UTUHINA STREAM MONITORING 2009: FISH AND AQUATIC INVERTEBRATES

CBER CONTRACT REPORT 106

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Utuhina Stream monitoring 2009: fish and aquatic invertebrates

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SUMMARY

This report presents the results of an assessment of the fish and aquatic macroinvertebrate communities of the Utuhina Stream, and an assessment of the bioavailability of aluminium in fish and koura to satisfy annual resource consent conditions 9.6, 9.8 and 9.7, respectively, for the discharge of alum.

Sampling of macroinvertebrates, fish and koura were conducted in June 2009. Catch rates for common bully were slightly lower compared to previous sampling conducted in July 2008, however, densities of juvenile trout and koura were similar. No obvious effect of alum dosing on stream fish community was observed.

Semiquantitative analysis of stream macroinvertebrates showed no differences between upstream control and alum-exposed sites, with similar MCI scores to previous samples obtained before and after commencement of alum dosing in 2006. Overall, all sites were characterised as bordering between fair and good quality for a soft bottomed stream.

No evidence was found for significant bioaccumulation of aluminium in the tissues of either koura or common bully due to alum dosing. Tissue aluminium concentrations were higher in koura than common bully tissues but within species were similar across control and alum-exposed sites.

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INTRODUCTION

The Lakes Rotorua and Rotoiti Action Plan (EBOP, 2007) proposed to lower the trophic level index (TLI) of Lake Rotorua from 4.9 to 4.2 by reducing internal and catchment-derived nutrients (N and P). Catchment reduction targets of 250 tonnes N and 10 tonnes P have been established. The Utuhina Stream carries an estimated 7.6 tonnes of P into Lake Rotorua each year, of which approximately 2 tonnes is in the form of dissolved reactive phosphorous (DRP). The Action Plan proposed P-locking in up to three streams (Utuhina, Puarenga and one other) to reduce 6 tonnes of DRP entering into Lake Rotorua using continuous alum (aluminium sulphate) treatment. It has been estimated that an alum dosing rate of 1 ppm (1 g/m3) should remove the majority of DRP (i.e. ~2 tonnes) in the Utuhina Stream. Alum dosing of the Utuhina Stream began on a trial basis in 2006 and the Bay of Plenty Regional Council granted a resource consent in November 2008 for the continuation of alum dosing until 2018. This report presents the results of an assessment of the fish and aquatic macroinvertebrate communities of the Utuhina Stream, and an assessment of the bioavailability of aluminium in fish and koura to satisfy annual resource consent conditions 9.6, 9.8 and 9.7, respectively, for the discharge of alum.

METHODS

FISH COMMUNITY SURVEY

The occurrence of fish species, approximate relative density and catch per unit effort (CPUE) were determined for three 50 m reaches of the Utuhina Stream (Fig. 1) on 17th June 2009. Site 1 (control) was 50 to 100 m upstream of the alum discharge in-stream diffuser, site 2 was 50 to 100 m downstream of the diffuser, and site 3 was several hundred meters further downstream in the vicinity of Lake Rd. Relative fish density and CPUE (fish captured per hour) were estimated using a two-pass electrofishing procedure. A MAF Aquatronics pulsed DC mains set electrofishing machine, powered by a Honda 3-kVA petrol generator, operating at 420 V and approximately 3 A with two hand-held anodes was used to enable simultaneous fishing of each stream side (Fig. 2). Two teams of three people performed the fishing while one person remained on the bank for machine operation and safety. Estimates of total fish numbers (absolute density) in this stream could not be calculated from the two-pass removal method as variable and occasionally greater fish numbers are captured in the second fishing passes. Common bully, *Gobiomorphus cotidianus*, is the most abundant species in the Utuhina Stream and obtaining consecutive reductions in this species using multiple pass electrofishing is notoriously difficult. For practical purposes, an estimate of minimum fish density was determined by simply adding the total catch from both passes at each site. Total CPUE and CPUE for each pass at each site could be determined normally. All fish/koura were counted, adult trout were measured, and all fish were returned alive to their respective stream reaches, except for those retained for elemental analysis (see below).

AQUATIC MACROINVERTEBRATE COMMUNITY SURVEY

Semiquantitative analysis of aquatic macroinvertebrates was undertaken within the same three stream reaches examined for relative fish abundance above. Sampling and analysis was carried out as prescribed for soft-bottomed streams by Stark et al. (2001). Briefly, a 0.5 mm mesh, 0.3 m-wide D-net was used to provide ten replicated 1-m sweeps through representative stream bank habitat, sampling a total area of approximately 3 m^2 at each site. True left and true right banks were sampled and enumerated separately at each of the three stream reaches. Samples were preserved in ethanol. Macroinvertebrate sampling was carried out one week prior to electrofishing to reduce the likelihood of either sampling method impacting upon the other.

