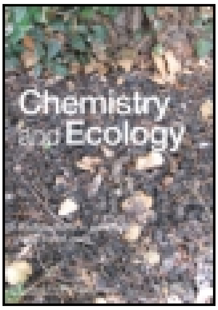

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Dativa J. Shilla [a] & Daniel A. Shilla [b]

[a] Department of Chemistry, Dar es Salaam University College of Education, Tanzania

[b] Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, Dar es Salaam, Tanzania

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The effects of catchment land use on water quality and macroinvertebrate assemblages in Otara Creek, New Zealand

Dativa J. Shilla[a] and Daniel A. Shilla[b]*

[a] *Department of Chemistry, Dar es Salaam University College of Education, Tanzania;* [b] *Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, Dar es Salaam, Tanzania*

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The effect of catchment land use on water quality and macroinvertebrate communities was examined by using data gathered during a 2004 reconnaissance of nine sites in the Otara Creek, New Zealand. Data collected included macroinvertebrate, water chemistry and sediments characteristics. Macroinvertebrate data were used in metric and index calculations. A total of 61 macroinvertebrate taxa, with 3032 total individuals, were identified from the macroinvertebrates samples collected from nine sites in Otara Creek. The greatest number of macroinvertebrate taxa was recorded within bush sites (mean >25), while the urban sites had the least number of taxa (mean $= 10$). Pasture sites were intermediate with the mean >17. Taxa number differed significantly across land use. Mean macroinvertebrates abundance varied across the sites and land uses. The highest macroinvertebrates mean abundance was recorded in urban and pasture sites, while bush sites had significantly lower mean abundance. Physico-chemical parameters decreased from bush toward urban streams. Biotic indices were sensitive to changes in macroinvertebrates community structure across land uses with mean scores decreasing from bush to urban and pasture streams. Ordination of biological data showed a clear separation of bush from urban and pastures streams. Analysis of similarities revealed significant differences in macroinvertebrates between both stream groups and land-use groups. The observed macroinvertebrate assemblage pattern was best correlated with a single variable, conductivity, temperature, turbidity, nitrate and dissolved oxygen. The combination of these environmental variables best explained the changes in the macroinvertebrate assemblages between sites. This study demonstrates that catchment land use may significantly affect the water quality and macroinvertebrate communities in an ecosystem.

Keywords: catchment; land use; water quality; macroinvertebrates; Otara Creek

1. Introduction

Streams are a product of their catchments [1] because they are intimately linked with catchments land use. The impact of land use on the health of streams has been described as the most significant environmental issue facing many countries, including New Zealand [2,3]. The biological community structure of urban streams is generally quite different from that of streams draining rural or natural watersheds. The typical urban stream exhibits a paucity of life with the inhabiting

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*Corresponding author. Email: dshilla@udsm.ac.tz

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organisms being those normally associated with stressed environments [4]. Degradation of stream ecosystems in urban areas can result from catchment development and instream modifications [5].

Catchment development affects the quality of water entering a stream as surface run-off and point discharge. Urban development results in increased sediment loading, heavy metals, oil products, nutrients, biological oxygen demand (BOD) and pathogenic microorganisms due to increased impervious land coverage [6]. Several changes that occur as result of urbanisation can affect the natural stream temperature regime. Klein [7], for example, documented an annual 11 °C difference between a wooded section along a Maryland stream and a poorly shaded pasture section of the same stream located 1.2 km below the woodland measurement point.

When the watershed is urbanised a portion of the shading vegetation is usually removed. With the combination of increased sunlight and nutrient inputs, conditions would seem right for a considerable increase in algae populations and other aquatic plants. However, excessive growth of plants can cause several changes: reduced dissolved oxygen levels in the stream; increased diurnal oxygen variations; and in extreme cases of benthic anoxia, only invertebrates such as bloodworms and oligochaetes that contain haemoglobin and can efficiently use oxygen at low concentrations are found in such streams [8]. It appears, however, that such plant growth seldom occurs in urban streams. This may be due to strong flows in urban streams which can scour plant biomass away, and the susceptibility of these plants to the adverse effects of urbanisation (e.g. increased contaminant loads). Therefore, the degraded character of urban streams is not the result of any single detrimental factor, but the synergistic interaction of all the detrimental factors mentioned above.

Biological monitoring of water quality is a valuable tool that provides a more integrated assessment of water and overall environmental quality [9]. Macroinvertebrates such as insect larvae, crayfish and other crustaceans, snails, small clams, aquatic worms and leeches, have long been used as a biomonitoring tool in appraising and monitoring the impact of anthropogenic stress in aquatic systems. For example, benthic macroinvertebrates display a wide range of sizes, habitat requirements, life histories and sensitivities to water-quality impairment. Some of these species are sensitive to changes in physico-chemical parameters. This wide range of living requirements make benthic macroinvertebrates excellent indicators of anthropogenic stress on aquatic systems and they are widely used by practioners [10]. Some of the advantages of using benthic macroinvertebrates in water-quality assessment have been described previoulsy [9].

Otara Creek presents a good opportunity to study the effects of urbanisation on benthic macroinvertebrates. Streams in Otara Creek originate in undisturbed catchments and then course through areas having different land uses, before emptying into Tamaki estuary. The present study investigated the effects of catchment land use on water quality and macroinvertebrate communities in Otara Creek.

