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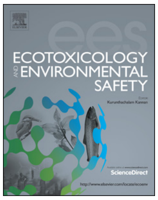

Hypersalinity reduces the risk of cyanide toxicosis to insectivorous bats interacting with wastewater impoundments at gold mines

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ABSTRACT

Wildlife and livestock that ingest bioavailable cyanide compounds in gold mining tailings dams are known to experience cyanide toxicosis. Elevated levels of salinity in open impoundments have been shown to prevent wildlife cyanide toxicosis by reducing drinking and foraging. This finding appears to be consistent for diurnal wildlife interacting with open impoundments, however the risks to nocturnal wildlife of cyanide exposure are unknown. We investigated the activity of insectivorous bats in the airspace above both fresh (potable to wildlife) and saline water bodies at two gold mines in the goldfields of Western Australian. During this study, cyanide-bearing solutions stored in open impoundments at both mine sites were hypersaline (range= 57,000–295,000 mg/L total dissolved solids (TDS)), well above known physiological tolerance of any terrestrial vertebrate. Bats used the airspace above each water body monitored, but were more active at fresh than saline water bodies. In addition, considerably more terminal echolocation buzz calls were recorded in the airspace above fresh than saline water bodies at both mine sites. However, it was not possible to determine whether these buzz calls corresponded to foraging or drinking bouts. No drinking bouts were observed in 33 h of thermal video footage recorded at one hypersaline tailings dam, suggesting that this water is not used for drinking. There is no information on salinity tolerances of bats, but it could be assumed that bats would not tolerate salinity in drinking water at concentrations greater than those documented as toxic for saline-adapted terrestrial wildlife. Therefore, when managing wastewater impoundments at gold mines to avoid wildlife mortalities, adopting a precautionary principle, bats are unlikely to drink solutions at salinity levels ≥50,000 mg/L TDS.

1. Introduction

Saline and hypersaline environments present specific problems to fauna, as they have a strong potential to cause dehydration (Gutierrez et al., 2011). Despite the risk of incurring significant physiological stress, a range of both invertebrate and vertebrate fauna live in, or temporarily use, saline habitats (Bentley, 2002). Many vertebrate taxa achieve this through physiological adaptations such as eliminating ingested salt via specialised salt glands (Hildebrant, 2001). Others employ behavioural strategies such as shaking prey before swallowing, or morphological adaptations such as bill lamellae that remove excess saltwater from prey prior to ingestion (Mahoney and Jehl, 1985a, 1985b).

Most terrestrial mammals cannot survive for a prolonged period when drinking water at a salinity concentration equivalent to seawater (≥30,000 mg/L total dissolved solids (TDS)) (Rugangazi and Maloiy, 1987; Bentley, 2002). However, several desert-adapted rodents in the Northern Hemisphere are able to cope with considerable salt loads by producing highly concentrated urine (Schmidt-Nielsen et al., 1948; Haines, 1964; Schmidt-Nielsen, 1964; Kenagy, 1973) and extremely dry faeces (Schmidt-Nielsen and Schmidt-Nielsen, 1952; Tracy and Walsberg, 2002). Among Australian marsupial mammals, the quokka (*Setonix brachyurus*) has been shown to survive for short periods when only brackish water is available (Bentley, 1955; Jones et al., 1990), while the tammar wallaby (*Macropus eugenii*) can survive for up to 25 days drinking seawater (Kinnear et al., 1968; Purohit, 1971). These species are exceptional among Australian native terrestrial mammals, which generally do not drink saline water or consume plants high in salt (Purohit, 1971).

Salinity tolerance in relation to drinking water in bats (Chiroptera) is not well understood. Two studies have reported anecdotal observations of flying foxes (Pteropodidae) drinking apparently salty water (Ratcliffe, 1961; Iudica and Bonaccorso, 2003). However, neither study recorded salinity concentrations at the time of the observed drinking events. While several species of

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Abbreviations: SDGM, Sunrise Dam Gold Mine; KBGM, Kanowna Belle Gold Mine; WAD, Weak acid dissociable; ICMI, International Cyanide Management Institute

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desert-adapted insectivorous bats (suborders Yangochiroptera and Yinpterochiroptera) in North America have been shown to reduce water loss by producing concentrated urine and relatively dry faeces (Geluso, 1978; Bassett and Wiebers, 1979; Bassett, 1982), tolerance of saline drinking water has not been investigated.

