Ecological values of Hamilton urban streams (North Island, New Zealand): constraints and opportunities for restoration

Kevin J. Collier[1,2*], Brenda M.T.A. Aldridge[2,3], Brendan J. Hicks[2], Johlene Kelly[1,4], Amy Macdonald[5,6], Brian J. Smith[3] and Jonathan Tonkin[5]

[1]Environment Waikato, PO Box 4010, Hamilton East, New Zealand
[2]Centre for Biodiversity and Ecology Research, Department of Biological Sciences, School of Science and Engineering, The University of Waikato, Private Bag 3105, Hamilton, New Zealand
[3]National Institute of Water and Atmospheric Research, PO Box 11-115, Hamilton, New Zealand
[4]Department of Conservation, PO Box 1146, Rotorua, New Zealand
[5]Institute of Natural Resources – Ecology, Massey University, Private Bag 11-222, Palmerston North, New Zealand
[6]Department of Conservation, PO Box 842, Whangarei, New Zealand
*Author for correspondence (Email: kevin.collier@ew.govt.nz)

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Abstract: Urban streams globally are characterised by degraded habitat conditions and low aquatic biodiversity, but are increasingly becoming the focus of restoration activities. We investigated habitat quality, ecological function, and fish and macroinvertebrate community composition of gully streams in Hamilton City, New Zealand, and compared these with a selection of periurban sites surrounded by rural land. A similar complement of fish species was found at urban and periurban sites, including two threatened species, with only one introduced fish widespread (*Gambusia affinis*). Stream macroinvertebrate community metrics indicated low ecological condition at most urban and periurban sites, but highlighted the presence of one high value urban site with a fauna dominated by sensitive taxa. Light-trapping around seepages in city gullies revealed the presence of several caddisfly species normally associated with native forest, suggesting that seepage habitats can provide important refugia for some aquatic insects in urban environments. Qualitative measures of stream habitat were not significantly different between urban and periurban sites, but urban streams had significantly lower hydraulic function and higher biogeochemical function than periurban streams. These functional differences are thought to reflect, respectively, (1) the combined effects of channel modification and stormwater hydrology, and (2) the influence of riparian vegetation providing shade and enhancing habitat in streams. Significant relationships between some macroinvertebrate community metrics and riparian vegetation buffering and bank protection suggest that riparian enhancement may have beneficial ecological outcomes in some urban streams. Other actions that may contribute to urban stream restoration goals include an integrated catchment approach to resolving fish passage issues, active reintroduction of wood to streams to enhance cover and habitat heterogeneity, and seeding of depauperate streams with native migratory fish to help initiate natural recolonisation.

Keywords: biodiversity; fish; functional value; impervious surface; invertebrates; seepage

Introduction

Urbanisation has homogenised otherwise heterogeneous physical environments, and replaced often diverse native flora and fauna with a variety of common urban-adapted species dominated by exotic taxa (McKinney 2005). Recently, interest has accelerated in ecological restoration of urban areas given that cities are where most people interact with native biodiversity most often. For urban streams, however, ecological rehabilitation can be problematic because of the overriding influence of stormwater on stream ecology (Bernhardt & Palmer 2007). Stream channels in cities are typically used to convey stormwater out of the urban environment as rapidly and efficiently as possible to avoid flooding and erosion, and catchments with impervious area as low as 10% can have significantly impaired aquatic macroinvertebrate communities (Walsh 2004). Indeed, the term ‘urban stream syndrome’ has been coined to describe the state of ecological degradation consistently observed in urban streams (Meyer et al. 2005).

Because stormwater enters streams directly via pipes, rather than naturally through overland flow and subsurface drainage, it significantly alters the hydrology of urban streams leading to more frequent floods, rapidly changing hydrographs, and higher peak flows (Walsh et al. 2005a). The erosive forces generated by this altered hydrology can cause channel incision and bank erosion, elevating fine sediment levels and resulting in increased water turbidity and smothering of streambed habitats (Chin 2006). Stormwater flushes can also increase water temperatures significantly and elevate concentrations of nutrients and a wide range of contaminants in streams (Walsh et al. 2005a). The desire for hydraulic efficiency has led to the piping or reconfiguration of many stream channels, and the reinforcement of stream banks and beds. In addition, stream channels are often cleared of aquatic plants and wood, and vegetation in riparian areas may be controlled to facilitate the rapid movement of floodwaters downstream. All these changes alter ecosystem function and influence the composition of biological communities in urban streams that are typically characterised by low diversity, few sensitive species and dominance by tolerant taxa (Meyer et al. 2005).

Roy et al. (2006) proposed that stream restoration in urban catchments should focus on the catchment drainage system rather than instream or riparian habitat. Improved drainage design can reduce the proportion of impervious area directly connected to streams through stormwater pipes by maximising runoff detention, infiltration and off-channel retention of water (Taylor et al. 2004; Walsh 2004; Walsh et al. 2005b). Appropriate technology can be implemented with relative ease in many new developments, but there are obvious difficulties and costs associated with retrospectively disconnecting stormwater systems to reduce effective impervious area in existing urban areas. Current attempts to restore natural vegetation sequences and foster native terrestrial biodiversity in the gullies of Hamilton City, New Zealand, have highlighted the potential to link terrestrial restoration with the protection and enhancement of aquatic values. In this paper we (1) compare selected attributes of urban streams (fish distribution, macroinvertebrate communities, habitat, and biogeochemical and hydraulic function) with periurban sites on the outskirts of Hamilton City, and (2) explore environmental factors associated with aquatic species' distribution in this urban environment. Based on the results of this work and other published studies, we discuss potential constraints and opportunities for urban stream restoration in Hamilton City.

