UTUHINA STREAM 2006 - 2020

IN-STREAM ALUM DOSING EFFECTS ON FISH AND AQUATIC INVERTEBRATES

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Utuhina Stream 2006-2020: In-stream alum dosing effects on fish and aquatic invertebrates

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SUMMARY

This report presents the results of an on-going assessment of the fish and aquatic macroinvertebrate communities of the Utuhina Stream, Lake Rotorua, from 2006 to 2020, and an assessment of the bioavailability of aluminium in fish and kōura to satisfy Bay of Plenty Regional Council's annual resource consent conditions 9.6, 9.8 and 9.7, respectively, for consent 65321 for the discharge of alum to the Utuhina Stream.

Macroinvertebrates, fish and kōura (freshwater crayfish) were sampled from one control and two treatment reaches of the Utuhina Stream annually. Common bully (*Gobiomorphus cotidianus*) is the dominant species in the fish community of the Utuhina Stream. Kōura (*Paranephrops planifrons*) and juvenile trout were always present at all sites but variable in abundance. Differences in species abundance from year to year are most likely due to flood-related disturbances to stream bank morphology and in-stream vegetative cover or physical displacement of fish. No obvious effects of alum dosing on stream fish or macroinvertebrate communities were observed between the upstream control site and sites downstream of the alum discharge.

Several other fish species were occasionally captured during sampling and the regular occurrence of juvenile koaro from 2016 to 2019 is possible evidence of this taonga species becoming established in the Utuhina.

Analysis of stream macroinvertebrates also showed no consistent differences between the upstream control site and the sites downstream of the alum dosing. Overall, all sites were characterised as fair to good quality for a soft-bottomed stream.

Some evidence of aluminium bioaccumulation was seen in some tissues of common bully (gills and liver) in some years, resulting from continuous alum dosing of the Utuhina Stream, but there was no evidence of bioaccumulation of aluminium in the tissues of kōura. Alum exposure in these species does not appear to affect their health or abundance in the stream.

Overall, continuous alum discharge does not appear to negatively impact the ecology of the lower Utuhina and improvements in the ecological condition of the Utuhina Stream will be achieved by ongoing riparian restoration and mitigation of the impacts of flood flows.

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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; Burns et al. 1999) of Lake Rotorua from 4.9 to 4.2 by reducing internal and catchment-derived nutrients (nitrogen (N) and phosphorus (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 phosphorus (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/m^3) 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 mid-2006 and the Bay of Plenty Regional Council granted a resource consent in November 2008 for the continuation of alum dosing until 2018. 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. Average discharge to the stream over the treatment period from July 2006 to June 2020 was 579 tonnes of alum annually (Figure 1), comprising 24.3 tonnes of aluminium per annum.

In order to assess the potential ecological impacts of continuous alum dosing in the Utuhina Stream, annual assessments of the fish and macroinvertebrate communities of the stream have been undertaken at an upstream control site and two sites downstream of the point of alum discharge since prior to the start of alum dosing in 2006. Assessment of the bioavailability of aluminium in fish and kōura (freshwater crayfish) has also been undertaken annually since 2009. This report summarises the results of these studies to satisfy annual resource consent conditions 9.6, 9.8 and 9.7, respectively, for consent 65321 for the discharge of alum to the Utuhina Stream.

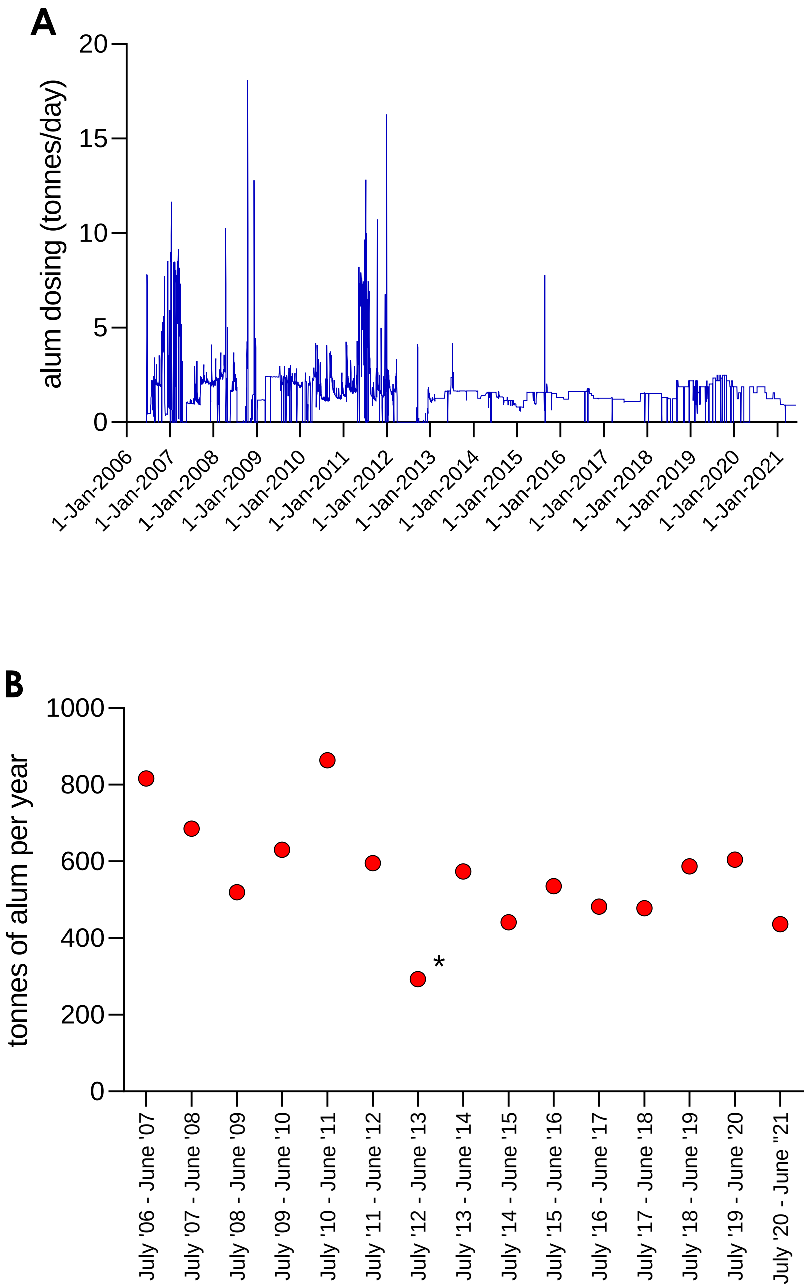


Figure 1. Quantity (tonnes) of alum discharged daily (A) and annually (B) to the Utuhina Stream since the commencement of dosing in June 2006.

