Biomagnification of potentially toxic elements from Tahmoor Colliery, Bargo NSW, from water and sediment into the surrounding biota and fur of the iconic Australian platypus (*Ornithorhynchus anatinus*)

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Abstract

This pilot study aimed to investigate the mobility of metals from mine wastes within a river ecosystem in New South Wales Australia. This study sought to detect potential biomagnification by identifying the movement of 11 potentially toxic elements from underground coal mine effluent, in sediment to the tissue of biota (Typha and Spirogyra sp.), invertebrates (prey) and the iconic Australian platypus (predator). Understanding bioaccumulation and magnification potential is crucial in determining conservation risks and informing environmental regulation. This study highlights the need for collaborative efforts between mining enterprises, environmental regulators and the community to protect species of high conservation value.

Keywords: Platypus, biomagnification, mining effluent, conservation, EPL, sediment

Introduction

The platypus is an iconic Australian monotreme, an egg-laying mammal. They are endemic to freshwater creeks and rivers across eastern Australia. Platypuses are semi-aquatic and spend approximately 16 hours per day foraging for macroinvertebrates. Platypus will consume 15–28% of their body weight per day and lactating females can consume up to three times that to maintain energy stores (Serena and Pettigrove 2005). Platypus in New South Wales are considered "Near Threatened" by the IUCN red list (Woinarski and Burbidge 2016). The species is vulnerable to many threats including, fishing litter, altered hydrology, extreme weather events, vehicles, feral cats and dogs, agricultural and urban land clearing and water pollution (Hawke, Bino and Kingsford 2019; Grant and Temple-Smith 2003). There is currently a gap in the literature as to how water pollution and bioaccumulation / biomagnification of potentially toxic elements can affect the health of platypuses. *Typha orientalis* (Bullrush) is a fast-growing, root dense wetland plant used in several bioremediation studies due to its effectiveness in removing potentially toxic metals from contaminated water and soil (Tongphanpharn et al. 2021). *Spirogyra sp.* is an algae that is commonly found in creeks and rivers across Australia, it is tolerant and thrives in nutrient and metal rich water, such as that found downstream of mining effluent. Spirogyra can accumulate nutrients and metals from its surrounding environment and usually creates large blooms during low flow and warmer climates (Townsend and Padovan 2005). These conditions are usually present during Australian summers and often during frequent drought periods.

Previous studies have investigated the disposal of effluent from Tahmoor Colliery to Tea Tree Creek and Bargo River. One reported impairment of macroinvertebrate assemblages in Bargo River, downstream of entry of Tahmoor wastes (Wright et al. 2015). Another documented how the waste from Tahmoor Colliery might affect receiving waterways (Fleming et al. 2021). The mine discharge contributed 67% of the median flow in the Bargo River and caused a plume of saline, nutrient and metal-enriched contamination which extended 9 km downstream (Fleming et al. 2021). Tahmoor Colliery dispose wastewater according to an Environmental Protection License (EPL) number 1389 (EPA, 2023), administered by the NSW Environmental Protection Authority (EPA). Compared to seven other EPL's used to regulate coal mine waste discharges in the Greater Sydney and Blue Mountains region of NSW (Belmer and Wright, 2020), the Tahmoor EPL (EPL 1389) allows the mine to release the most saline effluent (<2600 µS/cm), the largest concentration of zinc (<300 µg/L), and the equal highest nickel (<200 µg/L) and barium (<6440 µg/L).

Platypus activity has been recorded by the community in the Bargo River, in the vicinity of Tahmoor Colliery. This current research sought to confirm if platypus were present in the river near this mine and investigate if potentially toxic elements in the mine's wastewater are accumulating or magnifying in aquatic biota, including plants, algae, macroinvertebrates and platypus tissue. Shredder (herbivorous) macroinvertebrates, which are present in the Bargo River (Wright et al. 2015), consume sediment, plant and algae matter. These herbivorous macroinvertebrates are then consumed by predatory macroinvertebrates and platypus, thus platypus are vulnerable to the accumulation of pollutants discharged into the water by Tahmoor Colliery and build up in the sediment. The purpose of this pilot study was to investigate the movement of potentially hazardous elements across trophic levels of a freshwater ecosystem receiving treated mining effluent and evaluate how environment regulators of mining could consider more effective protection of conservation values when determining discharge limits of mining effluent released into waterways.

