

# Alum Dosing Effects on Fish and Aquatic Invertebrates: Utuhina Stream 2024

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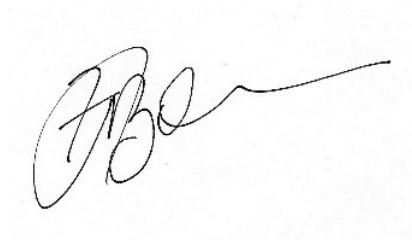
Cover image: Downstream view of Utuhina Stream above the alum dosing point.

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# Executive Summary

To reduce external phosphorus loading to Lake Rotorua, the Bay of Plenty Regional Council has been granted resource consent to dose the Utuhina Stream with alum (aluminium sulphate). Aluminium binds phosphorus, preventing its uptake by phytoplankton and thereby inhibiting growth. Aluminium forms monomeric species outside of circum-neutral pH (pH 6-8), and these species can disrupt osmoregulation and respiration of aquatic organisms. The alum dose rate to the Utuhina Stream is dependent on discharge, with a maximum application rate of 1 mg Al L<sup>-1</sup>. This report presents the results of an on-going assessment of the fish and aquatic macroinvertebrate communities of the Utuhina Stream for 2024.

Macroinvertebrates, fish and kōura (freshwater crayfish; *Paranephrops planifrons*) were sampled from one control (site 1) and two treatment (sites 2 & 3) reaches of the Utuhina Stream. Common bully (*Gobiomorphus cotidianus*) were the dominant species of the fish community, with juvenile trout and kōaro (*Galaxias brevipinnis*) also captured. Kōura were present at all sites but variable in abundance. There was a notable decline in the semi-quantitative macroinvertebrate community (for soft-bottomed streams; MCI-sb) score at Sites 1 and 3 in 2024 compared to long-term site averages, with Site 1 declining into the 'poor' category. Interannual variation in MCI-sb scores is typical for these reaches of the Utuhina Stream and have been attributed to flood-related disturbances to stream bank morphology and in-stream vegetative cover (Ling 2021).

Tissue aluminium concentrations were determined from common bully (flesh, gill, liver) and kōura (flesh, gill, hepatopancreas) by inductively coupled plasma mass spectrometry (ICP-MS). There was some evidence of aluminium bioaccumulation in the liver tissues of common bully at Site 2, but overall concentrations were similar to long-term averages and there were no notable differences for the same tissues between sites. Kōura tissue aluminium concentrations for 2024 were similar to long-term averages across all tissues and sites. A small number of individuals had elevated gill concentrations at Site 3 compared to long-term average concentrations, but this is unlikely to result in harmful physiological impacts. The data presented in this report further supports the conclusion by Tempero and Ling (2024) that alum dosing does not appear to have a notable effect on the fish and kōura community and that site and interannual differences appear to be due to hydrological and habitat variability.

# Table of Contents

Executive Summary .....	3
Table of Contents .....	4
Introduction .....	6
Methods .....	8
Study site .....	8
Fish community survey .....	8
Aquatic macroinvertebrate community survey .....	9
Tissue analysis .....	10
Results .....	11
Fish community .....	11
Macroinvertebrate community (MCI-sb) .....	15
Tissue aluminium concentrations .....	15
Discussion.....	17
Fish community .....	17
Macroinvertebrate community.....	18
Tissue aluminium concentrations .....	18
Conclusions .....	19
Acknowledgements .....	19
References .....	20

## LIST OF FIGURES

Figure 1. Quantity of aluminium discharged daily (A) and annually (B) to the Utuhina Stream since the commencement of dosing in June 2006. * alum dosing was mostly shut down from 1 July 2012 to 10 December 2012 for system maintenance and reduced in 2021 due to covid restrictions. ....	7
Figure 2. Macroinvertebrate and electrofishing sites on the Utuhina Stream including above the alum discharge (Site 1), in the alum mixing zone (Site 2) and upstream of Lake Rd (Site 3). ....	10
Figure 3. A female brown trout ( <i>Salmo trutta</i> ) (approximately 360 mm fork length) captured at site 2 downstream of the alum dosing point in 2024.....	11
Figure 4. Common bully numbers captured per site (A) and catch per unit effort (CPUE; B) in the Utuhina Stream (June 2006 – December 2024). Arrow indicates the commencement of alum dosing in the stream. Values for long-term averages are means $\pm$ 1 S.D.....	12
Figure 5. Total numbers of trout captured per site (A) and catch per unit effort (CPUE; B) of trout in the Utuhina Stream since June 2006. Arrow indicates the commencement of alum dosing in the stream. Values for long-term averages are means $\pm$ 1 S.D.....	13
Figure 6. Kōura captured per site (A) and catch per unit effort (CPUE; B) of kōura in the Utuhina Stream since June 2006. Arrow indicates the commencement of alum dosing in the stream. Values for long-term averages are means $\pm$ 1 S.D. ....	14
Figure 7. Soft-bottom stream macroinvertebrate community assessment (Sb-MCI) for the Utuhina Stream since June 2006. Values for long-term averages are means $\pm$ 95% confidence intervals. Note: values for sites 1 and 2 in 2006 are approximated from data in Clarke 2006. ....	15
Figure 8. Common bully tissue (liver, flesh and gill) aluminium concentrations ( $\text{mg kg}^{-1}$ WW) for 2024 and mean tissue concentrations for monitoring years 2009–2023 - geometric mean with lower and upper 95% confidence intervals (CI). Site 1 = upstream control reach, Site 2 = alum mixing zone, Site 3 = downstream reach.....	16
Figure 9. Kōura tissue (flesh, gill and hepatopancreas) aluminium concentrations ( $\text{mg kg}^{-1}$ WW) for 2024 and mean years tissue concentrations for monitoring years 2009–2023 - geometric mean with lower and upper 95% confidence intervals (CI). Site 1 = upstream control reach, Site 2 = alum mixing zone, Site 3 = downstream reach. ....	17

