Ecological Impacts of Contaminants in an Urban Watershed

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Abstract

Small, urban streams are affected by a variety of alterations including contamination, and the Brunette River drainage (Burnaby, BC) was studied as an example. We studied sediment chemistry, direct toxicity of sediments, patterns of benthic invertebrate community structure, and then experimentally tested the direct effects of metals on a “pristine” stream community. The Brunette watershed has concentrations of heavy metals, particularly copper, lead, and zinc, associated with sediments and transported during high flow that regularly exceed water quality guidelines. Sediments were toxic to organisms in toxicity assays but highly variable which may be attributable to interactions amongst contaminants and the variation in organic content of the sediments, a known binding site. A survey of benthic invertebrates across the lower mainland showed that there were large differences in the organisms present in urban versus rural streams. Species that were largely absent from the Brunette River watershed were also those species most sensitive to heavy metal exposure in our flow-through experimental stream experiment beside a clean, mountain stream. These results show that contaminants have a large effect on urban stream communities.

Résumé

Les petits cours d'eau urbains subissent toute une gamme de modifications incluant la contamination, et le bassin versant de la rivière Brunette (Burnaby, C.-B.) a été étudié à titre d'exemple. Nous avons étudié la chimie des sédiments, la toxicité directe des sédiments, la structure de la communauté des invertébrés benthiques, avant d'éprouver expérimentalement les effets directs de métaux sur la communauté d'un cours d'eau «vierge». Le bassin versant de la rivière Brunette présente des concentrations de métaux lourds, en particulier de cuivre, de plomb et de zinc, associés aux sédiments et transportés en période d'écoulement élevé, qui dépassent régulièrement les seuils établis dans les lignes directrices en matière de qualité de l'eau. Lors de tests de toxicité, les sédiments étaient toxiques pour des organismes, mais présentaient une grande variabilité qui peut être attribuable à des interactions entre contaminants et à la variation de la teneur en matière organique, un site de liaison connu. Un relevé des invertébrés benthiques exécuté dans la vallée du bas Fraser a révélé de grandes différences quant aux organismes présents entre les cours d'eau urbains et les cours d'eau ruraux. Les espèces en grande partie absentes du bassin de la rivière Brunette étaient également les espèces les plus sensibles à l'exposition aux métaux lourds dans le cadre de notre expérience en cours d'eau expérimental coulant à côté d'un cours d'eau de montagne propre. Ces résultats montrent que les contaminants ont un effet important sur les communautés des cours d'eau urbains.

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Introduction

Water and sediment quality monitoring have demonstrated that a variety of trace metal and organic contaminants are entering the aquatic environment of the Brunette River watershed as a result of non-point pollution from urban stormwater runoff. These contaminants vary considerably over a rainfall event, seasonally, and spatially throughout the watershed.

To determine the ecological impacts of these contaminants a variety of techniques can be utilised. The water and sediment quality values can be compared to quality guidelines and criteria to determine when the values, considered safe for the protection of aquatic life, are exceeded. There are a variety of criteria and objectives in the literature that can be selected for comparison. The problems with this kind of comparison is that the values can vary considerably over space and time compared to the movements and life history characteristics of the organisms that live in these environments. Also, the established values only consider a single substance at a time and in reality an aquatic organism has to respond to the cumulative effects of these contaminants. Therefore other techniques in addition to the chemical and physical conditions of the environment are often used to determine these overall integrative impacts. In the Triad approach, a combination of sediment chemistry, toxicity bioassays, and benthic invertebrate community structure studies are utilised to evaluate the ecological impacts of contaminants discharged to the aquatic environment (Chapman,1990; Chapman et al. 1996). To determine cause and effect relationships it is often necessary to set up controlled ecosystem experiment studies using containment systems such as mesocosms or microcosm studies so that one can compare the variables that impact the components of the ecosystem being investigated. For all of these studies, it is always important to establish appropriate controls for comparison purposes.

This section of the report uses these techniques to determine the health of the aquatic ecosystem in this urban watershed.

Comparison of Water and Sediment Quality to Established Criteria and Guidelines

The data presented in Table 1 summarises the water quality conditions at the three stormwater stations monitored over the period of a year in the Brunette watershed. The data are presented as the percent of the time that the storm event mean concentration of contaminant exceeds the water quality objectives. This comparison indicated that copper is a problem throughout the watershed during all storm events, while other metals such as zinc and lead are more predominant in the reaches of Still Creek that are more heavily impacted by traffic activity and have high levels of impervious surface.

