

Alum Dosing of Waitangi Stream: Biomonitoring of Aluminium 2021-2023



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By Grant Tempero and Nicholas Ling
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Environmental Research Institute – Te Tumu Whakaora Taiao
Division of Health, Engineering, Computing and Science
University of Waikato, Private Bag 3105
Hamilton 3240, New Zealand

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Cover image: Te Wairoa Bay, Lake Rotoehu, discharge point of the Waitangi Stream.

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Reviewed by:



Deniz Özkundakci
Toihuarewa Waimaori BOPRC Chair
University of Waikato

Approved for release by:



Charles Lee
Director
Environmental Research Institute

Executive Summary

Continuous alum dosing of the Waitangi Stream at Lake Rotoehu commenced in 2011 to reduce concentrations of dissolved reactive phosphorus in this inflow to the lake and improve water quality. The Bay of Plenty Regional Council contracted the University of Waikato to undertake monitoring of biota in the Waitangi Stream for potential impacts due to alum dosing. Macroinvertebrate community analysis and tissue aluminium concentrations in kōura (*Paranephrops planifrons*) and goldfish (*Carassius auratus*) have been undertaken annually since 2013 to determine the impacts and bioaccumulation of aluminium.

Adult kōura and goldfish were collected in October of 2021 and 2022 from Waitangi Stream. Aquatic macroinvertebrate community sampling was undertaken separately from three stream reaches in 2021. Macroinvertebrate sampling was not conducted in 2022 and 2023, along with kōura and goldfish sampling in 2023, due to unusually high lake levels inundating the Waitangi Stream and preventing access to the lake.

The macroinvertebrate community index scores for soft-bottom streams (MCI-sb) were poor for all three stream reaches but consistent with results from previous monitoring surveys. Tissue aluminium concentrations of kōura collected in 2021 and 2022 were similar to those observed in previous surveys of the Waitangi Stream, while goldfish gill and liver concentrations continued a decreasing trend from a peak in 2016. Overall, tissue aluminium concentrations have remained generally similar to those observed at other alum dosing sites or control sites. This analysis confirms previous findings that there is no evidence of enhanced bioaccumulation of aluminium in Lake Rotoehu biota.

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Introduction

Alum (Aluminium sulphate) dosing is widely used for wastewater treatment and restoration of freshwater ecosystems through the removal of dissolved phosphorus (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 (Al^{3+}) and hydroxy aluminium species occur in varying proportions with respect to acidic (i.e., Al^{3+} , 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).

Alum dosing of the Waitangi Stream was initiated in July 2011 to help control phosphorus loading to Lake Rotoehu. This action was undertaken as part of the Lake Rotoehu Action Plan, which aimed to lower the lake's Trophic Lake Index (TLI) from 4.6 (eutrophic) to 3.9 (mesotrophic) (Bay of Plenty Regional Council, 2007). Total phosphorus inputs to Lake Rotoehu have been estimated at 3.37 tonnes per annum (McBride et al. 2021), and alum dosing has been estimated to reduce dissolved phosphorus inputs to the lake by up to 0.7 tonnes per annum. Unlike alum dosing of the Lake Rotorua tributaries, which are dependent on stream flow, the Waitangi Stream is dosed at a standardised rate due to the constant flow of the springs discharge, although dose rates have varied over time (Figure 1). Alum dosing was halted in July 2018, then resumed from October 2020 to September 2021, before being halted again for repair and recertification of the tank and containment bund. However, dosing was not able to be resumed in 2023 due to high lake levels.