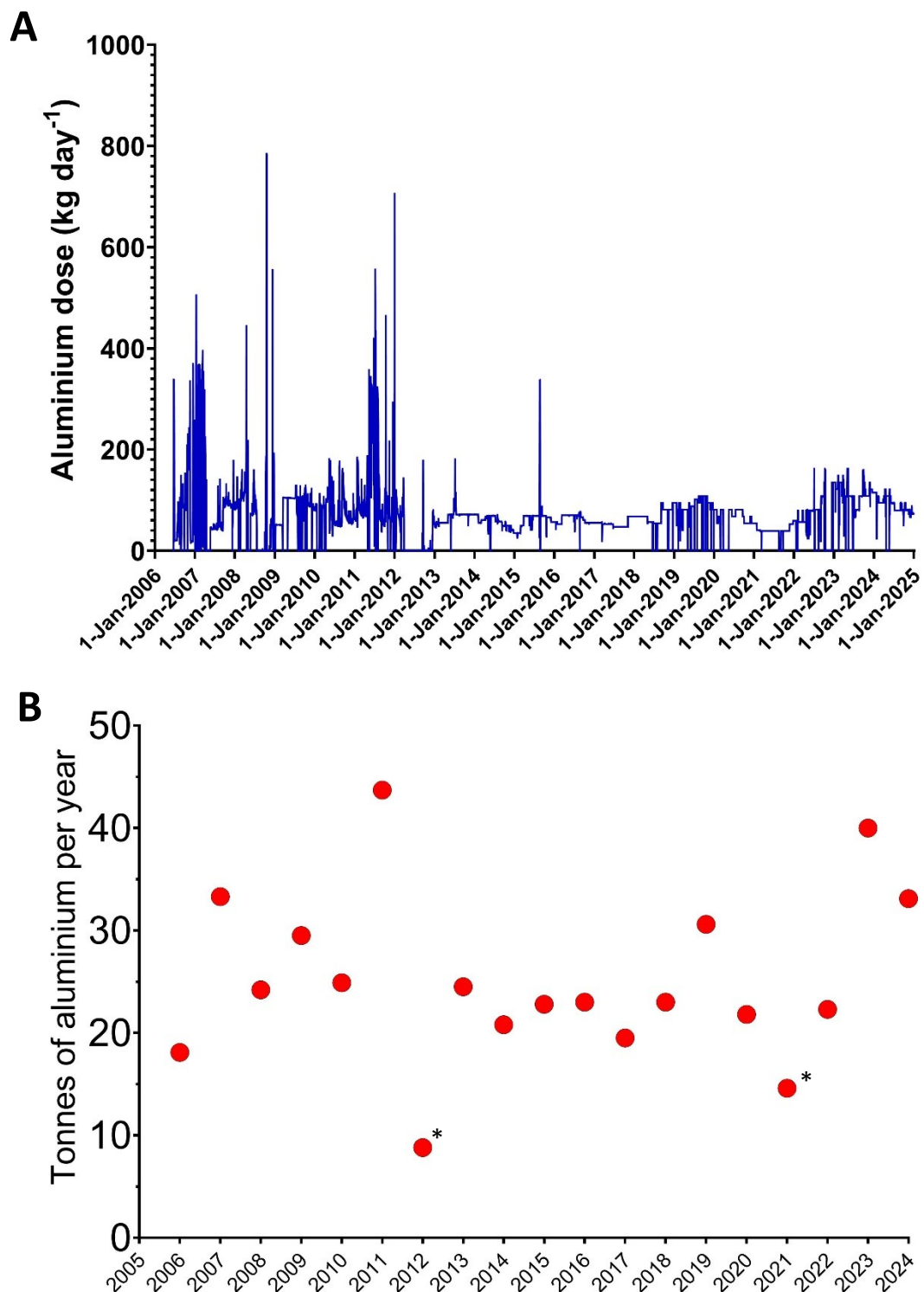
# Introduction

The water quality of Lake Rotorua has undergone significant eutrophication since the 1960s, with prevalent algal blooms driven by land use change, farm intensification and city sewage discharges (Donald et al. 2019). 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 nitrogen and phosphorus. The most recent estimates of phosphorus load to Lake Rotorua put the sustainable phosphorus load to reach a TLI target of 4.2 (in association with the 435 tonnes nitrogen target) between 33.7 to 38.7 tonnes per year (Tempero et al. 2015; McBride 2022). This was similar to the 37 tonnes per year proposed by Rutherford et al. (1989) which was set as a target in the Lakes Rotorua and Rotoiti Action Plan 2009. This requires a reduction in the phosphorus load to the lake of 10–15 tonnes per year or 43–64% of the current anthropogenic phosphorus load (Tempero et al. 2015).

The Utuhina Stream carries an estimated 4.0 tonnes of total phosphorus to Lake Rotorua each year, of which 1.62 tonnes is in the form of dissolved reactive phosphorus (DRP) (Hamill 2022). The Action Plan proposed phosphorus-locking in up to three streams (Utuhina, Puarenga and one other) to reduce 6 tonnes of DRP entering Lake Rotorua using continuous alum (aluminium sulphate) treatment (Bay of Plenty Regional Council, 2007). It was estimated that an alum dosing rate of 1 ppm ( $1 \text{ g m}^{-3}$ ) would remove the majority of DRP in the Utuhina Stream. Tempero (2015) assessed the toxicity of this dose rate and concluded that the rate was suitably conservative and unlikely to result in toxicological impacts within the circumneutral pH range. Alum dosing of the Utuhina Stream began on a trial basis in mid-2006. The Bay of Plenty Regional Council was granted a resource consent in November 2008 for the continuation of alum dosing until 2018. The resource consent was again renewed in March 2018 and is set to expire in July 2031. Alum dosing of the stream is varied according to stream flow and was occasionally altered in the early years to determine the optimum dose rate to remove phosphorus. Total application of alum to the stream over the treatment period from July 2006 to 1 January 2025 was 11,224 tonnes, at a mean dose rate of 25.2 tonnes of aluminium per annum (Figure 1).