Study area

Hamilton is New Zealand's seventh most populous city, with 185 000 inhabitants (2005 figures, www.stats.govt.nz). The Waikato River bisects the city, where its median discharge is 254 $m^3 s^{-1}$ (Environment Waikato, unpubl. data). Around 15 000 years ago, the river entered a period of downcutting, and as it deepened springs were exposed along the banks. These springs gradually undermined the riverbanks, and in a process known as spring sapping caused erosion of adjacent underlying sand, silt, peat and gravel, eventually creating gully streams that now flow through the city into the Waikato River (McCraw 2000). There are four major gully systems in Hamilton City (Kirikiriroa, Mangakotukutuku, Te Awa o Katapaki, and Waitawhiriwhiri) with numerous minor systems (Fig. 1), collectively occupying around 750 ha or 8% of the city area (Downs et al. 2000). Gully floor vegetation is frequently dominated by the deciduous exotic grey willow (*Salix cinerea* L.), though beneath this can be an understorey of indigenous plants including ground ferns, māhoe (*Melicytus ramiflorus* J.R.Forst. & G.Forst.) and cabbage trees (*Cordyline australis* (G.Forst.)Endl.).

Hamilton City gullies accommodate around 120 km of stream distinguished at the 1:50 000 mapping scale (Environment Waikato, unpubl. data). In addition, there is an unknown length of unmapped small stream channels, some of which now flow in pipes, as well as many springs and seepages. The larger streams originate in low-gradient agricultural catchments on the outskirts of the city, although some smaller streams have catchments that are entirely urbanised. In established urban areas, most impervious land appears to be highly connected to the stormwater network, which pipes stormflows directly into streams. The percentage of upstream catchment area with impervious surfaces can range from <5% for streams with most of their catchment still in rural land, to around 70% in some industrial suburbs (Environment Waikato, unpubl. data).

Methods

Study sites

A total of 56 sites was included in this study, comprising 28 urban streams, 19 periurban streams, and 9 urban seepages (Appendix 1; Fig. 1). Urban sites had residential or industrial development adjacent to them, although typically it did not extend to the stream edge due to the presence of parks and gullies. Periurban sites were surrounded by rural land (mostly farms and lifestyle blocks) at the time of sampling; rural land use dominated upstream catchments, although some periurban sites had residential development within their catchments (e.g. S1, S2). Of the streams sampled, 40 were assessed for fish occurrence, 33 for stream invertebrate community composition and habitat quality, and 28 for biogeochemical and hydraulic function. The seepages were sampled for adult caddisflies (Trichoptera) only. Fish, invertebrates and functional values were all assessed at 22 sites, and fish sampling only was conducted at 12 sites. Stream sampling reach lengths were 50–100 m, with all attributes measured in the same reach unless otherwise indicated (see Appendix 1; Fig. 1).

Channel widths ranged from 0.4 to 7 m but were similar on average at urban and periurban sites (Table 1).

Table 1. Physicochemical attributes of sampling sites in urban ($n = 28$) and periurban ($n = 19$) Hamilton City. Single measurements were made per site during daylight hours in 2005–2007 (Environment Waikato, unpubl. data).

	Urban				Periurban			
	Mean	SE	Min	Max	Mean	SE	Min	Max
Active channel width (m)	1.9	0.2	0.4	5.0	2.4	0.4	0.3	7.0
Sand/silt/clay (%)	71.5	4.6	10.0	100.0	84.5	5.2	10.0	100.0
Gravel-cobble (%)	26.9	4.3	0.0	90.0	12.4	3.3	0.0	50.0
Water temperature (°C)	18.0	0.4	15.3	24.0	18.6	0.4	16.2	22.8
Dissolved oxygen (%)	80.4	2.7	48.0	104.4	78.1	5.0	43.0	122.2
Dissolved oxygen (mg L^{-1})	10.2	2.6	4.7	79.4	7.3	0.5	4.1	11.0
pH	7.3	0.1	6.4	7.8	7.0	0.1	6.4	7.5
Conductivity (µS cm^{-1} @ 25°C)	198.8	20.1	55.1	673.0	219.6	9.3	123.3	302.1

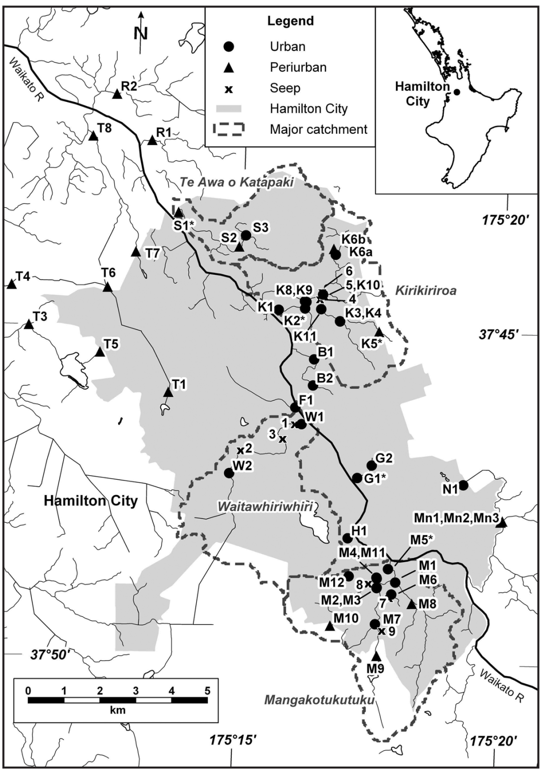

Figure 1. Map of sampling sites showing boundaries of the city and major catchments. * = fish and invertebrate sampling sites >100 m apart. See Appendix 1 for further details.

The percentage of fine substrates (sand, silt and clay) on the streambed was high at all sites (>70%), but significantly greater in periurban streams (Mann–Whitney $U = 356$, d.f. = 1, $P < 0.05$). This difference most likely reflected the higher gradient of urban streams as they approach the Waikato River, and the introduction of rocks to stabilise bank erosion which presumably contributed to gravel/cobble substrates in urban streams. Measured spot water temperatures did not exceed 24°C, and dissolved oxygen saturation was similar in urban and periurban streams (means = 80 and 78%, respectively), although low oxygen concentrations (<5 mg/L) were measured at some sites (Table 1). pH was circumneutral in both urban and periurban streams, but conductivity was significantly higher at periurban sites ($U = 382$, d.f. = 1, $P < 0.05$), potentially reflecting enrichment from agricultural development.

