UTUHINA STREAM MONITORING 2010/2011:

EFFECTS OF CONTINUOUS ALUM DOSING ON FISH AND AQUATIC INVERTEBRATES

CBER CONTRACT REPORT 128

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Utuhina Stream monitoring 2010/2011: effects of continuous alum dosing on fish and aquatic invertebrates

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SUMMARY

This report presents the results of an ongoing assessment of the fish and aquatic macroinvertebrate communities of the Utuhina Stream from 2010 and 2011, 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.

Macroinvertebrates, fish and koura were sampled from one control and two treatment reaches of the Utuhina Stream in June 2010 and June 2011. Catch rates for common bully, juvenile trout and koura have fluctuated across all sites since monitoring began in 2006. Abundance of all species was relatively high in June 2010 but significantly decreased in June 2011, probably resulting from alterations in stream habitat and morphology arising from very large flood flows early in 2011. No obvious effects of alum dosing on stream fish or macroinvertebrate communities were 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 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 resulting from continuous alum dosing of the Utuhina Stream, although the inclusion of common bully gill tissue in 2011 revealed some evidence for greater aluminium deposition on fish gills within the alum mixing zone that declined downstream. Tissue aluminium concentrations were slightly 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 (Bay of Plenty Regional Council, 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 22nd June 2010 and 22nd June 2011. 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.

