Development of regional water quality and catchment guidelines for the conservation of aquatic ecosystems: a case study from the Georges River catchment

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Key Points

- Urban development in the Georges River catchment is strongly associated with the degradation of stream ecosystems.
- The formulation of regional ecosystem and water quality guidelines, following the approach suggested by ANZECC (2000), is recommended to protect the remaining areas with clean and high conservation value waterways of the Georges River catchment.
- We suggest that management targets for the protection of freshwater streams include both ‘catchment effective imperviousness’ and ‘riparian habitat condition’ along with traditional water quality attributes.

Abstract

The conservation of freshwater ecosystems in Australia is commonly underpinned by comparing water quality data with the ANZECC water quality guideline values. In this study we formulate and recommend regional aquatic ecosystem guidelines for the Georges River catchment. We use a rapid assessment approach, undertaken by non-specialist personnel, based on the collection of freshwater macroinvertebrates, to directly measure the ecosystem health of freshwater reaches within the waterways of the Georges River catchment, in south eastern Australia. The 18-month study involved spring and autumn assessment of water quality (chemical and physical), benthic macroinvertebrates, riparian vegetation and calculation of catchment imperviousness. The results showed three distinct disturbance groups emerged which were categorized as ‘low', ‘moderate' and ‘high' effective impervious. We set out to develop a methodology that can be easily and practically applied by natural resource managers and consultants, rather than a methodology typically employed by specialist scientists. The study revealed that urbanised streams with high effective imperviousness had strongly degraded water quality and macroinvertebrate communities, compared to clean non-urban reference streams. Based on the results of this study, we recommend interim regional ecosystem and water quality guidelines for the assessment and conservation of the remaining clean freshwater streams in the Georges River catchment.

Keywords

Urban stream syndrome, ecosystem degradation, macroinvertebrates, imperviousness, Georges River

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Introduction

Assessment of the effects of human activity on water quality and stream ecology in Australia and New Zealand has been enhanced by a comprehensive series of guidelines for measuring water quality, known as the 'ANZECC water quality guidelines' (ANZECC, 2000). The ANZECC guidelines include water quality trigger values for several categories including aquatic ecosystems, primary industries and recreational use. In this paper we refer to guidelines for protection of aquatic ecosystems. In addition, the ANZECC guidelines outline the approach for designing a water quality assessment program and recommend that regionally specific guidelines are developed. However, given that many organisations do not have the resources necessary to develop their own region specific guidelines, ANZECC default values for broad regions within Australia and New Zealand (such as south-eastern Australia) are commonly used.

The primary objective of this study was to assess water quality, freshwater invertebrates and other environmental attributes within a partly urbanised and partly naturally vegetated catchment. Our intention was to formulate regionally derived water quality and environmental guidelines for protecting aquatic ecosystems in the Georges River catchment. To achieve these objectives we sampled stream macroinvertebrates, water quality and catchment indicators over 18 months from a diverse range of waterways across the Georges River catchment. Although this study has a specific geographical focus, the presented methodology could be easily used by non-specialist professionals in the field of natural resource management to derive region-specific guidelines elsewhere.

Field sites and methods

Sampling was undertaken at 31 freshwater sites spread across 22 waterways within the Georges River catchment (960 km^2) during spring 2009, autumn 2010 and spring 2010 in dry weather conditions. Site selection was based on the combination of accessibility and representation of the variation of land uses across the catchment.

Macroinvertebrate samples were collected according to the Australian National River Health Program protocols (DEST *et al.*, 1994; Chessman 1995, 2003). Macroinvertebrates were collected using a kick-net with a mesh size of 250 µm and square net frame (30 x 30 cm) in pool, edge and riffle habitats. Pool, edge and riffle sub-samples were combined into one homogenised sample to be representative of each study site. A total of 10 metres of stream habitat was sampled. Samples were live-picked in the field for 30 minutes and were identified in the field to order-level (Collembola, Nematoda, Bivalvia and Oligochaeta to Class) using 30 x magnification hand lenses and the recommended Australian taxonomic guides of Hawking & Smith (1997) and Gooderham & Tsyrin (2002). Order-level identification of freshwater macroinvertebrates has been found to be suitable for detecting water pollution impacts (e.g. Wright *et al.*, 1995; Bowman & Bailey, 1997).

