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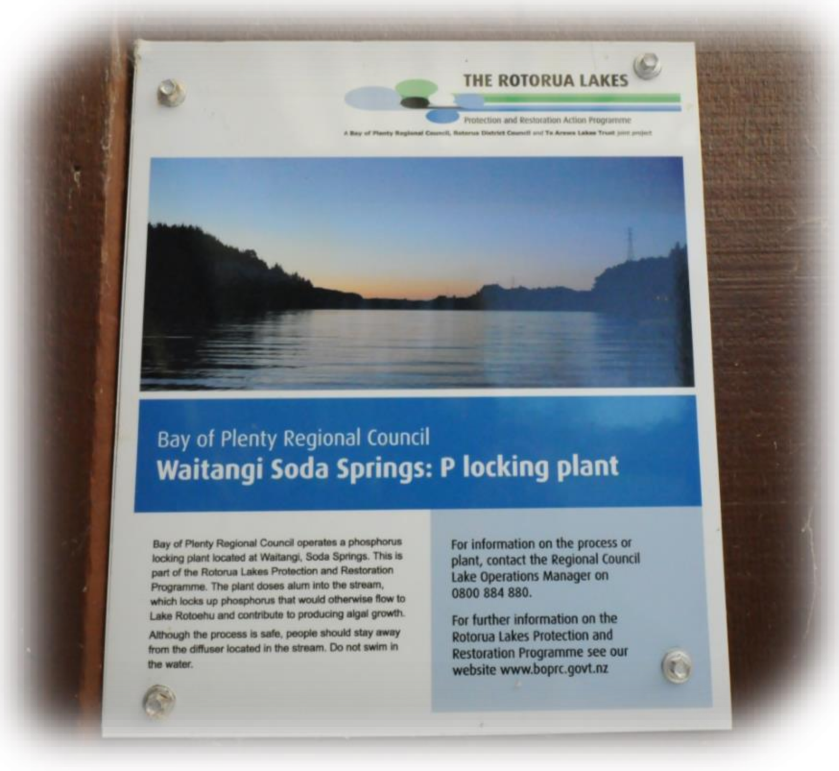
Waitangi Soda Springs Alum Dosing –
Bioavailability of aluminium 2011-2020



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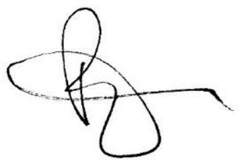

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Executive Summary

Continuous alum dosing of the Waitangi Soda Springs at Lake Rotoehu commenced in 2011 to reduce inflows of dissolved reactive phosphorus to Lake Rotoehu. Analyses of bioaccumulation in the tissues of kōura and goldfish from Lake Rotoehu were undertaken on animals collected annually since 2013 to determine the bioavailability and bioaccumulation of aluminium. Lake Rotoehu kōura and goldfish collected in 2013 showed slightly elevated aluminium concentrations in the gills indicating enhanced exposure to aluminium but little evidence for significant bioaccumulation in tissues. Concentrations in goldfish liver and gills were highest in 2016, but not significantly different to goldfish collected from Lake Rotorua in 2013 and flesh concentrations were low. Analyses of animals collected in 2020 confirm these earlier findings with no evidence of enhanced bioaccumulation of aluminium in Lake Rotoehu biota.