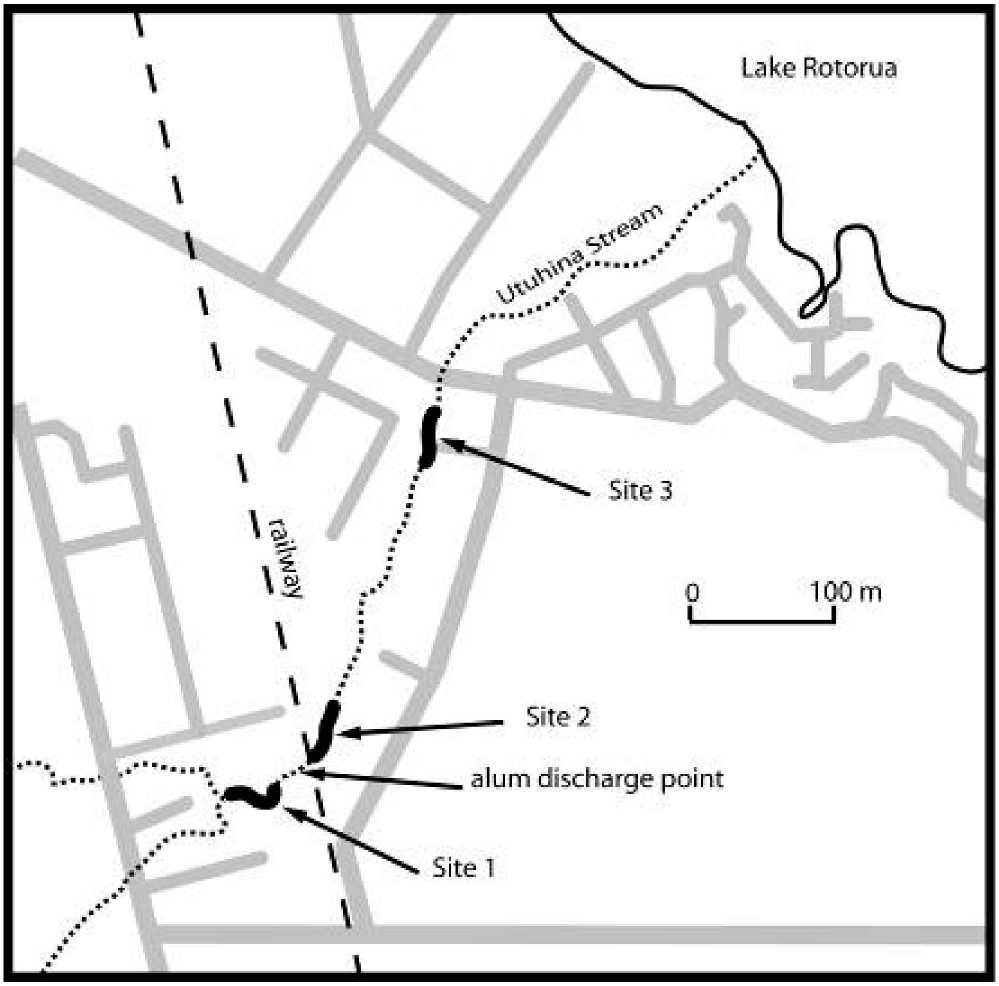


Fig. 1. The Utuhina Stream with fish community survey sites marked above the alum discharge (Site 1), in the alum mixing zone (Site 2) and upstream of Lake Rd (Site 3).

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 in 2010, and elemental analysis of gills from common bully was included in 2011. Hepatopancreas and tail muscle were analysed from up to ten adult koura from each site, however, no koura large enough to analyse were captured at 2 in 2010. Method blanks and matrix standards (DOLT and DORM; Canadian Research Council) were run in parallel with all samples.

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 all three stream sites by electrofishing in both years. Additionally, 1 shortfin eel (*Anguilla australis*) was captured in 2010, and 1 goldfish (*Carassius auratus*) and 1 mosquitofish (*Gambusia affinis*) were captured in 2011. Common bully relative density (fish per 50 m reach) and CPUE (fish/h) were relatively high in June 2010 but significantly decreased at all sites in June 2011 (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). Ling & Brijs (2009) speculated that the lower numbers observed at site 1 in 2009 may be related to some obvious recent clearance of stream bank vegetation. Significant scouring and loss of stream bank vegetation was observed at all sites in June 2011 compared to previous years as well as a slight lowering of the stream bed at site 3, probably as a result of two very large flood flows (2.5 m and 2.9 m) that occurred in late January 2011. These were the highest flows recorded in the Utuhina Stream since the start of the monitoring programme in 2006.