Electrical conductivity (EC), dissolved oxygen (DO), turbidity (NTU), pH and temperature were measured using a TPS 90FLMV field meter. In addition, water samples for the analysis of total nitrogen (TN), oxidised nitrogen (NOx), total phosphorus (TP) and alkalinity (ALK) were collected. Samples were analysed by a commercial National Associations of Testing Authorities (NATA) accredited laboratory. A one-off riparian vegetation was surveyed at each monitoring site using the Rapid Appraisal of Riparian Condition (RARC) Version 2 (Jansen *et al.,* 2005). Due to the variability of survey sites, a standardised approach was taken whereby a maximum of 100 m of stream bank with four transects at right angles to the channel were surveyed. Each transect was limited to a maximum of 40 m.

Multivariate analysis was used to assess macroinvertebrate community response to catchment and waterway disturbance and has been demonstrated to be a powerful and useful approach to evaluate the ecological condition of macroinvertebrates exposed to freshwater pollution (e.g. Marchant *et al.,* 1994). Non-metric multidimensional scaling (*n*MDS) was performed on a similarity matrix calculated with square root transformed macroinvertebrate data using the Bray-Curtis dissimilarity measure (Clarke, 1993; Warwick, 1993). Two-dimensional ordination plots were generated to give a representation of the dissimilarity among samples. By using the two-way analysis of similarity (ANOSIM: Clarke, 1993) data were grouped by the degree of catchment imperviousness (high, moderate and low) and time of sampling to test for ecological differences allowing the delineation of catchment disturbance thresholds.

A one-factor ANOVA was used to investigate whether water quality parameters, macroinvertebrate indices, riparian vegetation condition and % impervious surfaces varied according to imperviousness category (low, moderate or high).

Catchment imperviousness was quantified by using ESRI Arc-Map v 9.3.1 with sub-catchments delineated using 10 m contours. An impervious/pervious layer developed using remote sensing of SPOT imagery on a 10 m x 10m grid (SMCMA, 2009) was clipped by the digitised subcatchment layer. Subcatchment pervious/impervious areas were totaled allowing the percentage of impervious surface to be calculated. It was assumed that all impervious surfaces were effective. Effective Imperviousness (EI) is described as the percentage of impervious surface that directly connects to receiving waters via stormwater infrastructure (Booth and Jackson, 1997).

The degree of subcatchment disturbance was determined by using the percentage EI surfaces calculated for the catchment of each sampling site. Thresholds for categories of catchment EI as indicated by ANOSIM were defined as low, moderate or high (low < 5.0 %EI; moderate = 6.0 - 30%EI; high > 30.0% EI) Catchment EI was cross-checked with land use and a single sub-catchment containing a coal stockpile was grouped within the high EI category.

Four macroinvertebrate biotic indices were calculated for each macroinvertebrate sample: percentage EPT (Ephemeroptera, Plecoptera, and Trichoptera) (Cairns and Pratt 1993), taxonomic richness (Rosenberg and Resh 1993), Shannon Index (Krebs 1989) and order level SIGNAL score (Chessman 2003b).

For the development of local water quality guidelines for the Georges River catchment, we followed the rationale recommended in ANZECC (2000). Using this approach the 20^{th} and 80^{th} percentile of data collected from nine local clean reference sites, each sampled on three occasions were calculated to form upper and lower guideline limits for water quality parameters. This method is a common approach used in various studies throughout Australia (QEPA, 2001; Batley & Simpson, 2009). In addition local guidelines for catchment %EI, RARC scores and macroinvertebrate biotic indices were calculated by following the same rationale.