2. Materials and methods

2.1. *Study area*

The Otara Creek catchment (Figure 1) is located mostly within the Otara Ward of the City of Manukau with a small portion of it in the Papatoetoe Ward and the upstream reaches within the Clevedon Ward. The cathment covers ~3500 ha of land [11]. The catchment is bounded by the East Tamaki Road to the west and north, and the foothills of the east of Murphys Road, while Redoubt Road marks the southern boundary.

The catchment has three discrete subcatchments: the easternmost subcatchment (Flatbush); the northern section subcatchment, which consists of a number of discrete subcathments draining industrial areas; and the southern section subcatchment, which is mainly residential in nature and

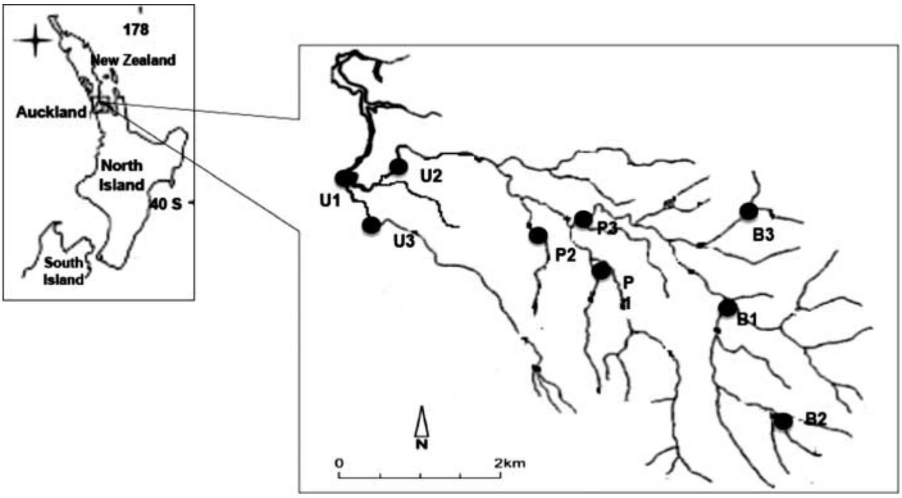

Figure 1. Otara Creek catchment showing the three discrete subcatchments.

has a small commercial area around the shopping centre. Land in the upper parts of the cathment between Chapel Road and the eastern boundary hills is still currently rural with largely livestock farming, including dairy farming, beef cattle, horses and sheep. Most of this part is zoned for the future east Tamaki/Flatbush Integrated Development Area. The area incorporates aspects of intensive residential development in close proximity to shopping services and a greenfield area. The lower part of the cathment has intensive industrial and commercial centres, for example, Otara Town Centre which is located south of Ngati Otara Park and is bounded by Bairds Road and Tamaki Road. This is the most developed part of the catchment for industrial, commercial and residential uses, and imposes a range of impacts on the Otara Creek. In this study, six sites represent the pastoral area and native bush are restricted to Flatbush subcatchment, and three urban sites are from the remaining subcatchments (Table 1).

In order to locate comparable sites within the Otara Creek catchment area that differed in land-use type (native bush, pasture and urban), an extensive survey of the stream was conducted before this study commenced. Areas up- and downstream in the cathment were visited in January 2004 for comparison and to locate sites with different land uses. The Kiwi Metromap (1:50,000) was also used to find comparable sites with different land uses along the cathchment. The sites were selected in such a manner that they allow research to contrast stream communities influenced by

Table 1. Summary of the three types of land use and the sites.

Land use	Site name	Site code	Stream order	Channel width (m)
Urbanised	Hamil Road bridge	U 1	Third	3
	East Tamaki Road	U 2	Second	1.5
	Preston Road	U 3	First	1.5
Pasture	Chapel road	P 1	Third	2
	Flat Bush School Road	P 2	First	1.5–3.4
	Road	P 3	Second	3
	Ormiston Road			
Bush	Murphys Bush	B 1	Second	2
	Reserve	B 2	First	1–2.5
	Redoubt Road	B 3	First	0.5–2
	Gracechurch Reserve			

three major land-use types in the area, while minimising differences in other factors including geology, landforms, elevation and gradient. A three-level nested design was employed in sample collection with each land use represented by three sites and each site by three sampling reaches of 30 m each. The field study was conducted in February 2004 (summer) and consisted of three sections, a description of habitat and channel conditions, semiquantitative sampling using a hand-net, and measurements of physico-chemical parameters of water quality.

2.2. *Sampling of macroinvertebrates*

Benthic macroinvertebrates were collected at each site from multiple habitats, including trailing vegetation, bottom substrate, channels banks and underbank-cut, to get a comprehensive species list and relative abundance. Macroinvertebrate samples were collected using a 250 μm mesh kick net from each habitat and at 90 m reach at each site. The net was dipped into each habitat and scooped against the current. The sample was allowed to drain to get rid of mud and silt before transferring the rest of the contents into an empty plastic container and preserved with 70% alcohol for later identification. All samples were collected on the same day to minimise variations due to climatic and hydrological changes. Sampling was not conducted during heavy rain and freshes (storm events).

In the laboratory, invertebrate samples were washed through a 500-μm mesh sieve. Large pieces of substrate and leaves were inspected for invertebrates, which were removed from the sample. The remaining invertebrates were empted into white trays for sorting. Invertebrates were identified according to Winterbourn and Gregson [12]. Macroinvertebrates were classified to lower taxonomic levels except for Ostracoda, Amphipoda, Oligochaeta and Nematoda, which were not classified further. Macroinvertebrate biotic indices (Macroinvertebrate Community Index [MCI], Quantitative Macroinvertebrate Community Index [QMCI], Semiquantitative Macroinvertebrate Community Index [SQMCI], Ephemeroptera, Plecoptera and Tricoptera [EPT]) were calculated according to the guidelines given by Stark and Maxted [13].