Fish

Fish were collected at 24 urban and 16 periurban sites between December 2005 and March 2006 (Appendix 1; Fig. 1). Five Gee minnow traps (5-mm mesh) were set at each site, and a fyke net (25-mm mesh) was also set if the water was deeper than about 1 m (13 sites; Appendix 1). A perforated container of cat biscuits was attached within each trap and net as an attractant. Streams with sufficiently clear water ($n = 13$) were also spotlighted at night, and 10 shallow sites with suitable access were electric fished using a backpack electrofishing machine (EMF 300, NIWA Instrument Systems, Christchurch). Three methods (minnow traps or fyke nets, electric fishing and spotlighting) were conducted together at eight sites (Appendix 1).

Macroinvertebrates

Of the 35 stream sites sampled for invertebrates, 25 were surrounded by urban development, and 10 were in periurban settings (Appendix 1; Fig. 1). Stream macroinvertebrates were collected from stable habitats in flowing water using a D-frame net (0.5-mm mesh) between December 2005 and January 2006 (see Collier & Kelly 2005). Collection involved kicking loose gravel-cobble substrate in front of the net, hand-brushing embedded substrate elements and wood, and jabbing the net in among macrophytes and along stream edges with a similar amount of effort at all sites. The resulting samples were preserved in c. 70% isopropanol, and were later processed by identifying at least 200 invertebrates (excluding pupae) from randomly selected subsamples, followed by a search for unrecorded taxa in the rest of each sample. Subsampling was achieved by dividing the processing tray into a grid and randomly selecting one cell for processing; additional cells were added until the desired number of macroinvertebrates was obtained with all animals in the final cell being removed. This process yielded an average of 213 individuals per site, with only one sample (G1) not reaching 200 individuals.

Identifications were based on Winterbourn et al. (2000) (insects), Winterbourn (1973) (molluscs), and Chapman & Lewis (1976) (crustaceans). The level of taxonomic resolution was genera for most insects and molluscs, and ranged from family to phylum for other groups, as recommended by Stark et al. (2001) for stream environmental monitoring in New Zealand. The total number of taxa, and the number of taxa and percentage abundance of sensitive Ephemeroptera, Plecoptera, and Trichoptera excluding Hydroptilidae (denoted as EPT*), were calculated from the macroinvertebrate data. Hydroptilidae was excluded because some species can proliferate among growths of filamentous algae, which are often typical of degraded conditions. In addition, the Macroinvertebrate Community Index (MCI) was calculated as described in Stark et al. (2001), and the Urban Community Index (UCI), which may be a more appropriate index for discriminating ecological conditions among streams that lacked sensitive species but were impacted by urban development, was calculated following Suren et al. (1998, unpubl. report) and Boothroyd & Stark (2000). The UCI uses Canonical Correspondence scores for taxa from a nationwide urban stream survey as tolerance values to weight species occurrence. These weighted values are then aggregated to provide the UCI. It was necessary to combine taxa belonging to *Zephlebia* and *Neozephlebia*, and *Orthopsyche* and *Aoteapsyche*, because not all taxa found in the present study were part of the original UCI dataset. Higher EPT*, MCI and UCI scores indicate better ecological condition.

Adult Trichoptera

Ultraviolet light traps were used to attract adult Trichoptera around seepages at three urban sites in each of the Mangakotukutuku, Kirikiriroa, and Waitawhiriwhiri catchments (total of nine sites). These catchments represented a gradient of urbanisation intensity, with the Mangakotukutuku having a significant proportion of its catchment outside the city, Waitawhiriwhiri with a high level of industrial land, and Kirikiriroa intermediate and characterised by more recent high density urban development. Each light trap consisted of a low power (6 W) model F6T5 blacklight fluorescent tube laid over a white dish (38 × 27 × 6 cm). The dish was half-filled with water into which a few drops of detergent had been mixed to break the water surface tension. The lights were powered by 12-volt batteries run from timing units that enabled all lights to be turned on and off, simultaneously. Light traps were set to run from 2100 to 2300 hours and 0200 to 0300 hours at all sites on the same night each month from November 2006 to January 2007. Samples were preserved in isopropanol and Trichoptera were later identified under a binocular microscope using Neboiss (1986) and Smith & Ward (unpubl. key to adult Trichoptera).

Habitat assessment

Habitat assessments were made at all sites where stream invertebrates were collected (Appendix 1), using the method described by Collier & Kelly (2005). This procedure provides an integrative score for riparian, bank, channel and instream conditions by visually evaluating nine attributes on a scale of 1 (lowest habitat value) to 20 (highest habitat value), with possible total scores ranging from 9 to 180 (see Results Fig. 5 for component attributes). Riparian zone buffering refers to the buffering from the adjacent land use provided by riparian vegetation; for example, grass next to a city stream would provide buffering from urban land, but it would not provide buffering from agriculture.

Stream Ecological Valuation (SEV)

Hydraulic and biogeochemical components of the SEV methodology (see Rowe et al. 2008, in press) were assessed at five periurban and 23 urban sites (Appendix 1; Fig. 1). Hydraulic functions included natural flow regime, connectivity to floodplain, connectivity for species migrations, and connectivity to groundwater. Biogeochemical functions included water temperature control, dissolved oxygen concentrations, organic matter input, instream particle retention, decontamination of pollutants, and floodplain particle retention. The SEV methodology involves measuring (at 10 cross-sections) or scoring (visually along the sampling reach) selected attributes, and then integrating them using algorithms that express the ability of the stream to perform certain ecological functions. Algorithms were developed by an expert panel and were tested on a range of urban streams in Auckland City (Rowe et al. 2008, in press). The outputs from these algorithms were aggregated relative to native forest reference conditions to provide an overall score for each function with a potential value between 0 and 1, with higher scores indicating greater similarity to the reference condition. The reference site used for this purpose was the closest native forest stream, located in the Hakarimata Ranges 11 km to the north-west of Hamilton City (NF in Quinn et al. 1997). Details of the field methodology for the SEV components are provided in Rowe et al. (2008).

