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Report on Periphyton and Invertebrate Communities in the Waiau River, February 1993

by

Barry J F Biggs

Prepared for:
Waiau Working Party

Freshwater Division
NIWA
PO Box 8602
Christchurch
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SUMMARY

An analysis of periphytic algae and invertebrates in the Waiau River between the Mararoa weir and the Borland Burn was carried out in February, 1993, to provide a background description of the communities and to indicate the likely effects of low flow regulation in the river. This work was also designed to complement the trout habitat analysis reported by Jowett (1993a). An abundant growth of periphyton was recorded in the Excelsior reach whereas a patchy, but generally low, growth occurred in the Redcliff and Blackmount reaches. Overall, highest biomasses of periphyton were located where velocities were low (< 0.1 m/s), particularly in the Excelsior reach where filamentous green algae dominated the communities. The two lower reaches were dominated by cosmopolitan taxa and one green filamentous alga (*Bulbochaete* sp.) which is not common elsewhere in New Zealand.

The occurence and distribution of many of the invertebrate taxa reflected these differences in periphyton development. Areas of high periphyton biomass (eg, the Excelsior reach) were dominated by small burrowing invertebrates (eg, chironomids and oligochaetes; which are normally indicative of polluted conditions) and some caddis-fly larvae. Conversely, areas with low periphyton (parts of the Redcliff and Blackmount reaches) had much lower densities of burrowing invertebrates, and higher proportions of taxa prefering clean substrates (eg, mayflies). These taxa are more available as food for adult trout. Thus, the low flows, and resulting low velocities in the river, appear to be having an important affect on the structure of benthic communities. An increase in mean water velocities in the study reaches to at least 0.3 m/s would help control the accumulation of periphyton and aid the development of a more diverse 'clean-water' invertebrate fauna.

INTRODUCTION

Recent research has shown that it is important to consider both periphyton (i.e., plant growth composed mainly of algae attached to the river bed) and invertebrates in investigations of fish habitat in New Zealand rivers (Biggs et al. 1990). Reasons include:

a) fish production is strongly correlated with the availability of large drifting invertebrates (Jowett 1993b) and the absence of such invertebrates has been attributed to the development of high periphyton biomass (Quinn & Hickey 1990b);

b) nuisance blooms of filamentous algae (to which regulated rivers are particularly prone) can potentially smoother benthic habitats (including trout spawning gravels) (Biggs 1985) reducing the ability for natural recruitment of fish;

c) high daily fluctuations in pH associated with the photosynthetic activity of the periphyton often develop in poorly buffered waters (Biggs 1982, Biggs & Hickey 1991) and this is potentially lethal to juvenile fish.

Background: mechanisms by which periphyton and invertebrates are affected by flow regulation

The mechanisms by which periphyton and invertebrates are affected by flow change, and how this can then influence fish populations, involve a somewhat complex series of ecological interactions. In unregulated rivers, which are not predominantly spring-fed, the following generalised model of production regulation can be invoked (after Biggs 1987a, and Biggs & Close 1989, Fisher & Grimm 1991). The functional controlling variables are summarised in Fig. 1.

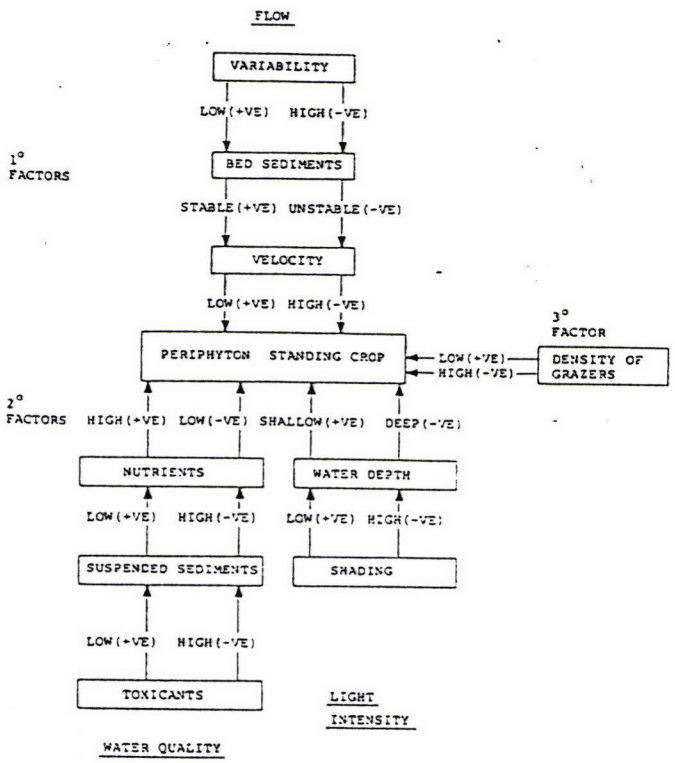


Figure 1 Summary of factors affecting periphyton standing crop in rivers. The factors are prioritized for their suggested importance in affecting the development of periphyton standing crop. The extremes for each factor are indicated and whether they are likely to have a beneficial (+ve) or detrimental (-ve) effect on periphyton development. High standing crops are generally dependent on all 1° factors (flow regime) being +ve. The extent of favourable conditions in the 2° factors (water quality and light intensity) will affect the degree of standing crop development.

Periphyton biomass is generally abiotically controlled for much of the year through disruption by fresh events. The degree of wash-out with any one event depends on the density of the pre-flood communities, the magnitude of increase in water velocities during the event, and stability of the bed sediments (Biggs & Close 1989). Between each event the extent of regrowth depends on the time available before the next flood disturbance and the rate at which the communities re-develop (this being a function of secondary factors such as water temperature, nutrients, light etc, Fig. 1). With regular (say monthly) floods a recurring pattern of growth and loss can often be identified (Fig. 2, Fisher & Grimm 1991). Such communities are said to be 'abiotically' (ie, physically) controlled. They are likely to have a 'bottom-up' food web structure where-by rates of production by fish (eg, trout) are controlled through the food chain by the degree of inter-flood periphyton, and then invertebrate, growth. In an extended period without floods (e.g., summer low flows) periphytic biomass can continue to accrue and biotic interactions become increasingly important as the dominant controller of community dynamics (Fig. 2). Invertebrate densities can become high, although diversity is expected to decrease. These organisms may start to control periphyton providing the periphyton has not prevented the colonisation of large grazers, eventually leading to 'top down' control of biomass accrual at the invertebrate and periphyton levels (Power 1992). In catchments with enriched waters, bed smothering by periphyton and a shift from stone surface dwelling invertebrates to burrowing and organic matter tolerant taxa can occur at such times (Quinn & Hickey 1990b).

