Trends in nuisance periphyton cover at New Zealand National River Water Quality Network sites 1990-2006

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Executive Summary

Periphyton cover has been assessed at 73 of the 77 National River Water Quality Network (NRWQN) sites during monthly site visits since autumn 1989. Periphyton is evaluated visually as percentage cover of a standard wadeable area by mats or filamentous algae. The NRWQN sites include those classed as baseline (minimally impacted by human activities in their catchments) and impact, often with paired baseline and impact sites along single rivers. The report addresses three questions in relation to the NRWQN sites for the period 1990-2006: (i) Does periphyton exceed Ministry for the Environment (MfE) guidelines for nuisance effects on aesthetic and recreational values? (ii) Do human pressures influence the periphyton levels in and along the NRWQN rivers? (iii) Is the situation getting better or worse?

The mean monthly riverbed cover of periphyton between 1990 and 2006 across all 73 sites was 4.9% for mats, 5.6% for filamentous growth, and 10.6% for total (filamentous + mat) cover. The mean annual maximum periphyton covers were 19.6% (range 0 – 56.7%) for mats, 20.4% (range 0.1 to 68.6%) for filamentous growths, and 33.5% for total periphyton (range 0 – 80.4%). Periphyton cover was sufficiently high to impact on river recreation and aesthetic values (as indicated by exceedence of MfE guideline values) at about a quarter of the NRWQN sites at some time during an average year between 1990-2006. This suggests that nuisance periphyton may be a fairly widespread problem in New Zealand rivers, although direct extrapolation of the NRWQN findings to all New Zealand rivers is not possible because the NRWQN sites were not selected randomly and are biased towards larger than average rivers.

Both annual mean and annual maximum total covers were significantly higher at impact than baseline sites. Moreover, 28% of impact sites had mean annual maximum filamentous cover over the threshold for aesthetic nuisance effects, compared with 6% of baseline sites, and downstream sites typically had higher periphyton cover than paired upstream sites along the same river. Mean filamentous periphyton cover was also strongly positively correlated with percentage pastoral land cover in the catchment. Together these findings indicate that human activities in catchments have increased the occurrence of nuisance periphyton in the NRWQN rivers.

Analysis of trends in annual mean and annual maximum periphyton cover during 1990-2006 found more sites with decreasing cover than increasing cover. This encouraging finding was not expected given the increasing agricultural intensification and associated increase in nutrient inputs and instream concentrations over this period. Some of the trends of declining cover may be associated with improvements in point source effluent management (e.g., Mataura and Manawatu Rivers), but it appears that other factors may also be influencing periphyton cover at NRWQN sites.

1. Introduction

Periphyton is algae that grows on the beds of streams and lakes. It plays a key role in streams by turning dissolved nutrients into nutritious food (i.e., periphyton biomass) for invertebrates, which are themselves food for fish and birds. However, there can be too much of a good thing. Periphyton blooms, as long filamentous growths or thick mats (Fig. 1) that cover much of the streambed, can make the stream unattractive for swimming and useless for angling, clog up water intakes, and reduce biodiversity by making the streambed habitat unsuitable for many sensitive invertebrate species (Biggs 2000). The Ministry for the Environment's (MfE) guidelines for threshold periphyton cover levels to protect against aesthetic and recreational nuisances in streams and rivers are <30% of the visible bed for filamentous algae and <60% for mats (Biggs 2000). Cyanobacteria (commonly called "blue-green algae") can cause off-flavours in water and fish flesh, foul-odours when they dry on stream margins, and may produce toxins (Biggs 2000).

Figure 1: Periphyton cover as filamentous green algae (left, photo J Quinn) and a thick diatom mat (right, photo from Biggs 1990).

Periphyton growth is controlled by sunlight reaching the streambed, time since the last scouring flow, streambed stability, current velocity, nutrients (mainly nitrogen and phosphorus), temperature and grazing by invertebrates (Biggs 2000). Healthy streams typically have little obvious periphyton, because growth is cropped by invertebrate grazers and turned into invertebrate biomass. Nuisance blooms are usually a symptom of a system stressed by factors like over-supply of nutrients and high temperatures (that increase algal growth rates and stress some invertebrate grazers). Therefore periphyton abundance can also be used as a measure of river health.

Periphyton monitoring in the National River Water Quality Network (NRWQN) was designed to answer the question: are periphyton growths that may cause an aesthetic nuisance becoming more frequent and/or worse over time? (Smith et al. 1989). In this report, we focus on changes associated with land use and effluent discharge pressures and have excluded the effects of the stalked diatom bioinvader *Didymosphenia geminata* (commonly known as didymo) that appeared in the South Island late in the monitoring period (see Methods section for details). Periphyton was evaluated visually as cover by filamentous algae and mats (>2 mm thick, to distinguish from thin biofilms[1]) during monthly site visits whenever flow conditions allowed safe wading. Observations at 73 of the 77 NRWQN sites (Fig. 2) commenced in March – April 1989, and this report provides an analysis of these data collected for the seventeen-year period starting January 1990 and ending December 2006.

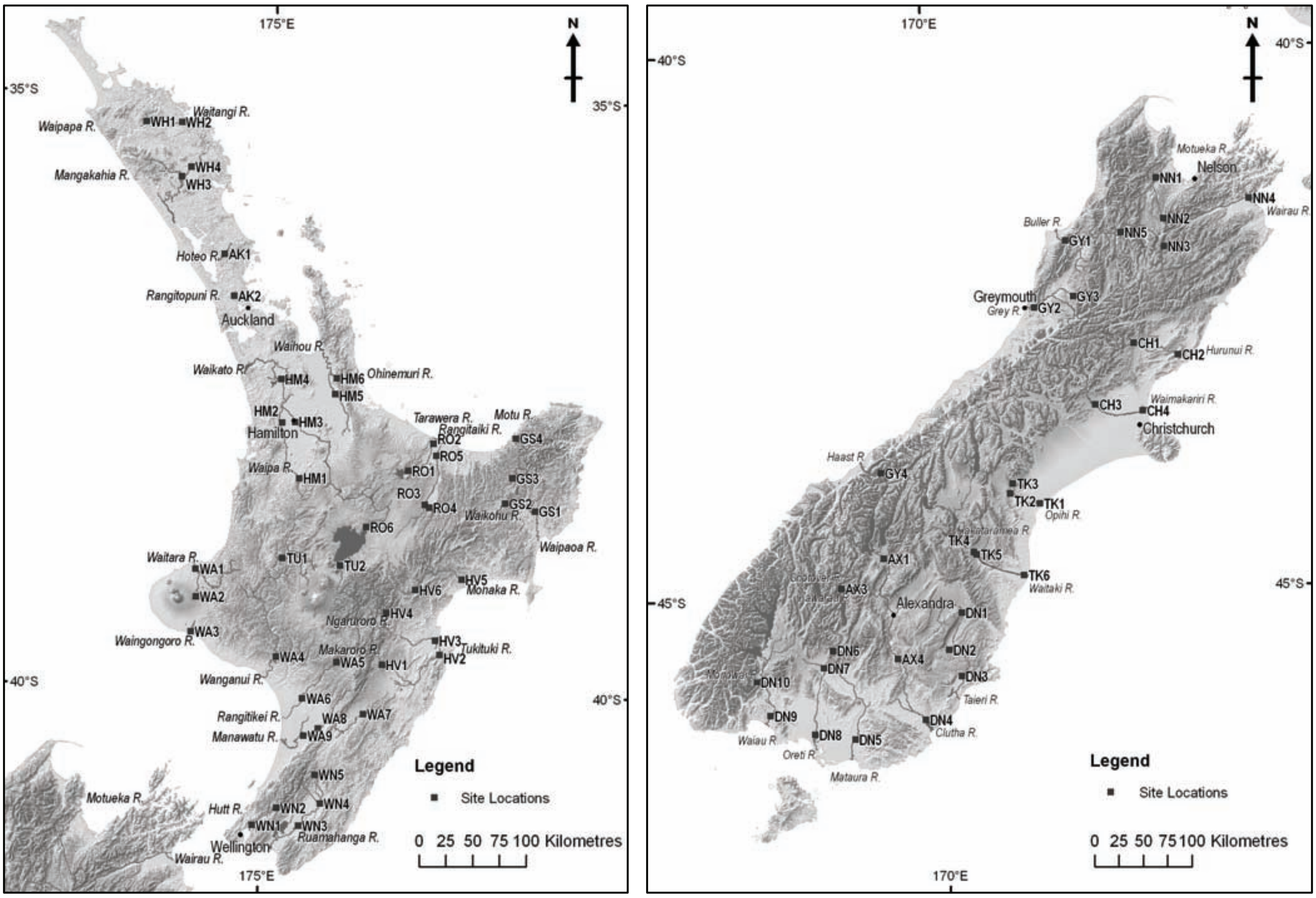

Figure 2: **Locations of the 77 sites in the National Rivers Water Quality Network (NRWQN)**

Smith et al. (1989) classified the NRWQN sites as nominally baseline ("likely to be no or little effect of diffuse or point source pollution and which will account for natural or near-natural effects or trends"), impact ("downstream of present or possible future areas of agriculture, forestation, industry and urbanisation") and pseudo-impact (not defined, but intermediate between the above).

