Can urban streams be restored? Linking vegetation restoration with urban stormwater mitigation

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ABSTRACT

Urban streams globally are characterised by degraded habitat conditions and low aquatic biodiversity, attributed in large part to the effects of stormwater inputs and channel modification and maintenance. Recent work in Hamilton City has highlighted the ability of some threatened fish species to survive in urban streams that retain habitat complexity in vegetated gullies, and the presence of diverse stream invertebrate communities in small streams and seepages that remain disconnected from the stormwater network. Recently completed research to assist the City's gully restoration programme has shown that it is comparatively easy to establish a low diversity indigenous forest canopy on bared sites within 20 years, and by this stage, some early maturing canopy species will be starting to regenerate. Shade and bank stability provided by restored vegetation should assist in mitigating some of the effects of stormwater inputs on stream biota. Furthermore, retention of large pieces of wood in stream channels will help provide refugia for fish from stormflows, and release of juvenile galaxiid fish may provide a method of population restoration. Active introduction and stabilisation of wood may be required until restored riparian vegetation matures sufficiently to provide a long-term supply of wood.

KEYWORDS

Fish; Giant kokopu; Invertebrates; Seepage; Impervious surface; Wood; Hamilton; New Zealand

PRESENTER PROFILES

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Professor Bruce Clarkson is Director of the Centre for Biodiversity and Ecology Research at the University of Waikato. Throughout his research career he has maintained a strong interest in applying aspects of his research on the ground to assist in the protection and restoration of native plants and ecosystems. He currently leads a FRST funded research programme on determining the best methods for restoring indigenous biodiversity in cities.

Brenda Aldridge recently completed a M.Sc. at the University of Waikato on restoring giant kokopu populations in Hamilton urban streams after previously having conducted the first comprehensive fishing survey of the City's streams. Brenda is currently employed as an Environmental Consultant with Kessels and Associates in Hamilton.

Associate Professor Brendan Hicks leads a programme of pest fish research under the Centre for Biodiversity and Ecology Research at the University of Waikato. He has an extensive background in the ecology of stream fish, including his previous position at Fisheries Research Division of the Ministry of Agriculture and Fisheries, and his PhD in salmonid ecology in the Oregon Coast Range. His recent research has focused on using stable isotopes to understand food webs, otolith microchemistry, and development of methods to estimate fish abundance in streams and lakes.

1 INTRODUCTION

Historically, cities have been built to meet the needs of one species, *Homo sapiens*. The resulting urbanisation has homogenised otherwise heterogenous physical environments, and replaced often diverse native flora and fauna with a widespread pool of common urban-adapted species dominated by exotic taxa (McKinney, 2005). Streams draining urbanised catchments have not been immune to these changes, and the term "urban stream syndrome" has been coined to describe their consistently observed state of ecological degradation worldwide (Meyer et al., 2005). Stream channels in cities are typically used to convey stormwater out of the built environment as rapidly and efficiently as possible to avoid flooding and erosion. Because urban stormwater runs off impervious surfaces and 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 spates, rapidly changing hydrographs, and higher peak flows (Walsh et al., 2005a).

The erosive forces generated by this altered hydrology can lead to channel incision and bank erosion, elevating fine sediment levels and resulting in increased water turbidity and smothering of streambed habitats. Stormwater flushes can also significantly increase water temperatures, and discharge nutrients and a wide range of contaminants to streams (Walsh et al., 2005a). The desire to convey stormwater as efficiently as possible without causing erosion or flooding of adjacent land has led to the piping or

reconfiguration of many stream channels, and the reinforcing of stream banks and beds. In addition, stream channels are often cleared of aquatic pants and wood, and vegetation in riparian areas may be sprayed to facilitate the rapid movement of floodwaters downstream. All of these changes alter ecosystem function and influence the composition of biological communities that occur in urban streams which are typically characterised by low diversity, few sensitive species and dominance by tolerant taxa (Meyer et al., 2005).

Recently, interest has accelerated in ecological restoration of urban areas given that cities are where most people interact with native biodiversity most often, although to date restoration work has focused mostly on terrestrial habitats. The rehabilitation and rejuvenation of urban streams can be problematic because of the over-riding influence of stormwater on stream ecology. Work carried out both overseas and in New Zealand has indicated that upstream catchment impervious area as low as 10% can substantially compromise the capacity of urban streams to support healthy aquatic macroinvertebrate communities (Walsh, 2004). Many of the adverse effects of catchment imperviousness can be circumvented by improved drainage design whereby the proportion of impervious area directly connected to streams by stormwater pipes is reduced through the use of low-impact urban design technologies that maximise runoff detention, off-channel retention and infiltration (Taylor et al., 2004; Walsh, 2004; Walsh et al., 2005b). Although these technologies can generally be implemented with relative ease in green-fields developments, there are obvious difficulties and costs associated with retrospectively disconnecting existing stormwater systems from the natural drainage network to reduce effective impervious area.

It has been proposed that restoration of streams in urban catchments should start with attention to the catchment drainage system rather than to instream habitat or riparian quality (Walsh, 2004). However, in Hamilton City some native and threatened species are known to persist in streams with high percentages of upstream imperviousness (Aldridge & Hicks, 2006; see below). With momentum underway to restore natural vegetation sequences and species in Hamilton's gullies, as described in Section 2, the opportunity exists to link this restoration to the rehabilitation of certain aquatic ecological values through riparian management in instream habitat enhancement. In this paper we outline the vegetation restoration work underway in Hamilton gully systems. We then review existing knowledge of the invertebrate and fish life in Hamilton's streams, and discuss factors limiting their distribution or enabling their persistence. Finally, we explore whether the desire for hydraulic efficiency can be moderated by the reinstatement of some habitat complexity in urban streams, and we challenge engineers and planners to integrate ecological design concepts for streams into future urban developments.

2 VEGETATION RESTORATION

2.1 HAMILTON'S STREAM AND GULLY SYSTEMS

There are four major gully systems in Hamilton City (Kirikiriroa, Mangakotukutuku, Mangaonua and Waitawhiriwhiri) and numerous minor systems (Figure 1). These gullies are the result of the undermining of a geological formation of sand, silt, peat and gravel known as the Hinuera formation (McCraw, 2000). Around 15,000 years ago, the Waikato River started to cut down through this material creating its present channel and as it deepened, springs were exposed along the riverbanks. As water drained from the surrounding land, the springs undermined banks, in a process known as spring sapping, causing slips and creating a network of streams draining into the Waikato River. This

process was repeated again and again giving rise to erosion and the formation of the steep-sided and intricate network of gullies that now adjoin the river.