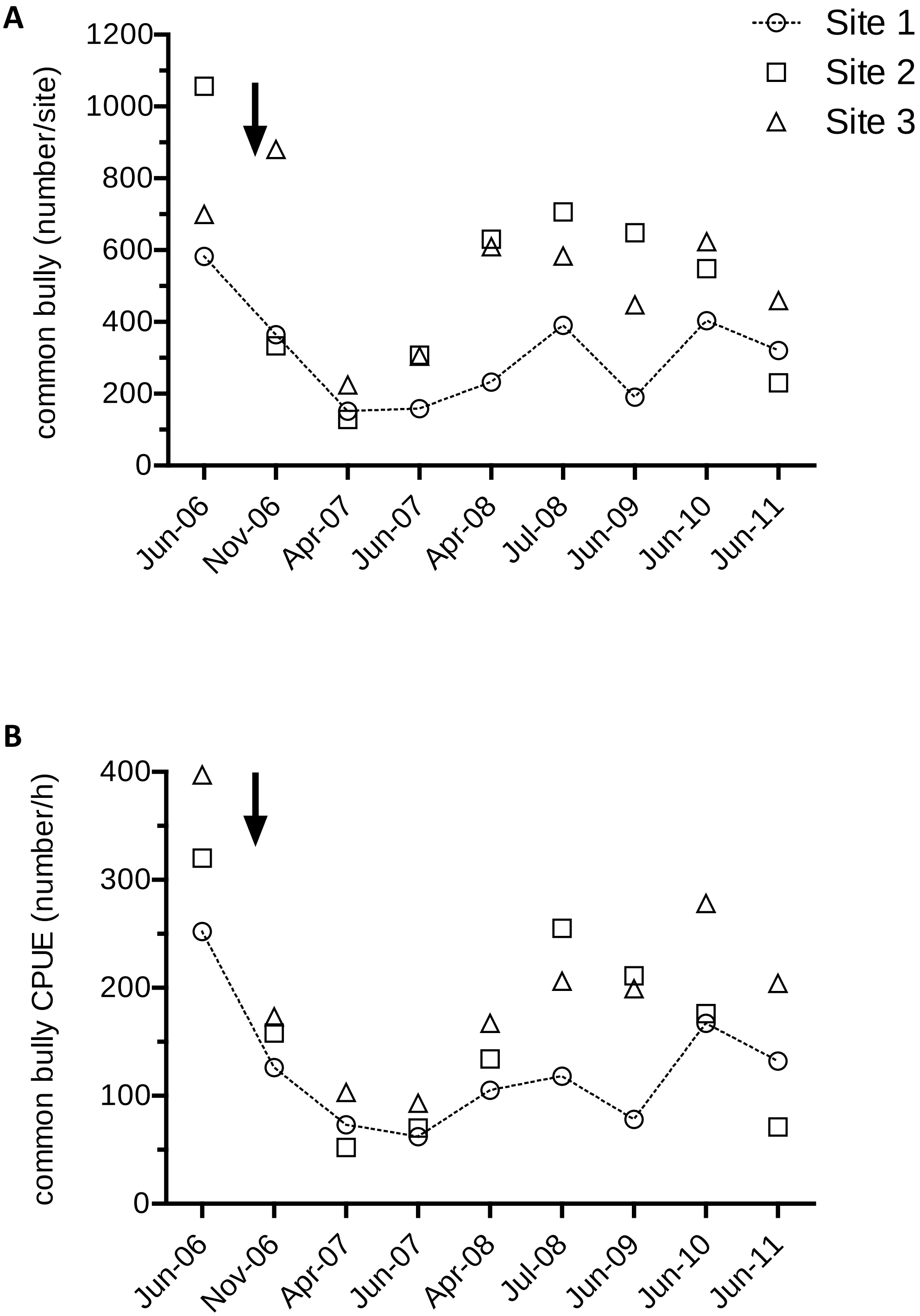


Figure 3. Relative density (A) and CPUE (B) of common bully in the Utuhina Stream since June 2006. Arrows indicate the commencement of alum dosing in the stream.

Numbers of juvenile trout and CPUE at all sites were much lower in 2011 than previous years and similar across all three sites (Fig. 4). No large adult trout were captured or seen in 2011.