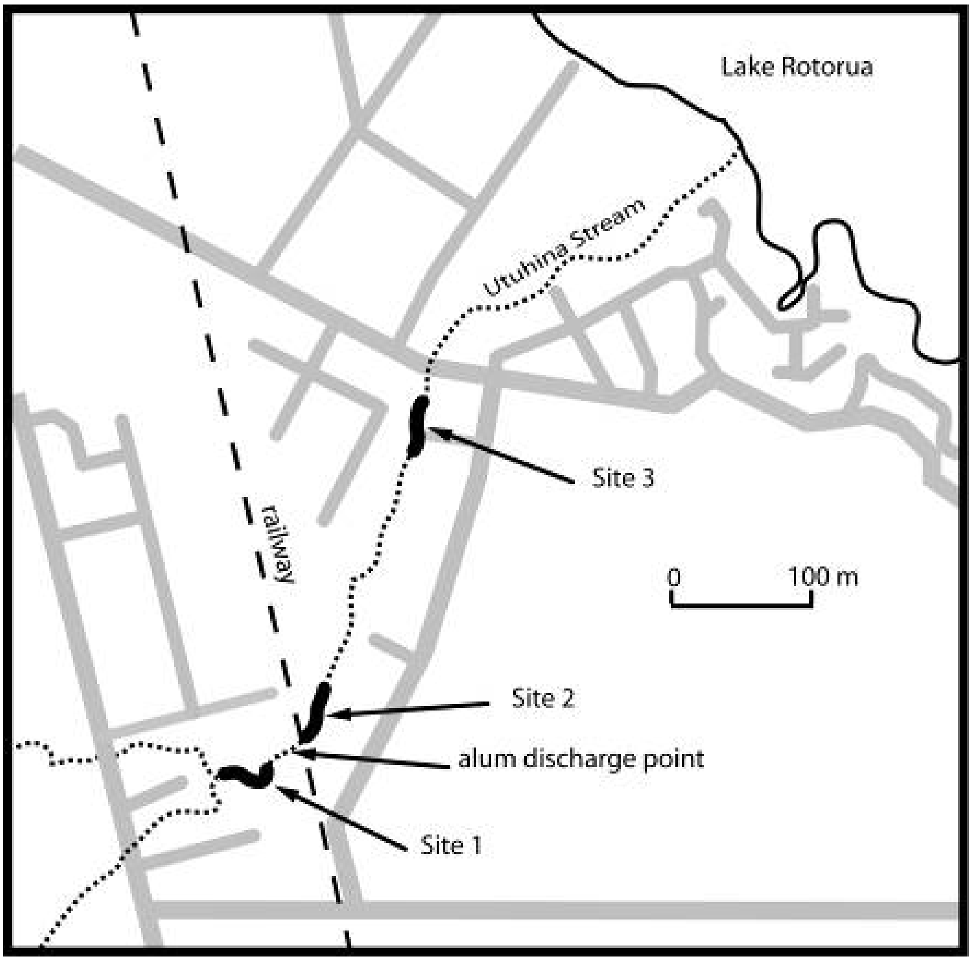


Fig. 1. The Utuhina Stream with fish community survey sites marked above the alum discharge (Site 1), in the alum mixing zone (Site 2) and upstream of Lake Rd (Site 3).

Fig. 2. Two teams of three people simultaneously electrofishing each bank in the alum mixing zone (Site 2) of the Utuhina Stream.

BIOACCUMULATION OF ALUMINIUM IN COMMON BULLY AND KOURA

A suite of 28 elements was measured in bully and koura tissue samples based on established methods (USEPA, 1987). In brief, tissue samples were accurately weighed and digested using tetramethylammonium hydroxide, heat and mixing. The colloidal suspension was then partially oxidized by the addition of hydrogen peroxide and metals solubilised by acidification with nitric acid and heating. Samples were diluted and filtered prior to analysis by inductively-coupled plasma mass spectrometry (Department of Chemistry, Waikato University, Hamilton, NZ). All tissue element concentrations were determined on a wet weight basis. Skeletal muscle and liver were analysed from ten common bully from each site. Hepatopancreas and tail muscle were analysed from ten koura from site 3, however, only two koura large enough to analyse were captured at each of sites 1 and 2.

RESULTS AND DISCUSSION

UTUHINA STREAM FISH COMMUNITY

Four species, common bully (*Gobiomorphus cotidianus*), rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), and koura (*Paranephrops planifrons*), were captured across the three stream sites by electrofishing. Unlike the fish survey conducted in April 2008, no shortfin eels (*Anguilla australis*) were seen. Common bully relative density (fish per 50 m reach) and CPUE (fish/h) were slightly lower at all sites compared to the previous survey July 2008 (Fig. 3). Landman et al. (2008) speculated that the decline in common bully at all sites in the Utuhina Stream after the commencement of alum dosing in 2006 followed by subsequent recovery may have been due to avoidance of high alum dose rates during the first twelve months when dose rates were manipulated to determine the most effective concentration for P removal. However, the lack of long-term monitoring prior to the commencement of alum dosing makes it impossible to assess whether the high fish numbers in June 2006 truly reflected the natural stream condition or were abnormally elevated. The subsequent decline in abundance at the upstream control site tends to suggest the latter. Bully numbers at the upstream site 1 have been consistently lower than the downstream sites due to limited habitat (fewer macrophytes) and the lower numbers in the latest survey may be related to some obvious recent clearance of stream bank vegetation.

