Bird mortality at tailings ponds: possible threats and solutions, with a particular focus on East Asia

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There is controversy about bird mortality at tailings ponds. Tailings ponds are known to directly cause deaths of birds and other animals in three ways, including oiling, poisoning and suffocation or dehydration/exhaustion. Tailings ponds are part of the industrial process and are used to store mine tailings, which are end-of-the-pipe waste sand products of mining operations. However, these ponds sometimes resemble lakes or wetlands. Their similarity to natural lakes attracts birds seeking roosting sites and foraging opportunities. The inability to differentiate between a natural lake and a tailings pond affects bird survival. Here we review reports on incidents, relevant findings and quantitative estimates of bird mortality from oiling and poisoning at tailings ponds across the world, and add a special focus on two White-naped Cranes *Antigone vipio* that we tracked. Effects of tailings ponds on bird populations, specifically on endangered or declining species and juveniles/subadults, are discussed, with a particular focus on China. Finally, some suggestions are given on the prevention of bird mortality at tailings ponds, such as light and sound deterrence, and a minimum safe distance between tailings ponds and places where birds congregate, such as migration corridors like rivers or lakes.

INTRODUCTION

Tailings are the leftovers of crushed ore from which valuable minerals are industrially extracted. Together with the water used in the recovery process, tailings are usually piped into tailings ponds or dams in a slushy form for wet storage (Hudson-Edwards *et al.* 2011, Coil *et al.* 2014, Australian Government 2016, Mining Association of Canada 2017). Apart from wet storage, another common disposal method is 'dry-stack' disposal (Coil *et al.* 2014). 'Dry-stack' is the dehydrated form of wet tailings that does not need to be stored in ponds or dams; thus, it takes up less space but it is more costly (Coil *et al.* 2014, Australian Government 2016). Wet tailings in dams or ponds can be very similar to lakes and wetlands from a bird's-eye view (Ramirez 2010), whereas 'dry-stack' involves little water and poses fewer threats to wildlife. Wet storage is also a common practice in oil sands production (Timoney & Ronconi 2010). Tailings ponds where wet tailings are stored attract birds that are looking for places to rest and forage. These tailings ponds feature a wetland-like surface that can be lethal to migratory or resident birds in three ways. Firstly, birds may get oiled when landing in oil sands tailings ponds, thus they may sink rapidly or 'suffer from reduced insulation, increased metabolic rate, and hypothermia' (Ronconi 2006, Timoney & Ronconi 2010). Secondly, birds may be poisoned by toxic substances such as heavy metal, oil, sodium and cyanide through inhalation, ingestion or skin contact (Ryan & Shanks 1996, Rattner *et al.* 2006, Sovacool 2009, 2012, Perez *et al.* 2017). Last but not least, when attracted to hard rock metalliferous tailings ponds (or oil sands tailings ponds that resemble natural bogs), birds may be trapped, weighed down and finally die from suffocation, dehydration or exhaustion (pers. obs., Flickinger 1981, Ramirez 2009).

Plate 1. The tailings pond in Loufan, Shanxi province, China, where two White-naped Crane *Antigone vipio* juveniles died. Left: tailings pond and its surroundings (red circle indicates the location where the juveniles died); right: the two dead juveniles entrapped in the tailings pond from aerial photography.