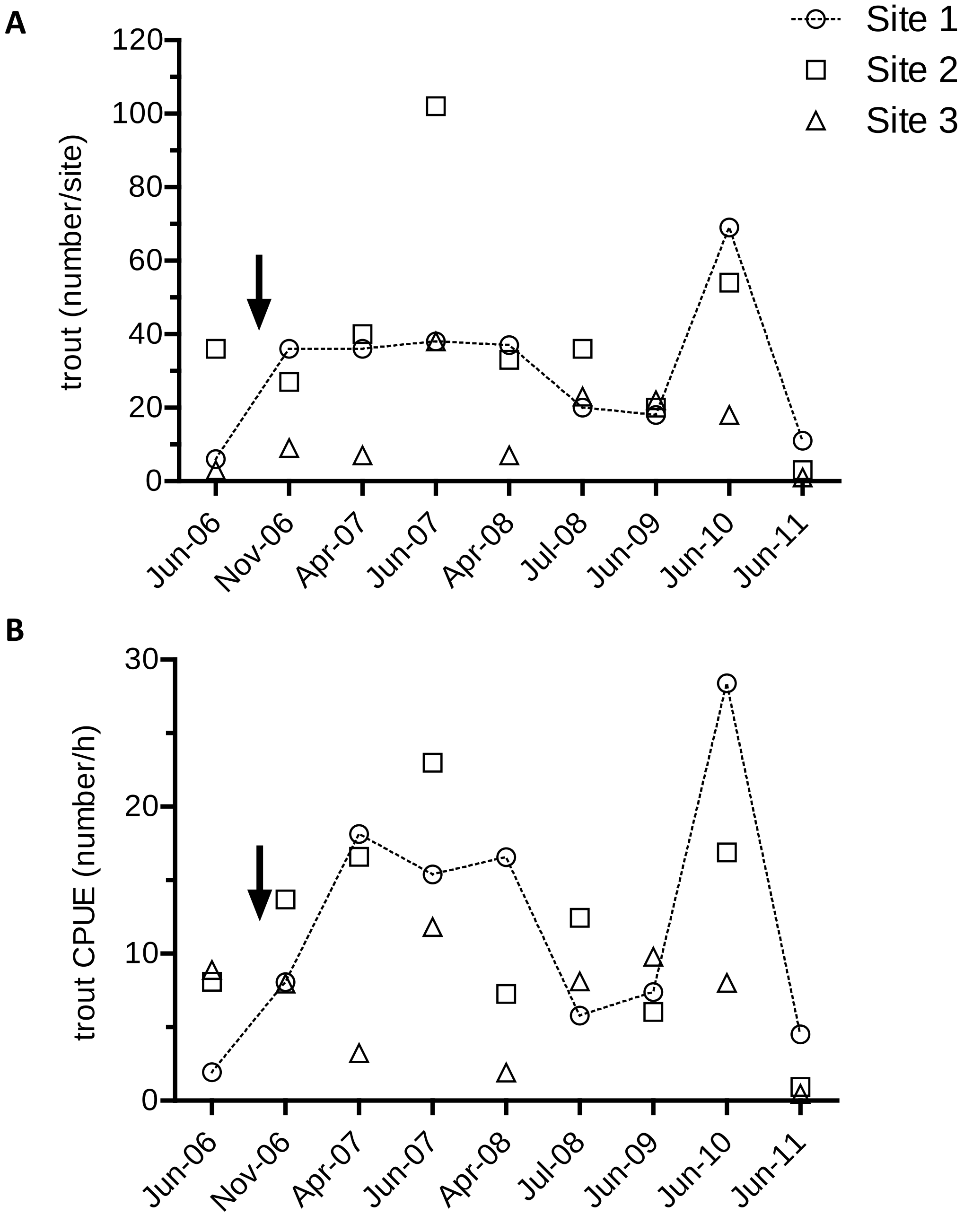


Figure 4. Relative density (A) and CPUE (B) of juvenile trout in the Utuhina Stream. Arrows indicate the commencement of alum dosing in the stream.

Koura abundance and CPUE were relatively high at all sites in June 2010 but decreased in June 2011 (Fig. 5). Koura abundance and CPUE remain consistently higher than prior to the commencement of alum dosing.