Bats drink from open water bodies by swooping down to lap at the water's surface while in flight (i.e. drinking on the wing) (Cockrum and Cross, 1964; Adams and Simmons, 2002), a mode of drinking similar to that adopted by swifts (Apodidae), swallows and martins (Hirundinidae) (Higgins et al., 2006). Mine waste-derived water bodies such as tailings dams may also be used as a source of water, particularly in arid environments (Clark and Hothem, 1991). Research conducted in North America shows conclusively that bats are at-risk, and significant cyanide-related mortality events can occur (Clark and Hothem, 1991; Henny et al. 1994). Both Donato and Smith (2007) and Smith et al. (2008) presented limited electronic monitoring of echolocation calls at mine sites in the eastern and northern goldfields of Western Australia. These studies found that bats were common visitors to the airspace above tailings dams, as well as other wastewater derived water bodies and natural water bodies at gold mines, but were unable to determine the degree to which bats ingested cyanide-bearing solutions. While bats are unlikely to drink saline and hypersaline solutions, it is not known whether they test for suitability of drinking water (in terms of salinity concentration) by tasting. Consequently, there is a significant knowledge gap in assessing and managing risks to bats interacting with saline and hypersaline cyanide-bearing waste solutions (Griffiths et al., 2009).

Gold mining operations in the eastern and northern goldfields regions of Western Australia extract saline to hypersaline ground water (≥35,000 mg/L TDS) for use in the gold extraction process, resulting in the discharge of saline solutions to wastewater impoundments. It has been suggested that the elevated levels of salinity in mine waste solutions in this region may act as a protective mechanism preventing wildlife cyanide toxicosis by eliminating drinking and reducing foraging (Smith et al., 2008). This has benefits for gold mining operations in this region in terms of compliance with The International Cyanide Management Code (the Cyanide Code). Since its inception in May 2000, the Cyanide Code has provided impetus for the gold mining industry to develop methods to investigate exposure of wildlife, including bats, to cyanide (and other toxicants) stored in open impoundments (ICMI, 2012). The Cyanide Code has adopted a prescriptive 'safe concentration limit' of 50 mg/L weak acid dissociable (WAD) cyanide for solutions stored in open impoundments (Ma and Pritsos, 1997; ICMI, 2005; Hagelstein and Mudder, 2006; Donato et al., 2008). The Cyanide Code's supporting documentation states that for signatory sites discharging tailings at cyanide concentrations greater than 50 mg/L WAD, the onus is upon the mine operator to prove that some form of protective mechanism renders cyanide-bearing open water bodies safe to wildlife (ICMI, 2005, 2007). While elevated salinity concentration of mine waste solutions appears to consistently reduce the risk of exposure to cyanide-bearing solutions for diurnal wildlife interacting with open impoundments (Adams et al., 2008a, 2008b), the risk to nocturnal wildlife of cyanide exposure has not previously been studied (Griffiths et al., 2009).

When present in gold mining wastewater solutions, molecular hydrogen cyanide (HCN) is a colourless liquid, sometimes characterised by a slight odour of bitter almonds (Ballantyne, 1983). However, there is no evidence that terrestrial wildlife, are able to detect, and thereby avoid, aqueous HCN (Eisler, 2000; Eisler and Wiemeyer, 2004; Donato et al., 2007). Tailings dams and associated wastewater impoundments at gold mines may contain a range of contaminants in addition to cyanide (Liang and Thomson, 2009; Kyle et al., 2011). However, as other potentially toxic elements were not sampled during this study they are not discussed further here (but see Lottermoser, 2010; Hudson-Edwards et al., 2011).

