MAMMALS AND MINING FOR MINERALS IN SULPHUR-BEARING ROCK FORMATIONS IN NORTHEASTERN MINNESOTA

A review prepared for Northeastern Minnesotans for Wilderness, 28 April 2017

Roger A Powell
Department of Applied Ecology, North Carolina State University, Raleigh, North Carolina

The Boundary Waters Canoe Area Wilderness, Quetico Provincial Wilderness Park, Voyageur National Park and their surrounding landscape within the Rainy River Watershed (hereafter "the Boundary Waters area") lie within the southern boreal forests of North America (Heinselman 1996). Besides providing humans with many usable resources, such as timber, energy, drinking water and recreation that depends on clean water (Keeler et al. 2015), boreal forests, and the Boundary Waters specifically, provide important ecosystem services, including carbon storage and clean water and air (Schindler & Lee 2010). Indeed, the benefits of protecting functioning, natural ecosystems exceed the cost of such protection by a ratio of at least 100-to-1 (Balmford et al. 2002, Costanza et al. 1997). The forests of the Boundary Waters area form a natural ecosystem that shows relatively few effects of colonization by European Man (Heinselman 1996). These forests support diverse plant and wildlife communities, including approximately 50 native mammals (Powell & Powell 2016).

Mining in rock formations with metallic ores poses a major threat for boreal forests worldwide, including threats to forest wildlife (Frelich 2013). Mine sites themselves destroy habitat for terrestrial wildlife directly with open pit and underground mines, with pipelines, with buildings and other facilities, with roads and railroads and with power line and other rights-of-way. Mine sites fragment wildlife habitat, disrupting wildlife spacing patterns and migration routes. In addition, mines affect the behavior and ecology of wildlife on the surrounding landscape. Close-by mines, noise and light pollution interrupt wildlife behavior. Air pollution affects forest growth and development, and thereby wildlife, over long distances from mine sites.

Mines in sulphur-bearing rock formations also pose a threat of water pollution through leaching of acid mine drainage from tailings and waste rock into ground water, through failure of tailings dams, through failure of and leaking from pipelines, and through failures other equipment. Mining has been proposed for copper, nickel and other heavy metals in sulphur-bearing rock formations in Boundary Waters area, such as the Duluth Complex. For some of the proposed mines, the mines themselves, the processing sites, the tailings basins, or all three, are within surface watershed or ground water flowage for the Boundary Waters Canoe Area Wilderness. Pollution of ground water may not appear immediately but will ultimately affect surface water, including surface water outside the surface watershed of the site of the pollution. The distribution of sediments polluted with metals and the distribution of acidic water will affect downstream waters and surrounding forests for tens of kilometers. The immediate deaths of fish and wildlife in the water would be overshadowed by the long-term effects of polluted sediments on fish, wildlife and forests that would last for decades to millennia (Kossoff et al. 2014, Lewin & Macklin 1987 [cited by Macklin et al. 2006], Macklin et al. 2006). Where plants are able to grow on polluted sediments, heavy metals can become incorporated into the plants (Gramss & Voigt 2014, Peplow & Edmonds 2005). The effects of polluted ground water will last for centuries to millennia (Myers 2016). Estimates of dam failures at mine sites generally range from about 0.1% per year to over 1% per year (Baker 2013, Macklin et al. 2006) but the causes of dam failures are poorly understood, even including how different dam structures affect failure (Kossoff et al. 2014, Yuan et al. 2015).

The effects of a tailings dam failure in the Boundary Waters area would be catastrophic (Kossoff et al. 2014, Yuan et al. 2013, 2015). The history of mining and the literature on tailings dams demonstrate clearly that the probability of accidents is so high that planning for accidents is required (Kossoff et al. 2014, Macklin et al. 2006, Yuan et al. 2015). Consequently, understanding the potential effects of accidents during and after mining in sulphur-bearing rock formations is mandatory.

Mining for copper, nickel and other heavy metals in sulphur-bearing rock formations within the Boundary Waters watershed will affect the resident mammals and other animals in both their aquatic and terrestrial habitats. Water pollution affects wildlife health via drinking water and via changes in plant food populations and distributions that affect prey populations. Ecological communities in terrestrial habitats affected by mining will change, affecting foraging habitat for mammals, thus forcing changes in foraging behavior, changes in dispersal and migration routes, changes in spacing patterns of individual mammals, and changes in intraspecific and interspecific interactions. Some plants will be unable to grow on polluted sediments, altering the foods available for mammals and making some remaining foods toxic.

Potential Effects of Water Pollution on Mammals

All mammals depend on water in at least one of three important ways: they drink water; they eat aquatic foods or eat foods that have obligate, aquatic life stages; and they spend significant portions of their lives in water.

Drinking Water

All mammals drink. Some small mammals of the Boundary Waters area appear able to obtain sufficient water from food and rain water and by making physiological water (Orrock 2000); they certainly drink water when it is available. Larger mammals must drink water and most need a reliable source of water. I have watched white-tailed deer (*Odocoileus virginianus*), moose (*Alces alces*), wolves (*Canis lupus*), black bears (*Ursus americanus*), American martens (*Martes americana*), minks (*Musetla vison*), snowshoe hares (*Lepus americanus*), red squirrels (*Tamiasciurus hudsonicus*), and chipmunks (*Tamias* spp.) drink from lakes and rivers. Mammals that weigh more than1 kg may travel fair distances to drink from wetlands. Forest game trails lead to the water's edge at regular intervals along shorelines.

Toxicity of heavy metals in drinking water is well documented (*e.g.* Ash & Stone 2003, Janicka et al. 2015, Kovaci et al. 2017, Larison et al. 2000, Liu 2015, Massanyi et al. 2014, Yoshida et al. 2016) and these toxins bioaccumulate up through food webs to have highest concentrations in top predators. Acidic water is able to maintain high concentrations of heavy metals, increasing exposure to the heavy metals and their effects. The end result is that almost all resident mammals will be exposed to, and be subject to, the health effects of heavy metal pollution following leaking from tailings ponds and pipelines, following movement of ground water contaminated by leachate from tailings ponds, waste rock piles and ore stockpiles and, obviously, following any failure of a pipeline or failure of a dam maintaining a tailings pond.

Aquatic Foods and Adaptations of Mammals for Foraging in Water

Heavy metal pollution in wetlands decreases growth and reproduction of aquatic plants and the metals become incorporated into the tissues of the plants (Gramss & Voight 2014, Peplow & Edmonds 2005). Consequently, any mammals that eat aquatic plants experience reduced availability of important foods and are exposed to toxic pollutants through the foods they eat. The health effects of heavy metal exposure on humans are well known (Crisponi et al. 2010, Hessett-Sipple et al. 1997, Mahaffey et al. 1997, Merger et al. 2007) and include cancer, heart disease, organ failure, nervous system dysfunction, and abnormal development of the nervous systems of fetuses through adolescents (Obiri et al. 2010, Mergler et al. 1994, Rodrigues-agudelo et al. 2006). Exposure to methy-mercury injures the nervous and cardio-vascular systems and can cause death. Exposure of pregnant women to any form of mercury leads to elevated blood levels in fetuses that average 1.7 times the blood levels in mothers. Tissue levels of mercury in otters (*Lontra canadenses*) and minks, which eat large numbers of fishes, amphibians and crustaceans, are usually about 10x the levels found in the food in their diets, whose levels of mercury can exceed by 10^6x the background levels in the water column (Grigal 2003, Rudd 1995, Scudder Eikenberry 2015, Ullrich et al. 2001). The mercury levels in otter and mink fetuses should be substantially higher than those in their mothers, as occurs in humans (Hesset-Sipple et al. 1997, Mahaffey et al. 1997). Humans are, after all, mammals and share most aspects of physiology and development with other mammals. Consequently, similar or identical effects are expected from exposure to heavy metals in other mammals as in humans.