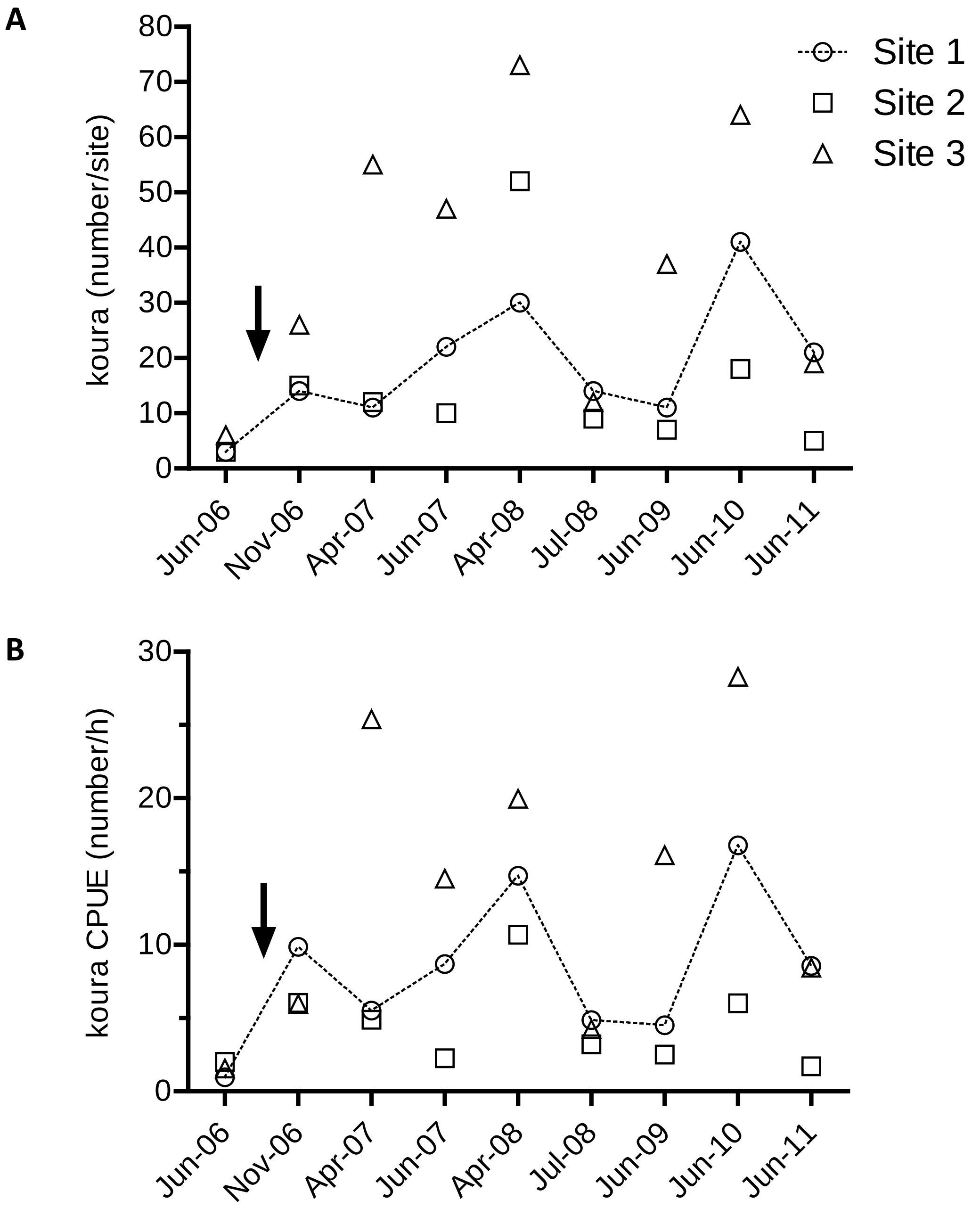


Figure 5. Relative density (A) and CPUE (B) of koura in the Utuhina Stream. Arrows indicate the commencement of alum dosing in the stream.

AQUATIC MACROINVERTEBRATES

Semi-quantitative macroinvertebrate community analysis showed no obvious differences between sites but a slight improvement in 2010 and 2011 compared with 2009 (Table 1). Values for the MCI-sb and SQMCI-sb indices fell within the “good” quality class (Table 2) of Stark & Maxted (2007) for all three sites. There was 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).

Eriksen et al. (2009) studied the effects of alum dosing a stream in combination with sulphuric acid (reducing the stream pH from 6.5 to 5.5) to enhance the toxicity of aluminium to the salmon ectoparasite *Gyrodactylus salaris*. They found that the treatment induced catashrophic drift in some but not all macroinvertebrate groups. Those most affected were ephemeroptera and trichoptera, whilst the plecoptera were least affected.

Barbiero et al. (1988) also found catastrophic effects of continuous alum dosing for one week in the Cuyahoga River, however, the dose rate in this study was extremely high resulting in massive accumulation of an anaerobic, benthic alum floc downstream of the alum diffuser. Invertebrate drift and mortality was assumed to have resulted from significant decrease in stream pH or anaerobic smothering by the alum floc.

No adverse impacts of continuous alum dosing have been seen in the Utuhina Stream since the initiation of alum dosing probably because the dose rate is low and highly controlled, being dependent on stream discharge, and the low dose rate does not significant decrease stream pH.

Table 1. Summary data for semi-quantitative macroinvertebrate community assessment for the Utuhina Stream in June 2009, 2010 and 2011.

