A comparative study of cadmium and copper in ruffed grouse (*Bonasa umbellus*) in regions with and without historic mining

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Abstract

Mining activities can increase the bioavailability of metals in aquatic and terrestrial ecosystems. Following over 100 years of copper mining in portions of Michigan’s Upper Peninsula (UP) terrestrial ecosystems retain vast quantities of waste rock with traces of cadmium and large concentrations of copper. We compared liver cadmium and copper concentrations in ruffed grouse (*Bonasa umbellus*), a popular game bird from landscapes with and without historic mining. We also used chickens (*Gallus domesticus*) to determine whether mine waste was a direct source of liver cadmium. Cadmium and copper levels did not differ between mining areas in Michigan and non-mining areas in Wisconsin. We found nearly significant difference between sexes in cadmium levels. Cadmium levels for all chickens were below the method detection limit of the lab (0.03 mg/kg) and copper levels did not differ in the experimental chickens. These results suggest that the historic mining in the western UP is not leading to higher cadmium or copper uptake in grouse.

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1. Introduction

Metallic mining often leaves a legacy of environmental pollution long after active mining has ceased. The ore belt that extends southwest to northeast through the western Upper Peninsula (UP) of Michigan supported one of the largest mineral mining industries in North American history between 1850 and 1950 (Babcock and Spiroff, 1970). Approximately 150 mines and 40 stamp mills were located along this synclinal spine (Fig. 1) and produced 4,800,000 tons of copper between 1850 and 1929 (Lankton, 1991). The stamp mills used to extract copper from the remaining lower-grade ore produced a large amount of stampsand, a waste material composed of crushed basalt and conglomerate rock. Two hundred million tons of this material was deposited near the stamp mills and along the waterways of this region (Coppersack and Mihelcic, 1999). Stampsand have become ubiquitous in this region through their use as winter road traction and as a base for road construction (EPA, 1992). Because the tailings from metal mines often contain trace heavy metals (Bradshaw and Chadwick, 1980) and cadmium and copper concentrations are comparatively elevated near copper smelters and mine tailings in this region (ATSDR, 1989), such mining legacies have the potential to affect local wildlife populations.

As a result of the extensive copper mining in the region, some of the more heavily impacted sites became designated as Environmental Protection Agency (EPA) superfund sites. Composite samples taken from sites in the region contained copper, cadmium, and other metals in the tailings and slag piles (EPA, 1992). Although a recent analysis of stampsand from the Gay stamps and site on the Keweenaw Peninsula found cadmium levels below the detection limit of the lab (0.03 mg/kg) (Michigan Department of Environmental Quality, A. Keranen, unpublished data, 2005), the presence of cadmium in the earlier EPA samples suggests that a more complete understanding of its distribution and potential for uptake into terrestrial food webs is needed. Although there have been investigations of the potential impacts of stampsand deposition on local aquatic systems (West and Mattson, 1993; Kerfoot and...
Lauster, 1994; Jeong et al., 1999; Kerfoot and Nriagu, 1999; Kerfoot et al., 1999), the potential impacts of trace heavy metals related to historic copper mining on the terrestrial environment has received little attention.

Cadmium is a relatively rare metal in natural environments but can be made ubiquitous and available to plants and animals through mining activities (Church et al., 1997). Cadmium is not an essential element for living organisms and there is no known homeostatic process to regulate its concentration (Eisler, 1985; Nriagu, 1979; Hopkins and Hames, 1994). For this reason, animals may accumulate cadmium in their livers and kidneys beyond levels found in their diet (Leach et al., 1979; Jenkins, 1981; Cain et al., 1983) and toxic levels can be reached with even low exposure (Scheuhammer, 1987). At toxic levels, cadmium affects the kidneys of vertebrates by interfering with calcium metabolism, disrupting the electrolyte balance, and causing the excretion of calcium, which can lead to brittle bones (Larison, 2001). Early successional woody plants such as willow (Salix spp.) and poplar (Populus spp.) have been shown to bioaccumulate cadmium (Larison et al., 2000; Robinson et al., 2000) and represent a possible pathway for the passage of cadmium from soil to herbivorous animals (Lipton et al., 1993) such as the ruffed grouse (Bonasa umbellus).

Mining and smelting can also elevate copper concentrations in soils (Harris and Jurgensen, 1977; ATSDR, 1989). Unlike cadmium, copper is a necessary element for living organisms and its concentration in body tissues can be regulated by vertebrates (Shroeder et al., 1966). Although some studies have examined copper toxicity in domestic birds such as chickens (Gallus domesticus), to our knowledge there are no data on the toxicity of copper in wild birds (Eisler, 1998). Birds do not retain much of the copper that they ingest (Bryan and Langston, 1992), but controlled studies using adult domestic chickens and chicks showed reduced weight gains when birds were given doses from 28 to 350 mg copper/kg of feed for 25 days (Bremner, 1979).
Aquatic birds, such as gulls and terns (family Laridae), have been the focus of most avian toxicological research (Anderson and Hickey, 1976, Weseloh et al., 1979, Mineau et al., 1984). In contrast, terrestrial birds have not typically been used as bioindicators in the Great Lakes region. However, in Norway (Pedersen and Myklebust, 1993; Wren et al., 1994; Pedersen and Saether, 1999), Ontario (Rose and Parker, 1983), and Colorado (Larison et al., 2000), terrestrial, non-migratory, gallinaceous species have been used as effective bioindicators of heavy metals. These studies have revealed that metals, notably cadmium, bioaccumulate through terrestrial food webs and can affect the health, behavior, and population status of gallinaceous birds.

