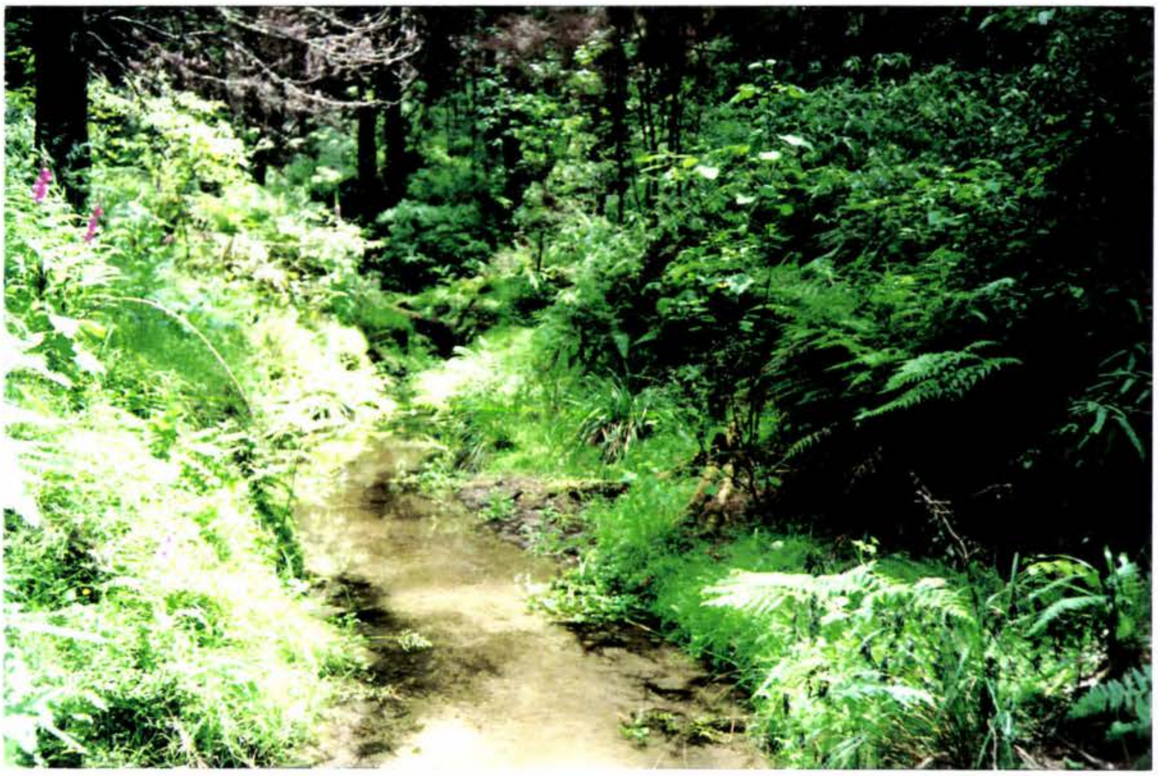
THE EFFECT OF LAND USE ON BENTHIC COMMUNITIES IN HAWKES BAY STREAMS OF DIFFERING GEOLOGY.



A thesis presented in partial fulfilment
of the requirements for the degree of
Master of Science in Ecology
at Massey University

JASON ROSS GIBSON

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Front page photograph: Pakuratahi Stream (2), Hawkes Bay. Taken 18 December 1996 by author.

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Errata Sheet

p. 9, line 18: should read: ...invertebrate **communities** and periphyton **biomass** through...

p. 10, line 5: should read: ...and periphyton **assemblages**, and to establish...

p. 10, line 7: should read: ...of periphyton **biomass** is also examined...

p. 17, line 9: should read: ...mesh) were **randomly** collected from...

p. 17, line 12: should read: ...mid channel within **riffles along** a 20m section...

p. 18, line 20: should read: ...and invertebrate data. **ANOVA calculations were conducted at the 0.05 level of significance, and** if necessary, data was log...

p. 19, insert after line 12: ***Community indices***

Two indices were used to assess species diversity.

These were:

1. Margalef's index (a simple measure of species richness) given by the formula:

$$D = (S - 1) / \ln N,$$

where S is the species number and N is the total number of individuals collected (Clifford and Stephenson 1975).

2. Berger Parker index (a simple measure of evenness, or dominance) given by:

$$D = N_{max} / N,$$

where N_{max} is the number of individuals in the most abundant species and N is the total number of individuals collected (Berger and Parker 1970).

Water quality was assessed by calculating the MCI (Macroinvertebrate Community Index) and QMCI (Quantitative Macroinvertebrate Community Index) (Stark 1985). An Ephemeroptera, Plecoptera, and Trichoptera (EPT) ratio was also calculated to assess water quality (Lenat 1988).

p. 21, line 1: omit: **'degrees of freedom,'**

p. 21, line 4: should read ...region. **The statistical level of significance for p-values is 0.05.**

p. 22, line 1: omit: **'4 replicate stone samples in'**

Figures on pp. 22, 24, 27, 29, 30, 31, & 32:

Bars equal the average site values, thus removing error bars for all exotic Pleistocene, logged limestone, & native limestone streams.

p. 23, line 1: should read: Total POM was **significantly** lower at...

pp. 24, 25, 27, & 29, line 1: omit: **'4 replicate Surber samples in'**

pp. 30, 31, & 32, line 1: omit: **'4 replicate Surber samples collected in'**

p. 39, insert at line 1:

Berger, W. H.; Parker, F. L. 1970: Diversity of planktonic Foraminifera in deep sea sediments. *Science 168*: 1345-1347.

p. 39, insert after line 14:

Clifford, H. T.; Stephenson, W. 1975: An introduction to numerical classification, Academic Press, London.

p. 42, insert after line 17:

Lenat, D. R. 1988: Water quality assessment of streams using a qualitative collection method for benthic invertebrates. *Journal of the North American benthological society 7*: 222-233.

p. 44, insert at line 1:

Stark, J. D. 1985: A macroinvertebrate community index of water quality for stony streams. *Water and soil miscellaneous publication 87*: 53p.

p. 64, line 14: should read: ...of land-use, **and in general geology appeared to be a more important determinant of macroinvertebrate community structure and periphyton biomass than did land use.**

ABSTRACT

ABSTRACT

Benthic macroinvertebrate and periphyton communities of streams draining four different land use types within four distinct geological types were sampled between December 1996 and January 1997. Catchment land use comprised either standing mature or logged exotic forest, native forest, or hill country pasture. The geological types of these catchments were either Mesozoic sandstone-greywacke, Pleistocene-greywacke, Tertiary mudstone, or limestone in origin. Pastoral stream invertebrate community structure was significantly different from that found in forested streams, with no clear distinction separating communities from standing exotic, logged exotic, and native forest sites. Pastoral communities were dominated by dipterans and trichopterans, while in contrast, macroinvertebrate communities in streams draining sandstone-greywacke catchments were dominated by ephemeropterans and plecopterans, showing a clear influence of catchment geology on benthic macroinvertebrate communities. This sandstone-greywacke effect appeared to be independent of land use. Periphyton biomass was greatest in pastoral and exotic sites, particularly those draining limestone catchments. High nutrient and conductivity levels, both of which are characteristic of limestone streams, appeared to override the effect of light restrictions on periphyton growth in exotic forest sites. Overall, both geology and land use played major roles in determining the structure of stream benthic communities, with factors such as altitude and stream temperature also important influences on these communities.

In November and December 1997, nutrient, shade, and disturbance effects were examined in periphyton communities colonising artificial substrates. These substrates were left in the 8 forested Hawkes Bay streams for 28 days with disturbance treatment substrates being physically abraded every 7 days. Nutrients (N + P) were added to nutrient treatment substrates and polythene cloth was used to create an artificially shaded environment for shade treatment substrates. Light availability and percentage canopy cover had the greatest effect upon periphyton, with light limitation being exhibited in closed canopy systems. Nutrient supply was also a factor determining periphyton biomass at both open and closed sites, although only up to a limit. Physical disturbance successfully removed organic matter from substrates as well as reducing chlorophyll *a* levels at open sites, however light and nutrient levels were more important determinants of chlorophyll *a* concentrations.

In summary, both land use and geology play a considerable role in influencing both macroinvertebrate community structure and periphyton biomass. The geological influence was mediated through direct effects on nutrient inputs into the stream (as measured by conductivity), as well as by the indirect influence upon stream water temperatures. The influence of land use on benthic communities is predominantly as a result of shade levels created by vegetation types and enrichment levels derived from agriculturally influenced land. These results are of particular importance when comparing or analysing results from studies involving different land use types, particularly when these land uses cover a range of altitudes or are found in more than one geological type.

INTRODUCTION

INTRODUCTION

Land use practises such as forestry, farming, and mining have been shown to disrupt habitats for aquatic fauna and flora (Quinn and Hickey 1990; Harding and Winterbourn 1995; Waters 1995; Ventura and Harper 1996, Quinn et al., 1997). The logging of plantation forests for example, can result in increases in stream temperature, nutrient concentrations, flow rate, light levels, and suspended solid loads (Winterbourn 1986) which can consequently alter the composition of benthic macroinvertebrate communities including the reduction of macroinvertebrate density and richness (Growns and Davis 1994; Brown et al., 1997). Lower taxonomic richness has also been found in pastoral streams where complete orders have been found to be absent (e.g., Plecoptera), attributed to by minimal riparian zones and high enrichment levels (Harding and Winterbourn 1995; Collier et al., 1997; Quinn et al., 1997). In contrast, stable, mature forest vegetation provides shade, stabilises water temperature, and reduces erosion and sediment flow (Rounick and Winterbourn 1982). Winterbourn and Rounick (1985) found that within 3 to 5 years after logging, stream faunas reverted to similar community structure to that found in unlogged podocarp *Nothofagus* catchments, indicating that the negative effects of logging on stream invertebrate communities may only be temporary.

Geology also influences stream invertebrate and periphyton communities through variations in the levels of alkalinity and suspended solid concentrations, mineral, ion, and nutrient levels (Lay and Ward 1987; Huryn et al., 1995). Geological type can have a direct effect on substrate stability, size, and texture and consequently in catchments of differing land use, geology may play a more important role in determining benthic community structure through substrate mediated influences. Ventura and Harper (1996) illustrated how local geology can influence stream chemistry and have more of an effect on macroinvertebrate communities than land use with local geology buffering the acidic effects of pine plantations on surrounding water and soil. Similar effects could also be expected to influence benthic communities from other factors differing between geological types, such as altitude, temperature, and channel form (Strayer 1983; Huryn et al., 1995; Harding et al., 1997).

The aim of this study is to determine the effects of different land use types, particularly forestry, upon stream invertebrate and periphyton communities, and to establish how geology plays a part in enhancing or reducing these effects. The response of periphyton communities is also examined in relation to light levels, nutrient enrichment, and physical disturbance, all of which are factors that vary between different land use types, and to some extent, different geological types.

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CHAPTER TWO

DETERMINANTS OF STREAM MACROINVERTEBRATE COMMUNITY STRUCTURE IN THE HAWKES BAY (THE INTERACTION OF GEOLOGY AND LAND USE).

ABSTRACT

The combined effects of geology and land use on macroinvertebrate community structure, periphyton biomass and water quality were investigated by surveying 37 first to fourth order streams in Hawkes Bay, New Zealand. Four replicate Surber samples were collected from each site between December 1996 and January 1997. Catchment land use comprised either standing or logged exotic forest, native forest, or hill country pasture. The geological types of these sites were either Mesozoic sandstone-greywacke, Pleistocene-greywacke, Tertiary mudstone, or limestone in origin. Pasture streams had a distinctly different invertebrate community structure to forest streams, regardless of whether these streams were draining standing exotic, native, or logged exotic catchments. Pastoral sites were dominated by dipterans and trichopterans, possibly indicating organic enrichment. Sandstone-greywacke streams had distinct macroinvertebrate communities from other geological types, independent of land use, and were dominated by Plecoptera and Ephemeroptera. Sandstone-greywacke streams were of high water quality, as measured by biotic indices, had low temperatures and sediment levels. Although all sandstone-greywacke streams were at high altitudes, and this can not be ruled out as a factor controlling community structure. Limestone streams had high periphyton biomass, and high abundance and richness of taxa. Overall, in the forested sites, geology appeared to be a more important determinant of macroinvertebrate community structure and periphyton biomass than land use type, although altitude and temperature may also play important roles in determining macroinvertebrate community structure.

***Keywords*:** forest, geology, land use, limestone, macroinvertebrate community structure, pasture, periphyton, temperature.

INTRODUCTION

Hynes (1975) noted that structural and functional characteristics of running water ecosystems are strongly influenced by both biotic and abiotic conditions of their catchments. Because of this, both land use (for example forestry practices) and the geology of a catchment may be expected to affect the characteristics of running water ecosystems. Forest vegetation provides shade, stabilises in-stream temperature regimes, provides energy (particulate organic matter) for in-stream fauna, aids in stabilising stream banks, reduces erosion (Rounick and Winterbourn 1982), and lowers nutrient input into the stream (Bormann and Likens 1979). Forest stream invertebrates tend to comprise Plecoptera, Ephemeroptera, or Trichoptera (Rounick and Winterbourn 1982; Friberg et al., 1997) but when catchments are logged, the fauna can change to one comprised predominantly of Oligochaetes and Chironomidae, which can utilise finer, softer substrates (Campbell and Doeg 1989).

Studies in New Zealand and overseas have identified detrimental effects of forestry practices on water and soil quality and invertebrate communities (e.g., Winterbourn 1986; Goh and Phillips 1991; Davies and Nelson 1994; Growns and Davis 1994; Fahey and Jackson 1997). The disturbance created by logging operations can result in increases of nutrient concentrations, flow rates, light levels, water temperatures, and/or suspended solid loads (Winterbourn 1986; Davies-Colley and Quinn 1998). Logging of forests can also lower macroinvertebrate density and richness (Growns and Davis 1994; Brown et al., 1997). Numerous studies have compared the macroinvertebrate and periphyton communities of agriculturally influenced streams with streams draining other land use types, such as tussock, native podocarp/broadleaf forest, and exotic plantation forest (e.g., Biggs 1995; Harding et al., 1997; Collier et al., 1997). Pastoral streams have generally been found to have lower taxonomic richness than streams draining less developed catchments and have invertebrate communities dominated by enrichment tolerant taxa such as trichopterans, dipterans, and molluscans (Harding and Winterbourn, 1995).

Geology also effects a range of in-stream characteristics such as alkalinity, suspended solids, mineral, ion and nutrient supply, and affects substrate stability, size, and texture (Strayer 1983; Close and Davies-Colley 1990; Ventura and Harper 1996). Catchment geology can also effect stream ecosystems indirectly by influencing riparian vegetation and turnover rates of organic matter (Miller 1968; Lay and Ward 1987). A number of studies have investigated the effects of geology on nutrient levels (Dillon and Kirchner 1975), periphyton communities (Biggs 1995) and freshwater mussels (Strayer 1983), but few studies have investigated the effects of geology on benthic macroinvertebrate communities. While in-stream physiochemical effects of land use have been relatively well documented (e.g., Corkum 1996; Fahey and Jackson 1997; Friberg et al., 1997; Quinn et al., 1997), few studies have investigated the effects of land use on invertebrate communities over a number of geological types.

In this study, I examine whether the effects of land use differ in their impact on invertebrate communities in streams of differing geology in the Hawkes Bay region, New Zealand.

STUDY SITES

The study sites were 37 streams located in 4 land use categories and 4 distinct geological types within Hawkes Bay, New Zealand. Land use categories (defined as the vegetation covering > 80% of the catchment) were mature exotic *Pinus radiata* (D. Don) plantations (20-26 years old), logged exotic *Pinus radiata* (1-5 years since logging, some of which is replanted), native podocarp/broadleaf forest, and hill country pasture. The geological types (being the lithology which covered > 80% of the catchment) were; 1. sandstone-greywacke: large, angular, alternating argillite and redeposited sandstone, greywacke conglomerates deposited in the Jurassic (Grindley 1960); 2. Pleistocene-greywacke: strongly weathered, well rounded greywacke terrace gravels deposited in the Pleistocene (Kingma 1962); 3. mudstone: calcareous, moderately cemented siltstone/sandstone with interbedded mudstone overlain by well rounded pumice and carbonised wood conglomerate (Cutten 1994); and 4. limestone: richly fossiliferous sands, silts, limestone and conglomerate, largely of marine deposition (Grindley 1960).

