Aquatic macroinvertebrates in urban waterways: comparing ecosystem health in natural reference and urban streams

Ian A.Wright[2], Peter Davies[1], David Wilks[1], Sophia Findlay[1,3] and Mark P. Taylor[3]

1 Open Space Department, Ku-ring-gai Council, Locked Bag 1056, Pymble, 2073. Email: pdavies@kmc.nsw.gov.au, dwilks@kmc.nsw.gov.au, and sfindlay@kmc.nsw.gov.au
2 University of Western Sydney, Locked Bag 1797, South Penrith DC, 1797. Email: iwright@uws.edu.au
3 Macquarie University, North Ryde, 2109. Email: mtaylor@els.mq.edu.au

Abstract

A macroinvertebrate survey and water chemistry study of small coastal upland streams was conducted in the Ku-ring-gai Council area in the northern suburbs of Sydney. The purpose of this six year investigation was to provide information on the ecological condition of its waterways. The study revealed that all streams draining urbanised catchments exhibited clear signs of ecological impairment, in contrast to local reference sites. The macroinvertebrate survey reported lower SIGNAL scores and fewer pollution sensitive Ephemeroptera, Plecoptera and Trichoptera in the urban streams when compared against naturally vegetated non-urban streams. Further, the urban waterways revealed different water chemistry than the reference sites that were soft, dilute and acidic.

Keywords

EPT taxa, SIGNAL index, urban stream syndrome

Introduction

Macroinvertebrates are widely regarded as one of the best biological indicators for assessing the effects of water pollution on rivers and streams (Hellawell, 1986; Rosenberg & Resh, 1993; Turak & Waddell, 2001). Several Australian studies have used them to assess the impact of urban landuse on waterways (Campbell, 1978; Arthington *et al.*, 1982; Chessman & Williams, 1999; Walsh *et al*., 2001). The degradation of urban waterways involves symptoms such as the loss of sensitive macroinvertebrates, invasion of pest species, deterioration of water quality, modification of flow regimes and reduction in habitat values. This has been referred to as 'the Urban Stream Syndrome' by Meyer *et al.* (2005).

Ku-ring-gai Council (Council) is responsible for managing the urban waterways within its local government area (LGA). It embarked on the macroinvertebrate monitoring program in 1998 to assess the relative level of ecosystem health and determine if the waterways health is changing. This research has since been used to inform other scientific studies commissioned by Council to map the condition of its urban streams (Findlay *et al.*, 2005; Taylor *et al.*, 2005), develop specific development control policies (Ku-ring-gai Council, 2004) and more recently an investigation into the use of terrestrial macroinvertebrates to assess broader ecosystem health (Ives, 2005).

This paper investigates the findings of a survey of freshwater macroinvertebrates and water chemistry attributes in urban waterways compared to local reference streams. The aim is to report a baseline data set for reference streams for the northern suburbs of Sydney and compare this against streams impacted by urban development.

Methods

Conducting waterway impact studies within the Ku-ring-gai local government area (LGA) is very difficult as the impacts of human activity have been gradually intensifying over nearly 200 years. It is practically impossible to conduct before/after control/impact (BACI) studies (e.g. Underwood, 1991) that would enable the progressive assessment of a natural catchment before, during and after it is subject to urban development. Comparison with multiple reference sites (Fairweather, 1990) is one of the few practical alternatives available to detect ecological effects of urban landuses on waterways and was chosen for this study.

Macroinvertebrate and water samples were collected in the northern suburbs of the Sydney metropolitan area of NSW from 1998 to 2004. The study area was predominantly located in the Ku-ring-gai LGA. The urban waterway sites are located within either the Middle Harbour (Moores Creek, Gordon Creek and Rocky Creek) or Lane Cove River (Coups Creek, Avondale Creek, Quarry Creek, Blackbutt Creek and Little Blue Gum Creek) catchments. Only one reference sites was located in the Ku-ring-gai LGA, an unnamed tributary of Kierans Creek, with the others located within nearby National Parks to the east (Deep Creek and McCarrs Creek) and north-west (Little Cattai Creek).