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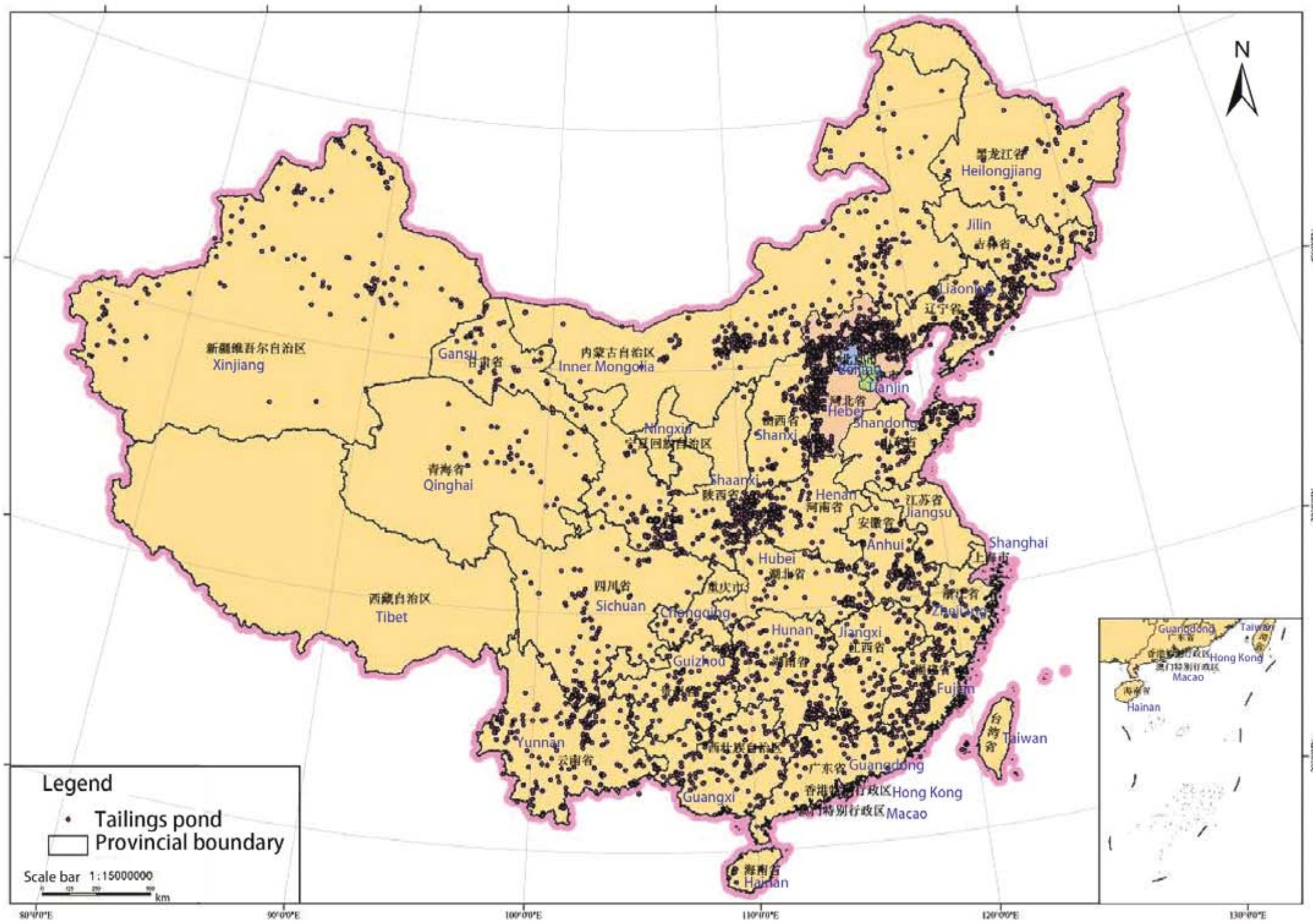
Figure 1. Distribution of tailings ponds in China (Lv 2014). Each dot represents a tailings pond, and curved lines represent provincial boundaries.



There are no bird deterring installations at most if not all tailings ponds in China, nor is there any literature that we are aware of concerning the connections between birds and tailings ponds in China. Therefore, bird mortality at tailings ponds is an issue that has long been overlooked in developing countries across the world. Here we first focus on the three direct causes of bird mortality at tailings ponds and associated mining facilities mentioned above, namely (1) oiling, (2) poisoning and (3) suffocation, dehydration or exhaustion. Secondly, the effects of tailings ponds on bird populations are discussed, with reference to case studies, specifically regarding endangered or declining species and juveniles/subadults. Thirdly, we zoom into the current situation of tailings ponds in China. Finally, some suggestions are proposed and discussed on the prevention of bird mortality at tailings ponds.

The purpose of this contribution is to present useful information concerning the long-overlooked issue of birds coming into contact with tailings ponds and to increase awareness of the consequences of birds' selection of tailings ponds as habitat.