MATERIALS AND METHODS

Sampling protocol

Four replicate Surber samples (0.1 m^2, 500 μm mesh) were collected from each of the thirty-seven sites between December 1996 and January 1997. Sampling was conducted under baseflow conditions and samples were collected by physically abrading all rocks and substrate within the Surber for 1 minute, mid channel within a 20 m section of stream. Samples were stored in 70% ethyl alcohol. Invertebrates were identified using Winterbourn (1973), Cowley (1978), and Winterbourn and Gregson (1989). After removal of invertebrates, the sample was split into coarse (>1mm) and medium (500μm-1mm) particulate organic matter (POM), dried at 80°C to constant weight and ashed at 600°C for 2 hours. Ten inorganic samples from each geology type were also incinerated to determine inorganic matter breakdown (the difference before and after incineration). Organic matter was determined as the difference before and after incineration of the sample, less inorganic breakdown.

Four stones (maximum diameter = 45 mm) were collected concurrently adjacent to the invertebrate sample for periphyton analysis. Pigments were extracted in 90% acetone for 24 hours at 5 °C. Absorbances were measured with a Jenway 6105

UV/V spectrophotometer at 410, 430, 665, and 720 nm and pigment concentration calculated following Moss (1967 a,b). Stone surface area was calculated using height, width, and length measurements following Graham et al. (1988) and used to express periphyton biomass per unit stone surface area.

Five water velocity readings, taken with a velocity head rod, were measured midstream at each sample point, along with 4 width and 5 depth measurements along the stream reach. Dissolved oxygen, temperature (YSI 59 Dissolved Oxygen meter), and conductivity (Orion 122 Conductivity meter) were recorded on site and a 500ml water sample was taken back to the laboratory for pH measurement (Orion 250A pH meter). 400 mls of this water sample was then filtered through GF/C microfibre filters (pore size = 1.2 μm) to calculate suspended solid concentration following Gordon et al. (1993). Stream stability was assessed with the Pfankuch (1975) Channel Stability protocol. Substrate composition and riparian vegetation were visually estimated to the nearest 5% along the 20 m reach. Substrate composition was broken into seven size classes ranging from bedrock to silt and riparian vegetation was categorised into five land use categories (native, exotic, scrub, pasture, and tussock), all of which were visually estimated to the nearest 5%.

Statistical analysis

A two-way Analysis of Variance (ANOVA) (fixed factors) using SAS (1989) was performed to examine univariate differences among land use and geology groupings for physical, chemical, and invertebrate data. If necessary data was log transformed to remove heterogeneity of variance. To examine overall trends in community structure, Detrended Correspondence Analysis (DECORANA) was performed using the PC-ORD statistical software package (McCune and Mefford, 1995). Pearson correlations between environmental variables and DECORANA axes were also calculated. A Multi Response Permutation Procedure (MRPP) (Sorensen distance measure) using PC-ORD (McCune and Mefford, 1995) was used to investigate multivariate differences in invertebrate community structure between land use and geology groupings.

RESULTS

Physicochemical characteristics

Streams were generally small to medium in size (depth ranging from 6 to 30 cm, and width from 0.4 to 6.3 m), with stream velocities between 10 and 100 cm/s (Table. 1). Sandstone-greywacke streams characteristically had high velocities, cool water temperatures, and were located at high altitudes. Streams draining limestone catchments had high conductivites, high concentrations of suspended solids, and pH values lower than streams draining catchments of other geological types. Pasture streams had typically high water temperatures. pH values for all sites were circumneutral ranging from 7.2 to 8.8 and suspended solid concentrations ranged between streams from 1.4 mg/l to 333.1 mg/l. Stability scores were not different between geology or land use types.

Periphyton

Mature exotic forest and pastoral streams had higher levels of chlorophyll *a* than native forest or logged exotic streams, with logged streams having the lowest levels (Fig. 1A). Limestone streams had significantly higher chlorophyll *a* than streams of any other geological type (Fig. 1B).

Table 1 Mean physico-chemical characteristics of 37 streams in 4 land use categories and 4 geological types sampled between December 1996 and January 1997 in the Hawkes Bay (range in parentheses).

	Sites	Geology	Altitude (m)	Mean Width (m)	Mean Depth (cm)	Mean Current Velocity (cm/s)	Temperature (°C)	pH	Conductivity (μs/cm)	Suspended Solids (mg/l)
EXOTIC:	Mangamauku Stm	sandstone	540	1.3 (0.2-1.5)	11 (9.3-12.5)	100 (83-108)	10.9	8.0	97	9.2
	Ohara Stream 2	sandstone	420	3.0 (2.7-3.1)	20 (17.8-21)	79 (31-99)	13.9	7.9	67	21.3
	Waikarokaro Stm	sandstone	570	3.5 (2.5-5.1)	11 (5.6-13.6)	45 (31-59)	11	7.6	106	25
	Pakuratahi Stream 1	limestone	230	1.1 (0.6-1.4)	6 (4-8.6)	20 (5-31)	15.6	7.4	216	144.6
	Pakuratahi Stream 2	limestone	240	0.4 (0.3-0.8)	6 (1.2-9.6)	24 (5-31)	14.1	7.3	243	131.4
	Pakuratahi Stream 3	limestone	40	1.8 (1.2-2.2)	23 (12-40.4)	26 (22-31)	15	7.3	211	91.3
	Pakuratahi Stream 4	limestone	100	0.9 (0.8-1.2)	15 (10.6-24)	22 (5-31)	14.6	7.6	206	115.9
	Pakuratahi Stream 5	limestone	60	0.9 (0.7-1.2)	11 (9-14.8)	40 (31-49)	15	7.9	198	125.9
	Anaura Stream 1	mudstone	390	1.8 (1.4-2)	16 (12-19.6)	37 (22-49)	15.2	7.7	170	32.3
	Anaura Stream 3	mudstone	240	3.1 (2.4-3.6)	17 (9.4-22)	53 (38-77)	20.6	8.3	144	26.5
	Mangamate Stm 1	Pleistocene	350	2.5 (1.5-3.8)	14 (9.8-19)	51 (22-77)	11.9	7.2	38	1.9
LOGGED:	Middle Upokororo Stm	sandstone	480	2.1 (2.0-2.2)	15 (12.5-17)	86 (63-104)	11.5	8.1	103	8.0
	Ohara Stream 1	sandstone	540	2.0 (1.8-2.2)	18 (12.5-21)	84 (54-108)	11.9	7.9	82	6.0
	Otekarara Stream 1	sandstone	650	2.4 (2.2-2.7)	17 (14-22.8)	51 (31-59)	10.2	7.8	123	54.8
	Otekarara Stream 3	limestone	300	2.5 (2.4-2.8)	20 (15.6-22)	56 (38-66)	12.2	7.3	149	77.4
	Kakariki Stream 1	mudstone	350	0.6 (0.5-0.8)	7 (2.2-11)	10 (5-22)	14.5	8.5	91	11.5
	Heruheru Stream	mudstone	260	1.8 (0.8-3.4)	11 (8-25.4)	62 (22-96)	21.3	8.4	148	31.3
	Mohaka River	mudstone	240	1.9 (1.5-2.7)	13 (10-19.4)	38 (31-44)	19	8.7	188	333.1
	Anaura Stream 2	mudstone	380	2.5 (2.4-2.7)	25 (16.2-31)	34 (22-54)	17.7	8.5	132	23.6
	Mangaonuku Stream 1	Pleistocene	400	1.6 (1.1-1.9)	9 (4.5-12)	37 (5-59)	15	8.4	75	2.1
	Deep Stream	Pleistocene	100	3.7 (2.8-4.6)	14 (6-20.2)	65 (44-77)	14.7	8.5	220	54.7
NATIVE:	Pinchgut Creek	sandstone	560	2.4 (2.3-2.5)	11 (7.5-14)	66 (31-89)	11.4	7.9	91	8.2
	Poutaki Stream	sandstone	520	3.1 (2.7-3.6)	16 (13-19.5)	69 (54-89)	14.1	8.4	80	6.9
	Omarowa Stream	sandstone	580	6.3 (5.4-6.8)	10 (7-12.6)	52 (31-63)	11.6	8.3	62	2.3
	Otekarara Stream 2	limestone	310	1.8 (1.2-2.3)	15 (9-18.4)	41 (22-59)	12.4	7.7	175	86.2
	Korongomairoa Stm 1	mudstone	440	2.5 (2.1-2.6)	24 (16.4-35)	40 (22-70)	16.3	8.7	116	18.7
	Korongomairoa Stm 2	mudstone	420	1.3 (0.9-1.5)	13 (5-20.2)	24 (5-31)	15.6	7.6	136	14.1
PASTURE:	Tamingimingi Stm 1	limestone	240	0.8 (0.7-2)	15 (10.4-24)	28 (22-38)	17	7.6	190	117.8
	Tamingimingi Stm 2	limestone	160	1.1 (0.7-1.7)	14 (9.3-18)	31(22-38)	17.2	7.3	228	106.3
	Tamingimingi Stm 3	limestone	120	1.2 (0.8-2.2)	17 (10.4-25)	51 (31-70)	18	7.6	179	109.0
	Tamingimingi Stm 4	limestone	50	1.7 (1.6-2)	26 (23-30.8)	41 (31-54)	15.2	7.6	194	135.6
	Tamingimingi Stm 5	limestone	80	1.2 (0.9-1.5)	30 (25-32.4)	38 (31-44)	15	7.3	252	128.1
	Kakariki Stream 2	mudstone	260	0.8 (0.7-0.9)	13 (12-14.8)	37 (22-49)	23.3	8.8	179	44.0
	Matahorua Stream	mudstone	270	1.1 (0.5-1.5)	7 (4.2-11)	41 (22-44)	20.4	8.5	145	85.5
	Mangamate Stream 2	Pleistocene	240	2.6 (2.3-2.9)	12 (10-13.5)	26 (22-31)	20.2	7.3	84	1.4
	Mangaonuku Stm 2	Pleistocene	300	3.2 (2.6-3.7)	17 (12-22.8)	36 (5-49)	21.7	8.2	92	2.4
	Maraekakaho Stream	Pleistocene	100	3.7 (1.3-9.7)	16 (11.5-18)	77 (54-94)	22	8.2	325	69.7

Table 2 F-values, degrees of freedom, and P-values for ANOVAs performed on physico-chemical, periphyton, and macroinvertebrate characteristics of 37 streams in one of four land use types (n = 4) and four geological types (n = 4) sampled in December 1996 - January 1997 in the Hawkes Bay region.

Variables	F-value	P-value
Land use		
v. altitude	2.67	0.07
v. suspended solids	0.70	0.56
v. stability	1.04	0.39
v. velocity	0.23	0.87
v. stream temperature	14.7	0.000
v. conductivity	1.85	0.17
v. pH	3.41	0.06
v. invertebrate abundance	14.77	0.000
v. taxa richness	4.11	0.008
v. margalef's index	1.15	0.61
v. berger parker index	0.74	0.53
v. MCI	19.88	0.000
v. EPT ratio	10.73	0.000
v. chlorophyll *a*	4.53	0.005
v. total POM	2.34	0.08
v. CPOM	0.56	0.64
v. MPOM	0.85	0.46
Geology		
v. altitude	13.39	0.000
v. suspended solids	9.46	0.000
v. stability	0.34	0.80
v. velocity	5.72	0.005
v. stream temperature	17.01	0.000
v. conductivity	8.39	0.000
v. pH	10.08	0.000
v. invertebrate abundance	2.58	0.06
v. taxa richness	3.66	0.01
v. margalef's index	3.07	0.03
v. berger parker index	0.82	0.58
v. MCI	29.92	0.000
v. EPT ratio	28.07	0.000
v. chlorophyll *a*	23.14	0.000
v. total POM	3.77	0.01
v. CPOM	2.84	0.06
v. MPOM	14.21	0.000
Land use / Geology Interaction		
v. altitude	0.78	0.61
v. suspended solids	0.37	0.91
v. stability	1.26	0.31
v. velocity	0.57	0.77
v. stream temperature	2.30	0.06
v. conductivity	1.78	0.14
v. pH	2.25	0.07
v. invertebrate abundance	9.27	0.000
v. taxa richness	3.65	0.001
v. margalef's index	1.06	0.39
v. berger parker index	2.15	0.07
v. MCI	2.76	0.01
v. EPT ratio	2.38	0.06
v. chlorophyll *a*	1.33	0.24
v. total POM	1.52	0.17
v. CPOM	0.80	0.59
v. MPOM	1.57	0.15

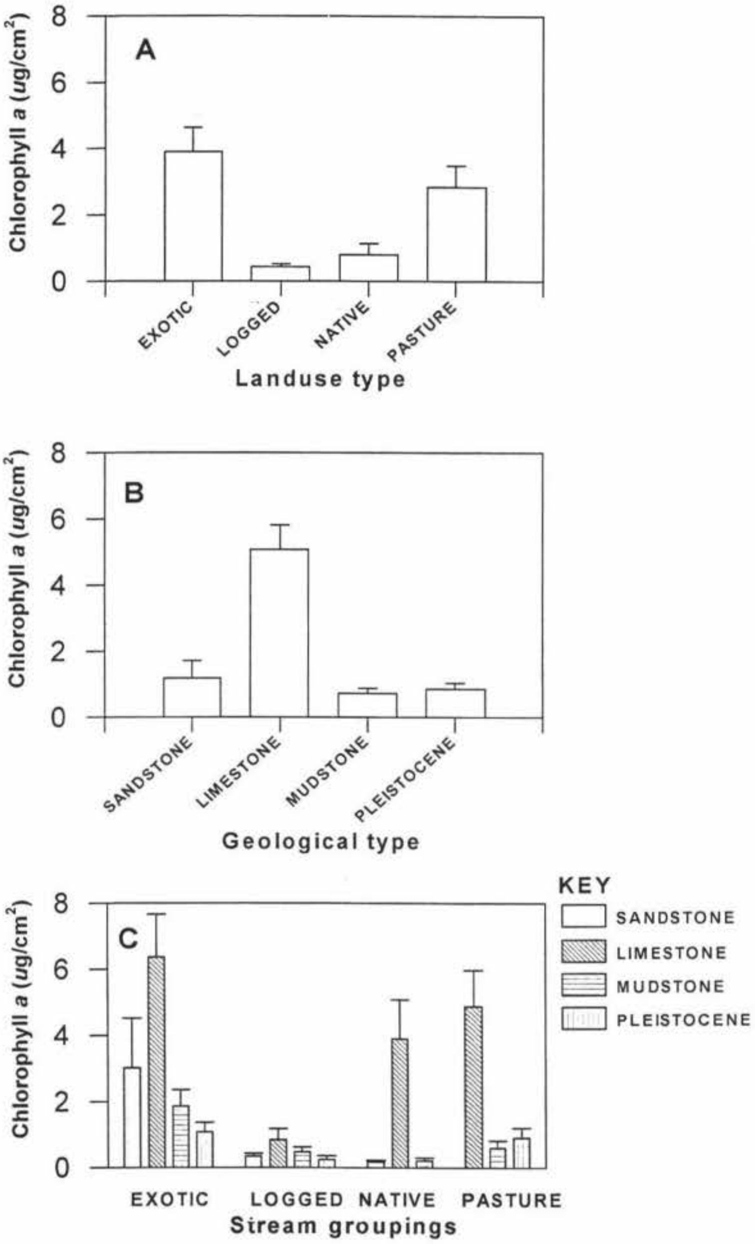

Fig. 1 Mean chlorophyll *a* (±1 SE) collected in 4 replicate stone samples in streams of differing geology and land use between December 1996 and January 1997. Sites grouped by (**A**) land use type, (**B**) geological type, and (**C**) both land use and geology.