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[1] Biggs (2000) used >3 mm thickness to distinguish mats from thin biofilms (c.f. >2 mm in Smith et al. 1989), but this is unlikely to result in marked differences in visual assessment of mat cover.

1.1 Periphyton guidelines used

Periphyton cover at each site was assessed in relation to the MfE guidelines to protect against aesthetic and recreational values of rivers, which are less than 60% cover of the visible streambed by mats and less than 30% cover by filamentous algae (Biggs 2000). Also because rivers often had a mix of mats and filamentous growths, we also adopted 40% cover as the maximum acceptable level of total periphyton (i.e., mats + filamentous periphyton growths). This threshold was based on Biggs' (2000) guidelines but weighted for the greater effect filamentous growths have on aesthetic value.

2. Methods

2.1 Monitoring methods used

The cover of wadeable areas of river beds by potential nuisance periphyton (i.e., mats and filamentous algae) was assessed at monthly intervals whenever flow conditions allowed safe wading at 73 of the 77 NRWQN sites (Fig. 1, Appendix 1) using methods described in Smith et al. (1989). The four sites excluded were: two Auckland region sites (Hoteo AK1 and Rangitopuni AK2), that have silty beds dominated by macrophytes rather than periphyton, and two Rotorua region sites (Tarawera at Awakaponga RO2 & Waikato at Reid's Farm RO6), that are too deep for wading.

Where possible ten observations of 0.5 m radius patches of riverbed were made at equally-spaced points across a wadeable cross-section of the river using an underwater viewer. However, because the NRWQN rivers are medium to large (mean baseflow width 54 m, range 7-200 m) some rivers were too deep/fast for this and observations were confined to the wadeable margin from one bank or, at 10% of sites, to observations from bridges or cableways. Responses to a 2004 questionnaire of NIWA field team personnel who carry out the monitoring found that on average eight (standard deviation (SD) = 3) observations of the bed are made at the standard points along these cross-sections/partial transects and transects cover an average 37% (SD 35%) of the total width (Appendix 1). Sites that are never suitable for wading (0% wadeable) are DN4, HV5, HM2, HM3, HM4, HM5 and WH3 (Appendix 1), and sites that are often not wadeable are DN1, GS1, WH2, TK4 and TK6 (Appendices 1 and 2). Less than 10% of the width is normally wadeable at AX1-4, CH1, CH3, CH4, GY1, GY2, GY4, TU1, WH4, RO5 and GS4 (Appendix 1). Despite these sampling constraints, the observation methods reflect the way the public would observe periphyton cover so that the methods are considered to be valid for answering the question of whether the aesthetic effects of riverbed cover by periphyton are increasing over time and/or along river systems.

The stalked diatom *Didymosphenia geminata*, commonly referred to as "Didymo", appeared at several South Island NRWQN rivers towards the end of the period covered by this report. It was first observed in 2004 at DN9, in 2005 at NN5, GY1, TK4, TK6, AX1, AX4, DN7 and DN8, and in 2006 at DN6. Didymo is unusual in that it often reaches very high biomass at pristine sites. Because it appeared late in the monitoring period and only formed very high biomass at a few sites, the decision was made to exclude from this analysis the data for infected Didymo sites for the years where it caused obvious large increases in cover, to avoid it confounding the general patterns and trends over the rest of the monitoring period. The data removed were for 2004 to 2006 at DN9, and 2006 at AX1 and AX4.

Field staff received field training and were provided with a training video and a methods manual. Methods were assured during biannual field visits for most of the monitoring period. Nevertheless, after a change in crew at one of the field teams, a measurement error occurred with thin brown biofilms recorded as periphyton mats giving erroneous high results until the error was detected and corrected. Because of this assessment error, matted periphyton data for the years 2003 to 2005 have been deleted for the sites WA1-9.

2.2 Trend analysis

Overall site trends of periphyton cover over the 17 years of monitoring were assessed using the annual mean and annual maximum cover data, rather than using monthly data that are highly variable due to the effects of floods. Analysis of variance was used to compare mean annual cover and mean maximum cover amongst sites classified as baseline (n = 23) and impact (n = 42) by Smith at al. (1989). The smaller number of pseudo-baseline sites (8) were excluded from this aspect of the analysis. Non-parametric Spearman’s Rank correlations (r_s) of periphyton cover versus time were used to evaluate whether there were statistically significant trends using Zar’s (1984) critical values for two-tailed tests. Trends are presented as statistically significant for *individual sites* at both the traditional 95% level of confidence ($P < 0.05$) and at the 90-95% confidence level ($0.1 > P > 0.05$), with the latter confidence level used to identify sites where there is a weaker trend for early warning. The Type I error rates (i.e., chance of detecting a false positive result) are <1:20 and 1:10 to 1:20, respectively when assessing whether a trend is occurring at an individual site, which is likely to be of interest to river users and regional councils. However, because the analysis involved multiple trend assessments, the risk of Type I statistical errors (i.e., false positives) within the whole dataset is increased by each additional correlation on the same dataset. This was allowed for in the assessment of trends in the whole data by calculating the False Discovery Rate (FDR) (Benjamini & Hochberg 1995) that controls for the number of false positives (set at 5%) when conducting multiple correlations on the same dataset.

Trends in *differences* in cover between baseline and impact sites on the same river were investigated (also using r_s) using the monthly data because observations were usually made at the paired sites on the same day. Mean annual and annual maximum total periphyton covers were also compared between individual upstream and downstream monitoring site pairs along rivers using paired t-tests ($P < 0.05$). The statistical significance of these trend and t-test comparisons are presented with and without FDR adjustments for multiple analyses.

3. Results

3.1 Frequency of periphyton cover observations

Unwadeable conditions, high turbidity, and operational constraints prevented periphyton observations on an average of 25% of the monthly visits to the 73 individual sites included in the periphyton cover monitoring (range 3% to 76%, Appendix 2). The Waipaoa River (GS1) has particularly high turbidity (median 85 NTU) and periphyton observations were only possible on 24% of site visits. The Waitaki River was often highly turbid due to “glacial flour” and periphyton observations were only possible on 32% of visits at the SH1 site (TK6) and 51% of visits at Kurow (TK4). Other sites where periphyton observations were frequently impossible due to flow/clarity conditions were: Rangataiki at Te Teko (RO5, observations on 50% of visits), Mangakahia at Titoki (WH3, 39%), Wairua at Purua (WH4, 37%), Wanganui at Te Maire (TU1, 56%), Waipa at Whatawhata (HM2, 41%), Taieri at Tiroiti (DN1, 46%), Clutha at Balclutha (DN4, 44%), Mataura at Seaward Downs (DN5, 59%), Motu at Houpoto (GS4, 57%) and Wanganui at Paetawa (WA4, 56%) (Appendix 2).

Missing data, from site visits when flow conditions prevent periphyton assessment, probably inflated the mean recorded cover at sites above the actual mean because periphyton cover was likely to have been low when sites were not wadeable. However, annual maximum cover was unlikely to have been affected by missing data because high cover typically occurs during stable low flows when wading conditions are optimal.

3.2 Overall occurrence of obvious periphyton

The mean monthly riverbed cover of periphyton over 1990-2006 across all 73 sites was 4.9% for mats, 5.6% for filamentous growth, and 10.6% for total (filamentous + mat) cover (Fig. 3, Appendix 2), and median cover of both periphyton growth forms was zero i.e., on at least 50% of visits across all 73 sites there was no cover by either periphyton mats or filamentous growths. Mean total cover (filamentous + mats) only exceeded our proposed guideline (>40% cover) at the Ohinemuri (HM6) and upper Wanganui (TU1) sites. Although no sites had *mean* cover of filamentous algae or mats above the MfE guidelines (> 30% and > 60%, respectively, Biggs 2000), the *maximum* observed filamentous cover was exceeded at 78.1% of the sites (Appendix 2).