METHODS

We used Google Scholar, Google and Web of Science for literature in English and mortality events, and we used China National Knowledge Infrastructure (CNKI) for literature in Chinese. At first, 'tailings pond', 'tailings dam' and 'bird' were searched as key words. Later, 'mortality' was added as one of the key words. Some literature was tracked down through references in searched papers. Publications concerning dam failures, oil spills and indirect contact were excluded since we only focus on birds actively choosing tailings dams as habitat.

We also included some observations that we made of tagged White-naped Cranes *Antigone vipio* that were equipped with GPS-GSM transmitters (HQLG4021S, Hunan Global Messenger Technology Co., Ltd, Changsha, China) from nesting grounds in Mongolia during the summer of 2018. The transmitter was fitted on the leg and weighed < 3% of body mass (less than 40 g). In total we tagged 40 White-naped Cranes, 19 of which were juveniles. Among these juveniles, two were captured from the same nest (for further details, see Hao *et al.* 2019). Coordinates were recorded once every hour, together with date, time, speed, aspect, altitude, temperature and battery voltage. This information was transmitted to us with a delay of a few minutes to a few hours. From temperature and speed, we inferred if the individual tracked was progressing well.

CAUSES OF BIRD MORTALITY AT TAILINGS PONDS

Oiling

'Bird oiling' is a major problem at oil sands tailings ponds (Wells *et al.* 2008, St. Clair *et al.* 2011). Bitumen extraction in Alberta's oil sands region in Canada has created many tailings ponds (Campbell 2014). The tailings produced during the separation of bitumen from sand consist of 'a mixture of process-affected water, residual hydrocarbons, brine, silts and clays, and metals' (Timoney & Ronconi 2010). The Canadian oil sands production region with many tailings ponds is located just 200 km south of the Peace–Athabasca Delta, which is a well-described, internationally significant staging area for birds (Nelson *et al.* 2014). Migratory birds flying through the Alberta's oil sands region in search of food, water and/or resting sites may land on these tailings ponds while mistaking them for natural water bodies, resulting in oil contact and subsequent death (Wells *et al.* 2008).

Table 1. Mass landing events in Alberta's oil sands tailings ponds.

Year	Number of deaths	Species	Possible reason for landing	Season	Sources
2008	c. 1,600	Waterfowl	Not specified	Spring	Nelson *et al.* 2014, St. Clair 2014, CBC 2010
2010	547	Not specified	Storm-forced	Winter	St. Clair *et al.* 2011
2014	122	Waterfowl	Heavy fog	Winter	CBC 2014
2015	30–31	Great Blue Heron *Ardea herodias*	Not specified	Summer	CBC 2015
2017	123	Horned Lark *Eremophila alpestris*	Exhausted by an impending storm	Autumn	CBC 2017

Table 2. Reported poisoning events by heavy metals.

Year	Number of deaths	Species	Cause of death	Sources
1995	342	Snow Goose *Anser caerulescens*	Consumption of metalliferous waters	Perez *et al.* 2017
2003	More than 50	Canada Goose *Branta canadensis*	Vanadium poisoning	Rattner *et al.* 2006
2004	60	Canada Goose	Vanadium poisoning	Rattner *et al.* 2006
2008	c. 300	Not specified	Selenium poisoning	Sovacool 2012
2008	40	Geese and ducks	Consumption of contaminated water	Sovacool 2009
2016	More than 3,000	Snow Goose	Consumption of metalliferous waters	Perez *et al.* 2017

Events of birds landing in oil sands tailings ponds are most likely in the spring, when natural water bodies are still frozen and the tailings ponds are available instead, and during severe weather conditions when migrating birds have to take refuge in any seemingly suitable habitat (Ronconi 2006, Ronconi & St. Clair 2006, Wells *et al*. 2008). Table 1 presents mass landing events in Alberta's oil sands tailings ponds. Gulley (1980) and Ronconi (2006) both found that ducks' use of tailings ponds is highly dependent on the availability of open water elsewhere.