Statistical analysis

Non-parametric tests were used for all statistical analyses because of the skewed nature of most of the data. Differences between urban and periurban sites for macroinvertebrate metrics, habitat scores, and SEV biogeochemical and hydraulic functions were assessed using Mann–Whitney *U* tests, whereas differences among urban catchment groupings (Kirikiriroa, Mangakotukutuku, other catchments combined) were assessed using Kruskal–Wallis tests. Relationships between macroinvertebrate metrics and habitat and SEV scores were explored using Spearman rank correlations. Fish catch data were not analysed statistically because various levels of effort were used at different sites depending on habitat characteristics.

Results

Distribution of fish

With the exception of juvenile galaxiids and torrentfish, a similar complement of fish species was found in urban and periurban settings (Fig. 2). Altogether, eight species of native fish and four species of introduced fish were caught in and around Hamilton City. The native fauna comprised the shortfin eel (*Anguilla australis* Richardson 1848), the longfin eel (*A. dieffenbachii* Gray 1842), banded kōkopu (*Galaxias fasciatus* Gray 1842), giant kōkopu (*G. argenteus* (Gmelin 1789)), inanga (*G. maculatus* (Jenyns 1842)), common smelt (*Retropinna retropinna* (Richardson 1848)), common bully (*Gobiomorphus cotidianus* McDowall 1975), and torrentfish (*Cheimarrichthys fosteri* Haast 1874). The latter was only found in a fast-flowing, stony section of one urban stream. The introduced koi carp (*Cyprinus carpio* Linnaeus 1758), gambusia (*Gambusia affinis* (Baird & Girard 1854)), catfish (*Amieurus nebulosus* Le Sueur 1819) and indeterminate trout were also caught in Hamilton urban streams. However, only gambusia, which was found at over a quarter of the sites sampled, was widespread (Fig. 2). Shortfin eel (61% of sites) and longfin eel (34%) were the most widespread species collected. Smelt, banded kōkopu, giant kōkopu and unidentified whitebait (juvenile Galaxiidae) were found at 2–6 sites within the city (Fig. 2). Catfish were found at only one periurban site, although they have been seen subsequently within the city in Waitawhiriwhiri Stream (JK, pers. obs.).

Stream macroinvertebrates

Macroinvertebrate communities of Hamilton's urban streams were dominated by tolerant species including *Potamopyrgus antipodarum* (31% of numbers across all urban sites), Oligochaeta (26%) and Chironomidae (21%). The freshwater crayfish/kōura (*Paranephrops planifrons*) was not caught in traps or nets at any site but was found at two urban and two periurban sites during electric fishing (Fig. 2). Median numbers of macroinvertebrate taxa per sample (taxa richness) and sensitive EPT* taxa were similar at urban and periurban sites (Fig. 3A, B). The typical urban and periurban site supported low %EPT* (median <2%; Fig. 3C), although there was considerable variability among sites, especially in EPT* taxa richness. The Mangakotukutuku samples included one urban site (with a predominantly gravel streambed) and one periurban site (characterised by soft bed sediments and willow roots) that had particularly diverse or abundant EPT faunas relative to other sites. Statistical comparisons of metrics indicated no significant difference between urban and periurban sites (U = 91 for both EPT* metrics, d.f. = 1, P > 0.05), but within the urban sites EPT* taxa richness was significantly higher in the Mangakotukutuku catchment (Kruskal–Wallis H = 9.1, d.f. = 2, P < 0.05).

Median MCI values for site groupings ranged from 68 to 74 at the periurban and urban sites (Fig. 3D) and ranges were indicative of poor to good stream quality (Wright-Stow & Winterbourn 2003). UCI values were more variable for urban than periurban streams (Fig. 3E) and no statistically significant differences were detected for either index between the two groups of sites (Mann–Whitney U = 63 and 84, respectively, d.f. = 1, P > 0.05) (Fig. 3);

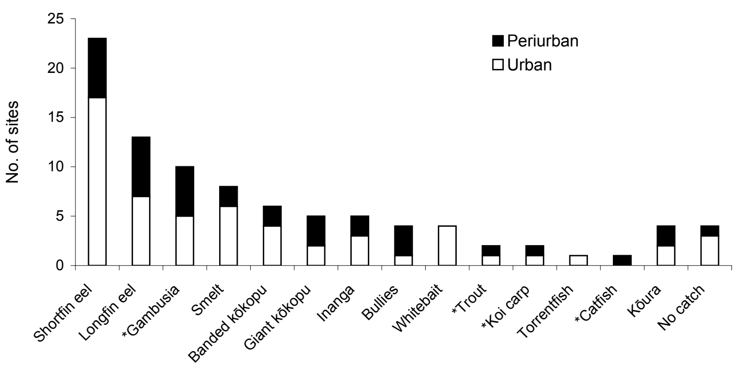

Figure 2. Number of sites where different fish species and freshwater crayfish (kōura) were caught during a survey of 24 urban and 16 periurban stream sites in and around Hamilton City. Whitebait includes all unidentified juvenile galaxiids and trout were not identified to species. * = introduced species