	Site 1		Site 2		Site 3	
2009	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
	Site 1		Site 2		Site 3	
2010	Left	right	left	right	left	right
Number of Taxa	22	27	19	23	15	22
EPT Value	11	11	7	12	7	10
% EPT (taxa number)	50.0%	40.7%	36.8%	52.2%	46.7%	45.5%
MCI Value	102.7	98.5	86.3	107.0	92.0	103.6
SQMCI Value	4.52	4.52	2.57	4.23	3.48	4.75
MCI-sb Value	112.5	112.2	100.8	115.0	109.6	112.5
SQMCI-sb	4.16	4.36	4.57	4.98	5.10	5.63
	Site 1		Site 2		Site 3	
2011	Left	right	left	right	left	right
Number of Taxa	24	21	20	21	19	28
EPT Value	11	8	8	9	8	9
% EPT (taxa number)	45.8%	38.1%	40.0%	42.9%	42.1%	32.1%
MCI Value	99.2	98.1	90.0	93.3	95.8	88.6
SQMCI Value	4.01	4.20	1.98	2.74	1.54	1.75
MCI-sb Value	112.2	108.7	102.1	106.7	110.5	93.4
SQMCI-sb	4.75	4.99	3.91	3.61	3.88	3.65

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 little evidence of significant bioaccumulation of aluminium downstream of the Utuhina Stream alum diffuser, and total aluminium concentrations were low in tissues from both species (Figs. 6 & 7). Concentrations of aluminium in the tissues of koura and common bully are highly consistent across years with higher aluminium in the hepatopancreas and liver of koura and common bully, respectively, than in the flesh. Because the