Timoney & Ronconi (2010) assumed a mortality rate of 80–90% for birds that came into contact with oil during spring migration. They estimated an annual mortality of 458 to 5,029 individuals in Alberta's oil sands region, which may represent only a fraction of the true mortality. This is partly due to the fact that bird carcasses may sink into the pond (Flickinger & Bunck 1987). Another estimate of annual bird mortality in the same area by Wells *et al.* (2008) reported 8,000 to well over 100,000 individuals. Nevertheless, the overall oiling rate of 0.2278% for birds landing on tailings ponds during spring migration by Timoney & Ronconi (2010) is in accordance with the finding that many birds land but few actually appear to die in the tailings ponds of Alberta's oil sands (St. Clair *et al*. 2012). It seems that the chances of getting oiled are low for birds landing in tailings ponds, but the majority of birds getting oiled die.

Commercial and centralised oilfield wastewater disposal facilities (COWDFs) and oil field production skim pits are also hazardous to birds and other animals. COWDFs use evaporation ponds and skim pits to dispose of oilfield waste water (Ramirez 2010). Sometimes, oil is left on the surface of evaporation ponds and skim pits. Animals mistaking the shiny surface for water come to drink, forage and rest. Some land directly on these ponds, some fall into them due to the steep banks, resulting in them getting oiled or entrapped until they die (Flickinger 1981, Ramirez 2005, 2010). In a three-year investigation between 2007 and 2010, 1,755 bird carcasses were recovered from 205 oil and gas facilities in eight states in the United States (Ramirez 2013). Trail (2006) estimated a total annual mortality of 500,000–1,000,000 birds at oil pits in the United States. Bernáth *et al.* (2001) calculated that a waste oil lake in Budapest, Hungary, could trap and kill 13,000–17,000 birds in 50 years before its removal.

Poisoning

Several cases of birds poisoned at mine tailings ponds, COWDFs or mining lakes have been documented (Rattner *et al*. 2006, Sovacool 2009, Perez *et al*. 2017). Poisoning can result from exposure to heavy metals, sodium, oil and cyanide (Grover 1983, Ryan & Shanks 1996, Rattner *et al*. 2006, Sovacool 2009, Ramirez 2010, Perez *et al*. 2017). Reported poisoning events by heavy metals are summarised in Table 2. Birds using COWDF ponds with hypersaline water can ingest the brine when preening and then die from sodium toxicity (Ramirez 2010). Oil ingestion can also have lethal and sub-lethal effect on wildlife (Ramirez 2009, U. S. Fish & Wildlife Service 2009, Beck *et al*. 2015).

Cyanide is used in gold extraction because it is economical and effective (Mudder & Botz 2004), but such advantages come at a price—it is highly toxic to almost all forms of fauna (Donato *et al*. 2007). Since the mid-1980s, the use of cyanide at gold mines in Nevada has killed more than 9,500 wildlife individuals, most of which were migratory birds (Henny *et al*. 1994). Similar events also happened in Australia: 2,700 waterbird carcasses were found at North Parkes, New South Wales, while 200 pratincoles died after landing on a heap leach in 1995, and 60,000 Budgerigars *Melopsittacus undulatus* died at Mt. Windarra, Western Australia, in 1985 (Ryan & Shanks 1996). These deaths were most probably caused by a mine waste solution containing cyanide (Ryan & Shanks 1996). Apart from these deaths, approximately 1,000 birds are reported to die annually in gold mine tailings dams in Australia (Minerals Council of Australia 1996). There is some evidence from a South African gold mine to suggest a learned behaviour among local birds of avoiding drinking from the tailings storage facility (TSF) (Hudson & Bouwman 2008). Similarly, Australian research suggests that some bird guilds have the ability to discern or differentiate between a tailing dam and other waterbodies at an Australian gold mine. As a result, the birds that can distinguish tailing dams from waterbodies are able to avoid the severe consequences of cyanide and salt poisoning at TSFs (Smith *et al*. 2008).

Cyanide poisoning is not restricted to birds. In terrestrial animals, adverse impacts of exposure to cyanide solutions at precious metals operations have been documented (Mudder & Botz 2004). For example, there have been 519 mammal, 38 reptile and 55 amphibian mortalities reported at leach ponds in California, Nevada and Arizona between 1980 and 1989 (Eisler 1991).