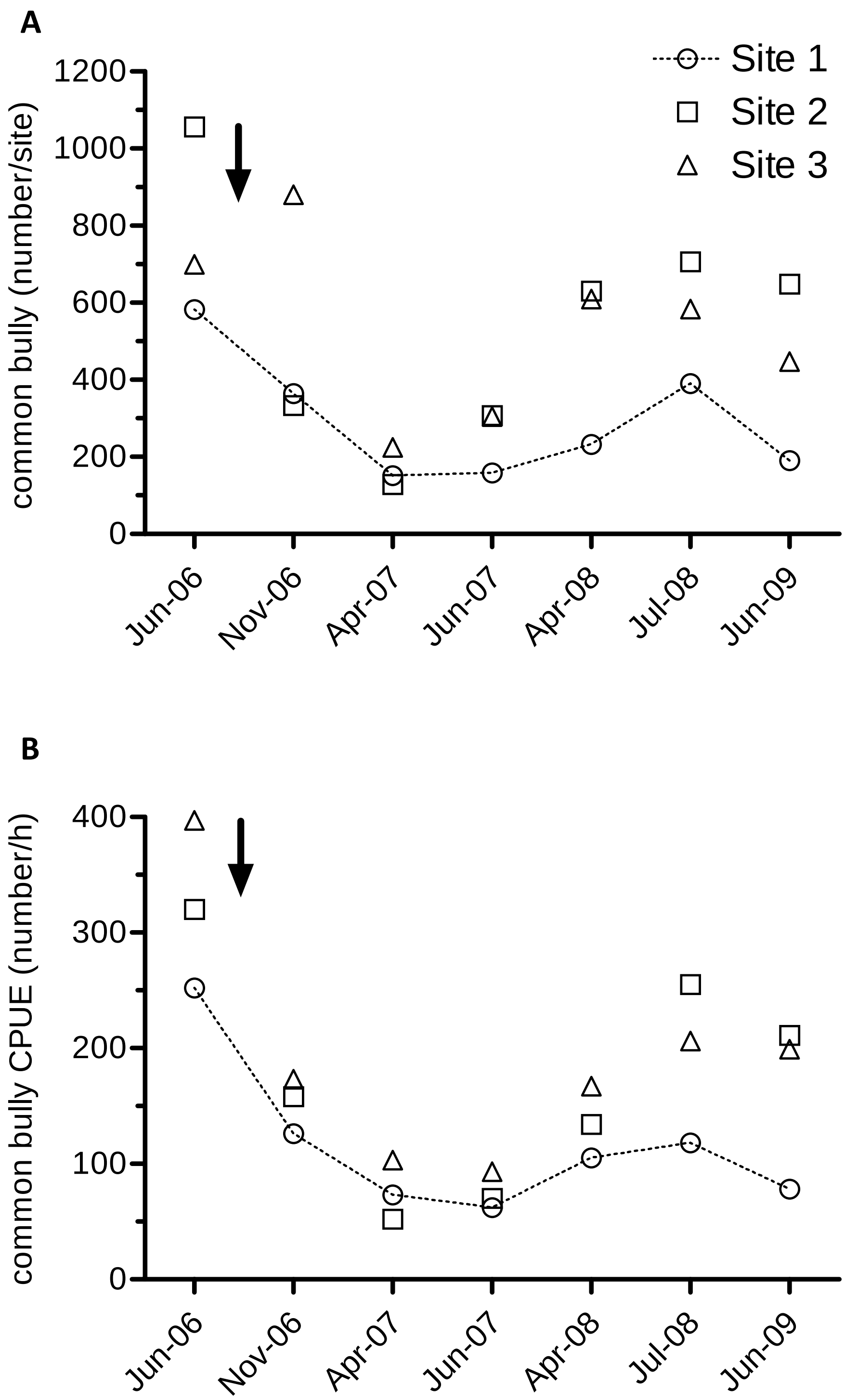


Figure 3. Relative density (A) and CPUE (B) of common bully in the Utuhina Stream. Arrows indicate the commencement of alum dosing in the stream.

Numbers of juvenile trout and CPUE at all sites were similar to previous years and similar across all three sites (Fig. 4). Only one adult trout was captured at site 1, at a location on the true left bank which has yielded adult trout on five previous occasions.

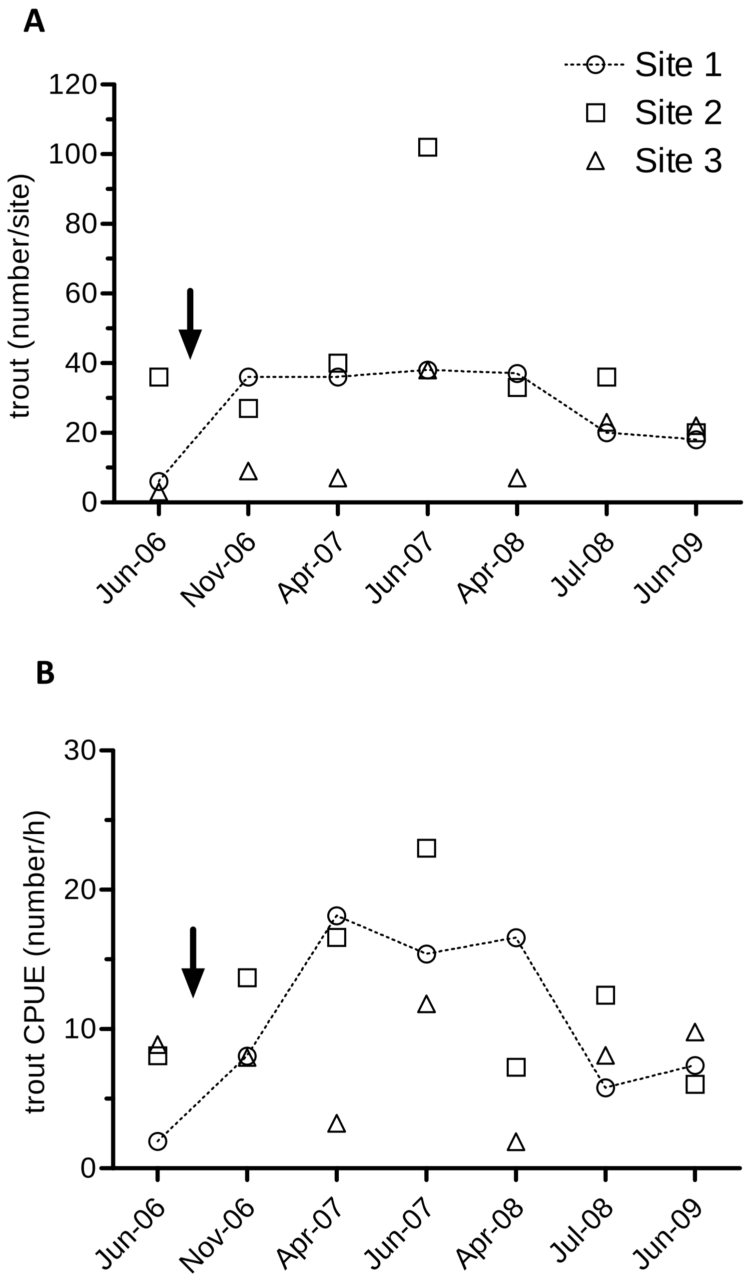


Figure 4. Relative density (A) and CPUE (B) of juvenile trout in the Utuhina Stream. Arrows indicate the commencement of alum dosing in the stream.