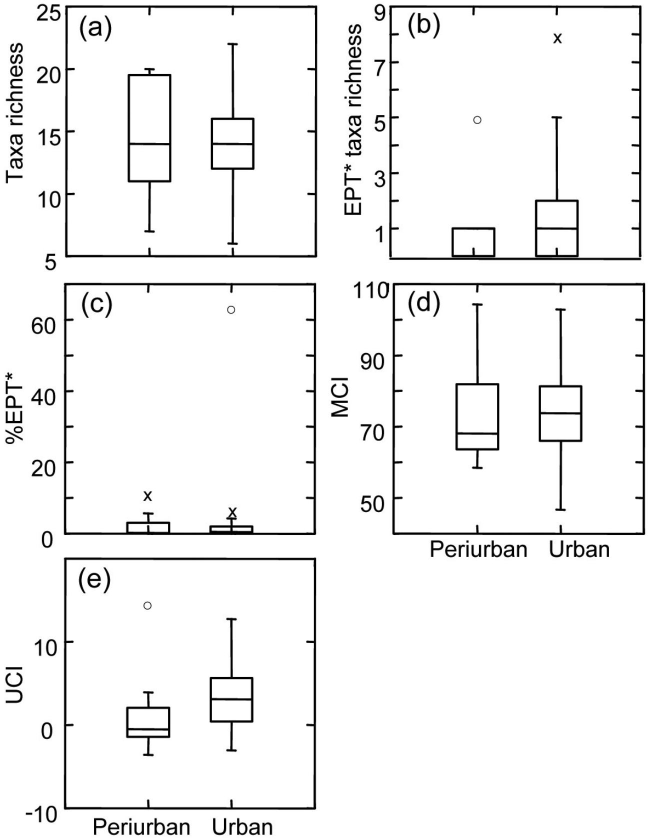

Figure 3. Box plots illustrating: A, total numbers of macroinvertebrate taxa (taxa richness); B, the number of Ephemeroptera, Plecoptera and Trichoptera (excluding Hydroptilidae) taxa (EPT* taxa richness); C, percentage EPT* abundance; D, the Macroinvertebrate Community Index (MCI); and E, the Urban Community Index (UCI) in periurban ($n = 8$) and urban ($n = 25$) sites. Horizontal lines = median; box = interquartile range; crosses and circles = outliers and extreme outliers, respectively.

however, there were differences between urban catchments ($H = 8.1$, d.f. = 2, $P < 0.05$) with UCI scores being highest in the Mangakotukutuku.

Adult Trichoptera faunas

In all, 1710 adult Trichoptera representing seven families and 23 species were collected in light traps around urban seepages (see Smith (2007) for species list). This contrasts with only three trichopteran taxa found in larval collections from streams near the light-trapping sites, and 10 larval taxa found across all stream macroinvertebrate sampling sites. Hydrobiosidae, represented by three genera and six species, was the most diverse family caught in light traps. Richness of adults (mean number of species per site) was greatest for the Mangakotukutuku Stream (13 species), followed by the more developed Kirikiriroa catchment (11 species), and the highly developed Waitawhiriwhiri catchment (6 species). The caddisfly catch included one previously undescribed species, the microcaddisfly *Oxyethira kirikiriroa* (Smith 2008), which was one of five species caught only at the Kirikiriroa seepages. The other four were *Aoteapsyche colonica*, *Hydrobiosis budgei*, *H. umbripennis* and *Pycnocentria funerea*. *Pycnocentrodes aeris* was only caught adjacent to Waitawhiriwhiri seepages, whereas *Orthopsyche thomasi* was only recorded from light traps set in the Mangakotukutuku seepages. Of the Trichoptera species collected, *Edpercivalia thomasoni*, *O. thomasi*, *Triplectidina moselyi* and *Pseudoeconesus bistirpis* are generally considered obligate forest species, and along with *Polyplectropus altera* and *P. aurifusca* indicate the presence of seepages or small stream habitats (B. Smith, unpubl. data).

Kirikiriroa light trap samples contained the greatest number of adult aquatic insects (1210), whereas the Waitawhiriwhiri and Mangakotukutuku traps produced similar numbers of individuals (260 and 240, respectively). Over half the species caught were represented by five or fewer individuals. Adults of the net-spinning Hydropsychidae (mainly *Aoteapsyche winterbourni*) were the most commonly caught, comprising 66% of total numbers. Hydropsychidae dominated adult Trichoptera catches at the Kirikiriroa and Waitawhiriwhiri sites, but relative abundances were similar across five families at the Mangakotukutuku sites (Fig. 4). Overall, the six species indicative of native forest seepages and small streams

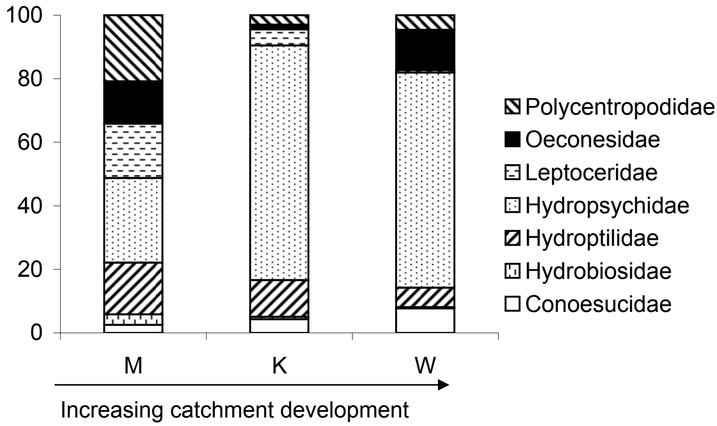

Figure 4. Percentage composition of Trichoptera families collected in light traps adjacent to urban seepages in three catchments (three sites combined per catchment) (see Fig. 1). M = Mangakotukutuku; K = Kirikiriroa; W = Waitawhiriwhiri.