Suffocation, dehydration or exhaustion

When birds land in hard rock metalliferous tailings ponds, which usually contain over 50% solids (Australian Government 2016), they get trapped and are unable to take off, and in some instances they even sink (pers. obs.). Therefore, birds die from either suffocation, dehydration or exhaustion in hard rock metalliferous tailings ponds. Similarly, birds die from the same causes in oil reserve pits or oil sands tailings ponds after exposure to oil (Flickinger 1981, Wells *et al.* 2008, Ramirez 2009).

The two White-naped Crane juveniles that we tracked in Mongolia from the same nest were entrapped and died at a tailings pond in Shanxi province, China, during their first autumn migration. The two siblings started their first migration in autumn with their parents, yet failed to make it to their wintering ground in the middle or lower reaches of the Yangtze River. Instead, their paths led to a site in Loufan County, Shanxi, where they stopped moving (38.023°N 111.733°E); more details can be found in Hao *et al.* (2019). On 14 November 2018, two weeks after they stopped progressing, we arrived at this location and found the two juveniles dead and stuck in a tailings pond of an iron mine (Jianshan Iron Mine, Tisco Corporation; Plate 1). Their position indicated that they struggled before dying. Physical exhaustion would be the most probable cause of their deaths.

EFFECTS OF TAILINGS PONDS ON BIRD POPULATIONS

Tailings ponds can easily influence populations in two ways. Firstly, the survival of a population requires a minimum number of individuals to withstand environmental fluctuations. This threshold is usually referred to as the minimum viable population (MVP) (Shaffer 1981, He *et al.* 2015). If the MVP cannot be sustained, the population will gradually die out. Secondly, because juveniles are the future of a population, a decimation of juveniles will lead to an unbalanced age distribution and further affect population dynamics (Sun 2006).

Tailings ponds and threatened/declining species

The presence of tailings ponds and waste ponds that store waste water poses great threats to migratory birds, especially those that are threatened or in decline. Mortality at such sites could represent a loss of a significant proportion of the population in a species with limited and/or dramatically declining numbers (Wells *et al.* 2008). In these species, populations are more likely to dwindle below the MVP, with considerable consequences.

For instance, the Whooping Crane *Grus americana* is listed as Endangered, with a total population in the wild numbering about 483 individuals (BirdLife International 2019b). The only self-sustaining population breeds in Northwest Territories/Alberta, Canada, and winters in Texas (BirdLife International 2019b). Part of its migratory route overlaps with Alberta's oil sands region. More than 40% of marked Whooping Cranes were found to fly over the oil sands region at least once in a two-and-a-half-year period, and more than 60% of these landed at least once in the oil sands region (Bidwell *et al.* 2016). Moreover, their stopover and flight locations were recorded in close proximity to tailings ponds during spring migration (Bidwell *et al.* 2016). When birds migrate over this region, it is quite likely that some individuals will actually perceive tailings ponds as stopover sites and get oiled. Unlike the Snow Goose *Anser caerulescens*, which numbers in the millions (BirdLife International 2019a), species like the Whooping Crane are susceptible to population decline following even a slight loss of individuals.

Another example is the Lesser Scaup *Aythya affinis*. Although its global population is large, it is estimated to have undergone a 70% decline since the late 1970s, and it is one of the most widely reported casualties of oil sands tailing ponds (Wells *et al.* 2008). The declining trend of the Lesser Scaup population is thought to be associated with declining recruitment rates caused by oil sands development in the Canadian western boreal forest (Afton & Anderson 2001).