All sites are located on coastal incised sandstone streams, under 200 m Australian Height Datum (AHD), and resemble small montane upland streams with frequent pool and riffle sections. Channels are rocky bottomed, sometimes bedrock, frequently combined with boulders and cobbles. Sand, silt and gravel was present in most habitats, particularly the urban waterways, which often had 'sediment slugs' dominating many stream habitats. All streams are small (1-3 m wide) and shallow (0.1-2 m deep) and generally have permanent flow, except during prolonged periods of drought. The majority of waterways have natural channels with well vegetated riparian zones, although weed invasion of the urban riparian zones has become a major environmental problem in the LGA (Lake & Leishman, 2004).

Macroinvertebrate samples were collected in accordance with the National River Health Program protocols (Anon. 1994) and NSW AUSRIVAS (Australian River Assessment) protocols (Turak & Waddell, 2001). Sampling was done using a 'kick' net, with 250-micron mesh, a square 30 x 30 cm net frame (Chessman, 1995; Turak & Waddell, 2001). Samples in 1998 and 2000 were collected from riffle, pool edge and pool rocks habitats and in later years (2001-2004) were collected only from pool edge habitats. Pool edge was selected as it was the only habitat present at every site (Williams & Silva, 1998). Electrical conductivity (EC), pH and alkalinity (ALK) were collected in conjunction with the macroinvertebrate sampling, following the AUSRIVAS protocols (Turak & Waddell, 2001). All sampling was conducted in dry weather conditions at least a week after significant rainfall events.

Richness of Ephemeroptera, Plecoptera and Trichoptera (EPT) families were calculated per site per sampling occasion. Measurement of EPT taxa has been found to be a useful method for detecting impacts from pollution as these three orders are often the most pollution-sensitive macroinvertebrate guilds (Lydy *et al.*, 2000; Camargo *et al.*, 2004). The macroinvertebrate results were also expressed as values of the SIGNAL biotic index (Chessman, 1995; Chessman *et al.*, 1997). Student's *t*-test was used to determine if mean macroinvertebrate (SIGNAL biotic index scores and EPT richness) or water chemistry results (pH, EC, ALK) varied significantly according to the site classification as reference site (pooled) or urban site (pooled). SIGNAL data is also compared to the Catchment Imperviousness (CI) determined for each sample site. This comparison has been completed as the importance of CI to stress of aquatic ecosystems has been established by several authors (see Walsh *et al.*, 2004). The CI data for each catchment was determined by applying representative values for land use imperviousness to council land use information (Findlay, 2006). The CI was only calculated for sites within Ku-ring-gai Council, and as such only one reference site (tributary of Kierans Creek) is represented. The CI for each site is shown in Table 1.

Table 1. Figures for catchment imperviousness within the Ku-ring-gai LGA (from Findlay, 2006).

SITE	CATCHMENT IMPERVIOUSNESS %
Trib. of Kierans Creek	6.12
Coups Creek	35.92
Quarry Creek	44.46
Gordon Creek	42.84
Moores Creek	35.82
Rocky Creek	44.17
Little Blue Gum Creek	42.51
Avondale Creek	43.58
Blackbutt Creek	42.75

Macroinvertebrate results

A total of 16 EPT taxa were recorded of which 14 were recorded at three or more sites. Macroinvertebrate EPT richness (Figure 1a) varied highly significantly between reference and urban sites (df = 99, t = 19, P <0.0001). The average number of EPT taxa at reference sites ranged from 3 to 6 taxa and an average of 0 to 2 were recorded from the urban sites (Figure 1a). Macroinvertebrate SIGNAL scores (Figure 1b) varied highly significantly between reference and urban sites (df = 64, t = -95, P <0.0001). The SIGNAL score recorded at reference sites ranged from 6 to 7 and from 4 to 5 at the urban sites (Figure 1b). Comparison of SIGNAL score and CI demonstrated a strong relationship (n = 9; r2 = 0.9677), despite the small number of sites analysed. As shown by Figure 1c, there is an absence of sites characterised by 7-35% CI. However, it does demonstrate the disparity in condition according to catchment imperviousness.