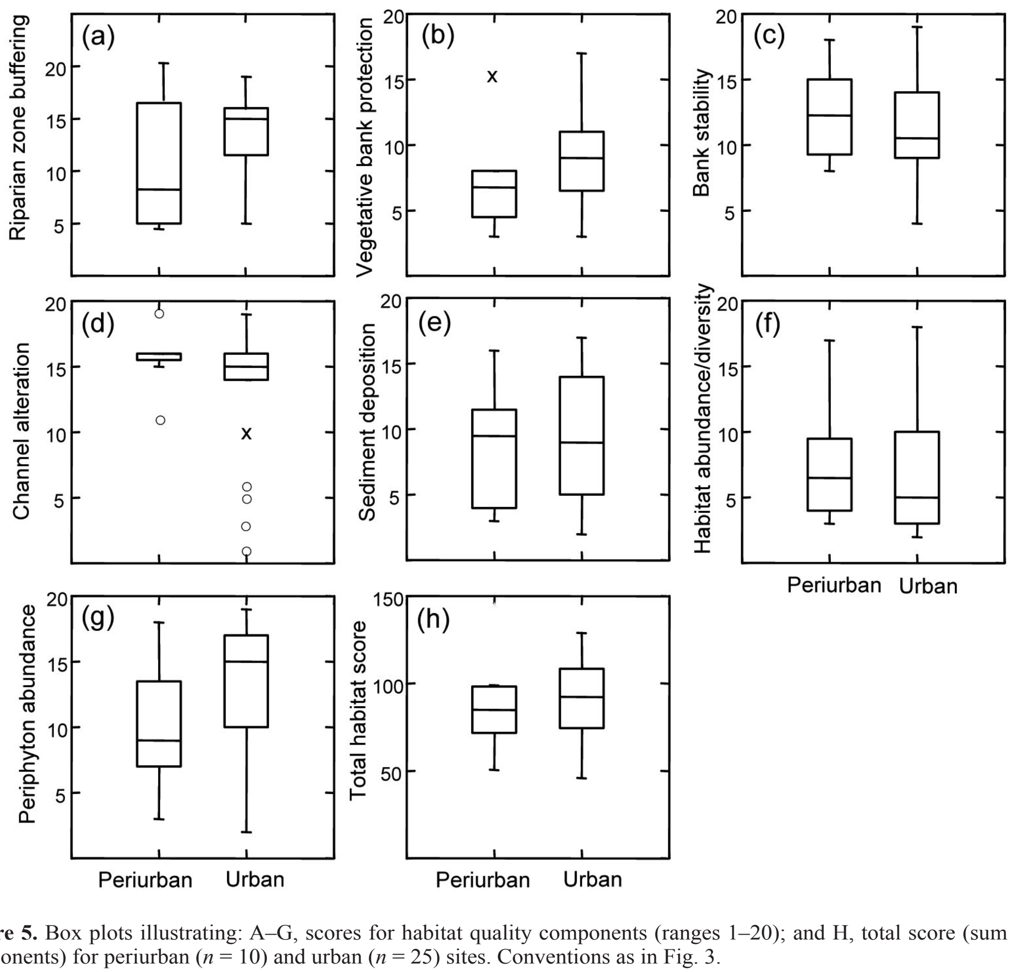

Figure 5. Box plots illustrating: A–G, scores for habitat quality components (ranges 1–20); and H, total score (sum of all components) for periurban (n = 10) and urban (n = 25) sites. Conventions as in Fig. 3.

represented 4.5%, 17.7% and 40.0% of total numbers in the Kirikiriroa, Waitawhiriwhiri and Mangakotukutuku sites, respectively. The relative abundance of trichopteran families did not appear to be directly related to degree of catchment development, although they were more evenly represented in the least developed catchment (Fig. 4).

Habitat

Riparian vegetation typically provided greater buffering from adjacent land use at urban than periurban sites (Fig. 5A), although variability within periurban sites was high, reflecting the occasional presence of willows and other trees that buffered streams from adjacent agricultural land. Nevertheless, median values for vegetative bank protection and bank stability were similar (7–9 and 11–12, respectively; Fig. 5B, C), as were other habitat components and the total scores (Fig. 5D–H). Within the urban sites (i.e. excluding periurban sites), total habitat score was significantly correlated with %EPT* ($r_s = 0.44$, $P < 0.05$, $n = 25$), and riparian buffering was correlated with EPT* taxa richness ($r_s = 0.54$, $P < 0.01$) and %EPT* ($r_s = 0.49$, $P < 0.05$). Similarly, MCI was significantly correlated with riparian buffering ($r_s = 0.48$, $P < 0.05$), and with degree of channel alteration ($r_s = 0.48$, $P < 0.05$). The UCI was significantly correlated with vegetative bank protection ($r_s = 0.46$, $P < 0.05$). Collectively, these relationships infer a positive association between the extent and vigour of riparian buffer zones, channel integrity, and the condition of macroinvertebrate communities in urban streams.

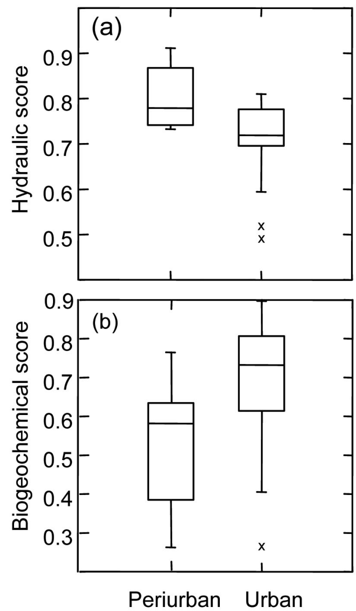

Figure 6. Box plots illustrating: A, hydraulic function; and B, biogeochemical function for periurban (n = 5) and urban (n = 23) sites following Rowe et al. (2008). Each function is expressed as a ratio of that measured at a native forest reference site, with higher scores indicating greater similarity to the reference condition. Conventions as in Fig. 3.

Hydraulic and biogeochemical components of the SEV

Stream Ecological Valuation analysis indicated that the median hydraulic function score was 0.78 for periurban sites and 0.72 for urban sites relative to the native forest reference condition, whereas biogeochemical function scores were 0.58 and 0.73, respectively (Fig. 6). Urban sites had significantly lower hydraulic function ($U = 94$, d.f. = 1, $P < 0.05$) and higher biogeochemical function ($U = 26$, d.f. = 1, $P = 0.05$) than periurban sites (Fig. 6). However, significant differences were not observed within urban catchments ($H = 0.6$ and 0.8 for hydraulic and biogeochemical function, respectively; d.f. = 2, $P > 0.05$). These functional values were not significantly correlated with any of the invertebrate metrics evaluated for urban sites.

Discussion

Urban stream values

Despite the well-documented effects of stormwater runoff, urban streams in Hamilton City appear to provide similar overall habitat quality to periurban streams and support a similar range of fish species. Indeed, two of the species recorded in city streams, longfin eel and giant kōkopu, are considered threatened and are in gradual decline (Hitchmough 2005). Some native fish species may be able to persist in urbanised catchments because of the availability of cover to provide refugia from stormwater flows. For example, giant kōkopu are often found associated with overhanging riparian vegetation and instream cover such as that provided by accumulations of wood and undercut banks (Bonnett et al. 2002; Baker & Smith 2007), and banded kōkopu prefer small streams with abundant cover (Rowe & Smith 2003). The ability of several galaxiid species to acquire significant proportions of their nutrition from terrestrial insects that fall into streams (e.g. Hicks 1997) may enable some species to survive in urban environments with depauperate instream food supplies.