Juveniles and subadults at tailings ponds

Juvenile survival is known to be a critical factor affecting population dynamics and persistence (Dittmar 2014). Population models indicate that survival of juveniles and subadults is a main driver of growth in the Aransas-Wood Buffalo population of the Whooping Crane (Wilson *et al.* 2016). Except for a mass landing due to severe weather conditions, birds seem to exhibit a differential ability to distinguish suitable habitat from unsuitable habitat depending on age stage. The two White-naped Crane juveniles that we tracked undoubtedly migrated together with their parents for their first migration, as has been documented for the species (Yang *et al.* 1991). However, only the two juveniles were entrapped and subsequently died. We presume that the adults did not get entrapped in the tailings pond or managed to extract themselves immediately as they were more experienced and stronger than juveniles or subadults. In both cases, juveniles are more vulnerable to tailings ponds. We surmise that the two juvenile cranes became tired during migration and found this pond available and attractive in the absence of nearby human activity. According to weather records (Tianqihoubao 2019), the day they stopped moving was sunny all along their flight path, with no precipitation and a very mild wind, so we can rule out a forced landing due to severe weather. If there had been any deterrents installed, this incident most probably would not have happened.

Grover (1983) found that in the summer, most wildlife losses found in waste disposal pits used by the oil and gas industry were young, inexperienced or recently fledged or weaned individuals. According to Esmoil (1995), there was a disproportionate number of Loggerhead Shrikes *Lanius ludovicianus* killed in oil field waste pits during a two-week period that coincided with fledging (Ramirez 2010). Other studies hardly discriminate juveniles and subadults from adults. From these three cases, we can infer that juveniles and subadults are more likely to choose a tailings pond due to habitat misjudgement. Juveniles' and subadults' misjudgements are based on their lack of experience. Thus, the harmful effects of tailings ponds are expected to be greater on juveniles and subadults, possibly leading to increased reductions of those age stages which may result in reduced recruitment rates as well as genetic stress.

DISCUSSION AND CONSERVATION IMPLICATIONS

Birds and other animals that come into contact with tailings ponds and other storage facilities in mining are in most cases visually deceived. They may die from suffocation, dehydration/exhaustion, cyanide or heavy metal poisoning, hypothermia or predation while they are in a weakened state (Flickinger & Bunck 1987, Ryan & Shanks 1996, Rattner *et al.* 2006, Ramirez 2009, Timoney & Ronconi 2010, Perez *et al.* 2017). Threatened and declining species are more vulnerable to mortality at tailings ponds and storage facilities. Mortality rates from tailings ponds and storage facilities are greater in autumn than in spring, caused by the presence of inexperienced juveniles which easily commit habitat misjudgement (Grover 1983, Ramirez 2010).

Currently, there are more than 12,000 tailings ponds in China (Jia *et al.* 2017; see Figure 1). Every one of these ponds is potentially deadly to migratory or resident birds. For instance, Poyang Lake (Jiangxi province) and Dongting Lake (Hunan province) are important wintering areas along the East Asian–Australasian Flyway, where several crane species overwinter, including the White-naped Crane, Hooded Crane *Grus monacha*, Siberian Crane *Leucogeranus leucogeranus* and Common Crane *G. grus* (Liu *et al.* 2017, Guan *et al.* 2016). However, as of 2018 there were already 454 tailings ponds in Jiangxi province (Jiangxi Emergency Management Office 2018) and 658 tailings ponds in Hunan province (Chen 2016). These tailings ponds pose a great threat to migratory birds wintering in the two regions. Furthermore, a tailings pond was built within the outer buffer zone of a provincial nature reserve in Gansu province, with only 500 m distance between the tailings pond and a river (Zhao *et al.* 2018). There could be other such instances undetected as there has not been any report as yet about bird deterrent devices and monitoring at tailings ponds in China.

Tailings ponds are the product of rapid industrial development, consumption and poor governance of wildlife and the environment. Mining activities may have started in Neolithic times, but were only expanded on a large industrial scale in the 19th century (Carvalho 2017). Birds are not able to adapt to these changes so quickly. For example, they still have not behaviorally adapted to the avoidance of tailings ponds; instead, they remain in the process of learning by trial and error. Regardless of how many precautions we take, impacts on populations are bound to persist. Currently, North America and Australia are taking a leading role in research on birds' contact with tailings ponds and its prevention (see e.g. Ryan & Shanks 1996, Martin *et al.* 1998, Read 1999, Ronconi & St. Clair 2006, Trail 2006, Timoney & Ronconi 2010, St. Clair *et al.* 2013, Cassidy 2015). To prevent bird mortality, deterrent systems and devices have been developed, such as sound cannons, rotating and intermittent beacons, gas-powered sonic guns, netting, bird balls, etc. (Martin *et al.* 1998, Read 1999, Fluker 2011). North America's experience provides lessons learned for other continents, especially Asia and Africa. Mining areas in China are mostly in relatively under-developed regions, where development is prioritised over conservation, requiring increased government guidance on conservation in mining areas. The prevention of wildlife mortality at tailings ponds should become a 'standard' in mining. With the development and promotion of the economy, it is most likely that in the future the implementation of deterrent programs that prevent bird mortality events at tailings ponds will be regulated by law in current developing countries, just like the *Migratory Birds Convention Act* and *Environmental Protection and Enhancement Act* in North America (Government of Canada 1994, Alberta Government 2010, Fluker 2011).