White-tailed Deer and Moose – White-tailed deer and moose are large hooved mammals. When in excellent nutritional condition, female white-tailed deer usually produce twins or triplets each spring and can even mate for the first time as fawns. Likewise, female moose in good nutritional condition produce twins and can mate for the first time as yearlings. When good food is not abundant and female deer or moose are not in good condition, litter sizes are reduced, first breeding takes places when the females are a year or 2 older, and reproduction can even be skipped altogether. When populations are reduced, rate of population recovery depends heavily on the nutritional condition of females.

Although white-tailed deer and moose are terrestrial mammals, both eat significant amounts of aquatic vegetation during spring and summer and often are seen up to their chests in water (Bowyer et al. 2003, personal observation). Sodium is a critical nutrient for all mammals and sodium shortage may limit moose populations (Belovsky 1981a). Aquatic plants are generally higher in sodium than terrestrial plants (Belovsky and Jordan 1978, Botkin et al 1973, Ceacero et al. 2014) so moose (and probably deer) budget their time to forage for aquatic vegetation to balance their sodium requirements (Belovsky 1978, 1981b). Given the importance of aquatic plants for moose and deer, reduction or loss of aquatic foods due to acid mine drainage or flooding could limit their populations or drive them locally extinct. This possibility is pertinent because the moose population in the Boundary Waters area is now critically low (DelGuidice 2017). When deer and moose populations decrease, so do populations of wolves (*Canis lupus*), who are also signature mammals of the Boundary Waters area.

Deer and moose swim across bodies of water in the Boundary Waters and sometimes flee to water when pursued by wolves (Carlson-Voiles 2012, Mech et al. 2015, personal observation). Cleaning their bodies after being in water exposes deer and moose further to heavy metals and other pollutants in the water.

Beaver – Beavers (*Castor canadensis*) are large, semi-aquatic rodents and are major herbivores on aquatic plants (Bakker et al. 2016). They build lodges and bank dens in water bodies deep enough for them to swim and they dam streams to create ponds (Baker & Hill 2003). Beavers live in colonies that are extended family groups, each with 2 parents and their offspring from the past 2-3 years. Young beavers do not reproduce until they have dispersed from the colonies of their birth when 2-3 years old, have found good habitat unpopulated by other beavers, and have found a mate. Beavers are, thus, 3-4 years old when they first reproduce and they produce only 1 litter per year (Bakker et al. 2016, Jenkins & Busher 1979), leading to relatively show population growth.

Water provides beavers with safety from predators and almost all predation on beavers occurs when beavers are not in water where they can swim (Gable et al. 2016). Beavers build canals through bogs and marshes to extend swimming areas. They must, nonetheless, come on land to cut down trees, so that they can eat the inner bark and obtain branches as construction material for dams and lodges. Beavers have preferences among local tree species and for sizes of trees to cut but always prefer trees close to shore, to minimize escape time to water (Belovsky 1984, Jenkins 1980, Jenkins & Busher 1979).

Beavers have evolved many physical and physiological adaptations for efficient swimming and for spending most of their foraging time in water (Baker & Hill 2003, Jenkins & Busher 1979). They have large, webbed hind feet; scaley, flat tails that they use for steering when swimming; ears and noses that they can close when under water; lips that can close behind their incisors, allowing them to cut tree branches from their under water food caches with their mouths closed; eyes that are protected by nictitating membranes when beavers swim under water; dense underfur protected by oily guard hairs, which keep beavers dry and warm, even in water approaching freezing temperature; and counter-current circulation that warms blood coming from cold extremities while cooling blood that goes to those extremities. Beavers are able to remain under water for at least 15 minutes (Irving and Orr 1035). When disturbed by potential danger, a beaver will slap its tail against the water surface when diving, making a loud crack that warns other members of its colony.

Before European colonization of North America, beavers created and maintained high biodiversity and, more importantly, highly diverse ecological communities across the continent (Johnston 2015, Naiman et al. 1988, Stringer & Gaywood 2016, Wright et al. 2002). Beavers dammed every stream into series of ponds and beavers occupied every lake, pond and river and lined shorelines with trees fallen into the water, creating habitat for fish, amphibians reptiles, crustaceans and aquatic insects. Beaver activity maintained high abundances and diversity of aquatic vegetation and affected forest succession everywhere, moving some forests to late successional stages but introducing early successional stages in other places. Where beaver ponds had been abandoned and then drained, beaver meadows maintained open areas for decades (Pastor 2016, Terwilliger & Pastor 1999). Beavers are major ecological engineers, affecting both species diversity and landscape diversity. No members of any other single species, except Man, have so large an effect on entire landscapes as do beavers.

Beaver populations decreased through the early 1900s due to over-trapping (Jenkins & Busher 1979). Despite protection during the early to mid 1900s, beavers have never returned to their original densities and, therefore, to their original influence on biodiversity and ecological diversity (Johnston 2015, Naiman et al. 1988). Fortunately, beaver densities in the Boundary Waters never dropped so low as they did in most of the United States, helping to maintain the pre-European biodiversity and ecological diversity in the Boundary Waters.

In summer and autumn, the diets of beavers can be dominated by aquatic vegetation (Baker &

Hill 2003, Milligan & Humphries, Svendsen 1980). Beavers also eat aquatic vegetation during winter under ice (Milligan & Humphries 2010, Svendsen 1980). As with deer and moose, aquatic plants are a major source of sodium for beavers (Belovsky 1984).

Any negative effects of acid mine drainage on aquatic vegetation or on beavers directly will affect the biodiversity, the ecological diversity, and the entire essence of the landscape of the Boundary Waters.

Muskrat – Muskrats (*Ondatra zibethicus*) are also large, semi-aquatic rodents. Aquatic plants provide a larger proportion of muskrats' diets year-round compared to beavers (Erb & Perry 2003, Errington 1961, Willner et al. 1980). Cattails and bullrushes are the most important foods for muskrats throughout the United States and cattails are the most important in Canada (Willner et al. 1075 cited by Erb & Perry 2003). Muskrats also use aquatic vegetation to build their lodges (Erb & Perry 2003, Errington 1961, Willner et al. 1980).

Muskrats share most of beavers' physical adaptations for living in water, such as large webbed feet and dense underfur and oily guard hairs. Like beavers, muskrats use water to avoid predators and are awkward on land (Baker & Hill 2003).

Unlike beavers, muskrats in boreal forests breed when 1 year old and can even produce multiple litters in a year. Muskrats are important prey for many carnivores (Willner et al. 1980). Errington (1943, 1961) outlined the multiple cause and effect relationships among fluctuating muskrat populations and predation by minks. Across most of their species ranges, when muskrat populations go up, mink populations go up and, likewise, when muskrat populations go down, mink populations go down (Ahlers et al. 2016, Errington 1943, 1961, Estay 2011, Shier & Boyce 2009)

Any negative effects of acid mine drainage on aquatic vegetation or on muskrats directly will affect the diverse predators of muskrats, especially minks, and their ecological communities.