Monitoring for potential ecological impacts of alum dosing on Waitangi Stream has been undertaken since 2013. In addition to macroinvertebrate community analysis (MCI-sb), aluminium content in the liver (goldfish) or hepatopancreas (kōura), muscle and gills has been reported by Ling (2015, 2016, 2017, 2021). Kōura and goldfish collected downstream of the alum dosing plant in 2013 showed slightly elevated aluminium concentrations in the gills indicating enhanced exposure to aluminium, but little evidence for significant bioaccumulation in tissues. Aluminium concentrations in goldfish liver and gills were highest in 2016, but not significantly different to goldfish collected from alum dosed Lake Rotorua in 2013 and flesh concentrations were low. Monitoring of macroinvertebrates has found diversity to be limited, with chironomid larvae and oligochaete worms the most abundant species, resulting in an MCI-sb classification of poor for both control and treatment sites (Ling 2021). However, it was noted that this result is not unexpected for geothermal streams which typically show very limited macroinvertebrate communities (Ling 2021).

This report details the results of monitoring conducted by the University of Waikato from the Waitangi Stream for the years 2021–2023, including macroinvertebrate indices for soft

bottom streams collected at three sites in the Waitangi Stream, and tissue aluminium concentrations in the muscle, gills and liver or hepatopancreas of goldfish and kōura.

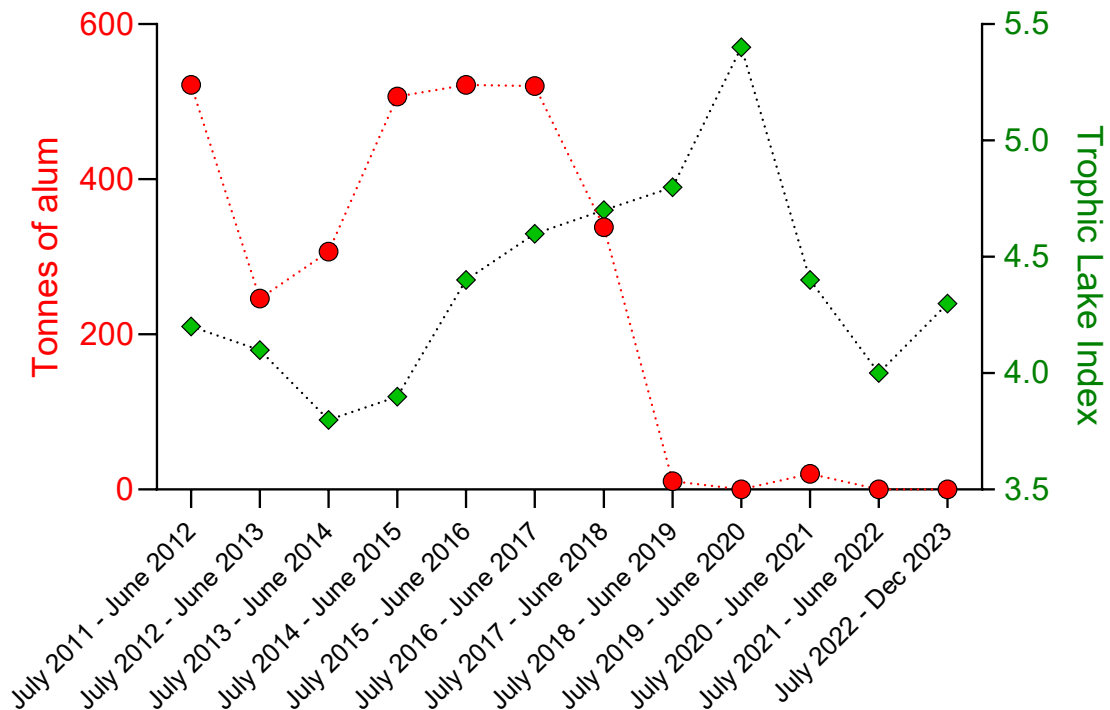


Figure 1. Annual Trophic Lake Index (TLI) and annual alum dosed to Waitangi Stream.

Methods

Study site

Lake Rotoehu is a 795-ha lake formed by the Rotoma eruption approximately 8,500 years ago. Lake Rotoehu is relatively shallow, with a mean depth is 8.2 m and a maximum depth of 13.5 m. The lake has no surface outlet and water exits the lake through a sinkhole in one of the northern lake arms and may have other subsurface outlets (Bay of Plenty Regional Council, 2007). The alum dosing plant was constructed on the major surface inflow to Lake Rotoehu, the Waitangi Stream, which comprises the geothermal Waitangi Soda Springs and nearby additional spring inflows that collectively discharge approximately $0.5 \text{ m}^3 \text{ s}^{-1}$.