Methods

Site Location and wastewater quality

Tahmoor Colliery is an underground coal mine that has been operating since 1987. It produces steel making coal, employing over 400 people and producing up to 4 million tonnes of coal per annum (SIMEC 2023). The mine is located on the south-western margins of the Sydney metropolitan area, near the township of Tahmoor (Fig. 1). It releases wastewater into a small tributary 'Tea Tree Creek' which flows for 1 km before entering the Bargo River. This is a high conservation-value river due to its reputation for containing platypus as well as its contribution to the lower reaches of Sydney's drinking water catchment. Previously published research on water quality by Fleming et al. (2021) reported median values of Tahmoor Colliery effluent for electrical conductivity (2182 µS/cm), alkaline (8.68 pH) and contained ecologically hazardous concentrations of arsenic (60 µg/L), nickel (60 µg/L), and zinc (44 µg/L). The Tahmoor effluent also had elevated total nitrogen (2400 µg/L) and unusually elevated median concentration of barium (3500 µg/L), lithium (1300 µg/L) and strontium (660 µg/L). Recent (Oct 22-Nov 23) results reported by Tahmoor Colliery (Tahmoor Colliery 2023) contained ecologically hazardous concentrations of pH (8.55), electrical conductivity (1645 µS/cm), nickel (40 µg/L), and zinc (67.5 µg/L). Results included exceeding high concentrations of arsenic (23.5 µg/L), barium (2465 µg/L) and nitrogen (2.45 mg/L).

Sample Collection

Sediment was collected at Tea Tree Creek, above Bargo River, in April and November 2019. Replicates of fine sediment were collected in sterilised glass jars from several test areas that contained both fast- and slow-moving water. These samples were kept chilled between 2–8°C before analysis at Envirolab, Sydney. Emergent macrophytes (Typha sp.) and filamentous algae (Spirogyra sp.) were abundant in Tea Tree Creek. Six samples of Typha sp. and Spirogyra sp. were collected from Tea Tree Creek, triple rinsed with deionised water and then dried at 40oC for approximately five days before being homogenised. Predatory macroinvertebrates (carnivorous diet) were also collected from Tea Tree Creek using 30 × 30 cm kick nets with 250 µm mesh. The macroinvertebrates were stored in deionised water in the field, until they were transported to the laboratory, rinsed in ethanol and frozen at −20°C before being freeze dried using an Edwards Freeze Dryer Modulyo with a Pirani 501 vacuum gauge control at −40°C for two 18 h cycles. Three fur samples were collected from two platypuses captured on the Bargo River, upstream of Tea Tree Creek confluence, on two occasions using a 25 m by 1.8 m, nylon mesh net. Captured platypuses were microchipped, and a fur sample taken from the upper dorsal region with animal clippers before being released back, unharmed, into the river. Fur samples were washed with deionised water to remove dirt and external material before analysis. All samples (sediment, macrophytes, algae, macroinvertebrates and fur) were analysed using standard methods by a National Associations of Testing Authorities (NATA) accredited laboratory for analysis of major anions and cations and total concentration of metals and metalloids (including, aluminium, arsenic, barium, cobalt, copper, iron, lead, lithium, manganese, nickel, strontium and zinc). While these platypuses were captured 1.5 km upstream of the entry of mine wastewater, platypuses have a home range between 6–11 km for males and 2–4 km for females (APC n.d.). It is possible that both platypuses may forage in Bargo River, where it is affected by mine waste.