Ruffed grouse have a number of traits that make them appealing as potential bioindicators for monitoring mining-related contaminants. They are non-migratory and have a relatively small home range, making them an appropriate surrogate because they are anatomically similar to ruffed grouse (both birds are in the family Galliformes), are widely available, and are easy to maintain in captivity. We hypothesized that grouse living in regions with stampsand as a grit source would have higher concentrations of cadmium and copper compared to chickens using commercial grit.

2. Materials and methods

Grouse were collected from volunteer hunters from the UP (Houghton, Keweenaw, and Ontonagon counties) and northern Wisconsin (Sawyer, Price, Langlade, and Oconto counties) during the fall 2001 hunting season. The four-county area in Wisconsin contrasts with the three-county area in the UP in that no large-scale mining has taken place in this portion of Wisconsin in modern times. Both Michigan and Wisconsin study sites contain similar soils and forest types (Dickman and Leefers, 2003). Frozen hunter-killed grouse were collected along with a map showing where each bird was shot. Frozen samples were brought to the wildlife lab at Michigan Technological University (MTU) and a subsample of 12 UP (6 female and 6 male) and 12 northern Wisconsin (6 female and 6 male) grouse were chosen at random. Stampsand for use as chicken grit was collected in the Keweenaw Peninsula from four locations: (1) the Gay stampsand site, (2) the Quincy smelter site, (3) the Isle Royale stampsand site, and (4) the railroad grade in Chassell. Stampsand metal content data came from samples from the Gay stampsand site. The samples were homogenized in the lab by mixing equal amounts of stampsands from each site.

Between June and August 2001, hatch-year female domestic chickens were used to assess metal accumulation in birds exposed to stampsands as the only available grit. Females were chosen over males because male aggression precluded keeping them in close quarters. Twelve domestic chickens were raised for 12 weeks (to adult size) in a pen containing only stampsand as grit, and 12 chickens were raised for 12 weeks in a pen in which only commercial chicken grit (Cherry stone fine grit, from New Ulm Quarite Quarries) was available. To ensure that the commercial grit was not a potential source of metals in tissues, a sample of the grit was analyzed using an inductively coupled plasma-mass spectrometer (ICP-MS) at the Michigan Technological University Materials Science Laboratory. Ten grams of the grit was put into a container with 115 mL HCL and shaken for 48 h, and this solution was analyzed. Grit consumption begins immediately after hatching in precocial gallinaceous birds (Haynes, 1978) and is correlated with age (Mayoh and Zach, 1986). Both groups were fed Prince Animal Feed 001154, 25% Broiler Ration. Both groups were given the same commercial chicken feed and had the same water source. Both the treatment (stampsand grit) and control (commercial grit) groups were then sacrificed and dissected, and their liver tissues were analyzed for metals.

Complete livers were removed with stainless steel tools, placed in whirlpak bags, and frozen until metal analyses could be completed. Ruffed grouse were sexed using plumage differences. Grit collected in the gizzards of the chicken samples was put in labeled bags to determine whether the chickens were using the available stampsands. The ruffed grouse samples were divided into the following groups for the comparison of mean cadmium and copper levels: all Michigan vs. Wisconsin birds (male and female combined) and all male vs. all female birds (Michigan and Wisconsin combined). To further quantify confidence in the sample mean as being representative of the population mean, the SPSS statistical analysis package was used to test for normality through the use of the Kolmogorov–Smirnov test. A Mann–Whitney U test was performed when the sample groups were not normal. An F test was performed for normal groups to determine variance so that the appropriate Student t test could be performed. A Dunn–Sidak-corrected t test was used to adjust the P-value for multiple comparisons. We also used the same statistical procedures for the chickens using the experimental (stampsand grit) group vs. the control (commercial grit) group.
3. Results

Mean grouse cadmium liver concentrations ± SD were MI male (2.40 ± 1.72 mg/kg; n = 6), MI female (1.62 ± 0.74 mg/kg; n = 6), WI male (5.03 ± 3.00 mg/kg; n = 6), and WI female (1.43 ± 0.50 mg/kg; n = 6) (Fig. 2). Mean grouse copper liver concentrations were MI male (3.82 ± 0.61 mg/kg; n = 6), MI female (4.50 ± 1.02 mg/kg; n = 6), WI male (5.98 ± 1.82 mg/kg; n = 6), and WI female (5.27 ± 2.58 mg/kg; n = 6) (Fig. 3).

Grouse liver cadmium levels were normally distributed for the MI vs. WI group (P = 0.013 using the Dunn–Sida´k procedure. Liver copper levels for MI vs. WI ruffed grouse did not differ (P = 0.018; t = 2.74; df = 12; Fig. 4b).