Since many of the contaminants are associated with sediments, it is relevant to compare the sediment contamination to sediment criteria (Table 2). These data are also presented as a percentage of the number of sites monitored (36) to provide some indication of the ecological risk involved in living in different areas of the watershed if you are a sediment dwelling organism. Lead appears to still be the most critical sediment contaminant when the data are compared to the federal PEL values, even though the removal of lead from gasoline has reduced levels when compared to previous studies (see Section 3.5). A comparison to the watershed specific criteria established by the provincial government indicate that Cu, Pb, and Zn all present major ecological problems in the sediments of this urban watershed. This creates a problem in determining which criteria should be used in trying to manage the contamination problem. Again, these criteria only consider the contaminants one at a time and do not consider the potential availability of the sediment bound contaminants to the organisms.

Toxicity Bioassays

Previous studies demonstrated that the stormwater runoff was periodically toxic to *Daphnia* (Hall and Anderson, 1985). Further laboratory investigations in the same study demonstrated that other water quality characteristics such as pH and the suspended solids level were also important in regulating trace metal toxicity to daphnia. The Microtox® photoluminescence bioassay demonstrated that it was the suspended solids component of the urban runoff that was the most toxic to bacteria (see section 3.3, Figure 8). Therefore toxicity studies during the current investigation placed emphasis on monitoring the sediment toxicity.

Chironomid (*Chironomus tentans*) and amphipod (*Hyalella azteca*) bioassays were conducted on stream sediment samples using the Environment Canada draft biological test methods (Environment Canada, 1997,1996). The chironomid bioassays included both survival and weight change compared to controls. Early chironomid bioassays compared changes to a control sediment from Musqueam Creek (Pacific Spirit Park) (Smith, 1994). while later bioassays used silica sand for controls and did standard toxicant tests. The Microtox® solid phase photoluminesence microbial bioassay was also conducted on stream bed sediments.

The sediment toxicity at three of the Still Creek stations was higher for all three toxicity indicators (chironomid survival, weight and the Microtox bioassay) when compared to the control Musqueam station (Table 3). During the month of August the toxicity of two Still Creek stations and the Musqueam station for the chironomid bioassay were similar with both areas showing poor survival. (22-36%) This is attributable to the low flow at the Musqueam station in August when there was some increase in the trace metals associated with the < 0.63 μ fraction which could come from the Marine Drive road crossing above the site. There were no good correlations between the bioassay results and the contaminant (trace metal and PAH) concentrations which indicates that the toxicity is probably related to a variety of contaminants some of which maybe be interacting . The three Still Creek stations which were the most toxic also had the highest sediment organic matter content which could relate to the biological availability of some of the contaminants.

Another set of sediment bioassays were conducted in 1996 with chironomids and *Hyalella* (Table 4). The controls in these bioassays were conducted on silica sand and standard toxicant tests were performed as per the Environment Canada protocol to compare the sensitivity of different broods of invertebrates. Overall these bioassays did not show the same level of sediment toxicity as the previous bioassays and there was no consistent relationship between the toxicity response of the two different organisms. Only one sample (Oct.1, 1996- Still Cr. at Renfrew) was statistically more toxic than the controls to *Hyalella* while two samples(April 24, 1997, at Still Cr. stations Renfrew and Douglas) demonstrated chironomid toxicity significantly different from the controls. One concern with the controls in this established protocol is that there is considerable build-up of ammonia in the samples (2-10 mg/L NH_3-N) which could affect their growth and survival (sometimes in the 80-85% region) and their statistical comparison to the field sediments.

Benthic Invertebrate Community Structure

The benthic invertebrates were sampled in the shallow water areas with a Surber sampler. Triplicate samples were taken at each stations. Several control streams with few anthropogenic impacts were also sampled as controls for comparison. The invertebrates were classified to the lowest practical taxon and a principal component analysis was conducted to segregate the stations that were impacted the most (Figure 1). The more impacted stations show up in the lower left hand corner (negative axes area) of this principal component analysis diagram. This area of the diagram is weighted heavily by high numbers of oligochaetes and this area of the diagram contains many of the Brunette watershed stations (BR- 08,11,16,28,30,and 32). The three Brunette stations at the top of this diagram (BR-06,19,& 20) are just downstream of the lakes in the watershed and are obviously affected by invertebrate drift from the lakes. The control streams, namely Pepin Cr. (PEPN), Bertrand Cr. (BTRD), Anderson Cr. (ANDN), the Little Campbell River (CAMP) and Salmon River (SA#), located in less developed areas of the Lower Fraser River valley, are on the far right side of the diagram and their positions on the diagram reflects larger numbers of the more pollution sensitive species. These community bioassays should be useful indicators of the cumulative effects of chemical and physical stress in these aquatic environments

Response of a stream macroinvertebrate community from a pristine, southern BC stream to metals in experimental mesocosms.