The mean annual maximum cover results give a more general picture of nuisance periphyton occurrence in these rivers: the mean for mats was 19.6% (median 18.0%, range 0 to 56.7%) and the mean for filamentous growths was 20.4% (median 14.6%, range 0.1 to 68.6%). The mean annual maximum cover for total periphyton cover (mats + filamentous cover) averaged 33.5% (median 32.6%, range 0 to 80.4%) (Fig. 3).

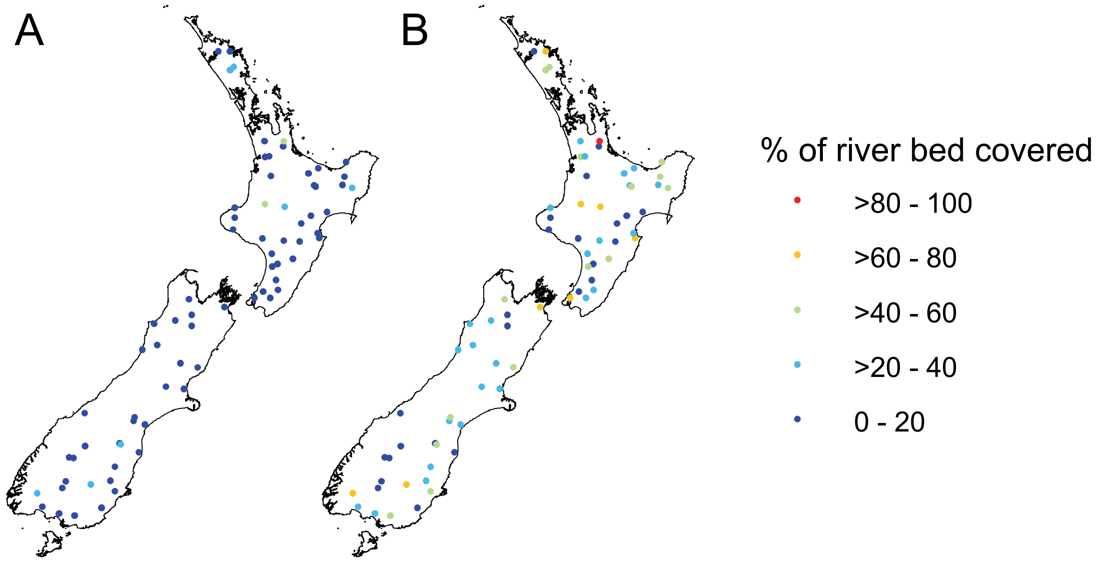


Figure 3: **Total periphyton cover (filamentous + mats) of wadeable areas of riverbed at 73 NRWQN sites during 1990-2006 as (A) mean % cover and (B) mean annual maximum % cover**

The mean annual maximum filamentous cover exceeded the MfE 30% guideline at 23.3% of the 73 sites, with more exceedence at impact (28% of impact sites), than baseline sites (6% of baseline sites) (Table 1, Appendix 2). The mean annual maximum total cover exceeded the recommended 40% threshold for aesthetic nuisance effects at 33% of sites (Appendix 2). Exceedence was more common at impact sites (45%) than baseline sites (13%). Over half of the sites had mat cover in excess of the MfE guideline on at least one occasion (i.e., maximum recorded >60%, Table 1, Appendix 2), but none had a mean annual maximum above the guideline level. Thus filamentous algae were the main cause of nuisance effects.

Table 1: **Percentage of mean annual cover for the 73 sites monitored for periphyton between 1990 and 2006 that exceed the MfE guidelines (Biggs 2000)**

Mean annual cover	**Guideline value used**	**Percentage of sites by type exceeding the guidelines**			
		Impact sites	**Pseudo-baseline sites**	**Baseline sites**	**All sites**
Mean mat	< 60 %	0	0	0	0
Mean filamentous	< 30 %	0	0	0	0
Mean total	< 40 %	2.6	12.5	0	2.6
Maximum mat	< 60 %	0	0	0	0
Maximum filamentous	< 30 %	28	25	6	23.3
Maximum total	< 40 %	45	25	13	33

Annual maximum total periphyton cover at impact sites (mean = 40.2%) was significantly higher than at baseline sites (24.0%) ($F_{1,64} = 11.0$, $P = 0.001$), as was annual maximum filamentous cover (means 25% and 13%, respectively, $F_{1,64} = 7.7$, $P = 0.007$) and annual mean total cover (12.5% and 7.6% respectively, $F_{1,64} = 4.4$, $P = 0.04$) (Table 2). Annual mean mat cover was also higher at impact (mean 5.8%) than baseline sites (mean 3.8%) ($F_{1,64} = 6.2$, $P = 0.016$), but annual maximum mat cover did not differ significantly between impact and baseline sites (means and SD = 22.5% (14.6) and 16.6% (15.6), respectively).

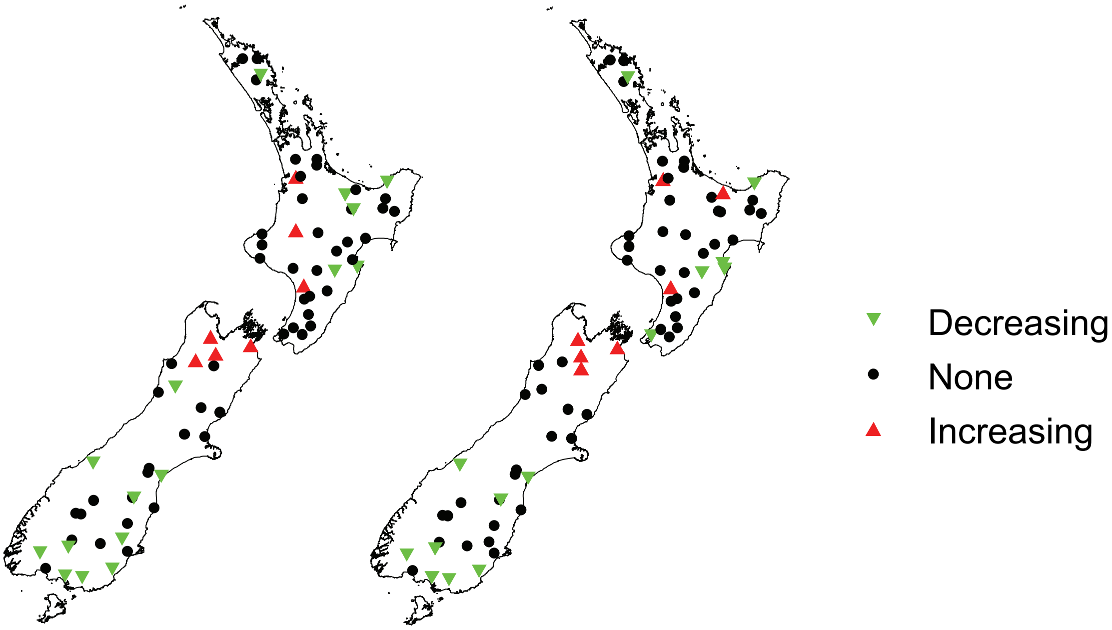
Table 2: Comparison of mean percentage cover of periphyton between 42 impact and 23 baseline sites monitored between 1990 and 2006

Annual cover	Mean per cent cover		
	Impact sites	Baseline sites	Significant difference
Mean mat	5.8	3.8	Yes ($P = 0.016$)
Mean filamentous	6.8	3.6	Yes (P = 0.001)
Mean total	12.5	7.6	Yes ($P = 0.04$)
Maximum mat	22.5	16.6	No (P = 0.059)
Maximum filamentous	24.6	13.0	Yes ($P = 0.007$)
Maximum total	40.2	24.0	Yes ($P = 0.001$)

3.3 Trends in obvious periphyton cover at NRWQN sites

Trend analysis for individual sites over the period 1990-2006 showed that the majority of the sites had statistically significant trends (at $P < 0.1$, without false discovery rate (FDR) adjustment for multiple comparisons) in annual mean or maximum periphyton cover as mat and/or filamentous (Appendix 3), with more sites having negative (decreasing) trends than positive (increasing) trends (Table 3, Fig. 4). For example, mean annual total periphyton cover decreased at 16 sites (22%) and increased at seven sites (9%) (Table 3).

The proportion of sites showing statistically significant increases (at $P < 0.1$, without FDR adjustment for multiple comparisons) in one or more classes of periphyton cover was similar among impact compared to baseline/pseudo-baseline sites (21% and 23%, respectively), whereas the proportion of sites showing declines was slightly larger amongst the impact sites (45%) compared to the baseline/pseudo-baseline sites (32%). Adjusting these trend analyses for a 5% FDR for more robust assessment of trends amongst the whole dataset (c.f. at individual sites) indicates significant declines in one or more classes of periphyton cover at five (16%) of the baseline sites and six (14%) of the impact sites and increases at two (5%) of impact sites (Table 3).