Results and discussion

A total of 7,746 freshwater macroinvertebrates from 20 taxonomic groups (generally orders) were collected in the 18-months study. Diptera was the most widely detected and abundant group with 1,128 (14.6% of total abundance), then Odonata with 1,054 (13.6%) and Hemiptera (884, 11.4%). The majority (64.1%) of invertebrates detected were insects. A total of 1,394 (18.0%) invertebrates were collected from the sensitive Mayfly (Ephemeroptera), Stonefly (Plecoptera) and Caddisfly (Trichoptera) orders.

Multivariate analysis revealed that the order-level macroinvertebrate community structure varied significantly according to the classification of waterway condition (high, moderate or low EI). Two-dimensional ordination showed that the low EI sites clustered discretely and separately from the moderate EI and high EI waterway sites (Figure 1). ANOSIM confirmed the significance of the ecological differences apparent in macroinvertebrate communities between the three disturbance categories (Global R = 0.444, p=<0.001). The time of sampling was not associated with ecological differences (Global R = -0.007, p=0.478). Pairwise ANOSIM comparison of communities between each class of disturbance confirmed that the largest difference was detected between low and high EI sites (R-statistic = 0.720, p <0.001), then medium versus high EI sites (R-statistic = 0. 316, p <0.001). Differences between the low and moderate EI sites were smaller but still significant (R-statistic = 0.302, p <0.001).

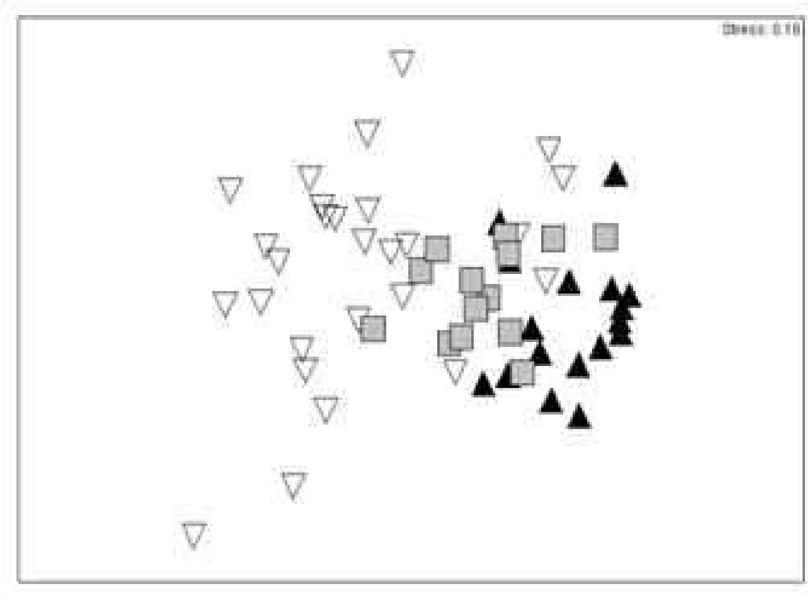

Figure 1. *n*MDS two-dimensional ordination of macroinvertebrate communities samples collected from the Georges River catchment grouped by the level of % effective imperviousness (EI) (low EI catchments = black triangles, moderate EI = grey squares and high EI = unshaded triangles).

Mean water quality attributes were generally highest at sites with high EI. Most water quality attributes displayed highly significant differences, based on the level of EI (Table 1). Effective imperviousness varied highly between categories with mean EI of 46.9 % at high EI sites, 15.5 % at moderate EI sites and 1.8 % at low EI sites. Riparian habitat scores (RARC) also varied significantly according to the level of EI with the lowest mean RARC values at high EI sites (23.7/50), followed by moderate EI sites (34.1/50) with the highest mean values at low EI sites (37.1/50).

Table 1. Catchment % effective imperviousness, riparian vegetation, macroinvertebrate and water quality results and proposed interim ecosystem guidelines for protection of clean freshwater streams in the Georges River catchment.