Biota sampling

Adult kōura (*Paranephrops planifrons*) and goldfish (*Carassius auratus*) were collected in October of 2021 and 2022 from Waitangi Stream by Ian Kusabs. Ten samples from each species were frozen and supplied to the University of Waikato for tissue analysis. Samples

were not collected in 2023 due to exceptionally high lake water levels preventing access to the lake.

Aquatic macroinvertebrate community analysis (MCI-sb) was undertaken separately to collection of kōura and goldfish from three stream reaches indicated in Figure 2. As a control site was unavailable upstream of the alum diffuser, samples were taken from a tributary stream that joins the Waitangi Stream 140 m downstream of the alum diffuser. 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 m² at each site. Macroinvertebrate diversity was examined 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. Macroinvertebrate sampling was not able to be undertaken in 2022 and 2023 due to high water levels.

Tissue analysis

Samples of liver (goldfish) or hepatopancreas (kōura), flesh and gills were carefully dissected using acid-washed instruments. A suite of 28 elements was 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 0.1 mg, 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 dry 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.

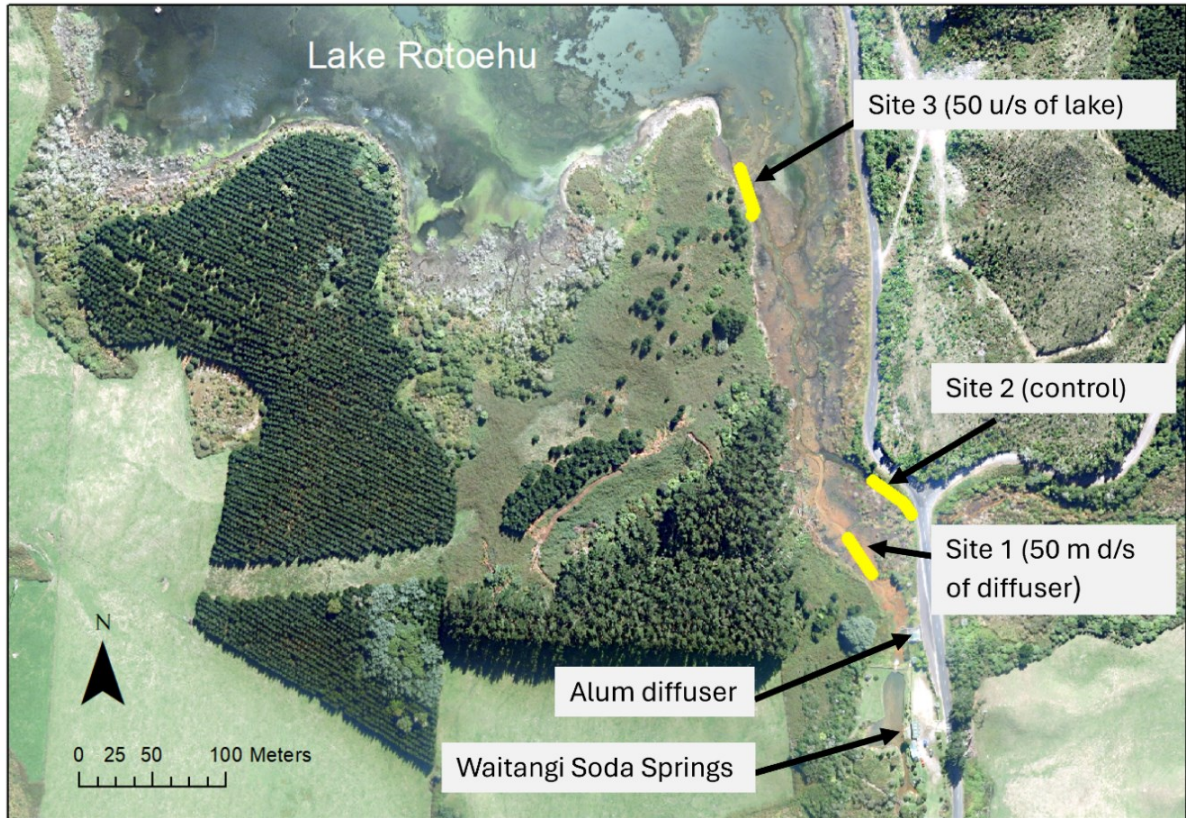


Figure 2. Macroinvertebrate sampling sites downstream of the Waitangi Soda Springs alum diffuser and a control site on a tributary to the Waitangi Stream.

Results

Macroinvertebrate community (MCI-sb)

Macroinvertebrates were not sampled from the Waitangi Stream in 2022 and 2023 due to high water levels in the lake inundating the stream and raising the water level by approximately 2 m. For 2021, the macroinvertebrate community index scores for soft-bottom streams (MCI-sb) were classified as poor for all three monitoring sites (Figure 3), with chironomid larvae and oligochaete worms the most abundant taxa.