Small, urban streams are potentially impacted by an assortment of effects from changes in hydrology, modifications of the channel form, to alteration of water quality. In the Brunette River in the lower mainland, surface water concentrations of trace metals regularly exceed drinking water standards and are likely to contribute to impairment of the biological communities of the river and its tributaries. Survey work on a series of streams within the Brunette River drainage and into agricultural and forested land showed a clear gradient in the community structure of benthic invertebrates associated with the degree of urban development. With increasing development there was a decline in densities of several species of mayflies that are otherwise common in less disturbed streams, and increases in oligochaete worms and chironomids. This indicates modification of the stream network has detrimental effects on the ecosystem but does not identify the actual cause.

One hypothesis for the apparent impairment of the biological community in urban streams is the toxic effect of elevated concentrations of various trace metals. To test this hypothesis we chose to experimentally elevate metal concentrations to streamside experimental stream troughs receiving water and colonists from an otherwise "pristine", forested stream. The site for the experiment was Mayfly Creek in the Malcolm Knapp Research Forest of the University of British Columbia. The experiment was performed twice, first in September 1995 and then in July 1996, each time using mixtures of metals in fixed ratios but at a range of dose levels. Copper and zinc were added in both years, and in 1995 lead and manganese were also included. After a period to allow colonisation of the experimental channels the metal doses were added for a one-week period during which measures of emigration rate, dissolved metal concentrations, and final benthic densities were taken.

The elevated metal concentrations had a significant negative impact on the final densities of the overall benthic community ($p<0.025$, Figure 2). These impacts were not uniformly distributed amongst taxa. Some taxa showed strong declines in abundance as metal doses increased, such as the mayflies *Paraleptophlebia* spp. and *Baetis* spp. and the oligochaete worms. Other taxa showed no significant change in densities associated with trace metal additions, such as chironomid midges or the caddisflies *Lepidostoma* spp. It is possible that there may have been shifts in the composition of chironomid species since we did not identify that taxon beyond the family level.

Rates of emigration (“drift”) turned out to be a poor measure of biological response to the experiment. There was a weak trend to increasing rates of emigration as dose increased, but there was too much variation in the measure to detect a significant relationship. The latter was true regardless of whether species or total numbers were considered. Other measures, such as bacterial respiration rates, chlorophyll *a* concentrations, and algal composition showed no detectable impact of the experimental additions.

The results of these experiments indicate that taxa that were sensitive to the toxic effects of trace metals in the stream channels were many of the same taxa that occurred at lower densities in urban streams. These results don’t necessarily confirm that the trace metals are the sole causal agent for impairment of urban streams, but are consistent with the hypothesis that metal pollution has impacts on the stream ecosystem. Whether other taxa are reduced in abundance in urban streams for other reasons and whether there are interactive effects of other modifications to the streams in reducing benthic densities and diversity cannot be addressed at the experimental scale. Trace metals are a contributing factor to modification of urban stream ecosystems.

Summary

From the invertebrate sediment toxicity bioassays and the community structure analysis it is obvious that the aquatic ecosystem of the Brunette is being impacted. However, there is considerable variability in the sediment toxicity at the different stations to the different organisms during the different sampling periods. This is not unexpected considering the highly dynamic nature of the flow and contaminant transport and deposition in the watershed. The mesocosm flow through studies at the low trace metal concentrations indicated that some groups of organisms are affected. It would be very difficult to set up the complexity of flow variation, contaminant ratios, and loading variation that the natural populations experience in some streams of the highly urbanised Brunette watershed.