Particulate Organic Matter (POM)

Total POM was lower at Pleistocene-greywacke sites than sites of other geological type (Fig. 2B), but no difference existed between land use types (Fig. 2A). CPOM was not different between land use and geology types but sandstone-greywacke and limestone streams had significantly higher levels of MPOM than mudstone or Pleistocene-greywacke streams, while land use types showed no difference in MPOM.

Composition of macroinvertebrate taxa

Mature exotic sites were characterised by large numbers of Diptera (mostly Simuliidae and Chironomidae) and Ephemeroptera (e.g., *Deleatidium* spp. and *Zephlebia dentata*) (Fig. 3). Seventy three benthic macroinvertebrate taxa were identified from streams in mature exotic catchments with 8 taxa (the mayflies: *Acanthophlebia cruentata*, *Mauiulus luma*, *Zephlebia spectabilis;* the caddisflies: *Hudsonema aliena*, *Orthopsyche* sp.; the shore fly: *Ephydrella* sp. and 2 species of Acari) found exclusively at mature exotic sites. The 11 logged exotic sites were dominated by trichopterans and coleopterans, predominantly *Helicopysche* sp., *Hydrobiosis parumbripennis*, *Pycnocentrodes* sp., and Elmidae. Seven taxa were only found at logged exotic sites (the mayfly: *Oniscigaster wakefieldi;* the crane flies: *Mischoderus* sp., *Molophilus* sp.; the moth fly: Psychodidae; the shore fly: ?*Brachdeutera* sp.; one species of Acari, and Collembola). Native forest sites were numerically dominated (over 50%) by mayflies while pastoral sites were dominated by Diptera, Trichoptera, and Coleoptera, in much the same way that logged exotic sites were. All taxa identified are listed in the appendix along with the taxa counts for all thirty-seven sites.

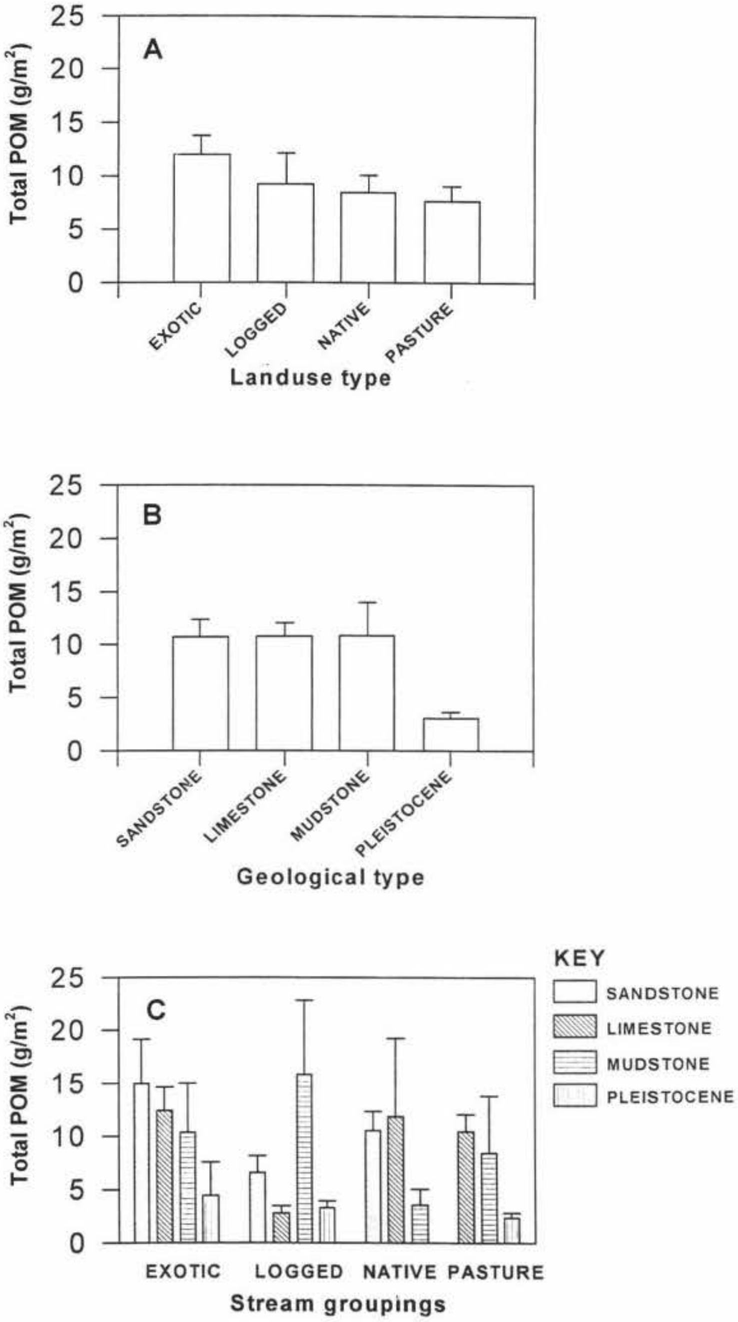

Fig. 2 Mean total particulate organic matter (POM) (±1 SE) collected in 4 replicate Surber samples in streams of differing geology and land use between December 1996 and January 1997. Sites grouped by (**A**) land use type, (**B**) geological type, and (**C**) both land use and geology.

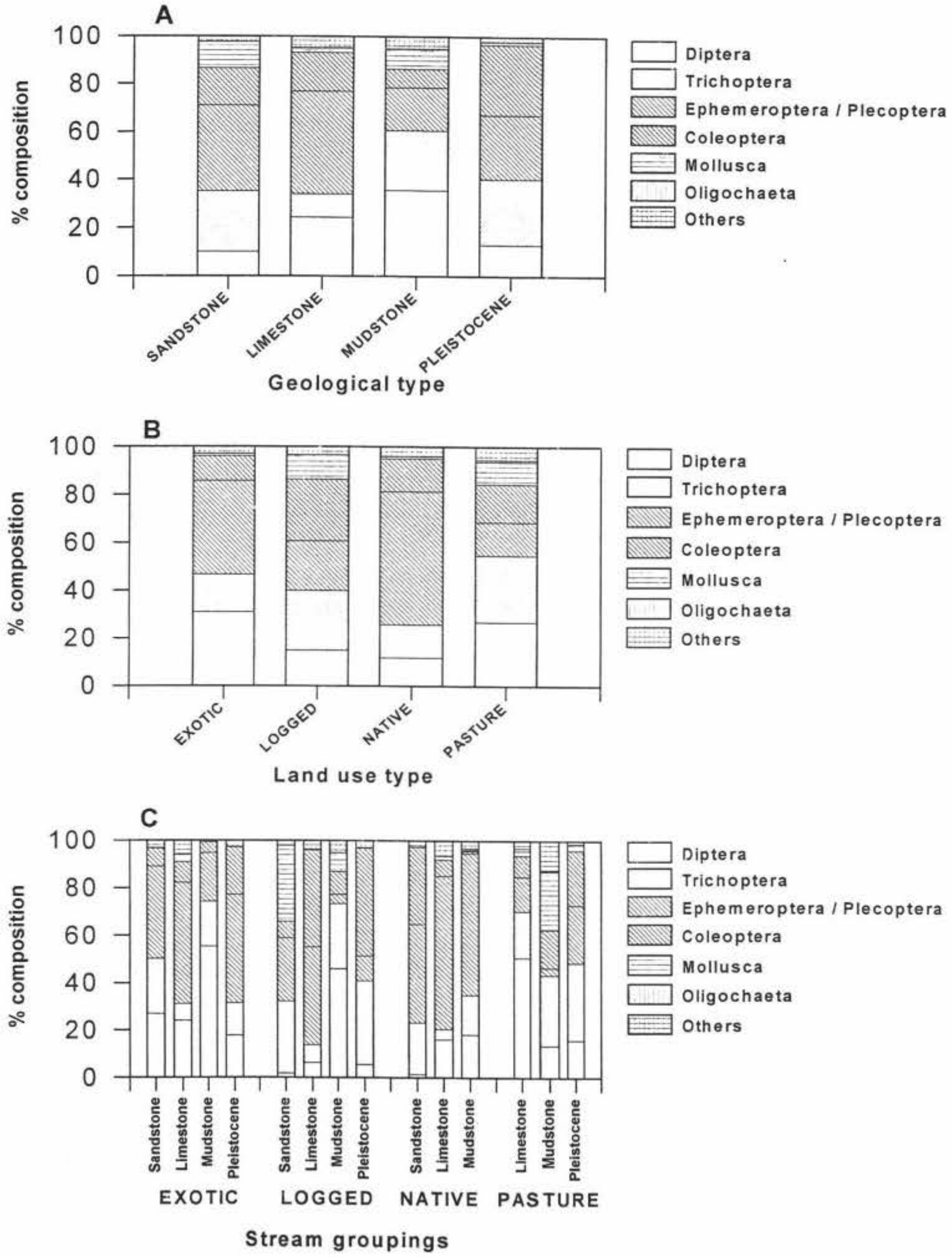

Fig. 3 Mean relative abundance of higher order taxa collected in 4 replicate Surber samples in streams of differing geology and land use between December 1996 and January 1997. Sites grouped by (**A**) geological type, (**B**) land use type, and (**C**) both land use and geology.

The effect of geology on invertebrate abundance differed between land use type (Fig. 4C). For example mudstone sites in general had low numbers of individuals, but mudstone sites within mature exotic forest had considerably more individuals than any other group. Overall, limestone sites had higher invertebrate abundance than sites from other geological types (Fig. 4B) and between land use groupings, pastoral sites had the highest abundance of invertebrates, with mature exotic forest sites having significantly higher invertebrate abundance than native forest or logged exotic sites (Fig. 4A).

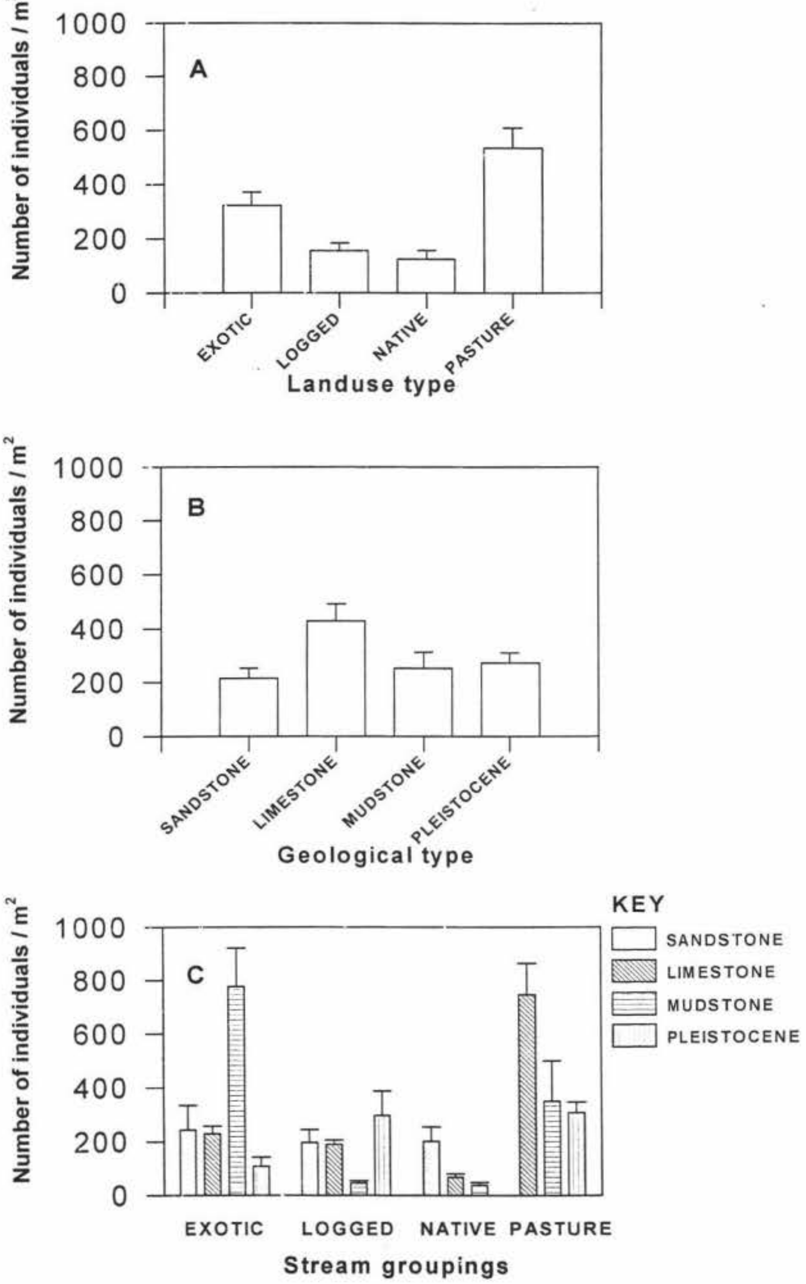

Fig. 4 Mean total number of individuals (±1 SE) collected in 4 replicate Surber samples in streams of differing geology and land use between December 1996 and January 1997. Sites grouped by (**A**) land use type, (**B**) geological type, and (**C**) both land use and geology.

Overall, mature exotic forest and pastoral sites had higher taxa richness than native forest or logged exotic sites (Fig. 5A). Similarly, limestone sites had more taxa per site than sites of other geological type (Fig. 5B). However, the effect of forest type differed between geology type (Fig. 5C), with mudstone sites having the highest taxa richness within mature exotic forest catchments, while in other land use types, mudstone sites had low taxa richness. This effect was similar to that found for invertebrate abundance.

Diversity indices

Diversity (Margalef's Index) didn't differ between land use types, but Pleistocene-greywacke sites had a lower diversity than sites of other geological types (Fig. 6A). No difference in community evenness (Berger Parker index) existed between land use or geology type (Fig. 6B).

Native forest streams had higher MCI scores than streams of other forest types while pastoral sites had the lowest overall MCI scores (Fig. 7A). MCI scores were highest in sandstone-greywacke streams, lowest in mudstone and limestone sites and intermediate at Pleistocene-greywacke sites (Fig. 7B). QMCI scores yielded a similar pattern to the MCI scores.

EPT ratios were highest in native forest sites, followed by mature exotic forest sites, then logged exotic sites, and were lowest in pastoral sites (Fig. 8A). In geological groupings, EPT ratios were highest overall in sandstone-greywacke sites, with Pleistocene-greywacke sites having a higher ratio than mudstone sites (Fig. 8B).