Today these gullies occupy around 750 hectares or 8% of the City area and are considered a unique feature of Hamilton (Downs et al., 2000). They accommodate around 120 km of mapped stream, some of which now flows in pipes, along with many other unmapped small streams and seepages. The length of gully streams is much greater that the c. 8 km of Waikato River flowing within the City boundary, highlighting that gully streams have the potential make a major contribution to aquatic biodiversity values in Hamilton. Most streams originate in agricultural catchments on the outskirts of the City, although some such as Bankwood Stream and Gibbons Creek have entirely urbanised catchments. In established urban areas, most impervious land appears to be connected to the stormwater network and much of this is piped directly into streams. Upstream impervious area can range from around 5% for streams with most of their catchment still in rural land, to around 70% in some industrial suburbs (Environment Waikato, unpubl. data).

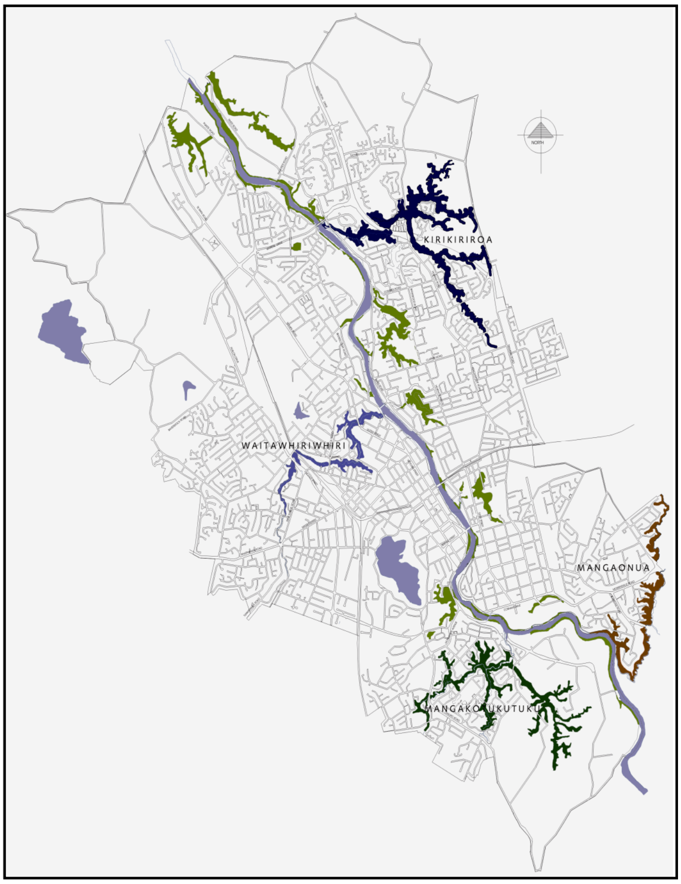


Figure 1. Map showing the four major gully systems in Hamilton City: Kirikiriroa, Mangaonua, Waitawhiriwhiri and Mangakotukutuku. Over 120 km of streams occur in gullies compared to around 8 km of Waikato River within the City boundary. In addition, many unmapped small streams and seepages in gullies can provide important habitat for aquatic invertebrates. From Clarkson and McQueen (2004).

2.2 RESTORATION OPPORTUNITIES

Despite being poorly treated in the past, Hamilton's gullies have now been recognised as the central focus of a city-wide restoration of indigenous ecosystems because they are the main wildlands in an otherwise entirely built landscape (Clarkson & Downs, 2000). Extant vegetation ranges from kanuka (*Kunzea ericoides*) forest on well-drained river and gully scarps, to raupo (*Typha orientalis*) and reedlands fringing peat lakes, with many intermediate types. Gully floor vegetation is frequently dominated by the deciduous exotic tree grey willow (*Salix cinerea*), though beneath this is often an understorey dominated by indigenous plants including ferns, mahoe (*Melicytus ramiflorus*) and cabbage tree (*Cordyline australis*).

Information on the original gully vegetation from historical records, extant remnants and macrofossil deposits has been used to identify a diverse range of native plants appropriate for restoration plantings (Clarkson & Clarkson, 2000; Clarkson & McQueen, 2004). We now know that it is possible to have a good canopy cover of native trees established in a gully setting within 15-20 years. With an increasing appreciation of urban biodiversity, it is being recognised that gully restoration can benefit aquatic life in streams as well as enhancing terrestrial habitats (see Figure 2). In particular, riparian planting can lead to cooler water, and more shaded streams with increased habitat for native fish species (see Section 4). It has also been suggested that improving instream habitat quality can reduce the abundance of some nuisance introduced species such as mosquitofish (Ling, 2004).

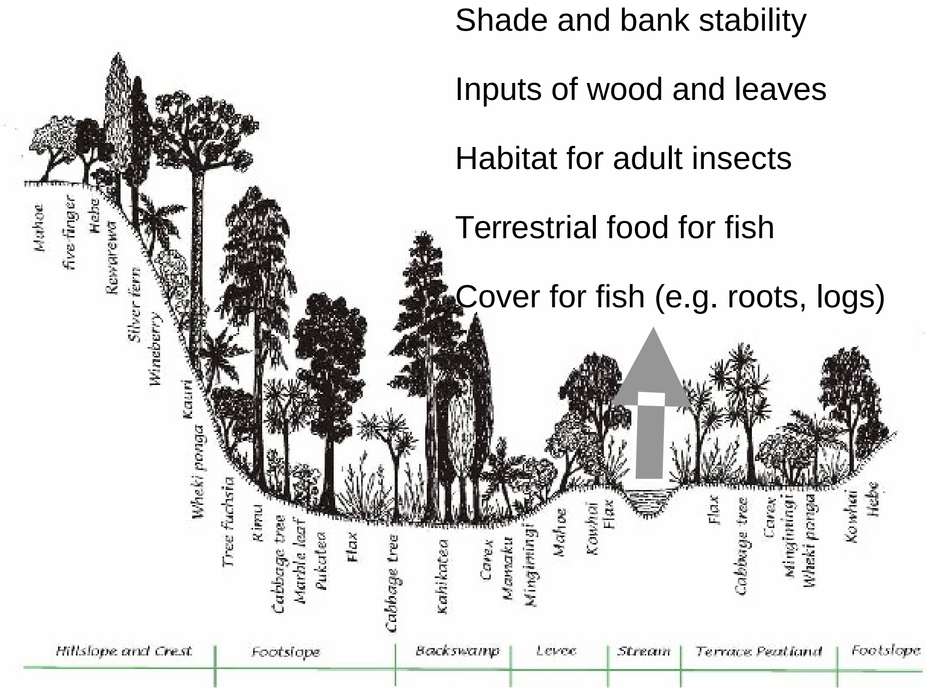


Figure 2. Gully profile with locations of native plant species proposed for vegetation restoration (adapted from Wall & Clarkson, 2001). Riparian planting next to streams can provide a number of benefits for aquatic life (as listed) if stormwater impacts can be mitigated.