		Level of catchment effective imperviousness						
		High (>30% EI)		Moderate (6-30% EI)		Low (0-5% EI)		
Source of variation	**F-value (*p*) Degrees of freedom**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Recommended guideline for protection of aquatic ecosystems in clean Georges River freshwater streams**
				Catchment and riparian habitat				
Sub-catchment % effective impervious	45.2 (***) 2,29	19-71	46.9	9-28	15.5	0-4	1.8	< 3.0
RARC score	13.4 (***) 2,29	14.5-37	23.7	22.6-40.5	34.1	30.5-43	37.1	> 33.7
				Biotic Indices				
SIGNAL	76.0 (***) 2,58	1.71-4.73	2.66	3.04-5.30	4.02	4.47-6.46	5.03	> 4.64
EPT%	44.4 (***) 2,58	0-17.5	1.96	0-48.4	20.1	13.1-55.3	31.1	> 22
Richness	28.0 (***) 2,58	2-10	7	6-13	10	6-13	10	> 10
Shannon Index	33.9 (***) 2,58	0.36-1.76	1.40	1.43-2.16	1.90	1.48-2.22	1.93	> 1.70
				Water Quality				
pH (pH units)	26.4 (***) 2,59	5.97-8.99	7.60	5.85-8.85	7.67	4.07-7.78	6.13	5.1-7.1
Electrical conductivity (μS/cm)	10.6 (***) 2,58	114.4-3310	911.5	101-2680	834	67.7-370	166.3	< 212
Dissolved oxygen (% saturation)	11.8 (***) 2,59	0-122.5	60.5	30.4-132.3	81	55.5-124	87.4	> 79.0
Total nitrogen (μg/l)	20.2 (***) 2,59	300-6900	1392	5-1800	535	5-400	200	< 200
NOx (μg/l)	8.9 (**) 2,58	5-1790	378	5-1100	127.9	5-500	40.4	< 300
Total phosphorus (μg/l)	10.8 (***) 2,58	5-940	172	5-290	60.1	5-110	27.1	< 48
Total alkalinity (mg/L)	1.97 (ns) 2,25	44-993	178.5	18-984	261.6	2-33	4.1	< 8.6

*p < 0.05; ** p < 0.001; *** p < 0.0001, ns = not significant*

This study found that freshwater aquatic ecosystems across the Georges River catchment varied from near-pristine to highly degraded, based on analysis of water chemistry, effective imperviousness, condition of riparian vegetation and macroinvertebrate communities. The waterways in the most degraded ecological condition were typically flowing in highly urbanised catchments with high EI. The degree of impact to macroinvertebrate communities (i.e. the extent of deviation from assemblages found at low EI streams) was generally associated with the extent of EI and urban land uses.

We found that as the percentage of EI increased, the condition of riparian vegetation, macroinvertebrate communities and water quality declined. The results indicate that waterways draining urban catchments of the Georges River are highly degraded and are consistent with the 'urban stream syndrome' (Meyer *et al.,* 2005) and that waterways of low disturbance catchments had clean near-pristine qualities.

The average EI coverage of catchments of low EI in this study was 1.8% and in high EI catchments was 46.9%. This is very similar to a recent macroinvertebrate study of urban and natural streams in northern Sydney (Davies *et al*., 2010a) where the catchments of clean non-urban streams had an average impervious cover of 1.5 % and urban streams had an average of 29.5%. Both studies reinforce the work of Walsh *et al.* (2004) which recommended that to protect the aquatic ecosystem of streams, effective impervious surfaces should be limited to less than 5% within a catchment.

The Georges River headwaters flow within waterways that have generally had minimal human disturbance, however further downstream there are peri-urban to highly modified urban subcatchments. In order to protect and preserve waterways of the upper Georges River catchment we propose a set of region specific guidelines for the protection of ecosystems of high ecological value (Table 1).