Note: See Table 3 and Appendix 3 for details on trends and site locations.

Figure 4: **Trends in annual mean (left) and maximum (right) total periphyton cover (ie, mats + filamentous growths) 1990-2006 (as r_s with year, $P < 0.1$, without false discovery rate adjustment).**

Table 3: **Listing of sites where statistically significant trends in mean annual periphyton have occurred over the period 1990 to 2006**

Filamentous mean cover	Mats mean cover	Total mean cover	Type	Site	Filamentous maximum cover	Mats maximum cover	Total maximum cover
			B	AX1	▲		
			I	CH4		▼	
	▼▼		I	DN1		▼	
▼▼*	▼▼	▼▼*	B	DN2	▼▼*		
	▼	▼	I	DN4		▼▼	▼▼
▼	▼▼	▼▼	I	DN5		▼▼	▼
▼▼	▼▼*	▼▼	PB	DN7	▼▼	▼▼*	▼▼
▼▼*	▼▼*	▼▼*	I	DN8	▼▼	▼▼*	▼▼
▼▼*	▼▼*	▼▼*	B	DN10	▼▼*	▼▼	▼▼*
▼			I	GS1			
	▼▼*	▼▼	I	GS4		▼▼	▼
▲			I	GY1	▲		
	▼▼		I	GY2		▼▼	
	▼▼*	▼	B	GY3		▼▼	
	▼▼*	▼▼	B	GY4		▼▼	▼▼
	▲▲	▲▲	I	HM2		▲	
▼▼			I	HM4	▼▼		
▼▼		▼▼	B	HV1	▼▼		▼▼
▼		▼	I	HV2	▼		▼
▼			I	HV3	▼		▼
	▲▲	▲	I	NN1		▲▲	▲▲
	▲▲	▲▲	B	NN2		▲▲	▲▲
			B	NN3			▲
▼▼	▲▲*	▲	I	NN4	▼	▲▲	▲
	▲▲	▲	PB	NN5		▲	
▼▼		▼	B	RO1			
		▼	B	RO4			
	▼		I	RO5	▲▲		▲
▼▼*		▼▼	I	TK1	▼▼*		▼▼*
▼▼*			I	TK2	▼▼*		
	▲▲		PB	TK3			
▼▼*		▼▼	I	TK5	▼▼		▼▼
▼▼*			I	TK6	▼▼		
▲▲		▲	I	TU1	▲▲*		
			B	TU2	▲▲		
▼			I	WA3	▼		
▲		▲	I	WA6	▲▲		▲▲
			PB	WA7	▼		
▼			B	WH1	▼		
	▼▼		I	WH2		▼▼	
▼▼		▼▼	I	WH4	▼		▼
▼▼*			I	WN1	▼▼*		▼▼
	▲		B	WN2		▲	
▼▼			I	WN3	▼		
	▲▲		I	WN4		▲	

Note: See Appendix 2 for summaries of mean and annual maximum cover and Appendix 3 for a list of r_s values for all sites. ▲ = increasing ($0.05 < P < 0.1$), ▲▲= increasing ($P < 0.05$), ▼ = decreasing ($0.05 < P < 0.1$), ▼▼ = decreasing ($P < 0.05$) for individual sites. * = significant correlations adjusted for a False Discovery Rate of 0.05 amongst correlations at all sites for each periphyton cover attribute. B = baseline, PB = pseudo-baseline; I = impact (Smith et al. 1989).

3.4 Downstream changes in periphyton cover between NRWQN sites

Twenty-four rivers had more than one site (usually an upstream “baseline” or “pseudo-baseline” and downstream “impact” site) on their length. These paired sites can be used to identify changes in periphyton conditions that might be linked to catchment activities between the two sites.

Table 4: Comparisons of total periphyton cover at paired sites and time trends (r_s) in *difference* between 27 site pairs along 24 New Zealand river systems from 1990 to 2006

Paired sites (downstream – upstream)	Mean of annual mean total cover	Mean of the annual maximum total cover	Time trends in up-down-stream difference in monthly total cover (r_s) (fig. 5)
Hurunui CH2 – CH1$^{\#}$	8 – 5	40 – 35	0.28*
Waimakariri CH4 – CH3$^{\#}$	2 – 2	21 – 20	n.s.
Taieri DN3 – DN2$^{\#}$	15 – 12	**57 – 36***	0.301*
Mataura DN5 – DN6$^{\#}$	**18 – 2***	**53 – 13***	-0.41*
Oreti DN8 – DN7+	**11 – 1***	**40 – 8***	-0.34*
Waipaoa GS1 – GS2$^{\#}$	24 – 10	41 – 38	n.s.
Motu GS4 – GS3	16 – 13	53 – 56	-0.29*
Buller GY1 – NN5+	**6 – 4**	24 – 24	-0.25
Grey GY2 – GY3$^{\#}$	11 – 7	35 – 27	n.s.
Waipa HM2 – HM1$^{\#}$	**18 – 2***	**41 – 10***	0.26
Waikato HM4 – HM3	11 – 10	36 – 33	-0.19
Ngaruroro HV3 – HV4$^{\#}$	**4 – 0***	**22 – 3***	n.s.
Mohaka HV5 – HV6+	3 – 0	**10 – 0**	n.s.
Tukituki HV2 – HV1$^{\#}$	**19 – 1***	**62 – 5***	-0.22
Motueka NN1 – NN2$^{\#}$	**11 – 1***	**60 – 10***	n.s.
Wairau NN4 – NN3$^{\#}$	**15 – 1***	**64 – 8***	n.s.
Rangitaiki RO5 – RO4$^{\#}$	**8 – 17***	**25 – 51***	n.s.
Opihi TK1 – TK2	10 – 7	37 – 37	n.s.
Waitara WA1 – WA2$^{\#}$	**17 – 1***	**49 – 4***	0.19
Wanganui WA4 – TU1	**5 – 43***	**16 – 78***	n.s.
Rangitikei WA6 – WA5+	7 – 8	31 – 29	n.s.
Manawatu mid WA8 – WA7+	**7 – 16***	**26 – 51***	n.s.
Manawatu lower WA9 – WA8	**14 – 7***	**54 – 26***	-0.32*
Hutt WN1 – WN2$^{\#}$	**18 – 0***	**66 – 1***	-0.30*
Ruamahanga mid WN4 – WN5$^{\#}$	**8 – 0***	**37 – 4***	n.s.
Ruamahanga lower WN3 – WN4	6 – 8	28 – 37	-0.235
Ruamahanga WN3 – WN5$^{\#}$	**6 – 0***	**28 – 4***	-0.45*

Note: $^{\#}$ = baseline; $^{+}$ = pseudo-baseline (otherwise impact, after Smith et al. 1989). Bold font indicates a statistically significant difference between each individual site pairs (paired-t test, $P < 0.05$). Statistically significant r_s values of differences between site pairs over time since 1990 ($P < 0.05$) are listed. * = Statistically significant differences in means or correlations after adjusting for a False Discovery Rate of 0.05 amongst all sites for each periphyton cover attribute. n.s. = not statistically significant at $P < 0.05$ for time trends in difference between individual site pairs.

The majority of paired sites had more periphyton cover at the downstream site, although this did not always occur (Table 4). Thirteen of the 24 paired sites on individual rivers had significantly higher mean or annual maximum periphyton cover at the downstream site than at the upstream site (Table 4, paired t-tests, $P < 0.05$ with false discovery rate adjustment). The downstream increase in periphyton cover was particularly striking in the Tukituki, Motueka, Wairau, and Hutt Rivers. The cover at the upstream site in these rivers was low (1-10%) whereas the annual maximum observed total cover was typically equal to or greater than 60% at downstream sites (Appendix 2).