3 LIFE IN HAMILTON'S URBAN STREAMS

3.1 MACROINVERTEBRATES

3.1.1 KEY FEATURES OF MACROINVERTEBRATE COMMUNITIES

Aquatic invertebrates include a wide range of insects such as mayflies, caddisflies and dragonflies, along with other groups such as worms, crustaceans such as the freshwater crayfish or koura, beetles, leeches and worms (see Collier & Winterbourn, 2000 for reviews). Insects typically have a larval stage that lives in water, usually for around one year, and a much shorter flying adult stage which emerges from the water and lives amongst riparian vegetation where it mates and then lays eggs back in the stream. The flying adult stage of insects can be an important dispersal stage, potentially enabling it to colonise restored sections of stream in other catchments. However, work in Christchurch urban streams has suggested that road culverts could act as partial barriers to upstream flight of insects, with potential consequences for larval recruitment in restored sections of stream (Blakely et al., 2006). While in the water, most invertebrates are relatively sessile, although they may drift with the water current so that upstream healthy

sections of stream can potentially provide a source of colonists to downstream restoration sites. One species of freshwater crustacean, the shrimp *Paratya curvirostris*, migrates from estuaries into freshwater environments and so needs suitable passage up stream networks to colonise habitats.

3.1.2 STREAM MACROINVERTEBRATE COMMUNITIES IN HAMILTON CITY

Macroinvertebrate communities of the larger streams in Hamilton City are typical of the generally depauperate communities found in urban settings elsewhere, despite the riparian buffering provided by existing gully vegetation. Sampling of 27 Hamilton urban streams sites in 2006 indicated that macroinvertebrate communities were dominated overall by tolerant species such as snails (*Potamopyrgus antipodarum*; 31% of numbers), worms (Oligochaeta; 26%) and midges (Chironomidae; 21%) (Environment Waikato, unpubl. data). Few urban streams around Hamilton appear to support the migratory shrimp despite this species being abundant in the Waikato River, or freshwater crayfish/koura (*Paranephrops planifrons*) which is also rarely encountered in Auckland urban streams (Allibone et al., 2001). Invertebrate diversity in Hamilton urban streams is, on average, similar to that in adjacent periurban/pastoral settings, with about half the total number of taxa found in a nearby native forest stream and little difference among major gully systems (Figure 3).

The number of sensitive mayfly, stonefly and caddisfly (EPT) taxa making up the total species pool was also much lower in urban and pasture-periurban streams than a nearby native forest stream. However, significantly more (Kruskall-Wallis test, $P < 0.05$) sensitive EPT taxa were collected in tributaries of the Mangakotukutuku Stream than other urban gully streams in Hamilton (see Figure 3). In particular, a short section of a Mangakotukutuku Stream tributary draining the Peacockes Rd area and flowing through Sandford Park within the City boundary supported 21 invertebrate taxa including 8 sensitive EPT taxa which comprised 64% of total abundance, comparable to 82% in a native forest stream (Environment Waikato, unpubl. data). This section of stream has sufficient gradient to maintain a largely cobble-gravel substrate and currently has only c. 6% impervious area upstream, although there are longer term plans for the urbanisation of this catchment. A stream care group has recently been formed to actively promote the values of this stream, and to protect and enhance existing ecological values in the catchment (see www.streamcare.org.nz; see also Photograph 1).

The general dominance of urban stream macroinvertebrate communities by tolerant species is thought to reflect in part the physicochemical and hydrological constraints imposed by stormwater flowing off impervious surfaces. As found elsewhere, marked effects on sensitive species of macroinvertebrates become evident when upstream impervious area exceeds around 10% (Figure 4). Inputs of iron-rich water also occur in some streams, often where drainage works or channel downcutting appear to have intersected iron pans and/or iron-rich groundwaters which precipitate iron on reoxygenation. Iron flocs in streams are known to limit invertebrate communities (Wellnitz et al., 1994). As noted above and shown in Figure 3, macroinvertebrate communities in pastoral streams outside the city upstream can also be depauperate, suggesting that upstream land use may also influence the composition of communities occurring in downstream urban settings. Historical legacies such as drainage from old landfills may also play a role in limiting the biological potential of streams in some parts of the City.

3.1.3 IMPORTANCE OF SMALL STREAMS AND SEEPAGES

Although invertebrate communities in the larger streams generally seem to be constrained by stormwater impacts and associated habitat changes, recent work has highlighted that seepages and small streams not highly connected to the stormwater

network can retain high aquatic insect biodiversity values. Light-trapping of adult mayflies and caddisflies in tributaries and seepages alongside the three largest streams in Hamilton City revealed the presence of at least 26 species, comprising 8 families and 16 genera, yielding a total of 31 caddisfly species when these records were combined with other trapping data from the Mangakotukutuku catchment (Smith, 2007). These caddisflies include species normally associated with native forest settings (e.g., *Orthopsyche thomasi*), and the discovery of a species new to science, *Oxyethira kirikiriroa* whose larvae apparently inhabit seepages (Smith, 2008). Based on knowledge of larval habitat requirements, seepages appeared to contribute around 30% of the overall caddisfly and mayfly diversity found in Hamilton City. In addition, seepages also provide habitat for immature stages of the iconic Giant Bush Dragonfly (*Uropetala carovei*). These findings underscore the importance of protecting and enhancing small streams and seepages in urban environments, and maintaining their disconnection from stormwater. These ecosystems are particularly important for invertebrate biodiversity which does not appear to be as resilient to the effects of high impervious connection as some native fish species (see below).

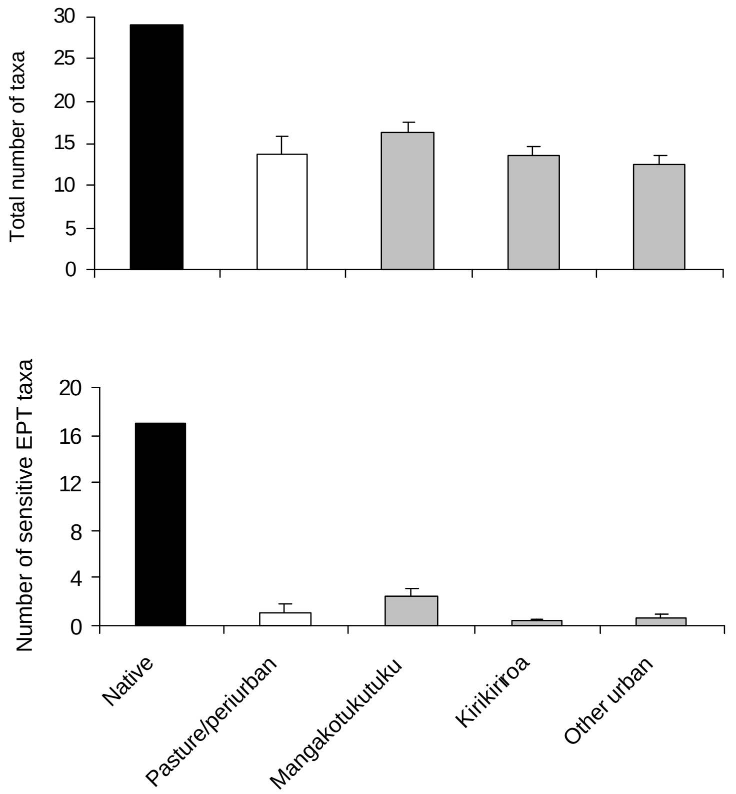


Figure 3. Mean number (+1 standard error where applicable) of total macroinvertebrate taxa (upper graph) and the number of sensitive mayfly, stonefly and caddisfly (EPT) taxa (lower graph) found in a native forest stream close to Hamilton City (n = 1), pasture and periurban sites on the outskirts of the City (n = 8), and urban sites on Mangakotukutuku Stream (n = 11), Kirikiriroa Stream (n = 6) and other gully streams (n = 8). Streams were sampled in summer 2006 using standard collection protocols and processed using 200+ counts and a search for rare taxa (Collier & Kelly, 2005).