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Figures

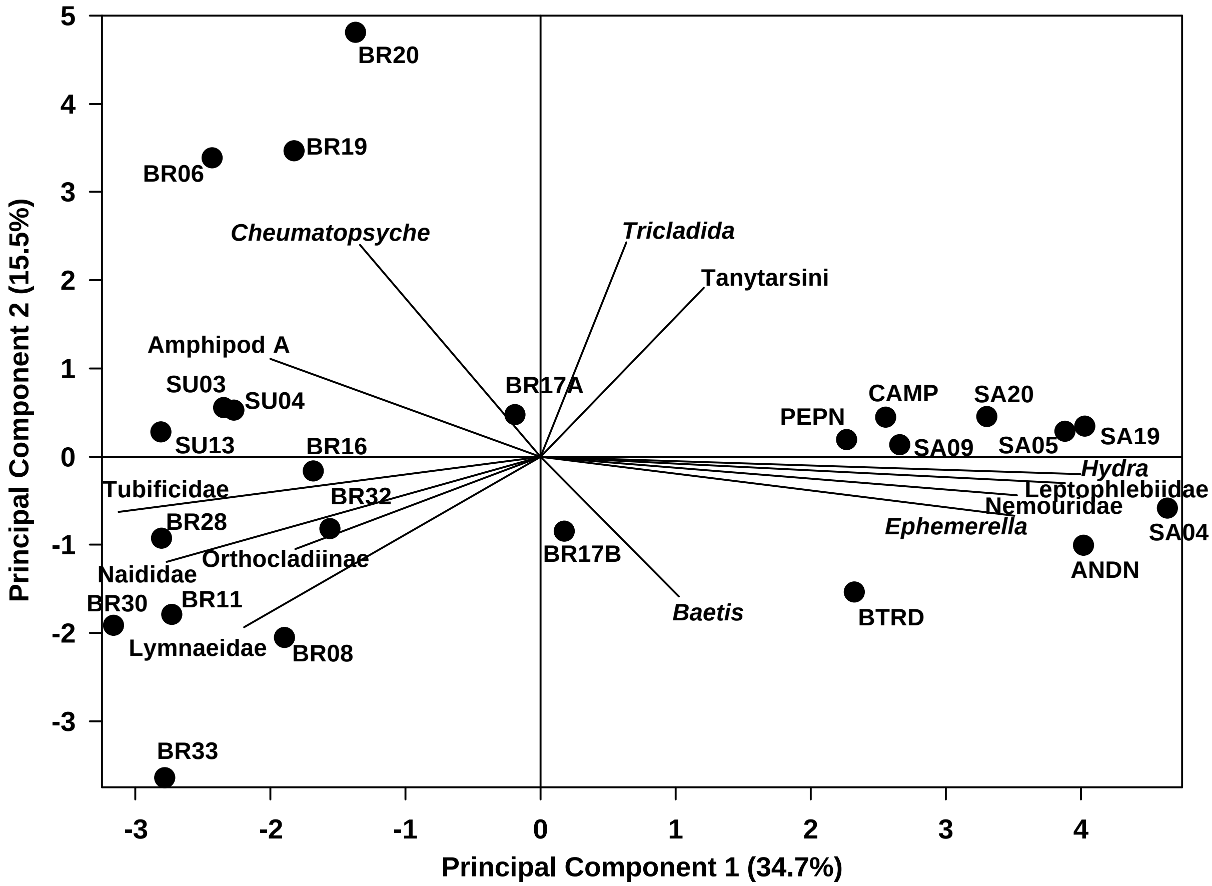

Figure 1. Ordination (principal components analysis) of benthic communities from small, urban, agricultural and forestland streams. Sample sites identified by circles with site code beside them (BR# - Brunette River watershed, SU# - Sumas River watershed, SA# - Salmon River watershed, others are additional "control" streams: ANDN - Anderson; BTRD - Bertrand; PEPN - Pepin; CAMP - Little Campbell River). Lines with taxonomic names indicate the loading and direction of the numerically predominant taxa with significant loadings.

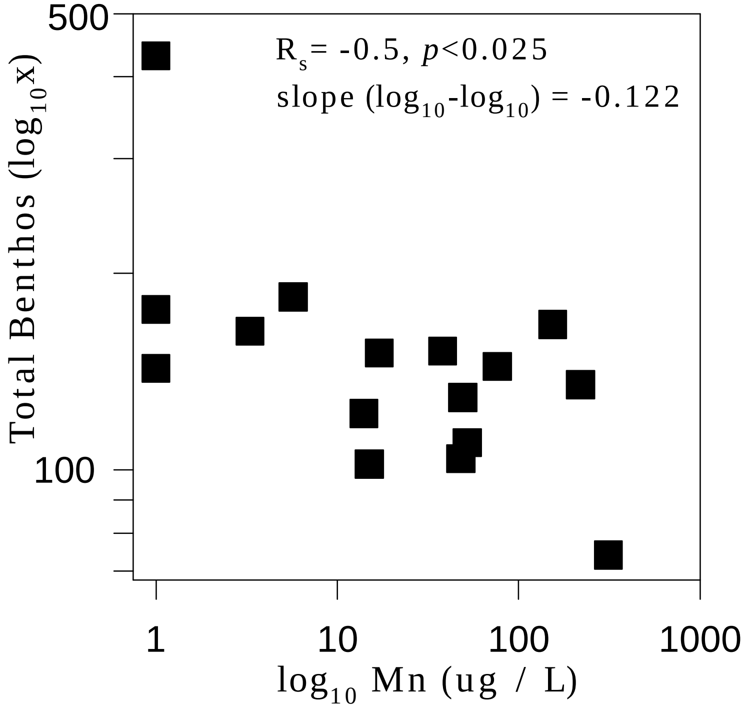

Figure 2. Relationship between final benthos density and metal dose rate from experimental stream channels at Mayfly Creek, 1995. The coefficient from the Spearman's Rank Correlation (R_s) is shown along with the slope from a linear regression of log-log data.

