. 2013, NZ Government 2014).

Note that subsequently in this report, the abbreviation NPS-FM is used specifically to refer to the rules around the periphyton attribute in the National Objective Framework in the National Policy Statement for Freshwater Management (NZ Government 2014).

Compliance with regional guidelines and the NPS-FM requires regular measurements or estimates of periphyton abundance in rivers. The measurement of interest is the quantity of periphyton at a site a particular time, referred to as "standing crop" and measured as mass per unit area. The NPS-FM specifies periphyton in terms of chlorophyll *a* (per square metre of river bed). Some regional periphyton standards specify standing crop in terms of percentage cover of the bed by periphyton mats or filaments (from visual estimates).

Different measures of periphyton are needed to provide information about the state of rivers in relation to different river values. In the Biggs (2000a) guideline, acceptable periphyton thresholds were defined for protecting aesthetic values; river recreation (swimming, boating); benthic biodiversity (as indicated by invertebrate community composition); and trout habitat and angling. Since 2000, an additional value recognised for rivers concerns protection of human and animal health. The health issue has arisen because of the increasing prevalence of the potentially toxic benthic cyanobacterium *Phormidium* in rivers throughout New Zealand (McAllister et al. 2016). The different measures do not necessarily coincide with each other. Thus chlorophyll *a* (representing overall ecosystem health) comprises contributions from a range of different types of algae, in various proportions. Therefore coverage by a single category of periphyton (such as green filaments, or cyanobacteria) is not expected to correlate with chlorophyll *a*.

In addition to estimates of periphyton standing crop, estimates of productivity or growth rates may also be of interest. Standing crop is what is left following processes that remove periphyton, such as invertebrate grazing; or processes that influence colonisation, such as abrasion by fine sediment.

Therefore the true potential for periphyton growth at a site might be better represented by looking at more holistic measures of production.

In the following, we review the range of options available, or under development, for estimating periphyton in rivers. We focus mainly on measures that aim to estimate standing crop because that is what the current standards in New Zealand specify. The review begins with a brief mention of sampling location, because selecting a representative survey area is critical for providing defensible data for assessment against standards. An overview is then provided of the various methods available for each measure, applications, and practical considerations. Applications are considered in relation to the protection of different river values. Methods for estimating productivity are covered briefly. A summary comparison of all the measures and methods discussed is provided in tabular form, including a description, pros and cons, and applicability in different situations. The term "standing crop" is used to refer to the measured amount of periphyton at a site; the term "biomass" is used in a more general sense, to refer to the biological material that is being quantified.

2.2 Sampling location

However periphyton standing crop is estimated, a choice has to be made at some stage of where to locate periphyton sampling sites. Guidance on this is provided in Biggs & Kilroy (2000). In the MfE periphyton guidelines published in 2000 (Biggs 2000a) the habitat to which the guidelines apply is generally stated to be unshaded wadeable areas in runs; this was the recommendation for the Horizons periphyton monitoring programme (Kilroy et al. 2008). Runs are defined as having smooth water flow with an unbroken surface, with variable water velocity, but generally slower than in riffles. Riffles, on the other hand, are defined by shallow, faster-flowing turbulent water and stable substrata.

Runs are advised as most appropriate for periphyton monitoring for the following reasons:

1. runs are the most common habitat type in most rivers;
2. standardising the habitat to runs means that application of the guidelines is nationally consistent;
3. periphyton standing crop in runs tends to be more variable and more responsive to the effects of both high flows and nutrient supply than that in riffles. (Stable substrata in riffles can lead to persistent high standing crop over a range of conditions.)

Within each run, samples are collected on transects in wadeable depths. Sample collection on transects ensures that the combined sample integrates periphyton from the range of depths and water velocities at the site.

The NPS-FM does not provide advice on locations for periphyton surveys in terms of habitat, but leaves the choice up to regional councils by requiring "freshwater management units" to be specified. A "freshwater management unit" is defined as "the water body, multiple water bodies or any part of a water body determined by the regional council as the appropriate spatial scale for setting freshwater objectives and limits and for freshwater accounting and management purposes" (NZ Government 2014).

2.3 Estimating periphyton standing crop

Procedures for estimating periphyton standing crop fall into two broad groups:

1. laboratory analysis of the biomass of samples collected from known areas of river bed;

2. assessments or images of periphyton cover *in situ* on the river bed.

The ability of any periphyton assessment to accurately represent standing crop at a site depends on all steps in the method, including: choice of sampling/survey area, sample collection techniques, numbers of samples, estimation of substratum surface area, operator experience/skill, laboratory techniques, data analysis.

2.3.1 Laboratory-estimated biomass from field samples

Laboratory analyses include processing samples for chlorophyll *a* (photosynthetic pigment) or ash-free dry mass (total organic matter) content; and taxonomic analyses to determine the composition and biovolume of algae. These methods were reviewed by Biggs & Kilroy (2000). Other methods for estimating biomass include determining settled volume, and quantitative measurements of carbon, N and P content. For all methods based on laboratory analyses of samples, a critical step is collection of a quantitative sample (or samples) that adequately represents the reach of interest.

Collection of a representative sample

Before sample collection, decisions need to be made on where to collect the samples from within the reach, how many samples (rocks) to collect, and how to define the rock area from which each sample is taken. Methods used in the Horizons programme generally follow the recommendations in Biggs & Kilroy (2000).

A recent series of trials conducted in three Canterbury rivers attempted to quantify errors associated with sampling procedures, including effects of inter-operator differences, sample size, and rock selection (Kilroy et al. 2013). One conclusion was that many samples (>20) can be required to obtain very precise estimates of reach-averaged chlorophyll *a* (95% confidence of being within 20% of the true mean), depending on the variability and patchiness of the periphyton. However, fewer are required for determining whether chlorophyll *a* is above or below a threshold (unless the true mean is close to the threshold). Typically at least 10 sub-samples collected along a transect or transects are pooled into a single sample to represent a reach. Collection of 10 samples requires moderate sampling effort, but achieves reasonable representation of the whole reach in most cases.

There are two broad methods for defining the surface area represented by each sample: (a) collection of periphyton from the entire rock, and estimation of the rock surface area from its dimensions (see Biggs & Kilroy 2000; and note that Matheson et al. 2012 provided an alternative equation in Appendix K of that report); and (b) collection of the sample from a known area of the rock, usually defined by a circle. There is scope for inaccuracy in both methods. Method (b) is generally recommended and is used in the Horizons periphyton programme. The advantage of (b) is that the main source of error (selection of a representative area for sampling on the selected rock) is controllable by the observer. In contrast, in (a) the formula for calculating rock surface area can introduce large errors, depending on rock shape, and once the data are collected the errors cannot be checked. Methods for estimating surface area were reviewed by Bergey & Getty (2006), who concluded that the fixed area method was very appropriate for field use, required no additional laboratory processing to determine stone size, but was unsuitable for irregular particles.

Cell biovolume

The “gold standard” measure for estimating algal biomass has historically been microscopic determination of densities of different taxa, followed by conversion of the counts to biovolume based on the average dimensions of each taxon (Kasprzak et al. 2008, Stancheva et al. 2012, Kahlert & McKie 2014). The method was originally used for estimating the biomass of phytoplankton in lakes (Jones & Lee 1982). Biovolume estimates are frequently applied to periphyton for research purposes (e.g., Villeneuve et al. 2011, Kilroy & Bothwell 2012). Detailed counts of algal species composition in periphyton are also a routine part of river monitoring in some European countries. In these cases, the data are generally used to calculate river condition from species tolerance scores, rather than biovolume (Kelly et al. 2008, Schneider & Lindstrom 2011). This application of periphyton taxonomic composition data has not been routinely applied in New Zealand.

Flow cytometry allows for automated estimation of cell biovolume. For example, see www.fluidimaging.com/applications/algae-technology. Recent advances in cytometry and associated imaging include identification of cyanobacteria within a mixed sample, and accurate cell size estimation. The method is more appropriate for planktonic algae than benthic algae although it has been used in studies of individual benthic algal taxa (Spaulding et al. 2012). However, the wide variety of cell sizes and growth forms present in periphyton mean that even if samples could be prepared so that they were suitable for passing through the measuring equipment, analysis of the mixed community would be challenging.

Although estimating periphyton biomass from cell biovolume generates potentially useful information for biomonitoring (see above), considerable effort and expense are required to obtain the data. More approximate, but still useful, estimates of taxonomic composition for indicator purposes can be obtained using quick assessment methods (e.g., coded relative abundance, Biggs & Kilroy 2000). Whether samples are analysed using coded relative abundance or more rigorous counts depends on how the data are intended to be used. For quick comparisons in which an idea of the dominant taxa is all that is required, coded relative abundance is generally adequate. As an example, comparisons of communities upstream and downstream of discharges for resource consent compliance might include both biomass, and a rapid assessment of the main taxa in the two communities, to highlight any major differences. If the community composition data are intended for use in research programmes, then formal counts provide data on which statistical analyses can be performed, including multivariate analyses.

Chlorophyll *a*

The most common and internationally accepted method of estimating the biomass of periphyton samples is laboratory analysis of quantitatively collected samples for chlorophyll *a* (Stevenson & Bahls 1999; Biggs & Kilroy 2000). Chlorophyll *a* is particularly useful because all algal types contain this photosynthetic pigment. This measure therefore provides a single measure to represent an entire algal assemblage and, for monitoring purposes, is used as an indicator of general ecosystem health. Low to moderate quantities (e.g., less that 50 milligrams per square metre of river bed) indicate a healthy ecosystem; high quantities (e.g., more than 200 mg/m^2) indicate that too much primary production may affect other components of the ecosystem

Laboratory-based methods for measuring concentrations of chlorophyll *a* and other pigments were originally developed for use in the marine environment and in lakes as a surrogate for the time-consuming (i.e., expensive) method of cell counts (Jones & Lee 1982). The measure is not exact because chlorophyll *a* varies with both species composition (Kasprzak et al. 2008) and with environmental conditions such as nutrient concentrations and light (Baulch et al. 2009). Issues with analytical methods have also been raised (e.g., Schilling et al. 2006, and see review in Kilroy et al. 2012). Therefore, chlorophyll *a* should be viewed as one component of periphyton that generally represents algal standing crop. Nevertheless, widespread use of chlorophyll *a* for monitoring rivers has led to general acceptance that this pigment-based metric is meaningful. This view is supported by the fact that chlorophyll *a* can often be related to aspects of stream nutrient chemistry and other environmental factors (Dodds et al. 1997; Biggs 2000b), although the relationships are not necessarily very clear (Royer et al. 2008).

Widespread acceptance and use of the chlorophyll *a* metric led to its adoption as the measurement unit for periphyton standing crop in the NPS-FM (NZ Government 2014, and see also MfE 2013). Despite this, the narrative around the periphyton attribute in the National Objective Framework acknowledges that visual assessment methods are often preferred for reasons of efficiency and practicality (Snelder et al. 2013). Importantly, it is generally possible to estimate chlorophyll *a* from visual estimates of cover (Kilroy et al. 2013; and see Section 2.3.2 below).

Laboratory measurement of chlorophyll *a* is relatively straightforward and inexpensive, but requires the use of specialist equipment (filtration equipment, water bath, spectrophotometer). Samples can be stored frozen for several weeks prior to analysis, with little loss of pigment. Chlorophyll *a* can be extracted using a range of different reagents, which do not produce exactly equivalent results. In New Zealand, the method recommended is based on extraction in hot 90% ethanol (Biggs & Kilroy 2000). For a discussion of laboratory procedures see Section 3 in Kilroy et al. (2012).

As with all laboratory analyses, there are issues with accuracy both within laboratories and, most critically, when samples are submitted to different laboratories for analysis. Even though laboratories operate to strict internal standards and use standard methodologies, inter-laboratory checks need to be carried out from time to time to confirm that the results are consistent. Since 2010, Horizons Regional Council has carried out studies to (a) evaluate the extent and magnitude of discrepancies in chlorophyll a measurements in two laboratories; (b) identify the source of discrepancies. Results were reported in detail in Kilroy et al. (2012). In brief, slight differences in procedures and methods were identified between the two laboratories, but none was considered significant in explaining small discrepancies (a slight bias towards higher values in one laboratory). In any case, the difference was very small and had little effect on compliance with guidelines.

Ash-free dry mass

Measurements of ash-free dry mass (AFDM) represent the amount of organic material in a periphyton sample, including living and dead algal and non-algal material (Biggs & Kilroy 2000). It is calculated as the difference between dry weight (dried to a constant weight at 105 °C) and the weight after ashing (usually at 400 °C). The method recommended in New Zealand is described in detail in Biggs & Kilroy (2000). Chlorophyll *a* and AFDM are often closely correlated, but not always. Differences in the relationship can arise because AFDM includes non-algal organic material such as small invertebrates, bacteria and organic detritus.

AFDM can be a useful additional measure alongside chlorophyll *a* if the heterotrophic component of periphyton is of interest (i.e., organisms such as bacteria and small invertebrates that are non-photosynthetic). The ratio of AFDM to chlorophyll *a* is referred to as the autotrophic index[2] (AI), which can be an indicator of organic pollution (see Biggs 2000a, section 7.3), particularly in rivers below point-source discharges. Excessive organic material promotes dominance of periphyton by heterotrophic organisms (sometimes visible as sewage fungus), raising the AI. If point-source

[2] Strictly speaking, the ratio of AFDM to chlorophyll *a* should be referred to as the heterotrophic index rather than autotrophic index, because increasing values of the index indicate a larger heterotrophic component in periphyton. However the definition of AI is well established, and we therefore retain it for consistency.

discharges add nutrients to the river rather than organic material, then calculating the AI is unlikely to be informative.

In the first year of the Horizons periphyton monitoring programme (2008-09), AFDM was determined from all periphyton samples collected upstream and downstream of point-source discharges. Analysis of that data showed that at five of the eight pairs of sites, chlorophyll *a* and AFDM were significantly greater at the downstream site. However, the AI did not show the expected downstream increase at any pair of sites and was always low (Kilroy et al. 2010). It was concluded that AI may not be an appropriate indicator for the types of discharges being monitored, and a recommendation was made to review its use. Consequently measurement of AFDM was discontinued in the programme.Shifts in periphyton community composition can also change the AI because AFDM also includes the non-cellular organic components of algae, such as the polysaccharide exudates of diatoms, including the mucilaginous stalk material that makes up the bulk of blooms of *Didymosphenia geminata* (didymo). For this reason, AFDM generally represents the standing crop of periphyton communities dominated by didymo better than chlorophyll *a* (e.g., Kilroy et al. 2007, Larned & Kilroy 2014). Other diatoms also produce copious mucilage (both as stalks and in amorphous form), which can lead to high AFDM compared to chlorophyll *a* (i.e., high AI).AFDM also allows calculation of the mass and proportion of inorganic material in a sample. As they develop, periphyton mats trap fine sediments from the water column and re-suspended from the surrounding river bed. The proportion of inorganic material in periphyton will change as cover and biomass increases, depending on flow conditions, periphyton community composition, and available sediment supply. Untangling all these effects is likely to be beyond the scope of routine monitoring programmes, but may be relevant in more intensive experiments such as studies of periphyton accrual patterns.

As for chlorophyll *a*, laboratory measurement of AFDM is relatively straightforward and inexpensive, but does require some specialist equipment (filtration equipment, drying and ashing ovens). Samples can be stored frozen prior to processing. For both measures there is a time lag (i.e., lab processing time) before results can be reported.

Settled volume

Matheson et al. (2012) described a method for determining the “settled volume” of periphyton, as an inexpensive, quantitative, method for determining average periphyton thickness at a site. The method requires collection of periphyton from a known surface area on the river, using the same procedures as for samples for chlorophyll *a* or AFDM. The sample is allowed to settle out in the laboratory, and the volume of the settled material is estimated and used to calculate thickness per unit area of river bed.

Informal trials have been conducted by NIWA to investigate relationships between settled volume (converted to average periphyton thickness) and both chlorophyll *a* and AFDM (J. Quinn, NIWA, pers. comm.). These trials indicated that the correlation between thickness and AFDM was generally stronger than that with chlorophyll *a*. Settled volume explained up to 64% of the variance in AFDM, but variance explained was lower for chlorophyll *a*. The composition of the periphyton can affect the relationships: samples with high proportions of filamentous algae had lower than expected AFDM and chlorophyll *a* in relation to thickness because of the disproportionately high volume of entangled filaments. This suggests that samples should be blended prior to estimating settled volume, to break up filaments and other clumped algae.

The method requires minimal and non-specialist equipment and is rapid (even including a blending step). However, further testing of relationships with chlorophyll *a* in particular are required before the method could be considered for routine use. The method already has potential utility for informal quantitative comparisons of periphyton abundance between sites.

2.3.2 Field estimates of periphyton cover

Field assessments include direct visual assessments of percentage cover at various levels of detail and imagery using digital devices that can subsequently be analysed by (for example) colour matching. Visual assessments can be converted into various indices [e.g., weighted composite cover (Matheson et al. 2012) or derived chlorophyll *a* (Kilroy et al. 2013)].

Cover estimates could also be combined with laboratory measures of chlorophyll *a* for assessing periphyton bands in the NPS-FM. For example, a default programme of cover estimates could include sample collection only when the cover reaches a level that is close to one of the critical thresholds. This decision could be made (in the field or from images – see below) using pre-agreed criteria (e.g., collect a sample only if mean cover by mats and / or filaments exceeds a certain amount).

Direct visual estimates

Direct estimates of the extent and type of periphyton cover on a river bed are best made using an underwater viewer, which allows a clear view of the bed. Estimates of percentage cover by algae in different categories are usually made by eye. Photography is an option but this requires post-survey processing (see below). To represent a reach, periphyton cover is recorded at multiple views, usually on transects spanning the wadeable area of the reach.

The visual estimate method used in the Horizons periphyton monitoring programme is a modification of the RAM-2 method described in Biggs & Kilroy (2000) and was described in detail by Kilroy et al. (2008). Periphyton cover categories based on colour and thickness were simplified from the RAM-2 method, to improve consistency between operators. The RAM-2 method specifies 12 categories (not including no algae), and most methods currently in use include seven or eight categories (e.g., see Section 3 in this report). It is generally possible to convert data collected using the RAM-2 method to the simplified form.

Trials in Canterbury confirmed that the standard method of viewing 20 areas of river bed is adequate to represent cover within a larger reach (95% probability of being within 10% of the mean estimated from 120 views) in most cases (Kilroy et al. 2013). Estimates of % cover were relatively consistent among observers for % cover by filaments and cyanobacteria. The largest differences among observers were between the categories “no algae” and “film”, which can be difficult to separate consistently when films are very thin. Because both these categories normally represent low periphyton standing crop, discrepancies in cover estimates are not usually important.

Conversion factors can be used to convert % cover of different periphyton types to chlorophyll *a* (Kilroy et al. 2013). In the Horizons region, $\log_{10}$derived chlorophyll *a* explained up to 75% of the variance of $\log_{10}$chlorophyll *a* (measured from samples), using mean values at sites averaged over three years of data (Kilroy et al. 2012). The relationship between observed chlorophyll *a* and chlorophyll *a* derived from visual assessments varied across sites, suggesting that different conversion factors may apply at different sites. The same pattern was observed in Canterbury Rivers (ECan data). Use of site-specific conversion factors is clearly impractical; however, there is scope for developing conversion factors applicable to different river types and different regions.

Linking % cover data, or chlorophyll *a* derived from % cover estimates, to environmental variables is generally less successful than for direct measurements of chlorophyll *a* (e.g., Kilroy et al. 2012). The reasons are unclear, but possible explanations include: (a) the direct response of chlorophyll *a* to nutrient conditions, and especially to nitrogen (Menendez et al. 2002); and (b) the varying proportions of live algae in observed % cover.

One important advantage of direct estimates of cover is that the results are available immediately for management purposes such as compliance with the cyanobacteria guideline (Wood et al. 2009).

The potential for lack of objectivity in % cover estimates made by eye (e.g., observer selection of areas for viewing) can be largely eliminated by defining viewing areas prior to the survey by placing markers on the stream bed along predetermined transects. A further drawback is the potential for inter-operator variability. Kilroy et al. (2013) concluded that such variability can be relatively low, given adequate training. One technique that facilitates more consistent estimates of percentages is to mark a grid on the viewer window.

Metrics derived from visual estimates

The raw data from visual estimates is multi-variate, which makes data reporting more challenging than for single measures such as chlorophyll *a* or AFDM. One option is to convert the data to a derived chlorophyll *a* (see above). The other extreme is to present all the data in graphical form. An example is shown in Figure 2-1.

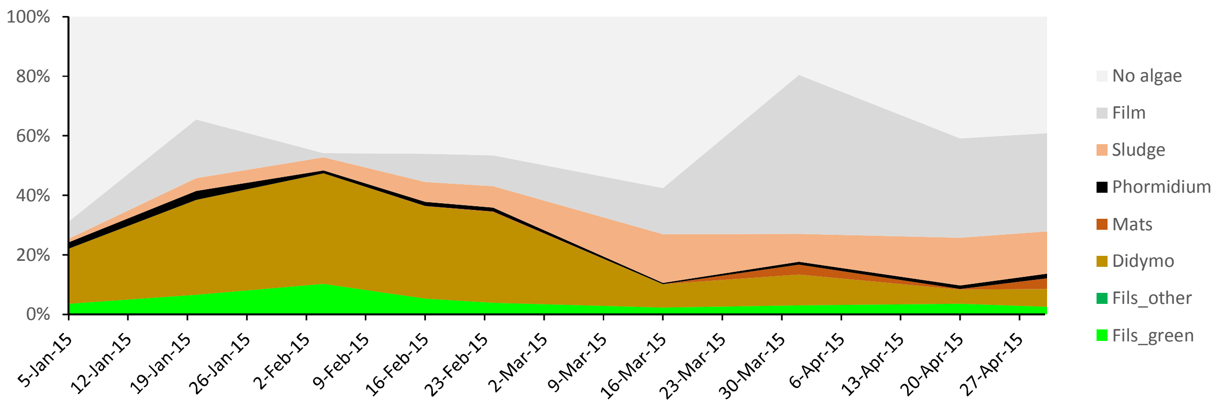


Figure 2-1: Example of visual estimate data plotted over time, including all cover categories. In this case, surveys were conducted approximately fortnightly. The plot shows a reduction in didymo cover following a high flow event on 6 March.

Between the two extremes, the relevant categories in the visual estimate data can be combined for reporting percentage cover by mats (the sum of mats and sludge) and filaments (the sum of green, slimy filaments and other filaments). Matheson et al. (2012) suggested that cover by mats and filaments could be combined into a single index of weighted composite cover (PeriWCC). The index is calculated as:

$$\text{PeriWCC} = \text{\% cover by filaments} + (\text{\% cover by mats} / 2)$$

The rationale for the weighting was that the New Zealand Periphyton Guideline (Biggs 2000a) specified limits of 60% cover by mats and 30% cover by filaments, implying that mats had half the "nuisance" value of filaments. Derivation of conversion factors linking cover categories to chlorophyll *a* supports this view: the chlorophyll *a* content of periphyton comprising 100% filaments can be up to four times the chlorophyll *a* equivalent of mats (Kilroy et al. 2013). Provisional general guidelines of

PeriWCC <20, 20-39, 40-55 and >55 were recommended by Matheson et al. (2012), as indicating, respectively, excellent, good, fair and poor ecological condition (at sites where other stressors are minimal). The need for further refinement of the guidelines was acknowledged.

Photography / spectral imaging

Photographic imagery has long been used to document ecological patterns at a range of scales from microscopic to landscape-scale. Spectral imagery extends photography by including information from discrete wavelength bands, including those beyond the narrow range of light visible to the human eye. At all scales, there is scope to apply various methods of image analysis, from visual recognition of organisms to automated analysis based on the spectral composition of the image (which itself depends on the sensor used to record the information).

At small scales (microscopic to centimetre scales) photography provides a straightforward way to track ecological processes in aquatic environments *in situ*. For example, the effects of invertebrate grazing on biofilms (thin layers of periphyton) were followed photographically at high magnifications (Lawrence et al. 2002). At a larger scale, image analysis using a grey scale was used to track the effects of snail grazing, non-destructively, on algae growing on white tiles (Kawata et al. 2001).

Photographic imagery at larger scales (metres to tens of metres) is commonly used in the marine environment. For example, identification of reef organisms from still photographs of random quadrats was sufficient to detect assemblage changes with depth (Deter et al. 2012), and video photography documented changes in the benthos following dredging (Carbines & Cole 2009). However, analysis of photographs was not necessarily the most efficient or accurate method of assessing cover (Drummond & Connell 2005). Photographic imagery has also been used in lakes and wetlands (e.g. Marshall & Lee 1994, Madrid et al. 2012).

In the past 20 years, much scientific effort has been devoted to the use of remote sensing (generally using data from airborne or satellite sensors for monitoring freshwater environments, e.g., see review by Ashraf et al. 2010). Despite difficulties in accounting for other variables such as water depth and water quality (Hunter et al. 2010, Zou et al. 2013), the method has generally been seen as a potentially powerful tool. Remote sensing has also been deemed promising for monitoring algal blooms in lakes (Matthews et al. 2010). The use of such imagery in rivers presents special problems because of reflection and irregularity at the water-air interface, and the effect of depth and turbidity. Nevertheless, there have been advances in using imagery to monitor river water depth and river morphology (Legleiter et al. 2004, 2009, Legleiter & Roberts 2005).

There appear to be few published examples of remote sensing of plants in rivers, but recent studies have reported some success using instruments deployed at relatively close range. For example, Lee et al. (2011) found reasonable correspondence between vegetation surveys and estimates of general vegetation types and plant biomass (including periphyton) using a portable spectroradiometer held close to the water surface.

At NIWA a project is underway trialling the use of above-water photography to record changes in periphyton cover over time. As discussed above, interpretation of images of the stream bed taken above the water can be difficult to impossible. However, photography may produce useful results in shallow river reaches, with run habitat (i.e., a smooth water surface). Since periphyton monitoring is usually recommended in runs, there is ample scope for the method to be useful.

A trial camera was installed at a suitable site, and set to take photographs at hourly intervals to allow determination of the optimal time of day for images. There were start-up issues of obtaining suitable images and maintaining adequate power supply. Nevertheless, the photographs obtained to date look promising subjects for automatic analysis. Obtaining "baseline" photographs (of bare rock only – no algae) was critical for the method to work, and this should be possible in most rivers. A trial of more sophisticated imagery using specific spectral bands has also been carried out. In this method we were able to highlight patches of *Phormidium*-dominated algae in the images, with minimal post-processing required. This suggests that the spectral camera may have potential for continuous monitoring of *Phormidium* at key sites.

In both photography and spectral imaging, the most important step in obtaining a quantitative measure of periphyton is image processing. This step still needs considerable work. The focus of the NIWA research to date has been on obtaining suitable images.

Overall, photographic and imaging methods (at least with current technology) seem unlikely to ever have universal applicability for routine periphyton monitoring because of the inherent issues of obtaining useful images through the air – water boundary. However, many sites in river runs may be suitable. Setting up the equipment and communications is time-consuming, and the risk of vandalism or equipment failure must be managed.

2.3.3 Field-based fluorometry

Portable fluorometers have generally been used for estimating chlorophyll *a* concentrations in the water column of lake and marine environments. The benthic application is relatively new. Two methods are discussed.

BenthoTorch

A recent development in monitoring of benthic algae is the BenthoTorch (http://www.bbe-moldaenke.de/chlorophyll/benthotorch), which is based on fluorometry. The BenthoTorch (hereafter BT) is a hand-held instrument with a light source/sensor at one end. Light is emitted at five different wavelengths corresponding to different algal groups (diatoms, cyanobacteria, etc.) and the fluorescence response from the algae surface being tested is read at 690 nm (i.e., chlorophyll *a*). For a detailed description of the instrument and its operation see Aberle et al. (2006).

Although the BT has been available for almost a decade (and has been used in New Zealand for research purposes) only a few published studies examining its performance are currently available. Both Kahlert & McKie (2014) and Harris & Graham (2015) found that the instrument provides comparable results to lab-measured chlorophyll *a* up to standing crop of about 50 mg/m^2, but estimates of the composition of the periphyton did not correspond well with microscope observations. Harris & Graham (2015) also noted underestimation of chlorophyll *a* at standing crop higher than 50 mg/m^2. An informal evaluation by NIWA concurred with these results (J. Quinn, NIWA, pers. comm.). Carpentier et al. (2013) identified inconsistencies with BT readings caused by different substratum types, and developed a method for applying a correction factor to account for this. An interesting use of BT was described by Piano et al. (2015), who used the instrument to determine patterns of contamination of a natural cave biofilm with autotrophic organisms as a result of artificial lighting. As a result of the survey and analysis, the authors were able to suggest strategies for minimising the impact of tourism on the cave ecosystem.

Underestimation of the total chlorophyll *a* biomass in thick periphyton mats (as opposed to thin films) is to be expected in BT because the instrument can only sense pigment from the surface layer of cells. Further tests of the BT are underway at NIWA, Christchurch, to try to identify the range of accurate measurements more precisely.

The BT is easy to use. Standard protocols, such as definition of transects and sampling density, would need to be developed for use of the instrument in routine river monitoring. The area sampled in each BT reading is approximately 1 cm^2. Therefore many readings need to be taken obtain an average value of chlorophyll *a* over a whole reach. To cover an area equivalent to 10 samples from a fixed area on a rock (typically the minimum required to represent a reach, see Section 2.3.1 above), about 120 BT readings would be required. Each reading takes ~20 seconds. Field trials are required to determine the optimum number of readings.

Pulse-amplitude modulated fluorometry

Pulse-amplitude modulated fluorometry (PAM) was developed in the mid-1980s and revolutionised the study of chlorophyll fluorescence to assess the photosynthetic performance of plants. PAM does not directly measure photosynthetic rates, but generates metrics that can represent photosynthesis in some circumstances or are related to plant stress. Various instruments using the PAM principle have been developed for specific uses (e.g., foliage imaging, planktonic algae, benthic algae *in situ*). For detailed descriptions of PAM and its principles / applications, see (for example) Schreiber et al. (1996), Kromkamp & Forster (2003), Klughammer & Schreiber (2004), Whorley & Francouer (2013) and the manufacturer's manuals (e.g., http://www.walz.com/downloads/manuals/diving-pam/DIVING3EB.pdf).

Measurements of minimum fluorescence using PAM (after dark adaptation) (F_o) reflect the density of chlorophyll *a* in a sample and therefore can be used to represent biomass or standing crop. In one example of this application, Honeywill et al. (2002) found that the chlorophyll *a* – F_o relationship became weaker in thicker samples. Thus the method has the same drawback as BT (see above) in that the instrument senses only the surface layer of periphyton.

In terms of usability the PAM, like BT, reads a small area. The requirement for dark-adaptation also adds an extra, time-consuming, step in the field. Furthermore, the output must first be calibrated with biomass measurements before quantitative estimates of chlorophyll *a* density can be made. PAM has proved useful for research in rivers (e.g., non-destructive measurements to track periphyton accrual over the time-course of nutrient limitation experiments, Whorley & Francouer 2013). However, as indicated above, PAM output also goes well beyond that required to simply estimate biomass. Therefore this instrument is not recommended for routine monitoring but is mentioned here for completeness.

2.4 Whole stream productivity and metabolism

Measures of periphyton standing crop reflect the net amount of periphyton present at a site under the influence of a range of processes that cause biomass loss, particularly physical disturbance and grazing (see Figure 8 in Biggs 2000a). The potential for periphyton growth at a site may therefore be better represented by measuring periphyton productivity rather than standing crop. Measures that include whole-biofilm activity may also be applicable; this would involve measuring whole-community benthic metabolism, which includes heterotrophic activity (i.e., from bacteria and larger animals) as well as autotrophic (photosynthetic) activity.

Benthic metabolism is estimated from measurements of dissolved oxygen (DO) production from a known area of stream bed, or individual rocks, using a chamber that isolates the area or rocks from the rest of the stream as the measurements are made. The rate of uptake of DO by **ecosystem respiration (ER)** is determined by measuring DO uptake in the dark. **Gross primary production (GPP)** is calculated from the sum of DO production and the equivalent DO taken up in respiration (scaled up to a rate per day). Other metrics can be calculated including **net metabolism** (the difference between GPP and total ER for 24 h). The strong dependence of both GPP and ER on temperature (Demars et al. 2011) can be accounted for using a temperature-correction method (e.g., see Clapcott et al. 2010). For a full description of the methods, refer to Biggs & Kilroy (2000), or published studies such as Fellows et al. (2006) and Young and Collier (2009).

While estimates of GPP and metabolism require considerably more field effort than collection of a periphyton sample, they are intuitively likely to be a more accurate indicator of stream productivity based on a small number of measurements. In a synoptic survey in Australia, GPP, ER and net metabolism explained twice as much of the variance in an index of catchment disturbance in cobble-bedded streams (including land use and nutrient enrichment) than periphyton standing crop as chlorophyll *a* (mean of ~85% vs. ~43% respectively) (Fellows et al. 2006). Periphyton standing crop measured on a single occasion has been subjected to unknown loss processes and therefore usually carries limited information in isolation. Consequently, programmes of regular monitoring are required to document periphyton standing crop under a range of conditions in order to calculate an appropriate metric for assessing stream condition (see below).

GPP, ER and net metabolism can be thought of as functional indicators of river condition, as opposed to periphyton standing crop, which is a structural component of the ecosystem. Other processes that are potentially useful functional indicators include rates of decomposition of organic material (e.g., Young & Collier 2009, Imberger et al. 2010) and nutrient uptake rates (Hall & Tank 2003). These indicators are outside the scope of this overview.

2.5 Periphyton metrics for representing site condition

Site condition can be assessed in relation to a range of values, each of which requires a different measure of periphyton (see Section 2.1). Whichever measure is used (e.g., biomass as chlorophyll a or a percentage cover measure), single measurements of periphyton standing crop are rarely useful on their own (with the exception of estimates of cover by nuisance periphyton such as *Phormidium*). Normally time series of data are needed to enable calculation of appropriate periphyton metrics for comparison with guidelines or standards, or for use in developing periphyton – environment relationships. Metrics vary according to the purpose of the monitoring programme or data analysis. For example, non-compliance with the Horizons One Plan periphyton targets is determined by simply calculating the proportion of occasions on which the target is exceeded. The periphyton attribute in the NPS-FM specifies bands based on a chlorophyll *a* value for the 92nd percentile (i.e., the value not exceeded in 11 out of 12 surveys) which should not be exceeded over a three-year time-series of monthly surveys.

The 92nd percentile approximates the mean annual maximum value and is likely to represent the maximum biomass typical at a site. Maximum values are arguably the most relevant for management purposes because they reflect the carrying capacity for periphyton under optimum conditions. Across a group of sites, we might expect GPP (see above) to be correlated more closely with maximum chlorophyll *a* than with single observations of chlorophyll *a*.

Mean and median values in addition to the maximum (or 92nd percentile) can provide a more complete picture of the overall status of periphyton at a site than the maximum (or 92nd percentile) alone. Snelder et al. (2013) showed that at most sites, periphyton cover conforms to an exponential distribution. In other words, a time series of chlorophyll *a* measurements will typically contain a few large values and many small values. Such a distribution is defined by the mean value. In that case, the mean and maximum (and also various percentiles) are closely correlated. That implies that for developing relationships between environmental variables and periphyton, using the mean, 92nd percentile or maximum value should yield similar relationships. However, at some sites, such as those with very stable substrate and flows (persistent high biomass) or heavy shade (persistent low biomass), the frequency distributions of biomass may not conform to an exponential distribution: there may be more high and medium values in a time series than expected, because periphyton is not easily removed by high flows (or flows are very stable, as in many regulated rivers). In these cases, use of more than one metric (e.g., the mean, median and 92nd percentile) would reveal differences in distribution.

Alternative measures of periphyton such as AFDM have been included in previous guidelines (Biggs 2000a). As noted above (Section 2.3.1), Horizons Regional Council initially included measurement of AFDM upstream and downstream of point source discharges but dropped the measurement following a recommendation in Kilroy et al. (2010). Currently only chlorophyll *a* and percentage cover are included as periphyton measures in the One Plan, and only chlorophyll *a* in the NPS-FM. Accordingly, other metrics (including AFDM) do not currently fit into the framework of rules and policies around periphyton.

2.6 Summary of periphyton measures

All methods discussed are listed in Table 2-1, with a summary of their practicality and applications. In all cases it is assumed that sample / data collection is aimed at producing a mean value that is representative of periphyton biomass across the site or reach of interest, as outline in Sections 2.2 and 2.3.1 above.

Table 2-1: Summary of measures of periphyton discussed in the text. For each method, features, advantages and disadvantages are listed, along with general comments on the current or potential use of the method, and other features that are neither advantageous nor disadvantageous. In all cases, it is assumed that field sample or data collection was conducted so as to allow adequate representation of the area of river bed of interest.

Method	Description	Pros	Cons	Comments
Lab-estimated biomass from field samples				
Cell biovolume	Measure of the total biovolume of all algal taxa in a sample, determined from identification and counts of cells, followed by conversion to biovolume using estimated volume of cells for each taxon.	The most direct method for determining algal biomass Taxonomic information can be used to apply existing methods for assessing stream condition, or to develop new region-specific methods	Time consuming (i.e., expensive) Requires specialist expertise Delays before reporting results can be long because of complexity of the analysis	Options for automating cell counts and identifications require specialist equipment (e.g., flow cytometers) and are currently relatively untested for mixed periphyton Not practical for biomass assessment unless taxonomic composition data are specifically required. Taxonomic data may be useful for identifying indicator taxa or calculating indicator metrics (an alternative way of assessing river condition)
Chlorophyll *a*	Quantitative measure of a photosynthetic pigment found in all algae by dissolving the pigment from a known area into an extractant followed by spectrophoto-metric or fluoro-metric measurement of colour density, then conversion to a biomass equivalent.	Internationally accepted surrogate for algal biomass Single measure, therefore reporting is straightforward Relatively inexpensive laboratory analysis	Collection of multiple samples can be time-consuming Analysis requires specialist facilities Delay before results available Density is influenced by community composition and nutrient conditions, as well as biomass	Widely used in NZ, often following standard analysis methodology (Biggs & Kilroy 2000) Adopted as a attribute in the NPS-FM Recognised need for time-series of data to generate useful metrics for comparing periphyton between sites *(N. B. this applies to all lab-estimated biomass methods)* Used to assess ecosystem health by providing an estimate of instream biomass of all primary producers.
Ash-free dry mass	Measure of the total organic component of a sample, from the difference between dry weighed and weight after combustion of organic material.	Single measure, therefore reporting is straightforward Relatively low-cost laboratory analysis Used with chloro-phyll *a* allows to calculate the Autotrophic Index Enables estimation of inorganic content of periphyton provided pre-combusted weight is known.	Collection of multiple samples can be time-consuming Measure includes non-living organic material, which may confuse interpretation Analysis requires specialist lab facilities Delay before results available	Used in NZ mostly for research, often following standard analysis methodology (Biggs & Kilroy 2000). Particularly useful for biomass estimates of communities dominated by didymo. Currently not included as a required or recommended measure in any national or regional policy framework.

Method	Description	Pros	Cons	Comments
Settled volume	Measure of volume of a quantitative periphyton sample after settling, allowing calculation of mean periphyton thickness at a site	Simple, fast (i.e., inexpensive) lab processing No specialist facilities required Potential for quick processing and therefore reporting with minimal delay	Relationships to chlorophyll *a* and AFDM require more investigation	Not in general use, but has been used informally in comparisons of biomass between sites
Field estimates of periphyton cover				
Direct estimates using underwater viewer	Measure of percentage cover of periphyton on the river bed, with division into different visual categories based on colour, thickness and growth form	Relatively rapid field procedure Immediate results Provides information about periphyton types as well as quantity Easy to understand Potential to convert % cover data to a chlorophyll *a* estimate (e.g., to check compliance with NPS-FM)	Potential for subjectivity and inter-operator variability (but see Kilroy et al. 2013)	Widely used in New Zealand, generally using a fairly consistent methodology Requires some training/practice of operators to ensure consistent assessments. Photographic guides are available. Used as a measure that reflects aesthetic and recreational values in rivers (e.g., Suplee et al. 2009)
Photography / spectral imaging	Measure of percentage cover of periphyton or types of periphyton assessed from images	Potential for automated continuous monitoring of periphyton cover Remote access of images possible Spectral imaging shows promise for highlighting specific algal groups (e.g., cyanobacteria)	Limited utility: Image capture above water surface feasible only in runs (i.e., smooth water surface) Time-consuming set-up process and relatively expensive equipment (esp. spectral imaging) Risk of vandalism / equipment failure at unattended sites Image analysis techniques needed for acquisition of monitoring data – still in development	Imaging technology (including image analysis) is still under development at various institutions (including NIWA). It is unclear how useful the technology will be in rivers in the long-term Potential for automated monitoring of nuisance algae such as *Phormidium* at key sites justifies some effort to advance this methodology
Metrics from visual estimates	(Refers to measures of % cover that are extracted from more comprehensive field assessments, including for comparison with standards)			
	% Mats and % Filaments aesthetics	Well established metrics included in guidelines since at least 2000. Easily understood	Mats and Filaments may not respond in the same way to environmental changes	Targets of 60% Mats and 30% filaments widely applied

Method	Description	Pros	Cons	Comments
	Weighted composite cover	Easy to derive from above two metrics to provide a single number Known correlations with invertebrate metrics	Not yet defined	In development
Field-based fluorometry				
Bentho-Torch	Measure of chlorophyll *a* density and broad community composition from direct instrument readings	Estimates chlorophyll *a* density with no sample collection or laboratory analyses Immediate results Non-destructive sampling – can re-sample repeatedly at the same place User-friendly instrument – easy to set up and operate Instrument appears to be robust and reliable	Instrument is relatively expensive (at least $21500*) Estimates of high chlorophyll *a* densities (e.g., > ~50 mg/m^2) may be unreliable Small sample area (1 cm^2), i.e., many subsamples may be required to represent a reach – could be time consuming. (*2011 price)	Currently used in marine applications in NZ, and is being trialled in fresh waters by at least two organisations Community composition output consistently reported as not accurate (but not important if main focus is chlorophyll *a*) More field testing is needed to (a) establish range of accurate readings; (b) determine optimum number of readings to represent a wider area
PAM	Measure of chlorophyll *a* density derived from reading of minimum photosynthetic activity after dark-adaptation	Research applications (No real advantages for routine periphyton monitoring)	Expensive instrument with complex output Requires expertise to interpret output Requires calibration to obtain estimates of chlorophyll *a* Likely low accuracy for estimates of chlorophyll *a* in thick mats (i.e., high biomass)	In use in NZ in many and varied research projects. Not appropriate for routine monitoring
Whole stream productivity and metabolism				
GPP (and related metrics)	Measure of the rate of gross primary production from estimates of O_2 production, allowing for O_2 uptake in respiration	GPP probably best way to summarise stream productivity A few measurements likely to be more informative than biomass	Time-consuming procedure requiring specialised equipment	Mainly used in research

3 Periphyton monitoring in the Manawatu-Whanganui region: methods and data

Key messages

In 2008 Horizons Regional Council commenced a periphyton monitoring programme comprising regular monthly surveys at 48 sites throughout the Manawatu-Whanganui region. Additional sites have been included in the programme over the years, making a total of 61 sites by April 2015

Consistent methods for data and sample collection have been used since the start of the programme. Periphyton data collected consists of visual estimates of cover, and a sample for subsequent laboratory analysis of chlorophyll *a*.

A range of environmental data is linked to each survey, including dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) concentrations, water temperature and conductivity, and river bed substrate composition.

Since mid-2011, data on cover by cyanobacteria have been collected at most sites.

Fifty-three sites have a linked hydrological record.

3.1 Background

State of the Environment (SoE) monitoring is a statutory requirement of Regional Councils under the Resource Management Act (1991). The Horizons' periphyton programme needs to provide for three key aspects of water quality monitoring:

i. determining the state and trends of periphyton growth/water quality;

ii. developing cause and effect relationships between nutrient levels and periphyton growth/water quality; and

iii. monitoring water quality policy effectiveness.

From 1999 to 2008 Horizons' periphyton monitoring programme consisted of once-yearly monitoring alongside the macroinvertebrate monitoring programme. Fourteen sites were monitored yearly with another set of sites being monitored on a rolling basis every third year. In total, 83 sites were monitored. Monitoring consisted of a visual assessment of percentage cover, sample collection for chlorophyll *a* analysis. For several years, periphyton community composition was also analysed. During the development of the Horizons One Plan for regional environmental management (http://www.horizons.govt.nz/assets/publications/about-us-publications/one-plan/Schedule-E-Surface-Water-Quality-Targets-2014_2.pdf), management initiatives and water quality targets were set for the social, economic, cultural and environmental management of waterways. As a result the existing programme was not adequate to report on policy performance.

In 2007 the monitoring programme was reviewed in partnership with NIWA and Massey University to produce recommendations for a new, appropriate and cost-effective long term monitoring plan. The review was funded through Envirolink. Aims for the new monitoring programme included monitoring with respect to the targets defined in the proposed One Plan; obtaining a comprehensive, spatially-representative picture of periphyton–nutrient concentration relationships in the region; and identifying trends and changes in the future. The review included recommendations for developing a regional model linking nutrient levels and periphyton growth (Kilroy et al. 2008).

3.2 Methods

3.2.1 Site selection

In the first year of the new programme (from December 2008) monitoring was conducted at 48 sites on 22 rivers, with sites selected to cover the full range of nutrient conditions and frequency of flood events in the region (see Table 1 in Kilroy et al. 2010). Sites were selected from 63 sites in the Horizons water quality SoE programme, and from other sites in the discharge monitoring network. Sites were assigned to cells in a nutrient/flood frequency matrix, with three levels of nutrients and three levels of flood frequency (low, medium and high in each case) making nine combinations. The aim was to achieve an even spread of nutrient level/flood frequency regime combinations, with at least three representatives in all nine combinations. This process followed the methodology suggested in Kilroy et al. (2008). Many of the region's reference sites are located within the central volcanic plateau and have naturally high flood frequencies as well as high nutrient levels. However, other combinations are rare. For example, in the assessment in Kilroy et al (2010) no sites represented the low nutrient/ low flood frequency category.

Several sites have been added to the programme since 2009, to extend the range of nutrient concentrations and flow conditions. By April 2015, periphyton data was being collected at 61 sites on 25 rivers. Eight sites do not have associated flow records, but these may be available for future analyses. Allocation of each of the 53 sites with flow records to each of the nine nutrient level/flood frequency regime combinations is shown in Table 3-1. Designations of high, medium and low status were based on the ranges observed in rivers across in the region using data from 2012 to 2015, in DIN and FRE3. DIN was used as the main determinant of nutrient status because all sites in the region have relatively high DRP (e.g., minimum mean value at a site of 6.3 mg/m^3, compared to a median value of 4.8 mg/m^3 across all 77 sites in the the National River Water Quality Monitoring Network (NRWQN). Also, the range of mean DIN in the region spans two orders of magnitude (12 to >1350 mg/m^3) while the range of DRP spans only one (6 to 60 mg/m^3), apart from one extremely high outlier downstream of a waste-water treatment plant (site 6, mangatera_ds_dan[3]).

Location details of 61 sites currently being monitored, with data available up to April 2015, are shown in Table 3-2 and their locations are shown on Figure 3-2. Refer to Appendix 3 for a summary of site characteristics, including the mean nutrient concentrations and flood frequency (as FRE3 – the mean annual number of flow events exceeding 3 x median flow) that were used to allocate the nutrient level/flood frequency regime combinations.

The original site selection method was not designed to achieve uniform representation of all waterway types in the region, but to ensure that cells in the matrix in Table 3-1 were populated as

[3] **Site notation**: In Table 3-2 and Figure 3-2, sites are numbered from the most upstream to the most downstream in successive catchments and sub-catchments. Subsequently in this report, sites are referred to by their full or abbreviated name with the site number, so that sites can be located easily on the maps.

evenly as possible. Sites have been added to the programme since 2008 in order to capture information of value to the council's consenting and planning operation.

Since this programme was initiated, the NPS-FM has become operative. One requirement of the NPS FM was that councils develop Freshwater Mangement Units in their regions. FMUs are defined in the NPS-FM as "the water body, multiple water bodies or any part of a water body determined by the regional council as the appropriate spatial scale for setting freshwater objectives and limits and for freshwater accounting and management purposes." These have been defined by Horizons (Figure 3-1) and may be used as the basis for reviewing the sites in the periphyton montoring programme.

In other regions, representativeness of SOE monitoring sites has been assessed by comparing proportions of sites in different REC classes with the overall coverage of each class in the entire river network (e.g., Greenwood et al. 2013), and such an exercise may be useful in the Horizons region in light of the requirements of the NPS-FM.

Table 3-1: Matrix of monitoring sites falling into three categories of flood frequency and nutrient concentrations. Categories are based on data from the sites from May 2012 to April 2015. Boundaries between categories were defined at natural breaks in the data which separated the sites into three approximately equal groups based on flood frequency and nutrients. The assumption is that the range of values across the sites represents the range within the region. Numbers refer to the the HRC site code shown in the first column (N) of Table 3.2.

			Nutrient concentration (mean DIN in 2012-15, mg/m^3)		
			Low	Medium	High
		Range	< 100	> 100-< 400	> 400
Flood frequency (FRE3, mean annual no. events > 3 x median flow)	High	> 11	1, 2, 3, 27, 37, 60	30, 61, 62	7, 10, 18, 19, 20, 21, 22, 24, 31, 32
	Medium	> 8 ≤11	4, 11, 52, 53, 59	26, 29, 33, 34, 46, 49, 57, 58,	12, 13, 17, 23, 28, 35, 36
	Low	≤ 8	38, 39, 40, 43, 44, 45, 51	9, 47, 48, 50	8, 14

3.2.2 Monitoring procedure

The same monitoring procedure has been used throughout the programme. All monitoring sites were sampled monthly following the methods described in Kilroy et al. (2008, 2010) (based on the RAM-I and RAM-II methods in Biggs & Kilroy (2000)). Briefly, at each site a visual assessment of periphyton was carried out using a Nuova Rade underwater viewer. Estimates of percentage cover were made at five points on each of four transects spaced 10 metres apart. Periphyton was assessed in the following seven categories:

- no cover (clean stones)
- thin film (green or brown colour, slimy texture)
- loose "sludge" (usually brown)
- cohesive mats (usually brown/black, don't fall apart when handled)
- slimy, fragile filaments (usually bright green but can be brown or dark coloured)

Figure 3-1: Freshwater Management Units defined for the Horizons region.

- tough, coarse filaments (usually green or brown)
- cyanobacteria mats (usually dominated by the potentially toxic taxon *Phormidium*: smooth black/brown mats with a white/grey underside) were added as an additional category (a subdivision of cohesive mats) (from May 2011).

Following each visual assessment a sample was collected for analysis for chlorophyll *a* content. Periphyton was scrubbed/scraped from a defined area on each of 10 rocks (from one or two transects) and all 10 samples were pooled into a single sample. One objective of both recording visual cover and collecting samples for chlorophyll *a* analysis was to calibrate the relationship between the two estimates. At sites where the relationship is close, survey cost-effectiveness can be improved by carrying out visual assessments rather than collecting samples for biomass analysis.

A visual assessment of substrate composition was conducted on each survey occasion, where possible. Additional data available included a flow record for most sites, monthly concentrations of DIN and DRP, and measurements of other water quality variables (see below).

3.3 Data

Periphyton data from 62 sites were initially available for analysis (Table 3-2). Surveys commenced in December 2008 at 48 sites and continued monthly until April 2015, making a total of 77 surveys per site. Six sites were added during 2010-2011, three in 2012 and five in 2013. Periphyton monitoring was conducted fortnightly at the five sites added in 2013, and fortnightly monitoring started at three existing sites at the same time. Data from these three sites were reduced to monthly for calculation of some average values, to ensure consistency of data in comparisons over time. One site (Tiraumea d/s Mangatainoka confl, site 25) had only a 20-month record from December 2008 to August 2010 and was omitted from the analyses. The final dataset therefore contained data from 61 sites.

All sites had dates with missing data, when flows were too high or water clarity too low to conduct a survey or collect samples. The overall rate of missing data (across all sites) was 7% for chlorophyll *a* samples, and 15% for periphyton visual assessments. The highest proportions of missing data (up to 31%) were from sites in main stems of the Manawatu and Rangitikei Rivers.

A flow record was available for 53 of the 61 periphyton monitoring sites (Table 3-2). In some cases multiple periphyton sites were linked to a single flow recording site, but flow sites were generally within 10 km of the periphyton monitoring sites. An exception was that site 1 (makakahi_doc) was linked to flow recorded at Makakahi at Hamua, ~35 km downstream. We used the record of daily mean flows at each of the 30 flow recording sites to calculate a series of hydrological metrics to link to each site and periphyton survey date. Selected metrics were used in the subsequent analyses of periphyton state and trend (Section 4) and seasonality (Section 6).

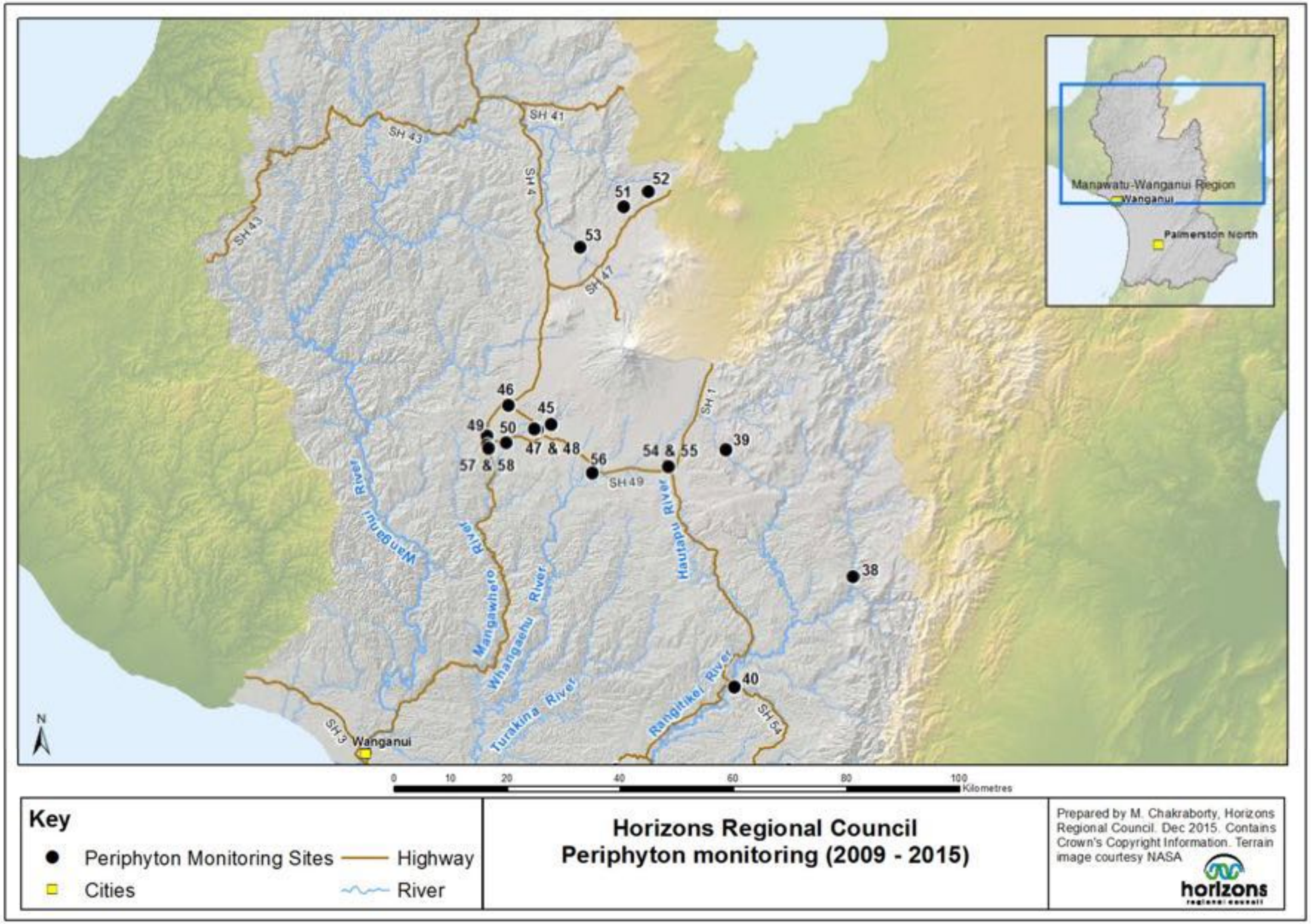
All sites had linked water quality data. In >90% of cases, water quality measurements and samples were collected on the same day as the periphyton samples. A further 5.2% of water quality samples were collected on the day before or day after the periphyton survey. Water quality variables included DIN, DRP, total dissolved phosphorus (TDP), total phosphorus (TP), total nitrogen (TN), and non-nutrient variables including water conductivity and total suspended solids (TSS). Refer to Appendix A for a summary of water quality at each site.

Nine sites were downstream of point-source discharges. These sites were treated as a separate group the assessments of periphyton state and compliance with thresholds and standards.

Table 3-2: List of periphyton monitoring sites used in the analysis, with location details. LSC class is the Life-supporting capacity class assigned by Horizons (see text) and Sub-region is the One Plan management unit for the site. PSD = yes means a point-source discharge is upstream of the site. Monitoring continued until April 2015 at all sites except for Site 25, tiraumea_ds_mangat. (**), where monitoring ceased in October 2010. Refer to map (Figure 3-1) for distribution within the region. Sites are in order of the HRC site number (N), which sorts sites from upstream to downstream in successive catchments. FF-N is the flow-nutrient category, as defined in Table 3-1. L = low group, M = medium group, H = high group, for flood frequency then nutrients. For example, sites in group HL have high flood frequency and low nutrients.