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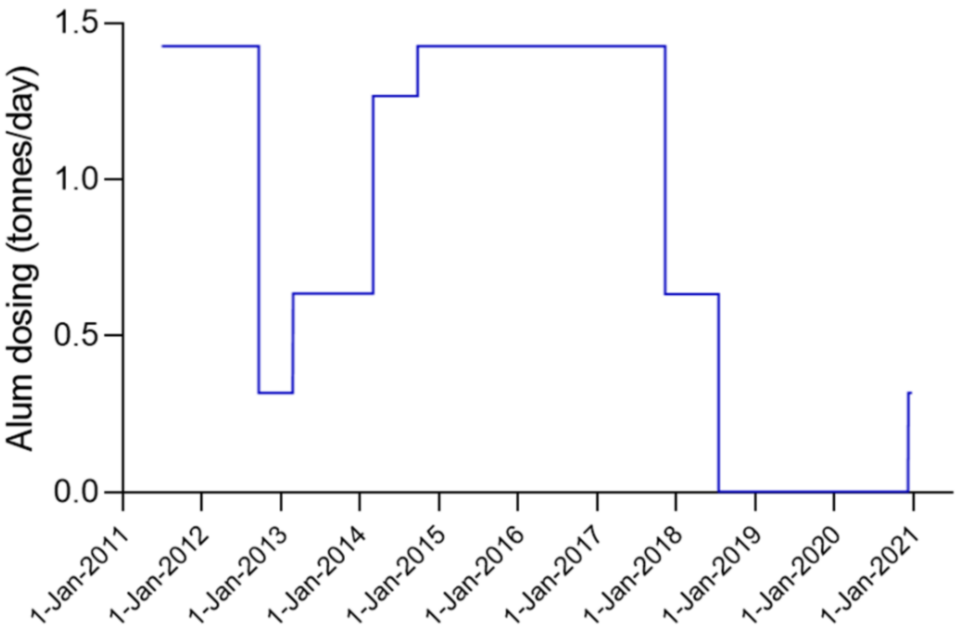
Introduction

Water quality of Lake Rotoehu is historically poor with trophic lake index (TLI) values exceeding 4, corresponding to a eutrophic condition. The Lake Rotoehu Action Plan (Bay of Plenty Regional Council, 2007) proposed to lower the TLI of Lake Rotoehu from 4.6 to 3.9 by reducing internal and catchment-derived nutrients (nitrogen (N) and phosphorus (P)). The Action Plan proposed a wide variety of actions to improve water quality and, following the successful establishment of continuous alum dosing plants on other streams in the Rotorua lakes district, an alum dosing plant was constructed in 2010/2011 on one of the major inflows to the lake, the Waitangi Stream, which comprises the Waitangi Soda Springs and additional spring inflows that collectively discharge around 0.5 $m^3 \bullet s^{-1}$. Alum dosing of this inflow commenced in July 2011 and is estimated to reduce dissolved phosphorus inputs to Lake Rotoehu by up to 0.7 tonnes per annum. Total phosphorus inputs to Lake Rotoehu have been estimated at 3.37 tonnes per annum (McBride et al. 2021). Unlike dosing of Lake Rotorua tributaries, which is dependent on stream flow, the Waitangi Soda Springs dosing is standardised due to the constant flow of the springs discharge, although it has varied over time (Figure 1A) and was discontinued in 2019/2020 due to having no observable effect on lake trophic status (Figure 1B). However, dosing recommenced on 10 December 2020 and has been increased above earlier rates to assist in nutrient limitation in the lake.

Alum dosing of tributaries to Lake Rotorua began on a trial basis in 2006 in the Utuhina Stream and the Bay of Plenty Regional Council granted a resource consent in November 2008 for the continuation of alum dosing until 2018. 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 phosphorus (DRP). The Puarenga Stream discharges a similar annual phosphorus load to Lake Rotorua and continuous alum dosing began on the Puarenga Stream in early 2010. The Puarenga Stream discharges into Sulphur Bay, a continuously active geothermal area and a designated wildlife reserve on the southern shores of Lake Rotorua. Landman & Ling (2009) measured bioaccumulation of aluminium in a variety of Lake Rotorua biota to provide baseline data on natural aluminium bioavailability prior to the commencement of alum dosing and subsequent studies have assessed the potential for aluminium bioaccumulation as a result of alum dosing of both the Utuhina and Puarenga streams (Ling 2021a, 2021b). However, no baseline assessments of aluminium bioaccumulation were undertaken on biota from Lake Rotoehu prior to the commencement of alum dosing and so comparisons can only be made by comparing samples taken from organisms sampled from other lakes in the region, albeit that the Rotorua lakes may differ substantially from one another with respect to water and sediment chemistry due to the differing influences of catchment, groundwater and geothermally derived inflows. This report provides data on aluminium concentrations in adult kōura and goldfish from Lake Rotoehu since 2013 along with comparative data from the same species in Lake Rotorua sampled in 2013 and 2015 to assess whether alum dosing of the Waitangi Soda Springs is providing bioavailable aluminium to lake macrobiota resulting in bioaccumulation and potential toxicity.