Results and discussion

Barium

Of the 11 potentially toxic elements found in sediment from Tea Tree Creek (Fig. 1), the most abundant was barium, with a mean concentration of 9945 mg/kg. The biota with the greatest barium concentration, in this study, was Spirogyra sp. (mean 6343 mg/kg). Typha leaves had a much smaller barium content than roots (mean 3454 mg/kg compared to mean 134.2 mg/kg respectively). Barium is known to have deleterious effects on plants and has also been previously found to bioaccumulate in plant roots and leaves (Sleimi et al. 2021). Currently there are no Australian water or sediment quality guidelines for barium, there is, however, a recreational guideline value (1000 µg/L) (ANZECC/ARMCANZ 2000). The barium content in macroinvertebrates (mean 105.2 mg/kg) and platypus fur (mean 46.7 mg/kg) was considerably less than was

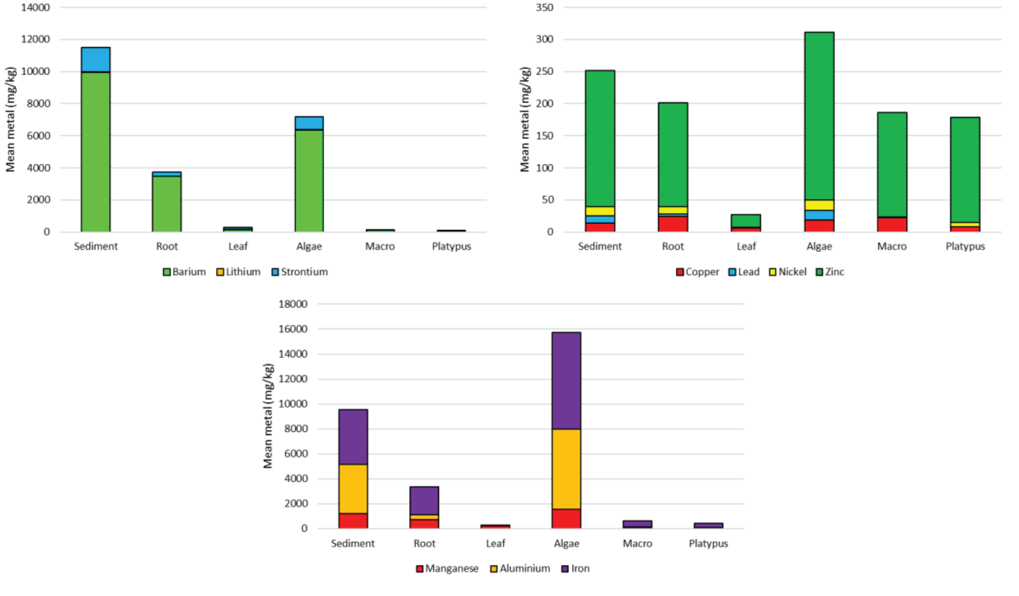

Figure 1: *Stacked graphs displaying the concentration of metals (1) Top Left: barium, lithium, strontium (lithium accumulation is very small relative to barium and strontium) 2. Top right: copper, lead, nickel, zinc and (3) Bottom: manganese, aluminium and iron; in sediment and in Typha (root and leaf), Spirogyra algae, predatory macroinvertebrates and platypus fur*

found in plant tissue (root 3454 mg/kg and leaf 134 mg/kg). No other coal mine in the Sydney basin is permitted to release barium in wastes (Belmer and Wright, 2020). Whilst platypus fur had a relatively small mean concentration compared to other trophic levels, barium is a non-essential element, yet was the equal third most abundant metal detected in the platypus fur.

Iron

The second most abundant element in sediment was iron (mean 4373 mg/kg; Fig. 1). Spirogyra sp. bioaccumulated iron (mean 7743 mg/kg) with a lower concentration in Typha roots (2264 mg/kg). Typha leaf had a mean concentration of 50.8 mg/kg. There are currently no Australian water or sediment quality guidelines for iron (ANZECC/ARMCANZ 2000). Mean iron concentration found in macroinvertebrates (470 mg/kg) and platypus fur (370 mg/kg) were considerably less than found in plants.