We advocate a lower pH value for clean ecosystems in the Georges River (pH 5.1-7.0), rather than the default range suggested by ANZECC of pH 6.5-8.0 for upland streams in south east Australia. There are difficulties applying the ANZECC guideline for pH in streams of the Sydney basin and the Blue Mountains area, where natural pH is often strongly acid. This is due to the naturally acidic nature of the upland swamps where many of these creeks have their headwaters and pH levels of less than 6.5 are frequently recorded (Ian Wright, *personal observation*).

The ANZECC (2000) guidelines for electrical conductivity (EC) are currently very difficult to apply in the Georges River catchment. The catchment streams vary across the upland and lowland categories, with the current default guidelines for south east Australia suggesting 30-350 μS/cm for upland streams and 125-2200 μS/cm for lowland rivers. Based on the results from our survey we recommend a trigger value of less than 212 μS/cm for the protection of regional waterways.

The nutrient guidelines that we recommend for the protection high conservation ecosystems in the Georges River catchment is <48 μg/L TP, broadly similar to those given in ANZECC (2000) of 20 μg/l for upland streams and 50 μg/L for lowland rivers. We also recommend <300 μg/L TN compared to the ANZECC guidelines of 250 μg/L for upland streams and 500 μg/l for lowland rivers.

We have also recommended a guideline for total alkalinity of <8.6 mg/L. Total alkalinity does not feature in the ANZECC guidelines, however recent research by Davies *et al* (2010)b in northern Sydney show that alkalinity levels are significantly affected by concrete stormwater infrastructure and increases pH levels in urban streams.

It is noted that the ANZECC (2000) guidelines recommend monitoring reference condition(s) sites monthly over a two year period to formulate a regional specific guideline. However, the number of replicate reference sites (n=9), all sampled three times in 18 months and the inclusion of EI, riparian condition and macroinvertebrates used in this study provides adequate results to form a set of interim local guidelines for the protection of clean stream ecosystems.

We have formulated a set of regional guidelines for protecting waterways under-pinned by order-level assessment of freshwater macroinvertebrates. Order-level identification may be regarded as a coarse tool for the assessment of stream biodiversity, but it provides the powerful advantage of immediate assessment in the field, with considerable time and resource savings. A more detailed (e.g. family, genus or species) level of identification would be much more expensive, slower and would be out of the reach (in terms of technical skills or financial costs) of many natural resource managers (Wright *et al.*, 1995).

A number of the environmental indicators that we recommend differ from the array of default guidelines (often chemical) suggested in ANZECC (2000) for the protection of aquatic ecosystems. As explained above, our Georges River guidelines include catchment imperviousness, riparian condition (RARC scores) and macroinvertebrates which are not included in the ANZECC guidelines. Furthermore, the ecological drivers of catchment imperviousness and riparian vegetation condition are two which local councils and natural resource managers often have a strong ability to influence.

Conclusion

The Georges River catchment offers an unusually diverse range of waterways of differing environmental conditions. Many waterways in the catchment are heavily modified by urban development, while the upper reaches of the catchment include several near-pristine waterways. The major source of degraded ecological stream communities is urban development, which covers approximately half of the catchment. It is anticipated that these 'regional' guidelines will assist natural resource managers and other stakeholders who are responsible for the conservation of stream ecosystems and water quality within this catchment. The first challenge is to ensure that the cleanest streams in the catchment are protected. These streams have very high conservation significance, particularly given their proximity to such a large urban development. The second challenge is to help urban stream managers protect and improve the environmental condition of urban streams that are already modified and environmentally degraded. We recommend that to holistically assess and protect freshwater ecosystems the inclusion of effective imperviousness, riparian condition and macroinvertebrate assessment is taken into consideration when investigating the condition of catchments and freshwater ecosystems. Furthermore, ANZECC water quality guidelines should be used as guides until region specific trigger values can be generated by following a simple, yet thorough approach such as the one described by this study.

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