3.2 FISH

3.2.1 KEY FEATURES OF FISH COMMUNITIES

New Zealand has about 36 species of freshwater fish, about half of which migrate to and from the sea to complete their life cycles. The importance of unimpeded access up and down rivers in structuring freshwater fish communities is demonstrated by the reduction in species diversity and fish density with distance from the coast (Jowett & Richardson, 1996; McDowall, 1993). Lowland fish communities are dominated by inanga (*Galaxias maculatus*), bullies (*Gobiomorphus* spp.), smelt (*Retropinna retropinna*), torrentfish (*Cheimarrichthys fosteri*), and shortfin eels (*Anguilla australis*). Inland fish communities are characterised by species with better climbing abilities such as longfin eels (*Anguilla dieffenbachii)* and koaro (*Galaxias brevipinnis*), and by non-migratory bullies and galaxiids. Some migratory galaxiids and longfin eels are able to climb vertical wet

surfaces of considerable height, enabling them to penetrate to sites that are inaccessible to smelt and inanga. Dams and poorly-designed road culverts restrict upstream passage of migrating juveniles, especially galaxiids and bullies. Spawning habitats are varied, ranging from large submerged substrates for most bullies, around stream edges and riparian vegetation for several galaxiids, and far out to sea for eels.

Land use is another key factor influencing fish community composition in streams. Land clearance increases fine sediment, diel water temperature fluctuations, periphyton productivity, and peak storm flows, all of which act alone or in combination to reduce habitat suitability for native species, especially forest stream dwellers such as banded kokopu (*Galaxias fasciatus*) (Hicks & McCaughan, 1997; Rowe et al., 1999). Paradoxically, fish biomass is usually greater in unshaded streams than shaded forest streams because of the predominance of shortfin eels in more open environments. Some native species, such as the giant kokopu (*Galaxias argenteus*), frequent streams draining wetlands, and appear to be able to tolerate the high acidity and strongly humic nature of these environments as long as suitable physical habitat and cover are available. Most native freshwater fish are opportunistically carnivorous, and several galaxid species can acquire significant proportions of their nutrition from terrestrial insects that fall into streams (e.g., Hicks, 1997). This feeding strategy can enable them to survive in environments with depauperate stream invertebrate communities where there is overhanging vegetation to deliver terrestrial insects to the stream.

Introduced fish have been released into many freshwater locations, and are more abundant and diverse in lowland habitats. European perch (*Perca fluviatilis*), rudd (*Scardinius erythrophthalmus*), brown bullhead catfish (*Amieurus nebulosus*), goldfish (*Carassius auratus*), mosquitofish (*Gambusia affinis*) and koi carp (*Cyprinus carpio*) are widespread in various regions. Koi carp can degrade instream habitats by feeding on aquatic plants and sediment, an activity that can lead to accelerated erosion of unconsolidated banks. Mosquitofish is the most widespread exotic species in urban environments, and has been reported to attack native species although its impacts on aquatic invertebrates may be more significant (Ling, 2004). Catfish have been reported to out-compete native species and salmonids, notably brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*), which have spread widely by management agencies and self-introduction via sea routes. In many instances, they overlap in distribution with native fish and have the potential to cause community changes and local extinctions (McIntosh et al., 1992; Townsend & Crowl, 1991). This is particularly noticeable in southern areas of New Zealand, but appears much less pronounced in northern areas (e.g., Hicks, 2003), where mostly diadromous native species thrive in streams also occupied by brown and rainbow trout. In such northern streams, brown trout are close to their natural upper thermal tolerance for spawning and rearing (Scott & Poynter, 1991).

3.2.2 FISH IN HAMILTON STREAMS

A total of eight species of native fish was caught in and around Hamilton City by Aldridge and Hicks (2006). These comprised both species of eel, the galaxiids banded kokopu, giant kokopu and inanga, smelt, common bully (*Gobiomorphus cotidianus*), and torrentfish (*Cheimarrichthys fosteri*) which only occurs in fast-flowing, stony sections of stream. There are also historical reports of mudfish (*Neochanna* sp.) being found within the current City boundary. Of the native species caught by Aldridge and Hicks (2006), longfin eel and giant kokopu (along with the freshwater koura) are considered threatened species by the Department of Conservation, with populations being in gradual decline (www.doc.govt.nz). The introduced koi carp, catfish, mosquitofish and trout were also caught in Hamilton urban streams, although only mosquitofish was widespread occurring at over a quarter of the sites sampled (Figure 5). This species

along with shortfin eel (61% of sites) and longfin eel (34%) were the most widespread species collected. Smelt, banded kokopu and giant kokopu were found at five or more sites within the City (Figure 5).

In contrast to macroinvertebrate communities, no relationship between the number of native fish found and upstream impervious area was evident for a limited set of Hamilton urban streams sampled by spotlighting, trap-netting and electric fishing (Figure 4). In fact, some native fish species appeared able to persist in streams with highly urbanised catchments, including both species of eels, banded kokopu, and the threatened giant kokopu which is listed by the Department of Conservation as in gradual decline (Hitchmough et al., 2007). The latter species is often found associated with overhanging riparian vegetation and in-stream cover such as that provided by accumulations of wood and undercut banks (Bonnett et al., 2002; Baker & Smith, 2007). Banded kokopu is also found in small streams with abundant cover (Rowe & Smith, 2003). A habitat quality score that integrates nine riparian, bank and channel attributes (Collier & Kelly, 2005) explained 59% of the variance in native fish community diversity across seven streams in and around Hamilton City. These findings suggest that some native fish, including threatened species, can persist in urban streams where there is sufficient physical structure, presumably to provide refuge from stormwater runoff. The ability of some species to survive in urban streams may also be partly related to an apparently broad tolerance of chemical conditions reflecting their ability to live in the acidic, peatland environments that originally surrounded Hamilton.