N	Site name	Abbreviation*	E	N	LSC	Sub-zone	PSD	start	Flow site	FF_N
1	Makakahi at DOC Reserve	makakahi_doc	2729456	6051399	HM	Mana_8d	no	13-Aug-13	Makakahi at Hamua	HL
2	Mangatainoka at Putara	mangatainoka_putara	2725500	6055099	UHS	Mana_8a	no	9-Dec-08	Mangatainoka at Larsens Br	HL
3	Mangatainoka at Larsons Road	mangatainoka_lars	2730878	6059626	UHS	Mana_8a	no	13-Aug-13	Mangatainoka at Larsons Road	HL
4	Tamaki at Reserve	tamaki_res	2768598	6115899	UHS	Mana_3	no	10-Dec-08	Tamaki at Water Supply Weir	ML
5	Mangatera u/s Dannevirke STP	mangatera_us_dan	2773957	6104367	HM	Mana_2b	no	10-Dec-08	NO FLOW SITE	
6	Mangatera d/s Dannevirke STP	mangatera_ds_dan	2773970	6104182	HM	Mana_2b	yes	10-Dec-08	NO FLOW SITE	
7	Mangatainoka at Hukanui	mangatainoka_huk	2740072	6067395	HM	Mana_8b	no	13-Aug-13	Mangatainoka at Larsons Road	HH
8	Kumeti at Te Rehunga	kumeti_tr	2766500	6104991	UHS	Mana_4	no	10-Dec-08	Kumeti at Te Rehunga	LH
9	Manawatu at Weber Road	manawatu_weber	2775096	6102500	HM	Mana_1a	no	10-Dec-08	Manawatu at Weber Rd	LM
10	Makakahi at Hamua	makakahi_ham	2742599	6067399	HM	Mana_8d	no	9-Dec-08	Makakahi at Hamua	HH
11	Oroua at Apiti Gorge	oroua_apiti	2760199	6136499	HM	Mana_12a	no	11-Dec-08	Oroua at Almadale	ML
12	Tamaki at Stephensons	tamaki_ste	2770914	6101859	HM	Mana_5b	no	10-Dec-08	Tamaki at Stephensons	MH
13	Oruakeretaki at SH2	oruakeretaki_sh2	2768237	6101204	HM	Mana_5d	no	10-Dec-08	Oruakeretaki at SH2(Napier)	MH
14	Makuri at Tuscan Hills	makuri_tuscan	2758500	6071501	ULi	Mana_7d	no	19-Dec-08	Makuri at Tuscan Hills	LH
15	Pohangina at Piripiri	pohangina_pir	2760843	6123817	UHS	Mana_10b	no	15-Dec-08	NO FLOW SITE	
16	Mangatainoka at Scarborough Konini Road	mangatainoka_scarb	2747160	6077271	HM	Mana_8b	no	13-Aug-13	Mangatainoka at Larsens Br	
17	Tiraumea at Ngaturi	tiraumea_nga	2757748	6077929	HSS	Mana_7b	no	19-Dec-08	Tiraumea at Ngaturi	MH
18	Mangatainoka at Pahiatua Town Bridge	mangatainoka_pahiatua	2750283	6080248	HM	Mana_8c	no	13-Aug-13	Mangatainoka at Pahiatua	HH
21	Mangatainoka u/s Pahiatua STP	mangatainoka_us_pah	2751269	6081437	HM	Mana_8c	no	9-Dec-08	Mangatainoka at Pahiatua	HH
22	Mangatainoka d/s Pahiatua STP	mangatainoka_ds_pah	2751656	6081282	HM	Mana_8c	yes	9-Dec-08	Mangatainoka at Pahiatua	HH
19	Mangatainoka at SH2	mangatainoka_sh2	2753015	6082998	HM	Mana_8c	no	9-Dec-08	Mangatainoka at Pahiatua	HH
20	Mangatainoka d/s DB Breweries	mangatainoka_ds_db	2753600	6083400	HM	Mana_8c	yes	9-Dec-08	Mangatainoka at Pahiatua	HH
23	Manawatu at Hopelands	manawatu_hop	2761799	6089499	HM	Mana_5a	no	11-Dec-08	Manawatu at Hopelands	MH
24	Mangatainoka u/s Tiraumea confl	mangatainoka_us_tir	2755838	6085354	HM	Mana_8c	no	14-Jan-11	Mangatainoka at Pahiatua	HH
25	Tiraumea d/s Mangatainoka confl**	tiraumea_ds_mangat	2755829	6085578	HSS	Mana_7b	no	19-Dec-08	Tiraumea at Ngaturi	
26	Mangapapa at Troup Road	mangapapa_troup	2752115	6092008	HM	Mana_9b	no	19-Dec-08	Mangapapa at Troup Rd	MM
27	Pohangina at Mais Reach	pohangina_mais	2747118	6105154	HM	Mana_10c	no	15-Dec-08	Pohangina at Mais Reach	HL
28	Manawatu at Upper Gorge	manawatu_ug	2749590	6092568	HM	Mana_9a	no	11-Dec-08	Manawatu at Upper Gorge	MH
29	Oroua at Almadale	oroua_almadale	2736799	6110997	HM	Mana_12a	no	11-Dec-08	Oroua at Almadale	MM

N	Site name	Abbreviation*	E	N	LSC	Sub-zone	PSD	start	Flow site	FF_N
30	Oroua u/s Feilding STP	oroua_us_fei	2726681	6101660	HM	Mana_12b	no	11-Dec-08	Oroua at Kawa Wool (modelled)	HM
31	Oroua d/s Feilding STP	oroua_ds_fei	2726109	6101599	HM	Mana_12b	yes	11-Dec-08	Oroua at Kawa Wool (modelled)	HH
32	Oroua at Awahuri Bridge	oroua_awahuri	2724600	6100103	LM	Mana_12c	no	11-Dec-08	Oroua at Kawa Wool (modelled)	HH
33	Manawatu at Teachers College	manawatu_tc	2734398	6088683	HM	Mana_10a	no	15-Dec-08	Manawatu at Teachers College	MM
34	Manawatu u/s PNCC STP	manawatu_us_pncc	2729885	6087742	HM	Mana_11a	no	15-Dec-08	Manawatu at Teachers College	MM
35	Manawatu d/s PNCC STP	manawatu_ds_pncc	2729400	6086801	HM	Mana_11a	yes	15-Dec-08	Manawatu at Teachers College	MH
36	Manawatu at Opiki	manawatu_opik	2720025	6082268	HM	Mana_11a	no	18-Dec-08	Manawatu at Teachers College	MH
37	Tokomaru at Horseshoe Bend	tokomaru_hb	2724295	6076368	LM	Mana_13c	no	18-Dec-08	Tokomaru at RiverlandFarm	HL
38	Rangitikei at Pukeokahu	rangitikei_puk	2771500	6170599	UHS	Rang_2a	no	16-Dec-08	Rangitikei at Pukeokahu	LL
39	Moawhango at Waiouru	moawhango_waiouru	2749046	6193020	UVM	Rang_2d	no	23-Sep-10	Moawhango at Waiouru	LL
40	Rangitikei at Mangaweka	rangitikei_man	2750500	6151099	HM	Rang_3a	no	16-Dec-08	Rangitikei at Mangaweka	LL
41	Porewa u/s Hunterville STP	porewa_us_hun	2729637	6136845	HSS	Rang_4c	no	3-Oct-12	NO FLOW SITE	
42	Porewa d/s Hunterville STP	porewa_ds_hun	2729508	6136457	HSS	Rang_4c	yes	3-Oct-12	NO FLOW SITE	
43	Rangitikei at Onepuhi	rangitikei_one	2721393	6122388	HM	Rang_3a	no	19-Dec-08	Rangitikei at Onepuhi	LL
44	Rangitikei at McKelvies	rangitikei_mk	2705863	6099094	HM	Rang_4a	no	19-Dec-08	Rangitikei at McKelvies	LL
45	Mangawhero at DoC	mangawhero_doc	2718100	6197500	UVA	Whau_3d	no	17-Dec-08	Mangawhero at Pakihi Rd Br	LL
46	Makotuku at SH49	makotuku_sh49	2710500	6200899	UVA	Whau_3b	no	17-Dec-08	Makotuku at SH 49A Br	MM
47	Mangawhero u/s Ohakune STP	mangawhero_us_oha	2715636	6196590	UVA	Whau_3d	no	17-Dec-08	Mangawhero at Pakihi Rd Br	LM
48	Mangawhero d/s Ohakune STP	mangawhero_ds_oha	2715200	6196694	UVA	Whau_3d	yes	17-Dec-08	Mangawhero at Pakihi Rd Br	LM
49	Makotuku at Raetihi	makotuku_rae	2706701	6195500	UVA	Whau_3c	no	17-Dec-08	Makotuku at Raetihi	MM
50	Mangawhero at Pakihi Road Bridge	mangawhero_pakihi	2710100	6194301	UVA	Whau_3d	no	17-Dec-08	Mangawhero at Pakihi Rd Br	LM
51	Mangatepopo d/s Genesis Intake	mangatepopo_gi	2731007	6236021	UVA	Whai_1	no	24-Sep-10	Mangatepopo Intake at Spillweir	LL
52	Whanganui d/s Genesis Intake	whanganui_ds_gen	2735298	6238634	UVA	Whai_1	no	24-Sep-10	Whanganui R. at D/S Intake	ML
53	Whakapapa d/s Genesis Intake	whakapapa_ds_gen	2723315	6228846	UVA	Whai_2b	no	24-Sep-10	Whakapapa at Footbridge	ML
54	Waitangi u/s Waiouru STP	waitangi_us_wai	2738867	6190310	UVM	Whau_1b	no	16-Dec-08	NO FLOW SITE	
55	Waitangi d/s Waiouru STP	waitangi_ds_wai	2738879	6190109	UVM	Whau_1b	yes	16-Dec-08	NO FLOW SITE	
56	Tokiahuru at Karioi	tokiahuru_kar	2725435	6188945	UVA	Whau_1c	no	17-Dec-08	NO FLOW SITE	
57	Makotuku u/s Raetihi STP	makotuku_us_rae	2706764	6193797	UVA	Whau_3c	no	19-Jul-10	Makotuku at Raetihi	MM
58	Makotuku d/s Raetihi STP	makotuku_ds_rae	2707001	6193299	UVA	Whau_3c	yes	17-Dec-08	Makotuku at Raetihi	MM
59	Waikawa at North Manakau Road	waikawa_nmr	2698900	6052801	HM	West_9a	no	18-Dec-08	Waikawa at Nth Manakau Rd	ML
60	Ohau at Gladstone Reserve	ohau_gladstone	2707799	6057500	UHS	Ohau_1a	no	18-Dec-08	Ohau at Rongomatane	HL
61	Ohau at SH1	ohau_sh1	2699599	6056900	HM	Ohau_1b	no	18-Dec-08	Ohau at Rongomatane	HM
62	Ohau at Haines Farm	ohau_haines	2695804	6057886	HM	Ohau_1b	no	17-Dec-12	Ohau at Rongomatane	HM


Horizons Regional Council
Periphyton monitoring (2009 - 2015)
Key
Periphyton Monitoring Sites
Highway
Cities
River
Prepared by M. Chakraborty, Horizons Regional Council. Dec 2015. Contains Crown's Copyright Information. Terrain image courtesy NASA
horizons
Manawatu-Wanganui Region
Wanganui
Palmerston North
0
10
20
40
60
80
100
Kilometres
N
Wanganui
SH 3
SH 43
SH 41
SH 4
SH 47
SH 1
SH 49
SH 54
Wanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
51
52
53
46
45
49
50
47 & 48
57 & 58
56
54 & 55
39
38
40

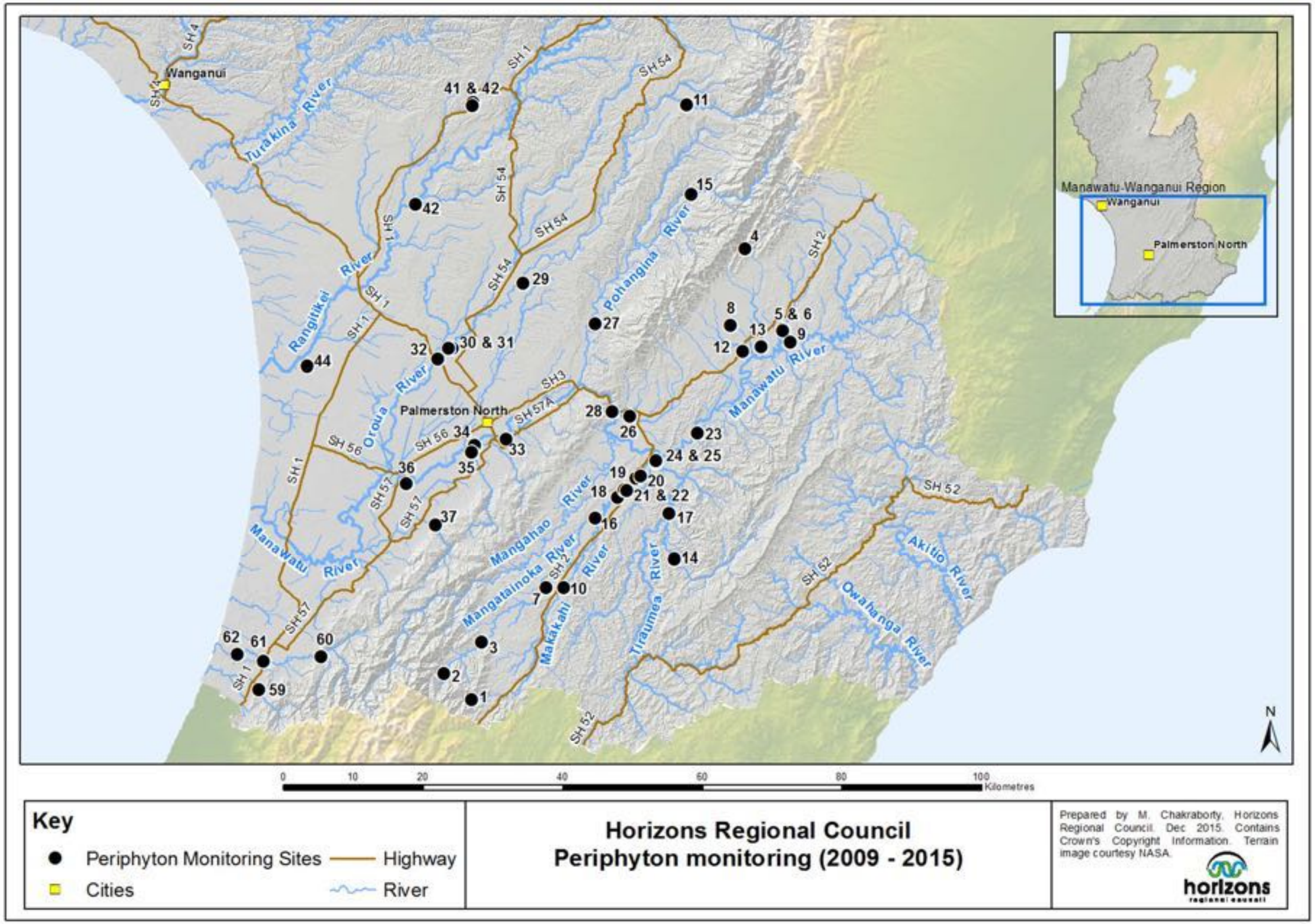


Figure 3-2: Locations of periphyton monitoring sites in the Manawatu-Whanganui Region northern area (top) and southern area (bottom). For key to site numbers, refer to Table 3-1.

4 State and trends of periphyton

Key messages

1. State for chlorophyll *a* and % cover by mats and filaments

Periphyton state was assessed at each site as chlorophyll *a*, and % cover by mats and filaments, split into five categories from Vlow (i.e., good) to VHigh (i.e., poor).

State as assessed by chlorophyll *a* represents a different river value (i.e., ecosystem health) from that assessed by % cover (aesthetics and recreation). The two assessments do not necessarily correspond.

Mean chlorophyll *a* calculated from the six-year dataset (47 sites) was in the VLow or Low categories (i.e., < 5 or > 5< 15 mg/m^2, respectively) at 50% the sites. No sites had VHigh mean chlorophyll *a* (> 120 mg/m^2) and 13% were in the High category (>50 <120 mg/m^2).

Over the most recent three years (May 2012 to April 2015), mean chlorophyll *a* was Low or VLow at 40% of sites and High or VHigh at 19%. This indicated that chlorophyll *a* had increased at some sites since 2008.

In contrast, the occurrence of High and VHigh cover by both mats and filaments from May 2012 to April 2015 was 11% and 45%, respectively, which was lower than across the whole monitoring period (25% and 51%).

An analysis of river flows from 2008 to 2015 indicated a general trend towards lower flows later in the period. Therefore increases in chlorophyll *a* likely reflected climatic change. Lower cover by mats and filaments at some sites in the most recent three years could reflect changes in algal composition linked to flows.

In most catchments, there was a downstream gradient of increasing mean chlorophyll *a*. Exceptions included a cluster of sites in the mid-Manawatu catchment (including the lower Mangatainoka, Makuri and Tiraumea Rivers) and sites in the upper Porewa River, all of which had higher than expected chlorophyll *a* given their location in the catchment.

Sites below point-source discharges were generally placed in a state category lower (i.e., higher chlorophyll *a*) than the paired site upstream.

Sites in the High and VHigh mean chlorophyll *a* state groups (i.e., poor conditions) (during 2012 to 2015) were generally at sites whose catchments comprised more than 60% under intensive agriculture and where dissolved inorganic nitrogen (DIN) concentrations exceeded about 300 mg/m^3.

Most sites in the VLow chlorophyll *a* state group had DIN of less than 100 mg/m^3, conductivity of less than 80 µS/cm, and variable proportions of their catchments under intensive agriculture.

Continued

2. Trends in chlorophyll *a* and % cover by mats and filaments

Without accounting for the effects of the change in flow conditions over the monitoring period, chlorophyll *a* increased between December 2008 and May 2015 at 56% of sites and did not decline at any sites. Over the same period % cover by mats and filaments declined at 27% and 2%, and increased at 0% and 10% of sites, respectively.

When flow was taken into account chlorophyll *a* increased at 15% of sites and there was no evidence for a trend at the remaining 85%. In contrast % cover by mats decreased at 24% and a trend was not detectable at 76% of sites; % cover by filaments increased at 5% and decreased at 7% a trend was not detectable at 88% of sites.

Trends of increasing chlorophyll *a* were recorded only at sites with low chlorophyll *a* (in the Low or VLow state categories). Trends of decreasing cover by mats occurred across all state categories, and trends (increasing and descreasing) in filaments were at sites with High and VHigh cover.

Opposite trends in chlorophyll *a*, % mats or % filaments at five sites were likely to have been caused by shifts in periphyton community composition over time.

Both periphyton and dissolved reactive phosphorus (DRP) declined between 2008 and 2015 at two sites (sites 21, 34) and increased at two sites (38, 46), suggesting possible cause-effect relationships at these sites. Opposing trends in periphyton and nutrient concentrations were observed at two sites (40, 49).

3. State and trends for % cover by cyanobacteria

Cyanobacteria monitoring began in May 2011. Periphyton state as % cover by cyanobacteria was assessed in five state categories from VLow (no occurrences) to VHigh (>20% cover in one of every 12 surveys).

Over four years of monitoring, cyanobacteria cover was VLow at seven of 53 sites and VHigh at eight sites. All sites in the High and VHigh categories were either in the lower Mangatainoka and Tiraumea catchments or at sites below point-source discharges. Most sites in the Rangitikei, Oroua, and Pohangina catchments had VLow or Low cover.

The record was too short for a formal trend analysis. However, state categories assigned using data from May 2012 to April 2015 showed fewer sites with VHigh cover and more sites with Low or VLow cover indicating that some sites had more cyanobacteria in 2011-12 than in subsequent years.

Sites in the High and VHigh categories almost always had DIN concentrations greater than 620 mg/m^3 and at least 60% of their catchments in farmland. The exception was Tokomaru at Horseshoe Bend (mean DIN < 80 mg/m^3 and less than 1% farmland).

4.1 Introduction

The "state" of a water quality or biological variable at a particular site is usually determined by comparing the median or mean value of that variable over the period of interest with recognised thresholds or standards that have been set to protect certain river values. Alternatively, the comparison could be with medians representing "reference" state in a river, or representing the variable of interest in another region or a wider area. A comparison of periphyton at sites in the Manawatu-Whanganui region with the One Plan targets set for individual sites, and NPS-FM bands for periphyton targets, is provided in Section 5 of this report. In this section, the state of periphyton is assessed in more detail, especially at the lower end of the range of periphyton. Ideally, an assessment of current state would incorporate observations over a period long enough for hydrological conditions to be considered average in the context of long-term hydrology, yet short enough to be considered "current". In the analysis below, we consider two periods to illustrate the effect of length of record on the assessment.

Periphyton standing crop is a dynamic variable in rivers, and is influenced by a range of external factors. Apparent trends in periphyton can be caused by natural shifts in hydrological conditions over time, because river flow is the primary driver of variability of periphyton standing crop (Biggs & Close 1989). From a management perspective, trends attributable to changes in other factors, such as nutrient supply or fine sediment deposition, are of most interest, because these may result from activities in the river catchment.

In the following analysis, we assessed trends over the region and at each site in the context of the flow record with the aim of identifying overall trends and also any trends that may have occurred independently of flow conditions.

The state and trends of three different measures of periphyton were considered: chlorophyll *a*, representing ecosystem health, and percentage cover by mats and filaments, both representing aesthetic and recreational values. River state was also assessed in terms of percentage cover by the potentially toxic cyanobacterium, *Phormidium*, representing human and animal health values.

4.2 Methods

4.2.1 Hydrological context

To provide a context for interpreting the state and trend results, we first compared hydrological conditions in each year of the Horizons dataset with long-term conditions. The following flow metrics were calculated from the record of daily mean flows at each of the 30 hydrological recording sites associated with one or more periphyton monitoring sites, for each hydrological year (i.e., July to June) of the monitoring period (2008-09 to 2014-15), for the whole monitoring period (2008-15) and for the longer term (2000-2015):

- mean and median flow;
- annual frequency of high flow events exceeding *n* x median flow, where *n* = 2, 3, 5, 7 and 10;
- total annual duration (days) when flow exceeded *n* x median flow, where *n* = 2, 3, 5, 7 and 10.

Metrics in each period were compared with the 15-year period from July 2000 to June 2015. Departure from the long-term average for each flow metric was calculated as a percentage of the long-term value at each site. Overall regional departure from the long-term average was compared between years using the average of the percentage departures across all sites.

In addition, we used the Seasonal Kendall trend test (Time Trends v. 5 software; http://www.jowettconsulting.co.nz/home/time-1, and see Section 4.2.3 below) to identify whether there were detectable trends in mean monthly discharge at each of the 30 sites over the period of the periphyton monitoring programme.

4.2.2 Periphyton state

In the present dataset, we determined river state in terms of periphyton using mean and median chlorophyll *a*, and the 92nd percentile of percentage cover by mats, filaments and cyanobacteria. These variables describe river state in relation to, respectively, ecosystem health, aesthetics and recreational values, and human and animal health values. The 92nd percentile is the amount that is not exceeded by 92% of all samples, or one in 12 samples. This statistic is also used to assess compliance with the NPS-FM (see Section 6). The 92nd percentile is more practical for assessing state in % cover data than the median, because the sporadic nature of cover led to high proportions of median values of zero (33%, 48% and over 70% for mats, filaments and cyanobacteria, respectively), which provided no information about the extent of cover in the 50% of samples above the median.

Five bands were defined for each measure to allow coding of the sites from best state to worst state. The high chlorophyll *a* and % cover bands used were based on thresholds in the MfE guideline (2000), and later the One Plan and the NPS-FM (Table 4-1). In setting the thresholds for the low-biomass bands for mean and median chlorophyll *a*, we also took into consideration the likely dominant cover type (for chlorophyll *a*), and the relationships between chlorophyll *a* and invertebrate indices identified by Matheson et al. (2016). The low concentration thresholds of 1 and 10 mg/m^2 used by Matheson et al. (2016) (their Figure 3-7) were amended because so few sites in the Horizons dataset fell into the >1 mg/m^2 group. Both mean and median metrics were used to differentiate sites at which chlorophyll *a* is occasionally very high (i.e., exceeding guidelines), which would inflate the mean value.

The thresholds for % cover by mats and filaments represent a range from barely visible (set at 5% and 2.5% respectively, because mats tend to be less visible than green filaments) to exceeding the 60% and 30% targets in the One Plan. Based on the conversion factors for chlorophyll *a* derived in Kilroy et al. (2010) these thresholds for peak values (92nd percentile) roughly correspond to the chlorophyll *a* thresholds, assuming that no other algae are present. For example, 100% cover assessed as mats (i.e., the sludge or mats category) is equivalent on average to approximately 90 mg/m^2 chlorophyll *a*. Therefore 5% mats would account for approximately 5 mg/m^2 chlorophyll *a*.

Two periods were considered for assessing periphyton state: the entire dataset (maximum of six years and four months) and the most recent three years (May 2012 to April 2015). A three-year period was selected because the period represents current data, but includes sufficient samples for a statistically robust assessment.

To place the Horizons sites in a national context, the 92nd percentile percentage cover by mats and filaments at all sites in the National River Water Quality Monitoring Network (NRWQN) were categorised in the same way, using data from January 2012 to December 2014 (the most recent three years of compiled data available). Percentages of sites in each state category were compared in the two datasets.

Table 4-1: Definitions of periphyton state in bands from very low to very high chlorophyll *a* and percent cover. Very low represents the best state (i.e., least periphyton) and very high represents the worst state (most periphyton).

	Range of values in coding category					Justification for bands
Periphyton metric	VLow	Low	Mod	High	VHigh	
Mean chlorophyll *a*	<5	5 - <15	15 - <50	50 - <120	>120	Vlow and Low thresholds in range for high quality invertebrates and dominant cover by film. Low – Mod threshold set at mean value to protect biodiversity (Biggs 2000a). VHigh set at One Plan middle range.
Median chlorophyll *a*	<3	3 - <15	15 - <50	50 - <120	>120	As above. VLow – Low threshold lower because mean tends to be higher than median if maximum is high.
92nd percentile, % mats	<5	5 - <15	15 - <30	30 - <60	>60	VLow starts at barely visible peak cover, approximately equivalent to 5 mg/m^2 if no other algae present. VHigh band uses threshold for protection of aesthetic/recreation values in Biggs (2000a).
92nd percentile, % filaments	<2.5	2.5 - <5	5 - <15	15 - <30	>30	As above for mats – range Vlow to Mod covers barely visible to easily visible cover. VHigh band uses threshold for protection of aesthetic/recreation and trout habitat/angling values in Biggs (2000a).
92nd percentile, % cyanobacteria	0	0-<2	2-<10	10-<20	>20	The VLow band is effectively extremely low or no occurrence of cyanobacteria; VHigh is exceedance of the "alert" level in the cyanobacteria guidelines.

4.2.3 Periphyton trends

Trends in periphyton chlorophyll *a* and percentage cover by mats and filaments over time were calculated using the non-parametric Seasonal Kendall trend test using Time Trends software (v. 5). The test was considered appropriate for periphyton because periphyton abundance typically shows seasonal patterns. The software calculates the Sen Slope (the median annual slope of all possible pairs of values in each season, where each season is a month), then applies a Seasonal Kendall test of the hypothesis that there is no monotonic trend in the data (Hirsch et al. 1982).

Trends were assessed using the monthly time series at sites where the full six years of data were available (total of 47 sites, 41 of which have flow records). At each site, trends were calculated using the raw dataset, using two methods. First, the classical Seasonal Kendall trend test was applied (as used by Snelder et al. 2014a). Trends were estimated both unadjusted and flow-adjusted data, applying an appropriate flow variable at each site, as described below. Second, we ran the Seasonal Kendall trend test using unadjusted data, and then applied an equivalence test (see below) to determine whether identified trends were ecological or practically meaningful.

Preliminary analyses were also run on the shorter time series of % cover by cyanobacteria. However, in most cases, the results were indeterminate because the record was too short. Therefore trends in cyanobacteria cover are not considered further in this report.

Classical trend testing with flow adjustment of time series

Flow at the time of sampling is commonly included as a covariate in trend analyses on time series of water quality variables such as nutrient concentrations because water quality variables often vary predictably as flow changes (e.g., McDiffett et al. 1989). The adjustment process compensates for the effect of flows on the variable in question so that the trends identified are then independent of flows. Because relationships with flow vary from site to site, flow-adjusted trends should be interpreted with care. In particular, the percentage of variability explained by flow should always be considered.

Flow at the time of sampling can be significantly correlated with chlorophyll *a*. However, the hydrological metrics more *directly* related to periphyton standing crop are the magnitudes of high flows (which remove periphyton) and the length of the flood-free periods prior to each survey (which allow periphyton to accumulate; i.e., the accrual period). The size of the high flow that resets periphyton before accrual commences differs between sites. The correlation between chlorophyll *a* and flow on the day of sampling likely arises because flow on any given day may also be correlated with the time elapsed since a high flow.

In the present analysis, we accounted for both accrual period and the size of the flow required to reset periphyton biomass by conducting a series of trend analyses using accrual-period-adjusted data, where accrual periods were the variable AP_*n*xmed (days since a flood greater than *n* times median flow, where *n* = 1.5, 2, 3, 5, 7, 9, 10, 12 and 15). We used the Seasonal Kendall trend test in Time Trends v. 5, which tests the null hypothesis that there is no monotonic trend, while adjusting for seasonal changes. Accrual-time adjustment was performed in Time Trends using the non-parametric method LOWESS (LOcally WEighted Scatterplot Smoothing) with a 30% span, to quantify the relationship between accrual time and chlorophyll *a* and % cover. All data-points in the record were then adjusted according to the accrual time at that point so that the adjusted value = raw value – smoothed value + median value (where the smoothed value is predicted from the LOWESS relationship) (Smith et al. 1996). The relevant accrual period at each site was taken to be the one that explained most variability in the periphyton metric (either chlorophyll *a* or % mats or % filaments).

Equivalence tests

Traditional significance tests in trend testing are based on the null hypothesis of no trend (e.g., as performed by Snelder et al. 2014a). The test can demonstrate that a trend shows significant departure from zero, usually at the 5% level (i.e., less than 5% probability of the trend having occurred by chance, leading to rejection of the null hypothesis). However, failure to reject the null hypothesis result does not prove that there is no trend because high variability of data within and between months could lead to an insignificant Z-statistic (which is derived from the sum of monthly statistics comparing the slope of all pairs of values within that month). In this case, additional observations may increase the chances of the test returning a significant result. Hence rejection of the null hypothesis of no trend may be more to do with increased numbers of observations, than with difference in the magnitude of within-month pairwise differences). An alternative approach is to use equivalence tests, which include testing the null hypothesis that there is a trend by comparing an equivalence interval (slopes of trends that would, *a priori*, be considered important) with the confidence intervals around the slope of the data being tested (Dixon & Pechmann 2005). Equivalence tests determine whether the trend falls within limits that are considered to be to be ecologically or practically meaningful. The limits must be specified prior to the test.

We ran the trend analyses using equivalence tests using the Seasonally Adjusted trend test routine in TimeTrends software v. 5, which includes an option for applying an equivalence test. The routine addresses the question “is there a practically important change over time?" by testing three hypotheses: (1) H_0, no significant slope to the trend; (2) H_i, slope lies beyond limits (inequivalence); (3) H_e, slope lies within limits (equivalence). Seasonality is accounted for by comparing values within each month of the year. There are five possible outcomes to the test:

1. strong evidence for a practically important trend - beyond equivalence limits (H_0 rejected, H_i not rejected and H_e rejected);
2. moderate evidence for a practically important trend - close to equivalence limits (H_0 rejected, H_i and H_e not rejected);
3. some evidence for a trend, but the trend is trivial when compared to equivalence limits (H_0 and H_i rejected, H_e not rejected);
4. no evidence for a trend (H_0 not rejected, H_i rejected, H_e not rejected);
5. inconclusive - more data required (all three hypothesis not rejected).

The limits for chlorophyll *a* (i.e., change representing a meaningful trend) were set between -3 and +3 mg/m^2 per year. Over five years, a positive trend of this magnitude is equivalent to reaching the threshold for protecting biodiversity values (Biggs 2000a) from a baseline of zero. Another way of looking at it is that an average annual increase or decrease of 3 mg/m^2 over 12 monthly samples could include one or more high peak values that and potentially change the status of the site in terms of the One Plan target or NPS-FM periphyton bands.

The thresholds for a practically or ecologically meaningful annual change in percentage cover by mats or filaments were set at, respectively, 3% and 2%. The chlorophyll *a* content of periphyton mats has been estimated to be 70–120 mg/m^2 (Kilroy et al. 2013). Therefore 3% cover approximates the annual change of 3 mg/m^2 used for chlorophyll *a* (see above). Green filamentous algae has a much higher estimated chlorophyll *a* content of up to 400 mg/m^2. The 2% threshold was adopted because a 2% change in a year is very small, but over six years amounts to a change of over 10% on average, and is likely to represent a noticeable shift in cover. The equivalence tests were run on the raw data only: no flow adjustment was performed.

New approach to water quality trend assessment

In a recent analysis of water quality in New Zealand's lakes and rivers (Larned et al. 2015), trend analyses were performed using a new approach based on the use of confidence intervals around the observed trend and comparison with specified intervals signifying important trends (see Appendix A in Larned et al. 2015). The method followed that set out in McBride et al. (2014) and in Dixon & Pechmann (2005). Time Trends software used in the present analysis generates 5% and 95% confidence slopes for the data (i.e., a confidence interval of 100 (1–2α) % around the Sen Slope of the data). If the confidence interval contains zero, then the conclusion must be that there are insufficient data to detect the direction of any trend. The P-value in traditional test of of the null hypothesis that there is no monotonic trend to the data is therefore not the primary determinant of whether a trend is detectable (see discussion in Apendix A, Larned et al. 2014). In the present analysis we conducted the trend analyses in the traditional way for consistency with previous analyses. We note that P-values < 0.05 (taken as a, the significance level) generally corresponded to 100 (1–2α) % confidence intervals that did not include zero.

4.2.4 Potential role of nutrient concentrations

Assessment of trends in nutrient concentrations was not included in the scope of this report. However, confirmation of nutrient trends over the same period would aid interpretation of the trend results for periphyton. Seasonal Kendall Trend Tests were performed on the time series of monthly DIN and DRP concentrations at each site, both with and without adjustment for mean flow on the date of the survey. Sites showing significant trends in both unadjusted and flow-adjusted data were identified, for qualitative comparison with the results of the periphyton trend analyses.

4.3 Results

4.3.1 Hydrological conditions, 2008 to 2015

Flow metrics in the Horizons region in the monitoring period (2008-15) were, on average, close to the long-term values (2000-15). Averaged mean and median flows over that period were within 1% of the 15-year values (Table 4-2). High-flow events were slightly more frequent over the seven-year period including all the periphyton monitoring dates than over the 15-year period from 2000.

The largest departures from the long-term condition in individual years were in 2010-11, when mean and median flows at over 90% of the sites were greater than the long-term median flow, and in 2012-13, when mean and median flows were less than the long-term median at all sites and 90% of sites, respectively. Average deviations from the long-term state indicate that the annual frequency of flood events defined by a low threshold (2 x median flow) remained relatively stable over the region between 2008 and 2015, but mean and median flows have been lower in the last three years of the periphyton monitoring programme (2011-12 to 2014-15) compared to the first three years (2008-09 to 2010-11), and the duration of flows exceeding moderate (3 x median) and high (7 x median) thresholds has varied widely across years (Figure 4-1).

Table 4-2: Summary comparison of selected flow metrics from 2008-09 to 2014-15 with the long-term average (2000-15). The top panel shows percentage departures from the long-term mean values, using means calculated from all 30 hydrological records linked to periphyton monitoring sites. The lower panel shows the percentage of sites with a flow metric greater than the long-term metric: 50% indicates a similar condition to the long-term mean, on average. 2010-11 (blue highlight) was the wettest year, and 2012-13 (pink highlight) was the driest year. Values for the periphyton monitoring period (2008-15) are also shown at the bottom.

	Mean flow	Median flow	FRE2	FRE3	Percent time >3xmed	Percent time >7xmed
Mean percentage departure from 2000-15 flow metric						
2008-09	10	3	3	3	34	25
2009-10	4	10	1	15	12	-6
2010-11	17	15	2	6	35	58
2011-12	-4	6	30	15	-20	-6
2012-13	-18	-14	-10	-7	-30	-47
2013-14	0	4	16	21	-2	5
2014-15	-5	-1	17	21	-2	-23
2008-15	-0.3	0.6	5.1	5.0	2.2	3.8
Percentage of sites with flow metric greater than the 2000-15 mean						
2008-09	76	48	52	52	90	66
2009-10	69	86	48	72	72	48
2010-11	97	93	59	55	93	97
2011-12	31	72	93	79	10	38
2012-13	0	10	34	28	3	7
2013-14	52	66	79	79	41	55
2014-15	34	34	69	69	24	24
2008-15	38	57	83	66	48	59

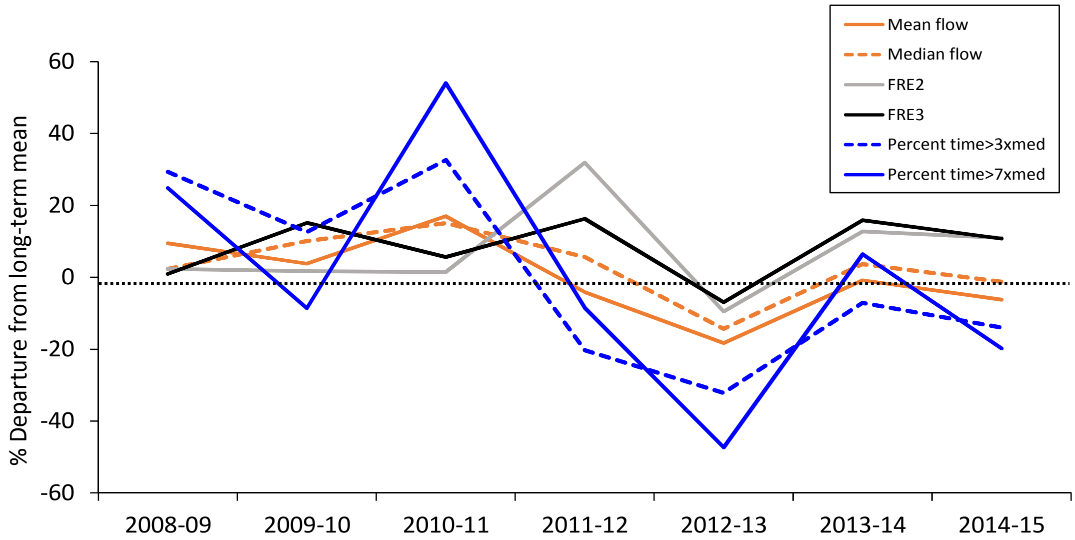


Figure 4-1: Average departures from the long-term mean value of selected flow metrics from 2008-09 to 2014-15. The plot shows the data presented in the top panel of Table 4-3. The plot illustrates how hydrological conditions shifted over the period of the periphyton monitoring programme, although the shift shows up differently depending on the particular metric.

Seasonal Kendall trend tests identified declines ($P < 0.05$) in monthly mean flow at four flow recording sites on three rivers (Makotuku, Rangitikei and Tokomaru) from 2008 to 2015. The average percentage annual decline in median flow at these sites was over 6.5%, compared to a mean annual decline of 3.4% across all 30 flow recording sites. Statistically significant declines ranged from almost 4% per year at Rangitikei @ McKelvies to over 12.5% in the Tokomaru (Table 4-3).

The assessment of a shift from wetter to drier conditions between 2008 and 2015 (including evidence for declining flows at some individual sites) indicated that using flow-adjusted data would be essential to detect trends in periphyton which were attributable to factors other than flows.

Overall, the statistics showed that the hydrological year 2010-11 was unusually wet, and the year 2012-13 unusually dry. These patterns are evident on the hydrographs, although the wet year is more obvious at some sites than others. All seven hydrographs illustrated in Figure 4-2 show the lack of high flows during most of 2012-13. However, highest flood frequency and magnitude was not in 2010-11 at all sites. For example, the records and flow statistics from Makotuku @ Raetihi and Makura @ Tuscan Hills indicate that 2008-09 and 2009-10 were wetter years than 2010-11. While 2010-11 is subsequently referred to as the wettest year, it was not the wettest year at all sites.

Table 4-3: Summary of flow statistics and results of trend analyses at four flow recording sites where a significant trend in monthly mean flow was detected. At all four sites, a significant negative trend ($P < 0.05$) was detected over the period of periphyton monitoring programme. No significant trend in monthly mean flow was detected at the other 26 flow recording sites.

	Period	Flow statistics (m^3/s)				Trend analysis, mean flow	
Flow recording site	(months)	Mean	Max.	Min.	Median	P	PAC
Makotuku at Raetihi	75	1.5	6.6	0.1	1.2	0	-10.0
Rangitikei at McKelvies	76	69.0	275.3	11.4	62.6	0.02	-3.8
Rangitikei at Onepuhi	77	64.2	242.8	11.2	60.7	0.02	-5.1
Tokomaru at Riverland Farm	67	2.3	6.0	0.3	1.9	0.01	-12.8

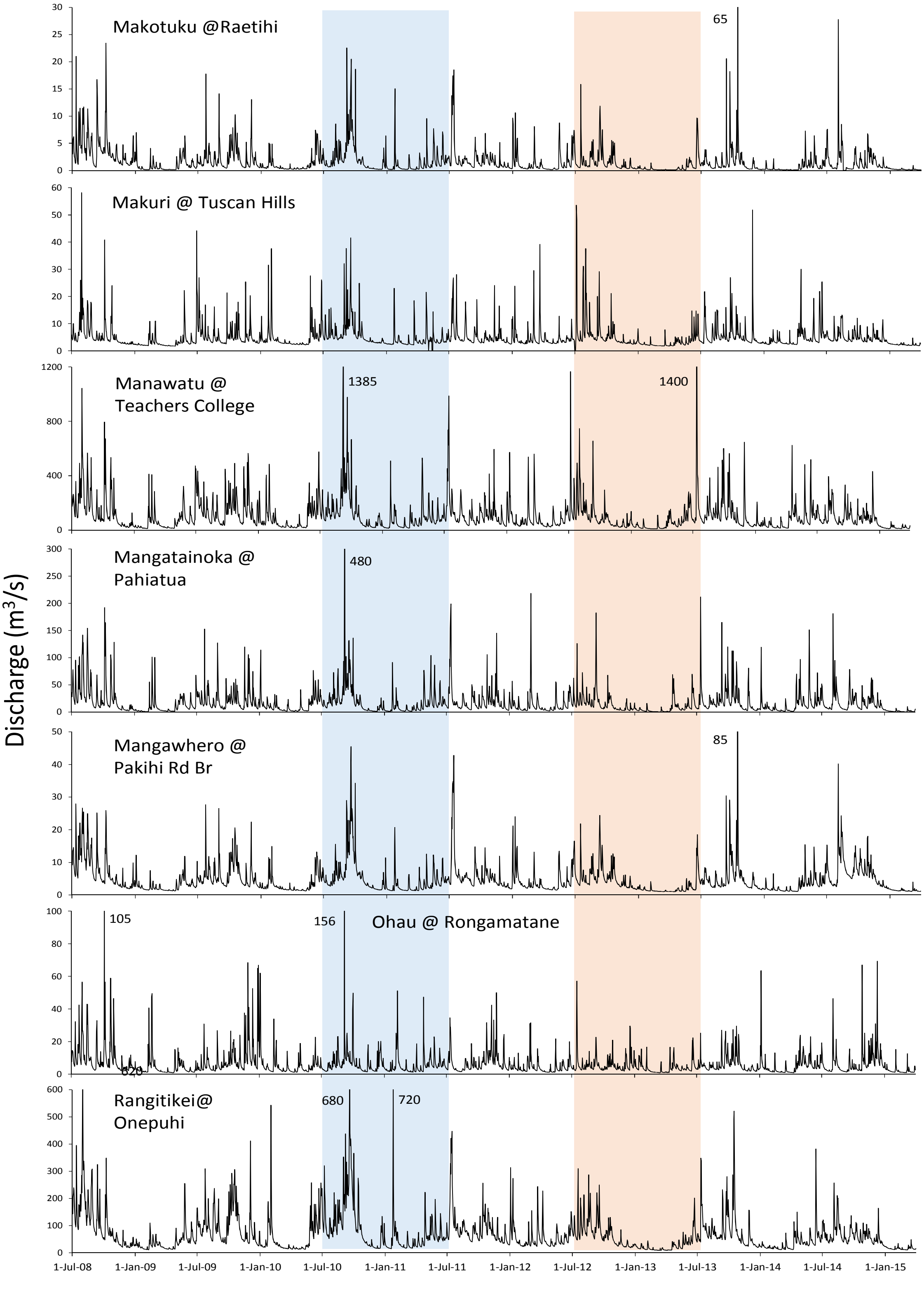


Figure 4-2: Plots of daily mean flows at seven hydrological recording sites linked to periphyton monitoring sites in the Horizons region. Data are shown from July 2008 to April 2015, and cover the entire period of the periphyton monitoring programme. The seven flow records are linked to 21 periphyton sites (see Table 3-1). The vertical axis is truncated on some plots, so that the lower flows can be seen more clearly. Numbers indicate the magnitudes of peak flows that exceeded the maximum on the scale are shown. Blue and orange shading show, respectively, the years identified as wettest (July 2011 to June 2011) and driest (July 2012 to June 2103) across all sites during the monitoring period.

4.3.2 Periphyton state

Chlorophyll *a*, mats and filaments

Chlorophyll *a* and percentage cover by mats and filaments varied across the Manawatu-Whanganui region and within sites (Table 4-4, Figure 4-3, Figure 4-4 to Figure 4-7). Over the whole monitoring period (December 2008 to April 2015), median chlorophyll *a* was in the very low (Vlow) or Low groups at 34 (73%) of the 47 sites having complete data over this period (Table 4-5). In other words, chlorophyll *a* at these sites was less than 3 mg/m^2 for at least 50% of surveys. No sites were placed in the very high (Vhigh) category. For mean chlorophyll *a*, a lower percentage of sites in the Vlow and Low groups (~50% compared to 70% for the median) indicated that some sites had occasional high chlorophyll *a* that increased the mean. Only two sites had persistent high cover by mats (site 39, moawhango_waiouru, and site 49, makotuku_rae). In contrast, over 50% of sites were in the High or Vhigh groups for percentage cover by filaments (Table 4-4, Table 4-5).

In the southern part of the region there was a general spatial pattern of increasing chlorophyll *a* (both mean and median) in a downstream direction in most catchments, except for an obvious cluster of sites with moderate to high chlorophyll *a* (sites 17 to 24), in the mid-Manawatu catchment and including sites in the lower Mangatainoka and Tiraumea Rivers (Figure 4-4, Figure 4-5). In the northern part of the region, most sites are in the upper reaches of rivers and therefore upstream - downstream gradients are less clear. Over the whole region, sites below point-source discharges were placed in a state category lower (i.e. higher chlorophyll *a*) than the paired site upstream. Sites 5 and 6 (mangatera_us_dan and mangatera_ds_dan) were exceptions, with the same state at both sites.

The spatial pattern for chlorophyll *a* was not reflected in state as assessed by percentage cover by mats and filaments. Several headwater sites (e.g., sites 10, makakahi_ham; 14, makuri_tuscan; and 39, moawhango_waiouru; Figure 4-6) were placed in the two worst categories for mats (Figure 4-6). For filaments, although six of the eight sites downstream of discharges were placed in the worst state category and their upstream sites were generally better, several sites well upstream in catchments were also in the worst category (e.g., sites 10, makakahi_ham; 40, rangitikei_man) (Figure 4-7).

State calculated over the last three years (May 2012 to April 2015) generally suggests a possible increase in chlorophyll *a* at some sites compared to the state calculated over the whole monitoring period, but an improvement in terms of percentage cover by mats and filaments compared to the whole monitoring period (Table 4-5 and see maps in Appendix B). Changes at individual sites are summarised in Table 4-6. This highlights that no individual sites showed improved state in terms of either median or mean chlorophyll *a* when state was calculated using data from 2012-15 compared to 2008-15; nineteen (40%) and 10 (21%) sites, respectively, were in a lower state band in 2012-15. In contrast, there were improvements in terms of % cover by mats and filaments at 30 (64%) and 15 (32%) sites respectively, and few cases of movement into a category with worse state (i.e., higher peak cover) (Table 4-6).

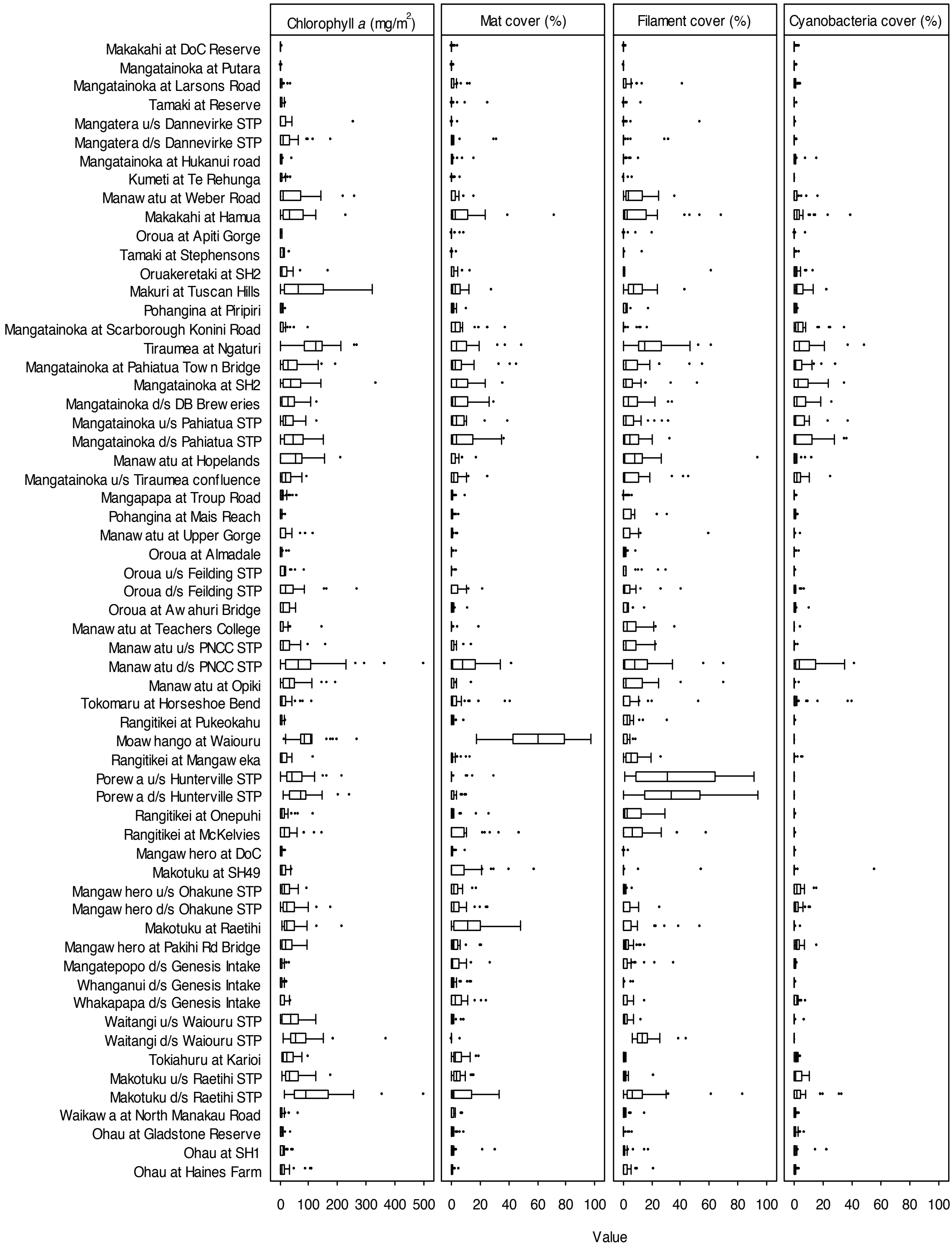


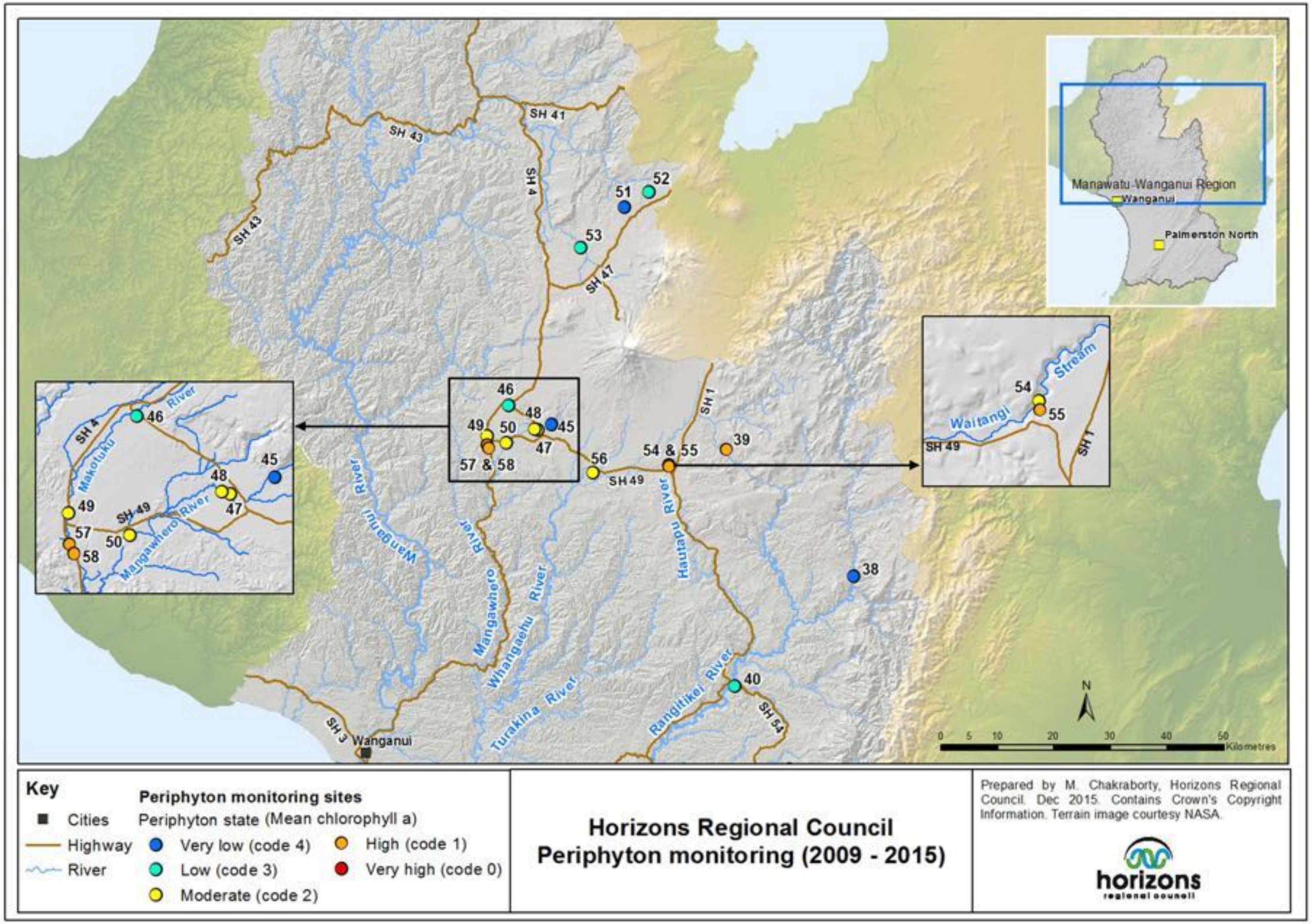
Figure 4-3: Box plots summarising periphyton data at all monitoring sites in the most recent three years (May 2012 to April 2015). Sites are listed in order of the Horizons site number in Table 3-2, which orders sites from the top to the bottom of catchments.

Table 4-4: Summary results of an assessment of the relative state of periphyton at 61 river sites in the Manawatu – Whanganui region. Assessments were carried out using data from the whole of the monitoring period (from December 2008 to April 2015) and for the last 3 years up to April 2015 (or all the available data). Values are shown for mean and median chlorophyll *a* and the 92nd percentile of percent cover by mats, filaments and cyanobacteria. Categories in Table 4-1 are colour-coded as follows: blue - very low periphyton, aqua - low; yellow - moderate; amber - high; red - very high. Sites for which statistics were calculated using different numbers of surveys are indicated in the No. surveys column: *less than 3 years of data; **more than 3 years of data but less than 6 years. The results from these sites are not strictly comparable with the results from sites with complete data, but are included for completeness.

