UTUHINA STREAM MONITORING 2012:

EFFECTS OF CONTINUOUS ALUM DOSING ON FISH AND AQUATIC INVERTEBRATES

NICHOLAS LING

CBER
University of Waikato

Centre for Biodiversity and Ecology Research

Utuhina Stream monitoring 2012: effects of continuous alum dosing on fish and aquatic invertebrates

Nicholas Ling

Centre for Biodiversity and Ecology Research, The University of Waikato, Private Bag 3105, Hamilton 3240, New Zealand. nling@waikato.ac.nz

Client report prepared for Bay of Plenty Regional Council.

22 April 2013

SUMMARY

This report presents the results of an ongoing assessment of the fish and aquatic macroinvertebrate communities of the Utuhina Stream from 2006 to 2012, 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 September 2012. Catch rates for common bully, juvenile trout and koura have fluctuated across all sites since monitoring began in 2006. Common bully abundance was very much lower than in previous years but numbers of juvenile trout and koura were comparable to previous sampling occasions. It is possible that continuing alterations in stream bank habitat and morphology arising from large flood flows throughout winter 2012, and following extreme floods in early 2011, contributed to the observed decline in common bully. 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 fair to 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. Tissue aluminium concentrations were slightly higher in koura than common bully tissues but within species were similar across control and alum-exposed sites. Tissue concentrations of aluminium were slightly greater in the gills of koura and common bully at both downstream sites compared with the upstream control site but this does not correspond with greater accumulation of aluminium in internal tissues.

Table of Contents

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 sampled in September 2012, 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. Results from September 2012 are compared with those from previous years since the commencement of alum dosing in the Utuhina Stream in 2006.

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 14th September 2012. Sampling occurred later than in previous years due to the occurrence of regular flood flows throughout winter that prevented fishing until the stream level dropped to near base flow. 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 (if captured) or their size estimated, and all fish were returned alive to their respective stream reaches, except for those retained for elemental analysis (see below).

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.
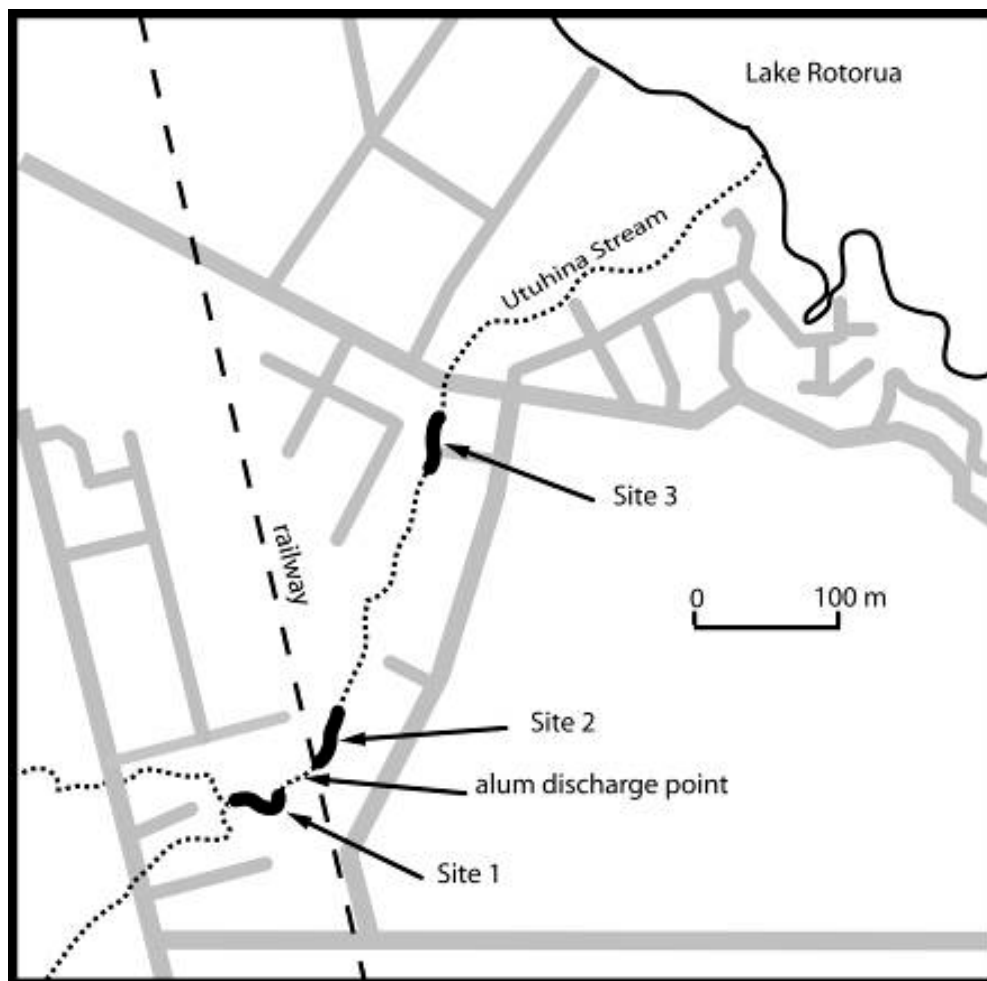