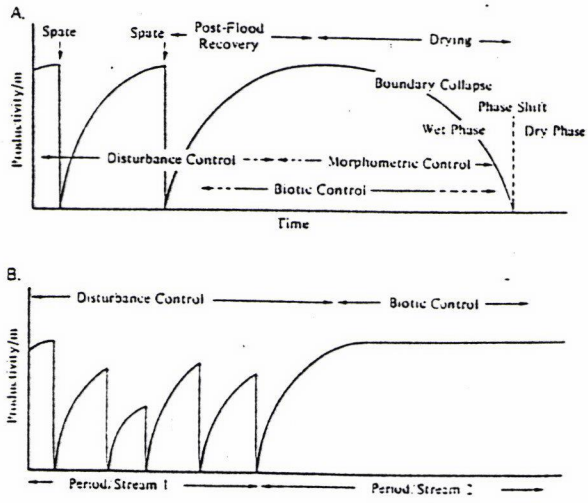


Fig. 2: Conceptual model of temporal shift in control of ecosystem functioning in a stream influenced by flash flooding (freshes). The dependant variable (vertical axis) is the amount of productivity per linear metre of stream bed. A decline in productivity during the drying period (natural or by impoundment regulation of flow) is caused by stream shrinkage. Panel A: Initially the system is physically controlled by disturbance and as biotic interactions intensify with time after initial flood disturbance then they become a more important controller of dynamics. At late stages, these interactions may be disrupted by morphometric constraints. Panel B: In streams where floods are frequent (stream 1), disturbance-related variables are influential in shaping ecosystem structure and functioning. Where flow is more stable (eg, spring-fed, or regulated flows), biotic interactions control the system. This difference may also apply to a single stream that experiences periodic shifts in disturbances (eg, regulated flows where excess water is periodically spilled from the

Regulated rivers fall into this second category of processes. Flood events are infrequent (mainly when reservoir spillage occurs) leading to long periods of stable, and sometimes low, flow. The bed sediments are generally very stable making for excellent substrates upon which periphyton can accumulate, water velocities are low (a function of the low channel gradients and generally low regulated flows), and there is often enrichment from groundwaters (with low flows there is little dilution of these nutrient rich seepages) (Biggs 1982). In such circumstances periphytic biomass can accrue quickly to substantial levels (Fig. 2, Panel B, stream 2). Thus, the invertebrate communities can become more typical of those in polluted environments (a result of an over-accumulation of primary production) and degradation of water quality can also occur. Large amounts of potentially suitable hydraulic habitat for trout probably cannot be occupied because the secondary environment is so degraded. In natural lake out-flows the balance between abiotic and biotic control appears to be maintained through a combination of some bed sediment movement, higher water velocities tearing accumulations of periphyton from the bed, and grazer densities developing over longer periods of stable flows which match the primary production and keep excessive growths from accruing.

Benthic communities in other regulated rivers of New Zealand

Two regulated South Island rivers have had studies of periphyton and invertebrate development. These are the Hawea and Ohau Rivers. Biggs (1982) and Biggs & Malthus (1982) found summer proliferations of periphyton in the Hawea, very high densities of invertebrates (mainly burrowing chironomids which were very highly correlated in density with periphyton biomass), daily pH fluctuations which increased moving down the river (pH 7.7 to 9.0), and water temperatures exceeding 18 ^{o}C. Locals reported that the fishing was always poor soon after the green filmentous algae appeared in the river, this being a month or so after flow reductions in spring. A drift dive survey of the lower half of the river at such a time revealed only 2 adult trout in 6 km (Biggs unpublished data).

For the Ohau River, Biggs & Hickey (1991) reported high periphyton biomass in July and August during the trout spawning season even though nutrient concentrations were low. As in the Hawea River a high pH was recorded at certain times of the year and experiments with the periphyton established a quantitative link between productivity and pH change. High mucilage accumulation in response to localised increases in shear stress was also identified in areas of shallow and swift water (high

Froude number) because the communities were dominated by stalked diatoms. Invertebrate communities in riffles of the river were dominated by chironomids just downstream of the control gates, and this changed to a chironomid/*Pycnocentrodes/Deleatidium* fauna further down the river (James et al. 1990). The composition of these communities was considered to reflect the stable flows, large sediment size and high periphyton biomass.

STUDY OBJECTIVES

The objectives of the following study were to: a) carry out an initial resource assessment of the benthic communities in the Waiau river; b) suggest effects of current low-flow regulation on benthic communities; and c) identify more detailed studies which may be necessary for assessment of alternative flow regimes.

The study was designed to conform to a set budget and thus only includes a once-off set of samples from three sites. As such it must be recognised that no comment is possible on the natural variability of communities, the extent of periphyton development during critical fish spawning periods, the effects of changes in flow on nutrient limitation, nor the effects of periphyton on pH/dissolved oxygen dynamics in the river. James et al. (1990) speculated that any accumulation of periphyton and silt may result in lower trout stocks than projected from habitat modelling in the Ohau River. This emphasises the need to consider the whole ecosystem when carrying out environmental assessments for rivers.

METHODS

Periphyton and invertebrate sampling was carried out on 17/18 February, 1993. One cross-section was sampled in each of the three fish habitat study reaches described by Jowett (1993a) (Fig. 3). These were cross-sections no. 4 in the Excelsior reach, no. 7 in the Redcliff reach, and no. 6 in the Beaumont reach.