Otter – Otters (*Lontra canadensis*) are medium-sized, semi-aquatic, predatory mammals that prey predominantly on fish (Melquist et al. 2003). They have long, slender, hydrodynamic bodies with no discernable contraction for a neck and tails that taper. They have thick, dense fur with dense underfur and oily guard hairs that cover and protect them; they can swim in freezing water. Otters' eyes are adapted to focus under water, making them far sighted when out of the water. Their ears are small and able to be flattened to their heads to reduce drag. Their vibrissae are dense, very thick and prominent. Otters' heads are modestly flattened. They swim by paddling with their large webbed feet but often clutch their legs tightly to their bodies and swim by undulating, like porpoises.

Although otters spend long periods in water, they rest on land and sometimes cross land to reach adjacent watersheds. They rest, and females sometimes produce litters, in abandoned beaver lodges and bank dens. Litter sizes are usually 3-4 and females usually do not deliver their first litters until 3 years old or older. Thus, population growth is slow when populations are low. Although otters can live into their teens, few live to be 10 years old (Melquist et al. 2003).

In general, aquatic or semi-aquatic animals, dominated by fish, constitute more than 90% of otters' diets, which also include crustaceans, frogs and, occasionally, muskrats and waterfowl and gulls and their eggs. Except in shallow bodies of water, otters forage by swimming in the water, looking and listening for fish or detecting the turbulence trails of fish, which they undoubtedly follow, as do other fish-eating mammals, using their prominent vibrissae (Dehnhardt et al. 2001, Weiskotten et al. 2011). After catching prey, otters often surface to eat them.

Otters appear to be favorite wildlife for people to observe, probably because they are so curious and playful, as are all members of the weasel family (the Mustelidae). Family groups of otters play and wrestle both on land at rest sites and in the water. They will slide down muddy slopes, across wet grass, and down snowy slopes.

Heavy metal pollution affects individual fish, amphibians and crustaceans, their populations and ecosystem health (Au 2004, Egea-Serrano et alii 2012, Gürkan et al. 2014, Kouba et al. 2010, Lahman et al. 2015, Marcogliese 2005, Rowe et al. 2001, Teh et al. 1997, Vidal-Martinez et al. 2010, Webster et al. 2002). Otter populations will decrease where fish populations are affected by acid mine drainage, due both to decreased fish populations as well as to bioaccumulation of toxins in otters' bodies (Ben-David 2001). Otters are also exposed significantly to pollutants through grooming after swimming in polluted waters (Duffy et al. 1999). The limit set by the Environmental Protection Agency (EPA) for mercury levels in wetlands that support otters is 42 pg/l (Mahaffey et al. 1997). Of 6 bird and mammal species evaluated by the EPA, otters appear less sensitive to mercury pollution than only belted kingfishers (*Megaceryle alcyon*) and more sensitive than minks, common loons (*Gavia immer*), osprey (*Pandion haliaetus*; these latter 3 species were considered equally sensitive) and bald eagles (*Haliaeetus leucocephalus*).

Mink – Like otters, though much smaller, minks are semi-aquatic predators with long, slender, hydrodynamic bodies. Minks are, nonetheless, very different from simply being small otters. Although minks do forage in the water (Harrington et al. 2012), most of their foraging is along shore, exploring rock crevices and holes, especially under banks, and walking on rocks and on trees fallen looking into the water. When a mink sees prey in the water, it dives to capture the prey, which it then brings to shore to eat (Ben-David et al. 1996, Harrington et al. 2012, Larivière 2003). Minks' feet are not enlarged and the toes are only partially webbed. Their maximum dive time is about a minute and most minks spend well less than an hour diving per day. Because minks forage extensively on land and water, their diets are more diverse than diets of otters and include muskrats, diverse small mammals, small fish, crayfish, frogs, shorebirds, water birds, small birds and birds' eggs (Larivière 2003). Throughout the year, muskrats, voles and mice dominate their diets (Erb & Perry 2003, Eagle & Whitman 1987, Errington 1943, 1961, Willner et al. 1980).

Clearly, minks are generalist predators. Nonetheless, their dependence on diverse aquatic prey led the EPA to set 57 pg/l as the environmental limit for mercury concentration in wetlands that support minks (Mahaffey et al. 1997). Minks were considered more sensitive to mercury pollution than bald eagles. Minks' predator-prey relationship with muskrats is critically important and mink populations rise and fall in response to the large population fluctuations of muskrats. Minks rest and females often produce litters in abandoned muskrat lodges and bank dens. Acid mine drainage that affects muskrat populations will have similar effects on mink populations.

Raccoon – Raccoons (*Procyon lotor*) gained their scientific name, which means "pre-dog that washes", because they sometimes forage in wetlands by putting their dextrous forepaws into the water to feel for such aquatic prey as crayfish, frogs and other amphibians, and mussels. They may also rub their food with a washing motion. Nonetheless, plant foods, especially terrestrial fruits and nuts, are more common foods for raccoons than aquatic prey generally (Gehrt 2003, Lotze & Anderson 1979). Raccoons are at the northern extent of their range in the Boundary Waters area and have low population sizes (Gehrt 2003, Lotze & Anderson 1979). Loss of prey due to acid mine drainage will cause raccoons to need larger home ranges and, therefore, will lower their already low population densities. Raccoons will bioaccumulate heavy metals from polluted waters.

Water shrew – Water shrews (*Sorex palustris*) are little-known, very small mammals that are highly adapted for foraging in water. They are seldom found far from streams and other bodies of water and they eat aquatic insect larvae, aquatic insects, small fish and terrestrial invertebrates (Beneski & Stinson 1987, Harris 1999, Whitaker & Schmeltz 1973). Water shrews have particularly hairy paws, which they use as paddles when swimming. These shrews are also able to run across the surface of smooth water. They detect prey under water by sight and shape, by movement and by smell (Catania et al. 2008) and must eat the equivalent of 15 minnows a day (Gusztac et al. 2005). Water shrews are potentially long-lived (up to 2 years) for such small mammals (Punzo 2004). Given their high metabolic rates and consequent high food requirements, water shrews have the potential to bioaccumulate heavy metals if exposed to polluted waters.

Water shrew populations decrease in response to nearby logging (Wilk et al. 2010) and are expected to respond similarly to logging and to construction at mine sites. Any negative effects of acid mine drainage on populations of aquatic insects and small fish will cause decreases in water shrew populations. Increases in heavy metals in waters of the Boundary Waters will have direct, negative effects on water shrews and indirect, negative effects through reduced food supply.

Star-nosed mole – The Boundary Waters area constitutes the far northwestern extent of the range of star-nosed moles (*Condylura cristata*). In areas with many large bodies of water, star-nosed moles forage in water extensively for aquatic prey and aquatic insect larvae (Petersen & Yates 1980). Some of their tunnels open directly into water. Where large lakes are not common, however, these moles forage mostly for earthworms and other invertebrates that live under the ground surface. Earthworms, however, are not native to the Boundary Waters area and do not occur in most places, leading star-nosed moles to depend more on aquatic prey. Star-nosed moles build extensive tunnel systems with deep tunnels for living spaces and shallow tunnels, sometimes humping the surface of the ground, for foraging. Given the shallow soils in the Boundary Waters area, loss of aquatic prey caused by acid mine drainage will reduce the already low population sizes of star-nosed moles.