*** - alum dosing was mostly shut down from 1 July 2012 to 10 December 2012.**

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. 2) annually since 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 diffuser, and site 3 was 400 m further downstream in the vicinity of Lake Rd. 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 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. 3). 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 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).

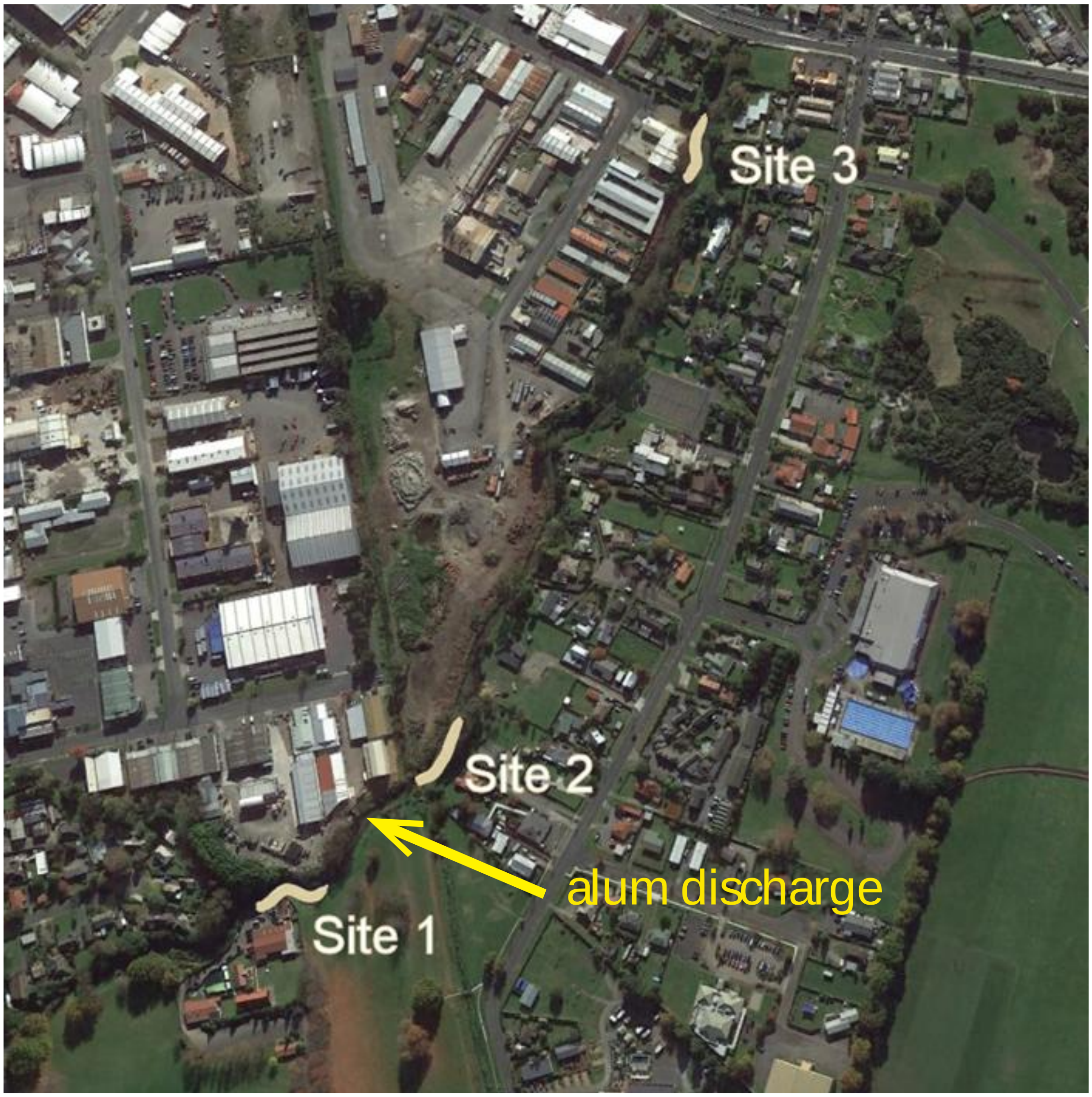


Figure 2. The Utuhina Stream with fish community survey sites marked above the alum discharge (site 1), in the alum mixing zone (Site 2) and upstream of Lake Rd (Site 3).

Figure 3. Electrofishing shallow bankside vegetation at site 2 of the Utuhina Stream.

AQUATIC MACROINVERTEBRATE COMMUNITY SURVEY

Aquatic macroinvertebrate community analysis was undertaken separately to electrofishing from the same three stream reaches examined for relative fish abundance above. Invertebrates were sampled at least two weeks either before or after electrofishing to avoid effects of electrofishing disturbance. 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 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.

BIOACCUMULATION OF ALUMINIUM IN COMMON BULLY AND KŌURA

A suite of 28 elements was measured in bully and kōura tissue samples based on established methods (USEPA, 1987). In brief, tissue samples were accurately weighed and then digested using tetramethyl-ammonium hydroxide, heating to 60°C and mixing. The colloidal suspension was then partially oxidized by the addition of hydrogen peroxide and metals solubilised by acidification with nitric acid and further heating (90°C). Samples were diluted and filtered prior to analysis by inductively-coupled plasma mass spectrometry (School of Science, University of Waikato, 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 up to ten kōura from each site (Figure 4). Sometimes insufficient numbers of large kōura were obtained at some sites. Method blanks and matrix certified reference material standards (DOLT and DORM; Canadian Research Council) were run in parallel with all samples.

Figure 4. A sample of Utuhina Stream kōura from site 3.