Alum dosing is widely used for wastewater treatment and restoration of freshwater ecosystems through the removal of DRP, but it is not without risk (Cooke et al. 2005). At circumneutral pH (6–8), common to most surface waters, alum forms aluminium hydroxide ( $\text{Al}(\text{OH})_3$ ), a non-toxic white insoluble precipitate which adsorbs dissolved phosphorus, reducing its availability for phytoplankton growth. However, at high ( $>8.5$ ) or low ( $<5.5$ ) pH, dissolved monomeric ( $\text{Al}^{3+}$ ) and hydroxy aluminium species occur in varying proportions with respect to acidic (i.e.,  $\text{Al}^{3+}$ ,  $\text{AlOH}^{2+}$ ,  $\text{Al}(\text{OH})_2^+$ ) and alkaline (i.e.,  $\text{Al}(\text{OH})_4^-$ ) conditions, with increasing toxicity to aquatic organisms. In aquatic animals, aluminium toxicity is primarily due to disruption of osmoregulation and respiration by dissolved aluminium species at the

gills (Alexopoulos et al. 2003; Gensemer et al. 2018) which are the primary site of gas exchange, ion transport, and waste excretion in fish and crustaceans (Playle and Wood 1989).



**Figure 1. Quantity of aluminium discharged daily (A) and annually (B) to the Uthina Stream since the commencement of dosing in June 2006. \* alum dosing was mostly shut down from 1 July 2012 to 10 December 2012 for system maintenance and reduced in 2021 due to covid restrictions.**

The University of Waikato has undertaken annual assessments of potential ecological impacts on the fish and macroinvertebrate communities at an upstream control site and two sites downstream of the alum discharge point. Evaluation of the bioavailability of aluminium in common bully (*Gobiomorphus cotidianus*) and kōura (freshwater crayfish; *Paranephrops planifrons*) has also been undertaken annually since 2009. Recent surveys of stream macroinvertebrates have shown no consistent differences between the upstream control site and the sites downstream of the alum dosing (Tempero and Ling 2024). There was some evidence of aluminium bioaccumulation in the gill and liver tissues of common bully in some years, but there has been no evidence of aluminium bioaccumulation in the tissues of kōura (Tempero and Ling 2024).

## Methods

### Study site

Lake Rotorua is the largest of 12 lakes jointly managed under the Rotorua Te Arawa Lakes Programme. It has a surface area of 80.6 km<sup>2</sup> and a mean depth of 10.8 m (maximum depth 45 m) (Burger et al. 2011). Lake Rotorua is currently classified as eutrophic but has experienced significant improvements in water quality since the mid-2000s, with the TLI fluctuating around the target of 4.2 since 2010 (Donald et al. 2019). The Utuhina Stream is one of nine major inflows to Lake Rotorua. It drains a catchment of around 60 km<sup>2</sup>, with land-use divided approximately evenly between urban, dry stock, bush and scrub, and forestry (Tempero et al. 2015). The Utuhina Stream arises west of Lake Rotorua and flows through residential and industrial areas within Rotorua City where it receives geothermal and stormwater inflows before discharging into the lake at Te Ruapeka Bay. The stream becomes highly channelised as it passes through the city; with a mean discharge of 1.85 m<sup>3</sup> s<sup>-1</sup> at the State Highway 5 bridge (Depot Street) (Wallace 2014).

### 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 (Figure 2) annually in December from prior to the commencement of alum dosing in June 2006. 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 alum diffuser, and Site 3 was 400 m further downstream in the vicinity of Lake Road. Relative fish density (total numbers captured) and CPUE (fish captured per hour) were estimated using a two-pass electrofishing procedure according to the method of Landman et al. (2008). A Ministry of Agriculture and Fisheries 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. 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 are the most abundant species in the Utehina Stream and obtaining consecutive reductions in this species using multiple pass electrofishing is 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 based on fish caught and fishing effort (time fishing). All fish and kōura were counted. Captured adult trout were measured or their size estimated if observed, and all fish were returned alive to their respective stream reaches, except for those retained for elemental analysis (see below).

#### Aquatic macroinvertebrate community survey

Aquatic macroinvertebrate community analysis was undertaken separately to electrofishing but from the same three stream reaches examined for relative fish abundance. Invertebrates were sampled in October, two months before electrofishing, to avoid effects of electrofishing disturbance. Sampling and analysis were 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<sup>2</sup> at each site. True left and true right banks were sampled and enumerated separately at each of the three stream reaches to provide a value for the macroinvertebrate community index for soft bottomed streams (MCI-sb) according to Stark & Maxted (2007). Samples were preserved in isopropyl alcohol until sorting and enumeration.



**Figure 2. Macroinvertebrate and electrofishing sites on the Utuhina Stream including above the alum discharge (Site 1), in the alum mixing zone (Site 2) and upstream of Lake Rd (Site 3).**

#### Tissue analysis

Samples of liver (common bully) or hepatopancreas (kōura), flesh and gills were carefully dissected using acid-washed instruments. A suite of 28 elements were measured in samples based on established methods (USEPA, 1987). Samples were dried at 60°C for 72 hours to constant weight, weighed to the nearest 0.001 g, and digested using tetramethylammonium hydroxide, heat (60°C) and mixing. The colloidal suspension was then cooled in ice and partially oxidized by the addition of cooled hydrogen peroxide and allowed to oxidize

overnight at 4°C. Metals were solubilized by acidification with nitric acid and heating (90°C for 2 hours). After cooling to room temperature, samples were diluted and filtered prior to analysis by inductively coupled plasma mass spectrometry (ICP-MS) by the University of Waikato Mass Spectrometry Facility. All tissue element concentrations were determined on a wet weight basis. Method blanks and matrix certified reference material standards (DOLT and DORM; Canadian Research Council) were run in parallel with all samples. Only results for aluminium are presented here.