					All data: 2008 to 2015					Last 3 years: May 2012 to April 2015				
					Ecosystem health		Aesthetics and recreation		Human health	Ecosystem health		Aesthetics and recreation		Human health
Site no.	Site abbreviation	Sub-zone code	LSC code	No. surveys	Chl a, median	Chl a, mean	Mats, 92nd Pc	Fils, 92nd Pc	Cyano, 92nd Pc	Chl a, median	Chl a, mean	Mats, 92nd Pc	Fils, 92nd Pc	Cyano, 92nd Pc
Sites not affected by point source discharges														
1	makakahi_doc	Mana_8d	HM	21*						1.1	1.4	1.2	0.9	1.2
2	mangatainoka_putara	Mana_8a	UHS	78	0.5	0.8	0.3	0.0	0.1	0.7	1.0	0.3	0.0	0.0
3	mangatainoka_lars	Mana_8a	UHS	21*						2.1	4.3	5.7	9.7	2.8
4	tamaki_res	Mana_3	UHS	77	1.4	3.2	1.3	1.4	0.0	2.8	4.7	3.6	1.7	0.0
5	mangatera_us_dan	Mana_2b	HM	77	1.9	10.9	0.8	2.3	0.0	3.8	16.4	0.5	3.2	0.0
7	mangatainoka_huk	Mana_8b	HM	21						2.0	3.8	3.3	3.9	1.5
8	kumeti_tr	Mana_4	UHS	77	1.9	4.9	1.2	0.5	0.0	3.0	7.0	2.0	0.5	0.0
9	manawatu_weber	Mana_1a	HM	77	7.5	33.3	11.9	36.4	4.1	11.5	43.6	5.9	24.8	5.9
10	makakahi_ham	Mana_8d	HM	78	34.0	48.1	38.8	42.0	25.1	33.3	52.8	23.3	46.1	14.2
11	oroua_apiti	Mana_12a	HM	77	0.4	3.1	6.9	8.4	0.5	1.5	1.9	3.1	4.5	0.3
12	tamaki_ste	Mana_5b	HM	77	1.0	8.5	8.9	0.5	0.4	3.0	5.4	0.5	0.0	0.5
13	oruakeretaki_sh2	Mana_5d	HM	77	2.0	12.3	7.9	2.0	4.7	6.5	17.4	7.5	1.0	7.5
14	makuri_tuscan	Mana_7d	ULi	77	50.0	84.7	44.9	21.6	14.7	65.0	101.5	11.2	23.7	11.2
15	pohangina_pir	Mana_10b	UHS	77	0.9	2.5	5.1	4.6	2.1	1.7	3.4	2.8	3.8	2.1
16	mangatainoka_scarb	Mana_8b	HM	21*						3.9	11.2	23.6	11.2	22.7
17	tiraumea_nga	Mana_7b	HSS	77	90.0	84.9	52.9	44.9	34.5	122.5	121.9	39.1	53.8	39.1
18	mangatainoka_pahiatua	Mana_8c	HM	21*						29.8	43.7	27.9	25.8	12.9
19	mangatainoka_sh2	Mana_8c	HM	78	26.5	40.6	30.0	33.6	31.8	35.8	50.9	20.0	16.0	19.9

					All data: 2008 to 2015					Last 3 years: May 2012 to April 2015				
					Ecosystem health		Aesthetics and recreation		Human health	Ecosystem health		Aesthetics and recreation		Human health
Site no.	Site abbreviation	Sub-zone code	LSC code	No. surveys	Chl a, median	Chl a, mean	Mats, 92nd Pc	Fils, 92nd Pc	Cyano, 92nd Pc	Chl a, median	Chl a, mean	Mats, 92nd Pc	Fils, 92nd Pc	Cyano, 92nd Pc
21	mangatainoka_us_pah	Mana_8c	HM	77	16.5	29.3	38.1	20.9	11.2	20.8	30.7	10.3	21.2	10.2
23	manawatu_hop	Mana_5a	HM	78	13.5	52.7	53.7	32.8	6.2	55.0	52.8	7.6	21.9	6.4
24	mangatainoka_us_tir	Mana_8c	HM	52**	20.0	32.4	24.7	24.5	24.9	18.5	25.6	10.5	33.3	10.1
26	mangapapa_troup	Mana_9b	HM	77	2.9	7.2	2.5	3.6	1.8	5.0	10.2	2.2	4.0	1.0
27	pohangina_mais	Mana_10c	HM	77	1.3	4.5	6.7	33.9	2.7	2.6	3.0	2.5	24.0	1.9
28	manawatu_ug	Mana_9a	HM	77	1.5	14.9	9.1	14.9	1.4	3.6	17.4	2.7	11.7	0.5
29	oroua_almadale	Mana_12a	HM	77	0.9	3.6	1.7	8.0	1.2	1.2	3.9	1.7	3.3	1.1
30	oroua_us_fei	Mana_12b	HM	77	2.7	8.6	3.0	29.9	0.3	3.3	12.0	2.0	20.8	0.3
32	oroua_awahuri	Mana_12c	LM	77	7.5	18.8	19.4	19.0	1.6	11.0	16.3	1.9	7.1	1.6
33	manawatu_tc	Mana_10a	HM	77	1.2	8.2	4.6	12.9	0.0	3.8	12.9	3.0	22.0	0.0
34	manawatu_us_pncc	Mana_11a	HM	77	3.5	25.3	16.8	28.4	0.5	9.5	25.1	5.9	18.4	0.5
36	manawatu_opik	Mana_11a	HM	77	7.5	33.0	3.3	70.6	1.1	30.5	46.0	3.4	37.5	0.7
37	tokomaru_hb	Mana_13c	LM	77	3.5	11.1	14.0	11.8	16.0	7.0	17.2	17.1	16.2	14.2
38	rangitikei_puk	Rang_2a	UHS	77	2.1	4.6	14.5	12.5	0.1	3.1	5.5	3.6	11.5	0.0
39	moawhango_waiouru	Rang_2d	UVM	55**	82.5	80.2	88.1	7.0	0.0	85.0	96.0	92.5	4.9	0.0
40	rangitikei_man	Rang_3a	HM	77	4.9	11.4	17.9	31.3	5.5	5.5	14.1	7.8	19.8	3.0
41	porewa_us_hun	Rang_4c	HSS	31*						43.0	59.5	12.4	84.2	0.0
43	rangitikei_one	Rang_3a	HM	77	1.4	8.9	8.2	19.5	0.1	4.5	15.0	14.8	26.1	0.2
44	rangitikei_mk	Rang_4a	HM	77	3.6	18.8	36.7	40.0	0.1	13.0	25.1	30.6	32.9	0.0
45	mangawhero_doc	Whau_3d	UVA	77	1.6	3.9	6.0	0.7	0.0	2.2	3.8	2.2	1.2	0.0
46	makotuku_sh49	Whau_3b	UVA	77	2.6	6.5	19.8	0.0	0.2	8.0	11.4	29.4	0.7	0.6
47	mangawhero_us_oha	Whau_3d	UVA	77	9.3	17.3	18.7	2.6	14.9	13.5	21.7	7.4	2.2	6.1
49	makotuku_rae	Whau_3c	UVA	77	25.5	40.5	77.2	30.4	4.3	25.5	41.2	34.1	33.3	0.4
50	mangawhero_pakihi	Whau_3d	UVA	77	12.0	22.0	25.5	12.8	18.2	19.3	27.4	11.5	11.6	5.8

					All data: 2008 to 2015					Last 3 years: May 2012 to April 2015				
					Ecosystem health		Aesthetics and recreation		Human health	Ecosystem health		Aesthetics and recreation		Human health
Site no.	Site abbreviation	Sub-zone code	LSC code	No. surveys	Chl a, median	Chl a, mean	Mats, 92nd Pc	Fils, 92nd Pc	Cyano, 92nd Pc	Chl a, median	Chl a, mean	Mats, 92nd Pc	Fils, 92nd Pc	Cyano, 92nd Pc
51	mangatepopo_gi	Whai_1	UVA	56**	2.3	4.9	14.3	15.6	3.0	2.7	5.7	10.2	12.9	1.0
52	whanganui_ds_gen	Whai_1	UVA	56**	3.0	6.8	13.2	7.3	0.5	3.0	5.4	9.4	1.2	0.5
53	whakapapa_ds_gen	Whai_2b	UVA	56**	3.5	7.3	21.0	16.2	4.2	3.8	9.0	17.4	6.6	4.1
54	waitangi_us_wai	Whau_1b	UVM	77	26.3	35.6	29.9	11.9	1.3	38.5	42.1	6.0	5.8	0.2
56	tokiahuru_kar	Whau_1c	UVA	71	8.0	16.7	22.4	1.1	2.3	23.0	28.9	14.2	1.3	2.5
57	makotuku_us_rae	Whau_3c	UVA	58**	44.3	63.4	22.0	31.3	7.9	33.8	49.0	14.4	3.7	6.5
59	waikawa_nmr	West_9a	HM	77	2.3	5.3	7.3	16.1	2.3	3.6	7.4	5.8	4.8	1.5
60	ohau_gladstone	Ohau_1a	UHS	77	1.5	3.0	8.2	6.0	3.2	2.4	4.3	4.0	3.1	3.8
61	ohau_sh1	Ohau_1b	HM	77	1.9	9.6	27.8	7.7	12.6	3.0	9.1	3.1	6.7	2.1
62	ohau_haines	Ohau_1b	HM	28*						7.3	20.5	1.9	9.5	1.9
Sites downstream of point source discharges														
6	mangatera_ds_dan	Mana_2b	HM	77	6.0	24.5	17.3	34.7	1.1	11.0	27.1	12.2	11.5	1.0
20	mangatainoka_ds_db	Mana_8c	HM	77	18.3	35.9	43.8	30.3	31.4	30.0	32.9	19.0	22.1	16.2
22	mangatainoka_ds_pah	Mana_8c	HM	77	37.0	47.4	40.9	33.0	28.7	47.5	50.4	27.4	19.6	27.4
31	oroua_ds_fei	Mana_12b	HM	77	7.0	30.7	21.5	29.5	4.4	18.0	39.5	11.4	21.8	4.6
35	manawatu_ds_pncc	Mana_11a	HM	77	19.8	68.7	34.4	65.0	32.7	65.0	99.7	32.5	43.6	27.7
42	porewa_ds_hun	Rang_4c	HSS	31*						70.0	76.0	8.5	74.4	0.0
48	mangawhero_ds_oha	Whau_3d	UVA	77	15.0	26.3	24.1	8.9	11.7	22.5	34.5	19.7	8.9	9.5
55	waitangi_ds_wai	Whau_1b	UVM	77	55.0	79.4	24.9	43.3	0.0	55.0	74.8	0.0	25.3	0.0
58	makotuku_ds_rae	Whau_3c	UVA	77	87.5	118.7	31.9	78.0	21.5	87.5	122.0	31.1	37.1	22.8


Key
Periphyton monitoring sites
Cities
Periphyton state (Mean chlorophyll a)
Highway
Very low (code 4)
High (code 1)
River
Low (code 3)
Very high (code 0)
Moderate (code 2)
Horizons Regional Council
Periphyton monitoring (2009 - 2015)
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horizons
regional council
Manawatu-Wanganui Region
Wanganui
Palmerston North
SH 43
SH 41
SH 4
SH 47
SH 1
SH 49
SH 3
SH 54
Wanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
Makotuku
Waitangi
Stream
Wanganui
57 & 58
54 & 55
0 5 10 20 30 40 50
Kilometres
N

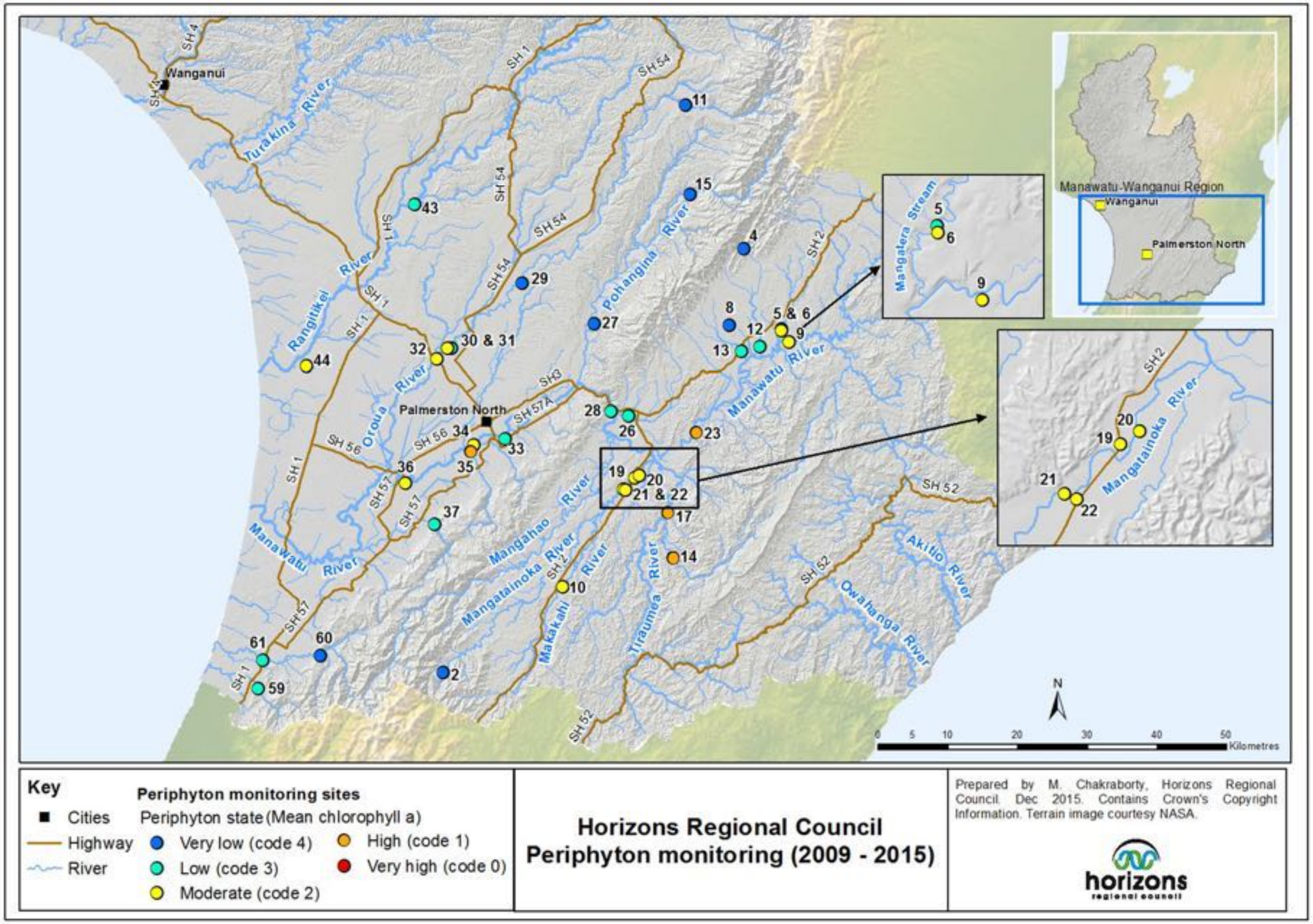
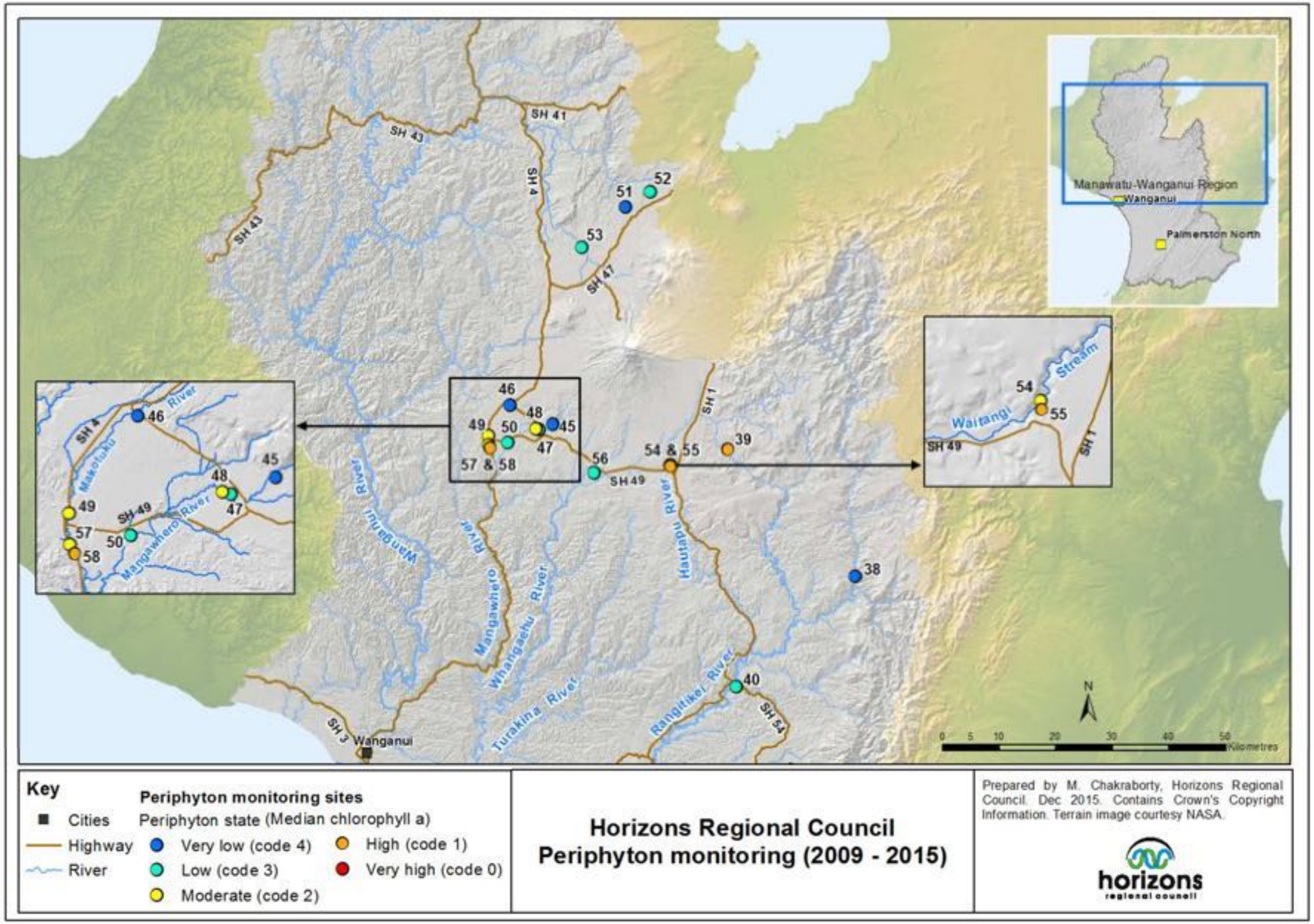


Figure 4-4: Maps showing periphyton state in five categories of mean chlorophyll *a* calculated from December 2008 to April 2015. Refer to Table 4-1 for definitions of each category. An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.


Key
Periphyton monitoring sites
Cities
Periphyton state (Median chlorophyll a)
Highway
River
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Horizons Regional Council
Periphyton monitoring (2009 - 2015)
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horizons
regional council
Manawatu-Wanganui Region
Wanganui
Palmerston North
SH 41
SH 43
SH 4
SH 47
SH 1
SH 49
SH 3
SH 54
Whanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
Makotuku
Waitangi Stream
Wanganui
Kilometres
0 5 10 20 30 40 50
51
52
53
46
48
45
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40
57
58
54
55

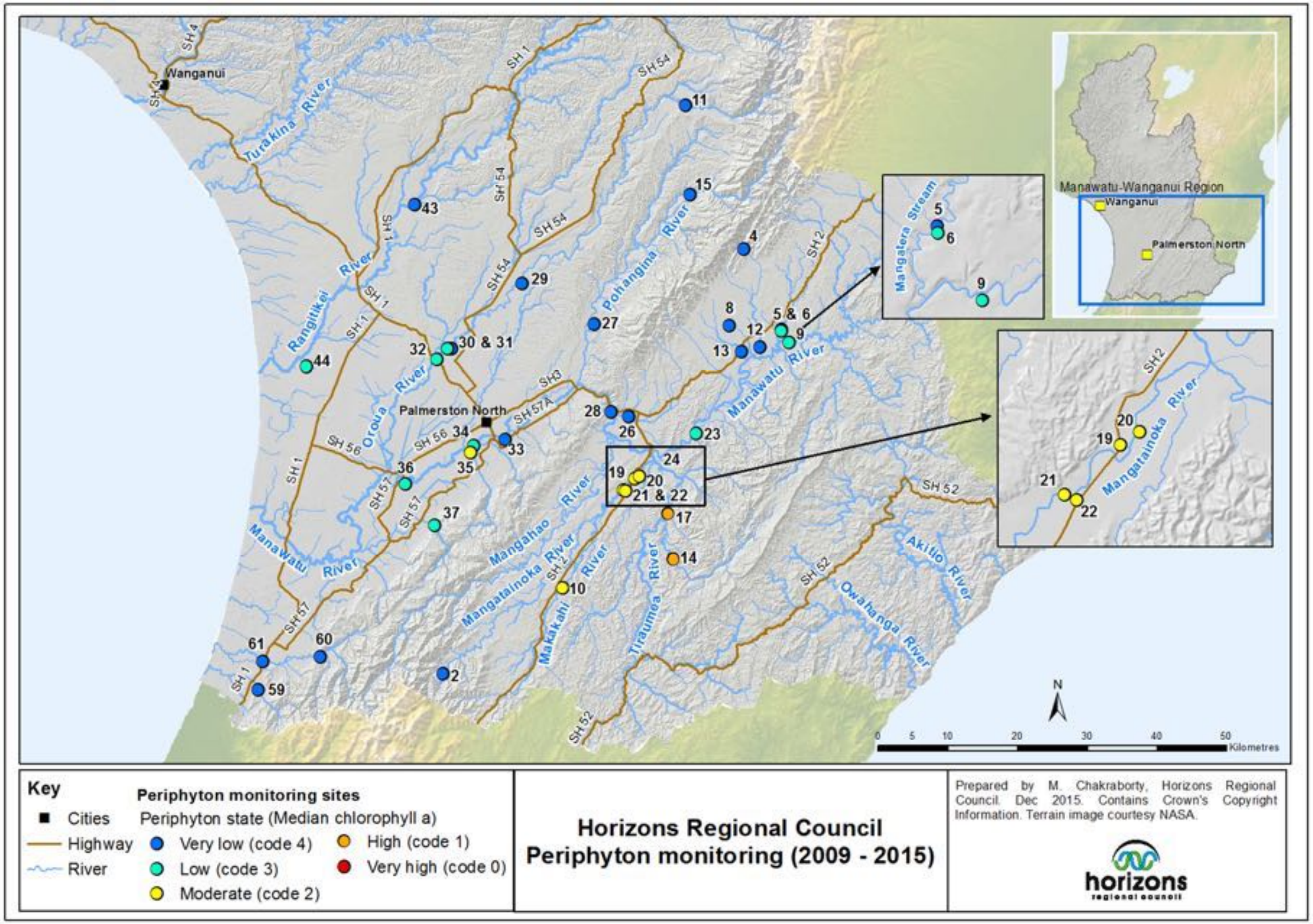
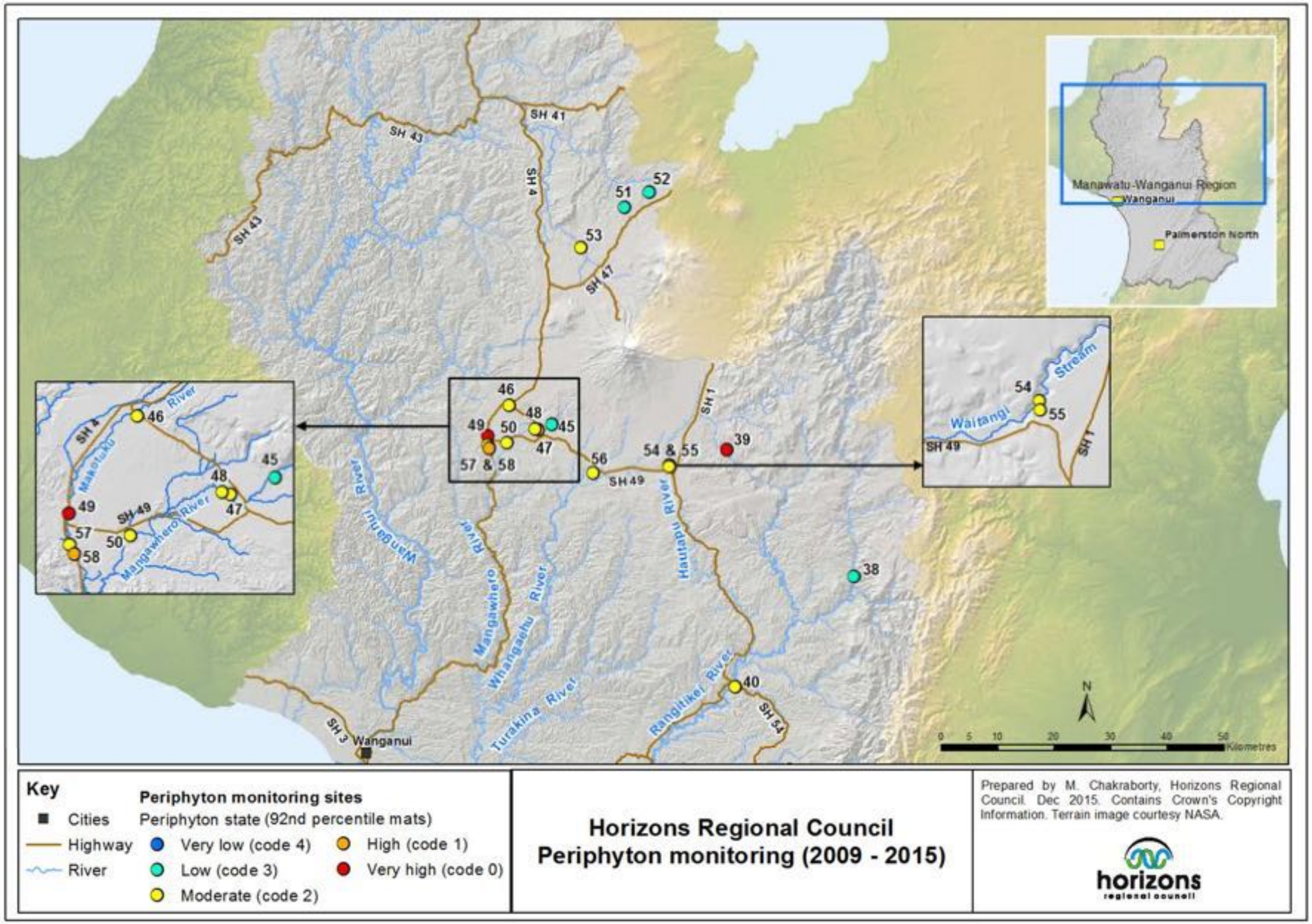


Figure 4-5: Maps showing periphyton state in five categories of median chlorophyll *a* calculated from December 2008 to April 2015. Refer to Table 4-1 for definitions of each category. An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.


Key
Cities
Highway
River
Periphyton monitoring sites
Periphyton state (92nd percentile mats)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Horizons Regional Council
Periphyton monitoring (2009 - 2015)
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horizons
regional council
Manawatu-Wanganui Region
Wanganui
Palmerston North
Kilometres
SH 41
SH 43
SH 4
SH 47
SH 1
SH 49
SH 3
SH 54
Wanganui
Whanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
Makotuku
Waitangi
Stream
38
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45
46
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53
54 & 55
56
57 & 58

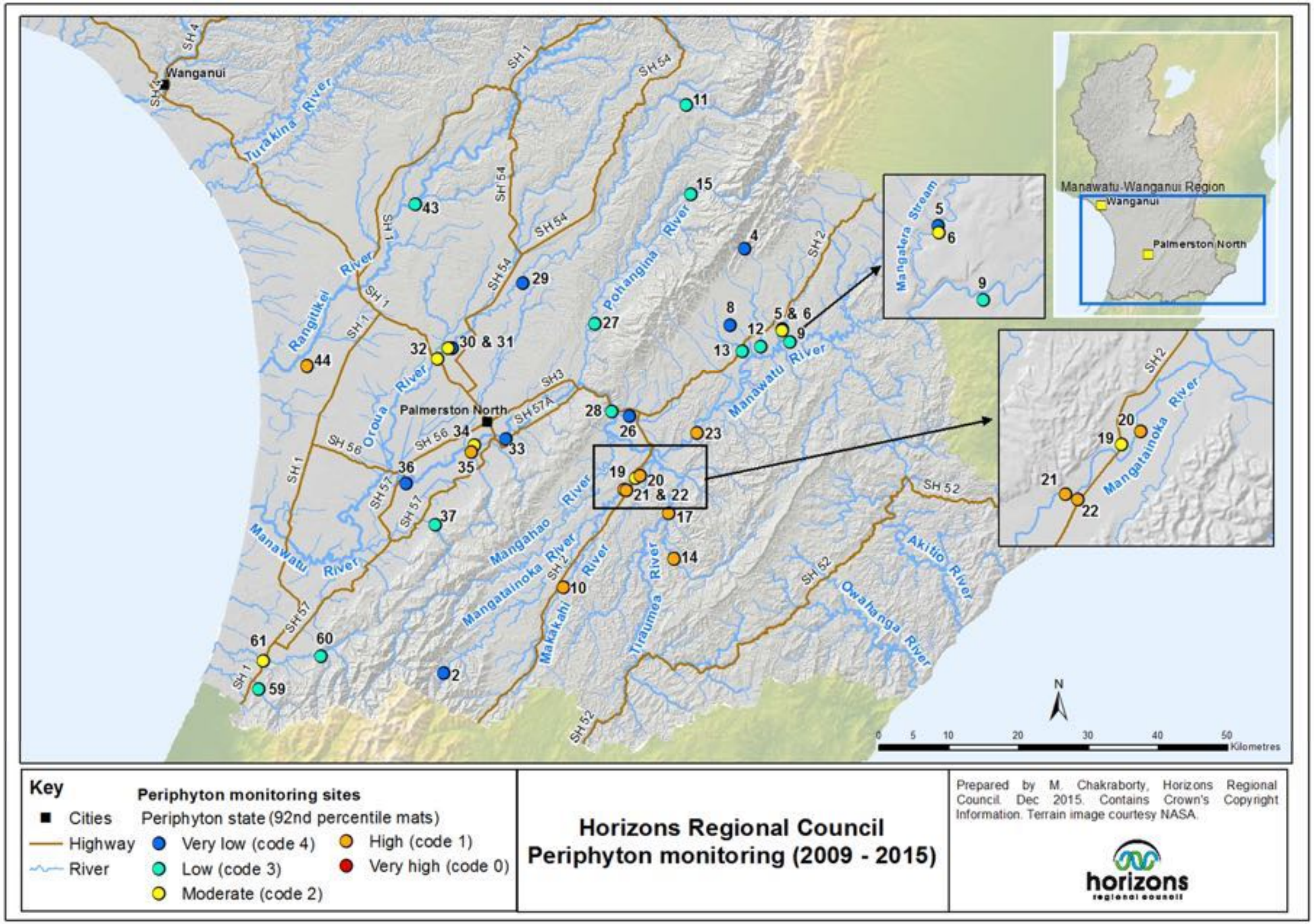
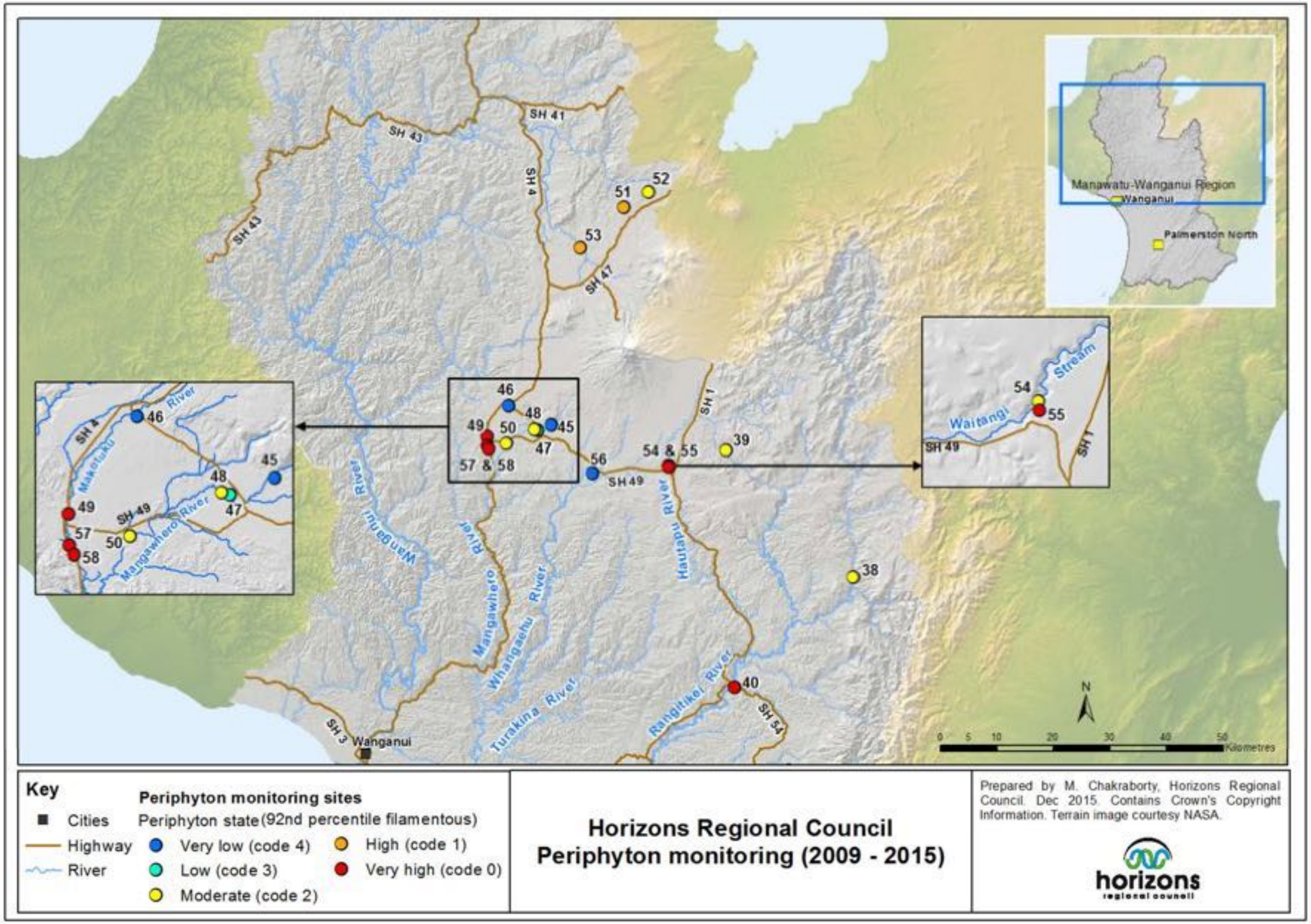


Figure 4-6: Maps showing periphyton state in five categories of the 92nd percentile of % cover by mats calculated from December 2008 to April 2015. Refer to Table 4-1 for definitions of each category**.** An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.


Horizons Regional Council
Periphyton monitoring (2009 - 2015)
Key
Cities
Highway
River
Periphyton monitoring sites
Periphyton state (92nd percentile filamentous)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Prepared by M. Chakraborty, Horizons Regional Council. Dec 2015. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons regional council
Manawatu-Wanganui Region
Wanganui
Palmerston North
Waitangi Stream
Wanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
Makotuku River
SH 1
SH 3
SH 4
SH 41
SH 43
SH 47
SH 49
SH 54
Kilometres

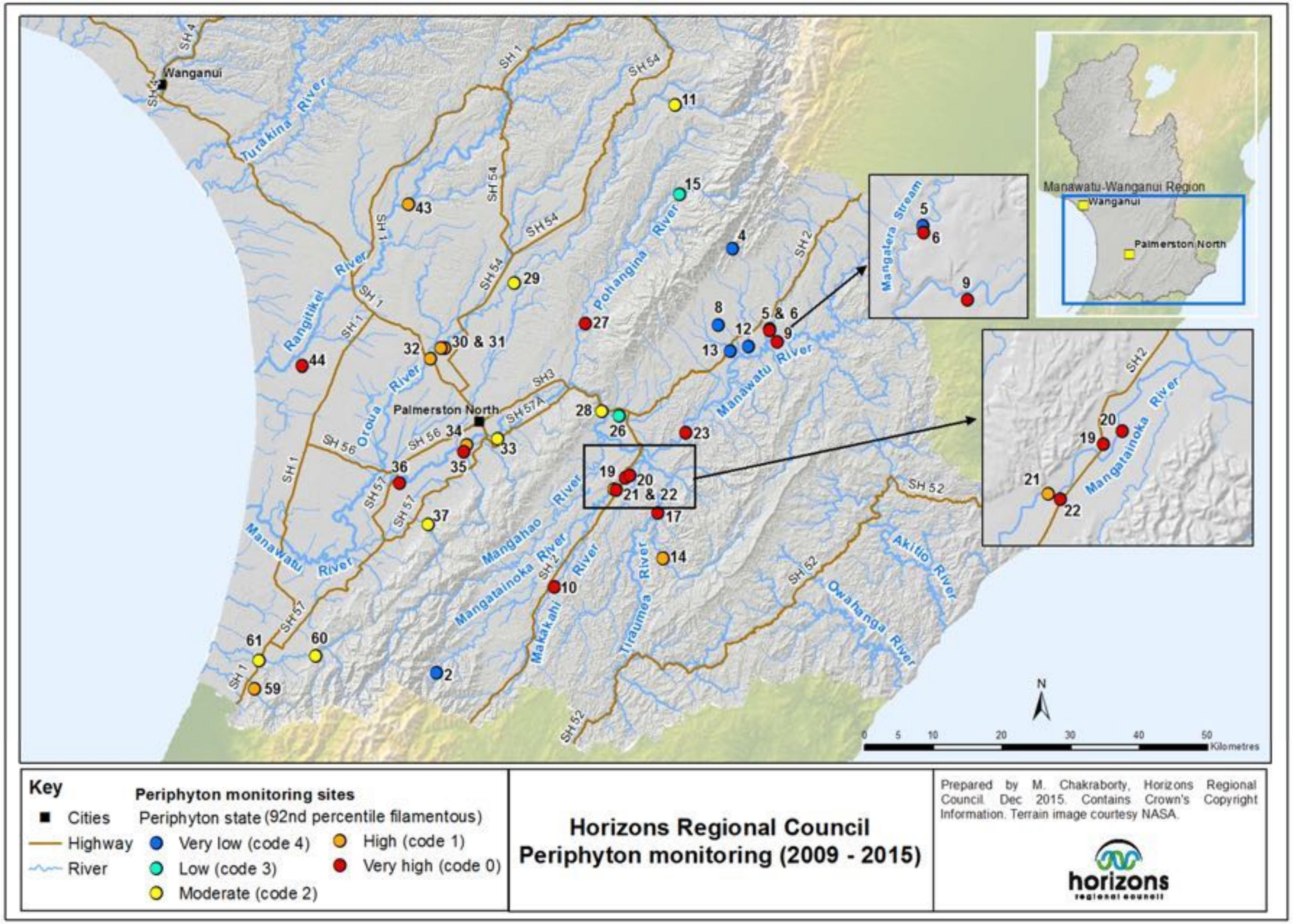
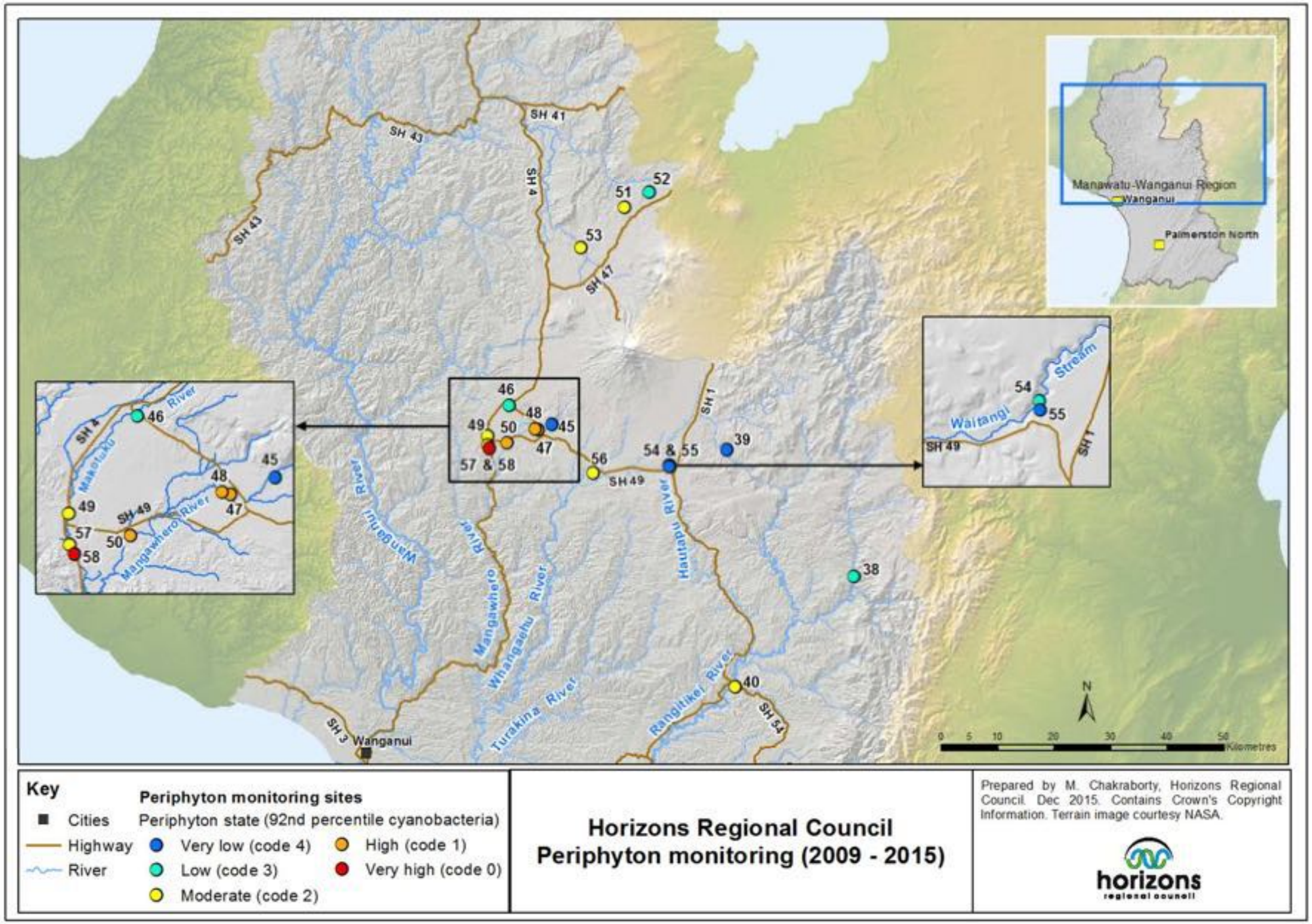


Figure 4-7: Maps showing periphyton state in five categories of the 92nd percentile of % cover by filaments calculated from December 2008 to April 2015. Refer to Table 4-1 for defintions of each category. An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.


Horizons Regional Council
Periphyton monitoring (2009 - 2015)
Key
Periphyton monitoring sites
Cities
Highway
River
Periphyton state (92nd percentile cyanobacteria)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Prepared by M. Chakraborty, Horizons Regional Council. Dec 2015. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons
regional council
Manawatu-Wanganui Region
Wanganui
Palmerston North
Kilometres
0 5 10 20 30 40 50
N
SH 43
SH 41
SH 4
SH 47
SH 1
SH 49
SH 3
SH 54
Wanganui
Whanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
Makotuku
Waitangi Stream
38
39
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54 & 55
56
57 & 58

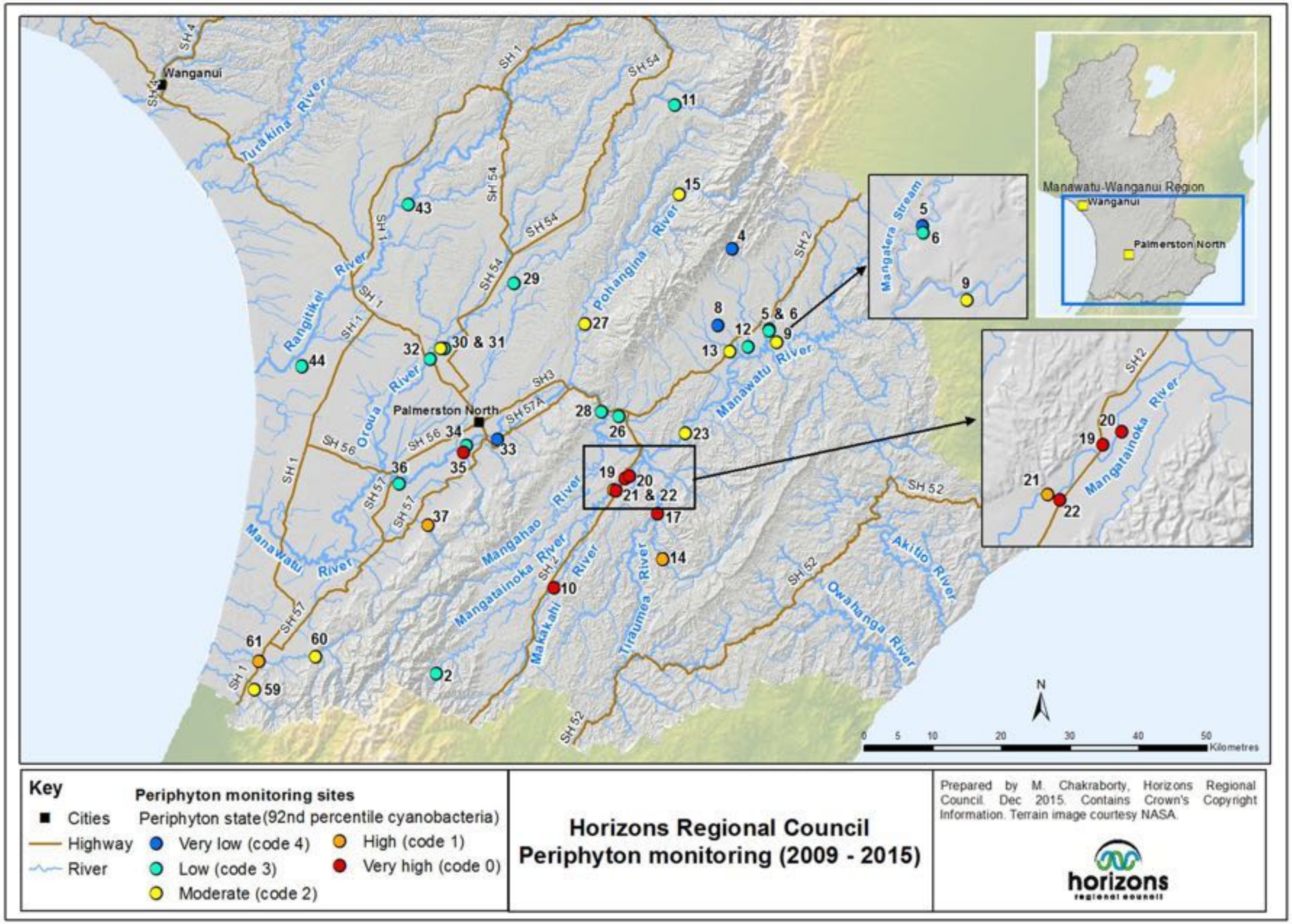


Figure 4-8: Maps showing periphyton state in five categories of the 92nd percentile of % cover by cyanobacteria calculated from May 2011 to April 2015. Refer to Table 4-1 for definitions of each category. An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.

Table 4-5: Summary of percentage of all sites falling into periphyton states as defined in Table 4-1. N = 47 sites for all data (2008 to 2015) and 53 sites for the last 3 years. Sites with incomplete data are not included. Note shifts in median and mean chlorophyll *a* into higher levels in the last 3 years compared to the whole dataset, but mixed patterns for % mats and filaments. See trend analysis for more detail.

	All data: 2008 to 2015 (*n* = 47)					Last 3 years: May 2012 to April 2015 (*n* = 53)				
	Ecosystem health		Aesthetics/recreation		Human health	Ecosystem health		Aesthetics/recreation		Human health
Level	Chl a, median	Chl a, mean	Mats, 92nd Pc	Fils, 92nd Pc	Cyano,* 92nd Pc	Chl a, median	Chl a, mean	Mats, 92nd Pc	Fils, 92nd Pc	Cyano, 92nd Pc
Vlow	45	21	19	19	13	17	15	38	19	19
Low	28	28	28	6	32	43	25	36	17	34
Moderate	19	38	28	23	26	26	42	15	19	26
High	9	13	23	17	13	11	15	9	30	13
Vhigh	0	0	2	34	15	2	4	2	15	8

* The time series for cyanobacteria ran from May 2011 to April 2015, *n* = 53.

Table 4-6: Summary of direction of change in state as defined in Table 4.1. Ony sites with a complete record of data from 2008 to 2015 are included. Cyanobacteria monitoring began in May 2011. Therefore the comparison is between 2011-2015 and 2012-2015.

Change in state compared to 2008 to 2015	Last 3 years: May 2012 to April 2015				
	Ecosystem health		Aesthetics/recreation		Human health
	Chl a, median	Chl a, mean	Mats, 92nd Pc	Fils, 92nd Pc	Cyano, 92nd Pc
Improvement	0	0	30	15	12
No change	28	37	16	29	35
Worsened	19	10	1	3	0

Cyanobacteria

Over the four years of the cyanobacteria monitoring programme, eight of the 53 sites (15%) were in the VHigh category, of which four were below point-source discharges (Table 4-4, Table 4-5). The other four were in the Manawatu catchment. Sites with High status occurred in a range of catchments (Figure 4-8). Over the most recent three years, five sites were placed in the Vhigh category, of which one was a new site (site 16, mangatainoka_scarb). None of the 47 sites with the full four year record showed worse state (higher cover) when state was calculated from 2012-15 rather than 2011-15 and 12 sites (21%) were in a better state.

Comparison with national data

A higher proportion of rivers in the Horizons region fell into the two categories with lowest % cover by both mats and filaments than in the 77 sites in the NRWQN (Table 4-7). The patterns were similar in a comparison of the Horizons sites with NRWQN North Island sites only (*n* = 42), except that a higher proportion of NRWQN sites was in the Vhigh category for % cover by filaments (45% compared to 15% in the Manawatu-Whanganui region).

Table 4-7: Percentages of sites in five periphyton state categories in the Manawatu-Whanganui region and throughout New Zealand and North Island. Horizons data on % cover with mats and filaments from May 2012 to April 2015 (see Table 4-5) were compared with three years of NRWQN data from January 2012 to December 2014. Sites with soft-bottomed substrate were omitted from the NRWQN dataset. Note that four sites in the NRWQN dataset are in the Horizons dataset.

	% cover, Mats (92nd percentile)			% cover, Fils (92nd percentile)		
State	NRWQN (all sites)	NRWQN (North Is)	HMW	NRWQN (all sites)	NRWQN (North Is)	HMW
Vlow	31	38	38	20	1	19
Low	15	17	36	8	7	17
Mod	12	10	15	27	12	19
High	33	36	9	13	10	30
Vhigh	9	0	2	32	45	15

4.3.3 Periphyton trends – classical trend tests

Chlorophyll *a*

Trend analysis was performed on data from 41 sites with a complete record of data from 2008 to 2015, and also a linked flow record. Plots of the raw data suggested that there have been trends over time chlorophyll *a* at some sites (Figure 4-9). Using unadjusted data, trends of increasing chlorophyll a between 2008 and 2015 were detected at 23 of the 41 sites (56%). No decreasing trends were detected at any sites. The time elapsed since a high flow explained from 5% to 64% of the variation in chlorophyll a over the monitoring period. The size of the high flow that explained maximum variation at each site ranged from 1.5 to 10 times median flow. After adjustment of the chlorophyll *a* data using the metric (days since a high flow) explaining maximum variation at each site, trends of increasing chlorophyll *a* were detected at six (15%) sites (2, mangatainoka_putara; 4, tamaki_res; 38, rangitikei_puk; 43, rangitikei_one; 46, makotuku_sh49; 59, waikawa_nmr) (Table 4-8). Slopes suggesting decreasing chlorophyll *a* were identified at several sites (e.g., 28, manawatu_ug; 34, manawatu_us_pncc), but the slopes were not statistically significant (and the 100 (1-2α)% confidence interval included zero).

Mats and filaments

Using unadjusted data, the trend tests indicated strong trends of decreasing percentage cover by mats of at least 16% per year at 11 of the 41 sites (27%) (Table 4-9). Time since a high flow explained between 59% (negative correlation) and 100% (positive correlation) of the variation in cover over the monitoring period. After adjustment of the data using the metric explaining maximum variation at each site, there evidence for a decreasing trend at 10 sites, of which eight coincided with the unadjusted result. Very large percentage annual changes (e.g., site 40, rangitikei_man) reflected situations where high cover by mats was recorded frequently in the first few years of the programme, followed by repeated records of zero cover for the most recent 1-2 years.

For percentage cover by filaments, trends identified using unadjusted data were increases in cover at four sites and a decline in cover at one site. Time since a high flow explained between 25% (negative correlation) and 81% (positive correlation) of the variation in cover over the monitoring period. After adjustment of the data using the time since a flood metric explaining maximum variation at each site, there was a significant decreasing trend at three sites (9, manawatu_weber; 34, manawatu_pncc; 58, makotuku_ds_rae), and a trend of increasing cover by filaments at two sites (14, makuri_tuscan; 17, tiraumea_nga) (Table 4-10).

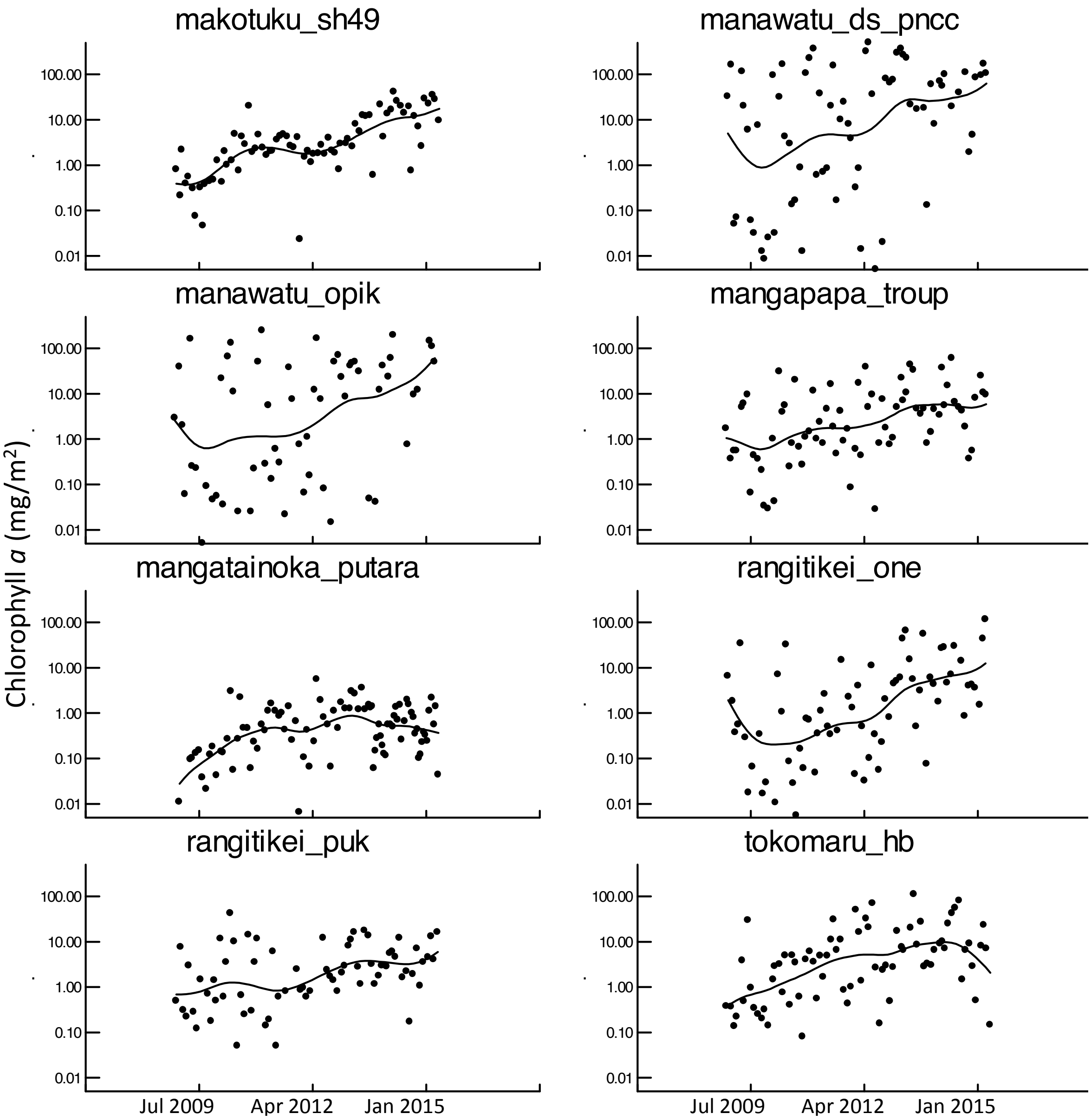


Figure 4-9: Example plots of changes over time in chlorophyll *a* that suggest increasing standing crop at some sites. Of the eight examples shown, flow-adjusted trend tests indicated significant increases in chlorophyll a at four sites (makotuku_sh49, mangatainoka_putara, rangitikei_one, rangitikei_puk) and no evidence for a trend at the others. Equivalence tests indicated either trivial or moderate trends (i.e., within or close to the specified limit of 3 mg/m^2 per year) at all sites except rangitikei_puk. Distance-weighted least squares (DWLS) smoothing lines through the data indicate overall trends.

Table 4-8: Results of classical trend tests for detecting trends in chlorophyll *a* between 2008 and 2015. Results using raw data are shown alongside results using data adjusted by the the flow metric (time since a high flow exceeding *n* x median flow for each observation, with *n* shown under Flow) that explained the highest proportion of variance in the data at each site. *P* is the outcome of a Seasonal Kendall test of the hypothesis that there is no monotonic trend in the data; P<0.05 indicates rejection of the hypothesis. PAC is the percentage annual change in chlorophyll *a*, calculated by dividing the median annual Sen Slope by the overall median value for the monitoring period. Red cells indicate evidence for an increase over time.

		Chlorophyll *a* (mg/m²)		Trend, unadjusted		Trend, flow adjusted			
N	Site abbreviation	Mean	Median	P	PAC	Flow	%Expl	P	PAC
Sites unaffected by point-source discharges									
2	mangatainoka_putara	0.8	0.5	**0.00**	23	5	31	**0.00**	21
4	tamaki_res	3.2	1.4	**0.01**	18	5	30	**0.00**	15
8	kumeti_tr	4.9	1.9	0.14	21	2	27	0.31	12
9	manawatu_weber	33.3	7.5	**0.03**	14	5	21	0.41	20
10	makakahi_ham	50.4	35.0	0.09	11	3	31	0.14	10
11	oroua_apiti	3.1	0.4	**0.00**	13	3	28	0.83	-2
12	tamaki_ste	8.5	1.0	0.45	4	3	37	0.59	-4
13	oruakeretaki_sh2	12.3	2.0	0.06	13	1.5	33	0.07	20
14	makuri_tuscan	84.7	50.0	**0.03**	13	3	38	0.45	7
17	tiraumea_nga	84.9	90.0	**0.00**	20	5	64	0.07	6
19	mangatainoka_sh2	40.8	30.4	**0.00**	18	10	34	0.46	3
21	mangatainoka_us_pah	29.3	16.5	**0.01**	9	9	26	0.92	-1
23	manawatu_hop	54.0	18.5	0.47	1	2	26	0.54	-4
26	mangapapa_troup	7.3	2.9	**0.00**	31	12	9	0.07	21
27	pohangina_mais	4.5	1.3	**0.00**	19	3	14	0.14	14
28	manawatu_ug	14.9	1.5	0.14	4	2	37	0.21	-36
29	oroua_almadale	3.6	0.9	0.39	4	1.5	40	0.91	-1
30	oroua_us_fei	8.6	2.7	0.45	1	2	17	0.69	2
32	oroua_awahuri	18.8	7.5	0.17	1	1.5	48	0.78	1
33	manawatu_tc	8.3	1.2	**0.00**	26	1.5	17	0.09	11
34	manawatu_us_pncc	25.3	3.5	0.21	9	3	31	0.18	-27
36	manawatu_opik	33.0	7.5	**0.00**	58	2	44	0.56	20
37	tokomaru_hb	11.1	3.5	**0.00**	40	15	23	0.18	10
38	rangitikei_puk	4.6	2.1	**0.00**	23	1.5	28	**0.05**	11
40	rangitikei_man	11.4	4.9	0.26	9	5	18	0.71	-13
43	rangitikei_one	8.9	1.4	**0.00**	69	5	25	**0.02**	50
44	rangitikei_mk	18.8	3.6	0.08	17	2	41	0.06	37
45	mangawhero_doc	3.9	1.6	**0.00**	15	2	7	0.32	8
46	makotuku_sh49	6.5	2.6	**0.00**	64	2	27	**0.00**	57
47	mangawhero_us_oha	17.3	9.3	**0.00**	23	3	19	0.11	11
49	makotuku_rae	40.5	25.5	0.75	-2	5	5	0.18	8
50	mangawhero_pakihi	22.0	12.0	0.54	4	12	25	0.41	6
59	waikawa_nmr	5.3	2.3	**0.00**	16	9	27	**0.01**	24
60	ohau_gladstone	3.0	1.5	**0.01**	14	5	30	0.16	12
61	ohau_sh1	9.6	1.9	**0.04**	10	1.5	61	0.73	1
Sites downstream of point-source discharges									
20	mangatainoka_ds_db	35.9	18.3	0.30	7	10	36	0.43	-6
22	mangatainoka_ds_pah	47.5	37.0	0.24	6	15	33	0.15	10
31	oroua_ds_fei	30.7	7.0	0.49	1	1.5	37	0.60	4
35	manawatu_ds_pncc	68.7	19.8	**0.00**	27	2	30	0.49	15
48	mangawhero_ds_oha	26.3	15.0	**0.01**	16	10	19	0.96	0
58	makotuku_ds_rae	118.7	87.5	0.19	-6	1.5	16	0.46	-5

Table 4-9: Results of classical trend tests for detecting trends in percentage cover by mats between 2008 and 2015. Refer to to Table 4-8 for explanatory notes. Green cells indicate evidence for decreasing trend in % cover by mats.