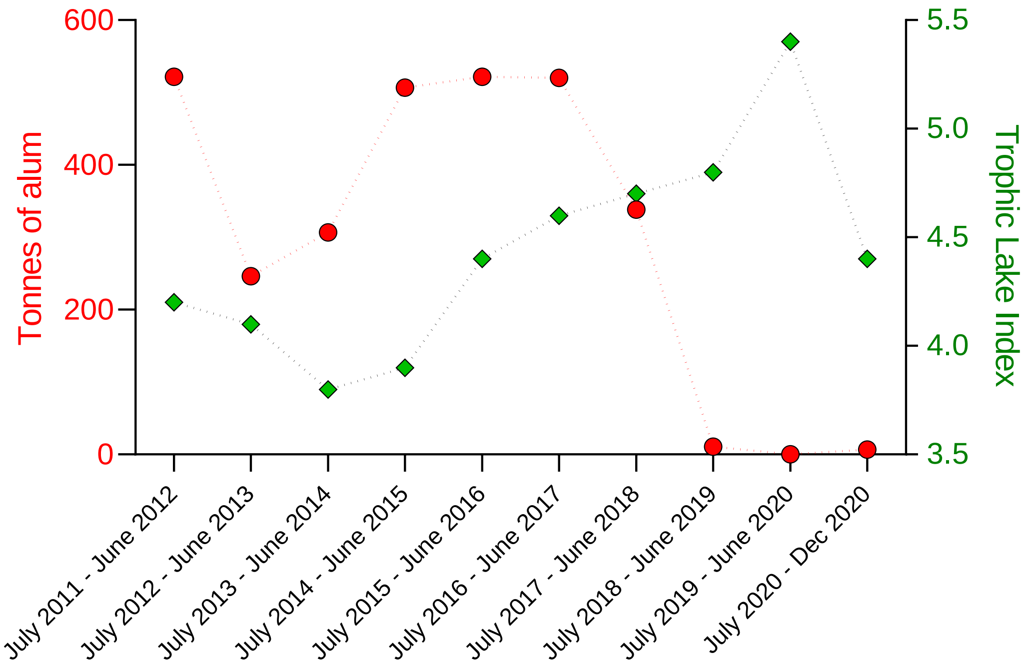


Figure 1. Tonnes of alum dosed per day (A) and per year (B) to the Waitangi Soda Springs and changes in Lake Rotoehu trophic lake index (TLI) over the period of alum dosing. Dosing was suspended in 2019/2020.

Methods

Sampling

Samples of frozen adult kōura (*Paranephrops planifrons*) and goldfish (*Carassius auratus*) from Lake Rotoehu and Waitangi Soda Springs were collected and supplied annually by Ian Kusabs together with adult kōura collected from Lake Rotorua in 2013 and 2015. Adult goldfish were collected for comparative purposes from the Ohau Channel of Lake Rotorua by boat electrofishing in 2013 and 2015.

Aquatic macroinvertebrate community analysis (MCI-sb) was undertaken separately to collection of kōura and goldfish from three stream reaches indicated in Figure 2. Macroinvertebrate sampling commenced in 2015. Because a control site was unavailable upstream of the alum diffuser, samples were taken from a tributary stream that joins the Waitangi Springs 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 m^2 at each site.