Koura abundance and CPUE were similar to July 2008 at sites 1 and 2 but increased at site 3 (Fig. 5). Koura abundance and CPUE have been consistently higher than prior to the commencement of alum dosing.

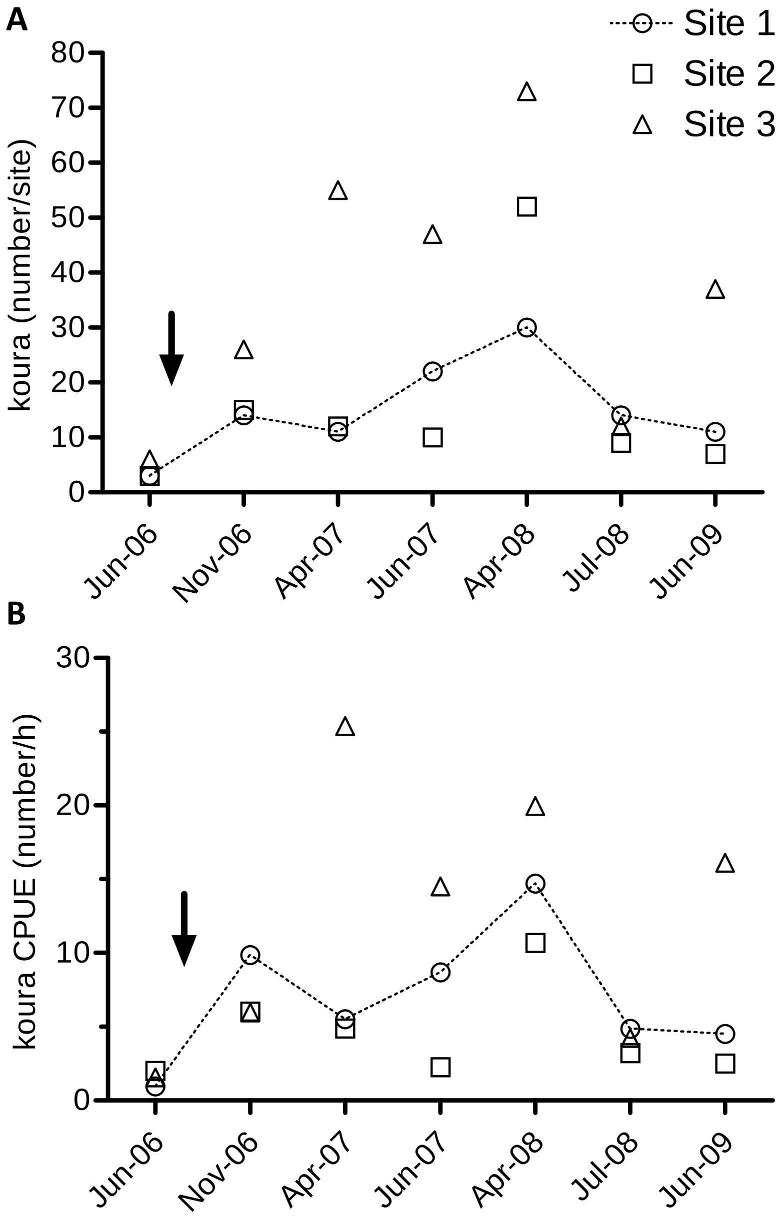


Figure 5. Relative density (A) and CPUE (B) of koura in the Utuhina Stream. Arrows indicate the commencement of alum dosing in the stream.

AQUATIC MACROINVERTEBRATES

Semiquantitative macroinvertebrate community analysis showed no obvious differences between sites (Table 1). Values for the MCI-sb and SQMCI-sb indices fell within the upper range of the "fair" quality class (Table 2) of Stark & Maxted (2007) for all three sites. Furthermore, there is no pattern of change across the sites that could indicate impacts of the alum dosing on macroinvertebrate community composition. Previous studies of macroinvertebrates at the same study sites, both prior to the commencement of alum dosing (May/June 2006), and subsequently (June/July 2006, Feb 2007) showed very similar MCI scores with no significant differences between sites (Clarke 2006, EBOP Unpubl. Data).

Table 1. Summary data for semi-quantitative macroinvertebrate community assessment for the Utuhina Stream in June 2009.

	Site 1		Site 2		Site 3	
	left	right	left	right	left	right
Number of Taxa	23	27	27	25	21	19
EPT Value	8	8	8	8	7	7
% EPT (taxa number)	34.8%	29.6%	29.6%	32.0%	33.3%	36.8%
MCI Value	91.3	83.7	88.1	87.2	92.4	86.3
SQMCI Value	1.64	4.19	2.64	2.33	2.04	3.16
MCI-sb Value	109.0	97.6	101.9	92.0	100.9	86.8
SQMCI-sb	4.06	5.04	4.49	4.06	4.07	4.60

Table 2. Interpretation of soft-bottomed stream MCI indices.