Fig. 1. The Utuhina Stream with fish community survey sites marked above the alum discharge (Site 1), in the alum mixing zone (Site 2) and upstream of Lake Rd (Site 3).

Fig. 2. Two teams of three people simultaneously electrofishing each bank in the control zone (Site 1) 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, liver and gills were analysed from ten common bully from each site. Hepatopancreas, tail muscle and gills were analysed from ten koura from each site. Method blanks and matrix certified reference material 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. Additionally, 1 mosquitofish (*Gambusia affinis*) was captured in 2012 at each of sites 2 and 3. Common bully relative density (fish per 50 m reach) and CPUE (fish/h) were relatively high in June 2010 but decreased at all sites in June 2011 and were significantly lower again in 2012 (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. Large flood flows also occurred throughout the winter of 2012 and reduced stream bank vegetation was again observed. The lowering of the stream bed at site 3 was greater than in 2011 making this site unfishable (deep water), which necessitated moving the fished reach upstream by around 50 m.
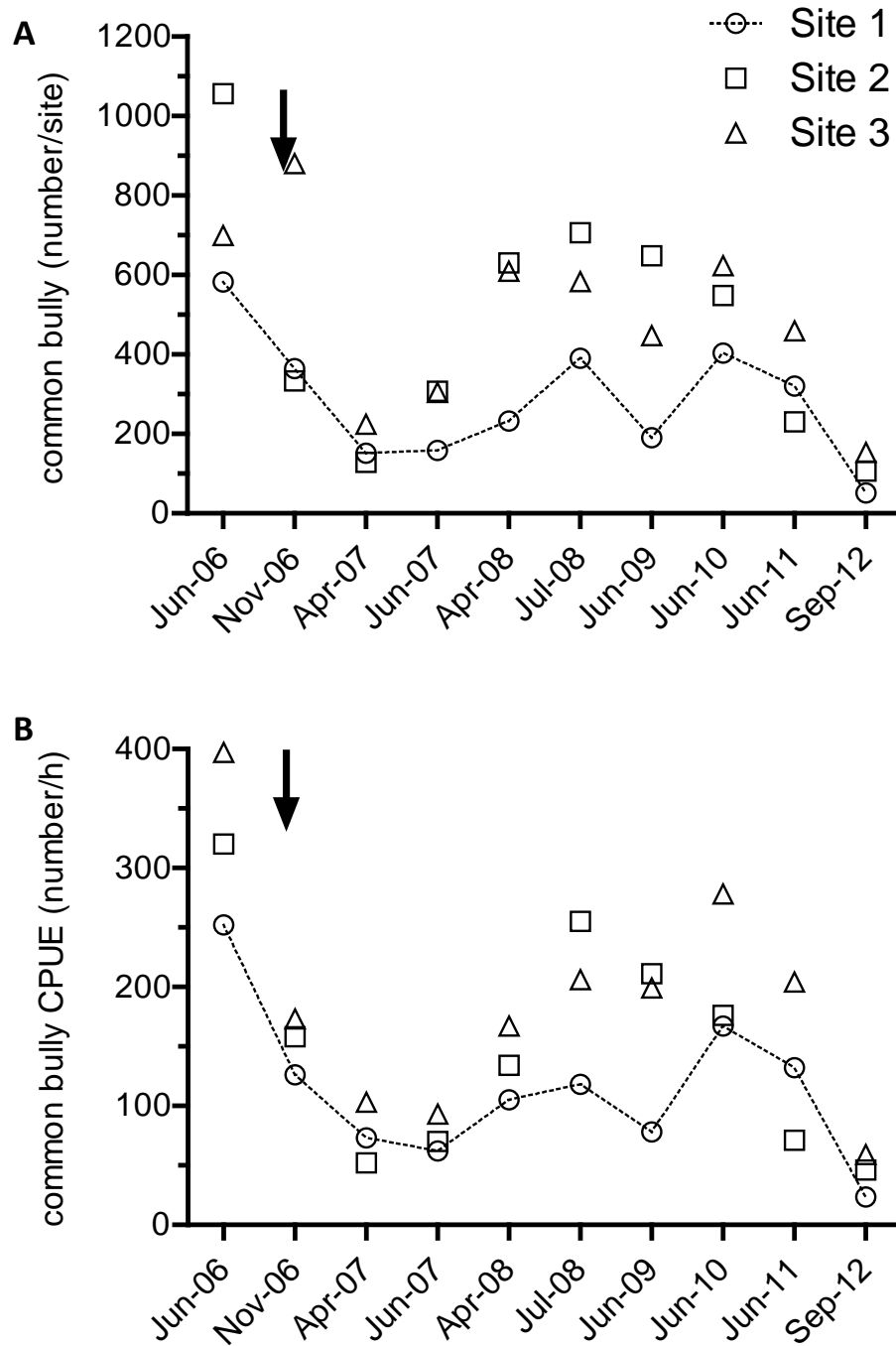
Figure 3. Relative density (A) and CPUE (B) of common bully in the Utuhina Stream since June 2006. Arrows indicate the commencement of alum dosing in the stream.