Little brown bat – Little brown bats (*Myotis lucifugus*) are, indeed, little, and beautiful, bats. Their average weight is 10 g, the weight of a US quarter or a €2 coin. Their wings are not particularly short or long, making them modestly fast and maneuverable fliers but not racers. Female little brown bats give birth to one pup per year, a small litter size for mammals so small, yet these bats have been documented to live over 30 years (Brunet-Rossinni 2004). Their population growth rates are similar to those of moose.

Little brown bats are completely insectivorous and eat a wide variety of insects, which they catch on the wing using echolocation to locate individual insects and a tail-tuck maneuver to make the final catch. In summer, they forage for long periods at night, sometimes in large groups, over lakes and ponds, mostly flying within 2 m of the water surface. Their major prey are insects with obligate aquatic larvae, such as caddisflies (Trichoptera), mayflies (Ephemeroptera), midges and mosquitoes (Diptera). Most nights, a little brown bat eats half its weight in insects. During pregnancy and lactation, females eat up to their whole weight in insects each night (Fenton 1999, Fenton & Barclay 1980). Both acidity and heavy metals in acid mine drainage will decrease survival of aquatic insect larvae and, therefore, decrease population sizes of little brown bats. Given their low reproductive rates, populations of little brown bats recover slowly from any population size decreases.

Little brown bats have experienced some of the greatest population collapses of any bats in response to white-nose syndrome, a new disease of bats caused by the recently-introduced fungus *Pseudogymnoascus destructans*. This disease has caused over 70% decreases in some little brown bat populations (Frick et al 2010, Ingersoll et al. 2013 2016, Langwig et al. 2016). Although some affected little brown bat populations stabilize at roughly 30% of their previous population sizes, the disease process allowing stable, low population sizes is not understood (Langwig 2017). White-nose syndrome has reduced by at least 70% the numbers of little brown bats using the winter hibernation roost in the Soudan Mine, the largest winter roost known in the Boundary Waters area (Badalamenti et al. 2016, Myers 2017). Little brown bat populations in the Boundary Waters are, therefore, particularly sensitive to any threats to their food supplies. The potential exists that this species will be proposed for listing as "Threatened" or "Endangered" under the US Endangered Species Act.

Long-eared bat – Long-eared bats (*Myotis septentrionalis*) are listed as "Threatened" on the US Endangered Species List (https://www.fws.gov/midwest/endangered/mammals/nleb/ last accessed 5 March 2017). Although these bats do not forage generally over water, they prey on many insects with aquatic larvae (Neuroptera, Hemiptera; Caceres & Barclay 2000). Loss of prey with aquatic larvae, due to acid mine drainage, will have a minor but negative affect on long-eared bat populations.

Long-eared bats often share winter roosts with little brown bats and, like little brown bats, are threatenen by white-nose syndrome. Any negative effects caused by mining will exacerbate the precarious existence of these bats and lead them closer to extinction locally.

Hoary Bat – Hoary bats (*Lasiurus cinereus*) are relatively common, relatively large bats with beautiful hoary coats. They weigh 2-3 times the weights of little brown bats. They have relatively long wings and fly swiftly. Their diet emphasizes moths but they do prey on dragonflies, whose larvae are aquatic (Shump 2003). Loss of prey with aquatic larvae, due to acid mine drainage, will have a minor but negative affect on hoary bat populations.

Silver-haired bat – Silver-haired bats (*Lasionycteris noctovagans)* are widespread bats that, like hoary bats, eat many moths but also include some insects with aquatic larvae in their diets, such as midges. They forage in forests, over fields and over water. Loss of prey that have aquatic larvae, due to acid mine drainage, will have a minor but negative affect on silver-haired bat populations.

Terrestrial Effects of Mining Activities on Mammals

Mine sites destroy and fragment wildlife habitat with their open pit or underground mines but also with their buildings and other facilities, pipelines, roads and railroads, and power line and other rights-of-way. Such habitat destruction often facilitates colonization by non-native species. House mice (*Mus musculus*) and rats (*Rattus* spp.) colonize the buildings at mine sites.

Mine sites in the Boundary Waters area will disrupt wildlife spacing patterns, forcing resident individual animals to adjust their home ranges or to seek new home ranges entirely. All of the mammal species in the Boundary Waters area (except for house mice and rats) are long-term residents. Even species such as white-tailed deer, which were not common at the time of European colonization, have had resident populations in the Boundary Waters area for over 100 years. Consequently, mammals and other terrestrial wildlife maintain populations that hover near their carrying capacities, meaning that the landscape has no vacancies for individual mammals that are displaced from mining sites. The end result is that most displaced mammals die early, lowering population sizes. Moose, whose population is of special concern (Del Giudice 2017), and lynxes (*Lynx canadensis*), whose population is listed as Threatened (http://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=A073 last visited 5 March 2017) can ill afford population reductions caused by extensive habitat destruction by mining. In 2016, 6 of 9 moose sampling plots censussed for moose in the areas of Superior National Forest proposed to be withdrawn from mining were of medium or high moose density; in 2017 the results were 6 of 8 plots (DelGuidice 2016, 2017). Thus, the areas proposed to be withdrawn from mining provide important habitat for moose.

Destruction and fragmentation of wildlife habitat will also disrupt dispersal movements of young mammals seeking places to establish home ranges. In 2006 only 13 travel corridors existed for wildlife through the approximate 160 km (100 mi) of Minnesota's Mesabi Iron Range (Emmons & Olivier 2006). The corridors averaged at that time only about 1¾ km wide (± 2.3 km (standard deviation), range 0.25 - 5.4 km). Of those 13 corridors, planned expansion of mining operations was slated to eliminate 1 and to reduce 3 more. Adding further mines to the east of the Mesabi Iron Range will extend the restricted area with few corridors. For moose and lynxes, restricted dispersal holds the danger of reducing gene flow and increasing inbreeding, increasing the probabilities of local extinction.

Loss of mature, forested habitats removes old trees and snags from the forest. Cavities in mature trees and snags are important as rest sites and den sites for fishers (*Pekania pennanti*) and American martens. Female fishers give birth only in such cavities. Thus, loss of mature forests will lead to decreases in fisher and marten populations, which have both decreased in recent years (Erb et al. 2014).

Cutting trees for mine sites, roads, pipelines and power line rights-of-way causes habitat fragmentation that increases interfaces between open areas and forests. These interfaces allow light penetration into forests, with concomitant increases in local temperatures (Fischer and Lindenmayer 2007). The new conditions facilitate invasion by non-native, invasive plant species (Hawbaker and Radeloff 2004), which, in turn, lead to changes in mammal communities. These interfaces between open areas and forest constitute a type of habitat edge, because ecological edges are defined as interfaces between 2 different types of habitat. Within the wildlife literature, the dogma is that habitat edges are good for wildlife. In reality, a habitat edge benefits only animals that need both habitats that form the edge (Ries et al. 2004). The characteristics of habitat made by clearing and fragmenting forests and building roads and rights-of-way do not match characteristics of any natural habitats to which mammals of the Boundary Waters area have evolved. Consequently, habitat edges created by mining activities will not benefit mammals of the Boundary Waters area.