2.3. *Water-quality measurements*

Water samples for the measurement of nitrate, sulfate and phosphate were collected from each site, kept in plastic bottles at low temperature (in a chilly bin) and transported to the laboratory freezer. All water samples taken to the laboratory were analysed 1 day after the field study. Physico-chemical parameters were measured *in situ* using field meters calibrated before each day of sampling [14]. Nitrate and phosphate were analysed using the HACH DR700 colorimeter and the reagents provided. The analysis of nitrate was given as nitrogen (N), the value of nitrogen obtained was multiplied by 4.4 to get the value for nitrate (NO_3).

2.4. *Data analysis*

A multiple approach that comprises a number of biotic indices, each with different discriminatory power to detect different environmental stresses and to enable a broad-scale biological assessment, was used to analyse the data [15]. Non-metric multidimensional scaling (NMDS) was used for graphical representation of community relationships [16]. All data were $\log(x + 1)$ transformed and then tested for normality prior to analysis. KMO and Bartlett's test of sphericity were run using the statistical computer program SPSS (version 11.5) as a test for normality which produced $p < 0.0001$ (KMO Index $= 0.803$) showing that the requirements for multivariate normal were satisfied [17].

Two-way analysis of similarities (ANOSIM) was used to test whether there were any significant differences between the streams in three land uses, and the site groups within those land uses [17]. In order to see which environmental variables were responsible for macroinvertebrates variation among the studied sites, biota environmental (BIOENV) matching was preferred [17].

3. Results

3.1. *Physical conditions and water quality*

Seven water-quality parameters were measured and compared from each land use (Table 2). Temperatures varied according to land uses showing daily maximunm temperatures that were 5–6 °C higher in urban and pasture streams than in bush streams. In general, urban streams had the highest average temperatures, followed by pasture streams and then bush streams. The differences were statistically significant between the bush and the remaining land uses (Table 2).

Stream pH readings did not differ significantly among the land uses ($p > 0.05$), indicating that the stream water was neither acidic nor alkaline. Conductivity values varied according to land use. Urban streams had generally higher mean conductivity values than pasture and bush streams. The trend was urban > pasture > bush (Table 2). Turbidity was highest in pasture streams, with intermediate conditions in the urban streams, while bush had the lowest turbidity (Table 2). One-way analysis of variance (ANOVA) revealed significant differences in turbidity between the urban, pasture and bush streams ($p < 0.05$). However, there was no significant difference in turbidity between streams found in pasture and urban sites ($p > 0.05$).

There was a decreasing concentration of dissolved oxygen among the three land uses from bush toward urban (Table 2). One-way ANOVA showed significance difference ($p < 0.05$) in dissolved oxygen concentration across land uses. No significant difference was observed in dissolved oxygen concentration between urban and pasture streams ($p > 0.05$).

Total phosphate was highest in pasture streams and lowest in bush streams (Figure 1). The difference was statistically significant between land uses ($p < 0.05$). Nitrate concentration was significantly different ($p < 0.05$) across all three land-use streams (Table 2). Mean nitrate

Table 2. ANOVA results showing F-ratio (F) and significance value at $p < 0.05$) for the mean values of indicated variables across the land use at Otara Creek.

Indices/water parameter	Sites				
	Urban	Pasture	Bush	F	p
No. of individuals	1337.67 (164.80)	828.33 (109.93)	385.56 (99.91)	6.97	*
No. of taxa	13.22 (1.80)	16.44 (1.28)	26.00 (2.04)	30.53	**
MCI	65.82 (6.22)	74.77 (8.30)	112.08 (10.34)	11.09	*
QMCI	3.32 (0.18)	4.04 (0.29)	6.08 (2.01)	14.28	**
SQMCI	3.35 (0.27)	4.06 (0.28)	5.89 (1.86)	10.93	*
% EPT	0.00 (0.00)	0.00 (0.00)	34.48 (8.35)	11.21	**
No. EPT taxa	0.11 (0.09)	0.44 (0.12)	9.67 (3.04)	19.35	**
Dissolved oxygen	7.923 (2.48)	8.233 (1.66)	11.35 (3.25)	10.27	**
Conductivity	296.92 (47.59)	243.42 (51.35)	216.42 (61.76)	23.02	*
pH	6.89 (3.13)	6.93 (3.21)	6.67 (3.38)	3.47	ns
Temperature	14.27 (4.80)	13.46 (1.25)	10.33 (4.23)	39.62	**
Turbidity	6.51 (1.56)	2.92 (0.21)	1.10 (0.18)	30.04	**
Total nitrate	9.38 (2.09)	4.92 (1.11)	2.25 (0.99)	21.89	**
Total phosphate	7.11 (0.98)	1.85 (0.40)	1.57 (0.57)	79.85	**

Notes: *Significant at $p < 0.05$, **significant at $p < 0.01$ and ns, not significant at $p < 0.05$. Data presented as the mean with standard deviations in parentheses. EPT, Ephemeroptera, Plecoptera and Tricoptera; MCI, Macroinvertebrate Community Index; QMCI, Quantitative Macroinvertebrate Community Index; SQMCI, Semiqunatitative Macroinvertebrate Community Index.

concentration were higher in pasture streams and lower in bush streams. The high nitrogen in pasture streams may originate from animal waste and increased fixation of nitrogen by clover in pasture, and suggests a strong land-use effect with high nitrogen input to pasture streams.