		% cover, Mats		Trend, unadjusted		Trend, flow adjusted			
N	**Site abbreviation**	**mean**	**median**	**P**	**PAC**	**Flow**	**%**	**P-value**	**PAC**
Sites unaffected by point-source discharges									
2	mangatainoka_putara	0.1	0.0	0.82	0	15	20	0.47	0
4	tamaki_res	0.7	0.0	0.81	0	12	-4	1.00	0
8	kumeti_tr	0.3	0.0	0.21	0	2	-59	0.74	0
9	manawatu_weber	2.7	0.5	0.10	0	3	26	**0.00**	-61
10	makakahi_ham	14.6	10.5	**0.00**	-26	15	15	**0.00**	-27
11	oroua_apiti	2.1	0.0	0.36	0	1.5	33	0.21	0
12	tamaki_ste	2.7	0.0	**0.00**	0	10	100	**0.03**	0
13	oruakeretaki_sh2	3.1	0.0	0.34	0	1.5	41	0.50	0
14	makuri_tuscan	14.7	8.2	**0.00**	-53	1.5	25	**0.00**	-43
17	tiraumea_nga	17.1	8.6	**0.00**	-34	5	29	**0.00**	-50
19	mangatainoka_sh2	10.4	5.6	0.45	0	3	18	0.22	-7
21	mangatainoka_us_pah	10.5	5.6	0.12	-7	5	19	**0.00**	-37
23	manawatu_hop	8.6	0.0	0.41	0	1.5	11	**0.00**	0
26	mangapapa_troup	0.7	0.0	0.72	0	7	8	0.18	0
27	pohangina_mais	2.5	0.0	0.93	0	2	14	0.41	0
28	manawatu_ug	3.0	0.0	0.36	0	5	15	0.08	0
29	oroua_almadale	0.6	0.0	0.56	0	9	-8	0.46	0
30	oroua_us_fei	1.4	0.0	0.74	0	15	7	0.26	0
32	oroua_awahuri	3.5	0.0	0.50	0	15	15	0.74	0
33	manawatu_tc	1.8	0.0	0.16	0	3	14	**0.04**	0
34	manawatu_us_pncc	4.5	0.0	0.46	0	2	11	**0.00**	0
36	manawatu_opik	0.9	0.0	0.56	0	10	-7	0.35	0
37	tokomaru_hb	3.7	0.5	0.74	0	1.5	-11	0.45	0
38	rangitikei_puk	3.1	0.3	**0.00**	-80	3	18	**0.03**	-93
40	rangitikei_man	4.1	0.3	**0.01**	-56	12	16	**0.00**	-213
43	rangitikei_one	2.0	0.0	0.46	0	1.5	23	0.10	0
44	rangitikei_mk	8.4	0.0	0.28	0	12	13	1.00	0
45	mangawhero_doc	1.6	0.1	**0.00**	-283	12	26	0.64	-9
46	makotuku_sh49	3.6	0.0	0.98	0	9	12	0.31	0
47	mangawhero_us_oha	5.8	2.0	**0.03**	-16	5	9	0.18	-15
49	makotuku_rae	29.1	19.2	**0.00**	-42	1.5	32	**0.00**	-37
50	mangawhero_pakihi	9.2	4.8	**0.00**	-39	12	19	**0.01**	-30
59	waikawa_nmr	1.3	0.0	0.52	0	12	14	0.17	0
60	ohau_gladstone	2.2	0.0	0.18	0	15	-6	**0.04**	0
61	ohau_sh1	6.6	0.0	0.17	0	1.5	42	0.15	0
Sites downstream of point-source discharges									
20	mangatainoka_ds_db	13.3	4.1	0.75	0	3	11	0.19	-24
22	mangatainoka_ds_pah	14.4	8.5	**0.02**	-16	3	28	**0.01**	-29
31	oroua_ds_fei	4.6	0.2	0.89	0	15	24	0.39	-91
35	manawatu_ds_pncc	10.8	2.9	0.44	0	5	21	0.31	-11
48	mangawhero_ds_oha	7.7	2.2	0.19	-6	7	16	0.12	-21
58	makotuku_ds_rae	11.1	5.1	**0.05**	-20	9	22	0.26	-9

Table 4-10: Results of classical trend tests for detecting trends in percentage cover by filaments between 2008 and 2015. Refer to to Table 4-8 for explanatory notes. Green cells indicate evidence for a decreasing trend in % cover by filaments, and red cells an increasing trend.

		% cover, Filaments		Trend, unadjusted		Trend, flow adjusted			
N	**Site abbreviation**	**mean**	**median**	**P**	**PAC**	**Flow**	**%**	**P-value**	**PAC**
Sites unaffected by point-source discharges									
2	mangatainoka_putara	0.0	0.0	0.08	0	16	11	0.25	0
4	tamaki_res	1.7	0.0	1.00	0	5	14	0.25	0
8	kumeti_tr	0.3	0.0	0.57	0	5	9	0.43	0
9	manawatu_weber	11.2	3.0	0.95	0	7	23	**0.00**	-42
10	makakahi_ham	11.1	4.2	0.82	0	7	12	1.00	0
11	oroua_apiti	2.0	0.0	0.52	0	3	23	0.40	0
12	tamaki_ste	0.5	0.0	0.44	0	9	11	**0.00**	0
13	oruakeretaki_sh2	1.3	0.0	0.26	0	15	23	0.86	0
14	makuri_tuscan	7.4	3.9	**0.00**	33	12	38	**0.01**	30
17	tiraumea_nga	14.5	9.0	**0.00**	33	1.5	25	**0.01**	30
19	mangatainoka_sh2	7.6	0.9	0.07	15	1.5	-3	0.92	5
21	mangatainoka_us_pah	5.2	1.4	0.83	0	7	21	0.25	-21
23	manawatu_hop	9.0	1.3	0.27	0	2	17	0.62	3
26	mangapapa_troup	0.9	0.0	0.45	0	3	14	0.59	0
27	pohangina_mais	7.1	0.3	0.49	0	1.5	14	0.23	-28
28	manawatu_ug	4.6	0.0	0.54	0	3	34	0.08	0
29	oroua_almadale	1.5	0.0	0.34	0	10	21	**0.03**	0
30	oroua_us_fei	7.2	0.0	0.23	0	15	40	1.00	0
32	oroua_awahuri	5.8	0.3	0.67	0	2	33	0.55	-41
33	manawatu_tc	3.6	0.0	**0.01**	0	1.5	33	0.12	0
34	manawatu_us_pncc	7.6	1.0	0.87	0	3	29	**0.01**	-37
36	manawatu_opik	12.3	0.1	0.38	0	2	18	0.22	-637
37	tokomaru_hb	3.3	0.3	**0.05**	0	2	10	0.23	53
38	rangitikei_puk	4.1	2.5	0.95	0	10	8	0.85	1
40	rangitikei_man	10.0	5.6	0.95	0	1.5	23	0.07	-20
43	rangitikei_one	5.3	1.6	**0.03**	13	1.5	62	0.76	-1
44	rangitikei_mk	10.4	2.8	0.14	0	2	-25	0.28	-2
45	mangawhero_doc	0.7	0.0	0.60	0	5	8	0.83	0
46	makotuku_sh49	0.9	0.0	0.66	0	10	26	0.66	0
47	mangawhero_us_oha	0.8	0.2	**0.04**	17	3	12	0.10	32
49	makotuku_rae	8.8	1.0	0.33	-11	10	28	0.94	-14
50	mangawhero_pakihi	4.3	1.7	1.00	0	9	28	0.61	-6
59	waikawa_nmr	3.6	0.0	1.00	0	7	37	0.50	0
60	ohau_gladstone	1.9	0.0	0.25	0	1.5	81	0.53	0
61	ohau_sh1	2.3	0.0	1.00	0	3	-15	0.75	0
Sites downstream of point-source discharges									
20	mangatainoka_ds_db	8.0	1.8	0.48	0	2	12	1.00	0
22	mangatainoka_ds_pah	10.3	4.0	0.10	-17	12	11	0.15	-28
31	oroua_ds_fei	8.2	0.3	0.89	0	2	-34	0.20	-264
35	manawatu_ds_pncc	14.7	3.3	0.55	0	15	25	0.35	-12
48	mangawhero_ds_oha	2.8	0.3	0.27	0	3	6	0.39	-44
58	makotuku_ds_rae	27.0	13.9	**0.00**	-48	2	28	**0.00**	-44

Combined result

Combining all the results using flow-adjusted data, there was evidence for a trend in at least one metric at 17 sites (41%). Four sites showed trends in two metrics and, of these, the trend was in the same direction at one (a decline in both mats and filaments at site 9, manawatu_weber). There were opposing trends at the other three sites: a decline in mats, but an increase in filaments at sites 14, makuri_tuscan and 17, tiraumea_nga, and an increase in chlorophyll *a* along with a decline in cover by mats at site 38, rangitikei_puk. The summary results for all three periphyton metrics are shown alongside the equivalence test results (see below) in Table 4-11, and are summarised in Table 4-12.

4.3.4 Periphyton trends – equivalence tests

Chlorophyll *a*

Equivalence tests were performed on unadjusted data from 47 sites with a complete record of data from December 2008 to May 2015. The equivalence tests indicated increases in chlorophyll *a* at 19 sites (40%), six trivial (i.e., within the limit of 3 mg/m^2 per year), 10 moderate (close to the limit), and three strong (14, makuri_tuscan; 17, tiraumea_nga; 56, tokiahuru_kar) (Table 4-11). At 18 sites, the equivalence test result was inconclusive, which is the outcome when all three hypotheses cannot be rejected: there was no evidence for a significant slope, and no evidence for a trend either outside or inside the limits. Such a result indicates variability in the data that prevents detection of any trend over the relatively short time series. There was no evidence for a trend in chlorophyll *a* at seven sites. Three sites showed a trivial or moderate decline in chlorophyll *a* (Table 4-11).

Mats and filaments

Using equivalence tests, trends detected for both mats and filaments indicated decreasing cover (i.e., green on Table 4-11) more often than increasing cover. Strong declines in cover by mats were detected at two sites (14, makuri_tuscan; 49, makotuku_rae), moderate declines at 12 sites, trivial declines at 13 sites, and trivial increases at two sites (43, rangitikei_one; 46, makotuku_sh49) (Table 4-11). There were strong declines in % cover by filaments at sites 57 and 58 (makotuku_us_rae, makotuku_us_rae), moderate declines at nine sites and trivial declines at three sites (Table 4-11). Moderate increases in % cover by filaments were detected at sites 14 (makuri_tuscan) and 17 (tiraumea_nga), and trivial increases at four further sites (Table 4-11).

4.3.5 Spatial patterns in trends

Using both the classical method and equivalence tests, sites at which there was evidence for an increase in chlorophyll *a* occurred throughout the region. All the increases in chlorophyll *a* identified using flow-adjusted classical tests were in headwater sites with low mean and median chlorophyll *a* (Table 4-8, Figure 4-10). Sites with trivial increases identified using equivalence tests also tended to be in the upstream reaches of catchments (e.g., mangatainoka_putara, site 2; tamaki_res, site 4; kumeti_tr, site 8; and pohangina_pir, site 15). Moderate and strong increases identified using equivalence tests were recorded in both small tributaries and in river main stems (Table 4-11).

Both the classical and equivalence tests showed a possible geographical pattern of trends in % cover by mats in that sites located to the east of the Ruahine Range and in the showed declines in cover, while there was no evidence for a trend, or declines (shown by equivalence tests) at sites to the west of the range (Table 4-11, Figure 4-11). No such pattern was seen for % cover by filaments (Figure 4-12). This pattern was not seen in the relatively small number of sites at which trends were detected using the classical method.

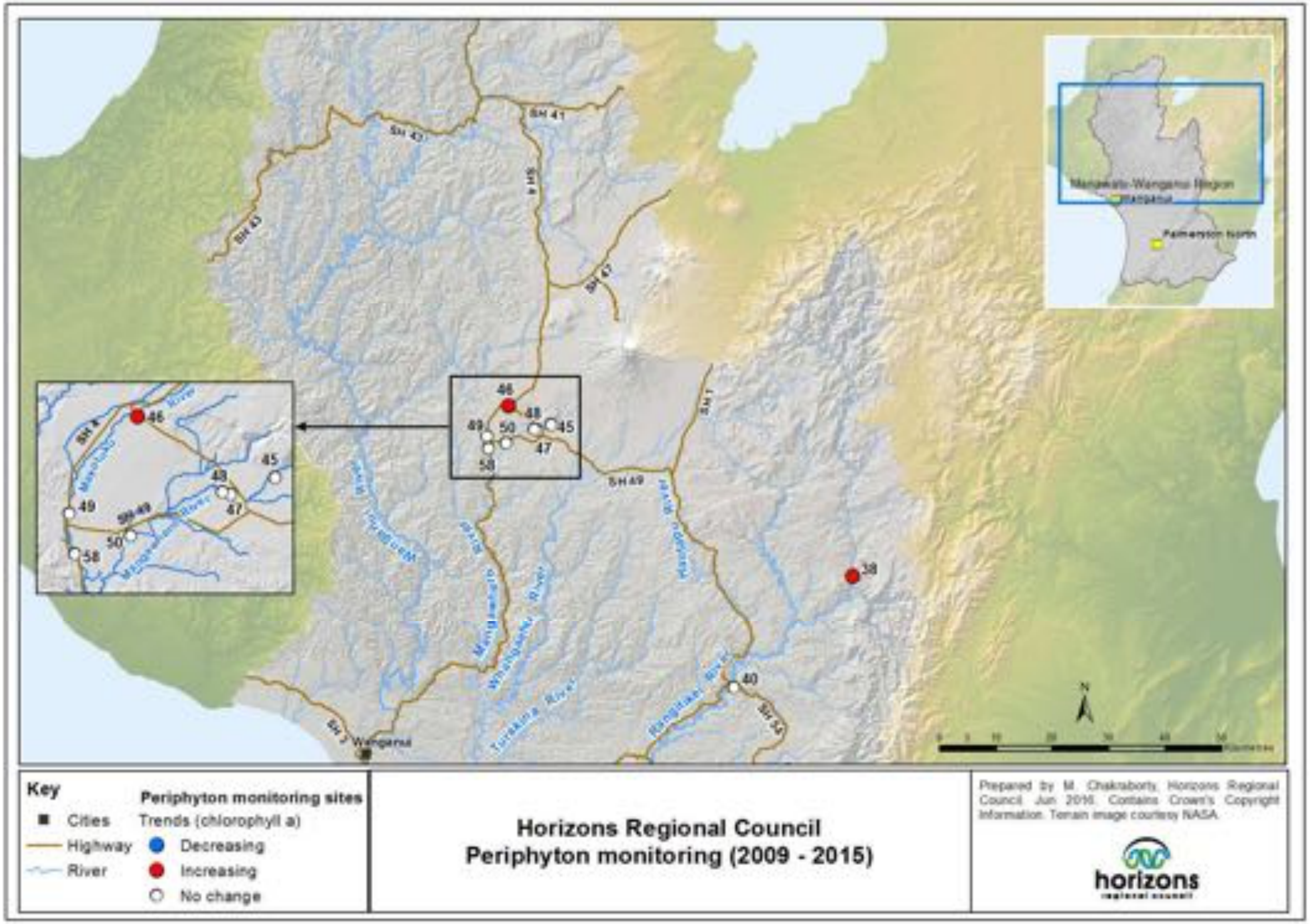
Table 4-11: Summary of trends in chlorophyll *a* and % cover by mats and filaments at 47 sites in the Manawatu-Whanganui region over six years. Trends were identified using classical Sen Slope trend testing, without and with flow adjustment (see text) and equivalence tests. For classical trend tests, the percentage annual change (PAC) is shown, with evidence for trends indicated by green cells (for declines in periphyton) and red cells (for increases in periphyton). Grey cells indicate that the null hypothesis of no trend was not rejected. For equivalence tests, meaningful changes in chlorophyll a were set at 3 mg/m^2 per year, and % mats and filaments and 3% and 2% per year, respectively. Grey ↔ = no evidence for a trend; light green ↓ = trivial decline; green ↓↓ = moderate decline; blue ↓↓↓ = strong decline; yellow ↑ = trivial increase; amber ↑↑ = moderate increase; red ↑↑↑ strong increase (outside limits); light blue, "weak" indicates too much variability (not enough data) for a definitive result.

N	Site abbreviation	Chlorophyll a			% cover by Mats			% cover by filaments		
		Unadj.	Flow adj.	Equiv. test	Unadj.	Flow adj.	Equiv. test	Unadj.	Flow adj.	Equiv. test
2	mangatainoka_putara	23	21	↑	0	0	↔	0	0	↔
4	tamaki_res	18	15	↑	0	0	↔	0	0	↓
5	mangatera_us_dan			weak			↔			↔
8	kumeti_tr	21	12	↑	0	0	↔	0	0	↔
9	manawatu_weber	14	20	↑↑	0	-61	↓	0	-42	↓↓
10	makakahi_ham	11	10	↑↑	-26	-27	↓↓	0	0	weak
11	oroua_apiti	13	-2	↓	0	0	↓	0	0	↔
12	tamaki_ste	4	-4	↓↓	0	0	↓	0	0	↔
13	oruakeretaki_sh2	13	20	weak	0	0	↓	0	0	↔
14	makuri_tuscan	13	7	↑↑↑	-53	-43	↓↓↓	33	30	↑↑
15	pohangina_piri			↑			↔			↔
17	tiraumea_nga	20	6	↑↑↑	-34	-50	↓↓	33	30	↑↑
19	mangatainoka_sh2	18	3	↑↑	0	-7	↔	15	5	weak
21	mangatainoka_us_pah	9	-1	weak	-7	-37	↓↓	0	-21	↔
23	manawatu_hop	1	-4	weak	0	0	↓↓	0	3	↔
26	mangapapa_troup	31	21	↑	0	0	↔	0	0	↔
27	pohangina_mais	19	14	↔	0	0	↔	0	-28	weak
28	manawatu_ug	4	-36	weak	0	0	↓	0	0	↔
29	oroua_almadale	4	-1	↔	0	0	↔	0	0	↔
30	oroua_us_fei	1	2	↔	0	0	↔	0	0	↓↓
32	oroua_awahuri	1	1	weak	0	0	↓	0	-41	↓↓
33	manawatu_tc	26	11	weak	0	0	↔	0	0	↑*

N	Site abbreviation	Chlorophyll a Unadj.	Chlorophyll a Flow adj.	Chlorophyll a Equiv. test	% cover by Mats Unadj.	% cover by Mats Flow adj.	% cover by Mats Equiv. test	% cover by filaments Unadj.	% cover by filaments Flow adj.	% cover by filaments Equiv. test
34	manawatu_us_pncc	9	-27	weak	0	0	↓	0	-37	weak
36	manawatu_opik	58	20	↑↑	0	0	↔	0	-637	weak
37	tokomaru_hb	40	10	↑↑	0	0	↔	0	53	↑
38	rangitikei_puk	23	11	↔	-80	-93	↓	0	1	↔
40	rangitikei_man	9	-13	↔	-56	-213	↓	0	-20	↓↓
43	rangitikei_one	69	50	↑↑	0	0	↑	13	-1	↑*
44	rangitikei_mk	17	37	weak	0	0	weak	0	-2	weak
45	mangawhero_doc	15	8	↔	-283	-9	↓	0	0	↔
46	makotuku_sh49	64	57	↑↑	0	0	↑	0	0	↔
47	mangawhero_us_oha	23	11	↑↑	-16	-15	↔	17	32	↔
49	makotuku_rae	-2	8	weak	-42	-37	↓↓↓	-11	-14	weak
50	mangawhero_pakihi	4	6	weak	-39	-30	↓↓	0	-6	↔
54	waitangi_us_wai			↔			↓↓			↓
56	tokiahuru_kar			↑↑↑			↓			↑
57	makotuku_us_rae			↓↓			↓↓			↓↓↓
59	waikawa_nmr	16	24	↑	0	0	↔	0	0	↓↓
60	ohau_gladstone	14	12	↔	0	0	↓	0	0	↓
61	ohau_sh1	10	1	weak	0	0	↓↓	0	0	↔
6	mangatera_ds_dan			weak			↓			↓↓
20	mangatainoka_ds_db	7	-6	weak	0	-24	↓↓	0	0	weak
22	mangatainoka_ds_pah	6	10	weak	-16	-29	↓↓	-17	-28	↓↓
31	oroua_ds_fei	1	4	weak	0	-91	↔	0	-264	↓↓
35	manawatu_ds_pncc	27	15	↑↑	0	-11	↔	0	-12	weak
48	mangawhero_ds_oha	16	0	↑↑	-6	-21	↔	0	-44	↔
55	waitangi_ds_wai			weak			↓↓			↓↓
58	makotuku_ds_rae	-6	-5	weak	-20	-9	↓↓	-48	-44	↓↓↓

Table 4-12: Percentages of sites in each trend category as assessed in trend analyses for chlorophyll *a*, % mats and % filaments. Analyses were performed on sites with data from December 2008 to April 2015 (n = 47). For explanations of categories, see Section 4.2.3.

	Percentage of sites in each trend category, for:		
Trend category	Chlorophyll a	% Mats	% Filaments
Classical trend tests, unadjusted			
Signficant increase	56	0	10
No evidence for a change	44	73	88
Significant decrease	0	27	2
Classical trend tests, flow adjusted			
Signficant increase	15	0	5
No evidence for a change	85	76	88
Significant decrease	0	24	7
Equivalence tests			
Strong increase	6	0	0
Moderate increase	21	0	4
Trivial increase	13	4	9
No evidence for a change	15	38	40
Trivial decline	2	28	4
Moderate decline	4	23	19
Strong decline	0	4	4
Inconclusive (not enough data)	38	2	19


SH 41
SH 43
SH 4
SH 47
SH 49
SH 1
SH 3
Wanganui
Manawatu-Wanganui Region
Palmerston North
46
48
49
50
45
47
58
38
40
Turakina River
Rangitikei River
Whangaehu River
Mangawhero River
Key
Cities
Highway
River
Periphyton monitoring sites
Trends (chlorophyll a)
Decreasing
Increasing
No change
Horizons Regional Council
Periphyton monitoring (2009 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council, Jun 2016. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons

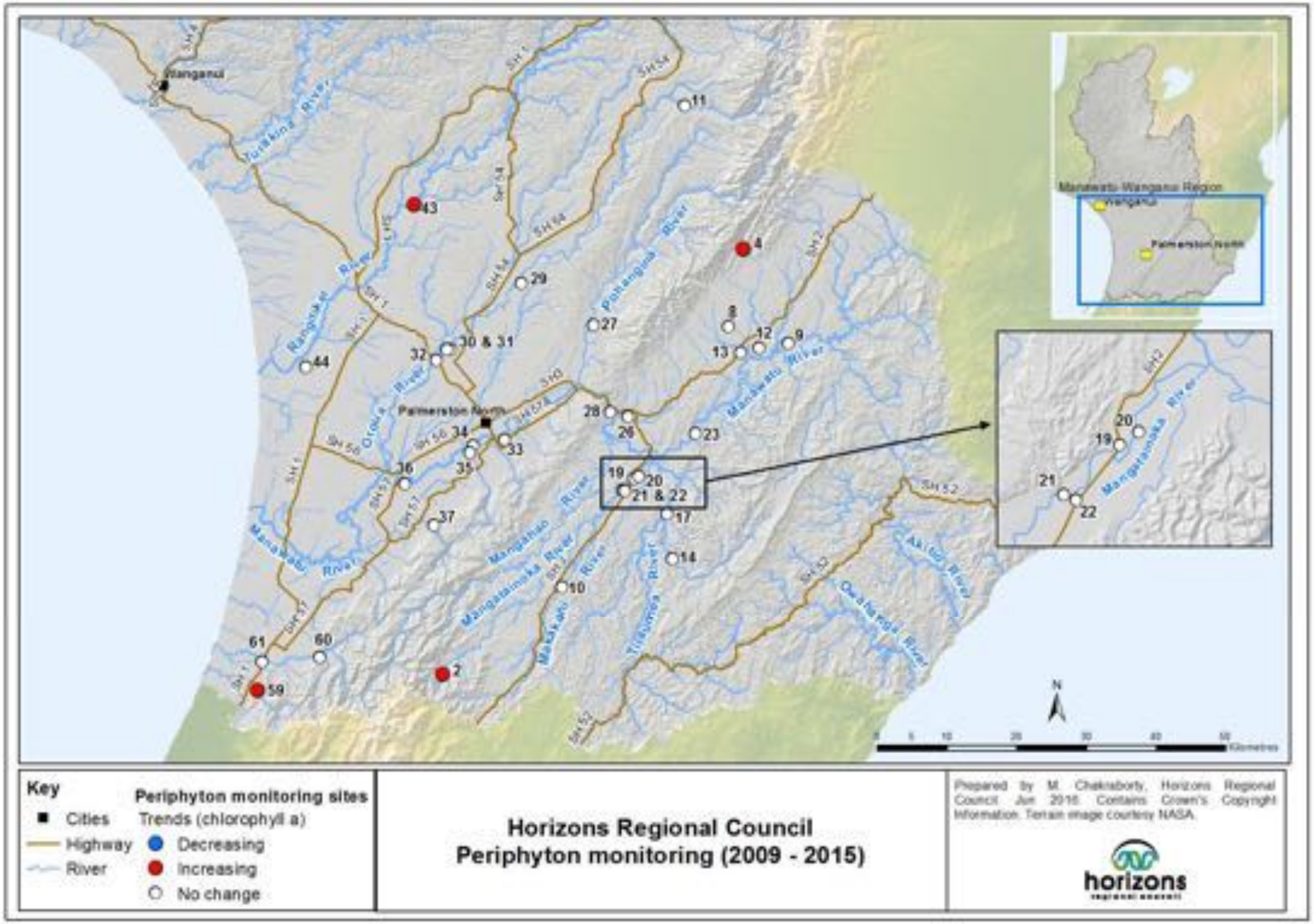
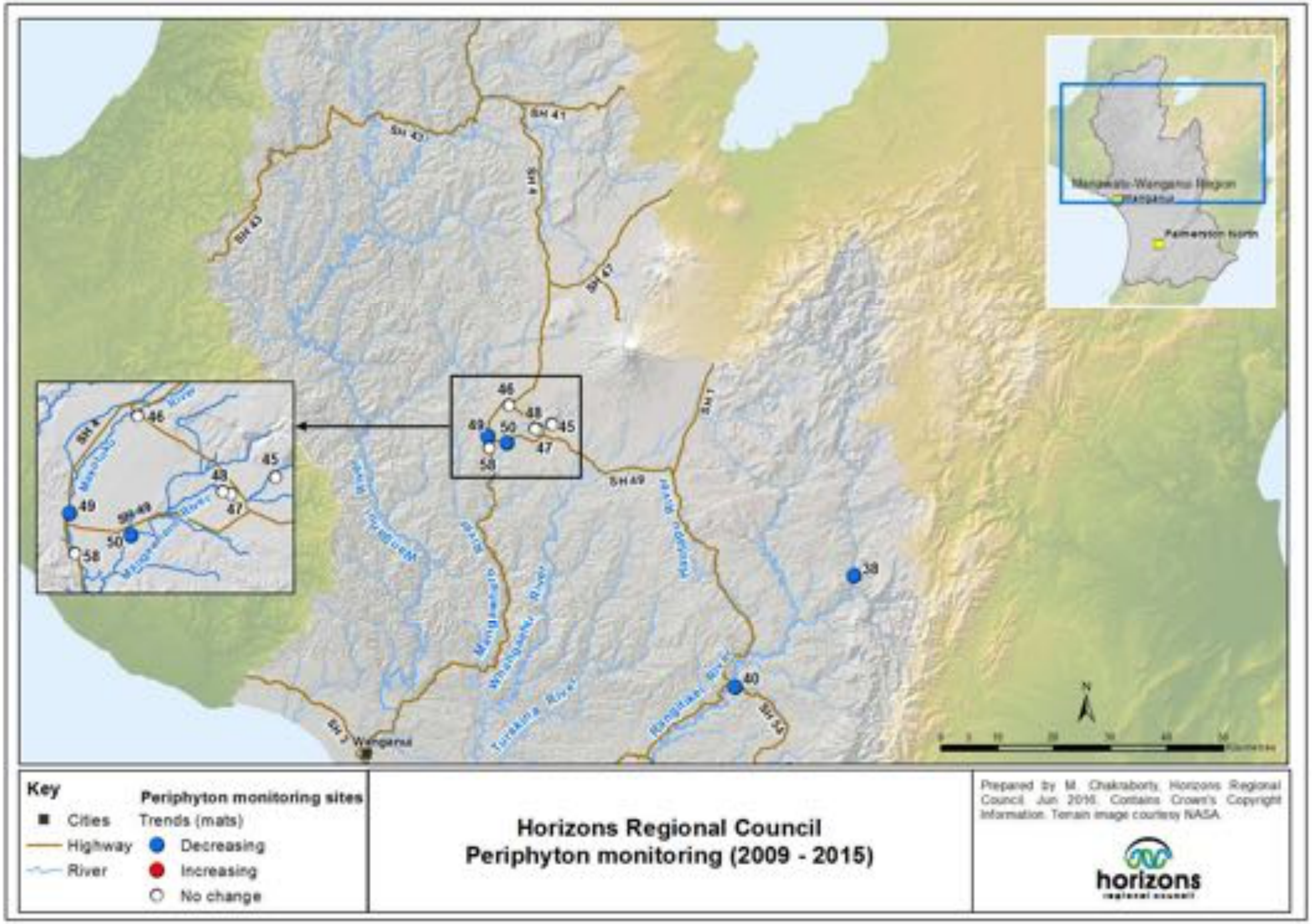


Figure 4-10: Maps showing trends in periphyton chlorophyll *a* in eight categories from 2009 to 2015. Trends were determined using flow-adjusted data. "No change" means that there was no evidence from the data of either an increase or decrease in chlorophyll *a*.


SH 41
SH 43
SH 47
SH 49
SH 1
SH 3
Wanganui
Manawatu-Wanganui Region
Palmerston North
46
48
45
49
50
47
58
38
40
Whangaehu River
Turakina River
Rangitikei River
N
Key
Cities
Highway
River
Periphyton monitoring sites
Trends (mats)
Decreasing
Increasing
No change
Horizons Regional Council
Periphyton monitoring (2009 - 2015)
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horizons

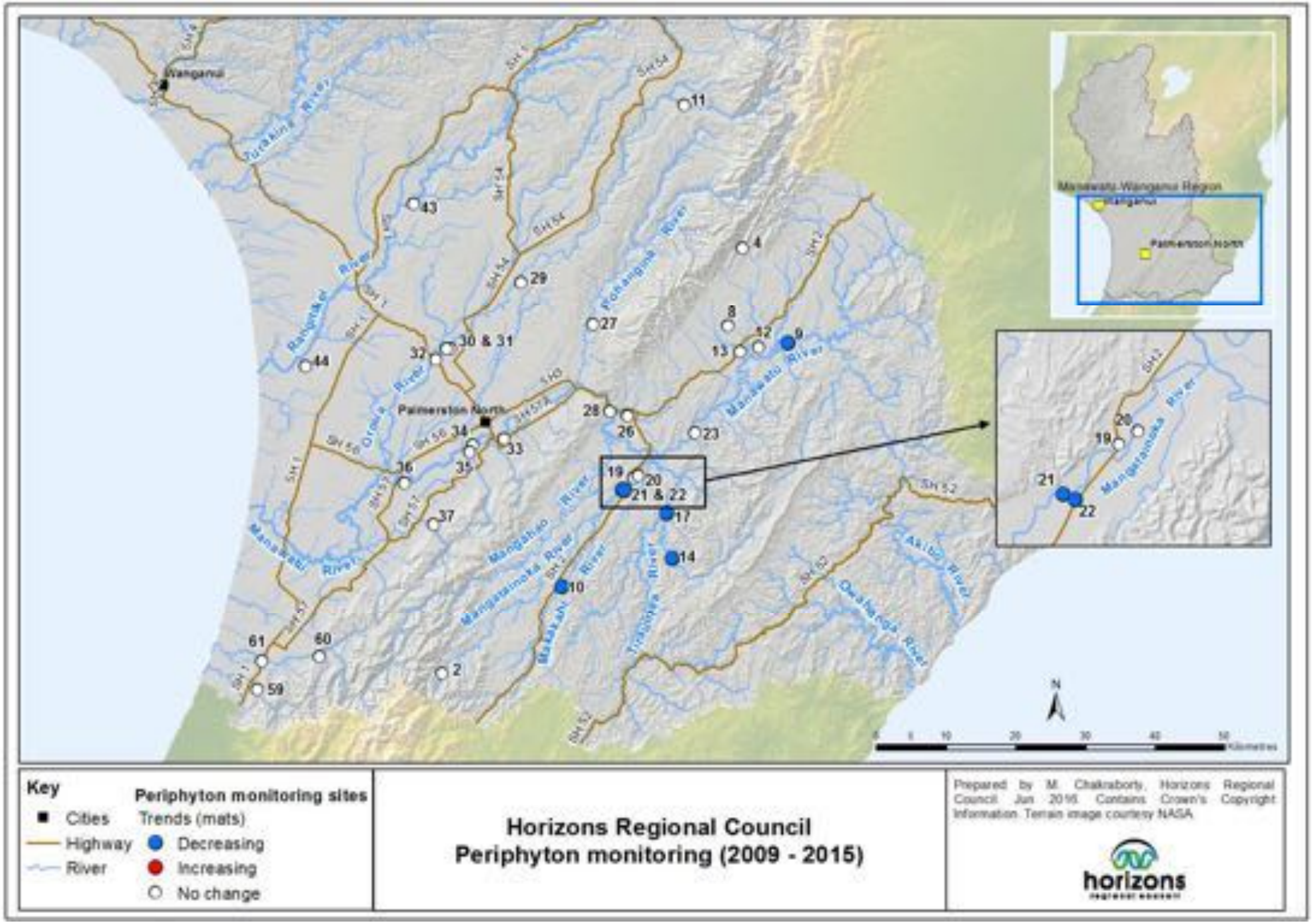
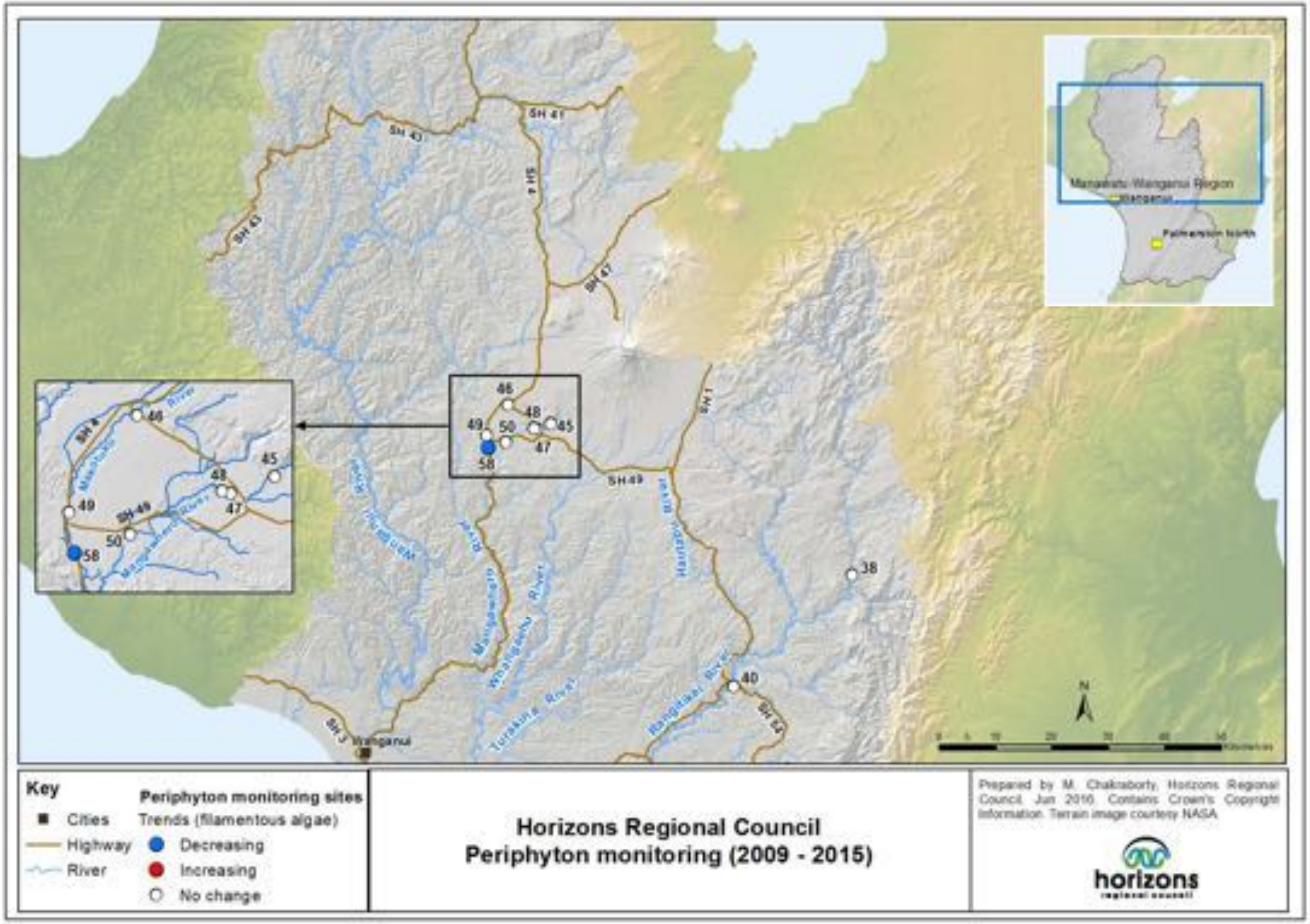


Figure 4-11: Maps showing trends in % cover by periphyton mats in eight categories from 2009 to 2015. Trends were determined using flow-adjusted data. "No change" means that there was no evidence from the data of either an increase or decrease in chlorophyll *a*.


SH 43
SH 41
SH 4
SH 47
SH 49
SH 1
SH 3
Wanganui
Whanganui River
Turakina River
Rangitikei River
Hautapu River
Manawatu-Wanganui Region
Palmerston North
46
48
45
49
50
47
58
38
40
Key
Cities
Highway
River
Periphyton monitoring sites
Trends (filamentous algae)
Decreasing
Increasing
No change
Horizons Regional Council
Periphyton monitoring (2009 - 2015)
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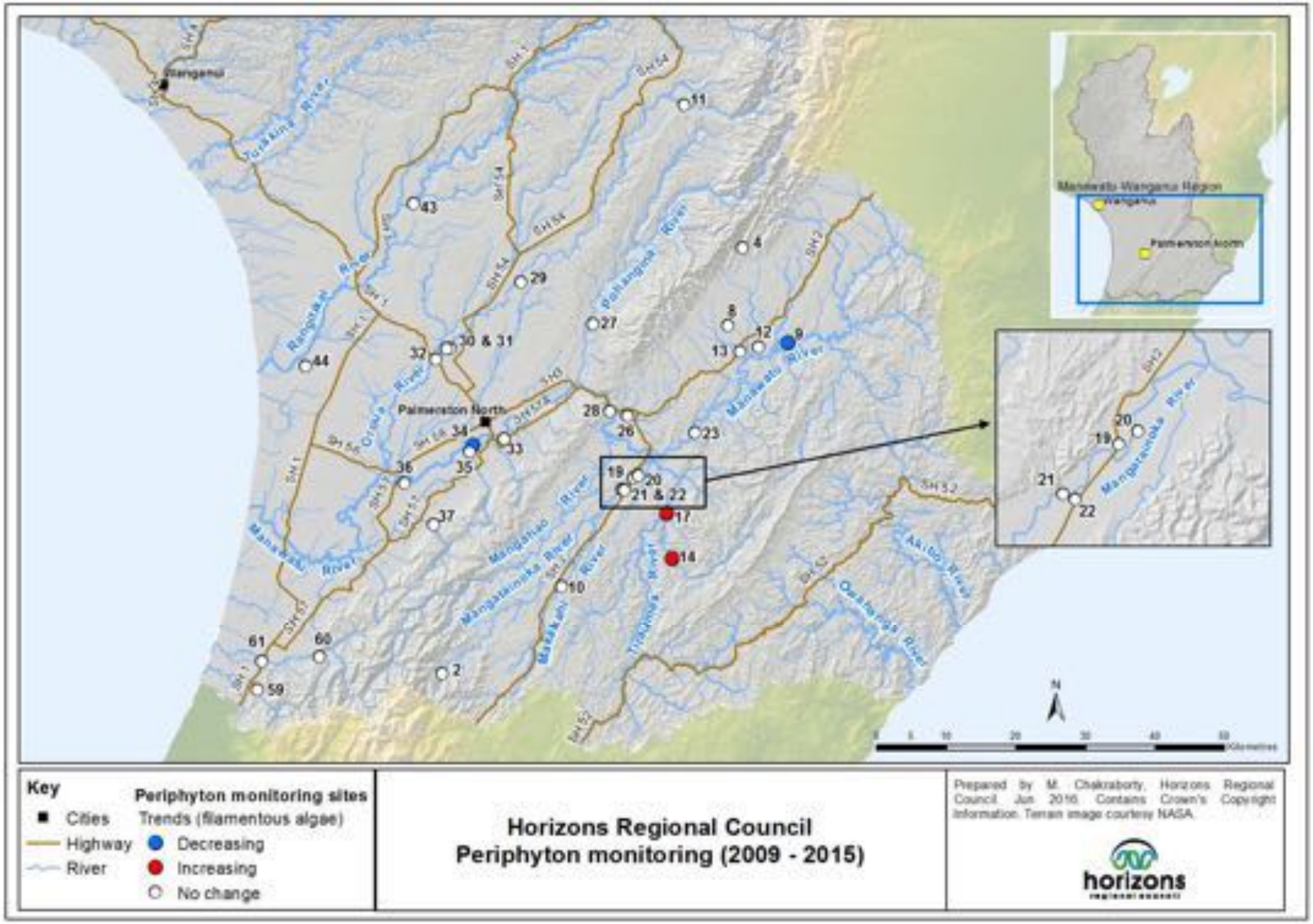


Figure 4-12: Maps showing trends in % cover by periphyton filaments in eight categories from 2009 to 2015. Trends were determined using flow-adjusted data. “No change” means that there was no evidence from the data of either an increase or decrease in chlorophyll *a*.

4.3.6 Trends in nutrient concentrations

There was evidence for a decline in DRP concentrations over the monitoring period at 12 sites in seven rivers (Table 4-13). The declines ranged between 0.5 and 4.7 mg/m^3 per year, or at least 7% per year compared to the median value. DRP increased over the same period at seven sites in four different rivers, from 0.5 to 2.9 mg/m^3 per year (17.7% increase per year, on average). Mean flow on the day of the survey explained less than 30% of the variation in DRP at most sites. DIN concentrations declined over the monitoring period at six sites in four rivers (Table 4-13). No increases in DIN were detected.

Table 4-13: Periphyton monitoring sites at which a trend in nutrient concentration (DIN or DRP) was detected over the monitoring period. Tests were run with and without flow adjustment; the flow adjusted result is shown where the percent explained exceeded 30%. Green-shaded cells indicate declines in nutrient concentrations, and pink-shaded cells increases

N	River	Site	% explained if flow adjusted	No. samples used	Median (mg/m^3)	P	Sen slope (annual)	% annual change
Sites with evidence for a change in DRP								
8	Kumeti	kumeti_tr	unadjusted	76	10.0	0.01	-0.8	-8.0
36	Manawatu	manawatu_opik	39.7	73	16.0	0.04	-1.2	-7.2
34		manawatu_us_pncc	unadjusted	72	15.8	0.02	-1.25	-9.65
26	Mangapapa	mangapapa_troup	unadjusted	69	13.0	0	-1.0	-7.7
20	Mangatainoka	mangatainoka_ds_db	unadjusted	70	7.5	0	-1.0	-13.2
21		mangatainoka_us_pah	unadjusted	72	7.0	0	-0.8	-10.7
11	Oroua	oroua_apiti	unadjusted	77	7.0	0.04	-0.5	-7.1
32		oroua_awahuri	unadjusted	77	19.0	0	-3.0	-15.8
31		oroua_ds_fei	unadjusted	77	20.0	0	-4.7	-23.5
30		oroua_us_fei	unadjusted	73	15.0	0.02	-2.0	-13.3
13	Oruakeretaki	oruakeretaki_sh2	unadjusted	77	14.0	0.01	-1.0	-6.9
55	Waitangi	waitangi_ds_wai	no flow data	73	60	0	-7.3	-12.5
49	Makotuku	makotuku_rae	unadjusted	68	6.0	0	1.5	25.2
46		makotuku_sh49	unadjusted	68	9.5	0	2.5	26.4
45	Mangawhero	mangawhero_doc	unadjusted	77	14.0	0.04	1.0	7.2
40	Rangitikei	rangitikei_man	49.2	67	7.0	0	0.5	7.0
43		rangitikei_one	59.2	67	7.0	0.03	0.5	7.2
38		rangitikei_puk	unadjusted	76	6.0	0	0.8	13.9
37	Tokomaru	tokomaru_hb	unadjusted	67	7.0	0.03	0.6	8.3
Sites with evidence for a change in DIN								
46	Makotuku	makotuku_sh49	30.7	59	211.6	0.01	-22.3	-10.5
34	Manawatu	manawatu_us_pncc	unadjusted	72	524.4	0	-37.7	-7.2
26	Mangapapa	mangapapa_troup	32.4	68	356.8	0.01	-49.0	-13.8
48	Mangawhero	mangawhero_ds_oha	unadjusted	70	227.6	0	-23.7	-10.4
47		mangawhero_us_oha	unadjusted	71	159.3	0	-29.7	-18.6
30	Oroua	oroua_us_fei	unadjusted	69	392.0	0	-79.2	-20.2

4.4 Discussion

4.4.1 Patterns in periphyton state

A detailed appraisal of river state in terms of periphyton chlorophyll *a* and percent cover over six years confirmed that many river sites in the Manawatu-Whanganui region have mean and median chlorophyll *a* well below existing or previous guidelines. Over 70% of all sites had chlorophyll *a* of < 15 mg/m^2 for at least 50% of the time. Almost 50% of sites had mean value of < 5 mg/m^2. Cover by mats was also low at many sites. In contrast to mats, many sites experienced higher cover by filamentous algae over the same period. Discrepancies between state assessed using different metrics is partly a reflection of the metric itself, but large differences between state based on mats and filaments may reflect differences between sites that lead to the development of different types of algae.

While state as assessed using chlorophyll *a* metrics tended to worsen in a downstream direction (i.e, increasing chlorophyll *a*), this pattern was not always seen in cover by mats and filaments. High cover occurred well upstream in some catchments. This discrepancy between spatial patterns in chlorophyll *a* state and periphyton cover state is likely to reflect the fact that occasional high cover by some types of algae can occur in a wide range of conditions, and species composition may differ. For example, the type of green filamentous algae typical downstream of sewage treatment plant discharges is likely to be different from that forming occasional high cover at a headwater site. Species composition data from each site at times of peak biomass could be helpful for interpreting the spatial patterns.

A preliminary investigation into environmental variables associated with river state was carried out by inspecting box plots of a range of variables plotted against river state in terms of mean chlorophyll *a*, and the 92nd percentile of mats, filaments and cyanobacteria. Variables included DRP, DIN, conductivity, % fine and coarse substrate, and flow metrics. No variable clearly distinguished river state based on the 92nd percentile of % cover by mats. Some of the stronger patterns detected are shown in Figure 4-13.

Vlow mean chlorophyll *a* was generally reported only at sites where mean $\log_{10}$DIN < 2 (i.e., DIN of <~100 mg/m^3) (exception: site 7, maingatainoka_huk); and where mean conductivity was < 80 µS/cm (exceptions: site 27, pohangina_mais; and site 29, oroua_almadale). High and Vhigh mean chlorophyll *a* were observed only where the percentage of the catchment in farmland was > 60% (exceptions: site 39, moawhango_waiouru and site 55, waitangi_ds_wai) (Figure 4-13, left panel). Patterns for state based on % cover by filamentous algae were similar to those for chlorophyll *a*.

The two exceptions from the pattern of association of high chlorophyll *a* with catchments with >60% in farmland can be explained. Site 39, moawhango_waiouru is in a regulated river with stable flows for much of the year, which could lead to persitent periphyton mats. DRP is moderate to high at this site (median 14 mg/m^3), and DIN very low (median 5 mg/m^3), which would favour development of stable algal mats possibly dominated by nitrogen-fixing cyanobacteria, and/or diatoms such as *Epithemia* and *Rhopalodia* which have N-fixing endosymbionts (i.e., cyanobacteria living within the diatom cells in a mutually beneficial relationship). Site 55, waitangi_ds_wai, is downstream of a wastewater treatment plant (WWTP), which explains higher nutrient concentrations and periphyton in a catchment that is largely undeveloped.

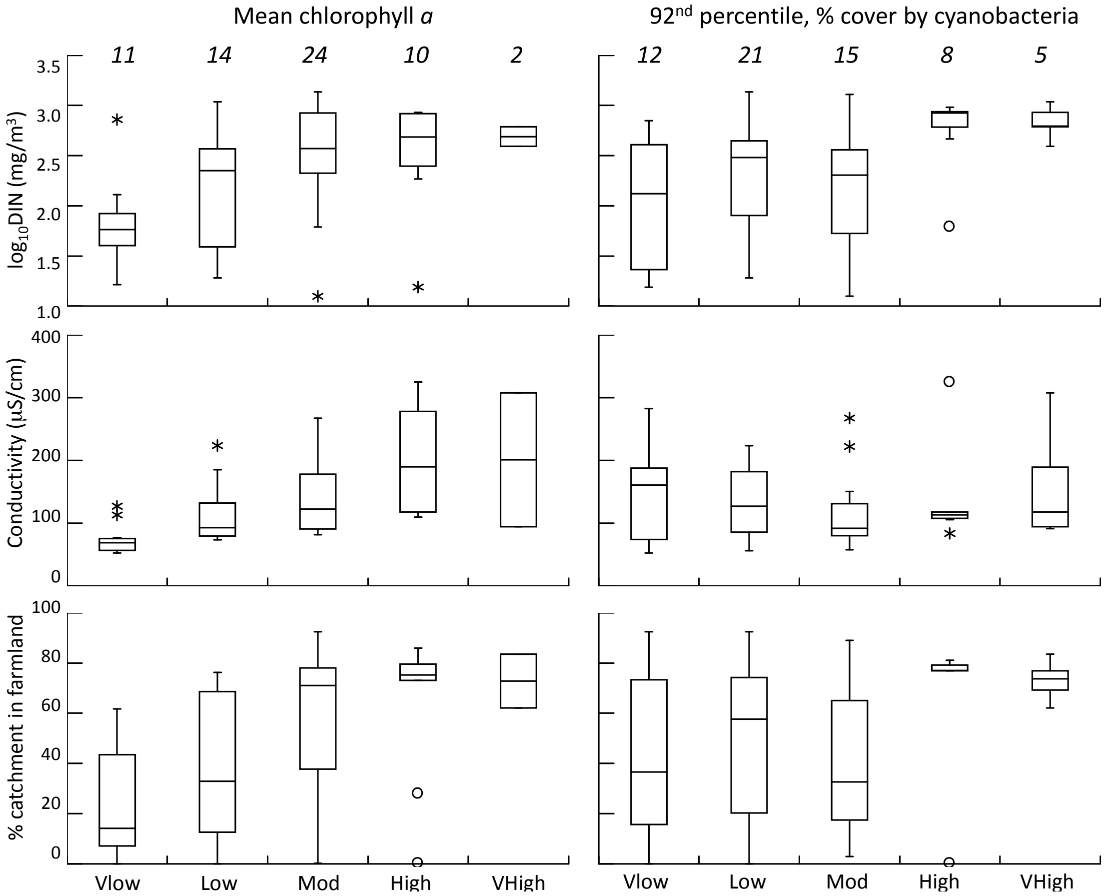


Figure 4-13: Box plots showing values of DIN, conductivity and % catchment in farmland river state categories for chlorophyll *a* (left) and cyanobacteria (right). Vlow to Vhigh refers to increasing biomass or cover. Data are from the latest three years of the dataset (2012-15) to maximise the number of sites (n = 61). Numbers of sites assigned to each state are shown in italics at the top of each set of plots. The boxes represent the range of 50% of the data, with the median shown by the line within the box; whiskers show values up to 1.5 times the range of the 50% of values around the median Outliers are shown by asterisks and circles.

The pattern for the 92nd percentile of % cover by cyanobacteria was different in that the High and Vhigh categories were defined by mean DIN > 620 mg/m^3 (exception: site 37, tokomaru_hb, where DIN was less than 100 mg/m^3). The association between High or Vhigh state and % of catchment area in farmland was striking. The exception to this pattern was again site 37, tokomaru_hb, which, according to the LCDB3 had less than 1% farmland in its catchment. There is no obvious explanation for this exception. However, DRP had increased at this site (average of 8% per year) between December 2008 and April 2015, which may reflect changes in the catchment not detectable in the LCDB dataset. Highest cover by cyanobacteria was recorded from April to June 2012, which coincided with DIN of 130 mg/m^3. Note that it is assumed that the cyanobacteria cover recorded was the nuisance taxon *Phormidium*. However this needs to be verified. Across all sites, there was no apparent link between % cover by cyanobacteria and conductivity (Figure 4-13, right hand panel).

The patterns in Figure 4-13 were reflected in correlation analyses of the underlying periphyton data against mean DIN, conductivity and % farmland at at each site. Kendall's tau (τ) (non-parametric correlation coefficient based on ranks) was highest for conductivity vs. chlorophyll *a* (0.469). While mean DIN and % farmland and mean conductivity and % farmland were relatively strongly correlated, the correlation between DIN and conductivity was much weaker (Table 4-14).

Table 4-14: Correlation coefficients (Kendall's tau) between mean DIN, conductivity and % farmland, and the underlying periphyton data. Correlations between the environmental variables are also shown.

	Chlorophyll *a*	92nd p'ntile, % cyanobacteria	Mean DIN	Mean conductivity
Mean DIN	0.337	0.290		
Mean conductivity	0.469	0.002	0.240	
% catchment in farmland	0.369	0.214	0.593	0.414

4.4.2 Comparison between trends assessed using different methods

Trends in periphyton assessed using unadjusted classical trend tests and equivalence tests produced the same general patterns of increases in chlorophyll *a* at a relatively high proportion of sites, more evidence for decreases than increases in % cover by mats, and some evidence in increases in % cover by filaments but no change at most sites. However, there were inconsistencies and examples are described below.

Most sites identified as having increasing chlorophyll *a* using equivalence tests showed non-significant results when the classical trend test was run using flow-adjusted data, indicating that the increase detected could generally be attributed to the change in flow conditions over the monitoring period, as identified in Table 4-2. There was one exception. At site 38, rangitikei_puk, chlorophyll *a* was identified as increasing using both unadjusted and flow-adjusted data in classical tests, but the equivalence test returned no evidence for a change. Examination of the raw data (bottom left plot in Figure 4-9) indicates that there appeared to be a shift over time to fewer very low values, but no increase in the higher range. Scrutiny of monthly variabililty in relation to the defined meaningful annual change of 3 mg/m^2 might help to understand why the equivalence test returned no evidence for a trend even within the limits, despite the raw data suggesting a trend.

The equivalence test results for % cover by mats returned more declines in cover than the classical tests (both unadjusted and flow adjusted), but most declines were trivial (within the defined meaningful annual change of 2%). The stronger trends identified by equivalence testing were generally reflected in the results of classical tests using unadjusted data. Exceptions were sites 23, manawatu-hop; 61, ohau_sh1; and 20, mangatainoka_ds_db (Table 4-11). In all three cases, a trend was detected using the equivalence test but not using the classical test with either unadjusted or flow-adjusted data. As an example, raw data for site 61, ohau_sh1 are shown in Figure 4-14. The data suggest a change over time from frequent–occasional to almost no records of moderate cover by mats (i.e., > 20% cover). In this case the result from the equivalence test appears to refect the data more accurately than those from the classical tests.

For percent cover by filaments, four of the five significant trends detected using classical tests with unadjusted data showed corresponding results using equivalence tests. The exception was site 47, mangawhero_us_oha, where both the equivalence test and the classical test using flow-adjusted data returned no evidence for a trend (Table 4-11). At six sites, the equivalence test returned evidence for a moderate decline in cover by mats while the classical tests indicated no evidence for a trend. The raw data from oroua_us_fei are shown in Figure 4-15, as an example. Similar to the examples in Figure 4-14, the data do suggest a trend from occasional records of high cover by filaments, to no records of high cover in the past two years. However, there are many zero values and missing data (20 of 77 cases missing). Therefore, inadequate data may explain the failure of the classical test to reject the null hypothesis.

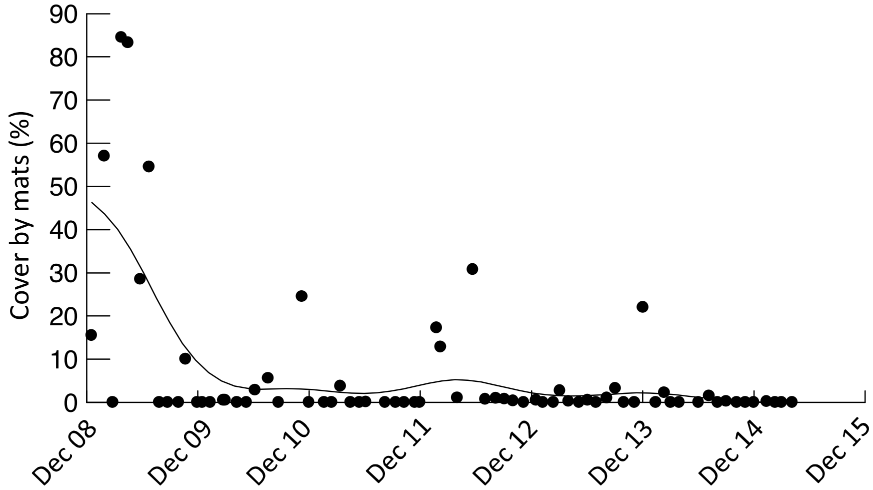


Figure 4-14: Percentage cover by mats recorded at site 61, ohau_sh1, between December 2008 and April 2015. An equivalence test returned a moderate decreasing trend in mats at this site. Classical trend tests using both unadjusted and flow-adjusted data failed to reject the null hypothesis of no monotonic trend.

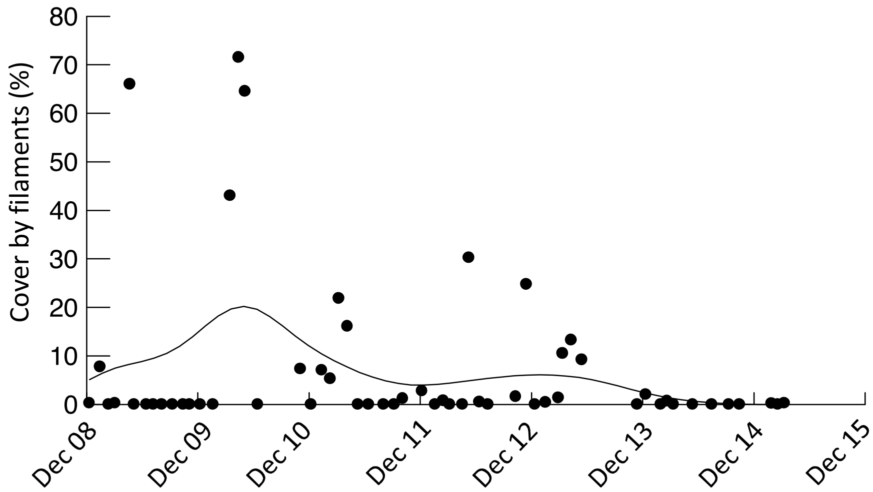


Figure 4-15: Percentage cover by filaments recorded at site 30, oroua_us_fei, between December 2008 and April 2015. An equivalence test returned a moderate decreasing trend in cover by filaments at this site. Classical trend tests using both unadjusted and flow-adjusted data failed to reject the null hypothesis of no monotonic trend.

Overall, the results from the classical trend tests and the equivalence tests were only partly interchangeable, and it is difficult to determine which is the more "correct". Because equivalence tests used in the context of trend-testing are relatively untested, at this stage, the classical approach is the more pragmatic choice; classical trend testing also allows for direct comparisons with previous results. Also, until flow adjustment can be incorporated into the equivalence test code, direct comparisons with flow-adjusted classical testing will not be possible.

4.4.3 Explanations for contrasting trends in chlorophyll *a*, mats and filaments

In view of the inconsistent results returned using classical trend tests versus equivalence tests, here we consider contrasting trends identified only using the classical tests using flow-adjusted data, summarised at the end of Section 4.4.3. There were opposing trends at only three sites.

At makuri_tuscan (site 14) and tiraumea_nga (site 17), strong increases in chlorophyll *a* were accompanied by a decline in % cover by mats, and increases in % cover by filaments. It seems likely that the flow driven increases in chlorophyll *a* at these sites also drove a change in periphyton community structure, with filaments increasing at the expense of mats, as flows declined.

A site 38, rangitikei_puk, chlorophyll *a* increased over time, % cover by mats declined and % cover by filaments did not change. All three of chlorophyll *a*, % mats and % filaments were low at this site (see Table 4-8, Table 4-9, Table 4-10). The raw data from the site showed that between 2008 and 2015, the percentage cover occupied by bare rock (no algae) declined to low levels (<20% in 2015) while cover by "film" increased to >80% in many surveys. Therefore at rangitikei_puk, chlorophyll *a* likely was derived mostly from algae in films, and the very low cover by both mats and filaments made a smaller contribution to total biomass.