gills are a major site of aluminium accumulation in fish, particularly at pH values below 6.5, Ling & Brijs (2009) recommended that the gills of common bully should be analysed for comparison with other tissues and this was done in the 2011 assessment. Aluminium concentrations were higher in gill tissue than other tissues at all sites and there was some evidence of higher aluminium in common bully gills downstream of the alum diffuser (site 2) that declined slightly at the farthest downstream site (site 3), but the increased aluminium accumulation on gills is not thought to be detrimental and clearly does not translate to greater aluminium bioaccumulation in other fish tissues.

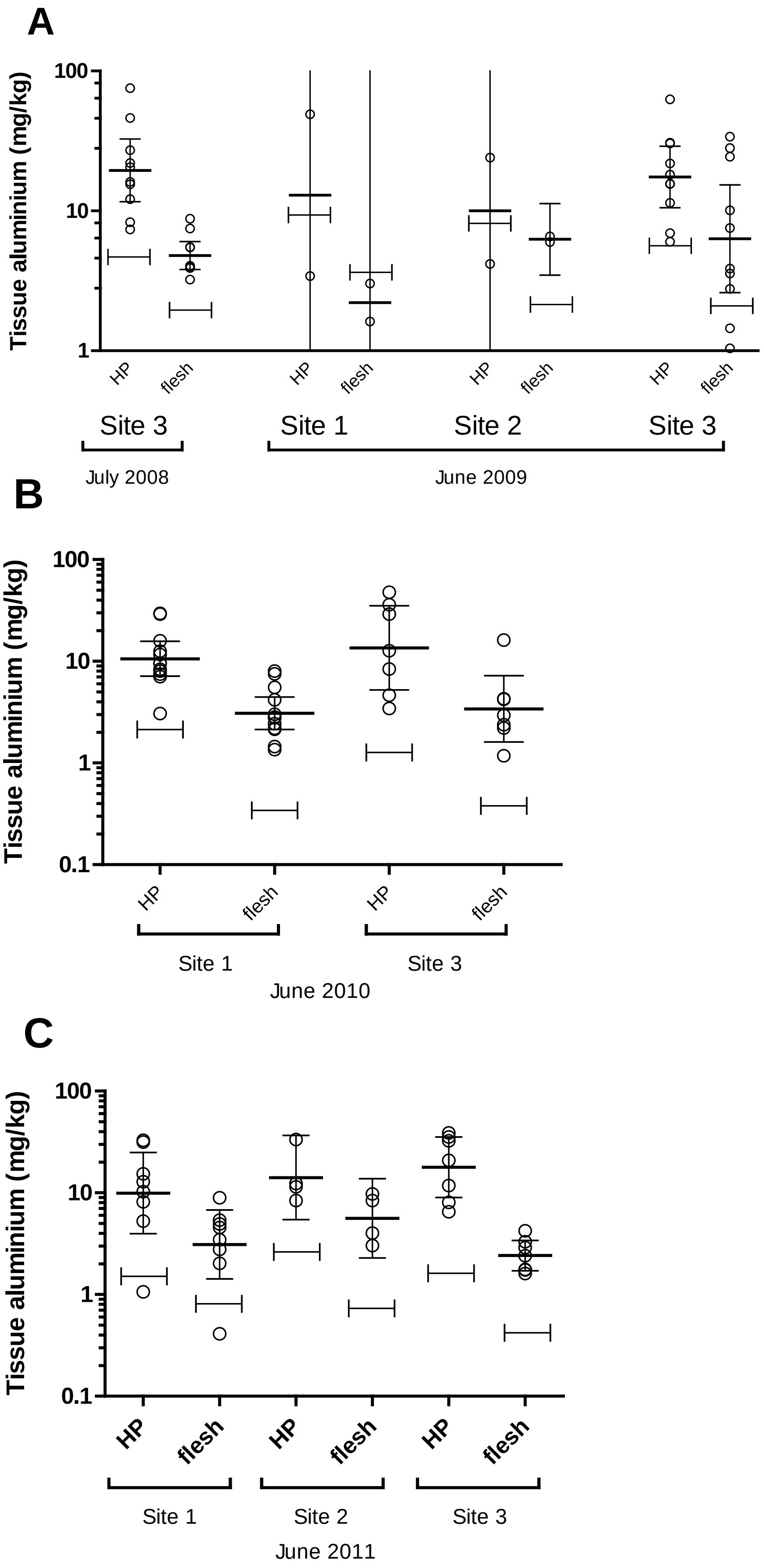
It is possible that comparisons of aluminium accumulation between sites may be compromised by the movement of bully and koura within the stream, however, adult common bully and koura are more likely to be locally resident than would be the case for juveniles. There are no studies of aluminium depuration 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. The slightly elevated gill aluminium concentrations in common bully downstream of the alum diffuser suggests that fish are locally resident rather than highly mobile.