Tables

Table 1. Water quality in the Brunette River Watershed during storm events.

Parameter[1]	Storm Event SMC[2]			Exceedence of Water Quality Objectives[3]		
	Renfrew	Gilmore	Eagle	Renfrew	Gilmore	Eagle
Specific Conductivity	118	132	108	---	---	---
Total Suspended Solids	55	98	39	80	90	50
COD	40	46	23	---	---	---
NO_3-N	0.91	0.88	0.68	---	---	---
NH_3-N	0.43	0.62	0.29	10	20	20
Total Phosphorus	0.22	0.39	0.15	---	---	---
Total Copper	0.066	0.060	0.020	100	100	100
Total Lead	0.007	0.011	0.003	0	10	0
Total Zinc	0.096	0.122	0.043	92	100	58
Total Manganese	0.139	0.250	0.270	---	---	---

[1] All values in mg/L except for Specific Conductivity in µS/cm.
[2] Storm event sample mean concentration is a technique where each sample during the storm event is normalized for flow and a weighted single value calculated for the entire storm event. Data is for 10 to 12 storm events over a 16 month period.
[3] Water quality objectives are for the Brunette watershed and are presented as the percent of the SMC values that exceeded the objectives. For trace metals the quality data were compared to the maximum allowable objective not the average objective since storm events are episodic in nature and do not persist for long

Table 2. Trace metals in surface sediments in the Brunette River Watershed.[1]

Trace Metal	Median Concentration[2]		Exceedence of Sediment Quality Criteria (%)[3]		
	Total	Extractable	TEL	PEL	Brunette
Cadmium	<3	-	-	-	-
Chromium	26	4	19.4	0	-
Copper	71	31	83.3	5.5	94.4
Iron	2.1	0.62	-	-	-
Lead	50	46	86.1	41.6	100
Manganese	768	486	-	-	-
Mercury	0.102	-	14.2	2.8	57.1
Nickel	13.6	<6	25	0	-
Zinc	154	75	74.2	2.8	97.2

[1] Three surface sediments samples were collected in 1993-94 at each of 36 stations.
[2] All values in mg/kg dry weight except iron as %. Values are for the <180µ fraction of sediment. Total for hot nitric acid digestion, extractable for cold 0.5 M HCl digestion.
[3] Exceedence relates to total metal of the <177µ fraction and is expressed as % of the total number of stations: n=36 except for mercury, n=33. TEL = threshold effects level and PEL = probable effects level reported by the Federal government, while Brunette criteria have been established specifically by the B.C. Provincial government for the Brunette River watershed.

Table 3. **Sediment toxicity in the Still Creek area of the Brunette Watershed.**

Date	Chironomid Survival (%)		Chironomid Weight (mg)		Microtox (EC_{50})	
	Still	Musqueam	Still	Musqueam	Still	Musqueam
July 4	30	73	1.3±0.6	2.1±1.1	3.6	19.0
Aug. 2	36	35	1.5±0.7	1.5±0.5	11.5	NT
Aug. 24	26	22	2.0±1.0	2.0±0.6	2.96	10.98
Oct. 14	12	69	1.1±0.6	2.7±1.1	0.41	NT
Dec. 4	13	73	0.4±0.2	1.2±	4.28	NT

Microtox is for 15 min. contact and is for whole sediment solid phase test. Still Creek stations were all different for each bioassay and sediments were from Willingdon, Douglas, Atlin, Lougheed, and Westburne stations in the sequential order presented above. The Musqueam station sediment samples were from the same station on all dates and served as a control

Table 4. Chironomid and *Hyalella* sediment toxicity in the Brunette Watershed.

Date	Station	Chironomid Survival (%)	*Hyalella* Survival (%)
Oct.1, 1996	Still Cr. (Renfrew)	90	20
	Still Cr. (Gilmore)	90	97.5
	Still Cr.(Douglas)	100	90
	Eagle Cr.(Piper)	97.5	100
Apr.24, 1997	Still Cr. (Renfrew)	82.5	100
	Still Cr. (Gilmore)	95	95
	Still Cr. (Douglas)	85	100
	Eagle Cr. (Piper)	75	100