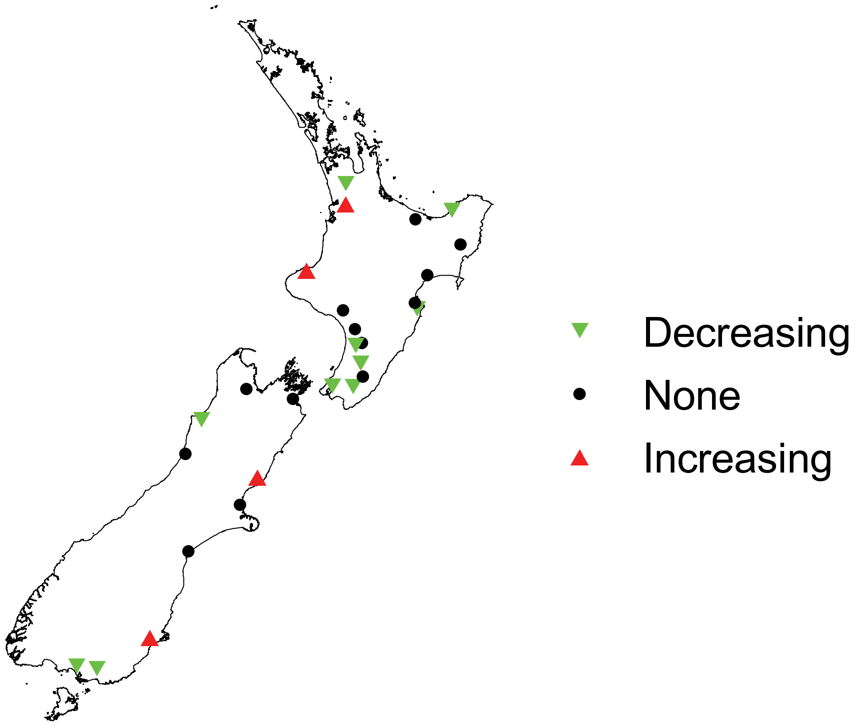
These downstream increases indicate that changes in catchment activities/characteristics between upstream (baseline) and downstream (impact) sites frequently result in increased periphyton cover, often to “nuisance” levels (greater than 40% total cover) at least once a year. It is likely that human activities between these sites contribute to these increases. In some cases there are known point sources of nutrients (e.g., from municipal and industrial discharges to the Mataura and Manawatu Rivers), and intensive land-use practices are generally expected to cause downstream increases in diffuse nutrient inputs (Ballantine & Davies-Colley 2009; Larned et al. 2004).

Only three rivers had lower total periphyton cover at the downstream sites than upstream (Table 4). High turbidity at the downstream Wanganui site (WA4) probably restricted the periphyton development by reducing light penetration to the riverbed (Davies-Colley & Nagels 2008). Along the Manawatu River, periphyton cover dropped between the site near Dannevirke (WA7) and downstream at Palmerston North (WA8), indicating changes in periphyton growth conditions, but increased again below wastewater discharges from Palmerston North and associated industries (WA9). The Rangitaiki River also had a higher cover upstream (RO4) than downstream (RO5), probably due to a higher streambed stability at the upstream site.

Streambed stability and turbid water probably also limited periphyton growth at several of the downstream sites that did not have higher cover than their upstream pair (e.g., Waikato at Rangiriri (HM4), Waipaoa at Kanakanaia (GS1)). However, the downstream sites on the Rangitikei, Grey, Hurunui, Waimakariri and Opihi Rivers had similar periphyton cover to their upstream paired site, indicating that changes associated with land management between these sites have not been large enough to cause increased periphyton growth.

The trends in the *difference* in percentage of total periphyton cover (mats + filamentous) between downstream and upstream sites on individual rivers provide another way of assessing trends in river health. Four paired-site comparisons had significant increasing trends and ten paired-site comparisons had significant decreasing trends (Table 4, Fig. 5). Adjusting for a false discovery rate of 5% when viewing the data as a whole (c.f. as individual sites) revealed two significant increases in difference over time and six declines (Table 4). The increase in the differences through time for the Waipa, Taieri, Waitara, and Hurunui Rivers indicate that either the upstream sites have declining cover or the downstream sites have increasing cover. The individual site annual mean trends (Table 3) indicate that for the Taieri, the increase in difference was likely due to reduced cover at the upstream site (DN2), whereas in the Waipa the increased cover at the downstream site probably produced the increased difference between upstream and downstream sites over time.

Similarly, rivers with significantly decreasing differences between paired sites could result from the upstream having increasing cover or the downstream having decreasing cover. The trend towards smaller downstream increase in total cover along the Mataura appears to have been driven by reduced cover at the downstream site (DN5, see Table 3) and may be related to improved wastewater treatment and removal of significant point sources over the last decade. Significant trends of declining difference downstream on the Motu, Waikato, Hutt rivers appeared to be due to reductions in annual mean cover at the downstream sites on the (GS4, HM4 and WN1, Table 3).



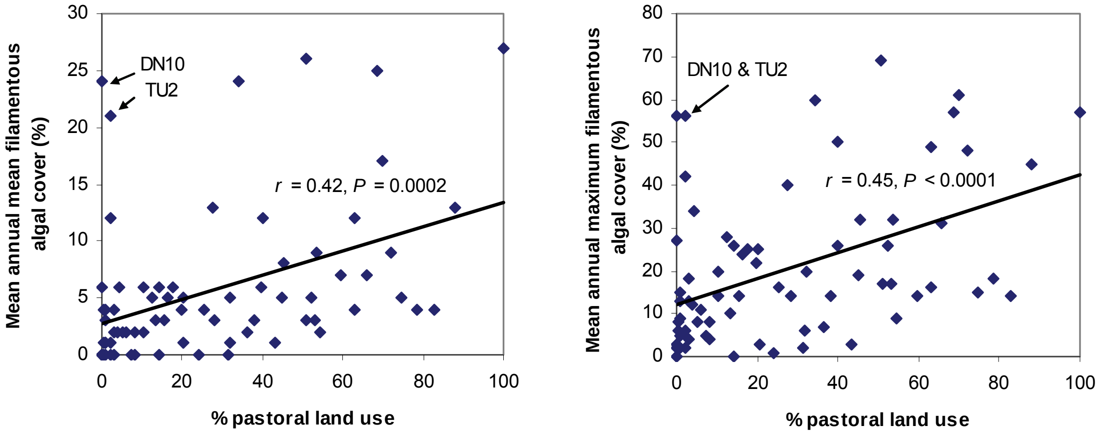
Note: see Table 4 for details.

Figure 5: **Trends in difference in monthly total periphyton cover (filamentous + mats) between upstream and downstream sites at 24 NRWQN rivers as assessed for individual site pairs (without FDR adjustment)**

4. Discussion

Periphyton cover, mainly as filamentous algae, was sufficiently high to impact on river recreation and aesthetic values (as indicated by exceeding New Zealand guideline values) at about a quarter of the NRWQN sites at some time during an average year between 1990-2006. This suggests that nuisance periphyton may be a fairly widespread problem in New Zealand rivers. Note, however, that extrapolation of the NRWQN findings to all New Zealand rivers is not possible because the NRWQN sites were not selected randomly and are biased towards larger than average rivers.

The annual maximum filamentous algal cover exceeded the MfE guideline for protection of recreational and aesthetic values more commonly at nominal impact sites (28%) than baseline sites (6%), indicating that human activities in catchments have increased the frequency of nuisance periphyton occurrence. The two baseline sites where annual maximum filamentous cover exceeded 30% (TU2, Tongariro, and DN10, Monowai) were below dams that reduce flow variability and therefore probably contributed to periphyton development at these sites (Clausen and Biggs 1997). The higher proportion of pastoral land use at the impact sites (mean = 36%) than baseline sites (mean = 11%) is a likely contributor to the higher occurrence of nuisance levels at impact sites. Ballantine and Davies-Colley (2009) found nutrient concentrations were strongly correlated with percentage pasture amongst these NRWQN sites and that trends of increasing nitrogen and phosphorus were correlated with percentage pasture in the catchment. This was confirmed by the strong relationships between annual mean and maximum filamentous algal cover and percentage pasture in the catchment upstream (Fig. 6). Periphyton cover was also typically higher at downstream than upstream sites along the same river, indicating that periphyton is responding to human pressures that typically increase in downstream along rivers.



Note: that the two outliers are DN10 and TU2, both downstream of dams.

Figure 6: **Relationships between mean annual mean and mean annual maximum filamentous algal cover and the percentage of pasture in the catchment of 73 NRWQN sites (1990-2006)**

The MfE aesthetic/recreation use guideline for mat cover (<60% cover) was exceeded less frequently than the lower filamentous algal cover guideline (<30% cover), and annual mean and maximum mat covers at sites were not correlated significantly with percentage pastoral land use in the catchment upstream of the sites. The higher mean mat cover at impact than baseline sites did indicate some influence of human activities on this component of the periphyton, but that was weaker than for filamentous algae.