4.4.4 Can trends in periphyton be linked to changes in nutrient concentrations over time?

Trends in both periphyton and nutrient concentrations were detected at seven sites (Table 4-15). Coincident declines or increases may indicate a causal relationship. Coincident trends were observed for DRP and a periphyton measure at one site each in the Mangatainoka, Manawatu, Rangitikei, and Makotuku rivers.

In two cases the trends were opposing. At sites 40 (rangitikei_man), DRP at least doubled from a baseline level of 3 to 4 mg/m^3 in 2008-9 to 8 – 9 mg/m^3 in 2014-15, but cover by mats declined. There were similar changes at makotuku_rae. These counterintuitive trends are difficult to explain, even by referring to the raw data. Shifts in periphyton community composition may be responsible, but cannot be confirmed without more detailed information. Trends were detected in both DIN (a decline) and DRP (an increase) at makotuku_sh49, and these were accompanied by an increase in chlorophyll a. From examination of the raw data it is clear that the increase in DRP has been more prounouced than the decline in DIN. Therefore DRP is more likely to have driven the change in chlorophyll *a*.

Table 4-15: Summary of trends at sites where both periphyton and at least one of DIN, DRP or flow showed a significant change over time. Trends are those identified using classical trend testing on flow-adjsuted data. In many cases coincident trends were as expected (e.g., increases in periphyton and nutrient concentrations). Refer to text for a discussion on counterintuitive patterns.

N	Site abbreviation	Sub-zone code	Narrative of trends	Comment
21	mangatainoka_us_pah	Mana_8c	decline in DRP, decline in mats	DRP moderate (7)
34	manawatu_us_pncc	Mana_11a	decline in DRP and DIN, decline in filaments	DRP (15.8) and DIN (524) already high
38	rangitikei_puk	Rang_2a	increase in DRP, increase in chlorophyll a, decline in mats	DRP moderate/low (6)
40	rangitikei_man	Rang_3a	increase in DRP, decline in mats	DRP moderate (7)
43	rangitikei_one	Rang_3a	decline in flow, increase in chlorophyll *a*	
46	makotuku_sh49	Whau_3b	decline in DIN, increase in DRP, increase in chl *a*	DIN moderate (212), DRP moderate (9.5)
49	makotuku_rae	Whau_3c	increase in DRP, decline in flow, decline in mats	DRP moderate/low (6)

One potentially important factor influencing periphyton standing crop is invertebrate grazing. Interactions between nutrients, periphyton biomass and community composition have been demonstrated in streams. For example, periphyton community changes resulting from nutirent enrichment may alter palatability of periphyton to different invertebrates, which may then alter grazing pressure (McCall et al. 2014). Such responses could account for some of the unexplained variation in periphyton trends.

4.4.5 Summary of state and trends across all sites

In Table 4-16 below, the assessments of state at each site for each periphyton metric (median and mean chlorophyll *a*, and percentage cover by mats and filaments) are combined with the trends (identified using classical trend tests on flow-adjusted data for chlorophyll a, % mats and % filaments) assessed over six-year and three-year periods.

Table 4-16: Summary of the number of sites in each state category for four periphyton metrics, separating sites at which trends were identified. State categories are defined in Table 4.1. Sites included are all those with the complete 6 years of data and a flow record (n = 41). Trends were calculated using classical trend testing (Seasonal Kendall Sen Slope Estimator) on flow-adjusted data. The flow metric used was the time elapsed since a high flow for each observation. The magnitude of the high flow was in multiples of median flow, and at each site was the flow that explained the highest proportion of variance in periphyton over the monitoring period. State for cyanobacteria at all sites is included for comparison.

		State: calculated from 2008 to 2015 data					State: calculated from 2012 to 2015 data				
		VLow	Low	Mod	High	VHigh	VLow	Low	Mod	High	VHigh
		Median chlorophyll *a*									
Trend	Increasing	6	0	0	0	0	2	4	0	0	0
	Not detected	13	11	9	2	0	5	15	10	4	1
	Decreasing	0	0	0	0	0	0	0	0	0	0
		Mean chlorophyll *a*									
	Increasing	3	3	0	0	0	2	4	0	0	0
	Not detected	6	9	15	5	0	5	7	15	6	2
	Decreasing	0	0	0	0	0	0	0	0	0	0
		Percent cover by mats (92nd percentile)									
	Increasing	0	0	0	0	0	0	0	0	0	0
	Not detected	8	10	8	5	0	16	7	5	3	0
	Decreasing	0	2	2	5	1	1	5	2	2	0
		Percent cover by filaments (92nd percentile)									
	Increasing	0	0	0	1	1	0	0	0	1	1
	Not detected	7	2	10	6	11	8	5	6	12	5
	Decreasing	0	0	0	1	2	0	0	0	2	1
		Percent cover by cyanobacteria (92nd percentile)									
		State: calculated from 2011 to 2015 data					State: calculated from 2012 to 2015 data				
	All sites	4	14	9	7	7	7	14	10	6	4

The summary highlights that:

- for all periphyton measures, trends were identified at a small proportion of sites, after taking the effects of flows into account;
- trends of increasing chlorophyll *a* were recorded only at sites with low chlorophyll *a* (in the VLow or Low state categories for median and mean chlorophyll *a* in both periods);
- trends of decreasing cover by mats occurred across all state categories;
- the sites at which a trend (either up or down) in percentage cover by filaments was recorded were in the two worst categories (High or VHigh).

Percentage cover by cyanobacteria could not be summarised in the same way because no trend analysis was performed due to the short record. In Table 4-16, the numbers in each state show how removing 2011 from the calculation resulted in a general shift to better state (lower cover) in the most recent three years of the dataset.

5 Comparison with One Plan targets, NPS-FM bands and the cyanobacteria guideline

Key messages

One Plan targets for periphyton chlorophyll *a* and % cover by mats and filaments apply to all river management sub-zones in the region. Chlorophyll *a* targets are 50, 120 or 200 mg/m^2, and % cover targets are 60% mats and 30% filaments.

Between 2008 and 2015 the chlorophyll *a* target was exceeded in 6.3% of all surveys. At 13 sites (28%) the target was exceeded in more than one in 20 surveys; at 15 sites (34%) the target was never exceeded (i.e., 100% compliance).

Overall exceedance rates of the targets for % cover by mats and filaments were 1% and 4.8% respectively; 70% of sites were 100% compliant with the mat target and 39% with the filaments target.

Rates of compliance were lower at sites downstream of point-source discharges. None of these sites were 100% compliant with the chlorophyll *a* target, and only one of 8 sites complied with the filaments target.

There was a higher rate of 100% compliance for all three targets from May 2012 to April 2015 (45%, 98% and 55%, respectively). Compliance with the targets was highest in headwater sites, and non-compliance occurred throughout the region.

The National Objective Framework in the National Policy Statement for Freshwater Management (NPS-FM) defines four periphyton bands, from A (best state) to D (below the national bottom line).

In the Horizons region, 53 sites had sufficient data to enable assignment to a state, using data from May 2012 to April 2015. Over 50% of these sites were assigned to band A, and 30% to Band B. Four sites (8%) were in band D.

There was no clear spatial pattern of NPS-FM bands for chlorophyll *a* except that headwater sites were usually in the A band, and sites downstream of point-source discharges were always B band or lower (including two sites in band D).

The NZ cyanobacteria guideline specifies “alert” and “action” thresholds of 20% and 50% cover, respectively, by potentially toxic benthic cyan obacteria, for protection of animal and human health.

About 75% of all sites did not exceed the alert level over the four-year period of cyanobacteria monitoring. Most exceedances of the action level (at 7 of 55 sites, 12.5%) occurred in the first year of the monitoring programme. Only one exceedance occurred between 2012 and 2015, at Makotuku at SH49, although this site usually had very low cover. Over 70% of exceedances of the alert threshold were at sites in the lower Mangatainoka cachment and Tiraumea catchment.

In an overall summary, all sites were ranked in terms of all the metrics calculated to describe state and compliance using a range from 4 (best state) to 0 (worst state), and a total rank sum generated.

The 12 top-ranked (best) sites were mostly in the upper reaches of rivers, with an average of 35% farmland in their catchments (range 0 – 92%). All sites downstream of point-source discharges ranked 28th or more of 47 sites. Other low-ranked (worst) sites had an average of 76% of their catchments in farmland.

There was evidence of increasing chlorophyll *a* at some top-ranked sites. Repeat trend tests in 2-3 years are suggested.

5.1 Background

5.1.1 One Plan targets

Horizon's One Plan targets for periphyton were established in the proposed One Plan in 2007 for all river sites in the region. The thresholds largely reflect the guidelines for periphyton biomass for various instream values described in the Ministry for the Environment guideline of 2000 (Biggs 2000a). The current targets are specified for all surface water management sub-zones in schedule E of the operative One Plan (December 2014; http://www.horizons.govt.nz/assets/publications/about-us-publications/one-plan/Schedule-E-Surface-Water-Quality-Targets-2014_2.pdf). The targets for chlorophyll *a* are 50, 120 or 200 mg/m^2 chlorophyll *a*, depending on water management zone. No sites in the periphyton monitoring programme had a target of 200 mg/m^2. Targets for cover by periphyton mats and filaments are 60% and 30% in all water management zones.

Although the One Plan provides no guidance on assessing compliance with periphyton biomass (chlorophyll *a*) and coverage (filamentous algae and mats) targets, the technical document that recommended these standards/targets provided commentary on assessing compliance for each of the metrics (Ausseil & Clark 2007). In the One Plan itself, the commentary around the target for chlorophyll *a* is: "The algal biomass on the river bed must not exceed […] milligrams of chlorophyll *a* per square metre". Where targets are exceeded from time to time, monthly sampling allows calculation of rates of exceedance of the targets at each site, which provides an additional measure of river status and compliance with the targets.

5.1.2 NPS-FM bands

The periphyton attribute in the National Policy Statement for Freshwater Management (NPS-FM, NZ Government 2014) specifies chlorophyll a (in mg/m^2) as the attribute unit, and targets ecosystem health as the value for protection (rather than aesthetics, recreation, or human health, which are more appropriately covered by measures of percentage cover). The thresholds for periphyton set in the NPS-FM are nominally the same as the One Plan targets, and define four attribute states as follows (with the narrative for each state reproduced in italics):

A. Periphyton chlorophyll *a* exceeds 50 mg/m^2 less than 8% of the time (i.e., one or fewer exceedance per 12 monthly surveys) ("*Rare blooms reflecting negligible nutrient enrichment and/or alteration of the natural flow regime or habitat*")

B. Periphyton chlorophyll *a* exceeds 50 mg/m^2 more than 8% of the time and 120 mg/m^2 less than 8% of the time (i.e., one or fewer exceedance per 12 monthly surveys) (*"Occasional blooms reflecting low nutrient enrichment and/or alteration of the natural flow regime or habitat*")

C. Periphyton chlorophyll *a* exceeds 120 mg/m^2 more than 8% of the time and 200 mg/m^2 less than 8% of the time (i.e., one or fewer exceedance per 12 monthly surveys) ("*Periodic short-duration nuisance blooms reflecting moderate nutrient enrichment and/or alteration of the natural flow regime or habitat*")

D. Below the national bottom line: Periphyton chlorophyll *a* exceeds 200 mg/m^2 more than 8% of the time (i.e., more than one exceedance per 12 monthly surveys) (*"Regular and/or extended-duration nuisance blooms reflecting high nutrient enrichment and/or significant alteration of the natural flow regime or habitat"*).

One exception is provided for. Attribute states for rivers that are naturally productive are defined by exceedances of 17% of the time (i.e., two or more exceedances per 12 monthly surveys). Naturally productive sites are defined by their classification in the River Environment Classification and are explained in the NPS-FM as follows:

> "Dry" Climate categories (i.e., Warm-Dry (WD) and Cool-Dry (CD)) and REC Geology categories that have naturally high levels of nutrient enrichment due to their catchment geology (i.e., Soft-Sedimentary (SS), Volcanic Acidic (VA) and Volcanic Basic (VB)). Therefore the productive category is defined by the following REC defined types: WD/SS, WD/VB, WD/VA, CD/SS, CD/VB, CD/VA. The Default class includes all REC types not in the Productive class.

Five sites in the Horizons dataset are defined as naturally productive on this basis, two with with REC type CD/VA: site 54, Waitangi u/s Waiouru STP, 55 Waitangi d/s Waiouru STP), and three with CD/SS (32 Oroua at Awahuri Bridge, 41 Porewa u/s Hunterville STP; 42 Porewa d/s Hunterville STP).

Assignment of a periphyton attribute state to a river site is based on a monthly monitoring regime, and the minimum record length for grading a site in terms of chlorophyll *a* is three years. Records at 53 of the 62 sites in the Horizons dataset were long enough to be assigned to a state for periphyton in the NPS-FM. The records at sites 41 and 42 (productive class, see above) were less than three years.

5.1.3 Cyanobacteria guideline

The NZ cyanobacteria guideline (Wood et al. 2009) includes a section on benthic cyanobacteria in rivers. This refers mainly to *Phormidium*, which can potentially be toxic and appears to be becoming more common in lowland rivers (Quiblier et al. 2013). The conditions under which *Phormidium* produces toxins are still under investigation. The guideline assumes that the higher the percentage cover, the higher the risk of toxins being present. The guideline also refers to the presence of detached mats along the water's edge. Detached mats present an additional risk to animal health because they are very accessible to dogs. In the present assessment, compliance with the guideline is assessed for percentage cover only. The guideline recommends two thresholds of % cover on the river bed for protection of human and animal health.

Alert level: > 20% and <50% cover of the river bed (indicates that *Phormidium* cover may be reaching problem levels)

Action level: > 50% cover of the river bed. At this coverage river managers are required to act (e.g., by posting notices to warn the public of the potential hazard).

5.2 Methods

All exceedances of the One Plan target were identified at each site. The rate of exceedance (% of surveys) was calculated in 12-month periods (in hydrological years of July to June, at each site) and also for the entire survey period at each site (maximum of 77 months, starting in December 2008). Each site was assigned to an attribute state in the NPS-FM, based on the three years of data up to April 2015, and also on the entire dataset.

For the cyanobacteria guideline, the proportion of surveys in which the site was at Amber (>20<50% cover) and Red (>50% cover) status are reported for each site.

In these calculations, surveys with missing data because flows were too high were assumed to be below all the thresholds. If these occasions were counted as missing data, then the rates of exceedance of targets could be unjustifiably high. At most sites, the proportion of surveys with missing data was low enough to make little difference.

All the data are presented in table and map format. In the tables, the nine sites below point-source discharges are shown in a separate block. Trends over time are covered in Section 4.

5.3 Results and discussion

5.3.1 One Plan targets

Across the whole survey period (i.e., n = 47 sites), the rate of exceedance of the One Plan target for chlorophyll *a* was 6.3% (one in every 16 surveys). Chlorophyll *a* was below the target for the entire monitoring period at 18 of the 47 sites (39%). The target was exceeded for more than 10% of the time at nine sites, four of which were below point-source discharges (Table 5-1, Figure 5-1).

Compliance with the One Plan target for % cover by mats was generally high (100% compliance at 70% of all sites with a complete record. The overall rate of exceedance in all surveys was less than 1%. Compliance was less than 90% at only one site (site 49, makotuku_rae). The nine sites downstream of point-source discharges were all compliant for at least 95% of the time (Table 5-1, Table 5-2, Figure 5-2).

The 30% targets for % cover by filamentous algae was exceeded in 4.8% of surveys (i.e., a lower exceedance rate than chlorophyll *a* target). However, the proportion of 100% compliant sites was the same as for the chlorophyll *a* target (39%), because individual sites tended to have fewer exceedances (Table 5-1).

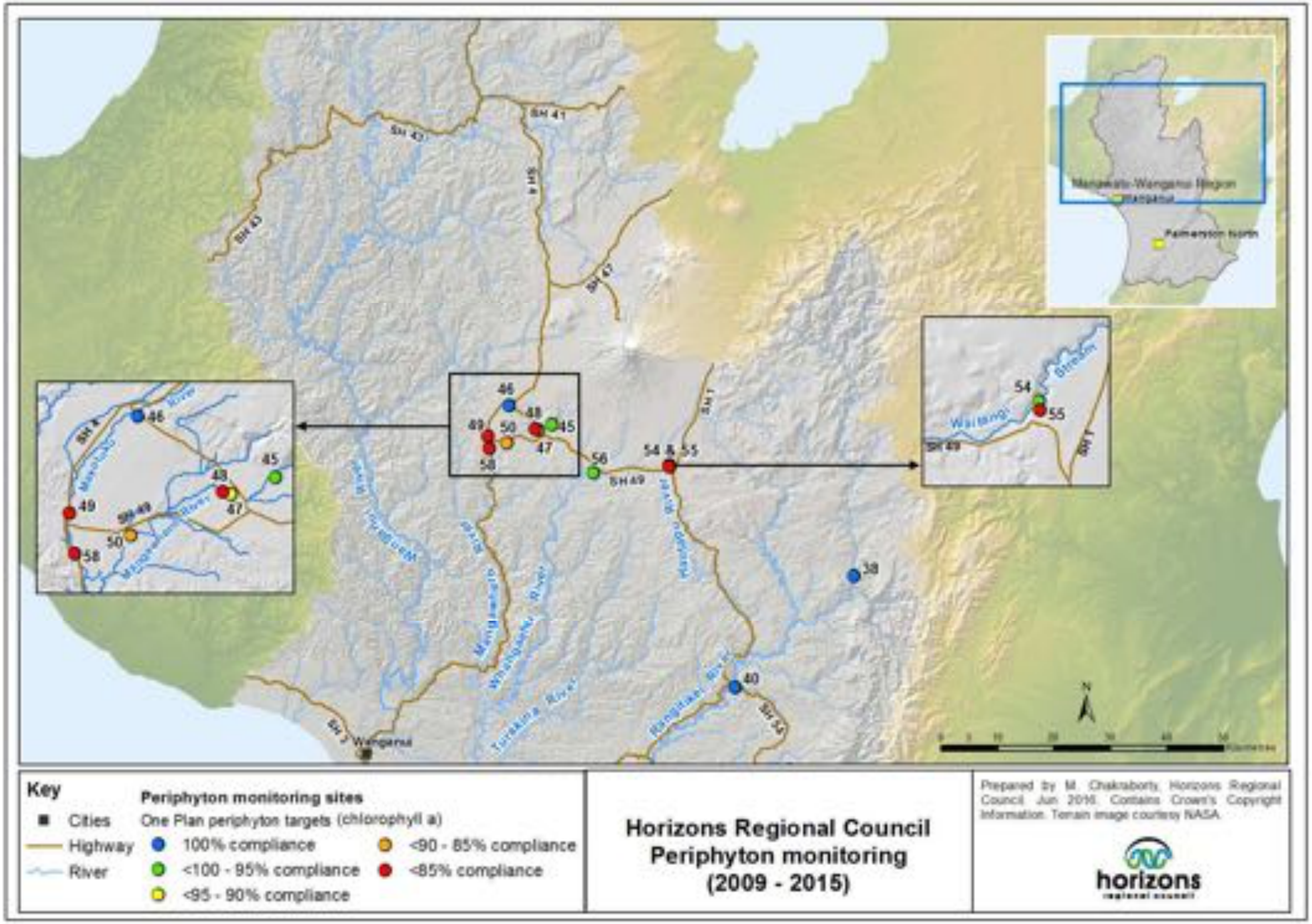
The overall rate of exceedance of the chlorophyll *a* target, calculated using only data from the most recent three years (May 2012 to April 2015, n = 53 sites), was 6.5% (i.e., only slightly higher than the whole period, even though the three-year period included the driest year, 2012-13). Higher proportions of sites were 100% compliant for all three periphyton metrics than proportions calculated over the whole time series (Table 5-1, Table 5-2). The 2012-15 dataset also showed slightly more sites with high rates of non-compliance.

Headwater sites tended to be 100% compliant. While non-compliances occurred throughout the region, a high proportion of sites in the northern region (eight of 17 sites, or 47%) were non-compliant for chlorophyll *a* for at least 10% of the time (Figure 5-3).

Table 5-1: Rates of compliance with One Plan targets for periphyton chlorophyll *a* and percent cover by mats and filaments at all sites. Compliance is expressed as a percentage of all surveys on which periphyton did not exceed the target. Sites are arranged in order of their One Plan limit (50 or 120 mg/m^2), then by HRC site number. Sites downstream of point source discharges are shown at the end. Sites where compliance was calculated using fewer surveys are indicated by: *less than 3 y data; **>3 y and <6 y. The results from these sites are not strictly comparable with the results from sites with complete data.

				OP target	% compliance, all data			% compliance 2012-2015		
N	Site abbreviation	LSC	Sub-zone	Chl a	Chl a	Mats	Fils	Chl a	Mats	Fils
Sites unaffected by point-source discharges										
2	mangatainoka_putara	UHS	Mana_8a	50	100	100	100	100	100	100
3	mangatainoka_lars*	UHS	Mana_8a	50				100	100	98
4	tamaki_res	UHS	Mana_3	50	100	100	97	100	100	100
8	kumeti_tr	UHS	Mana_4	50	100	100	100	100	100	100
15	pohangina_pir	UHS	Mana_10b	50	100	100	100	100	100	100
37	tokomaru_hb	LM	Mana_13c	50	95	100	97	89	100	97
38	rangitikei_puk	UHS	Rang_2a	50	100	100	99	100	100	97
45	mangawhero_doc	UVA	Whau_3d	50	99	100	99	100	100	100
46	makotuku_sh49	UVA	Whau_3b	50	100	100	99	100	100	97
47	mangawhero_us_oha	UVA	Whau_3d	50	95	100	100	94	100	100
49	makotuku_rae	UVA	Whau_3c	50	77	86	94	81	100	94
50	mangawhero_pakihi	UVA	Whau_3d	50	88	100	100	86	100	100
51	mangatepopo_gi**	UVA	Whai_1	50	100	100	98	100	100	97
52	whanganui_ds_gen**	UVA	Whai_1	50	98	100	100	100	100	100
53	whakapapa_ds_gen**	UVA	Whai_2b	50	100	100	98	100	100	100
56	tokiahuru_kar	UVA	Whau_1c	50	96	100	100	92	100	100
57	makotuku_us_rae**	UVA	Whau_3c	50	60	98	93	67	100	100
60	ohau_gladstone	UHS	Ohau_1a	50	100	100	99	100	100	100
1	makakahi_doc*	HM	Mana_8d	120				100	100	100
5	mangatera_us_dan	HM	Mana_2b	120	99	100	99	97	100	97
7	mangatainoka_huk*	HM	Mana_8b	120				100	100	100
9	manawatu_weber	HM	Mana_1a	120	93	100	92	89	100	97
10	makakahi_ham	HM	Mana_8d	120	95	97	91	92	97	89
11	oroua_apiti	HM	Mana_12a	120	100	100	99	100	100	100
12	tamaki_ste	HM	Mana_5b	120	99	100	100	100	100	100
13	oruakeretaki_sh2	HM	Mana_5d	120	99	100	99	97	100	97
14	makuri_tuscan	ULi	Mana_7d	120	75	100	97	67	100	97
16	mangatainoka_scarb*	HM	Mana_8b	120				100	100	100

N	Site abbreviation	LSC	Sub-zone	OP target Chl a	% compliance, all data			% compliance 2012-2015		
					Chl a	Mats	Fils	Chl a	Mats	Fils
17	tiraumea_nga	HSS	Mana_7b	120	78	97	91	64	100	89
18	mangatainoka_pahiatua*	HM	Mana_8c	120				93	100	95
19	mangatainoka_sh2	HM	Mana_8c	120	95	97	91	92	100	94
21	mangatainoka_us_pah	HM	Mana_8c	120	97	97	96	97	100	97
23	manawatu_hop	HM	Mana_5a	120	87	97	92	94	100	97
24	mangatainoka_us_tir**	HM	Mana_8c	120	98	96	94	100	100	92
26	mangapapa_troup	HM	Mana_9b	120	100	100	100	100	100	100
27	pohangina_mais	HM	Mana_10c	120	100	100	92	100	100	97
28	manawatu_ug	HM	Mana_9a	120	100	100	99	100	100	97
29	oroua_almadale	HM	Mana_12a	120	100	100	100	100	100	100
30	oroua_us_fei	HM	Mana_12b	120	100	100	94	100	100	97
32	oroua_awahuri	LM	Mana_12c	120	97	100	96	100	100	100
33	manawatu_tc	HM	Mana_10a	120	99	100	99	97	100	97
34	manawatu_us_pncc	HM	Mana_11a	120	96	99	95	97	100	100
36	manawatu_opik	HM	Mana_11a	120	92	100	91	92	100	94
39	moawhango_waiouru**	UVM	Rang_2d	120	91	59	100	86	58	100
40	rangitikei_man	HM	Rang_3a	120	100	100	94	100	100	100
41	porewa_us_hun*	HSS	Rang_4c	120				90	100	55
43	rangitikei_one	HM	Rang_3a	120	100	100	100	100	100	100
44	rangitikei_mk	HM	Rang_4a	120	99	97	92	97	100	94
54	waitangi_us_wai	UVM	Whau_1b	120	99	100	100	97	100	100
59	waikawa_nmr	HM	West_9a	120	100	100	95	100	100	100
61	ohau_sh1	HM	Ohau_1b	120	99	97	97	100	100	100
62	ohau_haines*	HM	Ohau_1b	120				100	100	100
Sites downstream of point-source discharges										
48	mangawhero_ds_oha	UVA	Whau_3d	50	84	99	100	78	100	100
58	makotuku_ds_rae	UVA	Whau_3c	50	34	97	72	39	100	92
6	mangatera_ds_dan	HM	Mana_2b	120	97	100	91	97	100	97
20	mangatainoka_ds_db	HM	Mana_8c	120	96	97	92	97	100	94
22	mangatainoka_ds_pah	HM	Mana_8c	120	94	97	90	94	100	97
31	oroua_ds_fei	HM	Mana_12b	120	92	100	95	92	100	97
35	manawatu_ds_pncc	HM	Mana_11a	120	84	97	88	83	100	92
42	porewa_ds_hun*	HSS	Rang_4c	120				81	100	55
55	waitangi_ds_wai	UVM	Whau_1b	120	79	100	84	86	100	94


Key
Cities
Highway
River
Periphyton monitoring sites
One Plan periphyton targets (chlorophyll a)
100% compliance
<100 - 95% compliance
<95 - 90% compliance
<90 - 85% compliance
<85% compliance
Horizons Regional Council
Periphyton monitoring
(2009 - 2015)
horizons
Wanganui
Manawatu-Wanganui Region
Palmerston North

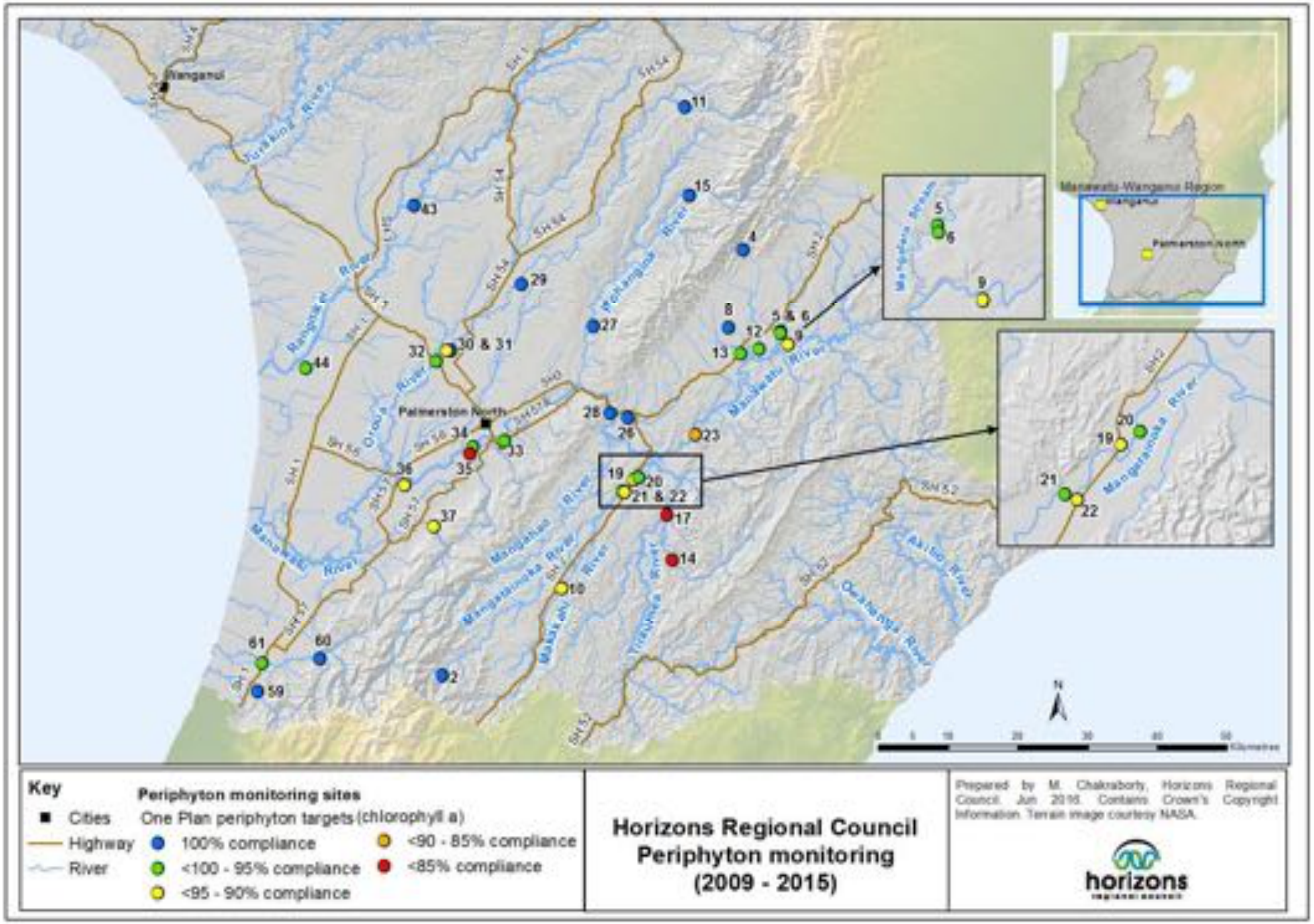
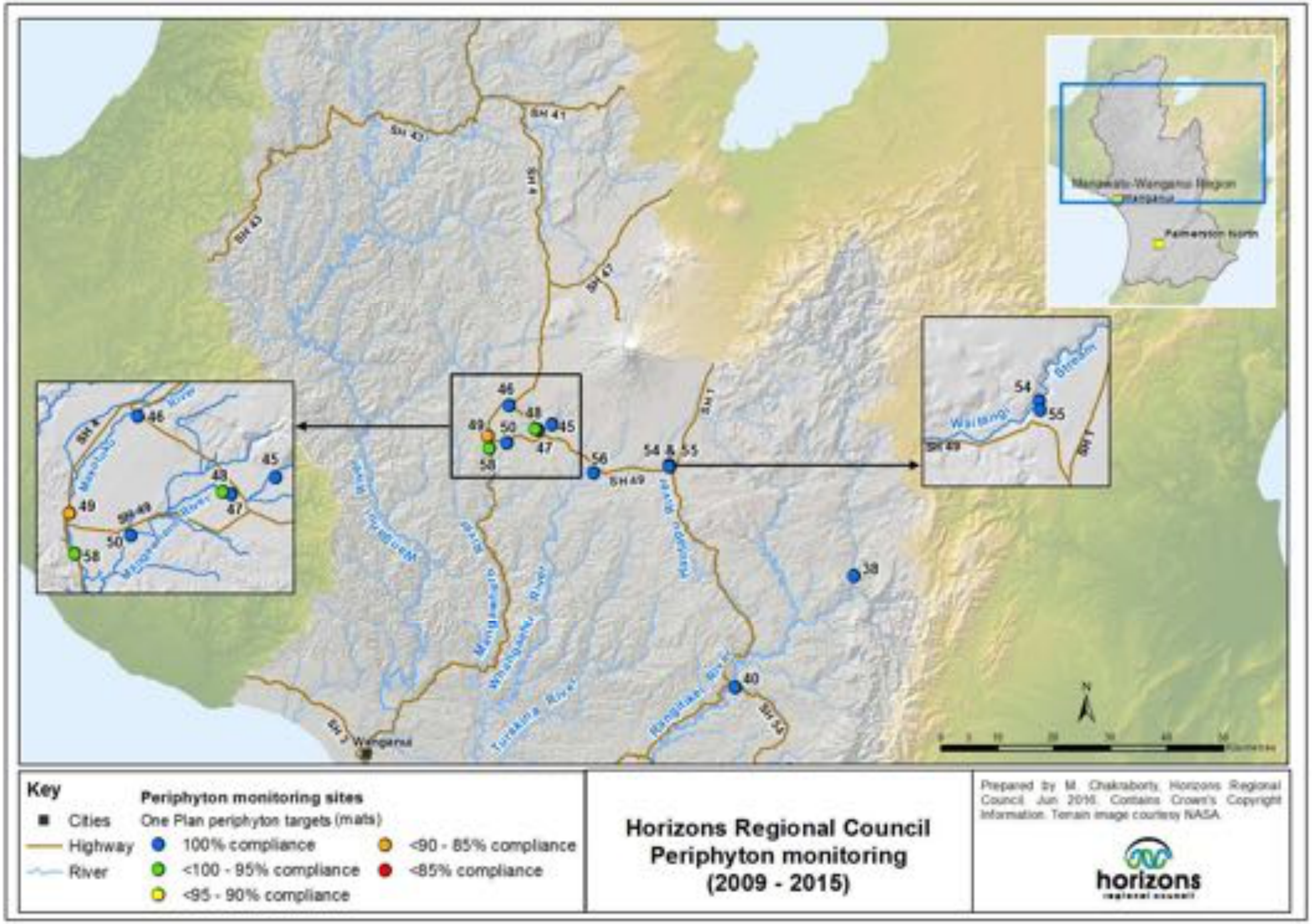


Figure 5-1: Maps showing rates of compliance with the One Plan chlorophyll *a* targets calculated from 2009 to 2015. Targets are either 50 or 120 mg/m^2 chlorophyll *a*. An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.



Key
Cities
Highway
River
Periphyton monitoring sites
One Plan periphyton targets (mats)
100% compliance
<100 - 95% compliance
<95 - 90% compliance
<90 - 85% compliance
<85% compliance
Horizons Regional Council
Periphyton monitoring
(2009 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council. Jun 2016. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons
Wanganui
Manawatu-Wanganui Region
Palmerston North
SH 41
SH 43
SH 4
SH 47
SH 49
SH 1
SH 3
Whanganui River
Manganuioteao River
Whangaehu River
Turakina River
Rangitikei River
Hautapu River
Waitangi Stream
46
48
49
50
45
47
58
56
54 & 55
54
55
38
40

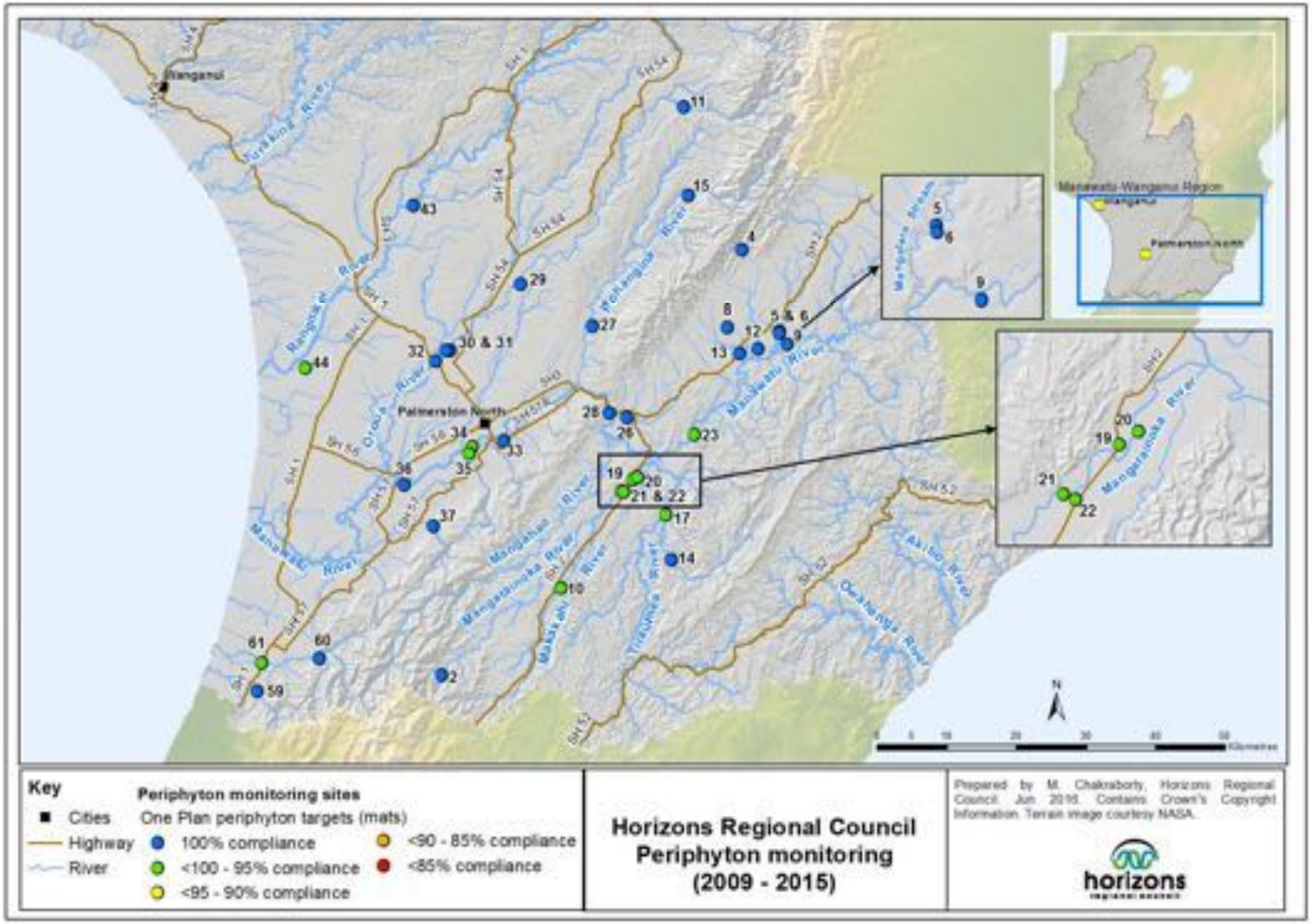
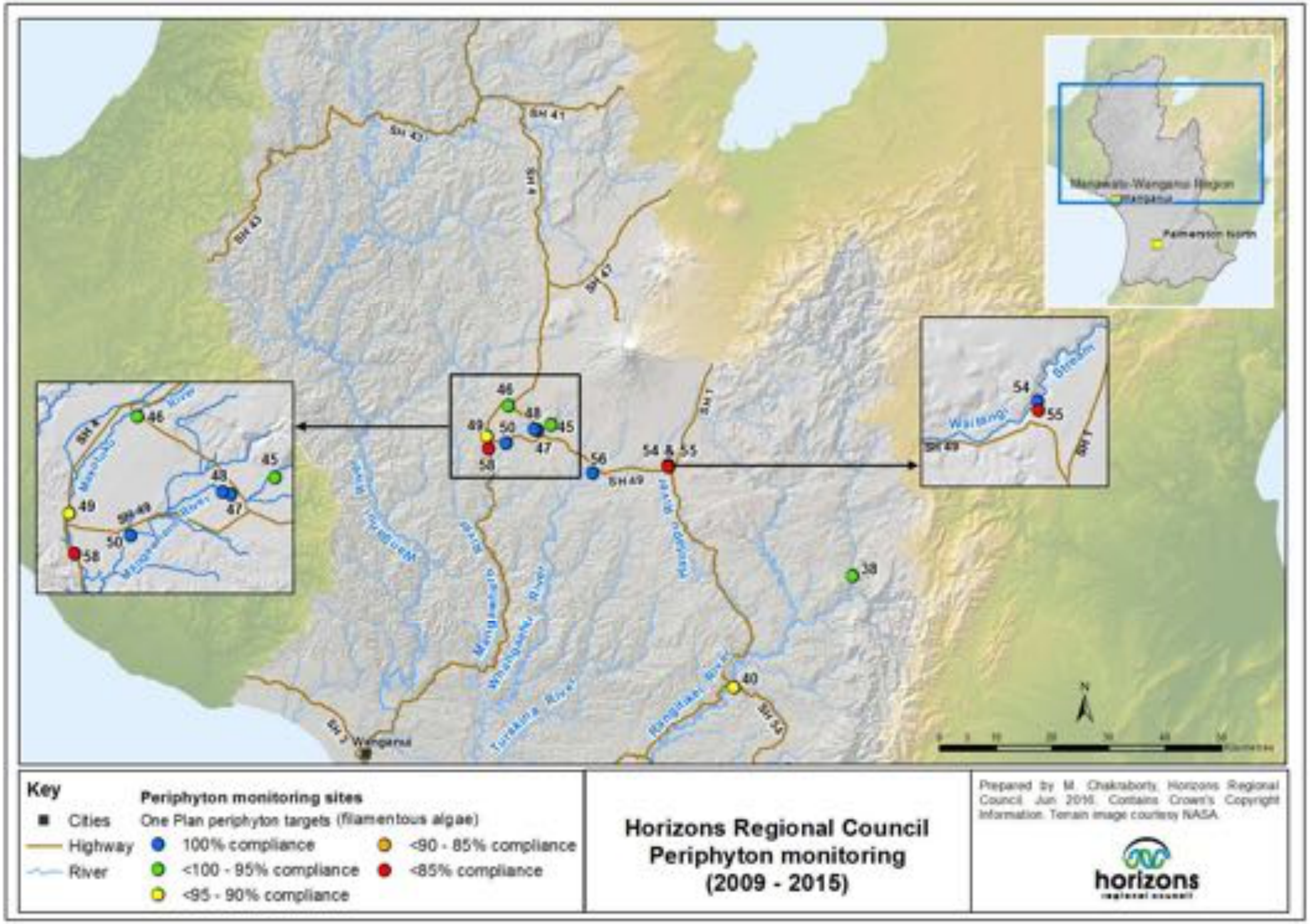


Figure 5-2: Maps showing rates of compliance with the One Plan target for % cover by periphyton mats calculated from 2009 to 2015. The target is 60% cover by mats. An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.


SH 41
SH 43
SH 4
SH 47
SH 49
SH 1
SH 3
SH 54
Manawatu-Wanganui Region
Wanganui
Palmerston North
46
49
50
48
45
47
58
56
54 & 55
54
55
38
40
Waitangi
Stream
Whanganui
Wanganui
Key
Cities
Highway
River
Periphyton monitoring sites
One Plan periphyton targets (filamentous algae)
100% compliance
<100 - 95% compliance
<95 - 90% compliance
<90 - 85% compliance
<85% compliance
Horizons Regional Council
Periphyton monitoring
(2009 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council Jun 2016. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons

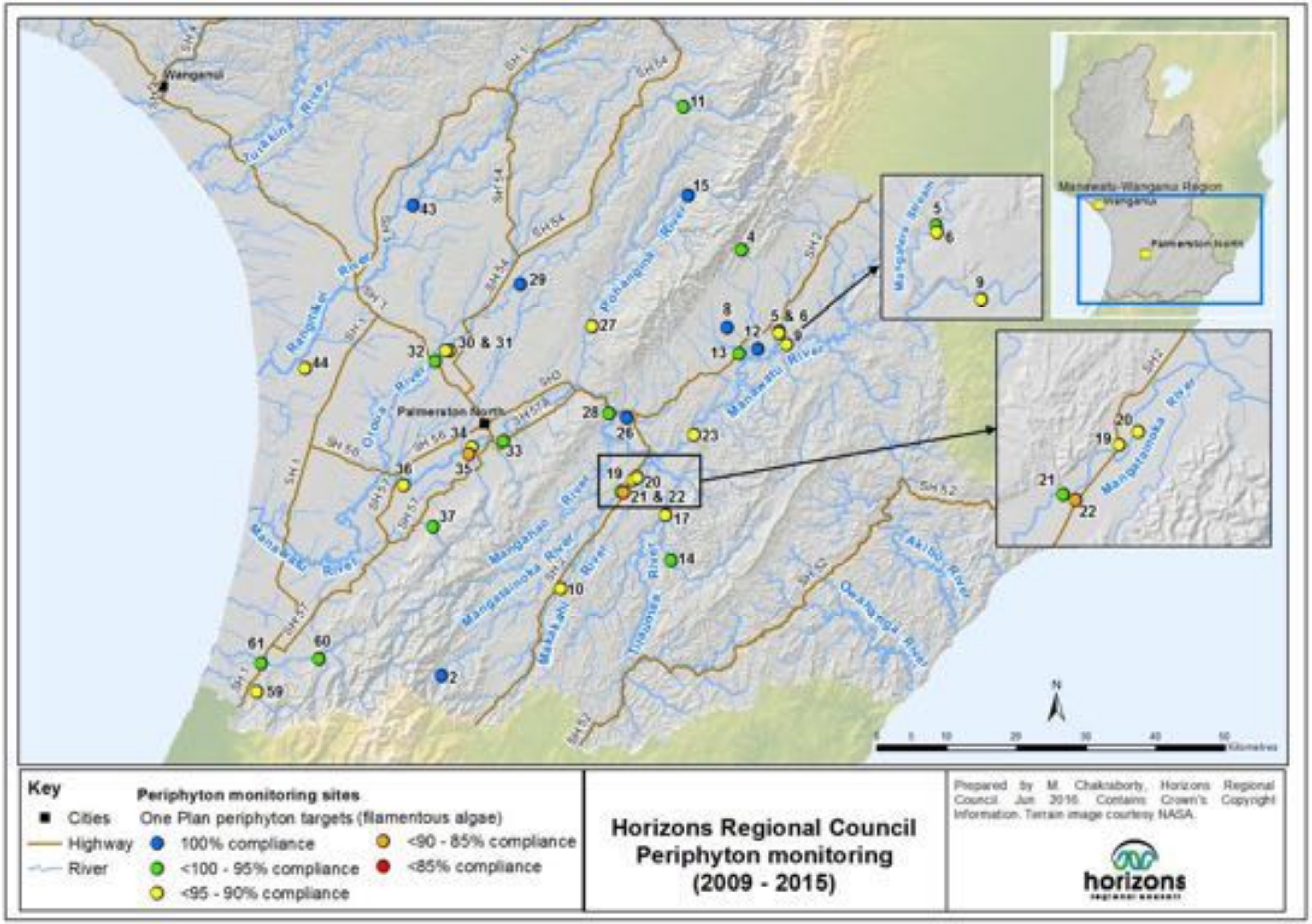


Figure 5-3: Maps showing rates of compliance with the One Plan target for % cover by periphyton filaments calculated from 2009 to 2015. The target for filaments is 30%**.** An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.

Table 5-2: Percentages of sites with five levels of compliance with the One Plan targets for periphyton. Compliance rates were calculated using all data (from 2008 to 2015) and using data from the last three years (May 2012 to April 2015). Only sites with complete records were used to compute the percentages (i.e., sites with asterisks in Table 5-1 are excluded).

		% sites with complete data from 2008 to 2015 (*n* = 47)			% sites: May 2012 to April 2015, complete data (*n* = 53)		
	Compliance (%)	**Chl. *a***	**Mats**	**Filaments**	**Chl. *a***	**Mats**	**Filaments**
No point-source discharges	100	41	77	28	53	96	53
	95 - <100	31	21	38	16	2	31
	90 - <95	15	0	33	13	0	11
	85 - <90	5	3	0	9	0	4
	<85	8	0	0	9	2	0
Downstream of point source discharge	100	0	38	13	0	100	13
	95 - <100	25	63	0	25	0	38
	90 - <95	25	0	38	25	0	50
	85 - <90	0	0	25	13	0	0
	<85	50	0	25	38	0	0

5.3.2 NPS-FM periphyton bands

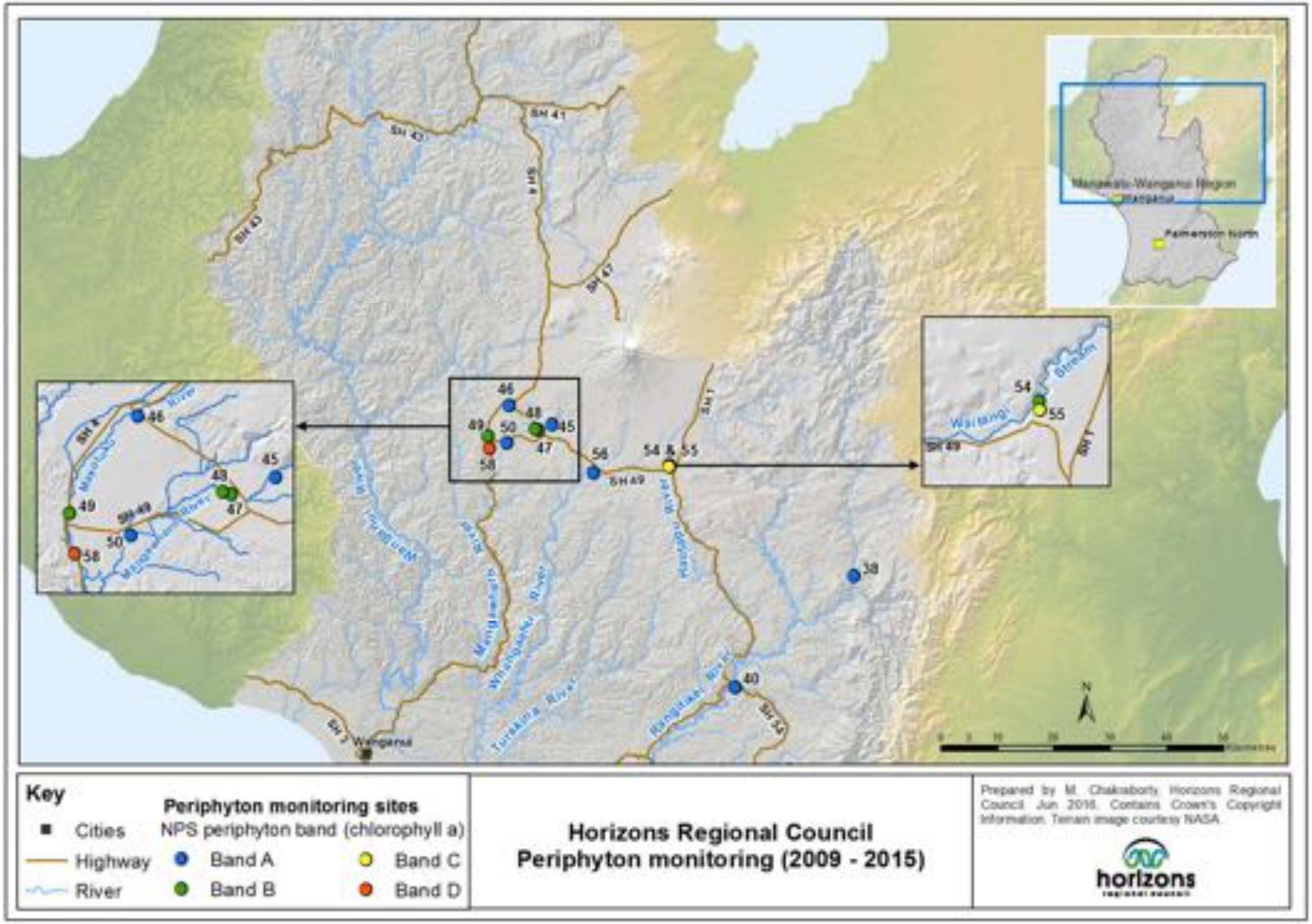
Fifty-four sites had at least three years of data, enabling assignment to an NPS-FM periphyton band. In both the six-year and three-year periods, over half of all sites were assigned to band A and a 30% to band B (Table 5-3, Table 5-4). Differences in bands between the two periods were caused by small changes in percentages of exceedance to just above or just below the threshold (Table 5-3).

There was no apparent spatial pattern of NPS-FM periphyton bands, except for headwater sites generally falling into the A band, and no A bands at sites downstream of point-source discharges (Figure 5-4). Sites upstream and downstream of point-source discharges were generally in different bands, except for the two pairs of sites on the Mangatainoka River, which were all in band B.

Table 5-3: Assignment of periphyton monitoring sites in the Manawatu - Whanganui region to NPS-FM periphyton bands. Bands were assigned using all data and using data from the last three years. **Sites with >3 y data, but < 6 y. The results from these sites are not strictly comparable with the results using complete data. ‡Sites in the productive class: 17% exceedance of the threshold used to assign the NPS-FM band.

			% above thresholds, all data				% above thresholds, 2012-2015			
N	**Site abbrev**	**Sub-zone**	**50**	**120**	**200**	**BAND**	**50**	**120**	**200**	**BAND**
Sites unaffected by point-source discharges										
2	mangatainoka_putara	Mana_8a	0.0	0.0	0.0	A	0.0	0.0	0.0	A
4	tamaki_res	Mana_3	0.0	0.0	0.0	A	0.0	0.0	0.0	A
5	mangatera_us_dan	Mana_2b	1.3	1.3	1.3	A	2.8	2.8	2.8	A
8	kumeti_tr	Mana_4	0.0	0.0	0.0	A	0.0	0.0	0.0	A
9	manawatu_weber	Mana_1a	18.4	6.6	3.9	B	27.8	11.1	5.6	C
10	makakahi_ham	Mana_8d	32.5	5.2	2.6	B	38.9	8.3	2.8	C
11	oroua_apiti	Mana_12a	0.0	0.0	0.0	A	0.0	0.0	0.0	A
12	tamaki_ste	Mana_5b	3.9	1.3	0.0	A	0.0	0.0	0.0	A
13	oruakeretaki_sh2	Mana_5d	3.9	1.3	0.0	A	5.6	2.8	0.0	A

N	Site abbrev	Sub-zone	% above thresholds, all data 50	120	200	BAND	% above thresholds, 2012-2015 50	120	200	BAND
14	makuri_tuscan	Mana_7d	45.5	24.7	9.1	D	47.2	33.3	11.1	D
15	pohangina_pir	Mana_10b	0.0	0.0	0.0	A	0.0	0.0	0.0	A
17	tiraumea_nga	Mana_7b	46.8	22.1	5.2	C	61.1	36.1	11.1	D
19	mangatainoka_sh2	Mana_8c	31.2	5.2	1.3	B	38.9	8.3	2.8	C
21	mangatainoka_us_pah	Mana_8c	19.5	2.6	0.0	B	19.4	2.8	0.0	B
23	manawatu_hop	Mana_5a	37.7	13.0	3.9	B	47.2	5.6	2.8	B
24	mangatainoka_us_tir**	Mana_8c	19.2	1.9	1.9	B	13.9	0.0	0.0	B
26	mangapapa_troup	Mana_9b	1.3	0.0	0.0	A	2.8	0.0	0.0	A
27	pohangina_mais	Mana_10c	1.3	0.0	0.0	A	0.0	0.0	0.0	A
28	manawatu_ug	Mana_9a	7.8	0.0	0.0	A	8.3	0.0	0.0	B
29	oroua_almadale	Mana_12a	0.0	0.0	0.0	A	0.0	0.0	0.0	A
30	oroua_us_fei	Mana_12b	2.6	0.0	0.0	A	5.6	0.0	0.0	A
32	oroua_awahuri‡	Mana_12c	9.1	2.6	0.0	A	5.6	0.0	0.0	A
33	manawatu_tc	Mana_10a	2.6	1.3	0.0	A	2.8	2.8	0.0	A
34	manawatu_us_pncc	Mana_11a	14.3	3.9	2.6	B	16.7	2.8	0.0	B
36	manawatu_opik	Mana_11a	13.0	7.8	1.3	B	16.7	8.3	0.0	C
37	tokomaru_hb	Mana_13c	5.2	0.0	0.0	A	11.1	0.0	0.0	B
38	rangitikei_puk	Rang_2a	0.0	0.0	0.0	A	0.0	0.0	0.0	A
39	moawhango_waiouru**	Rang_2d	53.6	8.9	1.8	C	66.7	13.9	2.8	C
40	rangitikei_man	Rang_3a	1.3	0.0	0.0	A	2.8	0.0	0.0	A
43	rangitikei_one	Rang_3a	3.9	0.0	0.0	A	8.3	0.0	0.0	B
44	rangitikei_mk	Rang_4a	9.1	1.3	0.0	B	13.9	2.8	0.0	B
45	mangawhero_doc	Whau_3d	1.3	0.0	0.0	A	0.0	0.0	0.0	A
46	makotuku_sh49	Whau_3b	0.0	0.0	0.0	A	0.0	0.0	0.0	A
47	mangawhero_us_oha	Whau_3d	5.2	0.0	0.0	A	5.6	0.0	0.0	A
49	makotuku_rae	Whau_3c	23.2	5.8	1.4	B	19.4	5.6	2.8	B
50	mangawhero_pakihi	Whau_3d	11.7	0.0	0.0	B	13.9	0.0	0.0	B
51	mangatepopo_gi**	Whai_1	0.0	0.0	0.0	A	0.0	0.0	0.0	A
52	whanganui_ds_gen**	Whai_1	1.8	0.0	0.0	A	0.0	0.0	0.0	A
53	whakapapa_ds_gen**	Whai_2b	0.0	0.0	0.0	A	0.0	0.0	0.0	A
54	waitangi_us_wai‡	Whau_1b	27.3	1.3	0.0	B	36.1	2.8	0.0	B
56	tokiahuru_kar	Whau_1c	4.2	0.0	0.0	A	8.3	0.0	0.0	B
57	makotuku_us_rae**	Whau_3c	39.7	8.6	3.4	C	33.3	5.6	0.0	B
59	waikawa_nmr	West_9a	1.3	0.0	0.0	A	2.8	0.0	0.0	A
60	ohau_gladstone	Ohau_1a	0.0	0.0	0.0	A	0.0	0.0	0.0	A
61	ohau_sh1	Ohau_1b	1.3	1.3	0.0	A	0.0	0.0	0.0	A
Sites downstream of point-source discharges										
6	mangatera_ds_dan	Mana_2b	20.8	2.6	0.0	B	16.7	2.8	0.0	B
20	mangatainoka_ds_db	Mana_8c	20.8	3.9	1.3	B	16.7	2.8	0.0	B
22	mangatainoka_ds_pah	Mana_8c	35.1	6.5	0.0	B	41.7	5.6	0.0	B
31	oroua_ds_fei	Mana_12b	14.3	7.8	1.3	B	13.9	8.3	2.8	C
35	manawatu_ds_pncc	Mana_11a	33.8	15.6	10.4	D	47.2	16.7	13.9	D
48	mangawhero_ds_oha	Whau_3d	15.6	2.6	0.0	B	22.2	5.6	0.0	B
55	waitangi_ds_wai‡	Whau_1b	54.5	20.8	5.2	C	50.0	13.9	2.8	C
58	makotuku_ds_rae	Whau_3c	65.8	34.2	11.8	D	61.1	30.6	13.9	D


Key
Periphyton monitoring sites
Cities
NPS periphyton band (chlorophyll a)
Highway
Band A
Band C
River
Band B
Band D
Horizons Regional Council
Periphyton monitoring (2009 - 2015)
horizons
Wanganui
Palmerston North
Manawatu-Wanganui Region
SH 41
SH 43
SH 47
SH 49
SH 4
SH 1
SH 3
SH 54
Whangaehu River
Turakina River
Rangitikei River
Waitangi Stream
Mangawhero River
Manganui River
Mangawhero River
Whanganui River
46
48
49
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45
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58
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54 & 55
54
55
38
40

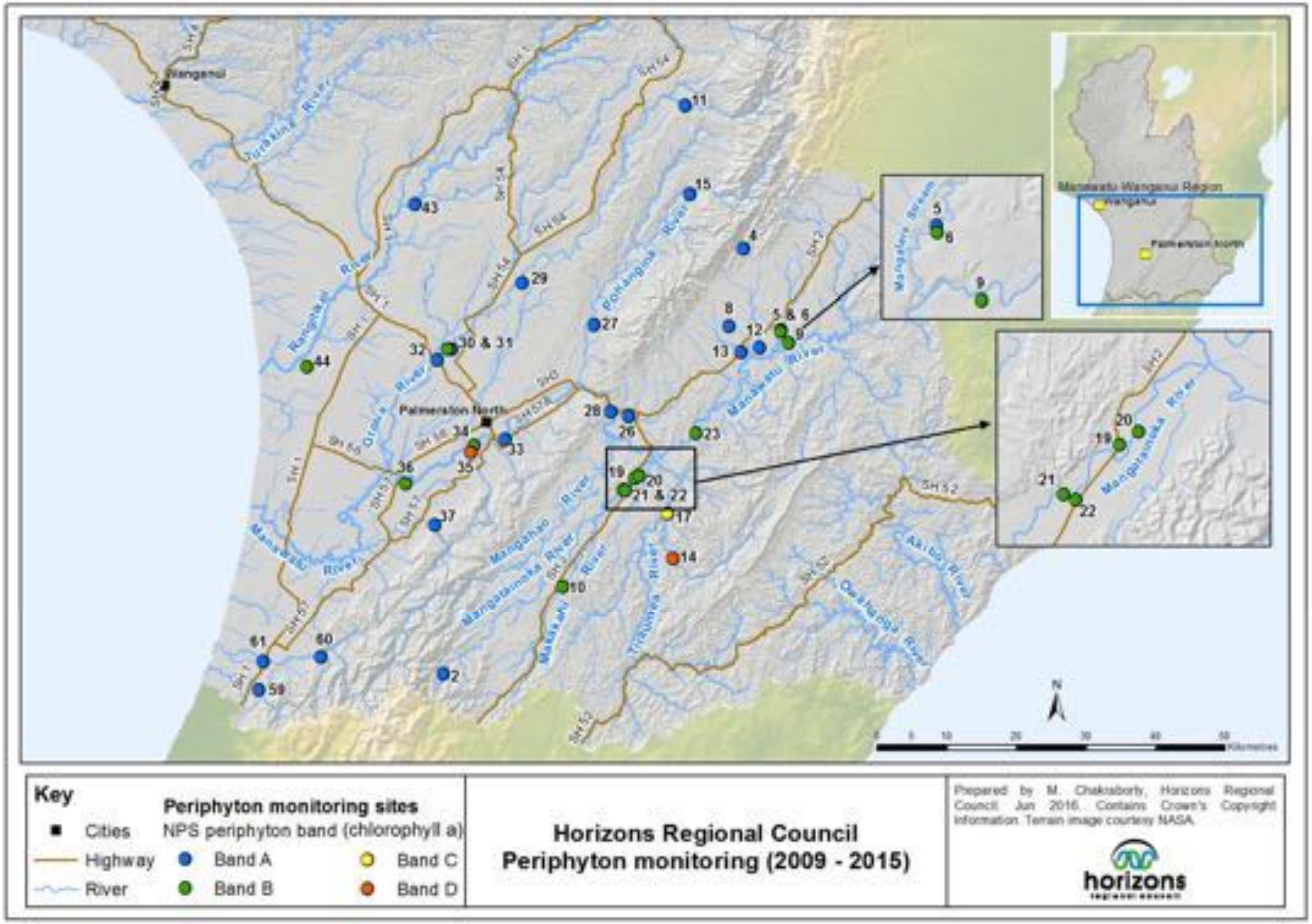


Figure 5-4: Maps showing assignment of river sites in the Manawatu-Whanganui region to bands defined in the NPS-FM for periphyton (as chlorophyll *a*). Data from December 2008 to April 2015 were used in the assessment. Refer to explanation in Section 5.1. An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.