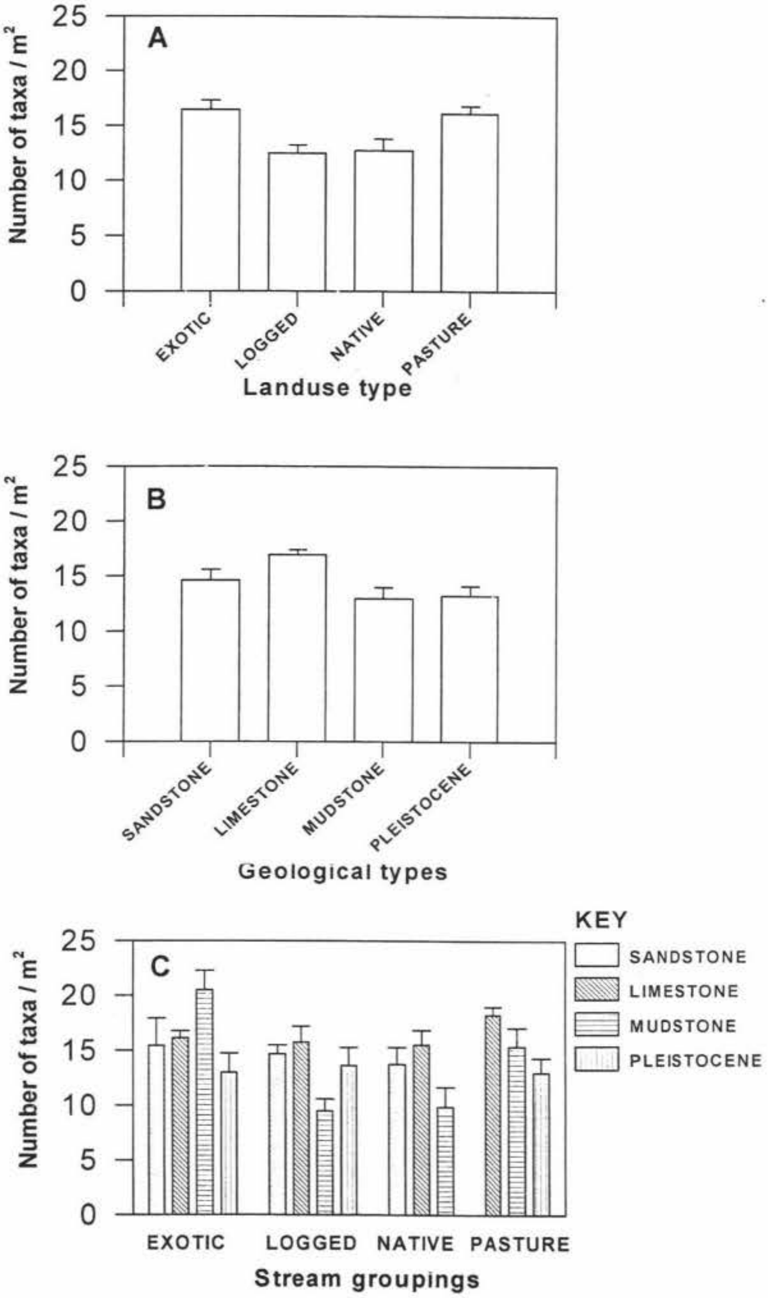

Fig. 5 Mean total number of taxa (±1 SE) collected in 4 replicate Surber samples in streams of differing geology and land use between December 1996 and January 1997. Sites grouped by (**A**) land use type, (**B**) geological type, and (**C**) both land use and geology.

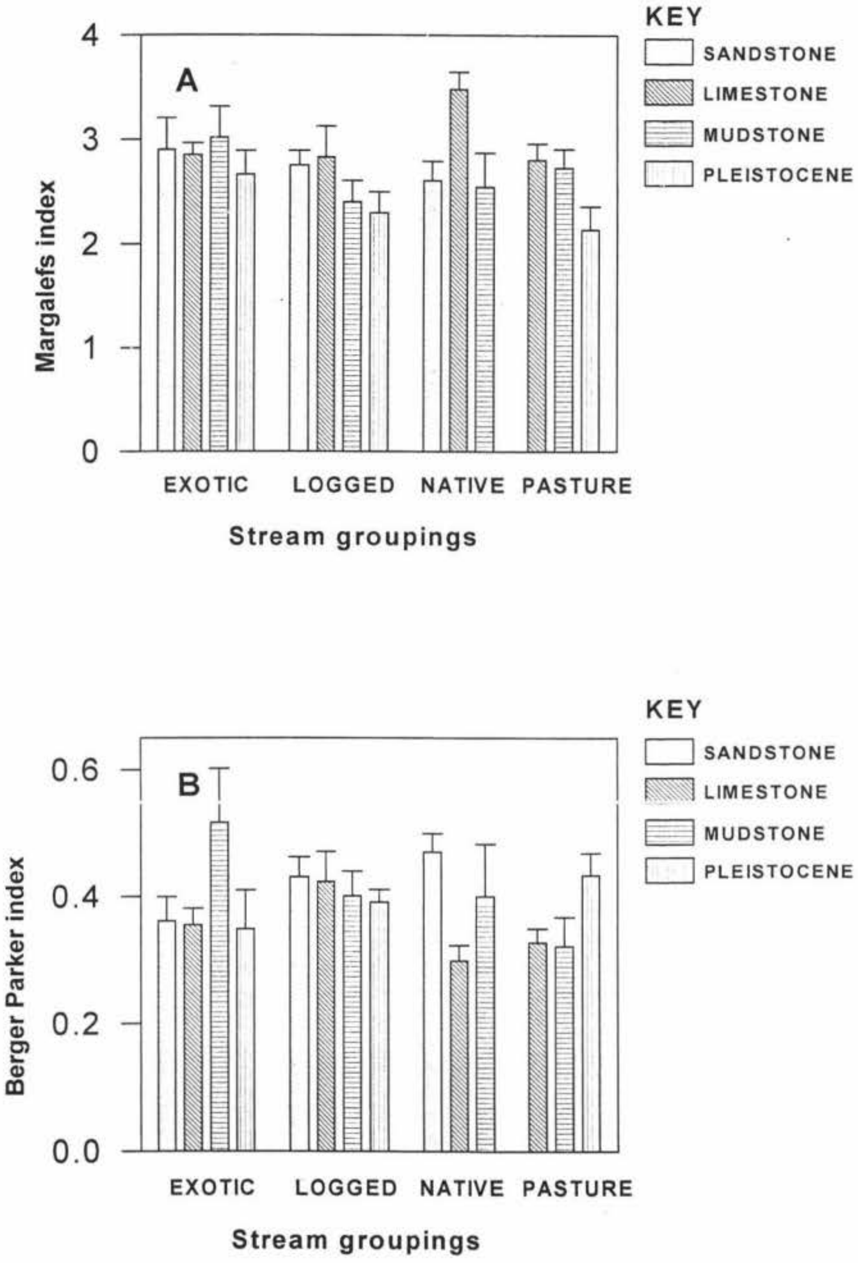

Fig. 6 Mean Margalef's Diversity Index (±1 SE) (**A**) and mean Berger Parker Dominance Index (±1 SE) (**B**) for 4 replicate Surber samples collected in streams of differing geology and land use between December 1996 and January 1997.

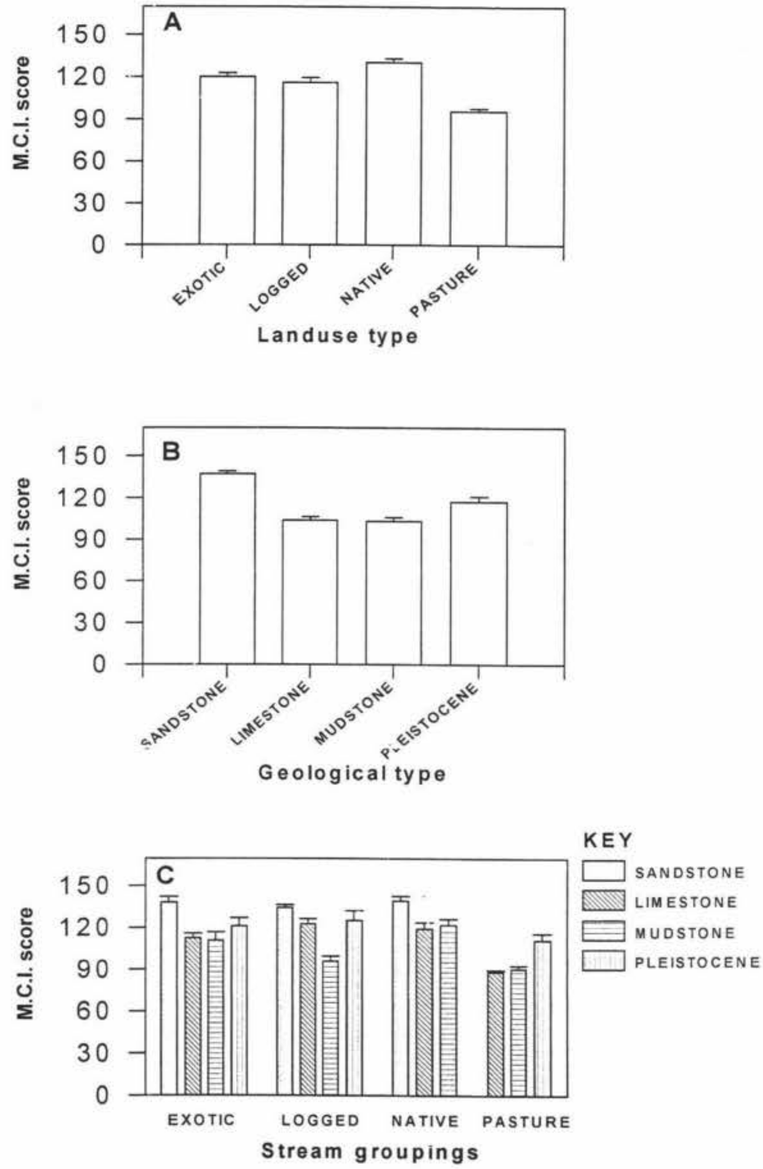

Fig. 7 Mean Macroinvertebrate Community Index (MCI) (±1 SE) for 4 replicate Surber samples collected in streams of differing geology and land use between December 1996 and January 1997. Sites grouped by (**A**) land use type, (**B**) geological type, and (**C**) both land use and geology.

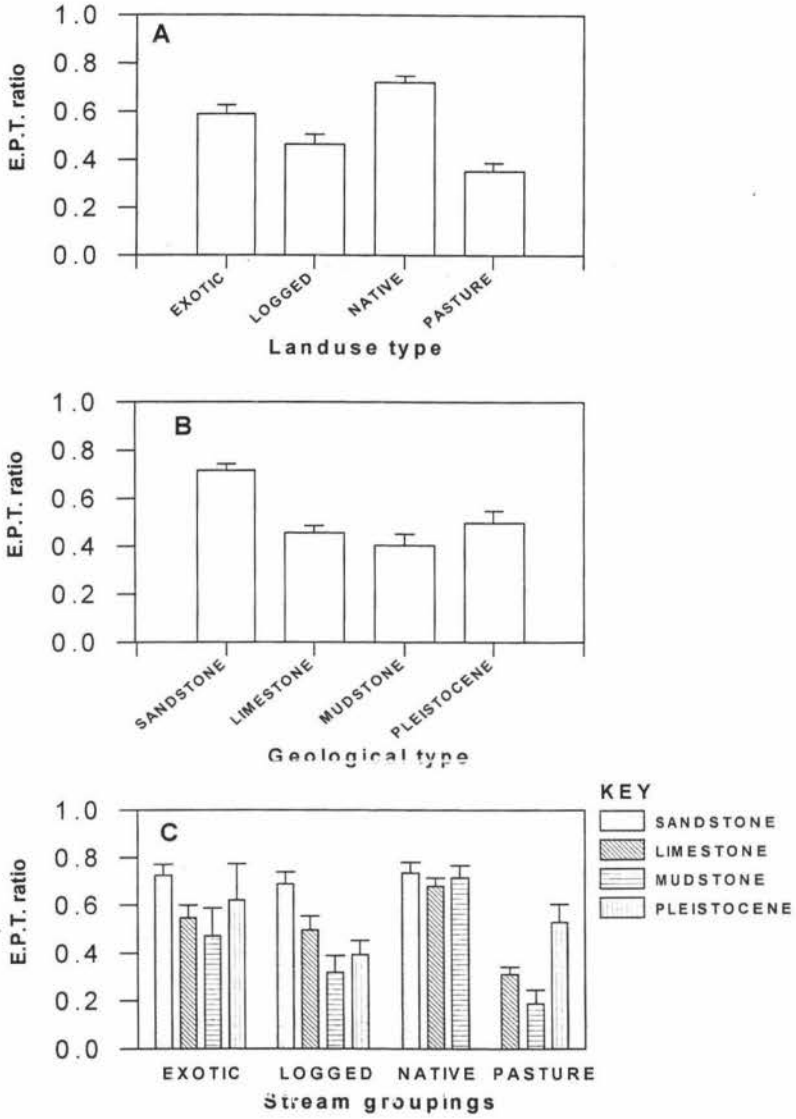

Fig. 8 Mean Ephemeroptera, Plecoptera, and Trichoptera ratio (EPT ratio) (±1 SE) for 4 replicate Surber samples collected in streams of differing geology and land use between December 1996 and January 1997. Sites grouped by (**A**) land use type, (**B**) geological type, and (**C**) both land use and geology.

Ordination

A plot of the first two DECORANA axes grouped pastoral sites to the left of axis one, native forest sites to the bottom right with mature exotic forest and logged exotic sites in between (Fig. 9A). Native forest sites do not form a clear grouping separate from logged exotic or mature exotic forest sites, although they are clearly distinct from pastoral communities. The same ordination labelled by geology reveals a clear grouping of sandstone-greywacke sites to the right of axis one, with the other geology types indicating no distinct groupings (Fig. 9B).

Variables differentiating between forest and grassland (and between the various geological types) were those correlated with axis one of the DECORANA i.e., temperature and percent bedrock (both negative) (Table 3). Taxa characteristic of sites to the right of axis one (sandstone-greywacke sites and native forest sites) were predominantly ephemeropterans and plecopterans (Table 4). Those taxa characteristic of sites to the left of axis one (e.g., pasture sites) were predominantly dipterans and trichopterans. Multi Response Permutation indicated a significant difference in community composition between land use type ($T = 4.27$; $R = 0.05$, $P < 0.001$) and geology type ($T = -8.80$; $R = 0.09$, $P < 0.001$).

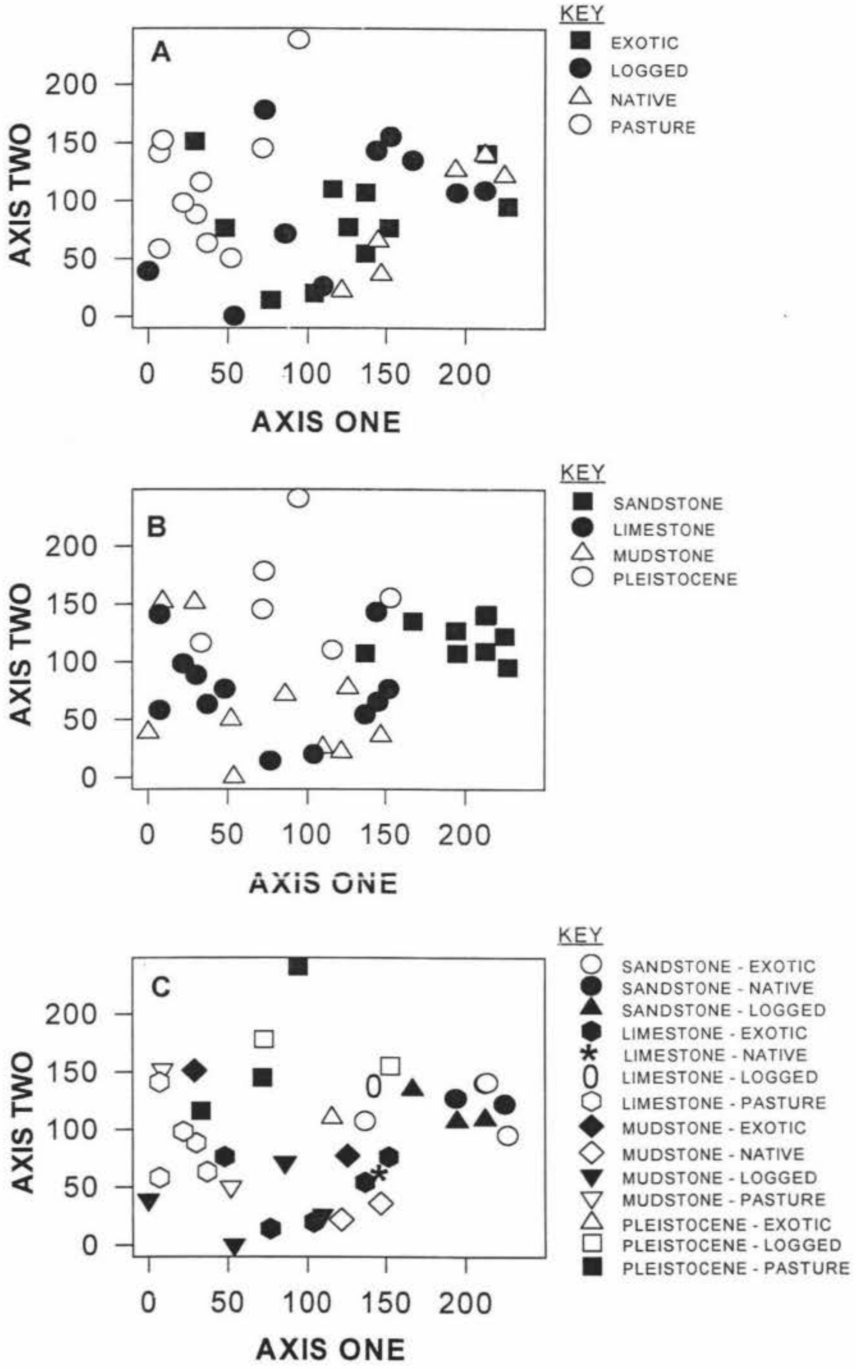

Fig. 9 Axis one of a Detrended Correspondence Analysis (DECORANA) as a function of axis two for macroinvertebrate communities of the 37 forested and pastoral sites. Sites are classified by (**A**) land use type, (**B**) geology type, and (**C**) both land use and geology.