Fragmentation by roads leads to increased mortality of mammals by road kill. Many mammals adapted to early successional communities use rural roads, especially dirt roads, for travel routes, allowing mammals, such as bobcats (*Lynx rufus*), to establish healthy populations in the Boundary Waters area where they have not existed extensively in the past. Bobcats are major predators of fishers and American martens (Erb et al. 2014, Wengert et al. 2014) and major competitors with lynxes (Hoving et al. 2005, Peers et al. 2013). Forest fragmentation, road building and rights-of-way around mine sites will lead to local population decreases for martens and fishers through bobcat predation and to local population decreases of lynxes through competition with bobcats (Hoving et al. 2005, Peers et al. 2013). Loss of habitat to mines and the associated rights-of-way for roads and pipelines, etc., restricted dispersal and movements from loss of corridors through mining districts, and competition with bobcats could be all that is required to cause local extinction of lynxes in the Boundary Waters. Other, similar, indirect effects caused by mining sites are expected.

Ecological communities that have become fragmented and otherwise highly altered by humans take decades to recover. Consequently, effects on mammals by mines do not disappear when mines close but last for decades. Contamination of mine sites with heavy metals has the potential to last for decades to millennia. Where plants are able to grow on mine-contaminated sediments, heavy metals can become incorporated into the plants(Gramss & Voigt 2014, Peplow & Edmonds 2005). Thus, terrestrial mammals in these areas are exposed to heavy metals through their plant foods for decades to millennia.

Summary Statement

Mining for copper, nickel and other metals in the sulphur-bearing rock formations below the Boundary Waters area has the potential to have negative effects on populations of many mammal species, predominantly through contamination of water and loss of aquatic foods and through habitat loss and fragmentation. Cumulative effects of leaching from tailings ponds, leaks from pipelines, and other leaks will affect surface water down stream and will affect ground water potentially in all directions for centuries to millennia. Charismatic mammals such as moose, lynxes and otters will face large potential population losses. Beavers, which are responsible for the very biodiversity and ecological diversity that characterize the Boundary Waters area, will also face large population losses. Moose, lynx, long-eared bat and little brown bat populations already face serious threats in the Boundary Waters area and are not in position to withstand the potentially extended, negative effects of mining for heavy metals. Their populations could become extinct locally. Water shrews and star-nosed moles, seldom seen by people but important to the biodiversity of the Boundary Waters area, will lose critical foraging habitat should mining pollute the waters. Some signature predator-prey systems, such as the mink-muskrat system, have the potential to be disrupted as populations fall, should mining pollute the waters. Acid mine drainage, through pollution of surface water and ground water, and a tailings dam failure, through pollution of surface water, ground water and through deposition of contaminated sediments, should they occur, will affect mammal populations in the Boundary Waters area for millennia. Habitat loss and fragmentation will displace mammals, reduce population sizes, and reduce mammal movements and dispersal.

The precedent exists for leaving mineral resources in the ground despite their being accessible and their extraction being economically feasible (McGlade & Elkins 2015). Leaving copper, nickel and other minerals in their sulphur-bearing ore in the ground is important for maintaining the characteristic biodiversity and ecological diversity across a large portion of the Boundary Waters. Without mining, the signature mammals of the Boundary Waters area will continue to be valuable components of local ecological communities and to be prized by the local citizens and by visitors.

Literature Cited

Ahlers, A. A., E. J. Heske and R. L. Schooley. 2016. Prey distribution, potential landscape supplementation, and urbanization affect occupancy dynamics of American mink in streams. Landscape Ecology 31: 1601-1613.

Ash, C. and R. Stone. 2003. A question of dose. Science 300: 925.

Au, D. W. T. 2004: The application of histo-cytopathological biomarkers in marine pollution

monitoring: A review. Marine Pollution Bulletin 48: 817-834.
Badalamenti, J. P., J. D. Erickson and C. E. Salomon. 2016. Complete genome sequence of *Streptomyces albus* SM254, a potent antagonist of bat white-nose syndrome pathogen *Pseudogymnoascus desrtuctans*. Gewnome Announcements 4(2):e00290-16. doi:10.1128/genomeA.00290-16.
Baker, B. W. and E. P. Hill. Beaver *Castor canadensis*. Pp. 288-310. In: Feldhamer, G. A., B. C. Thompson and J. A. Chapman (editors). Wildl Mammals of North America: Biology, Management, and Conservation. The Johns Hopkins University Press, Baltimore, Maryland.
Baker, L. A. 2013. Potential ecological impacts of the Twin Metals Mine. Report prepared for Northeastern Minnesotans for Wilderness. 28 pp.
Bakker, E. S., K. A. Wood, J. F. Pagès, G. F. (Ciska) Veen, M. J. A. Christianen, L. Santamaría, B. A. Nolet and S. Hilt. Herbivory on fresdhwater and marine macrophytes: A review and perspective. Aquatic Botany 135: 18-36.
Balmford, A., A. Bruner, P. Cooper, R. Constanza, S. Farber, R. E. Green, M. Jenkins, P. Jeffriss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment S. Rosendo, J. Roughgarden, K. Trumper and R. K. Turner. 2002. Economic reasons for conserving nature. Science 297: 950-953.
Barber, J., H. Parker, D. Froswt, J. Hartley, R. White, C. Martin, R. Sterrett, J. Poeck, T. Eggleston, L. Gormely, S. Allard, S. Annavarapu, R. Radue, M. Malgesini and M. Pierce. 2014. Twin Metals Minnesota Projhect, Ely, Minnesosta, USA. Technical Report on Pre-feasibility Study NI 43-101. https://www.dropbox.com/s/s7m406l827lnyst/Twin%20Metals%20Minnesota%20Project%20-%20Ely%20Minnesota%20USA%20-%20NI%2043-101%20Technical%20Report%20on%20Pre-feasibility%20Study.pdf?dl=0 (Last accessed 23 March 2017).
Belovsky, G. E. 1978. Diet optimization in a generalist herbivore: The moose. Theoretical population biology 14: 105-134.
Belovsky, G. E. 1981a. A possible population response of moose to sodium availability. Journal of Mammalogy 62: 631-633.
Belovsky, G. E. 1981b. Optimal activity times and habitat choice of moose. Oecologia 48: 22-30.
Belovsky, G. E. 1984. Summer diet optimization by beaver. American Midland Naturalist 111: 209-222.
Belovsky, G. E. and P. A. Jordan. 1978. Sodium dynamics and adaptations of a moose population. Journal of Mammalogy 62: 613-621.
Ben-David, M., R. T. Bowyer and J. B. Faro. 1996. Niche separation b y mink and river otters: Coexistence in a marine environment. Oikos 75: 41-48.
Ben-David, M., L. K. Duffy, G. M. Blundell and R. T. Bowyer. 2001. Natural exposure to coastal river otters to mercury: Relation to age, diet, and survival. Environmental Toxicology and Chemistry 20: 1986-1992.
Beneski, J. T., Jr. and D. W. Stinson. 1987. *Sorex palustris*. Mammalian Species 296: 1-6.
Botkin, D. B., P. A.Jordan, A. S. Dominski, H. S. Lowendorf and G. E. Hutchinson. 1973. Sodium dynamics in a northern ecosystem. Proceedings of the National Academy of Science 70: 2745-2748.
Bowyer, R.T., V. Van Ballenberghe and J. G. Kie. 2003. Moose *Alces alces*. Pp. 931-964. In: Feldhamer, G. A., B. C. Thompson and J. A. Chapman (editors). Wildl Mammals of North America: Biology, Management, and Conservation. The Johns Hopkins University Press,