Numbers of juvenile trout and CPUE at all sites were much higher than in 2011 and similar to previous years (Fig. 4). Three large trout (130 mm, 180 mm and 350 mm) were seen at Site 1 (upstream control; true left bank) where larger trout have often been observed in the past.
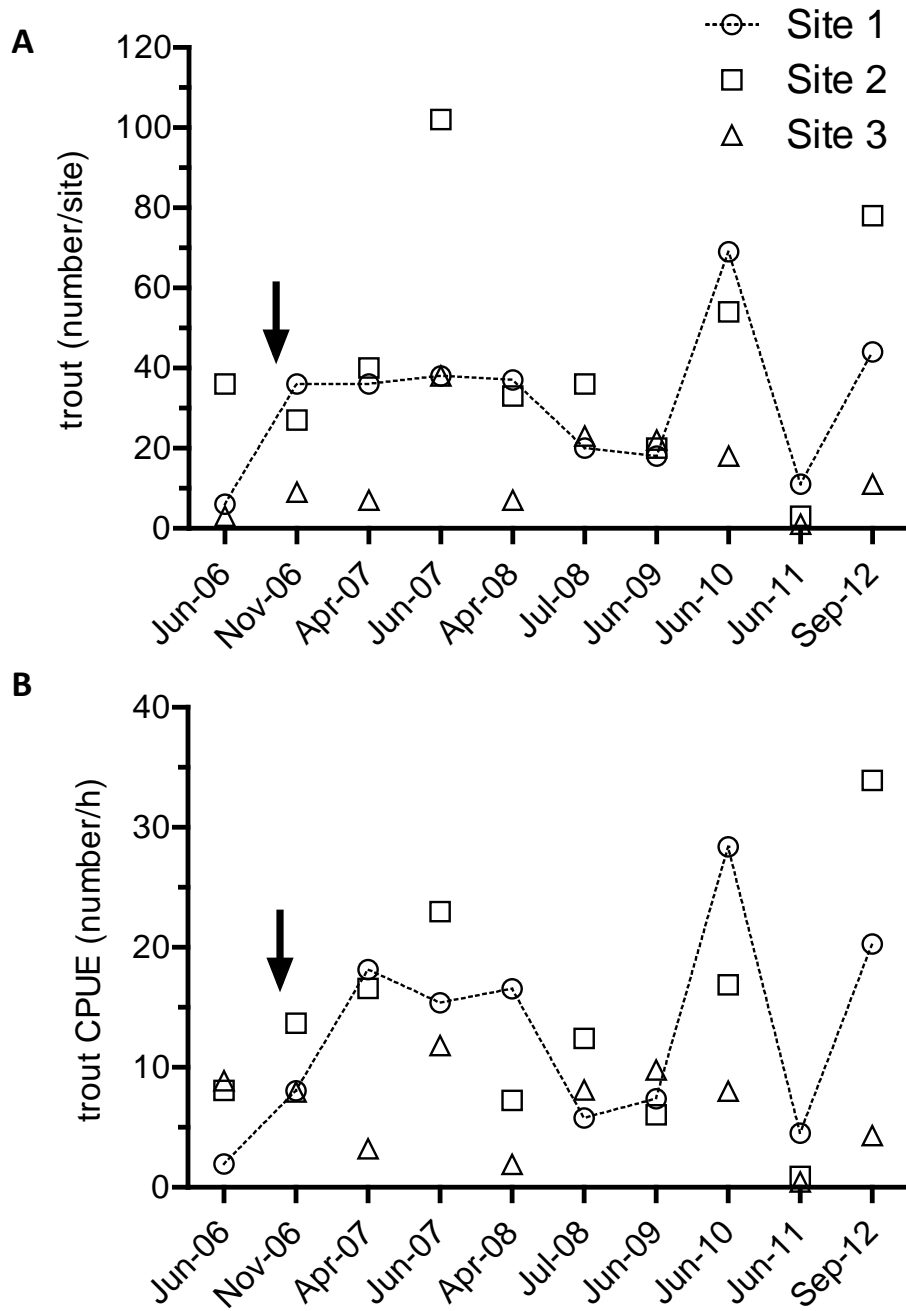