Zinc

Zinc was recorded in the sediment (mean 212 mg/kg; Fig. 1). This exceeds the Australian sediment quality guidelines (<200 mg/kg). Zinc concentration was highest in Spirogyra sp. (261 mg/kg) followed by platypus fur, macroinvertebrates and Typha roots which all reported similar mean concentrations (163, 162, 161 mg/kg respectively). Typha leaf had the smallest concentration of 20 mg/kg. Current Australian water quality guidelines for zinc are <8.0 µg/L (ANZECC/ARMCANZ 2000). Zinc is permitted to be discharged by Tahmoor Colliery under EPL 1389 in effluents with a maximum concentration of 300 µg/L. This is approximately four times higher than the 12-month average zinc content that Tahmoor Colliery reports in their effluent (Tahmoor Colliery, 2023). Tahmoor EPL 1389 has the second highest discharge limit for zinc and the highest of active regional coal mines (Belmer and Wright 2020).

Aluminium

Results show that Aluminium had the third highest concentration sediment (mean 3963 mg/kg; Fig. 1). Biota with the greatest concentration was Spirogyra sp. (6471 mg/kg) followed by Typha root (378 mg/kg), macroinvertebrates (80 mg/kg), platypus fur (47 mg/kg) and Typha leaf (10 mg/kg). The current Australian water guideline for aluminium is 55 µg/L (when pH >6.5; ANZECC/ARMCANZ 2000). It is not permitted to be discharged by Tahmoor Colliery under EPL 1389. According to Belmer and Wright (2020) only two coal mines in the Sydney Basin are permitted to discharge aluminium at concentrations of 450 µg/L and 800 µg/L.

Arsenic

Arsenic concentrations were reported highest in the sediment (55 mg/kg), which exceeds the Australian sediment guideline (Simpson et al. 2013); <20 mg/kg; Fig. 1). The content was similar in Typha roots (54 mg/kg), and less in Spirogyra sp. (35 mg/kg) and Typha leaf (2 mg/kg). Arsenic was not detected in either macroinvertebrates or platypus fur. Tahmoor is permitted to discharge the highest concentration of 200 µg/L under EPL 1389 (Belmer and Wright 2020). Monitoring data from Tahmoor Colliery over the last 12-month period report that on average arsenic is discharged at 24 µg/L, which is almost twice the recommended Australian water quality guidelines (13 µg/L) (ANZECC/ARMCANZ 2000).

Copper

The mean concentration of copper was highest in Typha root (24.5 mg/kg) followed by macroinvertebrates (22.5 mg/kg), Spirogyra sp. (18.3 mg/kg) and sediment (13.27 mg/kg; Fig. 1). Concentration was lowest in Typha leaf (5.75 mg/kg) and platypus fur (7.7 mg/kg). Tahmoor Colliery is permitted to discharge copper into Tea Tree Creek below 5 µg/L concentration, the mean monitoring report for the previous 12 months was 1 µg/L. This is less than the recommended Australian water quality guidelines for species protection (1.4 µg/L; ANZECC/ARMCANZ 2000).

Nickel

The mean concentration of nickel in sediment was 14.73 mg/kg, which is less than the sediment guideline (<21 mg/kg, Simpson et al. 2013; Fig. 1). Nickel was slightly greater in

Spirogyra sp. (15.7 mg/kg). Nickel in Typha roots (11.6 mg/kg) were greater than Typha leaf (0.6 mg/kg). Nickel content in platypus fur (7.3 mg/kg) was more than 11 times greater than in macroinvertebrates (0.62 mg/kg). Tahmoor Colliery is permitted to discharge nickel <200 µg/L (EPL 1389) which is 18 times higher than the Australian water quality guidelines (11 µg/L) (ANZECC/ ARMCANZ 2000). Over the last 12 months Tahmoor Colliery reported an average of 59 µg/L, approximately five times higher than Australian guidelines.

Lithium

The mean concentration of Lithium in sediment (24 mg/kg) was about half the mean concentration in Typha leaf (50.7 mg/ kg) and was slightly less in Spirogyra sp. (29.1 mg/kg; Fig. 1). Lithium in Typha root (20.5 mg/kg) and macroinvertebrates (7.75 mg/kg) were both less and lithium was not detected in platypus fur. Tahmoor Colliery is not permitted to discharge lithium (ELP 1389).