For each cross-section, ten stones were collected from the bed at equi-distant points and taken to the river bank where the periphyton within an area defined by a 6cm diameter circle was removed using a scalpel. Five invertebrate samples were then collected, also at equi-distant points, using a Surber sampler with a 350 um mesh net and a 0.1 square metre quadrat. The samples were thoroughly rinsed to remove fines

and then coarse gravels picked out before placing the remaining material in a container. Samples were preserved in iso-propyl alcohol.

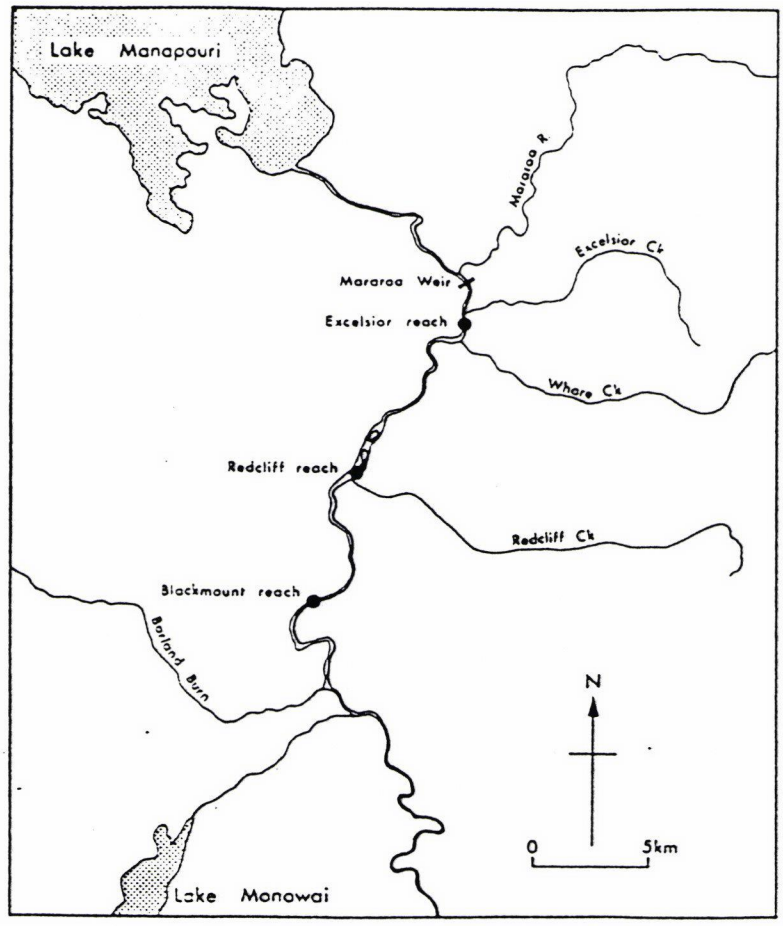


Fig. 3: Location of the in-stream habitat and benthic biota study reaches.

In the laboratory, the periphyton was blended and three subsamples removed for analysis of chlorophyll *a* (a measure of algal biomass) and ash-free dry weight (AFDW, a measure of the total organic matter). The autotrophic index (AI) was calculated as the ratio of AFDW/chlorophyll *a* (after correcting for differences in units). This indicates the relative proportion of total organic matter to live biomass, and the percent organic weight (AFDW/dry weight) as a measure of the amount of inorgainc detritus (silt) in the mat. Chlorophyll *a* was extracted in boiling ethanol and AFDW determined after drying at 105 ^{o}C for 24 hours and combusting at 500 ^{o}C over 4 hours (Biggs 1987b). The relative abundance of periphyton taxa was determined using an inverted microscope and scoring on a 1-8 scale. Invertebrates were sorted and counted under magnification (up to 100 times) and their diversity calculated using the Shannon-Weaver index (Quinn & Hickey 1990a).

RESULTS

General habitat

The Excelsior reach was a single well confined channel with a pool-riffle-run character and bed materials dominated by boulders (Jowett 1993a). The surveyed cross-section had moderately deep waters, a low gradient, low water velocities, and a flow of only 0.52 m^3/s. Unlike the overall reach, the substrate of the surveyed cross section was dominated more by gravels (Table 1). The physical character of this reach was analogous to that surveyed in the Ohau River just downstream of the control gates (James et. al 1990). Thick mats of periphyton were observed on the river bed, particularly the large cobbles and boulders. In places where velocities were very low 'slime debris' accumulated on the gravels.

The Redcliff reach was a more diverse habitat, probably as a result of its less confined nature, predominantly cobble bed, and more frequent channel movement. The reach included two riffles, one of which was quite steep, a run, and a 2 metre deep pool which was fed by a broad riffle (Jowett 1993a). It had the appearance of a typical New Zealand foothills-fed river, but with substantially reduced flows (compared with the channel width). Flow here had increased to 2.11 m^3/s with the addition of further tributaries upstream of the site. The surveyed cross section went across a fairly shallow run which had a moderate to low mean velocity, and a bed dominated by cobbles and gravels (Table 1).

The Blackmount reach was very broad (55 m) and with a uniformly low gradient resulting in a structure of long slow runs and shallow pools. The substrates were dominated by cobbles and gravels (Jowett 1993a). Flow in the river had increased to 3.91 m^3/s. The surveyed cross-section went across a very broad run which was generally < 0.3m deep and had a mean velocity of 0.28 m/s. Bed composition here was predominantly gravels and cobbles with conspicuous periphyton growth in the shallows of the true left side.

Table 1: Habitat characteristics of sampling reach (from Jowett pers. comm.).