Table 3 Correlation (r) of environmental parameters with axis one and two of the Detrended Correspondence Analysis. Significant correlations are shown with an *.

	AXIS ONE	AXIS TWO
Dissolved Oxygen	0.03	-0.19
pH	0.05	0.12
Conductivity	-0.29	-0.11
Temperature	-0.60 *	0.05
Velocity	0.31	0.38
Depth	-0.25	0.01
Width	0.05	0.22
Stream Bottom Stability	0.18	-0.21
Total Stream Stability	0.19	-0.14
Geology Type	0.17	-0.08
Land use Type	-0.37	0.12
% Bedrock	-0.55 *	-0.19
% Boulder	0.08	0.09
% Large Cobble	0.18	0.48 *
% Small Cobble	0.22	0.45 *
% Gravel	0.05	-0.29
% Sand	0.02	-0.36
% Silt	0.16	-0.06
% Riparian Native	0.00	-0.01
% Riparian Exotic	0.39	0.31
% Riparian Scrub	0.14	-0.07
% Riparian Pasture	-0.41	-0.03
% Riparian Tussock	0.05	-0.42
Suspended Solids	-0.21	-0.17
CPOM	0.24	-0.41
MPOM	0.35	-0.15
Ratio (CPOM:MPOM)	0.01	-0.21
Chlorophyll *a*	-0.20	-0.26

Table 4 Macroinvertebrate taxa significantly correlated with axis 1 and 2 of the Detrended Correspondence Analysis. An asterix indicates a positive correlation between the taxa and the axis and a + indicates a negative correlation.

Axis 1	Axis 2
EPHEMEROPTERA	TRICHOPTERA
Acanthophlebia cruentata *	*Polyplectropus* sp. *
Ameletopsis perscitus *	*Psilochorema* sp. +
Coloburiscus *	*Pycnocentria funerea* *
PLECOPTERA	*Pycnocentrodes* sp. *
Stenoperla prasina *	COLEOPTERA
TRICHOPTERA	Elmidae larvae *
Aoteapsyche sp. +	DIPTERA
Helicopsyche sp. *	Chironomid sp.A +
Psilochorema sp. +	Chironomid sp.E +
Pycnocentria evecta +	Eriopterini *
Pycnocentrodes sp. +	
COLEOPTERA	
Elmidae Adult +	
Hydraenidae Adult *	
DIPTERA	
?*Brachydeutera* sp. +	
Chironomid pupae +	
Chironomid sp.B +	
Empididae +	
Ephydrella sp. +	
HEMIPTERA	
Sigara sp. +	
ACARI	
Acari sp.F +	

DISCUSSION

Forested site invertebrate communities are clearly different from pastoral site communities, with no clear differentiation existing between the forest types. Friberg et al., (1997) found a similar response in the South Island with established, exotic coniferous plantations having minimal negative effects upon stream invertebrate communities when compared to native forest streams. As with work by Friberg et al., (1997), Harding and Winterbourn (1995), and Quinn et al., (1997), native forest sites were dominated by Plecoptera and I found Ephemeroptera that were abundant at exotic sites.

A number of overseas studies have shown detrimental effects of logging on invertebrate communities (e.g., Grown and Davis 1994; Brown et al., 1997), however in this study, as elsewhere in New Zealand, the communities at logged exotic sites were not significantly different from those of standing exotic forest or native forest sites. The majority of logged sites in my study had catchments that had been logged 3 to 5 years prior to sampling and replanted with exotic conifers. Winterbourn and Rounick (1985) found in the South Island that for the same period after logging, streams in catchments replanted with conifers had invertebrate faunas similar to that of streams of unlogged podocarp *Nothofagus* catchments.

Pastoral macroinvertebrate communities were numerically dominated by Diptera, Coleoptera, Mollusca, and Trichoptera; taxa that are generally less sensitive to environmental extremes. Pastoral sites had low numbers of mayflies and stoneflies with plecopterans recorded at only one site. Pastoral changes to invertebrate communities appeared to be independent of geological type, although it should be noted that no pastoral streams draining sandstone-greywacke catchments were sampled. Other New Zealand land use studies (e.g., Scott et al., 1994; Harding and Winterbourn 1995; Quinn et al., 1997) have found similar low abundances and / or absences of ephemeropterans and plecopterans from streams in agricultural land.

Biggs (1990) found catchment geology to be one of the most important factors effecting composition and biomass of periphyton communities where as Huryn et al., (1995) found limestone-dolomite streams had high periphyton biomass, regardless of land use type. All the limestone streams in this study, regardless of land use, had high periphyton biomass. Numerous studies (e.g., Death and Winterbourn 1995; Friberg et al., 1997) have found positive correlations between periphyton biomass and invertebrate abundance and high invertebrate abundances in limestone streams in this study is consistent with this. While streams draining sandstone-greywacke catchments appeared to have distinct macroinvertebrate communities, no pastoral sites draining sandstone-greywacke catchments were included in this study and this may have equally been a land use effect as a geology effect. It is also possible the higher altitude of the sandstone-greywacke sites may have affected community structure (Jacobsen et al., 1997).

A number of studies have concluded that geology, vegetation, and land use are important influences on benthic invertebrate and periphyton community structure (e.g., Biggs 1990; Biggs 1995; Ventura and Harper 1996; Harding et al., 1997). Quinn and Hickey (1990) found that catchment geology was less important than land use in determining macroinvertebrate community structure. In some streams in the present study, land use overrode the effects of geology, while in others geology appeared to play a more dominant role in influencing macroinvertebrate community structure and periphyton biomass. In the forested sites, geology appears to be a more important determinant of invertebrate community structure than the type of forest. Overall, both land use and geology appeared to be important determinants of periphyton biomass and macroinvertebrate community structure in these Hawkes Bay streams.

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CHAPTER THREE

THE EFFECT OF SHADE, DISTURBANCE, AND NUTRIENTS ON LOTIC BIOFILM COMMUNITIES.

ABSTRACT

The effects of shade (both natural and artificial), nutrient enrichment, and disturbance on periphyton biomass and ash free dry weight (AFDW) were investigated experimentally in 8 forested streams within the Hawkes Bay, New Zealand. Nutrient diffusing substrata containing nitrogen and phosphorus were placed in streams draining mature and logged *Pinus radiata* plantations, native podocarp/broadleaf forest, and a standing *Eucalyptus delegatensis* plantation. Disturbance treatment substrata were physically abraded weekly, with one tray (control and nutrient treatments) of undisturbed substrates being artificially shaded. Experimental trays were removed after 28 days and chlorophyll *a* concentrations and AFDWs determined for each substrate. Light availability had the greatest effect on periphyton biomass with periphyton communities in mature *Pinus radiata* and native forest sites being light limited. While light levels overrode any effect of nutrient enrichment in native sites, nutrient enrichment significantly enhanced periphyton biomass in mature and logged *Pinus radiata* catchments. Physical abrasion significantly reduced organic matter levels (AFDW) and open site chlorophyll *a* concentrations, but light and nutrient levels appeared to be more important determinants of periphyton biomass.

Keywords: AFDW, canopy cover, disturbance, light limitation, logged *Pinus radiata* streams, nutrient enrichment, periphyton, shade.

INTRODUCTION

A large number of studies have examined the effects of nutrient enrichment, particularly nitrogen and phosphorus, on periphyton growth and algal community composition (e.g., Winterbourn 1990; Rader and Richardson 1992; Hepinstall and Fuller 1994; Friberg and Winterbourn 1997). Several of these studies were conducted in response to increased levels of eutrophication found in streams, particularly those draining agricultural catchments. Increases in nutrient supply to streams has also been associated with forestry operations and the removal of protective streamside vegetation (Waters 1995). Forestry operations such as logging and burning can increase the amount of nutrients entering streams by disrupting forest ecosystem nutrient cycles and increasing sediment inputs to waterways (Winterbourn 1986). Numerous studies have compared the effects of nutrient addition on periphyton communities between streams draining open pastoral and closed canopy forest catchments (e.g., Chessman et al., 1992; Corkum 1996a; Friberg and Winterbourn 1997). Friberg and Winterbourn (1997) found nutrient addition increased algal biomass in both closed canopy and open pastoral streams. Fewer studies, particularly in the North Island, New Zealand, have compared the effects of nutrient enrichment on periphyton communities between streams draining logged and mature standing production forest catchments.

Light is a key requirement for algal photosynthesis (Hill 1996). Numerous studies have illustrated the limiting effects that light can have on periphyton growth in forested streams (e.g., Winterbourn and Fegley 1989; Rosemond 1993; Kjeldsen 1996; Quinn et al. 1997). Friberg and Winterbourn (1997) and Winterbourn (1990) found chlorophyll *a* levels to be significantly higher in open canopy streams than in closed canopy streams, independent of nutrient treatment.

Holopainen and Huttunen (1992) noted that while the removal of shade trees increases incoming light to streams, this effect may be counter-balanced by higher turbidity caused by increased sediment loads during clear-cutting. Disturbances from increases in suspended sediments can abrade and suffocate periphyton and decrease photosynthetic rate through the clouding of waters (Waters 1995). Flood events are now recognised as one of the dominant factors controlling stream periphyton communities (Peterson 1996; Biggs 1996; Biggs et al., 1998) and Biggs (1995) found that the water velocities that occur during flooding can remove >70% of the periphyton by water shear alone. While a number of studies have examined the effects of physical disturbance upon periphyton communities (e.g., Humphrey and Stevenson 1992; Biggs and Thomsen 1995; Jowett and Biggs 1997), few have examined the interaction of nutrients, light levels, and disturbance upon periphyton biomass.

In this study I examine the effects of disturbance, nutrient addition, and light availability on periphyton biomass in streams draining mature exotic *Pinus radiata* forest, logged exotic *Pinus radiata*, native podocarp/broadleaf forest, and mature exotic *Eucalyptus delegatensis* forest catchments.

METHODS

Study area

The experiment was carried out within Gwavas Forest, Hawkes Bay, North Island, New Zealand. Catchment geology consisted of either large angular greywacke gravels or small tertiary conglomerates of pumice and Pleistocene gravels. Sites were in one of four forest types: 2 sites were in standing *Pinus radiata* plantations (20 - 26 years), 3 sites were in logged *Pinus radiata* catchments (3 - 4 years), 2 sites were in native podocarp/broadleaf forest, and 1 site was in a standing *Eucalyptus delegatensis* plantation (22 years), the latter had no riparian zone and was considered an open canopy site along with the logged sites.

Maximum, minimum, and current water temperatures were measured weekly near the artificial substrates using maximum-minimum thermometers. Conductivity at 25°C (Orion 122 Conductivity meter), width, depth, and velocity (Velocity head rod) were also recorded weekly.

All streams were similar in size and velocity (Table 1) with water temperatures relatively similar between streams, although open sites had a greater temperature range.

Table 1 Mean (range in parentheses) physico-chemical characteristics of 4 open canopy and 4 closed canopy sites measured weekly during November and December 1997 in streams of the Hawkes Bay.

Stream	Forest type	Temperature (°C)	Minimum temperature (°C)	Maximum temperature (°C)	Width (m)	Depth (cm)	Velocity (m/s)	Conductivity (µs/cm)
Mangamate stm	Exotic	13.4 (12 - 14)	11.3 (10 - 12)	16.3 (15 - 19)	1.96 (1.7 - 2.0)	10 (9 - 13)	0.21 (0.18 - 0.22)	79.4 (76 - 88)
Ohara stm (lower reach)	Exotic	15.6 (13 - 19)	10.8 (9 - 13)	20.5 (20 - 22)	2.36 (2.2 - 2.4)	11 (10 - 11)	0.23 (0.18 - 0.31)	120.9 (115 - 128)
Pinchgut Creek	Native	12.5 (10 - 14)	9.8 (9 - 12)	15 (13 - 17)	2.09 (1.8 - 2.2)	7 (6 - 8)	0.17 (0 - 0.18)	116.6 (115 - 119)
Poutaki stm	Native	15.6 (12 - 23)	9 (7 - 12)	22 (20 - 24)	2.39 (2.2 - 2.7)	10 (8 - 14)	0.20 (0 - 0.22)	109.6 (107 - 112)
Middle Upokororo stm	Logged	12.5 (11 - 14)	10.3 (9 - 12)	15 (15)	1.78 (1.5 - 1.9)	10 (9 - 11)	0.22 (0.18 - 0.31)	145.6 (143 - 148)
Ohara stm (upper reach)	Logged	19 (13 - 27)	9 (7 - 12)	26 (23 - 29)	1.81 (1.6 - 1.9)	11 (10 - 13)	0.22 (0.18 - 0.26)	114 (110 - 118)
Mangaonuku stm	Logged	15.6 (11 - 26)	6.5 (5 - 9)	25.5 (24 - 27)	1.31 (1.3 - 1.3)	7 (6 - 9)	0.20 (0.18 - 0.22)	84.8 (80 - 88)
Poporangi stm	Eucalyptus	14.5 (12 - 20)	8.3 (7 - 9)	19.7 (18 - 21)	2.95 (2.7 - 3.3)	7 (6 - 9)	0.37 (0.22 - 0.63)	173.8 (165 - 179)

Diffusion substrata

Nutrient diffusing substrata were constructed following Winterbourn (1990) and comprised 80 ml plastic cups tightly fastened into inverted plastic tray moulds, filled with either 2% agar (nutrient control) or 2% agar and 0.5 mol $NaNO_3$ and 0.1 mol KH_2PO_4 (nutrient treatment). The upper surface (area 20 cm^2) of the agar was covered with fine (250µm) plankton netting held in place with a plastic tie. Control cups were placed in the upstream half of the mould. The plastic moulds were firmly anchored to the stream bed using tent pegs and large stones.

Three trays (10 pottles in each; 5 nutrient control and 5 nutrient treatment) were placed in each stream. Every 7 days the disturbance treatment surfaces (1 tray in each stream) were physically abraded, using a rigid plastic bristle brush, to imitate sediment and flow abrasion. Within one stream of each canopy type, polythene cloth which reduced 90% of ambient light levels was placed over 1 tray. After 28 days, the trays were removed and the plankton netting stored on ice for transport to the laboratory.

Periphyton analysis

Half of the plankton netting was immersed in 10 mls of 90% acetone overnight at 5°C for pigment extraction. Absorbances were measured at 410, 430, 665, and 720nm with a Jenway 6105 UV/V spectrophotometer and chlorophyll *a* concentration calculated following Moss (1967a, b). The remainder of the netting was dried to constant weight and incinerated at 600°C for 2 hours to determine ash free dry weight (AFDW); dry weight minus ash weight corrected for mesh combustion.

Statistical analysis

A fixed, four-way fully factorial Analysis of Variance (ANOVA) was performed using SAS (1989) to determine univariate differences in chlorophyll *a* concentration and AFDW between canopy cover, nutrient, disturbance, and artificial shade treatments. Where necessary, data were log transformed to remove heterogeneity of variance.

