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Environmental change in a modified catchment downstream of a gold mine, Solomon Islands☆

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ABSTRACT

Solomon Islands is rapidly developing its natural resource exploitation sector, but data needed to assess consequent environmental impacts are scarce. We assessed catchments surrounding the Gold Ridge gold mine (Guadalcanal, Solomon Islands) and found that extensive changes in river course, and water and sediment quality have occurred downstream of the gold mine since its development. Sediment run-off from exposed areas associated with the mine pit has increased, elevating turbidity (up to 2450 NTU) and metal and arsenic levels, with levels of the latter being up to 0.141 mg/L in surface waters and 265 mg/kg in sediments. An overfull, inoperative tailings storage facility associated with the currently inactive gold mine with fluctuating arsenic levels (up to 0.087 mg/L in the water; 377 mg/kg in the sediment) presents an ongoing threat to the environment. Arsenic, due to its toxicity, appears to be the greatest threat, with sediment and water guideline levels in rivers exceeded 10-fold and exceeded nearly 20-fold in the tailings dam sediments. Despite elevated metal and arsenic content in the area, no toxic inorganic arsenic was found to have bioaccumulated in locally harvested food. In summary, the natural environment surrounding the Gold Ridge mine has been modified substantially and requires an ongoing monitoring program to ensure the ecosystem services of food and water for the local communities continue to be safe. This study informs not only the local area but also provides a microcosm of the broader global challenges facing the regulation of extractive industries in proximity to subsistence communities.

1. Introduction

Relatively few pristine ecosystems can be found on Earth today and areas rich in natural resources are being rapidly exploited, often causing damage to ecosystems (Lewis et al., 2015; Hodges, 1995; Cimon-Morin et al., 2016). In order to mitigate detrimental effects on the environment from anthropogenic activities, managers must be able to identify areas of concern. Key tools for early detection of environmental changes, including water quality changes, are baseline data and information on the natural variability of a locality (Moss et al., 2005; Herlihy et al., 2008; Nordstrom, 2015; Mcintyre et al., 2016). These data can be used to establish guidelines for chemicals of concern, allow for detection of changes over time, and can inform on suitable reference conditions (Cude, 2001; Moss et al., 2005; De Rosemond et al., 2009; Bilotta et al., 2012; Pardo et al., 2012).

In developing countries, both baseline data and region-specific environmental guidelines on chemical of concerns are sometimes lacking (Albert et al., 2015b). Identifying environmental degradation and mitigating further loss therefore becomes problematic. This issue is of particular relevance and urgency in countries such as Solomon Islands, where the majority of the population are directly dependant on their surrounding environment for survival through subsistence living (Andersen et al., 2013; Albert et al., 2015a).

Solomon Islands is a country consisting of over 900 islands in the South-west Pacific and is rich in natural resources and highly biodiverse rainforest and coral reef ecosystems. Commercial logging and fisheries have been the predominant industries in the past, but in recent times a small number of commercial mining operations have been established and new projects are being considered for economic development (Allen and Porter, 2016; Albert et al., 2015a).

Most of the land in Solomon Islands is under customary land ownership of local communities (Tolia and Petterson, 2005) and the

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local population may benefit financially from companies seeking to exploit the natural resources on their custodial land. However, the value of these monetary gains in relation to the potential negative impacts on the surrounding environment – and therefore directly on their subsistence livelihood – have been questioned (Allen and Porter, 2016).

Beyond causing damage to terrestrial habitats, logging and mining have additional potential to degrade the surrounding aquatic environment (Hodges, 1995; Pokhrel and Dubey, 2013). There may be increased terrestrial run off, leading to increased sediment loads in rivers and coastal areas (Klein et al., 2012; Pokhrel and Dubey, 2013; Lobo et al., 2016; Haywood et al., 2016). Suspended sediments in turbid river waters limits its use as a drinking water source and the in-stream biota can be negatively impacted (Bilotta and Brazier, 2008). Terrestrial runoff may further impact the coral reefs lining the coast, resulting in coral mortality, biodiversity loss and thereby associated fisheries decline (Nugues and Roberts, 2003; Fabricius, 2005; Weber et al., 2006; Haywood et al., 2016).

Mining operations have previously been observed to result in exposure and mobilisation of harmful elements into the surrounding environment (Muezzinoglu, 2003; Pokhrel and Dubey, 2013). Arsenic, lead, antimony, cyanide, cadmium and mercury are pollutants that are frequently associated with mining processes (Pokhrel and Dubey, 2013; Alvarez-Ayuso et al., 2012; Drahota et al., 2012; Foulds et al., 2014; Levei et al., 2014; Macgregor et al., 2015; Lortzie et al., 2015). These, and other compounds, may cause direct harm to the environment and pose a threat to human health through drinking water and food contamination (Bempah and Ewusi, 2016; Alpers et al., 2016; Alvarez-Ayuso et al., 2012; Foulds et al., 2014).