3.2. *Species diversity, composition and abundance of macroinvertebrates*

In total, 61 macroinvertebrate taxa, with 3032 total individuals, were identified from the macroinvertebrate samples collected from nine sites in Otara Creek during 2004. The greatest number of macroinvertebrate taxa was recorded within bush sites (mean >25) while the urban sites had the least number of taxa (mean $= 10$). Pasture sites were intermediate with a mean >17 (Table 2). Taxa number differed significantly across the land uses ($p < 0.01$). Mean macroinvertebrates abundance varied across sites and land uses. The highest macroinvertebrate mean abundance was recorded in urban and pasture sites, while bush sites had significantly lower mean abundance ($p < 0.05$).

There was a high variation in macroinvertebrates abundance and dominance across the bush sites. For example, one of the bush sites (Grace Church Reserve, B3) comprised predominantly Ephemeroptera (39%) and Trichoptera (18%), whereas in pasture sites, crustaceans (>67%) and molluscs (>20%) were the dominant taxa, and in urban sites the dominant taxa were molluscs (>70%) and annelids (>10%).

3.3. *Biotic indices*

Taxon richness in urban sites was significantly lower than in bush sites ($p < 0.01$), but more similar to the pasture streams ($p > 0.05$). The patterns of taxon richness were, however, more variable within bush sites compared with other land uses. The highest level of taxon richness was found in Grace Church Reserve bush site (B3). Within other land uses the pattern was more similar and was not significantly different from each other ($p > 0.05$).

The MCI was sensitive to changes in macroinvertebrates community structure across land uses (Table 2). Mean MCI scores show that bush sites had higher water and habitat quality than comparative land uses (mean MCI $= 107$), indicating mildly polluted water. The pasture sites had moderate water quality (mean MCI $= 76$), and urban sites had low water and habitat quality (mean MCI $= 70$). The mean MCI scores were significantly higher for bush streams than other comparative land uses ($p < 0.010$) (Table 2).

The QMCI and SQMCI showed a similar pattern with fairly good water quality for bush sites (mean QMCI $= 5.62$; mean SQMCI $= 5.98$). The pasture sites had moderate quality (mean QMCI $= 4.27$; mean SQMCI $= 4.42$), whereas urban sites showed a severe enrichment (mean QMCI $= 3.77$; mean SQMC $= 3.78$). Mean QMCI was significantly higher in bush sites ($p < 0.05$) than urban and pasture sites, while SQMC was significantly higher ($p < 0.05$) in bush sites compared with other land uses (Table 2).

An assessment of the per cent abundance and the taxa richness of environmentally sensitive taxa in the macroinvertebrate community using % EPT indicated that the sensitive species proportion of the benthic fauna was significant in bush streams than other land uses ($p < 0.01$). On average, the number of EPT taxa was higher in the bush sites (mean $= 9$) than in pasture (mean < 3) and urban sites (mean < 1) (Table 2).

3.4. *Macroinvertebrate communities*

Ordination of biological data shows a clear separation of sites, the bush streams being clearly separated from urban and pastures streams (Figure 2). Based on Table 3, the first axis (axis 1) was

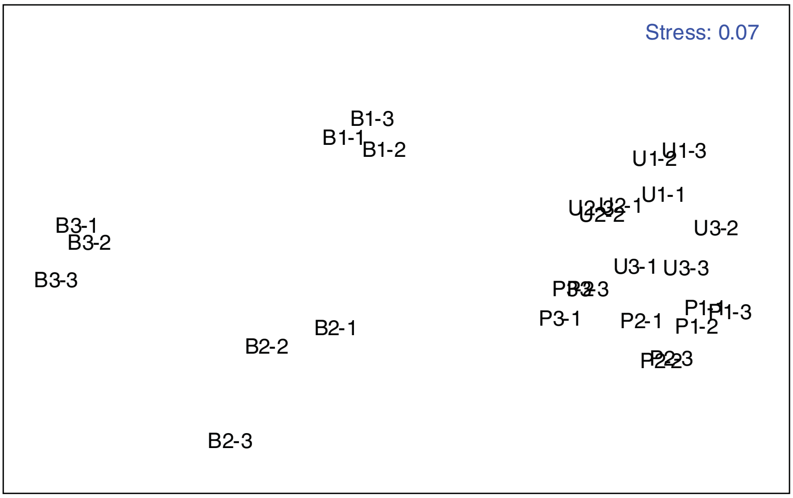

Figure 2. Ordination (non-metric multidimension scaling) of Otara Creek stream sites based on macroinvertebrates taxa. Site codes are as follows: U1–U3, urban stream replicates 1–3; P1–P3, pasture stream replicates 1–3; B1–B3, bush stream replicates 1–3. Stress value is indicated in the plot.

Table 3. Non-metric multidimension scaling (NMDS) ordination axes showing correlation statistics for macroinvertebrate groups.