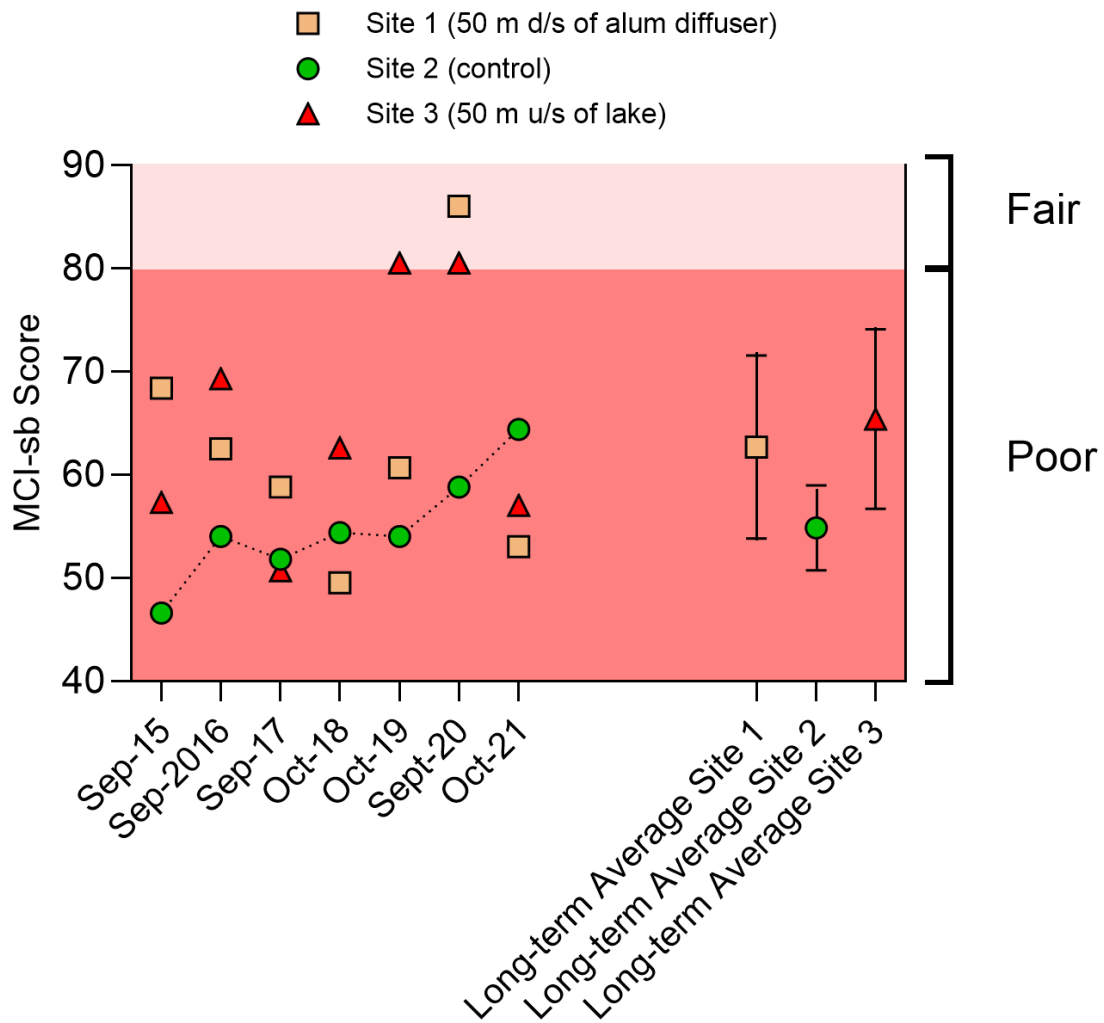


Figure 3. Annual and long-term MCI-sb scores for three sites on the Waitangi Stream. Transverse bars are geometric means with 95% confidence limits. Note: Macroinvertebrate sampling was not conducted in 2022 and 2023 due to high water levels.

Total tissue aluminium

Aluminium concentrations in goldfish liver and gill tissues were lower in 2021 and 2022 compared to previous years, although there was no change in flesh concentrations (Figure 4). Aluminium concentrations in kōura flesh and hepatopancreas collected in 2021 and 2022 were somewhat elevated compared to previous years (cf. 2019 and 2020) but were generally within the range of concentrations observed in specimens from lakes Rotoehu, Rotorua and the alum dosed Utuhina Stream (Figure 4). Despite some inter-annual variation, the distribution of tissue aluminium concentrations in kōura has remained relatively consistent within tissue types, while goldfish liver and gill tissue concentrations have been variable over time.