RESULTS

Pigment concentration

Pigment concentrations in logged and mature *Pinus radiata* sites were twice that on surfaces which had nutrient added than those without (Fig. 1). This effect was independent of disturbance treatment. Canopy cover also had a significant effect on pigment concentration with both logged *Pinus radiata* and mature *Eucalyptus delegatensis* sites having chlorophyll *a* levels significantly higher than those found in closed canopy sites (Table 2). Overall, the chlorophyll *a* concentrations found at open sites were 3 times higher than those found at closed sites. At all open sites, chlorophyll *a* concentrations on disturbed substrates were lower than on undisturbed substrates (Fig. 2).

Treatments not covered with polythene cloth had 70 - 80% higher levels of chlorophyll *a* than those artificially shaded (Fig. 3). An interaction existed between nutrient addition and the artificial shade treatment with only native forest sites having significantly higher chlorophyll *a* concentrations on artificially shaded nutrient enriched substrates than on artificially shaded nutrient control substrates.

Ash free dry weight

Streams draining mature *Eucalyptus delegatensis* plantations had 50% more AFDW than streams in other forest types, with streams in logged *Pinus radiata* catchments having significantly higher AFDW than native forest stream sites. Surfaces at the *Eucalyptus* site that were undisturbed were found to have significantly higher AFDW's than surfaces that were physically abraded (Fig. 4). Overall AFDW levels were not significantly different between nutrient treatments, although nutrient enriched substrata in logged *Pinus radiata* sites did have significantly higher AFDWs than control substrata (Fig. 5). Artificial shading reduced AFDWs on shaded substrates below those found on non-artificially shaded substrates in native forest and logged exotic forest catchments (Fig. 6).

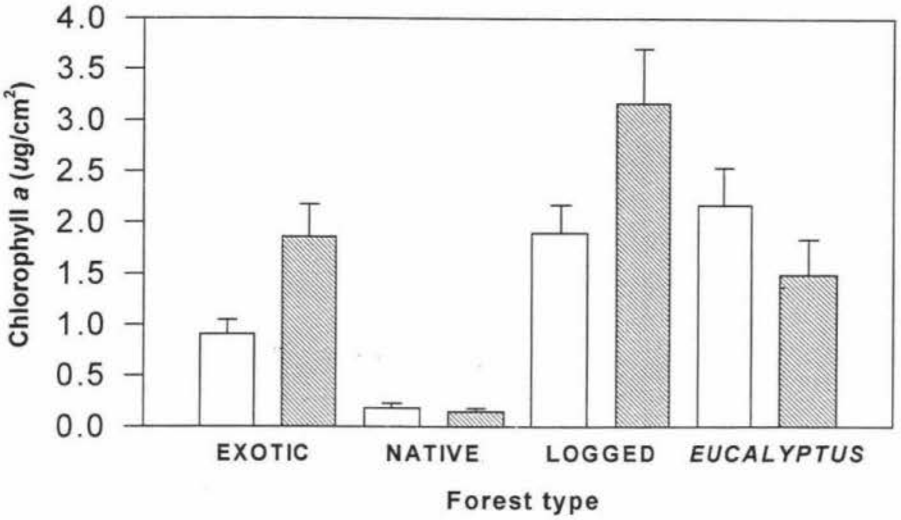

Fig. 1 Chlorophyll *a* levels (±1 SE) for artificial substrates in four forest types on control (open bars) and enriched (hatched bars) substrata.

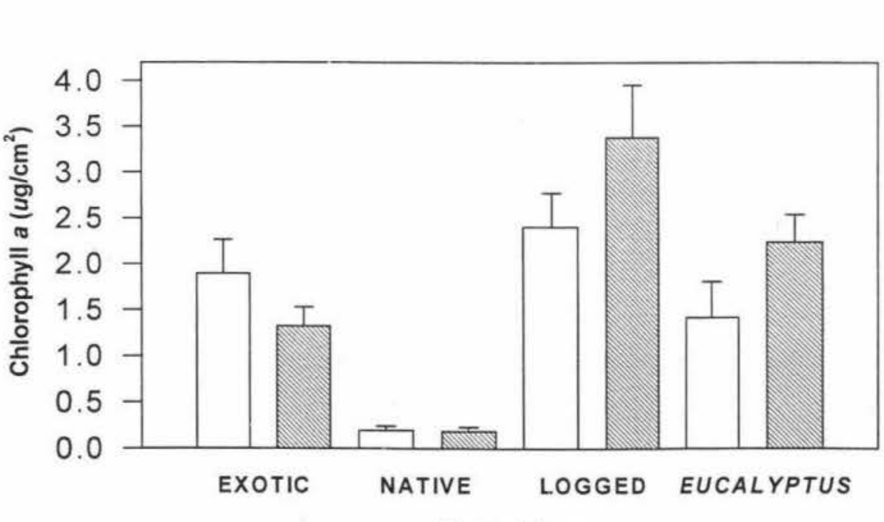

Fig. 2 Chlorophyll *a* levels (±1 SE) for artificial substrates in four forest types on disturbed (open bars) and undisturbed (hatched bars) substrata.

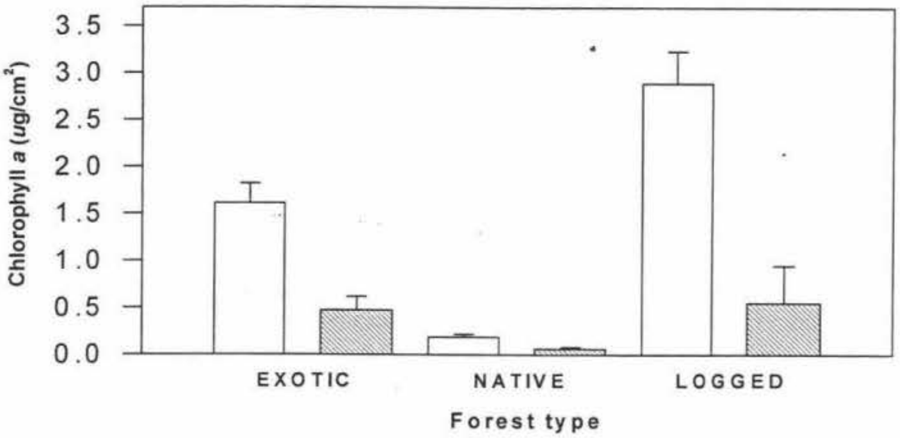

Fig. 3 Chlorophyll *a* levels (±1 SE) for artificial substrates in four forest types on unshaded (open bars) and shaded (hatched bars) substrata.

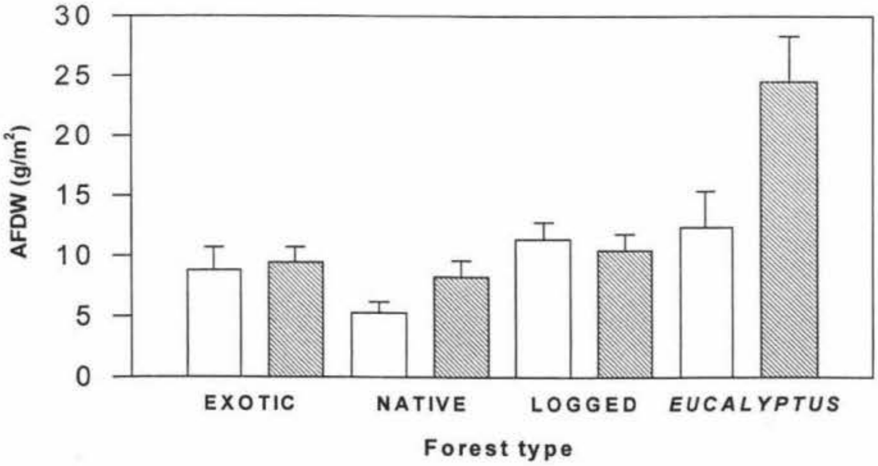

Fig. 4 AFDW (±1 SE) for artificial substrates in four forest types on disturbed (open bars) and undisturbed (hatched bars) substrata.

Table 2 F-values, degrees of freedom, and P-values for four-way ANOVAs performed on Ash free dry weights and chlorophyll *a* concentrations of artificial substrata removed from 8 Hawkes Bay streams in December 1997. An asterix indicates a significant interaction between the variables.

Variables	F-value	d.f.	P-value
Canopy cover			
v. chlorophyll *a*	37.49	3,173	0.000*
v. AFDW	6.69	3,135	0.000*
Nutrient addition			
v. chlorophyll *a*	1.87	1,173	0.17
v. AFDW	0.02	1,135	0.90
Disturbance			
v. chlorophyll *a*	2.58	1,173	0.11
v. AFDW	5.08	1,135	0.03*
Artificial shade			
v. chlorophyll *a*	29.09	1,173	0.000*
v. AFDW	2.84	1,135	0.09
Canopy cover * Nutrient addition			
v. chlorophyll *a*	3.33	3,173	0.02*
v. AFDW	3.02	3,135	0.03*
Canopy cover * Disturbance			
v. chlorophyll *a*	1.49	3,173	0.22
v. AFDW	2.49	3,135	0.06
Nutrient addition * Artificial shade			
v. chlorophyll *a*	8.69	1,173	0.004*
v. AFDW	0.08	1,135	0.78
Nutrient addition * Disturbance			
v. chlorophyll *a*	0.01	1,173	0.93
v. AFDW	0.85	1,135	0.36

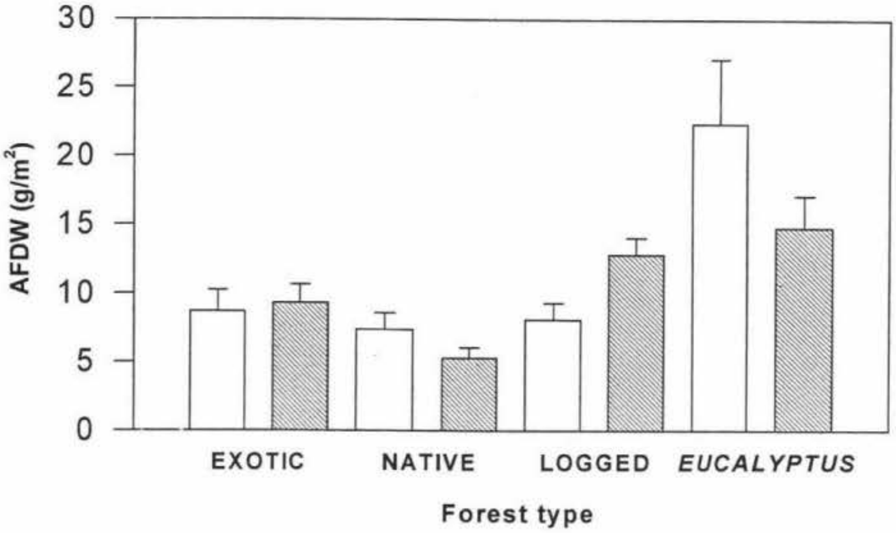

Fig. 5 AFDW (±1 SE) for artificial substrates in four forest types on control (open bars) and enriched (hatched bars) substrata.

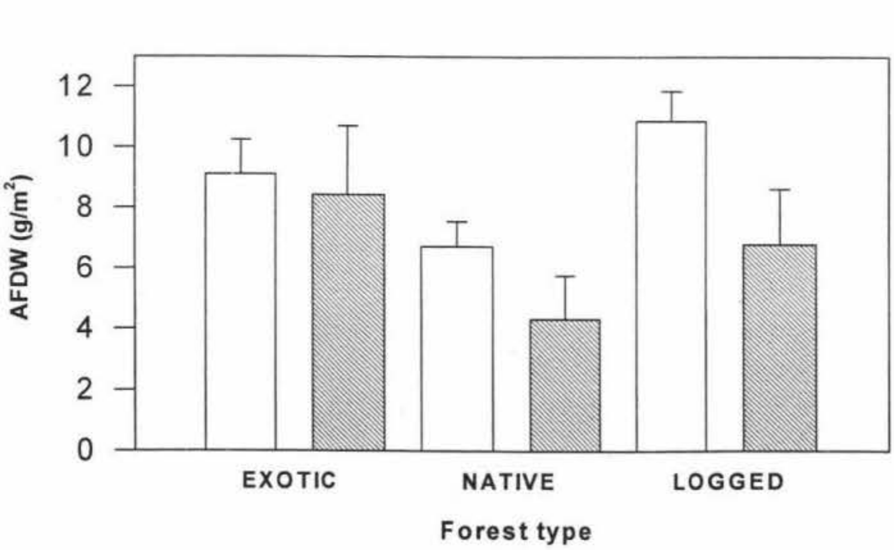

Fig. 6 AFDW (±1 SE) for artificial substrates in four forest types on unshaded (open bars) and shaded (hatched bars) substrata.

DISCUSSION

Light availability, dictated by percentage canopy cover or artificial cover, played the major role in determining chlorophyll *a* concentrations and AFDW's on the artificial substrates. Nutrient enrichment increased periphyton biomass on substrates within mature and logged *Pinus radiata* forest streams. Biofilm development was greater on surfaces that were undisturbed, but only at open sites.

A number of studies have found light to be limiting algal growth in streams (e.g., Hill and Knight 1988; Steinman 1992; Hepinstall and Fuller 1994; Quinn et al. 1997). Where streams in my study had ample sunlight, algal biomass was considerably higher compared with streams where shade from overhead vegetation was limiting light penetration. Artificial shading effects on periphyton further illustrated this. Chlorophyll *a* levels were significantly lower on artificially shaded substrates than non shaded substrates, even at closed canopy sites. Thus although closed canopies reduced light levels, sufficient light was still getting through for some algal growth. In a similar study, Hepinstall and Fuller (1994) found comparable results, with open sites having the highest chlorophyll *a* levels, and artificially shaded closed canopy sites the lowest.

In other studies, periphyton communities have been shown to be nutrient limited within both open and closed canopy systems, both in New Zealand and overseas (e.g., Winterbourn and Fegley 1989; Chessman et al. 1992; Walton et al., 1995; Friberg and Winterbourn 1997). Sites on both mature and logged *Pinus radiata* streams in the present study showed an increase in chlorophyll *a* biomass with the addition of nutrients, while native streams did not, indicating light was more important than nutrients at these sites. Minshall (1978) has also found that streams that are heavily shaded are less likely to experience nutrient limitation. The fact that, at the *Eucalyptus delegatensis* site, nutrient addition didn't increase periphyton biomass significantly above levels found on control substrates, could also be due to grazer control. During the experiment, browsing mayflies were observed on substrate surfaces, and a number of other studies have found a reduction of algal biomass by grazing invertebrates, particularly at open sites (e.g., Kjeldsen 1996; Rosemond 1993; Winterbourn and Fegley 1989). However, lack of response of periphyton to nutrient addition at the *Eucalyptus* site indicates nutrients were not limiting periphyton growth. At this site, long strands of filamentous algae were observed along large portions of the stream, perhaps indicating that neither light or nutrient levels were limiting periphyton growth in this stream.

Several authors have shown that increases in flows and sediment movements can reduce periphyton biomass (e.g., Horner et al. 1990; Corkum 1996b; Peterson 1996; Biggs 1996). Overall, in this study, surfaces that were physically disturbed showed no significant response with respect to chlorophyll *a* levels, however in the open sites, physical abrasion did reduce chlorophyll *a* concentrations on disturbed substrates below those found on control substrates. This tends to indicate that at closed canopy sites, light was a more important determinant of periphyton biomass than level of physical disturbance. However, AFDWs were affected by disturbance, with this effect most prominent at the open *Eucalyptus* site. During the experiment, periphyton was able to colonise the under surface of the nutrient diffusing substrate, so that while the outer surface was abraded and the majority of organic matter removed, periphyton on the under surface was less affected. Winterbourn (1990) also found algae colonised the underside of artificial mesh.

In conclusion, light availability was the dominant factor affecting periphyton colonisation and growth in Hawkes Bay forested streams. Light was also the main determinant of AFDWs on substrates in this study, with disturbance playing a secondary role. While not all streams were nutrient limited, nutrient limitation was exhibited by periphyton communities in both open and closed streams. Repeated physical disturbance was effective in reducing chlorophyll *a* levels only at open sites, however, light and nutrients were more important determinants of periphyton biomass.