	Excelsior	Redcliff	Blackmount
Distance from Mararoa weir (km)	1.2	10.8	18.3
Reach length (m)	324	167	237
Gradient	0.009	0.0064	0.0026
Flow (m3/s)	0.52	2.11	3.91
Mean depth of transect (m)	0.351	0.262	0.276
Mean velocity of transect (m/s)	0.100	0.265	0.281
Width of transect (m)	20.0	26.6	55.0
Substrates (%)			
Boulders	21	4	15
Cobbles	22	63	26
Gravel	57	35	45
Fine gravel	0	0	0
Sand	0	0	0
Silt & Vegetation	0	0	15

Periphyton

A thick mat of periphyton was present at the Excelsior reach, 1.2 km downstream of the Mararoa weir. Just under half the water in this reach was derived from Excelsior Creek (Jowett 1993a), but the periphyton accumulation was much greater than was observed in the creek itself reflecting the more stable, low velocity regime, of the study reach (see later). Periphyton biomass (as chlorophyll a and AFDW) was significantly higher in this reach than at either of the other reaches (Table 2). By comparison with other rivers in New Zealand this site could be classified as having a 'medium-biomass' (the median AFDW of this class of sites in the '100 Rivers' study was 28.5 g/m^2, Biggs 1990). The communities forming these growths were dominated by the green filamentous alga *Oedogonium* sp. and the blue/green bacteria *Tolypothrix* sp., with a range of diatoms within this filamentous matrix (Appendix 1). While these taxa are commonly found elsewhere (Biggs & Price 1987, Biggs 1990), *Oedogonium* sp. is normally associated with moderate levels of agricultural development (c. 20% intensive land development) and associated moderate enrichment (Biggs 1990).

Table 2: Periphyton data for the Waiau River cross-sections

Variable	Excelsior	Redcliff	Blackmount	ANOVA
Chlorophyll *a* (mg m^{-2})	97	5.3	9.7	0.000
Ash-free dry weight (g m^{-2})	24	4.0	4.5	0.009
Autotrophic index	251	758	471	0.001
Organic Weight (%)	29	33	24	0.062
Dominant taxa	*Oedogonium* sp. *Tolypothrix* sp. *Phormidium* sp. *Synedra ulna*	*S. ulna* *Bulbochaete* sp. *Cymbella kappii*	*S. ulna* *C. Kappii* *Microspora* sp.	

The distribution of biomass across the cross-section was moderately even (Fig. 3). The velocities were all low enough to allow for major biomass accrual (see later). The average AI at this site was low indicating that the communities were dominated by healthy algae. The percentage organic matter values were high indicating that there was little silt accumulation in the matrix. The inverse relationship between the Autotrophic Index and water velocity (Fig. 4), though weak, implies that the areas of higher velocity maintained a community containing less organic detritus. Such patches could provide a higher quality food resource for invertebrate grazers.

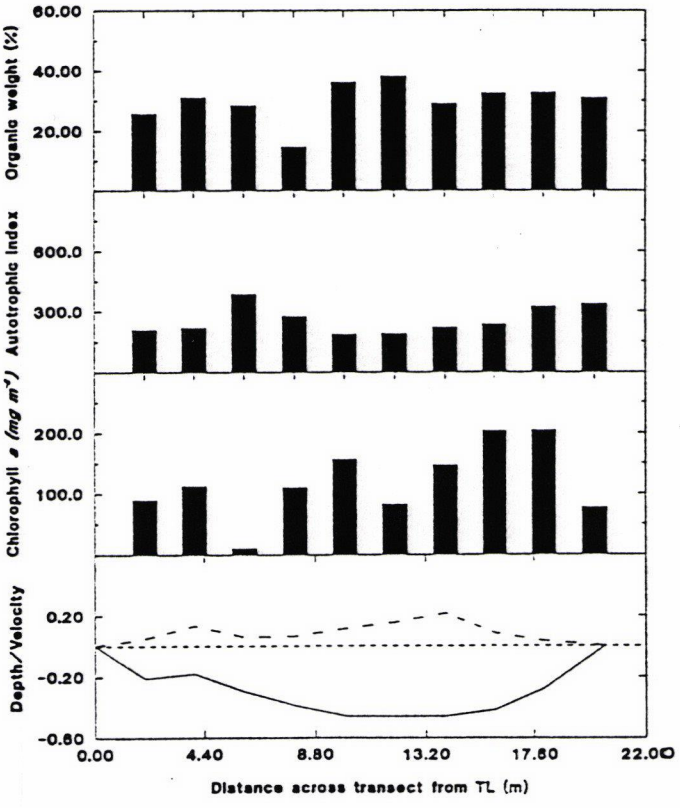


Fig. 4: Surveyed cross-section at the Excelsior reach showing distribution of periphyton across the river and the depth/velocity regime.

The communities at both the Redcliff and Blackmount reaches had AFDW values (Table 2) typical of unenriched, 'low-biomass class', rivers elsewhere in New Zealand (Biggs 1990). Communities at both sites were dominated by the same set of diatoms (commonly *Synedra ulna* and *Cymbella kappii/minuta*, Table 2), but the small green filamentous alga *Bulbochaete* sp. was also abundant in patches at Redcliff. The diatoms are among a core group found extensively throughout New Zealand, but *Bulbochaete* sp. is not common elsewhere (Biggs & Price 1987, Biggs 1990).

Periphyton distribution across the river at each of these sites was patchy, with higher development along one side compared with its opposite, presumably in response to greater bed sediment stability there (Figs. 5 & 6). Larger amounts of silt appeared to have accumulated in the matrix at the Blackmount reach (Table 2) and the AI values were higher at both sites indicating that a lower proportion of the community was composed of productive algae than occurred in the Excelsior reach. There was a weak inverse relationship between the AI and water velocity across the Redcliff reach.