Baltimore, Maryland.
Brunet-Rossinni, A. K. 2004. Reduced free-rtadical production and extreme longevity in the little brown bat (*Myotis lucifugus*) versys two non-flying mammals. Mechanisms of Ageing and Development 125: 11-20.
Caceres, M. C. And R. M. R. Barclay. 2000. *Myotis septentrionalis*. Mammalian Species 634: 1-4.
Carlson-Voiles, P. 2012. Glassy water morning. International Wolf 22(2): 20-21.
Catania, K. C., J. F. Hare and K. L. Campbell. 2008. Water shrews detect movement, shape, and smell to find prey underwater. Proceedings of the National Academy of Science 105: 571-576.
Ceacero, F., T. Landete-Castillejos, M. Miranda, A. J. Garcia, A. Martinez and L. Gallego. 2014. Why do cervids feed on aquatic vegetation? Behavioural Processes 103: 28-34.
Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260.
Crisponi, G., V. M. Nurchi, D. Fanni, C. Gerosa, S. Nemolato and G. Raa. 2010. Copper-related diseases: From chemistry to molecular pathology. Coordination Chemistry Reviews 254: 876-889.
Dehnhardt, G., B. Mauck, W. Hanke and H. Bleckmann. 2001. Hydrodynamic trail-following in harbor seals (*Phoca vitulina*). Science 293: 102-104.
DelGiudice, G. D. 2016. 2016 Aerial moose survey. Minnesota Department of Natural Resources, Section of Wildlife, unpublished report. St. Paul, Minnesota. 7 pp.
DelGiudice, G. D. 2017. 2017 Aerial moose survey. Minnesota Department of Natural Resources, Section of Wildlife, unpublished report. St. Paul, Minnesota. 7 pp.
Duffy, L. K., M. K. Hecker, G. M. Blundell and R. T. Bowyer. 1999. An analysis of the fur of river otters in Prince William Sound, Alaska: Oil related hydrocarbons 8 years after the *Exxon Valdez* oil spill. Polar Biology 21: 56-58.
Eagle, T. C. & J. S. Whitman. 1987. Mink. Pp. 614-624. In Novak, M., J. A. Baker, M. E. Obbard and B. Malloch (editors). Wild Furbearer Management and Conservation in North America. Ontario Ministry of Natural Resources.
Egea-Serrano, A., R. A. Relyea, M. Tejedo and M. Torralva. 2012. Ecology and Evolution 2: 1382-1397.
Emmons & Olivier Resources, Inc. 2006. Cumulative effects analysis on wildlife habitat and travel corridors in the Mesabi Iron Range and Arrowhead Regions of Minnesota. Report prepared for Minnesota Department of Natural Resources. 53 pp.
Erb, J., P. Coy and B. Sampson. 2014. Survival and causes of mortality for fishers and martens in Minnesota. Pp. 83-91. In Forest Wildlife Populations and Research Group, 2014 Wildlife Research summaries, Minnesota Department of Natural Resources, St. Paul, Minnesota.
Erb, J. and H. R. Perry, Jr. 2003. Muskrats *Ondatra zibethicus* and *Neofiber alleni*. Pp. 311-348. In: Feldhamer, G. A., B. C. Thompson and J. A. Chapman (editors). Wildl Mammals of North America: Biology, Management, and Conservation. The Johns Hopkins University Press, Baltimore, Maryland.
Errington, P. L. 1943. An analysis of mink predation on muskrats in North-Central United States. Agricultural Experiment Station, Iowa State College of Agriculture and Mechanic Arts. Research Report 320: 797-924.
Errington, P. L. 1961. Muskrats and March Management. Stackpole Company, Harrisburg, Pennsylvania, and the Wildlife Management Institute, Washington, DC. 183 pp.

Estay, S. A., A. A. Albomoz, M. Lima, M. S. Boyce and N. C. Stenseth. 2011. A simultaneous test of synchrony causal factors in muskrate and mink fur returns at different scales across Canada. PLoS ONE 6(11): e27766. doi:10.1371/journal.pone.0027766.

Fauteux, D., M. J. Maxerolle, L. Imbeau and P. Drapeau. 2013. Site occupancy and spatial co-occurrence of boreal small mammals are favoured by late-decay woody debris. Canadian Journal of Forest Research 43: 419-427.

Fenton, M. B. 1999. Little brown bat *Myotis lucifigus*. Pp. 94-95. In Wilson, D. E. And S. Ruff (editors). The Smithsonian Book of North American Mammals. Smithsonian Institution Press, Washington, DC.

Fischer, J., and D.B. Lindenmayer. 2007. Landscape modification and habitat fragmentation: A synthesis. Global Ecology and Biogeography 16: 265-280.

Frelich, L. E. 2013. Boreal Biome. In Gibson, D. (Editor). Oxford Bibliographies in Ecology. Oxford University Press. New York http://www.oxfordbibliographies.com/view/document/obo-9780199830060/obo-9780199830060-0085.xml

Frick, W. F., J. F. Pollock, A. C. Hicks, K. E. Langwig, D. S. Reyenolds, G. G. Turner, C. M. Butchkoski and T. H. Kunz. 2010. An emerging disease causes regional population collapses of a common North American bat species. Science 329: 679-682.

Gable, T. D., S. K. Windels, J. G. Bruggik and A. T. Homkes. 2016. Where and how wolves (*Canis lupus*) kill beavers (*Castor canadensis*). PLoS ONE DOI:10.1371/journal.pone.0165537

Gramss, G. And K.-D. Voigt. 2014. Forage and rangeland plants from uranium pine soils: Long-gterm hazard to herbivores and livestock? Environmental Geochemistry and Health 36: 441-452.

Gerht, S. D. 2003. Raccoon *Procyon lotor*. Pp. 611-634. In: Feldhamer, G. A., B. C. Thompson and J. A. Chapman (editors). Wild Mammals of North America: Biology, Management, and Conservation. The Johns Hopkins University Press, Baltimore, Maryland.

Grigal, D. F. 2003. Mercury sequestration in forests and peatlands: A review. Journal of Environmental Quality 32: 393-405.

Gürkan, M., A. Çetin and S. Hauretdağ. 2014. Acute toxic effects of cadmium in larvae of the green toad, *Pseudepidalea variabilis* (Pallas, 1769) (Amphibia: Anura). Arh Hig Toksikol 65: 301-309.

Gusztak, R. W., R. A. MacArthur and K. L. Campbell. 2005. Bioenergetics and thermal phusiology of American water shrews (*Sorex palustris*). Journal of Comparative Physiology B 175: 87-95.

Harrington, L. A., G. C. Hays, L. Fasola, A. L. Harrington, D. Richton and D. W. Macdonald. 2012. Dive performance in a small-bodied, semi-aquatic mammal in the wild. Journal of Mammalogy 93: 198-212.

Harris, A. H. 1999. Water shrew *Sorex palustris*. Pp. 38-39. In Wilson, D. E. And S. Ruff (editors). The Smithsonian Book of North American Mammals. Smithsonian Institution Press, Washington, DC.

Hassett-Sipple, B., J. Swartout, K. R. Mahaffey, G. E. Rice and R. Schoeney. 1997. Mercury study report to Congress. Volume V: Health effects of mercury and mercury compounds. EPS-452/R-97-007.

Hawbaker, T.J. and V.C. Radeloff. 2004. Roads and landscape pattern in northern Wisconsin based on a comparison of four road data sources. Conservation Biology 18: 1233-1244.

Heinselman, M.L. 1996. The boundary waters wilderness ecosystem. University of Minnesota Press, Minneapolis, Minnesota.