Figure 4. Relative density (A) and CPUE (B) of juvenile trout in the Utuhina Stream. Arrows indicate the commencement of alum dosing in the stream.

Koura abundance and CPUE had recovered in September 2012 compared with the low numbers observed in June 2011 (Fig. 5). Koura abundance and CPUE remain consistently higher than prior to the commencement of alum dosing.
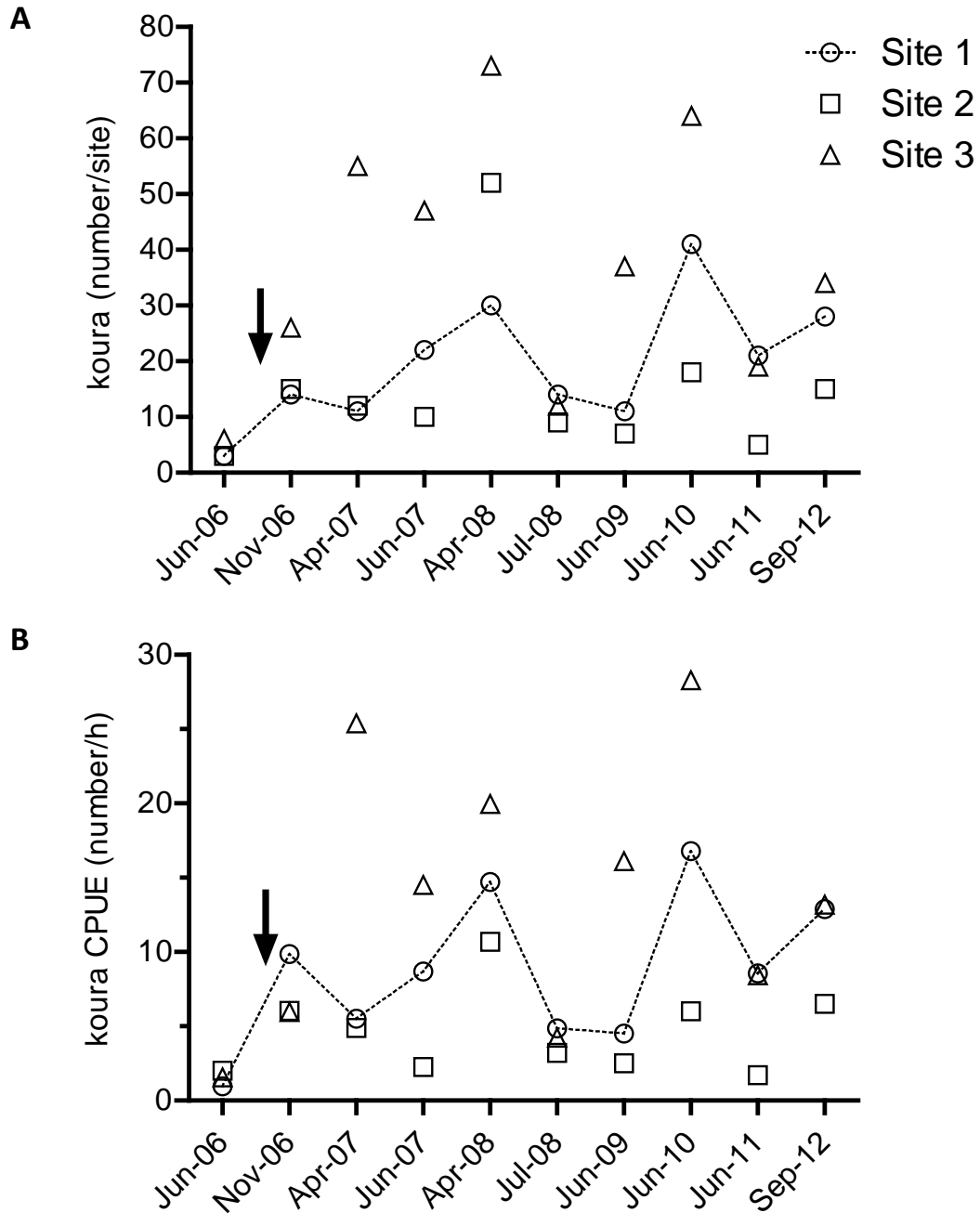