Table 5-4: Percentages of sites in the Manawatu-Whanganui region assigned to bands A to D of the NPS-FM national objective framework for periphyton. Percentages were calculated from sites with complete data from 2008 to 2015 (6 years and 5 months of data) (*n* = 47) and complete data from 2012 to 2015 (*n* = 53).

	No point-source discharges		Downstream of point-source discharges	
NPS-FW periphyton band	All data	Last 3 years	All data	Last 3 years
A (< 8% >50 mg/m^2)	67	56.5	0	0
B (> 8% with >50 < 120 mg/m^2)	28	28	63	50
C (> 8% with >120 < 200 mg/m^2)	2.5	10	12	25
D (> 8% with > 200 mg/m^2)	2.5	5	25	25

5.3.3 Cyanobacteria guideline

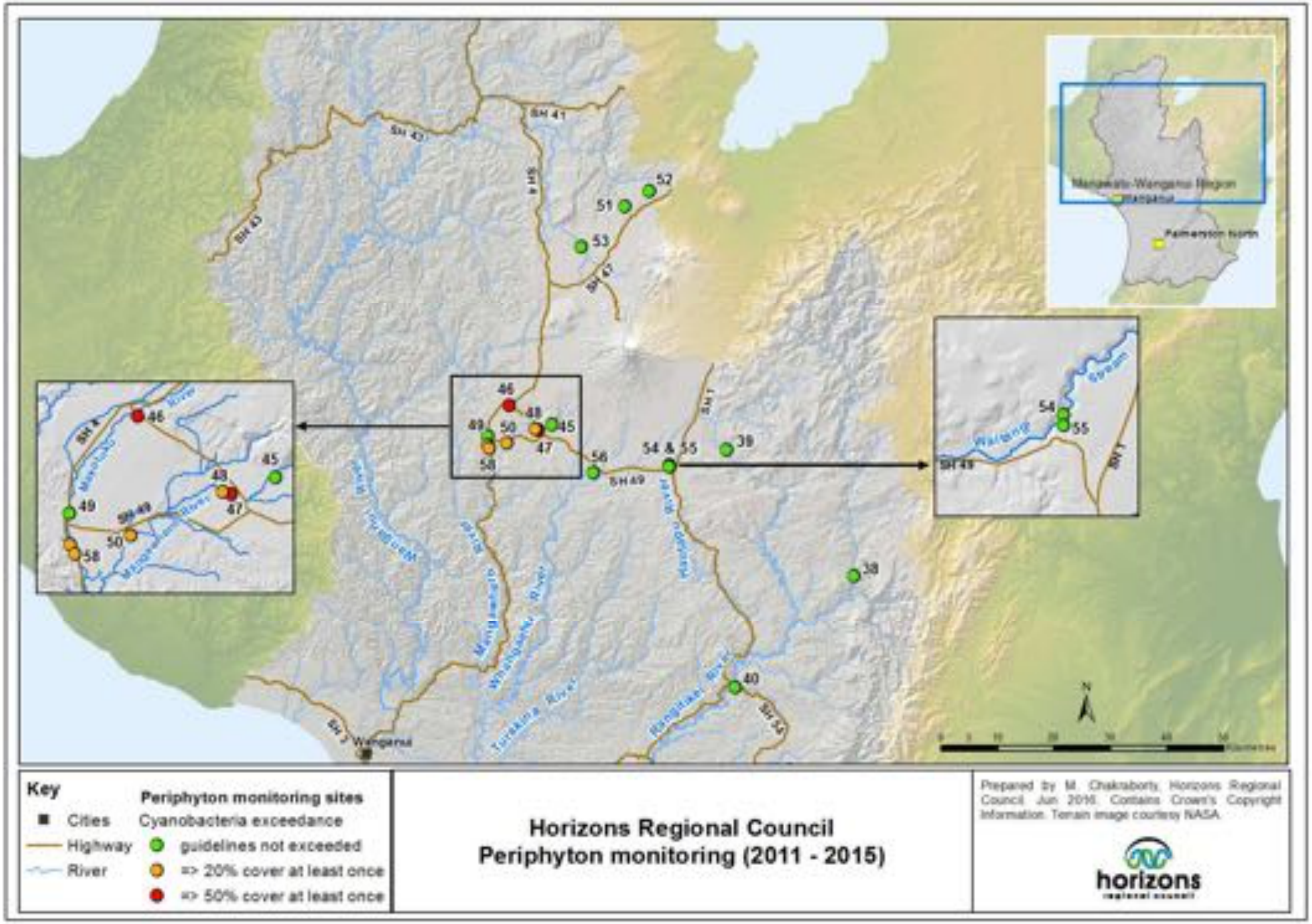
At least a quarter of all sites exceeded the criterion for amber (alert) status in the cyanobacteria guideline over the period of the monitoring programme. More sites exceeded this level over the four-year dataset than the three-year dataset, indicating that more exceedances occurred in the first year of the programme (May 2011 to April 2012) (Table 5-5, Table 5-6). There were also more exceedances of the criterion for red (action) status in that year. Rates of exceedance were higher at sites downstream of point-source discharges than those upstream (Table 5-5). Cover exceeding the alert level (20%) was concentrated at sites in the lower Mangatainoka River and its tributaries, with further occurrences at sites 35 (tokomaru_hb) and 61 (ohau_sh1) (Figure 5-5).

Site 46 (makotuku_sh49) was unusual in that the "action" criterion was breached once at the site (in December 2014), but there were no breaches of the alert level on any other survey in the time series. Very low cover (<5%) was recorded in three additional surveys between September 2014 and April 2015, but no cyanobacteria had been recorded in any earlier surveys.

Table 5-5: Compliance of sites in the Manawatu-Whanganui region with the 2008 guidelines for benthic cyanobacteria. The guideline specifies three bands: acceptable, green < 20% cover; alert level, amber >20% <50% cover; action level, red > 50% cover. The table shows the percentage of surveys in which cover by cyanobacteria met the criteria for amber and red status. Shading indicates which criteria were exceeded.

			% exceeding criteria, all data		% exceeding criteria, 2012-15	
N	Site abbreviation	Sub-zone	AMBER	RED	AMBER	RED
Sites unaffected by point-source discharges						
1	makakahi_doc	Mana_8d			0	0
2	mangatainoka_putara	Mana_8a	0	0	0	0
3	mangatainoka_lars	Mana_8a			0	0
4	tamaki_res	Mana_3	0	0	0	0
5	mangatera_us_dan	Mana_2b	0	0	0	0
7	mangatainoka_huk	Mana_8b			0	0
8	kumeti_tr	Mana_4	0	0	0	0
9	manawatu_weber	Mana_1a	0	0	0	0
10	makakahi_ham	Mana_8d	3.9	1.3	5.6	0
11	oroua_apiti	Mana_12a	0	0	0	0
12	tamaki_ste	Mana_5b	0	0	0	0
13	oruakeretaki_sh2	Mana_5d	0	0	0	0
14	makuri_tuscan	Mana_7d	2.6	0	2.8	0
15	pohangina_pir	Mana_10b	0	0	0	0
16	mangatainoka_scarb	Mana_8b			7.5	0

N	Site abbreviation	Sub-zone	% exceeding criteria, all data AMBER	RED	% exceeding criteria, 2012-15 AMBER	RED
17	tiraumea_nga	Mana_7b	3.9	0	8.3	0
18	mangatainoka_pahiatua	Mana_8c			2.5	0
19	mangatainoka_sh2	Mana_8c	5.2	1.3	5.6	0
21	mangatainoka_us_pah	Mana_8c	2.6	0	5.6	0
23	manawatu_hop	Mana_5a	0	0	0	0
24	mangatainoka_us_tir	Mana_8c	9.6	1.9	2.8	0
26	mangapapa_troup	Mana_9b	0	0	0	0
27	pohangina_mais	Mana_10c	0	0	0	0
28	manawatu_ug	Mana_9a	0	0	0	0
29	oroua_almadale	Mana_12a	0	0	0	0
30	oroua_us_fei	Mana_12b	0	0	0	0
32	oroua_awahuri	Mana_12c	1.3	0	0	0
33	manawatu_tc	Mana_10a	0	0	0	0
34	manawatu_us_pncc	Mana_11a	0	0	0	0
36	manawatu_opik	Mana_11a	0	0	0	0
37	tokomaru_hb	Mana_13c	2.6	0	5.6	0
38	rangitikei_puk	Rang_2a	0	0	0	0
39	moawhango_waiouru	Rang_2d	0	0	0	0
40	rangitikei_man	Rang_3a	0	0	0	0
41	porewa_us_hun	Rang_4c			0	0
43	rangitikei_one	Rang_3a	0	0	0	0
44	rangitikei_mk	Rang_4a	0	0	0	0
45	mangawhero_doc	Whau_3d	0	0	0	0
46	makotuku_sh49	Whau_3b	0	1.3	0	2.8
47	mangawhero_us_oha	Whau_3d	1.3	1.3	0	0
49	makotuku_rae	Whau_3c	0	0	0	0
50	mangawhero_pakihi	Whau_3d	3.9	0	0	0
51	mangatepopo_gi	Whai_1	0	0	0	0
52	whanganui_ds_gen	Whai_1	0	0	0	0
53	whakapapa_ds_gen	Whai_2b	0	0	0	0
54	waitangi_us_wai	Whau_1b	0	0	0	0
56	tokiahuru_kar	Whau_1c	0	0	0	0
57	makotuku_us_rae	Whau_3c	1.7	0	0	0
59	waikawa_nmr	West_9a	0	0	0	0
60	ohau_gladstone	Ohau_1a	0	0	0	0
61	ohau_sh1	Ohau_1b	1.3	0	2.8	0
62	ohau_haines	Ohau_1b	0	0	0	0
Sites downstream of point-source discharges						
6	mangatera_ds_dan	Mana_2b	0	0	0	0
20	mangatainoka_ds_db	Mana_8c	5.2	2.6	2.8	0
22	mangatainoka_ds_pah	Mana_8c	7.8	0	11.1	0
31	oroua_ds_fei	Mana_12b	0	0	0	0
35	manawatu_ds_pncc	Mana_11a	3.9	1.3	8.3	0
42	porewa_ds_hun	Rang_4c			0	0
48	mangawhero_ds_oha	Whau_3d	2.6	0	0	0
55	waitangi_ds_wai	Whau_1b	0	0	0	0
58	makotuku_ds_rae	Whau_3c	3.9	0	5.6	0



SH 41
SH 47
SH 43
SH 4
SH 49
SH 1
SH 3
SH 54
Wanganui
Manawatu-Wanganui Region
Palmerston North
52
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48
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47
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56
54 & 55
39
38
40
54
55
Whanganui River
Mangawhero River
Turakina River
Rangitikei River
Key
Cities
Highway
River
Periphyton monitoring sites
Cyanobacteria exceedance
guidelines not exceeded
=> 20% cover at least once
=> 50% cover at least once
Horizons Regional Council
Periphyton monitoring (2011 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council. Jun 2016. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons

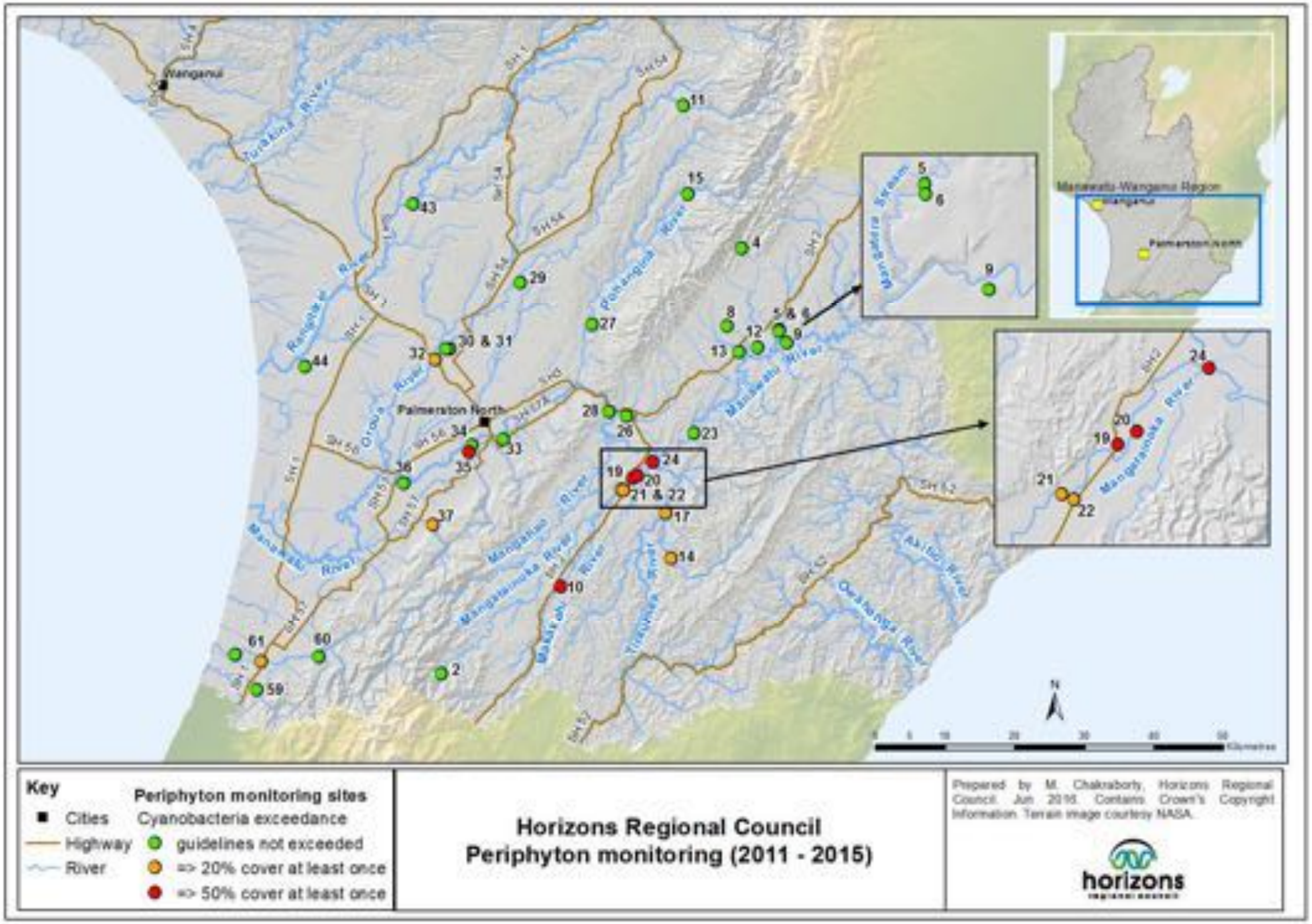

Figure 5-5: Maps showing sites that exceeded the alert (amber, 20%) and action (red, 50%) levels in the guideline for % cover by benthic cyanobacteria. Data from 2011 to 2015. An equivalent map for the period May 2012 to April 2015 is shown in Appendix C.

Table 5-6: Percentages of sites in the Manawatu-Whanganui region where % cover by cyanobacteria exceeded guidelines for protection of animal and human health. Percentages were calculated from sites with data from May 2011 to April 2015, and for the three years from May 2012 to April 205. Note that percentages add up to more than 100% because some sites exceeded the criteria for Amber and Red status at different times. The guideline specifies three bands: acceptable, green < 20% cover; alert level, amber >20% <50% cover; action level, red > 50% cover.

	No point-source discharges		Downstream of point-source discharges	
Cyanobacteria cover	**All data**	**Last 3 years**	**All data**	**Last 3 years**
20% cover not exceeded	74	81	38	56
Amber (>20% - 50% cover) >0 - 5% occurrence	20	8	38	11
Amber (>20% - 50% cover) >5 - 10% occurrence	2	12	25	22
Amber (>20% - 50% cover) >10% occurrence	0	0	0	11
Red (> 50% cover) any occurrence	11	2	25	0

5.4 Summary of state, trends and compliance at all sites

Periphyton abundance over a period can be summarised using a range of metrics (e.g., mean, median and maximum chlorophyll *a* or % cover by different categories of periphyton, exceedances of standards, etc.) each of which provides different information about biomass at a site. As discussed in Sections 4.2.2 and 5.1, a range of metrics and thresholds is needed to meet different objectives.

In order to provide an overall assessment of periphyton state and compliance rates we combined the results of the detailed state analyses (Section 4) with the assessments of compliance rates of periphyton with standards. The value for each of ten metrics was assigned a rank from 4 (best status) to 0 (worst status) based on the system in Table 4-1, rates of compliance with the three One Plan targets, the NPS periphyton bands (four levels A to D), and exceedances of the alert and action levels of the cyanobacteria guideline. All the ranks were added to produce a total score at each site. The final ranking is presented in Table 5-7. Three further columns in Table 5-7 indicate whether there was evidence for a trend in periphyton (as chlorophyll *a*, or percentage cover by mats and filaments) over the period of the monitoring programme at each site. Trends shown are those identified after adjusting the data to account for the effects of flow.

The ranking of sites in Table 5-7 shows that:

(a) The sites ranked up to 10 (i.e., the best 12) were in the upper Kumeti, upper Mangatainoka, upper Tamaki, Mangatera, Mangapapa, upper Tamaki, upper Oroua (2 sites), upper Pohangina, middle Manawatu, upper Mangawhero and middle Rangitikei. All these sites were placed in the top rank (4) for at least six of the 10 metrics, and the lowest rank was 2.

(b) The top 12 sites had from 0 to 92% (average 36%) of their catchment in farmland.

(c) All sites downstream of point-source discharges were ranked 28th or more (out of 47 sites);

(d) The 10 lowest ranked sites other than those downstream of point-source discharges were in the lower Manawatu, upper Manawatu, Makuri, Tiraumea, middle and lower Mangatainoka (3 sites), lower Makotuku, upper Mangawhero and coastal Rangitikei.

(e) These 10 sites had from 28 to 86% of their catchments in farmland (average 76%), and all were in the lowest or second-lowest rank (0 or 1) for at least one periphyton metric and in the top rank (4) for no more than three metrics. Half the sites were stable and half unstable.

(f) There was evidence for an increase in chlorophyll *a* at some top-ranked sites (albeit from a low baseline – see Table 4-8. Conducting further trend tests after 2-3 more years of data is suggested.

As would be expected, the sites with the best state and most consistent compliance with One Plan targets and the cyanobacteria guidelines were generally in the upper reaches of rivers. A surprising inclusion high in the ranking was site 5 (mangatera_us_dan) which ranked fifth overall despite a largely developed catchment, the highest concentration of DRP in the whole dataset, except for its paired site, 6 (mangatera_ds_dan), and relatively high DIN (see Appendix A).

Sites below point-source discharges were ranked below their paired upstream site, except for the only discharge not from a waste-water treatment plant (sites 19 and 20, mangatainoka_sh2 and mangatainoka_ds_db, ranked 41 and 39 respectively). Sites 47 and 48 (mangawhero_us_oha, mangawhero_ds_oha) also ranked close together (33 and 35).

The ten sites ranked worst (not including sites downstream of point-source discharges) could also be targets for management to reduce non-compliance rates in the region. Seven of these were in the Manawatu catchment, two in the Whagaehu and one in the Rangitikei. Although this cluster of sites is ranked lowest in the region, there has been no evidence for any increase in chlorophyll *a* between 2008 and 2015. Percentage cover by filaments has declined at four of the sites, and cover by mats has increased at two. At the site in the Rangitikei (44, rangitikei_mk) the low ranking was driven by a few exceedances of the One Plan targets for chlorophyll *a* and % cover by mats, but a higher number of exceedances of the target for filaments, which were reflected as the lowest rank for state in terms of filamentous algae.

Table 5-7: Periphyton monitoring sites ranked using combined ranks from ten metrics indicating periphyton state and compliance. Sites are listed in order of the sum of ranks (best to worst). Only sites with the full six years of data are included (*n* = 47). Groupings for One Plan targets are: 100% compliance (4), >95<100% (3), >90<95 (2), >85<90% (1), <85% (0). Categories for state are shown in Table 4.1. NPS-FM bands are A (4), B (3), C (2), D (1). **Sites downstream of point-source discharges. Trends shown are flow-adjusted; red = increase, grey = no change, green = decrease. See Section 4.3.2. Blank cells mean that the site does not have a linked flow record.

HRC no	Site abbreviation	Zone code	FARM (%)	OP Chla target	State Med chl	State Mean chl	State mats	State fils	State cyano	One Plan chl	One Plan mats	One Plan fils	NPS-FM band	Cyano guide-lines	Total score	Rank	Trends		
																	Chla	Mats	Fils
8	kumeti_tr	Mana_4	35	50	4	4	4	4	4	4	4	4	4	4	40	**1**			
2	mangatainoka_putara	Mana_8a	0	50	4	4	4	4	3	4	4	4	4	4	39	**2**			
4	tamaki_res	Mana_3	3	50	4	4	4	4	4	4	4	3	4	4	39	**2**			
45	mangawhero_doc	Whau_3d	38	50	4	4	3	4	4	3	4	3	4	4	37	**4**			
5	mangatera_us_dan	Mana_2b	92	120	4	3	4	4	4	3	4	3	4	4	37	**4**			
26	mangapapa_troup	Mana_9b	69	120	4	3	4	3	3	4	4	4	4	4	37	**4**			
29	oroua_almadale	Mana_12a	62	120	4	4	4	2	3	4	4	4	4	4	37	**4**			
15	pohangina_pir	Mana_10b	14	50	4	4	3	3	2	4	4	4	4	4	36	**8**			
12	tamaki_ste	Mana_5b	59	120	4	3	3	4	3	3	4	4	4	4	36	**8**			
38	rangitikei_puk	Rang_2a	31	50	4	4	3	2	3	4	4	3	4	4	35	**10**			
11	oroua_apiti	Mana_12a	14	120	4	4	3	2	3	4	4	3	4	4	35	**10**			
33	manawatu_tc	Mana_10a	75	120	4	3	4	2	4	3	4	3	4	4	35	**10**			
60	ohau_gladstone	Ohau_1a	11	50	4	4	3	2	2	4	4	3	4	4	34	**13**			
13	oruakeretaki_sh2	Mana_5d	68	120	4	3	3	4	2	3	4	3	4	4	34	**13**			
28	manawatu_ug	Mana_9a	79	120	4	3	3	2	3	4	4	3	4	4	34	**13**			
43	rangitikei_one	Rang_3a	50	120	4	3	3	1	3	4	4	4	4	4	34	**13**			
30	oroua_us_fei	Mana_12b	76	120	4	3	4	1	3	4	4	2	4	4	33	**17**			
56	tokiahuru_kar	Whau_1c	3	50	3	2	2	4	2	3	4	4	4	4	32	**18**			
46	makotuku_sh49	Whau_3b	20	50	4	3	2	4	3	4	4	3	4	0	31	**19**			
27	pohangina_mais	Mana_10c	49	120	4	4	3	0	2	4	4	2	4	4	31	**19**			
59	waikawa_nmr	West_9a	9	120	4	3	3	1	2	4	4	2	4	4	31	**19**			
54	waitangi_us_wai	Whau_1b	28	120	2	2	2	2	3	3	4	4	3	4	29	**22**			
40	rangitikei_man	Rang_3a	42	120	3	3	2	0	2	4	4	2	4	4	28	**23**			
61	ohau_sh1	Ohau_1b	21	120	4	3	2	2	1	3	3	3	4	3	28	**23**			
37	tokomaru_hb	Mana_13c	0	50	3	3	3	2	1	2	4	3	4	2	27	**25**			
32	oroua_awahuri	Mana_12c	80	120	3	2	2	1	3	3	4	3	3	3	27	**25**			
36	manawatu_opik	Mana_11a	74	120	3	2	4	0	3	2	4	2	3	4	27	**25**			

HRC no	Site abbreviation	Zone code	FARM (%)	OP Chla target	State Med chl	State Mean chl	State mats	State fils	State cyano	One Plan chl	One Plan mats	One Plan fils	NPS-FM band	Cyano guide-lines	Total score	Rank	Trends		
																	Chla	Mats	Fils
6	mangatera_ds_dan**	Mana_2b	92	120	3	2	2	0	3	3	4	2	3	4	26	**28**			
34	manawatu_us_pncc	Mana_11a	74	120	3	2	2	1	3	3	3	2	3	4	26	**28**			
50	mangawhero_pakihi	Whau_3d	46	50	3	2	2	2	1	1	4	4	4	2	25	**30**			
9	manawatu_weber	Mana_1a	89	120	3	2	3	0	2	2	4	2	3	4	25	**30**			
31	oroua_ds_fei**	Mana_12b	76	120	3	2	2	1	2	2	4	2	3	4	25	**30**			
47	mangawhero_us_oha	Whau_3d	28	50	3	2	2	3	1	2	4	4	3	0	24	**33**			
44	rangitikei_mk	Rang_4a	56	120	3	2	1	0	3	3	3	2	3	4	24	**33**			
48	mangawhero_ds_oha**	Whau_3d	30	50	2	2	2	2	1	0	3	4	3	2	21	**35**			
21	mangatainoka_us_pah	Mana_8c	77	120	2	2	1	1	1	3	3	3	3	2	21	**35**			
23	manawatu_hop	Mana_5a	86	120	3	1	1	0	2	1	3	2	3	4	20	**37**			
55	waitangi_ds_wai**	Whau_1b	28	120	1	1	2	0	4	0	4	0	2	4	18	**38**			
49	makotuku_rae	Whau_3c	58	50	2	2	0	0	2	0	1	2	3	4	16	**39**			
20	mangatainoka_ds_db**	Mana_8c	77	120	2	2	1	0	0	3	3	2	3	0	16	**39**			
10	makakahi_ham	Mana_8d	80	120	2	2	1	0	0	2	3	2	3	0	15	**41**			
14	makuri_tuscan	Mana_7d	81	120	1	1	1	1	1	0	4	3	1	2	15	**41**			
19	mangatainoka_sh2	Mana_8c	77	120	2	2	1	0	0	2	3	2	3	0	15	**41**			
22	mangatainoka_ds_pah**	Mana_8c	77	120	2	2	1	0	0	2	3	1	3	1	15	**41**			
17	tiraumea_nga	Mana_7b	83	120	1	1	1	0	0	0	3	2	2	2	12	**45**			
58	makotuku_ds_rae**	Whau_3c	62	50	1	1	1	0	0	0	3	0	1	2	9	**46**			
35	manawatu_ds_pncc**	Mana_11a	74	120	2	1	1	0	0	0	3	1	1	0	9	**46**			

Notes:

1. Colour coding in the table summarises the patterns seen in earlier maps and tables. However, note that (a) the metrics have different degrees of severity (i.e., some indicate lower ranks earlier than others); (b) no metrics are exactly consistent with each other, and (c) no metric reflected the overall ranking particularly well. Cover by filamentous algae was not necessarily low even at sites in the top 10 of the overall ranking.
2. The purpose of this table is not to compare the sensitivity of the metrics, but to combine a range of metrics (including those assessing differences at the low end of the range) in order to obtain a continuous ranking of sites in terms of overall periphyton state across the whole region.
3. All metrics were given the same weighting.

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6 Seasonality of periphyton standing crop and of compliance with targets and guidelines

Key messages

Maximum chlorophyll *a* was generally recorded from April to June; 50% of all maximum values were recorded in this quarter. Minimum chlorophyll *a* occurred mostly from August to November.

Consistent within-site seasonality in chlorophyll *a* was detected mostly at sites in the middle reaches of the Manawatu catchment (including tributaries).

Seasonality of rates of exceedance of targets for periphyton chlorophyll *a* and % cover by filaments were consistent with the overall seasonal pattern for chlorophyll *a*. However, targets for cover by mats were exceeded through the year, with no particular pattern.

Maxima in chlorophyll *a* and exceedances of targets for % cover by filaments were not associated with highest water temperatures, which peaked in January and February and were minimum in July. Patterns of maxima and exceedances also did not correspond with seasonal patterns in nutrient concentrations.

The overall seasonal pattern of chlorophyll *a* abundance and % cover by filaments appeared to be driven largely by flow patterns that were also seasonal. Highest flows occurred on average between August and October, coinciding with minimum chlorophyll *a*. Lowest flows tended to occur in April.

Exceedance of the "alert" and "action" levels for cover by benthic cyanobacteria (*Phormidium*) occurred most frequently in February, and least frequently in August and September. This seasonal pattern coincided approximately with the seasonal cycle of water temperatures in the region.

6.1 Background

Growth rates of algae depend on temperature, with maximum growth rates increasing with mean monthy temperature up to at least 20 °C, assuming that nutrient concentrations are not limiting growth (Bothwell 1988). For this reason, maximum periphyton biomass is generally expected to occur when water temperatures tend to be warmest, usually in late summer, provided that flow conditions are favourable for periphyton accrual. Seasonality of periphyton may also be driven by flow conditions. Lower biomass in certain months may reflect higher frequency and magnitude of high river flows at that time of year (often winter and spring, including the effect of snowmelt). Nevertheless, previous observations have shown that in some rivers, maximum biomass can occur at various times of the year (Biggs et al. 1999, Villeneuve et al. 2011).

Knowledge of seasonal patterns of periphyton can be important in the design of efficient and cost-effective monitoring programmes because regular seasonal fluctuations in biomass or cover could justify restriction of surveys to times of the year when biomass or cover is likely to be highest (i.e., problematic). From a river recreation perspective, high biomass in summer is more of an issue than in other seasons because recreational usage of rivers tends to be highest in summer, and periphyton in rivers is most visible. For this reason, the guidelines for protection of aesthetics and recreational values (as percentage cover by mats and filaments) set in the Biggs (2000) periphyton guideline applied only between 1 November and 30 April. Assessment of periphyton state into bands defined in the NPS-FM is based on year-round monitoring because the attribute is set to protect ecosystem health and applies at all times. However, seasonal monitoring could be justified for any river value if strong, consistent and predictable seasonal patterns can be identified.

Seasonality of periphyton biomass at individual sites might also be linked to seasonal patterns in nutrient availability, which may or may not be related to flows or land use patterns. Seasonality in DIN in particular may be linked to flow patterns, but a portion of seasonal variability can be independent of flow (e.g., Peterson et al. 2001, Rusjan et al. 2001). Relating seasonal patterns in dissolved nutrient concentrations to periphyton biomass in rivers is far from straightforward because summer minima may in part reflect instream uptake by periphyton when flows are very low. Uptake rates themselves depend on periphyton abundance and external physico-chemical factors (temperature, nutrient supply (flux), water velocity and nutrient limitation). Uptake can be measured directly (e.g., Larned et al. 2004) or may be estimated from measures of gross primary production (see Section 2.4) (King et al. 2014), all requiring considerable effort. Because of the potential complexity of nutrient concentration – biomass interactions, relationships between dissolved nutrient concentrations and periphyton biomass on single occasions (even using lagged data) are unlikely to be meaningful (Dodds 2003).

In the following we examined seasonal patterns in periphyton standing crop at each site in the Horizons dataset and in annual maximum periphyton across the whole region. The analysis focussed on chlorophyll *a* as the main metric representing periphyton abundance. The aims were (a) to determine whether there were consistent seasonal patterns in periphyton at the site, sub-region or larger scales, and (b) to identify potential drivers of those patterns, at a broad regional scale. Seasonality of exceedances of the One Plan, NPS-FM and Cyanobacteria guideline were also calculated.

6.2 Methods

6.2.1 Seasonality within sites

First, box plots were generated for monthly data at each site to visualise seasonal patterns. The data were normalised by standardising within each period (year) to the percentage of the mean value for that year. This removes the influence of overlying trends over time (e.g., higher chlorophyll *a* in the latter years of the monitoring programme at some sites) so that seasonal patterns are more easily detected. A Kruskal-Wallis test (non-parametric ANOVA) was applied (in Time Trends v. 5) to determine whether there were differences among months in median values. At sites where differences between months were detected, the month(s) with maximum and minimum median chlorophyll *a* were identified from the box plots. At least 48 samples were deemed to be necessary to run the analyses on individual sites (i.e., on average four samples per month). Strongly significant results were those with P values <0.005 (i.e., applying a correction to allow for false discovery rate of significance in multiple tests).

6.2.2 Regional seasonality of maximum periphyton

The month in which maximum periphyton occurred at each site in each complete hydrological year (July to June) of record was identified at each site. Total numbers of maxima occurring in each month were plotted as bar graphs by year. All data were reduced to monthly for this assessment, so that more frequent monitoring at some sites did not bias the results.

6.2.3 Potential drivers of seasonality

We investigated potential drivers of seasonal patterns by investigating seasonal patterns in the three sets of variables most likely to influence periphyton biomass: water temperature, flows and nutrients. Spot measurement of water temperature were available at all sites. The combined temperature data from all sites were plotted by month, and months of regional maximum and minimum temperatures determined from inspection of the plot. Kruskal-Wallis tests were run (as above) on mean monthly discharge for the flow record linked to each site, and on monthly DIN and DRP at each site. To allow direct comparison across sites, mean monthly flows were standardised to multiples of the long-term (2000-2015) mean flow at each site.

6.3 Results

6.3.1 Seasonality within sites

Sufficient data were available to test for seasonality at 52 sites. There was strong evidence for seasonal differences (among months) in chlorophyll *a* at eight sites ($P < 0.005$), and weaker evidence at a further 17 ($P < 0.05$). At these 25 sites, maximum chlorophyll *a* generally occurred from April to July, with 36% in April, and minimum chlorophyll *a* occurred between August and December, with 48% in August (Table 6-1).

Strong seasonality in percent cover by mats and filaments ($P < 0.005$) was detected at four and two sites, respectively. Five sites showed some seasonality in all three metrics (site 9, manawatu_weber; 17, tiraumea_nga; 24, maingatainoka_us_tir; 26, mangapapa_troup; and 6, mangatera_ds_dan). At most sites, there was high variability of periphyton within months (refer to box plots in Appendix C).

Significant seasonality of chlorophyll *a* within sites was largely concentrated at sites in the middle reaches of the Manawatu catchment (including tributaries) but not at the sites in the headwaters. Only two sites in other catchments (59, waikawa_nmr; 60, ohau_gladstone) showed seasonal patterns in chlorophyll *a*. There were seasonal patterns in % cover by filaments at all four sites on the Rangitikei River (Table 6-1).

6.3.2 Regional seasonality of maximum periphyton

Across all sites, and the five complete years in the programme, maximum annual chlorophyll *a* was recorded most frequently in May (18% of occurrences) followed by June (16%) and April (14%). Maxima were recorded least frequently in October (2%) and December (3%). The pattern varied across years (Figure 6-1).

The seasonal patterns at individual sites and of maxima at each site (regardless of the magnitude of the maximum value, Figure 6-1) were reflected in the overall regional pattern of chlorophyll *a* over the year (Figure 6-2). Median chlorophyll *a* was highest in April and May and lowest in August and September. At sites below point-source discharges chlorophyll *a* was variable from August to October. Note that the plots in Figure 6-2 are of the raw data on a log scale and the spread of the data within months reflects the ery high variability across sites and years.

Table 6-1: Summary results of tests to detect seasonality in periphyton at individual sites. Seasonality is possible where a Kruskal-Wallis test of periphyton (normalised within years) against months is significant (P< 0.05). Significant results are shown as shaded cells (chlorophyll *a*) or bold type (mats and filaments). Months of maximum and minimum (shown in the shaded cells at the right) chlorophyll *a* were identified from box plots (see Appendix C).

N	Site	Sub-zone	Mean chla	No. samples	Significance, seasonality (P) Chl *a*	Mats	Fils	Month of: Max. chl *a*	Min. chl *a*
Sites unaffected by point-source discharges									
2	mangatainoka_putara	Mana_8a	0.8	90	0.05	0.4	0.36		
4	tamaki_res	Mana_3	3.2	75	0.70	0.78	0.49		
5	mangatera_us_dan	Mana_2b	10.9	76	<0.005	0.14	**0.01**	5	8
8	kumeti_tr	Mana_4	4.9	75	0.68	0.66	0.73		
9	manawatu_weber	Mana_1a	33.3	71	<0.005	**0.02**	**<0.005**	6	8
10	makakahi_ham	Mana_8d	51.7	74	0.04	0.27	**0.01**	7	10
11	oroua_apiti	Mana_12a	3.1	70	0.10	**0.01**	0.23		
12	tamaki_ste	Mana_5b	8.5	71	0.03	**<0.005**	0.94	2, 4	8
13	oruakeretaki_sh2	Mana_5d	12.3	72	0.04	**0.01**	0.37	5	10
14	makuri_tuscan	Mana_7d	84.7	71	<0.005	**<0.005**	0.66	5	12
15	pohangina_pir	Mana_10b	2.5	71	0.11	0.4	0.56		
17	tiraumea_nga	Mana_7b	84.9	59	<0.005	**<0.005**	**0.05**	4	8
19	mangatainoka_sh2	Mana_8c	43.2	75	0.08	**0.02**	0.19		
21	mangatainoka_us_pah	Mana_8c	29.3	75	<0.005	**0.03**	0.25	4	10
23	manawatu_hop	Mana_5a	53.2	72	0.03	0.26	**0.01**	4	8
24	mangatainoka_us_tir	Mana_8c	32.4	49	<0.005	**0.05**	**0.04**	7	10
26	mangapapa_troup	Mana_9b	7.2	76	<0.005	**<0.005**	**0.01**	5	10
27	pohangina_mais	Mana_10c	4.5	74	0.03	0.27	0.13	5	8
28	manawatu_ug	Mana_9a	14.9	70	0.01	0.98	0.03	4	8
29	oroua_almadale	Mana_12a	3.6	68	0.04	0.33	0.35		
30	oroua_us_fei	Mana_12b	8.6	67	0.01	0.60	0.17	5	8
32	oroua_awahuri	Mana_12c	18.8	67	0.01	0.18	0.06	1, 4	8
33	manawatu_tc	Mana_10a	8.2	71	0.01	0.31	**0.01**	4	8
34	manawatu_us_pncc	Mana_11a	25.3	70	0.01	0.42	**0.01**	4	8
36	manawatu_opik	Mana_11a	33.0	59	0.16	0.52	0.06		
37	tokomaru_hb	Mana_13c	11.1	76	0.01	**0.01**	0.25	6	12
38	rangitikei_puk	Rang_2a	4.6	69	0.14	0.59	**0.02**		
40	rangitikei_man	Rang_3a	11.4	71	0.47	0.37	**0.02**		
43	rangitikei_one	Rang_3a	8.9	70	0.54	0.09	**0.01**		
44	rangitikei_mk	Rang_4a	18.8	66	0.11	0.18	**<0.005**		

					Significance, seasonality (P)			Month of:	
N	Site	Sub-zone	Mean chla	No. samples	Chl *a*	Mats	Fils	Max. chl *a*	Min. chl *a*
45	mangawhero_doc	Whau_3d	3.9	76	0.68	0.45	0.11		
46	makotuku_sh49	Whau_3b	6.5	76	0.93	0.83	0.84		
47	mangawhero_us_oha	Whau_3d	17.3	76	0.72	0.57	0.79		
49	makotuku_rae	Whau_3c	40.5	62	0.26	0.32	0.41		
50	mangawhero_pakihi	Whau_3d	22.0	67	0.11	0.28	0.17		
51	mangatepopo_gi	Whai_1	4.9	54	0.18	**0.03**	0.21		
52	whanganui_ds_gen	Whai_1	6.8	53	0.09	0.81	0.88		
53	whakapapa_ds_gen	Whai_2b	7.3	51	0.50	0.60	0.57		
54	waitangi_us_wai	Whau_1b	35.6	76	0.54	0.08	0.62		
56	tokiahuru_kar	Whau_1c	16.7	69	0.47	**0.05**	**0.05**		
57	makotuku_us_rae	Whau_3c	63.4	52	0.08	0.31	0.49		
59	waikawa_nmr	West_9a	5.3	76	0.05	0.21	**0.05**	6	11
60	ohau_gladstone	Ohau_1a	3.0	77	0.04	**0.05**	0.43	6	11
61	ohau_sh1	Ohau_1b	9.6	76	0.17	0.73	0.33		
Sites downstream of point-source discharges									
6	mangatera_ds_dan	Mana_2b	24.5	74	<0.005	**0.01**	**0.01**	2	10
20	mangatainoka_ds_db	Mana_8c	35.9	76	0.03	0.06	0.22		
22	mangatainoka_ds_pah	Mana_8c	47.4	69	0.01	0.06	**0.01**	7	10
31	oroua_ds_fei	Mana_12b	30.7	67	0.05	0.18	0.13	4	8
35	manawatu_ds_pncc	Mana_11a	68.7	70	0.11	0.41	**0.01**		
48	mangawhero_ds_oha	Whau_3d	26.3	73	0.28	0.16	0.14		
55	waitangi_ds_wai	Whau_1b	79.4	76	0.81	0.79	**0.04**		
58	makotuku_ds_rae	Whau_3c	118.7	68	0.13	0.49	**0.05**		

Exceedances of the One Plan targets are shown in Figure 6-3 as proportions of surveys in each month, across all years of data, for which the threshold was exceeded. The highest proportions of exceedances of both chlorophyll *a* and % cover by filaments occurred in May, reflecting the result for maximum chlorophyll *a*. The target for % cover by mats was exceeded less frequently, with no clear seasonal pattern.

The seasonal patterns for exceeding the NPS-FM thresholds separating the four periphyton bands were similar to the general pattern for exceeding the One Plan chlorophyll *a* targets, because the thresholds in the two systems coincide. Most exceedances of 200 mg/m^2 (separating NPS-FM bands C and D) occurred in April and May (Figure 6-4a).

Cyanobacteria % cover had a seasonal pattern roughly similar to that of chlorophyll *a*, in the Horizons dataset, but exceedance of the “action” level (> 50% cover) was highest in February (Figure 6-4b).

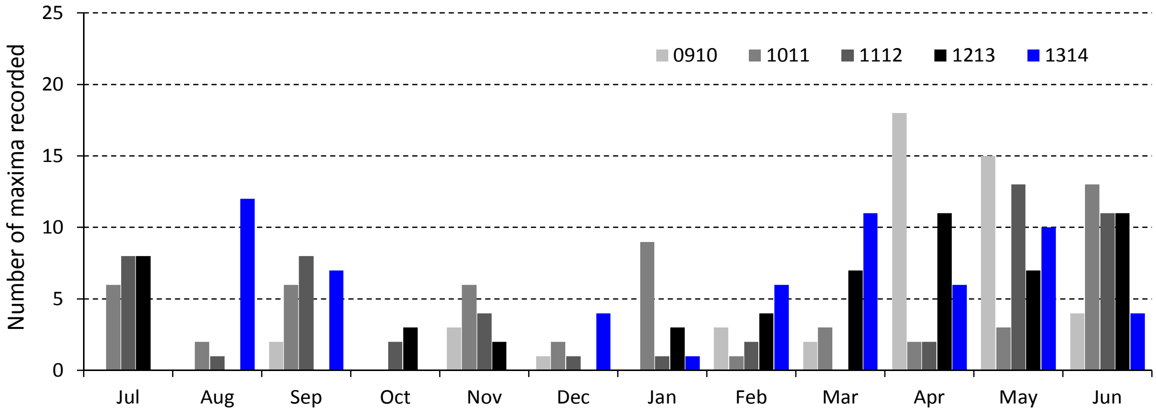

Figure 6-1: Numbers of occurrences of maximum chlorophyll *a* in hydrological years from 2009-10 to 2013-14 in the Manawatu-Whanganui region. Data from between 48 and 62 sites were available in each year. The month of annual maximum chlorophyll *a* may change slightly depending on how the year is defined, but using calendar years (January to December) produced a similar result.

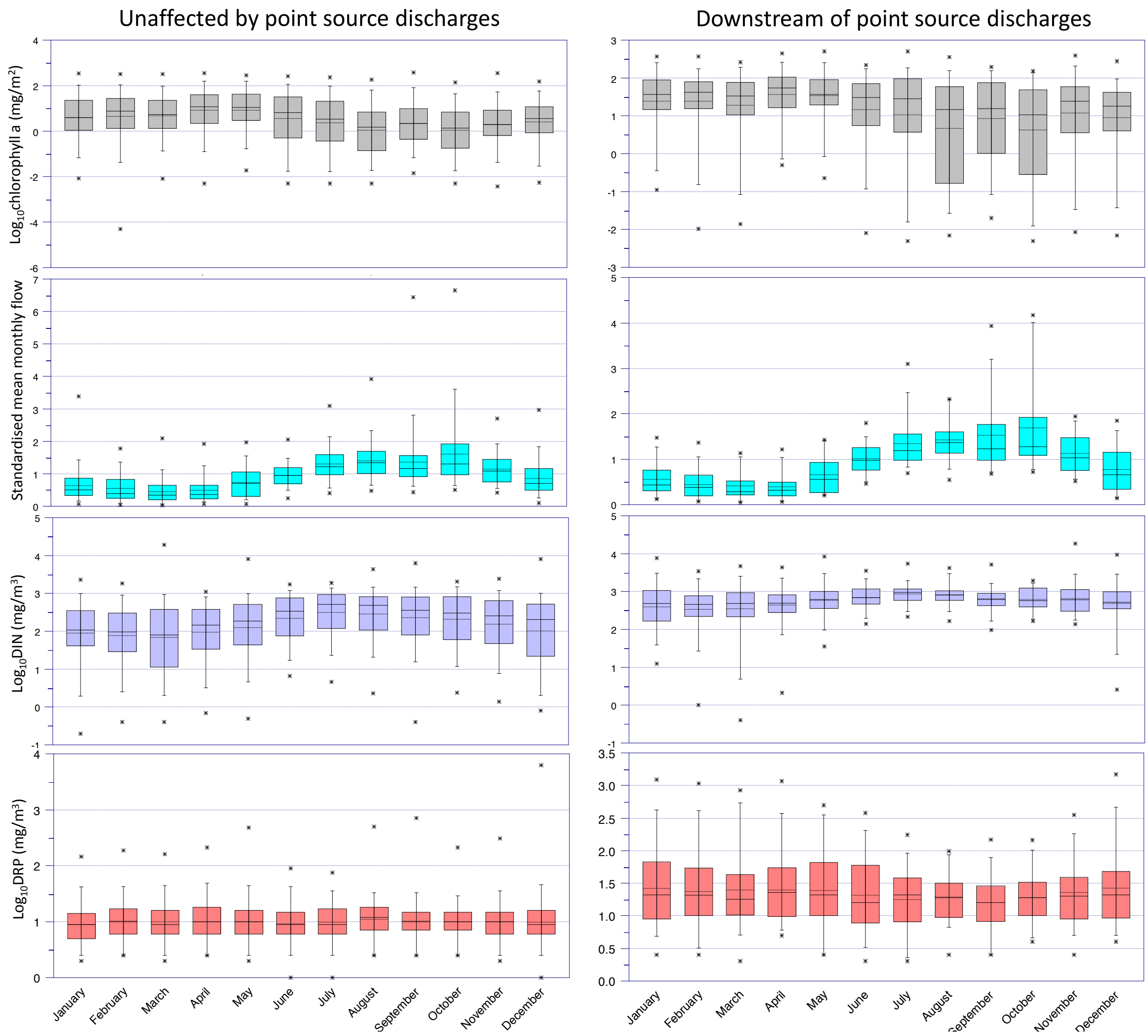

Figure 6-2: Box plots summarising log_{10}chlorophyll *a*, monthly mean flow, log_{10}DIN and log_{10}DRP data at all sites, by month. Note log-transformation of chlorophyll *a*, DIN and DRP data. Flow data were standardised to multiples of the mean flow at each site. Sites not affected and affected by point-source discharges are shown separately (n = 52 and 9 respectively). Refer to Figure 6-5 for an explanation of the box plots.

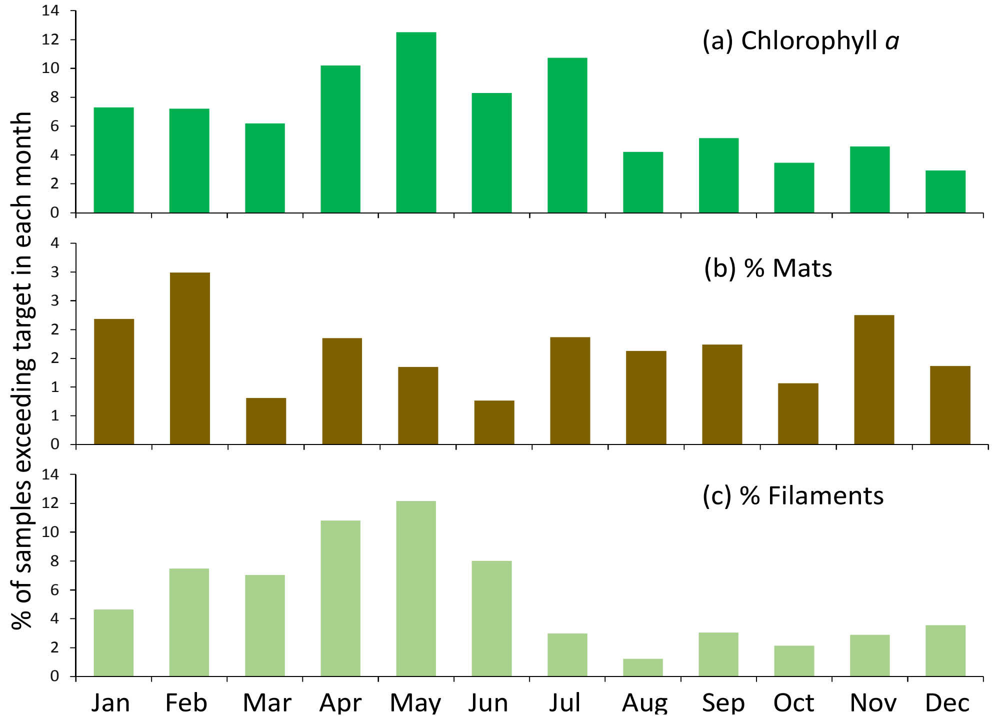

Figure 6-3: Percentages of surveys in which One Plan periphyton targets were exceeded in each calendar month. The percentages were calculated from combined data from all sites over the entire monitoring period. Chlorophyll *a* targets are 50 or 120 mg/m^2, depending on site; the target for cover by mats is 60%, and for cover by filaments 30%.

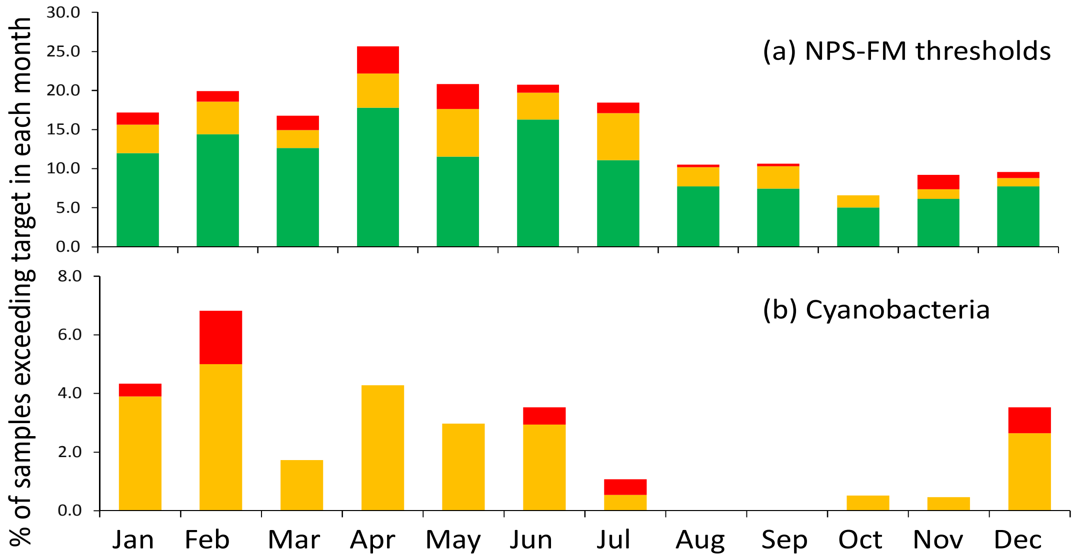

Figure 6-4: Percentages of surveys in which thresholds defining (a) NPS periphyton bands (chlorophyll *a*), and (b) cyanobacteria were exceeded. In (a) NPS-FM chlorophyll *a* thresholds are (in mg/m^2) 50 (green bars), 120 (amber bars) and 200 (red bars). In (b) cyanobacteria % cover thresholds are 20% (Amber alert level) and 50% (Red action level). All data were used for the assessment.

6.3.3 Potential drivers of seasonality

In most cases the minimum temperature (average across years) occurred in July, with an overall mean of 7.8 °C. The warmest months were January and February (overall means of 17.7 °C) (Figure 6-5).

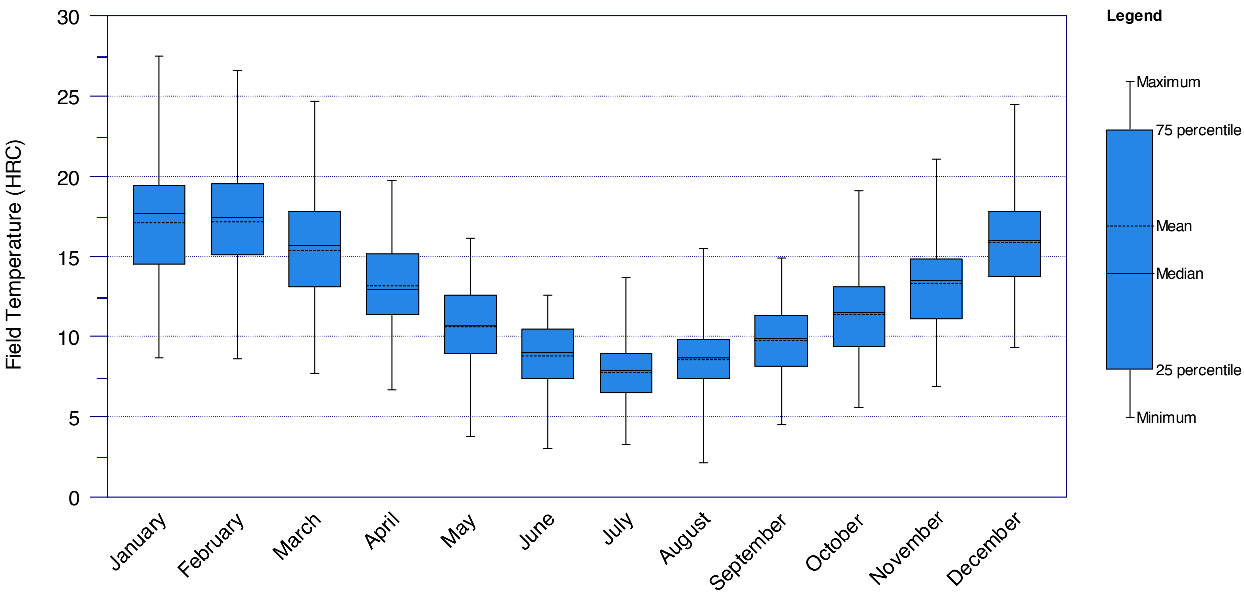

Figure 6-5: Mean spot water temperature (°C) across all sites and in all years plotted against month. Refer to the legend to the right for an explanation of the box plots.

There was no obvious correspondence between water temperature and the annual patterns of maximum chlorophyll *a* and exceedances of other periphyton guidelines (as shown in Figure 6-1, Figure 6-3, and Figure 6-4a). However the highest rates of exceedance of the cyanobacteria guideline coincided with the month with highest water temperatures (February); lowest rates of exceedance also occurred during months with low water temperature, although some exceedances were recorded in July, the month of minimum water temperature (compare Figure 6-4b and Figure 6-5). Mean percentage cover by cyanobacteria across all sites showed the same pattern (data not shown). This suggests a potential link between maximum cyanobacteria cover and higher water temperature (>15 ˚C), consistent with observations in the Hutt River (Heath et al. 2011).

A clear regional pattern of lowest mean monthly flows from January to April and highest from July to October indicates that flows probably exert more control over periphyton standing crop measured as chlorophyll *a* than temperature (Figure 6-2).

As discussed above, nutrient concentrations, particularly DIN, typically vary with season. Across all sites in the present dataset, DIN tended to be highest from June to September and lowest from December to March. No particular seasonal pattern was evident in DRP at a regional level (Figure 6-2).