Water chemistry results

Water chemistry results indicated that reference sites exhibited distinctly different chemical properties compared to the urban sites. Although pH varied highly significantly between reference and urban sites (df = 45, t = -9.6, P <0.0001), the reference sites were all acidic (mean pH 5.3 – 6.1) and the urban sites were mildly acidic to mildly alkaline (mean pH 6.6 – 7.7, Figure 1c). Electrical conductivity and alkalinity both varied significantly between reference and urban sites (EC: df = 37, t = -5.9 P <0.0001; ALK: df = 31, t = -6.5, P <0.0001) and both were lower at reference sites (Figure 1d and 1e). The properties of urban sites varied. Quarry Creek is labelled as it had extreme levels of electrical conductivity and alkalinity, possibly reflecting former catchment landuses including an incinerator and a small landfill.

Discussion

The results of the macroinvertebrate sampling from 1998 to 2004 assert that urban waterways in the Council LGA have poor ecosystem health as reflected by low numbers of sensitive taxonomic groups (EPT taxa, Figure 1a) and low SIGNAL scores (Figure 1b) in comparison to local, forested reference streams. The results reported in this study are similar to other Australian (Campbell, 1978; Arthington *et al.*, 1982; Chessman & Williams, 1999; Walsh *et al.*, 2001) and worldwide studies (Roy *et al.*, 2003) that have associated urbanisation with degraded waterway ecosystem health, particularly through representation by aquatic macroinvertebrates. As many other authors have noted (e.g. Walsh *et al.*, 2001), the loss of ecosystem health due to urbanisation is caused by complex linked changes referred to by Meyer *et al.* (2005) as the 'urban stream syndrome'. Our results suggest that this syndrome is affecting the urban creeks within the Ku-ring-gai LGA as a result of changes to hydrology, hydraulics, water quality, habitat, pest species, geomorphology, erosion and sedimentation (see Walsh *et al.*, 2004, Breen & Lawrence, 2003).

The water chemistry of the urban waterways was more variable and reported much higher pH, electrical conductivity and alkalinity than the reference streams (Figures 1 d-f). Non-urban reference streams were dilute, acid and were poorly buffered (low alkalinity) in contrast to the urban streams which had higher EC, were circumneutral to mildly alkaline and were much more buffered (medium to high alkalinity). Alkalinity was particularly different between the two groups of sites, ranging from 5-10 mg/L at reference sites and was 30-125 mg/L at urban sites. This has been noted in other studies of urban waterways (Walsh, 2006). The water chemistry results presented provide some clues as to the possible factors associated with urbanisation that may contribute to this ecological degradation of urban waterways, such as materials that affect pH and alkalinity. For example, Quarry Creek had much higher EC and alkalinity than the other urban sites which we speculate may be due to previous activities within the catchment such as the operation of a municipal waste incinerator, quarry and small landfill for vegetation and building waste.

Water chemistry was only measured in dry weather conditions, avoiding the high flow events that probably suffer the poorest water quality episodes. In this respect changes in water chemistry did not distinguish the impacts of sewerage overflows that are known to occur in the LGA.

In reference to general stream health, the assessment of the condition of riparian systems as undertaken by Findlay *et al.* (2005) reported that the physical condition of the 230 km of streams in the LGA was better than was expected, with 61 % being classified as being excellent and good. This was attributed to a large extent the comprehensive system of natural riparian corridors that have been retained within the LGA. This is in contrast to many other urban areas that have engineered their waterway through pipes and channels and straightening and de-snagged channels to achieve hydraulic efficiency. Recognising the broader ecological functions of waterways, Ku-ring-gai Council developed a 'riparian policy' to ensure protection of this sensitive environment whilst seeking to balance the risk of flooding and property protection (Ku-ring-gai Council, 2004). The long term effectiveness of this policy, in combination with other development control instruments that seek to promote water sensitive urban design are yet to be demonstrated.