RESULTS AND DISCUSSION

UTUHINA STREAM FISH COMMUNITY

Four species, common bully (*Gobiomorphus cotidianus*), rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), and kōura (*Paranephrops planifrons*), were captured every year across all three stream sites, with common bully numerically dominating the fish community. In addition, other species in low numbers have been occasionally captured. Longfin and shortfin eel (*Anguilla dieffenbachii, Anguilla australis*) have been recorded on five of the 18 survey dates and from each of the surveyed locations: the very large longfin (approximately 1.3 m total length) pictured in Figure 5 was captured at the upstream control site in 2016. Due to the presence of natural barriers to upstream migration on the Kaituna River, eels in Lake Rotorua tributary streams mostly likely result from accidental or deliberate stocking (Martin et al. 2007).

Figure 5. A large longfin eel (approximately1.3 m total length) captured at site 1 (upstream control) in 2016.

Goldfish (*Carassius auratus*), mosquitofish (*Gambusia affinis*) and common smelt (*Retropinna retropinna*) have been captured on one or two occasions since the commencement of the survey period. All three species are known to occur in Lake Rotorua (NZ Freshwater Fish Database). Of particular note is that juvenile koaro (*Galaxias brevipinnis*; Figure 6) were captured at sites 1 and/or 2 every year from 2016 to 2019, although none were seen in 2020. Koaro is a taonga species in the Te Arawa lakes and this species suffered a catastrophic decline in abundance following the introduction of trout and smelt in the early 1900s. This observation of koaro in the Utuhina Stream extends the known distribution of the species in tributary streams of Lake Rotorua. The Utuhina Stream was extensively surveyed in 2007/2008 for the presence of koaro and none were found (Rowe et al. 2008), although they were observed in four other tributaries of Lake Rotorua. Koaro were not recorded from the Utuhina Stream in the New Zealand Freshwater Fish Database prior to the survey of Rowe et al. and were also not observed in any of the fish population surveys associated with alum discharge monitoring from June 2006 to August 2015, but their presence in all three subsequent years is an encouraging indication that the species may now be established in the Utuhina.

Figure 6. Galaxiid (koaro) juvenile captured at Site 2 in 2016.

In addition to assessing the fish community by electrofishing in 2020, duplicate samples were taken at each site for environmental DNA (eDNA). Between 240 and 600 mL of stream water (sample volume able to be filtered depended on turbidity) were filtered through Wilderlab standard eDNA filters and analysed using Wilderlab's standard multispecies PRIMER sets (Wilderlab NZ Ltd., Wellington). DNA from common bully, rainbow trout, brown trout and kōura was detected at all three sites. Additionally, DNA from koaro and common smelt was detected only at site 2 (Figure 7). The presence of koaro DNA at site 2 is further evidence that koaro are established in the Utuhina and, although they were not captured in 2020, they have been captured at this site in every one of the previous four years. Shortfin and longfin eel DNA was not detected and no eels were captured in 2020, possibly indicating that eels may not be permanently resident in the stream.

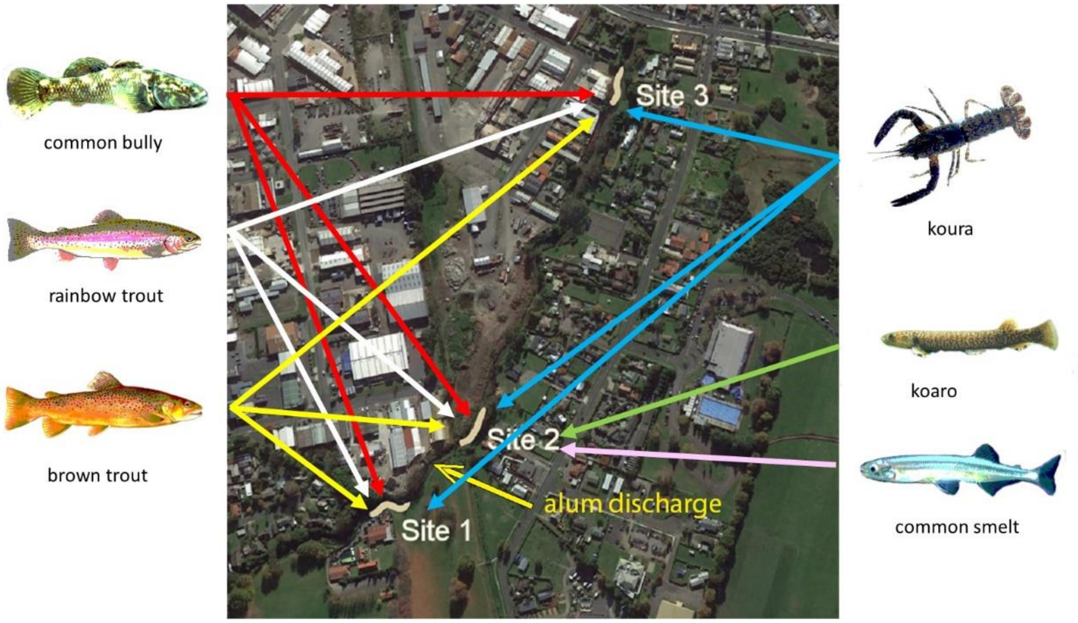


Figure 7. eDNA occurrence for freshwater fish and kōura in duplicate samples from each site on the Utuhina Stream.