DIN concentrations were strongly seasonal at 38 of the 46 sites that had sufficient data for the analysis. Of the eight showing no seasonal patterns, three were downstream of point-source discharges (site 6, mangatera_ds_dan; site 31, oroua_ds_fei; and site 55, waitangi_ds_wai). The remaining five were: site 14, makuri_tuscan; 17, tiraumea_nga; 32, oroua_awahuri; 45, mangawhero_doc; 46, makotuku_sh49). At all sites showing a seasonal pattern, DIN was also positively correlated with mean flow on the days of sampling (data not shown), indicating that the seasonal pattern in DIN was largely driven by the seasonal pattern of higher flows from July to October, noted above, shown in Figure 6-2. The tendency for DIN to be highest in late winter to spring, and also to be correlated with high flows suggests that seasonal fluctuations in DIN were not directly related to periphyton biomass at the regional scale. Highest DIN in late winter to spring generally corresponded with lowest chlorophyll *a* (Figure 6-2).

In contrast to the region-wide seasonal pattern of DIN, DRP showed a seasonal pattern at only three of the 46 sites with sufficient data. These sites were: site 5, mangatera_us_dan; 27, pohangina_mais; and 58, makotuku_ds_rae. The pattern was most marked at site 58, within minimum DRP in July and August. Periphyton chlorophyll *a* and % cover by filaments were persistently high at this site, with no seasonal pattern (see Figure 4-3, Table 6-1, and Appendix C); therefore it seems unlikely that short-term seasonal fluctuations in DRP are directly related to patterns in periphyton. Note that site 58 had amongst the highest periphyton and % cover by all types of periphyton (including cyanobacteria) in the dataset and ranked joint worst in the state assessment using combined metrics (see Section 5.4 and Table 5-7).

Refer to Appendix C for plots of DIN and DRP by month at each site.

6.4 Discussion

Mid- to late summer is usually assumed to be the period during which maximum periphyton is recorded, provided river flows are low. This assumption was supported by the tests of seasonality except that the number of chlorophyll *a* maxima recorded in May, June and July was unexpectedly high. This resulted in more exceedances of the One Plan target for chlorophyll *a* in May than in any other month. We identified that the high biomass over the region was more likely to be linked to hydrological conditions than to water temperature or nutrient concentrations.

Differences in hydrological conditions between years clearly affect the distribution of maxima across months (see Figure 6-1) and a similar pattern is seen in exceedances of the One Plan target for chlorophyll *a* between July 2009 and June 2014 (Figure 6-6). In 2012-13 (identified as the driest year in Figure 4-1) at least 10% of all sites exceeded the target in each of January to April, and June. In 2010-11 (the wettest year) more than 10% of sites exceeded the target only in January and May.

Of the 10 most problematic sites unaffected by point-source discharges (Table 5-7), the seven sites in the cluster around the central Manawatu catchment had few exceedances of the One Plan target for chlorophyll *a* between August and December, and peak rates of exceedance in May and June (Table 6-2). Between July 2009 and June 2014, all seven sites exceeded the target at least once in these months, and in three of the five years at two sites (14, makuri_tuscan; 17, tiraumea_nga). As a comparison, Table 6-2 shows months of exceedances at the four sites downstream of point-source discharges, which tended to be earlier in the year.

The small number of low-ranked sites in the Whangaehu catchment showed winter exceedances at both sites unaffected by point-source discharges (sites 47 and 49). At the three sites downstream of discharges, exceedances have occurred throughout the year, with highest rates in February (Table 6-2).

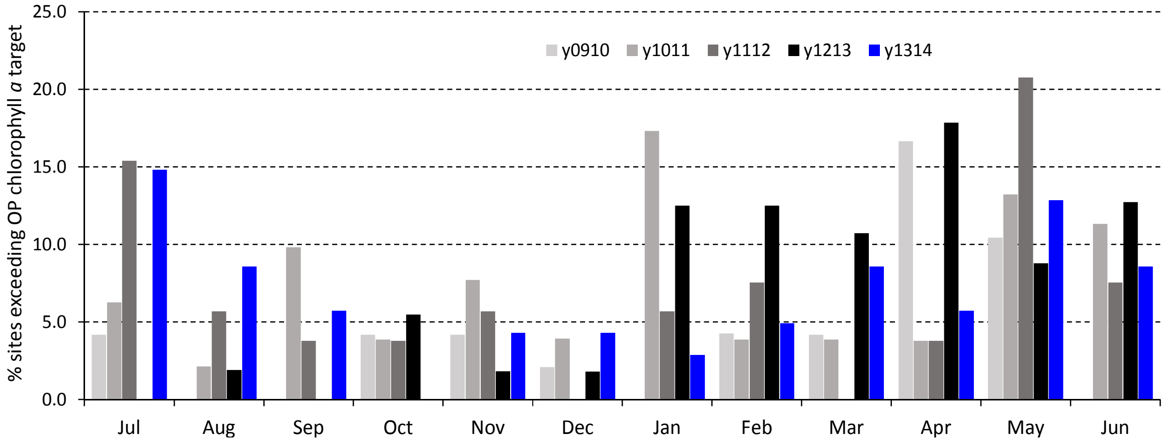

Figure 6-6: Percentages of surveys when the One Plan chlorophyll *a* target was exceeded, by year from 2009-10 to 2013-14 in the Manawatu-Whanganui region. Compare this Figure with Figure 6-1, which shows months of chlorophyll *a* maxima by year. The overall patterns are similar.

Table 6-2: Numbers and months of exceedances of the One Plan chlorophyll *a* targets at groups of low-ranked sites in Table 5.7. Sites grouped according to catchment and whether unaffected or downstream of a point-source discharge (PSD). The number of sites in each group is shown in parentheses. Numbers of exceedances are from five complete years from July 2009 to June 2014. Therefore the maximum number of exceedances in each month is 5 x no. of sites (*N*). Peak months for exceedances are shaded in grey (most) and pale grey (second most). Refer to text for further details.

	Manawatu catchment				Whangaehu catchment			
	Unaffected by PSD (7)		Downstream of PSD (4)		Unaffected by PSD (2)		Downstream of PSD (3)	
Month	Exceedances	*N*	Exceedances	*N*	Exceedances	*N*	Exceedances	*N*
January	6	4	4	2	0		6	3
February	4	2	3	2	1		**11**	3
March	6	3	2	2	2	1	8	3
April	6	3	**6**	3	0		7	2
May	**13**	6	5	4	2	1	8	3
June	8	6	1	1	3	2	6	3
July	5	4	3	3	**4**	2	6	3
August	0		1	1	3	2	3	2
September	0		0		0		5	3
October	1	1	0		0		7	3
November	1	1	0		3	2	8	3
December	3	3	1	1	2	1	3	2

The general seasonal pattern of exceedance of the cyanobacteria guideline differed from that of chlorophyll *a*, with exceedances earlier in the year. It is also clear from Table 5-7 that relatively high cover by cyanobacteria could also occur at sites with high overall rankings. Therefore, to look at seasonal patterns in % cover by cyanobacteria at sites where cover is most prevalent, months of exceedance of the alert level in the cyanobacteria guideline were considered. This level was exceeded at least once at 21 sites (between May 2011 and April 2015). The main outcome of the analysis (data not shown) was that the pattern of maximum rates of exceedance in mid-summer was confirmed. However, there was little consistency within sites. For example, over the four years of the dataset, > 20% cover was recorded 15 times in February, but this was at 11 sites, only three of which had >20% cover in two separate years. As discussed in Section 4.3.2, the strongest pattern was higher cover in the first year of the programme than in later years.

In summary, between July 2009 and June 2014, high levels of chlorophyll *a* (as indicated by exceedances of the One Plan target) occurred throughout the year, but more frequently from April to June than in other months. Rates of exceedance varied according to hydrological conditions, which also influenced the timing of exceedances over the year. Probable hydrological control of peak times for exceedances suggests that targeting particular times for management to reduce rates of exceedance does not seem feasible (because hydrological conditions cannot be predicted or controlled). The pattern at sites downstream of point-source discharges differed, with earlier exceedances or year-round exceedances. There may be scope for targeting certain months to reduce exceedances in these cases. The seasonal pattern for cyanobacteria cover was highest rates of exceedance of early in January – February. These exceedances occurred at sites throughout the ranking in Table 5-7.

7 Acknowledgements

This report was funded by Horizons Regional Council, in partnership with Dairy NZ. Jon Roygard is thanked for commissioning the work and for making available the most comprehehsive dataset on periphyton, nutrients and river flows available in New Zealand and probably the world. We thank Kathy Walter (NIWA) for initial data preparation on the flow records, Julian Sykes for provision of REC data, Doug Booker for advice on the use of R software, Scott Larned and Barry Biggs for helpful discussions, and Clive Howard-Williams, Phil Jellyman, Ton Snelder, Tom Stephens (DairyNZ) for constructive reviews.

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Appendix A Summary of periphyton and environmental characteristics at all periphyton monitoring sites

Values are calculated from data between May 2012 and April 2015. Records at some sites were shorter (see Table 3-1). PSD refers to whether sites are affected by a point-source discharge (y) or not (n). Refer to Table 7-6 for explanations of water quality and catchment abbreviations. REC Geology classes are: HS, hard sedimentary; SS, soft sedimentary; M, miscellaneous; AL, alluvium; VA, volcanic acidic. Substrate cells are are shaded according to the site stability class, as defined in Table 7-1: Grey shading = unstable (light, low; dark, medium); blue shading = stable (light, high; dark, undefined).

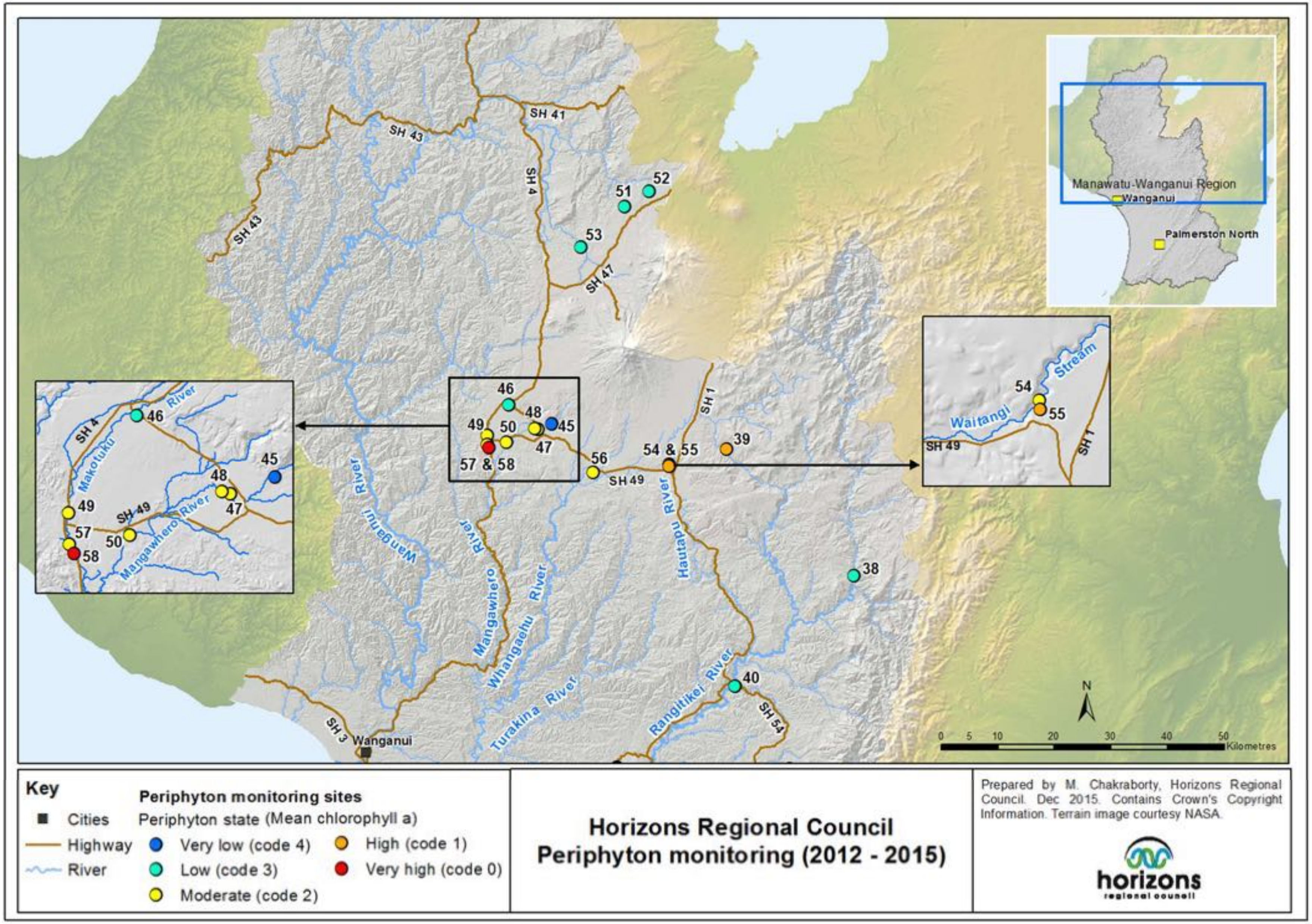
HRC				Substrate		Flows			Periphyton (92nd percentiles)				Water quality (means)							Catchment	
code	Site	Zone	PSD	% Fine	% Coarse	Mean (m^3/s)	Median (m^3/s)	FRE3	Chla mg/m^2	Mats (%)	Fils (%)	Cy (%)	Cond. µS/cm	TSS mg/L	DIN mg/m^3	DRP mg/m^3	TDP mg/m^3	TN mg/m^3	TP mg/m^3	FARM (%)	GEOL. class
1	makakahi_doc	Mana_8d	n	2	50	5.2	2.7	11.1	4.0	1.2	0.9	1.2	55.8	-	37	7.1	9.8	83	9.4	0.0	HS
2	mangatainoka_putara	Mana_8a	n	2	52	4.2	1.9	14.1	2.3	0.3	0.0	0.0	52.5	1.6	20	6.3	10.5	67	8.5	0.0	HS
3	mangatainoka_lars	Mana_8a	n	3	46	4.2	1.9	14.1	12.3	5.7	9.7	2.8	57.8	2.4	65	6.5	8.8	131	10.1	32.7	HS
4	tamaki_res	Mana_3	n	2	45	1.7	0.9	8.1	14.1	3.6	1.7	0.0	68.5	4.2	58	10.3	12.7	99	13.5	3.4	HS
5	mangatera_us_dan	Mana_2b	n	24	8	-	-		37.5	0.5	3.2	0.0	167.9	17.8	584	60.3	65.8	862	95.6	92.5	SS
6	mangatera_ds_dan	Mana_2b	y	19	18	-	-		98.9	12.2	11.5	1.0	192.2	18.0	1371	351.9	391.6	1717	402.2	92.5	SS
7	mangatainoka_huk	Mana_8b	n	6	36	4.2	1.9	14.1	7.6	3.3	3.9	1.5	77.1	1.5	725	7.2	9.9	823	15.1	57.6	HS
8	kumeti_tr	Mana_4	n	4	17	0.4	0.3	6.0	25.1	2.0	0.5	0.0	79.1	19.3	704	9.5	11.6	856	35.1	34.9	HS
9	manawatu_weber	Mana_1a	n	13	26	13.0	6.6	6.9	135.5	5.9	24.8	5.9	267.5	33.1	365	15.8	20.0	624	50.7	89.0	SS
10	makakahi_ham	Mana_8d	n	6	39	5.2	2.7	11.1	123.9	23.3	46.1	14.2	109.7	4.0	465	6.6	14.0	691	23.7	79.5	SS
11	oroua_apiti	Mana_12a	n	4	35	8.5	5.6	10.5	4.9	3.1	4.5	0.3	73.6	57.2	88	6.6	9.6	180	35.4	13.9	M
12	tamaki_ste	Mana_5b	n	3	33	3.2	2.0	8.4	13.4	0.5	0.0	0.5	79.5	17.3	446	9.7	14.2	522	22.5	58.9	HS
13	oruakeretaki_sh2	Mana_5d	n	9	31	1.9	1.3	8.7	44.0	7.5	1.0	7.5	103.3	6.4	933	13.6	17.1	1095	29.1	67.9	HS
14	makuri_tuscan	Mana_7d	n	13	50	4.7	3.6	7.5	270.6	11.2	23.7	11.2	324.8	24.2	853	8.4	13.2	1058	37.9	81.1	HS
15	pohangina_pir	Mana_10b	n	10	50	-	-		9.5	2.8	3.8	2.1	68.8	26.9	43	6.9	10.8	99	22.7	14.1	HS
16	mangatainoka_scarb	Mana_8b	n	5	38	14.6	8.0	11.4	45.5	23.6	11.2	22.7	91.1	4.4	1086	6.7	9.0	1191	14.6	69.3	AL
17	tiraumea_nga	Mana_7b	n	8	37	14.2	7.5	8.7	231.0	39.1	53.8	39.1	307.6	37.8	614	8.6	16.3	938	50.8	83.5	SS
18	mangatainoka_pahiatua	Mana_8c	n	9	36	14.6	8.0	11.4	127.4	27.9	25.8	12.9	105.5	4.2	958	9.4	14.3	1082	17.7	76.9	AL
19	mangatainoka_sh2	Mana_8c	n	3	43	14.6	8.0	11.4	125.1	20.0	16.0	19.9	114.2	4.1	829	6.8	11.2	1007	18.8	77.1	AL
20	mangatainoka_ds_db	Mana_8c	y	3	42	14.6	8.0	11.4	80.5	19.0	22.1	16.2	117.8	4.4	876	8.1	20.5	1005	20.1	77.1	AL
21	mangatainoka_us_pah	Mana_8c	n	4	43	14.6	8.0	11.4	63.9	10.3	21.2	10.2	111.9	4.7	860	6.8	9.7	1001	18.2	76.8	AL
22	mangatainoka_ds_pah	Mana_8c	y	3	47	14.6	8.0	11.4	113.5	27.4	19.6	27.4	118.0	6.0	855	9.1	14.6	991	22.6	76.9	AL
23	manawatu_hop	Mana_5a	n	6	24	23.1	13.4	8.1	119.3	7.6	21.9	6.4	222.1	30.1	506	23.3	27.7	758	57.1	85.9	SS
24	mangatainoka_us_tir	Mana_8c	n	3	45	14.6	8.0	11.4	63.6	10.5	33.3	10.1	117.5	5.3	798	8.3	13.3	967	21.6	79.0	AL

HRC				Substrate		Flows			Periphyton (92nd percentiles)				Water quality (means)							Catchment	
code	Site	Zone	PSD	% Fine	% Coarse	Mean (m^3/s)	Median (m^3/s)	FRE3	Chla mg/m^2	Mats (%)	Fils (%)	Cy (%)	Cond. µS/cm	TSS mg/L	DIN mg/m^3	DRP mg/m^3	TDP mg/m^3	TN mg/m^3	TP mg/m^3	FARM (%)	GEOL. class
26	mangapapa_troup	Mana_9b	n	14	17	0.5	0.3	10.2	35.8	2.2	4.0	1.0	129.0	7.9	302	12.2	18.6	523	31.2	68.6	M
27	pohangina_mais	Mana_10c	n	17	38	14.6	9.3	11.1	8.2	2.5	24.0	1.9	126.9	38.5	80	14.4	16.8	209	38.0	48.7	HS
28	manawatu_ug	Mana_9a	n	27	12	73.3	47.9	10.8	70.4	2.7	11.7	0.5	197.2	36.9	555	10.2	15.3	707	38.6	79.1	SS
29	oroua_almadale	Mana_12a	n	8	36	8.5	5.6	10.5	12.6	1.7	3.3	1.1	113.0	207.3	129	10.3	13.6	276	76.4	61.7	M
30	oroua_us_fei	Mana_12b	n	15	17	12.1	8.3	11.7	45.8	2.0	20.8	0.3	132.1	256.5	331	14.5	18.0	622	106.1	76.2	M
31	oroua_ds_fei	Mana_12b	y	10	21	12.1	8.3	11.7	157.6	11.4	21.8	4.6	150.6	284.6	1286	16.3	22.2	1607	110.8	76.2	M
32	oroua_awahuri	Mana_12c	n	9	24	12.1	8.3	11.7	49.1	1.9	7.1	1.6	162.6	347.8	820	24.4	32.8	1169	133.6	79.7	M
33	manawatu_tc	Mana_10a	n	4	29	89.4	59.5	8.7	34.5	3.0	22.0	0.0	185.1	44.0	369	11.5	15.4	558	36.3	75.0	HS
34	manawatu_us_pncc	Mana_11a	n	3	21	89.4	59.5	8.7	73.0	5.9	18.4	0.5	182.3	39.0	380	12.5	17.2	548	35.3	74.4	HS
35	manawatu_ds_pncc	Mana_11a	y	4	31	89.4	59.5	8.7	307.6	32.5	43.6	27.7	189.2	37.9	622	19.2	27.2	865	52.3	73.7	HS
36	manawatu_opik	Mana_11a	n	26	3	89.4	59.5	8.7	155.0	3.4	37.5	0.7	183.5	137.5	526	13.0	22.2	819	80.4	74.3	M
37	tokomaru_hb	Mana_13c	n	6	43	1.8	1.1	14.7	65.5	17.1	16.2	14.2	83.5	2.8	62	7.7	11.2	155	12.7	0.2	HS
38	rangitikei_puk	Rang_2a	n	15	45	19.7	15.4	6.3	15.5	3.6	11.5	0.0	82.8	2.9	26	7.8	10.0	101	10.2	30.8	VA
39	moawhango_waiouru	Rang_2d	n	1	38	0.8	0.7	5.1	187.7	92.5	4.9	0.0	153.4	-	15	15.8	19.0	-	-	0.2	VA
40	rangitikei_man	Rang_3a	n	9	52	51.7	40.9	5.7	31.1	7.8	19.8	3.0	124.4	21.3	50	7.4	8.9	151	23.4	41.9	VA
41	porewa_us_hun	Rang_4c	n	10	27	-	-	-	150.3	12.4	84.2	0.0	278.1	3.8	186	22.2	36.5	758	62.9	73.1	M
42	porewa_ds_hun	Rang_4c	y	9	22	-	-	-	155.8	8.5	74.4	0.0	282.6	3.8	248	24.2	42.1	850	72.9	73.5	M
43	rangitikei_one	Rang_3a	n	11	29	54.1	39.6	6.9	52.4	14.8	26.1	0.2	164.7	49.8	63	8.5	11.7	182	29.6	49.7	VA
44	rangitikei_mk	Rang_4a	n	10	27	62.2	43.6	7.8	85.0	30.6	32.9	0.0	173.3	30.7	95	12.1	16.3	234	34.6	55.8	M
45	mangawhero_doc	Whau_3d	n	3	61	4.3	2.9	6.6	11.1	2.2	1.2	0.0	55.2	5.2	16	18.5	20.0	91	22.5	38.4	VA
46	makotuku_sh49	Whau_3b	n	25	38	0.8	0.4	10.5	28.7	29.4	0.7	0.6	73.5	6.6	213	18.2	69.3	332	18.9	20.3	VA
47	mangawhero_us_oha	Whau_3d	n	6	47	4.3	2.9	6.6	50.0	7.4	2.2	6.1	81.7	17.2	180	15.1	24.8	252	24.1	28.1	VA
48	mangawhero_ds_oha	Whau_3d	y	8	54	4.3	2.9	6.6	97.0	19.7	8.9	9.5	84.1	22.2	203	23.8	22.9	385	44.6	29.6	VA
49	makotuku_rae	Whau_3c	n	9	57	1.3	0.5	9.0	98.5	34.1	33.3	0.4	87.5	11.1	332	11.2	12.8	550	25.5	58.3	VA
50	mangawhero_pakihi	Whau_3d	n	13	50	4.3	2.9	6.6	75.0	11.5	11.6	5.8	89.8	13.3	221	16.1	18.8	388	30.8	45.8	VA
51	mangatepopo_gi	Whai_1	n	8	57	0.6	0.5	4.2	14.6	10.2	12.9	1.0	223.6	-	23	17.7	17.3	-	-	0.0	VA
52	whanganui_ds_gen	Whai_1	n	17	47	0.6	0.4	8.7	18.4	9.4	1.2	0.5	94.6	3.0	19	31.6	33.4	2	1.2	0.0	VA
53	whakapapa_ds_gen	Whai_2b	n	11	62	6.8	3.6	10.8	22.2	17.4	6.6	4.1	135.4	1.9	39	29.7	33.5	68	80.5	12.6	VA
54	waitangi_us_wai	Whau_1b	n	15	23	-	-	-	100.0	6.0	5.8	0.2	184.2	9.0	243	32.4	31.8	342	42.3	27.9	VA
55	waitangi_ds_wai	Whau_1b	y	16	24	-	-	-	174.5	0.0	25.3	0.0	190.0	17.3	446	53.7	34.1	630	93.4	27.9	VA

HRC code	Site	Zone	PSD	Substrate % Fine	% Coarse	Flows Mean (m^3/s)	Median (m^3/s)	FRE3	Periphyton (92nd percentiles) Chla mg/m^2	Mats (%)	Fils (%)	Cy (%)	Water quality (means) Cond. µS/cm	TSS mg/L	DIN mg/m^3	DRP mg/m^3	TDP mg/m^3	TN mg/m^3	TP mg/m^3	Catchment FARM (%)	GEOL. class
56	tokiahuru_kar	Whau_1c	n	26	25	-	-	-	58.6	14.2	1.3	2.5	126.7	-	13	51.8	63.7	-	-	3.0	VA
57	makotuku_us_rae	Whau_3c	n	6	43	1.3	0.5	9.0	120.5	14.4	3.7	6.5	91.6	8.9	360	13.1	16.3	904	45.4	62.2	VA
58	makotuku_ds_rae	Whau_3c	y	10	34	1.3	0.5	9.0	265.0	31.1	37.1	22.8	94.3	7.4	391	21.0	26.8	650	46.9	62.2	VA
59	waikawa_nmr	West_9a	n	10	40	1.3	0.8	10.8	18.9	5.8	4.8	1.5	85.3	2.7	62	10.1	12.8	175	26.1	9.1	HS
60	ohau_gladstone	Ohau_1a	n	9	35	5.4	3.5	12.3	8.4	4.0	3.1	3.8	71.4	2.1	56	8.3	11.0	124	10.7	10.7	HS
61	ohau_sh1	Ohau_1b	n	8	36	5.4	3.5	12.3	36.4	3.1	6.7	2.1	77.8	-	235	9.4	17.8	-	-	20.7	HS
62	ohau_haines	Ohau_1b	n	14	29	5.4	3.5	12.3	96.3	1.9	9.5	1.9	86.0	2.4	325	7.4	9.8	414	14.2	27.8	HS

Appendix B Maps of periphyton state and compliance based on data from the most recent three years (May 2012 to April 2015)

The maps on the following pages are presented in the same order as the maps in Section 4 (State and trends) and Section 5 (Compliance with targets and guidelines), for comparison.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SH 43
SH 4
SH 47
SH 1
SH 49
SH 3
SH 54
Wanganui
Manawatu-Wanganui Region
Wanganui
Palmerston North
Waitangi
Stream
Makotuku
River
Mangawhero River
Whanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
51
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47
57 & 58
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54 & 55
39
38
40
57
58
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55
N
0 5 10 20 30 40 50
Kilometres
Key
Cities
Highway
River
Periphyton monitoring sites
Periphyton state (Mean chlorophyll a)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
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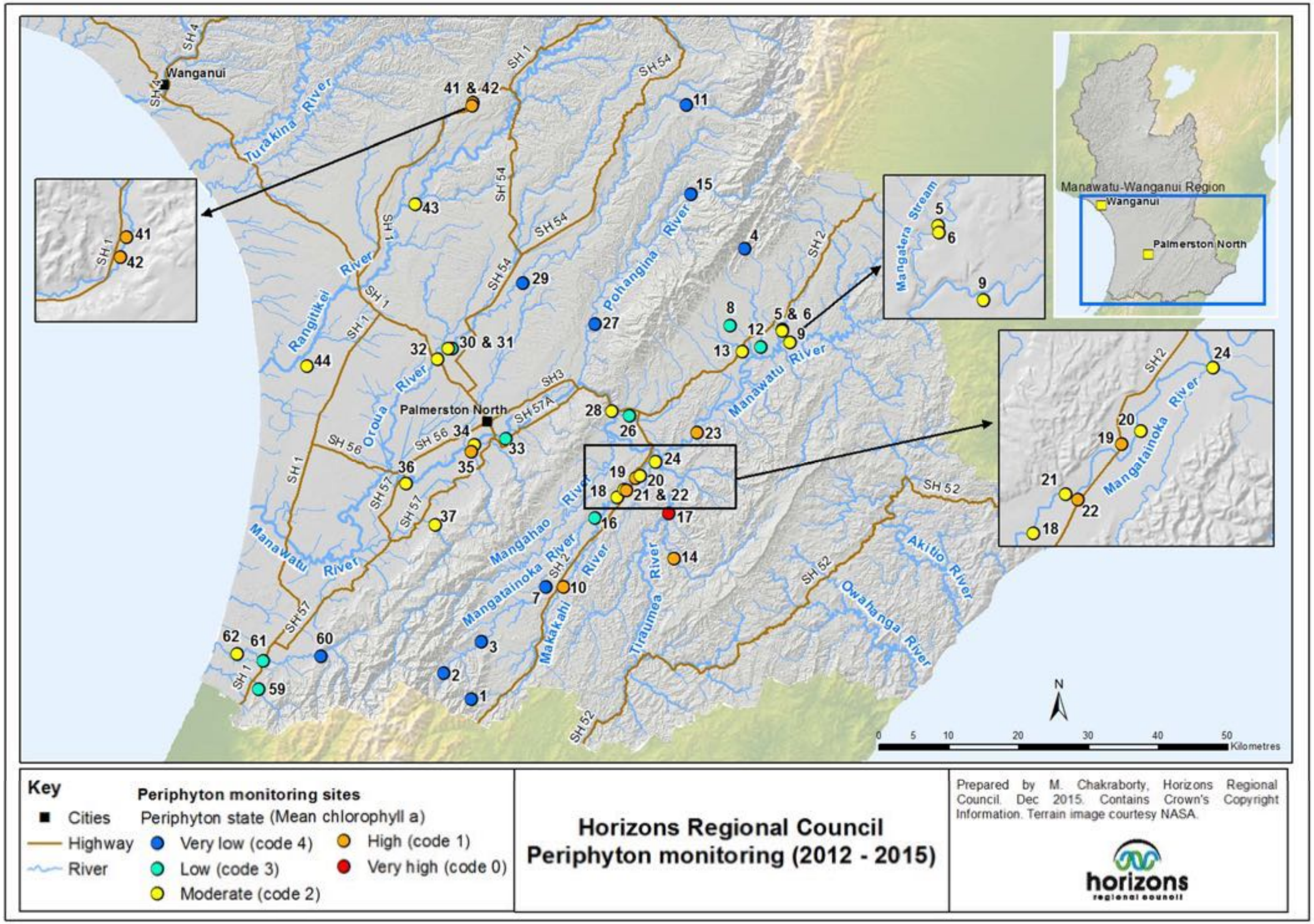
horizons
regional council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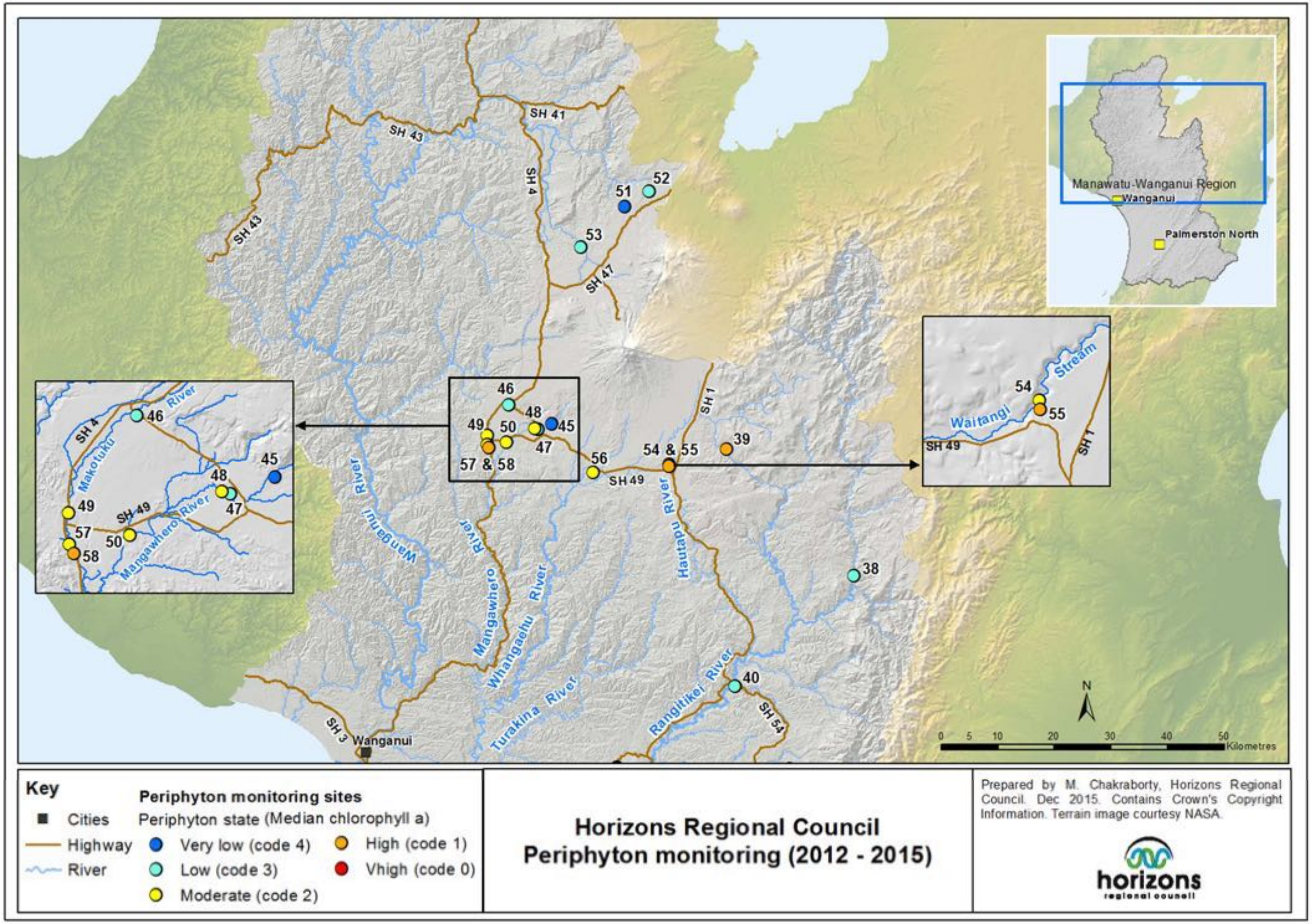
Periphyton monitoring sites
Cities
Highway
River
Periphyton state (Mean chlorophyll a)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council. Dec 2015. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons
regional council
Wanganui
Palmerston North
Manawatu-Wanganui Region
Turakina River
Rangitikei River
Oroua River
Pohangina River
Manawatu River
Mangahao River
Mangatainoka River
Makakahi River
Tiraumea River
Akitio River
Owahanga River
Mangatera Stream
Kilometres



SH 41
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SH 54
Wanganui
Whanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
Makotuku River
Waitangi Stream
Manawatu-Wanganui Region
Palmerston North
46
48
45
49
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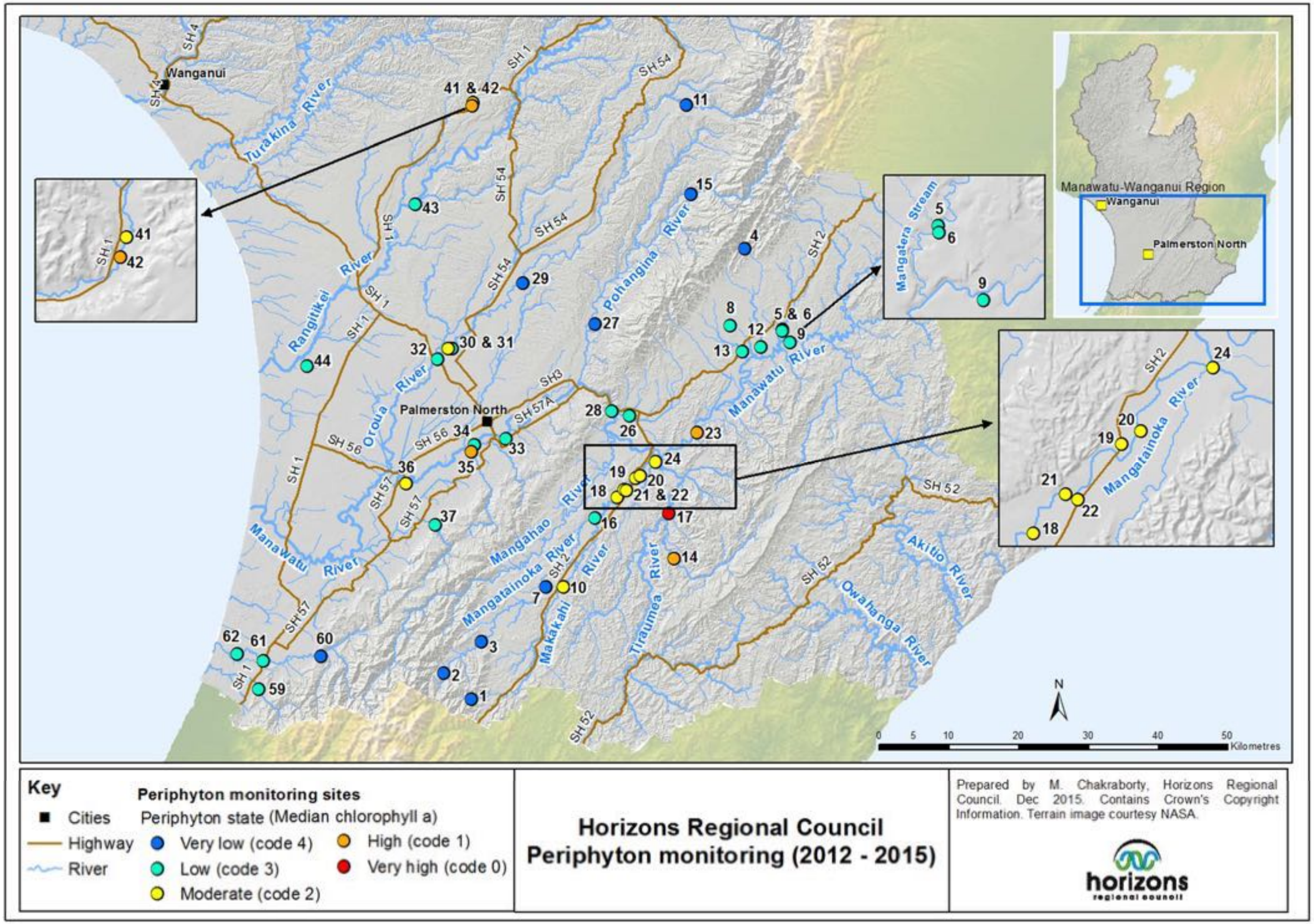
57 & 58
56
54 & 55
39
51
52
53
38
40
0 5 10 20 30 40 50 Kilometres
N
Key
Cities
Highway
River
Periphyton monitoring sites
Periphyton state (Median chlorophyll a)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Vhigh (code 0)
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council. Dec 2015. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons
regional council


Horizons Regional Council
Periphyton monitoring (2012 - 2015)
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Cities
Highway
River
Periphyton monitoring sites
Periphyton state (Median chlorophyll a)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
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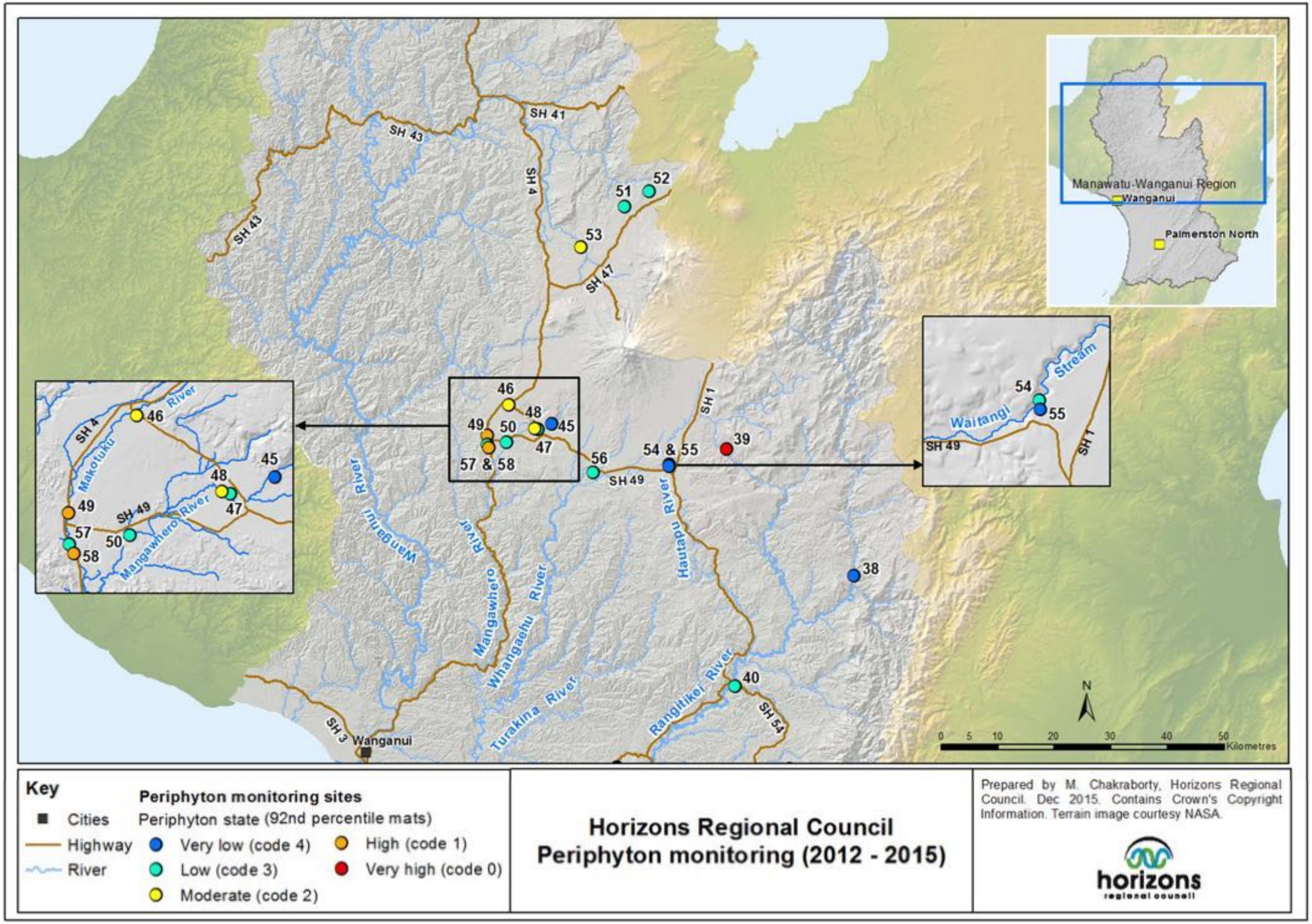
horizons
regional council
Manawatu-Wanganui Region
Wanganui
Palmerston North
Turakina River
Rangitikei River
Oroua River
Pohangina River
Manawatu River
Mangatera Stream
Mangatainoka River
Mangahao River
Makakahi River
Tiraumea River
Akitio River
Owahanga River
Kilometres



SH 41
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57 & 58
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54 & 55
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Waitangi
Stream
54
55
Makotuku
River
Mangawhero River
57
58
Whanganui River
Mangawhero River
Whangaehu River
Hautapu River
Turakina River
Rangitikei River
Wanganui
Manawatu-Wanganui Region
Wanganui
Palmerston North
N
0 5 10 20 30 40 50 Kilometres
Key
Cities
Highway
River
Periphyton monitoring sites
Periphyton state (92nd percentile mats)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
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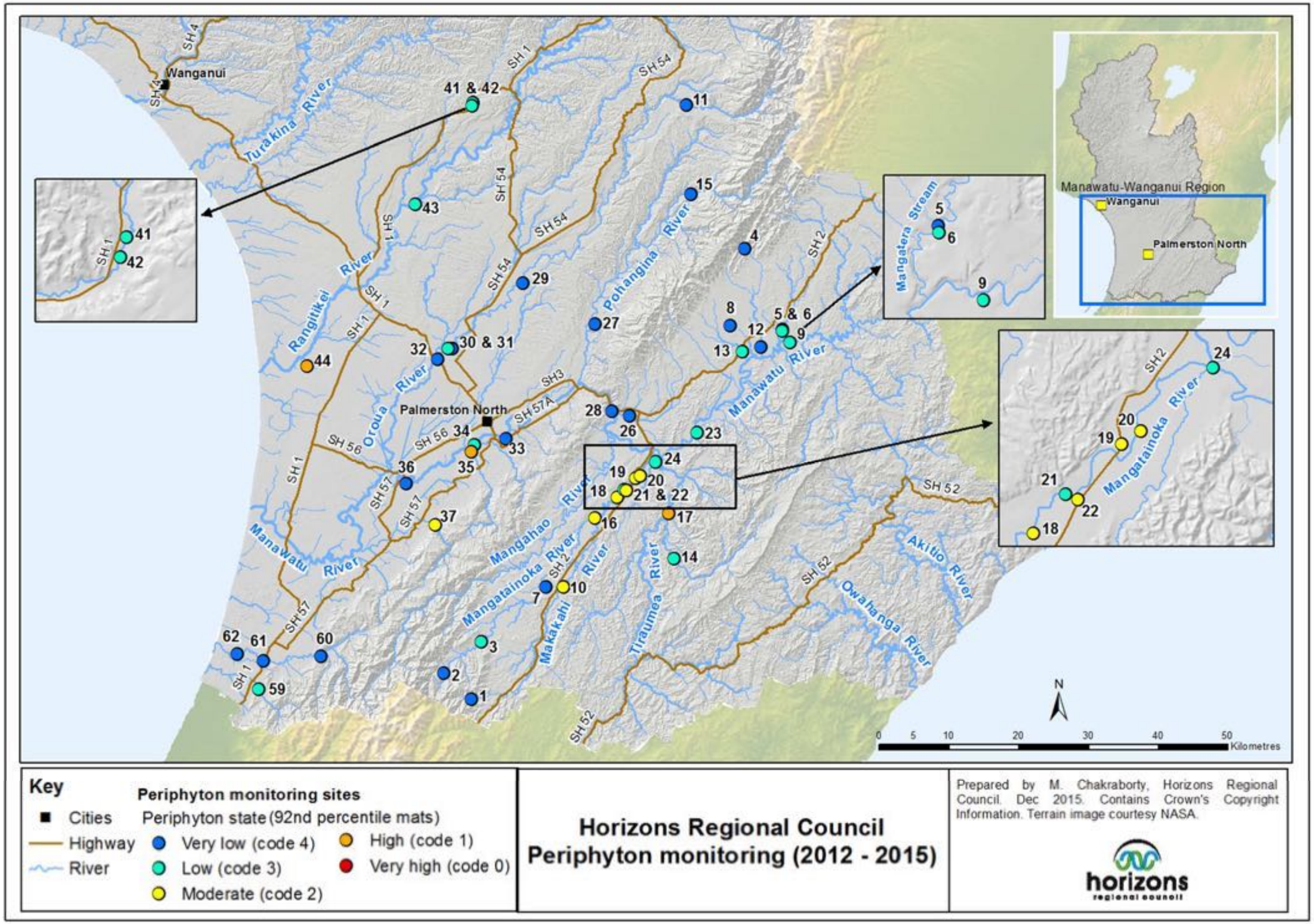
horizons
regional council


Horizons Regional Council
Periphyton monitoring (2012 - 2015)
Key
Cities
Highway
River
Periphyton monitoring sites
Periphyton state (92nd percentile mats)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
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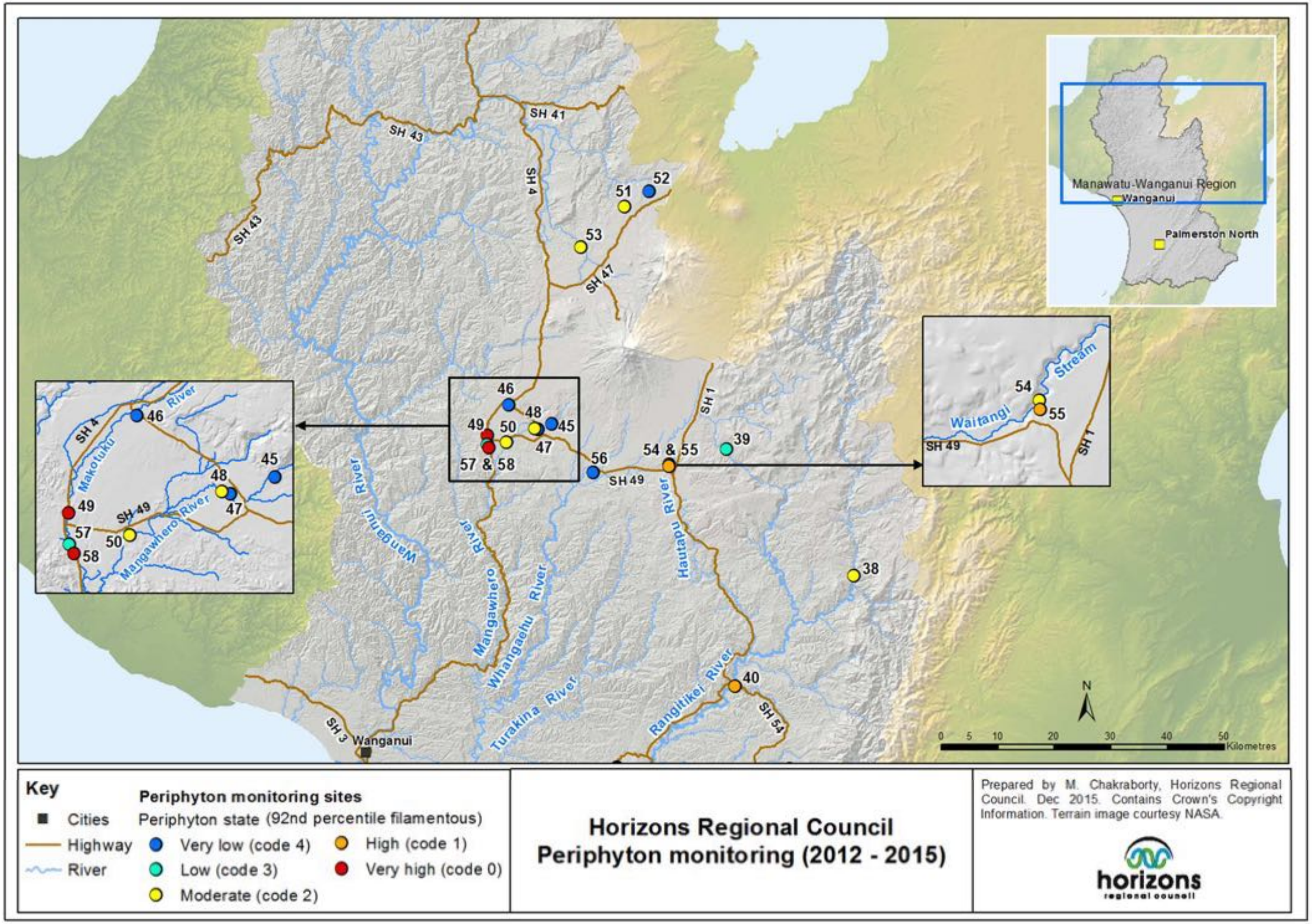
horizons
regional council
Manawatu-Wanganui Region
Wanganui
Palmerston North
Turakina River
Rangitikei River
Oroua River
Pohangina River
Manawatu River
Mangatera Stream
Mangatainoka River
Mangahao River
Makakahi River
Tiraumea River
Akitio River
Owahanga River
SH 1
SH 2
SH 3
SH 4
SH 52
SH 54
SH 56
SH 57
SH 57A
N
0 5 10 20 30 40 50
Kilometres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57 & 58
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Wanganui
Whanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
Makotuku
River
Mangawhero River
Waitangi
Stream
Manawatu-Wanganui Region
Wanganui
Palmerston North
N
0 5 10 20 30 40 50 Kilometres
Key
Cities
Highway
River
Periphyton monitoring sites
Periphyton state (92nd percentile filamentous)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
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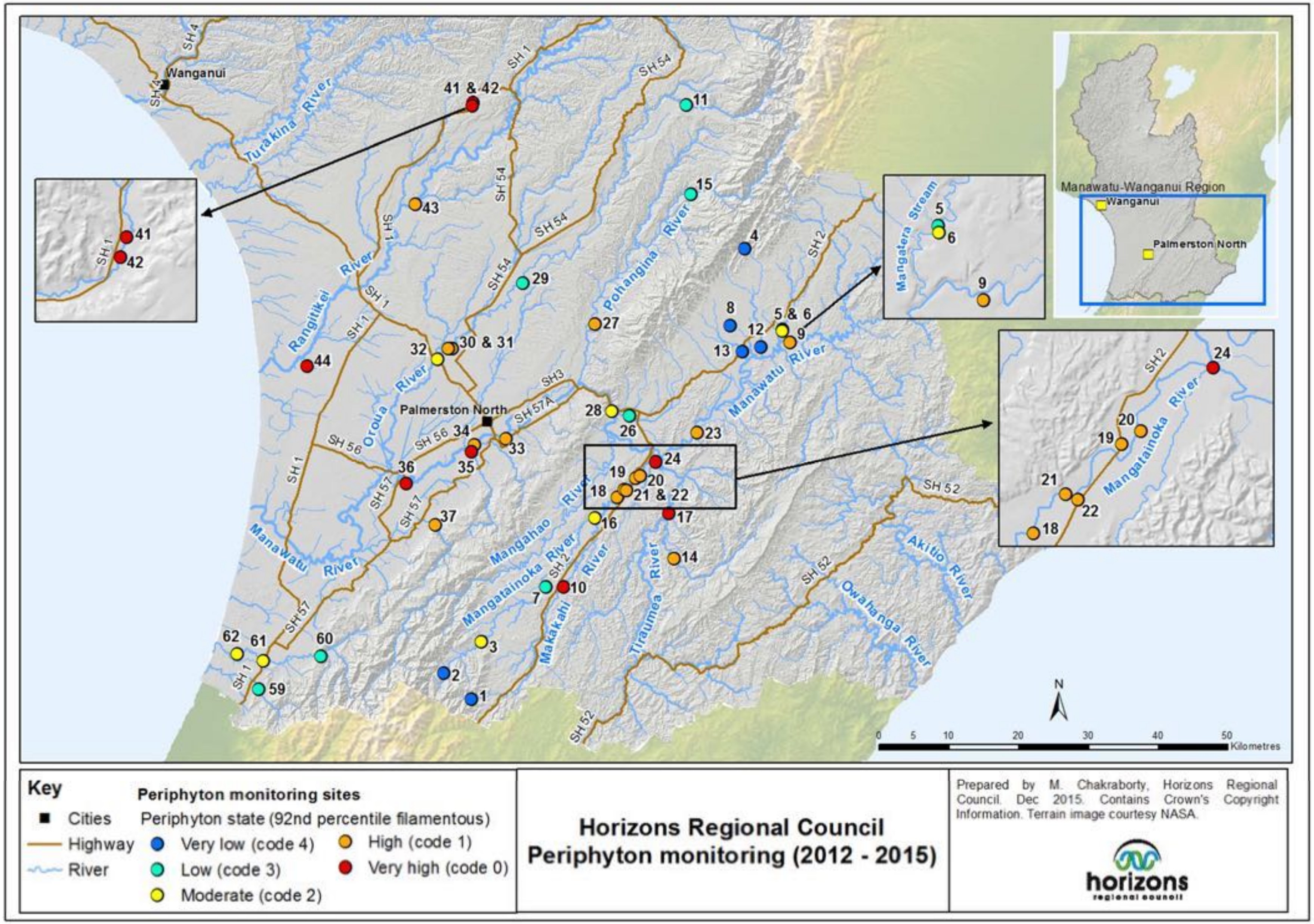
horizons
regional council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Highway
River
Periphyton monitoring sites
Periphyton state (92nd percentile filamentous)
Very low (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
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horizons
regional council
Manawatu-Wanganui Region
Wanganui
Palmerston North
Kilometres
0 5 10 20 30 40 50
N
Turakina River
Rangitikei River
Oroua River
Pohangina River
Manawatu River
Mangatera Stream
Mangatainoka River
Mangahao River
Makakahi River
Tiraumea River
Akitio River
Owahanga River
SH 1
SH 2
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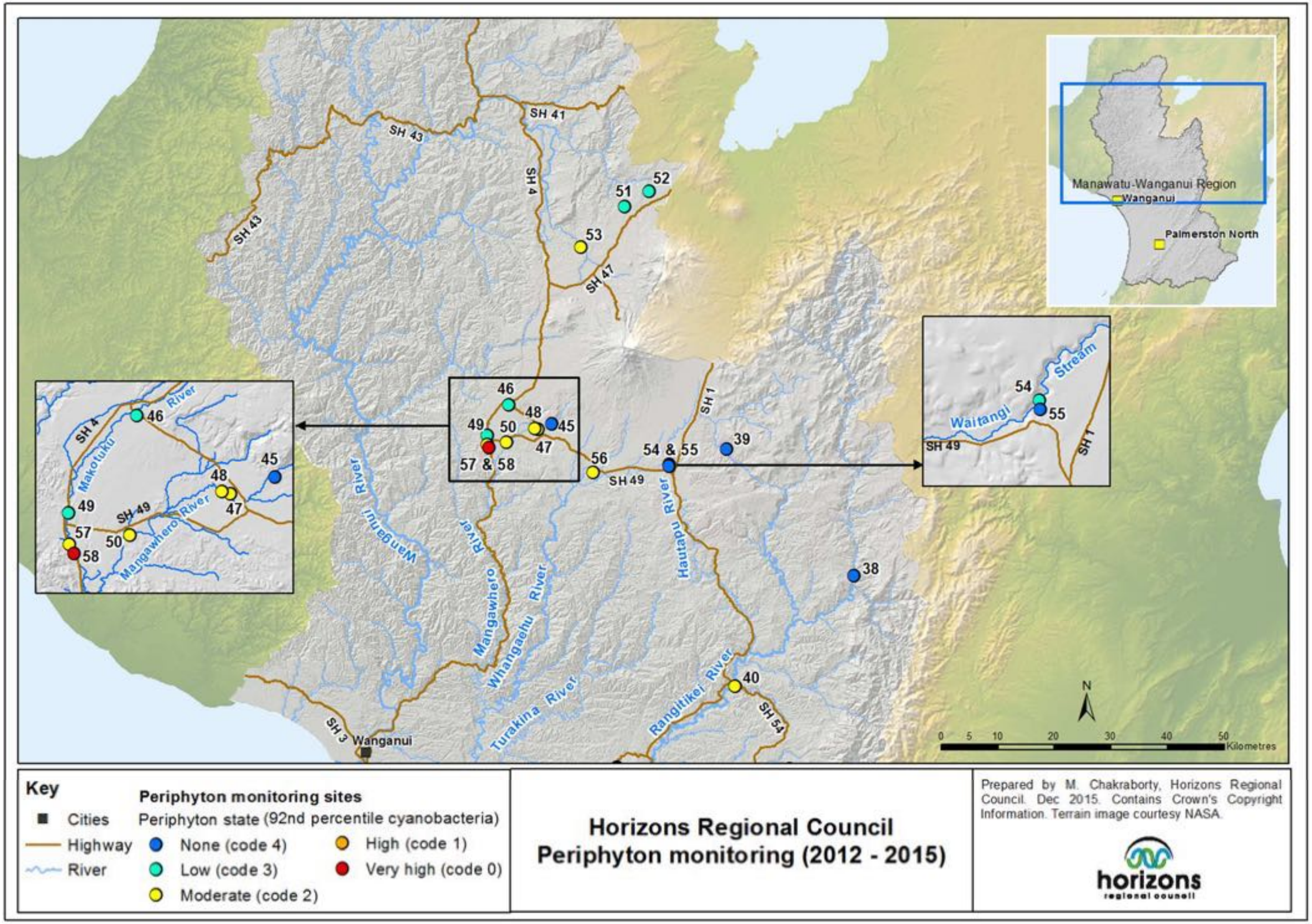
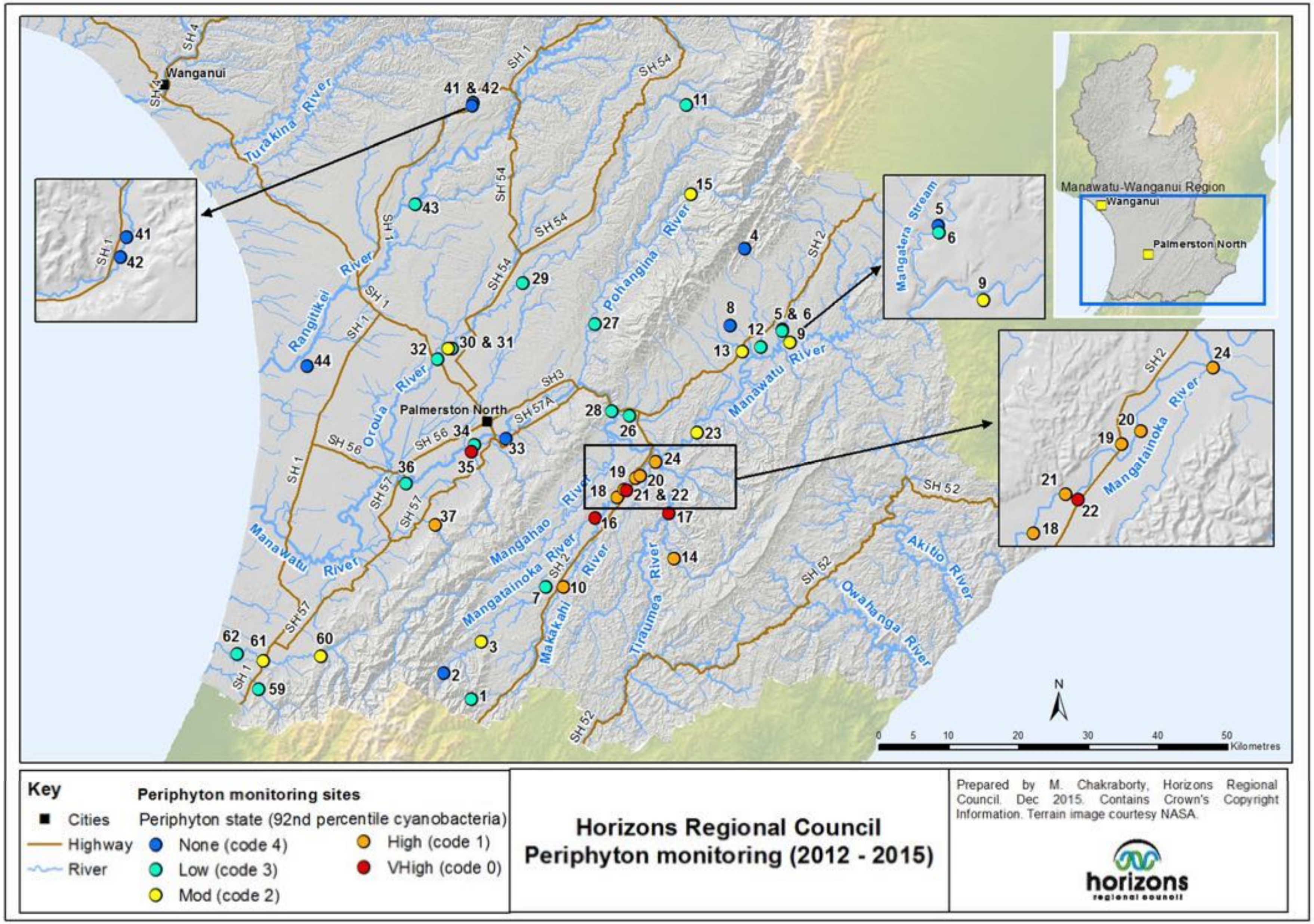
SH 4
SH 52
SH 54
SH 56
SH 57
SH 57A
41 & 42
5 & 6
30 & 31
21 & 22