Strontium

Strontium had a mean concentration in the sediment of 1518 mg/kg (Fig. 1). Biota with the greater strontium was Spirogyra sp. (810 mg/kg), then Typha root (269 mg/kg) and Typha leaf (110 mg/kg). Macroinvertebrates and platypus fur had the lowest mean concentrations of 29 and 3 mg/kg respectively. Tahmoor Coal is not permitted to discharge strontium (EPL 1389). According to Belmer and Wright (2020), no coal mine in the Sydney basin is permitted to discharge strontium and yet this non-essential element is commonly found in wastewater discharge (Green et al. 2018).

Manganese

Manganese had a mean concentration of 1187 mg/kg in sediment (Fig. 1). This magnified 1.3 times in Spirogyra to 1529 mg/ kg. It was less (732 mg/kg) in Typha root and less again (225 mg/kg) in Typha leaf. Mean concentration of manganese was lowest in macroinvertebrates and platypus fur at 71 and 25 mg/kg respectively. Tahmoor Colliery is not permitted to discharge manganese (EPL 1389). Australian water quality guidelines recommend <1900 µg/L (ANZECC/ ARMCANZ 2020).

Lead

Lead was not found in high concentrations across all trophic levels (Fig. 1). It biomagnified in Spirogyra sp. (mean 16 mg/ kg) compared to sediment (11 mg/kg). It was at lower concentration in Typha roots (4 mg/kg), then Typha leaf (1 mg/kg) and macroinvertebrates (0.6 mg/kg). Lead was not found in platypus fur. Fleming et al. (2021) reported lead at a mean concentration of 2 µg/L in Tea Tree Creek but was not detected in the reference site. Australian water quality guidelines recommend <3.4 µg/L for 95% species protection. Tahmoor Colliery is not permitted to discharge lead in their effluent under EPL 1389.

Conclusions

This case study demonstrates how disposal of wastewater from an underground coal mining operation can cause bioaccumulation of metals/metalloids in stream and river biota. Biomagnification of some metals was detected in biota downstream of the coal waste outfall. The lithium content of sediment (mean 24 mg/kg) in the stream receiving coal mine wastewater was about half the lithium content in Typha leaf tissue (mean 50.7 mg/ kg). An earlier study reported that lithium in reference sites was 2 µg/L and was 650 times greater (mean 1300 µg/L) in Tahmoor Colliery wastewater (Fleming et al. 2022). Lithium is a highly mobile element and has previously been reported to bioaccumulate in some plant species (Shakoor et al., 2023). Similarly, Australian water quality guidelines should develop appropriate guidelines for lithium. This is the first Australian study to demonstrate lithium bioaccumulation from lithium enriched coal mine waste. Manganese is a known pollutant and has an Australian water quality guideline of <1900 µg/L for protection of 95% of species in freshwater ecosystems. We detected the bioaccumulation of manganese in algae (Spirogyra ep.) tissue. Manganese (mean 1187 mg/kg) in sediment biomagnified 1.3 times in Spirogyra to 1529 mg/kg. Despite this, manganese and lithium had no discharge limits in EPL 1389.

This study demonstrates that Tahmoor Colliery is discharging pollutants not listed on EPL 1389 and are discharging these pollutants above the recommended water quality guidelines. Therefore, questions arise about how appropriate the pollutant concentrations in the Tahmoor Colliery, and other waste discharges, using EPL licences for protecting the water quality and river biota.

Overall, based on fur data, platypus health is not under threat from Tahmoor Colliery discharge, however this could be due to a varied diet of macroinvertebrates living upstream as well as downstream of Tea Tree Creek confluence. Further research is needed to determine if these potentially toxic elements are magnifying in the internal tissue of platypus as opposed to the external tissue as have been found in studies of other mammals such as bats (Mina 2019). That being said, EPLs and discharge limits need to consider the health of these high-value species and ecosystems.

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