In the future, more research should be conducted into wildlife coming into contact with tailings ponds and other storage facilities in China and other developing countries. The first step should be to conduct a thorough investigation of the location and distribution of these tailings ponds. If some ponds geographically overlap with migratory routes or are within the range of the wintering or breeding grounds of bird species, especially threatened species, then it is imperative to conduct environmental monitoring of these tailings ponds, coupled with the installation of bird deterrent devices to prevent mortality as far as possible.

Birds are mostly dependent on vision and hearing (Gill 2007), so effective deterrents should involve sound and light. An early study (Boag & Lewin 1980) found that a human effigy (model) could significantly reduce bird mortality compared with a falcon decoy and a moving series of reflectors. More advanced calls of predators, alarm calls and lasers are among secondary deterrent methods. For example, a thorough investigation should be carried out to acquire information about the temporal distribution of bird species, based on which the calls of predators should be recorded and played back correspondingly, at an increasing intensity to simulate the predator's approach (Guo *et al.* 2015). Read (1999) tested a rotating beacon, which could reduce total waterfowl abundance by more than 90%. Ronconi & St. Clair (2006) compared different deterrent systems and found that on-demand deterrent systems significantly reduced the probability of birds landing, with propane cannons being more effective than mechanised Peregrine Falcon *Falco peregrinus* decoys with speakers broadcasting calls. According to Cassidy (2015), green lasers are most effective in generating escape responses. However, some scientists argue that it is most effective to use physical exclusion such as 'bird balls' and netting that deny birds access to tailings ponds (Martin *et al.* 1998, Trail 2006, Ramirez 2010). Bird balls are hollow plastic balls that float on any liquid surface (Martin *et al.* 1998). Several trials have been carried out on bird balls, proving their effectiveness even in snowy weather (Martin *et al.* 1998, Ramirez 2010). Netting requires regular maintenance to function effectively; however, it is not feasible on large ponds and birds may get their heads and feet entangled in it (Martin *et al.* 1998, Ramirez 2010). In addition, Griffiths *et al.* (2009, 2014) found that elevated levels of salinity in mine waste solutions discourages wildlife from drinking and foraging at gold mining operations. Therefore, salinity elevation could also be a method to relieve mortality from cyanide and heavy metal poisoning.

Here we propose that a minimum safe distance between any tailings ponds and rivers be stipulated. St. Clair *et al.* (2011) suggested not building new tailings ponds within 3.5 km of rivers. Whooping Cranes were recorded to migrate along rivers (Alerstam 1996), akin to the two White-naped Cranes that we tracked. The shortest distance between the river they followed and the tailings pond where they eventually died is no more than half a kilometer. Birds—especially wading birds and waterfowl—have a propensity to use rivers as migration corridors (St. Clair *et al.* 2011, Higuchi 2012). For one thing, rivers provide a consistent landmark of reflected light (St. Clair *et al.* 2011); for another, wading birds and waterfowl can readily stop to rest and forage along rivers. It is quite likely that tailings ponds located at such short distance from rivers will lead migratory birds astray, giving birds a perception that those are wetlands to be used. Recently, the Ministry of Natural Resources of China demanded that ecological restoration of abandoned open pit mines within 10 km along the Yangtze River and its major tributaries be completed by 2020, which demonstrates that China is now taking a stand on the removal of tailings ponds near rivers (China News 2019).

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