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DISCUSSION

DISCUSSION

The macroinvertebrate communities in Hawkes Bay agricultural and forestry streams were clearly influenced by the land use of their surrounding catchments. Pastoral streams had characteristically high temperatures and minimal canopy shading (riparian zone) and their communities were dominated by dipterans and trichopterans. Native forest stream communities were dominated by Plecoptera and Ephemeroptera, in much the same way that exotic sites were. Other studies have found similar invertebrate communities in native forest and exotic plantation forest streams, indicating this to be widespread (Friberg et al., 1997; Quinn et al., 1997a). Sandstone-greywacke streams were also dominated by Plecoptera and Ephemeroptera, although as no sandstone-greywacke pastoral streams were found, this effect could equally be attributed to land use effects. Biggs (1990) found conductivity to be the best predictor of periphyton communities and conductivity clearly had an influence on periphyton biomass in streams in this study. Limestone streams exhibited very high conductivity levels and high periphyton biomass, independent of land use.

Canopy cover was not only an important determinant of macroinvertebrate community structure and composition, it controlled periphyton abundance in forested streams. On artificial substrates as well as on stone surfaces, Friberg and Winterbourn (1997) found higher chlorophyll *a* concentrations at open sites than closed sites. A number of other studies have also found light to be limiting to algal growth in streams (e.g., Hepinstall and Fuller 1994; Corkum 1996; Quinn et al., 1997b). At both open and closed sites and in artificially shaded treatments, the addition of nutrients significantly increased chlorophyll *a* concentrations on artificial substrates. Closed canopy mature exotic sites had periphyton communities that were both nutrient and light limited (Chessman et al., 1992; Biggs 1995; Friberg and Winterbourn 1997). While physical abrasion of periphyton significantly reduced chlorophyll *a* concentrations on substrates at open sites, light and nutrient levels appeared to be more important determinants of periphyton biomass in this study.

In conclusion, this study found both geology and land use to control the structure of macroinvertebrate and periphyton communities in streams. Differences in enrichment levels, temperatures, and levels of canopy cover appeared to be the dominant influences resulting from the different geological and land use types. Light and nutrients clearly limit periphyton communities, although disturbance may also be important.

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APPENDIX

MACROINVERTEBRATE DATA FROM ESK, GWAVAS, KAWEKA, MOHAKA, AND TANGOIO FOREST AND SURROUNDING CATCHMENT STREAMS (CHAPTER TWO SPECIES DATA).

NB: Values for each species are the average of four Surber samples, taken from each stream between December 1996 and January 1997.

SPECIES →	*Acanthophlebia cruentata*	Acari 1	Acari 2	Acari 3	Acari 4	Acari 5	Acari 6
STREAM ↓							
Mangamauku Stm		0.5					
Ohara Stm 2							
Waikarokaro Stm							
Pakuratahi Stm 1							
Pakuratahi Stm 2		2					
Pakuratahi Stm 3		0.75					
Pakuratahi Stm 4		8.75	0.25				
Pakuratahi Stm 5		43					
Anaura Stm 1		0.25					
Anaura Stm 3							0.25
Mangamate Stm 1	0.25						
Middle Upokororo Stm		1.25					
Ohara Stm 1							
Otekarara Stm 1		0.25				0.25	
Otekarara Stm 3							
Kakariki Stm 1		1.25					
Heruheru Stm		0.5					
Mohaka River		1		0.25			
Anaura Stm 2		1					
Mangaonuku Stm 1		0.5					
Deep Stm							
Pinchgut Creek							
Poutaki Stm							
Omarowa Stm		2.25					
Otekarara Stm 2					0.25	0.25	
Korongomairoa Stm 1		1.5					
Korongomairoa Stm 2							
Tamingimingi Stm 1		1.25					
Tamingimingi Stm 2							
Tamingimingi Stm 3							
Tamingimingi Stm 4							
Tamingimingi Stm 5		0.75					
Kakariki Stm 2		0.5					
Matahorua Stm		1.25					
Mangamate Stm 2							
Mangaonuku Stm 2							
Maraekakaho Stm							

SPECIES →	*Ameletopsis perscitus*	Amphipoda	*Aoteapsyche* sp.	*Aphrophila neozelandica*	*Archichauliodes diversus*
STREAM ↓					
Mangamauku Stm			0.25		2.5
Ohara Stm 2	0.5		1		2
Waikarokaro Stm				1.75	13.25
Pakuratahi Stm 1					2.5
Pakuratahi Stm 2					2.75
Pakuratahi Stm 3					
Pakuratahi Stm 4					0.5
Pakuratahi Stm 5			1.25		1
Anaura Stm 1				0.75	4
Anaura Stm 3			16.25	0.5	0.25
Mangamate Stm 1					2.5
Middle Upokororo Stm			1.25		3.5
Ohara Stm 1	0.25		7		3.25
Otekarara Stm 1			0.75		2
Otekarara Stm 3			1.25		6.75
Kakariki Stm 1				0.25	
Heruheru Stm			0.25		0.25
Mohaka River			0.25		0.25
Anaura Stm 2					0.25
Mangaonuku Stm 1					15
Deep Stm			10.75		0.25
Pinchgut Creek	1.75		1.25		6.75
Poutaki Stm	0.5				1.25
Omarowa Stm	0.75		3.5		0.75
Otekarara Stm 2					3.5
Korongomairoa Stm 1				0.5	0.5
Korongomairoa Stm 2					
Tamingimingi Stm 1			4	3.75	
Tamingimingi Stm 2			18	1.25	
Tamingimingi Stm 3			24.25	0.25	
Tamingimingi Stm 4			39	1	
Tamingimingi Stm 5			1.25		
Kakariki Stm 2					0.25
Matahorua Stm					
Mangamate Stm 2			19.5		2.5
Mangaonuku Stm 2					0.5
Maraekakaho Stm		0.75	4.5		

SPECIES →	*Austroclima* sp.	*Austroperla cyrene*	*Austrosimulium australense*-group	*Beraeoptera roria*	*Berosus*
STREAM ↓					
Mangamauku Stm	1.75	1		0.25	
Ohara Stm 2	1	0.25			
Waikarokaro Stm	36		1	1.75	
Pakuratahi Stm 1	0.5		0.75		
Pakuratahi Stm 2	1.5		0.75		
Pakuratahi Stm 3	3		1.5		
Pakuratahi Stm 4	5.5		4		
Pakuratahi Stm 5	3.5		3		
Anaura Stm 1	40	1	0.5		
Anaura Stm 3			1.5		0.25
Mangamate Stm 1		0.5	6		
Middle Upokororo Stm	0.5				
Ohara Stm 1	3.25			12	
Otekarara Stm 1	11.25	0.25			
Otekarara Stm 3	5		0.5		0.25
Kakariki Stm 1					
Heruheru Stm			0.25		0.25
Mohaka River	2.25				
Anaura Stm 2					
Mangaonuku Stm 1		1	0.25		
Deep Stm					
Pinchgut Creek		0.75		0.25	
Poutaki Stm		0.75			
Omarowa Stm		0.5		4	
Otekarara Stm 2	2		1.75		
Korongomairoa Stm 1		0.25			
Korongomairoa Stm 2			0.25		
Tamingimingi Stm 1			2.5		
Tamingimingi Stm 2			1.25		
Tamingimingi Stm 3					
Tamingimingi Stm 4					
Tamingimingi Stm 5			12.25		
Kakariki Stm 2			0.75		3.5
Matahorua Stm	0.25		4.25		
Mangamate Stm 2					
Mangaonuku Stm 2					
Maraekakaho Stm	0.75				

SPECIES →	*?Brachy-deutera*	Ceratopogonidae	Chironomidae pupae	Chironomidae 1	Chironomidae 2
STREAM ↓					
Mangamauku Stm			0.5	0.5	
Ohara Stm 2					
Waikarokaro Stm		0.25	5.75	120.25	11.75
Pakuratahi Stm 1				18.25	37
Pakuratahi Stm 2				2	2.5
Pakuratahi Stm 3				3.75	25
Pakuratahi Stm 4				2.25	31.25
Pakuratahi Stm 5				2.5	13.25
Anaura Stm 1			9	63.75	7.75
Anaura Stm 3			37.25	1	660.5
Mangamate Stm 1			0.25	7.5	5.25
Middle Upokororo Stm			0.5	0.75	
Ohara Stm 1			0.25	1.25	
Otekarara Stm 1				0.5	
Otekarara Stm 3			0.75	0.75	0.25
Kakariki Stm 1		0.25	0.25	2.25	0.75
Heruheru Stm	0.75		1.25	7.5	19
Mohaka River			2.25	6.5	1.5
Anaura Stm 2			0.25	3.5	1
Mangaonuku Stm 1					
Deep Stm			1	3.5	7.75
Pinchgut Creek			0.25	0.75	
Poutaki Stm					
Omarowa Stm			0.25	1.25	3.5
Otekarara Stm 2		1	0.75	4.75	0.5
Korongomairoa Stm 1				2.75	0.25
Korongomairoa Stm 2				1	0.25
Tamingimingi Stm 1		0.75	3	95.75	14.5
Tamingimingi Stm 2		0.25	4.5	108.75	22
Tamingimingi Stm 3			16.75	347.75	35.75
Tamingimingi Stm 4			16.25	12.75	48
Tamingimingi Stm 5			25	94	97.25
Kakariki Stm 2			2.5	2.25	57.25
Matahorua Stm			1	10.25	0.25
Mangamate Stm 2			0.25	49	78
Mangaonuku Stm 2				0.25	
Maraekakaho Stm			1.25	4.25	0.75

SPECIES →	Chironomidae 3	Chironomidae 4	Chironomidae 5	Chironomidae 6	Coleoptera: unidentified
STREAM ↓					
Mangamauku Stm					
Ohara Stm 2					
Waikarokaro Stm	48	1.75	2		
Pakuratahi Stm 1	4.5				
Pakuratahi Stm 2	5.5		0.75		
Pakuratahi Stm 3	34.75		3	0.5	
Pakuratahi Stm 4	6				
Pakuratahi Stm 5	62.75		2.25		
Anaura Stm 1	55	0.25	6.5	0.5	
Anaura Stm 3	5	1.75	1.75		
Mangamate Stm 1		0.25			
Middle Upokororo Stm	0.25				
Ohara Stm 1	3	0.25	0.25		
Otekarara Stm 1	2.5				
Otekarara Stm 3	1				
Kakariki Stm 1	0.5		3.75		
Heruheru Stm	7	0.25	3		
Mohaka River	0.25		2.25		
Anaura Stm 2			1.25		
Mangaonuku Stm 1					
Deep Stm	1.5	1	1.5		
Pinchgut Creek	0.25	0.25			
Poutaki Stm					0.25
Omarowa Stm					
Otekarara Stm 2	1				
Korongomairoa Stm 1	2.5		2.75		
Korongomairoa Stm 2	0.25		0.5		
Tamingimingi Stm 1	22.25	2	22		
Tamingimingi Stm 2	45	9.75			
Tamingimingi Stm 3	316	31			
Tamingimingi Stm 4	227.75	115.25	1.25		
Tamingimingi Stm 5	99.75	26.5	9.25		
Kakariki Stm 2	1.25	10.5			
Matahorua Stm	3		1	0.5	
Mangamate Stm 2	3.5	2.5			
Mangaonuku Stm 2					
Maraekakaho Stm	5.5		0.25		

SPECIES →	Collembola	*Coloburiscus* sp.	Crayfish (juvenille)	*Deleatidium* sp.	Diptera (unidentified)
STREAM ↓					
Mangamauku Stm		6		14.25	
Ohara Stm 2		13		33	
Waikarokaro Stm		2.75		109	
Pakuratahi Stm 1		74		29.25	
Pakuratahi Stm 2		30		17.25	
Pakuratahi Stm 3				26.25	
Pakuratahi Stm 4		0.5	0.25	56	
Pakuratahi Stm 5				27.75	0.25
Anaura Stm 1		7		103.5	
Anaura Stm 3				4.75	
Mangamate Stm 1		4.5		24.5	
Middle Upokororo Stm	0.25	2.5		37.5	
Ohara Stm 1		8		34	
Otekarara Stm 1		13.5		38.5	
Otekarara Stm 3		4		23.5	
Kakariki Stm 1				0.25	
Heruheru Stm				1	
Mohaka River				23.75	
Anaura Stm 2				0.75	
Mangaonuku Stm 1		8.5		6.75	
Deep Stm		0.75		42.25	
Pinchgut Creek		4.25		29.5	
Poutaki Stm		13.5		21	
Omarowa Stm		6.75		152.75	
Otekarara Stm 2		0.25	0.25	11.25	
Korongomairoa Stm 1				3.75	
Korongomairoa Stm 2					0.25
Tamingimingi Stm 1		0.25		28.5	
Tamingimingi Stm 2				7.25	
Tamingimingi Stm 3				151.5	
Tamingimingi Stm 4				303.5	
Tamingimingi Stm 5				12	
Kakariki Stm 2				13.5	
Matahorua Stm		0.5		4.25	
Mangamate Stm 2		0.25		61.25	0.25
Mangaonuku Stm 2				85.75	
Maraekakaho Stm				75.25	

SPECIES →	Ecnomidae	Elmidae (adult)	Elmidae (larvae)	Empididae	*Ephydrella* sp.	*Eriopterini* sp.
STREAM ↓						
Mangamauku Stm			1.25			
Ohara Stm 2		0.25	10.75			
Waikarokaro Stm			20.25	0.25		
Pakuratahi Stm 1		0.25	2.25	0.75		0.5
Pakuratahi Stm 2	0.25		33.25	1.75		2
Pakuratahi Stm 3		0.75	60.75	1.25		0.75
Pakuratahi Stm 4			1.5			
Pakuratahi Stm 5				0.75		0.25
Anaura Stm 1			14.5			0.25
Anaura Stm 3		16.25	39	8.25	1.5	
Mangamate Stm 1		15.75	4.5			
Middle Upokororo Stm			2			0.5
Ohara Stm 1			10.25	0.25		
Otekarara Stm 1		14.25				
Otekarara Stm 3			76.5			4.25
Kakariki Stm 1		0.25				
Heruheru Stm		0.25				
Mohaka River		4.5	9.5			
Anaura Stm 2			0.5			0.25
Mangaonuku Stm 1		42.75	38			3.25
Deep Stm		41.25	145.75			4.75
Pinchgut Creek			5.5	0.5		0.25
Poutaki Stm			2.25	0.25		0.25
Omarowa Stm		2.25	171.25			0.75
Otekarara Stm 2			4.5			
Korongomairoa Stm 1			0.25			
Korongomairoa Stm 2		0.25				
Tamingimingi Stm 1		9.5	5.5			0.25
Tamingimingi Stm 2		13.5	5.5			1.5
Tamingimingi Stm 3		117	21.75	0.25		
Tamingimingi Stm 4		74.75	83.25	2		
Tamingimingi Stm 5			1.25			
Kakariki Stm 2		49.25	59	1		0.25
Matahorua Stm			0.25			
Mangamate Stm 2		2.25	24	0.5		1.25
Mangaonuku Stm 2		0.75	72.5			
Maraekakaho Stm		5	107.25			