Figure 5. Relative density (A) and CPUE (B) of koura in the Utuhina Stream. Arrows indicate the commencement of alum dosing in the stream.

Figure 6. A recently installed drain (Site 1 true right bank) without adequate bank reinforcement.

Although common bully abundance was lower in 2012 at all sites compared with previous years, fish abundance was particularly low on the true right bank at site 1 where a drain had been installed at some time during the previous year without adequate bank reinforcement which had resulted in significant scouring of the stream bank downstream of the pipe (Figure 6). Poorly conceived structures such as this and the frequent high flood flows over the preceding 2 years have resulted in continuing degradation of stream bank habitat for fish, however, the recent initiation of restoration bankside planting of the Utuhina should assist in stabilizing the banks, restoring instream habitat and providing flood flow refugia for fish and koura.

Higher numbers of juvenile trout observed in 2012 could be due to sampling occurring later than in previous years or could be due to interannual variation.

AQUATIC MACROINVERTEBRATES

Semi-quantitative macroinvertebrate community analysis showed no obvious differences between sites but a slight decline since 2011 (Figure 7). Values for the MCI-sb index fell within the "fair" to "good" quality class (Table 1) of Stark & Maxted (2007) for all three sites. As has been observed in previous years, 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. No evaluations have so far been undertaken on the sensitivities of New Zealand stream macroinvertebrates to alum.

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 significantly decrease stream pH which would cause greater toxicity and an increase in bioavailable aluminium species.

Figure 7. Summary data for semi-quantitative macroinvertebrate community assessment for the Utuhina Stream since June 2009.
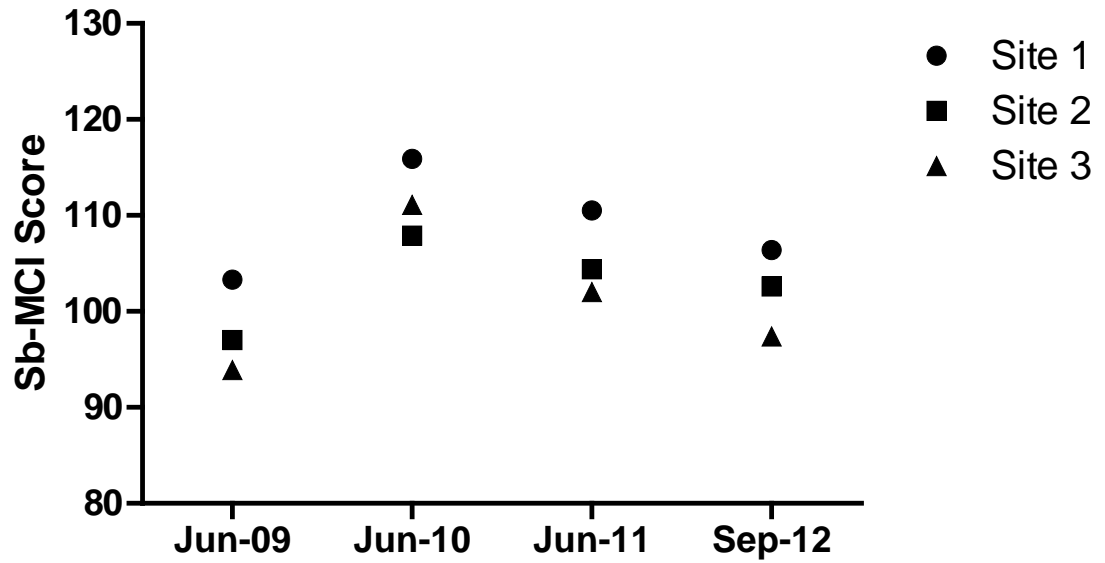

Table 1. Interpretation of soft-bottomed stream MCI indices.