The macroinvertebrate communities of most streams in Hamilton City were generally comparable with urban settings elsewhere in being dominated by taxa that are tolerant of moderately poor water quality and habitat conditions (Blakely & Harding 2005; Suren & McMurtrie 2005; Walsh et al. 2005a). Communities in most periurban streams were also characterised by tolerant taxa, suggesting that upstream land use could partly influence the composition of communities occurring in downstream urban settings, although direct comparisons were complicated by physicochemical differences between periurban and urban sites (Table 1). Nevertheless, macroinvertebrate communities at one urban site with a low level of upstream development on the Mangakotukutuku Stream formed a clear outlier in terms of macroinvertebrate metrics, highlighting that broad-scale ecological knowledge is required to identify high-value sites that persist within urban environments.

Seepage habitats that are disconnected from the stormwater network harboured around 30% of the caddisfly diversity known from Hamilton City (BJS, unpubl. data), underscoring the role these often small and overlooked habitats can play in maintaining urban biodiversity values. A combination of soft benthic sediments, shade offered by low-growing riparian grasses, and ample food resources (leaves and small sticks) may enable caddisfly species typical of forested settings to persist in urban seepages. The retention of vegetated gully systems throughout Hamilton City seems to have protected many seepage habitats as part of the riparian complex. Our results suggest that local aquatic biodiversity may be higher where extensive vegetated riparian areas and natural groundwater flows interact than where development and drainage occur to the stream edge.

Constraints to urban stream restoration

Hydraulic functions such as maintenance of a natural flow regime and retention of connectivity to the floodplain appear to be constrained in urban settings, most likely reflecting the combined effects of channel modification and stormwater hydrology. In contrast, biogeochemical function was enhanced in urban streams relative to periurban environments because riparian vegetation provided shade, potential food supplies and habitat in gully streams. Hydrology also appeared to constrain the diversity of urban stream macroinvertebrate communities, which showed a marked decline in the richness of sensitive macroinvertebrate taxa when upstream impervious area exceeded around 10% (KJC, unpubl. data), consistent with the findings of Walsh (2004) who concluded that factors associated with stormwater connection limit the ecological potential of stream macroinvertebrate communities in urban settings. As well as stormwater effects, iron deposition and associated bacterial growths are extensive in several of Hamilton's urban streams (KJC, pers. obs.), reflecting inputs of iron-rich groundwater. Growths associated with such inputs are known to limit stream macroinvertebrate communities (Wellnitz et al. 1990).

Freshwater crayfish are rarely encountered in Hamilton streams, although they can be common and achieve relatively high biomass in nearby pasture streams (Parkyn et al. 2002). Similarly, the migratory shrimp *Paratya curvirostris* was notably absent from urban stream samples obtained as part of this study, despite shrimps having been seen in a Mangakotukutuku tributary with low upstream impervious area (BMTAA, pers. obs.) and in the nearby Waikato River. The reason for the poor representation of large Crustacea in urban streams is unclear, but it may partly relate to high susceptibility to contaminants carried in stormwater and accumulating on sediments where they live (crayfish) or feed (shrimp), or barriers to the movement of migratory shrimps (e.g. Resh 2005).

Assessment of the severity of passage impedance to upstream migrating fish at 45 road crossings in Hamilton City indicated that 42% of culverts were likely to prevent upstream passage at most flows or low flows (Aldridge & Hicks 2006). The frequency of passage restrictions in urban streams reflects the high density of roading and suggests that culverts have the potential to be major modifiers of the distribution of native diadromous fish (and shrimps where other conditions allow) in cities. Thus, impediments to passage need to be addressed before physical habitat restoration to ensure the long-term sustainability of migratory populations. An important factor when considering culvert remediation work is the potential risk of enhancing access for troublesome exotic species, such as koi carp and catfish, which our survey indicated were not currently widespread in Hamilton City streams. Work in Christchurch urban streams has suggested that road culverts could also act as partial barriers to upstream flight of insects, with potential consequences for larval recruitment in restored sections of stream (Blakely et al. 2006).

Opportunities for urban stream restoration

A key forerunner to establishing restoration priorities is the identification and protection of existing high-value sites so they do not become further degraded. As demonstrated in our study, high-value aquatic sites can persist within cities despite the varied effects of urbanisation on water quality, fish passage, habitat, and hydrology. Seepage habitats were associated with high biodiversity of adult caddisflies, and likely also harbour a range of other wetland species. For example, the giant bush dragonfly *Uropetela carovei*, occasionally seen around Hamilton City, spends 5–6 years living in wetland burrows (Rowe 1987). Similarly, streams with low stormwater connectivity may harbour comparatively healthy macroinvertebrate communities and warrant protection to ensure these values are retained. Given these potential sources of colonists present within Hamilton City, connectivity is unlikely to be a concern for stream insect recolonisation, as in Christchurch for example (Suren & McMurtrie 2005). These findings underscore the importance of maintaining the disconnection from stormwater of high-value streams and seepages in urban environments and areas proposed for development.

Our results point to a positive association between riparian buffering and macroinvertebrate metrics, suggesting that riparian planting may enhance the distribution and abundance of some moderately sensitive taxa in urban streams. Furthermore, riparian planting may enhance some of the biogeochemical functions of urban streams, such as water temperature regulation through shading, and by promoting organic matter inputs and particle retention. It has also been suggested that improving instream habitat quality, for example through riparian planting, may reduce the abundance of some nuisance introduced species such as gambusia (Ling 2004). However, development of riparian shade can decrease grass growth on streambanks and destabilise deposited sediments, leading to channel widening as a shaded-channel morphology re-establishes (Davies-Colley 1997; Collier et al. 2001). This phenomenon has been documented in small Waikato pasture streams, but it is not clear to what extent it would occur along urban streams following riparian planting because altered hydrology due to stormwater runoff is likely to modify the process.