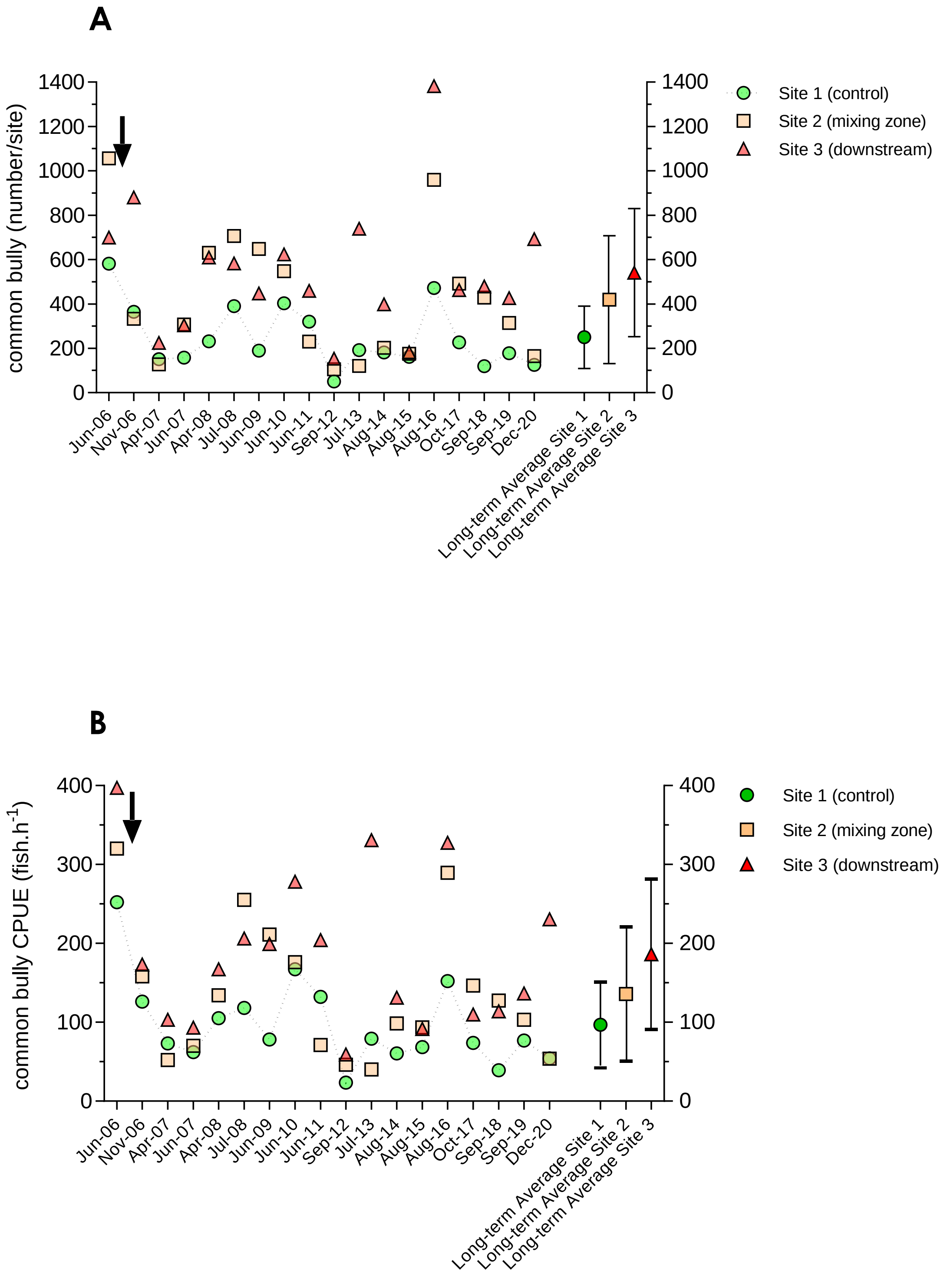


Figure 8. Numbers captured (A) and catch per unit effort (CPUE; B) of common bully in the Utuhina Stream since June 2006. Arrow indicates the commencement of alum dosing in the stream. Values for long-term averages are means ± 1 S.D.

Common bully relative density (fish per 50 m reach) and CPUE ($fish.h^{-1}$) has varied significantly between years and across sites (Figure 8). Much of the interannual variation can be tentatively ascribed to major changes in habitat arising from factors such as major flood events that have changed the extent of instream bankside vegetative cover and the stream bed profile, or created significant erosion of the banks as noted by Ling (2013) at site 1 (true right bank) and shown in Figure 9. Reinforcement of the bank at this location with large boulders improved the habitat for kōura which subsequently increased in abundance at this site. Ling (2017) noted that the presence of large longfin eels at this site in 2015 and 2016 may have been due to this increased abundance of kōura, a favoured food (Jellyman, 1989). However, kōura numbers have subsequently declined, possibly due to eel predation or sediment infilling between the boulders.

Figure 9. A stormwater drain (Site 1 true right bank) installed without adequate bank reinforcement (From: Ling, 2013).

The Utuhina is a typical urban stream susceptible to extreme variation in discharge. Figure 10 illustrates the variation in discharge throughout 2020, showing several significant floods peaking in excess of 8 $m^3 \bullet s^{-1}$, compared with base flow of approximately 1 cumec. The largest flow recorded in the Utuhina since the commencement of alum dosing in mid-2006 peaked at 28.4 $m^3 \bullet s^{-1}$. Common bully prefer relatively low flow velocities of around 0.4 $m^3 \bullet s^{-1}$ (Jowett & Richardson, 1995) and are likely to be physically displaced by high velocities associated with major floods. Other pressures on the lower reaches of the Utuhina Stream are also typical for urban catchments such as discharge of fine sediment and substances leached from impervious surfaces like roading and roofs. Two significant tributaries that both drain industrial areas of the city join the Utuhina mainstem at site 2 (Figure 11).

Interannual increases and declines in common bully density are relatively consistent between sites supporting the hypothesis that instream effects not related to alum discharge are the principal source of varying fish abundance. For example, common bully abundance (CPUE) at site 1 (upstream control) is highly correlated with site 2 (mixing zone: Figure 12A, Pearson r = 0.744, P = 0.0004) and site 3 (downstream; Figure 12B, Pearson r = 0.779, *P* = 0.0001). It is possible that alum discharge impacts on sites 2 and 3 could affect recruitment upstream to the control site but this is not considered the principal reason for interannual fluctuation in abundance in the stream. There have also been times throughout the dosing period when significant short-term increases in dosing have occurred (Figure 1A) but these do not apparently correlate to any obvious decreases in fish abundance and are not considered to have adversely impacted the fish community of the stream. Obvious changes in stream habitat year by year are considered to be the driving force underlying fish density.