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

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 and repeated in 2012 for both common bully and koura. Aluminium concentrations were higher in gill tissue than other tissues at all sites and there was some evidence of higher aluminium in the gills of both common bully and koura 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 bioaccumulation of aluminium in other 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 and koura downstream of the alum diffuser suggests that these species are locally resident rather than highly mobile and therefore tolerant of the instream alum plume.

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 (Ling & Brijs 2009). Subsequent refinements to the analytical method have resulted in a decrease in method detection limit and more than 99% of samples returning values above the MDL.

Figure 8 (following page). Tissue aluminium concentrations (mg/kg) for hepatopancreas, flesh and gills of koura from the Utuhina Stream from A. 2011 and B. 2012. 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.
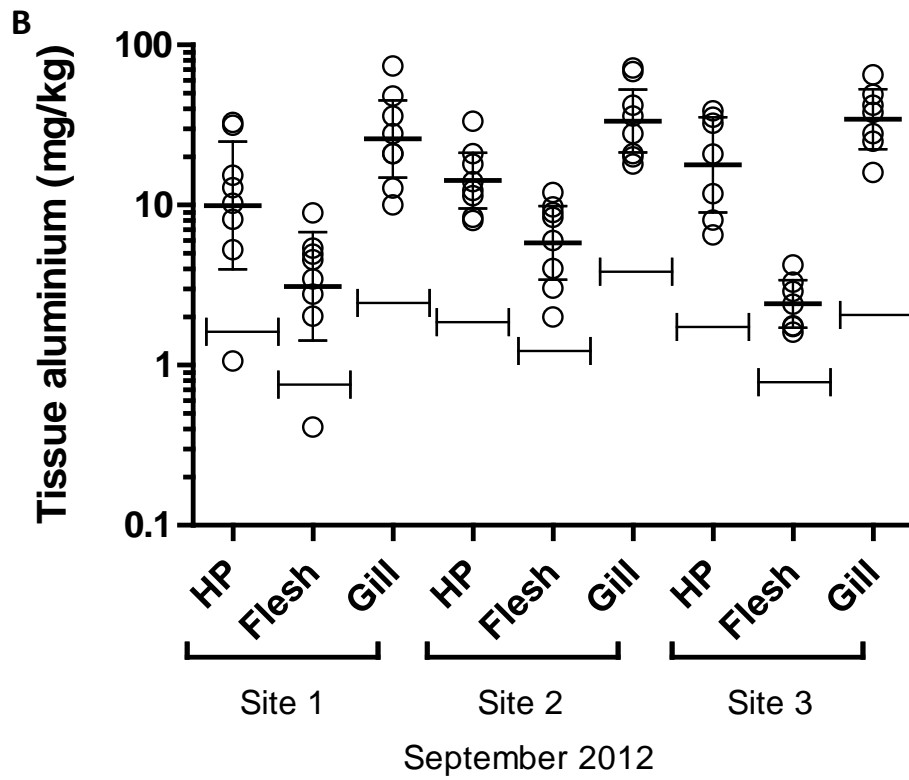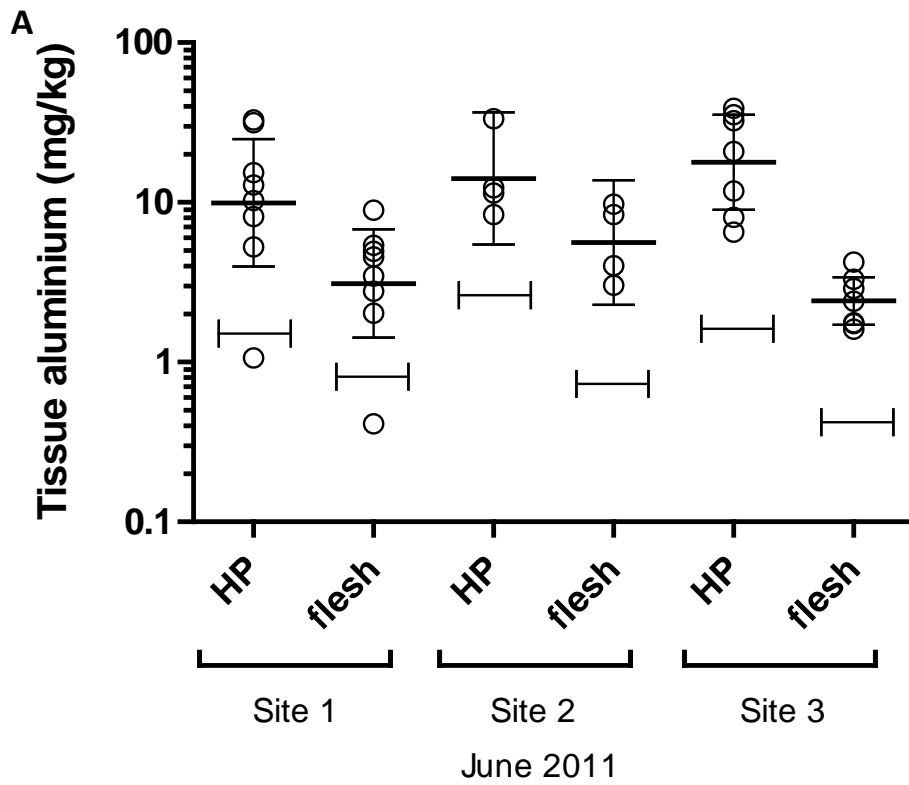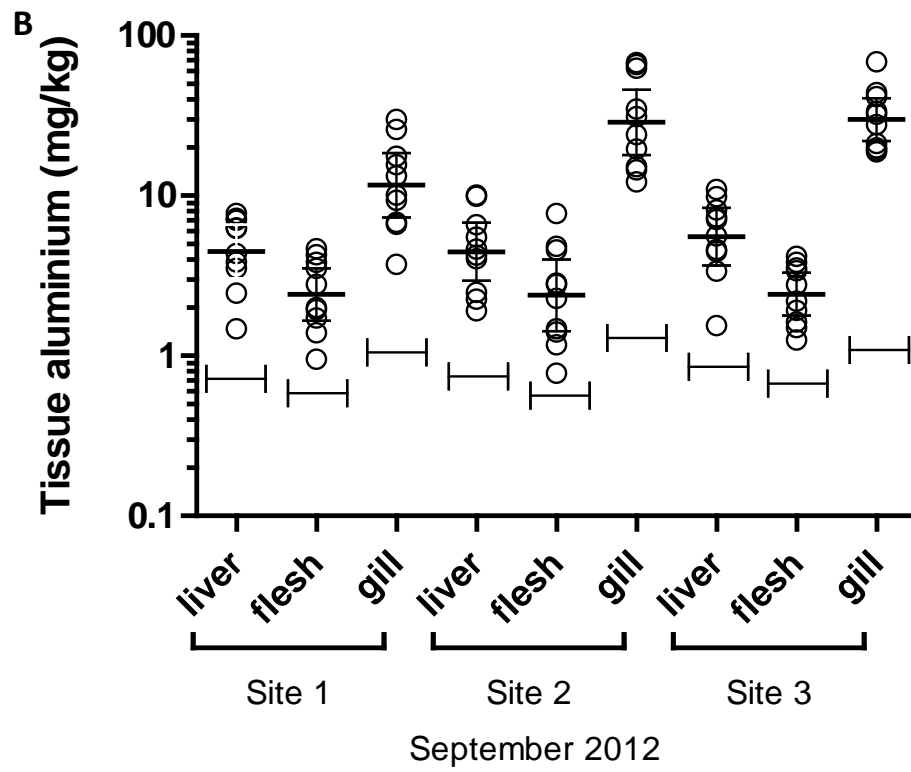
Figure 9 (preceding page). Tissue aluminium concentrations (mg/kg) for liver, flesh and gill tissues of common bully from the Utuhina Stream from A. 2011 and B. 2012. Site 1 is upstream of the alum discharge diffuser. Site 2 is within the alum mixing zone. Site 3 is 250 m downstream of the alum diffuser. Summary statistics are geometric mean (bold lines) ± 95% confidence limits. Transverse bars represent average method detection limits for each sample.
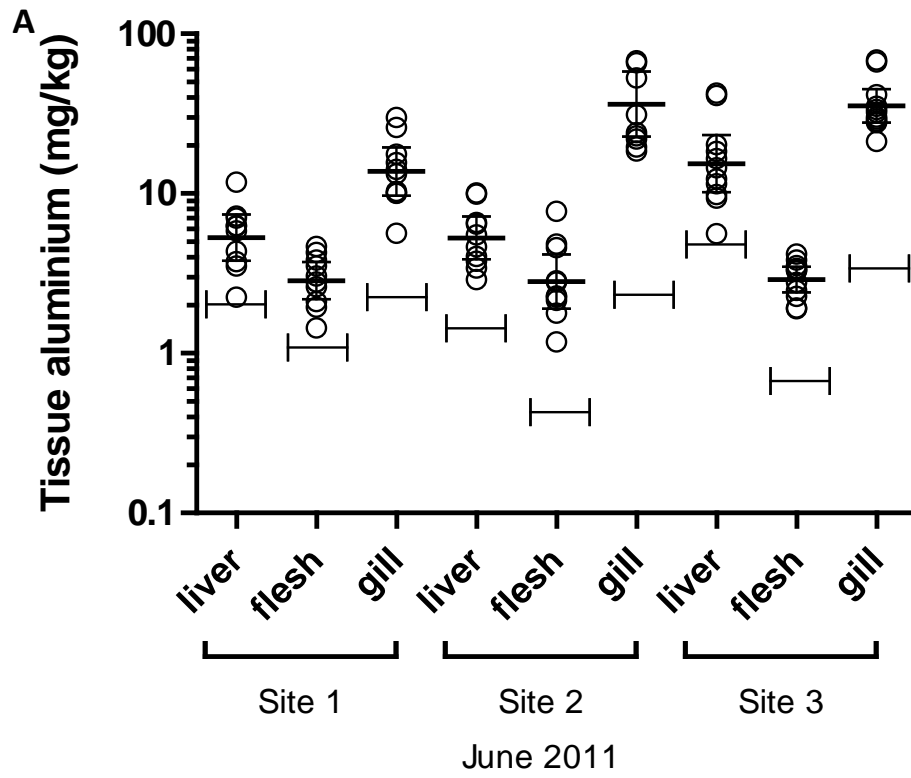
Allin, C.J., Wilson, R.W. (2000) Effects of pre-acclimation to aluminium on the physiology and swimming behaviour of juvenile rainbow trout (*Oncorhynchus mykiss*) during a pulsed exposure. *Aquatic Toxicology* 51: 213-224.