This study extends the findings of the previous research conducted in the Western Australian goldfields (Smith et al., 2008; Griffiths et al., 2009) by investigating the activity of bats in the airspace above water bodies at two Cyanide Code certified gold mines. Both mines extract hypersaline ground water for use in milling and processing of ore; consequently all wastewater and tailings solutions stored in open impoundments are hypersaline. Our specific research questions were:

- Are there differences in the level of bat activity in the airspace above saline versus fresh (potable) water bodies at gold mines?
- Do bats drink saline solutions stored within wastewater impoundments?
- What are the implications of the influence of salinity on bat interactions with gold-mining wastewater bodies in relation to achieving compliance with the Cyanide Code?

2. Materials and methods

2.1. Study sites

2.1.1. Sunrise Dam Gold Mine

AngloGold Ashanti's Sunrise Dam Gold Mine (SDGM) (−29° 04′ 58.33″ S, 122° 25′ 59.65″ E) is located in the northern goldfields region of Western Australia. The climate is arid, characterised by hot summers (average summer maximum 35 °C), mild winters (average winter maximum 19 °C), and average annual rainfall of 234 mm (Australian Bureau of Meteorology). The mine site is situated immediately to the east of Lake Carey, an ephemeral, natural hypersaline lake.

SDGM is composed of an open-cut pit and underground mining operations with mill process facilities designed to treat ore by conventional carbon-in-leach, including the use of sodium cyanide. The tailings dam is a 320-ha single-cell central discharge system, elevated 30 m above the surrounding terrain. The thickened tailings are deposited at approximately 65 percent solids through the multi-spigot centrally located discharge system, resulting in conical stacking of dry tailings. Under normal operational conditions there is minimal supernatant liquor formed associated with tailings discharge. The tailings dam has a circular footprint and is fringed by sparse native vegetation. An electric fence has been erected to exclude domestic stock and larger terrestrial wildlife (Donato and Smith, 2007). Vegetation has been cleared within the internal perimeter of the structure to reduce attractiveness to stock and wildlife.

SDGM is certified under the Cyanide Code and conducts daily cyanide sampling at the tailings dam (ICMI, 2010). Results from this sampling regime showed that during this study tailings slurry was discharged into the tailings dam at cyanide concentrations exceeding the industry protective limit of 50 mg/L WAD (mean spigot discharge concentration $=86.3\pm2.1$ mg/L WAD; $N=11$). However, downstream of the spigot, cyanide concentration in supernatant pooling at tailings dam site 1 (bat activity monitoring site 1, see Fig. 1) was well below 50 mg/L WAD on all days (mean $=11.5\pm4.0$ mg/L WAD; $N=11$). These cyanide concentrations are within the site-specific safe-operating levels for the SDGM tailings dam prescribed by the Cyanide Code: cyanide concentration at the discharge spigot limited to a maximum of 70 mg/L WAD for 75 percent of the time, and not exceeding 124.5 mg/L WAD cyanide (Donato, 2009; ICMI, 2010).

2.1.2. Kanowna Belle Gold Mine

Barrick Gold Corporation's Kanowna Belle Gold Mine (KBGM) (−30° 35′ 15.85″ S, 121° 35′ 45.98″ E) is located in the eastern goldfields of Western Australia. The climate is semiarid to arid, characterised by hot summers (average summer maximum 32 °C), mild winters (average winter maximum 18 °C), and annual average rainfall of 242 mm (Australian Bureau of Meteorology).

The KBGM processing plant has an annual throughput capacity of 1.88 million tonnes. It consists of a primary crushing circuit, a grinding circuit mill and a ball mill. Refractory ores are processed by conventional carbon-in-leach and sulphide floatation technologies, including the use of sodium cyanide. The plant uses a two-celled peripheral discharge paddock-style tailings dam, covering an area of approximately 170 ha and elevated 30 m above the surrounding terrain.

KBGM is certified under the Cyanide Code and conducts daily cyanide sampling at the tailings dam (Golder Associates, 2008). During this study, cyanide concentration in tailings slurry discharged into the KBGM tailings dam was consistently below the 50 mg/L WAD industry protective limit (mean $=32.3\pm5.4$ mg/L WAD; $N=11$). Cyanide concentration data from supernatant pooling in the centre of the tailings dam were not available during this study, however natural degradation processes were likely to have rendered supernatant cyanide concentrations well below the tailings discharge concentrations (Henny et al., 1994; Botz and Mudder, 2000).