Copper levels were not normally distributed for the MI (P = 0.2; df = 12) and WI (P = 0.046; df = 12) test groups but were normally distributed for the male (P = 0.145; df = 12) and female (P = 0.245; df = 12) test groups. Liver copper levels for the MI vs. WI grouse did not differ (U = 102; n = 12; Fig. 4c). Grouse copper liver levels for the male vs. female group had equal variance (P = 1.84; F = 0.163; df = 11), Copper levels for male vs. female ruffed grouse did not differ (P = 0.787; t = 0.274; df = 22; Fig. 4d).

Cadmium levels in all livers from the chicken group were below the methods detection limit for the metals screening of 0.3 ppm. Liver copper levels for the experimental (stampsand grit) (mean = 4.03 ± 0.42 SD; n = 12) and control (commercial grit) (mean = 4.12 ± 0.51; n = 12) groups did not differ (U = 54; n = 12). The metals assay of the commercial grit using the ICP-MS yielded copper level of 18.9 mg/kg rock and cadmium levels below the detection limit of 0.1 mg/kg, both dry weight.

4. Discussion

To evaluate the potential for elevated concentrations of metals in ruffed grouse in an area with widespread historic mining, we compared cadmium and copper concentrations in the livers of wild grouse populations in the UP and northern WI. Surprisingly, mean grouse liver cadmium and copper concentrations were higher in WI than in MI, although concentrations of neither metal differed significantly between areas with and without historic mining. This suggests that the legacy of historic copper mining in Houghton and Keweenaw counties has not or is no longer increasing the mobilization of cadmium into the diet of ruffed grouse. Because grouse are generalist omnivores whose fall diet includes dozens of plant species and arthropods (M. Snively, unpubl. data), our findings suggest that neither metal is being freely mobilized into the region’s terrestrial food web.

Because cadmium levels in the livers of ruffed grouse could not be found in the literature we used the results from Larison et al. (2000) to define normal (0–3 mg/kg), elevated (4–8 mg/kg), and toxic (>9 mg/kg) levels of wet weight liver cadmium from the closely related white-tailed ptarmigan (Lagopus leucurus). Two UP grouse had elevated levels of cadmium, one from Houghton County (5.0 mg/kg) and one from Keweenaw County (3.9 mg/kg). Three of 12 WI grouse (25%) had elevated, near toxic, or toxic levels of cadmium in their livers.

Chickens using stampsands as the only available source of grit had cadmium levels that were below the methods detection limits (0.03 ppm). Stampsands do not appear to be a pathway for mobilizing cadmium into tissues of chickens. The chickens for this experiment were sacrificed at 3 months, which was sufficient time for cadmium to accumulate in their livers; Larison et al. (2000) saw an accumulation of cadmium in 1-week-old ptarmigan chicks from contaminated areas.
Although past research on cadmium in gallinaceous birds has found that females have higher cadmium levels than males (Larison et al., 2000), our data suggest the opposite pattern for grouse. We consider three possible explanations for this finding: physiological and/or behavioral differences between the sexes and potentially skewed age/sex sampling. First we believe that sex-based differences in physiology are an unlikely explanation for this pattern. Female birds are characterized by the calcium sink (from body tissues to eggs) related to the production of eggs, making them more susceptible to cadmium toxicity (Simkiss, 1975). Hens transfer only a very small amount of cadmium to eggs (Sell, 1975), so this is not a likely mechanism for lowering liver cadmium levels relative to males. Second, males and females may utilize different parts of the habitat, which could expose male grouse to higher levels of cadmium than females. For example, Larison et al. (2000) reported that in Colorado, female, but not male ptarmigan overwintered in lowlands directly below abandoned mines and browsed on contaminated willow buds. Third it is possible that grouse with elevated cadmium are older birds that just happen to be male as a consequence of random selection by hunters or by us.

The statistical power of our comparisons was relatively low as a result of small samples. Future research should involve metals screening for aspen tissues, especially the male catkins, an important component of winter grouse diets, to determine whether aspen species of the Great Lakes Basin bioaccumulate cadmium as similar species did in the Robinson et al. (2000) study. We also recommend testing the livers and/or kidneys of herbivorous mammals.

Fig. 4. Ruffed grouse liver: (a) cadmium levels of grouse from MI (mean = 2.01 ± 1.32 SD; n = 12) and WI (mean = 3.23 ± 2.78 SD; n = 12) male and female combined, (b) cadmium levels between male (mean = 3.72 ± 2.71 SD; n = 12) and female (mean = 1.53 ± 0.61 SD; n = 12) grouse MI and WI combined, (c) copper levels of grouse from MI (mean = 3.98 ± 0.50 SD; n = 12) and WI (mean = 5.63 ± 2.16 SD; n = 12), and (d) copper levels between male (mean = 4.90 ± 1.72 SD; n = 12) and female (mean = 4.70 ± 1.85 SD; n = 12) grouse MI and WI combined.
such as white-tailed deer (*Odocoileus virginianus*), especially those that browse on early successional plant species.

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