Barbiero, R, Carlson, R.E., Cooke, G.D., Beals, A.W. (1988) The effects of a continuous application of aluminium sulphate on lotic benthic invertebrates. *Lake and Reservoir Management* 4: 63-72.

Bay of Plenty Regional Council (2007) Proposed Lakes Rotorua and Rotoiti Action Plan: A programme for the long-term restoration of Lakes Rotorua and Rotoiti's water quality. Environmental Publication 2007/11. Environment Bay of Plenty, Whakatane, New Zealand. 165 pp.

Clarke, H. (2006) The effects of alum on the macroinvertebrate community index (MCI) in the Utuhina Stream. Unpublished project report. Auckland University of Technology.

Eriksen, T.E., Arnekleiv, J.V., Kjærstad, G. (2009) Short-term effects on Riverine Ephemeroptera, Plecoptera, and Trichoptera of rotenone and aluminum sulfate treatment to eradicate *Gyrodactylus salaris*. *Journal of Freshwater Ecology* 24: 597-607.

Landman, M., Ling, N., Taylor, S. (2008) Fish community surveys and biomonitoring in selected Rotorua Streams. Technical report prepared for Environment Bay of Plenty. Scion, Rotorua New Zealand. 28 pp.

Ling, N., Brijs, J. (2009) Utuhina Stream monitoring 2009: fish and aquatic invertebrates. CBER Contract Report 106. Client Report prepared for Environment Bay of Plenty. University of Waikato, Hamilton. 19 pp.

Sparling, D.W., Lowe, T.P. (1996) Environmental hazards of aluminium to plants, invertebrates, and wildlife. *Reviews of Environmental Contamination and Toxicology* 145: 1-127.

Stark, J.D., Maxted, J.R. (2007) A user guide for the Macroinvertebrate Community Index. Prepared for the Ministry for the Environment. Cawthron Report No. 1166.   58 p.

Stark, J.D., Boothroyd, I.K.G., Harding, J.S., Maxted, J.R., Scarsbrook, M.R. (2001) Protocols for sampling macroinvertebrates in wadeable streams. New Zealand Macroinvertebrate Working Group Report No. 1. Prepared for the Ministry for the Environment. Sustainable Management Fund Project No. 5103. 57p.

Succop, P.A., Clarke, S., Chen, M., Galke, W. (2004) Imputation of data values that are less than a detection limit. *Journal of Occupational and Environmental Hygiene* **1**: 436-441.

United States Environmental Protection Agency (USEPA). (1987) Determination of Metals in Fish Tissue by Inductively Coupled Plasma – Atomic Emission Spectrometry. EPA Method 200.11, Revision 1.3, April 1987.