## Results

### Fish community

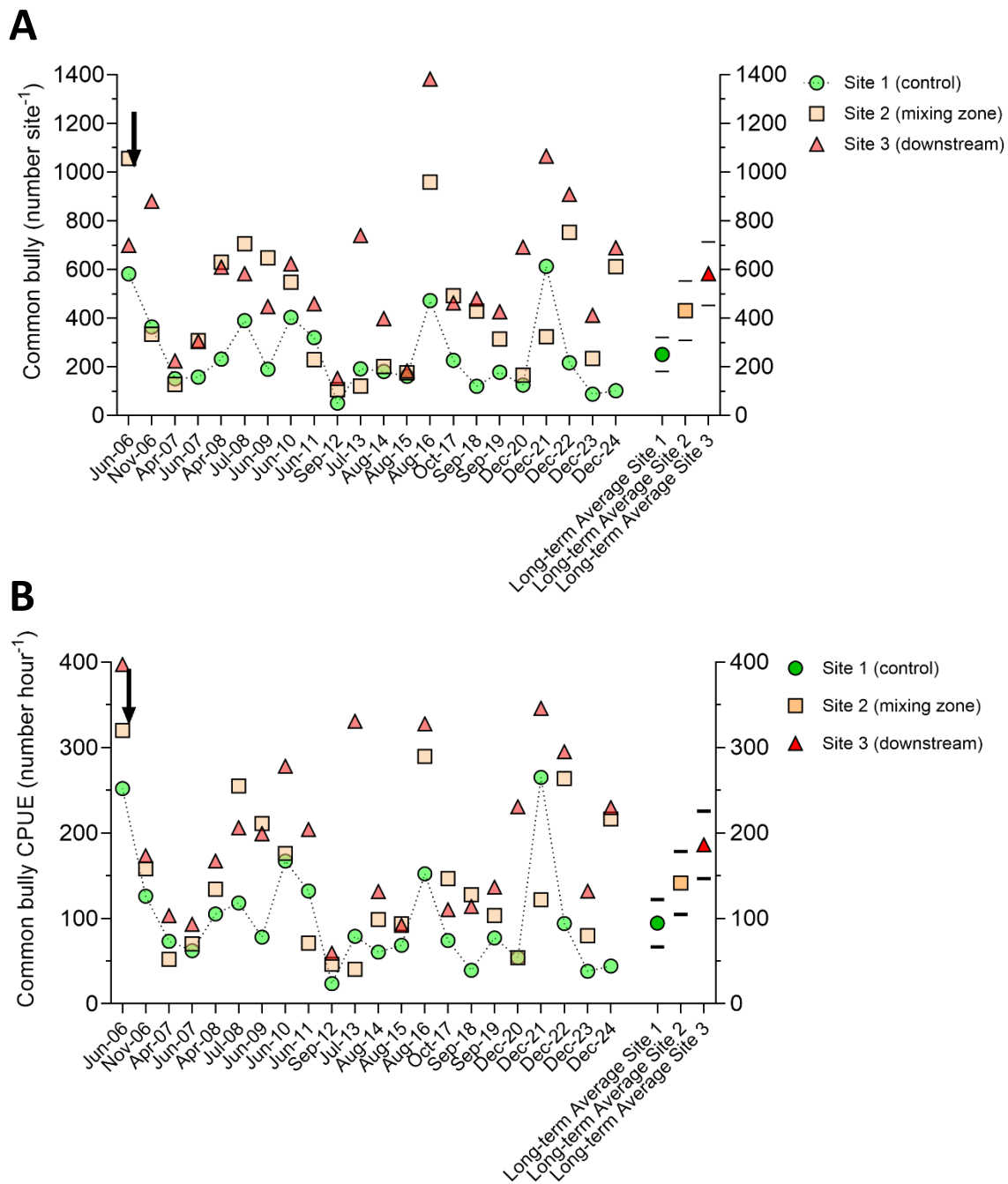
Common bully (*Gobiomorphus cotidianus*), juvenile trout (species undetermined), adult brown trout (*Salmo trutta*) (Figure 3), kōaro (*Galaxias brevipinnis*) and kōura (*Paranephrops planifrons*), were captured in the 2024 electrofishing survey. Common bully were the most numerically dominant fish species at each site.



**Figure 3. A female brown trout (*Salmo trutta*) (approximately 360 mm fork length) captured at site 2 downstream of the alum dosing point in 2024.**

Common bully relative density (fish per 50 m reach; Figure 4A) and CPUE (number h<sup>-1</sup>; Figure 4B) has varied substantially between years (2006–2024) and across sites. However, both measures indicate that common bully abundance was lower at the upstream control site (Site 1; long-term averages: 250.8 fish site<sup>-1</sup>, CPUE 94.3 fish hour<sup>-1</sup>) compared to Site 2 (long-term averages: 430.5 fish site<sup>-1</sup>, CPUE 141.4 fish hour<sup>-1</sup>) and Site 3 (long-term averages: 582.5 fish