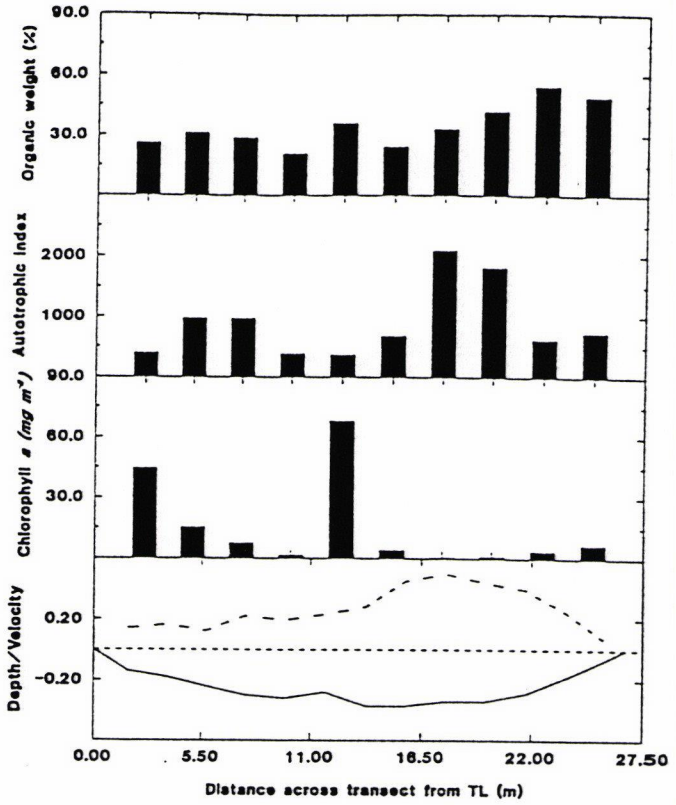


Fig. 5: Surveyed cross-section at the Redcliff reach showing distribution of periphyton across the river and the depth/velocity regime.

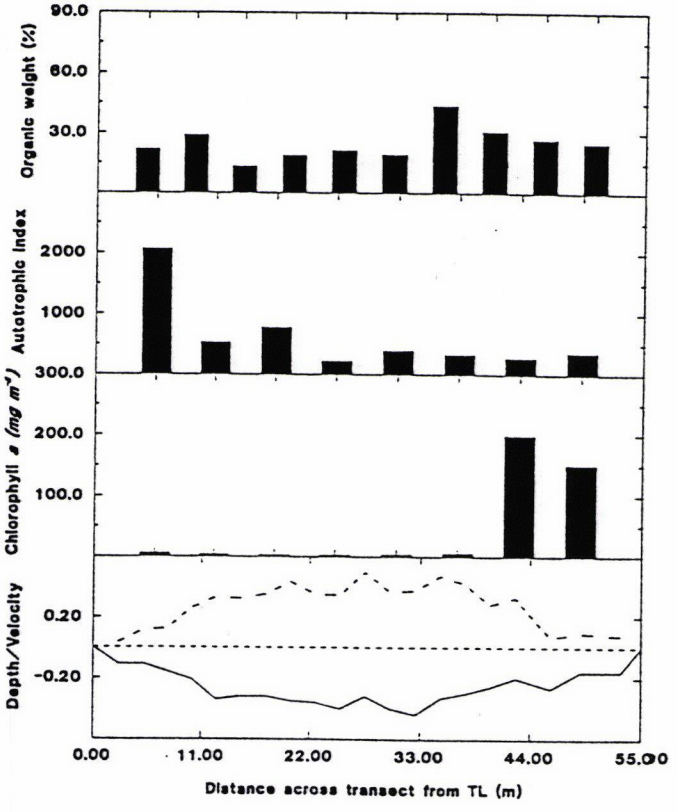


Fig. 6: Surveyed cross-section at the Blackmount reach showing distribution of periphyton across the river and the depth/velocity regime.

Overall, there was a strong inverse relationship between periphytic biomass (as chlorophyll *a*) and site hydraulics across the dataset. As shown in Fig. 7 accumulated periphyton decreased as water velocity increased to 0.6 m/s and Froude number increased to 0.3. This implies physical control of summer biomass accumulation. The low velocities, and associated low shear stress, at some sampling points were facilitating the accumulation of large amounts of organic matter. Thus, the higher biomass recorded at the Excelsior reach can be explained by its lower average cross-section velocity (Table 1). Low biomass was generally recorded where velocities were > 0.3 m/s. Similar physical control of spatial differences in accumulated algae has been found previously in the regulated Hawea River (Biggs & Malthus 1982) and the Motueka River catchment, Nelson (Biggs & Gerbeaux 1993).

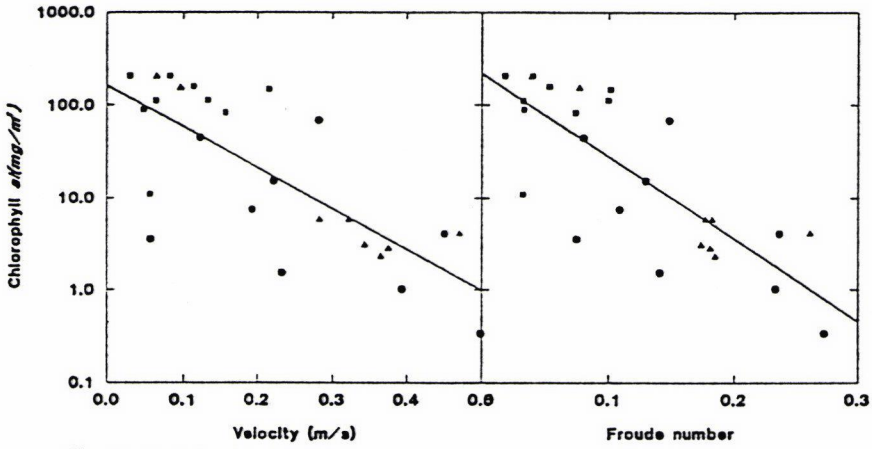


Fig. 7: Relationship between periphyton biomass (as chlorophyll *a*) and hydraulic parameters among the survey reaches (r=-0.758 for velocity, r=-0.801 for Froude). Squares = Excelsior reach, circles = Redcliff, triangles = Blackmount.