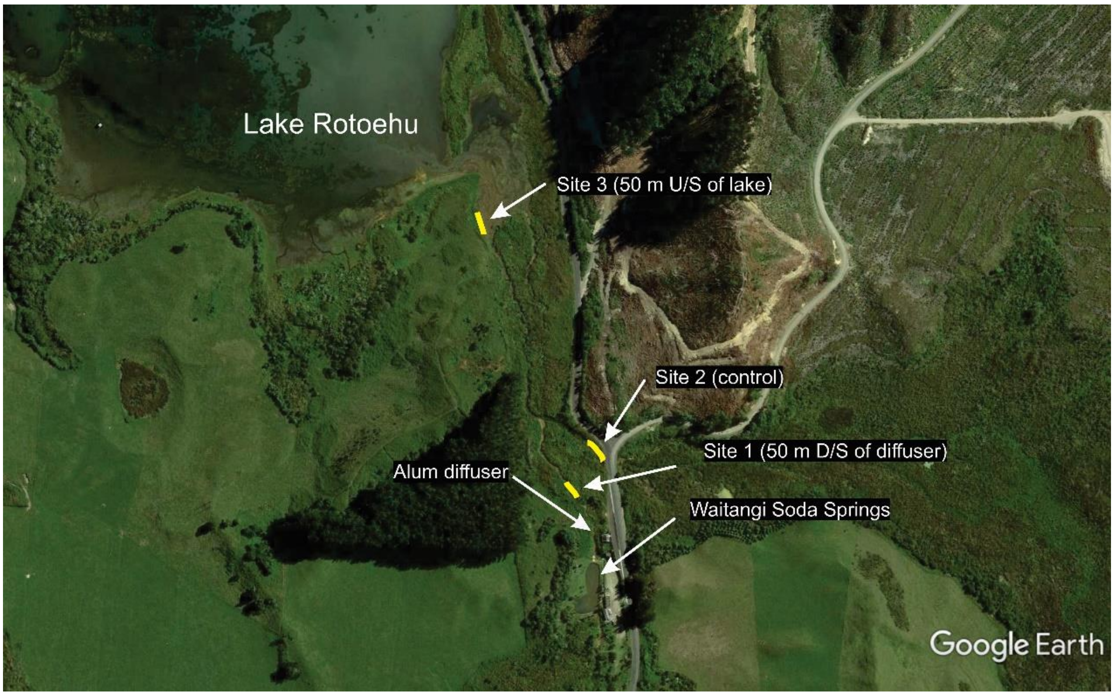


Figure 2. Macroinvertebrate sampling sites downstream of the Waitangi Soda Springs alum diffuser

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.

Sample 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 24 h 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 (Waikato Mass Spectrometry Facility, School of Science, University of Waikato, Hamilton, NZ; http://www.mass-spec.co.nz/). 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.

Results

Macroinvertebrate community (MCI-sb)

All sites were classified as poor, including the control site located on the tributary stream that was not subjected to effects of the alum discharge. This result is not unexpected for geothermal streams which typically show very limited macroinvertebrate communities. The diversity at all sites was limited to primarily chironomid larvae and oligochaete worms which are both highly tolerant of poor water quality and extreme physicochemical conditions.

Although it is tempting to conclude that the higher MCI-sb values at sites 1 and 3 in 2019 and 2020 could be due to the cessation of alum dosing, this is more likely an artefact of the way that the MCI-sb scores are calculated and the low number of taxa recorded at all three sites. The number of taxa recorded at site 2 was still greater than at sites 1 and 3 in both those years.