It is unlikely that differences in riparian shading, that can control periphyton biomass (Davies-Colley & Quinn 1998; Quinn et al. 1997), had a significant influence on these patterns of higher periphyton cover and more frequent exceedence of nuisance guideline levels in impacted sites than baseline site and in a downstream direction because, none of the relatively wide NRWQN sites were heavily shaded (Appendix 1).

Our trend analysis found more declines than increases in the occurrence of obvious periphyton growths in the NRWQN rivers over the 17 years of monitoring since 1990. This encouraging finding was not expected given the increasing agricultural intensification and associated increase in nitrogen inputs over this period (Ministry for the Environment 2007) and general trends of increasing nutrient levels at the NRWQN sites between 1989 and 2007 (Ballantine & Davies-Colley 2009). This suggests that other factors, such as flow variability, grazing by macroinvertebrates or changes in periphyton community composition, may be influencing the responses of periphyton cover to increased nutrient concentrations at the NRWQN sites over the study period.

Some of the trends of declining cover along river systems may be associated with improvements in point source effluent management (e.g., Mataura and Manawatu Rivers). Previous studies have shown increases in periphyton biomass are commonly associated with nutrient enrichment from wastewater discharges (Welch et al. 1992) and concentrations of Biochemical Oxygen Demand (BOD) and ammonium, that are associated with wastewater discharge, declined between 1989 and 2005 at the NRWQN sites (Scarsbrook 2006). Phosphorus concentration also declined at the lower Manawatu site (WA9, Opiki) over 1989-2007, suggesting a possible nutrient link to trend of reduced difference in periphyton cover between the sites upstream and downstream of the effluent discharges near Palmerston North. However, phosphorus and nitrogen have increased in the lower Mataura at DN5 (Ballantine & Davies-Colley 2009) indicating that factors other than mean nutrient levels caused the decline in periphyton cover.

Water clarity can limit periphyton development by reducing the amount of light reaching the riverbed (Davies-Colley et al. 1992) and this is the likely cause of the downstream decrease in periphyton cover along the Wanganui River (between TU1 and WA4). However, clarity generally improved at the NRWQN sites over 1989-2007 (Ballantine & Davies-Colley 2009), so this cannot explain the trends that we found of more common occurrence of declining than increasing periphyton cover.

This initial analysis of the NRWQN periphyton database from 1990-2006 has provided a broad description of the state and trends in cover of potential nuisance periphyton cover and its association with general human pressures encapsulated in the classification of the sites as baseline, pseudo-baseline and impact. Better definition of the reasons for the patterns between sites and site-specific trends will require further analysis to consider factors that can control periphyton cover, including nutrients, substrate size and stability, flow variability, temperature and abundance of invertebrate grazers at the sites. This more detailed analysis is beyond the scope of the present report, but is likely to provide valuable insights to support targeted management of pressures to reduce the occurrence of nuisance periphyton levels in our rivers.

5. Acknowledgements

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7. Appendix 1. Summary of NRWQN periphyton assessment site locations, characteristics and constraints

Site	River name	Easting	Northing	Site name	Impact/baseline	% wade	Obs. method	% shade
AX1	Clutha	2215500	5601900	Luggate bridge	Baseline	1-10	Wade	<10
AX2	Kawarau	2184376	5569787	Chards	Pseudo-baseline	1-10	Wade	<10
AX3	Shotover	2172199	5571035	Bowen's Peak	Pseudo-baseline	1-10	Wade	<10
AX4	Clutha	2230200	5498800	Millers Flat	Impact	1-10	Wade	<10
CH1	Hurunui	2472514	5824007	Mandamus	Baseline	1-10	Bridge/banks	10-30
CH2	Hurunui	2517897	5812110	SH1 bridge	Impact	10-25	Bridge/banks	<10
CH3	Waimakariri	2433142	5760479	Gorge	Baseline	1-10	Bridge/banks	10-30
CH4	Waimakariri	2481804	5754678	Old Highway Br.	Impact	1-10	Bridge/banks	<10
DN1	Taieri	2295855	5546607	Tiroiti	Impact	25-50	Wade	30-50
DN2	Sutton Stn.	2283172	5508439	SH87	Baseline	100	Wade	<10
DN3	Taieri	2295809	5481042	Outram	Impact	50-75	Wade	<10
DN4	Clutha	2258996	5436246	Balclutha	Impact	0	Bridge/banks	<10
DN5	Mataura	2186569	5416006	Seaward Downs	Impact	10-25	Wade	<10
DN6	Mataura	2163536	5507277	Parawa	Baseline	50-75	Wade	<10
DN7	Oreti	2154070	5489203	Lumsden	Pseudo-baseline	25-50	Wade	<10
DN8	Oreti	2145365	5420798	Riverton Hwy Br.	Impact	10-25	Wade	<10
DN9	Waiau	2099363	5439848	Tuatapere	Impact	10-25	Wade	30-50
DN10	Monowai	2085337	5475050	Below gates	Baseline	10-25	Wade	10-30
GS1	Waipaoa	2935881	6292331	Kanakanaia	Impact	10-25	Combination	<10
GS2	Waikohu	2908293	6299695	No1 bridge	Baseline	75-100	Wade	50-80
GS3	Motu	2914723	6323286	Waitangirua	Impact	75-100	Wade	10-30
GS4	Motu	2918077	6360863	Houpoto	Impact	1-10	Wade	<10
GY1	Buller	2401960	5929475	Te Kuha	Impact	1-10	Wade	<10
GY2	Grey	2369993	5860128	Dobson	Impact	1-10	Wade	<10
GY3	Grey	2410022	5872000	Waipuna	Baseline	10-25	Wade	<10
GY4	Haast	2212857	5689490	Roaring Billy	Baseline	1-10	Wade	<10
HM1	Waipa	2715637	6323441	Otewa	Baseline	75-100	Wade	10-30
HM2	Waipa	2699656	6376025	Whatawhata	Impact	0	Bridge/banks	<10
HM3	Waikato	2711831	6376412	Hamilton traffic Br.	Impact	0	Bridge/banks	<10
HM4	Waikato	2698887	6416748	Rangiriri	Impact	0	Bridge/banks	<10
HM5	Waihou	2749432	6402603	Te Aroha	Impact	0	Bridge/banks	<10
HM6	Ohinemuri	2750577	6417205	Karangahake	Pseudo-baseline	25-50	Wade	10-30
HV1	Makaroro	2792800	6148800	Burnt bridge	Baseline	100	Combination	10-30
HV2	Tukituki	2846597	6158135	Red bridge	Impact	75-100	Combination	<10
HV3	Ngaruroro	2842492	6171513	Chesterhope	Impact	75-100	Combination	<10
HV4	Ngaruroro	2796945	6197400	Kuripapango	Baseline	25-50	Combination	10-30
HV5	Mohaka	2867237	6228523	Raupunga	Impact	0	Bridge/banks	<10
HV6	Mohaka	2823979	6218769	Glenfalls	Pseudo-baseline	75-100	Combination	10-30
NN1	Motueka	2495112	5994300	Woodstock	Impact	100	Wade	10-30
NN2	Motueka	2502787	5952647	Gorge	Baseline	100	Wade	10-30
NN3	Wairau	2503477	5923767	Dip Flat	Baseline	10-25	Combination	10-30
NN4	Wairau	2590635	5973743	Tuamarina	Impact	100	Wade	<10
NN5	Buller	2458970	5937980	Longford	Pseudo-baseline	10-25	Combination	10-30

Note: Combination = more than one observation method used, depending on the flow conditions; % wade = the percentage of the total stream channel that can be safely waded; % shade is the percentage of the stream channel that is shaded, taking into account all times of the day, based on a visual assessment by field staff carried out in summer 2007.