SPECIES →	*Helicopsyche* sp.	*Hudsonema aliena*	*Hudsonema amabilis*	Hydraenidae (adult)	*Hydrobiosella* sp.
STREAM ↓					
Mangainauku Stm	12			1.25	
Ohara Stm 2	1.5			6.25	
Waikarokaro Stm	18			13	
Pakuratahi Stm 1					0.5
Pakuratahi Stm 2					1.5
Pakuratahi Stm 3					
Pakuratahi Stm 4					
Pakuratahi Stm 5					
Anaura Stm 1	0.25			0.5	
Anaura Stm 3			8		
Mangamate Stm 1	0.25	0.25			
Middle Upokororo Stm	28.25			3.5	0.25
Ohara Stm 1	102.25			4.75	0.5
Otekarara Stm 1	1.75			4.5	
Otekarara Stm 3					
Kakariki Stm 1					
Heruheru Stm					
Mohaka River					
Anaura Stm 2					
Mangaonuku Stm 1	0.5				
Deep Stm			0.25	0.25	
Pinchgut Creek	35.25			6.5	
Poutaki Stm	0.5			0.75	
Omarowa Stm	36.5			5.75	
Otekarara Stm 2	0.25			0.25	
Korongomairoa Stm 1	1.75				
Korongomairoa Stm 2				0.25	
Tamingimingi Stm 1					
Tamingimingi Stm 2					
Tamingimingi Stm 3					
Tamingimingi Stm 4			80.25		
Tamingimingi Stm 5			8.25		
Kakariki Stm 2			2.5		
Matahorua Stm					
Mangamate Stm 2			6		
Mangaonuku Stm 2			3.75		
Maraekakaho Stm	1.5				

SPECIES →	*Hydrobiosis clavigera*	*Hydrobiosis parumbripennis*	Hydrophilidae	*Hygraula nitens*	*Ichthybotus* sp.
STREAM ↓					
Mangamauku Stm	0.25			0.5	0.25
Ohara Stm 2	0.5	0.25			
Waikarokaro Stm	0.75	4.75			2.25
Pakuratahi Stm 1		3.5			9
Pakuratahi Stm 2					2.5
Pakuratahi Stm 3		4.25			0.25
Pakuratahi Stm 4		2.25			1
Pakuratahi Stm 5		3			
Anaura Stm 1	4.25	6.5			0.5
Anaura Stm 3	1.5	6.75			
Mangamate Stm 1		1.5			
Middle Upokororo Stm	0.25			0.5	
Ohara Stm 1	0.5	0.25			
Otekarara Stm 1	0.75	0.5			
Otekarara Stm 3	0.5	2.5			
Kakariki Stm 1		0.25			
Heruheru Stm		0.25			
Mohaka River		8.5			
Anaura Stm 2					
Mangaonuku Stm 1		1.75			0.25
Deep Stm	3.75	1.5		0.25	
Pinchgut Creek	0.25				
Poutaki Stm	0.5	0.5		0.25	
Omarowa Stm	1.5	0.25			0.75
Otekarara Stm 2	0.5	0.25			
Korongomairoa Stm 1		0.25		0.25	0.25
Korongomairoa Stm 2		0.25			
Tamingimingi Stm 1		11.75			
Tamingimingi Stm 2		7.5			
Tamingimingi Stm 3		88.25			
Tamingimingi Stm 4	3	3.25			
Tamingimingi Stm 5	3.5	19			
Kakariki Stm 2	1	4.5			
Matahorua Stm		1.5	0.25		
Mangamate Stm 2		4.25			
Mangaonuku Stm 2		0.25			
Maraekakaho Stm	1	1			

SPECIES →	*Mauiulus luma*	*Megaleptoperla diminuta*	*Megaleptoperla grandis*	*Mischoderus* sp.	*Molophilus* sp.
STREAM ↓					
Mangamauku Stm					
Ohara Stm 2					
Waikarokaro Stm					
Pakuratahi Stm 1	0.5	1.75			
Pakuratahi Stm 2		0.5			
Pakuratahi Stm 3	20.75				
Pakuratahi Stm 4					
Pakuratahi Stm 5					
Anaura Stm 1		5.5			
Anaura Stm 3					
Mangamate Stm 1					
Middle Upokororo Stm					
Ohara Stm 1					
Otekarara Stm 1		0.25			
Otekarara Stm 3			0.25		
Kakariki Stm 1					
Heruheru Stm					
Mohaka River				0.25	0.5
Anaura Stm 2		1.25			
Mangaonuku Stm 1					
Deep Stm					
Pinchgut Creek					
Poutaki Stm					
Omarowa Stm		0.25			
Otekarara Stm 2					
Korongomairoa Stm 1					
Korongomairoa Stm 2					
Tamingimingi Stm 1					
Tamingimingi Stm 2					
Tamingimingi Stm 3					
Tamingimingi Stm 4					
Tamingimingi Stm 5					
Kakariki Stm 2					
Matahorua Stm					
Mangamate Stm 2					
Mangaonuku Stm 2					
Maraekakaho Stm					

SPECIES →	*Neozephlebia scita*	*Nesameletus* sp.	*Neurochorema* sp.	*Oeconesus maori*	Oligochaete (large)
STREAM ↓					
Mangamauku Stm		0.5			
Ohara Stm 2					
Waikarokaro Stm	40.25	2.5	0.25		
Pakuratahi Stm 1		0.25			
Pakuratahi Stm 2			1.75		
Pakuratahi Stm 3		0.25		0.25	0.75
Pakuratahi Stm 4		1.25		0.5	
Pakuratahi Stm 5	0.25		0.5		
Anaura Stm 1	3.5	107.25	0.75		
Anaura Stm 3		2.75			
Mangamate Stm 1					
Middle Upokororo Stm	0.5				
Ohara Stm 1	1				
Otekarara Stm 1					
Otekarara Stm 3		0.25	0.5		
Kakariki Stm 1		0.75		0.25	
Heruheru Stm		0.75			
Mohaka River		0.5			
Anaura Stm 2		12.75			0.25
Mangaonuku Stm 1					
Deep Stm			0.75		
Pinchgut Creek	0.75			0.25	
Poutaki Stm	0.25				
Omarowa Stm	5	3.5			
Otekarara Stm 2		2			
Korongomairoa Stm 1	1.75	4.5		0.5	
Korongomairoa Stm 2		1.75		0.25	
Tamingimingi Stm 1				0.25	0.5
Tamingimingi Stm 2				0.25	0.5
Tamingimingi Stm 3					11
Tamingimingi Stm 4			2	3	
Tamingimingi Stm 5		0.25	0.75		1
Kakariki Stm 2					1
Matahorua Stm	0.5				
Mangamate Stm 2			1.5		0.5
Mangaonuku Stm 2					
Maraekakaho Stm					

SPECIES →	Oligochaete (medium)	*Olinga* sp.	*Oniscigaster wakefieldi*	*Orthopsyche fimbriata*	Ostracoda 1	Ostracoda 2
STREAM ↓						
Mangamauku Stm		4		1.25		
Ohara Stm 2		15.25			0.25	
Waikarokaro Stm		34			1.25	0.25
Pakuratahi Stm 1		0.25		4.75		
Pakuratahi Stm 2				7.25		
Pakuratahi Stm 3					2	
Pakuratahi Stm 4						
Pakuratahi Stm 5						
Anaura Stm 1		2.25			0.25	
Anaura Stm 3	0.25				1	
Mangamate Stm 1		0.5				
Middle Upokororo Stm		2.5		0.25		
Ohara Stm 1		13				
Otekarara Stm 1		2		0.5		
Otekarara Stm 3				1		
Kakariki Stm 1	1.25					
Heruheru Stm					1.5	
Mohaka River						
Anaura Stm 2		0.25			0.5	
Mangaonuku Stm 1			0.25			
Deep Stm						
Pinchgut Creek		10				
Poutaki Stm		4				0.25
Omarowa Stm		31.5			0.25	
Otekarara Stm 2		0.75				
Korongomairoa Stm 1	0.5	4.75				
Korongomairoa Stm 2						
Tamingimingi Stm 1	9				10.75	
Tamingimingi Stm 2	1.5				1	
Tamingimingi Stm 3	4	1			3	
Tamingimingi Stm 4	17.25				90.75	
Tamingimingi Stm 5	2.5				2.5	
Kakariki Stm 2	1.75				64.25	
Matahorua Stm	0.5				3.5	
Mangamate Stm 2					1.75	
Mangaonuku Stm 2				4	0.25	
Maraekakaho Stm	1.75				3.5	

SPECIES →	Ostracoda 3	*Oxyethira albiceps*	*Paradixa* sp.	*Paralimnophila skusei*	*Physa* sp.	*Polyplectropus* sp.
STREAM ↓						
Mangamauku Stm				0.5		
Ohara Stm 2						
Waikarokaro Stm	0.25			4		
Pakuratahi Stm 1		0.75				
Pakuratahi Stm 2						
Pakuratahi Stm 3		19				
Pakuratahi Stm 4		5.5				
Pakuratahi Stm 5		13.5				
Anaura Stm 1		0.5		0.75		
Anaura Stm 3						
Mangamate Stm 1		1.25				
Middle Upokororo Stm				0.25		
Ohara Stm 1				0.25		
Otekarara Stm 1						
Otekarara Stm 3						
Kakariki Stm 1		0.25				
Heruheru Stm		1.25				0.25
Mohaka River		0.25		0.5		
Anaura Stm 2						
Mangaonuku Stm 1						
Deep Stm						
Pinchgut Creek				0.5		
Poutaki Stm	0.25					
Omarowa Stm				0.25		0.25
Otekarara Stm 2				0.25		
Korongomairoa Stm 1				0.5		0.75
Korongomairoa Stm 2				2.25		
Tamingimingi Stm 1		6.25				
Tamingimingi Stm 2		4.5		1		
Tamingimingi Stm 3		0.5				
Tamingimingi Stm 4		1.5			3	
Tamingimingi Stm 5		183.75	2.5			
Kakariki Stm 2		1.5		0.25	7.25	1
Matahorua Stm					8.25	
Mangamate Stm 2		25.75				1
Mangaonuku Stm 2						1.25
Maraekakaho Stm						

SPECIES → **STREAM ↓**	*Potamopyrgus* sp.	*Psilochorema* sp.	Psychodidae	Ptilodactylidae	Pupae 1
Mangamauku Stm	0.5				
Ohara Stm 2	0.75	0.5			
Waikarokaro Stm	1.25	2.75		2	1.25
Pakuratahi Stm 1	13	4			
Pakuratahi Stm 2	0.75	2.25		1.25	
Pakuratahi Stm 3	1.25	0.25			0.25
Pakuratahi Stm 4	3	3			0.25
Pakuratahi Stm 5	18.25	1.25			0.5
Anaura Stm 1		1.25		0.5	0.5
Anaura Stm 3	1	0.5		0.25	
Mangamate Stm 1	0.25			1.25	
Middle Upokororo Stm	1	0.25		1	
Ohara Stm 1	187			0.5	
Otekarara Stm 1	0.25				0.25
Otekarara Stm 3	0.75				
Kakariki Stm 1	0.5	0.25			0.25
Heruheru Stm	0.25				
Mohaka River	0.75	0.5	0.25		
Anaura Stm 2	0.5		0.25		
Mangaonuku Stm 1	0.5	0.75		1.25	
Deep Stm	1.25	2		0.25	0.25
Pinchgut Creek	2.75				0.25
Poutaki Stm	1				0.25
Omarowa Stm					
Otekarara Stm 2	1	0.75			0.25
Korongomairoa Stm 1	0.25	0.5			
Korongomairoa Stm 2	0.25	0.75			
Tamingimingi Stm 1	3.75	8.75			1.5
Tamingimingi Stm 2	12.75	6			0.25
Tamingimingi Stm 3	9.25	23			2
Tamingimingi Stm 4	7.5	12			5.25
Tamingimingi Stm 5	34.5	3			
Kakariki Stm 2	128.75	0.25			
Matahorua Stm	26.25				0.25
Mangamate Stm 2	4	9.75			
Mangaonuku Stm 2	0.25	0.5			
Maraekakaho Stm	19.75				0.5

SPECIES →	Pupae 2	Pupae 3	*Pycnocentrella eruensis*	*Pycnocentria evecta*	*Pycnocentria funerea*
STREAM ↓					
Mangamauku Stm			0.25		
Ohara Stm 2					
Waikarokaro Stm				33	0.25
Pakuratahi Stm 1					
Pakuratahi Stm 2					
Pakuratahi Stm 3	0.25			0.25	
Pakuratahi Stm 4					
Pakuratahi Stm 5					
Anaura Stm 1				0.25	0.5
Anaura Stm 3		0.25		37	
Mangamate Stm 1					10.75
Middle Upokororo Stm					
Ohara Stm 1					
Otekarara Stm 1				1	
Otekarara Stm 3					
Kakariki Stm 1					
Heruheru Stm					0.25
Mohaka River					
Anaura Stm 2					0.5
Mangaonuku Stm 1					0.5
Deep Stm				2.5	
Pinchgut Creek					
Poutaki Stm					
Omarowa Stm					
Otekarara Stm 2					
Korongomairoa Stm 1			0.75		
Korongomairoa Stm 2					
Tamingimingi Stm 1					
Tamingimingi Stm 2					
Tamingimingi Stm 3					
Tamingimingi Stm 4					1.25
Tamingimingi Stm 5					
Kakariki Stm 2				26.75	
Matahorua Stm					
Mangamate Stm 2					
Mangaonuku Stm 2					40.5
Maraekakaho Stm					

SPECIES →	*Pycnocentrodes* sp.	*Sigara* sp.	*Stenoperla prasina*	Tabanidae	*Zelandobius* sp.
STREAM ↓					
Mangamauku Stm			0.5		1.75
Ohara Stm 2	0.5		0.5		0.75
Waikarokaro Stm	36				0.25
Pakuratahi Stm 1					36.75
Pakuratahi Stm 2					6.75
Pakuratahi Stm 3	0.5				
Pakuratahi Stm 4	0.25				8.75
Pakuratahi Stm 5					2
Anaura Stm 1	15.25		0.25		5.5
Anaura Stm 3	191.5	1			
Mangamate Stm 1			0.25		
Middle Upokororo Stm					0.25
Ohara Stm 1			0.5		0.75
Otekarara Stm 1	3				1.75
Otekarara Stm 3	8.25				44
Kakariki Stm 1					
Heruheru Stm		20.25			
Mohaka River		1.5			0.25
Anaura Stm 2					
Mangaonuku Stm 1	0.25				
Deep Stm	185.5	0.25			
Pinchgut Creek			2.75	0.25	1.5
Poutaki Stm	0.5				0.25
Omarowa Stm	0.5		0.75		0.75
Otekarara Stm 2	0.5				6.5
Korongomairoa Stm 1	1				
Korongomairoa Stm 2	1.25				0.25
Tamingimingi Stm 1					4.25
Tamingimingi Stm 2					1.25
Tamingimingi Stm 3		0.25			
Tamingimingi Stm 4	158				
Tamingimingi Stm 5	2.5				
Kakariki Stm 2	149.5	16.75			
Matahorua Stm					
Mangamate Stm 2	22				
Mangaonuku Stm 2	157.25				
Maraekakaho Stm	17	0.75			

SPECIES →	*Zelandoperla* sp.	*Zephlebia dentata*	*Zephlebia spectabilis*	*Zephlebia versicolor*
STREAM ↓				
Mangamauku Stm		4.5		
Ohara Stm 2				
Waikarokaro Stm	0.25	9		
Pakuratahi Stm 1		131.25		3.5
Pakuratahi Stm 2		50.75		1.75
Pakuratahi Stm 3				
Pakuratahi Stm 4		15.25		7.25
Pakuratahi Stm 5		4		1
Anaura Stm 1		30.75	0.25	0.75
Anaura Stm 3		1.5		
Mangamate Stm 1		18		0.75
Middle Upokororo Stm		1.25		
Ohara Stm 1		0.75		
Otekarara Stm 1		0.25		
Otekarara Stm 3	0.5	0.5		
Kakariki Stm 1		3.5		
Heruheru Stm				0.5
Mohaka River		4.75		
Anaura Stm 2		1.5		
Mangaonuku Stm 1		0.25		2.75
Deep Stm				
Pinchgut Creek		1		
Poutaki Stm		0.25		
Omarowa Stm				
Otekarara Stm 2		20.75		0.75
Korongomairoa Stm 1		10.75		5.5
Korongomairoa Stm 2		16.5		
Tamingimingi Stm 1		16.75		0.5
Tamingimingi Stm 2				
Tamingimingi Stm 3				
Tamingimingi Stm 4				
Tamingimingi Stm 5		7		
Kakariki Stm 2				
Matahorua Stm		2.75		
Mangamate Stm 2				
Mangaonuku Stm 2				
Maraekakaho Stm	0.25			