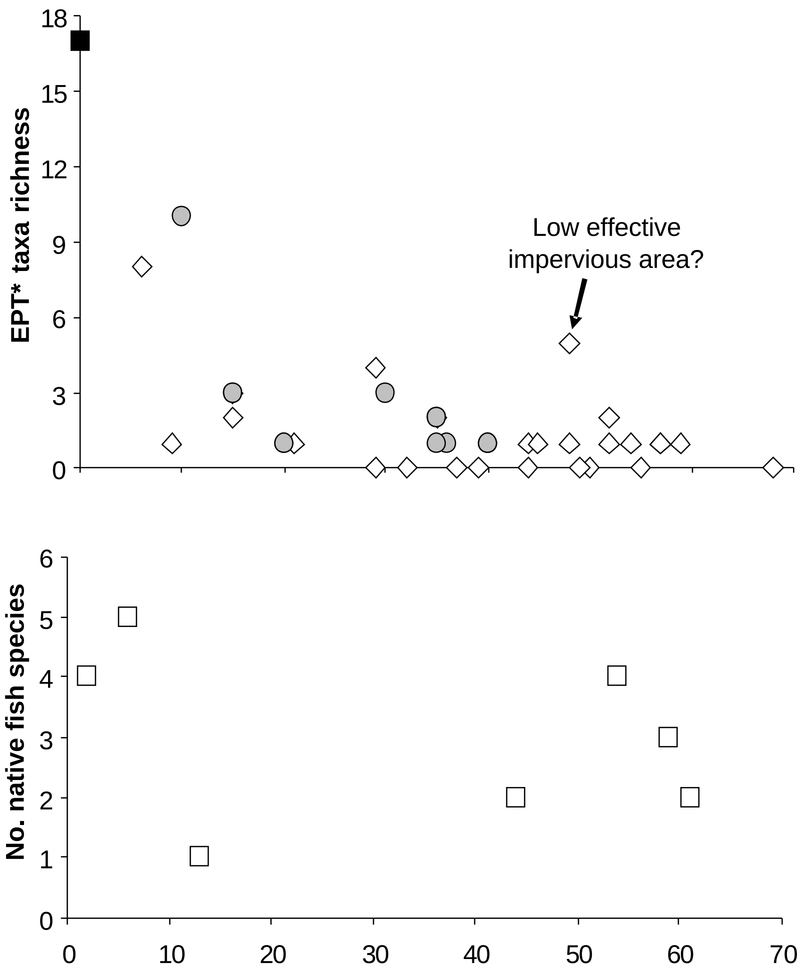


Figure 4. Relationship between upstream imperviousness and the diversity of sensitive invertebrates (EPT; upper panel) and native fish (lower panel). For the invertebrate graph, the solid square represents a native forest stream close to Hamilton; the open diamonds represent Hamilton urban and pasture/periurban streams sampled on 2006, and the grey circles represent data from Auckland urban streams sampled by Allibone et al. (2001). Richness of sensitive species declines rapidly with increasing impervious area, but several fish species appear able to tolerate high catchment imperviousness. Low effective imperviousness may enable some sensitive invertebrate species to survive in highly urbanised streams.

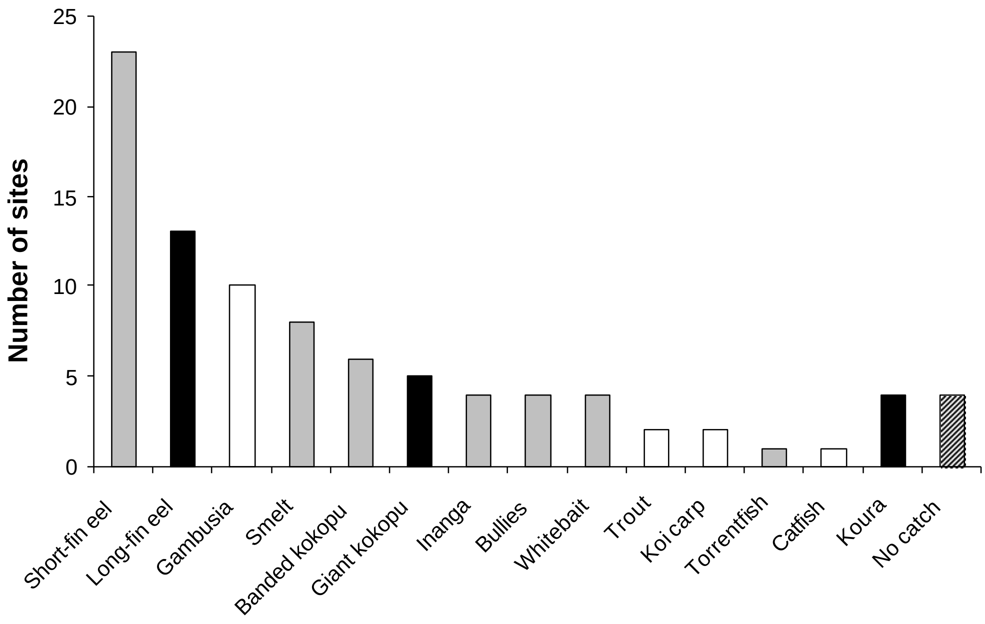


Figure 5. Number of sites that different fish species and freshwater crayfish (koura) were caught at during a survey of 41 Hamilton stream sites by Aldridge and Hicks (2006). Filled bars indicate native species with threatened species shown in black; open bars indicate introduced species. Whitebait comprise unidentified juvenile galaxiids. Striped bar indicates number of sites sampled where no fish were caught.