Site	River name	Easting	Northing	Site name	Impact/baseline	% wade	Obs. method	% shade
RO1	Tarawera	2817441	6330344	Lake outlet rec.	Baseline	25-50	Combination	<10
RO3	Rangitaiki	2832905	6298355	Murupara	Impact	10-25	Wade	30-50
RO4	Whirinaki	2837043	6295952	Galatea	Baseline	25-50	Wade	10-30
RO5	Rangitaiki	2843629	6344416	Te Teko	Impact	1-10	Wade	<10
TK1	Opihi	2376168	5658589	Waipopo	Impact	100	Wade	<10
TK2	Opihi	2345438	5669013	Rockwood	Impact	100	Wade	10-30
TK3	Opuha	2348185	5679030	Skipton bridge	Baseline	100	Wade	<10
TK4	Waitaki	2308015	5608817	Kurow	Baseline	100	Combination	<10
TK5	Hakataramea	2311170	5606221	Above MH bridge	Impact	100	Wade	10-30
TK6	Waitiki	2360000	5585000	SH1 bridge	Impact	100	Combination	10-30
TU1	Wanganui	2699812	6248985	Te Maire	Impact	1-10	Wade	30-50
TU2	Tongariro	2753749	6241697	Turangi	Baseline	75-100	Wade	10-30
WA1	Waitara	2618682	6238934	Bertrand road	Impact	25-50	Wade	10-30
WA2	Manganui	2618865	6213047	SH3	Baseline	100	Wade	50-80
WA3	Waingongoro	2614004	6180263	SH45	Impact	75-100	Wade	10-30
WA4	Wanganui	2693722	6156603	Paetawa	Impact	10-25	Wade	10-30
WA5	Rangitikei	2750370	6151340	Mangaweka	Pseudo-baseline	25-50	Wade	<10
WA6	Rangitikei	2718305	6117218	Kakariki	Impact	25-50	Wade	<10
WA7	Manawatu	2775061	6102713	Weber road	Pseudo-baseline	75-100	Wade	30-50
WA8	Manawatu	2733100	6089200	Teachers college	Impact	25-50	Wade	<10
WA9	Manawatu	2719420	6082710	Opiki bridge	Impact	25-50	Wade	<10
WH1	Waipapa	2573046	6658281	Forest Ranger	Baseline	100	Wade	30-50
WH2	Waitanga	2606139	6657724	Wakelins	Impact	25-50	Bridge/banks	<10
WH3	Mangakahia	2605914	6607059	Titoki bridge	Impact	0	Bridge/banks	10-30
WH4	Wairua	2614941	6615862	Purua	Impact	1-10	Bridge/banks	<10
WN1	Hutt	2671222	5999194	Boulcott	Impact	75-100	Wade	<10
WN2	Hutt	2694176	6015002	Kaitoke	Baseline	100	Wade	10-30
WN3	Ruamahanga	2714559	5998412	Waihenga	Impact	10-25	Wade	<10
WN4	Ruamahanga	2734728	6019152	Wardells	Impact	50-75	Wade	10-30
WN5	Ruamahanga	2729914	6046092	SH2	Baseline	100	Wade	<10

Note: Combination = more than one observation method used, depending on the flow conditions; % wade = the percentage of the total stream channel that can be safely waded; % shade is the percentage of the stream channel that is shaded, taking into account all times of the day, based on a visual assessment by field staff carried out in summer 2007.

8. Appendix 2. Summary statistics for annual mean and maximum percentage cover by obvious periphyton mats and filamentous algae at 73 NRWQN sites for the period 1990-2006

			% of visits with no obs	Mean			Mean annual maximum			Maximum		
Site	Visits	No. of obs	obs	Fil	Mat	F+M	Fil	Mat	F+M	Fil	Mat	F+M
AX1	202	177	12	4	3	7	15	19	26	**100**	**86**	**100**
AX2	202	143	29	1	0	1	6	0	6	20	2	20
AX3	202	138	32	0	1	1	2	6	8	13	**79**	**79**
AX4	201	154	23	12	15	27	**42**	49	**63**	**77**	**96**	**96**
CH1	204	198	3	1	4	5	9	28	35	**55**	**76**	**76**
CH2	204	196	4	2	5	8	11	34	40	**69**	**87**	**100**
CH3	204	196	4	0	2	2	5	16	20	**50**	57	**100**
CH4	204	195	4	0	2	2	4	17	21	24	**77**	**100**
DN1	208	96	54	4	8	12	16	23	31	**57**	**62**	**72**
DN2	208	178	14	3	8	12	14	33	36	**46**	**68**	**68**
DN3	208	143	31	12	3	15	**50**	17	**57**	**96**	**63**	**96**
DN4	208	91	56	2	2	4	8	12	20	**54**	59	**82**
DN5	208	123	41	8	10	18	**32**	29	**53**	**90**	**96**	**96**
DN6	208	154	26	1	1	2	6	7	13	**88**	40	**88**
DN7	208	166	20	0	1	1	2	7	8	17	48	**55**
DN8	208	134	36	5	6	11	26	24	40	**55**	57	**85**
DN9	208	127	39	4	5	9	18	18	33	**100**	**98**	**100**
DN10	208	199	4	24	14	38	**56**	50	**74**	**100**	**99**	**100**
GS1	209	50	76	7	17	24	14	34	**41**	**54**	**87**	**95**
GS2	209	181	13	4	6	10	18	30	38	**56**	**67**	**76**
GS3	209	152	27	7	7	13	**31**	36	**56**	**81**	**77**	**100**
GS4	208	119	43	6	10	16	25	38	**53**	**71**	**94**	**95**
GY1	204	130	36	2	4	6	8	18	24	18	**87**	**87**
GY2	204	133	35	6	5	11	20	20	35	**87**	**95**	**100**
GY3	204	166	19	3	4	7	13	18	27	**49**	**72**	**98**
GY4	202	144	29	1	3	4	6	12	16	22	55	**58**
HM1	204	155	24	1	1	2	3	8	10	24	27	27
HM2	204	84	59	5	12	18	15	32	**41**	**55**	**83**	**83**
HM3	204	178	13	5	4	10	20	19	33	**67**	**58**	**69**
HM4	204	141	31	5	7	11	19	30	36	**55**	**71**	**80**
HM5	204	124	39	2	1	3	9	5	13	**61**	40	**61**
HM6	204	187	8	26	16	**42**	**69**	47	**80**	**100**	**82**	**100**
HV1	204	198	3	0	0	1	4	1	5	**46**	12	**46**
HV2	204	194	5	17	2	19	**61**	10	**62**	**100**	**88**	**100**
HV3	204	185	9	4	0	4	22	2	22	**62**	28	**62**
HV4	204	194	5	0	0	0	2	2	3	21	25	29
HV5	204	162	21	3	0	3	10	0	10	**67**	1	**67**
HV6	204	194	5	0	0	0	0	0	0	6	0	6
NN1	209	164	22	2	9	11	14	50	**60**	**79**	**97**	**100**
NN2	208	189	9	0	1	1	0	10	10	1	**66**	**66**
NN3	209	173	17	0	1	1	3	6	8	23	30	**40**
NN4	209	167	20	6	9	15	**34**	38	**64**	**94**	**100**	**100**
NN5	209	172	18	0	3	4	5	20	24	**40**	**72**	**82**
RO1	203	177	13	6	1	7	27	10	30	**48**	41	**48**
RO3	203	156	23	1	14	14	3	36	37	9	**68**	**68**

				Mean			Mean annual maximum			Maximum		
Site	Visits	No. of obs	% of visits with no obs	Fil	Mat	F+M	Fil	Mat	F+M	Fil	Mat	F+M
RO4	203	145	29	2	15	17	12	47	**51**	**65**	**98**	**98**
RO5	203	100	51	3	5	8	14	14	25	**44**	43	**57**
TK1	204	182	11	6	4	10	26	20	37	**100**	**100**	**100**
TK2	204	171	16	3	4	7	17	23	37	**85**	**100**	**100**
TK3	204	186	9	6	11	18	26	39	**50**	**91**	**90**	**100**
TK4	204	104	49	4	1	5	8	6	10	**100**	**61**	**100**
TK5	204	190	7	13	7	20	**40**	34	**55**	**100**	**100**	**100**
TK6	204	65	68	1	0	1	2	1	4	24	8	32
TU1	209	117	44	24	19	**43**	**60**	57	**78**	**99**	**86**	**100**
TU2	209	179	14	21	12	33	**56**	35	**66**	**95**	**91**	**100**
WA1	208	137	34	9	8	17	**32**	28	**49**	**75**	**80**	**97**
WA2	208	196	6	0	0	1	1	3	4	10	7	10
WA3	208	161	23	4	2	5	14	8	20	**56**	17	**73**
WA4	208	116	44	2	4	5	7	10	16	**35**	3	35
WA5	208	156	25	5	3	8	24	13	29	**86**	25	**86**
WA6	208	157	25	5	2	7	25	9	31	**70**	8	**70**
WA7	208	150	28	13	3	16	**45**	10	**51**	**76**	27	**80**
WA8	208	129	38	4	3	7	16	15	26	**65**	36	**65**
WA9	207	139	33	12	2	14	**49**	11	**54**	**100**	37	**100**
WH1	204	187	8	2	0	2	13	1	14	**67**	13	**67**
WH2	204	143	30	9	5	14	**48**	24	**63**	**100**	**100**	**100**
WH3	204	79	61	27	1	27	**57**	3	**57**	**95**	58	**95**
WH4	204	75	63	25	1	25	**57**	2	**59**	**100**	33	**100**
WN1	204	179	12	5	13	18	28	53	**66**	**87**	**88**	**100**
WN2	204	193	5	0	0	0	0	0	1	4	4	5
WN3	204	148	27	3	3	6	14	19	28	**43**	**90**	**90**
WN4	204	129	37	3	4	8	17	22	37	**79**	**64**	**100**
WN5	204	192	6	0	0	0	2	2	4	16	16	32
Mean			25.4	5.7	4.9	10.6	20.4	19.6	33.5	61.3	59.7	77.4
Minimum			2.9	0	0	0	0	0	0	1	0	5
Maximum			76.1	27	19	43	69	57	80	100	100	100
Median			23	4.0	3.0	8.0	15.0	18.0	33.0	65.0	66.0	86.0
% sites > guideline				0.0	0.0	2.7	23.3	0.0	32.9	78.1	56.2	86.3