Hodgdon, H. E., and J. S. Larson. 1973. Some sexual differences in behavior within a colony of marked beavers (*Castor canadensis*). Animal Behaviour 21: 147-152.

Hoving, C. L., D. J. Harrison, W. B. Krohn, R. A. Joseph and M. O'Brien. 2005. Broad-scale predictors of Canada lynx occurrence in eastern North America. Journal of Wildlife Management 69: 739-751.

Ingersoll, T. E., B. J. Sewell and S. K. Amelon. 2013. Improved analysis of long-term monitoring data demonstrates marked regional declines of bat populations in the eastern United States. Plos one 8(6): e65907. Doi:10.1371/journal.pone.0065907

Ingersoll, T. E., B. J. Sewell and S. K. Amelon. 2016. Effects of white-nosed syndrome on regional populations patterns of 3 hibernating bat species. Conservation Biology 30: 1048-1059.

Irving, L., and M. D. Orr. 1935. The diving habits of the beaver. Science 82: 569.

Janicka, M., L. J. Binkowski, M. Blaszczyk, J. Paluch, W. Wojtas, P. Massanyi and R. Stawarz. 2015. Cadmium, lead and mercury concentrations and their influence on mephological parameters in blood donors from different age groups from southern Poland. Journal of Trace Elements in Medicone and Biology 29: 342-346.

Jenkins, S. H. 1975. Food selection by beavers: A multidimensional contingency table analysis. Oecologia 21: 157-173.

Jenkins, J. H. 1980. A size-distance relation in food selection by beavers. Ecology 61: 740-746.

Jenkins, J. H. and P. E. Busher. 1979. *Castor canadensis*. Mammalian Species 120: 1-8.

Johnston, C. A. 2015. Fate of 150 yeasr old beaver ponds in the Laurentian Great Lakes Region. Wetlands 35: 1013-1019.

Keeler, B. L., S. A. Wood, S. Polasky, C. Kling, C. T. Filstrup and J A. Downing. 2015. Recreational demand for clean water: Evidence from geotagged photographs by visitors to lakes. Frontiers in Ecology and the Environment 13: 76-81.

Kossoff, D., W. E. Dubbin, M. Alfredsson, S. J. Edwards, M. G. Macklin, and K. A. Hudson-Edwards. 2014. Mine tailings dams: Characteristics, failure, environmental impacts, and remediation. Applied Geochemistry 51: 229-245.

Kouba, A., M. Buřič and P Kozák. 2010. Bioaccumulation and effects of heavy metals in crayfish: A review. Water Air and Soul Pollution 211: 5-16.

Kovaci, A., J. Arvey, E. Tusimove, L. Harangozo, E. Tvrda, K. Zbnovska, P. Cupka, S. Andrascikova, J. Tomas and P. Passanyi. 2017. Seasonal variations in the blood concenbtrations of selected heavy metals in sheed and their effects on the biochemical and hematological parameters. Chemosphere 168: 365-371.

Lahman, S. E., K. R. Trent and P. A. Moore. 2015. Sublethal copper toxicity impairs chemical orientation in the crayfish, *Orconectes rusticus*. Ecotoxicology and Environmental Safety 113: 369-377.

Langwig, K. E., W. F. Frick, J. R. Hoyt, K. L. Parise, K. P. Drees, T. H. Kunz, J. T. Foster and A. M. Kilpatrick. 2016. Drivers of variation in species impacts for a multi-host fungal disease of bats. Philosophical Transactions of the Royal Society B 371: 20150456. http://dx.doi.org/10.1098/rstb.2015.0456.

Langwig, K. E., J. R. Hoyt, K. L. Parise, W. F. Frick, J. T. Foster and A. M. Kilpatrick. 2017. Resistance in persisting bat populations after white-nose syndrome invasion. Philosophical Transactions of the Royal Society B 372 20160044. http://dx.doi.org/10.1098/rstb.2016.0044

Larison, J. R., G. E. Likens, J. W. Fitzpatrick and J. G. Crock. 2000. Cadmium toxicity among wildlife in the Colorado Rocky Mountains. Nature 406: 181-183.

Larivière, S. 2003. Mink *Mustela vison*. Pp. 662-671. In: Feldhamer, G. A., B. C. Thompson and J. A. Chapman (editors). Wildl Mammals of North America: Biology, Management, and Conservation. The Johns Hopkins University Press, Baltimore, Maryland.

Lewin, J. and M. G. Macklin. 1987. Metal mining and floodplain sedimentation in Britain. Pp. 1009-1027. In Gardiner, V. (Editor). International Geomorphology 1986 Part 1, Wiley, Chichester, United Kingdom.

Liu, J., J. Liang, X. Yuan, G. Zeng, Y. Yuan, H. Wu, X. Huang, J. Liu, S. Hua, F. Li and X. Li. 2015. An integrated model for assessing heavy metal exposure risk to migratory birds in wetland ecosystem: A case study of Dongting Lake Wetland, China. Chemosphere 135: 14-19.

Lotze, J.-H. and S. Anderson. 1979. *Procyon lotor*. Mammalian Species 119: 1-8.

Macklin, M. G., P. A. Brewer, K. A. Hudson-Edwards, G. Bird, T. C. Coulthard, I. A. Dennis, P. J. Lechler, J. R. Miller, and J. N. Turner. 2006. A geomorphological approach to the management of rivers contaminated by metal mining. Geomorphology 79: 423-447.

Mahaffey, K., G. E. Rice, R. Schoeney, J. Swartout and M. H. Keating. 1997. Mercury study report to Congress Volume VII: Characterization of human health and wildlife risks from mercury exposure in the United States. EPA-452/R-97-009.

Marcogliese, D. J. 2005. Parasites of the superorganism: Are they indeicators of ecosystem health? International Journal of Parasitology 35: 705-716.

Massanyi, P., R. Stawarz, M. Halo, G. Formicki, N. Lukac, P. Cupka, P. Szhwarcz, A. Kovacik, E. Tusinova and J. Kovacik. 2014. Blood concentration of copper, dacmium, zinc and lead in hourses and its relation to hematological and biochemical parameters. Journal of Environmental Science and Health, Part A, 49: 973-979.

McGlade, C. And P. Elkins. 2015. The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. Nature 517: 187-190.

Mech, L. D., D. W. Smith and D. R. MacNulty. 2015. Wolves on the Hunt: The Behavior of Wolves Hunting Wild Prey. University of Chicago Press.

Melquist, W. E., P. J. Polechla, Jr. and D. Toweill. 2003. River otter *Lontra canadensis*. Pp. 708-734. In: Feldhamer, G. A., B. C. Thompson and J. A. Chapman (editors). Wildl Mammals of North America: Biology, Management, and Conservation. The Johns Hopkins University Press, Baltimore, Maryland.

Mergler, D. G. Huel, R. Bowler, A. Iregren, S. Belanger and M. Baldwin. 1994. Newvous systems dysfunction among workers with long-term exposure to manganese. Environmental Research 64: 151-180.

Mergler, D., H. A. Anderson, L. H. M. Chan and K. R. Mahaffey. 2007. Methylmercury exposure and health effects in Humans: A worldwide concern. AMBIO: A Journal of the Human Environment 36: 3-11.

Milligan, H. E. & M. M. Humphries. 2010. The importance of aquatic vegetation in beaver diets and the seasonal and habitat specificity of aquatic-terrestrial ecosystem linkages in a subarctic environment. Oikos 119: 1877-1996.