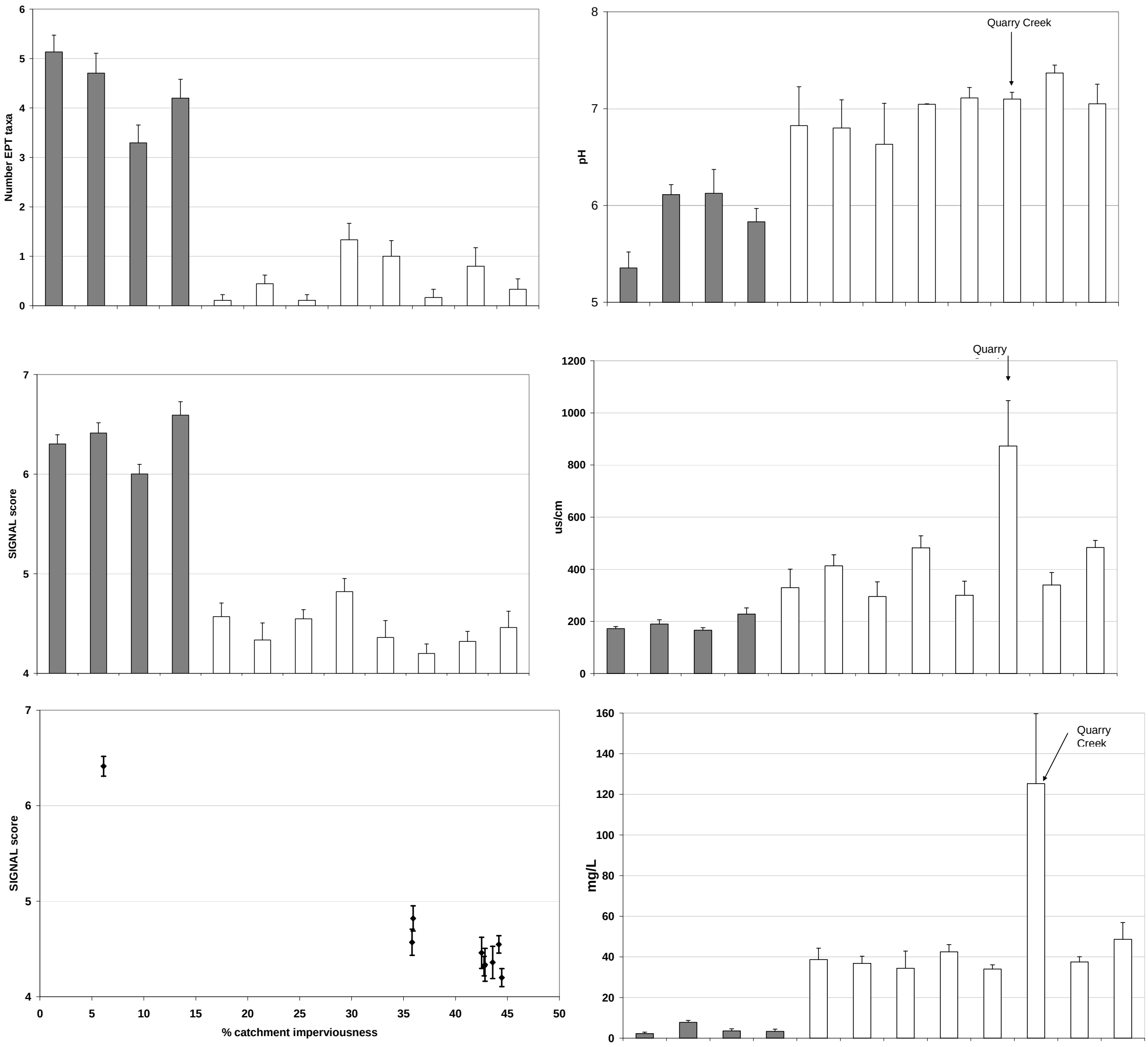

Figure 1. Macroinvertebrate (left) and water quality (right) results.
a) (Top Left) EPT richness (plus std. error) at reference (grey) and urban sites.
b) (Mid Left) Mean SIGNAL score (plus std. error) at reference (grey) and urban sites.
c) (Bottom Left) Mean SIGNAL score (plus std. error) compared to catchment imperviousness for sites within the Ku-ring-gai LGA (n=9, r^2 = 0.9677).
d) (Top Right) Mean pH (plus std. error) at reference (grey) and urban sites.
e) (Mid Right) Mean EC (plus std. error) at reference (grey) and urban sites.
f) (Bottom Right) Mean alkalinity (plus std. error) at reference (grey) and urban sites.