Stark & Maxted (2007) quality class	Stark (1998) descriptions	MCI-sb	SQMCI-sb
Excellent	Clean water	>119	>5.99
Good	Doubtful quality or possible mild pollution	100-119	5.00-5.99
Fair	Probable moderate pollution	80-99	4.00-4.99
Poor	Probable severe pollution	<80	<4.00

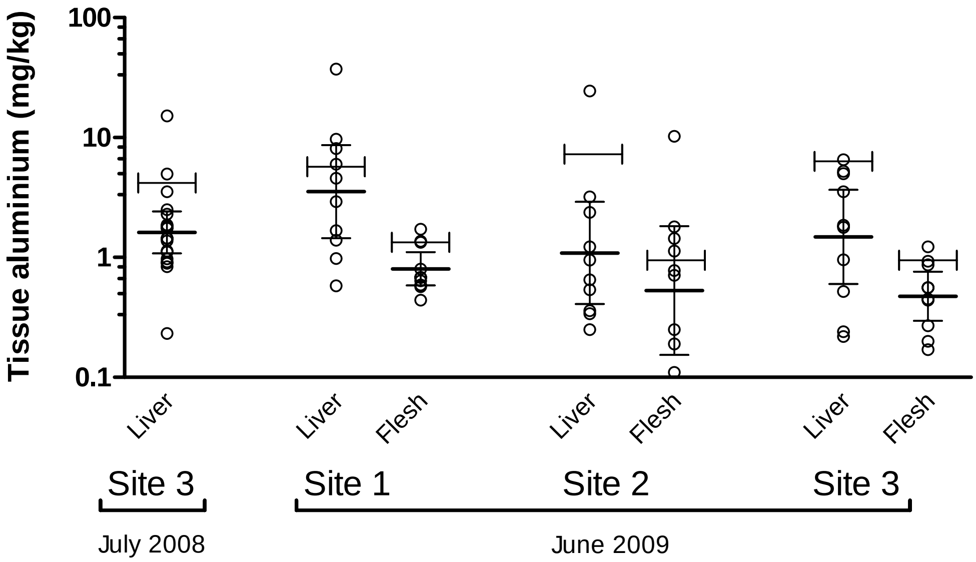
BIOACCUMULATION OF ALUMINIUM

Toxic effects of aqueous aluminium follow a bimodal distribution with declining water pH. Asphyxiation due to polymerization of aluminium on gill surfaces occurs in the pH range of 6.5 to 5.5, whereas impaired ion regulation dominates in the pH range of 5.5 to 4.5 (Sparling & Lowe 1996). There was no evidence of increased bioaccumulation of aluminium downstream of the Utuhina Stream alum diffuser, and total aluminium concentrations were low in tissues from both species (Fig. 6). Mean aluminium concentrations in tissues of common bully were typically slightly below the method detection limit due to very limited sample weights, while those of koura were higher, although low sample numbers at sites 1 and 2 limits any comparison of koura results between sites. Mean concentration in koura hepatopancreas from site 3 was equal to that reported by Landman et al. (2008) from koura sampled from the same site in July 2008. It is possible that comparisons of aluminium accumulation between sites may be compromised by the movement of bully and koura within the stream, however, adult common bully and koura are more likely to be locally resident than would be the case for juveniles. There are no studies of aluminium depuration from fish or crayfish internal organs, but fish gills can depurate aluminium within 2 days of removal from exposure (Allin & Wilson 2000). If the internal half-life for aluminium is short enough then movement between sites would have to be rapid and regular to eliminate inter-site comparisons. As reported by Landman et al. (2008) aluminium concentrations were approximately three to five-fold greater in the hepatopancreas compared to the tail flesh, indicating tissue-specific accumulation of this element. Aluminium was also concentrated in the livers of common bully by an equivalent factor when compared to flesh. It is therefore recommended that future monitoring of bioavailable aluminium be limited to only analyzing the hepatopancreas of koura and the livers of common bully rather than flesh, however, aluminium toxicity in fish is typically associated with aluminium polymerization at the gill surface and measuring gill aluminium concentration in addition to liver/hepatopancreas would provide a more thorough and instantaneous assessment of aluminium exposure.

METHOD DETECTION LIMITS AND REPORTING

The Method Detection Limit (MDL) is the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero, and will vary depending on the analyte, the sample matrix, and the sample volume/weight. A common problem encountered in tissue contaminant analysis is values that lie below the nominal method detection limit. Non-reporting of such values leads to overestimation of average tissue concentration (left censored data). A variety of simple solutions have been employed to deal with such data including reporting these values as zero concentration, as equal to the MDL (Environment Canada), as equal to the MDL divided by 2 (Environment Canada), as equal to the MDL divided by √2 (Centres for Disease Control). However, Succop et al. (2004) determined that such procedures may generate considerable bias, particularly when a significant proportion of values lie below the MDL. They recommended that numerical values be reported for all samples but that values below the MDL are indicated accordingly. This approach has been adopted here for aluminium values.

A



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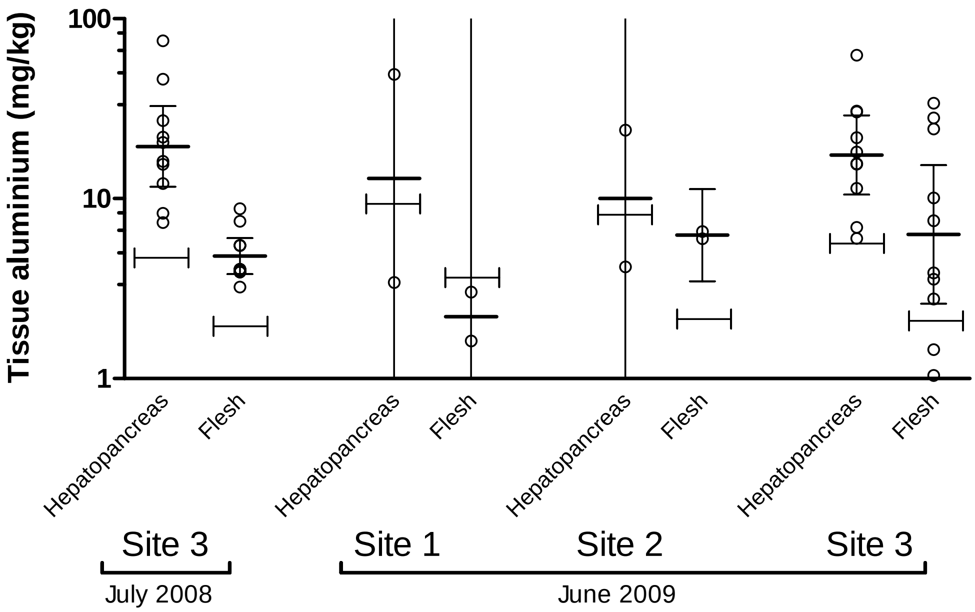