4 RESTORATION OF URBAN STREAMS

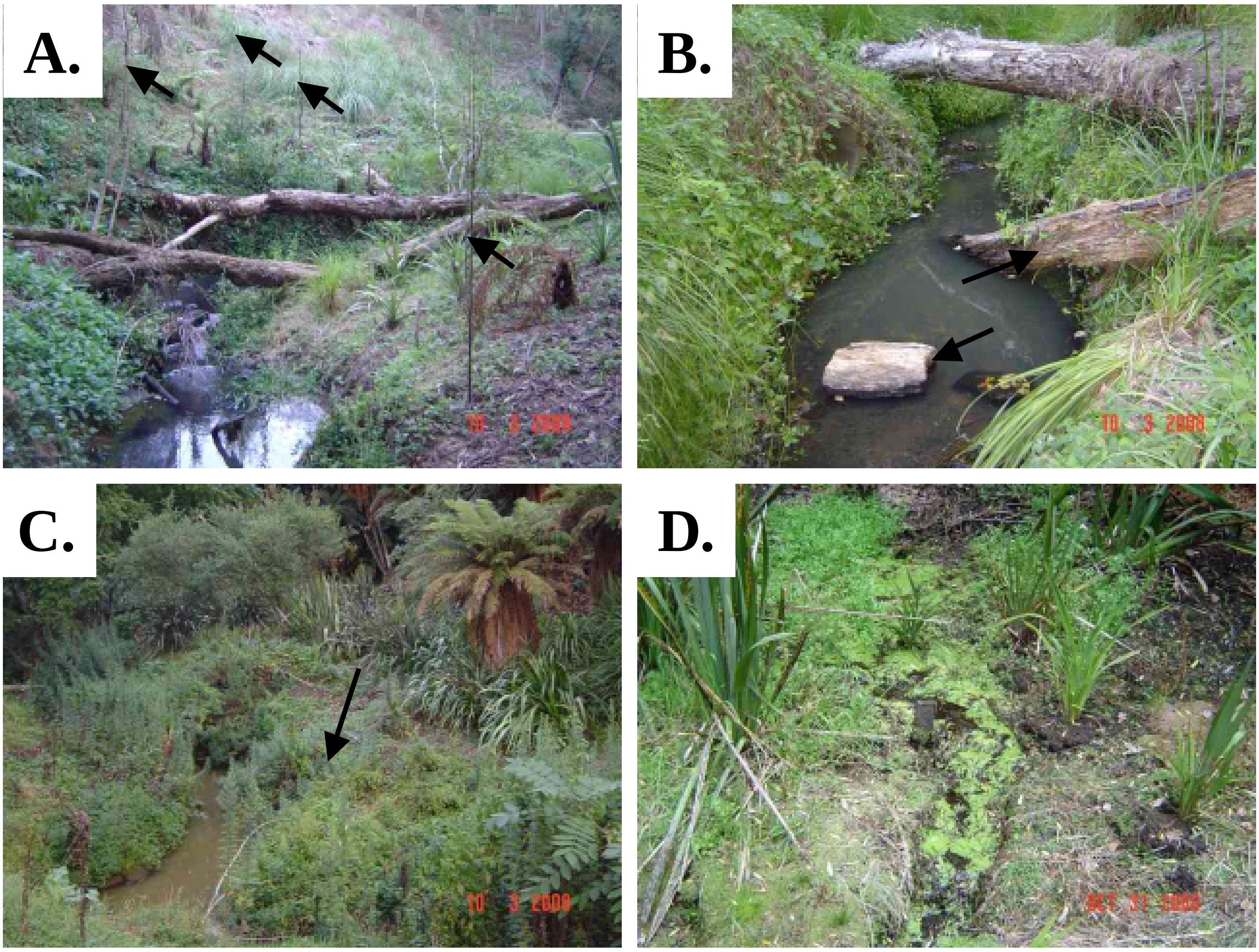
4.1 RESTORATION GOALS

Restoration goals for urban streams may be different for macroinvertebrate communities and native fish because of the apparently different susceptibility to stormwater inputs. In addition, the traditional gully restoration goal of recreating natural vegetation sequences may need to be reassessed at sites where the focus is on recreating instream habitat for aquatic life. This is because the combination of plant species providing greatest instream benefit may not necessarily be the same as the one that naturally occurred at a particular site, or a different planting configuration from that normally expected may be required to optimise instream benefit. For example, ribbonwood (*Plagianthus regis*) has been planted at regular intervals along a high value tributary of Mangakotukutuku Stream in an attempt to future-proof the banks from erosion that may potentially eventuate following urban development planned upstream (Photograph 1A).

4.1.1 MACROINVERTEBRATE COMMUNITIES

Invertebrates appear to be constrained by effects associated with upstream impervious area, and restoration of aquatic habitat structure is unlikely to yield significant benefit unless stormwater drainage connection can be addressed. For larger streams with current low levels of upstream imperviousness and reasonably healthy invertebrate faunas that are not otherwise constrained by upstream landuse, such as the tributary of Mangakotukutuku Stream shown in Photographs 1A and B, the focus should be on maintaining or enhancing existing high values as such sites are rare in urban settings. Green-fields development of such catchments will need to integrate sustainable urban design practices that involve stormwater detention, retention and infiltration (e.g., swales, soakage pits, rain-gardens and pervious pavers) if these values are to be maintained. Elsewhere, restoration measures for macroinvertebrate communities are

more likely to bear fruit if focused on small streams and seepages that have low existing connectivity with the stormwater network. Recent data clearly demonstrate that sensitive, uncommon, iconic and even new species currently live in these habitats in Hamilton's gullies. These species provide a pool of aerial recolonists that is available to colonise sites where habitats are reinstated (e.g. by restoring seepage hydrology) or enhanced (e.g., through riparian planting of small streams).



Photograph 1. Examples of riparian management and the role of wood in Mangakotukutuku Stream. In A, arrows indicate Plagianthus regis *saplings planted to provide bank stability to future-proof the banks from planned urban development upstream. This species is not part of the natural sequence of gully vegetation originally considered present on river terraces. Photograph B shows examples of large pieces of wood creating habitat, in this case a pool. In C, banks have been left uncleared of weeds and native panting has been undertaken around existing exotic trees that provide a bank stability function until native riparian trees become established. Photograph D shows a small seepage, typical of those that can provide important habitat for aquatic invertebrates.*

4.1.2 NATIVE FISH

It may be difficult to restore the natural structure of native fish communities at urban sites because of the varied combination of factors that can limit the distribution and abundance of the range species that once occurred in gully streams. Rather, a more attainable goal may be to increase the distribution of iconic native species by identifying specific aspects of their habitat and biology that constrain populations and can be enhanced. It is accepted that organisms survive disturbances, such as the harsh hydrological conditions caused by stormwater inflows, by sheltering in refugia which can

be lost through anthropogenic degradation (Lake et al., 2007). The apparent ability of some fish species, notably the threatened longfin eel and giant kokopu, to survive in Hamilton streams despite an apparently harsh physicochemical environment underscores the potential for habitat enhancement to increase their abundance and distribution where other factors such as downstream passage are not limiting. To achieve this, restoration goals involving the re-establishment of native vegetation may differ from the traditional gully restoration goal of recreating natural vegetation sequences, because it would involve planting riparian species that would maximise instream cover and habitat structure. By doing this, perhaps Hamilton City could be promoted as "The giant kokopu capital of New Zealand".

Some juvenile galaxiids respond positively to certain concentrations of adult pheromones released into the water by established populations (Baker & Hicks, 2001). These pheromones may serve to attract juvenile fish to suitable adult habitat, suggesting the existing presence of adults may be important for attracting recruits. Recent work in Hamilton urban streams has highlighted the potential for actively introducing naïve farm-reared giant kokopu into sites where natural recruitment may be limited (Aldridge, 2008). These farm-reared giant kokopu grew rapidly (up to 0.11 g per day) in urban streams, and some remained at release sites for up to 11 months (Aldridge, 2008). Where populations have been extirpated, active reintroductions of fish to physically suitable sites may be needed to ensure new recruits are attracted to restored sites so that the long-term sustainability of populations can be maintained.