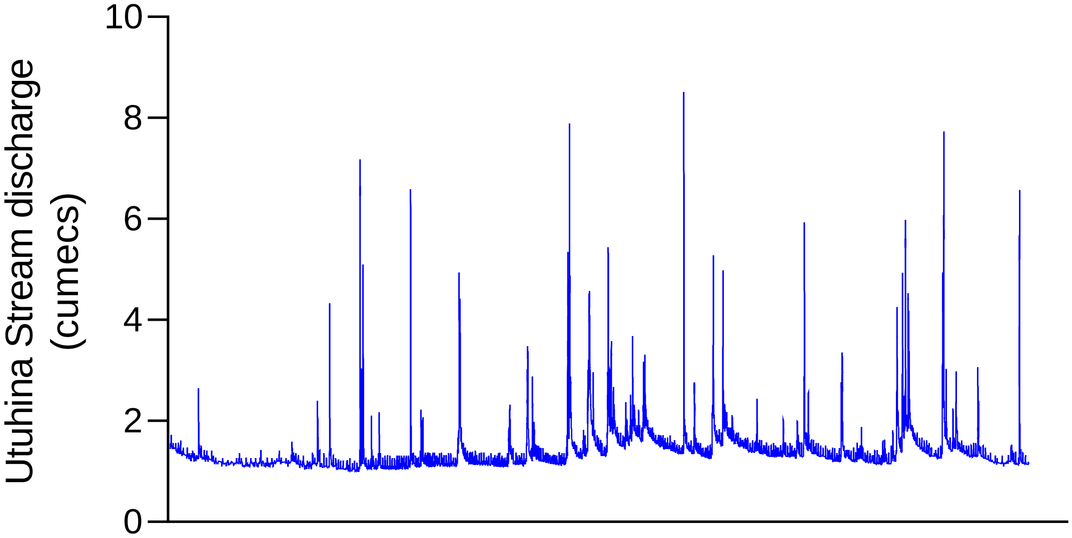


Figure 10. Utuhina Stream discharge from 01 Jan 2020 to 31 Dec 2020.

Figure 11. Sediment laden tributary on true right bank of the Utuhina at site 2 (left). Channelised tributary draining a large industrial site which joins with the true left bank of the Utuhina at site 2 (right).

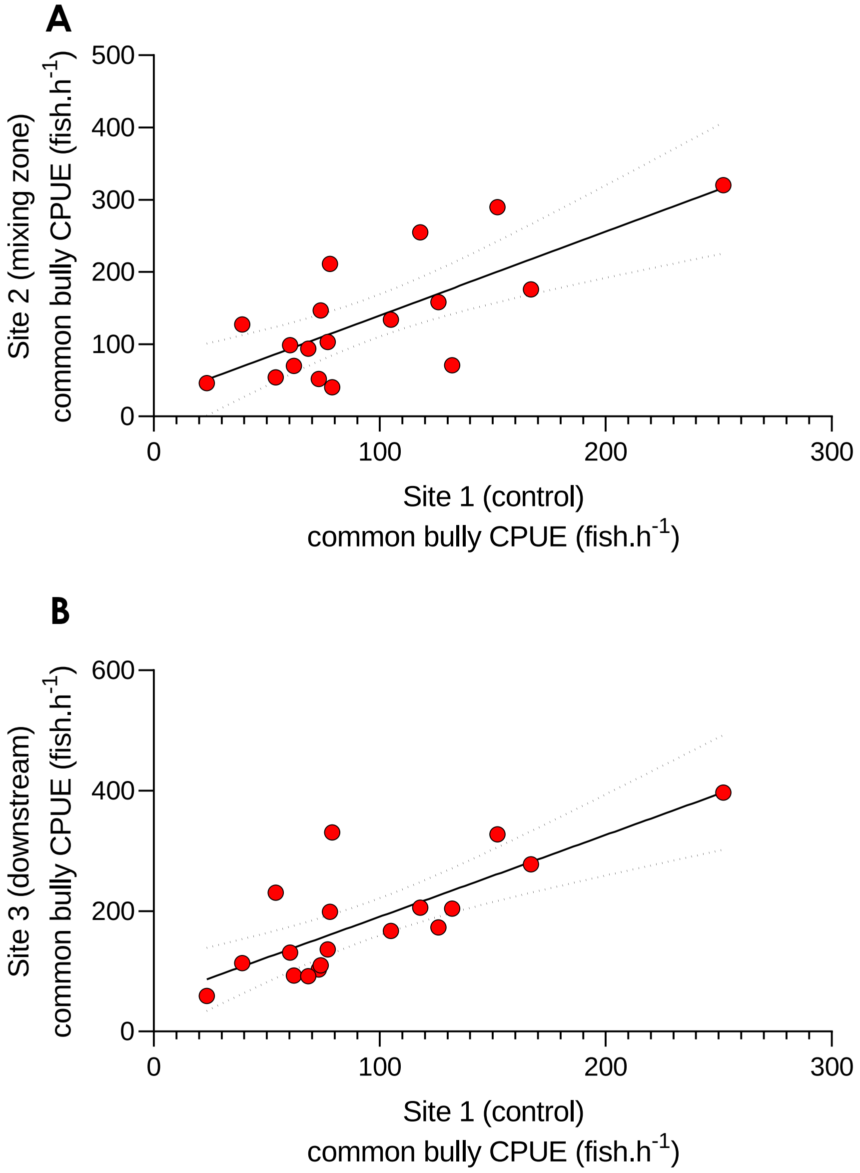


Figure 12. Correlation of common bully CPUE at site 1 with site 2 (A) and site 3 (B). Dashed lines are 95% confidence intervals.