Key
Cities
Highway
River
Periphyton monitoring sites
Periphyton state (92nd percentile cyanobacteria)
None (code 4)
Low (code 3)
Moderate (code 2)
High (code 1)
Very high (code 0)
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council. Dec 2015. Contains Crown's Copyright Information. Terrain image courtesy NASA.
Manawatu-Wanganui Region
Wanganui
Palmerston North
SH 41
SH 43
SH 4
SH 47
SH 49
SH 1
SH 3
SH 54
Whanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
Makotuku River
Waitangi Stream
Wanganui
Kilometres


Wanganui
Palmerston North
Turakina River
Rangitikei River
Oroua River
Pohangina River
Manawatu River
Mangahao River
Mangatainoka River
Makakahi River
Tiraumea River
Akitio River
Owahanga River
Mangatera Stream
Manawatu-Wanganui Region
Key
Cities
Highway
River
Periphyton monitoring sites
Periphyton state (92nd percentile cyanobacteria)
None (code 4)
Low (code 3)
Mod (code 2)
High (code 1)
VHigh (code 0)
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
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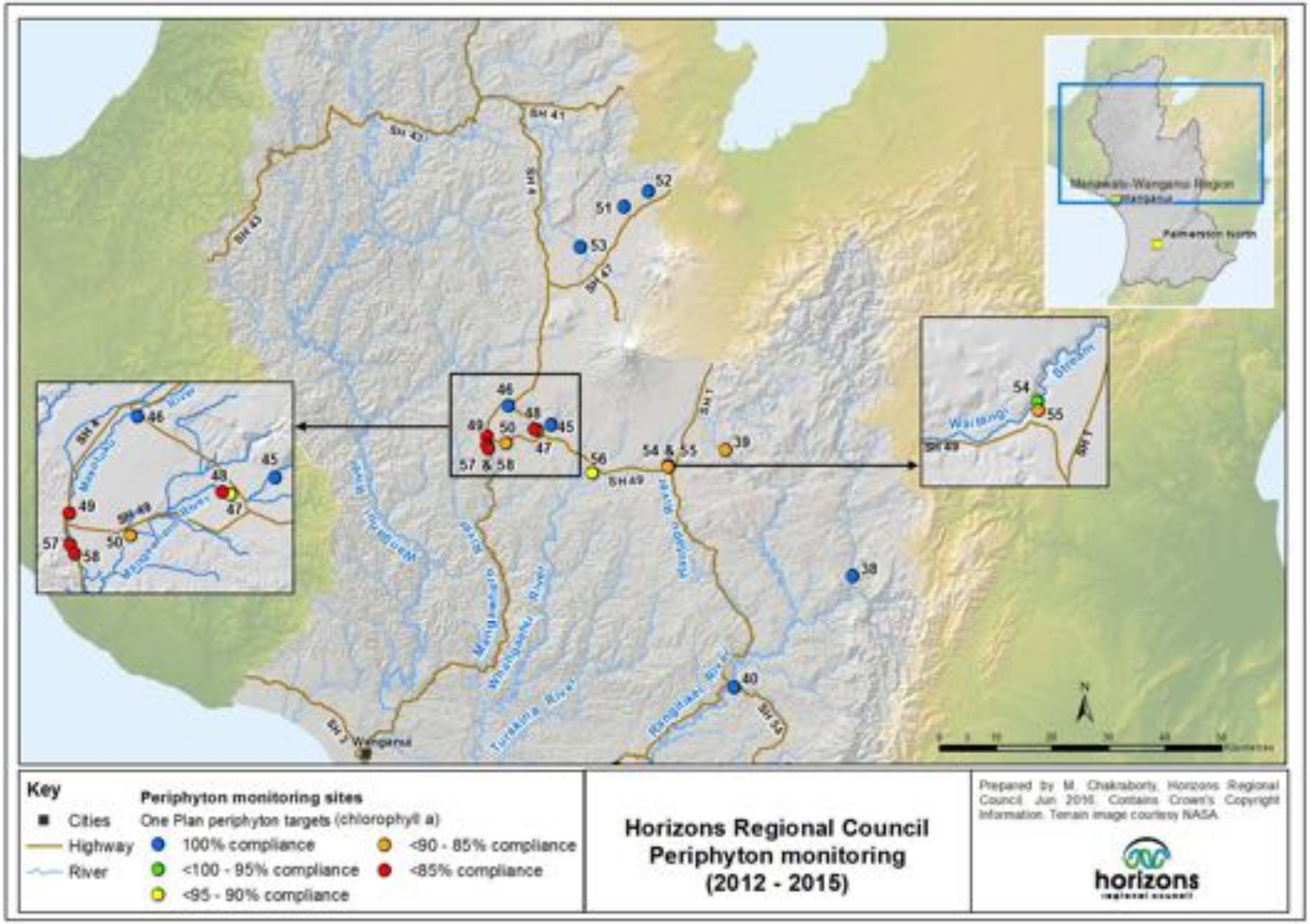
Kilometres


Horizons Regional Council
Periphyton monitoring
(2012 - 2015)
Key
Cities
Highway
River
Periphyton monitoring sites
One Plan periphyton targets (chlorophyll a)
100% compliance
<100 - 95% compliance
<95 - 90% compliance
<90 - 85% compliance
<85% compliance
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horizons
SH 41
SH 43
SH 47
SH 49
Whanganui River
Manganui o te Ao River
Mangawhero River
Whangaehu River
Turakina River
Rangitikei River
Waitangi Stream
Wanganui
Manawatu-Wanganui Region
Palmerston North
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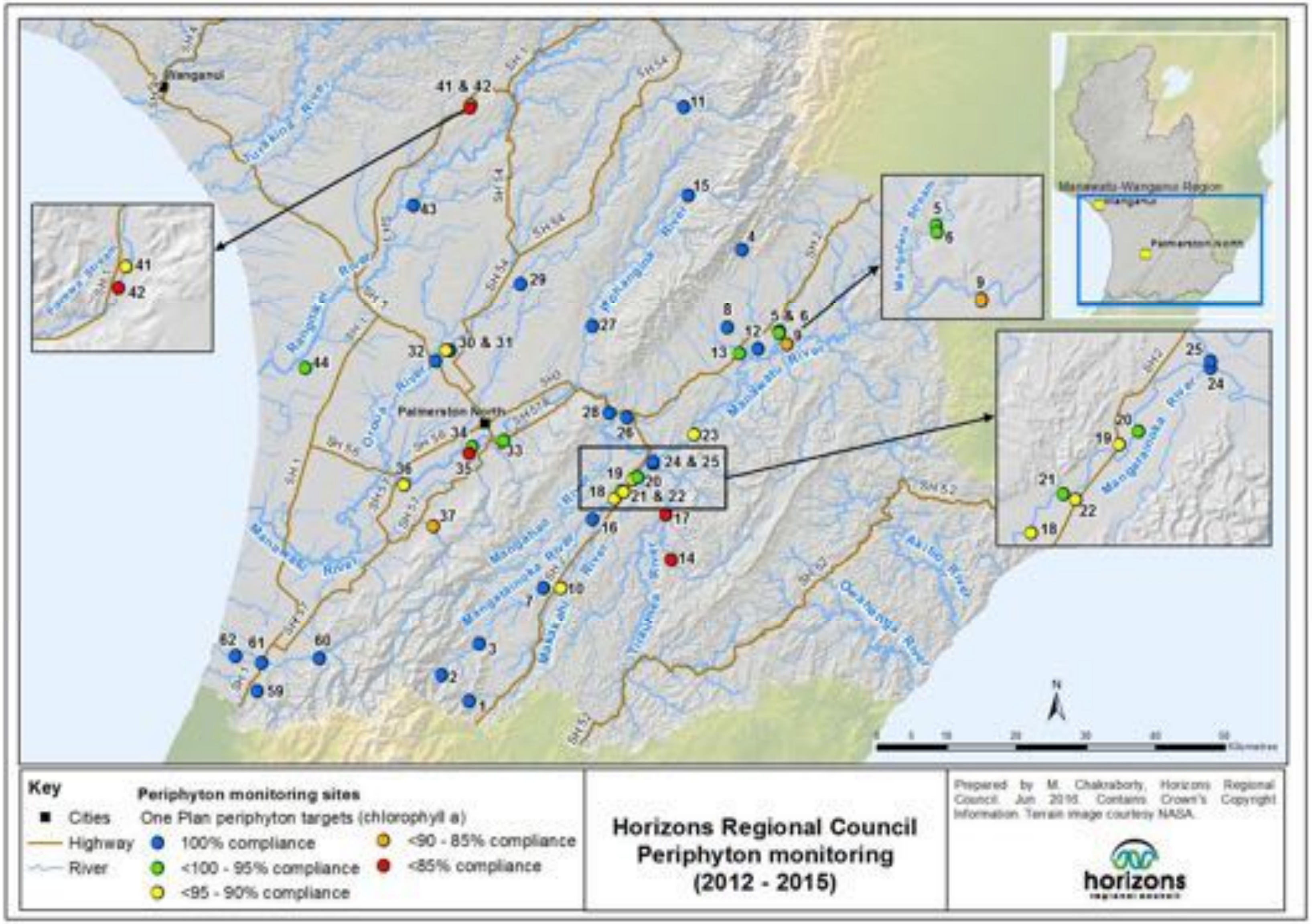
Key
Cities
Highway
River
Periphyton monitoring sites
One Plan periphyton targets (chlorophyll a)
100% compliance
<100 - 95% compliance
<95 - 90% compliance
<90 - 85% compliance
<85% compliance
Horizons Regional Council
Periphyton monitoring
(2012 - 2015)
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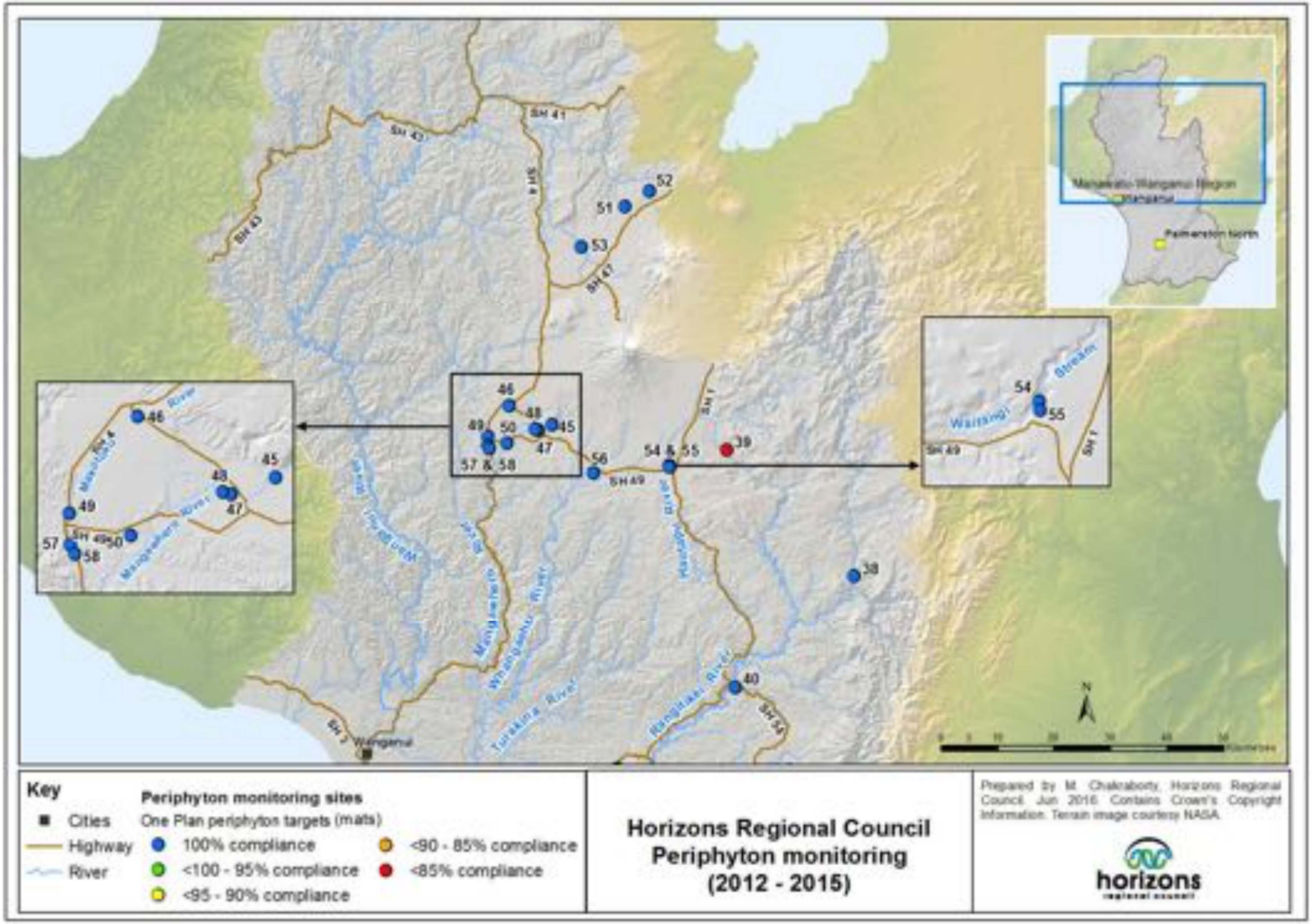
horizons
Palmerston North
Manawatu-Wanganui Region
Manawatu River
Mangatainoka River
Makakahi River
Tiraumea River
Akitio River
Owahanga River
Pohangina River
Rangitikei River
Turakina River
Oroua River
Mangahao River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Highway
River
Periphyton monitoring sites
One Plan periphyton targets (mats)
100% compliance
<100 - 95% compliance
<95 - 90% compliance
<90 - 85% compliance
<85% compliance
Horizons Regional Council
Periphyton monitoring
(2012 - 2015)
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horizons
Manawatu-Wanganui Region
Wanganui
Palmerston North
Whanganui River
Manganui River
Turakina River
Rangitikei River
Hautapu River
Waitangi Stream
Manganuiatera River
Wanganui
SH 1
SH 2
SH 3
SH 4
SH 41
SH 43
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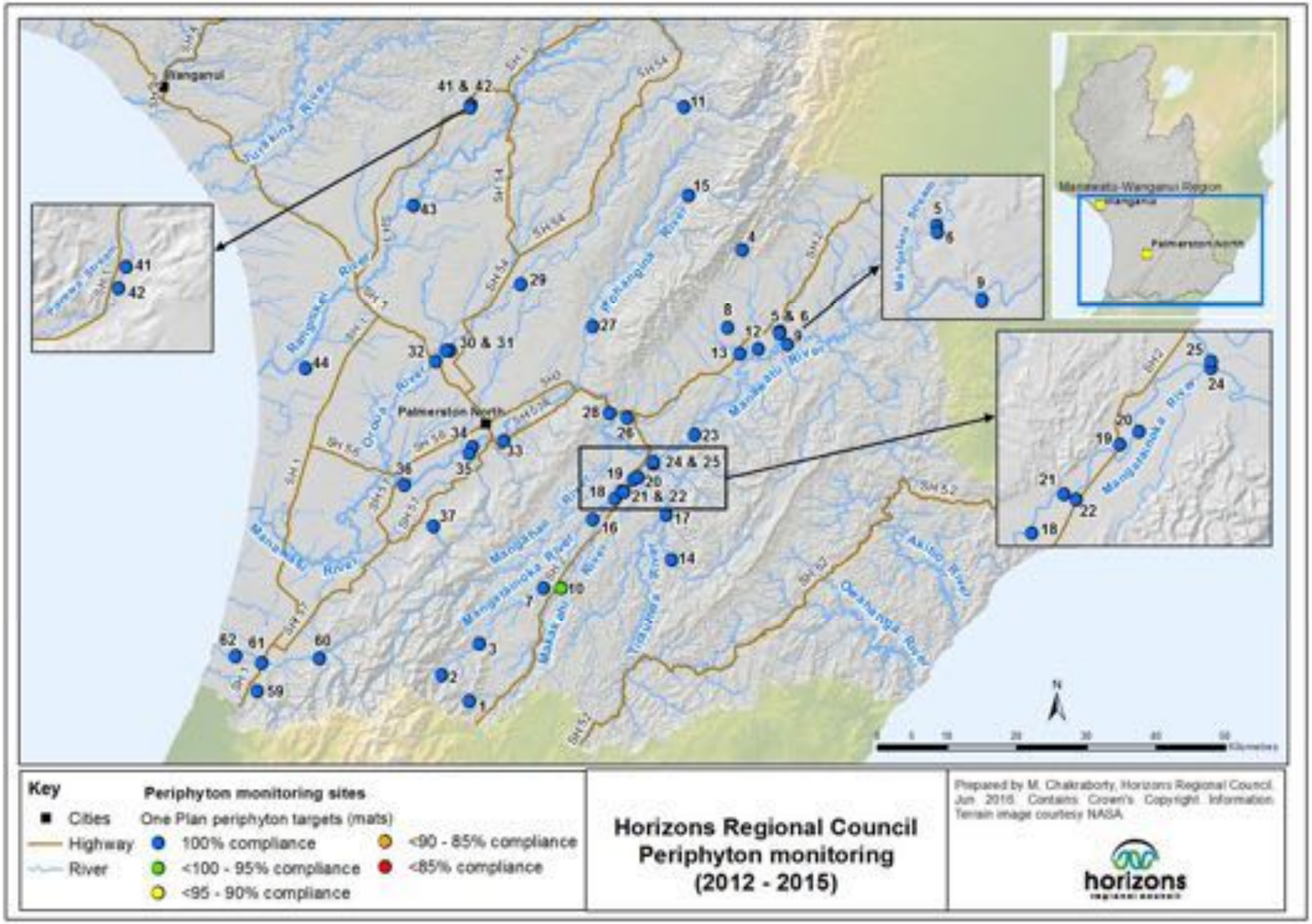
Key
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Highway
River
Periphyton monitoring sites
One Plan periphyton targets (mats)
100% compliance
<100 - 95% compliance
<95 - 90% compliance
<90 - 85% compliance
<85% compliance
Horizons Regional Council
Periphyton monitoring
(2012 - 2015)
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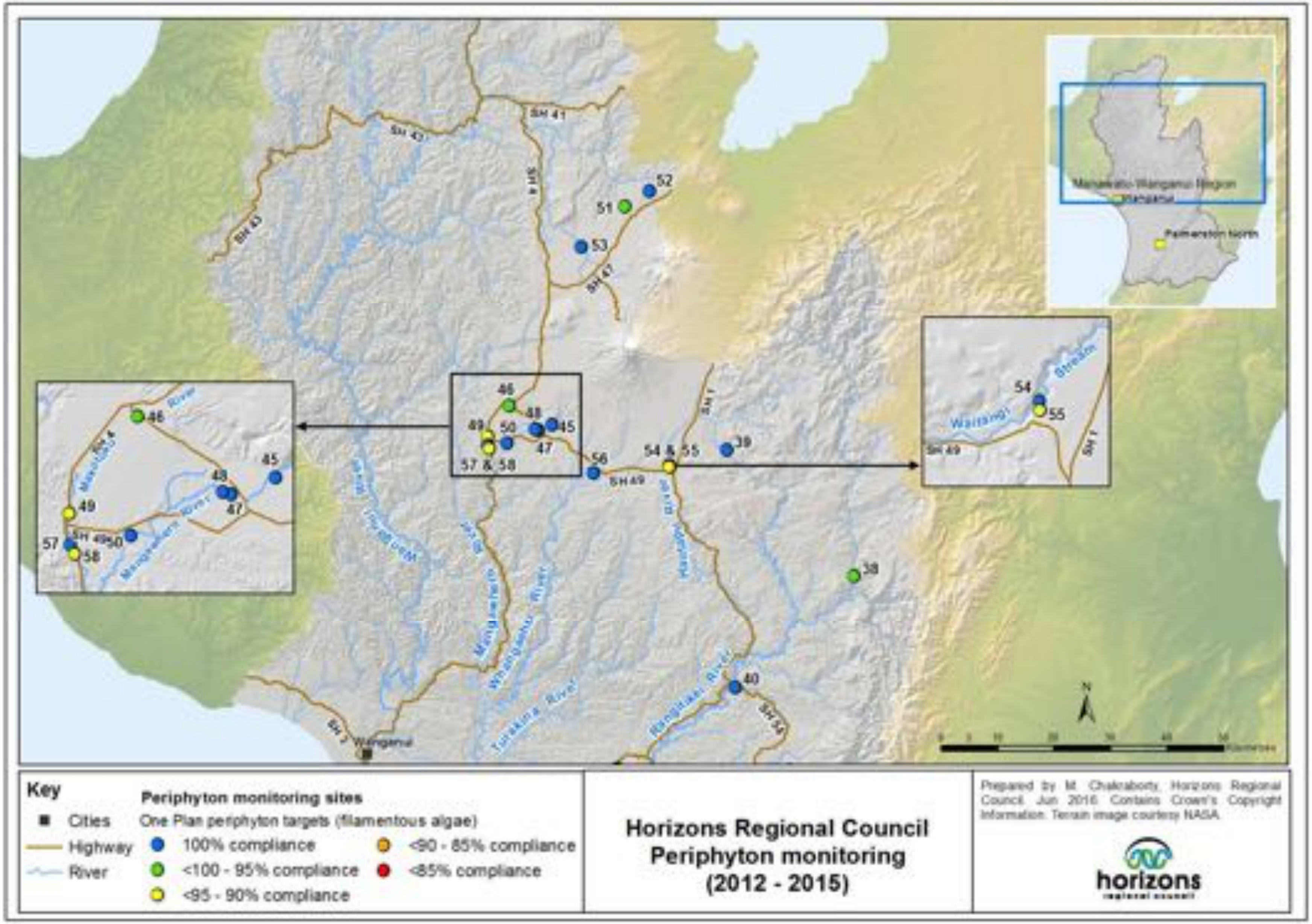
horizons
Palmerston North
Wanganui
Manawatu-Wanganui Region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Highway
River
Periphyton monitoring sites
One Plan periphyton targets (filamentous algae)
100% compliance
<100 - 95% compliance
<95 - 90% compliance
<90 - 85% compliance
<85% compliance
Horizons Regional Council
Periphyton monitoring
(2012 - 2015)
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horizons
regional council
Wanganui
Palmerston North
Manawatu-Wanganui Region
Whanganui River
Manganui o te Ao River
Mangawhero River
Turakina River
Rangitikei River
Hautapu River
Waitangi Stream
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57 & 58
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SH 1
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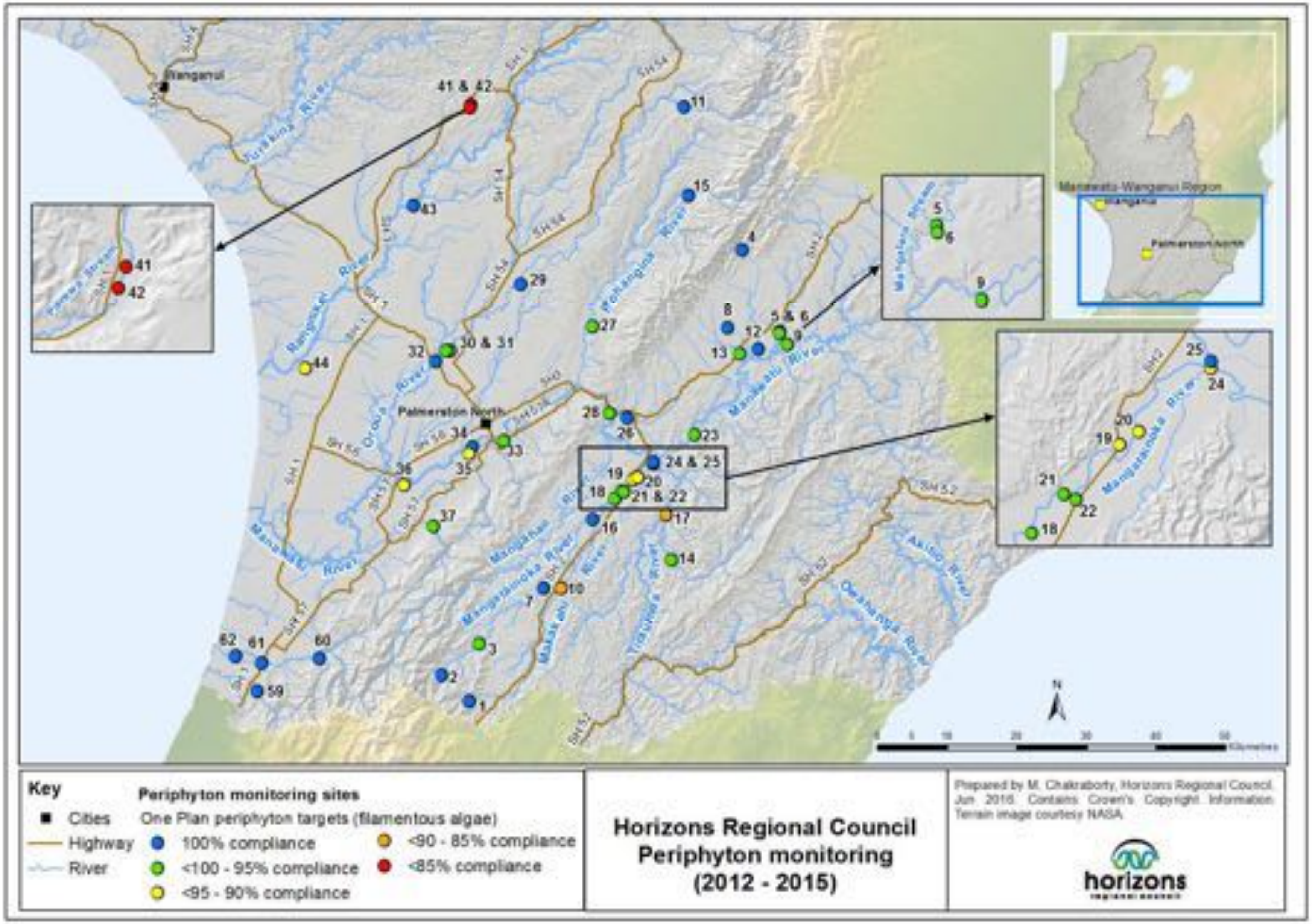
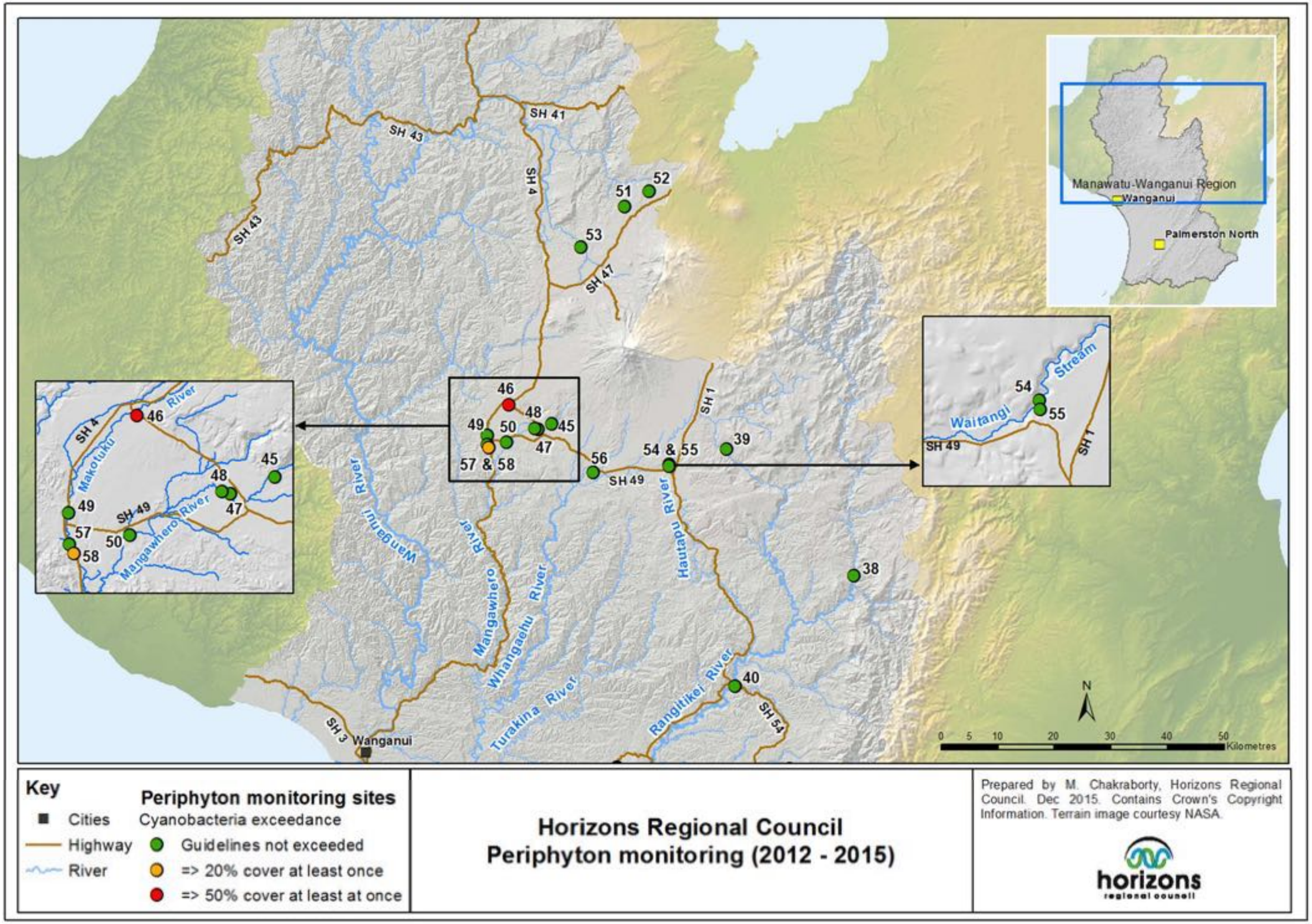
SH 47
SH 49
SH 54


Key
Periphyton monitoring sites
Cities
Highway
River
One Plan periphyton targets (filamentous algae)
100% compliance
<100 - 95% compliance
<95 - 90% compliance
<90 - 85% compliance
<85% compliance
Horizons Regional Council
Periphyton monitoring
(2012 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council. Jun 2016. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons
Palmerston North
Manawatu River
Pohangina River
Mangatainoka River
Manawatu-Wanganui Region



SH 41
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57 & 58
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SH 49
54 & 55
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SH 1
38
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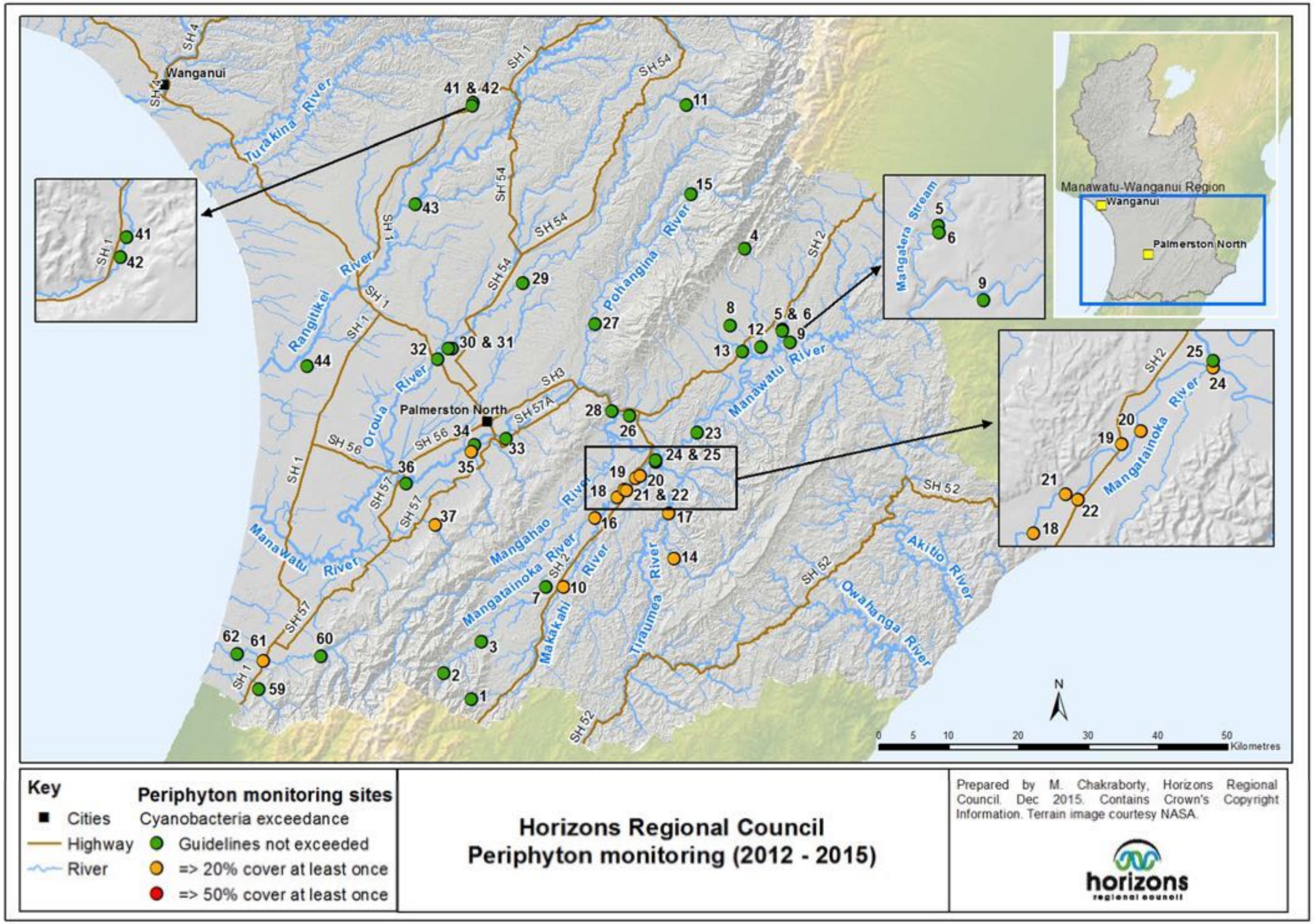
SH 54
SH 3
Wanganui
Wanganui River
Mangawhero River
Whangaehu River
Turakina River
Hautapu River
Rangitikei River
Makotuku
River
Mangawhero River
Waitangi
Stream
Manawatu-Wanganui Region
Palmerston North
N
0 5 10 20 30 40 50 Kilometres
Key
Cities
Highway
River
Periphyton monitoring sites
Cyanobacteria exceedance
Guidelines not exceeded
=> 20% cover at least once
=> 50% cover at least at once
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council. Dec 2015. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons
regional council

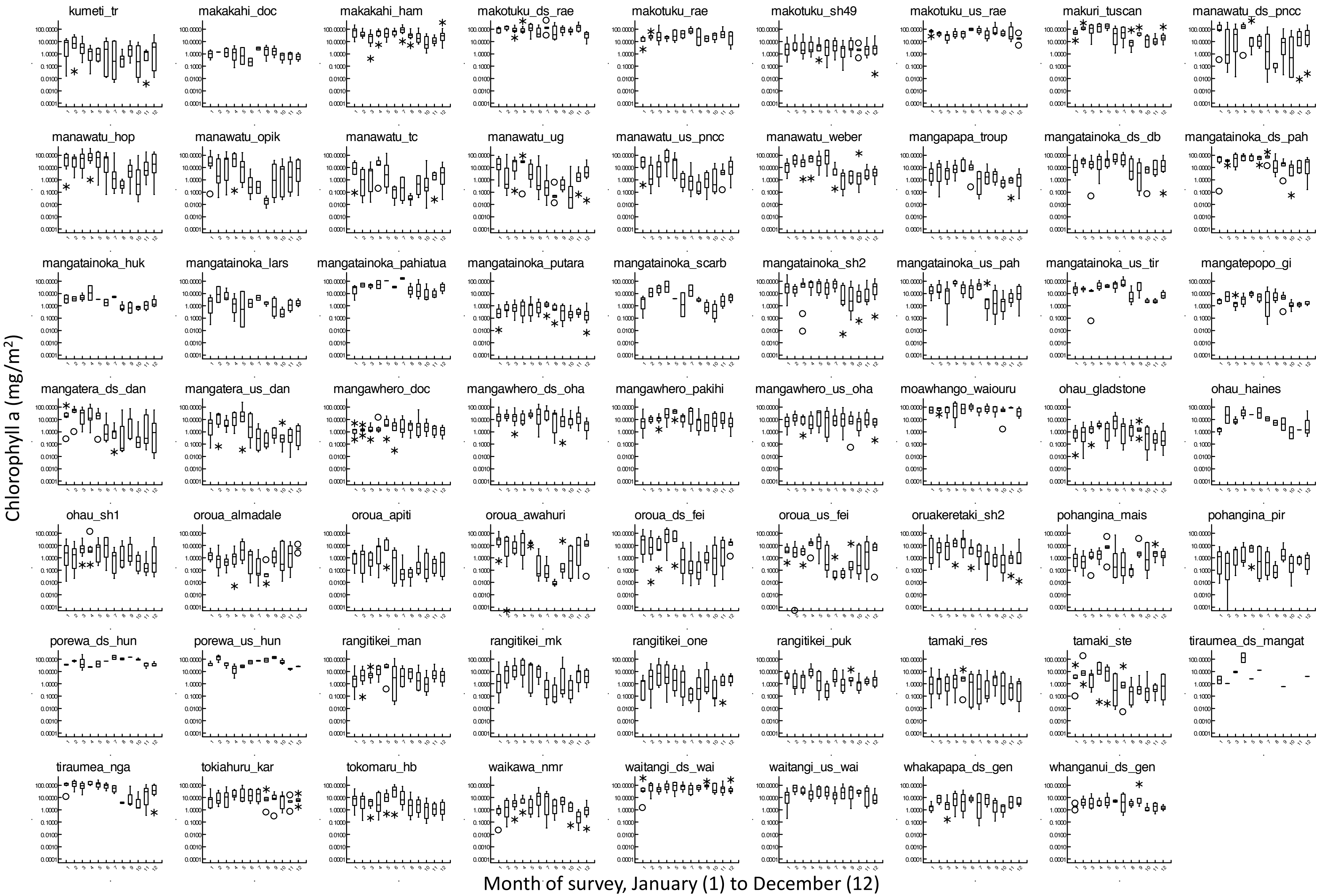

Wanganui
Palmerston North
SH 1
SH 2
SH 3
SH 4
SH 52
SH 54
SH 56
SH 57
SH 57A
Turakina River
Rangitikei River
Oroua River
Pohangina River
Manawatu River
Mangahao River
Mangatainoka River
Makakahi River
Tiraumea River
Akitio River
Owahanga River
Mangatera Stream
Manawatu-Wanganui Region
41 & 42
5 & 6
24 & 25
30 & 31
21 & 22
Kilometres
Key
Cities
Highway
River
Periphyton monitoring sites
Cyanobacteria exceedance
Guidelines not exceeded
=> 20% cover at least once
=> 50% cover at least once
Horizons Regional Council
Periphyton monitoring (2012 - 2015)
Prepared by M. Chakraborty, Horizons Regional Council. Dec 2015. Contains Crown's Copyright Information. Terrain image courtesy NASA.
horizons
regional council

Appendix C Box plots of chlorophyll *a*, % cover by mats, % cover by filaments, DIN and DRP at each site, by month

In the series of box plots on the next five pages, sites are ordered alphabetically. All available data were used for each site, plotted against month of sample collection. Data have been transformed to enable the seasonal patterns to be seen more clearly.

In each plot, the length of each box shows the range within which the central 50% of the values fall, with the box edges (called hinges) at the first and third quartiles. The whiskers show data within 1.5 times of the central 50% range (plus or minus), and the asterisks show data within 1.5 to 3 times the central 50%. Values more than 3 times the central range are shown by circles.

In most plots, each monthly box plot is derived from 6 or 7 values.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oroua_awahuri
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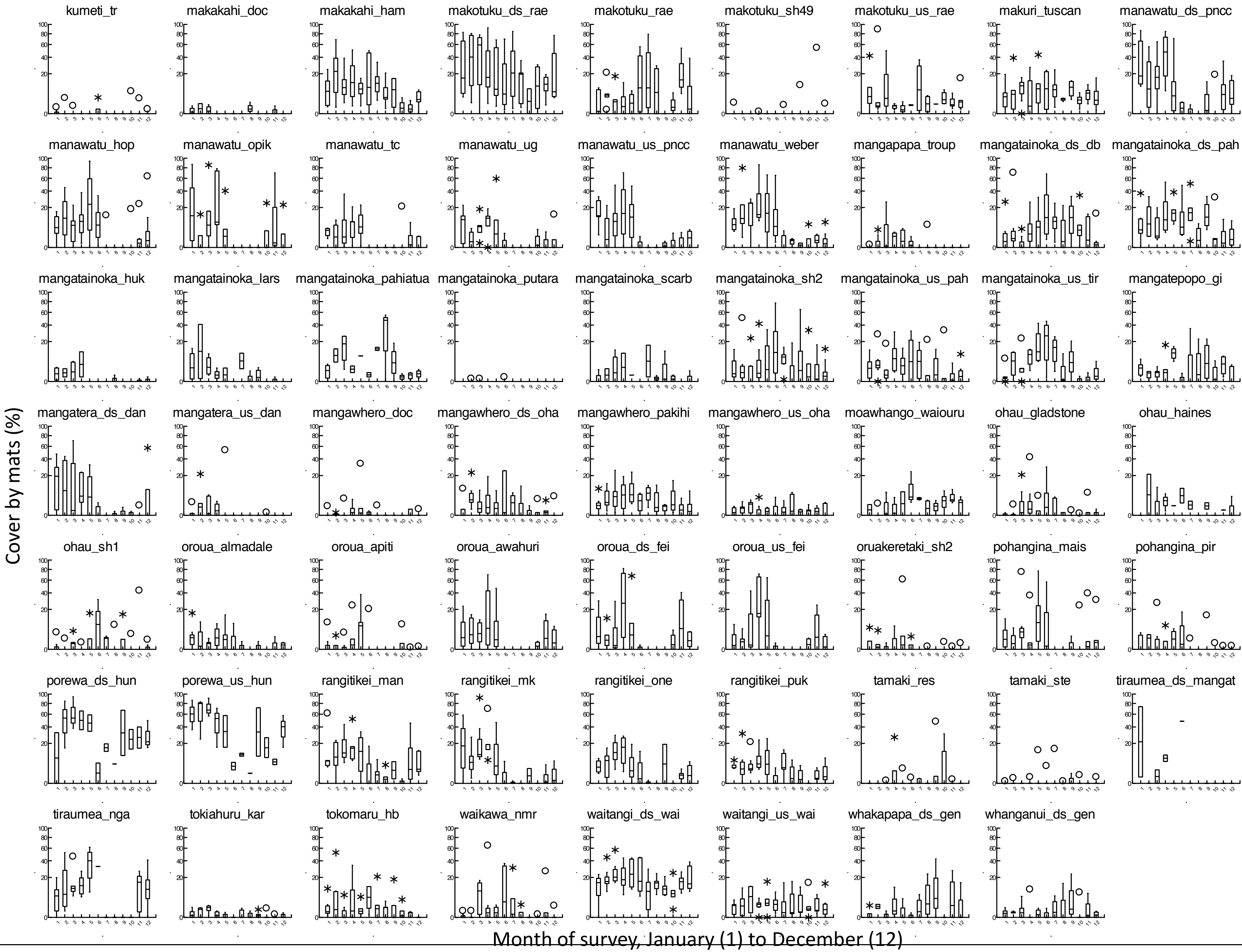
rangitikei_one
rangitikei_puk
tamaki_res
tamaki_ste
tiraumea_ds_mangat
tiraumea_nga
tokiahuru_kar
tokomaru_hb
waikawa_nmr
waitangi_ds_wai
waitangi_us_wai
whakapapa_ds_gen
whanganui_ds_gen
Chlorophyll a (mg/m^2)
Month of survey, January (1) to December (12)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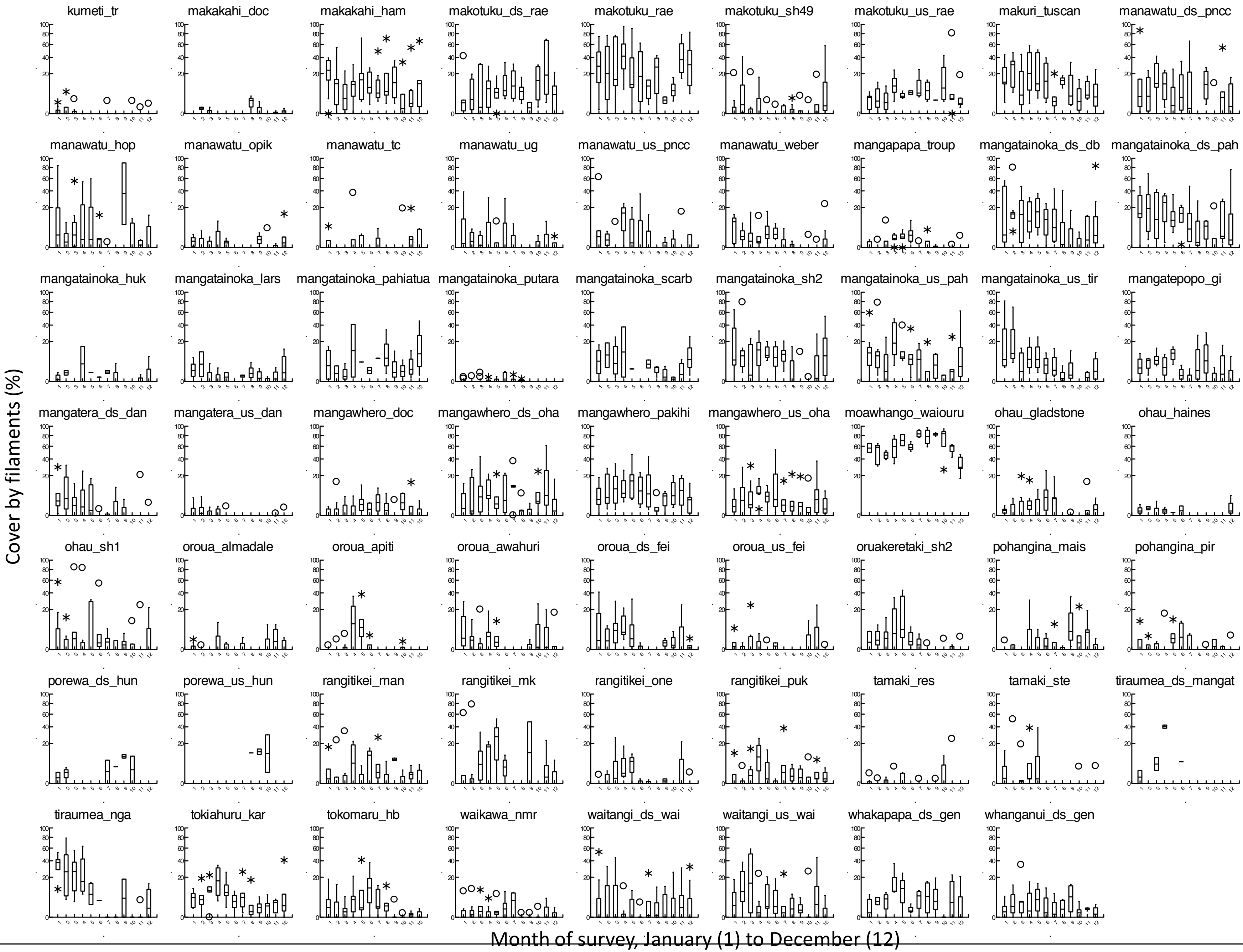
Cover by mats (%)
Month of survey, January (1) to December (12)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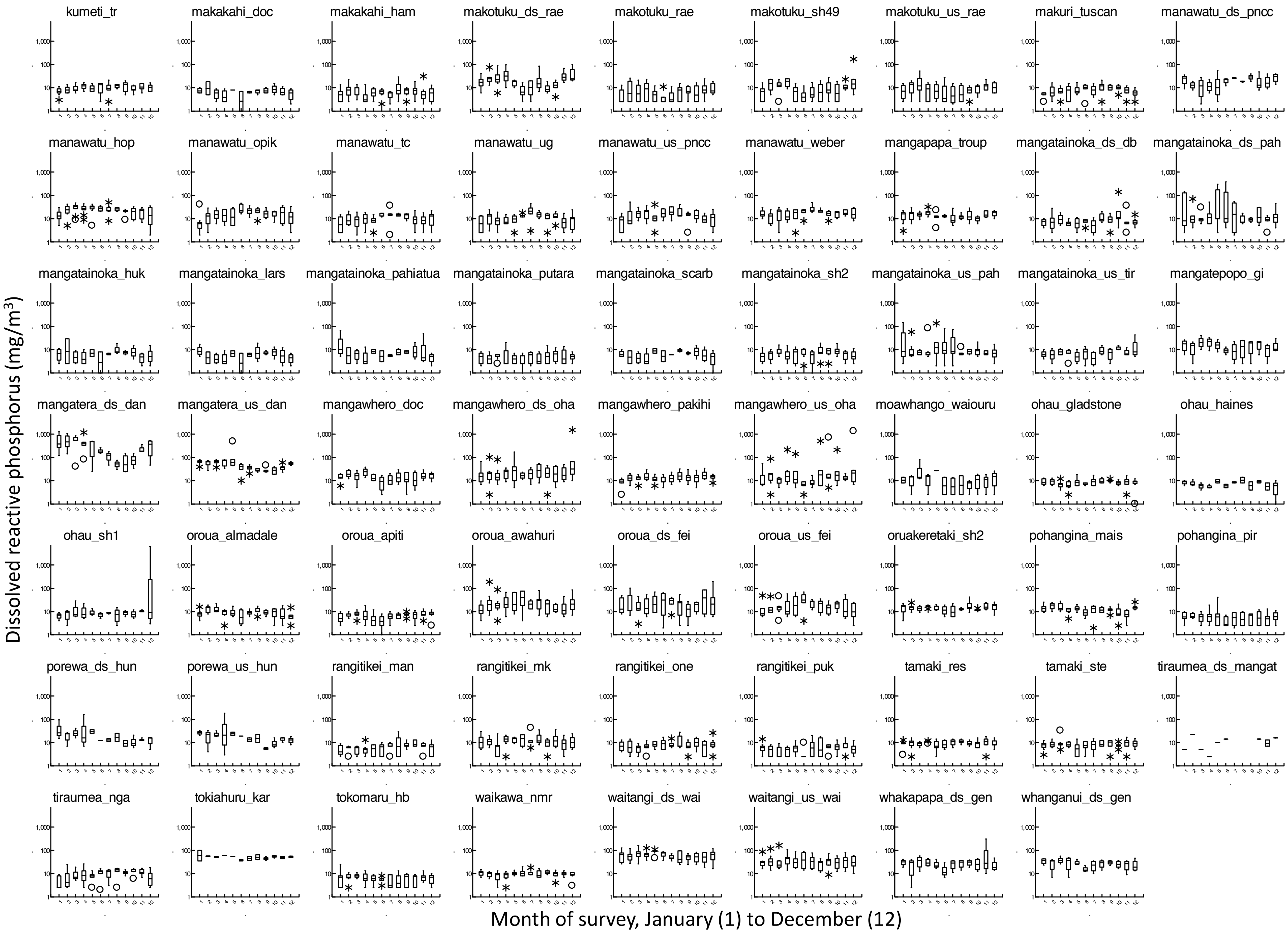
whanganui_ds_gen
Cover by filaments (%)
Month of survey, January (1) to December (12)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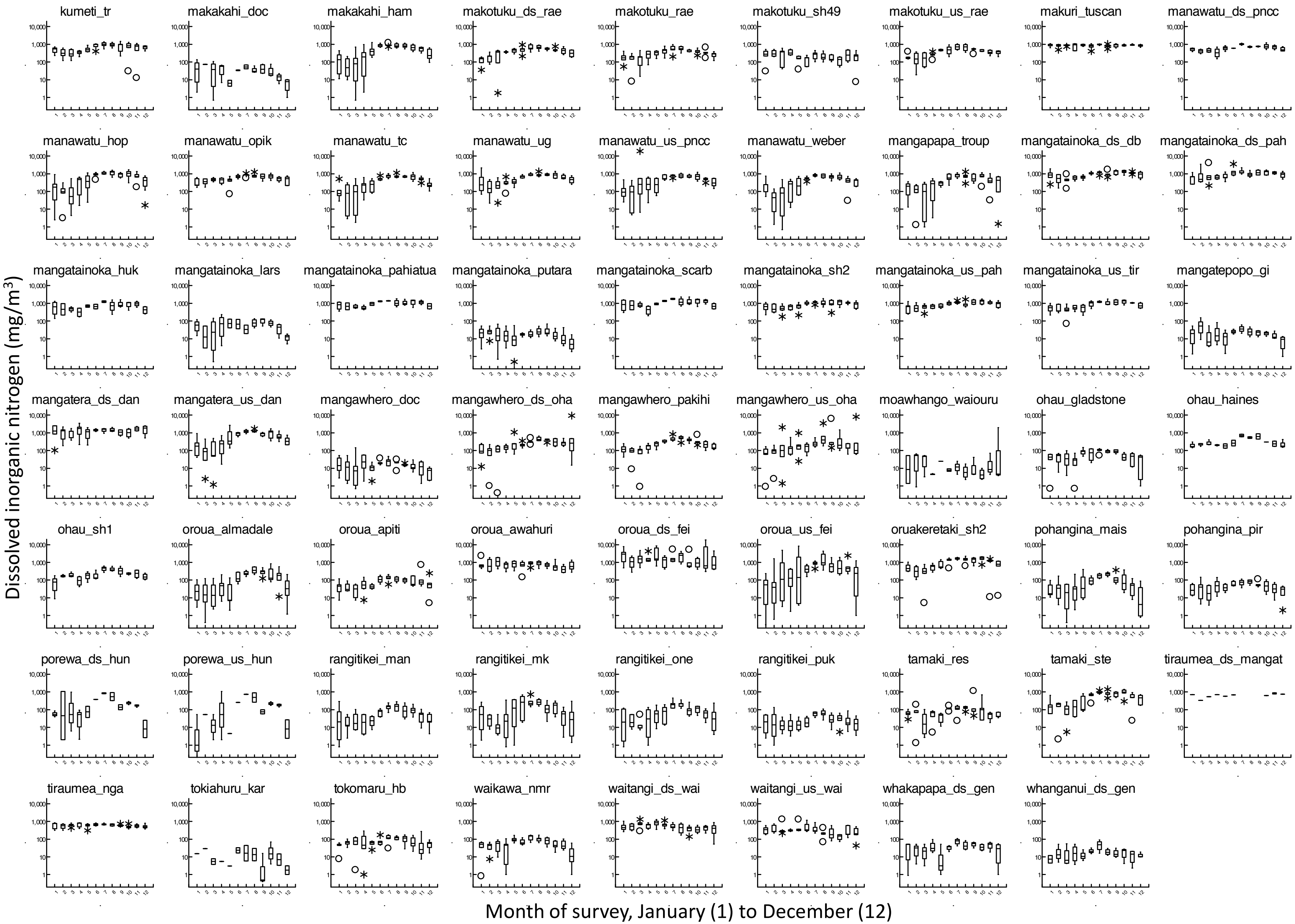
whanganui_ds_gen
Dissolved reactive phosphorus (mg/m³)
Month of survey, January (1) to December (12)



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Dissolved inorganic nitrogen (mg/m³)
Month of survey, January (1) to December (12)

horizons