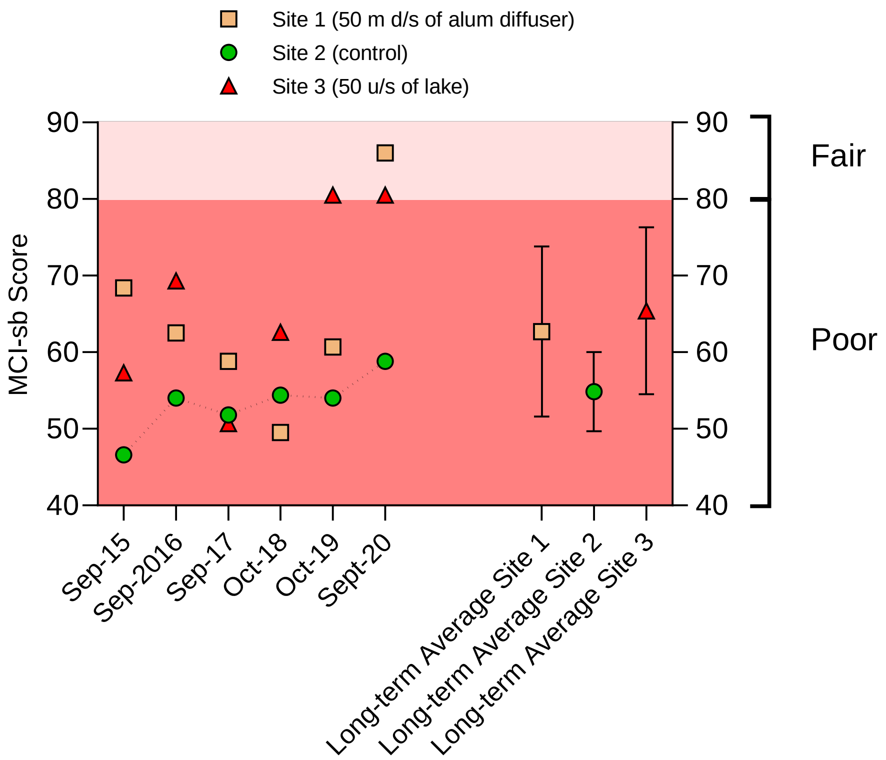


Figure 3. MCI-sb scores for three sites on the Waitangi Soda Springs stream.

Total tissue aluminium

Values for total tissue aluminium are presented in Figure 2. Tissue aluminium was generally higher in all tissues of kōura from Lake Rotoehu compared with animals from Lakes Rotorua which also receives inputs of alum via the dosing plants located on the Puarenga and Utuhina streams. Kōura from the downstream alum receiving zone in the Utuhina Stream had the highest levels of alum in all tissues overall, however, all differences between years and localities were not statistically significant due to high variability between individuals. In Lake Rotoehu, alum concentrations were generally lower in 2019 and 2020 which may relate to the cessation of alum dosing in the Waitangi Springs over this period (Figure 1) although overall (2013 to 2020) there was no significant correlation between tissue aluminium and total alum application to the lake. Higher tissue aluminium in kōura from the Utuhina Stream appears to be unrelated to the alum discharge (Ling, 2021) and the fish community of the Utuhina Stream appears unaffected by continuous alum dosing over many years. Aluminium concentration was much greater in the gills of kōura compared with other tissues. The gills of crayfish are most susceptible to bioaccumulation of aluminium with very little bioaccumulation occurring in internal organs even under chronically toxic conditions (Alexopoulos et al., 2003).

No significant differences in tissue concentrations were found when comparing goldfish from Lake Rotoehu with fish from Lake Rotorua or Lake Rotoiti.