Invertebrates

Invertebrate communities at the study reaches were well developed and composed predominantly of insect taxa (Table 3). Densities in the Excelsior reach were particularly high at over 5,000 individuals /m^2 (within the top 10 % of rivers in the '100 Rivers' survey, Quinn & Hickey 1990a). These dropped to just over 1000 /m^2 at the two downstream reaches which is close to the median for rivers elsewhere in New Zealand. The number of taxa (ie, species richness) recorded at two of the sites was among the top 5% of the '100 Rivers' survey, and the taxonomic richness at Redcliff exceeded that of all the rivers in the '100 Rivers' study. The species diversity index of the Redcliff site was also particularly high (2.16), being equivalent to the highest reported by Quinn & Hickey (1990a), and showing that there were many taxa with a moderate to high relative abundance. Diversity at the other two sites was equivalent to that of the top 25% of rivers surveyed in the '100 Rivers' study.

There was some overlap in community structure between the reaches (Fig. 8), with samples from Redcliff and Blackmount clustering closely. In contrast, samples from the Excelsior reach appeared more discrete reflecting the dominance of oligochaete worms and chironomids, with the small

Table 3: Summary of geometric mean invertebrate densities per square metre from five surber samples at three cross-sections in reaches of the Waiau River, February 1993.

	Excelsior	Redcliff	Blackmount	ANOVA
Nematoda	0	0.8	0	-
Annelida (worms)				
Oligochaeta sp.	2282	58	177	0.007
Mollusca (snails)				
Gyraulus corrina	0.6	0	0.6	-
Lymnea collumella	4	14	12	0.591
Physa sp.	4	26	13	0.365
Potamopyrgus antipodarum	9	95	3.8	0.041
Insecta-Coleoptera (beetles)				
Berosus sp.	23	0.6	3.0	0.118
Coleoptera (adults)	0	8.6	0.6	-
Elmidae	180	245	148	0.644
- Diptera (two-winged flies)				
Aprophila sp.	0	38	2.9	-
Austrosimulium sp.	0	7.8	0.6	-
Chironomidae	1,240	25	185	0.002
Empididae	130	2	1.8	0.025
Eriopterini	0.6	0	0	-
Muscidae	10	2	1.1	-
Stratiomyidae	2	0	0	-
- Ephemeroptera (mayflies)				
Deleatidium sp.	12	142	60	0.095
Nesameletus sp.	0	0.6	4.9	-
Rallidens sp.	0	0	0.6	-
- Megaloptera (dobson fly)				
Archichaulioides diversus	0.6	3	3.9	0.604
- Plecoptera (stonefly)				
Zelandobius sp.	0.6	1.6	0	-
Zelandoperla sp.	0.6	0.4	0	-
- Trichoptera (caddisfly)				
Aoteopsyche sp.	50	318	49	0.168
Hydrobiosis sp.	0	0.6	0	-
Hydroliciosis umbripennes	0.6	0.2	0	-
Olinga feredayi	2.4	5.1	0	-
Oxythira albiceps	695	154	68	0.152
Polyplectropus sp.	0.6	4	0	-
Pycnocentrella sp.	374	17	512	0.004
Pycnocertrodes sp.	7.4	1.9	2.6	0.808
Arachnidia (mites)				
Acarinae	3	7.3	4.7	0.624
Total density (per m^2)	5,032	1,179	1,255	
Number of Taxa	24	27	22	
Diversity (H')	1.54	2.16	1.85	

cased-caddis larvae *Oxyethira albiceps* and *Pycnocentrella* sp. being abundant. Quinn & Hickey suggested that the high abundance of oligochaetes in such stony run habitats indicates nutrient and organic enrichment, and they also considered that *Oxyethira* is a useful indicator of filamentous periphyton biomass.

In contrast, samples from Redcliff were dominated by net spinning caddis larvae, *Aoteapsyche colonica*, elmid beetles, and the mayfly larvae *Deleatidium* sp. *Oxyethira albiceps* was present at much lower densities than upstream, but was still an important component of the fauna. The Blackmount cross-section was intermediate of the two up-stream communities with *Pycnocentrella* and chironomids being dominant, and oligochaetes and elmid beetles being abundant.

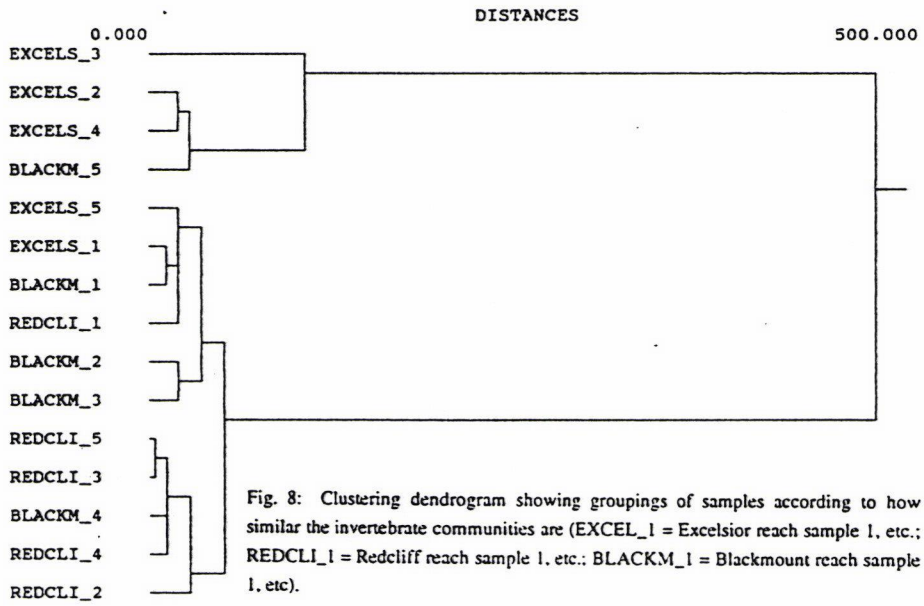


Fig. 8: Clustering dendrogram showing groupings of samples according to how similar the invertebrate communities are (EXCEL_1 = Excelsior reach sample 1, etc.; REDCLI_1 = Redcliff reach sample 1, etc.; BLACKM_1 = Blackmount reach sample 1, etc).