Species	Axis 1	Axis 2
Potamopyrgus	0.76	0.50
Physa	0.73	0.38
Lymnaea	0.54	0.44
Oligochaeta	0.68	−0.59
Flatworms	0.50	−0.24
Leeches	0.57	0.29
Amphipoda	0.67	0.53
Shrimps	0.43	−0.50
Isopoda	0.63	0.57
Xanthocnemis	0.50	−0.35
Deleatidium	−0.67	−0.25
Acanthophlebia	−0.57	−0.30
Polyplectropus	−0.66	−0.52
Triplectides	−0.55	−0.50
Chironomous	−0.07	−0.60
Tanytarsus	−0.54	−0.45
Zelandotipula	−0.61	−0.34
Microvelia	0.45	0.08
Sigara	0.55	−0.12
Elmidae	−0.64	0.25
Scritidae	−0.60	0.35

associated with higher counts of mollusca (e.g. *Potamopyrgus antipodarum*, *Physsa*, *Lymnaea*), Annelida (e.g. Oligochaeta, Nematoda, leeches-Hirudinea), Crustacea (e.g. Amphipoda, Isopoda, shrimps), Odonata (e.g. *Xanthocnemis* spp., *Austrolestes* spp.), Diptera (e.g. chironomids, *Tanytarsus* spp., *Zelandotipula* spp.), Hemiptera (e.g. *Sigara*) to the right-hand side of the axis which was associated with urban and pasture sites, and Ephemeroptera (e.g. *Zephlebia*, *Deleatidium*, *Acanthophlebia*), Trichoptera (e.g. *Polyplectropus*, *Hydrobiosis*, *Triplectides*), Hemiptera (e.g. *Microvelia*), Coleoptera (e.g. Elmidae, Hydrophylidae) to the left-hand side of the axis which was associated with bush sites.

Axis 2, by contrast, was represented by higher counts of Mollusca (e.g. *Gyraulus* spp., *Sphaeridii* spp.) to the top side of the axis and were associated with urban and pasture sites, while Crustacea (e.g. shrimps) occurred in both urban and pasture streams, as well as bush streams. Pollution-sensitive organisms such as those belonging to Ephemeroptera (e.g. *Deleatidium*, *Acanthophlebia*), Trichoptera (e.g. *Polyplectropus* spp.) were associated with the positive side (top side) of axis 2, whereas other ephemeropterans (e.g. *Zephlebia* spp.), trichopterans (e.g. *Hydrobiosis* spp., *Triplectides* spp.), dipterans (e.g. *Zelandotipula* spp.), coleopterans (e.g. Elmidae) were associated with the negative side (bottom side) of the axis (Table 3).

There was a decrease in counts of pollution-sensitive macroinvetebrates (e.g. EPT taxa) as one moves from bush to urban and pasture streams, whereas the number of pollution-tolerant organisms belonging to taxa such as Mollusca, Annelida, Crustacea (except shrimps) and Diptera increase in the same direction (Figure 2).

3.5. *Two-way nested ANOSIM*

Analysis of similarities (two-way nested ANOSIM) revealed significant differences in macroinvertebrates between both stream and land-use groups. The analysis for between stream groups was significant at $p < 0.001$, whereas the between land-use groups was significant at $p < 0.004$ with significant global R values, as presented in Table 4. Pair-wise comparisons between the three land uses failed to reveal any significant difference ($p > 0.05$) between pasture and urban streams, however, the separations of sites based on macroinvertebrates were adequately good as indicated by the values of global R (Table 5).

3.6. *Linkage of macroinvertebrate assemblages to environmental variables (BIOENV)*

A step was allowed for the BIOENV program to select the environmental variables responsible for macroinvertebrate variation among the studies sites. Correlation of biota and environmental variables revealed groups of environmental variables considered to influence the macroinvertebrates community pattern among the three sites studied. The results of this procedure are presented in Table 6.

The observed macroinvertebrates assemblage pattern was best correlated with a single variable, conductivity ($r = 0.70$), followed by temperature ($r = 0.63$), turbidity ($r = 0.57$), nitrate

Table 4. Comparison between stream sites and land-use for biota dataset.

	Sites (averaged across land use)	Land use (using site as sample)
Sample statistics (Global R)	1	0.794
Significance level	0.10%	0.40%
p	0.001**	0.004*

Note: **Significant difference at 1% level, *significant difference at 5% level.

Table 5. Pairwise comparisons between streams for biota dataset.

Groups	R	Significance level	p
U vs P	0.60	19%	0.19
U vs B	0.78	1.2%	0.0012
P vs B	0.74	0.35%	0.0035

Table 6. Results of the multivariate Spearman rank correlation of environmental data to benthic community data using BIOENV, showing the importance of a single variable as well as a combination of environmental variables. The matches of the environmental variables that best explain the separation of biological data are indicated in bold.

	Variables	R	Significance
Single variables	Conductivity	0.70	*
	Temperature	0.63	*
	Turbidity	0.57	*
	Nitrate	0.44	*
	Dissolved oxygen	0.39	*
Combined variables	**Conductivity, Temperature, Turbidity, Nitrate, Dissolved Oxygen**	**0.94**	*

Note: *Significant at $p < 0.05$.

($r = 0.44$), and dissolved oxygen ($r = 0.39$). The combination of these environmental variables best explained the changes in the macroinvertebrate assemblages between sites ($r = 0.94$).