The influence of CI on altered flow conditions and transport of pollutants in urban streams has frequently been identified as a highly influential cause of degradation to urban waterway ecosystems with researchers suggesting a reverse in impervious areas could improve stream health (Walsh *et al.,* 2005 and Ladson *et al.,* 2006). Figure 1c provides an indication that such an assumption is valid; however additional data is required to fill the gap between 7-35% in order to determine the target CI for the Ku-ring-gai landscape.
A key result of this study was characterising four local reference sites and for comparison with urban waterways. The reference sites all benefit from a large proportion of their watershed being protected through

National Park estate lands. Reference waterways are becoming increasingly rare within urban environments. Within the Ku-ring-gai LGA only tributary of Kierans Creek can serve as an example of how the natural waterway would have existed pre development. Given the marked difference in aquatic macroinvertebrates and water chemistry, as investigated in this study, such locations deserve greater legislative protection due to their scarcity and conservation value. Legislative instruments could include protection of the catchment of each reference waterway under the *Threatened Species Conservation Act 1995* NSW as an endangered ecological community. This would complement current controls via part 3A approvals pursuant to the *Rivers and Foreshores Improvement Act 1948* NSW that is soon be repealed by the *Water Management Act 2000* NSW.

References

Anonymous (1994). *River Bioassessment Manual*, Version 1.0, National River Processes and Management Program, Monitoring River Health Initiative. Department of the Environment, Sport and Territories; Commonwealth Environment Protection Agency and Land & Water Research & Development Corporation, Canberra.

Arthington, A.H., Conrick, D.L., Connell, D.W., & Outridge, P.M. (1982). *The ecology of a polluted urban creek.* Australian Water Resources Council. Technical Paper No. 68. Australian Government Printing Service, Canberra.

Breen, P.F., & Lawrence I. (2003) Chapter 13 Urban Waterways. In *Australian Runoff Quality*. Wong T. (editor) Australian Institute of Engineers, Crow Nest.

Campbell, I.C. (1978) A biological investigation of an organically polluted urban stream in Victoria. *Australian Journal of Marine and Freshwater Research,* 29, 275-291.

Chessman, B.C. (1995) Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat-specific sampling, family level identification and a biotic index. *Australian Journal of Ecology*, 20, 122-129.

Chessman, B.C., Kotlash, A., & Growns, I. (1997) Objective derivation of macroinvertebrate family sensitivity grade numbers for the SIGNAL-HU97 biotic index: application to the Hunter River system, New South Wales. *Australian Journal of Marine and Freshwater Research*, 48, 159-172.

Chessman, B.C., & Williams, S.A. (1999) Biodiversity and conservation of river macroinvertebrates. *Pacific Conservation Biology,* 5, 36-55.

Camargo, J.A., Alonso, A., & De La Puente, M. (2004) Multimetric assessment of nutrient enrichment in impounded rivers based on benthic macroinvertebrates. *Environmental Monitoring and Assessment*. 96, 233-249.

Fairweather, P.G. (1990) Sewage and the biota on seashores: assessment of impact in relation to natural variability. *Environmental Monitoring and Assessment,* 14, 197-210.

Findlay, S. J. (2006) Natural research management of urban streams. Unpublished MSc. (Hons) Thesis, Macquarie University, Sydney.

Findlay, S., Taylor, M.P., & Davies, P. (2005). Application of the Rapid Riparian Assessment on Ku-ring-gai streams. In Khanna, N., Barton, D., Beale, D., Cornforth, R., Elmahdi, A., McRae, J., Seelsaen, N., Shalav, A. (Eds), *Environmental Change: making it happen*: *9th Annual Environmental Research Conference*, 29th November to 2nd December 2005, Hobart, Tasmania.