Gold mining on a variety of scales has been shown to lead to negative environmental outcomes in a number of locations. For example, the Migori Gold Belt in Kenya experienced associated land degradation, acid mine drainage, water pollution, and toxic heavy metal and metalloid impacts (Ogola et al., 2002). Similar issues have been reported in a farming and mining region in Western Ghana, where the mining operations have resulted in extensive land degradation, erosion and ecosystem services loss, as well as deforestation and loss of farmland (Schueler et al., 2011). Other studies have shown that the environment close to operating or abandoned gold mines becomes enriched in toxic compounds and that vegetable crops and animals contain higher than average levels of heavy metals and arsenic (Alpers et al., 2016; Olivero-Verbel et al., 2016; Bortey-Sam et al., 2015; Bempah and Ewusi, 2016). Perhaps the most dramatic example of environmental modification comes from the Ok Tedi mine in Papua New Guinea's Star Mountains, which has led to forest dieback of 2000 km^2 and siltation of the Fly River, impacting the lives of more than 30,000 people (Kirsch, 2007). Artisanal mining in Papua New Guinea has also been shown to contribute to degradation of terrestrial and aquatic environments (Crispin, 2003) and in Ghana, Kenya, Colombia and Brazil, heavy metal contamination, deforestation, land degradation and biodiversity loss have been linked to artisanal and small-scale gold mining (Cordy et al., 2011; Odumo et al., 2014; Rajaee et al., 2015; Affum et al., 2016; Lobo et al., 2016; Obiri et al., 2016).

At Gold Ridge, Solomon Islands' first – and so far only – large-scale mine, civil unrest, poor management and extreme rainfall have led to repeated abandonment of operations at this gold mine prior to completion of environmental monitoring and rehabilitation. The mine, which is situated in a coastal area on the island of Guadalcanal, 25 km SE of the capital, Honiara (Fig. 1) has had a number of foreign owners and multiple contractors have performed environmental assessments, yet the ecosystem impacts are unclear. Activities at Gold Ridge have included clear-felling of native forest to accommodate the mine area and associated infrastructure, ore extraction at the mining pit, transportation of ore, and gold extraction using methods such as cyanidation and acid wash. Resulting waste products (tailings) have been stored in a 65 ha tailings storage facility (TSF) - a dam located north of the mine pit at 550 m above sea level (Fig. 1). In addition to the large scale mine, local artisanal alluvial mining has also occurred.

Operations at Gold Ridge commenced in 1998, when the mine was owned by an Australian company, but the mine remained closed from 2000 to 2010 due to civil unrest. Operations recommenced in 2010, but ceased in 2014 due to a combination of factors: poor profitability, heavy rainfall leading to flooding; local disputes; and ongoing challenges to maintain safe water levels in the TSF (Allen and Porter, 2016).

With evidence that tailings entering the environment may contaminate the food and water chains (Kossoff et al., 2014) and that heavy metals and other chemical compounds could be released into the environment by leaching and erosion processes (Pokhrel and Dubey, 2013; Alvarez-Ayuso et al., 2012; Drahota et al., 2012; Levei et al., 2014; Macgregor et al., 2015), uncontrolled water release from the TSF dam at Gold Ridge and contamination of downstream areas represents a real risk.

Given the clear need for an external and independent assessment of the environment around the Gold Ridge mine, we conducted surveys of river water and sediment quality, and metal and toxin analyses of food, to identify environmental risks. During the course of the study, in April 2016, an uncontrolled release from the TSF occurred. This study provides baseline sediment and water quality data immediate prior to this release. The study further documents changes in land use, river course, and water and sediment quality since the development of the mine.

2. Methods

2.1. Study area

The study area encompassed the coastal catchment surrounding the gold mine (Gold Ridge). The mine is situated at 550 m above sea level and 20 km from the coastline on the island of Guadalcanal in Solomon Islands, 25 km SE of the capital Honiara. The upper catchment is characterised by basaltic andesite geology from Pliocene volcanics. Whilst the lower coastal plains are comprised of alluvial sediments deposited from the major rivers. There are five sub-catchments within this catchment system: the upper systems of Charivunga, Chovohio, Kwara and Tinahulu catchments, which all flow into the lower Metapona River (Fig. 1). However, the establishment of a tailings storage facility (TSF) dam within the Kwara River has dammed catchment flows within this sub-catchment. The mine pit is located within the Charivunga catchment (Figs. 1 and 2). The area has a steep topography and rainfall is estimated at 4000 mm per year, with a wet season from November–April and a drier period from May–October. The area has a mean air temperature of 27 °C with little change throughout the year. A south-east tradewind season dominates from June–August, followed by north-west winds from December–March.

2.2. Historic river channel changes

To respond to local community reports on observed changes in the flow of the Metapona River, aerial and satellite imagery from 1987 to 2014 was analysed to assess changes over that period. The monitored area included the lower reaches of the Metapona River at 0–3 km inland from the river mouth (blocked river channel in Figs. 1 and 3). Archived aerial imagery of the lower reaches of Metapona River was sourced from Solomon Islands Government