4. Discussion

4.1. *Relationship between macroinvertebrates and land-use*

The abundance of *P. antipodarum* and Oligochaeta was elevated in urban and pasture streams relative to bush streams, and was positively correlated with the nutrient inputs. It is possible that enrichments in these streams were responsible for such high numbers of *P. antipodarum* and Oligochaeta. Most of these organisms have short generation times and rapid habitat invasion potential [8,18,19] enabling them to adapt to the fluctuating environment and establish populations opportunistically. Both Mollusca and Oligochaeta in this study showed clear overlap in abundance in both urban and pasture streams. This suggests that these taxa may not be particularly useful for distinguishing between urban and pasture impacts, although a community that is dominated by Oligochaeta is indicative of severe degradation [8,20]. Crustaceans (e.g. *Parenephrops* and *Paratya*) gave an inconsistent response to land use and tended to be abundant within a single site or reach. For example, a high abundance of *Parenephrops* was recorded in urban sites and bush sites. Such variation suggests that these species may be more responsive to small-scale variation than broader scale changes in land use. The abundance of Ephemeroptera (e.g. *Deleatidium* spp.) and Trichoptera, primarily *Polyplectropus* spp., was also variable in pasture and bush streams, but was absent in the urban streams sampled, suggesting that *Polyplectropus* and *Deleatidium* may have limited use as biomonitoring organisms for detecting low-intensity pastoral impacts, although they have potential for detecting more severe impacts associated with urban development [20].

4.2. *Relationship between biotic indices and land use*

In this study, taxon richness, the MCI, QMCI and SQMCI indicated that land use had an impact on the structure of macroinvertebrate communities of Otara Creek. This is supported by the results of the multivariate ordination, which revealed distinct differences in the structure of macroinvertebrate communities in the streams draining urban, pasture and bush sites. The response of taxon richness to urban development was strong with a clear reduction in taxon richness occurring in the urban followed by pasture as compared with bush streams. This pattern has been reported elsewhere [8,21,22]. Both MCI and QMCI reflected the general representation of the increased pollution-tolerant taxa from bush to pasture and urban streams as their values were significantly higher in the bush streams than in the pasture and urban streams.

MCI and QMCI, as well as number of EPT taxa, were sensitive to changes in invertebrate community structure across land uses, the highest mean values being recorded for bush sites and the lowest mean values for urban sites. This indicated a shift in community structure from pollution-intolerant to pollution-tolerant invertebrates, as consistently reported elsewhere [23]. The response of macroinvertebrate community indices reflected the general trends in water quality observed by Smith et al. [24].

All indices indicated that representation of pollution-sensitive taxa decreased from urban to pasture to bush streams. Several studies have reported similar trends in biotic indices scores in relation to land use across a wider selection of streams in New Zealand [25]. QMCI demonstrated a strong relationship with land use, indicative of changes in macroinvertebrate communities as a result of land-use influence [20]. Biotic indices indicating high water quality were consistently associated with increased size of bottom substrate composition and both lower conductivities and nutrients.

4.3. *Relationship between water-quality variables and land use*

The strongest water quality trends relating to land use in this study were increases in nitrates, conductivity, turbidity, temperature and dissolved oxygen, with levels increasing from native bush to pasture to urban streams, except for dissolved oxygen which exhibited the opposite trend. Higher stream temperatures may reduce the stream's oxygen-carrying capacity, increase rates of organic decomposition and influence the rate at which nutrients are released from suspended sediments [26]. Increased temperature levels in urban and pasture streams may be associated with the removal of riparian vegetation and other common earthworks during catchment development. Other studies [27] in addition to ours, have reported that urbanisation had an effect of reducing shade, which in turn elevates temperature in streams.

High temperatures have been reported to pose negative effects on most macroinvertebrate fauna. Quinn et al. [28] for example, reported that mayfly *Deleatidium autumnale* was significantly more susceptible to higher temperatures than the snail *P. antipodarum*. This attribute may explain the absence of invertebrates such as mayflies in urban and some pasture streams. Sweeney [29] arrived at the same conclusion stating that changes in temperature of 3–5 °C in streams lacking riparian cover was sufficient to deleteriously alter larval recruitment and growth for many mayfly taxa. Rabeni [30] has further stated that reduced macroinvertebrate diversity has been attributed to high maximum temperatures in regulated rivers. The lack of pollution-sensitive taxa in urban and pasture streams in this study suggest that among other factors, higher water temperatures may have disfavoured these taxa from surviving in these streams [31]. The effects of higher stream temperature are also reflected in a negative correlation between temperature and all the biotic indices (e.g. number of taxa, MCI, QMCI, SQMCI, %EPT and number of EPT) and a positive correlation between temperature and number of individuals (Table 7). This means that an absence of sheltering vegetations in urban and pasture streams corresponded with increased stream water temperatures and the number of pollution-tolerant macroinvertebrates (e.g. *P. antipodarum* and Oligochaeta).

There was no significant difference in pH among the land uses (ANOVA, $p > 0.05$). Although weak negative correlations were found between pH and all the biotic indices (except number of individuals which had positive correlation), this variable seemed to have no effect on the macroinvertebrate community pattern in this study [27] (Table 7).

Conductivity was highest in urban streams and lowest in bush streams. Higher conductivities in urban and pasture streams reflect an increase in dissolved ions and therefore a reduction in water quality. An increase in conductivity may have been caused by increased in non-point source pollution such as surface run-off or soil erosion. In general, elevated suspended solids and dissolved ions are a result of catchment activities such as earthworks, and instream processes such

Table 7. Correlation between Macroinvertebrate Community Index and physico-chemical parameters.