Figure 6. Tissue aluminium concentrations (mg/kg) for liver and flesh of common bully (A) and hepatopancreas and flesh of koura (B). Summary statistics are geometric mean (bold lines) ± 95% confidence limits. Transverse bars represent average method detection limits for each sample. N = 10 individuals per site except for koura at sites 1 and 2 (n = 2).

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APPENDIX

Table A1. Aquatic macroinvertebrate community data for the Utuhina Stream (June 2009).

Taxa	MCI score	MCI-sb score	Site 1 Left	Site 1 Right	Site 2 Left	Site 2 Right	Site 3 Left	Site 3 Right
Mayfly *Acanthophlebia*	7	9.6						
Mayfly *Ameletopsis*	10	10.0						
Mayfly *Arachnocolus*	8	8.1						
Mayfly *Atalophlebioides*	9	4.4						
Mayfly *Austroclima*	9	6.5	R	C	R	R	R	R
Mayfly *Austronella*	7	4.7						
Mayfly *Coloburiscus*	9	8.1						
Mayfly *Deleatidium*	8	5.6						
Mayfly *Ichthybotus*	8	9.2						
Mayfly *Isothraulus*	8	7.1						
Mayfly *Mauiulus*	5	4.1						
Mayfly *Neozephlebia*	7	7.6						
Mayfly *Nesameletus*	9	8.6						
Mayfly *Oniscigaster*	10	5.1						
Mayfly *Rallidens*	9	3.9						
Mayfly *Siphlaenigma*	9	9.0						
Mayfly *Tepakia*	8	7.6						
Mayfly *Zephlebia*	7	8.8	A	A	A	C	C	C
Stonefly *Acroperla*	5	5.1						
Stonefly *Austroperla*	9	8.4						
Stonefly *Cristaperla*	8	8.0						
Stonefly *Megaleptoperla*	9	7.3	R	R	C	R	R	R
Stonefly *Nesoperla*	5	5.7						
Stonefly *Spaniocerca*	8	8.8						
Stonefly *Stenoperla*	10	9.1						
Stonefly *Taraperla*	7	8.3						
Stonefly *Zelandobius*	5	7.4	A	VA	C	R	C	C
Stonefly *Zelandoperla*	10	8.9						
Caddisfly *Alloecentrella*	9	9.0						
Caddisfly *Aoteapsyche*	4	6.0				R		
Caddisfly *Beraeoptera*	8	7.0						
Caddisfly *Confluens*	5	7.2						
Caddisfly *Costachorema*	7	7.2						
Caddisfly Ecnomidae *Zelandoptila*	8	7.0						
Caddisfly *Edpercivalia*	9	6.3						
Caddisfly *Helicopsyche*	10	8.6						
Caddisfly *Hudsonema*	6	6.5	R	R	R	R		R
Caddisfly *Hydrobiosella*	9	7.6						
Caddisfly *Hydrobiosis*	5	6.7		R	R			
Caddisfly *Hydrochorema*	9	9.0						
Caddisfly *Kokiria*	9	9.0						
Caddisfly *Neurochorema*	6	6.0						
Caddisfly *Oecetis*	6	6.8						
Caddisfly Oeconesidae	9	6.4						
Caddisfly *Olinga*	9	7.9						
Caddisfly *Orthopsyche*	9	7.5						
Caddisfly *Oxyethira*	2	1.2	C	C	R	C	R	R
Caddisfly *Paroxyethira*	2	3.7						
Caddisfly *Philorheithrus*	8	5.3						