Myers, J. 2017. Deadly fungus decimates Minnesot'as largest bat wintering colony. Twin Cities Pioneer Press. http://www.twincities.com/2017/03/11/deadly-fungus-decimates-minnesotas-largest-bat-winte ring-colony/ . Last accessed 15 March 2017.

Myers, T. 2016 Acid mine drainage risks – A modeling approach to siting mine facilities in Northern Minnesota USA. Journal of Hydrology 533: 277-290.

Naiman, R. J., C. A. Johnston and J. C. Kelley. 1988. Alteration of North American streams by beaver. BioScience 38: 753-762.

Obiri, S. D. K. Dodoo, D. K. Essuman and F. A. Armah. 2010. Cancer and non-cancer risk assessment from exposure to arsenic, cadmium and copper by resident adults and children in the Obuasi Minicipality, Ghana. International Journal of Human Ecological Risk assessment 160: 651-658.

Orrock, J. L., J. F. Pagels, W. J. McShea and E. K. Harper. Predicting presence and abundance of a small mammal species: The effect of scale and resolution. Ecological Applications 10: 1356-1366.

Pastor, J. 2016. What Should a Clever Moose Eat? Island Press. Washington, DC. 298 pp.

Peers, M. J., D. H. Thornton and D. L. Murray. 2013. Evidence for large-scale effects of competition: Niche displacement in Canada lynx and bobcat. Proceedings of the Royal Society B 280: 20132406 http://dx.doi.org/10.1098/rspb.2013.2495 (Last accessed 26 April 2017)

Peplow, D. And R. Edmonds. 2005. The effects of mine waste contamination at multiple levels of biological organization. Ecological Engineering 24: 101-119.

Powell, R. and C. Powell. 2016. Mammals of the North Woods. Kolath+Stensass, Duluth, Minnesota.

Punzo, F. 2004. Early-life nutritional environment and spatial navigation in the water shrew, *Sorex palustris* (Insectivora). Journal of Environmental Biology 25 :403-411.

Ries, L., R. J. Fletcher Jr., J. Battin and T. D. Sisk. 2004. Ecological responses to habitat edges: Mechanisms, models and variability explained. Annual Review of Ecology, Evolution, and Systematics 35: 491-522.

Rodriguez-agudelo, Y., H. Riojas-Rodriguez, C. Rios, I. Rosas, E. Sabido and J. Miranda. 2006. Motor alterations associated to environmental exposure to manganese in Maxico. Science of the Total Environment 368: 542-556.

Rowe, C. L., W. A. Hopkins and V. R. Coffman. 2001. Failed recruitment of southern toad (*Bufo terrestris*) in a trace element-contaminated breeding habitat: Direct and indirect effects that may lead to a local population sink. Archives of Environmental Contamination and Toxicology 40: 399-405.

Rudd, J. W. M. 1995. Sources of methyl mercury to freshwater ecosystems: A review. Water, Air, and Soil Pollution 80: 697-713.

Schindler, D.W. and P.G. Lee. 2010. Comprehensive conservation planning to protect biodiversity and ecosystem services in Canadian boreal regions under a warming climate. Biological Conservation 143: 1571-1586.

Scudder Eikenberry, B. C., K. Rive-Murray, C. D. Knightes, C. A. Hourney, L. C. Chasar, M. E. Brigham and P. M. Bradley. 2015. Optimizing fisher sampling for fish–mercury bioaccumulation factors. Chemosphere 135: 467-473.

Shier, C. J. And M. S. Boyce4. 2009. Mink prey diversity correlates with mink-muskrat dynamics. Journal of Mammalogy 90: 897-905.

Stringer, A. P. and M. J. Gaywood. 2016. The impacts of beavers *Castor* spp. On biodiversity and the ecological basis for their reintroduction to Scotland, UK. Mammal Review 46: 270-283.

Svendsen, G. E. 1980. Seasonal change in feeding patterns of beaver in southeastern Ohio. Journal of Wildlife Management 44: 285-290.

Teh, S. J., S. M. Adams and D. E. Hinton. 1997. Histopathologic biomarkers in feral freshwater fish populations exposed to different types of contaminant stress. Aquatic toxicology 37: 51-70.

Terwilliger, J. And J. Pastor. 1999. Small mammals, ectomycorrhizae, and conifer succession in beaver meadows. Oikos 85: 83-94.

Ullrich, S. M., T. W. Tanton and S. A. Abdrashitova. 2001. Mercury in the aquatic environment: A review of factors affecting methylation. Critical Reviews in Environmental Science and Technology 31: 241-293.

Vidal-Martinez, V. M., D. Pech, B. Sures, S. T. Purucker and R. Poulin. 2010. Can parasites really reveal environmental impact? Trends in Parasitology 26: 45-51.

Webster, P. W., L. T. M. Van der Ven, A. D. Vethaak, G. C. M. Grinwis and J. G. Vos. 2002. Aquatic toxicology: Opportunities for enhancement through histopathology. Environmental Toxicology and Pharmacology 11: 289-295.

Wengert, G. M., M. W. Gabriel, S. M. Matthews, J. M. Higley, R. A. Sweitzer, C. M. Thompson, K. L. Purcell, R. H. Barrett, L. W. Woods, R. E. Green, S. M. Keller, P. M. Gaffney, M. Jones and B. N. Sacks. 2014. Using DNA to describe and quantify interspeficic killing of fishers in California. Journal of Wildlife management 78: 603-611.

Whitaker, J. O. and L. L. Schmeltz. 1973. Food and external parasites of *Sorex palustris* and *Sorex cinereus* from St Louis County, Minnesota. Journal of Mammalogy 54: 283-285.

Wieskotten, S., B. Mauck, L. Miersch, G. Dehnhardt and W. Hanke. 2011. Hydrodynamic discrimination of wakes caused by objects of different size or shape in harbour seals (*Phoca vitulina*). The Journal of Experimental Biology 214: 1922-1930.

Wilk, R. J., M. G. Raphael, C. S. Nations and J. D. Ricklefs. 1020. Initial response to small ground-Dwelling mammals to forest alternative buffers along headwater streams in Washington Coat Range, USA. Forest Ecology and Management 260: 1567-1578.

Willner, G. R., J. A. Chapman and J. R. Goldsberry. 1975. A study and review of muskrat food habitats with special reference to Maryland. (Publication on Wildlife Ecology 1). Maryland Wildlife Administration.

Willner, G. R., G. A. Feldhamer, E. E. Zucker and J. A. Chapman. 1980. *Ondatra zibethicus*. Mammalian Species 141: 1-8.

Wright, J. P., Cl G. Jones and A. S. Flecker. 2002. An ecosystem engineer, the beaver, increases species richness at the landscape level. Oecologia 132: 96-101.

Yoshida, S., S. Matsumoto, T. Kanchika, T. Hagiwara and T. Minami. 2016. The organic mercury compounds, methymercury and ethylmercury, inhibited ciliary movement of ventricular cells in the mouse brain around the concentrations reported for human poisoning. NeuroToxicology 57: 69-74.

Yuan, L.-W., L.-Z. Jin, Y.-M. Chen. 2013. Research of tailings pond supervision level classification system based on disaster risk. Metal Mine 445: 153-158.

Yuan, L.-W., S.-M. Li, B. Peng and Y.-M. Chen. 2015. Study on failure process of tailing dams based on particle flow theories. International Journal of Simulation Modelling 4: 658-668.