Note: Number of observations ('No. of obs') is the number of monthly samples that were obtained within the 17-year period for both filamentous and mats and the combination of these two. 'Mean' is the mean of annual mean per cent cover. 'Mean annual maximum' is the mean of the maximum monthly per cent covers for each year (Fig. 3). 'Maximum' is the absolute maximum per cent cover recorded over the 17-year period (Fig. 3). Fil = filamentous. F+M = both filamentous and mats. Bold values exceed MfE guidelines for aesthetic and recreational effects for filamentous algae or mats (Biggs 2000) for total periphyton cover proposed in this report.

9. Appendix 3. Spearman rank (r_s) correlations between year and annual means and maximums for periphyton as filamentous, mat and total obvious (i.e., filamentous + mat) cover

Site code	Filamentous annual mean	Mats annual mean	Filamentous + mats annual mean	Filamentous annual maximum	Mats annual maximum	Filamentous + mats annual maximum
AX1	0.35	0.33	0.40	**0.42**	0.28	0.36
AX2	-0.22	-0.15	-0.22	-0.19	-0.15	-0.19
AX3	0.31	0.28	0.37	0.32	0.28	0.37
AX4	-0.31	0.30	0.03	-0.22	0.04	-0.16
CH1	-0.02	-0.35	-0.37	-0.01	-0.33	-0.34
CH2	0.29	0.10	0.18	0.20	0.03	0.02
CH3	-0.18	-0.29	-0.35	-0.18	-0.32	-0.39
CH4	-0.18	-0.36	-0.21	-0.18	**-0.42**	-0.26
DN1	0.21	**-0.50**	-0.22	0.12	**-0.46**	-0.12
DN2	**-0.89**	**-0.49**	**-0.70**	**-0.82**	-0.20	-0.29
DN3	0.18	-0.28	0.02	0.15	-0.12	0.16
DN4	-0.11	**-0.48**	**-0.48**	-0.18	**-0.53**	**-0.55**
DN5	**-0.42**	**-0.53**	**-0.49**	-0.23	**-0.53**	**-0.41**
DN6	-0.15	0.01	-0.10	-0.12	0.05	-0.07
DN7	**-0.53**	**-0.72**	**-0.66**	**-0.49**	**-0.72**	**-0.63**
DN8	**-0.65**	**-0.73**	**-0.73**	**-0.54**	**-0.54**	**-0.51**
DN9	0.09	-0.25	-0.17	0.05	-0.22	-0.09
DN10	**-0.93**	**-0.84**	**-0.93**	**-0.72**	**-0.73**	**-0.82**
GS1	**-0.46**	0.00	-0.13	-0.41	0.04	-0.03
GS2	-0.18	-0.38	-0.31	-0.15	-0.29	-0.33
GS3	-0.12	-0.04	-0.13	-0.08	-0.17	-0.28
GS4	-0.21	**-0.66**	**-0.54**	-0.25	**-0.61**	**-0.48**
GY1	**0.48**	0.02	0.17	**0.42**	0.03	0.09
GY2	-0.10	**-0.56**	-0.28	-0.19	**-0.51**	-0.28
GY3	0.01	**-0.69**	**-0.47**	0.01	**-0.53**	-0.31
GY4	-0.10	**-0.69**	**-0.63**	-0.08	**-0.60**	**-0.49**
HM1	0.36	0.39	0.39	0.31	0.33	0.23
HM2	-0.20	**0.50**	**0.49**	-0.18	**0.44**	0.41
HM3	-0.22	0.32	0.23	-0.19	0.32	0.25
HM4	**-0.54**	-0.09	-0.35	**-0.54**	-0.12	-0.34
HM5	0.23	0.06	0.22	0.27	0.04	0.27
HM6	-0.16	0.35	0.03	-0.06	0.06	-0.05
HV1	**-0.56**	-0.36	**-0.59**	**-0.54**	-0.36	**-0.59**
HV2	**-0.54**	-0.36	**-0.56**	**-0.42**	-0.36	**-0.48**
HV3	**-0.41**	-0.36	-0.37	**-0.42**	-0.36	**-0.42**
HV4	-0.37	-0.17	-0.34	-0.36	-0.17	-0.32
HV5	-0.20	-0.08	-0.20	-0.06	-0.08	-0.06
HV6	-0.01	n/a	-0.01	-0.01	n/a	-0.01
NN1	-0.28	**0.54**	**0.47**	-0.18	**0.57**	**0.60**
NN2	-0.20	**0.62**	**0.59**	-0.20	**0.55**	**0.54**
NN3	0.16	0.35	0.34	0.15	0.30	**0.42**
NN4	**-0.51**	**0.65**	**0.45**	**-0.42**	**0.64**	**0.42**
NN5	0.16	**0.51**	**0.47**	0.14	**0.41**	0.38
RO1	**-0.57**	-0.04	**-0.45**	-0.39	-0.03	-0.35

Site code	Filamentous annual mean	Mats annual mean	Filamentous + mats annual mean	Filamentous annual maximum	Mats annual maximum	Filamentous + mats annual maximum
RO3	-0.15	-0.29	-0.37	0.10	-0.15	-0.15
RO4	-0.16	-0.36	**-0.43**	0.06	-0.28	-0.21
RO5	0.24	**-0.44**	-0.20	**0.49**	-0.10	**0.47**
TK1	**-0.67**	0.01	**-0.64**	**-0.74**	-0.08	**-0.75**
TK2	**-0.87**	0.11	-0.38	**-0.88**	0.12	-0.37
TK3	-0.16	**0.63**	0.40	-0.17	0.38	0.09
TK4	-0.16	-0.26	-0.14	-0.12	-0.23	-0.09
TK5	**-0.65**	-0.35	**-0.66**	**-0.56**	-0.39	**-0.65**
TK6	**-0.60**	-0.07	-0.34	**-0.60**	-0.07	-0.31
TU1	**0.64**	-0.14	**0.42**	**0.78**	0.05	0.36
TU2	0.38	0.07	0.40	**0.54**	0.10	0.35
WA1	0.24	-0.27	0.27	0.16	-0.31	0.12
WA2	0.21	0.45	0.22	0.21	0.45	0.21
WA3	**-0.43**	0.01	-0.41	**-0.42**	0.01	-0.45
WA4	-0.05	-0.22	-0.08	-0.03	-0.22	-0.03
WA5	-0.03	0.33	0.01	0.07	0.34	0.11
WA6	**0.44**	0.05	**0.48**	**0.57**	0.05	**0.57**
WA7	-0.20	0.44	-0.13	**-0.57**	0.44	-0.35
WA8	0.01	0.39	0.08	-0.01	0.39	0.09
WA9	-0.18	0.07	-0.11	-0.32	0.07	-0.38
WH1	**-0.47**	0.36	-0.40	**-0.44**	0.36	-0.37
WH2	0.29	**-0.57**	-0.30	0.29	**-0.60**	-0.10
WH3	-0.30	0.12	-0.25	-0.34	0.12	-0.34
WH4	**-0.53**	0.24	**-0.55**	**-0.46**	0.24	**-0.44**
WN1	**-0.65**	-0.14	-0.35	**-0.66**	-0.33	**-0.54**
WN2	0.19	**0.45**	0.31	0.19	**0.45**	0.31
WN3	**-0.49**	0.03	-0.29	**-0.48**	0.13	-0.04
WN4	0.01	**0.60**	0.40	-0.08	**0.48**	0.39
WN5	0.09	0.18	0.07	0.11	0.11	-0.01

Note: Data representing a significant trend ($P < 0.10$) are in bold; n/a is correlation was not applicable to these data (e.g., all zero values). Values of $r_s > 0.485$ are significant at $P < 0.05$).