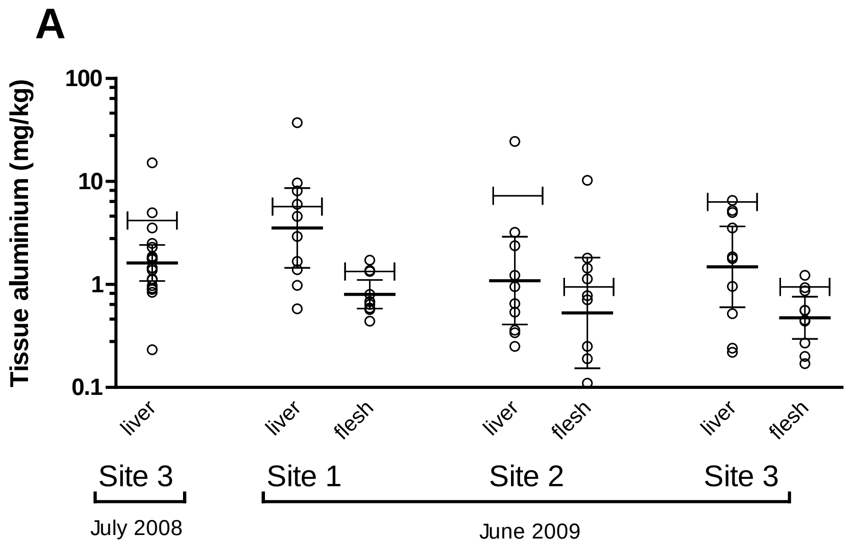
METHOD DETECTION LIMITS AND REPORTING

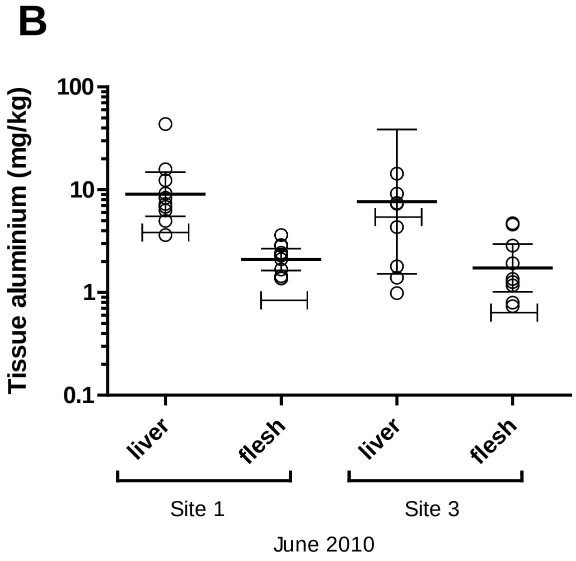
The Method Detection Limit (MDL) is the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero, and will vary depending on the analyte, the sample matrix, and the sample volume/weight. A common problem encountered 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.

Results for common bully tissues analysed in 2009 were compromised by low tissue sample weight, with many samples returning values at or below the average method detection limit. Subsequent refinements to the analytical method has resulted in a decrease in method detection limit and more than 99% of samples returning values above the MDL.

Figure 6 (facing page). Tissue aluminium concentrations (mg/kg) for hepatopancreas and flesh of koura from the Utuhina Stream from A. 2008 & 2009, B. 2010, C. 2011. Site 1 is upstream of the alum discharge diffuser. Site 2 is within the alum mixing zone. Site 3 is 250 m downstream of the alum diffuser. Summary statistics are geometric mean (bold lines) ± 95% confidence limits. Transverse bars represent average method detection limits for each sample.


A
Tissue aluminium (mg/kg)
100
10
1
HP
flesh
HP
flesh
HP
flesh
HP
flesh
Site 3
Site 1
Site 2
Site 3
July 2008
June 2009
B
Tissue aluminium (mg/kg)
100
10
1
0.1
HP
flesh
HP
flesh
Site 1
Site 3
June 2010
C
Tissue aluminium (mg/kg)
100
10
1
0.1
HP
flesh
HP
flesh
HP
flesh
Site 1
Site 2
Site 3
June 2011


A
Tissue aluminium (mg/kg)
100
10
1
0.1
liver
liver
flesh
liver
flesh
liver
flesh
Site 3
Site 1
Site 2
Site 3
July 2008
June 2009


B
Tissue aluminium (mg/kg)
100
10
1
0.1
liver
flesh
liver
flesh
Site 1
Site 3
June 2010

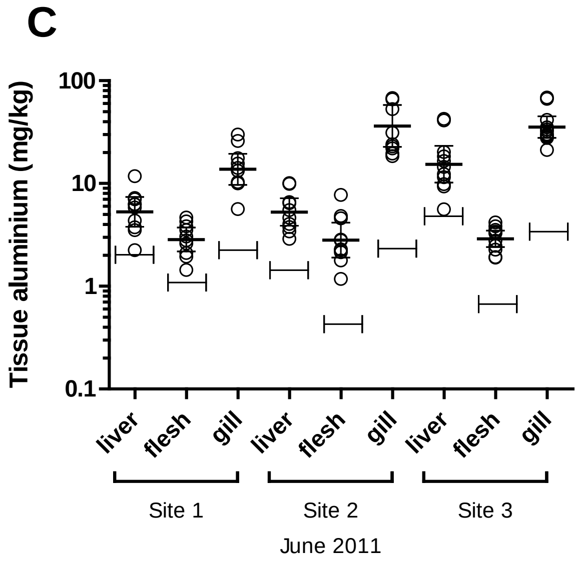

C
Tissue aluminium (mg/kg)
100
10
1
0.1
liver
flesh
gill
liver
flesh
gill
liver
flesh
gill
Site 1
Site 2
Site 3
June 2011

Figure 7 (facing page). Tissue aluminium concentrations (mg/kg) for liver, flesh and gill tissues of common bully from the Utuhina Stream from A. 2008 & 2009, B. 2010, C. 2011. Site 1 is upstream of the alum discharge diffuser. Site 2 is within the alum mixing zone. Site 3 is 250 m downstream of the alum diffuser. Summary statistics are geometric mean (bold lines) ± 95% confidence limits. Transverse bars represent average method detection limits for each sample.

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