	MCI	QMCI	SQMCI	%EPT	# EPT	# taxa	#TI	DO	COND	pH	TEMP	TURB	TN	TP
MCI	1													
QMCI	0.88**	1												
SQMCI	0.79**	0.85**	1											
%EPT	0.90**	0.92**	0.82**	1										
# EPT	0.86**	0.87**	0.73**	0.95**	1									
# taxa	0.74**	0.69**	0.56**	0.73**	0.83**	1								
#TI	−0.70**	−0.64**	−0.62**	−0.73**	−0.71**	−0.59**	1							
DO	0.78**	0.68**	0.53**	0.75**	0.79**	0.79**	−0.66**	1						
COND	−0.65**	−0.77**	−0.69**	−0.67**	−0.54**	−0.37**	0.48**	−0.44**	1					
pH	−0.46**	−0.45**	ns	−0.46**	−0.53**	−0.45**	ns	ns	ns	1				
TEMP	−0.75**	−0.68**	−0.59**	−0.70**	−0.70**	−0.78**	0.56**	−0.81**	0.42*	0.36*	1			
TURB	−0.61**	−0.50**	−0.53**	0.64**	−0.60**	−0.47**	ns	−0.58**	ns	ns	0.46**	1		
TN	−0.60**	−0.49**	−0.47**	−0.63**	−0.56**	ns	0.60**	−0.42*	0.42*	ns	ns	0.53**	1	
TP	−0.40*	−0.40*	−0.39*	−0.50**	−0.52**	−0.35*	ns	ns	ns	ns	ns	0.36**	0.39*	1

Notes: MCI, Macroinvertebrate Community Index; QMCI, Quantitative Macroinvertebrate Community Index; SQMCI, Semiquantitative Macroinvertebrate Community Index; % EPT, percentage of Ephemeroptera, Plecoptera and Tricoptera; # EPT, number of Ephemeroptera, Plecoptera and Tricoptera; # taxa, number of taxa; # TI, number of total individuals; DO, dissolved oxygen; TEMP, temperature; COND., conductivity; TURB., turbidity; pH, measure of alkalinity/acidity; TN, total nitrogen; TP, total phosphate.

as stream bed and bank erosion (accelerated by flow variations arising from urbanisation). Friberg et al. [32] documented that higher conductivities in streams can be a result of contaminants that have previously entered and been retained in stream sediments, which are slowly released into the water column exerting continual stress on various stream life forms.

Turbidity was highest in streams draining pasture and lowest in bush streams in this study. High turbidity in the streams draining pasture watershed was probably a direct consequence of the stock access to most of these streams. Grazing animals in the area are largely cattle and sheep, with very few horses seen during the study. Most of the pasture streams had minimal fencing and a result was stock grazing to the stream edge. Animal tramping and grazing to most of the pasture streams, particularly in pasture sites together with other factors may contribute to the turbidity pattern observed in this study. These results were consistent with those of Quinn et al. [28] who reported high turbidity in pine streams followed by pasture streams.

Dissolved oxygen results in this study were limited to daytime measurements made during sampling. A decrease in daytime dissolved oxygen concentration was observed in streams draining urban sites. This reflects the effects of organic waste inputs, which can depress dissolved oxygen markedly because of the low dilution offered by small urban streams. This finding is consistent with those of NIWA [33] who reported that Otara Creek has particularly elevated organic matter (BOD) levels, with organic loadings accounts for the lower dissolved oxygen observed in this stream, and dissolved oxygen as low as $0\,\mathrm{mg{\cdot}L^{-1}}$ have been recorded in this stream [33]. Biggs [34] also reported that streams with low dissolved oxygen may suggest presence of organic or industrial pollutants.

Higher dissolved oxygen conditions in bush streams may be associated with less organic matter inputs and the dominance of large bottom substrates. Boulton et al. [35] reported that streams in native forest yielded significantly higher mean dissolved oxygen than pasture and pine streams. Some invertebrates such as ostracods, nematodes and oligochaetes have been reported to be tolerant of low oxygen environments [35]. Dissolved oxygen in this study correlated positively with all biotic indices except total number of individuals which has negative correlation.

Nitrates were highest in pasture, followed by urban streams, and were lowest in bush streams. Agricultural influences in these sites probably contribute to the observed higher nitrate concentration. Higher nutrients may have negative effects on some macroinvertebrates because they stimulate algae and other aquatic plant growth, which in turn depletes dissolved oxygen in stream water, disfavouring those invertebrates sensitive to a lack of oxygen. This is likely to be the case with most of the pasture streams sampled in Otara Creek. There was an increase in macrophyte growth, algal bloom and flocs of algae floating on the surface of the streams, all of which might be associated with increased solar radiation and nutrients. High nitrate and phosphate in pasture and urban streams in the current study correlated with a lack of pollution-sensitive invertebrate taxa in these sites. These streams had little shading due to the loss of riparian vegetation and the banks were poorly consolidated. These conditions may have further affected the concentrations of nitrate during heavy rain. Negative correlations were established between nutrients and biotic indices except for the total number of individuals, which exhibited positive correlation with nitrate and lacked any correlation with total phosphate. The negative correlations between most water-quality variables and the biotic indices may suggest that water quality decreased with decreasing macroinvertebrate assemblage integrity.