The densities of chironomids, *Pycnocentrella*, Oligochaetes, *Potamopyrgus*, and Empididae varied significantly among the sites (Table 3). Only two stone-fly taxa were recorded and these were present at very low abundances.

Some important relationships occurred between the distribution of many invertebrate taxa and periphyton biomass (Table 4). Oligochaete worms, all the common dipteran larvae, and three of the four main caddis larvae, all increased in abundance with increasing periphyton biomass. Densities of *Oxyethira* were also significantly positively correlated with periphyton biomass, as expected from Quinn & Hickey (1990a). However, densities of the two principal mayfly taxa and the dobson-fly larvae (*Archichaulioides*) were all negatively correlated with periphyton biomass. Taxa which increased in abundance with periphyton were mainly those that burrow into the periphyton matrix for shelter and also food, and also cased grazers, browsers, or algal piercing suckers (Winterbourn 1981, Quinn & Hickey 1990a).

Taxa whose densities were inversely related to periphyton mainly were the stone surface dwelling mayflies which are normally associated with, and probably graze, thin films of diatoms (Winterbourn et al. 1984, Jowett & Richardson 1990). The dobson-fly larva is a predator and has been most commonly found at sites with low periphyton development elsewhere in New Zealand (Quinn & Hickey 1990a). These results suggest that high periphyton development (associated with low water velocities in some parts of the river - particularly in the Excelsior reach) is having a major impact on the invertebrate fauna of the river. This has important implications for fish food availability (see Discussion).

Table 4: Correlations between common invertebrates and periphyton development.

Variables	r	P
1 Annelida		
Ln Oligochaeta * chlorophyll *a*	0.661	0.007
2 Insecta-Diptera		
Chironomidae * chlorophyll *a*	0.592	0.020
Ln Empidae * chlorophyll *a*	0.728	0.002
Ln Muscidae * Chlorophyll *a*	0.642	0.010
* AFDW	0.557	0.031
- Ephemeroptera		
Ln *Deleatidium* sp. * Ln AFDW	-0.547	0.035
Nesamaletus sp. * Ln chlorophyll *a*	-0.546	0.035
* Ln AFDW	-0.539	0.038
- Megaloptera		
Ln *Archichaulioides diversus* * Ln chlor. *a*	-0.547	0.035
* Ln AFDW	-0.505	0.034
- Trichoptera		
Oxythira albiceps * Ln chlorophyll *a*	0.554	0.032
* Ln AFDW	0.611	0.015
Pycnocentrella sp. * chlorophyll *a*	0.632	0.011
* AFDW	0.571	0.026
Pycnocentrodes sp. * Ln chlorophyll *a*	0.603	0.017
* Ln AFDW	0.566	0.028

DISCUSSION

The composition and abundance of periphyton and invertebrates showed major changes down the Waiau River from the Mararoa weir to the Borland Burn. Immediately below the weir (Excelsior reach) many of the physical and biological features of a low disturbance regime stream were found, such as a high abundance of periphyton and invertebrates (see Introduction). However, the composition of the invertebrates was somewhat degraded, and did not reflect the high quality of the overlying waters (Stark 1985) This is most likely a result of the high periphyton developments under the current flow regulation regime.

Downstream from Excelsior there is a progressive change in river bed gradient, and introduction of tributary waters. These appear to mitigate the effects of the flow management regime. Average reach velocities increase, river bed sediments become finer and appear less stable (see Jowett 1993a, Table 1), and periphyton biomass decreases. There is an associated reduction in invertebrate density, but an important increase in diversity. Large drifting taxa, such as mayflies, then start to become important in the fauna.

It is well recognised that lake outlet faunas are different from inflow rivers because of the effects of the lake on flows, sediment movement, and carbon fluxes (Ward & Stanford 1979). Thus, we should not expect the Waiau to be analogous to 'normal' streams. However, impoundment of outflows can further alter physico-chemical and bed sediment properties. These modifications have been shown to greatly alter invertebrate composition compared with unregulated outflows elsewhere in New Zealand (Biggs 1982, Biggs & Malthus 1982, Harding 1992). Even with regulation, net-spinning caddis larvae, and a range of other taxa, are expected to be common. However, these taxa were not abundant in the Excelsior reach, probably as a result of the high periphyton development.

Biggs (1982), and James et al. (1991), both emphasised the importance of periphyton in controlling the abundance and distribution of different invertebrate taxa in regulated rivers and, as indicated earlier, it is probably the development of periphyton which is having the greatest direct impact on the invertebrates in the Waiau. High accumulations of periphyton appear to affect invertebrate communities through several processes. These include: changing food availability, altering the substrate surface, smoothering the interstices of the cobbles causing oxygen depletion, and confering strong daily changes in oxygen and pH (Biggs 1982, Quinn & Hickey 1990a, 1990b). These factors help explain why invertebrate communities in many of the samples were more typical of polluted environments rather than for a river of such pristine water quality.

These findings are relevant to assessing trout food availability in the river. Jowett (1993b) found that food availability was the single most important factor with which brown trout abundance was correlated in New Zealand rivers. The loss of large "behavioural drifting" stoneflies and mayflies, and their replacement by small chironomids, algal piercing caddis larvae, and snails that occur less in the drift (Brittain & Eikland 1988), would be expected to reduce the feeding efficiency of

larger, drift feeding fish such as adult brown trout. Organisms that burrow into the periphyton mats, such as chironomids and oligochaetes, are utilised by foraging juvenile trout (J. Hayes, NIWA- Freshwater pers. comm.). However, adult trout tend to be opportunistic scavengers of large drift organisms and, in particular, mayflies (McLennan & MacMillan 1984). Thus, the exclusion of larger taxa by periphyton proliferations in the upper section of the river could conceivably greatly reduce the amount of food available for adult trout. The results of Quinn & Hickey (1990b), in the '100 Rivers' study, support this suggestion since they found that median trout biomass in rivers with high periphyton development was only about a third of that in rivers with moderate to low periphyton biomass. The low trout biomass rivers were dominated by oligochaete and chironomid invertebrates such as those recorded in the Waiau (particularly the Excelsior reach) during this study.