Hellawell, J.M. (1986) *Biological Indicators of Freshwater Pollution and Environmental Management*. Elesvier, London.

Ives, C., Taylor, M.P., Davies, P., & Wilks, D. (2005) How wide is wide enough? The relationship between riparian buffer width, condition and biodiversity: an assessment of urban creek systems in the Ku-ring-gai local government area, North Sydney, NSW. In Khanna, N., Barton, D., Beale, D., Cornforth, R., Elmahdi, A., McRae, J., Seelsaen, N., Shalav, A. (Eds), *Environmental Change: making it happen, 9th Annual Environmental Research Conference*, 29th November to 2nd December 2005, Hobart, Tasmania.

Ku-ring-gai Council (2004) *Riparian Policy*. Ku-ring-gai Council, Gordon.

Ladson, A.R., Walsh, C.J., & Fletcher, T.D. (2006) Improving stream health in urban areas by reducing runoff frequency from impervious surfaces. *Journal of Water Resources* 10(1), 23-33

Lake, J. C., & Leishman, M.R. (2004) Invasion success of exotic plants in natural ecosystems: the role of disturbance, plant attributes and freedom from herbivores. *Biological Conservation* 117, 215-226.

Lydy, M.J., Crawford, C.G., & Frey, J.W. (2000) A comparison of selected diversity, similarity and biotic indices for detecting changes in benthic-invertebrate community structure and stream quality. *Archives of Environmental Contamination and Toxicology*, 39, 469-479.

Meyer, J. L., Paul, M. J., & Taulbee, W. K. (2005). Stream ecosystem function in urbanizing landscapes. *Journal of the North American Benthological Society*, 24, 602–612.

Rosenberg, D.M., & Resh, V.H. (1993) *Freshwater biomonitoring and benthic macroinvertebrates*. Chapman & Hall, New York, London.

Roy, A.H., Rosemond, A.D., Paul, M.J., Leigh, D.S., & Wallace, J.B. (2003). Stream macroinvertebrate response to catchment urbanisation (Georgoia, U.S.A.). *Freshwater Biology*, 48, 329-346.

Taylor, M.P., Findlay, S., Fletcher, A., & Davies, P. (2005). A Rapid Riparian Assessment tool for local council urban creek assessment: Ku-ring-gai Council, Sydney, NSW. In Rutherfurd, I.D., Wiszniewski, I, Askey-Doran, M.A., & Glazik, R. (Eds), *Proceedings of the 4th Australian Stream Management Conference; Linking rivers to landscapes*, Department of Primary Industries, Water and Environment, Hobart, (pp. 597-601).

Turak, E., & Waddell, N. (2001), Development of AusRivAS Models for New South Wales, NSW Environment Protection Authority, Sydney.

Underwood, A.J. (1991). Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Australian Journal of Marine and Freshwater Research*, 42, 569-587.

Walsh, C.J., Sharpe, A.K., Breen, P.F., & Sonneman, J.A. (2001) Effects of urbanisation on streams of the Melbourne region, Victoria, Australia. I. Benthic macroinvertebrate communities. *Freshwater Biology*, 46, 535-551.

Walsh, C.J. (2006) Biological indicators of stream health using macroinvertebrate assemblage composition: a comparison of sensitivity to an urban gradient. *Marine and Freshwater Research*, 57, 37-47.

Walsh, C.J., Leonard, A.W., Ladson, A.R. &d Fletcher, T.D. (2004) *Urban stormwater and the ecology of streams.* Cooperative Research Centre for Freshwater Ecology, Water Studies Centre, Monash University, Victoria.

Walsh, C.J., Fletcher, T.D., & Ladson, A.R. (2005) Stream restoration in urban catchments through re-design stormwater systems: looking to the catchment to save the stream. *Journal of the Northern American Benthological Society*, 24(3), 690-750

Williams, S., & Silva, L. (1998) *Ecological health and biodiversity assessment of streams in the Ku-ring-gai Council area.* Report No. 98/161. Australian Water Technologies, PO Box 73, West Ryde, NSW.