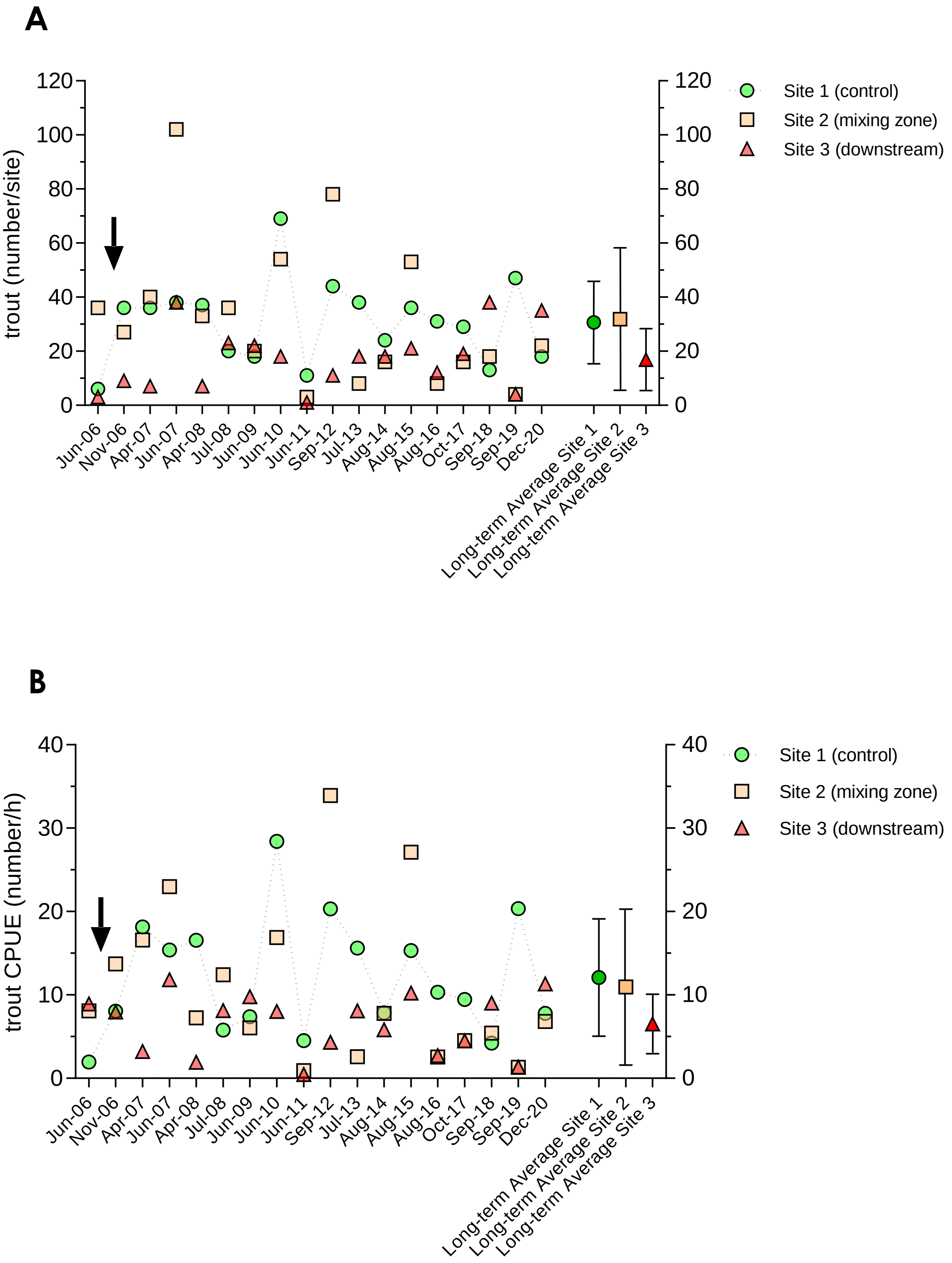
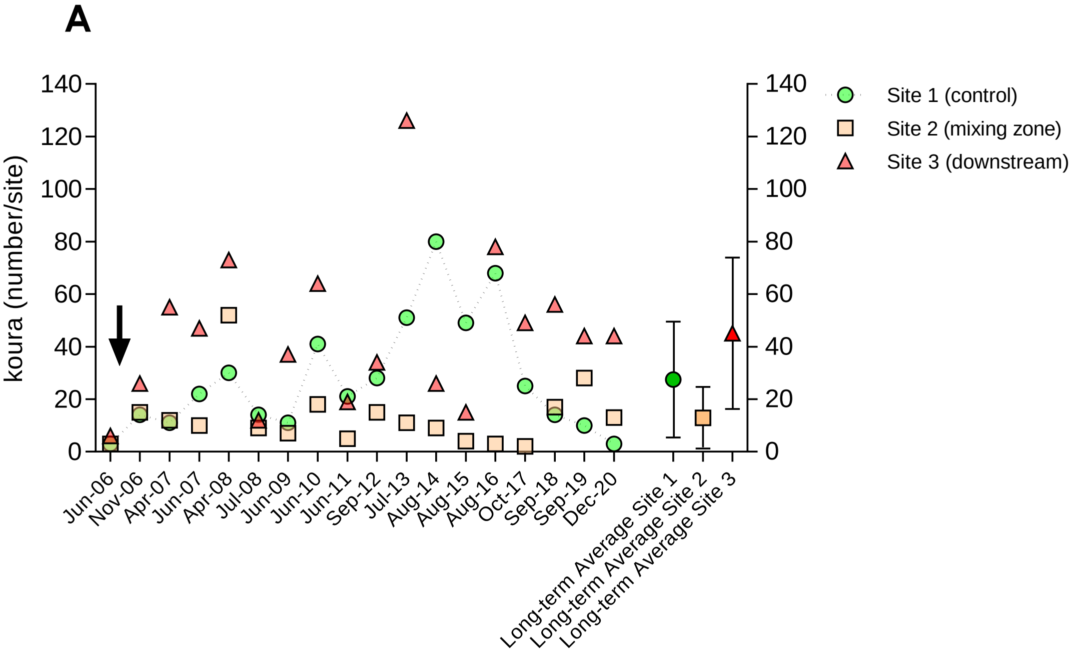


Figure 13. Numbers captured (A) and catch per unit effort (CPUE; B) of juvenile trout in the Utuhina Stream since June 2006. Arrow indicates the commencement of alum dosing in the stream. Values for long-term averages are means ± 1 S.D.

Juvenile trout (young of the year) were always present at all sites in all years, even though sampling date varied between April and December, indicating a wide spawning season in the Utuhina. Trout density was almost always greatest at the upstream control site (Figure 13) but numbers varied considerably between sampling dates. This is not surprising given that numbers of trout fry will vary depending on the timing and number of spawning adults and the timing of downstream migration of parr into the lake. Juvenile trout abundance did not show a significant correlation between sites, unlike common bully. Adult brown (Figure 14) and rainbow trout have been regularly seen at all sites since 2006.

Figure 14. Adult brown trout captured at site 2 (alum mixing zone) in December 2020.