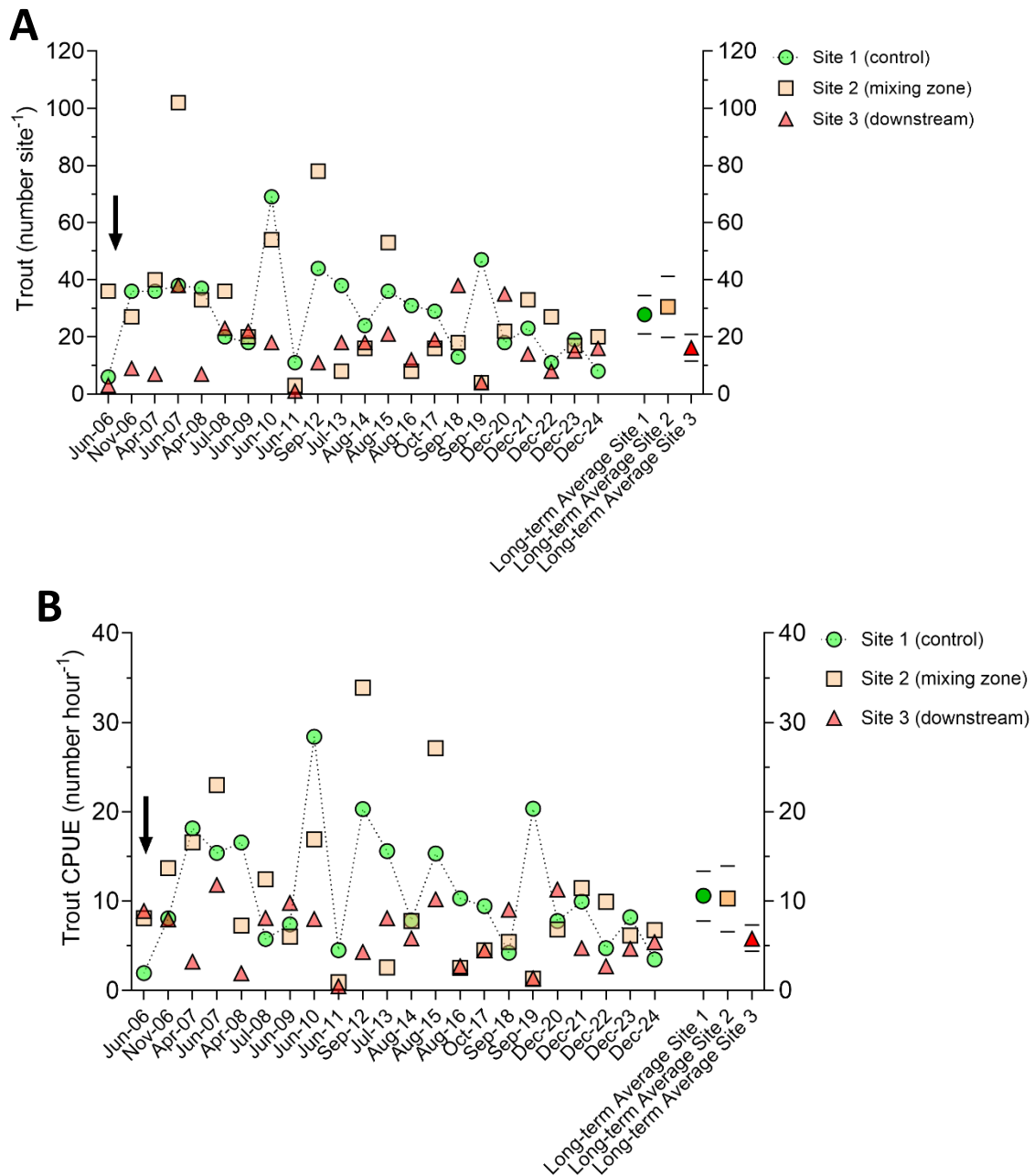
site<sup>-1</sup>, CPUE 186.0 fish hour<sup>-1</sup>), which are downstream of the alum dosing point, although the magnitude of the difference is generally stable between years.



**Figure 4. Common bully numbers captured per site (A) and catch per unit effort (CPUE; B) in the Utuhina Stream (June 2006 – December 2024). Arrow indicates the commencement of alum dosing in the stream. Values for long-term averages are means  $\pm$  1 S.D.**

Juvenile trout (young of the year) were present at all sites, with density similar between the upstream control site (Site 1; long-term averages: 27.8 fish site<sup>-1</sup>, CPUE 10.6 fish hour<sup>-1</sup>) and

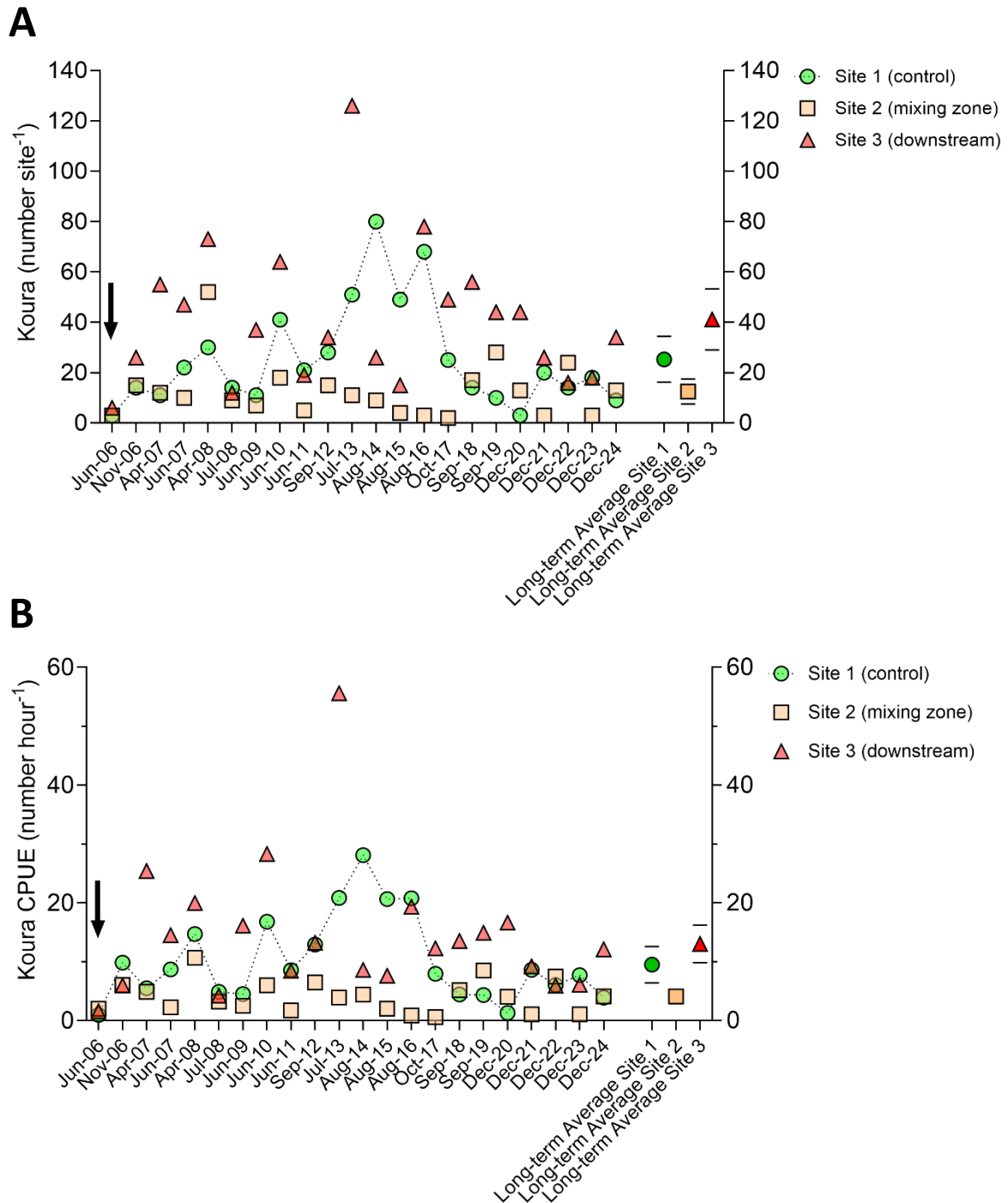
Site 2 (long-term averages: 30.5 fish site<sup>-1</sup>, CPUE 10.3 fish hour<sup>-1</sup>), while fish density at Site 1 has lower than the long-term average for the past 3 years (long-term averages: 16.2 fish site<sup>-1</sup>, CPUE 5.8 fish hour<sup>-1</sup>) (Figure 5).