Table A1 continued

Taxa	MCI score	MCI-sb score	Site 1 Left	Site 1 Right	Site 2 Left	Site 2 Right	Site 3 Left	Site 3 Right
Caddisfly *Plectrocnemia*	8	6.6						
Caddisfly *Polyplectropus*	8	8.1					C	
Caddisfly *Pseudoeconesus*	9	6.4						
Caddisfly *Psilochorema*	8	7.8	R					
Caddisfly *Pycnocentrella*	9	9.0						
Caddisfly *Pycnocentria*	7	6.8						
Caddisfly *Pycnocentrodes*	5	3.8						
Caddisfly *Tiphobiosis*	6	9.3						
Caddisfly *Triplectides*	5	5.7	R	C	R	C	C	R
Caddisfly *Zelolessica*	10	6.5						
Damselfly *Austrolestes*	6	0.7						
Damselfly *Ischnura*	6	3.1						
Damselfly *Xanthocnemis*	5	1.2				R		
Dragonfly Aeshnidae	5	1.4						
Dragonfly *Antipodochlora*	6	6.3						
Dragonfly *Hemicordulia*	5	0.4						
Dragonfly *Procordulia*	6	3.8						
Bug *Anisops*	5	2.2						
Bug *Diaprepocoris*	5	4.7						
Bug *Hydrometra*	5	4.6						
Bug *Mesovelia*	5	5.0						
Bug *Microvelia*	5	4.6						
Bug Saldidae	5	3.9						
Bug *Sigara*	5	2.4						
Dobsonfly *Archichauliodes*	7	7.3						
Scorpionfly *Nannochorista*	7	7.0						
Lacewing *Kempynus*	5	5.0						
Lacewing *Sisyra*	5	5.0						
Beetle *Antiporus*	5	3.5			R			
Beetle *Berosus*	5	5.0						
Beetle Dytiscidae	5	0.4						
Beetle Elmidae	6	7.2		C	R		R	
Beetle Hydraenidae	8	6.7						
Beetle Hydrophilidae	5	8.0						
Beetle *Liodessus*	5	4.9						
Beetle Ptilodactylidae	8	7.1						
Beetle *Rhantus*	5	1.0						
Beetle Scirtidae	8	6.4						
Beetle Staphylinidae	5	6.2						
True Fly *Aphrophila*	5	5.6	R	R				
True Fly *Austrosimulium*	3	3.9		C	R	R	R	
True Fly Blephariceridae	7	7.0						
True Fly Ceratopogonidae	3	6.2	R	R				
True Fly *Chironomus*	1	3.4	VA	C	A	A	VA	R
True Fly *Corynoneura*	2	1.7						
True Fly Culicidae	3	1.2						R
True Fly Dolichopididae	3	8.6						
True Fly Empididae	3	5.4		R	C		R	
True Fly Ephydridae	4	1.4						
True Fly Eriopterini	9	7.5						
True Fly *Harrisius*	6	4.7			R			
True Fly Hexatomini	5	6.7				R		
True Fly *Limonia*	6	6.3						
True Fly *Lobodiamesa*	5	7.7						
True Fly *Maoridiamesa*	3	4.9						
True Fly *Mischoderus*	4	5.9			R			
True Fly *Molophilus*	5	6.3	R		R	R		
True Fly Muscidae	3	1.6	R	R	R	R		

Table A1 continued

Taxa	MCI score	MCI-sb score	Site 1 Left	Site 1 Right	Site 2 Left	Site 2 Right	Site 3 Left	Site 3 Right
True Fly *Nothodixa*	4	9.3						
True Fly Orthocladiinae	2	3.2	A	A	VA	A	A	A
True Fly *Paradixa*	4	8.5						
True Fly *Paralimnophila*	6	7.4						
True Fly Pelecorhynchidae	9	9.0						
True Fly Podominae	8	6.4						
True Fly *Polypedilum*	3	8.0	C	A	A	C	C	C
True Fly Psychodidae	1	6.1	R	R	R			
True Fly Sciomyzidae	3	3.0						
True Fly *Stictocladius*	8	8.0						
True Fly Stratiomyidae	5	4.2		R	R			
True Fly Syrphidae	1	1.6						
True Fly Tabanidae	3	6.8						
True Fly Tanypodinae	5	6.5	A	R	C	R		
True Fly Tanytarsini	3	4.5						
True Fly Thaumaleidae	9	8.8						
True Fly *Zelandotipula*	6	3.6						
Moth *Hygraula*	4	1.3						
Collembola	6	5.3	C	C	A	C	C	C
Crustacea Cladocera	5	0.7					R	
Crustacea Copepoda	5	2.4	R			C	R	R
Crustacea *Halicarcinus* crabs	3	5.1						
Crustacea *Helice* crabs	3	6.6						
Crustacea Isopoda	5	4.5						
Crustacea Mysid shrimps	5	6.4						
Crustacea Ostracoda	3	1.9				R	R	R
Crustacea *Paracalliope*	5	5.0						
Crustacea *Paraleptamphopus*	5	5.0						
Crustacea *Paranephrops*	5	8.4	R				R	
Crustacea *Paranthura*	5	4.9						
Crustacea *Paratya*	5	3.6						
Crustacea *Phreatogammarus*	5	5.0						
Crustacea Talitridae	5	5.0						
Crustacea Tanaidacea	4	6.8						
MITES	5	5.2	C	R	C	A	A	C
SPIDERS *Dolomedes*	5	6.2						
TARDIGRADES	4.5	4.5						
Mollusc *Ferrissia*	3	2.4						
Mollusc *Glyptophysa*	5	0.3						
Mollusc *Gyraulus*	3	1.7						R
Mollusc *Hyridella*	3	6.7						
Mollusc *Latia*	3	6.1						
Mollusc Lymnaeidae	3	1.2			R	R		
Mollusc *Melanopsis*	3	1.9						
Mollusc *Physella*	3	0.1		R				
Mollusc *Potamopyrgus*	4	2.1	A	VA	R	C	C	R
Mollusc Sphaeriidae	3	2.9		R		R		
OLIGOCHAETES	1	3.8	VVA	A	VA	VA	VA	A
LEECHES	3	1.2						
PADDLEWORMS	3	6.7						
FLATWORMS	3	0.9						
Rhabdocoel Flatworms	3	0.9		R				R
NEMATODES	3	3.1						
NEMERTEANS	3	1.8						
NEMATOMORPHS	3	4.3						
HYDROIDS (*Hydra viridis*)	3	1.6						
BRYOZOA	4	4.0						
Number of Taxa			23	27	27	25	21	19

Table A2. Elemental concentrations (mg/kg wet weight) determined by ICPMS in common bully liver and flesh from the Utuhina Stream. Values are geometric mean with 95% confidence intervals in parentheses. Missing values were below method detection limits for all samples (MDL). MDL values varied with element and tissue type. N = 10 for each tissue and site.