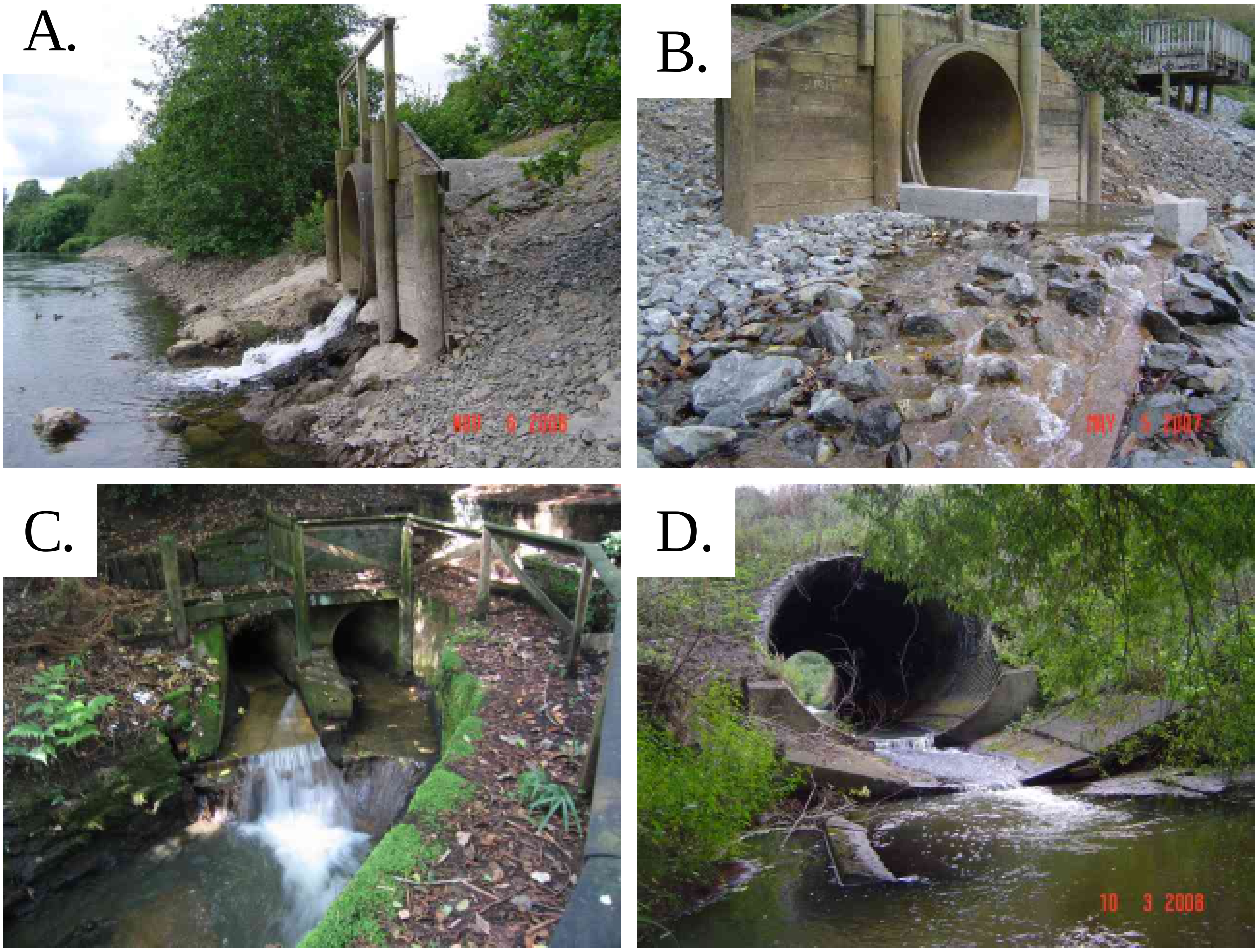
4.2 RESTORING CONNECTIVITY

Connectivity along stream networks and between catchments is important for facilitating recolonisation following habitat restoration and for allowing migratory species to complete their life cycles. For aquatic insects, recolonisation routes may be via drift from upstream sources in higher quality habitats within or outside the City boundary, or along riparian corridors and across catchments by aerial adults surviving in seepages, small streams disconnected from the stormwater network, and larger streams with low upstream impervious area. All these potential sources of colonists exist in places within Hamilton City suggesting that connectivity is unlikely to be a significant factor constraining invertebrates, as it is thought to do in Christchurch City for example (Suren & McMurtrie 2005). Migratory freshwater shrimp appear generally absent from most Hamilton urban streams, even those with no passage restrictions, suggesting factors other than connectivity are constraining the distribution of that species.

An assessment of the severity of passage impedance to upstream migrating fish at 45 culverts in Hamilton City indicated that 42% were likely to prevent upstream passage of native fish at most flows or low flows (Aldridge & Hicks, 2006). These results demonstrate that fish passage restrictions can be major modifiers of native fish distribution in urban streams, and these need to be addressed before physical habitat restoration to ensure the long-term sustainability of migratory populations. Work has been recently completed on a fish pass to facilitate passage of native migratory species from the Waikato River into Bankwood Stream (Photographs 2A and B), although a road culvert a short distance upstream (Photograph 2C) still prevents fish access to most of the catchment. This situation underscores the importance of a catchment-wide perspective when restoring access for fish. Key constraints within catchments need to be identified and remediated over a short timeframe to maximise the ecological return from such expenditure.

An important factor to consider when undertaking such work is the potential risk of increasing the distribution of troublesome exotic species such as koi carp and catfish by enhancing access through culverts. An example of this occurs on the Mangakotukutuku

Stream at Peacockes Rd (Photograph 2D) where the culvert enables at least some individuals of several native species to penetrate upstream while keeping koi carp downstream of the road. To maintain this situation and enhance passage for native fish, a local stream care group recently acquired permits to trap migrating whitebait, which congregate below the culvert, and transfer them upstream of the road. Remediation of culverts in urban areas needs to consider how to enhance the passage of native fish while at the same time preventing the spread of introduced fish.



Photograph 2. Examples of culverts on Hamilton urban streams. The two upper photographs show the exit of Bankwood Stream into the Waikato River (A) prior to remediation and (B) following the construction of a fish pass that provides a ramp to the start of the culvert and a resting pool for migrating fish. Another culvert a short distance upstream (C) prevents access to the rest of the catchment. Photograph D shows the culvert under Peacockes Rd on Mangakotukutuku Stream; this culvert, although not ideal for native fish, does allow several species to access upstream habitat while at the same time preventing pest fish such as koi carp moving upstream.

4.3 LINKING VEGETATION MANAGMENT WITH STREAM RESTORATION

4.3.1 RIPARIAN MANAGEMENT

As shown in Figure 2, riparian vegetation can provide a number of benefits to aquatic biota, with particular plant species better able to provide certain benefits than other species. Riparian trees can be used to enhance stream bank stability where rooting depth exceeds bank height (Abernethy & Rutherfurd, 2001). However, where bank height exceeds tree rooting depth, undercutting and treefall may occur leading to localised areas of instability. As a consequence of their shallow-rooted habit, many of

New Zealand's indigenous plants have limited effectiveness where channel hydraulic conditions lead to undercut stream banks with very steep and unstable slopes exceeding ~2 m height (Marden et al., 2005). The effectiveness of riparian restoration programmes using indigenous species, though potentially high for low-order stream, may be therefore be limited for bank stabilisation purposes on larger urban streams without the prior installation of other protection works. However, planting trees along larger urban streams will have other benefits such as providing shade (Davies-Colley & Quinn, 1998).