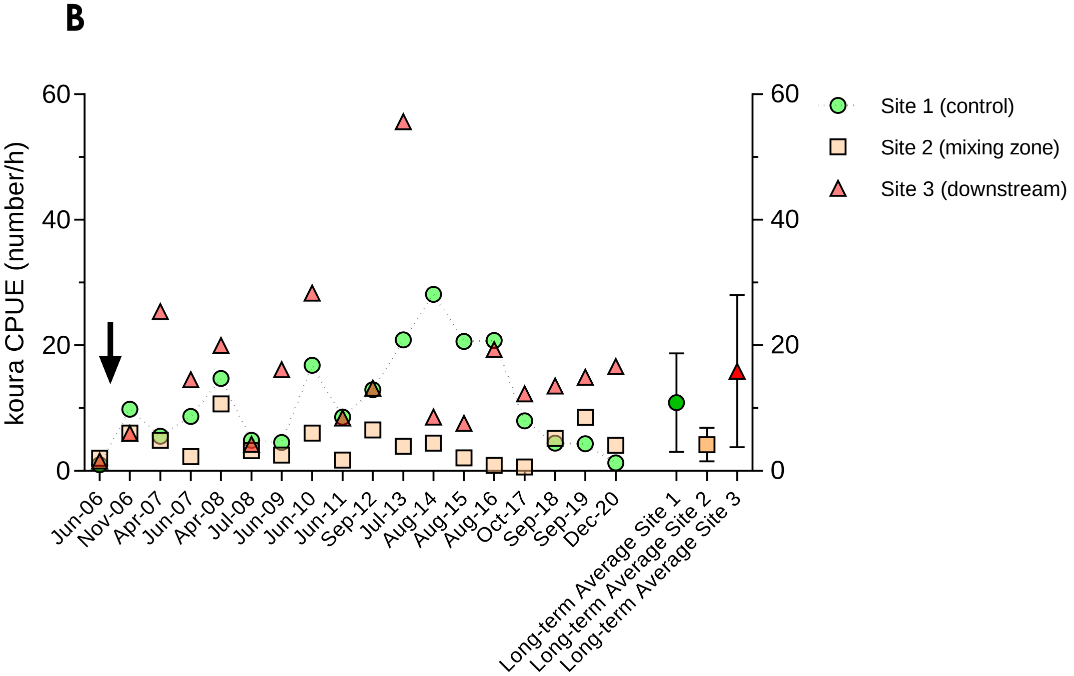


Figure 15. Numbers captured (A) and catch per unit effort (CPUE; B) of kōura in the Utuhina Stream since June 2006. Arrow indicates the commencement of alum dosing in the stream.

Kōura have always been captured at all three sites but are typically most abundant at the downstream site (Figure 15). Kōura were generally least abundant at site 2 (the alum mixing zone), although some large individuals are sometimes encountered at this site in dense bankside vegetation on the true right bank (Figure 16). Kōura numbers fluctuated significantly from year to year but unlike common bully were not correlated between sites, possibly indicating greater heterogeneity of habitat between sites for kōura than for common bully. Similarly to common bully, kōura prefer relatively low water velocities (Jowett et al., 2008) and are significantly impacted by flood events (Parkyn & Collier, 2004), but kōura numbers were not correlated with abundance of common bully, indicating that repopulation by kōura after floods differs to that of common bully.

Figure 16. A large adult kōura captured at site 2 in December 2020.

AQUATIC MACROINVERTEBRATES

Semi-quantitative macroinvertebrate community analysis (for soft-bottomed streams; MCI-sb) showed no significant differences between sites, although the downstream site 3 typically scored lowest in most years (Figure 17). Values for the MCI-sb index fell within the “fair to good” quality classes (Table 1) of Stark & Maxted (2007) for all three sites. Over the entire time period 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 sites 1 and 2, 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). Although Clarke recorded a decline in MCI scores following commencement of alum dosing in 2006, this decline occurred at all sites including the upstream control site so was unlikely to be related to effects of alum and mirrored the decline in common bully during the same time period. Clarke’s calculation of MCI scores was based on the existing stony-bottom stream protocols prior to development of the soft-bottomed method (Stark & Maxted 2007) and the values given in Figure 17 for June 2006 are estimated from the respective stony-bottom MCI values given by Clarke.

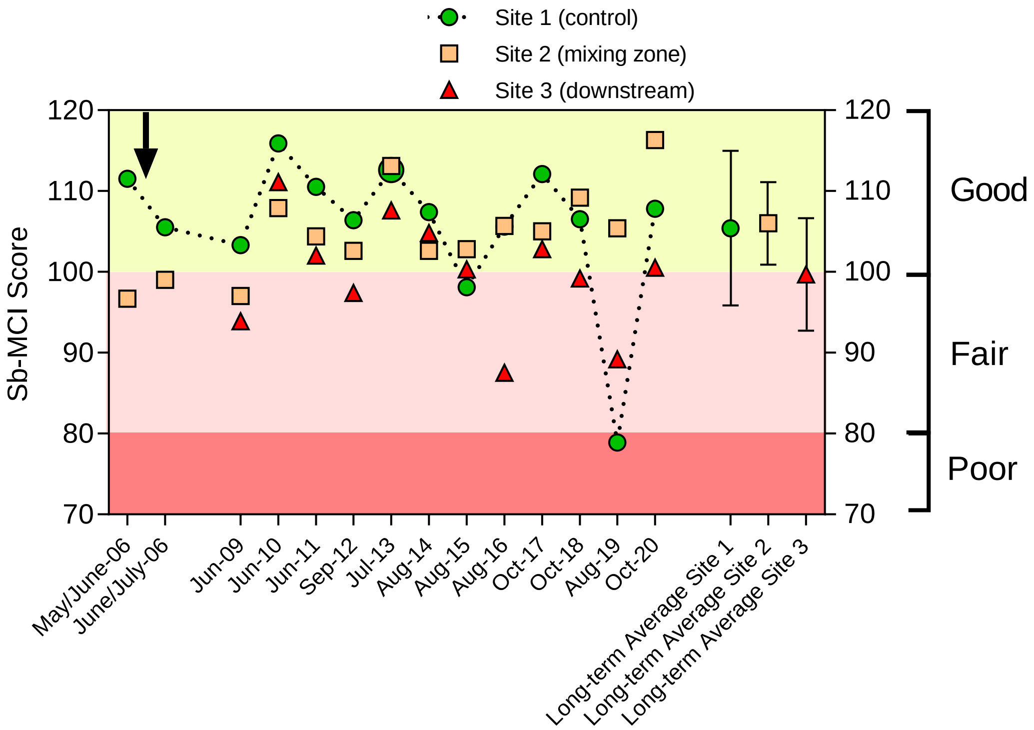


Figure 17. Soft-bottom stream macroinvertebrate community assessment (Sb-MCI) for the Utuhina Stream since June 2006. * – values for sites 1 & 2 in 2006 are approximated from data in Clarke 2006.

BIOACCUMULATION OF ALUMINIUM

Analysis of tissue aluminium concentrations in kōura and common bully revealed significant differences between tissues with the highest concentrations in gill, followed by liver and flesh.