4.4. *Macroinvertebrate communities*

4.4.1. *Macroinvertebrate community differences across land use*

From the MDS ordinations, the first dimension appeared to represent a biologically meaningful gradient attributing the lowest values to the urban and pasture streams, whereas the highest values were consistently recorded for bush sites. As seen from the taxa abundance plots, a shift in community composition from pollution-intolerant to pollution-tolerant was apparent in the streams studied. Large proportions of taxa found in bush sites were absent in the urban and pasture streams. Although there was a close association between the macroinvertebrate communities collected from certain areas of pasture and bush, separation of the sites was clear and without an overlap. This may be explained by the fact that pasture sites had dense riparian vegetation on both sides and the stream was well shaded, which suggest that the stream has a better quality of habitat that was also reflected in most of the biotic indices. The stream had also high abundance of high scoring trichoptera (*Polyplectropus* ssp. and *Triplectides obsoleta*). It is likely that these taxa benefit from the presence of wide riparian vegetation. However, part of bush sites comprised predominantly crustaceans and snails which were also more abundant in pasture and urban sites, respectively. The macroinvertebrate communities composition of this site suggested that the site is not completely free of human disturbance. The reason for this is probably that Murphys Road runs beside the stream and there is also a large stormwater pipe discharging into the stream. Therefore, despite its appearance as a relatively unimpacted, part of bush site is subject to a number of pressures that result in its relatively degraded state.

The presence of pollution-tolerant macroinvertebrates in urban and pasture streams could be attributed to a lack of riparian vegetation alongside these streams, which through reduction of leaf litter input and light penetration to streams changed the energy base of the ecosystem. This has been addressed in other studies [18,31,36] as a determinant of impacts of riparian grazing on the invertebrates in small streams. Amphipods feed on fine detritus and are more abundant in the presence of macrophytes, as reported by James et al. [37], and macrophytes usually prefer to grow in an open, unshaded streams trapping fine particulate matter. The mollusc *P. antipodarum* appeared to reflect stream temperature, as reported by Quinn et al. [28], and be moderately tolerant to higher temperatures (up to 28 °C). Oligochaetes are deposit feeders and need fine detritus, hence their abundance in urban and pasture streams where there was high proportion of the fine bottom substrates.

Bush streams that supported the rich and most sensitive macroinvertebrate communities were characterised as having intact riparian zones, high dissolved oxygen concentrations, low water temperatures, and a high percentage of coarse substrates (cobbles, boulders, coarse organic particulate matter and wood debris). Biotic indices were highly correlated with all of these environmental variables, indicating that as physical and chemical conditions have become impaired by increased land-use intensity across the streams (as seen in urban and pasture streams), macroinvertebrate communities also have been compromised.

ANOSIM showed significant differences (at $p < 0.001$ and 0.004) in macroinvertebrate community structure between both stream groups and land-use groups. One aspect of disturbance which was not measured directly in this study, yet is known to significantly affect both the form and function of streams, was hydrologic modification by urban and pasture-related land use. Urban development, in particular, significantly alters stream hydrology [38]. Water velocity, depth and seasonal flow patterns are important factors that influence species distribution and life-cycle activities of stream organisms. Stream velocity affects oxygen levels, the retention of organic materials and the ability of aquatic organisms to move up and down the stream. Loss of riparian vegetation (as result of urbanisation and pasture development) can affect streams and aquatic communities by increasing the intensity and frequency of flood events and the degree and duration of low-flow conditions during droughts. Increased impervious areas within a catchment can result in less rainfall infiltration and an increase in storm water run-off. An example of this phenomenon is in the lower reaches of Otara Creek, where there is a high level of imperviousness, and a high proportion of industrial, commercial and residential properties which have impacted the natural character of the stream.

4.4.2. *Linkage of macroinvertebrate assemblages to environmental variables*

The BIOENV procedure [39] was used to identify which underlying environmental variable best correlated with the observed community patterns. The variety of factors believed to influence macroinvertebrate communities (e.g. temperature, conductivity, dissolved oxygen, turbidity and nutrient) that differed between the streams in the different land uses makes it difficult to establish the exact causes of changes. However, correlation of environmental variables with macroinvertebrate communities (using BIOENV procedure) indicated that conductivity, temperature, nitrate, phosphate and dissolved oxygen were particularly important in the distribution of macroinvertebrates across the land use.

It is obvious that changes in these parameters can be attributed to a variety of human disturbances (e.g. inputs of contaminants into the streams). In some urban and pasture reaches, the loss of riparian vegetation greatly reduced shading and the capability of trapping non-point source pollutants. This has consequently resulted in more run-off and contaminants draining into the watercourses, deteriorating the stream health and conditions. This is reflected in the low abundance and perhaps absence of more sensitive taxa at the pasture and urban streams. Pollution-sensitive taxa such as mayflies *Deleatidium* spp. and *Zephlebia* prefer a larger substrate size with high interstitial oxygen levels [40], and shaded streams with lower in-stream temperature. The blanketing effect of filamentous algae (observed in pasture) streams, combined with higher suspended sediment concentrations may have reduced interstitial oxygen levels making these streams unfavourable for sensitive species. Less sensitive species (*P. antipodurum* and Oligochaeta) which were more abundant in urban and pasture streams are generally known to prefer smaller substrate sizes [41] and unshaded reaches [42]. Change in catchement land use, particularly moving from native forest to pasture and urban development can affect the type of organic matter present in a stream. The quantities of leaves and wood entering a stream will be reduce and, the food bases may shift from allochthonous to autochthonous [43] This was observed in the current study in that pasture and urban streams had less organic particulate matter, and woody debris compared to bush streams.

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