It has been suggested that riparian planting along pasture streams may shade out grasses that stabilise deposited sediments, leading to channel widening as the stream resumes a shaded channel morphology (Davies-Colley, 1997; Collier et al., 2001). It is not clear to what extent this process occurs following periurban development, but it seems likely that the altered hydrology due to stormwater runoff would modify this process. However, it should also be recognised that low levels of erosion can lead to stable bank overhangs or increased habitat heterogeneity, for example amongst tree roots, and may in fact enhance habitat for instream life. Erosion is a natural process and has been the driving force behind gully formation; a small amount occurring where property or infrastructure are not threatened might be beneficial.

Practical experience in planting gully stream banks in Hamilton, with a view maintaining bank stability, indicates that it is beneficial to make the most of what is already there and underplant and/or manipulate rather than remove exotic trees that are performing bank stabilisation functions. Over the longer term, as native bankside plantings grow, existing exotic species can be removed to enable native forest succession. Also, planting amongst weeds such as *Tradescantia* and Inkweed (*Phytolacca octandra*) along the edges of banks may reduce the risk of bank failure following vegetation clearance because these weeds can reduce the erosive forces of floods and facilitate the deposition of sediment entrained in floodwaters (see Photograph 1C). The longer term goal would be to replace these with native groundcover species as riparian plantings become established. Roughness elements in the form of rigid riparian plant stems that reduce water velocities during floods can also reduce hydraulic stress on instream biota. This process may lead to lower but extended flood peaks and increase the duration of any localised flooding. Often bankside vegetation is sprayed to facilitate the rapid movement of flood flows. However, in situations where the risk to property and life is low, and potential restored value is high, the inconvenience of extended periods of floodplain innundation needs to be weighed against the potential benefits for aquatic life. Flooding, like erosion, is a natural process and some may in fact benefit instream life. For example, eels are known to follow rising water levels during floods, allowing them to use inundated areas as supplementary feeding habitat (Jowett & Richardson, 1994).

4.3.2 CREATING INSTREAM STRUCTURE

The risk of causing channel blockages and flooding has led to the regular removal of "debris" such as wood falling into urban streams. However, the role of large pieces of wood is being increasingly recognised in creating more diverse instream habitats (see Photograph 1B), 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). However, natural inputs of large wood to New Zealand forest streams may not occur for centuries based on known longevities of native canopy tree species (Mealson & Hall, 2005), and even where vegetation is restored using rapidly growing native tree species it may be many decades before wood is naturally recruited to stream channels. The timescales involved suggest that active introduction of wood to stream channels will be required if it is to be used as a tool for restoring instream habitat structure.

Recent work investigating the effect of habitat enhancement structures on fish in Hamilton urban streams has suggested faster growth rates of introduced giant kokopu juveniles in sections of stream supplemented with logs, potentially reflecting increased food supply on organic matter accumulations (Aldridge, 2008). However, fish densities did not appear to be influenced by habitat enhancement using wood or clay pipes, compared to unmodified control sections of stream. Rather initial habitat selection seemed to influence juvenile giant kokopu distribution, suggesting that habitat should be established first and allowed to stabilise in advance of any fish introductions (Aldridge, 2008). Moreover, larger streams may require larger logs to be effective and they may need to be secured to edges rather than in the channel to create suitable habitat, as suggested by Bonnett et al. (2002).

5 CONCLUSIONS AND RECOMMENDATIONS

Several workers have concluded that re-establishing riparian forests alongside urban streams would provide minimal benefits for fish assemblages at sites impaired by high sediment levels and hydrological alteration (Roy et al., 2006). While we agree that urban stream restoration should be integrated with broader catchment management strategies that simultaneously address hydrologic, sediment, and riparian disturbance (Bernhardt & Palmer, 2007), as well as impediments to migration, we also recognise that disconnecting existing stormwater networks from waterways is not practical in most established urban settings. In Hamilton City, the potential for rejuvenation of macroinvertebrate communities appears to be constrained at highly developed sites, as has been found elsewhere due to high heavy metal concentrations in sediments, hydrological factors associated with stormwater inputs, and possibly the presence of barriers to aerial recolonisation by adult insects (Suren & McMurtrie, 2005; Blakely & Harding, 2005). In this situation, priority should be given to the protection and enhancement of sites with existing or potential high ecological value, in particular seepages and small streams with low levels of stormwater connection. Green-fields developments should integrate stormwater design measures that promote retention, detention and infiltration of runoff to protect sensitive stream environments.

Restoration goals for fish in streams draining highly urbanised catchments may stand more chance of success if focused on certain species and key constraints to long-term population viability. Recent work demonstrating that some threatened fish species can persist in highly urbanised streams indicates that there is high potential to enhance their distribution and abundance within the City limits. 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 species conservation. Actions required to achieve this include an integrated catchment approach to resolving passage issues, and planting of riparian areas with tree species that provide overhanging vegetation, bank stability and over the longer term inputs of wood to streams. Natural wood recruitment to streams may take many decades to achieve, so in the interim the potential exists to actively put wood back into streams to enhance cover and habitat heterogeneity for native fish species. Recent work has also highlighted the potential to introduce farm-reared juvenile galaxiids to urban streams to speed-up natural recolonisation processes. Streams in green-fields developments provide opportunities to maintain conditions suitable for a wider range of species and achieve a more natural fish community structure, as habitat and stormwater issues can be addressed at the planning stage.

Finally, we address the question, "Can the enthusiasm for hydraulic efficiency be tempered by the ecological benefits obtained from stream habitat enhancement?" Are there such things as "good debris", "good erosion", and "good flooding" in urban stream

environments? We suggest there are. As noted above, wood, often viewed as debris that must be removed, can play an important ecological function by helping to create fish habitat and refugia from the hydrological impacts of stormwater inputs. Managed placement of logs should enable the dual goals of enhanced habitat and water conveyance to be achieved. Small amounts of erosion may not be a problem where property and infrastructure are not at risk, and could possibly enhance habitat for native fish by creating cover among tree roots and under stable bank overhangs. Larger scale erosion, however, needs to be addressed to control sediment inputs and, along larger streams at least, may require a combination of riparian planting and soft engineering. Detaining flood flows by using riparian vegetation and wood as roughness elements may help reduce the erosive forces of high stormwater flows. This could also extend periods of localised floodplain innundation which may prove beneficial for some fish in private gullies and reserves if safety and property are not at risk. Acceptance of these concepts will require a fundamental shift in approaches to stormwater design and maintenance, and their implementation will benefit from greater communication between City planners, engineers, maintenance workers and ecologists.

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