In some years there was some evidence of aluminium bioaccumulation downstream of the Utuhina Stream alum diffuser, but total aluminium concentrations were generally low in tissues from both species (Ling 2015). Mean concentrations of aluminium in the tissues of kōura (Figure 18) and common bully (Figure 19) are generally highly consistent across years with highest concentrations occurring in the gill tissue followed by the hepatopancreas (HP) and liver of kōura and common bully. All animals appeared healthy and unaffected by these relatively low tissue aluminium levels. Overall, there were no significant differences in tissue concentrations between the upstream control site and sites downstream of the alum discharge.

Variation in tissue concentrations between individuals was much greater than variation between years. Although such intraspecific variability in the body burdens of non-essential metals is well recognized it is poorly understood. While differences might be expected due to obvious factors such as sex, size, age, diet and metabolic rate, individuals selected 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. Pan & Wang (2009) examined inter-individual variations in the bioaccumulation of cadmium and zinc in scallops and found that intrinsic variation existed independent of dietary assimilation, possibly arising from individual differences in efflux rate.

Aluminium bioaccumulation primarily affects the gills of fish (Sparling & Lowe 1996) and crayfish (Alexopoulos et al. 2003) with little bioaccumulation occurring in internal organs even under chronically toxic conditions. Toxicity is associated with disruption of gill osmoregulatory and respiratory functions. Alexopoulos et al. (2003) observed significant accumulation of aluminium on the gills of freshwater crayfish and significant changes in behavior at concentrations similar to those used to dose the Utuhina Stream although these were only apparent in the absence of any material (snail mucus in their study) that could act as a sink for removing aqueous aluminium. Production of alum floc and sorption to other materials, e.g., sediment and macrophytes, in the stream are likely to reduce aluminium bioavailability, and measured concentrations in the gills of Utuhina Stream kōura were significantly lower than those recorded by Alexopoulos et al., which exceeded 1000 mg/kg dry weight (values reported here in Figures 18 & 19 are wet weight values and need to be multiplied approximately five-fold to convert to dry weight).

Tempero (2005) reviewed the ecotoxicology of alum applications to the Te Arawa lakes and determined that the principal concerns of alum dosing were the effects of flocculant accumulation and benthic smothering , and potential toxicity when pH changes in the lakes driven by algal photosynthesis causing formation of toxic soluble forms of aluminium. Due to the low continuous dosing in the Utuhina and the significant stream discharge it is highly unlikely that significant accumulation of flocculated material will occur within the stream. The low continuous dose, which is proportional to stream flow, also does not significantly alter stream pH and therefore is unlikely to result in the presence of highly toxic aluminium species that principally occur at very low or very high pH values. Continual exposure of fish and kōura in the Utuhina Stream to low continuous alum dosing does not appear to result in either chronic toxicity or significant bioaccumulation of aluminium and did not affect abundance at downstream sites compared to the control site.

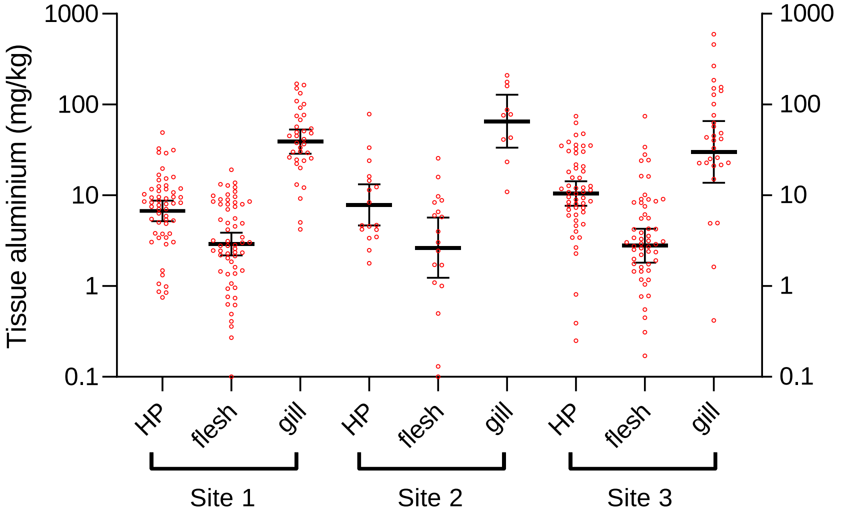


Figure 18. Kōura tissue (hepatopancreas, flesh and gill) aluminium concentrations (mg/kg WW) for all years 2009-2020- geometric mean with lower and upper 95% confidence intervals (CI). Site 1 = upstream control reach, Site 2 = alum mixing zone, Site 3 = downstream reach.

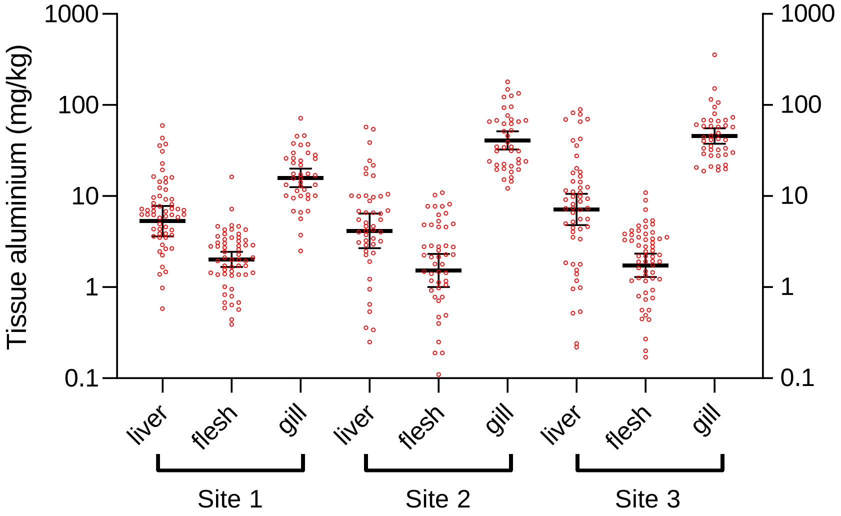


Figure 19. Common bully tissue (liver, flesh and gill) aluminium concentrations (mg/kg WW) for all years 2009-2020 - geometric mean with lower and upper 95% confidence intervals (CI). Site 1 = upstream control reach, Site 2 = alum mixing zone, Site 3 = downstream reach.

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