**Figure 5. Total numbers of trout captured per site (A) and catch per unit effort (CPUE; B) of trout in the Utuhiina Stream since June 2006. Arrow indicates the commencement of alum dosing in the stream. Values for long-term averages are means  $\pm$  1 S.D.**

Kōura numbers have fluctuated between years but were captured at all three sites in 2024. Numbers were similar to the long-term averages at Site 2, which has generally been the least abundant site (long-term averages: 12.5 kōura site<sup>-1</sup>, CPUE 4.1 kōura hour<sup>-1</sup>), and most abundant at Site 3 (long-term averages: 41.5 kōura site<sup>-1</sup>, CPUE 13.0 kōura hour<sup>-1</sup>) but were

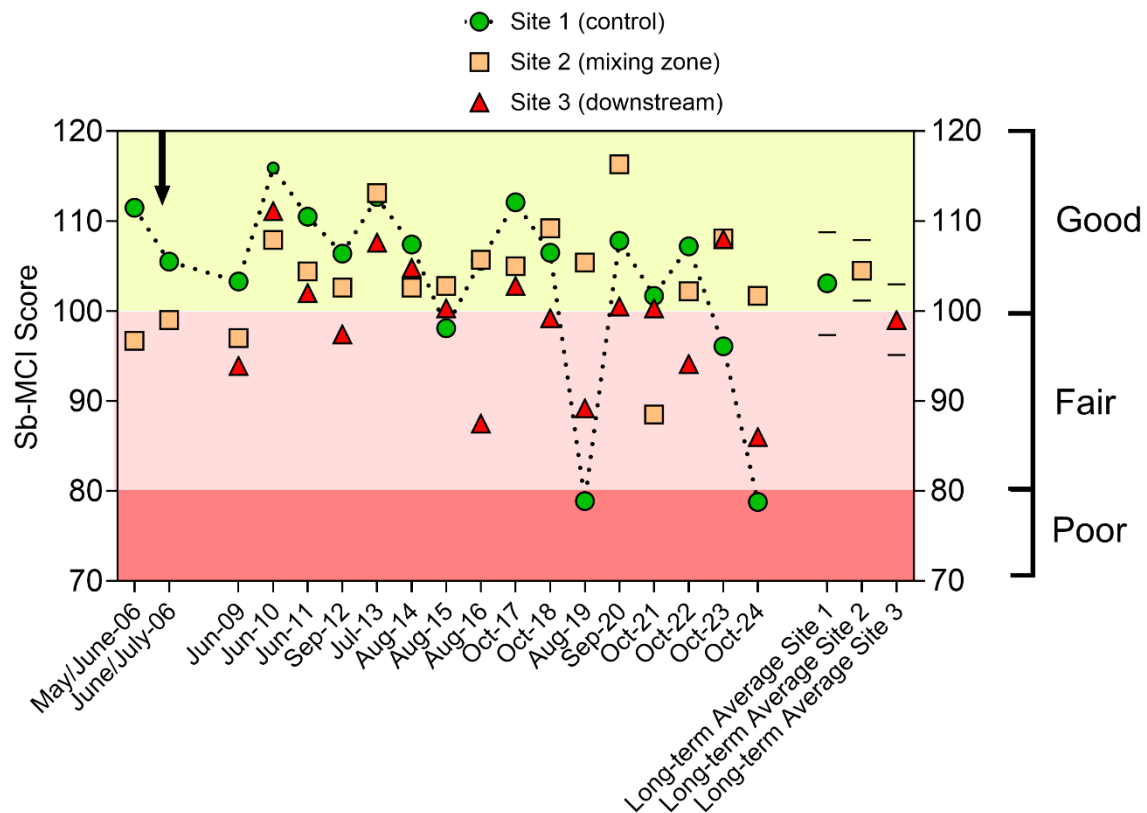
lower than the long-term average at Site 1 (long-term averages: 25.3 kōura site<sup>-1</sup>, CPUE 9.5 kōura hour<sup>-1</sup>) (Figure 6).