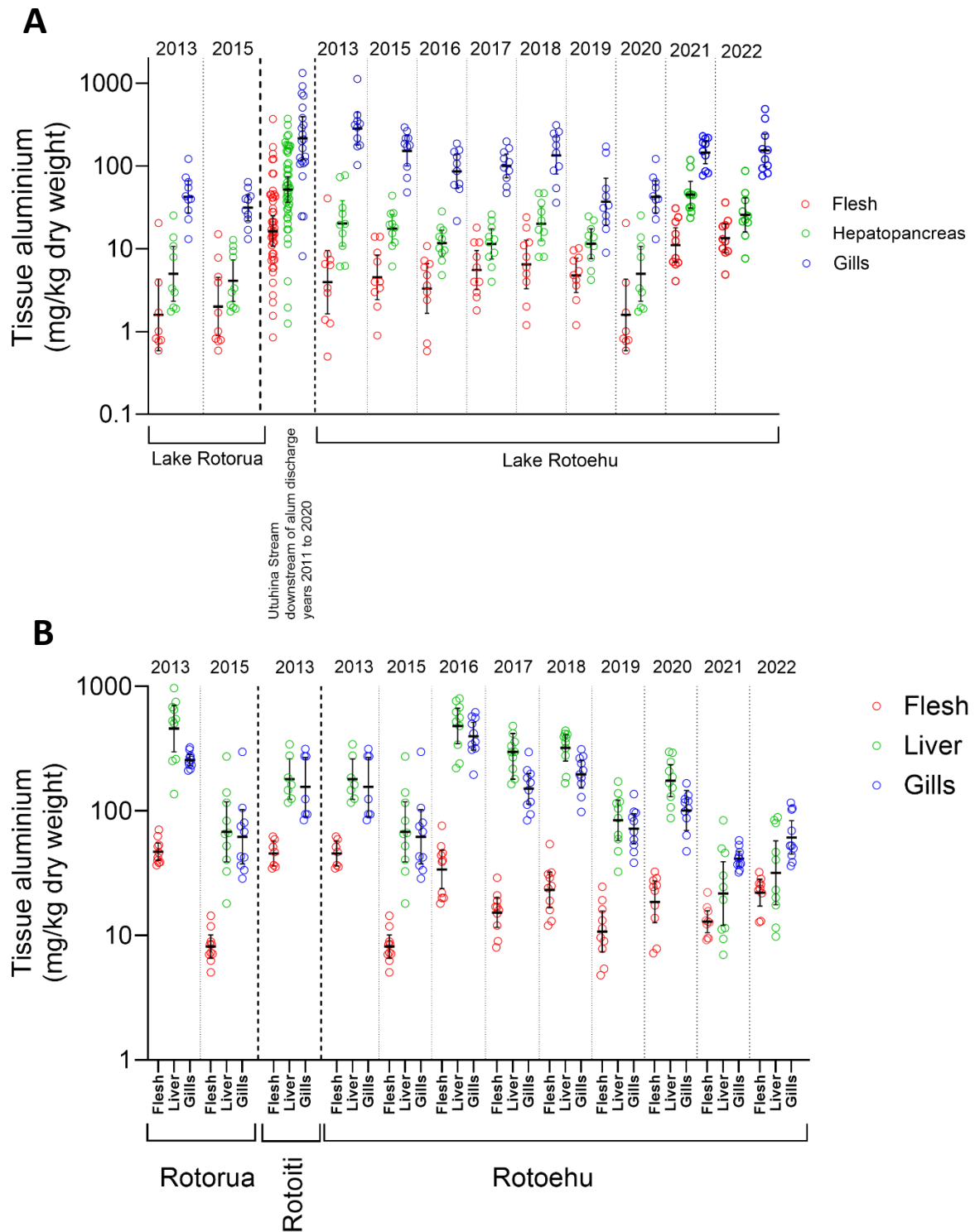


Figure 4. Aluminium concentrations in tissues of (A) kōura and (B) goldfish from Lake Rotoehu, with comparative values for these species from Lake Rotorua and the alum receiving zone of the Utuhina Stream (Lake Rotorua tributary). Transverse bars are geometric means with 95% confidence limits. Note: Goldfish and kōura were not collected in 2023.

Discussion

Macroinvertebrate sampling was not conducted in 2022 and 2023 due to inundation of the Waitangi Stream from Lake Rotoehu. The 2021 MSI-sb scores were similar to previous years with species primarily limited to chironomid larvae and oligochaete worms, both of which are highly tolerant of poor water quality and extreme physicochemical conditions associated with inflow from the geothermal Waitangi Soda Springs (Armitage et al. 1995; Stucker et al. 2023).

Potential correlations between alum dosing rates and tissue aluminium concentrations were not investigated due to the large degree of sample variation and the large uncertainty in subject exposure rate and duration. It is also possible that changes in environmental conditions not related to alum dosing such as geothermal inflows, water level or may vegetation have an influence on tissue aluminium concentrations (Sprenger and McIntosh 1989; Howells et al. 1994). Because the gills are the main site of uptake for water-derived aluminium uptake in fish, concentrations in gill tissue are generally higher than any internal tissue (Howells et al. 1990). Acute toxicity of aluminium due to respiratory and ionoregulatory effects on gills typically only occurs at water pH values below 5.2, which is well below that expected in waters of Lake Rotoehu (pH range 6.9–9.2 over the study period). Bioaccumulation of aluminium through ingestion is limited as it generally occurs under circum-neutral pH where monomeric aluminium does not form (Gensemer et al. 2018). In addition, aluminium levels in the flesh of goldfish and kōura have remained comparatively unchanged over time and similar to those observed at other alum dosing sites or control sites.

Conclusions

Despite the near cessation in alum dosing to the Waitangi Stream in 2021-2023 there have been no notable changes in MCI-sb or tissue aluminium concentrations in goldfish and kōura collected from Lake Rotoehu. Addition of alum to the Waitangi Soda Springs inflow is therefore likely to have less than minor effects' on Lake Rotoehu biota in the long-term.

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References

Alexopoulos E, McCrohan CR, Powell JJ, Jugdaohsingh R and White KN (2003). Bioavailability and toxicity of freshly neutralized aluminium to the freshwater crayfish *Pacifastacus leniusculus*. *Archives of Environmental Contamination and Toxicology* **45**: 509-514.