The relationship between periphyton biomass and water velocity (Fig. 7) suggests that an increase in flows in the Waiau could be used to control the accrual of the periphyton. This would then most likely improve the quality of the matrix for invertebrates, and result in an overall improvement in invertebrate communities. Flows which gave a mean reach velocity of greater than 0.3 m/s should be sufficient to do this. There would still be little sediment movement (if the current sediment supply regime is unaltered) for retaining a stable invertebrate habitat, but the shear stress associated with such velocities should prevent periphyton accrual detrimental to other biota.

FURTHER STUDIES

Two further, relatively small scale, studies seem warranted. Firstly, a paired comparison should be carried out between periphyton/invertebrate communities at a site in the Wairau River (between Te Anau and Manapouri) with one in the Excelsior reach of the Waiau. Sampling should be structured so that (say) three velocity categories are covered (including those typically found in the Wairau), with the lowest emulating the conditions in the Excelsior reach. This would give a more definitive picture of possible benefits to invertebrate community structure in the Waiau of increasing the residual flows and specifically test the hypothesis that "under higher velocities periphyton biomass would be more restricted and, associated with this, there would be a shift toward a more diverse invertebrate fauna with higher proportions (and densities) of larger stone surface dwelling mayflies and stone flies". Thus, there would be a testing of the general un-coupling of the biotic

periphyton/invertebrate link (ie, there would be no correlation between the density of most invertebrates and periphyton biomass) with higher velocities. A simple nutrient limitation experiment should be carried out at the sites also. This would indicate whether nutrients in the waters from Excelsior Creek are compounding the hydraulic effects of low-flow regulation in the Excelsior reach. Such a study would allow critical examination of the likely success of using higher flows/velocities in the river to control periphyton accumulation as well as obtaining some useful background data on the Wairau.

Secondly, a more comprehensive analysis of hydraulic habitat preferences of periphyton would be useful if the recommended velocity of 0.3 m/s became a critical issue in determining future flow management policies.

In the 'nice to do' category would be an investigation to see for how much of the year periphyton and invertebrate biomass/densities are correlated. At present we can only say that the observed relationships are a summer phenomenon and thus this characterisation and the predictions are most relevant to that period.

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WAIAU PERIPHYTON

Only the more common species were identified. Other species were present.

Cross-section 1: 1 & 2

7 *Oedogonium* sp.
7 *Synedra ulna*
5 *Achnanthes linearis*
5 *Gomphonema parvulum*
4 *Tolypothrix* sp.
4 *Cymbella kappii*
4 *Gomphoneis herculeana*

Diverse flora

Cross-section 1: 3 & 4

8 *Oedogonium* sp.
7 *Synedra ulna*
6 *Phormidium* sp.
4 *Gomphonema angustum*
4 *Tolypothrix* sp.
4 *Cymbella minuta*
3 *Cymbella kappii*
3 *Gomphonema parvulum*

Diverse flora

Cross-section 1: 5 & 6

8 *Tolypothrix* sp.
5 *Phormidium* sp.
5 *Synedra ulna*
4 *Gomphonema parvulum*
3 *Oedogonium* sp.
3 *Navicula avenacea*

Diverse flora

Cross-section 1: 7 & 8

8 *Tolypothrix* sp.
5 *Oedogonium* sp.
5 *Synedra ulna*
5 *Phormidium* sp.
4 *Gomphonema parvulum*
4 *Cymbella kappii*
4 *Cymbella minuta*

Diverse flora

Cross-section 1: 9 & 10

8 *Oedogonium* sp.
6 *Synedra ulna*
5 *Cymbella kappii*
5 *Cymbella minuta*
4 *Phormidium* sp.
4 *Tolypothrix* sp.
4 *Gomphonema parvulum*

Diverse flora

Cross-section 2: 1 & 2

Synedra ulna
Cymbella minuta
Navicula avenacea
Bulbochaete sp.
Microspora sp.

Very sparse sample, only one or two of each species seen.

Cross-section 2: 3 & 4

Synedra ulna
Cymbella kappii
Gomphonema parvulum
Gomphoneis herculeana
Melosira varians

Very sparse sample, only one or two of each species seen.

Cross-section 2: 5 & 6

8 *Synedra ulna*
4 *Bulbochaete* sp.
3 *Cymbella kappii*
3 *Tolypothrix* sp.
2 *Achnanthes linearis*

Sparse sample, more in 6.

Cross-section 2: 7 & 8

8 *Bulbochaete* sp.
7 *Synedra ulna*
4 *Microspora* sp.
3 *Cymbella kappii*
2 *Oedogonium* sp.

Sparse sample.

Cross-section 2: 9 & 10

8 *Bulbochaete* sp.
6 *Synedra ulna*
3 *Cymbella kappii*
2 *Spirogyra*
2 *Oedogonium* sp.
2 *Gomphonema parvulum*

Cross-section 3: 1 & 2

8 *Synedra ulna*
7 *Phormidium* sp.
3 *Spirogyra*
3 *Oedogonium* sp.
3 *Gomphoneis herculeana*
2 *Cymbella kappii*

Cross-section 3: 3 & 4

Synedra ulna
Cymbella kappii
Microspora sp.

Very sparse sample

Cross-section 3: 5 & 6

Synedra ulna
Gomphoneis herculeana
Cymbella kappii
Gomphonema parvulum

Very sparse sample

Cross-section 3: 7 & 8

8 *Synedra ulna*
3 *Cymbella kappii*
3 *Microspora* sp.
2 *Gomphonema clevei*
2 *Achnanthes linearis*

Sparse sample

Cross-section 3: 9 & 10

8 *Synedra ulna*
5 *Microspora* sp.
4 *Cymbella kappii*
3 *Gomphonema parvulum*
3 *Tolypothrix* sp.?
3 *Bulbochaete* sp.