**Figure 6. Kōura captured per site (A) and catch per unit effort (CPUE; B) of kōura in the Uthuhina Stream since June 2006. Arrow indicates the commencement of alum dosing in the stream. Values for long-term averages are means  $\pm$  1 S.D.**

### Macroinvertebrate community (MCI-sb)

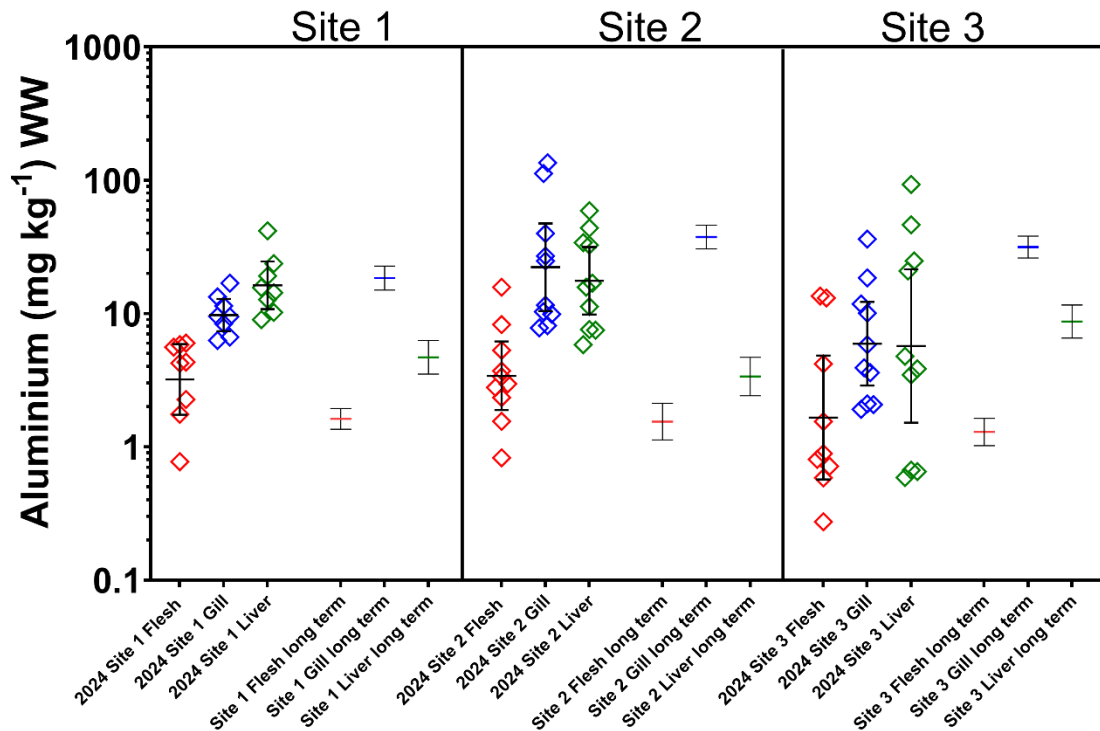
The semi-quantitative macroinvertebrate community analysis for soft-bottomed streams; (MCI-sb) score notably declined at Sites 1 and 3 in 2024 compared to the long-term average, with Site 1 declining into the poor-quality class (<80) of Stark & Maxted (2007) (Figure 7). However, Site 2 scored >100 placing it in the good-quality class for the 2024 survey.



**Figure 7. Soft-bottom stream macroinvertebrate community assessment (Sb-MCI) for the Uthuhina Stream since June 2006. Values for long-term averages are means  $\pm$  95% confidence intervals. Note: values for sites 1 and 2 in 2006 are approximated from data in Clarke 2006.**

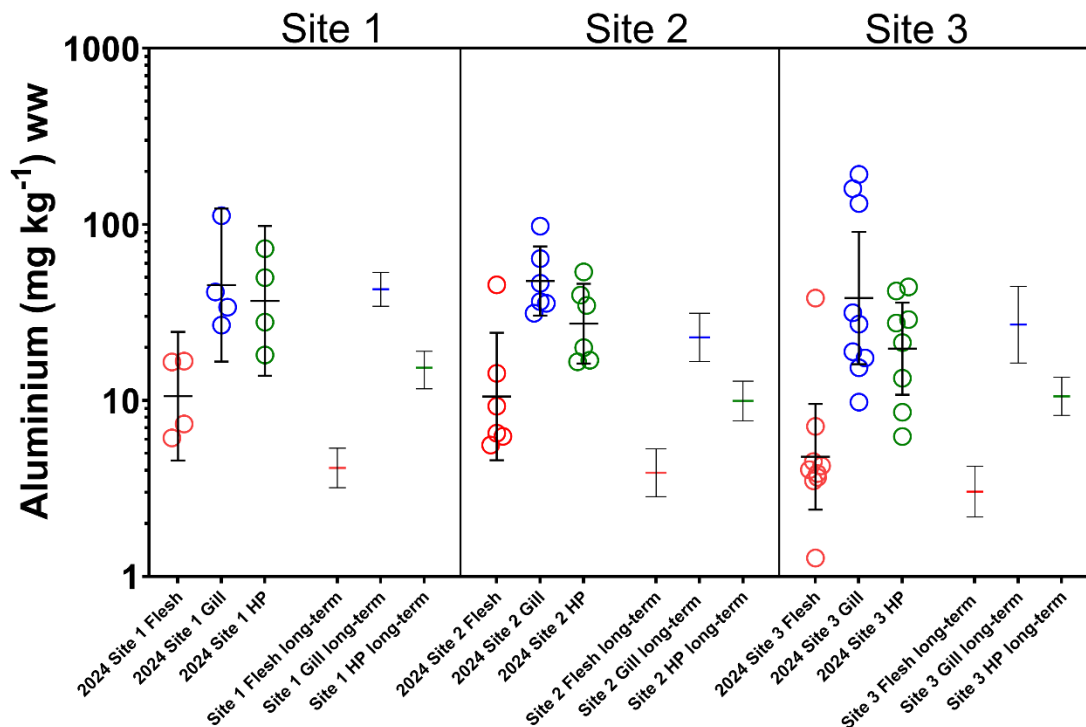
### Tissue aluminium concentrations

Tissue aluminium concentrations in the flesh, gill and liver of common bully sampled in 2024 were equivalent to long-term means. Common bully mean liver aluminium concentrations were elevated in comparison to long-term means at Site 1 and Site 2, but lower than the long-term mean at Site 3. Although aluminium tissue concentrations are lowest in flesh and similar in liver and gill tissues there appears to be no notable difference in the same tissues between sites (Figure 8).