Armitage PD, Cranston PS, Pinder LCV (1995). *The Chironomidae: biology and ecology of non-biting midges*. London: Chapman & Hall.

Bay of Plenty Regional Council (2007). *Lake Rotoehu Action Plan*. Environmental Publication 2007/19. Bay of Plenty Regional Council, Whakatane, New Zealand. 70 pp.

Cooke GD, Welch EB, Peterson S, Nichols SA (2005). *Restoration and Management of Lakes and Reservoirs*. CRC Press. Boca Raton. 601 pp.

Gensemer RW, Gondek JC, Rodriguez PH, Arbildua JJ, Stubblefield WA, Cardwell AS, Santore RC, Ryan AC, Adams WJ, Nordheim E (2018). Evaluating the effects of pH, hardness, and dissolved organic carbon on the toxicity of aluminum to freshwater aquatic organisms under circumneutral conditions. *Environmental Toxicology and Chemistry* **37**: 49-60.

Howells G, Dalziel TRK, Reader JP, Solbe JF (1990). EIFAC water quality criteria for European freshwater fish: report on aluminium. *Chemistry and Ecology* **4**: 117-173.

Howells G, Dalziel TRK, Reader JP, Solbe JF (1994). *Aluminium and freshwater fish water quality criteria*. Water Quality for Freshwater Fish (G. Howells Ed.). Gordon and Breach Science Publishers. Switzerland.

Ling N (2015). Waitangi Soda Springs alum dosing – bioavailability of aluminium 2013. ERI Report No. 67. Client report prepared for Bay of Plenty Regional Council. Environmental Research Institute, Faculty of Science and Engineering, The University of Waikato, Hamilton, New Zealand.

Ling N (2016). Waitangi Soda Springs alum dosing – bioavailability of aluminium 2015. ERI Report No. 83. Client report prepared for Bay of Plenty Regional Council. Environmental Research Institute, Faculty of Science and Engineering, University of Waikato, Hamilton, New Zealand. 8 pp

Ling N (2017). Alum dosing at Waitangi Soda Springs – bioavailability of aluminium in 2016. ERI Report No. 103. Client report prepared for Bay of Plenty Regional Council. Environmental Research Institute, Faculty of Science and Engineering, The University of Waikato, Hamilton, New Zealand. 8 pp.

Ling N (2021). Waitangi Soda Springs alum dosing – bioavailability of aluminium 2011-2020. ERI Report Number 159. Client report prepared for Bay of Plenty Regional Council. Environmental Research Institute, School of Science, The University of Waikato, Hamilton, New Zealand. 9 pp.

McBride CG, MacCormick A, Verburg P (2021). Estimated catchment loads of nitrogen and phosphorus to the Rotorua Te Arawa Lakes. ERI Report Number 143. Client report prepared for Bay of Plenty Regional Council. Environmental Research Institute, School of Science, The University of Waikato, Hamilton, New Zealand. 93 pp.

Playle RC, Wood CM (1989). Water chemistry changes in the gill micro-environment of rainbow trout: experimental observations and theory. *Journal of Comparative Physiology. B, Biochemical, Systemic, and Environmental Physiology* **159**: 527-537.

Sprenger M, McIntosh A (1989) Relationship between concentrations of aluminum, cadmium, lead, and zinc in water, sediments, and aquatic macrophytes in six acidic lakes. *Archives of Environmental Contamination and Toxicology* **18**: 225-231.

Stark JD, Boothroyd IKG, Harding JS, Macted JR, Scarsbrook MR (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. 57 pp.

Stark JD, Macted JR (2007). A biotic index for New Zealand's soft-bottomed streams. *New Zealand Journal of Marine and Freshwater Research* **41**: 43-61.

Stucker VK, Curtis JC, Britten K (2023). Comparison of hydrothermal fluids and fields of the northern Okataina Volcanic Centre: Fifty years ago to present time. *Journal of Volcanology and Geothermal Research* **435**: 107757.