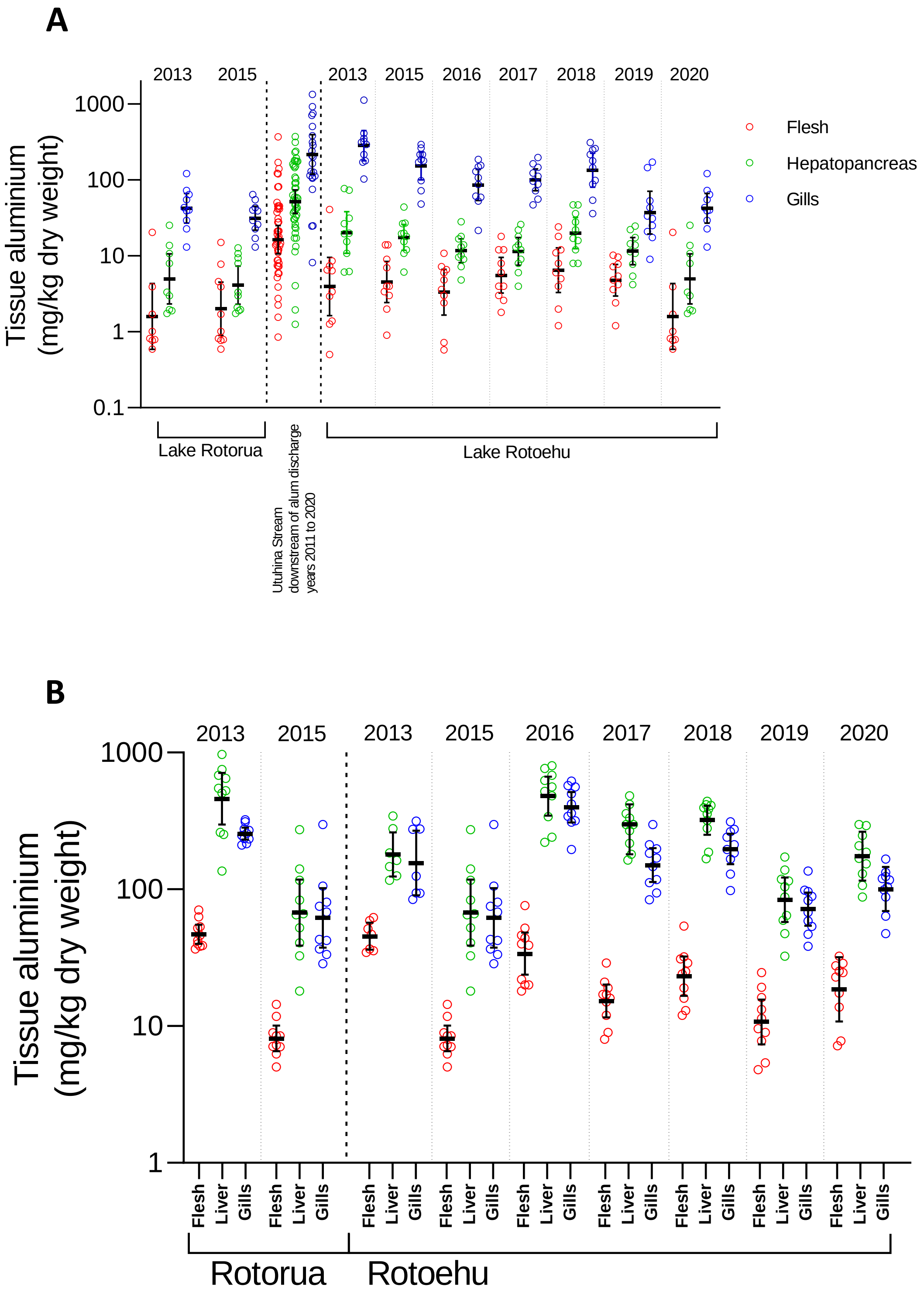


Figure 4. Aluminium concentrations in tissues of (A) kōura and (B) goldfish from Lake Rotoehu, with comparative values for these species from Lake Rotorua and the alum receiving zone of the Utuhina Stream (Lake Rotorua tributary). Transverse bars are geometric means with 95% confidence limits.

Conclusions

Higher levels of aluminium in the gill tissue of both kōura and goldfish from Lake Rotoehu are evidence of greater water-borne exposure to this element, possibly as a result of the continuous addition of alum to the Waitangi Soda Springs inflow. However, there is no evidence that greater exposure links to greater bioaccumulation because the aluminium levels of internal tissues of both species were not elevated when compared with these species from Lake Rotorua. Because the gills are the main site of uptake for water-derived aluminium uptake in fish, concentrations in gill tissue are generally much higher than any internal tissue (Howells et al. 1990) but acute toxicity of aluminium due to effects on fish gills typically only occurs at water pH values of around 5.2, which is well below that expected in waters of Lake Rotoehu. Addition of alum to the Waitangi Soda Springs inflow is therefore unlikely to have any negative effect on Lake Rotoehu biota in the long-term.

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