**Figure 8. Common bully tissue (liver, flesh and gill) aluminium concentrations ( $\text{mg kg}^{-1}$  WW) for 2024 and mean tissue concentrations for monitoring years 2009–2023 - geometric mean with lower and upper 95% confidence intervals (CI). Site 1 = upstream control reach, Site 2 = alum mixing zone, Site 3 = downstream reach.**

Only four kōura were of sufficient size for tissue analysis at Site 1 and six at Site 2 in 2024. Despite this, there were no notable differences in tissue concentrations of the flesh, gill and hepatopancreas compared to the long-term means (Figure 9). Tissue aluminium concentrations remained similar across all sites.



**Figure 9. Kōura tissue (flesh, gill and hepatopancreas) aluminium concentrations (mg kg<sup>-1</sup> WW) for 2024 and mean years tissue concentrations for monitoring years 2009–2023 - geometric mean with lower and upper 95% confidence intervals (CI). Site 1 = upstream control reach, Site 2 = alum mixing zone, Site 3 = downstream reach.**

## Discussion

Annual surveys for effects of alum dosing to the Utuhiina Stream have been conducted since 2006 as part of the Bay of Plenty Regional Council resource consent to use alum to control phosphorus loading to Lake Rotorua. Macroinvertebrate and fish community surveys were undertaken and aluminium content in the tissues of common bully and kōura were determined through ICP-MS. Macroinvertebrate surveys were conducted at least two months before the electrofishing survey in the same stream reaches. Two 50 m reaches downstream of the alum dosing point were surveyed along with one upstream reach as a control site.

### Fish community

Apart from 2020, juvenile kōaro have been captured at every year from 2016 to 2024. Kōaro are a taonga species in the Rotorua Te Arawa lakes and this species suffered a catastrophic decline in abundance following the introduction of trout and smelt in the early 1900s. The observation of kōaro in the Utuhiina Stream extends the known distribution of the species in tributary streams of Lake Rotorua. The Utuhiina Stream was extensively surveyed in 2007/2008 for the presence of kōaro and none were found (Rowe et al. 2008). Their

consistent presence in the Utuhina Stream is an encouraging indication that the species may now be established in the stream.

There is typically large interannual variation in fish and kōura CPUE across all three surveyed reaches, much of which can be tentatively ascribed to modification of habitat as the stream is highly channelised as it passes through the city. During major flood events the stream bed becomes highly disturbed as the extent of instream and bankside vegetative cover is limited and significant erosion of the banks has been observed (Ling 2021). Common bully and kōura prefer relatively low flow velocities of around  $0.4 \text{ m}^3 \text{ s}^{-1}$  and stable substrate, while the Utuhina is primarily composed of mobile pumice sands and graves at Sites 2 and 3 (Jowett and Richardson, 1995; Collier and Smith, 2003; Jowett et al., 2008) which are likely to be physically displaced by high velocities associated with major flood events. The data presented in this report further supports the conclusion by Tempero and Ling (2023) that alum dosing does not appear to have a notable effect on the fish and kōura community and that site and interannual variations appear to be due to hydrological conditions and habitat variability.

#### Macroinvertebrate community

There was a notable decline in the semi-quantitative macroinvertebrate community (for soft-bottomed streams; MCI-sb) score at Sites 1 and 3 in 2024, compared to the long-term means, although the score for Site 2 was analogous to the long-term mean (Figure 7). The decline in MSCI-sb at Site 1, above the dosing point, and no change at Site 2 just below the dosing point, suggests that the decline at Site 3 was due to natural variation rather than alum dosing. Similar declines have previously been observed at Sites 1 and 3 in previous years, while Site 2 has remained more consistent.

#### Tissue aluminium concentrations

Analysis of tissue aluminium concentrations in kōura and common bully were within the ranges of those observed in previous surveys. There were expected differences between tissues, with the highest concentrations occurring in gill tissue, followed by liver (hepatopancreas) and flesh within sites. There was some evidence that bully liver aluminium concentrations were elevated compared to long-term means at Sites 1 and 2 in the 2024 survey period, however tissue concentrations were broadly similar across all three sites indicating there was no enhanced accumulation of aluminium in the tissues due to alum dosing. Kōura tissue aluminium concentrations were generally equivalent previous years and showed no notable differences between sites for the same tissue type. A small number of individuals had elevated gill concentrations at Site 3 compared to the long-term average concentrations, but this is unlikely to result in harmful physiological impacts (Fensham et al. 2022).

Although intraspecific variability in the tissue concentrations of non-essential metals is well recognised, it is poorly understood (Pan and Wang 2009). While differences might be expected due to obvious factors such as sex, size, age, diet and metabolic rate, individuals chosen for analysis in this study were selected to be the largest individuals captured on each

occasion to reduce some of the influence of such effects. All animals appeared healthy and unaffected by the exposure to alum. Overall, there were no appreciable differences in tissue concentrations between the upstream control site and sites downstream of the alum discharge.

## **Conclusions**

Exposure of macroinvertebrates, fish and kōura in the Utohina Stream to low continuous alum dosing does not appear to result in changes in community abundance. While there was some indication of aluminium accumulation in the gill tissue of fish and kōura downstream of the dosing site this does not appear to affect abundance at downstream sites compared to the control site or result in chronic toxicity.

## **Acknowledgements**

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