	Common bully liver			Common bully flesh		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Li	—	—	—	—	—	—
B	—	—	—	—	—	—
Na	977 (866,1102)	816 (721, 923)	912 (781, 1065)	699 (611, 799)	726 (598, 881)	852 (795, 913)
Mg	196 (176, 219)	204 (176, 236)	189 (160, 220)	254 (228, 284)	207 (174, 246)	218 (211, 224)
Al	3.54 (1.45, 8.64)	1.09 (0.41, 2.91)	1.49 (0.60, 3.67)	0.80 (0.58, 1.11)	0.53 (0.15, 1.83)	0.47 (0.30, 0.76)
P	2463 (2351, 2581)	2087 (1788, 2436)	1863 (1610, 2156)	2042 (1750, 2383)	1541 (1292, 1839)	1726 (1600, 1861)
K	2961 (2805, 3125)	2818 (2518, 3154)	2743 (2368, 3178)	3914 (3564, 4299)	3075 (2655, 3561)	3562 (3421, 3709)
Ca	116 (81, 167)	454 (238, 864)	322 (268, 387)	497 (317, 779)	483 (354, 658)	524 (407, 675)
V	—	—	—	—	—	—
Cr	—	—	—	—	—	—
Fe	43.4 (33.3, 56.5)	25.8 (18.3, 36.3)	28.0 (20.3, 38.6)	4.27 (2.48, 7.36)	4.24 (1.22, 14.7)	1.22 (0.30, 4.94)
Mn	1.03 (0.86, 1.25)	0.74 (0.57, 0.96)	0.70 (0.53, 0.92)	0.23 (0.15, 0.35)	0.15 (0.08, 0.26)	0.15 (0.10, 0.23)
Co	—	—	—	—	—	—
Ni	—	—	—	—	—	—
Cu	2.51 (1.85, 3.41)	1.60 (1.12, 2.18)	1.39 (1.15, 1.66)	0.42 (0.28, 0.63)	0.28 (0.21, 0.38)	0.34 (0.27, 0.42)
Zn	25.7 (23.3, 28.5)	26.9 (21.5, 33.8)	27.4 (23.6, 31.8)	8.1 (6.4, 10.2)	10.1 (8.0, 12.8)	12.3 (10.2, 14.8)
As	0.87 (0.45, 1.66)	0.53 (0.26, 1.09)	0.74 (0.36, 1.52)	0.54 (0.42, 0.69)	0.57 (0.45, 0.73)	0.45 (0.36, 0.57)
Se	1.04 (0.62, 1.75)	0.78 (0.51, 1.19)	0.79 (0.49, 1.26)	0.44 (0.35, 0.53)	0.38 (0.29, 0.50)	0.44 (0.37, 0.54)
Sr	0.39 (0.26, 0.58)	1.11 (0.58, 2.15)	0.61 (0.44, 0.84)	1.37 (0.81, 2.31)	1.36 (0.91, 2.02)	1.43 (1.04, 1.96)
Ag	—	—	—		—	—
Cd	—	—	—	—	—	—
Ba	—	—	—	0.62 (0.36, 1.09)	0.48 (0.30, 0.76)	0.49 (0.29, 0.82)
La	—	—	—	—	—	—
Hg	—	—	—	0.10 (0.07, 0.15)	0.08 (0.05, 0.11)	0.11 (0.08, 0.15)
Tl	—	—	—	—	—	—
Pb	—	—	—	—	—	—
Bi	—	—	—	—	—	—
U	—	—	—	—	—	—

Table A3. Elemental concentrations (mg/kg wet weight) determined by ICPMS in koura hepatopancreas and flesh from the Utuhina Stream. Values are geometric mean with 95% confidence intervals in parentheses. Missing values were consistently below method detection limits (MDL). MDL values varied with element and tissue type. N = 2 for sites 1 and 2, n= 10 for site 3.

	Koura hepatopancreas			**Koura flesh**		
	Site 1	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**
Li	—	—	—	—	—	—
B	—	—	—	—	—	—
Na	2074	2275	2187 (1988, 2405)	1710	1538	1628 (1486, 1783)
Mg	176	271	207 (191, 224)	275	336	266 (247, 287)
Al	13.0	10.0	17.5 (10.6, 29.0)	2.2	6.3	6.3 (2.6, 15.3)
P	1787	1894	1611 (1506, 1723)	1870	1711	1401 (1314, 1494)
K	2236	2709	2315 (2129, 2518)	3705	4105	3499 (3286, 3725)
Ca	611	1430	1038 (933, 1155)	390	817	573 (508, 647)
V	—	—	—	—	—	—
Cr	—	—	—	—	—	—
Fe	—	—	65.6 (45.3, 94.8)	—	—	1.9 (0.2, 18.7)
Mn	13.5	9.78	24.1 (17.9, 32.3)	0.88	0.77	1.24 (0.76, 2.02)
Co	—	—	0.38 (0.28, 0.51)	—	—	—
Ni	—	—	—	—	—	—
Cu	30.5	34.0	32.2 (20.8, 49.9)	12.3	9.2	6.9 (6.1, 7.7)
Zn	101	83	122 (102, 146)	14.1	15.3	13.5 (11.7, 15.6)
As	—	—	—	—	—	—
Se	—	—	—	—	—	—
Sr	6.5	12.3	14.6 (12.5, 17.1)	2.0	4.4	3.7 (3.2, 4.3)
Ag	—	—	—	—	—	—
Cd	0.46	0.50	0.35 (0.29, 0.42)	—	—	—
Ba	7.5	10.3	23.3 (18.1, 30.0)	1.0	2.1	2.2 (1.6, 2.9)
La	—	—	—	—	—	
Hg	—	—	—	—	—	0.08 (0.07, 0.10)
Tl	—	—	—	—	—	—
Pb	—	—	—	—	—	—
Bi	—	—	—	—	—	—
U	—	—	—	—	—	—