The development of riparian forest is also likely to lead to natural recruitment of large wood to streams in due course. Large, stable pieces of wood in the stream channel are increasingly being recognised for their role in creating more diverse instream habitats, providing cover for fish, and serving as a substrate for macroinvertebrates where bed sediments are unstable (Hildebrand et al. 1998; Collier & Halliday 2000; Gerhard & Reich 2000; Bonnett et al. 2002). Stable wood in channels and rigid riparian plant stems can impede water flow during floods, thereby reducing hydraulic stress on instream biota and leading to lower but extended flood peaks and longer periods of localised flooding (Collier et al. 1995). This may benefit species such as eels, which are known to follow rising water levels during floods, allowing them to use inundated areas as supplementary feeding habitat (Jowett & Richardson 1994). However, the timescale required to achieve natural wood recruitment from native trees is considerable (Meleason & Hall 2005). This time factor, coupled with the need to protect downstream infrastructure and property, suggests that managed introductions would be required if large wood were to be used as a habitat restoration option in urban streams.

Restoration goals for urban streams may differ for macroinvertebrate and native fish communities because of their apparently different susceptibilities to stormwater inputs. Although some native fish species appear to be resilient to urban development, it is difficult to restore the natural structure of fish communities at urban sites because of the varied combination of local and downstream factors that regulate fish distribution and abundance. Thus, rather than striving for natural fish community structure, a more attainable goal may be to enhance the distribution and abundance of iconic native species (e.g. large galaxiids) by identifying the specific aspects of their habitat and biology that constrain populations. Recent work in Hamilton urban streams has highlighted the potential for actively introducing naïve farm-reared giant kōkopu into sites where natural recruitment may be limited (Aldridge 2008). These farm-reared giant kōkopu grew rapidly (up to 0.11 g per day) in urban streams, and some remained at release sites for up to 11 months. Some juvenile galaxiids also respond positively to specific concentrations of adult pheromones released into the water by fish in established populations (Baker & Hicks 2003), and are thought to attract juvenile fish to suitable adult habitat. Thus, where desired species are absent or population numbers are very low, active reintroductions of fish to physically suitable sites may be needed to ensure new recruits are attracted to restored streams so that the long-term sustainability of populations can be maintained.

Conclusions

This study illustrates that some urban streams and seepages can provide important habitat for a range of native fish and invertebrate species in city environments, and underscores the importance of identifying and protecting existing ecological values to avoid degradation from future development. The potential for rejuvenation of macroinvertebrate communities appears to be constrained at highly developed sites due to factors primarily associated with stormwater inputs. However, riparian vegetation may help enhance community structure along with biogeochemical function in some streams draining less intensively urbanised catchments. Due to the varied range of local and downstream factors (e.g. passage for migrating species) that can influence native fish community composition, restoration goals for fish in urban streams may be best focused on certain flagship species (e.g. giant kōkopu) and key constraints to long-term population viability (e.g. barriers to migration). While this may not constitute 'restoration' in the literal sense of returning a stream and its biotic assemblages to a previous condition, it would nevertheless make an important contribution to urban biodiversity and conservation of threatened species. Actions potentially contributing to urban stream restoration goals include (1) an integrated catchment approach to resolving passage issues, (2) planting of riparian areas with tree species that provide overhanging vegetation and improved bank stability, (3) active reintroduction of wood to streams to enhance cover and habitat heterogeneity, and (4) seeding of depauperate streams with native fish to help initiate natural recolonisation.

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Appendix 1. Locations and types of samples collected at Hamilton urban and periurban sites. * fish and invertebrate sampling sites more than 100 m apart. M, minnow trapping; S, spotlighting; E, electric fishing; F, fyke netting; + invertebrates and habitat assessed or SEV (Stream Ecosystem Valuation) conducted; A, adult insect sampling.

Sire code	Easting	Northing	Fishing method	Invertebrates	SEV
Urban					
B1	2710500	6380300	M	+	+
B2	2710467	6379571	M, S	+	+
F1	2709972	6378958	M, S	+	+
G1*	2711696	6376986	M	+	+
G2	2712102	6377333	M, E, S		
H1	2711426	6375305	M	+	+
K1	2709514	6381687	M, F		
K10	2710753	6382107	M, E, S	+	+
K11	2710700	6381700		+	
K2*	2710250	6381720	M, S	+	+
K3	2711226	6381356	M, F	+	+
K4	2711223	6381362	M, F	+	+
K6a	2711108	6383218	M	+	+
K8	2710288	6381903	M, F		
K9	2710246	6381922	M, E	+	+
M1	2712751	6374066	M, E, S	+	+
M11	2712228	6374204		+	+
M12	2711453	6374244		+	+
M2	2712231	6373913	M, F	+	+
M3	2712235	6373926	M, F	+	+
M4	2712236	6374178	M, E, S	+	+
M5*	2712550	6374441	M, E	+	+
M6	2712640	6373733	M, E, S	+	+
M7	2712184	6372905	M, S	+	+
N1	2714653	6376777		+	+
S3	2708605	6383764	M, S	+	+
W1	2710146	6378492	M	+	+
W2	2708124	6377130	M	+	
Seep9	2712575	6373665		A	
Seep8	2712000	6374070		A	
Seep7	2712195	6372955		A	
Seep6	2708445	6377795		A	
Seep5	2709616	6378115		A	
Seep4	2709955	6378520		A	
Seep3	2710730	6382208		A	
Seep2	2710781	6382111		A	
Seep1	2710666	6382008		A	
Periurban					
K5*	2712315	6381065	M, E, S	+	+
K6b	2711106	6383232	M		
M10	2710928	6372869	M, F	+	
M8	2713210	6373473	M, F, E, S	+	+
M9	2712223	6372022	M	+	
Mn1	2715690	6375746	M, F		
Mn2	2715741	6375765	M, F		
Mn3	2715690	6375739	M, E, S		
R1	2705995	6386435		+	+
R2	2705016	6387727		+	+
S1*	2706727	6384425	M	+	
S2	2708416	6383454	M, F	+	+
T1	2706427	6379403	M		
T3	2702543	6381305	M, F		
T4	2702065	6382426	M		
T5	2704524	6380532	M, F		
T6	2704741	6382341	M		
T7	2705533	6383325	M		
T8	2704351	6386562	M		